Papers 9th International Drainage Workshop, September 10-13, 2003 Utrecht The Netherlands

KEYNOTES

TOPIC 1

INNOVATIVE DRAINAGE TECHNOLOGIES IN AGRICULTURE

Subtopic 1.1 Soils and Installation
Subtopic 1.2 More Crop per Drop and Controlled Drainage
Subtopic 1.3 Decision Support Systems and Models

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**TOPIC 2:**

**DRAINAGE: A TOOL FOR IWRM IN AGRICULTURE**

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**Subtopic 2.2 Management of Drainage Water**

**Subtopic 2.3 Water Logging and Salinity**

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**TOPIC 3:**

**DRAINAGE INSTITUTIONS FOR PARTICIPATORY DEVELOPMENT**

**Sub topic 3.1 User Participation and Institutions**
### Sub topic 3.2 Managerial Aspects
### Sub topic 3.3 Socio-economic Impacts and Cost Recovery

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DEVELOPING A BASIN FRAMEWORK FOR PRIORITIZING INVESTMENTS IN WATER RESOURCES IN VIETNAM'S RED RIVER BASIN

N. Bakker, Chu Tuan Dat, P. Smidt and C. Steley

SYNOPSIS:
This paper presents lessons learned in implementing two integrated water resources management (IWRM) projects with particular emphasis on drainage. The first section describes the water resources sector. The second presents the main features of the first Red River Delta Water Resources Sector Project. The Project Completion Report, economic reevaluation, found drainage subprojects did not perform as well as expected at appraisal. This resulted in the hypothesis that drainage collection and delivery systems constrain the performance of pumped drainage outfalls requiring a more integrated approach to improve drainage. The third section presents the main features of the current Second Red River Basin Sector Project (SRRBSP) The fourth describes the preparation of the Water Sector Action Plan to provide a framework for selecting subprojects under SRRBSP. Irrigation diversion and drainage outfall capacities were found to explain 55% of the variation in irrigated agricultural production at the 0.015% significance level. The exponential production function provides a simple method of economic evaluation and subproject selection. It also supports the above hypothesis, indicating drainage system capacities may be a generic performance constraint, as the optimum drainage outfall capacity is only 3.2 lps/ha compared with present design standard of 5 to 6 liter per second per hectare adopted by the Ministry of Agriculture and Rural Development. The final section presents the proposed design of a drainage research study to assesses the performance of drainage subprojects, identify constraints and develop a participatory approach to prepare integrated drainage subprojects.

1 The Water Resources Sector
Vietnam has a long history of water management developed in response to water shortages during the dry season, a monsoon climate that regularly causes extensive flood damage, and a need to intensify agricultural production. Irrigation, drainage, and flood control have traditionally been the main focus of water sector development. At present, more than 2.6 million ha of agricultural land is irrigated through 75 large and medium-scales schemes and thousands of small-scale systems. These systems are managed by 173 state-owned irrigation management companies (IMCs) and thousands of agricultural cooperatives and water user groups. The Government recognizes that the country’s irrigation systems suffer from a number of constraints that limit performance. These include (i) degraded or inadequate irrigation infrastructure, (ii) weak institutional capacity to manage the systems, and (iii) inadequate integration of agricultural extension with developing cropping systems. This low performance contributes to rural poverty.

The Red River basin is the main river basin in the north of Vietnam (see map). It is home to about 25 million people or about one third of the country’s total population. Its total area is 169,000 square kilometres of which the upper half is in the Peoples’ Republic of China. The Red River basin has 25 provinces: 9 are in the delta, and the remaining 16 are in the uplands. Hanoi and Hai Phong, the second and third largest cities of Vietnam, are located in the basin’s delta. The rural delta is one of the most densely populated areas of the world supporting about 1,000 persons/km². Urbanization in the basin is about 15 percent, and the urban population is increasing by about 10 percent annually. The Red River delta has irrigation systems that were among the first to be developed in the country, several centuries ago. In the low-lying areas, drainage rather than irrigation is often the key factor affecting the stability and productivity of agricultural crops, and an extensive centuries-old system of river and sea dikes reduces vulnerability to flooding. Of the total hydropower potential of 8,600 megawatts (MW) in Vietnam, 8,480 MW or 45 percent is in the Red River basin. Agriculture accounts for about 35 percent of the gross domestic product in the Red River delta, compared with 24 percent for industry and 41 percent for services. Landholdings in the basin are small and scattered, particularly in the delta, where the average farm size is only 0.6 hectare (ha). Irrigated agriculture in the basin uses 78 percent of total water abstracted, followed by industry with 18 percent, and water supply for municipal and domestic use with 4 percent. The existing irrigation and drainage facilities in the basin are 30 large and medium-scale schemes in the delta, including 27 pumping stations, serving about 760,000 ha, and many small schemes in the uplands serving about 210,000 ha. About 20 percent of Vietnam’s annual rice production is produced in the Red River basin. Reliable and timely availability of water is essential throughout the basin to ensure double- or triple-cropping seasons, and to allow cultivation of high-yielding varieties, which are the only possible response to the scarcity of arable land.

Table 1 indicates the total population of the RRB was about 25 million in 2000 of which 10 million (40%) were poor compared with the national average of 37%. Poverty is most pronounced in rural areas which depend for their livelihood on agriculture, especially rice cultivation. Although the incidence of poverty is higher in the highlands (55% vs 37%), there are 25% more poor people in the densely populated rural delta (5.5 vs 4.4 million).

<table>
<thead>
<tr>
<th>Area</th>
<th>Population (million)</th>
<th>Poverty Incidence (%)</th>
<th>Poor Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Population and Poverty in the Red River Basin
Reducing poverty, sustaining economic development and improving management of natural resources remain challenges in the Red River basin. From an economic point of view, the most important challenge is to further increase agricultural productivity and reduce poverty in rural areas, despite the high population density and the consequently very small and scattered land holdings. The scope for expanding the cultivated area has been nearly exhausted. To lift and keep poor households out of poverty, it is necessary to increase and maintain agricultural productivity. Labour absorption in other sectors is not likely to be sufficient to keep pace with the reduction in the agricultural labour force that would be necessary to reduce the pressure on land. For many people, rice self-sufficiency is still the immediate way out of hunger and poverty. Because the poorer farmers typically live at the end of the water distribution system and in low-lying areas with poor drainage, rehabilitating irrigation and drainage infrastructure and improving water management is therefore directly targeting poorer farmers.

The Government has recognized the need to shift away from the past largely supply-driven approach, with a heavy focus on investment targets determined at central level, to a more demand-driven decentralized approach. The Government has also made a start with adopting integrated water resources management in river basins. Most significant in this process was the adoption of the Water Resources Law (WRL) in 1998. The National Water Resources Council was established in 2000 under the WRL to advise on national water resource management issues. River basin organizations are being operationalized to improve and integrate water resources management in the large Mekong, Dong Nai and Red River Basins. In November 2002, the Government took another important step by transferring the important stewardship and regulatory functions of water resources management to the new Ministry of Environment and Natural Resources (MNRE). The Ministry of Agriculture and Rural Development (MARD) has retained operational water resource management and service delivery functions in the key flood control, irrigated agriculture and rural water supply and sanitation subsectors.

The need to rehabilitate and upgrade the water resources infrastructure in the Red River Delta (the Delta) prompted the Government of Viet Nam to seek Asian Development Bank (ADB) assistance in the late 1980s. In response, ADB provided a $75 million loan in 1993 for the Irrigation and Flood Protection Project and a $60 million loan in 1994 for the Red River Delta Water Resources Sector Project (RRDSP). The main component of the first project was to rehabilitate the dyke providing flood protection for Hanoi. The objectives of the RRDSP were to upgrade and rehabilitate irrigation and drainage systems in the Red River delta. In 2002, ADB provided a loan of $70 million in 2001 for the Second Red River Basin Sector Project (SRRBSP), a follow-on project to the RRDWRSP. The SRRBSP is co-financed by AFD through a $30 million loan and by the Government of the Netherlands through a $10.6 million grant.

### 2 The Red River Delta Water Resources Sector Project (RRDSP)

Implementation of the project commenced in 1995 and ended in 2001. RRDSP included three components: (i) upgrading and rehabilitating water resources infrastructure, (ii) strengthening operational management of the Bac Hung Hai irrigation and drainage system—the largest in the basin—and (iii) enhancing environmental monitoring capacity. A $1.4 million advisory technical assistance (TA) complemented the RRDSP to strengthen the capacity of sector agencies in planning, design, construction, and the management of irrigation and drainage systems.

The RRDSP improved irrigation and drainage systems serving an area of about 530,000 ha benefiting around 2.3 million farm households. Works undertaken under the project included construction or rehabilitation of pumping stations, drainage outfalls, irrigation intake sluices and irrigation and drainage canals. ADB’s Project Completion Report (PCR) of 2002 concluded that the investments have indeed addressed important irrigation and drainage constraints.

However, the PCR concludes that the economic returns to project investments are lower than originally estimated. Irrigation performed better than drainage subprojects. The lower returns to investments in drainage subprojects were attributed to: (i) drainage generally benefits the summer wet season rice crop but not the spring dry season crop; (ii) the relatively high cost per area drained; (iii) the virtual absence of flood-inducing major storms since 1994; and (iv) project investments were limited to the main drainage system (or part of it) without addressing constraints in the secondary and tertiary drainage systems.

Despite the low apparent returns, farmers interviewed during the Project Completion Mission generally reported favourably on the drainage subproject facilities. Overall, the PCR rates the RRDSP as successful.

Several important lessons, learned through implementation of the first RRDSP, were considered during the design of the follow-on SRRBSP. Getting the design of system rehabilitation and improvement right is the key to subproject performance and impact. The RRDSP employed a traditional engineering approach, focusing almost entirely on primary infrastructure. Because of inadequate investments in the secondary and tertiary canal systems, system performance has remained below expectations resulting in the inability to fully capitalize on project investments.

Therefore future projects need to: (i) ensure parallel downstream investments are made in a timely manner, (ii) deploy a more holistic and participatory subproject preparation approach involving primary stakeholders and (iii) base project planning on a river basin development approach within an overall...
3 The Second Red River Basin Sector Project (SRRBSP)

The objective of this project is essentially the same as the RRDSP, i.e. improving agricultural performance through improvements in irrigation, better drainage, watershed protection, and flood protection. In addition, the SRRBSP promotes integrated water resource management within the entire Red River basin. Furthermore, the SRRBSP has a sharper poverty focus and promotes stakeholder participation in water management at local and basin levels.

Part A addresses aspects related to integrated water resource management and associated institution building. Part B provides infrastructure improvements and associated rural development support investments at the community level to optimize the benefits from the water services. A sector approach is employed for the implementation of Part B, i.e. investments are screened and appraised against a set of agreed selection criteria.

Part A has five components: (i) support for capacity building for the recently established Red River Basin Organization (RRBO); (ii) public awareness and education programs for water resource management; (iii) a pilot water licensing and wastewater discharge permit systems; (iv) a water quality monitoring network; and (v) project management support.

Part B comprises investments ("subprojects") to improve: irrigation systems and watershed protection in the uplands, (ii) delta irrigation and drainage systems, (iii) flood protection systems in the delta, (iv) complementary project implementation support, and (v) research studies.

Components (i) and (ii) above will comprise two complementary subcomponents: (i) improving water resources infrastructure through civil works and provision of equipment (pumps, gates, etc.); and (ii) rural development support (RDS) through agricultural support services and small-scale water-related infrastructure at community level through a decentralized and participatory approach. Flood protection subprojects may also include RDS subcomponents as needed. The rationale for the RDS activities is that the diverse needs of poor farmers for agricultural improvements and poverty reduction are best met through a participatory process approach.

The SRRBSP is to be implemented over six years beginning in 2002. As of mid-2003, the project is still in its start-up phase with several preparatory works ongoing.

4 The SRRBSP Water Sector Action Plan

The Water Sector Action Plan (WSAP) is required to provide a framework for selecting Part B investment subprojects. Agreement was reached in December 2002 to develop the WSAP in two stages:

- Stage 1 (WSAP1): Selection of systems based on their present performance, poverty levels and the potential for improved performance and increased agricultural production;
- Stage 2 (WSAP2): Selection of subprojects and other interventions based on the results of participatory diagnostic surveys (PDS) of priority systems selected during Phase 1.

This paper presents WSAP1 results and recommends priority delta systems for conduct of PDS to select irrigation and drainage subprojects under WSAP2. Different criteria may now be used to select upland subprojects. The inventory of the dyke system undertaken in 1999 will be used as a basis for further WASP2 development and flood protection subproject selection. The main findings of the analysis and interpretation are:

- Existing and optimum capacities are 1.9 and 3.5 lps/ha (irrigation) and 2.8 and 3.2 lps/ha (drainage) indicating both irrigation and drainage capacities are generic constraints;
- However average rice intensity (total/summer area) was 197% and rice yields were 5.4 T/ha and 4.8 T/ha in spring and summer respectively. High cropping intensities and spring rice yields indicate irrigation is not the limiting production constraint.
- The first RRDSP PCR found drainage subprojects were not as effective as irrigation.
- MARDs design capacities are about 1.8 and 5-6 lps/ha for irrigation and drainage. Thus the optimum capacities, estimated herein, are more than 1.5 times the MARD design standard for irrigation and only half the MARD design standards for drainage.
- The first RRDSP improved only outfalls (pumping stations and sluice gates). The PCR hypothesized that unimproved collection and delivery systems constrained drainage subproject performance and a drainage research study is now under preparation;
- The CPO proposed 16 irrigation and drainage subprojects in 11 polder systems. Twelve subprojects (75%), in 7 systems, and a further five systems are now recommended for priority consideration to develop the Stage 2 WSAP and select the non-core subprojects.

The present analysis is based on system data (Table 2) derived from the following sources:
97 – 01 agricultural production estimated from district data by polder system provided by the General Statistics Office (GSO);

Similar estimates of the incidence of poverty in each system explained below and;

Latest MARD data (March 2003) on irrigation delivery and drainage evacuation capacities for 27 systems. The small Yen Lap, Uong Bi and Dong Trieu schemes were excluded.

Both the Chi Linh and North Ninh Binh (including the Hoang Long flood retention area) systems exhibit relatively low productivity of land despite high pump capacities. They were both found to be outliers as the significance of the land productivity and capacity association was improved by their exclusion despite the loss of 2 degrees of freedom. The North Ninh Binh and upland Chi Linh systems were excluded from further analysis.

There is widespread belief that Vietnamese irrigated agriculture is not achieving its potential.\(^7\) Of 4 million hectares (mha) of cultivated rice land, 3 mha was found to be equipped with some kind of irrigation but only 2 mha was irrigated. Poor performance was attributed to incomplete systems, design deficiencies, deterioration of infrastructure and poor operation (but not water shortage). National rice yields were reported to be 70% of those achieved in China.

The 25 delta systems analysed grew 566,561ha of dry season rice in spring and 585,658ha in the summer wet season. Thus the average cropping intensity (CI = total rice area/summer area) was 197%. Soc Son is much lower (168%) but North Nam Ha Song Cau and Ba Vi are the only other systems with CIs below 190% indicating irrigation capacity constrains agricultural production. South Yen Dung is the only system with a large CI (223%) indicating a drainage constraint. Average rice yields were 5.4T/ha, in the spring dry season, and 4.8T/ha in the summer wet season. While this may be due to seasonal weather differences, especially during ripening, it may also indicate a generic drainage constraint. Table 3 summarizes the impact of irrigation service on rice production. IDMCs do not keep similar data on drainage services.

Table 3 indicates the downstream end of Dan Hoai system received a lower level of irrigation service in 2002. Both spring and summer rice yields were slightly lower at the downstream end of the system indicating irrigation and drainage were mild constraints. However the spring area was slightly higher than summer area indicating drainage, rather than irrigation, was the limiting constraint at the downstream end of the system (despite 2002 being about a one-in-three dry year\(^8\)). Irrigation is essential in the dry season which implies downstream farmers compensate for poor official service by re-pumping return flows. Thus MARD may well be justified in using an irrigation design standard of only 2.3 lps/ha as system efficiency will be relatively high. This discussion indicates land, and not water, may be limiting in the RRD and drainage capacity, rather than irrigation, is the more likely generic constraint limiting system performance.

Table 2 indicates average irrigation delivery and drainage evacuation capacities are only 1.9 & 2.8 lps/ha respectively. While the systems can supply 83% of the irrigation design standard (2.3 lps/ha) they have only about half the preferred drainage capacity (5 to 6 lps/ha). There are also large variations between systems. Irrigation delivery capacities range from 0.3 (Soc Son) to 5.8 lps/ha (Nghia Hung). Drainage evacuation capacities range from only 0.2 (North Duong) to 7.6 lps/ha (Song Nhue). Thus there is an apparent need to invest in increasing both irrigation and drainage capacities (apart from rehabilitating existing infrastructure).

### Table 2
**Irrigation Service and Rice Production; Dan Hoai System 2002**

<table>
<thead>
<tr>
<th>Irrigation Service</th>
<th>Downstream Commune</th>
<th>Spring Rice Crop</th>
<th>Summer Rice Crop</th>
<th>Cropping Intensity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area (ha)</td>
<td>Yield (T/ha)</td>
<td>Area (ha)</td>
<td>Yield (T/ha)</td>
</tr>
<tr>
<td>Full</td>
<td>56%</td>
<td>4,749</td>
<td>6.1</td>
<td>4,762</td>
</tr>
<tr>
<td>Partial</td>
<td>85%</td>
<td>1,810</td>
<td>6.1</td>
<td>1,892</td>
</tr>
<tr>
<td>None</td>
<td>100%</td>
<td>297</td>
<td>5.8</td>
<td>281</td>
</tr>
</tbody>
</table>

Table 3 indicates average irrigation delivery and drainage evacuation capacities are only 1.9 & 2.8 lps/ha respectively. While the systems can supply 83% of the irrigation design standard (2.3 lps/ha) they have only about half the preferred drainage capacity (5 to 6 lps/ha). There are also large variations between systems. Irrigation delivery capacities range from 0.3 (Soc Son) to 5.8 lps/ha (Nghia Hung). Drainage evacuation capacities range from only 0.2 (North Duong) to 7.6 lps/ha (Song Nhue). Thus there is an apparent need to invest in increasing both irrigation and drainage capacities (apart from rehabilitating existing infrastructure).

<table>
<thead>
<tr>
<th>RRDSP Subproject</th>
<th>Cost ($million)</th>
<th>Service Area (ha)</th>
<th>Capacity (cu m/hr)</th>
<th>Duty (lps/ha)</th>
<th>Unit Cost ($/lips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Khai Thai</td>
<td>3,085</td>
<td>4,200</td>
<td>75,600</td>
<td>5.00</td>
<td>147</td>
</tr>
<tr>
<td>Yen Lenh</td>
<td>2,789</td>
<td>4,472</td>
<td>78,000</td>
<td>4.85</td>
<td>129</td>
</tr>
<tr>
<td>South Ninh Binh</td>
<td>1,849</td>
<td>14,010</td>
<td>188,000</td>
<td>3.73</td>
<td>35</td>
</tr>
<tr>
<td>Co Do Van Thang</td>
<td>1,884</td>
<td>6,035</td>
<td>96,000</td>
<td>4.42</td>
<td>71</td>
</tr>
<tr>
<td>Huu Bi 2</td>
<td>2,147</td>
<td>11,250</td>
<td>86,400</td>
<td>2.13</td>
<td>89</td>
</tr>
<tr>
<td>Vinh Tri 2</td>
<td>2,324</td>
<td>20,006</td>
<td>90,180</td>
<td>1.25</td>
<td>93</td>
</tr>
<tr>
<td>Do Neo</td>
<td>2,553</td>
<td>3,910</td>
<td>72,000</td>
<td>5.11</td>
<td>128</td>
</tr>
<tr>
<td>Van Thai</td>
<td>2,186</td>
<td>4,329</td>
<td>75,600</td>
<td>4.85</td>
<td>104</td>
</tr>
<tr>
<td>Kim Doi - Trinh Xa</td>
<td>2,775</td>
<td>18,000</td>
<td>50,400</td>
<td>0.78</td>
<td>198</td>
</tr>
<tr>
<td>Soc Son</td>
<td>1,875</td>
<td>2,789</td>
<td>38,880</td>
<td>3.87</td>
<td>174</td>
</tr>
</tbody>
</table>
4.1 Agricultural Productivity and System Capacities:
Statistical associations between system irrigation diversion and drainage outfall capacities and the agricultural productivity of land were explored using simple linear, quadratic, semi-log and exponential (log-log) productivity functions. Exponential productivity functions proved the most significant for all applications. Surprisingly there was no significant difference between pumped and gravity capacity for either irrigation or drainage. Thus the analyses were based on total capacities. Regression analysis was used to estimate the following productivity functions:

\[ P = 8.5052D^{0.157569}, \quad R^2 = 0.426 \quad \text{and significance} = 0.04\% \]
\[ P = 8.4380I^{0.188945}, \quad R^2 = 0.395 \quad \text{and significance} = 0.08\% \]
\[ P = 8.1712I^{0.122754}D^{0.109789}, \quad R^2 = 0.553 \quad \text{and significance} = 0.015\% \quad \text{(Eq 1)} \]

where:
- \( P \) = productivity of land (T/ha) = annual production/crop area
- \( I \) = irrigation delivery capacity (lps/ha) = total irrigation capacity/crop area
- \( D \) = drainage delivery capacity (lps/ha) = total drainage capacity/gross area

Equation 1 is illustrated in Figure 1. It explains more than 55% of the variation in agricultural productivity, over the period 1997 to 2001, and is statistically significant at the 0.015% level. This is a slight improvement over the previous 2001 function (\( R^2 = 0.552 \) vs \( R^2 = 0.546 \)). The significance of the drainage function is, however, increased considerably (\( R^2 = 0.462 \) vs \( R^2 = 0.362 \)) while that of the irrigation function diminished commensurately (\( R^2 = 0.395 \) vs \( R^2 = 0.464 \)). These results are perplexing as 2001 and 1997 were particularly wet and dry respectively. Thus the original 2001 production function might have been expected to overestimate the effectiveness of drainage capacity rather than irrigation. Nevertheless the above production functions indicate irrigation capacity remains a more significant determinant of agricultural productivity than drainage capacity (exponent = 0.122754 vs 0.109789). Limited drainage collection and delivery capacity may be restricting the effectiveness of drainage outfall capacity.

![Figure 1](http://library.wur.nl/ebooks/drainage/drainage_cd/keynote%20dat%20134.html)

**Figure 1** WSAP Production Function \( P=8.1712 I \)

4.2 Cost of Pumps:
Capital cost influences optimum pump capacity. Table 4 summarizes relevant Red River Delta Sector Project subproject data. While irrigation capacities were reasonably consistent the design drainage duty varied considerably from less than 1lps/ha to more than 5lps/ha. The rationale for these large variations is not immediately apparent and SRRBSP should consider adopting a uniform drainage capacity.

Table 4 also indicates the unit cost of pumps varied considerably from 35 $/lps to nearly 500 $/lps. This variation is not, however, due to expected economies
of scale as there is no statistical association between capital cost and pump capacity \( (R^2 = 0.002) \). The three core subprojects \((\$307/ha)\) cost three times the non-core subprojects \((\$103/ha)\). In the absence of adequate explanations, for these large variations in cost, the present analysis was based on the average unit cost of RRDSP pumped subprojects \((\$119/lps)\). Sensitivity analysis was undertaken to estimate the impact of higher costs \((\$200/lps)\).

### 4.3 Optimum Capacities:

The methodology is summarized below:

- The PCR productivity of rice is \(\$110/T\) and production costs are about 40% of GVP;
- The present value of investing 1 unit/annum @ 12% IRR over 25 years is 7.843; [9]
- Typically electricity usage in the RRD is about 300 kWh/ha. The subsidized cost of electricity (VND 660/kWh) is reported to be only a third of its economic cost. Thus the economic cost of operation is \(\$39.6/ha\) or 7% of the capital cost of the average irrigation and drainage capacity \((4.7 \text{ lps/ha} @ \$119/lps = \$559/lps)\);
- The PCR for RRDSP allowed 10% of total capital cost every five years for major repair or equipment replacement. This is equivalent to 1% of direct capital costs per annum. Thus O&M costs are taken herein as 8% pa of direct capital costs of pumps;
- Capacities are optimum when marginal benefits equal incremental costs ie the slope of the production function \(= \frac{dP}{dI} = \frac{8.4380x0.1889I-0.811055}{119/ (7.843x66)} = 0.3741, I_{opt} = 6.0 \text{ lps/ha} \) and \(P_{opt} = 11.8T/ha\) and

\[
\frac{dP}{dD} = \frac{8.5052x0.1576D-0.842431}{119/ (7.843x66)} = 0.3741, D_{opt} = 4.5 \text{ lps/ha} \) and \(P_{opt} = 10.8T/ha\)

Either irrigation capacity of 6.0 lps/ha or drainage capacity of 4.5 lps/ha optimized agricultural production in 1997 to 2001 (3.1 and 2.5 lps/ha respectively for a unit pump cost of \(\$200/lps\)). Similarly for the combined production function Eq 1: \(l_{opt} = 3.5 \text{ lps/ha}, D_{opt} = 3.2 \text{ lps/ha}\) and \(P_{opt} = 10.8T/ha\). \((l_{opt} = 1.8 \text{ lps/ha}, D_{opt} = 1.6 \text{ lps/ha} \) & \(P_{opt} = 9.2T/ha\) for a unit pump cost of \(\$200/lps\). The range 1.8 to 3.5 lps/ha is a common irrigation capacity (corresponding to 40 to 80% efficiency) but the optimum drainage capacity of 1.6 to 3.2 lps/ha is very low compared with MARDs design standard (5 to 6 lps/ha). The results confirm irrigation delivery capacity is presently more effective than the capacity of drainage outfalls in contributing to the productivity of land.

### 4.4 Interpretation of Results:

PCR economic reevaluation of RRDSP core subprojects also found drainage did not perform as well as irrigation (Table 4) because: (i) drainage benefited the wet season (summer) crop only; (ii) Phan Dong unit costs were high; (iii) the virtual absence of flood inducing major storms in the period 1995 to 2001 and (iv) investments were limited to main drainage systems without addressing lower level constraints. These explanations for poor drainage performance are considered below.

First limited irrigation delivery capacity might explain why farmers were unable to take full advantage of improved drainage to increase dry season (spring) rice production. This implies all drainage subprojects should assess current irrigation service levels and provide increased delivery capacity and other improved services where required.

Second Table 5 confirms Phan Dong unit costs were high at \(\$771/ha\) or \(\$501/lps\). Table 4 also presents hypothetical pump subproject EIRRs adjusted to reflect: (i) average unit cost of only \(\$119/lps\) and (ii) the full economic cost of operation and maintenance.

**Table 4 Economic Reevaluation of RRDS Pumped Core Subprojects**

<table>
<thead>
<tr>
<th>Core Subproject</th>
<th>Area (ha)</th>
<th>Cost ($/ha)</th>
<th>EIRR (%)</th>
<th>Duty (lps/ha)</th>
<th>Benefit ($/ha/yr)</th>
<th>EIRR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thanh Diem Irrigation</td>
<td>7,574</td>
<td>492</td>
<td>17.1</td>
<td>1.32</td>
<td>95.6</td>
<td>52.6</td>
</tr>
<tr>
<td>Phan Dong Drainage</td>
<td>2,267</td>
<td>771</td>
<td>4.3</td>
<td>1.54</td>
<td>66.4</td>
<td>28.1</td>
</tr>
<tr>
<td>Trieu Duong Drainage</td>
<td>3,958</td>
<td>336</td>
<td>6.1</td>
<td>2.19</td>
<td>33.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Weighted Average</td>
<td>47,799</td>
<td>361</td>
<td>12.1</td>
<td>NA</td>
<td>53.6</td>
<td>15.9</td>
</tr>
</tbody>
</table>

Table 5 indicates accounting for the average unit cost improves economic performance of both the four core subprojects (and RRDSP) in general and Phan Dong in particular. However accounting for the full economic cost of O&M further reduces the Trieu Duong EIRR because of the relatively small benefit of increased agricultural production. Table 4 also confirms the poor performance of drainage relative to the irrigation subproject.
Third, from 1995 to 2001, the mean annual rainfall at Hanoi is reported to have been about the same as the long term average for 1890-1990 (1,690 mm) favouring the effectiveness of neither irrigation delivery nor drainage evacuation capacity.

Finally, the lack of sufficient drainage collection and delivery capacity remains the most likely explanation of poor main drainage performance together with a possible lack of irrigation delivery capacity to benefit by increasing dry season (spring) rice production.

4.5 System Ranking and Selection:
The ranking methodology is described below:

Eq 1 was used to estimate: (i) the incremental irrigation and drainage capacities required to increase present agricultural productivity to the optimum of 10.8T/ha and (ii) the incremental agricultural productivity resulting from increasing present irrigation and drainage capacities to the optimums of 3.5 and 3.2lps/ha respectively; This then allowed estimation of economic costs (C) and benefits (B) and calculation of two alternative benefit cost ratios from \( BCR = \frac{7.843 (66B - 0.08 x 119C)/119C)}{}; \) The average BCR was then multiplied by system poverty incidence (p) to give the average poverty impact ratio \( PIR = p \times BCR \) which was used to rank the systems.

Table 6 indicates Soc Son has the highest PIR. However, in view of its low agricultural productivity, the GOV is reported to have designated Soc Son as an industrial zone and the crop area has contracted from nearly 10,000 ha in 2001 to only 1,160 ha at present. MARD have now confirmed Soc Son should be excluded from further consideration. The following systems are now proposed for further consideration during preparation of Phase 2 of the WSAP.

Box 1: Systems Proposed for PDS during WSAP Stage 2

<table>
<thead>
<tr>
<th>RRD System</th>
<th>BCR</th>
<th>PIR</th>
<th>CPO Subprojects</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Yen Dung</td>
<td>2.11</td>
<td>1.07</td>
<td>1</td>
</tr>
<tr>
<td>Song Cau</td>
<td>2.11</td>
<td>1.07</td>
<td>1</td>
</tr>
<tr>
<td>Ba Vi</td>
<td>1.80</td>
<td>0.83</td>
<td>0</td>
</tr>
<tr>
<td>North Duong</td>
<td>2.04</td>
<td>0.78</td>
<td>1</td>
</tr>
<tr>
<td>Phu Sa</td>
<td>1.85</td>
<td>0.78</td>
<td>2</td>
</tr>
<tr>
<td>Lien Son</td>
<td>1.72</td>
<td>0.71</td>
<td>2</td>
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<tr>
<td>Thuy Nguyen</td>
<td>1.75</td>
<td>0.64</td>
<td>0</td>
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<tr>
<td>Bac Hung Hai</td>
<td>1.53</td>
<td>0.57</td>
<td>3</td>
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<tr>
<td>Kinh Mon</td>
<td>1.51</td>
<td>0.47</td>
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</tr>
<tr>
<td>An Thuy</td>
<td>1.17</td>
<td>0.43</td>
<td>0</td>
</tr>
<tr>
<td>An Kim Hai</td>
<td>1.33</td>
<td>0.42</td>
<td>0</td>
</tr>
<tr>
<td>North Nam Ha</td>
<td>1.38</td>
<td>0.42</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>

Box 1 shows use of the 1997 to 2001 production function has improved the potential for agricultural production increases through provision of increased system irrigation and/or drainage capacity. Nearly half the systems considered (12 of 25) now offer attractive economic returns (average BCR > 1). Systems may be divided into three groups:

- **CPO proposed 12 (75%) subprojects in 7 ranked systems (BCR > 1): South Yen Dung, Song Cau, North Duong, Phu Sa, Lien Son, Bac Hung Hai & North Nam Ha;**
- **CPO did not propose subprojects in the other 5 ranked systems (BCR > 1): notably Ba Vi but also including Thuy Nguyen, Kinh Mon, An Thuy and An Kim Ha and;**
- **CPO proposed four (25%) subprojects in 4 unranked systems (BCR < 1): Tien Lang, Hai Hua, Bac Ninh Binh and South Thai Binh. The only change from the previous ranking is that Tien Lang has now joined this group of less promising systems.**

4.6 Direct Economic Analysis:
The WSAP production function and GSO production data facilitate economic analysis of subprojects. There is still a risk the predicted benefits fail to eventuate but the analysis provides a transparent consistent method of ranking subprojects and identifying those that are unlikely to generate enough benefits to justify the investment. PDS may still be required to reformulate subprojects where preliminary analysis indicates a marginal BCR. The following example uses District data to illustrate the method. The benefit cost ratio (BCR) is estimated for the minimum discount rate (IRR) of 12%pa. Availability of Commune data would improve confidence in the results.

4.7 Example: Kinh Thanh 2 Drainage Subproject – North Nam Ha System
From the economic reevaluation of RRDSP in the PCR the price of rice is $110/T, production costs are about 40% of GVP and the gross margin or NVP is $66/T;

The Ha Nam Province Yearbook provides 97-01 agricultural production data in Binh Luc & Thanh Liem Districts which encompasses Kinh Thanh area in NNH system:

- Thanh Liem average spring rice yield was 5.26T/ha & cropped area 7,426ha. Summer rice yield was 4.55T/ha and cropped area 6,970ha (CI = 207%);
- Binh Luc average spring rice yield was 5.32T/ha and cropped area 9,106ha. Summer rice yield was 4.65T/ha and cropped area 9,246ha (CI = 198%);
- Regression analysis investigated rice area trends. For Thanh Liem the most significant quadratic functions indicate summer and total (spring + summer) areas will stabilize in 2006 at 7,154ha and 14,626ha respectively indicating a potential to increase summer area by 318ha. Binh Luc summer area already exceeds its spring area indicating irrigation, rather than drainage, constrains;
- Regression indicates Thanh Liem summer yield will be 5.1T/ha in 2005;
- Total rice productivity averaged 9.82T/ha (vs 5.30 + 4.61 = 9.91T/ha);

Existing Co Dam (37cumec), Kinh Thanh (19cumec) & Vinh Trang (64.5cumec) PS currently drain 35,045ha @ 3.44lps/ha. The Nam Dinh Consulting Company report five irrigation PS (total capacity 34.55cumec) serve 9,071ha of which only 6,671ha is cropped. Thus irrigation capacity is 5.2lps/ha (vs 2.2lps/ha in the WSAP). The two Kinh Thanh PS will drain 11,814ha of which 8,437ha (71%) is cropped. Unit cost of Kin Thanh 2 (34cumec) is only $4.8million/35,045 = $137/ha. The future situation is:

- Kin Thanh: 53cumec draining 11,814ha @ 4.49lps/ha
- Co Dam: 37cumec draining 8,500ha @ 4.35lps/ha
- Vinh Trang: 64.5 cumec draining 14,731ha @ 4.38lps/ha
- Total: 154.5cumec draining 35,045ha @ 4.41lps/ha

The WSAP production function provides the following estimates of rice production:

- \[ P = 8.1712 \times 5.2^{0.122754} \times 3.44^{0.109789} = 11.46T/ha \]
- \[ P = 8.1712 \times 5.2^{0.122754} \times 4.41^{0.109789} = 11.77T/ha \]

Thus alternative estimates of incremental rice production are: 1st method = 11.77 − 9.82 = 1.9T/ha, 2nd method = 11.77− 11.46 = 0.3T/ha and the average = 1.1T/ha;

- The estimated incremental O&M costs are $149,500/annum with the subproject;
- Average BCR = 7.843[66(35,045x1.1 + 318x5.1) − 149,500]/4,800,000 = 4.1
- Lowest BCR = 7.843[66(35,045x0.3 + 318x5.1) − 149,500]/4,800,000 = 1.1
- \[ \frac{(1+i)^{25}-1}{(1+i)^{25}} = \frac{4,800,000[66(35,045x1.1 + 318x5.1)]-149,500}{66(35,045x1.1 + 318x5.1)-149,500} = 1.9186 \]
- \[ \frac{(1+i)^{25}-1}{(1+i)^{25}} = \frac{4,800,000[66(35,045x0.3 + 318x5.1)]-149,500}{66(35,045x0.3 + 318x5.1)-149,500} = 7.3684 \]

Therefore by iterative solution i = average IRR = 52% and lowest IRR = 13%

5 The Proposed Drainage Research Study

The drainage research study is to develop and pilot field test a participatory process to assess the performance of selected pumped drainage subprojects, identify and quantify the major constraints to increased agricultural production, prepare conceptual improvement designs, specify detailed design requirements and document the participatory design process.

A local research institute/university will be engaged to implement the study over about nine months commencing around 1 March 2004. To ensure the action research meets international standards, and leads to a publication in an international research journal, the local institute will associate with a recognized international research institute. To ensure adequate participation of local stakeholders, local institutes are also encouraged to associate with a suitable NGO(s). The successful drainage research consortia will have a demonstrated capacity for participatory action research in agricultural drainage preferably in the Red River Delta.
DEVELOPING A BASIN FRAMEWORK FOR PRIORITIZING INVESTMENT RESOURCES INFRASTRUCTURE IN VIETNAM'S RED RIVER BASIN

The initial working hypothesis, to be tested, is the capacity of lower level drainage collection and delivery systems constrain the performance of pumped outfalls regardless of their evacuation capacity. Nevertheless other possible constraints will also be considered and assessed, e.g. operation of drainage outfalls etc. The proposed action research methodology is to follow a flexible participatory learning process but is likely to involve the following indicative activities:

5.1 Selection of Subprojects:
Two first RRDS drainage subprojects will be selected on the basis of initial appraisal of their relative performance and farmer satisfaction etc;

5.2 Definition of Drainage Catchments and Flood Affected Areas:
This is an essential prerequisite of drainage research requiring the participation of concerned farmers and communes. The delta polder systems are surrounded by dykes that prevent flooding from surrounding rivers. Thus both local rainfall and excess irrigation diversions require drainage from polders. The definition of subproject catchments should include:

• Preliminary definition of the subproject drainage catchments and flood affected areas based on available records, maps and discussions with IDMCs and farmers etc;
• Identification of communes/farmer groups within the specific subproject catchments;
• Confirmation of the subproject drainage catchments, flood affected areas and beneficiaries with the elected Subproject Drainage Committee (see below) and;
• Traverse the perimeter of the preliminary subproject catchments with SDC members to identify and inventory all water intakes to, and outfalls from, the sub-polder.

5.3 Representative Subproject Drainage Committee (SDC):
The DRC will propose and implement a process to identify the main target groups, in the subproject catchment area, and assist them to elect a representative Subproject Drainage Committee (SDC). As well as households in flood affected areas, target groups will include other poor and women headed households. The SDC Chairperson and a majority of its members and other officials should be individual farmers representing the main target groups.

5.4 Initial Orientation Meeting:
The SDC and study team will then meet with IDMC and commune representatives to discuss and agree the main agricultural production constraints within the drainage area and review and revise the study methodology accordingly. They will then prepare an implementation plan including timelines and responsibilities etc.

5.5 Participatory Survey of Drainage System:
The study team and SDC will then jointly undertake a survey of the drainage system from the on-farm level to the river outfall. This will refine the diagnosis of performance constraints, provide the necessary data for hydraulic calculation of system capacity and include the following indicative activities:

• Topographic mapping of the drainage catchment area at a suitable scale & contour interval. If suitable maps are not available this will require levelling of the area;
• Topographic survey of existing drains & preparation of longitudinal & cross sections;
• Assessment of the wet season rugosity (Manning’s “n”) of drainage channel;
• Inventory and survey of drainage structures, junctions, culverts and bridges etc to determine their hydraulic characteristics for calculation of system capacity.

5.6 Water Balance Measurements:
The study team and SDC will also jointly measure and calculate the weekly water balance within the drainage catchment area using a simple input-output model. This will involve the following complimentary activities:

• Installation, calibration and measurement of irrigation and drainage inflows;
• Installation and daily measurement of rain gauges at representative locations;
• Daily potential evapo-transpiration estimates from a representative station;
• Daily operation records (hours) for each pump in the outfall pumping station and;
Daily records of intake and minimum and maximum river water levels at the outfall.

5.7 Survey of Flooding and Drought:
The study team and SDC will jointly design and conduct a simple survey of the extent and severity of both flooding and drought. The sub-polder catchment area is to be divided into several zones with different levels of irrigation and drainage services based on farmer perceptions of the likely impact on agricultural production. The irrigation zones might be related to the IDMCs service fee assessment (full, partial and no irrigation). Farmer’s assessments of drainage services should be complimented by weekly measurements of the extent, depth and duration of flooding. This requires a network of staff gauges tied to the common survey datum. Any unplanted or unharvested areas will be identified and treated as a separate service zone. The area affected will be measured and the cause of crop failure explained.

5.8 Hydraulic Calculation of Drainage Capacity:
The study team will then calculate the capacity of the sub-polder drainage system, from field level to the outfall, accounting for fluctuations in river levels. The hydraulic model used should be as simple as possible to facilitate design of remaining SRRBSP drainage subprojects. The water balance and flood survey data should be used for model calibration. The model should also be used to assess capacity constraints and the effects of alternative measures to alleviate them.

5.9 Conceptual Designs for Improved Drainage Performance:
Based on capacities and constraints, the SDC will select a number of practical improvement options for further consideration. The study team will prepare alternative conceptual designs, and estimate their costs, to support informed inclusive farmer decision making facilitated by SDC members. Tangible equity cost contributions would enhance decision making. The preferred improvement option should then be agreed by all of the affected farmers.

5.10 Economic Evaluation:
Subproject economics will be reevaluated, and compared with appraisal estimates, using the first RRDSP Project Completion Report Methodology. The potential economics, of further drainage collection/delivery system improvements, will also be evaluated using the SRRBSP Water Sector Action Plan methodology. Both methods require compilation of commune production data, and possible reconciliation with official GSO district data, rather than special surveys of agricultural production.

5.11 Terms of Reference:
Subject to economics the study team will then prepare draft TOR for detailed design of the preferred improvement option selected by the farmers.

Process Documentation and Training: The study team will specify the participatory process in the form of an Implementation Manual for formulation and design of future drainage subprojects. Upon agreement with CPO and PME the study team will conduct a workshop to train about 30 design company staff to use the participatory process and will finalise the IM in the light of comments and feedback received from participants.

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[3] Using the national poverty line of about 35 cents/person/day vs the international standard of $1/person/day.
[4] The population of the Northern Highlands Region is more than 11 million but only 70% of the area is in the RRB.
[5] The high investment cost is largely because of the higher pumping rate required per hectare (up to 6 litres/sec/ha for drainage compared to about 2 litres/sec/ha for irrigation).
[6] Non-agricultural benefits were not been taken into account; these are likely to be more significant for drainage subprojects than for irrigation subprojects.
[8] The data analysis and interpretation were confirmed in discussions with staff of the Dan Hoai IDMC
ABSTRACT

Drainage needs to reclaim its rightful position as an indispensable element in the integrated management of land and water. An integrated approach to drainage can be developed by means of systematic mapping of the functions of natural resources systems (goods and services) and the values attributed to these functions by people. This mapping allows the exploration of the implications of particular drainage interventions. In that sense an analytical tool for understanding a drainage situation is proposed. It provides a framework for discussion and negotiation of trade-offs related to the different functions and values related to drainage. In that sense it is a communication, planning and decision-making tool. The tool is called DRAINFRAME, which stands for Drainage Integrated Analytical Framework.

1 Introduction

Drainage has almost disappeared from the international water discourse as a theme and a concern. It does not appear in important recent water policy documents and investments in drainage are going down, despite substantial potential for enhanced crop production through improved drainage. Drainage’s importance as an inherent element of the hydrological cycle and of natural resources management and rural development strategies needs to be reclaimed. A study was conducted in 2002 and 2003 under the World Bank-Netherlands Partnership Programme – Environment Window (BNPPEW) called Agricultural Drainage: Towards an Interdisciplinary and Integrated Approach. The first phase was a set of six country case studies covering different drainage situations: Bangladesh, Egypt, Indonesia, Mexico, the Netherlands and Pakistan. The final phase of the study uses the country case studies as its base material in an attempt to answer the question: what are the contours of an integrated approach to drainage?

The objectives of the study were the following.

Improve understanding of drainage systems as socio-technical and environmental systems by developing, at the macro-level, a typology of drainage situations including both technical/physical and social/managerial criteria, and, at a micro-level, a strategy to understand and deal with local diversity in the nature, function and organisation of drainage. Document and evaluate different institutional models in use in the drainage sector at both users and agency levels, including an evaluation of the appropriateness of users organisation approaches developed in the irrigation sector, by studying cases of the application of ‘irrigation models’ in drainage projects;

By generating this knowledge, contribute to improved design and implementation of interventions in the drainage sector, to meet users’, managers’ and funders’ objectives to produce integrated and sustainable drainage development. This paper summarizes the outcome of the study. The full report will appear as a World Bank publication.

2 Agricultural Drainage: Towards an Integrated Perspective

Drainage, with few exceptions, is generally considered from a narrow sector angle. A review of the global experience shows a
2.1 Impacts:
Drainage has many impacts, of which the main categories are agricultural impacts, public health impacts, protection of buildings and roads, and ecological impacts. In planning and designing drainage interventions these impacts are not equally addressed. The following are conclusions drawn from the country case studies:

- Drainage’s impact on agricultural production and productivity can be substantial, agricultural drainage investments may have short payback periods, but drainage planning needs a relatively long planning horizon and flexibility because drainage needs may change over time.
- Drainage’s contribution to public health, drinking water supply and sanitation can be substantial but is generally not acknowledged, and depends on the quality of operation and maintenance of the drainage system.
- Drainage’s importance for the protection of buildings and roads is under-emphasised. The appreciation of land value and the introduction of ‘sites-and-services’ approaches might be considered in drainage evaluation and planning.

Agricultural drainage has often had negative effects on ecological functions and has also acted as a conduit for the spread of wastewater and other pollutants. However there are examples of drainage enhancing ecological functions, but substantially more emphasis needs to be put on mitigating drainage’s negative effects and balancing its impact on production functions with that on other functions.

2.2 Diversity
Drainage situations exhibit diversity in terms of the combinations of natural resources systems functions affected, scale, historical evolution, environmental factors (climate, elevation, soil, groundwater quality, biology and ecology, vegetation cover), and social factors (prosperity and values, distribution of power and cultural background, socio-political structure). Listing of diversity in drainage situations encountered across the world and the variety of factors causing it shows that ‘drainage’ is a container concept, covering an extremely varied set of instances. Talking about drainage in general is therefore hardly useful – neither at an analytical level nor at an intervention level. A context-specific approach is required for both analysis and intervention.

2.3 Institutional trajectories
The starting point for enhancing institutional performance and/or institutional reform is quite different in different contexts. Three trajectories of drainage development can be distinguished:

1) focussed government initiatives,
2) spontaneous development of drainage through local initiative, and
3) incomplete or stagnating drainage development. The importance of local user initiatives may be underestimated because underreported in developing countries, and would merit closer study. Reform of centralised drainage bureaucracies is an issue that occurs only in a very limited number of cases.

Much more common is the situation in which drainage received limited attention and priority, and leads a fledgling existence. Though governments are necessary partners in the transformation of the approach to drainage, it is unlikely that central governments will be the main initiators of such an approach. Different mechanisms and strategies will have to be found to put drainage on a firmer footing. There are considerable hurdles in the present governance framework to make local users organisations effective on a large scale and new forms of regulation are required. There is a need to pitch ‘integrated’ drainage organisation at a higher level than the local users groups.
2.4 Drivers for change
The drivers for a change towards an integrated approach to drainage are the following:

- The increasing complexity of water control systems,
- The conflicts of interest in many water management systems,
- Re-prioritisation of land and water management objectives because of changing societal values, and
- The declining lustre of drainage as a professional sector and the need for the professional drainage community to rethink its position.

Based on this analysis of the present situation with regard to drainage a new, broader definition of drainage, less exclusively focussed on agricultural productivity, can be formulated as a first step towards an integrated approach.

Drainage consists of the processes of removing excess surface water and managing shallow water tables – by retaining and removing water -- and of managing water quality to achieve an optimal mix of economic and social benefits while safeguarding key ecological functions.

More specifically, integrated management of drainage would mean the following:

- Acknowledgement of the multiple objectives served by the management of excess surface water and shallow water tables and the disposal of drainage water, and of the need to reproduce the resource system over time (resource sustainability).
- Adaptation of drainage interventions to the natural resources system, taking into account the diversity of drainage situations and aiming at optimisation of goods and services produced by the natural resources system (understanding and managing diversity and multi-functionality)
- Inclusive forms of (drainage) governance/decision-making, having representation of the different stakeholders (democratisation).
- Improvement of the scientific knowledge base, implying a major shift in the focus of the scientific community towards the fields of sustainability, multi-functionality, and stakeholder representation in governance and decision making.

3 Mapping Diversity and Multi-Functionality: A Framework for Drainage Functions and Values Analysis and Assessment

3.1 Typologies of drainage situations
Diversity does not imply randomness. It is possible to distinguish between types of drainage situations at different levels of aggregation or geographical scale. The description of a drainage situation (or drainage type) is based on a set of characteristics and relationships that define the main and common features in a particular area. A finite number of drainage types can be described at any given scale-level. A series of drainage types at a particular scale-level forms a typology. Three levels of analysis can be defined.

- The hydro-ecological region is a macro-scale characterisation focussed on the physical characteristics of a region, broadly defining the main drainage issues at hand and drainage interventions that may be appropriate. Typologies at this level serve policy development.
The landscape level. A landscape provides a coherent set of functions that deliver goods and services for society (agricultural production, water supply and sanitation, tourism, navigation, fisheries, etc). Groups in society value these good and services and become stakeholders. Drainage interventions aim to enhance certain functions for the benefit of these stakeholders. Institutional arrangements are created to manage these interventions. Landscape level typologies serve the planning of such drainage interventions.

A system-level typology provided detailed and locally specific descriptions of drainage systems. Typologies at this level serve field-level design and implementation of drainage interventions in particular land and water resources control systems.

Landscapes are the logical level for integrated planning of drainage interventions, and the focus of the study. The landscape concept as elaborated in the study closely resembles the ecosystem approach as adopted in the Convention of Biological Diversity.

3.2 The DRAINFRAME tool
To operationalise an integrated approach to drainage a tool called Drainage Integrated Analytical Framework (DRAINFRAME) is proposed for planning and decision-making purposes. The first element of this tool is a functions and values analysis and assessment at landscape level (though in principle applicable to other levels also). The second element of the tool consist of the specification of the outcomes of that analysis and assessment towards 1) governance, management and finance institutions for drainage, and 2) technology for multi-functionality (see Figure 1).

![Figure 1 Schematic representation of DRAINFRAME](http://library.wur.nl/ebooks/drainage/drainage_cd/keynote%20safwat%20137.html)

A = operationalisation of defined negotiated functions and values; B = institutional requirements of technologies and vice versa.; C = feedback loop for the iterative process of matching institutional and physical design with defined/negotiated functions and values.

The terms ‘Functions’ and ‘Values’ are defined in the context of this analysis as follows: ‘Functions’ is a concept that summarises the products and processes that natural resource systems provide and perform. These functions include production functions, processing and regulation functions, carrying functions, and significance functions. ‘Values’ is the concept through which societal preferences, perceptions and interests with regard to resources are summarised. These values are social, economic and (temporal and spatial) ecological values. ‘Functions’ and ‘values’ are expressions of complex biophysical and societal processes, which are the object of study of a large number of scientific disciplines, and which are spoken for by an array of interest groups/stakeholders. A function/value matrix or framework can be considered as a ‘boundary object’: it is a device through which these
differentials become communicable and negotiable across the boundaries of disciplines and interests. Though a lot of science goes into this process as an input, the tool suggests that this ‘optimisation’ is not a straightforward calculating procedure, but a social process in which meanings and interests are negotiated.

The analytical framework for doing a functions and values analysis and assessment is presented in Figure 2. The starting point in this analysis is that people realise the values and utilise the products (goods) and services that are provided by landscapes. In economic terms, society constitutes the demand side, and the resources constitute the supply side. Simply stated, sustainability deals with the equilibrium in supply and demand, now and in the future. Perceived imbalances in this equilibrium trigger institutions to act by managing either the supply from nature or the demand from society, or both. The figure depicts how the need for institutional arrangements, technology and infrastructure, and knowledge and human resources capacity is triggered by a perceived disequilibrium in the relation between supply and demand. The demand for goods and services from nature may surpass the available supply, which leads to a present or expected future problem (e.g. over-exploitation or insufficient supply), or the potential supply may be larger than what is actually being used, representing a development opportunity.

The analysis itself proceeds by a series of analytical steps that look at both the physical and social change processes induced by a particular drainage intervention. Details can be found in the final report (Abdel-Dayem et al. 2003). The tool may also be used for scenario development, exploring the impacts and implications of different (sets of) interventions.

Figure 2  The three subsystems of the socio-ecological system: the natural resources subsystem, the societal subsystem and the land & water control subsystem.

4  The Institutional Dimensions of Drainage: Governance, Management and Finance
The general questions related to drainage institutions hardly differ from those of the rest of the land and water sector. How to design effective institutions to govern drainage in a way to support local demand as well as requirements at regional or basin
level? What are the roles the different actors can play? Who manages which tasks to the benefit of whom? Which is the adequate level for management? Who finances drainage?

However, answering these questions is less straightforward than in other land and water resources sectors because the institutional dimensions of drainage have not received much attention – neither in theory nor in practice. Other caveats are that context-specific approaches are required, implying that general recommendations to adopt particular institutional forms cannot be given. Lastly, not all issues related to drainage governance, management and finance derive from the need for an integrated perspective; there are many issues to be resolved also for drainage ‘as it is’.

The issues that are the focus of discussion in the drainage context are:

- The specific characteristics of drainage, notably its public good character, and the implications for drainage institutions.
- The appropriate scale-level or unit for effective drainage organization.
- Broadening the financial basis for drainage.

5 Specific characteristics of drainage: The specific features of drainage translate into a number of principles for development of drainage governance structures.

- Multifunctional aspects of drainage would require governance structures that either have representation systems where multiple beneficiaries have a voice, or have mechanisms and forums for coordination.
- The unevenly spread demand for drainage requires a diversity of governing units that are able to respond to diversified local demands.
- Technical externalities require arrangements to address negative effects and distribute costs among multiple beneficiaries and different jurisdictions.
- The public and private benefits provided by drainage are highly differentiated, and hence the costs have to be structured and shared accordingly. Due to the public good characteristics of drainage, governing bodies would develop, or rely on, effective collection strategies based on legally assigned authority to enforce legal and financial sanctions.

5.1 The unit of governance and management

Present institutional dynamics in the field of drainage includes trends of decentralisation of government institutions/departments at national level, and upscaling of user’s organisations to higher, intermediate levels. Experience with basin level organisation of coordination, regulatory authorities and private sector involvement is very limited, if not absent. A logical medium-term perspective is to support a polycentric governance structure that allows institutional experimentation and evolution.

5.2 Broadening the financial base

To remedy the poor financial resource base for drainage investment and management, combinations of public funding and cost-sharing arrangements are required. Additional resources need to be raised through introduction or strengthening of the benefit-pay (-say) principle.

There are many institutional challenges to be addressed, depending on the development trajectory as illustrated in Table 1.

Table 1 Drainage development trajectories and institutional issues: some examples
### Trajectories Issues

<table>
<thead>
<tr>
<th>Governance</th>
<th>Focussed government initiative</th>
<th>Users initiated development</th>
<th>Limited or stagnating development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transform highly centralized drainage / irrigation agencies to less centralized ones (implement principle of subsidiarity)</td>
<td>Create an appropriate regulatory structure within which local organizations can operate with sufficient autonomy</td>
<td>Define the institutional space(s) for drainage governance</td>
</tr>
<tr>
<td></td>
<td>Redefine the ‘ownership’ of drainage across sectors and include more constituencies than the agricultural in the planning and decision-making process</td>
<td>Constitutional and collective choice rules for local organizations (representation different stakeholder groups and charter)</td>
<td>Alignment of different constituencies for enhancing attention to drainage</td>
</tr>
</tbody>
</table>

### Management

<table>
<thead>
<tr>
<th>Management</th>
<th>Upwardly accountable public officials and poor maintenance to be transformed into managers responsive to local needs and incentives for better performance</th>
<th>Professionalise management if required, and consider appropriate scale-level of different activities</th>
<th>Support and mainstream local initiatives and practices for drainage management</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Create workable modes of collaboration between agriculture and other departments relevant for addressing multi-functionality</td>
<td>Define and create support services for local organisations</td>
<td></td>
</tr>
</tbody>
</table>

### Finance

<table>
<thead>
<tr>
<th>Finance</th>
<th>Change centralised, highly subsidized into cost-sharing between government and drainage beneficiaries</th>
<th>Define co-financing arrangements between government and local organizations for different aspects of drainage investment and maintenance</th>
<th>Resource mobilization: lobby for allocations in government budgets and/or mobilize private sector capital for investment and/or mobilize resources from beneficiaries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Include other constituencies than farmers in revenue generation</td>
<td>Balance financial contribution, benefits and say.</td>
<td></td>
</tr>
</tbody>
</table>

## 6 Drainage Infrastructure and Operation for Multi-Functionality

An integrated perspective will have implications for the drainage technology that needs to be deployed and the operational procedures that need to be adopted to use it. The physical design and operation of many drainage systems has a long-standing bias towards agricultural productivity. Multipurpose design and operation is still the exception rather than the rule in drainage. Yet if drainage systems are to serve a variety of objectives, from land productivity, to water conservation, to protecting buildings, to public health, then technology design and operation needs to be done differently. This provides a major technical professional challenge. Some examples and issues are the following.

### 6.1 Water retention, water table management and controlled drainage

If the prime meaning of drainage is redefined as comprising the management of shallow water tables, the ability to control water table depth and drainage canal water levels is very important. It allows regulation of soil-moisture for both irrigated and rain-fed crops and enables maintaining of water levels for fisheries, to prevent land subsidence, and other purposes, and also affects soil chemistry. The concept of controlled drainage has been subject to experimentation and proved technically feasible, but the challenge is to develop appropriate low cost, easily manageable water conservation technology. A main problem is how to coordinate the different priorities of different farmers (growing different crops) in the absence of a strong local organization, that is,
the ability to control water tables needs to be matched by the local institutional capacity to balance the different interests.

6.2 Flood management
Drainage and flood management need to be brought closer together at the level of (sub-)basin management, but the same is true at the level of drainage infrastructure design and operation. The capacity to store excess rainfall in the shallow aquifer is an important asset in flood management. In many cases investment in drainage infrastructure will complement flood mitigation strategies. In some cases drainage infrastructure has aggravated floods. This happens when the network of drainage pipes and canals quickly transports storm water to watercourses and rivers and there is no facility to store or slow-down the run-off.

6.3 Re-use and the management of effluent quality
The design of drainage infrastructure affects the quality of the drainage effluent. The quality of drainage water may be affected by high salinity, acidity or by chemical or bacteriological contamination. In the design or operation of drainage facilities the quality of the effluent and the possibility of mixing it or neutralizing it should be given a prominent place, but often this has been neglected. In addition to controlling pollution through using appropriate technology at the source a regulatory framework that controls the disposal of effluent from different sources in a drainage system is a prerequisite.

6.4 Vector control
Drainage infrastructure can have significant effects on vector organisms and improve local sanitary conditions. Yet drainage has in the past also added significantly to health problems, with stagnant water becoming a main source of transmission of diseases. Over the years a number of guidelines and good practices have been formulated that improve drainage’s positive impact on public health, but it is testimony to the isolated position of drainage that these have not been mainstreamed.

6.5 Choice of unit size
Multi-purpose drainage management raises the question of the size of the unit at which drainage is managed. Compartmentalisation into smaller units allows more or less tailor-made solutions to local water issues. This is particularly useful where local variation in drainage conditions and drainage interests is large. The downside however is that as management becomes more tailor-made and fragmented, the organisational requirements get more complicated and the cost of management increases.

6.6 Planning, design and evaluation technologies
Integrated water resources management aims at linking land and water resources in the regional and river basin context and dealing with the multi-functionality of drainage (crop production, water quality, landscape, environment), as well as conflicting interests of user groups (farmers, fisher(wo)men, industries and municipalities). These concepts are novel, and the implementation is not straightforward because data to support the operationalisation of these concepts is not always available and the number of variables and interactions would be far too great to be captured by the conventional methods and simple analysis. New tools that are able to capture enough information and simulate complex hydrological and environmental processes as well as social processes and responses are needed.

6.7 Knowledge management
There is scope for a far larger sophistication in the development of drainage infrastructure and the management of drainage systems than is common so far. The question is how? A fresh look at research agendas, with far larger attention for technologies and water management strategies that serve multifunctional resource use is necessary. Also, as the emphasis changes in water governance research and knowledge development, clients should also change. The natural recipient for knowledge and how to effectively disseminate should be more clearly defined. At the same time there is scope to learn more from ongoing practices and allow practitioners to innovate and upgrade their knowledge. In practice this means giving room for experimentation in water investment programmes and a much stronger link between research organizations and training institutes. In developing new drainage technology there seems to be little place for the classic field experiments as used in agricultural drainage and other types of single purpose water management.
New Policy for Drainage

There usually is no clear policy specifically on drainage. The development of policies that achieve integration raises several questions such as: Which policies can contribute to the mainstreaming of an integrated approach to drainage? And how? Which type of policy – top-down, bottom-up, comprehensive, step-by-step, linear, iterative, prescriptive, interactive – do we adopt to nurture an integrated approach to drainage?

Policy context

The World Bank’s Water Resources Sector Strategy paper (World Bank, 2003) stresses that it is now time for a pragmatic but principled approach (efficient, equitable and sustainable). It is suggested that ‘Progress takes place more through ‘unbalanced’ development than comprehensive planning approaches’. Such an approach would thus include a strong ‘learning by (and before) doing’ component. The major challenge is to develop context specific, prioritised, sequenced, realistic and patient approaches for implementation. The development of an integrated approach for drainage subscribes to this perspective. The framework proposed by this study tallies very closely with the World Bank’s strategy for rural development and its environmental strategy (World Bank 2002 and 2001). Drainage is part of integrated natural (land and water) resources management. The framework can also be seen as an operationalisation of the IWRM concept.

A realistic policy concept

Policies and related strategies can never be fully consistent. Inconsistencies exist vertically between levels of governance and horizontally between sectors of water management because water conditions change continuously, generic policies don’t have tailor made answers to the infinite variety of drainage problems; lack of resources prevent the realisation of ambitions; private interests often prevail over public interests.

Policies are nested, in a variety of ways. Policies can therefore not be conceived in isolation. It is neither wise nor possible to design a new drainage policy for all times. Policies, including drainage policy, should be continuously ‘under reconstruction’.

Steps towards new policy:

The main steps in a process towards new policies and policy reform regarding drainage are the following:

- Understanding of the drainage situation from an integrated perspective;
- Identification of problems and opportunities;
- Formulation of the long-term vision and ambitions;
- Implementation of small, sometimes opportunistic, steps in:
  - Setting the modalities for multifunctional "optimisation" of goods and services;
  - Principles and guidelines for implementation;
  - Making resources available and organisations responsible;
  - Setting gentle targets and time horizons;
  - Creating in-built learning and reform mechanisms.

Policy messages

Although the following messages have been formulated, with the donors and governments in mind, they carry general relevance.

- Dare to look at all costs and benefits. Expanding the assessment of drainage, and the management of water
resources more generally, to include both benefits and negative effects, and thus make it more balanced, would provide incentives for mobilising resources and financing for investment in multifunctional drainage systems, because it would show that the drainage sector is inseparable from the other water management sectors.

- **Move Towards an Integrated Approach with Pragmatism and Vision.** Because of the two-sided effects of agricultural drainage on poverty, it is obvious that agricultural drainage policies and strategies for implementation have to address both positive and negative sides of drainage. This is difficult. There is hardly any experience with the implementation of agricultural drainage following the concept of multi-functionality. Nevertheless, a paradigm shift towards integrated drainage is required. Pragmatism should be pursued within a visionary framework that fosters the main direction where to go.

- **Identify Drivers, Triggers and Carriers of Reform.** Strategic analysis and identification of opportunities and carriers of innovation and reform processes is required.

- **Learning before Doing.** In complex contexts understanding each situation and its specific needs is indispensable and comes before action.

- **Nature provides many functions: detect those functions;**

- **Agricultural drainage has impact on the resources: know the changes;**

- **Changing resources affect all functions: understand the effects;**

- **Functions have stakeholders: identify and involve them;**

- **Stakeholders attach values to functions: assess them;**

- **Stakeholders have different says in decision making: analyse it and reform it;**

- **Policies and institutions are lagging behind actual requirements for needed services: make an audit and put pressure on them.**

## 8 Conclusion

The main substantive message of the study is that drainage needs to be looked at and acted upon from an integrated perspective. This implies the following.

- **Acknowledgement of the diversity in drainage situations and the need for regionally and locally specific planning and intervention in drainage institutions and technology,**

- **Systematic mapping of the multi-functionality of landscapes influenced by drainage and the plurality of values attributed to these functions by different interest groups.**

- **Conception of institutions for governance, management and financing of agricultural drainage as well as the (re)design of physical interventions/technical infrastructure from the perspective of multi-functionality and plurality of values.**

- **Policies that create an environment conducive to change and that empower actors to make the necessary changes.**

## 9 References


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Integrated Drainage and Irrigation in Arid and Semi-Arid Regions

Dr. Reza Ardakanian

SUMMARY

Global food security and poverty alleviation are the major dilemma in the beginning of the third millennium. Water is essential for broad based agricultural production and rural development in order to improve food security and eradicate poverty. Water should continuously contribute to a variety of ever expanding roles including food production, economic growth and environmental sustainability. It is estimated that the cereal demand will increase at 37% up to 2025. Irrigation should provide 60% of these additional demands during this period (Shady 1999), while the future water availability for irrigation development in arid and semi-arid regions are not so encouraging. The available water resources in these regions are almost fully developed, therefore, the greater potential in realizing food security in these regions remain with increasing the productivity of already existing irrigation schemes and using all other non-conventional available water resources, including drainage water.

Drainage is, therefore, regarded as an important water management practice in these regions to increase irrigation productivity by lowering the water table and providing proper means to control salinity in the root zone, and it is also considered as a method to recycle irrigation water for further use in crop production.

Arid and semi-arid regions are characterized by climate with insufficient rainfall to meet the sustainable agricultural production. These regions are mostly inhabited by developing countries, and cover the great majority of world-irrigated lands. Poor irrigation water management combined with inadequate drainage infrastructure renders irrigated area at risk of becoming water logged and gradual build up of salt concentration leading to soil degradation. Some estimates, however, suggest that over 50% of the world’s irrigated land has developed drainage problems (Smedema 2000) Investments in improving drainage conditions in developing countries of the arid and semi-arid zone seem to be very modest. In the context of future development, drainage should be regarded as a multifunction instrument for food security and sustainability of irrigation development. Smedema (2000) estimated future drainage needs during the next 25 years by 10-15 million hectares.

There are three main challenges before the development of drainage infrastructures and disposing of drainage water, which can be summarized as below:

I. Investments in improving drainage conditions in arid and semi-arid region, particularly in developing countries, are very inadequate. Local governments and international donors should be encouraged to increase their involvement in financing drainage project considerably.

II. Drainage must be considered as an integrated part of irrigation development projects, not only for improving the soil environment for crop production and providing more sustainable irrigation scheme but also as a means for recycling irrigation water for further use.

III. Re-use of drainage water for food and biomass production should be regarded economically and environmentally sound activities. To achieve this objective there are certain institutional consideration, which have been mostly ignored so far, particularly in developing countries. These issues which are listed below should
be planned and implemented in parallel with other technical and managerial aspects of drainage water re-use:

- Setting objectives and targeting interest groups.
- Providing appropriate laws and regulations, nationally and regionally.
- Involving public and private agencies and water users in operation and maintenance of the systems.
- Providing incentives for water quality enhancement.
- Monitoring water and soil physical and chemical characteristics continuously through systematic collection and analysis of data.
- Conducting appropriate and related research topics and modeling studies.
- Introducing new cropping pattern particularly salt tolerant crops, halophyte cash crops and forestry.
- Setting up responsible management bodies consisting of all stakeholders for OMM of drainage, projects and re-use of their effluent

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1 Introduction

The selection of adequate materials and their proper installation and maintenance are essential for the effective and lasting performance of subsurface land drainage systems (FAO, 2000).

Although substantial developments have been made in drainage materials and installation techniques during the past two decades, there are still some important problems need to be solved.

The purpose of this paper is to highlight some issues concerning this sub-topic, to invite the drainage community to present papers to the 9th International Drainage Workshop, with the final goal of deriving appropriate conclusions after the Workshop discussions.

This discussion paper is only focused on subsurface land drainage systems.

2 Drainage materials

Materials for subsurface drainage systems include drainpipes and their accessories, envelope materials and auxiliary structures.

Existing knowledge on drainage materials have been reviewed in two recent publications:

- FAO. 2000. Materials for subsurface land drainage systems, by L.C.P.M. Stuyt, W. Dierickx and J. Martínez Beltrán, Irrigation and Drainage Paper No. 60, Rome; and

In addition, three chapters on this subject were included in the last American Society of Agronomy publication on land drainage:


In the following sections some key issues concerning drainage materials are highlighted.

2.1 Drainpipes and Their Accessories

PVC and PE are generally used as pipe materials for corrugated plastic lateral drains. Concrete pipes are used for larger collector drains. Specifications and standards for clay, concrete and corrugated plastic pipes are available in the USA and in Europe a standard for corrugated PVC pipes has been drafted.
Pipe accessories, such as end caps, couplers, pipe fittings and reducers, and rigid pipes for drain bridges and lateral outlets are also available.

Design criteria and hydraulic calculation procedures with respect to pipe diameters are well known. FAO is currently preparing simple computer programs for both single drains and multiple drains, in which the pipe diameter changes as a way to reduce material costs.

The selection of pipe material and size for a particular project depends mainly on local availability and cost. In this context the following questions can be considered:

- Are technical specifications commonly used in practice to check the quality of pipe materials used in drainage works?
- The contribution of the pipe size to the total cost of the subsurface drainage system is relevant, however, in some cases no special attention is paid to drain diameter calculations and pipes are over-dimensioned, especially if long drains are designed.

2.2 Envelopes
Drain envelopes restrict the entrance of soil particle into the drain, improve the hydraulic conductivity at the soil-drain interface and provide structural stability around the drain. Mineral granular envelopes and prewrapped fibrous organic envelopes have been used in the past, but currently synthetic envelopes -geotextiles and loose synthetic fibres- are being used.

Specifications and standards for envelope materials are also available, as well as rules and recommendations to predict the need of an envelope and design criteria for the selected material. However:

- methods validated by field experience to assess the need for drain envelopes;
- selection criteria for the most appropriate envelope material, depending on local soil conditions, need verification;
- case studies on the evaluation of the performance of drain envelopes in the field, especially for synthetic envelopes are important; and
- research activities required to support the above issues are necessary.

2.3 Auxiliary Drain Structures
Connection structures, inlets and outlets of water and special structures, such as cleaning facilities and structures for controlled drainage and subirrigation, are common auxiliary structures of subsurface drainage systems.

In the Workshop discussion, the following issues can be covered:

- Quality control and maintenance of outlet structures.
- In composite drainage systems, junction boxes and manholes are sometimes hardly used or not used at all and may be unnecessary with GPS availability. Examples with practical data about the comparison of savings in construction costs and increments in maintenance costs may be useful for future designs.
- Designs for special structures for controlled drainage in the lateral and collector outlets are available, but examples of construction and operation of such structures are not frequent.

3 Drainage machinery
Special machines are used for installation and maintenance of subsurface drains. Current knowledge on this subject has been recently reviewed in the last American Society of Agronomy publication on agricultural drainage:
In the following sections some key issues concerning machinery for implementation and maintenance of subsurface drainage works are highlighted.

3.1 Installation Machinery

Trenchers of various types have been used in the past and still are used with success to install subsurface drains, especially for clay and concrete pipes and for granular mineral envelopes. Since the introduction of corrugated plastic pipes and prewrapped envelope materials, the installation speed has increased by using trenchless drainage machines. However, although the use of the laser grade has improved the precision of installation, the control of the work quality has become more difficult, especially as far as the grade line accuracy is concerned.

Suggested topics for papers describing new developments and for discussion may be the following:

- Installation of drains under adverse conditions, such as in wet soils and in lands with shallow water tables.
- Subsurface drainage works in unstable soils.
- Checking the quality of drainage work during installation and after the drainage system has been installed.

3.2 Maintenance Equipment

Subsurface drainage systems adequately installed with appropriate drainage materials have low maintenance requirements. Dry rodding is sufficient to remove slight clogging, fresh ochre and roots proliferating inside the drainpipe, specially near the lateral outlet. To remove sediments and serious ochre deposits, and to clean clogged perforations jet flushing is necessary. Field experience achieved during the past years shows that medium pressure equipment is most recommended and flushing should be used only in case of dissatisfaction with or deterioration of drainage system performance.

The effective length of the flushing equipment is less than about 400 m. Therefore, this technology is effective for single drains with lengths up to 400 m and for multiple drains if manholes are constructed. However, extended laterals and composite drainage systems are sometimes installed without manholes. In these cases, are there other effective cleaning facilities or procedures?

The issues described above in this discussion paper are merely suggestions identified by the author in a call for papers. However, any paper describing case studies and other practical points concerning sub-topic 1.2, including maintenance

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DRAINAGE AND DEGRADING SALTY CLAY SOIL IN EGYPT [1]


ABSTRACT

The northeastern parts of Egypt may consider problematic areas. They are low-lying areas, salty clay soils with low permeability, shallow and salty ground water, and artesian zone. Drainage is an important factor to overcome these interference problems; wider spacing accompanied with auxiliary treatments should be tested to increase the efficiency of subsurface drainage. The aim is to study pipe drains-subsoiling for evaluating improvement soil condition to sustain land use and prevent soil deterioration. In a farm at El-Serw Research station, an experimental field using split plot design was designed with three-drain spacing treatments, 15m, 30m and 60m separated by buffer zones. Sub-main treatments represented two types of subsoiling, parallel and net subsoiling with 1.5m apart and 50cm depth.

Along three seasons, Tile drains combined subsoiling type treatments are more affected on lowering the values of total soluble salts than either tile drainage only or subsoiling method only. The best treatment is 15 m drain spacing combined with net subsoiling treatments. The highly soluble cation is sodium; it is more than 80 %. The magnesium ions are always exceeding calcium ions. With respect to exchangeable cations, it seems that drain spacing or combined with subsoiling are slightly effect on exchangeable sodium percentage especially on the soil surface layer. The net subsoiling is relatively more influence than parallel subsoiling.

Drain spacing and subsoiling type treatments are highly significant on soil moisture content. The bulk density decreases with decreasing drain spacing and subsoiling type; it is, also, evident that it decreases with net subsoiling than parallel one. The effect of subsoiling types increase high values of soil porosity in upper layer. The shrinkage percent is increased by increasing drain spacing and decreasing by net subsoiling than parallel one.

1 INTRODUCTION

Maximum plant growth requires, among other factors, a particular soil-water regime that may exist naturally or be provided by appropriate irrigation and drainage. Water table depth plays an important role for soil conservation as affected on soil properties and crop productivity. Artificial drainage becomes necessary to control the water table and maintain a suitable aerated zone. The shallow water table reduces growth due to decrease rooting volume and insufficient oxygen. Drainage technology has developed around two basic needs: (i) to ensure aeration and trafficability for agricultural soils, and (ii) to provide for salinity control. As a consequence, the goal usually has been to design systems that provide as much drainage as possible. Land drainage, as a tool to manage ground water levels, plays an important role in maintaining and improving crop yields: (i) it prevents a decrease in the productivity of arable land due to rising water tables and the accumulation of salts in the root zone. And (ii) a large portion of the land that is currently not being cultivated has problems of water logging and salinity. Drainage is the only way to reclaim such land. Various crops respond differently to specific soil-water environments; so the key element of the shallow water table concept is the drainage requirement of the crop being grown. The determination of the prevailing specific conditions will permit a good understanding of the problems and their solutions.

Abdel-Mawgoud (1987) showed that the instillation of tile drains is considered one of the important factors affecting soil aggregate formation directly and indirectly. The direct effect is due to wetting and drying cycle, which create better environmental conditions for aggregate formation, whereas the indirect effect of tile drainage on soil structure may be due to the redistribution of chemical constituents through the soil profile. Concerning the effectiveness of subsurface drains in the reclamation of salty lands, Madramootoo and Buckland (1990) found that soil salinity (EC) and sodicity (ESP) decreased by 18 and 13%, respectively in the upper 30-cm of the soil profile after two years from drain installation. Schellekens et al (1990) revealed that rapid desalinization might be achieved by the use of pipe–drains with reclamation leaching. Results indicated that the reclamation approach appears to have been relatively successful. Wenberg (1990) reported that subsurface drainage must be adequate to permit the necessary leaching, hold the water table to sufficient depth and prevent the upward movement of salty capillary water to reach to root zone.

Agricultural salt affected alluvial lands are commonly found throughout the northern periphery of the Nile Delta, and in the vicinity of northern lakes. The clay cap in this region is about 40 meters. Such lands are low-lying, heavy clay soil of poor productivity. The most important feature is the highly saline shallow ground water, which creates problems of soil water logging, salinity and/or alkalinity associated with severe decline in
soil structure and soil aeration. Clay-salt affected soils are known to be difficult to manage. Procedures for soil desalinization through leaching and drainage showed successful in some areas but were disappointing in other areas. As mentioned by FAO consultants (1980), local experience is rarely transferable to other locations. The difficulty of desalinization in clay soils might arise from the preferential type of water flow. Since leaching water may pass only through macro-pores and not within clay beds. Consequently improving leaching efficiency through artificial re-structure would be a possible solution (Moustafa, 1984; Tanton and Rycroft, 1990). Drainage, improving poor permeability, and enhancing water movement is an important factor for salt leaching and for preventing water logging in the rootzone. Armstrong et al (1990), in a field trial in Turkey proved the necessity for restricting the heavy clay soil through subsoling for better leaching efficiency.

Previous studies (Moukhtar et al, 1990 and El-Hakim et al, 1990) in one of the areas representing northern lands (an experimental field with open field drains under consideration in this work), pointed to the need of increasing the rate of water table drawdown after irrigation, through auxiliary drainage measures, in order to restrict detrimental effect of the saline groundwater around the rootzone. For the same soils, Michaelson et al (1993) found that hydraulic conductivity was highly dependent on the active pores system and changed (secondary and primary pores system) with any mechanical stress. The area of the field under study is representative of northern low lands, fluvio-marine clay salt affected soils of low productivity. Moreover, they are assumed to lie in the zone of hydrostatic pressure. A main controversial factor is the extreme salinity of the groundwater table, which renders the desalinization process of the soil profile rather difficult. The management of such soils depends essentially on providing efficient drainage conditions beside regular irrigation, to preserve the rootzone from salinity in the cropping season and to restrict capillary rise from the saline groundwater between cropping seasons. In late 1987, a pre-investigation of hydropedological studies were conducted in El-Serw Research Experimental Farm (Moukhtar et al, 1990). The clay content reaches 63.5% up to 90 cm depth. The soil is low permeable, average hydraulic conductivity is 0.0669 m/day. A permanent saline groundwater table (average 25 dS/m mainly sodium chloride) is the main source of soil salinization and alkalization due either to its direct contact with the subsurface soil or by capillary rise in the topsoil (Moukhtar et al, 1990).

Moukhtar et al, 1995 and 1996 also investigated monitoring soil desalinization and desodification. In general, the desalinization of the profiles occurred as a result of the decrease in salinity of the different soil layers. Data showed that prior to rice, the mean initial salinity in 20 m spacing treatment was higher than that in 40m treatments, whereas after rice the salinity decrease obtained was more pronounced in the narrower spacing treatment. After rice, electric conductivity values decreased to values around 4 dS/m in both treatments, in the surface 60 cm layers (the effective rootzone). Also EC values decreased in the subsurface layers, however they remained still saline. During the growing season, water increments are supplied every few days to the rice field to bring the level of the ponded water to about 6 cm. Thus a pressure head is always present and consequently a downward flux of water takes place. Some of the standing water infiltrates and percolates through the rootzone dissolving and carrying off soluble salts (Van Alphen, 1983). Another important beneficial effect of the standing fresh water, specific of the soil under study, is that it keeps the saline groundwater far enough from the rootzone and dilutes the upper part of it (El Hakim et al, 1990). The present work plan has been setup to investigate the possibility of restoring, through field drainage type, the deteriorated soil conditions and the effect of drainage and subsoling types on soil properties in order to sustain resource management.

## 2 MATERIALS AND METHODS

In the first stage of these studies, the saturated hydraulic conductivity was measured in the field by auger hole method (Van Bear, 1958). The saturated hydraulic conductivity is one of the most important soil properties. It is an important physical parameter for designing drainage system. It is play an essential role for water flow in soil. In general, the average hydraulic conductivity, $K_{sat}$, is 6.69 cm/day. Generally, according to Missland and Haskea (1985) the soil is considered low permeable. The experimental field has been carried out in the farm of Agricultural Research Station, which belongs to Agriculture Research Centre. The area is situated at the end of El-Dakhlia Governorate between two main drains, El-Sew drain and El-Harana drain, which they are, meet at a city called El-Alexandria El-Gadeidh. The two drains end in El-Sew pumping drainage station, which lifts the drainage water to El-Manzala Lake. The area of the field under study is representative of northern low lands, fluvio-marine clay salt affected soils of low productivity. Moreover, they are assumed to lie in the zone of hydrostatic pressure. A main controversial factor is the extreme salinity of the groundwater table.

The main treatments are subsurface drainage. The tile drainage system was mechanically installed four years ago. Corrugated plastic laterals are 100-m. length and 150 cm. depths at the tile end. The collector line is 600 m. long and its outlet (2.5-m. depth) is in the main drain El-Sew. The experimental field was designed with three drain spacing treatments separated by buffer zones (Dielman and Trafford, 1976): (i) 15 m. spacing (calculated spacing according to the steady state formula, (Houghoudt, 1940)); (ii) 30 m. spacing (conventional spacing adopted in the surrounding areas); and (iii) 60 m. spacing (double of the conventional spacing for future secondary drainage treatments). The sub-treatments are two types of subsoling; the distance between plowing two metre and the depth is 50 cm. There are: (i) One direction: Parallel orientation subsoling type and perpendicular on tile drains, and (ii). Two directions: Net structure subsoling type. Initial state soil samples were collected from each treatment and after crop harvest. The soil profiles were dug out at the middle between two drains up the depth of 150 cm. The soil
samples were collected every 30 cm. All samples were air dried and kept for soil chemical analysis. Undisturbed soil samples were taken using cores with diameter of 4.3 cm and height of 3.0 cm. Bulk density was determined using core method at field moisture condition (Vomicil, 1957). Air-dried soil sample was gently crushed and sieved through a 2 mm sieve. Electrical conductivity “EC”, soluble cations and anions were measured in soil solution extract (1:5) according to Black, 1965. Exchangeable sodium and potassium were determined using ammonium chloride (Jackson, 1973). All the data collected were subjected to the statistical analysis using statistical computer program.

3  RESULTS AND DISCUSSIONS

3.1  Wheat Winter Season

Total Soluble Salts: The statistical analysis for total soluble salts and ESP as affected by drainage combined subsoiling type treatments are shown in table (1) and diagramed in fig (1,2). In general, soil salinity is highly affected with drain spacing and drainage combined subsoiling type treatments and among them.

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>Degree of Freedom</th>
<th>Salinity</th>
<th>ESP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicates (R)</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Drainage (D)</td>
<td>2</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Error (a)</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil depth (L)</td>
<td>4</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>D X L</td>
<td>8</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Error (b)</td>
<td>24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsoiling (S)</td>
<td>2</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>D X S</td>
<td>4</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>L X S</td>
<td>8</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>D X L X S</td>
<td>16</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Error (c)</td>
<td>60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>134</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For drainage treatments only, the soil salinity is highly decreased in the surface layer, especially 0 - 30 cm, than the deeper layers. The total soluble salts values are 0.34, 0.60 and 0.63 percent in 0 - 30 cm layer for 15 m, 30 and 60 m drain spacing respectively. In the deeper layers, the values of total soluble salts are still very high and they did not change among drainage treatments. Generally, the total soluble salts for all treatments increase with increasing soil depth. Concerning subsoiling treatments, results indicate that the subsoiling is also highly affected on reducing soil salinity. The decreasing in the total soluble salts is followed the order net subsoiling>parallel subsoiling>No subsoiling treatments (fig.1). Regarding tile drainage combined subsoiling treatments; data indicated that the total soluble salts are highly affected with combined method. They are more affected on decreasing the values of total soluble salts than either tile drainage only or subsoiling method only. The best treatment to reduce soil salinity is 15 m drain spacing combined wit net subsoiling type treatments (fig.1). Also, statistical analysis for total soluble salts of soil surface layers (0-30 cm) indicate that there are highly significant effect between drain spacing and subsoiling treatments and also interaction between them (combined treatment) on reducing total soluble salts on the surface layer (fig. 1). As shown in figure (1), the best treatment to decrease soil salinity in the upper layer is drain spacing at 15 m combined net subsoiling structure type. Data of soluble cations and anions for different drain spacing and subsoiling types indicated that soluble cations and anions in soil profiles are followed trend of total soluble salts behaviour according to influence of drainage and subsoiling treatments. In general, data shown that the anions in soil solution extract followed that order: chloride>sulfate>bicarbonate>carbonate; and for cations: sodium>magnesium>calcium> potassium. The highly soluble cation in soluble is sodium; it is more than 73 %. Most of salt in soil is sodium chloride. The magnesium ions are always exceeding calcium ions.

Results indicate that cation exchange capacity ranges from 33 and 58 meq/100g soil. It is noticed that, exchangeable magnesium percentage exceeds exchangeable calcium. It seems drain spacing or combined with subsoiling does not appear any effect on exchangeable calcium or magnesium percentages. Highly magnesium percentage may be due to the soil nature, which closes to Lake. Regarding exchangeable potassium percentage is the minor. Concerning exchangeable sodium percentage, it is evident that soil treatments of drain spacing and combined with subsoiling types are highly significant effect on exchangeable sodium percentage (fig.2) especially on the soil surface layer than the other deep layers. A net subsoiling structure is relatively more influence to reduce exchangeable sodium percentage than parallel subsoiling. It is also noticed that exchangeable sodium percentage is very high in the deeper layer. These results could be attributed to the effect of highly
ground water salinity. Statistical analysis for the effect of drain spacing and subsoiling or combined treatments is highly significant on exchangeable sodium percentage on soil complex.

Figure 1 Total soluble salts in soil surface layer as affected by drain spacing and subsoiling treatment, winter season 96/97 (wheat). (Left image).

Figure 2 Exchangeable sodium percentage, ESP, in soil surface layer as affected by drain spacing and subsoiling treatments, winter season, 96/97 (wheat). (Right image).

Statistical analysis for exchangeable sodium percentage, ESP, of soil surface layers (0-30 cm) indicate that there are highly significant effect between drain spacing and subsoiling treatments and also interaction between them (combined treatment) on reducing total soluble salts on the surface layer (fig.1). As shown in figure 31, the best treatment to decrease soil salinity in the upper layer is drain spacing at 15 m combined net subsoiling.

3.1.1 Soil Physical Properties

The influence of drainage and subsoiling type treatments on some soil physical properties such as soil moisture content, bulk density, soil total porosity and shrinkage percent at 7, 13 and 20 days after irrigation are studied. The data are statistical analysis for the effect among drain spacing, subsoiling type and time after irrigation. The results of the analysis of variance are shown in table (2). In general, most of treatments are highly significant effect on these selected soil physical properties. Also, there are highly significant interactions among treatments on them.

Soil Moisture Content: The soil moisture content after several days of irrigation as affected by drain spacing and combined with subsoiling type are statistical analyzed and shown in table (2). It is obvious that the moisture percentage by weight decreases with days after irrigation and net subsoiling than parallel one. It is also evident that subsurface layer shows a lower moisture content than the upper layer in all treatments. Results are good agreement with that obtained by Moustafa (1984). This may be due to the frequent disturbance of soil particle system of packing under the different agricultural operations. The statistical analysis shows that there are highly significant of both drain spacing and subsoiling treatments on the soil moisture content. There are also highly significant interaction between drain spacing, subsoiling type and days after irrigation on soil moisture content.

Statistical analysis of soil moisture content for soil surface layer indicates that there is a highly significant effected by drain spacing and subsoiling treatments and also the interaction between them on soil dry after irrigation on surface soil. The 15 m drain spacing and net subsoiling and interaction between them are the most treatment affecting soil moisture content. The best treatment to dry soil and not to be longer logging is drain spacing at 15 m combined net subsoiling (fig.3,a,b and c).

Table 2 Analysis of variance for some soil physical properties.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Degree of Freedom</th>
<th>Moisture content</th>
<th>Bulk density</th>
<th>Total Porosity</th>
<th>Shrinkage Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicates (R)</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Drain Spacing (D)</td>
<td>2</td>
<td>**</td>
<td>**</td>
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<td>**</td>
</tr>
</tbody>
</table>
DRAINAGE AND DEGRADING SALTY CLAY SOIL IN EGYPT

<table>
<thead>
<tr>
<th>Error (a)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Time (T)</td>
<td>**</td>
</tr>
<tr>
<td>Soil depth (L)</td>
<td>**</td>
</tr>
<tr>
<td>Subsoiling (S)</td>
<td>**</td>
</tr>
<tr>
<td>T X L</td>
<td>**</td>
</tr>
<tr>
<td>T X S</td>
<td>**</td>
</tr>
<tr>
<td>L X S</td>
<td>**</td>
</tr>
<tr>
<td>T X L X S</td>
<td>**</td>
</tr>
<tr>
<td>D X T</td>
<td>**</td>
</tr>
<tr>
<td>D X L</td>
<td>**</td>
</tr>
<tr>
<td>D X S</td>
<td>**</td>
</tr>
<tr>
<td>D X T X L</td>
<td>**</td>
</tr>
<tr>
<td>D X T X S</td>
<td>**</td>
</tr>
<tr>
<td>D X L X S</td>
<td>**</td>
</tr>
<tr>
<td>D X T X L X S</td>
<td>**</td>
</tr>
<tr>
<td>Error (b)</td>
<td>102</td>
</tr>
<tr>
<td>Total</td>
<td>161</td>
</tr>
</tbody>
</table>

** Significant at 1%  * Significant at 5%  ns Not significant

Figure 3  Soil moisture content, in soil surface layer, as affected by: (a) drain spacing and subsoiling type; (b) drain spacing treatments and days after irrigation between two-interval irrigations; and (c) subsoiling treatments and days after irrigation between two-interval irrigations, winter season 96/97 (wheat).

Soil Bulk Density: The data of bulk density as affected by drain spacing, subsoiling, days after irrigation are shown in table (2). In general, the obtained results indicate that the bulk density decreases significantly with decreasing drain spacing. Also, it is evident that it decreases significantly with subsoiling type; the decrease of bulk density was decreased by net subsoiling more than parallel orientation type. The bulk density increases with increasing soil depth. Statistical analysis of soil bulk density for soil surface layer indicates that there is a highly significant effected by drain spacing and subsoiling treatments and also the interaction between them on soil dryer after irrigation on reducing bulk density. The 15-m drain spacing and net subsoiling and interaction between them are the most treatment affecting soil bulk density. The best treatment to loosen soil and lowering bulk density is drain spacing at 15 m combined net subsoiling (fig, 3,a,b and c.).

Total Soil Porosity: The soil porosity data as affected by drain spacing and subsoiling type treatments are shown in table (2). It is apparent from obtained results that soil porosity has been affected highly significant by drain spacing and subsoiling type treatments and days after irrigation. The effect of subsoiling type appears more in the upper soil layer than the deeper layer. The high values of soil porosity in the first layer in the treatments are due to its loosened structure. Statistical analysis of soil total porosity for soil surface layer indicates that there is a highly significant effected by drain spacing and subsoiling treatments and also the interaction between them on soil total porosity after irrigation. The 15 m drain spacing and net subsoiling and interaction between them are the most treatment affecting total porosity. The best treatment is drain

http://library.wur.nl/ebooks/drainage/drainage_cd/1.1%20moukhtar,%20el-hadidy%20and%20el-shewikh.html (5 of 11)26-4-2010 12:10:28
spaced at 15 m combined net subsoiling (fig. 4. a, b and c).

**Figure 4** Bulk density in soil surface layer, as affected by: (a) drain spacing and subsoiling type; (b) drain spacing treatments and days after irrigation between two-interval irrigations; and (c) subsoiling treatments and days after irrigation between two-interval irrigations, winter season 96/97 (wheat).

**Figure 5** Soil total porosity in soil surface layer, as affected by: (a) drain spacing and subsoiling type; (b) drain spacing treatments and days after irrigation between two-interval irrigations; and (c) subsoiling treatments and days after irrigation between two-interval irrigations, winter season 96/97 (wheat).

### Shrinkage Percent

Calculated shrinkage percent as affected by drain spacing and subsoiling types is shown in table (2) and presented in fig. (5). In general, results indicate that drain spacing and subsoiling types are highly affected on shrinkage percent. The statistical analysis shows that there is not significant for days after irrigation on shrinkage percent. In general, the shrinkage percent increased by increasing drain spacing and decreasing by subsoiling types which it is decreased by net than parallel subsoiling. Statistical analysis of soil shrinkage for soil surface layer indicates that there is a highly significant effected by drain spacing and subsoiling treatments and also the interaction between them on soil shrinkage after irrigation. The 15-m drain spacing and net subsoiling and interaction between them are the most treatment affecting soil shrinkage. The highly effective treatment is drain spacing at 15 m combined net subsoiling type in the surface layer (fig. 5).

### 3.1.2 Hydraulic Conductivity

The hydraulic conductivity values data are evident that there is no difference between the hydraulic values for all treatments; the values range from 0.0967 to 0.2029 m/day. These values are still low hydraulic conductivity; this may be due to determine hydraulic conductivity in the deeper layer at the level of drain depth.
Figure 6  Shrinkage percent in soil surface layer, as affected by: (a) drain spacing and subsoiling type; (b) drain spacing treatments and days after irrigation between two-interval irrigations; and (c) subsoiling treatments and days after irrigation between two-interval irrigations, winter season 96/97 (wheat).

3.2  Clover winter Season

Total Soluble Salts: The total soluble salts as affected by tile drainage only and tile drainage combined subsoiling treatments are shown in table (3) and diagramed in fig (6 and 7). In general, soil salinity is highly affected with drain spacing and drainage combined subsoiling treatments.

Table 3  Analysis of variance for total soluble salts and ESP.

<table>
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<tr>
<th>Source of variance</th>
<th>Degree of Freedom</th>
<th>Salinity</th>
<th>ESP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicates (R)</td>
<td>2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Drainage (D)</td>
<td>2</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Error (a)</td>
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<td></td>
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<tr>
<td>Soil depth (L)</td>
<td>4</td>
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<tr>
<td>D X L</td>
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</tr>
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<td>Error (b)</td>
<td>24</td>
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<td>Subsoiling (S)</td>
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<td>**</td>
</tr>
<tr>
<td>D X S</td>
<td>4</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>L X S</td>
<td>8</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>D X L X S</td>
<td>16</td>
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<td>**</td>
</tr>
<tr>
<td>Error (c)</td>
<td>60</td>
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</tr>
<tr>
<td>Total</td>
<td>134</td>
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</tbody>
</table>

For drainage treatments only, the soil salinity is highly decreased in the surface layer, especially 0 - 30 cm, than the deeper layers. The total soluble salts values decreased from 0.34% to 0.27% for 15 m drain spacing, from 0.60% to 0.35% for 30 m spacing and from 0.63% to 0.49% for 60 m drain spacing in 0 - 30 cm layer for 15 m, 30 and 60 m drain spacing respectively. In the deeper layers, the values of total soluble salts are decreased comparing to the previous winter season but still very high and they did not change between drainage treatments. Generally, the total soluble salts for all treatments increase with increasing soil depth.

Statistical analysis for total soluble salts of soil surface layers (0-30 cm) indicate that there are highly significant effect between drain spacing and subsoiling treatments and also interaction between them (combined treatment) on reducing total soluble salts on the surface layer (fig. 6). Results indicate that subsoiling treatments, they are highly affected on reducing soil salinity especially on the surface soil layers. The decreasing in the total soluble salts values is followed the order: net subsoiling > parallel subsoiling > No subsoiling treatments. Concerning the tile drainage combined subsoiling type treatments; data indicated that the total soluble salts are highly affected with combined method. They are more affected on lowering the values of total soluble salts than either tile drainage only or subsoiling method only. The best treatment to reduce soil salinity is still 15-m drain spacing combined with net subsoiling treatments. Data of soluble ions, cations and anions, for different drain spacing and subsoiling types are indicated that soluble cations and anions in soil solution extract are followed trend of total soluble salts behaviour according to influence of drainage and subsoiling treatments. In general, data shown that the anions in soil solution extract followed that order: chloride...
>sulfate > bicarbonate > carbonate; and for cations: sodium > magnesium > calcium > potassium. The highly soluble cation in soluble is sodium; it is more than 80%. Most of salt in soil is sodium chloride. The magnesium ions are always exceeding calcium ions.

Data of cation exchange capacity and exchangeable cations (meq/100 g and percentage) as affected by drain spacing and subsoiling treatments indicate that cation exchange capacity ranges from 33 and 58 meq/100g soil. It is noticed that, exchangeable magnesium percentage exceeds exchangeable calcium. It seems drain spacing or combined with subsoiling does not appear any effect on exchangeable calcium or magnesium percentages. Highly magnesium percentage may be due to the soil nature, which closes to Lake. Regarding exchangeable potassium percentage is the minor.

Concerning exchangeable sodium percentage, it is evident that soil treatments of drain spacing and combined with subsoiling are highly significant effect on exchangeable sodium percentage as shown in the variance of analysis in table (7). The soil alkalinity is especially lower in the soil surface layer than the other deeper layers. A net subsoiling is relatively more influence to reduce exchangeable sodium percentage than parallel subsoiling. It is also noticed that exchangeable sodium percentage is very high in the deeper layer. These results could be attributed to the effect of highly ground water salinity. Statistical analysis for the effect of drain spacing and subsoiling or combined treatments is highly significant on exchangeable sodium percentage on soil complex. Statistical analysis for exchangeable sodium percentage, ESP, of soil surface layers (0-30 cm) indicate that there are highly significant effect between drain spacing and subsoiling treatments and also interaction between them (combined treatment) on reducing exchangeable sodium percentage on the surface layer (fig. 7). Results indicate that subsoiling treatments, they are highly affected on reducing soil exchangeable sodium percentage. The decreasing in the total soluble salts values is followed the order: net subsoiling > parallel subsoiling > No subsoiling treatments. Concerning the tile drainage combined subsoiling treatments; data indicated that the exchangeable sodium percentage is highly affected with combined method. They are more affected on lowering the values of exchangeable sodium percentage than either tile drainage only or subsoiling method only. The best treatment to reduce soil salinity is still 15 m drain spacing combined with net subsoiling treatments.

### 3.2.1 Soil Physical Properties

The statistical analysis for the influence of drain spacing and subsoiling type after 9, 14 and 18 days after irrigation on soil moisture content, Bulk density, total porosity and shrinkage percent are shown in the analysis of variance table (4).

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Degree of Freedom</th>
<th>Moisture content</th>
<th>Bulk density</th>
<th>Total Porosity</th>
<th>Shrinkage Percent</th>
</tr>
</thead>
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<tr>
<td>Replicates (R)</td>
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<tr>
<td>Drain Spacing (D)</td>
<td>2</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Error (a)</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
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<td>Time (T)</td>
<td>2</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
</tbody>
</table>

Figure 7 Mean of total soluble salts for upper surface soil as affected by drain spacing and subsoiling treatments, winter season 97/98. (Left Image).

Figure 8 Mean of exchangeable sodium percentage, ESP, for upper surface soil as affected by drain spacing and subsoiling treatments, winter season 97/98. (Right Image).

Table 4 Analysis of variance of some soil physical properties.
Soil Moisture Content: The soil moisture content after some days of irrigation as affected by drain spacing and combined with subsoiling type are shown in table (4) and fig.(8). It is obvious that the moisture percentage by weight decreases with days after irrigation and net subsoiling than parallel one. It is also evident that subsurface layer shows a lower moisture content than the deeper layer in all treatments, due to the frequent disturbance of soil particle system of packing under the different agricultural operations. The statistical analysis shows that there are highly significant of both drain spacing and subsoiling treatments on the soil moisture content. There are also highly significant interaction between drain spacing, subsoiling type and days after irrigation on soil moisture content.

Soil Bulk Density: The data of bulk density as affected by drain spacing, subsoiling, days after irrigation are shown in table (4) and fig.(9). In general, the obtained results indicate that the bulk density decreases with decreasing drain spacing. Also, it is evident that it decreases with subsoiling type and decreases with net subsoiling than parallel one. The bulk density increases with increasing soil depth.

Figure 9 Soil moisture content, in soil surface layer, as affected by: (a) drain spacing and subsoiling type; (b) drain spacing treatments and days after irrigation between two-interval irrigations; and (c) subsoiling treatments and days after irrigation between two-interval irrigations, winter season 97/98. (Clover).
DRAINAGE AND DEGRADING SALTY CLAY SOIL IN EGYPT

Figure 10 Mean of bulk density for upper surface soil surface layer, as affected by: (a) drain spacing and subsoiling type; (b) drain spacing treatments and days after irrigation between two-interval irrigations; and (c) subsoiling treatments and days after irrigation between two-interval irrigations, winter season 97/98. (Clover).

Total Soil Porosity: The soil porosity data as affected by drain spacing and subsoiling data are shown in table (4) and fig. (10). It is apparent from obtained results that soil porosity has been affected by drain spacing and subsoiling type treatments. The effect of subsoiling type appears in most soil layers. The high values of soil porosity in the first layer in the treatments are due to its loosened structure.

Figure 11 Mean of total porosity for upper surface soil surface layer, as affected by: (a) drain spacing and subsoiling type; (b) drain spacing treatments and days after irrigation between two-interval irrigations; and (c) subsoiling treatments and days after irrigation between two-interval irrigations, winter season 97/98. (Clover).

Shrinkage Percent: Calculated shrinkage percent as affected by drain spacing and subsoiling types is shown in table (4) and fig.(11). In general, results indicate that drain spacing and subsoiling types are highly affected on shrinkage percent. The statistical analysis shows that there is highly significant for days after irrigation on shrinkage percent. The shrinkage percent is increased by increasing drain spacing and decreasing by subsoiling types which it is decreased by net than parallel subsoiling.

Figure 12 Mean of shrinkage percent for upper surface soil surface layer, as affected by: (a) drain spacing and subsoiling type; (b) drain spacing treatments and days after irrigation between two-interval irrigations; and (c) subsoiling treatments and days after irrigation between two-interval irrigations, winter season 97/98.
The impact of drain spacing treatments on the improvement of drainage conditions is illustrated by the rate of water table. The importance of the different water table depths is the positions of them midway between drains during two-interval irrigations. In general, it could be said that an improvement in drainage conditions is realized progressively as time proceeds, especially in the treatment having 15 m spacing combined with net subsoiling. For this spacing treatment, the improvement is continuous with a fast rate. It may worthwhile to mention that the drawdown changes irregularly from day to another. It might be attributed to preferential flow through macro-pores “bypass” flow (Moustafa, 1984). Generally, results indicate that drainage treatments have an enhancing effect on lowering the water table, particularly under narrow spacing between drains combined with subsoiling especially net treatment. Increasing downward water movement after irrigation gives the chance for the effective root zone to dry, shrink and form water pathways. It is worthy to mention that the drying process and its consequent play an important role in the drainage of heavy clay soils since it improves the soil structure and permeability. It may worthy to mention that these types of drainage especially in heavy clay low permeable soil the flow of water is highly accelerated drawdown as a result of loosening and fissuring up to the depth of subsoiling plow. Afterwards, water table drowan rate depends on the distance of drain spacing.

4 References


FIELD-SATURATED HYDRAULIC CONDUCTIVITY OF UNSATURATED SOILS FROM LABORATORY CONSTANT-HEAD WELL TESTS

Dr. M. Rodgers\(^{[2]}\), Mr. J. Mulqueen\(^{[3]}\)

ABSTRACT
Field-saturated hydraulic conductivities \((K_{fs})\) were derived from constant-head well percolation tests in 0.7 m and 1.0 m diameter laboratory sand tanks. Wells of 60 mm and 340 mm diameter, each 400 mm deep, were used in the 0.7-m and 1-m tanks respectively. Each tank was equipped with a multi-point tensiometer at 200 mm from the perimeter of each well. Tests were carried out in the field-saturated mode with zero porewater pressure (Zero PWP) on the sand surface maintained by spray irrigation and in the zero flux (Zero Flux) mode with no surface irrigation. Following saturation and stabilisation of the well pressure heads, drainage ports were opened instantaneously and the rate of inflow into the well, to balance the infiltration into the soil, was recorded using a Mariotte bottle mounted on a weighing scale, reading the tensiometers at the same time. \(K_{fs}\) of the sand was measured independently in a constant-head permeameter. A model study using a finite element programme was carried out, using the boundary and initial conditions in the sand tanks and was validated with the experimental data. Steady-state axisymmetric analyses were carried out for the pressure heads of 0.4, 0.3 and 0.2 m in the wells using three soils of known \(K_{fs}\) differing by over two orders of magnitude. The \(A\) value in the Glover formula \((K_{fs} = A\times Q)\), where \(A\) is a model parameter to be determined and \(Q\) is the steady-state infiltration rate from a well into soil) was shown to be nearly identical for the three soils at each pressure head. Infiltration rates into the experimental tank sand were multiplied by the \(A\) values from the finite element model for each specific pressure head and for the Zero PWP and Zero Flux modes to derive \(K_{fs}\). Values for \(K_{fs}\) from percolation at high pressure heads were within 13% of the constant-head permeameter value in both modes. The Glover formula also gave good agreement for the Zero PWP mode. It is necessary to have the soil field-saturated before application of the proposed method. The procedure appears promising for field use following modelling using appropriate boundary and initial conditions and field-testing.

Keywords: Field-Saturated, Hydraulic, Conductivity, Constant-Head

1 Introduction
The field-saturated hydraulic conductivity \((K_{fs})\) of unsaturated soils is widely used in environmental and geotechnical engineering investigations and designs. Applications include designs for septic tank percolation fields, estimation of seepage and groundwater mounding from landfills, reservoirs and canals and designs for land drainage. The constant-head well permeameter method (Amoozegar 1992, 1997) is commonly used to measure \(K_{fs}\); it is considered to replicate the field conditions as close as possible for the many applications for which the measurements are used, as recommended by Bouwer (1978). In septic tank practice, it is the percolation rate from either a constant-head or falling-head well test that is used (ASTM, 1997; BSI, 1983; NSAI 1991). However, the percolation rate depends on many factors such as the diameter of the well and the pressure head employed among others (Elrick and Reynolds, 1986) whereas \(K_{fs}\) is a constant for any given soil. In this paper, \(K_{fs}\) is derived from constant-head well tests in large laboratory sand tanks while maintaining (i) zero porewater pressure on the sand surface by spray irrigation and (ii) zero flux at the sand surface, and employing the finite element package SEEP/W Version 4.24 (GEO-SLOPE, 2001).

2 Literature review
The constant-head well test, first developed by Glover (in Zangar, 1953), is based on saturated flow from a cylindrical test well drilled into unsaturated soil with a deep watertable. A general solution developed by Glover (Zangar, 1953) is

\[
\begin{align*}
\frac{Q_s}{\pi} & = \frac{K_{fs}}{2} \times H \\
Q_s & = \text{steady-state outflow from the well (m}^3/\text{s)} \\
H & = \text{steady-state height of water in the well (m)} \\
r & = \text{radius of the well (m)}
\end{align*}
\]

where \(A\) = a model parameter to be determined (\(1/\text{m}^2\))

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Eqn. (3) shows that A depends only on H and r. It assumes the soil through which the flow takes place is saturated (maintained by spray irrigation on the soil surface for example), takes into account only pressure heads in the well neglecting gravitational and matric potential gradients and does not take into account flow out of the well through the open base. Nonetheless, the Glover solution can provide good estimates of $K_{fs}$ in small diameter wells with large $H/r$ ratios, e.g. $>10$. (Zangar, 1953), in low capillarity soils with high background pore-water contents, e.g. coarse sands (Stephens and Neuman, 1982a) and well-structured soils (Elrick and Reynolds, 1992). $K_{fs}$ can be out by an order of magnitude or more in dry soils (Elrick and Reynolds, 1992), but in practice this can be overcome by pre-soaking the soil and by surface irrigation during the test. The method is adaptable for stony and gravelly soils (Bouwer and Jackson, 1974).

Stephens and Neuman (1982a) analysed free-surface (the surface where porewater pressure is atmospheric and with no flow crossing that surface) and saturated-unsaturated flow models for the constant-head well test, when no surface irrigation is applied. Their analysis in the main applies to large $H/r$ ratios, $\geq 10$. Saturated-unsaturated numerical simulations show that only a small pear-shaped volume of soil adjoining the well wall in contact with the steady head of water is saturated with the remainder of the flow zone unsaturated and containing streamlines crossing the free-surface boundary and invalidating the free-surface flow assumption. For a $H/r$ ratio of 50, the Glover solution would overestimate the $K_{fs}$ of a silt loam by 160% for a H of 0.5 m and underestimate it by 35% for a H of 10.0 m compared with saturated-unsaturated simulation; this is due to the non-uniqueness of the C and H/r relationship when unsaturated flow is considered (Stephens and Neuman, 1982a). While these problems can be overcome by maintaining the soil in a saturated state (at zero porewater pressure) by surface (spray) irrigation, this can be difficult in practice.

In a 2nd paper, Stephens and Neuman (1982b), using the same saturated-unsaturated flow models, showed that the infiltration rate from a constant-head well test stabilised after the establishment of steady state in the saturated pear-shaped zone while the wetting front continued to extend, as also illustrated in Elrick and Reynolds (1992). The former also examined the influence of degree of saturation, hydraulic conductivity and soil anisotropy and of well geometry (H, r, and B - the length of well in contact with the soil) on the infiltration rate and on the time required to reach steady flow rate from the well. The results were as expected: steady infiltration rate is reached much earlier as degree of saturation and hydraulic conductivity increase; infiltration rate increases as H, r and B increase. These results point to the impact of porewater conditions in the soil surrounding the well on the measurement of $K_{fs}$ and to the importance of selecting appropriate well geometries for the test conditions.

Reynolds and Elrick (1985), Reynolds and Elrick (1986), Elrick and Reynolds (1986), Elrick et al. (1989) and Elrick and Reynolds (1992) carried out analyses of infiltration from constant-head well tests using pressure, gravitational and matric potential gradients. The Richards (1931) equation, eqn. (4), which describes such flows is non-linear and must be linearised using the matric flux potential, introduced by Gardner (1958), and an assumed exponential relationship between the unsaturated hydraulic conductivity $[K(h)]$ and $K_{fs}$, eqn. (5),

$$\frac{\partial s}{\partial t} = \alpha \frac{\partial}{\partial h} [\partial h \cdot K(h)]$$

where $\alpha$ is the $\alpha$ parameter, an indicator of capillarity

$h$ is the matric potential.

The $\alpha$ parameter is assumed constant over the considered range of $h$, which may not be the case. $K_{fs}$ can be determined from measurements of constant-head percolation from an uncased cylindrical well, using two steady-state pressure heads in the well and employing eqn. (5). The unsaturated flow component is represented by an unknown parameter that must be determined independently, estimated from selected soil properties or calculated simultaneously (Amoozegar and Wilson, 1999). Simplifications may be necessary (Elrick and Reynolds, 1992). Eqn. (6) (Elrick et al., 1989) can be used to derive the A value of eqn. (1)

$$A = \int_0^{H} \frac{K_{fs}}{C} dh$$

where $C = a$ parameter depending on $H/r$ and the soil capillarity ($\alpha$ parameter).

As $\alpha$ increases to 36 (minimal capillarity as in a coarse sand), saturated flow becomes predominant.

### 3 Experimental

Athlone sand, a silt fine sand with a $D_{10} = 0.023$ mm; a $D_{60}/D_{10} = 3.4$ and a $D_{30}/[D_{60}D_{10}] = 1.5$, was used in the percolation tests. Initially, the hydraulic
conductivity of this sand was measured in a constant-head arrangement. A 150 mm diameter Perspex tube was filled with a 0.3 m high column of oven-dried sand, that overlay a thin membrane that in turn rested on a 30 mm high layer of 3 mm glass beads. The sand was poured into the tube in layers using the tension forces from a rising watertable maintained about 75 mm below the sand surface to compact the sand and achieve a uniform packing. A 30 mm layer of 3 mm glass beads also overlay the sand surface. A constant head of water in the range 0.10-0.16 m above the surface of the sand was maintained in five tests by Mariotte arrangement. The average temperature of the water was 15.5°C. The mean hydraulic conductivity of the sand was 7.6x10^{-6} m/s.

Two tanks were used for the percolation tests. Tank no.1 was 0.7 m diameter and contained a 0.7 m depth of Athlone sand overlying a thin filter screen on 75 mm of 10 mm gravel. The gravel functioned to allow free drainage from the overlying sand. Holes were bored in the base of the tank to which plastic tubes were fitted; these tubes could function in a drainage or refill mode. Four equally spaced holes at the side just below the base of the sand were used as standpipes. The tank was filled with oven-dried Athlone sand that was poured in layers, using the tension forces from a rising watertable as for the constant-head permeameter test to compact the sand and achieve a uniform packing. A cylindrical geotextile membrane well liner, 60 mm diameter, was placed in the centre of the tank at a depth 400 mm below the final sand surface and a multipoint tensiometer, at 200 mm from the perimeter of the well, was also installed and the sand poured around it. Constant-head tests were conducted using this well; a Mariotte bottle arrangement resting on a weighing scale on a laboratory jack was used to maintain a constant head and measure inflow rate into the well. Both saturated (by spray irrigation) and saturated-unsaturated tests were carried out in this tank; saturated tests provided zero porewater pressure (Zero PWP) conditions, and saturated-unsaturated tests provided zero flux (Zero Flux) conditions on the soil surface. Saturation was achieved by spraying the sand surface with water to maintain a glistening surface and saturation was monitored using the tensiometers. Constant-head tests at pressure heads of 400, 300 and 200 mm in the well were conducted.

Tank no.2 was 1.0 m diameter and contained a 0.63 m depth of Athlone sand overlying a thin filter screen on 50 mm of 10 mm gravel. Drainage-refilling tubes and standpipes were provided as for the 0.7-m diameter tank and filling procedures were the same. A multipoint tensiometer was located at 200 mm from the edge of a central well that was 340 mm in diameter and 400 mm deep below the sand surface. Only saturated tests were carried out in this tank. Two constant-head levels were employed, viz. 0.3 m and 0.2 m heads in the well. Flow rates into the well were measured by an arrangement similar to that used with the 0.7m diameter tank.

4 Modelling

SEEP/W Version 4.24 finite element programme (GEO-SLOPE, 2001) was used to analyse the constant-head percolation of water from cylindrical wells 60 mm diameter (Figure 1) and 340 mm diameter and 400 mm deep using a sand, a fine sand and a silt loam (Figure 2). The plan area of the 340 mm diameter well is practically identical to the plan area of a 300 mm square hole commonly used in septic tank practice (BSI, 1983; NSAI, 1991). Experimental data from the sand tank were available to validate the outputs from the model. The governing differential equation (Richards, 1931) used in the formulation of SEEP/W for this axisymmetric problem is

\[ H = \text{total head} \]
\[ z = \text{the elevation and} \]
\[ r = \text{the radial distance from the z axis} \]

In the model the left hand vertical boundary of the tanks was taken as the axis of revolution of the well and soil and z-axis for the analyses; no flow occurred normal to this and the right hand vertical boundary – the modelled wall of each tank. Quadrilateral elements with 4 nodes and dimensions of 5 mm in the radial and z-direction were used. The modelled soil depth outside the 60 mm diameter well (Figure 1) was 0.7 m and under the well was 0.3 m, and the tank radius was 0.35 m; for the 340 mm diameter well the values were 0.63 m sand (outside the well) and 0.23 m sand (under the well) and the tank radius was 0.5 m. Steady-state axisymmetric analyses with the water level at 0.4 m, level with the soil surface, 0.3 m and 0.2 m above the base of the 60 mm diameter well in Tank no. 1 and with the water level 0.3 m and 0.2 m above the base of the 340 mm diameter well in Tank no. 2 were carried out. Convergence tolerances were set at 1%. For the Zero PWP condition, a boundary pore-water pressure head (h) of 0.0 m was assigned to the topsoil boundary – simulating spray irrigation for a field-saturated state – and also to the bottom boundary. For the Zero Flux mode, a vertical flux of 0.0 m/s was assigned to the top soil boundary and 0.0 m was assigned to the bottom boundary. No flow boundary conditions were assigned normal to the z-axis and the tank wall (Figure 1). The percolation from the well was modeled using SEEP/W.
The sand, fine sand and silt had $K_{fs}$ values of $5.4 \times 10^{-5}$, $4.3 \times 10^{-6}$ and $2.5 \times 10^{-7}$ m/s respectively and cover the range of hydraulic conductivities of 4.7 to 0.02 m/d, which are considered suitable in Ireland for septic tank percolation fields. The hydraulic conductivity versus pore-water pressure head functions of the sand, fine sand and silt were given in the SEEP/W software and are shown in Figure 2.

5 Results
Table 1 shows A values for the Zero Flux condition and Table 2 shows A values for Zero PWP condition (with spray irrigation) at the soil surface from the SEEP/W analyses. For each depth at both conditions, the A values for the 3 soils – differing in $K_{fs}$ by over 2 orders of magnitude are nearly identical indicating that the A value does change for this hydraulic conductivity range at these constant heads.
Table 1  SEEP/W $A/(m^2)$ values for a 0.4 m deep, 60 mm diameter well in a 0.7 m diameter sand tank for three soils with Zero Flux at the soil surface for use in the equation $K_{fs} = A*Q$ where $K_{fs}$ (m/s) is the field saturated hydraulic conductivity of the soil and Q ($m^3/s$) the flow rate into the well from the Mariotte vessel.

<table>
<thead>
<tr>
<th>Constant head of water in well (m)</th>
<th>$K_{fs}$ (m/s)</th>
<th>$K_{fs}$ (m/s)</th>
<th>$K_{fs}$ (m/s)</th>
<th>Average $A$ (1/m$^2$) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>5.4e-5</td>
<td>2.09</td>
<td>2.10</td>
<td>2.09</td>
</tr>
<tr>
<td>0.3</td>
<td>2.46</td>
<td>2.52</td>
<td>2.48</td>
<td>2.50</td>
</tr>
<tr>
<td>0.2</td>
<td>3.27</td>
<td>3.34</td>
<td>3.23</td>
<td>3.30</td>
</tr>
</tbody>
</table>

Table 2  SEEP/W $A/(m^2)$ values for a 0.4 m deep, 60 mm diameter well in a 0.7 m diameter sand tank for three soils with Zero PWP at the soil surface for use in the equation $K_{fs} = A*Q$ where $K_{fs}$ (m/s) is the field saturated hydraulic conductivity of the soil and Q ($m^3/s$) the flow rate into the well from the Mariotte vessel.

<table>
<thead>
<tr>
<th>Constant head of water in well (m)</th>
<th>$K_{fs}$ (m/s)</th>
<th>$K_{fs}$ (m/s)</th>
<th>$K_{fs}$ (m/s)</th>
<th>Average $A$ (1/m$^2$) value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>5.4e-5</td>
<td>3.35</td>
<td>3.36</td>
<td>3.36</td>
</tr>
<tr>
<td>0.3</td>
<td>5.38</td>
<td>5.42</td>
<td>5.40</td>
<td>5.40</td>
</tr>
<tr>
<td>0.2</td>
<td>9.21</td>
<td>9.27</td>
<td>9.23</td>
<td>9.23</td>
</tr>
</tbody>
</table>

Steady-state flow was established in the 0.7 m diameter tank 2.5 minutes following the start-up of drainage with Zero PWP and after 5-6 minutes with Zero Flux (Figures 3 and 4). A and $K_{fs}$ values and spray irrigation rates are shown in Table 3 for steady-state flow. Irrigation rates increased steadily as pressure heads in the well were lowered, indicating that the use of high pressure heads in the well makes spray irrigation less demanding. Inflow rates into the well under Zero Flux were 1.6, 2.4 and 1.6 times those under Zero PWP for the 0.4 (Figure 3), 0.3 (Figure 4) and 0.2 m (not shown) pressure heads respectively. Inflow rates were less variable under Zero Flux than under Zero PWP.

Table 3  Steady-state results from Zero Flux and Zero Porewater tests in the 0.7-m tank by SEEP/W

<table>
<thead>
<tr>
<th>Pressure Head (m)</th>
<th>Irrigation Rate ($m/s \times 10^{-6}$)</th>
<th>A (Zero Flux) (1/m$^2$)</th>
<th>A (Zero PWP) (1/m$^2$)</th>
<th>$K_{fs}$ (Zero Flux) ($m/s \times 10^{-6}$)</th>
<th>$K_{fs}$ (Zero PWP) ($m/s \times 10^{-6}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.4</td>
<td>4.69</td>
<td>2.09</td>
<td>3.36</td>
<td>8.57</td>
<td>8.60</td>
</tr>
<tr>
<td>0.3</td>
<td>8.49</td>
<td>2.50</td>
<td>5.40</td>
<td>9.71</td>
<td>8.83</td>
</tr>
<tr>
<td>0.2</td>
<td>10.40</td>
<td>3.23</td>
<td>9.23</td>
<td>10.31</td>
<td>10.43</td>
</tr>
</tbody>
</table>

$K_{fs}$ values, determined by multiplying A values determined by SEEP/W by the inflow rates into the well, are shown in Table 3. $K_{fs}$ values by SEEP/W were similar by the Zero Flux and Zero PWP at each pressure head but increased as pressure was reduced in the well. Zero PWP $K_{fs}$ values were 13%, 16% and 37% higher under 0.4, 0.3 and 0.2 m well pressure heads respectively than that measured in the constant-head permeameter.
Figure 3  Flowrate into well with a pressure head of 0.4 m for both zero porewater pressure and zero flux conditions at the soil surface against time in minutes (min).
Table 4 shows a comparison of $K_{fs}$ computed by the Glover formula and the SEEP/W model. While the SEEP/W values were higher, the Glover values were lower by 21% at 0.4 and 0.3 m pressure heads and about the same at 0.2 m pressure head as that measured in the constant-head permeameter.

SEEP/W model and experimental porewater pressure heads at 0.20 m (Figure 5) from the perimeter of the 60 mm diameter test well with 0.3 m pressure head were almost coincident at depths of 200, 300, 400 and 500 mm below the sand surface (the depths measured) for zero PWP and zero flux conditions.

Table 4  A Comparison of $K_{fs}$ from SEEP/W model and Glover model under saturated conditions

<table>
<thead>
<tr>
<th>Pressure Head</th>
<th>$A$ (Glover)</th>
<th>$K_{fs}$ (Glover)</th>
<th>$K_{fs}$ (SEEP/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m)</td>
<td>(1/m²)</td>
<td>(m/s x 10^{-6})</td>
<td>(m/s x 10^{-6})</td>
</tr>
<tr>
<td>0.4</td>
<td>2.34</td>
<td>6.0</td>
<td>8.6</td>
</tr>
<tr>
<td>0.3</td>
<td>3.71</td>
<td>6.0</td>
<td>8.8</td>
</tr>
<tr>
<td>0.2</td>
<td>6.90</td>
<td>7.8</td>
<td>10.4</td>
</tr>
</tbody>
</table>

Figure 5  Comparison of the porewater pressures from SEEP/W model and experimental values for zero PWP and zero flux at the soil surface for the tensiometers located 0.20 m from the well perimeter at a pressure head of 0.3 m in the well.

Results for the 1-m tank with the 340-mm diameter well are shown in Table 5. $K_{fs}$ values were calculated from the SEEP/W model and from the Glover formula [eqns. (1-3)]. $K_{fs}$ results computed by SEEP/W and by the Glover formula are close to the value determined by the constant had permeameter (7.6x10^{-6} m/s).

Table 5  Steady-state results from zero porewater tests* in 1-m diameter tank

<table>
<thead>
<tr>
<th>Pressure Head</th>
<th>Irrigation Rate</th>
<th>Inflow Rate</th>
<th>$K_{fs}$ (SEEP/W)</th>
<th>$K_{fs}$ (Glover)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(m)</td>
<td>(m/s x 10^{-6})</td>
<td>(m^3/s x 10^{-6})</td>
<td>(m/s x 10^{-6})</td>
<td>(m/s x 10^{-6})</td>
</tr>
<tr>
<td>0.3</td>
<td>4.9</td>
<td>6.09</td>
<td>8.34</td>
<td>8.3</td>
</tr>
<tr>
<td>0.2</td>
<td>7.2</td>
<td>3.02</td>
<td>6.22</td>
<td>7.2</td>
</tr>
</tbody>
</table>

* $K_{fs}$ from constant-head permeameter tests = 7.6x10^{-6} m/s
6 Conclusions

- From the SEEP/W model, the ratio, A, of the hydraulic conductivity to the infiltration rate from the well into the soil had a unique value for a particular well pressure head under particular surface boundary conditions. Unique values were obtained at well pressure heads of 0.4, 0.3 and 0.2 m with the boundary conditions of zero porewater pressure and zero flux at the soil surface, and zero porewater pressure at the base.

- Field saturated hydraulic conductivity, $K_{fs}$, by the SEEP/W model, under the boundary conditions of zero porewater pressure and zero flux at the soil surface, and zero porewater pressure at the base compared favourably with that measured in a constant head permeameter. Results derived using the SEEP/W model and the experimental data from the percolation tests, using the highest well pressure heads employed in the 2 large laboratory sand tanks were within 13% of the constant head permeameter value indicating that high pressure heads in wells give best results.

- Saturation of the soil is necessary before the application of the proposed technique using either surface boundary condition, but the zero flux condition gives more uniform infiltration data and is easier to apply.

- $K_{fs}$ values by Glover theory were close to that measured in the constant head permeameter under saturated conditions.

- The procedure appears promising for field application following modelling using appropriate boundary conditions and field testing.

7 Acknowledgements

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8 References


ASSESSMENT OF LASER TECHNOLOGY APPLICATION ON THE PERFORMANCE OF SUBSURFACE DRAINAGE SYSTEMS

M. Akmal Omara

ABSTRACT
Laser equipment is used widely in different agricultural processes in order to solve land management problems: i.e. testing seed quality, land levelling for better distribution of irrigation water, and construction of irrigation and drainage systems, with high accuracy. An evaluation of laser application in the construction of subsurface drainage system was conducted at Mit Kenana pilot area, in Eastern Delta, Egypt. This area has sandy subsoil layers with high water table, which creates failure of drainage trenches during installation of subsurface drainage systems using trencher lying machines. Long term monitoring of subsurface drainage system at studied locations implemented with laser equipment is quite satisfactory after 5 years from construction. Application of laser equipment to control lateral and collector levels and slopes achieved under existed problematic unstable soil conditions in Mit Kenana pilot area, high correlation between design and actual levels for composed laterals and single ones are obtained.

Keywords: Drainage, Technology, Performance, Design

1 INTRODUCTION
One of the major constraints to agriculture production in Egypt is a water logging and salinity problem. The need for drainage becomes obvious soon after controlled irrigation system replaced free flooding. Surface and subsurface drainage systems are used to solve drainage problems in Egypt and for sustainability of crop productivity. In the past, manual construction of drainage systems caused severe siltation problems due to poor quality of installation. With the introduction of collector and lateral lying machines in the construction of drainage networks in Egypt, the quality of installation was improved as well as the performance of subsurface drainage systems. Moreover, laser technology was also introduced later to control pipe levels and slopes of both lateral and collector drains. In subsurface land drainage, considerable attention should be paid to the precision of the grading of installed drains. Past experience showed that it was difficult to attain acceptable precision by manual means. Poor grades badly influence the drains performance and limit their efficiency. Every deviation from the straight grade line can cause a large or small increase inflow resistance.

Standards for depth and grade control of subsurface drains vary from one country to another; however, there is general agreement that the deviation of the drain pipe from the desired grade line may not be more than half of the internal pipe diameter. The ICID guidelines on subsurface drain construction (Schultz, 1990) require that the maximum allowable deviation for the grades per 100 m should not be more that 20% of the inside pipe diameter. Accuracy of grades controlled by laser can reach +/- 5 mm per 100 m. About five depth checks per second are normally made by the laser automatic control during drainage machine operation.

The classical method of marking the alignments and levels is by placing stakes in the soil at both ends of a drain line, with the top of the stakes at a fixed height above the trench bed. The slope of the drain line is there by implicitly indicated.

Grade control on a drainage machine is essential for high quality work. Grade control can be made manually using grade stake and sighting across adjustable arms by the eye of the machine operator (Cavelaars, 1980). The results were acceptable but this was primarily possible due to the slow forward speed of the drainage machines used in the 1960's. Still, the quality of drain grades depended on the skills of the operator. With the introduction of the drainage plow (trench-less machine) in 1968, the increased forward speed demanded an improved system. A radio controlled surveying level was used but was not efficient in labor nor really accurate in results (Irwin and Johnson, 1982).

Nowadays, most of drainage machines provided with grade control using laser equipment. The successful operation of drainage equipment is dependent upon the ability to control and maintain the gradient of the drain tube installed (Fouss, 1965). One of the first experimental laser beam automatic grade control system was designed to meet the requirements for the drain tube plow equipment (Fouss and Fausey; 1967 and Fouss; 1968).

Laser technologies provide high precision capabilities in land leveling and improve the performance and increase the efficiency of the drainage system. Precision land leveling enables significantly improved on farm water management, increases irrigation efficiency, reduces labor requirements and reduced energy requirements for pumping water.
Laser was introduced in Egypt for subsurface drainage construction at the end of 1970’s and early 1980’s. The improvement of grade control was very promising although some deviations were observed mainly due to lack of experience. By the end of the 1980’s use of laser equipment for grade control became obligatory. All new contracts by the Egyptian Public Authority for Drainage Projects (EPADP) including the application of laser control system for subsurface drainage construction.

Laser beam grading system became available, however, before operational drainage plows and the new automatic system soon were accepted and used by contractors in the conventional trenching machines. An emitter, placed on a tripod near the edge of the field, establishes an adjustable reference plane over the field by means of a rotating laser beam. A receiver, mounted on the digging part of the drainage machine, picks up the signal. The control system of the machine continued by keeps a fixed mark in the laser plane. One position of the emitter can serve the installation of a fairly large number of drains. The reference plane of laser can be set to a grade with an accuracy of 5 mm per 100 m (0.005%). About five depth checks per second are normally made. The most of laser tracking receivers consist of a vertical array of closely spaced photocells, which are mounted to logic and a controller circuit. The controller in turn operates the machine hydraulics to provide the corrective feedback motion and thus automatically keep the receiver centered on the laser beam or laser plane reference. Some of the new systems include a device for changing grade without resetting the projected laser beam or plane reference (ICID, 1990). This device causes the tracking receiver unit to slowly move vertically, relative to machine mounting as a function of ground travel distance. Thus, any desired grade can be created for a given laser or plane slope (Westland et al., 1990). Three types of laser systems are in use:

1. A single laser light beam on line projected to the desired grade and along the direction of travel;
2. A partial plane or segment of circle projected parallel to the desired grade in the direction of travel and to the cross-slope;
3. A circular laser plane reference described by rapidly rotating the laser source where one axis in the plane is aligned parallel to the desired drain gradient and the cross axis is aligned either horizontally or parallel to the general land slope.

The third type of laser system has become very popular because the elevation or grade datum covers a large field area of the order of a 40 ha circle, with each set up of the laser transmitter unit.

The basic concept of the laser control system is to use a laser beam fixed at a certain position as a reference to measure the depth of the cutting blade or digging mechanism of an earth moving machine to be able to correct its position instantaneously during operation. Laser equipment consists of several components which together realize this objective (Dedrick, 1979; El-Hammamy, 1988; and de Boer, 1987):

- **Transmitter**: A rotating laser beam from a laser transmitter fixed on a tripod creates a plane of light over the land surface. The transmitter can be fixed vertically or tilted to a given angle with the vertical axis to produce either a horizontal or inclined plane. The angle of inclination can be precisely adjusted according to a predetermined grade. The maximum range of a laser beam is about 300 m but can be less because of dusty or windy conditions. Signals from one transmitter with a rotating beam can be used with more than one machine moving at the same time in the field.

- **Detector**: A laser beam detector mounted on a special measuring staff is used to determine the laser beam height above any ground spot. The detector is moved up and down on the staff until it intercepts the fixed or rotating beam. When the beam is set horizontal, at a known elevation, any checked beam height above a given point will identify the elevation of the point. The detector and the staff are used in grid surveys or in adjusting the work depth of a machine at a starting point.

- **Receiving, Monitoring and Control Unit**: A laser beam receiver is fitted to a vertical mast mounted on the machine. The receiver rotates 360° so that it can always be set to face the transmitter. The mast height is adjusted to enable intercepting the laser beam. The receiver contains light sensitive silicone photocells. When the receiver intercepts the laser beam, it relays its position to the laser control box.

- **Control Box**: A control box is mounted on the control panel of the machine. It receives and processes signals from the receiver and displays the machine position in relation to the laser. Arrows and/or colored lamps on the display indicate whether the machine is working at the right height or in the right direction.

It is important to check the elevation and grade of lateral drains. Dip and humps in laterals can cause air pockets, which will severely restrict flow. Generally, specifications require that drains do not deviate more than half the diameter from the design alignment. In stable soils, when the trench remains open, it is easy to check the elevation and grade with standard survey equipment (leveling instrument). However, when the trench collapses soon after passage of the trencher, or when drains are constructed with the trench less techniques, which is not possible.

The objective of this paper is to highlight the findings related to the evaluation of Laser equipment as one of the drainage technologies, which could be used to improve the quality of construction under Egyptian conditions.

### 2 METHODOLOGY

The study was conducted at Mit Kenana pilot area, which located 40 km North of Cairo. It represents an area of 830 feddan (350 ha) including agricultural and village areas, while the net area is 500 feddan. **Figure 1.** The pilot area is limited by Barsomia irrigation canal in the west and south, and the Kasabia irrigation canal in the east. The main crops in the area are maize, clover, wheat, rice, and vegetables, beside fruit crops.
The drainage system in the pilot area (500 feddan) consists of eight collectors 1, 2, 2m, 3, 4, 5, 6, 8, and single laterals as shown in Figure 2. Seven collectors discharging their water into Mit Kenana branch open drain. Collector 4 was selected to carry out this study because it is the only collector having single lateral drains and also many problems were faced regarding soil instability conditions during construction. Lateral drains 18, 19, 20, 21, 22, and 23 were considered in the study. At the same time, single laterals 10, 11, and 12 were also regarded during the study.

Five non-homogenous soil texture were chosen, it is indicated the soil texture in the area and the locations of sampling were A, B, C, D, and E as shown in Figure 2. Soil samples were collected at these locations from soil surface until 2.0 m below soil surface at every change in soil texture. The particle size distribution was determined according to Piper (1950), and soil hydraulic conductivity according to Van Beers (1976).

Observation wells were installed midway between drains to monitor the water table fluctuation below soil surface at the chosen laterals of collector 4. The levels of the laterals were measured using survey mast and LB-4 laser beacon which emits a continues 360° rotating plane of infrared laser light, and the operating ring is 610 diameter circle working area. The levels of the studied laterals were taken every 50 m starting from the outlet of the lateral. A hole was dug by auger till the inverts level of lateral and a steel bar was put on it. Then, the mast was placed on the top of the steel bar and the readings were collected from laser beacon and converted to level values. Comparison was made between the measured levels of lateral drains in 1991 and levels measured in 1996.

3 RESULTS AND DISCUSSION
Table 1 summarizes the particle size distribution and soil texture for the soil samples collected from the studied locations at collector 4 in Mit Kenana pilot area. The results reveal that, all soil samples are characterized by high percentage of sand fraction. The maximum percentage of sand was 98.8% (location A), while the minimum was 35.8% (location C). The maximum and minimum percentage of silt fraction was 24% (location B) and 0.40% (location A) respectively. At the same time, the maximum and minimum percentage of clay fraction was 40.5% (locations C & D) and 0.37% (location B) respectively.
APPLING SOME NEW TECHNOLOGIES TO IMPROVE THE QUALITY OF INSTALLATION AND PERFORMANCE OF SUBSURFACE DRAINAGE SYSTEMS IN EGYPT

Figure 2

LENGEND

== DRAIN
ASPHALT ROAD
UNPAVED ROAD
MAIN IRRIGATION CANAL
SMALL IRRIGATION CANAL
BRIDGE
OBSERVATION WELLS

http://library.wur.nl/ebooks/drainage/drainage_cd/1.1%20omara%20akmal%20m.html (4 of 11) 26-4-2010 12:10:33
Layout of subsurface drainage system at Mit Kenana pilot area

The results of the soil hydraulic conductivity (K) at studied locations are presented in Table 1. The (k) values varied between 1.03 to 1.3 m/day. The high (k) values are due to lighter soil texture.

Table 1  Soil texture and hydraulic conductivity (k in m/day) in studied locations at Mit Kenana pilot area.

<table>
<thead>
<tr>
<th>Location</th>
<th>Depth (cm)</th>
<th>Particle Size (%)</th>
<th>Distribution</th>
<th>Soil Texture</th>
<th>K (m/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sand</td>
<td>Silt</td>
<td>Clay</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0-40</td>
<td>88.8</td>
<td>0.4</td>
<td>0.8</td>
<td>Sandy</td>
</tr>
<tr>
<td></td>
<td>40-100</td>
<td>86.6</td>
<td>0.6</td>
<td>0.8</td>
<td>Sandy</td>
</tr>
<tr>
<td></td>
<td>100-200</td>
<td>80.1</td>
<td>9.48</td>
<td>10.42</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td>B</td>
<td>0-50</td>
<td>71.74</td>
<td>18.16</td>
<td>10.1</td>
<td>Loamy Sand</td>
</tr>
<tr>
<td></td>
<td>50-120</td>
<td>85.6</td>
<td>6.8</td>
<td>7.6</td>
<td>Loamy Sand</td>
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<tr>
<td></td>
<td>120-180</td>
<td>99.2</td>
<td>0.43</td>
<td>0.37</td>
<td>Sandy</td>
</tr>
<tr>
<td></td>
<td>180-200</td>
<td>40.2</td>
<td>24.0</td>
<td>35.8</td>
<td>Clay Loam</td>
</tr>
<tr>
<td>C</td>
<td>0-60</td>
<td>82.8</td>
<td>8.0</td>
<td>9.2</td>
<td>Loamy Sand</td>
</tr>
<tr>
<td></td>
<td>60-100</td>
<td>80.6</td>
<td>12.3</td>
<td>7.1</td>
<td>Loamy Sand</td>
</tr>
<tr>
<td></td>
<td>100-200</td>
<td>35.8</td>
<td>23.7</td>
<td>40.5</td>
<td>Clay</td>
</tr>
<tr>
<td>D</td>
<td>0-55</td>
<td>67.8</td>
<td>11.0</td>
<td>21.2</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td></td>
<td>55-120</td>
<td>83.6</td>
<td>4.6</td>
<td>11.8</td>
<td>Loamy Sand</td>
</tr>
<tr>
<td></td>
<td>120-200</td>
<td>58.2</td>
<td>15.9</td>
<td>25.4</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>E</td>
<td>0-90</td>
<td>89.7</td>
<td>12.9</td>
<td>18.4</td>
<td>Sandy Loam</td>
</tr>
<tr>
<td></td>
<td>90-130</td>
<td>86.1</td>
<td>5.0</td>
<td>8.9</td>
<td>Loamy Sand</td>
</tr>
<tr>
<td></td>
<td>130-200</td>
<td>40.1</td>
<td>19.4</td>
<td>40.5</td>
<td>Clay</td>
</tr>
</tbody>
</table>
Figure 3  Comparison between design levels and actual levels of some lateral drains at Mit Kenana pilot area

In the case of single laterals which discharge directly into main open drain, the results of D1 and D2 of studied single laterals are shown in Figure 4. Lateral (10) with total length of 350 m, D1 and D2 values fluctuated between 0.06 to 0.08 m and 0.04 to 0.07 m respectively. These values are within the accepted values while lateral 12 showed that, the actual levels in 1991 and 1996 are below design level. This is due to soil conditions existed in the two sites, which are unstable conditions and this lead to severe problems and difficulties during construction of these drains. Lateral (11) with total length of 325 m, D1 and D2 values fluctuated between 0.0 to 0.16 m and 0.01 to 0.22 m respectively. In general, the long lateral length causes some deviations from the actual level because the machine driver has less experience to execute such long laterals. There are some problems noticed during the construction of subsurface drainage system such as the friction of the gears of the trencher machine due to the prevailing of sand in the surrounding area near the cutting knife of the machine. Also, the unsuitability of the soil affects the pulling force of the machine and consequently affects the engine working hours.

In addition, the regression analysis was made between designed level of lateral and actual level for different studied lateral drains. The results indicated that, the correlations are highly significant for all studied laterals. This means that the quality of construction is high in such problematic unstable soil conditions and this will lead to high performance of the drainage system. In the case of single laterals, there are highly significant correlations obtained and the values are differed between 0.98 and 0.99. It could be concluded that with laser equipment it is easy to construct long lateral drains under unstable soil conditions without problems.
The results of hydraulic head midway between studied lateral drains (served by collector 4) of lateral numbers 19, 21, and 23 during winter and summer season 95/1996 are shown in Figure 5. In some laterals the watertable depth below soil surface at certain intervals is around 0.40 m, while at another intervals it reached to about 1.0 m, taking into consideration that the average drain depth is about 1.30 m. In general, the watertable depth fluctuates between 0.35 m to 1.20 m below soil surface in winter and summer seasons. Consequently, the hydraulic head midway between drains is varied between 0.10 m to 0.90 m during winter season and between 0.15 m to 1.0 m during summer season. The results also indicated that during summer 1996 more irrigation water was given to the cultivated crops compared with winter season 1995/1996; however, water table depth is within the allowable design depth.

Figure 6 shows the results of hydraulic head midway between of lateral drains number 18, 20, and 22 in winter and summer seasons. The hydraulic head fluctuates between 0.10 to 1.0 m during winter season and 0.2 to 1.0 m during summer season below soil surface. The results also indicated that during summer 1996 more irrigation water was given to the cultivated crops compared with winter season 1995/1996. The watertable depth is within the allowable design depth.

Figure 7 shows the results of hydraulic head midway between single lateral drains number 10, 11, and 12 in winter and summer seasons. The hydraulic head fluctuates between 0.01 m to 0.87 m below soil surface. It is noticed that the hydraulic head between drains at collector 4 is higher than hydraulic head midway between drains in single laterals during winter and summer seasons.
In general, the water table depth below soil surface at certain intervals is around 0.40 m, while at another intervals it reached to about 1.0 m, taking into consideration that the drain depth is about 1.30 m. In general, the watertable depth fluctuates between 0.35 m to 1.20 m below soil surface in winter and summer seasons. Consequently, the hydraulic head midway between drains is varied between 0.10 m to 0.90 m during winter season and between 0.15 m to 1.0 m during summer season. The results also indicated that during summer 1996 more irrigation water was given to the cultivated crops compared with winter season 95/1996. The watertable depth is within the allowable design depth.

4 CONCLUSIONS AND RECOMMENDATIONS

Laser technology assist in obtaining drain lines with straight grades which improve the performance of subsurface drainage system and eliminate the possibility of air locks and siltation. Accurate grade control with drainage machines move with high speed is almost impossible without automatic laser control system. The following conclusions and recommendations can be drawn from the study conducted:

1. Regarding the hydraulic head fluctuation midway between lateral drains, the performance of subsurface drainage system in the studied locations is running well after five years since the construction of the system. The application of the laser technology played a vital role to control the leveling of the laterals constructed in such problematic area. Consequently, it helped in improving the performance of the drainage system.

2. Long lateral length causes some deviations from the actual level because the machine driver has less experience to execute such long laterals.

3. It is recommended to use laser equipment in the construction of subsurface drainage system not only in problematic areas but also in all areas will be provided with subsurface drainage system.

4. The use of laser equipment with single laterals in problematic unstable soils is strongly recommended.

5 REFERENCES

Hydraulic head midway lateral drains at Mit Kenana pilot area
Figure 6  Hydraulic head midway lateral drains at Mit Kenana pilot area
Figure 7  Hydraulic head midway lateral drains at Mit Kenana pilot area

ABSTRACT

Subsurface pipe and open drainage systems were installed in 8 and 5 ha area, respectively in farmers' fields at Konanki pilot area in Nagarjuna Sagar project right canal command in South India in the year 1999 to combat the problems of water logging (depth to water table, 0 to 3.74 m), salinity and sodicity (ECe, 1.3 to 18.6 dS/m; pH, 7.2 to 10.0 and ESP, 14.1 to 54.6). Two types of envelope materials, nylon mesh and geo-textile were used and two spacings of 30 m (design spacing) and 60 m (double the design spacing) were adopted for the pipe drainage system. The analysis of data collected on discharges from the individual pipe drains revealed that among both the spacings, the drains enveloped with geo-textile performed better (0.45 to 1.85 mm/day), when compared with those enveloped with nylon mesh (0.25 to 0.86 mm/day). The performance of drainage systems in the control of water logging has been monitored through a network of sixty one observation wells. The ground water table, which used to be almost at the ground surface during the main crop season (October to February) before installation of drainage systems, could be lowered by 0.2 to 0.35 m due to the installation of drainage systems. A total of 50.431 (@ 6.3 tons/ha) and 115.563 tons (@ 23.12 tons/ha) of salts have been disposed through pipe and open drainage systems, respectively during the period of three years (1999 to 2002).

Keywords: Subsurface drainage, Drain spacing, Envelope material, Water logging, Depth to water table

1 INTRODUCTION

Large areas of prime agricultural land in most of the irrigation commands in Andhra Pradesh state in India are constantly water logged, while others are affected only during the post monsoon season. The water logged and salt affected areas in Andhra Pradesh are estimated to be 0.344 and 0.81 million ha, respectively. Nagarjuna Sagar Project (NSP) is one of the important major irrigation projects of Andhra Pradesh commanding 0.475 and 0.43 million ha by its right and left bank canals, respectively. The average monthly rainfall and evaporation in the NSP right canal command are shown in Fig. 1. These values indicate that the rainfall is more than the evaporation during the months from August to November. Added to rainfall, large quantities of irrigation water are also applied during October to February to the paddy crop. This has disturbed the hydrologic equilibrium of the command area. It is estimated that the water table in this command area is rising at an alarming rate of 0.32 m/year (Singh, 1993) and as a result, about 28.6% of the command has become water logged (WAPCOS, 1999). Another estimate by the National Remote Sensing Agency indicated that about 6 % of the command has become salt affected (NRSA, 1996).

The ever increasing pressure on land and water resources demands that the areas affected by water logging and salinity be reclaimed for sustainable agriculture. In order to suggest suitable reclamation measures to combat water logging and salinity in NSP right canal command; a pilot area of 21.63 ha was selected near Konanki village in Prakasham district to conduct operational research. At the pilot area, the water table, which goes deeper to around 3 m below the ground surface by May/June of the year, starts rising after the receipt of monsoon rains from the first/second week of June onwards. In addition to rainfall, huge quantities of irrigation water are supplied from the last week of September. As a result, the water table comes close to the ground surface by the commencement of the second season (early October) and almost remains there till February. The area therefore becomes water logged during the period from October to February. Apart from this, the area also had salinity and sodicity problems. The average salinity (ECe) of the soil saturation extracts of 58 samples collected from three depths, viz. 0-15; 15-30 and 30-60 cm varied from 1.3 to 18.6 dS/m. The pH and ESP of these samples were in the range of 7.2 to 10.0 and 14.1 to 54.6, respectively. Drainage was therefore needed during the period from October to February to control water logging, salinity and sodicity problems at the pilot area.
Subsurface drainage systems were installed using Bell mouthed perforated stone ware pipes (100 mm dia., 60 cm length with 6 mm dia perforations) as drain pipes and coarse sand as the envelope material at Endakuduru village near Machilipatnam in coastal Andhra Pradesh to reclaim the water logged and salt affected soils (AICRPAD, 1986-1998). In the drained areas, soil conditions improved significantly and yield of paddy increased by 30%, sugarcane by 19%, betel vine by 30% and turmeric by 11%, as compared to the yield obtained from the fields that were not drained. Later, subsurface drainage systems were installed on a large scale to combat the problems of water logging and salinity in over 15,000 ha in Rajasthan state under Canadian Government assisted project, RAJAD (Sewaram et al. 2000) and over 1,200 ha in Haryana state under the Netherlands assisted project, HOPP (Achthoven, 2000) using the corrugated perforated UPVC pipes as drain pipes and synthetic materials as drain envelope with the imported drain laying equipment. Taking these successful projects into account, an Indo-Dutch Network project was started in the year 1996 under which, a pipe drainage system was constructed using perforated UPVC pipes and synthetic envelope materials such as geo-textile and nylon mesh for the first time in Andhra Pradesh at Konanki pilot area in an area of 8 ha. An open drainage system was also installed at the pilot in an area of 5 ha. The performance of these drainage systems in controlling water logging at the pilot area is presented in this paper.

2 MATERIALS AND METHODS

The Konanki pilot area is in the tail end of Yaddanapudi branch canal under Nagarjuna Sagar Project Right Canal Command and is located at the latitude of 50° 80' and longitude of 55° 16'. The project area is bounded by Kolkata – Chennai road (National Highway No.5) in the west and natural main drain in the east and the south (Fig. 2). The mean annual, summer and winter temperatures at the pilot area are 29.37, 31.63 and 25.73°C, respectively. The average annual rainfall is 902 mm. The texture of the soil varies from sandy loam to sandy clay loam. The depth to impermeable layer from the ground surface is 9 m. The average salinity of irrigation water is 0.6 m. Flooding method of irrigation is adopted under which the irrigation water is allowed to flow from one field to the other during the entire crop period. The number of irrigations varies from 10 to 13. The excess water from the tail end areas adjacent to the natural drains flows in to it as surface drainage/runoff.

A pipe drainage system was installed in an area of 8 ha in the central part of the pilot area in May 1999 (Fig. 2). On the northern side of the collector drain, ten pipe drains at design spacing of 30 m and on the southern side, five pipe drains at double the design spacing of 60 m were installed at a depth varying from 0.9 to 1.1 m below the ground surface (Satyanarayana et al. 2000). The first five pipe drains on the northern side and the first two pipe drains on the southern side of the collector drain were enveloped with nylon mesh and the remaining pipe drains were enveloped with geo-textile. An open drainage system with three drains of 1 m depth at a spacing of 100 m was also constructed in the northern part of the pilot area. The topography of the pilot area permitted gravity outflow at the end of the open drains and collector drain of the pipe drainage system to dispose off the collected drain water into the natural drain (Fig. 2). The design particulars of drainage systems are given in Table 1.

In order to evaluate the performance of drainage systems in controlling water logging, a network of ten pre-drainage and fifty one post-drainage observation wells was established in the pilot area (Fig. 2). The depth to water table in these observation wells is being measured daily. While the discharges from all the fifteen pipe drains as well as the gravity outlet of the pipe drainage system are measured volumetrically, the discharges from the three open drains in to the natural drain are measured daily by velocity-area method.
### Table 1  Details of drainage systems constructed at Konanki pilot area.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Particulars</th>
<th>Pipe drains</th>
<th>Open drains</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Drained area</td>
<td>8 ha</td>
<td>5 ha</td>
</tr>
<tr>
<td>2</td>
<td>Year of installation</td>
<td>1999</td>
<td>1999</td>
</tr>
<tr>
<td>3</td>
<td>Type of system</td>
<td>Composite</td>
<td>Singular</td>
</tr>
<tr>
<td>4</td>
<td>Spacing</td>
<td>30 and 60 m</td>
<td>100 m</td>
</tr>
<tr>
<td>5</td>
<td>Drain depth</td>
<td>0.9 to 1.1 m</td>
<td>1 m</td>
</tr>
<tr>
<td>6</td>
<td>Lateral pipe drain</td>
<td>Dia 0.08 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slope 0.1 to 0.2%</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>Collector pipe</td>
<td>Dia 0.16 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slope 0.6%</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Envelope material</td>
<td>Geo textile and Nylon mesh</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>Inspection chambers</td>
<td>Total No. 9</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Depth 1.8 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dia 0.75 m</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Dimensions of open drains</td>
<td></td>
<td>Bottom width 0.4 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Side slope 1:1</td>
</tr>
<tr>
<td>11</td>
<td>Type of outlet</td>
<td>Gravity</td>
<td>Gravity</td>
</tr>
<tr>
<td>12</td>
<td>Method of installation</td>
<td>Poclain and Manual labour</td>
<td>Poclain and Manual labour</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

It is essential to make a quantitative and qualitative assessment of the effectiveness of the drainage systems to ensure the best possible use of the technology and to formulate guidelines for future drainage works.

3.1 Performance of pipe drainage system

The discharge particulars of 30 m spaced pipe drains during three years 1999-2000, 2000-2001 and 2001-2002 are furnished in Table 2 (Satyanarayana et al. 2002). In the initial two years (1999-00 and 2000-01), among 30 m spacing laterals, the drains enveloped with geo-textile gave higher discharge (0.91 and 0.83 mm/day) when compared to those enveloped with nylon mesh (0.51 and 0.57 mm/day). However, in the third year (2001-02), the average discharge was same (0.45 mm/day) for both the types of drains. This was because, during that year the pipe drains LN6, LN7 and LN8 discharged at very low rate (0.45, 0.38 and 0.31 mm/day, respectively) when compared to previous years. Also, the pipe drain LN9 discharged for very low number of days (56 days) when compared to previous years. The pipe drain LN2 has also discharged for only 22 days during the year 2001-02. Taking this into view, the pipe drains LN2 and LN9 were excavated in June 2002 to check for any deviation in the alignment. It was observed that the alignment was disturbed at some places. They were later relayed by maintaining proper gradient and alignment in September 2002 after which they drained at the expected rate.

The discharge particulars of 60 m spaced pipe drains are given in Table 3. Among these laterals also, the drains enveloped with geo-textile gave higher average discharge (1.23, 1.63 and 1.85 mm/day during the years 1999-2000, 2000-2001 and 2001-02, respectively) when compared to those enveloped with nylon-mesh (0.86, 0.25 and 0.54 mm/day, respectively). The lowest discharge of 0.04 to 0.05 mm/day in case of LS2 is because the farmers are not irrigating most of the area drained by LS2. The drain LS4, which was found to discharge at a lower rate (0.14 to 0.31 mm/day) was also excavated during June 2002 to check its alignment and was reinstalled in September 2002 after which its performance has also improved.

Table 2  Discharge particulars of 30 m spacing lateral drains of pipe drainage system at Konaki pilot area

<table>
<thead>
<tr>
<th>Name of the Lateral</th>
<th>Nov '99 to Sep '00</th>
<th>Oct '00 to Sep '01</th>
<th>Oct '01 to Sep '02</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of days drain discharged</td>
<td>Average discharge (mm/ day)</td>
<td>No. of days drain discharged</td>
</tr>
<tr>
<td>LN1</td>
<td>87</td>
<td>0.46</td>
<td>79</td>
</tr>
<tr>
<td>LN2</td>
<td>79</td>
<td>0.64</td>
<td>75</td>
</tr>
<tr>
<td>LN3</td>
<td>144</td>
<td>0.69</td>
<td>141</td>
</tr>
<tr>
<td>LN4</td>
<td>133</td>
<td>0.42</td>
<td>135</td>
</tr>
<tr>
<td>LN5</td>
<td>134</td>
<td>0.36</td>
<td>137</td>
</tr>
<tr>
<td>Weighted average for drains</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3  Discharge particulars of 60 m spacing lateral drains of pipe drainage system at Konanki pilot area

<table>
<thead>
<tr>
<th>Name of the Lateral</th>
<th>Nov '99 to Sep '00</th>
<th>Oct '00 to Sep '01</th>
<th>Oct '01 to Sep '02</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of days drain discharged</td>
<td>Average discharge (mm/day)</td>
<td>No. of days drain discharged</td>
</tr>
<tr>
<td>LS1</td>
<td>101</td>
<td>1.99</td>
<td>87</td>
</tr>
<tr>
<td>LS2</td>
<td>143</td>
<td>0.05</td>
<td>139</td>
</tr>
<tr>
<td>Weighted average for drains enveloped with Nylon mesh</td>
<td>0.86</td>
<td>0.25</td>
<td>0.54</td>
</tr>
<tr>
<td>LS3</td>
<td>144</td>
<td>0.29</td>
<td>134</td>
</tr>
<tr>
<td>LS4</td>
<td>133</td>
<td>0.20</td>
<td>120</td>
</tr>
<tr>
<td>LS5</td>
<td>161</td>
<td>2.90</td>
<td>155</td>
</tr>
<tr>
<td>Weighted average for drains enveloped with Geo-textile</td>
<td>1.23</td>
<td>1.63</td>
<td>1.85</td>
</tr>
</tbody>
</table>

3.2 Quantities of salts disposed through drainage systems

The quantities of salts disposed through pipe and open drainage systems during the three consecutive years from 1999 to 2002 are given in Table 4. During this period, a total of 50.431 and 115.563 tons of salts were disposed through pipe and open drainage systems, respectively. The salts are disposed by the pipe drainage system at a faster rate during the main crop season than in the remaining part of the season (Fig. 3).

Table 4  Quantities of Salts disposed (tons) through drainage systems at Konanki pilot area

<table>
<thead>
<tr>
<th>Type of system</th>
<th>1999-00</th>
<th>2000-01</th>
<th>2001-02</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe drainage system</td>
<td>14.734</td>
<td>13.768</td>
<td>21.929</td>
<td>50.431</td>
</tr>
<tr>
<td>(1.84)*</td>
<td></td>
<td>(1.72)</td>
<td>(2.74)</td>
<td></td>
</tr>
<tr>
<td>Open drainage system</td>
<td>45.24</td>
<td>42.173</td>
<td>28.15</td>
<td>115.563</td>
</tr>
<tr>
<td>(9.1)</td>
<td></td>
<td>(8.43)</td>
<td>(5.63)</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td></td>
<td></td>
<td></td>
<td>165.994</td>
</tr>
</tbody>
</table>

* The figures in parentheses indicate the quantity of salts disposed in tons per hectare

3.3 Effect of subsurface drainage systems in controlling water logging

The ground water table fluctuations at the pilot area were monitored through a network of ten old observation wells constructed before the installation of drainage systems and fifty one new observation wells constructed after the installation of the drainage systems. In general, at the pilot area, during the main crop period from the months of October to February, the water table used to be close to the ground surface before installation of drainage systems (Fig. 4). However, a significant fall in water table during this period in the years 2000-01 and 2001-02 is noticed because of drainage systems. It is also observed that the water table is lowered considerably from March to September during the years 1999-2000 and 2000-2001 after the installation of drainage systems when compared to previous years. The sudden increase in water table level after June in the year 1999-2000 is because of high rainfall occurred in the pilot area during that period of the year. On an average, the depth to ground water table in the entire pilot area during the main crop growing period is lowered by 0.2 to 0.35 m after the installation of drainage systems, which has ultimately resulted in paddy crop yields considerably for the benefit of the farmers.
CONCLUSIONS

The results of analysis of data collected from the pilot areas indicate that the subsurface drainage systems are functioning effectively. Among both 30 and 60 m spacing pipe drains, the drains with Geo-textile as envelope material discharged drain water at a higher rate when compared to those...
Subsurface Drainage for the Control of Water Logging in a Pilot Area in Nagarjuna Sagar Right Canal Command in South India

enveloped with Nylon mesh. Due to the installation of drainage systems, the water table, which used to be almost at the ground surface during the paddy crop growing (late kharif/monsoon) season has been lowered by 0.2 to 0.35 m.

5 REFERENCES
QUALITY CONTROL OF SUBSURFACE DRAINAGE PROJECTS

Eng. Gehan A. H. Sallam

ABSTRACT
A subsurface drainage system has to function properly over a long period. Therefore it must be accurately and properly installed. There are currently about 470,000 feddans of land with pipe drainage in Egypt, approximately 11% of the total drained area, which are not functioning properly. The poor quality of subsurface drainage construction is due to several reasons, including: damaged pipe materials, poor pipe connections, misalignment and depth fluctuations of collectors and laterals during installation, pipe sedimentation, and lack of envelope. A quality control and quality assurance system for subsurface drainage projects was developed to improve their quality. A questionnaire was conducted within Egyptian Public Authority for Drainage Project (EPADP) to analyze the current construction practices and the main phases of the project. The main phases analyzed here are Field Investigation phase, Construction phase, and Operation and Maintenance phase. The specifications and standards of each phase and the main control points were determined. After that, the weakness points and the required corrective actions were also determined for each phase. The results showed that, the low quality of subsurface drainage system construction is attributed to the lack of adequate aspects of quality control and quality assurance for the phases of the project. To improve the quality control and quality assurance for the project, it is important to concentrate on the main control points of each phase and apply the required corrective actions.

Keywords: Quality assurance, Quality control, Quality system, Subsurface drainage system

1 INTRODUCTION
The Nile Delta and the Nile valley of Egypt, is one of the most fertile and intensively cultivated regions in the world having been under continuous cultivation for at least 5000 years. This is due to the Nile mud brought down by the Nile from the Ethiopian plateau (Amer and Ridder, 1989). The agricultural sector accounts for more than 30% of the gross national product (Abu-Zeid, 1990). At the turn of the 19th century, perennial irrigation was introduced in the Nile River Delta and Valley of Egypt. This lead to raise groundwater table, and increase problems of water logging and salinity. As a consequent result of these problems the productivity of the agricultural land decreased. If subsurface drainage is not provided, when needed, the crop yield will be reduced by as much as 20 percent in a very few years. In response to this challenge, the government gave high priority for installing drainage systems because it would be uneconomical to cultivate land with this reduced productivity (Johnston, 1976).

One of the main advantages of constructing subsurface drainage system in the Nile Delta is increasing the productivity of crops actually by 138%, 48%, 75% and 10% for Wheat, Clover, Maize and Rice respectively (Abdel-Dayem et al, 1990). In Egypt, it is estimated that up to 1995, approximately 4.3 million Feddans (1 Feddan = 0.42ha) have been subsurface drained and another 2.1 million Feddans will be implemented between 1996 and 2010 (Advisory Panel on Land Drainage, 1996). As part of the National Drainage Program, over US $ 35 million are to be spent on the rehabilitation of drainage systems. According to the performance indicators and measurements by the Drainage Research Institute (DRI, 1993) in selected areas, it was shown that the major reasons for system failure are the low quality of construction and lack of adequate inspection and supervision.

Given the significant public investments in subsurface drainage, it is imperative that systems be properly installed and maintained, and function effectively. Furthermore, considerable amounts of time, money and energy are expended in project formulation, financing, and engineering design. These investments need to be protected, and it is essential that full benefits of drainage be accrued, to ensure system sustainability. It is expected that if proper attention is paid to quality control and quality assurance in drainage construction, then the maintenance cost and need for renewal is minimum. Quality control and quality assurance of tile drainage projects is the main tool for proving the highest efficiency and durability of such projects. Thus the highest priority should be given to the implementation of tile drainage networks on the basis of the scientific study, which consider all the affecting factors. Although the general organizational arrangements within the agency responsible for implementation of subsurface drainage projects in Egypt, Egyptian Public Authority For Drainage Project
Quality Control of Subsurface Drainage Projects (EPADP), is satisfactory, there is always a need to improve construction planning and management, construction supervision and follow up. In order to address any weakness in implementation, development of guidelines and reporting procedures for the quality control of drainage work must be done.

The quality control and quality assurance system is the organizational structure, responsibilities, procedures, processes and resources for implementing quality management. The quality system has to control what is produced to make sure it meets the requirements of the client and, secondly, it has to provide confidence or assurance is needed by both the contractor and the client (Ashford, 1989). In this paper Quality Control and Quality Assurance system for subsurface drainage project is developed.

2 STUDY METHODOLOGY
Effective quality management of a project requires a considerable background of information. The nature of this study requires a study base in a construction engineering and management to evaluate the quality control and quality assurance system of subsurface drainage projects in Egypt. It also needs knowledge of new ideas and approaches about the quality management systems. Then discuss problems, ideas, and proposed approaches with many concerned people. This should be done through interviews and questionnaires. Therefore, the study approach (Figure 1) includes analyzing subsurface drainage project to define its specification and the main control points. Then, define the weakness points and the main reasons of problems and consequently, determine the required improving and corrective actions.

To accomplish the study objectives, a questionnaire was prepared about the steps and arrangements followed in the field investigation, construction and operation and maintenance of the subsurface drainage projects. This questionnaire was accomplished within the Egyptian Public Authority for Drainage Project (EPADP), which is responsible for the design, and implementation of all drainage works, as well as for maintaining field drainage systems in Egypt. The main aim of the questionnaire is to get the views of the involved engineers in the current techniques of project construction and their recommendations to improve its quality. The questionnaire consists of three parts. The first part is concerned with the field investigation phase. It is distributed through the Field Investigation and Research Department (FIRD) of the EPADP. The second part is concerned with the construction phase of the subsurface drainage works. It is divided into two subparts, the first subpart for the engineers of the EPADP who are responsible for the supervision of the construction of the projects. The second subpart for the engineers of the contractors who are responsible for the construction of the subsurface drainage works. The third part is concerning with the Operation and Maintenance of the subsurface drainage works. It is also distributed within EPADP through its directorates of maintenance and filled by engineers who are responsible for the maintenance work of the subsurface drainage systems.

Figure 1
3 RESULTS AND DISCUSSION

Each phase was divided to its main activities. The field investigation phase was divided to three main activities. They were defined as Preparing Maps, Fieldwork, and Processing of the Field Investigation Data. The Construction phase was divided also to three main activities as following: Tendering process, Planning of construction work, and Construction work. The Operation and Maintenance phase was considered as one activity. The main components of each activity were classified as Material, Planning, and Processing. After that, the specification and standards of each element were set. The control points of each activity were determined and evaluated. The control method was defined for each control points. This was done according to the data collected from the questionnaire. The main weakness points related to the control points were defined and the required corrective actions were determined. The specifications and control points of the field investigation phase activities are shown in tables (1, 2 and 3) respectively.
Table 1: Specifications and control points of preparing maps activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description and Specifications</th>
<th>Control Points</th>
<th>Control method</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field work maps</td>
<td>Map scale 1:25000 or 1:10000 with contour lines and spot levels from Survey Authority.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Update of maps</td>
<td>Update of the maps according to the information of EPADP Directorates.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Provide maps with grid system</td>
<td>Grid system with grid width of 500 m.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>– Make the lay-out of canals and drains</td>
<td>A topographical map 1:25000 is made with the layout of canals and drains.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>– Make cross sections of drains and canals</td>
<td>Make cross sections of drains and canals and their water levels and direction of water flow.</td>
<td>*</td>
<td>Inspect.</td>
<td></td>
</tr>
</tbody>
</table>

*: Control Point  E: Evaluation  1: Under control  0: Need more control

Table 2: Specifications and control points of fieldwork activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description and Specifications</th>
<th>Control Points</th>
<th>Control method</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– K Equipment</td>
<td>1 auger, 1 stopwatch, 1 tape. To measure electrical conductivity and store soil samples.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– EC meter &amp; plastic bags</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Provide maps with grid points</td>
<td>Maps are provided with a 500m grid, one grid covers 60 feddan. The field group consists of one engineer, one observer and two workmen for approx. 5000 feddan.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>– Arrange manpower and equipment for field work</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Making leveling for ground surface</td>
<td>The ground elevation must be checked during the fieldwork. Measure the ground water salinity and the ground water table. At each grid point, an auger hole is made to 2 m depth to measure K. Samples are taken at 0.2 and 0.5m below soil surface.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>– Measurements at each grid point</td>
<td></td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>– Measuring hydraulic conductivity (K)</td>
<td></td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>– Taking disturbed soil samples</td>
<td></td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
</tbody>
</table>

*: Control Point  E: Evaluation  1: Under Control  0: Need more control

Table 3: Specifications and control points of processing of field investigation data

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description and Specifications</th>
<th>Control Points</th>
<th>Control method</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td></td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>– Field measurements data and soil samples</td>
<td>Include ground water table, salinity, K and soil samples at each grid point.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Planning
- Sending soil samples to the laboratory
  The soil samples are stored out by the engineer and sent to the laboratory.

## Processing
- Analyze soil samples
  EC, pH, water ESP and soil texture.
- Store the data
  Collected data is stored in the computer.
- Drawing field data
  The assistant design engineer draws the field data on 1:25000 map.

### Table 4: Specifications and control points of tendering process activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description and Specifications</th>
<th>Control Points</th>
<th>Control method</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Tender document</td>
<td>Includes the necessary information and specifications about the project. The submitted tenders of the interested contractors.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>- Submitted tenders</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Pre-qualifying of the contractors</td>
<td>Contractors must be pre-qualified to measure their eligibility for bidding. EPADP advertise the documents and the interested contractors can obtain additional data from EPADP.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>- Advertise tender</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Submit and judge of the tenders</td>
<td>Contractors submit their tenders. The tenders are judged on the responsiveness of contractors to the specifications and total price. The contract is awarded to the tender with the lowest bid.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>- Awarding of the contract</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*: Control Point  E: Evaluation  1: Under Control  0: Need more control

The suggested corrective actions for the field investigation phase were determined in relation to the control points and according to the national and international experiences and approved with the experiences that collected through the questionnaire as following:

1. Old field investigation maps: The maps must be updated according to the information of the directorates of EPADP. Obstacles must be recorded during the investigation work.
2. Need for make leveling for the project area: The project area must be leveled before design work to determine optimum layout and avoid any suddenly changes during implementation.
3. The insufficient measurements of hydraulic conductivity: The number of grid points must be increased to one boring for every 40 feddans to increase the reliability of collected data. It is also recommended to make the permeability tests for different depths in case of variability with depth.
4. Delay of the laboratory analysis: The laboratories must be increased and provided with the required-trained personnel.

Tendering and construction phase was divided to its activities, components and elements. Specification and standards of each element were set. Control points of each activity were evaluated. Specifications and control points of the activities are shown in tables (4, 5 and 6).

### Table 5: Specification and control points of planning of construction work activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description and Specifications</th>
<th>Control Points</th>
<th>Control method</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Maps, drawings, and lists of quantities</td>
<td>They are laid in the project documents with the technical specification.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
</tbody>
</table>

*: Control Point  E: Evaluation  1: Under Control  0: Need more control
Quality Control of Subsurface Drainage Projects

Planning
- Organize planning meetings and collect the pre-experience
- Schedule the project time and draft plan

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description and Specifications</th>
<th>Control Points</th>
<th>Control method</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Engineering and Technicians.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>Manpower</td>
<td>Pipes, envelop material and water.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>Material</td>
<td>Connections, manholes, outlets.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>Structures</td>
<td>Leveling machine, the laying machines.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>Machines</td>
<td>Pre-experience of previous projects.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>Planning</td>
<td>Implementation time is scheduled and assure of availability of manpower.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>Schedule project time and responsibilities</td>
<td>To produce concrete pipes and store materials and machines.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>Preparing work-shop</td>
<td>Check quality and storage condition at work shop and field.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>Check plastic pipes and envelope material</td>
<td>Pre-experience of previous projects.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
</tbody>
</table>

Processing
- Prepare plan tools
- Follow up the work
- Submit progressing reports

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description and Specifications</th>
<th>Control Points</th>
<th>Control method</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processing</td>
<td>These tools are used in the field.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>Prepare plan tools</td>
<td>Using survey formats to follow up the work and evaluate its progress.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
<tr>
<td>Follow up the work</td>
<td>The engineer submits reports to the director to evaluate and follow up the progress of the work.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 6: Specification and control points of construction work activity

The suggested corrective actions for tendering and construction phase are as following:

1. Judging tenders: It is recommended to pre-qualify the public and private contractors periodically to measure their eligibility for bidding and increase competitiveness. It is also recommended to inspect the plant, equipment, and resources of the apparent low bidders, who will become the contractor if all other requirements are satisfied. This must be done after bid opening and before contract awarding to affirm suitability of contractor’s resources for project construction.

http://library.wur.nl/ebooks/drainage/drainage_cd/1.1%20sallam%20gehan%20ah.html (6 of 8) 26-4-2010 12:10:36
2. Lack of feedback information: The feedback information from previous projects must be registered and collected to help in work planning.

3. Lack of time schedule and manpower organization: The time of implementation must be scheduled according to cropping and water management conditions to avoid any problems or delay. Work team must be assigned full-time to project site.

4. Low quality of plastic pipes: Plastic Pipes must be routinely tested, stored regularly, protected from direct sunlight and transported and handled carefully to avoid damages. Drainage machine should be equipped with a power feeder to prevent stretch.

5. Bad construction of outlets: Pitching with stones and mortar must protect the outlets. It must have a free fall into the open drain.

6. Low accuracy of the laser work: drainage machine should never install drains further than 300m from laser command post. Do not drive the machinery close to the command post as the vibration may affect the laser beam. It is also recommended to check periodically with levelling instrument behind laser to check the accuracy.

7. Poor quality of pipes laying: The lateral must be laid at proper elevation by using a backhoe to excavate holes at lateral/main line connections. Use trenchless machine especially with collapsing soils to improve quality of construction.

8. Low accuracy of evaluation work: Examine new techniques for inspection and evaluation at wide scale to determine their suitability under Egyptian conditions.

The components and elements of the Operation and Maintenance phase were defined. Specification and standards of each element were set. Control points of each activity were evaluated. Specifications and control points of the activities are shown in Table 7.

The suggested corrective actions for Operation and Maintenance phase in relation to the control points are as following:

1. Need for organizing the operation and maintenance work: The operation and maintenance work must be scheduled and organized. It will be easier to the engineer to operate and maintain the system with the help of the farmers.

2. Need for improved technology flushing: Evaluate the performance of the high-pressure machines to determine their effect on the soil around the drain. The special connection must be used with laterals to make it easy to use flushing machines for cleaning laterals not connected to manholes.

3. Lack of using new procedures techniques of inspection: The recent procedures techniques of inspection and checking damages in the system must be improved and used with the subsurface drainage systems in Egypt.

Table 7: Specifications and control points of operation and maintenance activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description and Specifications</th>
<th>Control Points</th>
<th>Control method</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td><strong>Preserved maps</strong> The maps should show the location of all ditches and covered drains, their size and depth, and their grade and distance apart.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td>Planning</td>
<td><strong>The manpower and financial requirements</strong> It is important to provide maintenance directorates with required manpower and financial resource.</td>
<td>*</td>
<td>Inspect.</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td><strong>Planning of maintenance work</strong> Develop an organization and a schedule for the maintenance work.</td>
<td>*</td>
<td>Inspect.</td>
<td>0</td>
</tr>
</tbody>
</table>
Quality Control of Subsurface Drainage Projects

4 CONCLUSIONS
The main conclusions can be identified as following:

1. Low quality of the implemented subsurface drainage systems is attributed mainly to lack of adequate aspects of quality control.

2. The inadequate reliability of collected data in the field investigation is due to: the insufficient number of bore holes for field measurements, using of old date maps, make no leveling for the project area, and delay of the laboratory results. This also led to insufficient quality assurance for the construction phase.

3. Insufficient quality of subsurface drainage projects construction is related to: lack of planning before construction work and need for good distribution of responsibilities, bad conditions of transporting, storage and handling of material and need to improve inspection techniques.

4. To improve quality of the operation and maintenance work it is important to schedule and organize them and improve the use of inspection and flushing techniques.

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[2] Civil Engineer/Assistant Researcher, Drainage Research Institute (DRI), National Water Research Center (NWRC), El Kanater, EGYPT.
ABSTRACT

In spite of the considerable effect of the evaporation and root water uptake on the water table drawdown, they still do not explicitly be taken into account in the traditional design equations. Therefore, the effect of the evaporation and root water uptake on the water table drawdown and consequently on the lateral drain spacing had to be predicted. To achieve that, a coupled finite element model for water and heat flow was exploited. The coupled finite element model introduces the numerical solution for the governing differential equations of the water and heat flow in variably saturated porous media under the unsteady state conditions. Four case studies were applied on four different soil types cultivated with maize crop. The applied soil types were clay, clay loam, sandy clay loam, and loamy sand. It was achieved that, taking the evaporation and root water uptake into consideration in the design process, wider lateral drain spacing is required. The predicted lateral drain spacing results in more economical lateral drain spacing with corresponding saving varies between 22.4% to 50% according to soil type.

Keywords: Evaporation, root water uptake, Design, Drainage, Model

1 INTRODUCTION

Evaporation plays an important role in lowering the water table in the soil profile (Philip et al, 1957). The evaporation depends on meteorological conditions, soil characteristics and depth of water table (Hammad, 1962). The ambient temperature is the main meteorological factor that affects the water flow through the soil as a porous medium. Therefore, coupling the water and the heat flow in the soil is important to study the water flow in the porous media under thermal effects. It helps in a more accurate prediction of the water table drawdown and consequently on a more accurate prediction of the lateral drain spacing. In addition, Root water uptake is an important factor that affects the water table drawdown (Van Bakel, 1981) due to the extracted water by plant roots. It is usually added as a sink term for the water flow models.

Many of the researchers described the importance of considering the effect of the evaporation into account in the design process of the subsurface drainage systems. Pandey and Gupta (1990), Nikam, et al. (1992), Hathoot et, al (1993), and Hathoot (2002) concluded that, taking the evaporation into consideration in the design process increases drain spacing by 25%, 9-18%, more than 60%, and more than 50% respectively. However, they did not take the effect of the temperature distribution through the soil on varying the soil hydraulic properties. On the other hand, Most of the models proposed to deal with the coupled water and heat flow in porous media as Collin et al, (2001) and Mendes et al. (2002) did not study the effect of evaporation on the design of subsurface drainage systems.

A coupled mathematical model is exploited to study the water and heat flow in porous media. The coupled model consists of two sub-models, which are coupled by few coupling terms. The model is spatially discretized by Galerkin finite element method and temporally discretized by the finite difference method (Abdel-Fattah, 2003).

Several computational experiments were carried out for the sake of the verification based on actual and experimental field data and the results of a constructed experimental physical model. Then four design case studies were applied for different soil types to evaluate the effect of evaporation and root water uptake on the technical design criteria in Egypt. The results revealed that taking both factors into consideration in the design process lowers the water table and wider lateral drain spacing is required.

Therefore, The objective of this paper is studying the effect of considering the evaporation from the soil surface and root water uptake on the water table drawdown and consequently on the design of subsurface drainage systems.

2 DESIGN CRITERIA IN EGYPT

The design of the drainage systems is usually based on criteria that are derived from steady or unsteady state equations. The applied design criteria in Egypt are classified into agricultural and technical design criteria as described in Amer and de Ridder (1989).

2.1 Agricultural criteria

An average depth of the water table midway between tile drains might be at 1.0 m to guarantee favorable soil-water conditions for the deep rooting plants.
An average drainage rate of 1.0 mm/day to permit sufficient leaching and maintain soil salinity below the critical levels for crop production.

2.2 Technical criteria
A designed discharge rate for the determination of lateral drain varies from 1.0 to 1.5 mm/d, however for collector drainpipe capacity is 4.0 mm/day for rice areas and 3.0 mm/day for non-rice areas, including a safety factor of 33% the collector drains to take into account sedimentation and irregularities in the alignment.

An average drain depth is of 1.40 - 1.50 m for lateral drains and 2.50 m for collector drains. The criteria of the lateral drain spacing changes from 20m minimum spacing to 60 m maximum spacing depending on the soil type.

3 MATHEMATICAL MODEL
A coupled mathematical model is exploited to simulate the water flow through porous media under thermal effects. The coupled mathematical model consists of two sub-models that simulate two dimensional water and heat flow in porous media under the unsteady state conditions. The two sub-models are coupled by few coupling terms. The governing flow equation of the water flow sub-model is based on the modified form of the Richards' equation. Considering two-dimensional isothermal Darcian flow of water in a variably saturated porous media. However, The governing flow equation of the heat flow sub-model is based on the Sophocleous equation. Considering the movement of heat in the porous media due to conduction as well as convection by flowing water (Abdel-Fattah, 2003). To study the effect of the heat flow on the water flow in the soil as a porous medium. The coupling of the two sub-models was essential. The two sub-models are coupled by two coupling terms that are unsaturated hydraulic conductivity (K) and Darcian fluid flux density (q) as shown in equations (1,2) (Abdel-Fattah, 2003).

The governing flow equation of the water flow sub-model is based on the modified form of the Richards' equation. Considering two-dimensional isothermal Darcian flow of water in a saturated-unsaturated porous media and assuming that the air phase plays an insignificant role in the liquid flow process the equation is given by the following form (Simunek and van Genuchten, 1994):

\[ \theta \] is the volumetric water content [L^3 L^{-3}], \( h \) is the pressure head [L], \( S \) is a sink term, represents the volume of water removed per unit time from a unit volume of soil due to plant root uptake [t^{-1}], \( x_i (i = 1, 2) \) are the spatial coordinates [L], \( t \) is time [t], \( K_{ij} A \) are components of a dimensionless anisotropy tensor \( K^A \), and \( K \) is the unsaturated hydraulic conductivity [Lt^{-1}].

However, the heat transport equation considers the movement of heat through the porous medium by conduction as well as convection by flowing water.

Neglecting the effects of water vapor diffusion, two dimensional heat flow can be described as follows:

\[ (1) \]

\[ \lambda_{ij}(\theta) \] is the apparent thermal conductivity of the soil [Mh^3 oC^{-1}] e.g. [W/moC] and \( C(\theta) \) and \( C_w \) are the volumetric heat capacities [M/Lt^2 oC] [e.g. J/m^3oC] of the porous medium and the liquid phase respectively (Simunek and van Genuchten, 1994). The first term on the right-hand side of equation (2) represents heat flow due to conduction and the second term accounts for heat being transported by flowing water. We do not consider the transfer of latent heat by vapor movement.

Furthermore, due to high non-linearity of the governing differential equations of the sub-models, they had to be solved numerically. Therefore, the numerical solution for the coupled mathematical model is proposed following the Galerkin finite element method (Abdel-Fattah, 2003). In which the two partial differential equations are transformed into a set of ordinary differential equations. Furthermore, the achieved ordinary differential equations are transformed into a set of algebraic equations by using the backward implicit finite difference method. The proposed numerical solution had been verified to achieve the certainty of the proposed solution and an acceptable error norm had been achieved.

Chain-2D code is a computer software, which has been built by USSL (U.S. Salinity Laboratory) to simulate two-dimensional water flow, heat transport and multiple solutes transport in variably saturated porous media, Simunek and van Genuchten (1994). The CHAIN-2D is used to facilitate the proposed numerical solutions of the coupled mathematical model, the calculation processes and getting the final results.

4 PARAMETERS CALCULATION

4.1 Unsaturated hydraulic conductivity calculation
Van Genuchten (1980), used statistical pore size distribution model of Mualem (1976) to obtain a predictive equation for unsaturated hydraulic conductivity function. The K function is given by the following form:
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Where

\[ K = \text{unsaturated hydraulic conductivity; [L/t]}, \ K_s = \text{saturated hydraulic conductivity; [L/t]}, \ Kr = \text{relative hydraulic conductivity; [L/t]}, \ m = (n-1)/n, n \text{ is an empirical shape factor in soil water retention function}, \ \theta = \text{volumetric water content; [l}^3\text{l}^{-3}], \ \theta_s = \text{saturated water content; [l}^3\text{l}^{-3}], \ \theta_r = \text{residual water content [l}^3\text{l}^{-3}]. \]

\[ \theta(h) \]

The proposed analytical function of \( \theta(h) \) as follows (Van Genuchten, 1980):

Where, \( \theta_s \) is the saturated water content [l}^3\text{l}^{-3}], \( \theta_r \) is the residual water content [l}^3\text{l}^{-3}], and \( \alpha [L^{-1}] \) and \( n [-] \) are empirical shape factors. Those parameters are predicted from the laboratory analysis. \( \theta(h) \) is calculated to simulate the laboratory obtained pF curves through the numerical solutions.

\[ |q| \]

The apparent thermal conductivity \( \lambda_q \) of the porous media in case of the presence of the liquid flow is calculated as shown in the following equation (Simunek and van Genuchten, 1994):

Where, \( \lambda_0(\theta) \) is described by the following equation, Chung and Horton, (1987).

\[ C_n \]

Table 1  Soil thermal properties

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>( b_1 ) [ML/t^3 °C]</th>
<th>( b_2 ) [ML/t^3 °C]</th>
<th>( b_3 ) [ML/t^3 °C]</th>
<th>( C_n ) [ML/t^2 °C]</th>
<th>( C_0 ) [ML/t^2 °C]</th>
<th>( C_w ) [ML/t^2 °C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>-1.27E+16</td>
<td>-6.2E+16</td>
<td>1.63E+17</td>
<td>1.43E+14</td>
<td>1.87E+14</td>
<td>3.12E+14</td>
</tr>
<tr>
<td>Loam</td>
<td>1.57E+16</td>
<td>2.54E+16</td>
<td>9.89E+16</td>
<td>1.43E+14</td>
<td>1.87E+14</td>
<td>3.12E+14</td>
</tr>
<tr>
<td>Sand</td>
<td>1.47E+16</td>
<td>-1.55E+17</td>
<td>3.17E+17</td>
<td>1.43E+14</td>
<td>1.87E+14</td>
<td>3.12E+14</td>
</tr>
</tbody>
</table>

\[ C_l \]

4.4  Volumetric heat capacity calculation
The volumetric heat capacity \( C(\theta) \) of the heat transport model is calculated according to the described equation (Simunek and van Genuchten, 1994):

\[
C(\theta) = C_n \theta_n + C_o \theta_o + C_w \theta + C_g \theta_v
\]  
(9)

Where \( C_n, C_o, C_g \) and \( C_w \) are volumetric heat capacity \([\text{M/lt}^2\circ\text{C}]\) of, solid phase, organic matter, liquid phase and gas phase respectively. However, \( \theta_n, \theta_o, \theta_g \) and \( \theta \) are the volumetric fraction \([\text{l}^3\text{l}^{-3}]\) of solid phase, organic matter, liquid phase and gas phase respectively. \( \theta_v \) is the volumetric air content \([\text{l}^3\text{l}^{-3}]\). The values of \( C_n, C_o, C_g \) and \( C_w \) are listed in table 5.1 according to Chung and Horton (1987).

### 4.5 Potential evapo-transpiration rate

The potential evapo-transpiration values for the cultivated lands are calculated by multiplying the potential evapo-transpiration rate for bare soil by crop coefficient (Jensen, 1983). The crop coefficient differs according to the cultivated crop type. It was taken for the late season of the cultivated crop as the most period of evapo-transpiration. The calculated values are used in calculating the potential transpiration rate to be used in the numerical solutions.

### 4.6 Potential evaporation rate

The potential evaporation rate values are collected as average monthly readings of the evaporation pan of Zankalon Pilot Area (ZPA). The calculated average monthly value is multiplied by a correction factor to simulate the reading of cultivated media (Jensen, 1983).

### 4.7 Potential transpiration rate

The monthly potential transpiration rate is calculated as the result of subtracting the average monthly potential evaporation rate from the average monthly potential evapo-transpiration rate (Jensen, 1983).

### 4.8 Actual evaporation rate

In case of wet soil, actual soil evaporation is determined by the atmospheric demand and equals potential soil evaporation rate. When the soil becomes drier, the soil hydraulic conductivity decreases that reduce the potential soil evaporation to a lower actual evaporation rate. Actual evaporation rate \( E_A(t) \) is calculated by Darcy’s law (Van Dam, 2000).

\[
E_A(t) = K(h) q
\]  
(10)

Where, \( K(h) \) is the unsaturated hydraulic conductivity \([\text{L/t}]\), \( h \) is the pressure head \([\text{L}]\), \( q \) is the flux \([\text{L/t}]\) and \( E_A(t) \) actual evaporation rate \([\text{L/t}]\).

### 4.9 Actual root water uptake

The actual root water uptake rate is assumed to be uniformly distributed over two dimensional rectangular domain. It is calculated by the following equation, (Simunek and Van Genuchten, 1999):

\[
S(h,x,z) = T_p b(x,z) a_r(h)
\]  
(11)

Where, \( S(h,x,z) \) is the actual root water uptake distribution, \( T_p \) is the potential transpiration rate \([\text{L/t}]\), \( b(x,z) \) is normalized water uptake distribution \([\text{L}^{-2}]\), \( L_t \) is the width \([\text{L}]\) of the soil surface and \( a_r(h) \) is water stress response function [-]. \( a_r(h) \) is function of soil water pressure head \((0 \leq a_r \leq 1)\) as shown in Fig. (1). In which, that water uptake is assumed to be zero close to saturation (i.e., wetter than some arbitrary point, \( h_1 \)). For \( h < h_4 \) (the wilting point pressure head), water uptake is also assumed to be zero. Water uptake is considered optimal between pressure heads \( h_2 \) and \( h_3 \), whereas for pressure head between \( h_3 \) and \( h_4 \) (or \( h_1 \) and \( h_2 \)), water uptake decreases (or increases) linearly with \( h \).

### 4.10 Adjustments of the hydraulic conductivity surrounding the simulated drain

The tile drain is simulated in the finite element model as a single node, therefore the hydraulic conductivity around this node has to be adjusted. Adjustment of the hydraulic conductivity, \( K \), for the neighboring elements of the node that simulates the drain, correspond to the change in the electric resistance as follows (Simunek and Van Genuchten, 1999):

\[
K_{\text{drain}} = K_s C_d
\]  
(12)
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Where \( K_{\text{drain}} \) is the adjusted conductivity \([ L/t]\), \( K_s \) is the saturated hydraulic conductivity and \( C_d \) is the resistance adjustment factor (correction factor). \( C_d \) is determined from ratio of the effective diameter, \( d_{\text{eff}} \) \([L]\), of the drain to the side length, \( D_L \) \([L]\) of the square formed by finite elements surrounding the drain node. The effective drain diameter, \( d_{\text{eff}} \), calculated from the number and size of small opening in the drain tube (Mohammad and Skaggs, 1983).

Figure 1  Schematic of the plant water stress response function, \( \alpha(h) \), as used by Simunek and Van Genuchten (1999)

5  RESULTS AND DISCUSSION

Four application case studies were applied for different soil types. The chosen soil types are representative to the main Egyptian soils. These soil textures are clay, clay loam, sandy clay loam and loamy sand. The soil textures and the soil hydraulic properties are obtained from El-Tony (1982) as shown in tables 2 and 3.

The soil thermal properties for the four chosen soils are given in Abdel-Fattah (2003), and listed in table 4. Herein, the thermal properties for the partially loamy texture soils are assumed to be equal to the thermal properties for the loam soil described in table 1.

The listed values of soil hydraulic properties and soil thermal properties are used as input data for the four applied case studies.

Table 2  The texture of the soils used in the application case studies

<table>
<thead>
<tr>
<th>Soil No.</th>
<th>O. M. ( % )</th>
<th>CaCo3 ( % )</th>
<th>Coarse Sand ( % )</th>
<th>Fine Sand ( % )</th>
<th>Silt ( % )</th>
<th>Clay ( % )</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.56</td>
<td>5.57</td>
<td>1.25</td>
<td>7.05</td>
<td>22</td>
<td>62.37</td>
<td>Clay</td>
</tr>
<tr>
<td>2</td>
<td>1.04</td>
<td>3.73</td>
<td>1.1</td>
<td>41.7</td>
<td>20</td>
<td>32.3</td>
<td>Clay Loam</td>
</tr>
<tr>
<td>3</td>
<td>2.06</td>
<td>1.44</td>
<td>2.4</td>
<td>50.75</td>
<td>14.82</td>
<td>28.5</td>
<td>Sandy Clay Loam</td>
</tr>
<tr>
<td>4</td>
<td>6.0</td>
<td>1.23</td>
<td>28.45</td>
<td>52.10</td>
<td>6.99</td>
<td>10.51</td>
<td>Loamy Sand</td>
</tr>
</tbody>
</table>

Table 3  The hydraulic properties for the soils used in the application case studies
The atmospheric input data for the application case studies are the potential evaporation rate, \(E(t)\), the potential transpiration rate and the temperature degrees. The values of \(E(t)\) are calculated as the average monthly potential evaporation for 5 years (1992-1997) from Zankalon pilot area (ZPA) meteorological station of DRI. The \(T_p(t)\), average potential transpiration rate, is calculated as a subtraction of \(E(t)\) from average monthly value of the potential evapo-transpiration rate calculated for 17 years period (1980-1997) (Moursy, 1998). \(T(t)\) is calculated as an average monthly temperature degrees for 5 years (1993 to 1997) collected from ZPA meteorological station. The values of the atmospheric data are listed in table 5.

The typical domain that simulates a cross-section of real field domain is shown in Fig. (2). The typical domain extends horizontally between two lateral drains with different spacing and extends vertically from soil surface to the impermeable layer is going to be used for the next four case studies.
5.1 Case Study 1: Studying the effect of evaporation, root water uptake on the design for a clay soil considering heat transport

Two-dimensional unsteady water flow through homogeneous and isotropic clay soil under thermal effects is considered to study the effect of the evaporation and root water uptake on the design criteria of the clay soil in the summer season as a worst case of design process. The purpose for the study is to predict the optimum lateral drain spacing to satisfy the applied design criteria in Egypt. According to the Egyptian design criteria, lateral drain spacing for clay soil is considered to be equal to 20 m. It was assumed that the domain of the case study is cultivated with maize (corn) crop of a 40 cm uniformly effective root depth, Doorenbos and Pruit (1977). Herein, the numerical coupled model is going to be used to predict the pressure head midway between drains above the drain level to be correlated to the proposed value of the pressure head, 40 cm, according to the present applied criteria in Egypt.

The texture of the considered clay soil is given in table 2, the soil hydraulic properties are given in table 3 and the soil thermal properties are listed in table 4.

The domain of this case study has a rectangular shape as shown in Fig. (2) with a horizontal and vertical dimensions of 20 m and 6.4 m respectively. The depth of impermeable layer assumed to be equal 5.0 m below the drain level, (Abdel-Fattah, 2003).

5.1.1 Initial and Boundary conditions

The initial and boundary conditions for the 1st case study as shown in Fig. (2) are as follows.

5.1.1.1 The initial conditions

\[ h(x,z,t) = h_0(x,z,t_0) = 0 \quad \text{at soil surface for initial time } t_0 = 0 \]

\[ T(x,z,t) = T_i(x,z,t_0) = 20^\circ C \quad \text{for initial time } t_0 = 0 \]

5.1.1.2 The boundary conditions

\[ h(x,z,t) = h(x,z,t) = 0 \quad \text{at drain node through the time period of the problem.} \]

for \( t = 1 \) to \( 5 \) days of summer season;

\[ (x,z) = (0,5.0) \text{ and } (20.0,5.0) \text{ in meter for the left and right drain respectively.} \]

\[ T(x,z,t) = T(x,z,t) \quad \text{for } t = 1 \text{ to } 5 \text{ days; } \]

\[ (x,z) = (0,6.4), (0.4,6.4), (0.8,6.4), ..., (20.0,6.4); \]

for \( t = 1 \) to \( 5 \) days. \hspace{1cm} (13)

\[ (x,z) = (x,6.4) \quad \text{for } t = 1 \text{ to } 5 \text{ days. } \hspace{1cm} (14) \]
Where, $T_i$ is the initial soil temperature, $h_0$ is the initial pressure head linearly distributed with the domain depth, $h$ [L] is the pressure head function of $x$, $z$ and $t$, $K$ is the unsaturated hydraulic conductivity, $q$ is the water flux, $E(t)$ is the potential evaporation rate function of time, $T_p(t)$ average potential transpiration rate function of time and $T(t)$ is the time dependent temperature degree. The value of the saturated hydraulic conductivity, $K_s$, is 7.2 cm/d as shown in table 3. The values of $E(t)$, $T_p(t)$ and $T(t)$ for clay soil are listed in table 5.

The pressure head midway between lateral drains along the time cycle is calculated using the proposed model. It is noticed that the calculated value of the pressure head at the end of the case study period equals to 36.15 cm, which is less than the proposed value of 40 cm above the drain level midway between the lateral drains based on the applied design criteria. It proves that considering the evaporation and root water uptake in the design process leads to increase of water table depth than the required depth (1.0 m) according to the agricultural criteria of Egypt. In addition, the 20 m lateral drain spacing applied in Egyptian clay soils have to be checked and recalculated.

Therefore, to achieve the design criteria (40 cm pressure head above the drain level) under the effect of the evaporation and root water uptake, another run is applied for the same case study with the same input data. However, the drain spacing is assumed to be equal 30 m. Herein, the domain extends from (0,0) to (30.0,6.4) however; the dimension of the left and right tile drains will be (0,5.0) and (30.0,5.0) respectively.

It is found that the calculated pressure head midway between lateral drains along the 2nd run time period equals 39.98 cm, which almost coincides with the required pressure head. It indicates that 30 m drain spacing is the optimum spacing for the applied clay soil that satisfies the required criteria.

### 5.2 Case Study 2: Studying the effect of evaporation, root water uptake on the design for a clay loam soil considering heat transport

Two-dimensional unsteady water flow through homogeneous and isotropic clay loam soil under thermal effects is applied to study the effect of the evaporation and root water uptake on the design criteria of the clay loam soil for the summer season. The purpose for this case study is to predict the optimum lateral drain spacing for the clay loam soil to satisfy the applied design criteria in Egypt.

Based on the described design criteria, lateral drain spacing for clay loam soil is considered to be equal 40 m. Maize (corn) crop with a 40 cm uniformly effective root depth is considered (Doorenbos and Pruitt, 1977). The numerical coupled model is going to be used to predict the pressure head midway between drains above the drain level to be correlated with the proposed value of the pressure head (40 cm) above the drain level, according to the present applied criteria in Egypt.

The texture of the considered clay loam soil is given in table 2. The soil hydraulic properties are given in table 3. The soil thermal properties are given in table 4.

The domain has a rectangular shape as shown in Fig. (2) with a horizontal dimension of 40.0 m and vertical dimension of 6.40 m assuming that the depth of impermeable layer equals 5.0 m below the drain level (Abdel-Fattah, 2003).

#### 5.2.1 Initial and Boundary conditions

The initial and boundary conditions for the 2nd case study as shown in Fig. (2) are follows:

##### 5.2.1.1 The initial conditions

\[ h(x,z,t) = h_0(x,z,t_0) = 0 \text{ at soil surface for initial time } t_0=0 \]  
\[ T(x,z,t) = T_i(x,z,t_0) = 20 \degree C \text{ for initial time } t_0=0 \]

##### 5.2.1.2 The boundary conditions

\[ h(x,z,t) = h(x,z,t) = 0 \text{ at drain position through the time period of the problem.} \]
for $t=1$ to 5 days, of summer season;
\( (x,y) = (0,0.5) \) and \( (40,0.5) \) in meter for the left and right drain respectively.

\[ T(x,z,t) = T(x,z,t) \text{ for } t=1 \text{ to } 5 \text{ days}; \]
\( (x,z) = (0,0.4), (0.4,0.4), (0.8,0.4), \ldots, (40,0.4) \) \( \text{ for } t=1 \text{ to } 5 \text{ days.} \)
hydraulic conductivity, $K_s$, is 48 cm/d as shown in table 3. The values of $E(t)$, $T_p(t)$ and $T(t)$ for clay soil are listed in table 5.

According to the proposed model, the pressure head midway between lateral drains along time cycle is calculated. The calculated pressure head value is 30.44 cm, which is less than the proposed value of 40.0 cm above the drain level midway between the lateral drains based on the applied design criteria. This indicates that considering both evaporation and root water uptake in the design process leads to more lowering of the water table than the required depth (100 cm) according to the agricultural criteria of Egypt. In addition, the 40 m drain spacing applied in the Egyptian clay loam soils have to be checked and recalculated.

Therefore to achieve the design criteria (40 cm pressure head above the drain level) in case of taking the effect of the evaporation and root water uptake into consideration, another run is applied for the same case study. The input data is the same, however the drain spacing equals 60 m. Therefore, the domain extends from $(0,0)$ to $(60.0,6.4)$ however, the dimension of the left and right tile drains will be $(0,5.0)$ and $(60.0,5.0)$ respectively.

The pressure head midway between laterals along 2nd run time period is calculated. It is noticed that the calculated pressure head midway between lateral drains (40.0 cm) coincides with the required pressure head. It indicates that the 60 m drain spacing is the optimum spacing that can satisfy the required criteria for clay loam soil. The daily temperature distribution through the clay loam soil domain is also calculated along the 2nd run time period according to the proposed model.

5.3 Case Study 3: Studying the effect of evaporation, root water uptake on the design for a sandy clay loam soil considering heat transport

This case study is applied to simulate two-dimensional unsteady water flow through homogeneous and isotropic sandy clay loam soil under thermal effects. It is considered to study the effect of the evaporation and root water uptake on the design criteria of the sandy clay loam soil in the summer season. Then, predicting the optimum lateral drain spacing to satisfy the applied design criteria in Egypt. According to the described criteria, lateral drain spacing for sandy clay loam soil is considered to be equal 50 cm. Maize (corn) crop with a 40 cm uniformly effective root depth is considered, (Doorenbos and Pruitt, 1977). The numerical coupled model is going to be used to predict the pressure head midway between drains above the drain level to be correlated with the proposed value of the pressure head 40 cm according to the present applied criteria in Egypt.

The texture of the considered sandy clay loam soil is given in table 2. The soil hydraulic properties are given in table 3. The soil thermal properties are listed in table 4.

The domain of the 3rd case study has the same rectangular shape shown in Fig. (2) with a horizontal dimension of 50.0 m and vertical dimension of 6.40 cm assuming that the depth of impermeable layer equals 5.0 m below the drain level.

5.3.1 Initial and Boundary conditions

The initial and boundary conditions for the 3rd case study as shown in Fig. (2) are as follows:

5.3.1.1 The initial conditions

$$h(x,z,t) = h_0(x,z,t_0) = 0 \quad \text{at soil surface for initial time } t_0=0$$

(19)

$$T(x,z,t) = T_i(x,z,t_0) = 20 \, ^\circ C \quad \text{for initial time } t_0=0$$

(20)

5.3.1.2 The boundary conditions

$$h(x,z,t) = h(x,z,t) = 0 \text{ at drain position through the time period of the problem.}$$

(21)

for $t=1$ to 5 days, of summer season;

(x,z) equal $(0,5.0)$ and $(50.0,5.0)$ in meter for the left and right drain respectively.

$$T(x,z,t) = T(x,z,t)$$

(22)

for $t=1$ to 5 days;

$x= (0,6.4), (0.4,6.4), (0.8,6.4), ..., (50.0,6.4)$

(50.0,6.4)

for $t=1$ to 5 days.

(23)

Where, $T_i$ is the initial soil temperature, $h_0$ is the initial pressure head linearly distributed with the domain depth, $h$ [L] is the pressure head function of $x$, $z$ and $t$, $K$ is the unsaturated hydraulic conductivity, $q$ is the water flux, $E(t)$ is the potential evaporation rate function of time, $T_p(t)$ average potential transpiration rate function of time and $T(t)$ is the time dependent temperature degree. The value of the saturated hydraulic conductivity, $K_s$, is 77 cm/d as shown in table 3. The values of $E(t)$, $T_p(t)$ and $T(t)$ for sandy clay loam soil are listed in table 5.
The pressure head midway between lateral drains along the case study time period is calculated according to the proposed model. It is noticed that the calculated pressure head value equals 32.97 cm, which is less than the proposed value of 40.0 cm above the drain level midway between the lateral drains based on the applied design criteria. This indicates that the evaporation and root water uptake in the design process leads to lower the water table than the required depth, (100 cm), according to the agricultural criteria of Egypt. In addition, the 50 m lateral drain spacing applied is Egyptian sandy clay loam soil have to be checked and recalculated.

Therefore to achieve the design criteria (40 cm pressure head above the drain level) considering the effect of the evaporation and root water uptake, another run is applied for the same case study with the same input data. It is assumed that the drain spacing equals a 60 m. In this case, the domain dimension will be (0,0) to (60.0,6.40) however, the dimension of the left and right tile drains will be (0,5.0) and (60.0,5.0) respectively.

The recalculated pressure head midway between laterals along the 2nd run time period is 37.66 cm. It is noticed that the calculated pressure head midway between lateral drains still do not satisfy the required water table depth.

A 3rd run was applied with 66 m drain spacing of the same input data. In this case, the domain dimension will be (0,0) to (66.0,6.40) however, the dimension of the left and right tile drains will be (0,5.0) and (66.0,5.0) respectively. In this run the predicted pressure head had a value of 39.89 cm, which is nearly equals the proposed value of the design criteria.

As the predicted pressure head midway the lateral drains almost coincides with the required criteria pressure head, the 66 m tile drain spacing is considered the optimum drain spacing that can satisfy the required criteria for the sandy clay loam soil.

5.4 Case Study 4: Studying the effect of evaporation, root water uptake on the design for a loamy sand soil considering heat transport

In this case study, two-dimensional unsteady water flow through homogeneous and isotropic loamy sand soil under thermal effects is simulated. It is simulated to study the effect of the evaporation and root water uptake on the design criteria on loamy sand soil for the summer season. The purpose for this case study is to predict the optimum lateral drain spacing that satisfies the applied design criteria in Egypt.

Based on the described criteria, lateral drain spacing for loamy sand soil is considered to be equal 60 m. Maize (corn) crop of a 40 cm uniformly effective root depth is considered (Doorenbos and Pruit, 1977). The numerical coupled model is going to be used to predict the pressure head midway between drains above the drain level to be correlated with the proposed value of the pressure head (40 cm) above the drain level, according to the present applied criteria in Egypt.

The texture of the considered loamy sand soil is given in table 2. The soil hydraulic properties are given in table 3 and the soil thermal properties are given in table 4.

The domain of this case study has a rectangular shape as shown in Fig. (2) with a horizontal dimension of 60.0 m and vertical dimension of 6.40 m assuming that the depth of impermeable layer equals 5.0 m below the drain level, (Abdel-Fattah, 2003).

5.4.1 Initial and Boundary conditions

The initial and boundary conditions for the 4th case study are shown in Fig. (2) are as follows.

5.4.1.1 The initial conditions

\[ h(x,z,t) = h_0(x,z,t_0) = 0 \text{ at soil surface for initial time } t_0 = 0 \]  
\[ T(x,z,t) = T_i(x,z,t_0) = 20 \degree C \text{ for initial time } t_0 = 0 \]  

5.4.1.2 The boundary conditions

\[ h(x,z,t) = h(x,z,t) = 0 \text{ at drain position through the time period of the problem. } \]  
\[ \text{for } t = 1 \text{ to 5 days of summer season; } \]  
\[ (x,y) = (0,5.0) \text{ and (60.0,5.0) in meter for the left and right drain respectively. } \]  

\[ T(x,z,t) = T(x,z,t) \text{ for } t = 1 \text{ to 5 days; } \]  
\[ (x,z) = (0.6,40), (0.4,6.4), (0.8,6.4), \ldots, (60.0,6.4) \text{ for } \]  
\[ t = 1 \text{ to 5 days. } \]
EFFECT OF EVAPORATION AND ROOT WATER UPTAKE ON THE DESIGN OF SUBSURFACE DRAINAGE SYSTEMS IN ARID REGIONS

Where, \( T_i \) is the initial soil temperature, \( h_0 \) is the initial pressure head linearly distributed with the domain depth, \( h \) \([\text{L}]\) is the pressure head function of \( x \), \( z \) and \( t \), \( K \) is the unsaturated hydraulic conductivity, \( q \) is the water flux, \( E(t) \) is the potential evaporation rate function of time, \( T_p(t) \) average potential transpiration rate function of time and \( T(t) \) is the time dependent temperature degree. The value of the saturated hydraulic conductivity, \( K_s \), is 188 cm/d as shown in table 3. The values of \( E(t) \), \( T_p(t) \) and \( T(t) \) for loamy sand soil are listed in table 5.

The pressure head midway between lateral drains along the case study time period is calculated based on the proposed model. It is noticed that the calculated pressure head value equals 33.2 cm and is less than the proposed value of 40 cm above the drain level midway between the lateral drains based on the applied design criteria. This indicates that considering the evaporation and the root water uptake in the design process leads to lowering the water table than the required depth, (100 cm), according to the agricultural criteria of Egypt. In addition, the 60m drain spacing applied in is Egyptian loamy sand soil has to be checked and recalculated.

Therefore, to achieve the design criteria (40 cm pressure head above the drain level) taking the effect of evaporation and root water uptake into consideration, another run is applied for the same case study. It has the same input data however, the drain spacing is assumed to be equals 70 m. In this case, the domain dimension will be \((0,0)\) to \((70.0,6.40)\) however, the dimension of the left and right tile drains will be \((0,5.0)\) and \((70.0,5.0)\) respectively.

It is noticed that the calculated pressure head midway between lateral drains (38.25 cm) still do not satisfy the required criterion. Therefore, a 3rd run is applied with 73.5 m, drain spacing of a same input data. In this case, the domain dimension will be \((0,0)\) to \((73.5,6.4)\) however, the dimension of the left and right tile drains will be \((0,5.0)\) and \((73.5,5.0)\) respectively. In this run the predicted pressure head had a value of 39.99 cm, which is almost equals the proposed value of the agricultural criteria.

As the predicted pressure head midway the lateral coincides with the required criteria pressure head, then the 73.5m tile drain spacing that can satisfy the required criteria for loamy sand soil.

The relations between the predicted pressure head and tile drains spacing are drawn for the four soil types as shown in the Figs. (3, 4, 5 and 6). From the analysis of these figures, it is recognized that considering the evaporation and root water uptake into the design process requires a wider spacing than the recommended in the design criteria of Egypt for the chosen soil types. The variation in the lateral drills spacing and the corresponding pressure head midway between lateral drains is shown in table 6. It indicates that taking evaporation and root water uptake into consideration in the design process has a significant effect on lowering the water table and consequently wider lateral drain spacing is required.

Accordingly, the percentage of saving in the drain spacing is calculated and listed in table 6. It shows that applying the predicted spacing offers a more economic subsurface drainage system than the present applied system according the recommended criteria of Egypt.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Clay</th>
<th>Clay Loam</th>
<th>Sandy Clay Loam</th>
<th>Loamy Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard p. head [cm]</td>
<td>40.0</td>
<td>40.0</td>
<td>40.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Criteria spacing [m]</td>
<td>20</td>
<td>36.15</td>
<td>30.4</td>
<td>40</td>
</tr>
<tr>
<td>Opposite p. head [cm]</td>
<td>36.15</td>
<td>30.4</td>
<td>32.97</td>
<td>33.2</td>
</tr>
<tr>
<td>Modified spacing [m]</td>
<td>30</td>
<td>39.98</td>
<td>66</td>
<td>73.5</td>
</tr>
<tr>
<td>Opposite p. head [cm]</td>
<td>39.98</td>
<td>40</td>
<td>39.89</td>
<td>39.98</td>
</tr>
<tr>
<td>% Save in spacing [m]</td>
<td>50%</td>
<td>50%</td>
<td>30%</td>
<td>22.4%</td>
</tr>
</tbody>
</table>

### 5.5 Heat transport correlation

The heat distribution through the four soils versus space and time are shown in Figs. (7 and 8). In Fig. (7), the heat distribution through the four soil types used in the application is drawn versus depth of the domain below the soil surface at the 5th day of the case study. It is noticed that the temperature degree of the soil decreases with the increase of depth of the soil for the four applied soils. It is obvious that the heat transport rate through the clay soil is slower than the other types relative to the domain depth, however the rate through the loamy sand soil is the highest one among the others.
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Figure 3  The pressure heads outputs for the 1st and 2nd run of the 1st case study

Figure 4  The pressure heads outputs for the 1st and 2nd run of the 2nd case study

Figure 5  The pressure heads outputs for the 1st and 3rd run of the 3rd case study

Figure 6  The pressure heads outputs for the 1st and 3rd run of the 4th case study
Figure (7)  Comparison between temperature distribution versus depth for the different soil types
The temperature distribution function of time at 60cm depth for the four applied soil types is shown in Fig. (8). It is noticed that, the temperature increases with time for the four applied soil types. It was recognized that, the increase of the temperature degrees is higher, in case of loamy sand soil, than other soil types, however the temperature values of the clay soil is the lowest one.

### 6 CONCLUSION

Evaporation from soil surface and is one of the variables that affect the water table drawdown. In spite of its considerable effect on lowering the water table, it is not explicitly considered in drainage design equations commonly used for drain spacing calculation. In addition, water uptake by plant roots is also an effective parameter that leads to increase the water table depth due to the exhausted amount of water. Therefore, studying the effect of incorporating evaporation, root water uptake into the design of subsurface drainage systems is important. It is achieved through studying the effect of heat flow on the water flow through porous media under unsteady state condition.

The results it can be concluded that, considering the evaporation and root water uptake into design process satisfy better actual field conditions. In which, wider lateral drain spacing for the applied soils in the case studies is required than the recommended according to the design criteria of Egypt. The modified lateral drains spacing for the clay, clay loam, sandy clay loam and loamy sand would be 30, 60, 66 and 73.5 m respectively. This will result in drain spacing saving of 50%, 50%, 30% and 22.4%.

In addition, the heat transport through porous media changes with time and space relatively with soil type. Herein, the heat transport rate in clay soil is slower than in clay loam and sandy clay loam soil than in loamy sand soil.

### 7 REFERENCES

Abdel-Fattah, M., (2003). Effect of evaporation on the design criteria of subsurface drainage system in arid and semi arid regions. Faculty of Engineering, Zagazig University, Egypt.


ABSTRACT
Kuttanad, the low-lying tract in Kerala State (South-west India), is a region where excess water has caused the agricultural production to remain low. This is even more severe in the potential acid sulphate soils of Kuttanad. Besides the problems inherent to these soils, the region also experiences floods, lack of fresh water and intrusion of saline water from the Arabian Sea. A subsurface drainage system consisting of 10 cm diameter clay tiles, each of 60 cm length, was installed in a pilot area to study the effect of drainage in alleviating the problems faced by these soils. The drains were installed at a depth of about 1 m with spacings of 15 m (replicated 5 times with a drain length of 75 m) and 30 m (replicated twice with a drain length of 100 m) in order determine the drainage parameters from the field data.

The paper discusses on the evaluation of drainage parameters from field data obtained from a pilot area where subsurface drainage system was installed and the use these parameters for designing larger drainage systems. This particular study pertains to the polders of Kuttanad where the fields are always surrounded by water bodies.

With the collected drain outflow and water table subsidence data, the drainage parameters namely the hydraulic conductivity and the drainable porosity were determined. A study conducted in subsurface drained field has shown that the hydraulic conductivity values were comparatively higher for the topsoil in the experimental area. It varied directly with the mid-spacing water table height for drains close to the outside water body and exponentially for drains away from the outside water body. The transition in the mode of variation took place at a distance of 60 m from the water body. The values also showed a decreasing trend with the distance of the field from the water body for the same mid-spacing water table heights. For areas near to outside water bodies, the drainable porosity increased as the mid-spacing water table height decreased. For areas that are away from the water bodies, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. The average equivalent hydraulic conductivity computed was 0.167 m/d for regions up to 60 m from the water body and 0.055 m/d for regions beyond that. For areas near to outside water bodies, the drainable porosity increased as the mid-spacing water table height decreased. For areas that are away from the water bodies, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. The average equivalent drainable porosity for the flow domain that are away from the water bodies is 0.04.

Keywords: Subsurface drainage, Hydraulic conductivity, Drainable porosity

1 Introduction
In the context that rice holds the key to food security in India, there is an urgent need to realize the under and unexploited potential of less productive coastal wetlands through appropriate research and development interventions. In chronically low productive and problem areas where the area has begun to register negative growth rate, there is a dire need to enhance the income level of farmers to arrest this trend. This is possible only by imbibing new technologies and upgrading prevalent ones. Bridging the gap between the potential and realized yields in such areas calls for more productive research. This necessitates land and water use planning that guarantee optimum use of biophysical resources and economic security to the farmers by generation of more income and opportunities.

With a meagre geographical spread of less than 1.18% of the whole country, the state of Kerala supports over 3.43% of the its population. Farming in the State is characterized by pre dominance of tiny holdings that are incapable of sustaining farming communities with the increased population pressure. With the undulating topography arising from geological formations, rice
Kerala is cultivated in distinct macro environments ranging from 2-3 metres below mean sea level as in coastal lowlands of Kuttanad to near temperate situations at 2,500 m height in the high ranges. The coastal low lands provide favourable conditions for rice. Owing to its innate adaptation to waterlogged environment, rice can be the only food crop grown in the coastal tracts. The high rainfall coupled with undulating topography subject the low land rice fields to environmental vagaries of flash floods in the monsoon and tidal saline incursions during the summer. Impeded by poor drainage, excess water and poor water management, the potential of high yielding rice varieties is hardly realized in this region. The situation is further aggravated in acid saline problem soils owing to high acidity, salinity and accumulation of toxic salts etc inherent to these soils. This, coupled with the socio-economic constraints has tempted some of the farmers to switch over to other enterprises. In many areas, lowland rice fields have been systematically converted into coconut plantations, further altering the very ecology of these wetlands.

1.1 Relevance of Drainage

Poor drainage has been identified to be the single largest factor limiting the potentials of high yielding rice in these tracts. This is particularly true of the region where the elevation of the fields are lower than the mean sea level and natural leaching of the inherent toxic salts from the soil profile under gravity is not feasible. As a result, the cropping intensity in coastal low lands is the lowest (100% as against 161% of the state). The present trend of conversion of low productive rice lands for alternate enterprises will have serious environmental consequences and will disturb the unique ecological functions of these wetlands. In this context, subsurface drainage assumes great importance as no other method would be successful in leaching the root zone.

1.2 Importance of drainage parameters

Drainage planning is generally done after gathering information by surveying the area and collecting data from auger holes, piezometers, soil samples etc. The parameters obtained from the data thus collected are fed into groundwater flow or drainage equations to arrive at the drain spacings and drain depths. Such conclusions sometimes have the following drawbacks.

- The drainage equations are often over simplified models of a very complex reality.
- The aquifer through which the groundwater-flow takes place is not at all homogeneous.
- Soils, particularly in alluvial plains, are layered and the permeability varies considerably in both horizontal and vertical directions
- It is not unusual for the permeability measured in auger holes which are located in adjacent plots to differ by several hundred percent
- The infiltration rate and drainable pore space differ with changes in soil texture and structure, even within one field, and so will soil water storage and recharge to the groundwater reservoir from irrigation losses and rain
- The inadequacy of information obtained on field conditions, both in terms of quantity and quality.

Since hydraulic conductivity is one of the most important factors influencing spacing between lateral drains for subsurface drainage systems, lateral drain spacings should be determined based on the mean value of hydraulic conductivity measurements within the area to be drained. Point measurements, however, does not take into account spatial variability of the hydraulic conductivity, and may result in large areas where the water table is shallower or deeper than the design water-table depth. Areas of shallow water table will reduce crop yield, while deeper than required water tables will result in unnecessarily expensive drainage systems.

Drainable porosity is another basic input parameter in conventional method for predicting water table drawdown. Drainable porosity is usually defined as the volume of water per unit area released when the water table falls by a unit distance. In drainage design it is conventionally assumed to be constant and treated as a soil property. Point measurements of drainable porosity can affect the drainage designs in a big way. The effective drainage porosity determined from outflow measurements can offset all field heterogeneities and is a reliable parameter in proper design.
Considering the aforesaid reasons, drainage designs are to be tested in field conditions to collect data on soil hydrological qualities such as hydraulic conductivity, drainable porosity etc. This, and related information thus arrived will represent the average values over the drained area.

2 Methodology

2.1 Study area
The area selected for the study is in the farmers’ field of the Karumady village of Alappuzha District, Kerala, India. The map of the experimental field with all the necessary details is shown in Figure 1. The area is a typical and representative tract of acid sulphate soil with a definite boundary and found to be very severely affected by the drainage problems. The total cropping area is 75 ha. The area is bounded by a road in the north, and water courses (water body) in the east, south and west. These canals are connected to the extensive backwater system in Kuttanad and ultimately drain into the sea.

Figure 1 Experimental field

The area is 1-1.5 m below Mean Sea Level (MSL). It has strong earthen bunds along the boundary to protect floods during cultivation. Axial flow pumps are used to drain the impounded water collected during off-season. There are two pumping outlets, one with a 30 hp axial flow pump at the western boundary and another with a 20 hp axial flow pump at the southern boundary. Two main open drains, which are interconnected, lead water to the pumping bays. A number of secondary open drains join the main open drains from different parts of the field.

2.2 Subsurface drainage design layout
The layout of the drainage system is given in Figure 2. Considering the shape of the field and availability of farmers’ field for in situ experimentation, nine lines of parallel lateral drains were installed.
The first six lines close to the main collection sump were at 15 m spacing and the remaining at 30 m spacing. The length of first five lines was 75 m and the remaining was of 100 m. In order to offset the hydrologic interference between adjacent plots as much as possible, buffer lines were introduced between test spacings and at boundaries. Thus the first line, designated as 1B15, is a buffer line and so are the 6th and the 9th designated as 6B15/30 and 9B30 respectively. The lines 2E15, 3E15, 4E15, and 5E15 are experimental lines of 15 m spacing and the lines 7E30, and 8E30 are experimental lines of 30 m spacing. Further replication for 30 m spacing or some other spacing was not possible because of the geometry of the field.

Baked clay pipes were used as drains pipes. These pipes were of 60 cm length with an outside diameter of 125 mm and inside diameter of 100 mm, having bell mouth at one end. They were provided with fifteen 6 mm holes on 1/3rd of its peripheral area. These holes were arranged in three bands of 5 holes each. The drains were laid in a trench in which river sand was spread to a thickness of 10 cm at an average depth of 1 m. The tail end of each pipe was connected to the bell mouth of the succeeding. The pipes were placed with the peripheral holes facing the trench bottom. The main water entry is through the annular space at the joints between the bell mouth and tail end of the pipes. The average total annular space is found to be 53 cm² per metre length of the drain line. After laying the drains, river sand filter was spread again over the drains to a thickness of 8 cm. The trench was then backfilled. Rigid PVC pipes were used as collector drains to carry the drainage water into the main sump. The collector pipes were laid at 0.4% slope. Based on the design calculations, 110 mm pipes were used to connect the 30 m spaced drains and 160 mm pipes were used for the 15 m spaced drains.

2.2.1 Collection sumps for drain discharge measurements
Pre-fabricated concrete rings with 60 cm outer diameter, 50 cm inner diameter and 50 cm height were used for the construction of discharge measurement sumps. These sumps were placed at the discharge end of each drain line. They were provided with holes for the entry of drainpipe and collector pipes. Adequate spacing between the drain entry and collector entry was provided for facilitating the measurement of discharges at each collection sump. All the tile drains entered into their respective collection sumps at the same elevation. A 110 mm PVC pipe of 60 cm length was used as the connecting piece between the drain line and discharge measurement sump. This provided a clean free fall of drainage water into the sump making the discharge measurements easy and accurate. Pre-fabricated concrete rings with 110 cm outer diameter, 100 cm inner diameter, and 50 cm height were used to construct the main sump.
2.2.2 Observation wells for measuring water table subsidence

A series of observation wells were installed in the subsurface-drained area to record the fluctuations in the water table elevations during drainage. They were made with 40 mm PVC pipes, each having a length of 1.5 m. Five millimeter holes with a spacing of 10 cm have been drilled in six bands at the bottom 50 cm length and coil was wound around it. The bottom end of the tube is covered with polythene to prevent soil entry. The placement of observation wells in the tile-drained experimental area is shown in Figure 3.

Figure 3 Layout of the observation wells

They were installed in three bands, each band perpendicular to the drain lines at L/4, L/2, and 3/4 L distances from the discharge end where L is the length of the drain in meter. For a 75 m long drain these bands of observation wells were at 18.75 m, 37.5 m, and 56.25 m from the collection sump and for a 100 m long drain they were at 25 m, 50 m, and 75 m. The observation wells were placed on these bands at 0.40 m, at S/8 and S/2 from the drains where ‘S’ is the spacing in meter. The nomenclature of observation wells is based on the location of each drain. The first digit represents the band number, the second digit, the drain number and the third, the serial number of the observation wells towards the western side of the drain line. Thus, all observation wells ending with the digit 3 represents the mid-spacing observation wells. There were altogether 120 observation wells installed in the experimental area.

2.2.3 Data Collection

The field was initially flooded with water to bring the water table nearer to the surface. Once the water table was stabilized, initial reading from all the observation wells was taken. This was followed by continuous drainage pumping for 120 hours. Drawdown in observation wells and drain discharge into collection sumps were taken at varying time intervals during drainage. Initially, readings were taken at short intervals. The drain discharges were taken using a bucket and stop watch at varying time intervals from all the drains. Water table subsidence was measured using electric depth gauges.

2.2.4 Hydraulic conductivity

The field data collected from experimental area were used to determine the drainage parameters. It was assumed that the hydrologic, soil, and topographic conditions in the experimental area were representative of those prevailing in the entire area under investigation.
The van Schilfgaarde equation (1963) given below (1) was used for finding hydraulic conductivity values from the field data.

\[ L = \text{drain spacing, m}; \]
\[ A = \text{a constant}; \]
\[ K = \text{effective hydraulic conductivity, m/d}; \]
\[ t = \text{time, d}; \]
\[ d_e = \text{equivalent depth as defined by Hooghoudt, m}; \]
\[ h = \text{mid-spacing water table height, m at time t}; \]
\[ h_0 = \text{initial mid-spacing water table height, m}; \]
\[ f = \text{porosity}. \]

The term \( A \) is defined as

\[ A = \ldots \]

(2)

It was assumed that the water table is essentially flat and, therefore,

\[ q = \text{average drain outflow during time t, m/d}; \]

(3)

where

\[ q = \text{average drain outflow during time t, m/d}; \]

The equivalent depth, \( d_e \), is calculated from the expression after Hooghoudt (1940)

\[ d_e = \ldots \]

(4)

where

\[ u = \frac{\pi r}{2}, \text{r being the radius of the drain, m}; \]
\[ D = \text{depth to impermeable layer, m}; \]

Investigations had shown that the impervious layer is far below the soil and always exceeded more than half the spacing and hence \( D \) was taken as \( L/2 \).

Substituting Equation (3) into (1) and solving for \( K \), yields

\[ K = \ldots \]

(5)

The effective hydraulic conductivity was computed for the entire profile using Equation (5) for varying water table height, \( h \), of 1 cm interval starting from the initial water table height, \( h_0 \). The drain discharge, \( q \), for corresponding head was calculated first by computing the time required for the water table to drop to that head using the time-hydraulic head relationship developed from field data and then calculating the discharge rate for that time from the time-discharge relationship, also developed from field data. The equivalent hydraulic conductivity for each drain for the soil profile was found taking the weighted average using Equation- 6.

\[ K(h) = \ldots \]

(6)

where \( K(h) \) is the hydraulic conductivity as a function of mid-spacing water table height.

### 2.2.5 Drainable porosity

Drainable porosity, \( f \), defined as the ratio of the drained voids volume to the total volume of the voids plus the volume of the soil.
particles, is a necessary parameter in all equations that predict drawdown. During drainage it is not normally a constant, but is related, among other things, to the water table depth. Both the time of drawdown and the shape of the water table depend on the particular way in which drainable porosity is related to water table depth. The drainable porosity is not used as such in the drawdown equations. The average porosity value for a drawdown depth is used for calculations. This average value is called the equivalent drainable porosity, \( f_{eq} \). Drainable porosity at any point in the soil is not solely a function of water table depth but is also determined by the time during which the drainage is permitted before the water table falls to a new position. The time required for a prescribed drawdown is affected by the size, depth, and spacing of the drains. The importance of drainable porosity lies in the fact that all drawdown equations use this term to be multiplied with the drawdown to find the total volume of drainable water. The equivalent drainable porosity of the soil profile was determined using Equation 7 proposed by Taylor (1960).

\[
\begin{align*}
\text{where } & \begin{align*}
f &= \text{ equivalent drainable porosity;}
h &= \text{ water table depth, m;}
V &= \text{ cumulative outflow volumes, m}^3; \\
A &= \text{ area through water falls, m}^2; \text{ and}
n &= \text{ subscript showing the position of water table depth.}
\end{align*}
\end{align*}
\]

The entire drained soil profile was divided into slabs of 1 cm thick. The time required to lower the water table from initial depth, \( h_0 \), to 1 cm below was obtained from the time-hydraulic head relationship. The total volume of water drained during that period is the area below the drain discharge hydrograph for the same period, which was obtained by integrating the equation developed for time-drain discharge relationship for the same time period. The drainable porosity of the slab in the profile was obtained by dividing the total volume drained by the slab thickness. The drainable porosities for successive slabs of 1 cm thickness were found out for the entire range of water table drawdown for all the drains. Relationships were then developed for drainable porosity with respect to the mid-spacing water table. The average equivalent drainable porosity for each drain for the soil profile tested was found out by taking the weighted average using equation-8.

\[
\begin{align*}
\text{where } f(h) &= \text{ the drainable porosity as a function of water table height.}
\end{align*}
\]

3 Results

The field data on water table drawdown due to drainage were converted to their respective hydraulic heads. The average hydraulic head (average of 6 mid-spacing observation wells adjacent to each drain) was used for the analysis. The drain line and its respective adjacent observation well influenced by the drain are given in Table 1.

<table>
<thead>
<tr>
<th>Drain line</th>
<th>Observation wells</th>
</tr>
</thead>
<tbody>
<tr>
<td>2E15</td>
<td>113  213  313  123  223  323</td>
</tr>
<tr>
<td>3E15</td>
<td>123  223  323  133  233  333</td>
</tr>
<tr>
<td>4E15</td>
<td>133  233  333  143  243  343</td>
</tr>
<tr>
<td>5E15</td>
<td>143  243  343  153  253  353</td>
</tr>
<tr>
<td>7E30</td>
<td>163  263  363  173  273  373</td>
</tr>
</tbody>
</table>
The best-fit curves were drawn by plotting average hydraulic heads at mid-spacing versus time and drain discharge versus time. Figures 4 and 5 show the comparative discharges and drawdowns for all the drains. Looking at the figures it is observed that a progressive decline occurs in the discharge rates and hydraulic heads at identical times for different drains. This decline depends on the distance of these drains from the adjacent water body (see Figure 2 for location of drains from water body).

This is caused by the specific feature of the polders in the area that are surrounded by water bodies, the water level of which are always higher than that of the field and thereby contributes a substantial lateral seepage. The influence of the water bodies was visible up to a distance of 60 m though it decreased with distance. As the drainage continued, the drop in discharge rate and hydraulic head stabilized and almost became steady later on. The regression equations to predict the hydraulic head and drain discharges at various times are given in Table 2.

### 3.1 Hydraulic conductivity

The effective hydraulic conductivity was calculated using the drain outflow observations. Using the time-hydraulic head and time-discharge relationships developed (Table-2), the volume of water drained for a particular soil profile depth starting from initial water table depth, was estimated. Equivalent hydraulic conductivity was then calculated using equation-5 for a particular mid-spacing water table height.

**Figure 4** Drain Discharge with respect to time.
The relationship obtained for the hydraulic conductivity as a function of mid-spacing water table height is shown in figure 6. The values were higher for the topsoil. It varied directly with the mid-spacing water table height for drains close to the outside water body (2E_{15}, 3E_{15} and 4E_{15}) and exponentially for drains away from the outside water body (5E_{15}, 7E_{30} and 8E_{30}). The transition in the mode of variation took place at a distance of 60 m from the water body. The values also showed a decreasing trend with the distance of the field from the water body for the same mid-spacing water table heights.

The regression equations developed for hydraulic conductivity, \( K \), for each drain as a function of mid-spacing water table height, \( h \) at time, \( t \), along with its equivalent values, \( K_{eq} \), for the entire flow domain is given in Table 3. The equivalent hydraulic conductivity for the flow domain was found by taking the weighted average using Equation 6.

### Table 2  Regression equations to predict hydraulic head and drain discharge from field observations

<table>
<thead>
<tr>
<th>Drain No</th>
<th>Initial Water table height, ( h_0 ), (m)</th>
<th>Equations developed from field data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( h ) (m) vs time (h)</td>
</tr>
<tr>
<td>2E_{15}</td>
<td>0.69</td>
<td>( h = 0.835 \ t^{-0.113} )</td>
</tr>
<tr>
<td>3E_{15}</td>
<td>0.68</td>
<td>( h = 0.889 \ t^{-0.135} )</td>
</tr>
<tr>
<td>4E_{15}</td>
<td>0.66</td>
<td>( h = 0.821 \ t^{-0.135} )</td>
</tr>
<tr>
<td>5E_{15}</td>
<td>0.66</td>
<td>( h = 0.608 \ e^{-0.0029 \ t} )</td>
</tr>
<tr>
<td>7E_{30}</td>
<td>0.51</td>
<td>( h = 0.499 \ e^{-0.0043 \ t} )</td>
</tr>
<tr>
<td>8E_{30}</td>
<td>0.44</td>
<td>( h = 0.497 \ e^{-0.0046 \ t} )</td>
</tr>
</tbody>
</table>
Table 3  Regression equations for the variation of hydraulic conductivity within the flow domain in relation to mid-spacing water table heights

<table>
<thead>
<tr>
<th>Drain No</th>
<th>Equations developed for effective hydraulic conductivity near the vicinity of the drains</th>
<th>Equivalent hydraulic conductivity, $K_{eq}$ (m/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2E$_{15}$</td>
<td>$K = 0.028 + 0.287 \times h$</td>
<td>0.194</td>
</tr>
<tr>
<td>3E$_{15}$</td>
<td>$K = -0.063 + 0.414 \times h$</td>
<td>0.173</td>
</tr>
<tr>
<td>4E$_{15}$</td>
<td>$K = -0.096 + 0.438 \times h$</td>
<td>0.134</td>
</tr>
<tr>
<td>5E$_{15}$</td>
<td>$K = 0.0148 \times e^{3.62 \times h}$</td>
<td>0.100</td>
</tr>
<tr>
<td>7E$_{30}$</td>
<td>$K = 0.00434 \times e^{4.74 \times h}$</td>
<td>0.030</td>
</tr>
<tr>
<td>8E$_{30}$</td>
<td>$K = 0.00804 \times e^{4.18 \times h}$</td>
<td>0.036</td>
</tr>
</tbody>
</table>

The average $K_{eq}$ computed was 0.167 m/d (between 2E$_{15}$, 3E$_{15}$ and 4E$_{15}$) and 0.055 m/d (between 5E$_{15}$, 7E$_{30}$ and 8E$_{30}$) respectively for the two distinct regions (up to 60 m from the water body and beyond that).

### 3.2 Drainable porosity

The drainable porosity was also calculated using the drain outflow observations. Using the time-hydraulic head and time-discharge relationships developed (Table-2), the volume of water drained for a particular soil profile depth of small thickness (1 cm in this case), starting from initial water table depth, was estimated. The drainable porosity was calculated by dividing the total volume drained by the soil profile thickness from where the drainage has taken place. The drainable porosity for the entire profile was found out similarly. The relationship obtained for the drainable porosity as a function of mid-spacing water table height is shown in figure 7.
For areas near drains 2E_{15}, 3E_{15}, and 4E_{15}, the drainable porosity increased as the mid-spacing water table height decreased. These drains are located nearer to the outside water bodies (see Figure 2 for their locations) and a significant amount of recharge enters the field due to their proximity to the outside water bodies. During drainage, the water table fell at a faster rate and almost became steady at later stages (see Figure 5) because of the recharge from the adjoining water bodies. Thus the total volume of water drained is comparatively more attributing to higher drainable porosities at lower water table heights. This recharge effect was found to be prominent up to the drain 4E_{15}, which is located at a distance of 60 m away from the water body. The drainable porosity found out by this method for areas near drains 2E_{15}, 3E_{15}, and 4E_{15} does not represent the true values and would be considerably in error because of this recharge effect. This is true for the cases if an appreciable quantity of artesian water are entering the drained area or if deep seepage losses are great (Taylor, 1960). Hence drainable porosity values calculated near these drains (2E_{15}, 3E_{15}, and 4E_{15}) were not used for further analysis. For areas near drains 5E_{15}, 7E_{30}, and 8E_{30}, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. This showed that this region is away from the recharge influence and the drainable porosity values calculated represented the real values. The constant region of the graph for drains 5E_{15}, 7E_{30}, and 8E_{30}, implies a fairly homogenous soil. The slight decrease in drainable porosity in case of 5E_{15}, 7E_{30}, and 8E_{30}, with declining water table may be due to a compact soil layer immediately below the surface. Hence, drainage designs are to be made separately for areas up to 60 m away from water bodies and for distances beyond that. When drainage designs are made for areas nearer to water bodies, the recharge component should be incorporated for arriving at a proper design. The regression equations developed for drainable porosity, f, with respect to the mid-spacing water table height, h, at time, t, for the flow domain along with the equivalent drainable porosity values are given in Table 4. The equivalent drainable porosity for each drain catchments for the flow domain was found by taking the weighted average using Equation-8. The average equivalent drainable porosity for the flow domain for areas near drains 5E_{15}, 7E_{30}, and 8E_{30}, is 0.04.

Table 4  Regression equations for the variation of drainable porosity within the flow domain in relation to mid-spacing water table heights
4 Conclusion

Hydraulic conductivity is one of the most important factors influencing spacing between lateral drains in subsurface drainage systems. While methods for determining hydraulic conductivity and drainable porosity have been rigorously developed and thoroughly tested, the properties often vary widely from point to point in the field and usually require numerous measurements to obtain field-effective values. Accurate measurement of these two input parameters in drain spacing equations is important in the successful technical and economical design of any drainage system.

A detailed study conducted in subsurface drained field has shown that the hydraulic conductivity values ($K$) varied directly with the mid-spacing water table height for drains close to the outside water body and exponentially for drains away from the outside water body. The transition in the mode of variation in the experimental area took place at a distance of 60 m from the outside water body. The $K$ values also showed a decreasing trend with the distance of the field from the water body for the same mid-spacing water table heights. The computed average equivalent $K$ was 0.167 m/d for regions up to 60m from the water body and 0.055 m/d for regions beyond that.

Drainable porosity, defined as the ratio of the drained voids volume to the total volume of the voids plus the volume of the soil particles, is a necessary parameter in all drain spacing equations that predict drawdown. During drainage it is not normally a constant, but is related, among other things, to the water table depth for areas near to outside water bodies, the drainable porosity increased as the mid-spacing water table height decreased. Being nearer to the outside water bodies, a significant amount of recharge entered the field and was intercepted by the subsurface drain. During drainage, the water table fell at a faster rate and almost became steady at later stages because of the recharge from the adjoining water bodies. Thus the total volume of water drained was comparatively more attributing to higher drainable porosities at shallow water table heights. This recharge effect was found to be prominent up to a distance of 60 m away from the water body. For the drains that were away from the water bodies, the drainable porosity decreased with the mid-spacing water table height and became almost constant at lower mid-spacing water table heights. This showed that the drained region was away from the recharge influence and the drainable porosity values calculated represented the real values. Hence, drainage designs are to be made separately for areas away from water bodies and for areas nearer to water bodies if these water bodies have definite influence (like recharge) on the adjoining areas. When drainage designs are made for areas nearer to water bodies, the recharge component should be incorporated for arriving at a proper design. The average equivalent drainable porosity arrived at from the experiments for the flow domain of the drains that are away from the water bodies was 0.04.

5 References

CONTROLLED DRAINAGE IN THE NETHERLANDS REVISITED?[1]

Dr. Ir. P.J.Th. van Bakel[2]

An overview of recent developments in surface water level manipulation and results of case studies

ABSTRACT
In the Netherlands most Waterboards generally manipulate surface water levels in order to influence phreatic groundwater levels. The main aim is to improve working conditions for agricultural crop production.

This type of water management is questioned because the hydrological effectiveness is rather low and it may lead to unwanted effects on aquatic ecosystems and on adjacent nature areas. Together with a tendency towards self-regulating systems, these unwanted effects may lead to the idea that partly or fully controlled drainage has become an anachronism.

A number of developments ask for a revitalisation of controlled drainage such as a) the problem of ‘Verdroging’ (unwanted effects of improved drainage, water withdrawal and water supply on nature) can partly be overcome by surface water level management directed towards structural raising the groundwater levels in the winter period in buffer zones around nature areas b) growing awareness of farmers of the importance of water table management of ‘their’ water courses for reducing drought damage or for reducing the amount of sprinkling irrigation and c) the governmental and waterboards policy to reduce the peak flows in order to deal with the effects of climate change. Surface water level manipulation can have positive or negative effects on the peak flows.

The paper will elaborate these new developments and will analyse results of field studies and model calculations which specifically deal with the problem.

Keywords: Controlled drainage, Surface water level manipulation, Case studies

1 INTRODUCTION
In general in the Netherlands two types of surface water level management can be distinguished. In the free draining regions (roughly the South and the East) Waterboards generally manipulate surface water levels in order to influence phreatic groundwater levels. The main aim is (was) to improve working conditions for agricultural crop production. In the ‘polder’ areas the Waterboards are legally obliged to maintain a certain surface water level because of civil interest, such as damage to building foundations and the stability of dikes. The emphasis in this paper is on the design of the drainage system and operation of the surface water level with the purpose to influence drainage and occasionally make subsurface irrigation possible. In most cases it is certainly not fully controlled drainage. We will start with an overview of recent developments. Next a number of case studies and finally some conclusions will be presented.

2 RECENT DEVELOPMENTS
In general the ideal groundwater depth for agriculture is low in early spring and during the harvest period and high during the periods of high evapo-transpiration demands. The natural regime is just the opposite. Therefore most water managers have
designed a surface water level manipulation system where by the surface water level in a control unit is manipulated between certain bounds means of adjustable weirs and inlet structures. To give an idea: the winter and summer level is 1.20 and 0.80 m below mean soil surface level, respectively. The transition from winter level to summer level is around 1st of April and 1st of October and vice versa. A more sophisticated type of water management is to couple the surface water level with the actual groundwater level on one or more representative locations (see also Van Bakel, 1986 and Bierkens et al., 1999).

The rational of this type of water management is questioned for several reasons:

- the hydrological effectiveness in most regions is low very because the water level in the small water courses and pipe drains are not or only partly influenced. The reason is that the height of the bottom of these watercourses or the height of the drains is above the highest surface water level. Even in areas with favourable conditions water supply efficiency (defined as the quotient of average increase in evapo-transpiration and extra water supply) is not more than 20% (Van Bakel, 1986). As a consequence the economical feasibility is questionable;
- intensification of agriculture has led to an increase in sprinkling irrigation. With sprinkling irrigation there is less need for additional water supply through controlled subsurface irrigation;
- the use of pipe drains for infiltration is hampered because farmers think that drains under water has negative effects on its functioning. In some types of soils this is confirmed by experiments (Kalisvaart, 1958; Working Group Drainage, 1997);
- the primacy of agriculture has come to an end. So the basics of surface water manipulation may have changed drastically;
- water level manipulation for agriculture may lead to unwanted effects on the ecological functioning of water courses and of adjacent nature areas;
- to maintain a high summer water level external water supply is needed. In many cases this results in a deterioration of the surface water quality;
- high summer levels have effects on the growing of the vegetation in the water courses with negative effects on the stability of the side slopes;
- in wet areas water water courses are sometimes used as a fence or as a source for drinking water for the cattle. More and more the cattle stay indoors during the summer so this function of surface water management will become less important.

On the other hand we see developments which ask for more emphasis on surface water level manipulation/controlled drainage:

- the groundwater levels in many parts of the Netherlands are structurally lowered causing the so called ‘Verdroging’ problem (unwanted effects of improved drainage, water withdrawal and water supply on nature). With water supply for sprinkling irrigation or subsurface infiltration the lowering of the groundwater level in agricultural regions is reduced with positive side effects for adjacent nature areas.
- regions must be self reliant with respect to water. Surface level manipulation is an effective means to conserve part of the precipitation surplus for the summer period. By raising the surface water level in spring at the right time drainage can be reduced. Also during the summer period precipitation due to storm events can be conserved. The average amount of water conservation is about 20 mm per season;
- in some projects buffer zones around wet nature areas have been designed. The hydrological functioning depends on the groundwater level regime: the higher the better. By water supply for subsurface infiltration the groundwater level can be kept on a higher level in the summer;
- New technical developments in the construction of water level regulating structures have lead to lower prices (and therefore feasible applications on individual farms become possible) and less labour requirements due to automation;
Climate change will result in higher peak discharges. An important item: can these peak discharges be reduced by a different design of the surface water system and a different operation of surface water levels;

many Waterboards in the ‘polder’ areas are no longer bound to one fixed, legally obliged, surface water level but change to protocols or legally fixed relations between water levels and change of exceedance;

for the production of drinking water there is a tendency to shift from groundwater extraction to surface water extraction. A problem is the low discharges in the summer. Controlled drainage can raise the low flows.

a problem is that a number of desired changes in surface water management have negative effects on other desired changes. E.g. raising the groundwater level may result in higher peak flows because the storage possibilities in the unsaturated zone is reduced. Only a comprehensive analysis of the hydrological system can bring up such antagonisms (see also Van Bakel et al., 2001.)

In the next section we will discuss a number of studies performed in the last 2 decades which deal with one or more of the above mentioned aspects.

3 CASE STUDIES

3.1 Introduction
In this section a number of case studies will be discussed. The experiences with new forms of controlled drainage are seldom based on practical experiments. The reason is that the effects are not so big so it is difficult to distinguish them from the strong variations in the hydrological situation due to the variation in the weather conditions from year to year. Besides most plans are still in the stage of planning. Therefore in this section I will give an overview of results with numerical experiments with physically based calibrated groundwater flow models.

3.2 De Monden
De Monden is an area of about 10,000 ha in the North of the Netherlands, mainly used for arable purposes. It is part of a reclaimed raised bog peat area. During the reclamation, canals were dug at distance of about 170 m. these canals are now used for surface water management (drainage, water conservation and subsurface irrigation). The Waterboard is manipulating the surface water level on a daily or weekly schedule based on a model study (Van Bakel, 1986). The range between summer and winter level is rather large: up to 0.70 m. The study indicates a rather low efficiency of water supply despite the favorable physical circumstances. When the low lying parts of a control unit are pipe drained, the surface water level can be raised with approx. 0.20 m while the average evapo-transpiration is higher due to less water logging damage. Also the efficiency of water supply slightly improves. So, the installation of pipe drains has positive effects on agriculture and nature. Another important conclusion of this model study is that is the introduction of a formal coupling between surface water level and groundwater depth, makes water management more objective and more transparent. Monitoring of the groundwater depth indicates that its dynamics are strongly reduced and in agreement with the model predictions.

3.3 Groote Peel
This remnant of a former raised bog peat area in the South of the Netherlands, on the border of the provinces Noord-Brabant and Limburg, with an area of 1340 has the status of a National Nature conservation area because of the high potential of becoming an important wetland.

The area is suffering from the hydrological measures in the surrounding agricultural area and an important question was the optimization of hydrological measures in a buffer zone of 2 km around the nature area. The following measures were investigated:

installation of pipe drains;
CONTROLLED DRAINAGE IN THE NETHERLANDS REVISITED?

- sprinkling irrigation;
- manipulation of surface water levels, with and without external water supply;
- water withdrawal from the groundwater system for drinking water.

The effects were calculated with the model Simgro (Querner and Van Bakel, 1989) and are described in more detail in Van Walsum (1990). Only the results with controlled drainage will be discussed here.

In the present situation 9% of the downward seepage of the nature area (which must be as small as possible) is caused by pipe drainage and sprinkling irrigation. The autonomous development will cause an increase of 9%. A stand still of drainage and sprinkling irrigation in the buffer zone reduces this unwanted effect with 80%. Extra water supply to the agricultural land, to keep the surface water level during summer on 0.70 m minus soil level, results in a decrease in downward seepage of the nature area with 15%. A more significant improvement of the hydrological conditions for peat growth is possible when the buffer zone is wetted drastically, by raising the water level to the soil level, in combination with water supply and pipe drains for subsurface irrigation.

3.4 Bargerveen
The Bargerveen is a high bog peat reserve of about 2000 ha in the North of the Netherlands on the Dutch-German border. Drainage in the surrounding agricultural land causes lowering of the water levels in the peat area and an increase of the downward seepage, comparable with the Groote Peel case. With the model Simgro a great number of scenarios to restore hydrological conditions for peat growth were evaluated (Van Walsum, 1998). Especially the results of scenarios with controlled drainage in the agricultural area will be discussed here.

Raising the surface water levels in the Dutch part of the buffer zone (approx. 1000 ha), to the surface elevation heights and without water supply has a moderate effect on the increase of the area suitable for peat growth (2.5 ha). With water supply the groundwater levels in the buffer zones can be raised up to 0.50 m in winter. As a result the area suitable for peat growth increases with approx. 10 ha.

3.5 Beerze and Reusel
The catchment area of the small rivers (rivulets) Beerze and Reusel is about 44 000 ha and is situated in the South of the Netherlands. It is a weak undulating lowland stream landscape with high potential for nature development. Because of drainage of agricultural areas and the so-called improvement of the discharge capacity of the drainage system, nature has deteriorated. The question was: do measures to restore nature effect the peak flows and can measures to lower the peak influence hydrological conditions in a positive or negative way. The results are investigated with the numerical model Simgro and described in Van Bakel et al. (2002).

The main conclusion is that it is almost impossible to restore the hydrological conditions in nature areas without unwanted effects in agricultural area land and that only a part of these effects can be compensated with smart controlled drainage. This does not hold for peak flow reduction: a reduction of 30% of peak flows with a recurrence time of 50 years is possible.

3.6 Tungelroysche Beek
The Tungelroysche Beek is one of the tributaries of the river Meuse. Its catchment area of approx. 12 000 ha is situated in the middle of the province of Limburg and for a small part in Belgium. The main aims of the study were to investigate the effectiveness of measures to reduce the peak flows and to diminish the ‘Verdroging’ and drought damage in agriculture. From model calculations with Modflow and Sobek it was concluded that rewetting the area gives higher peak flows whereas raising the weirs during the peak situation during a limited number of days reduces the peak flows considerably. Furthermore the installation of a large number of small weirs operated by farmers may result in higher peaks because most of them operate locally and not regionally (TAUW, 2000, Van Bakel et al, 2001).
3.7 Benelux-Middengebied

In the late nineties in 4 provinces in the South of the Netherlands and the north of Belgium 1888 small weirs are installed. The farmers themselves control these weirs in order to conserve water by raising the weir level in spring at the right time, depending on the actual groundwater depth. The European Union finances this project. The average raise of the surface water level in spring is about 0.40 m. The hydrological effects, calculated with a numerical groundwater flow model (see Table 1), are equivalent with about 20 mm.yr\(^{-1}\) on 17.000 ha. The effect of water conservation per weir of about 1750 m\(^3\).yr\(^{-1}\) is much more than effect on the increase in evapo-transpiration (475 m\(^3\).yr\(^{-1}\)). The latter is not more than 1% of the total evapo-transpiration of the influenced area. These results indicate that water conservation for agriculture is not so effective but the effect on groundwater conservation are worthwhile. For more information, see De Louw (2001).

<table>
<thead>
<tr>
<th>Table 1 Average calculated effects of water conservation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>Water conservation (m(^3).yr(^{-1}))</td>
</tr>
<tr>
<td>Reduction in water shortage (m(^3).yr(^{-1}))</td>
</tr>
<tr>
<td>Influenced area (ha)</td>
</tr>
</tbody>
</table>

3.8 Flexible surface water management in low peat areas

In the West and North of the Netherlands approx. 300 000 ha low peat areas are allocated. They face a mayor problem: a surface water level which makes agriculture possible (at least 0.50 m below soil surface) results in the decay of the peat soil with a number of unwanted effects associated with it, such as bad surface water quality and on the long term a complete loss of the peat soil. The Waterboard of Rijnland investigates the possibilities of flexible surface water levels in areas. Up till now the surface water levels have been kept constant (within a few centimeters).

Preliminary calculations with the computer code Multi-SWAP (in this case 2 soil columns connected with one surface water reservoir), modeling an experimental site in the neighborhood of the Nieuwkoopse Plassen, show that by allowing more variation in surface water level (0.30 m) the amount of water supply reduces to 30% compared with no variation. With an extreme form of groundwater depth dependable surface water level manipulation (surface water level 0.20 m minus soil surface in case groundwater depth is more than 0.70 m; 0.70 m when groundwater depth is less than 0.30 m) the ‘normal’ groundwater lowering during the summer (on the average 0.10 m) is turned into a raise of 0.05 m. This has favorable effects on the decay of peat because wet conditions in periods with high temperature decrease the decaying process. It must be emphasized that the experimental site is only representative for situations with a very intensive relation between surface water and groundwater which in most cases only can be achieved with pipe drains.

4 CONCLUSION

Partly or fully controlled drainage, in order to improve the hydrological conditions for agriculture, was common practice in areas in the Netherlands with a moderately to densely intensive surface water system. The rational of this type of surface water management is questioned and some Waterboards tend to reduce their efforts in this respect. Recently there are a number of developments with ask for a re-evaluation. On the one hand: firstly the low winter levels are a mayor cause for the unwanted lowering of the groundwater levels and reduction of upward seepage of nature in the sandy area. Secondly, the water supply in the summer periods in order to keep the high summer levels has negative effects on the ecological quality of surface water bodies. On the other hand results of calculations with integrated models indicate that controlled drainage in agricultural areas can result in conservation of part of the precipitation surplus of the winter period and in a reduction of the lowering of the groundwater
level during the summer period. Both have favorable effects on agriculture and nature. In peat areas the deterioration of the peat soil can be reduced by raising the groundwater level during the summer. Results of calculations also indicate that the effectiveness is strongly improved when pipe drains are installed in the agricultural area. Although controlled drainage is against the actual preference for self-regulation, the demands on water management from society become so high that it is almost obligatory to investigate the possibilities of controlled drainage. On basis of the results one can state that controlled drainage needs revitalization.

Figure 1  Average groundwater depth during the year for 3 types of surface water management.

5  Acknowledgements
The author is most grateful to Henk van Hardeveld of Waterboard Rijnland for the permission to use his unpublished results of model calculations.

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[2] Senior research scientist Hydrology, Alterra, Wageningen
USING THE DEPLETED FRACTION TO MANAGE THE GROUNDWATER TABLE IN IRRIGATED AREAS

Marinus G. Bos and Wim G.M. Bastiaanssen

Abstract
The depleted fraction, defined as the ratio of $ET_{\text{actual}}$ over $(P + V_c)$, relates parameters of the water balance of an irrigated area with each other in such a way that the (water) manager obtains information on the rate of change of water stored in the area (soil moisture and groundwater). If the depleted fraction equals about 0.6 water storage in the area is stable, while water is stored for lower values of the depleted fraction.

If the value of the depleted fraction exceeds 0.6, the volume of water stored in the area decreases. Part of this decrease is due to natural drainage and part due to capillary rise into the root zone of the irrigated crop. Despite this capillary rise the actual evapo-transpiration drops below the potential $ET$ value. For most crops, a decrease of $ET$ by about 15% would result to a higher productivity in terms of yield per cubic meter water. However, the yield per hectare (and thus farm income) would decrease.

Management of an irrigation system is recommended in such a way that the monthly values of the depleted fraction range between 0.5 and 0.8. Such a management rule would provide sufficient water for leaching (at the 0.5 side of the range) and provide high crop yield per unit water consumed (at the 0.8 side).

Keywords: Groundwater, management, irrigation, semi-arid regions, drainage

1 Introduction
The diversion of irrigation water into an arid or semi-arid area in order to grow an agricultural crop is a human intervention in the local environment. The primary intended (positive) effect is a higher crop yield; the most common unintended (negative) effect is a rising groundwater table. This rising groundwater table in turn may cause water logging and soil salinity within the irrigated area and an increased drainage flow into the downstream environment. This drainage water usually transports a variety of chemicals (salts, pesticides, etc.).

The schematic water balance of an irrigated area (Figure 1) shows three inflows of water: precipitation ($P$), groundwater flow from upstream ($G_{in}$) and river diversion ($V_c$). Of these, the groundwater inflow is often the same order of magnitude as the groundwater outflow. Part of the river diversion plus precipitation ($P + V_c$) is actually evapo-transpirated ($ET_{\text{actual}}$) to produce a crop (the above positive effect), the remaining part is either stored within the irrigated area or drained (the above negative effects). The ratio of $ET_{\text{actual}}$ over $(P + V_c)$ thus can be used as an indicator to assess irrigation water use.

2 The depleted fraction
The depleted fraction is ratio that compares three components of the water balance of an (irrigated) area (Figure 1). It relates the actual evapo-transpiration from the area to the sum of all precipitation on this area plus the surface water inflow (irrigation water) into the area. It is defined as (Molden 1997: Bastiaanssen et al 2001):
Because it is not practical to measure the $ET_{actual}$ and the precipitation for only the irrigated part of the area, we consider the gross command area. As shown in Figure 1, the depleted fraction quantifies the surface water balance excluding the drainage component. The water manager can influence the value of $V_c$ while this in turn influences the water deficit ($ET_{potential} - ET_{actual}$) in the area.

Due to the above definition of the components of the water balance, the depleted fraction usually is quantified for the entire irrigated area. It is recommended to study the temporal variation of the depleted fraction for a time step that is long with respect to (natural) fluctuations in the above parameters. Thus, studies on a monthly basis are recommended to avoid ripples on the data due to rain showers and short canal closures (Bastiaanssen et al 2001).

At first glance, the depleted fraction looks alike the overall consumed ratio. The latter ratio (efficiency) quantifies the degree to which the crop irrigation requirements are met by irrigation water in the irrigated area (Bos and Nugteren 1974). Assuming negligible non-irrigation water deliveries to the area, the ratio is defined as:

Where $ET_{potential}$ is the potential evapotranspiration from the irrigated area and $P_e$ is the effective precipitation (USDA 1970; Bos et al 1996). The numerator of this ratio thus contains (ICID 1978): "the volume of irrigation water needed, and made available, to avoid undesirable stress in the crops throughout (considered part of) the growing cycle". The overall consumed ratio thus relates the
crop irrigation water requirements \(ET_{\text{potential}} - P_e\) for the irrigated area with the actual irrigation water supply \(V_c\) to this area. It is an operational indicator that informs the irrigation manager on the adequacy of water supply to the actually irrigated area. The **depleted fraction** quantifies the water balance of the gross irrigable area.

### 2.1 Three Examples

Since several decades applied research is done to facilitate the more efficient use of irrigation water and to reduce the negative effects of water logging and salinity (Bos and Nugteren 1974). Since then, several case studies were published containing data on water use and recommendations to improve this water use. Data to quantify the depleted fraction are accessible for three previously studied irrigated areas. Some information on the case studies is summarized in Table 1.

<table>
<thead>
<tr>
<th>Project</th>
<th>Fayoum depression, Egypt</th>
<th>Viejo Retamo lateral unit, Argentina</th>
<th>Nilo Coelho project, Brazil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross area, ha</td>
<td>150,000</td>
<td>4,890</td>
<td>33,800</td>
</tr>
<tr>
<td>Major soil type</td>
<td>clay</td>
<td>sandy loam</td>
<td>sandy loam</td>
</tr>
<tr>
<td>Annual precipitation, mm/year</td>
<td>10</td>
<td>234</td>
<td>586</td>
</tr>
<tr>
<td>Potential (ET), mm/year</td>
<td>1950</td>
<td>1340</td>
<td>1560</td>
</tr>
<tr>
<td>Method by which (V_c) is measured</td>
<td>calibrated inlet structures at Lahun</td>
<td>broad-crested weir at head of canal</td>
<td>Rating of pumping station at head of canal</td>
</tr>
<tr>
<td>Method by which (ET_{\text{actual}}) is determined</td>
<td>rest term in water balance</td>
<td>rest term in water balance</td>
<td>energy balance of satellite image pixels</td>
</tr>
</tbody>
</table>

As mentioned above, the part of the water within the irrigated area that is not evapo-transpired either goes into storage or has to drain from the area. The volume of water that goes into storage (as soil moisture or groundwater) changes as a function of the other components of the water balance and as a function of the discharge capacity of the (natural) drainage system. For the three case studies (Table 1) monthly values of the depleted fraction were plotted against the rate of change of the groundwater table (sandy loamy soils) and against the change of moisture in the soil (clay soils). In all three areas the groundwater depth fluctuated around 2.0m. As shown in Figure 2, the regression line intersects the x-axis near the 0.6 value of the depleted fraction.

### 3 Discussion

Comparing the three case studies of Figure 2 shows that the value of the depleted fraction influences the volume of water stored within the irrigated area. The intersection points of the three regression curves averages around 0.6. In other words: if \(ET_{\text{actual}}\) is less than about 0.6\((P + V_c)\) a portion of this available water goes into storage causing the groundwater table to rise while storage decreases if \(ET_{\text{actual}}\) is greater than 0.6\((P + V_c)\). Apparently, the natural drainage in the three arid and semi-arid areas has a capacity that is sufficient to discharge about 0.4\((P + V_c)\). Thus, the depleted fraction can be used as a performance indicator on irrigation water use. The volume of water diverted into the irrigated area can be reduced during months with a low depleted fraction. If this non-diverted water remains in a storage reservoir, which often is the case in arid and semi-arid regions, this water can be diverted during months.
Figure 2  The rate of change of the groundwater table (or volume of moisture in the soil) as a function of the depleted ratio of three irrigated areas.

The parameters $V_c$ and $ET_{actual}$ are not entirely independent of each other. As long as there is sufficient irrigation water, the $ET_{actual}$ will be near its potential value. However, $V_c$ is reduced in order to increase the depleted fraction, less water will be available for irrigation and $ET_{actual}$ will decrease. This impact of $V_c$ on $ET_{actual}$ is illustrated in Figure 3 for the Fayoum depression, Egypt. As shown, the evaporative fraction, $ET_{actual}/ET_{potential}$ remains about unity if the depleted fraction is less than 0.6. During part of the year such a high evaporative fraction is needed to leach accumulated salts, etc. from the root zone of the crop. For higher values the depleted fraction the value of $ET_{actual}/ET_{potential}$ decreases by 10 to 20 percent. Due to the shape of the yield versus $ET$ curve of most crops, a decrease within this range results to a higher yield per cubic meter water. However, crop yield per hectare will decrease. To sustain agriculture on the one hand (leaching of the root zone is needed) and to attain a high productivity in terms of yield per cubic meter of water on the other hand, the monthly values of the depleted fraction should range between 0.5 and 0.8.
The actual use of the depleted fraction as a performance indicator greatly depends on the method (and related cost) with which the parameters are quantified. Methods that provide sufficiently accurate data are summarized in Table 2.

Table 2 Parameters and their method of measurement.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method by which term is measured or source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual evapotranspiration, $ET_{actual}$</td>
<td>The spatial variation of $ET_{actual}$ can be calculated from the energy balance of the pixels of a satellite image (20% error). Low resolution images (NOAA or MODIS) are adequate to calculate monthly values.</td>
</tr>
<tr>
<td>Potential evapotranspiration, $ET_{potential}$</td>
<td>Potential ET can be calculated from a variety of equations. Most widely tested is Penman-Monteith (error 20%) (Bos et al 1996; Burt et al 2002)</td>
</tr>
<tr>
<td>Volume of water diverted from river, $V_c$</td>
<td>$V_c$ should be measured with a permanent flow measurement structure. If the volume of water is calculated from 15 or more individual flow measurements (readings) the error in the volume of water will be reduced to the systematic error in these measurements (e.g. undershot gates 5%, broad-crested weirs 2%).</td>
</tr>
<tr>
<td>Precipitation, $P$</td>
<td>Precipitation is measured with a gage that is installed in accordance to standardized rules (error 5%). Data commonly are already available from local meteorological stations. The spatial distribution of precipitation can be obtained from weather satellite data (error 10%).</td>
</tr>
<tr>
<td>Depth to groundwater table</td>
<td>The groundwater depth is measured by lowering a sounder or installing a transducer into an observation well. The random error is about 0.02m. A systematic error of 0.05m can occur in the reference elevation of the ground surface.</td>
</tr>
</tbody>
</table>

4 Conclusion
The depleted fraction relates parameters of the water balance of an irrigated area with each other in such a way that the (water) manager obtains information on the rate of change of water stored in the area (soil moisture and groundwater). At a depleted fraction of about 0.6 storage is stable while water is stored for lower values of the depleted fraction.

If the value of the depleted fraction exceeds about 0.6, the volume of stored water decreases. Part of this decrease is due to natural drainage and part due to capillary rise into the root zone of the irrigated crop. Despite this capillary rise the actual evapo-transpiration drops below the potential \( ET \)-value. For most crops, a decrease of \( ET \) by about 15% would result to a higher productivity in terms of yield per cubic meter water. However, the yield per hectare (and thus farm income) would decrease.

Management of an irrigation system in such a way that the monthly values of the depleted fraction range between 0.5 and 0.8 would provide sufficient water for leaching and provide high crop yield per unit water consumed.

5 References

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CONTROLLED WATER TABLE MANAGEMENT AS A STRATEGY FOR REDUCING SALT LOADS FROM SUBSURFACE DRAINAGE UNDER PERENNIAL AGRICULTURE IN SEMI-ARID AUSTRALIA

John W Hornbuckle, Dr Evan W Christen, Dr James E Ayars and Assoc. Prof. Richard D Faulkner

ABSTRACT
Recent community based actions to ensure the sustainability of irrigation areas and associated ecosystems in the Murrumbidgee Irrigation Area (MIA) of Australia has seen the implementation of Land and Water Management plans. These aim to improve land and water management within the irrigation area and minimise downstream impacts associated with irrigation. Part of the plan has seen objectives set to decrease current salt loads generated from subsurface drainage in perennial horticulture within the area from 20 000 tonnes/year to 17 000 tonnes/year. In order to meet such objectives Controlled Watertable Management (CWM) is being investigated as a possible ‘Best Management Practice’, which can be used to reduce drainage volumes and salt loads.

During 2000 – 2002 a trial was conducted on a typical 15 ha subsurface drained vineyard. This compared a traditional unmanaged subsurface drainage system with a controlled drainage system utilizing weirs to maintain watertables and changes in irrigation scheduling to maximize the potential crop use of a shallow watertable. Drainage volumes, salt loads and watertable elevations throughout the field were monitored to investigated the effects of controlled drainage on drain flow rates and salt loads.

Results from the experiment showed that controlled drainage significantly reduced drainage volumes and salt loads compared to unmanaged systems. However, there were marked increases in soil salinity which will need to be carefully monitored and managed.

Keywords: Controlled drainage, Water table management, drain salinity, EM38, Grapevines

1 INTRODUCTION
In the Murrumbidgee Irrigation Area (MIA) the development of high water table areas has been a major concern. Within the horticultural areas large losses in agricultural production have been experienced through waterlogging and salinisation throughout their history. Extensive subsurface drainage schemes have been implemented and currently 70% (12000 ha) of all horticultural areas are protected with subsurface drainage, (Polkinghorne, 1992). The success in preventing waterlogging and salinisation was clearly evident and benefits from an agronomic perspective have been reported in a number of studies (Talsma and Haskew 1959; van der Lely 1978). However, a major effect, which was not envisaged at the time of design and development of the subsurface drainage systems, was the environmental consequences associated with disposal of saline drainage water.

Major environmental problems are now emerging with the secondary effects associated with land drainage. These include contamination due to sediment, nutrients and pesticides found in drainage waters (Bowmer et al. 1998) and problems associated with saline drainage water (Blackwell et al. 2000; van der Lely and Ellis 1974; van der Lely 1984; van der Lely and Tiwari 1995).
These impacts affect both instream users such as fish and other aquatic biota as well as downstream consumptive users. Within the MIA the issues and restrictions on drainage water disposal have come from problems faced by downstream consumptive water users in the Wah Wah Irrigation Area, whose irrigation water contains drainage water from the Murrumbidgee Irrigation Area. Due to these pressures, options for reducing the salt load from subsurface drainage systems in the MIA are being investigated.

In reviewing options for reducing subsurface drainage salt loads it is interesting to look at how in the past subsurface drainage systems have been implemented and the associated outcomes. Figure 1 compares the traditional implementation of a subsurface drainage system and the outcomes with that of drainage implementation that also considers water quality. With traditional implementation no management occurs after installation with systems simply left to operate continuously. This has led to extensive problems with large volumes of drainage water being generated and hence disposal problems and also reduced irrigation water use efficiency (Christen, Ayars and Hornbuckle 2001).

Figure 1 Subsurface drainage design processes from a past and future perspective

Figure 1 also shows the alternative process of subsurface drainage design when drainage water quality and volume are considered, with a view to creating a sustainable, both agriculturally and environmentally, irrigation and drainage system. This process involves considering at early stages the off-site consequences of subsurface drainage and incorporating these factors into the design process. While alternative designs can produce more environmentally acceptable drainage systems its application is limited to new drainage installations. In areas with existing subsurface drainage then other options need to be considered which modify the management of the drainage system to minimise off-site environmental impacts. Modifying existing systems to incorporate water quality targets is commonly referred to as controlled drainage, (Ayars, Grismer and Guitjens 1997; Christen,
Considering the large majority of horticultural areas in the MIA are already drained through subsurface drainage and currently no management of the drainage systems is undertaken then the application of controlled drainage practices may have significant potential to reduce salt loads generated with these existing systems.

While previous field studies on controlled drainage have shown potential for drainage volume and hence salt load reduction in semi-arid areas (Ayars 1996, Ayars et al. 1999), these trials have been undertaken on annual crops. In the MIA subsurface drained lands coincide with the growing of perennial horticultural crops (grapevines, citrus, prunes, peaches) for which the application of controlled drainage practices need to be investigated. This work was undertaken to assess the possible benefits associated with the application of controlled drainage management in the MIA.

The specific aim of this research was to investigate the effects of controlled drainage on subsurface drainage volumes, salt loads, watertables and root zone soil salinities in an irrigated winegrape vineyard.

2 MATERIALS AND METHODS
This site was located in the Murrumbidgee Irrigation Area in south eastern Australia (34⁰, 146⁰). The vineyard was previously used for rice production before conversion to wine grapes 7 years prior to the installation of a subsurface drainage system in November 2000. The grapevines (*Vitis vinifera*) consisted of a mixture of cultivars Cabernet Sauvignon and Semillon. Surrounding areas are planted to a mixture of horticulture, rice and pastures all of which are irrigated.

2.1 Site
The soil was identified as an Alfisol, in the Red – Brown Earth’s of the Great Soil Groups of Australia outlined by Stace (1968). The surface soil is a shallow loam (0.1 – 0.3m) and passes into a clay loam at a depth of 0.6m. The deeper subsoil varies from a dark brown to red-brown in color and is associated with alternating sandy and clayey layers. Both soft and hard carbonates are present.

Soil salinity at the site was highly varied from the supply end to runoff end due to shallower water tables of higher salinity at the runoff end. Results from 16 cores taken at the site are shown in Figure 2.
CONTROLLED WATER TABLE MANAGEMENT AS A STRATEGY FOR... UNDER PERENNIAL AGRICULTURE IN SEMI-ARID AUSTRALIA

Figure 2 Soil salinity at the site determined from 16 cores. Error bars show standard deviation

The water table at the experimental site before drainage ranged from 0.9 to 1.3m below the soil surface. Groundwater salinity was rather varied and ranged from 0.5 to 15 dS/m
2.2 Drainage System Layout

Subsurface drainage was installed at the site in November 2000. Drain spacings were calculated using the design procedures outlined by Talsma and Haskew (1959), which led to a design spacing of 36m at a depth ranging from 1.8 to 2.2m. Perforated HDPE pipe (0.1m dia.) was used for laterals and the main was sealed (0.15m dia.) HDPE pipe. A gravel envelope was used on all laterals. Inspection sumps were installed at the junction of each lateral to the main.

2.3 Experimental Layout

A controlled and uncontrolled drainage area was implemented at the site. The Uncontrolled area was situated over drainage laterals 1-3 (Figure 4) where the Cabernet Sauvignon variety was grown. The controlled areas were situated over drainage laterals 4-7 where the Semillon variety was grown (Figure 4). The selection of these areas was based on the vine variety. Red grape varieties such as Cabernet Sauvignon typically require periods of water stress to improve grape quality hence a high water table would not be beneficial. White varieties such as Semillon do not require any periods of water stress and hence this area was chosen for the controlled drainage.

This design allowed for two drainage treatments, an uncontrolled free drainage treatment (F) and a controlled drainage treatment which had two plots C1 and C2. Monitoring of drain flow volumes and salinity was undertaken at sumps 2, 5 and 6 and testwells were installed at three drainage cross-sections in each treatment, Figure 4.

Implementation of controlled drainage was undertaken using PVC risers on the laterals entering sumps 4 to 7 as shown in Figure 4.
Figure 4  Experimental layout of field site showing drainage system and drainage treatments
3 RESULTS

3.1 Water Tables

Irrigation events which produce higher recharge emphasize the major differences between controlled and uncontrolled drainage systems and their effect on the water table regime. During the course of the experimental monitoring period the first irrigation of the 2000/2001 irrigation season produced the greatest recharge. This event has been used to demonstrate the differences in water tables created by having controlled drainage, Figure 6 and Figure 7.

Figure 6 Water surface under the free drainage plot F
CONTROLLED WATER TABLE MANAGEMENT AS A STRATEGY FOR... UNDER PERENNIAL AGRICULTURE IN SEMI-ARID AUSTRALIA

The water table elevation within plots had a general trend of a higher water table at the supply end compared to the drainage end. In the controlled drainage plots the water table rose more rapidly and remained higher for longer than the free drainage plot. The time that the average water table depth was above specified depths for a 17 day period between the start of the 1st irrigation and the commencement of the 2nd irrigation is shown in Table 1. It can be seen that the controlled drainage plots (C1,C2) had a higher proportion of time that the water table depth was above 1.5m allowing potential beneficial use by the crop. The controlled drainage did not significantly increase the time the water table was above 1m, hence waterlogging protection was still provided.

Table 1 Water table depths between the first and second irrigation

<table>
<thead>
<tr>
<th>Water table depth</th>
<th>Number of Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
</tr>
<tr>
<td>&lt; 1m</td>
<td>0</td>
</tr>
<tr>
<td>1 to 1.5m</td>
<td>5</td>
</tr>
<tr>
<td>&gt; 1.5m</td>
<td>12</td>
</tr>
</tbody>
</table>

The control structures placed on the drainage laterals were effective in maintaining a higher water table in the controlled drainage plots, which had a significant effect on the drainage volumes and salt loads as shown in the next section.

3.2 Drain flow and Salt loads

The drain discharge hydrographs during the first irrigation of the 2000/2001 irrigation season are shown in Figure 8. It can be seen the controlled drainage resulted in significantly less drainage than allowing free drainage. The controlled drains only flowed for between 38-41 hours, flows from the free drainage plot occurred for over 320 hours, flowing continuously until the next
irrigation event. Peak discharges were lower and occurred about 12 hours later with controlled drainage. This was the extra time required to fill the profile to the pipe weir depth before drainage could occur.

Figure 8 Drainage during the first irrigation of the 2000/2001 irrigation season

The different flow volumes had a large effect on the salt loads, Table 2. The free drainage removed significantly more salt than the controlled drainage treatment. The total irrigation applied was 120mm (EC 0.1 dS/m) resulting in a salt application of 77 kg/ha. It can be seen that free drainage removed more salt from the profile than was applied in the irrigation water.

Table 2 Total Drainage, average salinity and salt load for the 1st irrigation of 2000/2001 irrigation season

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Drainage (mm)</th>
<th>Average Salinity (dS/m)</th>
<th>Salt Removed (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>2.84</td>
<td></td>
<td>164</td>
</tr>
<tr>
<td>1</td>
<td>1.85</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>2.03</td>
<td></td>
<td>13</td>
</tr>
</tbody>
</table>

3.3 Removing the pipe weirs

For the 2nd irrigation event of the 2001/2002 irrigation season the pipe weirs were removed from the controlled drainage laterals to allow the drains to flow freely and some salt leaching to occur. This provided the opportunity to compare the performance of those laterals with and without pipe weirs. This event can be compared to the 1st irrigation event of the 2000/2001 irrigation season as a high recharge event. Drain discharges and electrical conductivities from these two periods are shown in Figure 9 for the C1 plot.
It can be seen that the control structures had a significant effect in reducing the drainage discharge volumes. The irrigation applied was four times more when the pipe weirs were in place on the laterals and yet drainage volumes were still significantly reduced compared to the period when control structures were removed (Table 3).

<table>
<thead>
<tr>
<th>Plot Status</th>
<th>Drainage Applied (mm)</th>
<th>Drainage %</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 Controlled</td>
<td>142</td>
<td>1</td>
</tr>
<tr>
<td>Uncontrolled</td>
<td>32</td>
<td>6</td>
</tr>
<tr>
<td>C2 Controlled</td>
<td>93</td>
<td>1</td>
</tr>
<tr>
<td>Uncontrolled</td>
<td>24</td>
<td>8</td>
</tr>
</tbody>
</table>

It can be seen from Table 3 that the control structures had a significant effect on reducing the drain flow and subsequently the amount of salt removed from the drainage system. Total drained amounts and the volume of salt removed from the plots over two irrigation seasons is shown in Table 4. Salt volumes were calculated based on relationship of 1dS/m = 640mg/L (Tanji 1990) for the irrigation and drainage waters and salt content of the rainfall was taken as 6.9mg/L based on studies undertaken by Blackburn and McLeod (1983) in the Griffith area.
It can be seen that the free drainage plot (F) had significantly higher drainage and salt loads than the controlled drainage plots (C1 and C2). Drainage volumes measured during the experimental period were considerably lower than those typically found in subsurface drained fields in the area, due to significantly lower volumes of irrigation water applied to the vineyard than the area average. Previous monitoring of tile drainage systems in the area reported by Christen and Skehan (2001) and van der Lely (1993) measured drainage volumes between 14-22% of applied water. The large differences between these studies and results shown above were due firstly to irrigation volumes being considerably less in this study (<350 mm/year compared to 600 to 1000 mm/year for the previous studies and secondly infall during the experimental period (322 mm for 2001 and 208 mm for 2002) was well below average (396 mm). The lower irrigation volumes applied to the treatment were due to high costs of available irrigation water and low returns for the Cabernet Sauvignon wine grapes grown on the free drainage plot.

It can be clearly seen that controlled drainage was effective in increasing water table heights in the controlled drainage treatments and this reduction in drainage had the benefit of reducing disposal problems due to the decreased drainage volumes and subsequent lower salt loads. However, two issues need to be considered regarding the suitability of controlled drainage. Firstly, if controlled drainage management is to be successful then it relies on the crop being able to successfully use water from the water table to meet part of its evapotranspiration requirements, secondly, it can be seen from Table 4 that salt accumulation occurred in the controlled drainage treatments (only 5% of applied salt was removed). Therefore, the effects of controlled drainage on soil salinity levels need to be thoroughly investigated in order to assess the sustainability of the system.

### 3.4 Soil Salinity

Soil salinity was monitored over the experimental period using EM38 surveys, calibrated with soil coring undertaken at selected well positions. The ESAP software program (Lesch, Rhoades and Corwin, 2000) was then used to create spatial maps of soil salinity for the field. A general trend was observed over the entire field of increasing soil salinity. This can be attributed to the upflux of water from the groundwater table, which occurred to meet crop water demands.

Soil salinity increased in all layers, higher increases were observed in the upper soil layers, particularly in the 0-0.3m and 0.3-0.6m layers. While the increases in soil salinity did not reduce the measured vine yields, it is apparent that sustainability issues will need to be carefully considered when implementing controlled drainage. Both the free drainage and controlled drainage areas experienced an increase in soil salinity over the experimental period, due to the large irrigation deficits that were present, promoting capillary upflow from the water table.

Therefore, any implementation of strategies which aim to increase plant water use from a shallow groundwater source will need to carefully consider soil salinity increases and implement appropriate monitoring. While the increase in soil salinity is a drawback associated with controlled drainage, mitigation of its effects should be possible by implementing periods of leaching between periods of controlled drainage, e.g. allowing free drainage during the winter to allow leaching by rainfall, or allow free drainage during the first irrigation of the season.
4 CONCLUSIONS

- Water table regimes and subsequently drain flow characteristics are significantly changed under controlled drainage practices
- Controlled drainage has the potential to reduce drainage volumes and subsequently salt loads
- The potential for root zone salinization will be a major consideration when developing management practices to ensure the sustainability of controlled drainage. Careful monitoring and management will be required when implementing controlled drainage

5 ACKNOWLEDGEMENTS

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INTRODUCTION

In Central Asian Region (CAR) water is one of the most important factors defining the possibility for life and development in an arid zone.

New Independent States of CAR acquired independence in 1991, namely the Republic of Kazakhstan, Kyrgyz Republic, Republic of Tajikistan, Turkmenistan and Republic of Uzbekistan. General area of region territory is about 3882 thousand square kilometres with a population of more than 53 million people.

By the end of 19th century, there were some 7-8 million people in the region. Irrigated land amounted to about 3.4 million hectares and was equipped by an irrigation network. Today the region's population has increased seven-fold and irrigated areas have broadened twice – up to 7.5 – 7.7 million hectares.

Arid climate and irrigated nature use contribute to land and pasture land degradation, which leads to significant decrease of agricultural productiveness. Significant parts of irrigated areas are subject to salinization, which is 16% and above in Tajikistan, up to 30% in Kazakhstan and about 70% in Turkmenistan.

Therefore, today the decision of tasks in the field of melioration and obtaining the supplementary sources of irrigation water has great importance.

In every individual case, the possible complex of measures and their mutual combination must be defined in view of natural conditions, technical economic purpose orientation. Surface and underground water-carrying horizons, vertical drainage, open and closed horizontal drainage, ant-filtering covers, machine irrigation and biotechnical drainage should be used widely in the complex of engineering constructions and measures in irrigation-melioration building.

Often, while conducting meliorative hydrogeological works, the proper attention is not paid neither to water balance and the balance of territorial groundwater nor to possible changes in position of level and mineralization of groundwater. For irrigated lands, the main components of subterranean water balance are filtration loss of irrigation waters, total evaporation from the soil and artificial drainage throw of water.

THE STATE OF ARTIFICIAL DRAINAGE IN TAJIKISTAN

In Tajikistan, the underground waters for irrigated lands are spent mainly on natural and artificial drainage flow and the total evaporation from the ground surface. The very fact of evaporation from the ground surface is the cause of that there are still great
areas of salinized lands. At the first stage of developing the virgin lands with the shallow soil the main part of filtration losses is to fill up the volume (static) store of underground waters, thus causing the corresponding rise of their level.

The surface and underground waters in Tajikistan are characterized by the considerable variety in mineralization degree and chemical composition. The least mineralized groundwater is observed near the filtration river sites and irrigation canals. The most marked difference in chemical composition of republican irrigation waters is observed in chloral ion contents, on the base of which the evaluation of ground salinization degree is given for the areas with sulphate and sulphate chloride salinization.

It is possible to establish some laws in changing of mineralization and chemical composition of underground waters in quarter deposits on irrigated lands, taking into account the chemical composition of irrigation waters of Vakhsh River and river waters in Hissar Valley. Irrigation waters of Vakhsh River contain up to 0.1-0.15 g/L of chloral ion. As to river waters of Hissar Valley, its content decreases to 0.002-0.004 g/L. Compared to Vakhsh Valley the precipitation in Hissar Valley is 2-3 times higher, the total evaporation from the ground surface is some times lower, and groundwater running is higher.

It should be mentioned that in Tajikistan the land salinization does not result in falling of free soluble salts into solid sediment. This is explained by the fact that lands in Tajikistan, which are subject to salinization, are characterized by the running of groundwater. At the same time sulphate and other more hardly soluble salts fall into solid sediment, right up to forming the independent layers in soil grounds.

Lands, irrigated for the long time, are characterized also by comparatively broad development of ground salinization. The part of these lands in the republic is over 116,000 ha. This situation is caused by the scanty development of drainage or its neglected condition, and as well by the insufficient depth of horizontal drains. As to amelioration, the only thing is poor in conditions of two-tier geological structure of these lands the main part of salts is focused in the highest layer of soil grounds. At the same time limited salt store and broadly developed bedding pebbles, which easily absorb water, with fresh subterranean and forceful waters are potentially favourable factors for relatively fast ameliorative improvement of these lands, if vertical drainage is possible to apply.

In the republic, the average part of horizontal drainage is 20 m/ha. According to data, obtained from large-scale topography, the average part of lands with the depth of groundwater to 4 meters, when they my influence actively the ground surface, is about 37% of the total topographed area. About 60% out of them are salinized to a different degree, including 20% of greatly salinized lands. The total area of salinized lands correlates with the areas, where the groundwater (mineralization is over 2 g/L) lies in the depth of 2 m. The area of greatly salinized lands correlates with that, where mineralization of groundwater is over 5 g/L.

On lands, irrigated for a long time the maximum level is observed almost everywhere in August-September, irrespective of their geomorphologic geological structure. Minimum level is observed in February-March. This course in level regime of groundwater is caused by the corresponding consumption regime of river waters and water supply for irrigation. It disguises the role of the rest factors, on which the level regime depends, including such a great one as the total evaporation from the ground surface in the hot season of the year.

But the considerable change in level regime in future may occur on the land massifs, where vertical drainage will be applied. As a result of pumping out on vast territories, the level may be on the depth of not over 3-5 m, when its regime fluctuations have no ameliorative meaning.

Mineralization and chemical composition of subterranean and forceful waters on irrigated lands in Tajikistan are also subject to regime changes. According to year seasons, the most marked changes in this respect are observed on greatly salinized lands. There in the hot season of the year the groundwater of the surface shallow grounds with sharply increased mineralization is spent on the total evaporation from the ground surface, thus increasing temporarily the salt store in the soil grounds of aeration zone and on the land surface. The waters with lesser mineralization come to their place from the bedding pebbles. By the next
vegetation period the adverse effect takes place – salts dissolve in the groundwater due to precipitation.

Large-scale application of vertical drainage on salinized lands will cause the gradual freshening of groundwater in the surface shallow grounds. But in the upper horizon of bedding pebbles, through which primary initial store of salts will be pumped out, the gradual increase in forceful waters mineralization will be observed for a number of years until at least on-time change of initial water store takes place within the whole range of rocks, which participate in pumping out. In consequence, a gradual decrease mineralization of pumped out water may be observed. Finally, after corresponding stabilisation under new conditions, mineralization degree of groundwater will be defined by the difference between for the total evaporation from the ground surface and the total depth filtration water throw from the irrigation network into exploited water-carrying horizon.

Mineralization and chemical composition of forceful waters of the second, third and deeper horizons (100-150 m) under the influence of vertical drainage in the most upper one (the first) will not be subject to considerable changes. The water from these horizons, as the least subject to pollution, is worthwhile being used for centralised water supply.

The essential change in mineralization and chemical composition of groundwater should be expected on the developed virgin lands with thick surface shallow grounds. At the first stage of developing these lands the descending waters currents will wash the salts out of the upper layers and transmit them into deeper horizons. When at the next stage the level approaches the day surface, the groundwater may have already somewhat less mineralization than at the initial state. At this moment the artificial drainage must begin functioning, gradually throwing the water and salts out of irrigated lands. The drainage flowing may be up to 30-40% of the total water-intake into irrigation systems. Due to this correlation between water-intake and the surface throw of drainage and thrown waters, the groundwater, already suitable for irrigation, may gradually being formed in the zone of active influence of drainage.

Filtration coefficient of water-carrying pebbles changes from the tenth parts of meter up to many tens and more meters per day along the separate irrigation sites. According to data from the main part, on the main irrigation massifs the value of filtration coefficient varies from 10-20 up to 30-40 meters per day.

In the upper layer of the surface shallow grounds, which is 3-5 meters thick and functions more actively under horizontal drainage, the filtration coefficient in most cases is 0.1- 0.5 m/d.

The considerable area, where the strong pebbly water-carrying horizons are spread, gives an opportunity to create almost unlimited regulation capacity there. The preliminary cutting off the level of underground waters by 5-10 m and more may ensure the regulation capacity, which is sufficient in most cases for using the water-carrying pebbly horizons as underground reservoirs to regulate seasonally and for many years the flowing of that part of surface waters, which is not used yet.

Water-carrying horizons in pebbles are characterized by the high ability to absorb water, great area spreading and considerable total capacity (power). They give an opportunity to develop the broad network of highly productive chinks of vertical drainage and centralised water supply. Their debit may vary from tens up to 100-200 L/s and higher, and draining effect may reach many tens and hundreds hectares.

In irrigation sites, supplied with water and requiring ameliorative improvement of salinized lands, chinks in pebbles may ensure more economical decision of ameliorative task. The above-mentioned debit is possible in most cases, when the dynamic level decreases by 10-15 m and the depth of chinks is approximately 50-100 m.

Large diameters of drilling, simplifying the task of creating the powerful gravel-sand filter around chink strainer finally will reduce considerably the specific cost of pumped out underground water.
3 **CONCLUSIONS**

In agricultural experience as a result of not regulated water use the surface throw of water directly from the irrigated lands reaches more than 30% of the total water intake into irrigation systems.

Therefore, it is necessary, first of all, to regulate well the water use. Now the filtration coefficient (K₀) is often used for calculation of horizontal drains. In many cases, the filtration properties of watered soils are changed over the short distances horizontally and vertically from the thousandth parts of meter up to several meters per day. The capacity of water-carrying horizons reaches many tens and hundreds meters, and the flakiness of the last horizon impedes the vertical water exchange. It is almost impossible to give the filtration coefficient value with proper accuracy for these conditions with relatively limited number of initial parameters.

Usually only the initial mineralization of groundwater in the upper part of water-carrying horizon is taken as a principle in project studies, aimed to change the existing meliorative and hydrogeological situation. The dynamic process of groundwater mineralization and, as the main thing, the possibility of managing them are not taken into account. By this approach it is possible to cause the land salinization in the near future, having at first fresh water and applying non-washing irrigation regime.

Critical correlations between bed depth and mineralization of groundwater for project conditions should be defined in view of other factors. First of all the project depth down to groundwater should be defined, which will define in its turn both the permissible degree of mineralization and necessary rate for prophylactic washing. Finally, the economical technical equipment for decreasing the level of groundwater should be taken into consideration, as it is limited for horizontal drainage.

Development of salinized lands with groundwater bedded in not deeply is usually carried out in complex with general washing and artificial drainage. Project washing water is defined usually by simple multiplication of total saline store, which is to be removed out of root stratum, to specific water consumption. This rate is sufficient only for regular water distribution over the area. If the water distribution over the area is not regular, the main water mass is filtered near the drains. As a result of it, the main part of the land remains unwashed. In this case, the potential of the permanent network, which is to support the level of groundwater at the depth of 1-2 m, should be taken into account. But it is possible enough, while washing, to close the groundwater with the surface washing waters. This leads both to decreasing manifold the productivity of drains and using the regulating capacity of soils in aeration zone and the time factors.

4 **List of ABBREVIATIONS**

- Hectare, ha
- Filtration coefficient, K₀

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CONTROLLED DRAINAGE FOR INTEGRATED WATER MANAGEMENT

W. F. Vlotman and H. C. Jansen

ABSTRACT

Controlled drainage is an essential component of Integrated Water Resource Management (IWRM) and Water Demand Management (WDM). Controlled drainage can play an important role to save water and nutrients and to improve and optimise downstream water availability and quality. Examples of controlled drainage practices in the Netherlands, USA, Egypt and brief references to work in other countries are given. Shifts in priorities of different aspects of water management take place. These shifts in paradigms to “do not drain unless absolutely necessary”, controlled drainage, and “give room to flood waters” (controlled flooding) are described. In the Netherlands, the new water management tool Waternood emphasises the relation between land functions and water management and aims at managing conflicting objectives. The impact of agricultural water management on nature and the use of Best Management Principles (BMP) to control downstream impacts are described. In the USA, sub-irrigation is also a component of BMP and controlled drainage. The options, advantages and constraints of controlled drainage are given, while on-going activities in the field are presented.

Keywords: Controlled Drainage, Best Management Principles, BMP, Integrated Water Management, Water Exploitation Index, WEI, EU Water Framework Directive. European Environmental Agency, EEA.

1 INTRODUCTION

Controlled drainage has been practiced for many years, but may not always have been referred to as “controlled drainage”. It is the principle of restricting free flow from drains, such that they only discharge when it is necessary, based on pre-determined water management criteria. In temperate climates drainage is primarily a function of rainfall, while in arid and semi-arid climates drainage is a function of irrigation and (monsoon) rainfall. Controlled drainage applies to both surface and subsurface drainage. On a larger scale (river basins) flood control is also an essential aspect of drainage. In dry years we often wish we had not drained so efficiently. Recently also the water requirements of nature, both in quantity and quality have become focus of attention. UNESCO and FAO are much concerned about a looming water crisis. Is there one or not? This and the role of drainage for Integrated Water Resources Management will be described in this paper.

1.1 Agricultural production and drainage

Good water management in the broadest sense is critical for the global food production. A well-designed drainage system is often a necessary component of the overall water management system, which enhances agricultural production and leads to reduction of negative environmental impacts. Drainage systems are applied in 15% of the world agricultural lands. Forty percent (40%) of the world food production is achieved in irrigated areas and in about a quarter of these areas man-made drainage has been installed. Irrigated crop production needs to increase by more than 80% by 2030 to meet future demand of food in developing countries (Fresco 2002). This cannot be met by an increase of 80% in the water supply, and hence other methodologies such as (genetic) improvements of crops, and more efficient water use (more crop per drop), will have to be developed. Sixty percent (60%) of the food production takes place in rain fed areas. In order to supply the increasing world population, increase of food production needs to be achieved primarily on the existing agricultural lands. Currently agriculture takes a share of about 70-80% of global freshwater use. Due to increased pressure on the (scarce) water resources, other potential users will critically consider this large share of water used by the agricultural sector. It is estimated that only 12% more water can be made available by 2030 (Fresco 2002). New and innovative water management tools offer considerable scope for the reduction of water use in agriculture. Integrated water management as mentioned in the Fourth National Policy Document on Water Management of the Netherlands, as well as, in numerous other international water policy documents, is aimed at balancing human, agricultural, environmental and industrial needs, and has, therefore, a wide scope of applicability in the world.

Controlled drainage or sub irrigation through sub-surface drains has been advocated for many years in North America. Yet, design criteria or guidelines are scant. The ASA Agricultural Drainage Monograph, devotes various chapters to water table management and controlled drainage, but limits the descriptions to general considerations. Although the text gives a very thorough description of the topic, emphasis is
on computer modelling and few practical experiences are reported. Most other literature also assumes sizeable farms, sizeable drainage and irrigation systems, and seems to ignore the needs of small farmers in developing countries and the potential role of water user groups in the planning, design and management of controlled drainage. Anticipated or actual water shortages in irrigated areas, or regions with a rainfall deficit, can be a major incentive for farmers and policy makers/executives to apply or stimulate controlled drainage. Unfortunately most existing drainage and irrigation systems are not designed for integrated management of irrigation and drainage waters. Drainage systems should be designed and built with additional water table control options built-in. This should already be planned during design stages of the irrigation or the drainage system. Practical drainage operation guidelines for small farmers in developing countries are required.

1.2 Water Scarcity, Water Savings, and Water Exploitation Index

Integrated Water Resources Management (IWRM) is a process that promotes the coordinated development and management of water, land and related resources, to maximise economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Drainage is a vital link in water management to secure adequate food production for the anticipated growth in world population.

In Europe and the Netherlands the concept of Water Demand Management (WDM) is often used, referring to managing the water demands for agriculture, industry, urban areas, households and tourism. Water demand management generally refers to initiatives aiming at satisfying existing needs for water with fewer resources (more efficient water use). The European Environmental Agency defines water demand management as the implementation of policies or measures, which serve to control or influence the amount of water used (EEA 2001). Water demand management seeks the right balance between the demand- and supply-side options (EEA 1999).

Although drinking water is a ready to use product and may be costly to produce if extensive treatment is required, leakage reduction is not always economically viable (EEA 2001). Guidelines for the state of water losses/efficiencies are shown in Table 1. Typical domestic use in Europe based on the UK, Finland, Switzerland (EEA 2001) and the Netherlands (Brouwer 2000) is shown in Figure 1. Water use for human consumption is surprisingly low. Research and development in the urban water use appliances has led to substantial reduction of water use by washing machines in Europe (Figure 2). Similar achievements with toilet flushing systems are reported. Efficiencies in agricultural water use (Figure 3) show that there may be ample scope for improvement of water use efficiency in the agricultural settings. It is expected that a major portion of the increase in water use will occur in urban areas (Figure 4).

Table 1  Benchmarks for drinking water distribution efficiency.

<table>
<thead>
<tr>
<th>Type of network</th>
<th>Bad (%)</th>
<th>Insufficient (%)</th>
<th>Average (%)</th>
<th>Good (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>&lt; 60</td>
<td>60 – 75</td>
<td>75 – 85</td>
<td>&gt; 85</td>
</tr>
<tr>
<td>Intermediate</td>
<td>&lt; 55</td>
<td>55 – 70</td>
<td>70 – 80</td>
<td>&gt; 80</td>
</tr>
<tr>
<td>Rural</td>
<td>&lt; 50</td>
<td>50 – 65</td>
<td>65 – 75</td>
<td>&gt; 75</td>
</tr>
</tbody>
</table>
A major development in IWRM and WDM is the awareness that the environment is not just another water user, which needs to be given its fair share. Much more, ecologically sound water systems are now considered essential for the survival of the very resource: without them there will soon be not enough water to satisfy the demands of all users. Within the agricultural context, there is another aspect that needs to be considered: the sustainability of the land resource. Drainage plays an essential role in reducing and managing waterlogging and salinity, thereby avoiding the degradation of the production potential of the land resource. Controlling drainage and thereby controlling water quality and quantity is essential for sound environmental management and crop production. Recently drainage has become an integral part of Best Management Practices (BMP), which aims at minimizing agricultural inputs to control environmental impact beyond the point of application and yet achieving optimal crop production.

In addition, the pressure on water systems is continuously increasing and the allocation of the scarce resource becomes more and more subject to priorities that need to be balanced. Often, more interests than (traditionally) agriculture put a claim on the water. Water management has thus become more politicised and more comprehensive, including water quality, groundwater and, sometimes, soil moisture.

Progress is being made in improving the quality and quantity of Europe’s water resources, particularly in the European Union. Much of this improvement has been made through measures aimed at reducing the pressures on Europe’s water from households and industry, often introduced through European policy initiatives. However, many of Europe’s groundwater bodies, rivers, lakes, estuaries, and coastal and marine waters are still significantly impacted by human activities. For example, pollutant
concentrations remain above, and water levels below, natural or sustainable levels. In many parts of Europe this leads to a degradation of aquatic ecosystems and dependent terrestrial ecosystems such as wetlands, and to drinking and bathing water that sometimes does not comply with human health standards.

The EU water framework directive represents a major advance in European policy with the concepts of ecological status and water management at the river basin level being included in a legislative framework for the first time. Ecological status must include an assessment of the biological communities, habitat and hydrological characteristics of water bodies as well as the traditional physic-chemical determinants. For the first time, measures will have to be targeted at maintaining sustainable water levels and flows and at maintaining and restoring riparian habitats. To quantify the needs of water for all the EEA (2003) uses the Water Exploitation Index (WEI). The WEI in a country is the average annual total abstraction of freshwater divided by the long-term average fresh water resources. It gives an indication of how the total water demand puts pressure on the water resource. The WEI identifies those countries that have high demand in relation to their resources and therefore are prone to suffer problems of water stress. It should be underlined that it is an indicator of the average water stress in a country and thus can hide considerable regional differences within a country.

A total of 20 countries (50 % of Europe’s population) can be considered as non-stressed (Figure 5), mainly situated in central and northern Europe. Nine countries can be considered as having low water stress (32 % of Europe’s population). These include Romania, Belgium, Denmark and southern countries (Greece, Turkey and Portugal). Finally, there are four countries (Cyprus, Malta, Italy and Spain), which are considered to be water stressed (18 % of population in the study region). Water stressed countries can face the problem of groundwater over-abstractions and resulting water table depletion and salt-water intrusion in coastal aquifers.

A major new component in the water balance identified by EEA (2003) is the use of water for energy cooling. This water is extracted temporarily from the system and returned at a higher temperature for use downstream. During exceptionally warm seasons, e.g. the summer of 2003, power plants have difficulties in maintaining the temperature of the disposal water below the maximum temperatures prescribed by EU Directives. Not enough cooling water was available and energy production had to be reduced in order to not affect aquatic life in the already much warmer surface waters.

2 WATER TABLE CONTROL IN THE NETHERLANDS

For hundreds of years the Dutch Water Boards, Provinces and Municipalities were principally responsible for flood control, drainage and creating liveable conditions in the country. It was only in the past two decades that water quality became an important issue in water
management. The deteriorating surface water quality was imposing a threat not only to public health but also to wildlife habitats. Since the late nineteen sixties, the problem of surface water pollution was systematically dealt with. Besides Water Boards, now also Sewage Water Treatments Boards were established that were principally responsible for the purification of water. This meant that quantitative and qualitative water management were addressed by different organisations.

Figure 5  Water exploitation index (WEI) across Europe (EEA 2003).

In the mid-nineteen eighties, there was a growing awareness that public (water) safety and optimal living conditions could not be viewed in isolation from that of healthy and sustainable water systems and that an integrated approach in water management would be more effective, which would then also include other relevant areas of policy.

An additional factor that started becoming an important consideration was the drying out of topographically higher (light textured) soils, primarily affecting natural areas. The area affected by this drying out was approximately 5000 km² or about 1/8th of the Netherlands. Although the rivers entering the Netherlands have ample fresh water supplies and there is no shortage of drainage water (generally), importing water in natural habitats proved to be not appropriate due to differences in the chemical composition of the water. The most valuable ecosystems depend on clean (nutrient free) water from (deep) ground water systems, while surface water is often nutrient rich. Hence water needed to be conserved and managed in the area itself. For this purpose controlled drainage amongst and other measures were introduced.

Another trend emerging was to not separate surface water and ground water in water management, and to also consider functionality of the area (nature reserve, industrial, urban, etc). This is described as the area function in the Netherlands. Water Boards were primarily responsible for surface waters and they now also have to deal with ground water, both quantity and quality. The water system became an important concept in regional planning. The water system is the starting point for operational water management.
In 1998, the Dutch national Union of Water Boards, together with the Government Service for Land and Water Management (DLG) decided to develop and apply a common methodology for the design of water management infrastructure and measures to implement regional water management. This methodology is referred to as “Waternood” (see Box 1). Waternood is not so much concerned about design criteria or specific safety features but considers the most appropriate water regime during the year in an area as function of its land use and soil. Regimes are determined for appropriate water management units.

Box 1 Some Dutch expressions and translations

2.1 Optimum and target ground- and surface water regime

Waternood aims at identifying the various area functions and soil types within a water management unit. For each combination (of area function and soil), the optimum hydrological regime is determined. This regime is referred to as “Optimum Ground- and Surface Water Regime”. Given the usual spatial variability of area functions and soils, the optimum ground- and surface water regime will vary within each water management unit.

This optimum ground- and surface water regime will, generally, not concur with the actual ground- and surface water regime. By means of an appraisal procedure (Figure 6), the desired or target ground- and surface water regime is determined.

Drainage systems are, generally, one of the most determining factors in terms of water table control and impacts on the groundwater regime. In the past, (rural) drainage systems were principally aimed at the optimum groundwater regime (soil moisture conditions) for agriculture. The target (ground) water regimes are, however, the result of a much broader appraisal of area functions. The management of existing drainage systems should, therefore, be adapted accordingly, and remodelling of drainage infrastructure may be required. Being such a determining factor for the water regime, existing and future drainage systems should be (re)designed as “controlled drainage systems”, which can serve as effective tools to establish and maintain target ground- and surface water regimes and allow for active intervention in water management.

2.2 Implementation of water management tool

The methodology, aimed at determining, establishing and sustaining target ground- and surface water regimes, does not only require other concepts of thinking on water management, but also more knowledge of the respective areas, geo-historical information and knowledge of the evaluation methods. For these reasons, a research programme has been implemented to provide the tools to determine the target ground- and surface water regime for a given area and to assist in the development and management of the water systems. The research programme will be concluded in 2002. Box 2 presents the various research topics. The result of the individual research activities will be disseminated as guidelines and computer applications. The research results will be integrated into the Waternood “tool”, which includes a computer application running in a GIS environment.
To judge whether a system has been optimised according the process depicted in Figure 6 the following criteria are used for each unit (Prak 2002, Figure 7):

A  Optimal sustainable functionality in 90 – 95% of the area
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B Acceptable but not optimal in 75 – 90% of the area (e.g. on average somewhat too wet or too dry);
C Not acceptable (and therefore not sustainable) situation in less than 75% of the area.

The objectives are to balance agricultural, nature and flood control needs and balance the expected damage (weighing of different damage functions). Note that in this process no mention is made of the water level because some need it dry, others wet. Yet, the water level in time and space determines in which class the area will fall as far as compliance with the objective functions of the area (Figure 7).

In time the water table may fluctuate as shown in Figure 7 but the optimal water level may not be the same in each period. Figure 7 shows typically a present state, where optimal ground water regimes have been determined, the actual ground (and surface) water is know, and where through appropriate measures the optimal ground water regime needs to be achieved as closely as possible. Hence, in the same area, the class allocation can differ. Details of this elaborate assessment system are not yet published, but are expected towards the end of 2002.

Box 2 Research topics of Waternood

2.3 Drainage

As drainage determines to a large extent the groundwater conditions, special attention should be paid to the proper quantification of the relationship between drainage systems and the groundwater regime.

One of the topics of the research programme is the relation between groundwater and surface water. This relationship is described with the concept of drainage resistance, assuming linear relationships between groundwater levels and surface water discharge. This concept does not make a distinction between natural and man-made drainage and also does not provide (direct) design guidelines. However, links with design aspects of main watercourses (geometry) have also been investigated.

The research programme assists in the quantification of the drainage resistances of existing systems, for various conditions, and impacts of future scenarios. Additional investigations are required to establish the relationship between a future “target” drainage resistance and the actual design of a (controlled) drainage system, which would incorporate the layout, drain depth, spacing, diameter or perimeter, structures, etc. In the case that (some of) the above-described water management practises be followed in countries or areas where new drainage systems are to be implemented, this is a possible research topic for Alterra-ILRI.

Methods to quantify surface water discharges as a function of the groundwater levels are based on existing data (principally a statistical analysis) or area information. For this purpose a GIS environment is used. The methodology developed allows for the calculation of drainage resistances for various groundwater depth intervals (classes, see Figure 7). Also lumped values can be calculated (for a certain “homogeneous sub-area”). This results in the spatially variable characterisation of drainage systems. Once the drainage resistances have
been quantified, various water management scenarios can be evaluated.

### 2.4 The role of controlled drainage

Controlled drainage is, often, an important water management tool for existing water systems. Design and operational parameters of controlled drainage refer both to infrastructure as well as to operational practices. For example, decisions must be made on the locations, sizes and type(s) of weirs, the weir levels and weir operation (incorporating seasonal target levels, response policies to rainfall events, dry periods, pollution loads, etc.). Discharge control infrastructure (such as drain outlets) and its operation should also be taken into account. Thereupon an assessment must be made of the intended measures, in terms of the expected ground- and surface water regime.

The assessment should address groundwater levels and soil water contents (both a function of time and space), as well as quality aspects such as the composition of the ground- and surface water, the discharge of nutrients, salts and pesticides from the land, etc. With the terrestrial nature and function appraisal, the agricultural yield reductions and information from the aquatic ecology, it should be assessed whether the expected ground- and surface water regime represents the optimum for the distinctive area functions. Should this not be the case, modified measures should be evaluated, etc, until the required ground- and surface water regime is established.

### 2.5 Area functions and required water management

The optimum ground- and surface water regime for agricultural area functions is, generally, much better known than for nature or specific ecological functions. The research programme, therefore, also includes the requirements in terms of the hydrological regime for (terrestrial) nature.

Although the research is aimed at The Netherlands, the methodology may also be applied in other countries. It is also noted, that in various countries, for example South Africa, valuable information on water quality requirements of aquatic ecosystems has already been investigated and is applied in operational water management (DWAF 1996).

### 2.6 Appraisal of area functions

The target ground- and surface water regime must be determined from the optimum ground- and surface water regimes with respect to each area function. In conflicting situations, a balancing of interests is required. As the required water regimes for the distinctive area functions are often conflicting (for example agriculture and wetlands), a scientifically robust assessment and optimisation method should be used. Such a methodology, in which the various requirements are appraised and balanced, is currently being developed.

### 2.7 Determination of adverse impacts on agriculture

As the target ground- and surface water regime for any area function may deviate from the optimum hydrological regime, the negative impacts should be quantified (Figure 6). This will allow for the allocation of any indemnities to affected parties. In The Netherlands, existing relationships between crop growth reductions and excessive or deficient soil water conditions are being (re)evaluated and incorporated in a GIS environment. The relationship between the crop yield and water regime are usually described by (Van Bakel and Huygen, 2001):

1. the yield versus groundwater depth relationships;
2. the HELP-method;
3. the SOW method;
4. the Regime curve method;
5. the Water table versus time method; and,
6. deterministic methods.

The first method was developed in the nineteen fifties, but can still be used. Limitations are that trafficability and other operational aspects were not included. The method evaluates both wet and dry conditions.

The HELP-method uses soil types and groundwater depth classes. For 70 soil types the yield reductions due to excessive and deficient soil water conditions can be assessed for grass and other cropland. The method is currently adapted and incorporated in the Waternood tool. As groundwater depth classes refer to an average situation, no information can be obtained on yield reductions in specific (or extreme) years or the period in the year in which the reduction occurs. In addition, the assessment of damage due to wet conditions is often tentative.

The SOW-method uses the concepts “Sum of Excessive Water” and “Sum of Deficient Water”. This method compares the actual
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groundwater tables with the critical groundwater tables for excessive and deficient soil water conditions. The groundwater regime should, therefore, be known, as well as relations between SOW and actual damage (yield reductions). The SOW-method allows for the evaluation of individual years and periods within a year. A disadvantage is that critical groundwater depths and damage coefficients are only known for a few soil types. In the USA an approached based on the original SOW of the Netherlands is used and referred to as SEW30 (Sum of Excess Water, Skaggs and van Schilfgaarde, 1999). The 30 denotes the target water table depth below the surface and can be any depth.

The regime curve method calculates the average groundwater tables (regime) during the year. The method requires at least 8 measurements per monitoring date (hence at least 8 years of monitoring). Reliability intervals of the groundwater regime are then calculated. For various periods during the year, critical groundwater tables for excessive and deficient soil water conditions can be defined. The method allows for the assessment of the probability of damage.

The "Water table versus time" and deterministic methods are under development not yet operational in The Netherlands.

The data acquired in The Netherlands is, most probably, not applicable abroad, given the specific climatic condition, soil characteristics and groundwater monitoring/evaluation practises. The developed methodologies of assessment may, however, be used and applied. In principle, similar relationships of adverse impacts should be determined for other area functions, but these data is much scarcer.

2.8 Monitoring

Integrated water management requires effective monitoring, in order to investigate and characterise the hydrological systems, to collect data necessary for the daily operations and to evaluate plans and measures. Guidelines to set up monitoring systems for water management have been developed in The Netherlands and can, most probably, be applied abroad (possibly with some minor adaptations). The monitoring system should prescribe the parameters to be monitored (qualitative and quantitative), locations, frequencies and data processing. In the case of controlled drainage systems specific performance monitoring may also need to be included.

3 WATER TABLE CONTROL AND BEST MANAGEMENT PRACTICES IN THE USA

The prime reasons for water table management from a drainage perspective is the removal of excess water to permit farming on poorly drained soils. This includes improving trafficability during certain times of the growing season (especially planting and harvesting time). Salinity control is another typical drainage objective. In irrigated areas, the amount of irrigation is of paramount importance for control of salinity in the root zone. This is slightly different in coastal zones, where salinity is caused by seepage/intrusion of seawater.

An extension of controlled drainage is the use of the drainage system for sub-irrigation. This was first reported in 1956 when experiences with sub-irrigation in California, Idaho, Utah and Colorado were described (Skaggs, 1999). The drainage system water level is controlled by a weir or gate. Water may be pumped into the drainage system through the manholes or in the open drain beyond the subsurface outlet. The...
weir that controls the water level is usually in the open drain. Early experiences with sub-irrigation are on the lighter textured soils. It was found that sub-irrigation requires only 5 – 25% of the energy required by sprinkler irrigation. Actual water savings have not been reported, as they vary widely based on the sophistication of local water management practices. Skaggs (1999) gives a thorough review of the state of the art of sub-irrigation in the US, while Fouss et al. (1999a&b) also describe the design and operational features and facilities required for water table management. Controlled drainage and sub-irrigation are seen as integrated water table management in the USA. Approximately 10% of cropland in the USA that has potential for controlled drainage is actually provided with a water table management system.

Controlled drainage is also applied at watershed scale, and this involves allowing drainage from the upper reaches of the watershed to supply the lower part of the watershed (Parsons et al. 1991 in Skaggs 1999). It has, in many cases, greater potential than it does on a field scale (Evans et al. 1992). In areas where deep drainage outlets have been constructed to provide drainage to the lowest elevations in the watershed, excessive drainage (or over drainage) of the higher elevation areas is typically the result. Over drainage frequently occurs in soils with higher permeability and low water holding capacity. In the Netherlands the drying out of forest and nature areas in the topographically higher portions of the Netherlands is also a typical example of this.

Another interesting development of controlled drainage, which applies both to field level and watershed level is the reuse of drainage water in a serial fashion. This practice is relatively advanced in the USA (FAO 1996) and Australia (Christen 2001) and was recently further discussed under the topic Bio-Drainage at the 8th International Drainage Workshop in New Delhi, India (ICID 2000).

Controlled drainage has been applied to conserve water and increase crop yield. It is also effective in reducing losses of plant nutrients and other pollutants to surface waters. It is currently promoted for the latter, in nutrient sensitive coastal areas. It is essential in the prevention of blue-green algae blooms in the USA (Evans et al. 1996) and Australia in the Murray Darling basin (MDBC 1995). Historically it is also used to control subsidence in peat (organic) soils, such as the Everglades in Florida, Western Johor in Malaysia, Indonesia and the Netherlands. Controlled drainage allows management of deficit and excessive soil water stress, and allows tillage and other field operations. Besides all the advantage some disadvantages need to be considered as well. These potentially are: deterioration of soil structure around pipe drains due to long submergence; biological clogging, ochre formation in iron laden waters, and sloughing of ditch banks.

Controlled drainage is considered one of the components of Best Management Practices (BMP) in the USA (Evans et al. 1996). Turning point in many of the measures that stimulate BMP is the 1985 Food Security Act that imposes considerable restrictions on land development and drainage. This Act seemed to have had similar effects on surface water quality as the 1970 Pollution of Surface Water Act (de Jong 2001) in the Netherlands had, which stimulated a major clean up of the water quality of surface waters. BMPs as promoted by the 1985 Act typically benefit the environment only. Controlled drainage was proven to benefit both agriculture and the environment. Since Controlled drainage, as part of Water Table Management was designated as a BMP it qualified for state and federal support, and in July 1989, more than 2 500 control structures have been installed in North Caroline alone (Evans et al. 1996). For BMP in Australia see Christen and Ayers (2001).

4 CONTROLLED DRAINAGE IN EGYPT

Water scarcity will become a major concern in the first half of the 21st century in Egypt. Already during the early eighties the Drainage Research Institute (DRI) in El Kanater, Egypt, introduced modified drainage for rice areas in the Nile Delta (Box 3). This meant that sections of the drainage system (3 – 20 ha) could be closed during the rice season. Water savings of up to 50% were possible depending on local conditions. Farmers saved considerable time irrigating (at least one irrigation less of a total of 4 – 5 per rice growing season). Direct pumping costs were reduced by as much as 43% of total seasonal pumping costs (DRP/DRI 2001). The farmers recovered investment in control structures in the subsurface drainage system in one to two seasons. The approach requires crop consolidation in the sub-catchments of the drainage system, adjustments in the traditional drainage design (more sub-collectors), willingness of farmers to consolidate, and passing on of the savings to the farmers by water user associations. In 1995 DRI re-introduced modified drainage as controlled drainage, through traditional field trials, new Participatory Rural Appraisal techniques, and by advertising the opportunities with all stakeholders. Controlled drainage is not only important to reduce water use during the rice-growing season, but will become an essential water management tool during water scarce situations for all crops.
Box 3  From modified drainage to controlled drainage in Egypt.

The principle of the system is shown in Figure 8. By providing subsurface sub-collectors and connecting these via manholes, and fitting the outlets in the manhole with simple locally produced gates, it is possible to drain the field with a non-rice crop and stopping discharge from the field with rice. The method requires more drainpipes, and it was calculated that the construction costs of a system with additional sub-collectors, manholes etc. would cost 16 - 25% more per hectare. Although this is a substantial increase, it actually only increased the cost component of the farmers seasonal budget by 5 – 10%. No detailed calculations of cost recovery of a system constructed completely as a controlled drainage system have been made yet, but the costs of installing gates in existing systems was recovered in one to two seasons. For primarily maintenance reasons, and reducing risk of area affected when a collector fails, the present Egyptian subsurface drainage systems has sub-collectors in about 16% of the area which can be used for the system described before. Except for the experimental areas of DRI none are equipped with gates. The typical area served by sub-collectors is between 10 and 40 feddans (approx. 4 – 17 ha).

Figure 8  The principle of modified drainage system design (DRP/DRI 2001).
Controlled drainage is a best management practice, which can only be achieved by appropriate planning, design and operation of the water conveyance systems and appurtenant structures. The management component is: drain only when there is a direct (and immediate) benefit, otherwisestore the water. This applies both to surface drainage (rivers, canals, main drains, field drains) and subsurface systems (tubewells, subsurface perforated plastic pipes, vertical wick drains). The objectives of controlled drainage are:

1. Achieving optimum production conditions (water table and salinity (leaching) control, trafficability) at minimum costs (irrigation, input of fertilisers);
2. Obtaining optimum water quality and quantity downstream (control of transport of salts and other solutes, such as nitrogen and phosphorus by drainage water).

Human activities that cause in-balances in the natural water resources are:

1. Damming of rivers and streams
2. Discharge of municipal, industrial waste directly into rivers, streams, estuaries
3. Urban and rural development resulting in more intense storm water runoff that may carry nutrients, suspended solids, etc.
4. Artificial drainage to promote agriculture and forestry
5. Introduction of nutrients from agricultural fertilisation, from live-stock and domestic waste
6. Alteration or conversion of wetlands to other uses such as agriculture, rural and urban development, recreation, and tourism.

In the previous sections the role and practice of controlled drainage in Integrated Water Resources Management has been sketched using experiences from the Netherlands, North America, Egypt and Australia. This does not mean that there are no experiences elsewhere with controlled drainage. On the contrary, the literature describes cases in Sweden, Pakistan, etc. As these cannot all be described here, they will receive attention in a more elaborate report of research carried out by ILRI (see www.ilri.nl/research). Nevertheless, some preliminary guidelines can be gleaned from the foregoing.

5.1 Layout

Controlled drainage requires an entirely different layout of water management than traditional systems. The design engineer should consider reuse and disposal of drainage water in a manner that is convenient and attractive to farmers and other users. Administrative, hydrological and physical boundaries should all be considered. It is not necessary that water be disposed off in the lowest part of the area, even though there were compelling technical and economical reasons to do so in the past. New, mostly environmental considerations have put additional value to clean water and therefore more expensive designs have to be considered (e.g. the modified drainage system for rice in Egypt).

5.2 Design and management

Irrigation and drainage should be considered in an integrated way, with major attention to water quality. Downstream users, either agricultural, industrial, domestic or ecological, require certain water qualities, which with forethought of planners and designers can be achieved by managing the water in a more appropriate way. Serial biological reuse is one of the options open to designers. For this, appropriate new control structures in the drainage system are necessary, and many are already available, both for surface systems and subsurface systems (Fouss et al. 1999a&b). Sub-irrigation has been a common practice for quite some time in the USA and in the Netherlands many of the surface drains and structures can work in either drainage or water supply mode.

A balance needs to be achieved by draining adequately to allow aeration of crops and to obtain good trafficability in the field when required, and at the same time using the soil as a water storage reservoir to the maximum extent possible. The latter is to prevent drying out of topographically high areas (typical for humid areas with rainfall deficit during part of the season) and to keep as much as possible water at location for possible contribution to the crop water requirement (typical for irrigated areas in the arid and semi-arid regions). In the case of flower bulb production this control requires accuracy of centimetres, for grassland in the Netherlands tens of centimetres, while for other crops, and other conditions (climate and elevation differences) less accuracy is required. In all cases a balance between function of the area and water table regimes needs to be achieved and new developments in the Netherlands with the Watermood programme perhaps point the way for other regions as well. The same balances and principles of water quantity and quality apply to wetlands, peat lands and nature reservations (protectorates; think of the Ramsar Convention sites).

Flood protection is critical, but room for water, such as the water policies in the Netherlands prescribe, requires different approaches to design. Whereas in the past design of flood plains was a given, with the intent to give room for water, most of these have been lost due to...
(illegal) construction of houses and industries. Value of property has increased many folds in the last decades (Schultz 2001), and economic balances and financial considerations have resulted in other priorities and policies. In the Netherlands this has lead to the situation that calamity polders are being considered (rather than using flood plains appropriately). Calamity polders are areas (polders) with relatively low property value and thus minimal economic loss during short periods of controlled flooding. In the USA similar experiences with loss of flood plains have also resulted in serious flooding problems during the last decade. Loss of flood plains is not the only reasons for the flooding, but it is significant.

5.3 Monitoring and Evaluation
Better monitoring and evaluation of the actual water management situation is pre-requisite for the intended sustainable integrated water resources management. Many automated measurement systems are available and are being developed for just this purpose. GIS is applied for example in the flood prediction system POLDEVC (van der Meulen 2002). Yet systems do not have to be sophisticated to be able to manage the ground water level as is shown in Australia, where farmers have developed a simple but effective water monitoring tool. Flow measurement in subsurface drainage systems takes some more original thinking but many new systems have and are being developed (Fouss et al. 1999b).

6 CONCLUDING REMARKS
Controlled drainage is an important component in Integrated Water Resources Management and Best Management Practices. The traditional role of drainage is still important, but additional objectives need to be considered in the planning, design and management process, as a distinct change in the paradigm of drainage has taken place: from (free) draining and keeping your feet dry (prevention of flooding) to preservation, storage, and multiple reuse of drainage water.

Drainage systems should not be designed anymore without considerable thought to controlling the drainage, both in quantity and quality. Existing drainage systems should be modified to become water management control systems. If appropriately designed, farmers themselves can exercise this control. There is a major role for policy makers and governments (through Water Boards for instance) to also stimulate control at watershed level.

Controlled drainage has the following benefits: it reduces water need at field level, it helps storing water in the soil profile, and it reduces solute loads on downstream surface waters. The application of controlled drainage can lead to an increase of areas with deteriorated soil structure around drain pipes, with biological and chemical clogged subsurface drains (under certain conditions), and to additional stretches sloughing of canal/ditch banks due to rapid changes in water level in open drains. These problems however also experienced with traditional drainage systems.

An aspect that is, generally, not mentioned in literature is the potential health hazard. Whereas, the first three effects are highly localised, and can be effectively dealt with locally, the effect on health, requires more investigation. In the past, drainage of wet areas contributed to the control of water-borne diseases, such as malaria and bilharzia (through the elimination of mosquito and bilharzia breeding grounds). The creation of wetlands and acceptance of higher water tables may lead to wet spots again, that encourage propagation of less desirable organism.

Controlled drainage can improve downstream water quality and quantity. It also may result that less irrigation water is needed, hence less diversion at the head of branch irrigation canals and more (fresh) water in the primary distribution system. With less irrigation water, also smaller amounts of solutes are leached from the fields, resulting in a decrease of the load of solutes to downstream areas. As a result, more water of better quality is available for downstream users. Serial reuse systems can also contribute to the increased availability of fresh water. However, still little is known on the management of the "end products" such as extremely poor quality water, marginal agricultural products (halophytes, Eucalyptus wood, etc.), and possibly contaminated salts.

Another aspect, advocated in different settings before, is that local control of drainage concentrates pollution at the source, and, the polluter pays!

And so we have a new paradigm for drainage design and an additional paradigm for IWRM: controlled drainage; do not drain unless absolutely necessary and give room to flood waters allowing nature to take it fair share of (good quality) water and space.
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[5] In the Netherlands it is customary to distinguish grassland or pastures as a separate main crop in many technical statistical and economic analyses. All other crops are then taken together under cropland (“bouwland” in Dutch).
WATER TABLE MANAGEMENT STRATEGIES FOR IRRIGATION WATER SAVING

M.A.S. Wahba[2], M.A. EL-Ganainy[3], and M. H. Amer[4]

ABSTRACT

Today, the world and especially the development countries are facing the challenges of providing water and food for the expanding population. These challenges necessitate reducing the losses of irrigation water and optimising the use of each drop of water to maximise the agriculture production. In order to select the best water table management strategy among different strategies under the conditions of Western Delta of Egypt, the water table management problem is formulated in a multi-criteria context, 13 alternative strategies have been selected and evaluated by 9 criteria. The impact assessments of each alternative with respect to each criterion are estimated. The selected WTM alternative strategies have been evaluated using a multi-criteria decision analysis model called Multi Deci Mode and four different weights for criteria have been applied using four multi criteria analysis techniques. The results of evaluating the different water table management strategies indicate that by increasing the spacing between drains to 2 times the design spacing and applying the controlled drainage (CD) at depth 60 cm at the beginning of the growing season and switching to the free drainage (FD) during the rest of the growing season we can save about 20% of irrigation water. By applying the CD at 60 cm at the beginning of the growing season with increasing drain spacing to 1.5 times and switching to the FD at the rest of the season we can save 15% of irrigation water.

1 Introduction

Today, the world and especially the development countries are facing the challenges of providing water and food for the expanding population. These challenges necessitate reducing the losses of irrigation water and optimising the use of each drop of water to maximise the agriculture production. Traditionally, irrigation and drainage systems were designed, constructed and managed separately. Almost of time the applied irrigation water exceeds the crop water requirement (over irrigation), the subsurface drainage system is over designed, and the drains are always designed at depths suitable for deeper root crops. All these lead to a lot of losses of irrigation water and in the applied fertilisers, which lead to the pollution of ground and drainage water.

Many of the recent studies indicate the importance of the integration between irrigation and drainage systems to avoid the negative impacts of working separately by each of the systems and some results of these studies recommended that the maximum intensity provided by surface drains is not usually needed at all times during the growing season, so there is opportunity to reduce drainage rates during some periods without compromising objectives of the drainage system (Skaggs, 1999). Removing the excess water to permit farming of poorly drained soils, Protecting the crop from excessive soil water conditions, controlling soil salinity, conserving soil water, increasing yield by reducing or eliminating stress caused by deficit soil water conditions, and reducing losses of nutrients and other pollutants via drainage water are the main objectives of water table control.

The objectives of this paper, is to select the proper water table management strategy among different strategies under the conditions of Egypt according to a variety of conflicting criteria, such as: technical performance, economics, social acceptability, environmental impacts, and water availability.

2 Water table management strategies

Three main systems, which are suggested for the water table management strategies: Conventional Drainage (FD), Controlled Drainage (CD), and combined drainage (FD-CD), which is combination between conventional and controlled drainage. For each of these systems, different management strategies were designed by changing each of the drain depth, drain spacing, and the amount of applied irrigation water. About 31 water table management alternative schemes were generated but after screening all the alternatives, only 13 alternatives were selected for this study for the selection of the proper water table management. Descriptions of the selected alternatives are described below as following:

1. Alt-1: which is the existing water able management strategy in the field (FD), as the spacing between drains is 32m and lateral drain at 1.15m depths, and normal amount of irrigation water (100%) is applied for the cultivated crops.

2. Alt-2: which is FD strategy, a subsurface drainage system with the spacing between drains is increased to 45m and lateral drains at 1.15m depths, and the applied amount of irrigation water for the cultivated crops is reduced by 10%.

3. Alt-3: which is FD strategy, a subsurface drainage system with the spacing between drains is increased to 60m and lateral drains at 1.15m depths, and the applied amount of irrigation water for the cultivated crops is reduced by 15%.

4. Alt-4: which is CD strategy, a subsurface drainage system with the spacing between drains is 32m and lateral drain at 1.15m depths, the water table is controlled at 60 cm depth during the study periods and normal amount of irrigation water (100%) is applied for the cultivated crops.

5. Alt-5: which is CD strategy, a subsurface drainage system with the spacing between drains is increased to 45m and lateral drain at 1.15m depths, the water table is controlled at 60 cm depth during the study periods and the applied amount of irrigation water for the cultivated crops is reduced by 20%.

6. Alt-6: which is CD strategy, a subsurface drainage system with the spacing between drains is increased to 45m and lateral drain at 1.15m depths, the water table is controlled at 60 cm depth during the study periods and the applied
amount of irrigation water for the cultivated crops is reduced by 15%.

7. **Alt-7**: which is CD strategy, a subsurface drainage system with the spacing between drains is increased to 45m and lateral drain at 1.15m depths, the water table is controlled at 70 cm depth during the study periods and the applied amount of irrigation water for the cultivated crops is reduced by 10%.

8. **Alt-8**: which is CD strategy, a subsurface drainage system with the spacing between drains is increased to 60m 1.c (85%) and lateral drain at 1.15m depths, the water table is controlled at 60 cm depth during the study periods and the applied amount of irrigation water for the cultivated crops is reduced by 20%.

9. **Alt-9**: which is CD strategy, a subsurface drainage system with the spacing between drains is increased to 60m 1.c (85%) and lateral drain at 1.15m depths, the water table is controlled at 70 cm depth during the study periods and the applied amount of irrigation water for the cultivated crops is reduced by 10%.

10. **Alt-10**: which is CD strategy, a subsurface drainage system with the spacing between drains is 32m and lateral drain at 1.15m depths, the water table is controlled at 60 cm depth during the study periods and the applied amount of irrigation water for the cultivated crops is reduced by 20%.

11. **Alt-11**: which is FD-CD (combined) strategy, the spacing between drains is 32m and lateral drain at 1.15m depths. The management in this strategy depends on applying controlled drainage at depth 60 cm during the initial stage of each growing season (November, December and January for winter crops, May, June, and July for summer crops), in these periods there is no need to the deeper drain depth and to switch to the FD strategy at depth 1.15 during the rest of each growing season where the roots start to grow and applying the drain at deeper depth will help in leaching the salts which may be accumulate during applying the CD strategy. In this strategy, the applied amount of irrigation water for the cultivated crops is reduced by 15%.

12. **Alt-12**: which is FD-CD (combined) strategy, the spacing between drains is 45m 1.c (40%) and lateral drain at 1.15m depths. The management in this strategy depends on applying controlled drainage at depth 60 cm during the initial stage of each growing season (November, December and January for winter crops, May, June, and July for summer crops). In these periods there is no need to a deeper drain depth and switching to the FD strategy at depth 1.15 during the rest of each growing season where the roots start to grow and applying the drain at deeper depth will help in leaching the salts which may be accumulate during applying the CD strategy. In this strategy, the applied amount of irrigation water for the cultivated crops is reduced by 15%.

13. **Alt-13**: which is FD-CD (combined) strategy, the spacing between drains is 60m 1.c (85%) and lateral drain at 1.15m depths. The management in this strategy depends on applying controlled drainage at depth 60 cm during the initial stage of each growing season (November, December and January for winter crops, May, June, and July for summer crops). In these periods there is no need to a deeper drain depth and switching to the FD strategy at depth 1.15 during the rest of each growing season where the roots start to grow and applying the drain at deeper depth will help in leaching the salts which may be accumulate during applying the CD strategy. In this strategy, the applied amount of irrigation water for the cultivated crops is reduced by 20%.

Under the conditions of Western Delta of Egypt, field experimental study has been carried out in the experimental station in Western Delta of Egypt (figure.1) and the DRAINMOD-S model has been calibrated for the simulation of water table management under these conditions (Wahba et al. 2002). Long-term simulations for the different scenarios of water table management using the DRAINMOD-S model for ten years have been carried out. One of the most crop rotation in the Nile delta will be used, which is a two-year crop rotation as following; wheat, maize, barseem, and cotton (table 1).
3 Evaluation criteria

Water table management strategies are evaluated by the following nine criterion:

- **Crop yield.** Crop yield criterion is considered quantitative criteria and is estimated for each water table management strategy by using the results of long-term simulation for 10 years using the DRAINMOD-S model. The 10 years consists of 5 rotations and each rotation consists of four crops, wheat, maize, barseem, and cotton.

- **Soil salinity.** The output results of ten years simulation using the DRAINMOD-S model is used to calculate the average soil salinity for each management strategy.

- **Total applied irrigation water.** The total applied irrigation water is estimated by calculating the total amount of irrigation water in m³ used under each management strategy for all crops during the 10 years study.

- **Total drainage water outflow.** The total amount of drainage water outflow was estimated for each of strategy during the ten years by using the results from DRAINMOD-S simulation.
• **Total Nitrate losses.** The average Nitrate concentration was estimated from the results of field study. The average Nitrate concentrations from the outlets were multiplied by their respective total drain flow depths and converted to total load on a kilogram per feddan basis.

• **Benefits /Costs ratio (B/C).** The Benefits / Cost ratio (B/C) is calculated as follows:

\[
B/C = \frac{B}{C}
\]

(1)

\(B_i\) = benefit in each year, \(C_i\) = cost in each year, \(n\) = number of years, and \(i\) = interest (discount) rate.

• **Farmer acceptance.** A scale range from 1-10 is given as basis for evaluating the different strategies concerning this criterion (El-Shorbagy, 1994). The number 10 is given for the strategy that gains the highest acceptance and 8 for the least preferred strategy.

• **Irrigation water availability.** A scale range from 1-10 is given as basis for evaluating the different strategies concerning this criterion. The number 10 is given for the strategy that gains the highest suitability for the irrigation water availability conditions and the number 7 for that gains the moderate suitability, and number 3 for that gains the least suitability.

• **Integrated management efficiency.** A scale range from 1-10 is given as basis for evaluating the different strategies concerning this criterion. The number 10 is given for the strategy that achieves the highest integrated management efficiency; the number 7 for that achieves a moderate efficiency and the number 5 is given for that achieves the lowest efficiency.

### 4 Assessment of weights

Three groups of specialists and experts of water management in Egypt have assessed the weights for the selected criteria. The first group is the decision makers group, which consists of 10 experts from the Ministry of water resources and Irrigation. The second group consists of 10 professors specialised in irrigation, drainage, agricultural, soil and water from the Egyptian universities. The third group consists of 10 researchers from the National Water Researcher Centre (NWRC) (table. 2).

### 5 Evaluation of management strategies

The multi criteria decision analysis model MultiDeciMode, which has been developed (Wahba, 2002) is used for the evaluation of these strategies, and this model is described below:

#### 5.1 MODEL DESCRIPTION

A Multi criteria Decision analysis Model called (MultiDeciMode) was developed to help the decision makers in water resources management problem, it is based on the used of three multi criteria decision analysis methods, the Weighted Summation (WS), Compromised Programming (CP), ELECTRE-II, and the ELECTRE-II method was modified to overcome its complexity and to be more simple for the users.
The **MultiDeciMode** was developed for specific purposes: 1) to be able to evaluate the different alternatives for integrated water table management and to select the best alternative among them 2) to the DM in solving sophisticated problems in water resources management 3) to provide useful tool for the DM, without requiring experience with the MCDA techniques 4) to have an easy, quick and practical user friendly interface valid for multi purposes application.

A software program for the four MCDAs methods, and the interface were developed and written using visual basic programming language and one version for windows was developed.

The interface was designed in a simple way to guide step by step the DM who has little computer experience to find solution for his complicated problems and to help users to get the information they need as quickly, as clearly, and as easily as possible. The interface provides graphs for alternatives utilities and ranking and text file for the output from each of the applied methods. Flow chart guide for the use of **MultiDeciMode** has been shown in Annex.1 and the user can follow all program steps easily without the need of any manual.

### 6 Input data
- **Criteria and Alternatives number**
  - Criteria Number = 9
  - Alternatives Number = 13

- **Normalization conditions**
The given scores values are not normalised and are normalised by the model

- **Max and Min values**
The model will calculate the maximum and minimum values of the scores for each criterion.

- **Criteria scores**
The criteria scores, which have been estimated for all water table management strategies are presented in table 3 as the evaluation matrix (impacts matrix).

- **Criteria weights**
  Four weights are used for the evaluation, the average of decision-makers’ group (W1), the average of University group (W2), the average of NWRC group (W3) and the equal weights (W4). All these weights are given in table 2. The model will normalise the weight values by using equation 2 as follows:

  \[
  w_i = \frac{w_i}{\sum_{i=1}^{n} w_i}
  \]

  Where: \( i = \) criterion No and \( n = \) Number of criterion

- **Criteria conditions**
The model consider two conditions for weight, the number 1 for maximisation and number 2 for minimisation and the values used for criteria conditions in this evaluation are given in table 4.

### 7 MODEL RUN

#### 7.1 Selection of techniques to Run
The weighted summation, Compromised programming, ELECTRE-II and modified-ELECTRE-II (Wahba, 2002) methods were selected to evaluate the water table management strategies and each method was applied for the four different weights.

For ELECTRE-II method, the threshold values are 0.8, 0.7, and 0.6 for concordance and 0.4, and 0.2 for discordance.

<table>
<thead>
<tr>
<th>Table 3 Criteria Conditions</th>
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<tbody>
<tr>
<td>Criteria</td>
</tr>
<tr>
<td>Crop yield</td>
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<tr>
<td>Soil salinity</td>
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<tr>
<td>Total irrigation water</td>
</tr>
<tr>
<td>Total drainage outflow</td>
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<tr>
<td>Total Nitrate losses</td>
</tr>
<tr>
<td>Benefits/Costs ratio (B/C)</td>
</tr>
<tr>
<td>Farmer acceptance</td>
</tr>
<tr>
<td>Irrigation water availability</td>
</tr>
<tr>
<td>Integrated management efficiency</td>
</tr>
</tbody>
</table>
7.2 Sensitivity analysis

To study the effect of changing criterion scores on the final ranking of water table management strategies, a sensitivity analysis has been carried out only for the quantitative criteria which are: crop yield, soil salinity, total irrigation water, total drainage water, total nitrate losses, and B/C ratio. The scores of these criteria could be changed due to spatial variability of field data or changes in field measurements, and simulation model approximation where these changes will affect ranking of the suggested strategies. A change from +25% to –25% with a step 5% is applied to the soil salinity criterion scores and from +10% to –10% with a step 5% is applied to the rest of the mentioned criteria for all weights using weighted summation, Compromised Programming, ELECTRE-II, and modified ELECTRE-II methods. The output of applying all the mentioned changes to the selected criteria using the MultiDeciMode, is average ranking for each alternative and the coefficient of variation for its ranking due to all changes in criteria scores.

8 RESULTS

The results of the ranking for all alternative strategies according to their ranking scores obtained for the different weights are presented in figure 2 for the weighted summation method, in figure 3 for the Compromised Programming method, in figure 4 for the ELECTRE-II method, and in figure 5 for the modified ELECTRE-II methods. The results indicate that the most preferred alternative strategy by all methods and for all different weights is alternative 13, and the most preferred alternatives after alternative 13 are 12, 11 and 3. Alternative 4 is ranked the last alternative by all methods and for all the different weights. It is notable that the top ranking alternative strategies 13, 12, and 11 are FD-CD (combined) strategies.

The results of sensitivity analysis for all methods are given in tables 5, 6, 7, and 8 for W1, W2, W3, and W4 respectively. The final ranking for any alternative in these tables is the average of 429 rankings due to all changes in criteria scores. All the methods agreed in ranking alternative 13, as the most preferred alternative followed by alternative 12 followed by alternative 12 and alternative 4 is ranked the last alternative. It is observed that the coefficient of variation (C.V) for alternatives 13 ranking is ranged between 13.41 to 18.61% for W1, W2, W4, and ranged between 17.27 to 25.93% for W4 with all methods, for alternative 12 is ranged between 12.47 to 18.29% for W1, W2, W3, and W4 for all methods, and for alternative 11 is ranged between 7.4 to 16.56% for W1, W2, W3, and W4 for all methods. This means that there is effect for the change of criteria scores on the ranking of these alternatives, and sometimes these alternatives exchange their ranking as the first, the second and the third, but the average of all these ranking is alternative 13 is the first, alternative 12 is the second, and alternative 11 is the third and they are the most preferred alternatives. It is observed that the C.V for alternatives 3 ranking is ranged between 5.98 to 10.52% for all weights with all methods, which means there is a little effect for the change in criteria scores on the ranking of this alternative, sometimes it ranked No 5, and 6, but most of times it ranked the fourth and it is the most preferred alternative after alternatives, 13, 12, and 11. It is observed that the C.V for alternatives 4, 1, 9, 7 ranking is ranged between 0 to 4.59% for all weights with all methods, which means that there is no much effect for the change of criteria scores on the ranking of the rest of alternatives, which almost of time are ranked in the middle.

Table 4: Sensitivity analysis results for all methods- decision-makers group weight (W1).

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Weighted summation</th>
<th>Compromised Programming</th>
<th>ELECTRE-II</th>
<th>Modified ELECTRE-II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Avg.-Rank</td>
<td>C.V (%)</td>
<td>Avg.-Rank</td>
<td>C.V (%)</td>
</tr>
<tr>
<td>Alt-1</td>
<td>12</td>
<td>0.57</td>
<td>12</td>
<td>0.57</td>
</tr>
<tr>
<td>Alt-2</td>
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Figure 2  Ranking of alternatives using weighted summation method.

Figure 3  Ranking of alternatives using Compromised Programming method.
Figure 4  Ranking of alternatives using ELECTRE-II method.

Figure 5  Ranking of alternatives using modified-ELECTRE-II method.

Table 5  Sensitivity analysis results for all methods- University group weight (W2).
### Table 6 Sensitivity analysis results for all methods- NWRC group weight (W3).

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<tr>
<th>Alternative</th>
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### Table 7 Sensitivity analysis results for all methods- Equal weight (W4).
### WATER TABLE MANAGEMENT STRATEGIES FOR IRRIGATION WATER SAVING

#### Alternative Weighted summation Compromised Programming ELECTRE-II Modified ELECTRE-II

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### 9 SUMMARY AND CONCLUSION

Based on the long-term simulation (10 years) of the different water table management strategies using the DRAINMOD-S, the impacts of each strategy on the crop yield, soil salinity, total irrigation water, and total drainage water have been estimated. The impacts on total nitrate losses have been estimated from the total drainage outflow (DRAINMOD-S results) and the average concentration during field experimental test. The impacts on the rest of criteria have been estimated from interview with farmer and experts. The selected WTM alternative strategies have been evaluated using the MultiDeciMode and four different weights for criteria have been applied and the results indicate that for the integrated water table management, four alternatives are identified as the most preferred strategies and ranked as alternatives, 13, 12, 11, and 3 as described above.

The results of the water table management strategies indicate that by adopting a combined (FD-CD) strategy i.e. by increasing the spacing between drains to about 2 times the conventional design spacing and controlling the water table to a 60 cm (CD) at the beginning of each growing season (November, Dec, Jan for winter crops, May, June, July for summer crops and switching to conventional drainage (FD) during the rest of the growing season, saving of 20% of irrigation water will be achieved.

Another alternative saving of 15% of irrigation water will be achieved for an increase of 1.5 times the design spacing between lateral drains and keeping drain depth at 1.15m, controlled water table depth at 60cm is applied during the initial stage of the growing season and switching to (FD) drainage at the rest of the season.

### 10 REFERENCES


### 11 Annex 1

#### 11.1 MultiDeciMode Flow Chart
Table 8  Evaluation matrix.

http://library.wur.nl/ebooks/drainage/drainage_cd/1.2%20wahba%20mas,%20el%20ganainy%20ma%20and%20amer%20mh.html (11 of 12)26-4-2010 12:10:53
### Water Table Management Strategies for Irrigation Water Saving

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</table>

[3] Prof. of Irrigation & Drainage structures, Department of Hydraulic and Irrigation Engineering, Faculty of Engineering, Alexandria University, Alexandria, Egypt. Prof and chairman of the Egyptian National Committee for Irrigation and Drainage, Drainage Research Institute, National Water Research Center, Egypt. E-mail: ENCID@link.net
ABSTRACT

Due to unavoidable, prolonged irrigation with marginal quality water, secondary salinization of irrigated soils in Pakistan has necessitated to a need for better understanding of the water management alternatives. Although $\text{H}_2\text{SO}_4$ and gypsum have far been recognized for their benefits in treating brackish water but during field trials, their relative performance still remains controversial for counteracting the Na-hazards in soil/water system. As alternative sulfur burners are also being marketed but up till now there is not even a single field study published in some journal about their efficiency and economical viability for the treatment of brackish water. Therefore a field study was carried out to compare the effectiveness of sulfuric acid generator (SAG) and other water/soil applied amendments on a normal, calcareous, well drained, sandy loam soil. Rice 2001, wheat 2001-02, and rice 2002 were planted in rotation during the experimentation period with a total of 54 treated and 8 untreated irrigations (each of 7.5 cm). Tube well water used had EC = 3.24 dS m$^{-1}$, SAR=17.23 and RSC = 5.44 mmolc L$^{-1}$. The treatments were: $T_0$ Brackish tube well water without any amendment; $T_1$ All irrigation with water passed through SAG; $T_2$ Soil applied gypsum to each crop equivalent to affect a decrease in WRSC of tube well water treated with SAG, and $T_6$ H$_2$SO$_4$ fertigation at each irrigation equivalent to affect a decrease in RSC of tube well water with SAG. Water analysis after treatment with SAG (an average of 20 irrigations) revealed that SAG treatment affected only one parameter i.e. water RSC from 5.44 to 3.55, and had no beneficial effect on SAR$_{iw}$ and EC$_{iw}$. After three crops, a minor decrease (up to 2.5%) and increase (up to 5.3%) in soil pH$_s$ over initial values was noted at 0-15 & 15-30 cm depth. After three crops the soil EC$_e$ and SAR were maintained below the threshold levels and the treatments had non-significant differences. On the basis of three crops, net benefit was maximum, from $T_4$ followed by $T_5$, $T_2$, $T_0$, $T_2$, $T_6$ and $T_1$. The use of sulfur burner/ sulfuric acid was found to be 5 times costlier than gypsum in our study. It is concluded that soil application of gypsum and/or farmyard manure to counter the sodic hazards of irrigation water will be useful as well as economical for rice-wheat rotation on a normal, calcareous well drained soil. However, for fine textured soils with low infiltration rates, to expect similar situation might not be correct for which additional studies are imperative.

1 Introduction

Under agro-climatic conditions of Pakistan, evapo-transpiration is several times higher than rainfall (2025 and 150 mm, respectively), which is responsible for net upward movement of salts through capillary action. The shortfall in irrigation water requirement is likely to reach 107 MAF by 2013 (Ghafoor et al., 2002b). In order to supplement to present canal water availability at farm-gate (43 MAF), more than 531,000 tube wells are pumping 55 MAF in Pakistan (Anonymous, 2003), of which 60-70% is hazardous owing to high EC RSC and/or SAR. For evaluation of the irrigation water quality, primary consideration is usually made to its total salt contents and sodium related hazards (Ayers and Westcot, 1985; Gupta, 1990; Gupta and Gupta, 1997). The carbonate and bicarbonate contents of irrigation water higher than Ca$^{2+}$,Mg$^{2+}$ strongly exaggerate the sodium hazards for soils and plants (Gritsenko and Gritsenko, 1999). Thus the continuous use of irrigation water containing residual sodium carbonate (RSC) causes soil deterioration in due course of time depending upon soil and agro-climatic conditions (Rengasamy and Olsson, 1993). In Pakistan, safe limit of 2.5 mmolc L$^{-1}$ for RSC has been proposed by Directorate of Land reclamation while 5.0 mmolc L$^{-1}$ by WAPDA (Muhammad and Ghafoor, 1992).

The sodicity hazards (SAR and RSC) of poor quality water could be decreased by increasing calcium through addition of chemical amendments like gypsum, calcium chloride etc (Gupta, 1990; Gupta and Gupta, 1997) or by decreasing its carbonate and bicarbonate contents with the addition of acids/acid formers, either to soil or water (Gumaa et al., 1976; Frenkel et al., 1978; Gupta, 1990; Burt, 1998; Griffen and Silvertooth, 1999). Thus neutralization of water RSC with the use of proper amount of gypsum or acid is widely recommended, although use of gypsum is highly economical (Chabbra, 1996; Ghafoor et al., 2001a) but has low solubility of 0.24-0.30 g per 100 ml water at 25 °C (US Salinity Lab. Staff, 1954, Gupta and Gupta, 1997) and thus from gypsum, a Ca$^{2+}$ concentration of up to 4 me L$^{-1}$ can be obtained in flowing irrigation water (Ayers and Westcot, 1985). On the other hand low dissolution rate of gypsum, however, is an additional advantage to sustain the availability of calcium and electrolyte concentration to maintain the hydraulic conductivity and structure of soils (Reeve and Doering, 1966; Juirinack et al., 1984; Ayers and Westcot, 1985; Rengasamy and Olsson, 1993). The use of commercial mineral acids has been found 5-7 times more expensive than gypsum (Agarwal et al., 1982; Abrol et al., 1988; Ghafoor et al., 2001a) and handling is also difficult and dangerous (Havlin et al., 2001). As alternative, Sulfurous Acid Generator (SAG) is a recently introduced technology to treat saline-sodic/sodic waters. Sulfur (S) is burnt to produce SO$_2$ in a chamber, which is made to dissolve in a fraction (1/15th - 1/20th) of tube well water to form sulfurous acid ($\text{H}_2\text{SO}_3$) although the solubility of SO$_2$ in water is limited. This $\text{H}_2\text{SO}_3$ neutralizes $\text{CO}_3^{2-}$ and $\text{HCO}_3^-$ ions of water so the RSC of such treated water is reduced, while theoretically, there would not be any benefit
Keeping in view the above facts, an experiment was carried out to study the economics and monitor the effectiveness of SAG treatment of brackish water and other water/soil applied amendments for rice – wheat - rice production on a normal soil using high EC, SAR and RSC tube well water.

2 Materials and Methods

A field experiment on 0.75 ha piece of alluvial soil was conducted at Post Graduate Agricultural Research Station (PARS), Univ. Agriculture, Faisalabad-Pakistan, on normal (non-saline and non-sodic), calcarceous soil using brackish tube well water (EC = 3.24 dS m\(^{-1}\), SAR = 17.23, RSC = 5.44 mmolc L\(^{-1}\), pH 7.6) during May 2001 to December 2002. The treatments included;

- **T\(_0\)** Control (all irrigation with untreated tube well water - T/W).
- **T\(_1\)** All irrigations with SAG treated water 1/15\(^{th}\) - 1/20\(^{th}\) water passes through SAG, then mixed with remaining flow of T/W water and used for irrigation.
- **T\(_2\)** Alternate irrigation of SAG treated water and one of tube well water.
- **T\(_3\)** One irrigation with SAG treated and two irrigations with untreated T/W water.
- **T\(_4\)** Farm Yard Manure (FYM @ 15 t/ha/yr before transplanting each rice crop)
- **T\(_5\)** Soil-applied gypsum (agri. Grade passed through 30 mesh sieve having 70% purity) to each crop equal to decrease in RSC as affected by SAG treatment (decrease in RSC equal to that of SAG treated water).
- **T\(_6\)** H\(_2\)SO\(_4\) applied through fertigation equivalent to that affected by SAG treatment (i.e. decrease in RSC equal to that of SAG treated water).

The experiment was laid out in RCBD with three replications following rice-wheat-rice crop rotation. Rice cv. *Basmati 2000* was transplanted in July 2001 followed by wheat cv. *Aqab 2000* during Rabi 2001 and rice cv. *Basmati 2000* during Kharif 2002. A total of 54 treated and 8 untreated irrigations (each of 7.5 cm) were applied to these three crops and there was negligible rainfall during the period of studies. Soil samples were drawn from 00-15 cm and 15-30 cm soil depths at the start of experiment and after the harvest of each crop. The cultural practices, like weeding, fertilizer application as well as amount of irrigation water was kept uniform for all the treatments. The NP fertilizer application rate was 100 and 50 kg ha\(^{-1}\) as urea and DAP respectively for both the rice and wheat crops. Soil analysis (pH, EC\(_e\), soluble Na\(^+\), Ca\(^{++}\), Mg\(^{++}\), K\(^+\), CO\(_3\)^{-}, Cl\(^-\), SAR, lime contents) was accomplished following the methods described by the US Salinity Lab. Staff (1954). The crops were harvested at biological maturity to record biomass; and were threshed manually to obtain ‘economic yields. The data were subjected to statistical analysis following the ANOVA technique and DMR test was applied to evaluate the treatment differences (Steel and Torrie, 1980) at 5% probability. The variable costs of all the experimental inputs and support prices of the produce were used to compute the economics. The experiment was terminated during December 2002 as the SAG was removed away by the donor agency (Sweet Water International and On Farm water Management Directorate, Punjab-Pakistan) to some other site.

### Table 1 Properties of soil at PARS before the experiment

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<th>Soil depth (cm)</th>
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<td>8.20</td>
<td>8.61</td>
<td>8.52</td>
<td>8.45</td>
</tr>
<tr>
<td></td>
<td>EC(_e) (dSm(^{-1}))</td>
<td>5.41</td>
<td>2.28</td>
<td>3.74</td>
<td>3.81</td>
</tr>
<tr>
<td></td>
<td>SAR</td>
<td>21.2</td>
<td>13.9</td>
<td>23.0</td>
<td>19.4</td>
</tr>
<tr>
<td>00-30</td>
<td>Texture</td>
<td>Sandy loam</td>
<td>Loamy sand</td>
<td>Sandy loam</td>
<td>Sandy loam</td>
</tr>
<tr>
<td>10-15</td>
<td>B.D (Mg m(^{-3}))</td>
<td>1.59</td>
<td>1.54</td>
<td>1.67</td>
<td>1.60</td>
</tr>
<tr>
<td>20-25</td>
<td>B.D (Mg m(^{-3}))</td>
<td>1.59</td>
<td>1.54</td>
<td>1.74</td>
<td>1.62</td>
</tr>
<tr>
<td>30-35</td>
<td>B.D (Mg m(^{-3}))</td>
<td>1.58</td>
<td>1.52</td>
<td>1.65</td>
<td>1.58</td>
</tr>
<tr>
<td>I.R (cm h(^{-1}))</td>
<td>1.01</td>
<td>1.26</td>
<td>1.06</td>
<td>1.11</td>
<td></td>
</tr>
</tbody>
</table>

2.1 Tube Well Water and Changes in Quality:

The quality of water was not suitable for irrigation (Table 2) considering the national irrigation water quality criteria of WAPDA, DLR, Hussain (Muhammed and Ghafoor, 1992), India (Gupta and Gupta, 1997; Agarwal et al., 1982; Gupta, 1997) or the other world (Abrol et al., 1988; Ayers and Westcot, 1985). As the
continued use of such quality water for irrigation will inevitably increase the price to be paid by the farmers to sustain irrigation farming (Rengasamy and Olsson, 1993) thus a sound management strategy is ever needed to take in to account the predictable long-term adverse effects of sodification and salinization on agriculture and environment (Gritsenko and Gritsenko, 1999). Proper rates and frequency of acids/acid formers can be used to reduce carbonates and bicarbonates in low quality water (Gumaa et al., 1976; Finck, 1982; Whipker et al., 1996; Burt, 1998; Griffen and Silvertooth, 1999; Halvin et al., 2002) and thus could be beneficial by reducing hardness (Christensen and Lyerly, 1954) and crusting in soils, where precipitated CaCO3 acts as a cementing agent (Stroehlein and Pennington, 1986).

Although use of sulfuric acid is most efficient to neutralize the soda and alkalinity in the irrigation water but the concentrations of Na+ and Ca2+ can only be equalized in the course of water treatment if M < 2.0 g/l and Na+/Ca2+ < 0.0 (Lotovitskii and Bilai, 2001). However experimental data are lacking about the effectiveness of recently introduced sulfur burners, which produce SO2 to form H2SO3 after mixing in water (Stroehlein and Pennington, 1986). Moreover economic considerations are essential whenever there is use of acid forming materials for the improvement of soil and water quality (Fuller and Ray, 1963; Alawi et al., 1980; Ghafoor et al., 2001a) and researchers like Christensen and Lyerly (1954) in a six-year study have found the use of sulfuric acid uneconomical for the treatment of water as well as soil.

### Table 2: Sulfurous acid generator treatment of tube well brackish water

<table>
<thead>
<tr>
<th>Tube well Water Quality Before SAG Treatment</th>
<th>Water Quality During SAG Treatment</th>
<th>Water Quality After SAG Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC</td>
<td>SAR</td>
<td>RSC</td>
</tr>
<tr>
<td>3.32</td>
<td>16.29</td>
<td>5.25</td>
</tr>
<tr>
<td>3.51</td>
<td>17.85</td>
<td>5.50</td>
</tr>
<tr>
<td>3.38</td>
<td>15.14</td>
<td>4.99</td>
</tr>
<tr>
<td>3.27</td>
<td>16.61</td>
<td>5.80</td>
</tr>
<tr>
<td>3.04</td>
<td>15.20</td>
<td>5.02</td>
</tr>
<tr>
<td>3.30</td>
<td>16.38</td>
<td>5.50</td>
</tr>
<tr>
<td>3.41</td>
<td>18.65</td>
<td>5.70</td>
</tr>
<tr>
<td>3.58</td>
<td>18.57</td>
<td>7.00</td>
</tr>
<tr>
<td>3.41</td>
<td>15.49</td>
<td>6.30</td>
</tr>
<tr>
<td>3.11</td>
<td>16.06</td>
<td>6.40</td>
</tr>
<tr>
<td>3.11</td>
<td>17.67</td>
<td>5.70</td>
</tr>
<tr>
<td>3.06</td>
<td>15.75</td>
<td>7.50</td>
</tr>
<tr>
<td>3.02</td>
<td>14.70</td>
<td>5.90</td>
</tr>
<tr>
<td>3.15</td>
<td>18.76</td>
<td>4.70</td>
</tr>
<tr>
<td>3.23</td>
<td>15.92</td>
<td>5.70</td>
</tr>
<tr>
<td>2.99</td>
<td>17.67</td>
<td>5.70</td>
</tr>
<tr>
<td>3.11</td>
<td>17.41</td>
<td>5.50</td>
</tr>
<tr>
<td>3.09</td>
<td>18.51</td>
<td>5.60</td>
</tr>
<tr>
<td>3.19</td>
<td>19.73</td>
<td>3.50</td>
</tr>
<tr>
<td>3.16</td>
<td>19.52</td>
<td>4.00</td>
</tr>
<tr>
<td><strong>Av.:</strong></td>
<td><strong>3.22</strong></td>
<td><strong>17.09</strong></td>
</tr>
<tr>
<td><strong>% Variation</strong></td>
<td><strong>101.9</strong></td>
<td><strong>-3.5</strong></td>
</tr>
</tbody>
</table>

It is clear from the data (an average of 20 irrigations) that SAG treatment of brackish water did not decrease ECiw, rather there was an average increase of 2.1% (Miyamoto et al., 1975; Stroehlein and Pennington, 1986). Moreover after treatment with SAG water pH comes down from 7.6 to 6.6 (13.2 % decrease, data not shown), which may be attributed to the negligible buffering capacity of the irrigation water. Several researchers in field (Christensen and Lyerly, 1954; Griffen and Silvertooth, 1999), green house (Thorne, 1944), laboratory (Gumaa et al., 1976), and pot (Aldrich and Turrell, 1950) studies have demonstrated desired reduction in pH of the irrigation water with the use of sulfuric acid. SAG did not put any significant decrease in SARiw (i.e. 1.3% decrease). This nominal decrease in SARiw may be due to a negligible improvement in the concentration of Ca2+ present in irrigation water or this might be due to release of Ca from silt/clay particles suspended in irrigation after acid treatment. In a study Miyamoto et al., 1975b, concluded that after addition of acid in to irrigation water reduces its SARadj, which shows that Ca2+ will tend to remain in solution rather than precipitating out as CaCO3. Our findings are further supported by the research work of Lotovitskii and Bilai (2001), who explored that “Acidification of irrigation water affects not only the concentrations of CO32- and HCO3- but, to a certain extent, the water chemistry as a whole, that is mainly caused by substitution/exchange reactions between salts of the acid and those dissolved in water. In the first minutes after treatment, Na+, and Cl- concentrations are unstable and are decreased by 5-15%; however, both almost recover their initial
value. The concentration of \( \text{SO}_4^{2-} \) increases by 10-16% (at the most efficient rate of \( \text{H}_2\text{SO}_4 \) to neutralize alkalinity problem i.e. 40 g m\(^{-3}\)). The concentration of \( \text{Ca}^{2+} \) in most cases increases by 8-14%, \( \text{Mg}^{2+} \) concentration decreases by up to 8%.

Although SAG treatment of brackish water decreased its RSC by about 34.4% (i.e. from 5.56 mmolc L\(^{-1}\) to 3.65 mmolc L\(^{-1}\) but still it was higher when compared to the safe limit of 2.5 mmolc L\(^{-1}\) which is mostly considered the maximum upper limit for safe irrigation in Pakistan (Muhammed and Ghafoor, 1992) and the world (Ayers and Westcott, 1985; US Salinity Lab. Staff, 1954; Gupta and Gupta, 1997). Such level of RSC is generally expected to create some infiltration problems on fine textured soils (Frenkel et al., 1978) or could induce disorders in the nutrient availability as well as plant assimilation (Ayers and Westcott, 1985; Abrol et al., 1988). The results are in line with those of Gale et al. (2001), who in a level basin irrigation study, monitored the efficiency of a sulfur burner, where pH was the only property of the water, significantly affected by the sulfur burner treatment. Summarily there was 7.5% decrease in pH, 0.96% increase in Na, 4.6% increase in Ca+Mg, 8.0% decrease in HCO\(_3\)\(^{-}\), and 4.2% decrease in SAR\(_{adj}\). The low efficiency of the sulfur burner was attributed to its ability of uptake and onward treating of only about 5% of the water flowing through water channel and again diverting that treated portion in to rest of 19 untreated portions. Moreover low efficiency of SAG may also be attributed to low solubility of SO\(_2\) in irrigation water (Miyamoto et al., 1975a; Cotton and Wilkinson, 1967). These results are supported by the research findings of Miyamoto et al., (1975a) who concluded that sulfuric acid not only increases the electrolyte content of the water, but also reduces or removes the carbonate and bicarbonate as well thus the adjusted SAR is decreased, which shows that Ca will tend to remain in solution rather than precipitating out as CaCO\(_3\).

As claimed by SAG manufacturing company (Sweet Water International), that brackish water treated with SAG may be used to reclaim saline-sodic/sodic soil successfully, the authors are of the view that SO\(_2\) may be too insoluble to accomplish soil reclamation if added to the water (Stroehlein and Pennington, 1986). Therefore low rates of amendments as commonly water-applied should be expected only to affect water quality and the surface soil rather than the entire root zone. Thus high Na soils should generally be treated directly and not by water treatment, with acids/acid formers/Ca providing materials (Stroehlein and Pennington, 1986).

2.2 Soil Properties:

2.2.1 pH\(_s\)

The data (Table 3) after three crops show a minor decrease (up to 2.5%) and increase (up to 5.3%) in pH\(_s\) at 0-15 and 15-30 cm soil depths. At 0-15 cm depth, there was maximum decrease in pH\(_s\) (2.5%) for farmyard manure (FYM) treatment, which could be attributed to the formation of carbonic acid upon the release of CO\(_2\) during its decomposition, while decrease was minimum (0.8%) with T\(_6\) where sulfuric acid (commercial grade) was applied through drip irrigation method. For 15-30 cm depth, all the treatments increased soil pH\(_s\) except gypsum treatment, increase being maximum with T\(_2\) (5.3%) and minimum with T\(_4\) (1.4%) and T\(_0\) (2.6%). Gypsum application perhaps maintained a high EC : SAR ratio at both the depths and high EC : SAR ratio tends to lower pH\(_s\) and vice versa, in general (Ghafoor et al., 2001b; Ayers and Westcott, 1985; Abrol et al., 1988). A decrease in soil pH\(_s\) after addition of gypsum has also been reported by Cates et al., (1982) while reclaiming a calcareous saline-sodic soil. Failure to obtain a marked decrease in soil pH\(_s\) may be attributed to buffering effect of the salts present in irrigation water against H\(^+\) addition (Christensen and Lyerly, 1954), and to the presence of CaCO\(_3\) in this calcareous soil which acts as a buffer and resists any appreciable change in soil pH\(_s\) in the alkaline range (Deverel and Fujii, 1990; Leoppert and Suarez, 1996). Moreover, it is uneconomical and quite impractical (Havlin et al., 2002) to lower the pH\(_s\) of calcareous soil because of too much amounts of acids/acidifiers required to serve the purpose (Imas, 2000).

2.2.2 EC\(_e\)

At the start of the experiment EC\(_e\) of soil at 0-15 and 15-30 cm depth on the average was 3.1 and 3.8 dS m\(^{-1}\) with non-significant differences among all the treatment plots. After the harvest of final crop relatively greater EC\(_e\) especially in surface soil was noted in continuous acid treated plots (T\(_1\) & T\(_6\)) against gypsum treated plots that might be due to acid reaction with native lime present in the soil. Mace et al., 1999 in a study have reported greater EC\(_e\) values compared to gypsum, presumably from the gypsum supersaturation and elevated alkalinity in the soil system. Similarly after the harvest of final rice crop, a decrease in soil EC\(_e\) was more in acid treated plots than control plots. The results are in line with those of Cate et al., (1982) who reported that acid treatment significantly lowered soil EC\(_e\) than control plots.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Before 1st rice</th>
<th>After 1st rice</th>
<th>After 1st wheat</th>
<th>After 2nd rice</th>
<th>EC : SAR</th>
<th>% var. after 3 crops</th>
</tr>
</thead>
</table>

Table 3 Average variation in Soil pH\(_s\) during SAG Experiment at PARS before start of Experiment (2001) up to after 2\(^{nd}\) Rice Crop –2002 (00-15 cm Depth)
Overall the soil EC_e (Table 4) decreased with all the treatments except with T4 at 0-15 cm. At both the depths, control plots showed maximum EC_e, which may be attributed to no treatment of soil and water. At 0-15 cm depth, maximum decrease was noted with T3 (45.8%) followed by T2, T1, T6, T0, and T5 (1.6%) while increase (37%) was only in FYM treatment plots. This increase in EC_e with FYM might be due to accumulation of salts after mineralization of organic matter as reported by (Hao and Chang, 2003) who explored significant increase in soil salinity levels due to increased levels of soluble Na^+, K^+, Mg^{2+}, Cl^-, HCO_3^-, and SAR, after 5, 10, 15, 20 and 25 years of manure application under both irrigated and non-irrigated conditions. The authors further estimated an annual increase in EC_e (0-150 cm of soil depth average) by 0.1108 dSm^{-1} for every ton of salt applied through the cattle manure under non-irrigated conditions during a long-term study. At 15-30 cm soil depth, decrease in EC_e, was maximum with T3 (66.0%) followed by T6, T4, T2, T1, T0 and T5 (42.0%). The observed values of soil EC_e at both the depths has been maintained below the critical level of 4 dS m^{-1} regarding the productivity of most of the crops and soils (Ayers and Westcot, 1985; US Salinity Lab. Staff, 1954; Gupta and Gupta, 1997) by all the treatments under investigation in this well drained, medium textured, moderately calcareous soil. This could be attributed to high leaching fraction (LF) achieved thus better management of irrigation water (Chang et al., 1982) as two rice and one wheat crop were grown with 62 irrigations (each irrigation of 7.5 cm). However, for fine textured soils with low infiltration rates, to expect similar situation might not be correct for which additional studies are imperative.

Table 4 Average variation in Soil EC_e during SAG Experiment at PARS before start of Experiment (2001) up to after 2nd Rice Crop –2002 (00-15 cm Depth)
The SAR of soil at 0-15 and 15-30 cm depth, on the average was 16.3 and 19.4 mmol L\(^{-1}\))\(^{1/2}\) as four plots each in replication 1 & 3 [under control (T\(_0\)), FYM (T\(_4\)), sulfuric acid fertigation (T\(_6\)), all irrigations with SAG treated water (T\(_1\)) treatments] were slightly Na-affected, which on the average tended to keep the soil SAR > 15 -- the critical limit of sodic soils (Ayers and Westcot, 1985, US Salinity Lab. Staff, 1954). The soil SAR (Table 5) fell to about 8 – 12 at both the depths with non-significant differences among all the treatments. At 0-15 cm depth, maximum decrease was noted with T\(_1\) followed by T\(_0\), T\(_6\), T\(_4\), T\(_2\), T\(_3\) and T\(_5\). The relatively better decrease for soil SAR in acid treatment plots i.e. T\(_1\) and T\(_4\) may be attributed to more efficient production of soluble Ca as a consequence of gypsum supersaturation with the acid treatment (Mace et al., 1999). The minimum decrease in soil SAR with gypsum might be due to very low rates of gypsum application and the results are in line with those of Alawi et al., 1980 who pointed out that when soil-applied gypsum is used at very low rates, the effects are minor and short lasting and thus sulfonic acid is superior to the gypsum treatment. At 15-30 cm soil depth, decrease in soil SAR was found maximum with T\(_4\) followed by T\(_5\), T\(_3\), T\(_6\), T\(_1\), T\(_2\), and T\(_0\). After 3rd crop similar effectiveness (non-significant differences among treatments) of acid and gypsum treatments for reducing soil SAR have also been reported by Cate et al., (1982) which was attributed to very low initial ESP (i.e. 32) of the soil. Our results are also similar with those of Chaudhry et al (1989) who reported that SAR in all plots was significantly decreased with non-significant differences among control, gypsum @ 50% SGR and sulfuric acid @ 50% SGR treatments used for reclamation of moderately salt-affected, loam soil by growing four rice and four wheat crops in rice-wheat rotation. In the current study, observed values of soil SAR at both the depths has been maintained well below the critical level of 15 regarding health of most of the crops and soils (US Salinity Lab. Staff, 1954, Ayers and Westcot, 1985; Gupta and Gupta, 1997) by all the treatments under investigations in this well drained, medium textured, moderately calcareous soil. However, for fine textured soils with low infiltration rates or non-calcareous soils, to expect similar behavior might not be correct for which additional studies for longer periods are imperative. Treatments like those under report are purely aim at to counter the sodicity hazards (SAR and RSC) of irrigation waters for soils and crops productivity. Moreover there is also reported potential danger of soil sodication as a result of the application of high sulfate irrigation water which might be due to the fact that SO\(_4^\text{-}\) ions in excess to Ca precipitating, may result in Ca-desorption from the colloidal complex to its neutrality in the soil solution (Javid and Ali, 1999).

The present results help to opine that for well drained soils, waters with SAR and RSC higher than conventional levels (Ayers and Westcot, 1985, Abrol et al, 1988, Muhammed and Ghafoor, 1992; Chabbra, 1996) could be successfully used to grow rice and wheat crops, and that the rate of amendments application could be decreased to make the soil-water-crop production system cost-effective. However, to validate and quantify the ideas expressed here, there is need of farm level studies to exploit the poor quality water resources for canal water deficit Pakistan (Ghafoor et al., 2002b) without disturbing the biosphere equilibrium of the crop husbandry and the environment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Before 1st rice</th>
<th>After 1st rice</th>
<th>After 1st wheat</th>
<th>After 2nd rice</th>
<th>% variation after 3 crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>T(_0)</td>
<td>16.64 ab</td>
<td>18.82</td>
<td>25.58</td>
<td>8.39</td>
<td>-49.6</td>
</tr>
<tr>
<td>T(_1)</td>
<td>21.07 a</td>
<td>17.88</td>
<td>22.38</td>
<td>10.69</td>
<td>-97.1</td>
</tr>
<tr>
<td>T(_2)</td>
<td>15.21 ab</td>
<td>15.68</td>
<td>23.03</td>
<td>10.87</td>
<td>-28.5</td>
</tr>
</tbody>
</table>

Table 5  Average variation in Soil SAR during SAG Experiment at PARS before start of Experiment (2001) up to after 2nd Rice Crop –2002(00-15 cm Depth)
Table 6 Effect of treatments on straw and paddy/grain yields (kg ha\(^{-1}\)) of rice and wheat crops

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Rice 2001</th>
<th>Wheat 2001-02</th>
<th>Rice 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Straw</td>
<td>Paddy</td>
<td>Straw</td>
</tr>
<tr>
<td>T(_0)</td>
<td>2845</td>
<td>1357 c</td>
<td>4486</td>
</tr>
<tr>
<td>T(_1)</td>
<td>4647</td>
<td>2354 ab</td>
<td>5175</td>
</tr>
<tr>
<td>T(_2)</td>
<td>3913</td>
<td>2048 b</td>
<td>5001</td>
</tr>
<tr>
<td>T(_3)</td>
<td>4723</td>
<td>2434 ab</td>
<td>4949</td>
</tr>
<tr>
<td>T(_4)</td>
<td>5136</td>
<td>2660 a</td>
<td>5231</td>
</tr>
<tr>
<td>T(_5)</td>
<td>4115</td>
<td>2237 ab</td>
<td>5060</td>
</tr>
<tr>
<td>T(_6)</td>
<td>4708</td>
<td>2339 ab</td>
<td>5218</td>
</tr>
<tr>
<td>LSD(_{0.05})</td>
<td>532.1*</td>
<td>282.6*</td>
<td></td>
</tr>
</tbody>
</table>

For 1\(^{st}\) rice crop yield, maximum crop yield was obtained with sulfuric acid fertigation treatment of brackish water compared to gypsum treatment, although with non-significant difference. Similar results were obtained by Chaudhry et al., 1989 for 1\(^{st}\) rice crop grown during kharif 1982. An increase in yield over control plots, with the addition of sulfuric acid have also been reported by Cate et al., (1982) in a field study during reclamation of a calcareous saline-sodic soil. Yasin
et al., 1998 have also reported significantly higher paddy yields with acid treatment, closely followed by gypsum while minimum paddy and straw yield was obtained from the control plots. Moreover a better crop growth with the use of sulfuric acid on normal calcareous soils has been demonstrated in several studies and is generally attributed to better nutrient availability (Ryan et al., 1975a, Ryan et al., 1975b; Ryan and Stroehlein, 1979). In a field study by Chapman an increase in rice grain yield of 16% with sulfuric acid treatment plots over gypsum treatments plots have been reported that was attributed to increased nutrient availability due to addition of sulfuric acid after its instantaneous reaction with the soil (Havlin et al., 2002).

For wheat crop, the acid and gypsum treatments had statistically similar yields but significantly higher than control. Results like these have been reported by Akram et al (1989) who explored similar yields of wheat for gypsum and acid treatments, which were significantly higher than control while comparing reclamation efficiency of gypsum and acid treatments in a laboratory study using a highly saline-sodic soil. For 2nd rice crop all the treatments showed non-significant differences for paddy yield.

2.4 **Economics Analysis**

Economic considerations are essential whenever there is use of acid forming materials for the improvement of soil and water quality (Fuller and Ray, 1963; Alawi et al., 1980). Several researchers in Pakistan (Ghafoor and Muhammed 1981; Ghafoor et al. 1986; Bhatti, 1986; Chaudhry et al, 1989; Ghafour et al, 1997; Ghafour et al., 1998; Ghafoor et al, 2001a), India (Yadav (1973), and else of the world (Christensen and Lyerly, 1954; Havlin et al., 2002) have already reported sulfuric acid application to soil as uneconomical and several times expensive than gypsum. On the other side, economic analysis have never been reported in several studies about the use of $\text{H}_2\text{SO}_4$ on calcareous soils (Throne, 1944; Overstreet et al., 1951; Overstreet et al., 1955; Mathers, 1970; Ryan et al., 1975a; Ryan et al., 1975b; Prather et al., 1978; Ryan and Stroehlein, 1979; Ashraf, 1979; Nadeem, 1981; Mian and Baig, 1982; Mace et al., 1999; Peterson, 2000).

For the present study economic analysis was done by using the partial budgeting appraisal. Gross benefit, variable cost and net benefit was computed for each treatment for the rice-wheat-rice rotation. The data (Table 7) show that both the gross benefit and variable costs remained relatively more for rice than those from wheat cultivation. On the basis of three crops, maximum total variable cost was incurred on $T_1$ followed by $T_6$, $T_2$, $T_3$, $T_5$ and $T_4$ while no variable cost on the control treatment. Total gross benefit realized was highest for the treatment $T_4$ followed by $T_5$, $T_0$, $T_2$, $T_6$ and $T_1$. Thus the economic analysis favours the use of organic matter and gypsum to counter the sodicity hazards of irrigation waters and for sustainable yield of rice and wheat crops. The use of sulfur burner/ sulfuric acid was found to be around 5 times costlier than gypsum in our study. Similar results have been reported by Chaudhry et al., 1989 where on economic grounds, gypsum application @ 100% GR was found most economical although maximum paddy and wheat grain yields, through out the experiment, were obtained with $\text{H}_2\text{SO}_4$ applied equivalent to 50% SGR. Similarly Christensen and Lyerly (1954) in a six-year study have also found the use of sulfuric acid uneconomical for the treatment of water as well as soil.

**Table 7 Economic analysis (US$ ha$⁻¹) of SAG and other treatments of brackish water for rice and wheat crops**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Gross benefit</th>
<th>Total Gross Benefit</th>
<th>Variable cost</th>
<th>Total Variable Cost</th>
<th>Net Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rice</td>
<td>Wheat</td>
<td>Rice</td>
<td>Rice</td>
<td>Wheat</td>
</tr>
<tr>
<td>$T_0$</td>
<td>261</td>
<td>396</td>
<td>582</td>
<td>1239</td>
<td></td>
</tr>
<tr>
<td>$T_1$</td>
<td>444</td>
<td>507</td>
<td>525</td>
<td>1476</td>
<td>326</td>
</tr>
<tr>
<td>$T_2$</td>
<td>388</td>
<td>523</td>
<td>541</td>
<td>1452</td>
<td>163</td>
</tr>
<tr>
<td>$T_3$</td>
<td>459</td>
<td>512</td>
<td>534</td>
<td>1504</td>
<td>109</td>
</tr>
<tr>
<td>$T_4$</td>
<td>500</td>
<td>516</td>
<td>600</td>
<td>1616</td>
<td>31</td>
</tr>
<tr>
<td>$T_5$</td>
<td>422</td>
<td>538</td>
<td>512</td>
<td>1473</td>
<td>58</td>
</tr>
<tr>
<td>$T_6$</td>
<td>441</td>
<td>527</td>
<td>526</td>
<td>1494</td>
<td>305</td>
</tr>
</tbody>
</table>

Note: Costs of inputs were calculated as per market rates and of produce as support prices

3 **Literature Cited:**


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INFLUENCE OF SUB-SURFACE DRAINAGE ON RICE CROP YIELDS IN SALINE AND WATER LOGGED SOILS OF KONANKI AND UPPUGUNDURU PILOT AREAS OF ANDHRA PRADESH

ABSTRACT
The effect of subsurface drainage systems on paddy crop yields in saline and waterlogged soils of Konanki and Uppugunduru pilot areas in Nagarjuna Sagar Right Canal Command and Krishna Western Delta, respectively in India was studied during the period from 1999-2002. The pre and post drainage agronomic practices were compared by conducting the surveys and crop cut experiments. The pre drainage investigations revealed the problems of the stunted crop growth, poor crop stand, nutrient deficiencies and meagre crop yields in these areas. The crop cut experiments were conducted at 58 grid locations at each of pilot area during the three years (1999-2000, 2000-01 & 2001-02). Post drainage agronomic studies revealed that the rice crop yields after the installation of drainage systems were increased at both pilot areas. At Konanki, the percent increase in rice yield in the area drained by open sub-surface drainage (OSSD) system was 23, 34.5 and 33.6 in the years 1999-2000, 2000-01 and 2001-02, respectively. Similarly, in the area drained by the closed sub-surface drainage system (CSSD), the corresponding percent increase in rice yield was 59, 73 and 75.6, respectively. At Uppugunduru, the percent increase in rice yield were 59, 67 and 86 in the years 1999-2000, 2000-01 and 2001-02, respectively in the area drained by OSSD system. Similarly, in the area drained by the CSSD system, the corresponding percent increase in yields were 23, 17 and 55, respectively. Farmers are very much encouraged by the improvement in soil health in the pilot areas due the installation subsurface drainage systems and they are now going for multiple cropping systems.

Keywords: Salinity, Drainage, Waterlogged, Crop cut experiments

1 INTRODUCTION
The combination of irrigation and drainage is one of the important input factors to maintain and improve the yields in the canal command areas. Drainage is a tool to manage the ground water levels and plays an important role in maintaining the crop yields. A large portion of land in India is currently not being cultivated because of problem of water logging and salinity. The command areas affected by water logging and salinity in Andhra Pradesh are estimated to be 0.274 and 0.115 m ha, respectively. In order to suggest practical solutions for combating these twin problems of water logging and soil salinity, two pilot areas near Konanki and Uppugunduru villages in Prakasham district under NagarjunaSagar project right canal command and Krishna Western Delta, respectively are selected for conducting operational research. The area selected for conducting operational research at both the pilot areas is 21.63 and 20.92 ha, respectively. The cropping pattern in these pilot areas was single crop of rice with long duration varieties.

2 MATERIALS AND METHODS
To study the influence of drainage systems on the rice crop yield at Konanki pilot area, the area has been divided in to six sections based on the predominant soil characters namely southern section, center section, northern section, lowest section, heavy clay section and uncultivated section. Closed horizontal and open sub surface drainage systems were constructed in an area of 8 and 5 ha in central (sandy loam/sandy clay loam) and northern sections (sandy clay loam) of the pilot area respectively. Uppugunduru pilot area has been divided into three blocks namely Block-I, Block-II and Block–III. The Block-I is again subdivided in to three sub-blocks. Closed and open sub-surface systems were installed in an area of seven and five hectares in Block-III (sandy clay loam) and sub-block-ii (sandy clay loam) of the pilot area. Konanki and Uppugunduru pilot areas are located at the ends of NSP Right Canal Command and Krishna Western Delta of Prakasham district in Andhra Pradesh, India. At Konanki, depth to water table, is ranged from 0 to 3.74 m, Electric conductivity (ECe) of soil saturation extract ranged from 1.3 to 18.6 dS/m, pH is ranged from 7.2 to 10.0 and ESP ranged from 14.1 to 54.6. At Uppugunduru, the depth to water table, ranged from 0 to 2.04 m and salinity (ECe) ranged from 1.0 to 52.7 dS/m and pH was range from 6.5 to 8.8. The soils of Konanki and Uppugunduru pilot areas are Clay loam and sandy clay loam, respectively.

3 RESULTS AND DISCUSSION
Crop cut experiments were conducted based on grid locations where the initial soil samples were collected to evaluate the performance of constructed drainage systems at Konanki and Uppugunduru pilot areas. The rice crop yield increased from pre-drainage to post drainage situations in all the sections. The weighted average of crop yields from all the sections at Konanki pilot area has risen from 3.11 t/ha (1998-99) to 5.01t /ha (2001 –2002) showing an increase of 2.27 (52.8%) from all the blocks from pre-drainage to post drainage periods (Table 2). At Uppugunduru pilot area, the percent increase in rice yield were 59, 67 and 86 in the years 1999-2000, 2000-01 and 2001-02, respectively in the area drained by OSSD system. Similarly, in the area drained by the CSSD system, the corresponding percent increase in yields were 23, 17 and 55, respectively. Farmers are very much encouraged by the improvement in soil health in the pilot areas due the installation subsurface drainage systems and they are now going for multiple cropping systems.

ABSTRACT
The effect of subsurface drainage systems on paddy crop yields in saline and water logged soils of Konanki and Uppugunduru pilot areas in Nagarjuna Sagar Right Canal Command and Krishna Western Delta, respectively in India was studied during the period from 1999-2002. The pre and post drainage agronomic practices were compared by conducting the surveys and crop cut experiments. The pre drainage investigations revealed the problems of the stunted crop growth, poor crop stand, nutrient deficiencies and meagre crop yields in these areas. The crop cut experiments were conducted at 58 grid locations at each of pilot area during the three years (1999-2000, 2000-01 & 2001-02). Post drainage agronomic studies revealed that the rice crop yields after the installation of drainage systems were increased at both pilot areas. At Konanki, the percent increase in rice yield in the area drained by open sub-surface drainage (OSSD) system was 23, 34.5 and 33.6 in the years 1999-2000, 2000-01 and 2001-02, respectively. Similarly, in the area drained by the closed sub-surface drainage system (CSSD), the corresponding percent increase in rice yield was 59, 73 and 75.6, respectively. At Uppugunduru, the percent increase in rice yield were 59, 67 and 86 in the years 1999-2000, 2000-01 and 2001-02, respectively in the area drained by OSSD system. Similarly, in the area drained by the CSSD system, the corresponding percent increase in yields were 23, 17 and 55, respectively. Farmers are very much encouraged by the improvement in soil health in the pilot areas due the installation subsurface drainage systems and they are now going for multiple cropping systems.

Keywords: Salinity, Drainage, Waterlogged, Crop cut experiments
Influence of Subsurface Drainage on Rice Crop Yields in Saline and WaterLogged Soils of Konanki and Uppugunduru Pilot Areas of Andhra Pradesh

2000, 2000-01 and 2001-02, respectively in the drained area by Open Sub-Surface Drainage System. Similarly, in the area drained by Closed Sub-Surface Drainage System, the corresponding percent increase in yields during the above three years were 23, 17 and 55, respectively (table 3). The increase in paddy crop yields is due to lowering down the water table to prevent the water logging situation and gone down the salinity to optimum level by leaching of slats through the pipe drains as well as open drains. In addition to this introduction of green manuring and adoption of salt tolerant rice varieties also contributed to improving the soil health and there by increase in the rice yields.

Table 1 Percent Increase in Rice Yields after Installation of Drainage Systems

<table>
<thead>
<tr>
<th>Years</th>
<th>Konanki Pilot Area</th>
<th>Uppugunduru Pilot Area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OSSD</td>
<td>CSSD</td>
</tr>
<tr>
<td>1999-2000</td>
<td>22.6</td>
<td>59.4</td>
</tr>
<tr>
<td>2000-2001</td>
<td>34.5</td>
<td>72.9</td>
</tr>
<tr>
<td>2001-2002</td>
<td>33.6</td>
<td>75.6</td>
</tr>
</tbody>
</table>

4 CONCLUSIONS

1. The sub-surface drainage technology has been found to be successful in improving the crop yields under Indian conditions too.
2. The cropping intensity has been increased due to the reclamation of soils. The farmers have started growing second crop after paddy in the pilot area.

5 REFERENCES

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  Indo-Dutch Network Project, Bapatla.

Table 2 Rice Yields during Pre & Post Drainage Conditions at Konanki Pilot Area

<table>
<thead>
<tr>
<th>6</th>
<th>Section</th>
<th>AREA (Ha)</th>
<th>PREDOMINANT SOIL TYPE</th>
<th>IMPROVED DRAINAGE SYSTEM</th>
<th>IMPROVED IRRIGATION SYSTEM</th>
<th>PRE-DRAINAGE 1998-1999</th>
<th>RICE YIELD (t/ha)</th>
<th>POST-DRAINAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1999-00</td>
<td>2000-01</td>
<td>2001-02</td>
</tr>
<tr>
<td>1</td>
<td>Southern Section</td>
<td>3</td>
<td>Loamy sand</td>
<td>No improvements foreseen</td>
<td>No improvements foreseen</td>
<td>2.83</td>
<td>3.15</td>
<td>3.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(internal drainage / surface drainage)</td>
<td>basin irrigation)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Center Section</td>
<td>8</td>
<td>Sandy loam / sandy clay loam</td>
<td>Closed horizontal subsurface drainage</td>
<td>Improve surface drainage during pre-irrigation, improved leaching)</td>
<td>3.40</td>
<td>5.42</td>
<td>5.88</td>
</tr>
<tr>
<td>3</td>
<td>Northern Section</td>
<td>5</td>
<td>Sandy clay loam</td>
<td>Open subsurface drainage</td>
<td>Improve surface drainage during pre-irrigation, improve leaching</td>
<td>3.54</td>
<td>4.34</td>
<td>4.76</td>
</tr>
<tr>
<td>4</td>
<td>Lowest Section</td>
<td>3</td>
<td>Loamy sand / Sandy loam</td>
<td>No improvements foreseen</td>
<td>No improvements foreseen</td>
<td>3.51</td>
<td>3.68</td>
<td>3.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(surface drainage)</td>
<td>(controlled flooding)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Heavy Clay Section</td>
<td>2</td>
<td>Loamy clay</td>
<td>No improvements foreseen</td>
<td>Improve surface drainage during pre-irrigation</td>
<td>3.88</td>
<td>4.10</td>
<td>4.56</td>
</tr>
<tr>
<td>6</td>
<td>Uncultivated Section</td>
<td>2</td>
<td>Sandy loam</td>
<td>--</td>
<td>--</td>
<td>0.00</td>
<td>2.52</td>
<td>2.2</td>
</tr>
</tbody>
</table>
### Table 3  Rice Yields during Pre & Post Drainage Conditions at Uppugunduru Pilot Area

<table>
<thead>
<tr>
<th>Section</th>
<th>AREA (Ha)</th>
<th>PREDOMINANT SOIL TYPE</th>
<th>IMPROVED DRAINAGE SYSTEM</th>
<th>IMPROVED IRRIGATION SYSTEM</th>
<th>PRE-DRAINAGE 1998-1999</th>
<th>POST-DRAINAGE 1999-00</th>
<th>POST-DRAINAGE 2000-01</th>
<th>POST-DRAINAGE 2001-02</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block- I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i)</td>
<td>0.65</td>
<td>Sandy clay loam</td>
<td>No improvements foreseen (internal / surface drainage)</td>
<td>No improvements foreseen (controlled flooding)</td>
<td>4.06</td>
<td>4.20</td>
<td>5.33</td>
<td>6.75</td>
</tr>
<tr>
<td>ii)</td>
<td>5.0</td>
<td>Sandy clay loam</td>
<td>Open sub surface drainage.</td>
<td>No improvements foreseen (controlled flooding)</td>
<td>3.24</td>
<td>5.54</td>
<td>5.4</td>
<td>6.04</td>
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<tr>
<td>iii)</td>
<td>3.68</td>
<td>Sandy clay loam</td>
<td>Natural drainage / Normal Soil.</td>
<td>No improvements foreseen (controlled flooding)</td>
<td>5.89</td>
<td>6.49</td>
<td>6.28</td>
<td>6.44</td>
</tr>
<tr>
<td>Block - II</td>
<td></td>
<td>Sandy clay loam/ Sandy loam.</td>
<td>Partial sub surface drainage/ Natural drainage.</td>
<td>No improvements foreseen (controlled flooding)</td>
<td>4.59</td>
<td>5.16</td>
<td>5.36</td>
<td>6.27</td>
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<tr>
<td>Block - III</td>
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<td>Sandy clay loam</td>
<td>Closed horizontal sub surface drainage.</td>
<td>No improvements foreseen (controlled flooding)</td>
<td>4.59</td>
<td>5.93</td>
<td>5.39</td>
<td>7.10</td>
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<tr>
<td>Weighted average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>4.3</strong></td>
<td><strong>5.5</strong></td>
<td><strong>5.55</strong></td>
<td><strong>6.57</strong></td>
</tr>
</tbody>
</table>

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[2] Scientist (Agronomy), Senior Scientist (Soil Science) and Principal Scientist (Soil & Water Eng.), Indo-Dutch Network Bridging Project, Acharya N.G.Ranga Agricultural University, Bapatla- 522 101, Andhra Pradesh, India.
Abstract

In Egypt, sewage water has been used to irrigate land for food production for many decades. This practice continues informally through the reuse of drain water, which contains big portion of sewage water. The oldest and most well known formal reuse scheme of raw sewage is at El Gabal El Asfar, East of Cairo. Since the year 1911, about 3,000 feddans (1 feddan = 4200 m²) in El Gabal El Asfar have been irrigated using sewage waste.

Yet, experience of large-scale and organized reuse of treated wastewater effluent is still limited in Egypt. However, there are a number of large-scale pilot projects, mostly irrigating trees beside some field crops, for example in Abu Rawash, Sadat City, Luxor, Ismailia, ... etc. This situation is changing rapidly in the major cities of Egypt due to the installation of modern Waste Water Treatment Plants (WWTPs) that provide secondary treatment that offers an opportunity for water resources planners to fill the gap between supply and demand. The national legislation on effluent reuse has also recently been revised by Decree 44/2000 to bring the standards for effluent quality and conditions of reuse inline with those adopted internationally.

With the recent commissioning of the first stage of El Gabal El Asfar WWTP, and the nearby Berka as well as Shoubra El Kheima WWTPs, there is a large and growing amounts of treated wastewater effluent being produced on the East Bank of Cairo. All of which will eventually be treated to a secondary standard. With a current combined treatment capacity of 2.2 million m³/day, this quantity of effluent is potentially sufficient to irrigate about 100,000 feddans. Large scale field trials were conducted in the successive seasons of 2000/2001 in two sites located about 20 km North East of Cairo; El Gabal El Asfar farm (fertile soil) and El Berka site (virgin soil). The trials aimed at evaluation of the response of selected field crops in terms of productivity and quality due to the reuse of secondary treated effluent for irrigation. The aim of this paper is to evaluate treated effluent reuse impact on crop yield and quality and soil under Egyptian conditions.

The identification of the necessary and appropriate reuse conditions originated from such trials and drawn from international and local experiences, is critical to the development of a cohesive and sustainable treated effluent reuse strategy for Cairo (and elsewhere in Egypt). A key benefit of such trials is in supporting the scientific and practical basis for a national code of practice on effluent reuse.

Keywords: Wastewater, Reuse, Irrigation, Pilot Studies

1. Introduction

Analysis of Egypt’s current water budget shows that the annual water demand exceeds the available fresh water by 6 billion m³/year (Abu Zeid, 1992). Water demand is increasing because of the ambitious land reclamation program, population growth, rural development and expansion of industrial sector. Wastewater has been used to support the agriculture production in many countries e.g., USA, Germany, India, Kuwait, Saudi Arabia, Oman, Jordan and Tunisia (El Sayed, 1997).

Several studies indicated the beneficial role of wastewater reuse in agriculture. It increases crop production with minimal risks to plant, soil, groundwater and health of workers and crop consumers (Palacios et al, 2000). In Egypt, implementation of Greater Cairo Wastewater Project will produce large quantities of secondary treated wastewater, which requires safe disposal. It is estimated that the treated wastewater will eventually reach 4 million m³/day in the next 15 years (Monier, 1998). Agriculture is one of the proposed disposal alternatives. Data about the...
Impact of wastewater treated effluent reuse on agriculture: A case study, Egypt

Impact of wastewater reuse on the soil is limited. In 2001, the National Water Research Center (NWRC) estimated that wastewater could offer about one third of the crop nutrients requirement in sandy calcareous soil in Alexandria. The aim of this work is to evaluate treated effluent reuse impact on crop yield and quality of soil under the Egyptian conditions (NWRC, 2001).

2. Approach and Methodology

2.1 Selection and Setup of the Trial Sites

Large-scale field trials were carried out in summer of 2000 and winter of 2000/2001 on two sites located about 20 km North-East of Cairo. The first site was El Gabal El Asfar farm, which is a Government-owned farm established on desert land in 1911. This site has been irrigated with untreated sewage effluent. Soil was classified as sandy. However, the soil classification has changed to organic-rich and fertile soil with relatively high concentrations of heavy metals. Additional target of this trial was to offer a model for environmental improvements when replacing the current source of partially treated wastewater by secondary effluent. Consequently this could reduce pollution loading within the site. The selected area was about 10 feddans close to the newly established El Gabal El Asfar Waste Water Treatment Plant (WWTP) so that the length of pipelines required for delivering treated effluent to the trial site would be minimized. The second site was within the surrounding region of El Berka WWTP with virgin soil and has nearly the same area as the first. Soil is classified as gravelly sand in El Berka site (Figures 1 and 2).

The trial sites were divided into large experimental units according to the crop and irrigation method. The design of each trial site was based on 16 large plots, eight of which receive effluent only and eight receive effluent plus supplementary fertilizer application to be adjusted for each crop according to normal recommended amount and for site conditions. Four crops were planned to be cultivated during each season on each site, thus there were two replicate plots for each treatment. During the winter of 1999/2000 and the winter of 2000/2001-crop cycle at El Berka the design of the trial was enhanced. The allocation of irrigation method to sixteen main plot areas remained the same, but each plot was divided into four equal portions, so that two crops, with and without fertilizer could be grown on each main plot. This modification provided greater replication and randomization across the site as well as direct comparisons (Final Report, 2001).

2.2 Selection of Crops

According to WHO [1989], only certain crops are permitted to be cultivated when irrigated with treated effluent. Based on WHO guidelines, crop selection included range of food, fodder and industrial (fiber and oil) crops. Most of the selected crops were sown by hand directly in ridges (furrow irrigation) or on the flat ground (drip irrigation crops) or by broadcast, except cotton at El Berka site, which was wet sown. Three irrigation systems were included in the trial to demonstrate and compare their effects on water use efficiency, crop production and potential health and environmental hazards. Surface, drip, and sprinkler irrigation systems were used.

Table (1) presents the crops selected and irrigation systems for each cycle. Sand filters, flow meters and distribution network were installed at each site. Effluent was consistently provided and fully recorded as well as routine maintenance was applied including weekly back-flushing of the sand filters and regular checking for blocked drip emitters. Fertilizers were applied according to the normal recommended rates in Egypt. Nitrogen, Phosphorus, and Potassium were applied as Ammonium Nitrate (33.5% N) Super phosphate (15.5% P₂O₅) and Potassium Sulphate (48% K₂O), respectively.
Impact of Wastewater Treated Effluent Reuse on Agriculture: A Case Study, Egypt

![Figure 2. Schematic Layout of the Plots and Allocation of Irrigation System](image)

Table 1. Tested Crops and Rotation Irrigation Systems

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Site I – El Gabal El Asfar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>Wheat</td>
<td>Soya bean</td>
<td>Canola</td>
</tr>
<tr>
<td>Drip</td>
<td>Faba bean</td>
<td>Maize</td>
<td>Lupin</td>
</tr>
<tr>
<td>Drip</td>
<td>Lupin</td>
<td>Sunflower</td>
<td>Faba bean</td>
</tr>
<tr>
<td>Surface</td>
<td>Berseem</td>
<td>Cotton</td>
<td>Wheat</td>
</tr>
<tr>
<td>Drip</td>
<td>Citrus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Site II – El Berka</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprinkler</td>
<td>Wheat</td>
<td>Soya bean</td>
<td>Canola</td>
</tr>
<tr>
<td>Drip</td>
<td>Faba bean</td>
<td>Maize</td>
<td>Lupin</td>
</tr>
<tr>
<td>Drip</td>
<td>Lupin</td>
<td>Sunflower</td>
<td>Faba bean</td>
</tr>
<tr>
<td>Surface</td>
<td>Berseem</td>
<td>Cotton</td>
<td>Wheat</td>
</tr>
</tbody>
</table>

2.3 Sampling
A comprehensive monitoring program was developed to assess the effects of treated wastewater effluent used for irrigation on the demonstration field trials at both sites. Sampling program included the following elements:

a. Effluent Quality:
Samples of El Gabal El Asfar and El Berka effluents were taken during the crop cycles and analyzed for a range of agronomic, environmental and health parameters. Nutrient and heavy metal loading rates to field trials were calculated to each crop in order to assess the acceptability of these effluent for reuse in the short- and long-term, full-scale operation of the WWTP. Another objective of these analyses was to determine effluent compliance with Egypt limit values (Decree 44/2000).

### b. Crop Growth and Yield Assessment:

During the two crop cycles, the crops were routinely inspected for disease, pests, weed control, and color. At crop maturity, the growth characteristics and yield components were assessed according to the type of crop. The individual plant measurements included plant height and weight, number of branches and tillers per plant. On areal bases, number, weight and dimensions of fruiting organs (pods, capsules, cobs, bolls, spikes, ... etc.) were assessed. The conventional assessment practices were followed to provide mean individual plot performance as well as biological, straw and seed yield per feddan. In this study we focused on the economic yield parameters.

### c. Crop Quality:

Samples of seeds were undertaken at harvest by collecting a number of randomly chosen sub-samples from each plot and mixed to create a representative sample from each plot. Samples were subjected to chemical and microbiological analysis. The parameters determined were nutrients, trace elements, heavy metals, and pathogens (APHA, 1992).

### 3. Results and Discussion

#### 3.1 Effluent Quality

The salinities of the effluents were quite consistent and low, well below the limit value of 2000 mg TDS/l set by Decree 44/2000. Such concentrations represent no major concerns for irrigation of a wide range of crops. The Sodium Adsorption Ratio (SAR) was on average of 6 in El Gabal El Asfar effluent and 4 in El Berka effluent, which are well below the Decree 44/2000 limit (20) for treated effluent. Thus long-term irrigation of these effluents will not cause sodicity or soil permeability problems. The concentrations of Nitrogen and Phosphorus were slightly lower in El Gabal El Asfar effluent than El Berka, but contained more Potassium. Based on these analyses, El Berka had a superior nutrient content and NPK ratio in relation to general crop requirements than El Gabal El Asfar. There are no concerns for potential specific ion toxicity to crops from the long-term irrigation of either effluent. Chloride ion concentration lied within the allowable limits. Boron concentrations were below levels that may cause problems to sensitive crops.

The heavy metal concentrations were very small in both effluents, and well below the limit values for secondary effluent reuse, usually by at least one order of magnitude. Since Zinc deficiency is widespread in Egyptian agriculture, effluent may provide a useful alternative source of this essential trace element. The numbers of Faecal Coliform found in both effluents were at level of 10^5 MPN/100 ml which is far in excess of that permitted, and salmonella were present in all samples. Under Decree 44/2000, secondary treated effluent can only be applied to cultivate processed crops or to non-edible crops provided that effluent achieves faecal coliform concentrations less than 1000 MPN/100 ml (as an indicator of removal of pathogenic bacteria and viruses) and enteric nematode ova number of less than 1/100 m1. However, this is not surprising as neither effluent is currently chlorinated which would be expected to reduce bacteria to permissible levels. Nematode ova were found in all samples of effluent in excess of the limit value for reuse (24 ova/l at El Gabal El Asfar and 49 ova/l at El Berka on the average). Whilst the risks to consumers at these levels would not be significant, field workers were exposed to high risk. Chlorination at levels to achieve Faecal Coliform compliance does not significantly reduce viable nematode numbers. Although high levels of chlorination can achieve adequate nematode kill, there are other environmental considerations due to the formation of trihalomethanes.

#### 3.2 Treated Effluent and Chemical Additions

The irrigation requirements of El Berka were of much greater than at El Gabal El Asfar due to the poor water holding capacity of the soil and need for more leaching to control salinization of the soil surface. Also more effluent was often applied to the unfertilized plots due to the poor growth of some crops, particularly at El Berka, where the natural fertility of the soil was very poor. These quantities of effluent applied to all crops are broadly inline with normal practice, with some exceptions, that are related to the basic water requirement, which varies among crops and the length of the growing season. The effluents of El Gabal El Asfar and El Berka provide a significant proportion of the normal recommended fertilizer rates under both fertile and infertile soil conditions (Table 2). With only one exception, the amounts of Nitrogen applied in effluent were less than the recommended N rate, but this was due to the high irrigation demand of this crop on desert soil and would not normally be grown under these conditions. These observations are important because one of the problems encountered with effluent reuse in other countries, was the over-supply of Nitrogen at normal crop irrigation duties due to the high concentrations in the effluent. This situation can lead to growth at the expense of economic yield and give rise to Nitrate leaching and pollution of groundwater.

The addition of Phosphorus by the effluent was closer to the recommended rates for the crops at both sites, with excess being applied only to cotton and maize. The Potassium contents of...
the effluent were large relative to crop requirements, compared with those for N and P. Consequently; crop requirements for Potassium (as K$_2$O) were generally exceeded by large margins for most crops at both sites. However, Potassium is held strongly by soils, particularly those with high cation exchange capacities, and even where this is exceeded and leaching occurs, it will be adsorbed further down the soil profile. In the long-term, groundwater quality could be affected but not adversely as there are no environmental problems associated with this, other than its contribution to salinity levels.

The data of chemical additions through effluent in both El Berka and El Gabal El Asfar varies according to crop water requirements at the duration of cultivation. The data showed that both El Gabal El Asfar and El Berka soil received small additions of heavy metals. Moreover, some elements such as Cd, Mo, and Co were below the detection limit. Such results clearly indicated the suitability of Cairo effluent for reuse on the agriculture land with minimum pollution threats in the short and long-term.

### 3.3 Crop Analysis

#### 3.3.1 Crop Yields

Detailed measurements of each crop were made at harvest to provide complete description of the growth habit and yield components on an individual plant basis and on an area basis. Crop density had a significant effect on plant growth and yield. Crops under drip irrigation with more widely spaced rows produced larger individual plant yields compared with furrow irrigated plants, but overall yields on an areal basis were smaller. Field crops would not normally be grown under drip irrigation on economic grounds, but this method was used for demonstration purposes in these trials on both sites so that relative crop performance can be compared.

#### Table 2  Proportion of Nutrients Supplied by Treated Effluents to the Field Trials

<table>
<thead>
<tr>
<th>Crop</th>
<th>Fertilizer Recommended (kg/feddan)</th>
<th>Wastewater additions (kg/feddan)</th>
<th>Nutrients Supplied by Effluent as % of Fertilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>P$_2$O$_5$</td>
<td>K$_2$O</td>
</tr>
<tr>
<td><strong>Fertile Soil (El Gabal El Asfar)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>105</td>
<td>15.5</td>
<td>24</td>
</tr>
<tr>
<td>Cotton</td>
<td>64</td>
<td>22.5</td>
<td>48</td>
</tr>
<tr>
<td>Soya bean</td>
<td>45</td>
<td>22.5</td>
<td>24</td>
</tr>
<tr>
<td>Sunflower</td>
<td>45</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>Sesame</td>
<td>30</td>
<td>31</td>
<td>36</td>
</tr>
<tr>
<td><strong>Winter Crops</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheat</td>
<td>80</td>
<td>15.5</td>
<td>24</td>
</tr>
<tr>
<td>Faba bean</td>
<td>45</td>
<td>22.5</td>
<td>24</td>
</tr>
<tr>
<td>Lupin</td>
<td>45</td>
<td>22.5</td>
<td>24</td>
</tr>
<tr>
<td>Canola</td>
<td>45</td>
<td>22.5</td>
<td>24</td>
</tr>
<tr>
<td><strong>Desert Soil (El Berka)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>105</td>
<td>15.5</td>
<td>24</td>
</tr>
<tr>
<td>Cotton</td>
<td>75</td>
<td>22.5</td>
<td>48</td>
</tr>
<tr>
<td>Soya bean</td>
<td>60</td>
<td>22.5</td>
<td>24</td>
</tr>
<tr>
<td>Sunflower</td>
<td>60</td>
<td>31</td>
<td>48</td>
</tr>
</tbody>
</table>
Impact of Wastewater Treated Effluent Reuse on Agriculture: A Case Study, Egypt

3.3.2 Crop quality
Chemical analysis of the economic components of crops demonstrated that nutrient content of NPK did not necessarily increase with fertilizer addition. In many instances it was decreased although few effects were statistically significant. This means that on a crop off-take basis, the fertilized crops utilised the added nutrients more efficiently than from effluent alone, and as a consequence, removed considerably more in the crop due to the much greater biomass production on the fertilized plots. All of the samples analysed had N, P and K concentrations within the normal ranges. The ranges of concentrations of heavy metals are within the normal ranges expected for these crops, and far below levels that would be of concern. Zinc and Copper are essential trace elements, which are often deficient in Egyptian crops due to the generally high pH of soils. However, wastewater especially is expected to have significant amount of Zinc, copper, and may be lead due to rusting of old metal pipes, bends, elbows, and valves.

There were only a few occasions where there statistically significant differences in concentrations in crops irrigated by effluent alone and those that had received additional fertilizers. In general the trend was for smaller concentrations in the fertilised crops due to the dilution effect of greater growth with the additional nutrients. Crop off-take of heavy metals would be much greater from these treatments despite the smaller crop concentration. This demonstrated and confirmed earlier findings (e.g., Cairo Sludge Disposal Study), that the heavy metals in El Gabal El Asfar soil are not readily bio-available for crop uptake and do not represent a threat to the quality of the crops grown on this for human or animal consumption.

The microbiological quality of seed and samples was examined for the presence of total and Faecal Coliform Bacteria, Salmonella, and Helminthes Ova. No pathogenic micro-organisms were found on any of the samples, although as expected there were low numbers of total coliform bacteria (ranges from nil to 4.5 x 10^2 MPN/100 ml). Consequently, the risks of microbial contamination of the edible portion of the crops tested are considered to be small, and any risks are further reduced since only arable crops that are processed, or fruits requiring peeling, prior to consumption may be grown under effluent irrigation. Similar results were obtained by Mahamoud, et al., (1998) and recently under Egyptian conditions by NWRC (2001).

### 3.4 Soil Quality

Soil samples were taken from each plot for physical and chemical analysis, initially to establish a baseline and after each harvest of the three seasons of trials. The first two sets of samples and the last after the third crop were taken at two depths (0-50 cm and 50-100 cm) in order to characterise the soil profile and changes that may occur as a result of treated wastewater irrigation. After the second harvest, samples were taken at 0-30 cm in order to characterize the topsoil in which most of the crop rooting and water and nutrient uptake occurs. The data from the profile samples after the third harvest is summarized in Tables 3 and 4.

<table>
<thead>
<tr>
<th>Winter Crops</th>
<th>Wheat</th>
<th>Faba bean</th>
<th>Lupin</th>
<th>Canola</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100</td>
<td>60</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td>pH</td>
<td>7.3</td>
<td>8.0</td>
<td>7.2</td>
<td>6.9</td>
</tr>
<tr>
<td>EC (ds/m)</td>
<td>1.2</td>
<td>1.5</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>WHC (g/m^2)</td>
<td>1.2</td>
<td>0.8</td>
<td>0.9</td>
<td>0.5</td>
</tr>
<tr>
<td>SBD (g/cm^3)</td>
<td>1.2</td>
<td>0.8</td>
<td>0.9</td>
<td>0.5</td>
</tr>
</tbody>
</table>

As expected, the profile sampling after the third harvest showed that the salinity in the upper layer was larger than in the lower layer, but the differences were not large and there were no apparent effects of the fertilizer or irrigation treatments. The changes in soil salinity over the period of the trials (note that the results for 2nd cycle is only to 30 cm depth) confirm that there was no salt accumulation resulting from treated wastewater irrigation and that the irrigation practices controlled the native salinity through adequate leaching. The cation exchange capacity (CEC) is the ability of soils to retain cations and exchange them with soil solution. Soils rich in organic matter or clay tend to have high CECs, and thus tend to have greater fertility than sandy soils.
soils. The topsoil at El Berka had 13.4 meq/100g, while at El Gabel El Asfar this was much greater at 34.5 meq/100g, reflecting the effect of long-term sewage irrigation and accumulation of organic matter and clay particles. The greater proportion of the exchange capacity of the soil was in the surface 30 cm depth layer while the CEC in the deeper layer (from 30 cm till 50 cm depth) was smaller (13.7 and 8.6 meq/10g at El Gabel El Asfar and El Berka, respectively), and further reduced at 50-100 cm depth (8.6 and 6.7 meq/100g, respectively).

The nutrient content of the soil (as total NPK) at El Berka was much smaller than at El Gabel El Asfar, as this soil had been fertilized or irrigated previously. After the second crop, in comparison with El Gabel El Asfar, the N, P, and K contents of the top soil at El Berka was 32%, 13% and 75% of those at El Gabel El Asfar, respectively. The proportions of NPK at 50-100 cm were about 70-80% of the amounts in the upper layer. However, at El Gabel El Asfar, the pattern was markedly different: in the lower layer the properties of NPK in comparison to the upper layer were 21%, 68% and 103% respectively. These differences can be explained by the proportions NPK exist in sewage in Egypt, which as relatively poor in N and P but rich in K in relation to crop requirements. The data suggests that most of the N and P applied previously has been retained in the surface layer and/or removed by crops, but the excess K leached down the profile, presumably because the adsorptive capacity of the soil for this element was exceeded, resulting in uniform concentration down the 1 m profile of the soil. This is a cumulative effect due to the long period of untreated wastewater irrigation of this site and is unrelated to the use of treated wastewater in irrigation during these trials, although this effect would be perpetuated by continued irrigation. Nitrate concentrations in the top soil were also much smaller at El Berka, (23.7 mg/kg) compared to 106 mg/kg at El Gabel El Asfar, demonstrating the low fertility status on El Berka soil after two seasons of wastewater irrigation.

Table (3): General Chemical Quality of soil profile Samples at Gabel Al Asfar and El Berka (Treatment Means after Third Crop Cycle)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Gabel Al Asfar</th>
<th>El Berka</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WHC (%)</td>
<td>pH</td>
<td>EC (ds/m)</td>
<td>OM (%)</td>
<td>CaCO3 (%)</td>
<td>CEC (meq/100g)</td>
</tr>
<tr>
<td>0-50 cm sampling depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Fertilizer</td>
<td>31.3</td>
<td>6.79</td>
<td>0.27</td>
<td>2.53</td>
<td>2.36</td>
<td>13.5</td>
</tr>
<tr>
<td>With Fertilizer</td>
<td>34.2</td>
<td>6.54</td>
<td>0.34</td>
<td>2.65</td>
<td>2.31</td>
<td>13.9</td>
</tr>
<tr>
<td>Drip</td>
<td>32.5</td>
<td>6.64</td>
<td>0.30</td>
<td>2.52</td>
<td>2.35</td>
<td>13.4</td>
</tr>
<tr>
<td>Surface</td>
<td>32.9</td>
<td>6.70</td>
<td>0.30</td>
<td>2.66</td>
<td>2.33</td>
<td>13.9</td>
</tr>
<tr>
<td>Sprinkler</td>
<td>25.4</td>
<td>4.85</td>
<td>0.59</td>
<td>0.59</td>
<td>4.01</td>
<td>8.8</td>
</tr>
<tr>
<td>Mean</td>
<td>32.7</td>
<td>6.67</td>
<td>0.30</td>
<td>2.59</td>
<td>2.34</td>
<td>13.7</td>
</tr>
<tr>
<td>CV%</td>
<td>15.4</td>
<td>5</td>
<td>149</td>
<td>28.5</td>
<td>27.9</td>
<td>41.3</td>
</tr>
</tbody>
</table>

Table (4): Heavy Metal Concentrations (mg/kg) in Soil Profile Samples at Gabel Al Asfar and El Berka (Treatment Means after Third Crop Cycle)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Gabel Al Asfar</th>
<th>El Berka</th>
<th>Zn</th>
<th>Cu</th>
<th>Cr</th>
<th>Cd</th>
<th>Pb</th>
<th>Ni</th>
<th>Zn</th>
<th>Cu</th>
<th>Cr</th>
<th>Cd</th>
<th>Pb</th>
<th>Ni</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-50 cm sampling depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Fertilizer</td>
<td>66.6</td>
<td>47.9</td>
<td>56.2</td>
<td>0.17</td>
<td>44.7</td>
<td>9.04</td>
<td>17.4</td>
<td>2.5</td>
<td>2.63</td>
<td>0.06</td>
<td>1.89</td>
<td>4.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>With Fertilizer</td>
<td>71</td>
<td>40.8</td>
<td>447</td>
<td>0.11</td>
<td>44.6</td>
<td>9.42</td>
<td>13.9</td>
<td>2.6</td>
<td>2.53</td>
<td>0.03</td>
<td>0.69</td>
<td>3.95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drip</td>
<td>67.3</td>
<td>37.9</td>
<td>43.90</td>
<td>0.1</td>
<td>43</td>
<td>8.66</td>
<td>15.5</td>
<td>2.4</td>
<td>2.42</td>
<td>0.09</td>
<td>1.25</td>
<td>3.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface</td>
<td>70.2</td>
<td>50.80</td>
<td>56.90</td>
<td>0.18</td>
<td>46.2</td>
<td>9.8</td>
<td>13.8</td>
<td>2.3</td>
<td>2.49</td>
<td>0.03</td>
<td>1.92</td>
<td>4.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprinkler</td>
<td>19.5</td>
<td>3</td>
<td>2.92</td>
<td>0.03</td>
<td>2.07</td>
<td>3.81</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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After the third season, Nitrate concentrations in the surface 50 cm layer were marginally greater at both sites where additional fertilizers had been applied. At 50-100 cm depth, concentrations were slightly smaller, but the relative differences between these treatments were maintained. This indicates that small quantities of Nitrate from fertilizer were migrating down the soil profile. However, a comparison between data with the mean values corresponding to the different irrigation methods indicates that irrigation method has no effect on the quantity of Nitrate in either of the two subsequent soil depths at El Gabel El Asfar. At El Berka, the interpretation of the data is more difficult since the value for surface irrigation in the surface layer was inexplicably small (mean of only 9 mg/kg), despite equivalent volumes of wastewater being used for irrigation by all methods. However, the results were comparable to the other treatments at the lower depth indicating that irrigation method did not influence the leaching of Nitrate at El Berka. Since it was not feasible to have a true control treatment in the trials, it is not possible to determine how much Nitrate the wastewater contributed as it was applied to all plots.

Heavy metal concentrations were characterized in the topsoil (0-30 cm) at both sites at the end of the second season. No effects of the treatments (irrigation quantities) were found but this is not surprising since the amounts of heavy metals added by treated wastewater were very small. As expected the concentrations of all heavy metals were much greater in El Gabel El Asfar soil than at El Berka. The concentrations at El Berka were typical of desert soil, and amounts of zinc and copper are marginally deficient for optimum crop production, particularly under the high pH conditions of this site. At El Gabel El Asfar, the concentrations of most elements were an order of magnitude greater, reflecting the ratio of these elements in the untreated wastewater previously used in irrigation. Nevertheless, concentrations were not excessive, being well within international soil quality standards and far below potential toxic threshold. Concentrations were variable, presumably in part due to the preparation of the site for the trails. Even at the maximum concentrations found, these are still with the limit values.

At the end of the third season, soil profile samples were analyzed for heavy metals. In addition to those listed, mercury was analyzed and the concentrations in all samples were below the analytical detection limit. Heavy metals concentrations in the upper 50 cm layer were smaller than those which were found previously in the topsoil indicating that the heavy metals are mostly retained in the rooting zone. At both sites, the concentrations in the lower 50-100 cm layer were much smaller than in the upper layer, indicating that there had been some movement of heavy metals down the soil profile.

After the harvests of the second and third seasons, soil samples were taken and examined for the presence of total and Fecal Coliform Bacteria, Salmonella and Helminth ova. Total coliform bacteria is found in most samples at up to 104 MPN/g. However such levels may be expected in the soil. Fecal coliform and salmonella were not detected in any of the samples. No helminthes ova were found after the second cycle, and occurred in only two samples at El Gabel El Asfar after the third season, but in low numbers (maximum 2 ova/10g). Consequently, the potential health risks to laborers handling soil (e.g. sowing the following season) were very minor.

### 3.5 Groundwater Quality

The data showed considerable spatial and temporal variability at both sites. This trend was most marked at El Berka. There was no discernible relationship between well location and irrigation of treated wastewater on the trails. This may be expected considering the depth to groundwater and the time required for leachate to travel down the unsaturated zone, to have a measurable impact on quality. At El Berka, the water table is much deeper than at El Gabel El Asfar (about 15 m) compared clay layer at 14 m depth at El Berka would impede drainage, and which ultimately would create a water mound that would require a drainage system if this land was under normal agricultural production.

At El Gabel El Asfar the groundwater was notably less polluted than at El Berka, despite the long period of untreated wastewater irrigation activity on this site. There were larger concentrations of nutrients that would probably be derived from untreated wastewater irrigation, but all of the other parameters measured were similar to, or less than, those found at El Berka. The salinity of El Gabel El Asfar groundwater was less than half of that at El Berka (1.17 dS/m compared to 2.34 dS/m in El Berka). Sodium and chloride ion concentrations were also much smaller than at El Berka. Heavy metal concentrations in the groundwater of both sites were similar and small. This is despite the elevated concentrations of heavy metals which have accumulated in El Gabel El Asfar from long-term untreated wastewater irrigation activity, but this data serves to generally susceptible to leaching when applied to soil but is strongly bound. Therefore, it leads to accumulation in top soil.

The numbers of all microrganisms were on average greater at El Berka than at El Gabel El Asfar. While justified at El Gabel El Asfar by the long-term irrigation with untreated wastewater, the source of this contamination is not clear for El Berka site. Reasons could be due to current or former cesspits in the area, or even leakage from the WWTP. At El Berka, 10-57% samples from each well contained salmonella, whereas El Gabel El Asfar, salmonella was not detected in five wells, and the occurrence in the other four wells was only 10-20% of samples.

<table>
<thead>
<tr>
<th>Mean</th>
<th>68.8</th>
<th>44.4</th>
<th>50.4</th>
<th>0.14</th>
<th>44.6</th>
<th>9.23</th>
<th>15.6</th>
<th>2.5</th>
<th>2.58</th>
<th>0.04</th>
<th>1.79</th>
<th>4.22</th>
</tr>
</thead>
<tbody>
<tr>
<td>CV%</td>
<td>23.6</td>
<td>60.1</td>
<td>74.7</td>
<td>79.4</td>
<td>55.3</td>
<td>45.6</td>
<td>50.6</td>
<td>42.1</td>
<td>25.8</td>
<td>118</td>
<td>77.7</td>
<td>37</td>
</tr>
</tbody>
</table>
numbers of fecal coliform were similar at both sites, in the range 102-103 MPN/100ml. Small numbers of parasite ova were also found in the majority of wells, with a greater number occurring at El Berka.

3.6 Health Monitoring of Field Staff
During the course of the three crop cycle some workers have left the project and been replaced by others. In total 15 workers have been screened one or more times according to the period they were engaged in the field trials. To preserve the confidentiality of the workers, a number was allocated to each worker. Four workers screened during the second and third crop cycles. The data shows that their urine and stools were normal, with the exception that three of them amoebic dysentery. Dysentery is common amongst such workers and is likely to be attributed to their living conditions. There were no cases of giardiasis, which had been detected previously, and there were no worm infections, which had been detected in any of the previous examinations.

4. CONCLUSIONS AND recommendations
Cairo’s East WWTPs are the largest source of treated wastewater in Egypt. The establishment of a major reuse scheme is an important economic and technical objective that could serve as a model for other re-use schemes to be developed in Egypt in the future. However, there has been a clear lack of studies that have taken a holistic approach to evaluating the practical options and the potential values, impacts and implications on agriculture, environment and human health. The field trials, and associated monitoring programmes carried out as part of the East Bank Effluent Reuse Study, have successfully demonstrated and assessed the reuse of treated wastewater from El Gabel El Asfar and El Berka WWTPs.

The monitoring of the treated wastewaters from El Gabel El Asfar and El Berka WWTPs has shown that both treated wastewaters have small concentrations of all chemical constituents that are of agronomic and environmental concern for both short-term and long-term reuse, but are well below the national limit values set by Decree 44/2000. The primary concern with these wastewaters for reuse is the potential for human infection by enteric diseases. In order to assess the potential health risks of this quality of treated wastewater in practice, the soils and crops from the trials were examined for fecal coliform and pathogens, but none were found (with the exception of a few soil samples at El Gabel El Asfar that contained very small numbers of helminthes ova). Consequently, the potential risks to the consumer are judged to be minimal. Furthermore, the health monitoring carried out on the workers employed on the trials revealed no discernable occupational risk of enteric infection from handling treated wastewater irrigation equipment (including sprinkler) and irrigated crops and soils. Consequently, the microbiological quality standards required for treated wastewater, coupled with the adoption of safe irrigation practices, are precautionary but necessary to cut potential pathway for human infection.

In addition to the potential treated wastewater-soil chemical interactions, there are concerns for the long-term accumulation of potentially toxic elements (mainly heavy metals) in soil and their impact on crops, which ultimately could cause loss of production or be unsuitable for human and animal consumption. Up to 90% of heavy metals in treated wastewater is transferred to sludge during treatment and concentrations in treated wastewater is generally small. However, heavy metals are strongly retained in soil and do not readily leach, and since treated wastewater irrigation schemes are likely to apply treated wastewater continuously over many decades, there is the potential risk of accumulation in soil. The concentrations of a range of heavy metals were determined in El Gabel El Asfar and El Berka treated wastewaters, and all were at very small levels compared with the maximum limit values adopted in Decree 44/2000, generally 10-100 times smaller. To ensure that the potential risks are fully characterized, soil and crop samples from the field trials were also analyzed.

The concentrations of heavy metals in crops were also well within the normally expected ranges and far below concentrations that would be of concern for crop toxicity or human and animal consumption. Even on El Gabel El Asfar Farm, where concentrations in soil are elevated due to its long history of sewage irrigation, the concentrations in plants were similar to those at El Berka. The potential long-term consequences to soil quality as a result of using treated wastewater for irrigation were modeled. This showed that it would take several hundred years to reach presentations, but if crop off-take is taken into account, then heavy metals input and output there would be more-or-less in balance and there would be minimal net impact on soil quality.

The ratio of nutrients in treated wastewater does not match exactly those required by crops. Under the irrigation duties achieved for the different crops on the two sites, the amounts of N, P and K applied were calculated from the treated wastewater quality and then compared with the normally recommended rates of fertilizer for these crops. This showed that these treated wastewaters would generally provide approximately 50% of N and about 70% of P requirements but about 200% of K requirements, although this varied widely according to the specific crop and whether this was calculated for a fertile or infertile soil. This nutrient ratio is not disadvantageous agronomically or environmentally. It allows farmers to make targeted additions of N and P to achieve optimum yields under the specific local conditions. It also saves the cost of K fertilizer, which is the most expensive nutrient in Egypt and as a consequence farmers tend to apply too little. A major concern for treated wastewater reuse is if nitrogen is added in excess of crop requirement since this can cause excessive crop growth at the detriment of economic yield. Excess nitrogen is at risk of being leached and potentially polluting the groundwater. However, the nitrogen contents of the treated wastewater from El Gabel El Asfar and El Berka WWTPs are quite small, and as a consequence, at normal irrigation duties, the risks of surplus nitrogen and Nitrate leaching are minimal.

http://library.wur.nl/ebooks/drainage/drainage_cd/1.4%20sayed,%20fahmy%20and%20abdel%20gawad.html (11 of 12) 26-4-2010 12:11:01
While treated wastewater does provide a useful contribution to crop nutrient needs, they are applied uniformly throughout the growing period of the crop, whereas fertilizer (specifically nitrogen) is applied deliberately in targeted split applications according to the changing crop requirements during the growing cycle. Irrigation with treated wastewater alone, particularly on low fertility soils, results in poor early crop growth due to nutrient deficiency. So normal levels of fertilizer should be applied during the early growth stages. No consistent effects could be detected in the analysis of either matrix, but this is expected in view of the small chemical additions by the treated wastewater and the treated wastewater/crop supply and demand ratio. The groundwater under both sites were similar and of poor quality, the data displaying large temporal and spatial variations, and would be unsuitable for potable or irrigation purposes. Long-term monitoring would be necessary to determine any effects on groundwater quality since the water table was relatively deep (50- m) and the quality of the treated wastewater was marginally better than the groundwater.

The results should also give confidence to all the stakeholders that the measures under decree 44/2000, supported by the code of practice and specific extension advice that are appropriate and provide a secured framework for the sustainable reuse of the treated wastewater from Cairo east bank and other cities in Egypt.

In an arid country such as Egypt, where water is scarce in general, wastewater reuse should be encouraged and promoted whenever, especially in terms of public health, it is safe and economically feasible. Every effort should be undertaken to safely make use of reclaimed water and encourage development of more treatment facilities. Meanwhile, a National Code shall be issued to control the reuse of wastewater. Results suggested that irrigation of field crops with secondary treated effluent could be an effective means of reusing such wastewater safely for irrigation while maintaining the quality of field crops. Future reuse projects should depend on a better planning and management of reuse operation.

5. References

Ministry of Housing Utilities and Urban Communities Decree No. 44/2000.

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[3] Director, Drainage Research Institute, National Water Research Center, MWRI
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ABSTRACT
The environmental benefits of water table management, controlled drainage and subirrigation are often stated. However, there are few published studies on the benefits of water table management as a method of increasing crop yields. This paper highlights the agronomic benefits of water table management (WTM) to increase grain corn yields. A study was conducted at a large scale WTM research facility in Eastern Canada. During the past two years (2001 and 2002), the region has experienced abnormally low growing season precipitation compared to the long-term rainfall data. The study's results have shown that by keeping the water table at about 80 cm below the soil surface, there were on average 35% increases in grain corn yields, compared to free outlet tile drainage. This increase in yields was due to the fact that there was a higher rate of capillary rise in the subirrigated plots, on the very fine sandy loam found on the field. This is very significant, given that subirrigation is a highly efficient water application technology, and can achieve water use efficiency (WUE) over 80%. Our research confirms that higher crop yields can be achieved with less water, when subirrigation is used.

INTRODUCTION
Water is essential for crop production. However, much of the world's food production comes from regions that experience precipitation deficits during the growing period. Irrigation has proven to be a powerful tool to boost crop production. Even though irrigated land only makes up 18% of the world's cultivated area, it provides an estimated 40% of the world's food production (Cogels 2003; UNESCO-WWAP 2003). The downside of irrigation is that it creates a greater pressure on the available water resources.

Water table management combines the characteristics of controlled drainage and subirrigation. During periods of water deficits, water is provided to the crop from an external source of water, via the tile drainage system (Fig.1). Conversely, when precipitation exceeds the amount of water required by the crop, subirrigation is stopped and a control structure allows for the storage of precipitation water above the drains, which reduces the amount of subirrigation water to be taken from the external source (Amatya et al. 1998; Evans et al. 1995; Tan et al. 1999).

Among the benefits of WTM generally stated in the literature, one can mention the increased water storage capacity, a general decrease of tile drainage flows and outflow volumes (Amatya et al. 1998; Tan et al. 2002), a strong reduction of nitrate concentrations and loads in tile drainage (Elmi 2002; Mejia and Madramootoo 1998). From the agronomic point of view, WTM is interesting, since it allows for the setting of a water table depth adapted for the crops and since it provides the crops with sufficient amounts of water at all times. Furthermore, the water use efficiency (WUE) of subirrigation systems can reach 80% in good conditions (presence of a restrictive layer to prevent deep seepage, flat topography: Dukes; Evans et al. 1992; Shirmohammadi et al. 1992). Based on these facts, the influence of WTM on grain corn yields were investigated to assess its value as a water-efficient way to increase yields.

MATERIALS AND METHODS
2.1 Site Description and Agronomy
The fieldwork took place in Coteau-du-Lac, 60 km of Montréal (Québec, Canada), on a 4.2-ha grain cornfield. The field's topography is flat, as often encountered in the Saint-Laurent lowlands. The soil is a Soulanges very fine sandy loam (Lajoie and Stobbes 1951), and has a depth of 0.5 to 0.9 m, below which clay deposits from the Champlain Sea are found. The limestone bedrock is located at 21 m below the ground surface (Broughton 1972). Fieldwork was carried out from late April 2001 to November 2002. The growing season extended approximately from the beginning of May to late October. The field was ploughed in the fall with a mouldboard plough, and in the spring with a cultivator.
2.2 Experimental design

The design water table depth of the WTM system was set at 0.6 m below the ground level in the treatment plots, whereas drainage was unrestricted in control plots. The WTM system implemented in the field allows the control of the water table for each individual plot. The system uses tanks equipped with a weir and a float valve that alternately control drainage and activate subirrigation, as needed. The field is made of 3 blocks of 8 plots each. The plots’ dimensions are 15 m by 75 m. They are drained individually by subsurface drainpipes installed at a depth of 1 m below the ground surface. The tile drains discharge in two buildings located in the field, where flow from each plot is monitored (Tait et al. 1995). Vertical plastic curtains separate the plots down to an approximate depth of 1.5 m, preventing lateral seepage (Madramootoo et al. 1994). Two treatment plots and two control plots were used in each block, the rest being used as buffers (Fig. 2). Water table management was implemented from the beginning of July to the beginning of October in both years.

2.3 Monitoring of water table depth

Water table observation tubes were used to monitor the water table depth in each plot. In 2001, 6 tubes were installed in each plot, along two lines and at 2, 8 and 13 m from the east border of the plots. In 2002, three lines were used, with one tube per line per plot, at 8 m from the plots’ east border. Weighted averages were calculated to estimate the difference in water table depths between plots under WTM and plots with conventional free drainage. The data used ranged roughly from the beginning of July to the beginning of October in both years.
2.4 Monitoring of soil moisture
In addition to water table depth, soil moisture near the water table observation tubes was monitored. However, the data collection only started at the beginning of September in 2001, whereas it was done throughout the growing season in 2002. Readings were taken on average once a week. A time-domain reflectometry (TDR) probe was used to measure the volumetric soil moisture at a depth of 20 cm.

2.5 Crop yield sampling and analysis
Crop yield samples were taken from three rows in each plot, before harvest. Corn plants were collected along 2.5 m in the centre of each plot. The cobs were dried and shelled. The mass of dry grain was converted into crop yield values in kg/ha to allow comparison with other sources.

2.6 Statistical Analysis
The Statistical Analysis System (SAS, from SAS Institute Inc.) was used for the statistical analysis. Analysis of variance (ANOVA) was chosen to analyse the data. The initial model for each analysis included drainage treatment, block differences and interaction between the block and the drainage treatment. The hypotheses of normal distribution, mean of zero and homogeneous variance for the residuals were not verified, due to the small amount of data. The data were analysed separately for each year.

3 RESULTS AND DISCUSSION

3.1 Climatic data
Both 2001 and 2002 were dry years compared with the average long-term data (Table 1). The precipitation scheme was the same in both years: abundant rainfalls at the beginning of the growing season and dry weather after mid June. From May to October 2001, the field received 12% less precipitation than the long-term average amount for the same period, but the water deficit is much higher if not taken in account the data for May, since more than 25% of the 2001 growing season’s precipitation fell during that month. In 2002, the total amount of precipitation recorded in May and June was nearly twice the long-term average. However, the rest of the growing season was dry and 23% less rain than average fell between July and October 2002.

Table 1  Climatic data from the Coteau-du-Lac weather station
3.2 Water table depth
The average water table depths calculated for both years show that the target of 0.6 m was not reached in plots under WTM, the average being about 0.8 m for both years (Table 2). Fig. 3a and 3b clearly show that WTM kept the water table from growing increasingly deeper, as observed in plots with conventional free drainage. In those plots, the apparent stabilisation of the water table depth around 1.5 m only results from the inability to measure the water table below this level with the water table observation tubes. Nevertheless, the difference in water table depth between plots with conventional free drainage and with WTM was generally greater than 0.6 m during most of the growing season. The clear-cut difference between both drainage treatments is confirmed by the statistical analysis.

3.3 Soil moisture
As observed with water table depth, soil moisture was always much higher in plots under WTM that in plots with conventional free drainage (Table 2). Fig. 4 presents the data for the 2002 growing season. It clearly shows that, whereas soil moisture stabilised around 40% in plots under WTM, it decreased steadily in plots with conventional free drainage and only went up at the beginning of September, when rainfall contribution became important again. However, by that stage, most of the crop’s growth was over and the additional moisture was of little use. In both years, the average soil moisture was more than doubled by WTM and the difference is very strongly significant statistically. The link between water table depth and soil moisture was expected, but these results show that a higher water table effectively provides more water to the crops, even at a greater distance from the water table.

Table 2 Average water table depth and equivalent yearly outflow volumes

<table>
<thead>
<tr>
<th>Period</th>
<th>Average water table depth (m)</th>
<th>Average soil moisture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
<td>2002</td>
</tr>
<tr>
<td>2001</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td>2002</td>
<td>0.77</td>
<td>0.83</td>
</tr>
<tr>
<td>Average FD†</td>
<td>1.41</td>
<td>1.41</td>
</tr>
<tr>
<td>Average WTM‡</td>
<td>0.77</td>
<td>0.83</td>
</tr>
<tr>
<td>trt*block§</td>
<td>NS††</td>
<td>0.0387*</td>
</tr>
<tr>
<td>block¶</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>trt#</td>
<td>&lt; 0.0001***</td>
<td>&lt; 0.0001</td>
</tr>
</tbody>
</table>

† FD: free drainage
‡ WTM: water table management
§ Interaction between the drainage treatment and the block
¶ Block factor
# Drainage treatment factor

(Source: Environment Canada)
3.4 Grain corn yields

For the 2001 and 2002 growing seasons, recorded grain corn yields were in average 2.5 t/ha (35%) higher in plots under WTM than in plots with conventional free drainage (Table 3). This confirms the importance of high water table and soil moisture in the proper development of crops. From this respect, WTM provided more a more constant and more adequate water supply to the crop, especially during dry periods. Consequently, its use results in higher yields. The yield increase was statistically significant both in 2001 and 2002, and the magnitude of the increase makes WTM interesting economically.

Figure 3a Fluctuation of the water table depth during growing season 2001
Figure 3b: Fluctuation of the water table depth during growing season 2002

Figure 4 Fluctuation of the soil moisture during growing season 2002

<table>
<thead>
<tr>
<th></th>
<th>Dry grain (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2001</td>
</tr>
<tr>
<td>Average</td>
<td>6.9</td>
</tr>
</tbody>
</table>
4 CONCLUSIONS

In summary, the use of WTM on a grain cornfield led to a water table depth consistently shallower (by at least 0.6 m) than that observed in plots with conventional free drainage. Volumetric soil moisture at a 20-cm depth was more than doubled in plots under WTM, compared with plots with conventional free drainage. As a result, grain corn yields were significantly increased (35%) both in 2001 and 2002 by the use of WTM.

Primarily due to a problem in the design of the control tanks and to the dry weather, the recorded drain flows were higher in plots under WTM than in plots with conventional free drainage. It is believed that minor changes to the system (such as a greater storage zone) could help improving its water-saving performance and provide a system that increases the crop yields while leading to a reduced use of water compared to traditional systems.

5 REFERENCES


SUBIRRIGATION: A TECHNOLOGY FOR ACHIEVING MORE CROP PER DROP


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ABSTRACT
One of the impacts drainage has on the downstream part of a water system is a higher risk of peak flows caused by heavy precipitation. In polders this is a well known problem. The heavy precipitation flows easily from the paved areas and with some delay from the unpaved areas into to many small canals and through these canals towards the downstream pump station. Here, high water levels occur resulting in an unacceptable high groundwater table. This problem has grown over the past years as more area has been paved and storm events have become more extreme. Until recent, the solution for this problem was to increase the pump capacity, but nowadays the Government’s and Water board’s opinion about solving this problem is changing. Rather than shifting the problem to more downstream lying parts of the water system, the philosophy has become ‘first retain, then store, only then discharge’ (Water Management for the 21st Century).

A way to retain water in upstream parts of the waters system is to use (Real-Time) control structures in the upstream canals. In this paper a control method is presented that can effectively retain water in the upstream parts, until the downstream part can accommodate for this amount of water. The method is based on upstream PI-control with adaptation of the set point. The control is referred to as Cascade PI-Control. Basically, the goal of the control method is to equally fill the available storage in the whole area.

Tests are performed with a calibrated model of an existing polder in the Netherlands. Results show that application of the control method is enough to avoid drainage problems.

Keywords: Real-Time Control, Drainage Control, Polders

1 INTRODUCTION
Large parts of the Netherlands, mainly in the West and North, are cultivated as polder land. These low-land areas serve as agricultural land as well as for living. Many cities, villages and small communities are situated throughout the polders. The water management of the polders is organized to serve the local water level requirements of each part of the polder resulting in many fixed drainage level areas.

During and directly after a storm event the precipitation drains into the many small canals and flows from one area to the next, towards the downstream pump station. Here, the ground water level sometimes rises to an unacceptable level, blocking the drainage from the land. A solution that normally is applied to solve this problem is to enlarge the capacity of the pump station. Clearly, by doing this the problem is shifted to the water system lying downstream of the polder. Recently, the government and the water boards have changed their opinion about this short term solution. New solution should fit into the philosophy “First retain, then store, only then discharge”.

A promising method to retain water, is to utilize the free board that is available in the upstream lying parts of the polder. How much water has to be retained depends on the actual situation and changes over time. This dependence of the actual situation requires measurements and adjustments of the structures between the fixed drainage level areas by means of Real Time Control.
In general, the best way to retain water in the polder and avoid local drainage problems is to continuously strive for an equal filling of all areas. In this article a control method is proposed that can achieve this goal. The method takes the basic requirements on controlled systems into account:

For robustness reasons, the structure of the control must be as simple as the requirements allow it to be;
To be general, tuning rules for the control must be available. In this way, the control method can be tuned without an extensive trial-and-error procedure and it can be re-used on other, similar water systems.
To be cost-effective the method should be applicable with minor infrastructural adjustments to the water system and should use standard hardware as much as possible;

2 CONTROLLED POLDER SYSTEM

A polder is divided into fixed drainage level areas. The polder Zuidplas that serves as a test case in this article consists of 133 areas each with their own set point and maximum allowed water level. The difference between maximum allowed water level and the set point (free board) is available for temporary storage of water. Rather than to use a fixed set point, an adaptive set point can ‘cut off’ the peak in the drainage flow by utilizing this volume in each of the fixed drainage level areas.

The maximum allowed water level is considered as the 100% volume filling of the area. The set point is the normal level, which is considered as the 0% filling. A percentage filling curve can be constructed for the level in between 0% and 100%. The curve is determined by area characteristics like the side slope of canals and extra available storage. In figure 1 and 2 the percentage filling curves of two areas are shown. Area 1 discharges into area 2.

Figure 1 Percentage filling curve area 1  Figure 2 Percentage filling curve area 2

At a certain moment in time area 2 has a water level \( h_2 \). From figure 2 the percentage filling \( V \) is found. If the same percentage is taken from figure 1, level \( h_1 \) can be found. If this level is taken as the set point for area 1, a local controller can steer the water level of area 1 towards this set point. This results in an equal filling of area 1 and 2. To avoid control actions on short wave disturbances (for example from wind effects) a first order discrete filter is applied with the following algorithm:

\[
(1)
\]

with \( k \) the time step index, \( h_{2,\text{fil}} \) the filtered water level of area 2 (m Mean Sea Level), \( f_c \) the filter constant and \( h_2 \) the measured water level in area 2 (m MSL). The filter constant can be chosen such that waves with a time period shorter than \( T_c \) are suppressed:

\[
(2)
\]
with $T_c$ the cross-over period and $T_s$ the sample time.

The local controller in area 1 that brings the water level to set point is a Proportional Integral controller. The algorithm used is the standard incremental PI algorithm [VandeVegte]:

$$
\begin{pmatrix}
\Delta Q \\
K_p \\
K_i \\
e
\end{pmatrix} = \begin{pmatrix}
1 \\
1 \\
0 \\
1
\end{pmatrix}
\begin{pmatrix}
\Delta Q \\
K_p \\
K_i \\
e
\end{pmatrix}
\begin{pmatrix}
0 \\
1
\end{pmatrix}
$$

with $\Delta Q$ the change in discharge (m$^3$/s), $K_p$ the proportional gain, $K_i$ the integral and $e$ the error between set point $r$ and measured water level $h$ (m). The control method is referred to as Cascade PI-control.

Once the discharge is derived, the structure setting is computed. In case of a pump this discharge is imposed or rounded to the nearest stage. In case of a gate the gate position is computed by inverting the structure’s discharge equation using measurements of the local water levels. Figure 3 shows a schematic overview of the control method.

Figure 3  Schematic overview of Cascade PI-control

3  ANALYSIS CONTROL METHOD

To guarantee a proper functioning of the controlled water system the performance and the stability need to be analyzed. If low gains and tight filtering are used the controller reacts too slow. On the other hand, if high gains and a low filter constant are used the controlled water system can become instable resulting in oscillating water levels.
The PI-controller is tuned according to the tuning rules for canals from [Schuurmans]. These rules result in stable control with high performance. If more controlled areas are lying in series the performance can decrease, though. In that case an optimization can be used to tune the controllers [Overloop]. In [Roos] a control system for a large urban drainage system consisting of closed conduits is developed. The local controllers are tuned with the optimization and the cascade set point adaptation is applied.

For the control loop between water level of the downstream area 2 and the set point of area 1 an analysis of the stability is made. For this analysis the parameters of the test case are used. The tests run with the test case show that the performance is sufficient, but the stability needs to be examined in more detail to be sure that no oscillating water levels will occur. The transfer function linearized around the worst case situation is analyzed. The water levels are at set point, so the least storage area that can serve as damping is available. Also the delay times are high as waves travel slower through shallow water [Chow]. The areas are modelled as the Integrator Delay model [Schuurmans] consisting of a delay time with a reservoir in series. The percentage filling transfer function is taken as a constant factor. Figure 4 shows the block scheme of two area is series.

![Figure 4 Block scheme of Cascade PI-control](http://library.wur.nl/ebooks/drainage/drainage_cd/1.2%20p.j%20van%20overloop_ab029.html)

The open loop continues transfer function $H$ is:

\[
(4)
\]

with

\[
(5)
\]

(see figure 1 and 2)

\[
(6)
\]

\[
(7)
\]
with s the Laplace operator, $T_{d,2}$ is the delay time of area 2 (s), $K_{p,1}$ is the Proportional gain of the local controller of area 1, $K_{i,1}$ is the Integral gain of area 1, $K_{p,2}$ is the Proportional gain of area 2, $K_{i,2}$ is the Integral gain of area 2, $e_1$ is the error between set point ($r_1$) and water level ($h_1$) of area 1 (m), $e_2$ is the error between set point ($r_2$) and water level ($h_2$) of area 2 (m), $A_1$ is the storage area of area 1 (m²), $A_2$ is the storage area of area 2 (m²).

The stability is analyzed in a Nyquist diagram (see figure 5) [Matlab]. Here, the Magnitude (ratio of output amplitude to input amplitude) and the Phase angle (phase angle of the output relative to that of the input) of sinusoidal input signals to the open loop transfer function are given as points in the complex plain. The points together form a graph that enables the analysis of the stability.
The point (-1, 0) is not encircled, indicating that the system is stable [VandeVegte]. In table 1 the parameter values are given that are used in the analysis.

**Table 1  Parameter values used in analysis**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_s$ (s)</td>
<td>300</td>
</tr>
<tr>
<td>$T_c$ (s)</td>
<td>600</td>
</tr>
<tr>
<td>$T_{d,2}$ (s)</td>
<td>2700</td>
</tr>
<tr>
<td>$C$</td>
<td>1.57</td>
</tr>
<tr>
<td>$A_1$ (m$^2$)</td>
<td>36000</td>
</tr>
<tr>
<td>$A_2$ (m$^2$)</td>
<td>60000</td>
</tr>
<tr>
<td>$K_{p,1}$</td>
<td>-13.3</td>
</tr>
<tr>
<td>$K_{i,1}$</td>
<td>2.5e-3</td>
</tr>
</tbody>
</table>
4 TEST CASE

The polder Zuidplas of the water board Schieland is used to show the functioning of the control method. A detailed hydro-dynamic is developed [Sobek] that is calibrated with measurements of real storm events [Zuidplas]. On the model the extreme storm event of May 1998 is simulated. In fixed drainage level area 2 the drainage water inundates the surface level due to drainage problems (see figure 6).

![Figure 6](image1.png) Water level in area 2 without control

![Figure 7](image2.png) Water level in area 1 without control

In the upstream lying area 1 there still is storage available during the inundation of area 2 (see figure 7). The discharge between area 1 and 2 is given in figure 8.

![Figure 8](image3.png) Discharge between area 2 and area 1 without control
Now, the inundation/drainage problem is tackled by applying the Cascade PI-control. Figure 9, 10 and 11 show the result of the controlled water system.

![Figure 9](https://example.com/figure9.png)  
**Figure 9**  *Water level in area 2 with control*  

![Figure 10](https://example.com/figure10.png)  
**Figure 10**  *Water level in area 1 with control*  

![Figure 11](https://example.com/figure11.png)  
**Figure 11**  *Discharge between area 2 and area 1 with control*  

It can be seen that the inundation is avoided now. During the period that inundation occurs in area 2 the discharge between area 1 and 2 is decreased by the control.

5  PRACTICAL IMPLEMENTATION

Cascade PI-control can be implemented in a robust and cost-efficient way. Locally, a Programmable Logic Controller together with cable measurements (water level upstream, water level downstream and the gate position) are required. The adaptation of the set point is only required during and directly after a storm event, so this communication system can 'wake up' once a certain water level is exceeded. The communication between the areas can be established by an existing wireless telephone network.
DRAINAGE CONTROL IN WATER MANAGEMENT OF POLDERS

using Short Message Service. Even if this communication fails for a certain period, the local controller will continue to function with its previous set point.

The control units can be applied in a modular way throughout the water system. In the test case for example, the performance of the control method is shown with only two fixed drainage level areas. When more areas are controlled the performance will improve even further, as unused available storage is then utilized in the upstream areas. A sensible procedure is to start with the areas that have maximum problems and to add modular control units in series in upstream direction until the problems are fixed.

6 CONCLUSIONS
A control method is presented that can equally fill the available storage in a water system during and directly after a storm event. In this way local inundation/drainage problems can be avoided. If the control is tuned correctly, the performance is sufficient and the controlled water system is stable.

The Cascade PI-control has a simple structure, is modular and easily applicable.

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WATER PRODUCTIVITY IN THE SYR-DARYA RIVER BASIN: TEMPORAL AND SPATIAL DIFFERENCES[1]

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ABSTRACT
Assessment of water use in the irrigated agriculture through water productivity analysis is a widely accepted approach. It is especially important for water short areas of the world. The possibility of new development of irrigated areas in Central Asia is very limited and also not desirable. Focus needs to be shifted toward the increase of water and land productivity, rather than to developing new areas. Thus, all efforts should be in this direction, and they should become a basis for water use strategy and water conservation. This paper is the first attempt to analyze water productivity spatially (for different levels of water resources management) and temporally (for 3 years - 1999-2001) in the Syr-Darya basin being the largest irrigation system of Central Asia. The analysis includes several types of productivity for 3 types of crops: cotton and rice during the vegetation season (April-September), and wheat during the winter season.

Data used for productivity calculations were collected under the Project “Adoption of Best Practices for Water Conservation in the Syr-Darya and the Amu-Darya River Basins of Central Asia” financed by IWMI.

Keywords: Irrigation, Syr-Darya basin, Water productivity

1 Introduction
The vast irrigation network, nested into the arable lands of the Syr-Darya basin plays an important role in agricultural development of the Central Asian Region. The irrigation system of the basin consists of three parts: conveyance, distribution, and field. The conveyance part includes water diversion, main canals, secondary canals, and the distribution part includes on-farm canals and distributaries (field canals).

At the conveyance, the level the losses in the main and inter-farm network from water intake point to the farm delivery point (with former borders) varies from (10 to 26%); in average - from 20 to 23%. To control these losses, larger investment and broader involvement of governments are required. The water conservation helping to ameliorate water losses at the higher level (irrigation systems, main canals) requires huge investments and workload, and can be fulfilled as a gradual state program.

At the level of on-farm (former) systems, the management and technical losses are averaging to 20-25%. This level has always been under responsibility of water users. During the soviet times, the rehabilitation, maintenance, and operation of on-farm canals and distributaries were under responsibility of kolkhozes and sovkhozes. At present, these canals are under responsibility of newly emerged agricultural and water use units, such as WUAs, shirkats, and cooperatives. These units are very weak financially, and cannot afford fast improvements of the on-farm irrigation infrastructure. The support of donors (both private and state) at the first stage is the main condition for water conservation at the on-farm system.

At the field level water conservation can be achieved by systematic dissemination of “best” water conservation methods being a practical and effective tool. It will not require heavy investments or infrastructure improvements. However, the water conservation at the on-farm level can equally and quickly bring improvements in water conservation.

Water conservation is very important for Central Asian region. The population growth in Central Asia is continuing even in the last 10 year (1990-2000) of the economical and social disharmony. Only in the last decade population growth were around 8 million people or growth rate is 2% (see figure 1). The population growth seriously affect on per capita water use, it dropped from 4500 m3/per capita per year in 1970s to 2500 m3/per capita per year in 2002 or 56% decrease in last 30 years.

Graph 1 Dynamics of population growth and per capita water use in Central Asia.

The same period the productivity of water use ($/m3) dropped around 0.1 $/m3, which equals to 17% decrease, comparing with 1990's level.
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From above discussions one can make following conclusions: first, population growth in Central Asia is very high and region is facing decline of per capita water use, it is much faster, in comparison with other developing countries. As result of economic crisis, the productivity of water use ($/m3) is progressively declining in the last decade and this tendency is continuing.

These all facts are not site specific of Central Asia, rather common for the most irrigated regions of the globe. However, there are some specific problems, which are unique only for the Central Asian region.

Following specific problems makes water management in Central Asia very complicated:

- Environmental pressure
- Drying of Aral sea
- Contamination of water systems
- Vanishing of the delta system
- Drying up small and medium rivers
- Competing Interests: Interstate and intersectorial
- Energy vs. Irrigation
- Upper located and source countries vs. lower located user countries
- Water is economic good vs. Water is environment and social good
- From unique management and economic system to different economical models and political system

The changes in political system (collapse of Soviet Union) and attempts to reform command – administrative economical system lead to fundamental differences among regions countries.

2 Structure of water productivity analysis.

As an output of the above mentioned project, an Access database was created. The database consists of information on water, agriculture, and climate for 1999, 2000, and 2001, for different water units (district water management organization, water users associations, collective, cooperative, and private farms). This database provides an opportunity to compare productivity data for the 3 years for different reaches of the river.

This paper presents the results of the following analysis:

- Comparison of the 3-year data (for 1999-2001) on water productivity by location and type of units;
- Analysis of water productivity on research plots, in which detailed and accurate water accounting was carried out in 2001;
- Analysis of impacts of different water conservation methods on water productivity at pilot plots;

2.1 General Background

The Syr-Darya River basin covers an area of 444,000 km² inhabited by about 18 million of people, with the overall population density of 19 people per km². The Syr-Darya rises in the Tien Shan Mountains, running approximately 2,500 km through the upstream countries, Kyrgyzstan and Tajikistan, flowing through Uzbekistan and Kazakhstan, and finally flowing into the Aral Sea (figure 1).

The average temperature in the basin is 14.2°C, with a range from -15°C to 8°C in January and 18°C to 38°C in July. The annual precipitation ranges from 60 mm at the Kzylorda meteorological station (tail reach) to 502 mm at the Djalalabad meteorological station (upper reach). Evaporation ranges from 1150 mm to 1420 mm throughout the basin.

The eastern part of the Syr-Darya basin is occupied by a mountain region, which belongs to the Kyrgyz Republic (Osh and Djalalabad Provinces). From there originate the Naryn and Karadarya rivers that then form the Syr-Darya. Numerous tributaries of the Syr-
In the beginning of the 1960s, the former Soviet Union (FSU) launched efforts to increase cotton production in Central Asia. The diversion of millions of cubic meters of water to irrigate cotton fields and rice paddies through a massive infrastructure development helped increase the command area from 5 mha in the 1950s to 8 mha in the 1990s. The irrigation infrastructure of the region is described as “one of the most complicated human water development systems in the world” (Raskin, et al. 1992) as human interventions have gradually modified the natural water flow and resource system. The diversions of water for agriculture from the Syr-Darya are almost equal to its total annual inflow. All of the available surface water is virtually diverted to irrigation; it eliminates the scope of further expansion of command areas. The only option to guarantee food security of the region remains improved water management and water productivity.

### 3 Productivity and Allocation of Irrigation Water

#### 3.1 Principles of assessing of water use and water distribution in Central Asia

“How water resources are used?” is a major question of irrigated agriculture in the arid zones. There are different indicators in different parts of the world for analyzing “how water resources are used” (Rao, 1993; Bos and Nugteren, 1974; Levine, 1982; Akhmedov, 1970, Dukhovny, 1985). However, the major goal of such analysis is to improve the existing water management in order to be able to produce enough food for the growing population.

During the “soviet era”, the state of water resources use in Central Asia was evaluated by applying “delivery efficiency coefficient” (DEC) for calculations. These calculations showed how much water from the higher level of system reaches the lower level (e.g., from main canal to inter-farm canal, from inter-farm to on-farm canal, and from on-farm canal to irrigated field). The “delivery efficiency coefficient” calculations represent the share of losses at each level of the system, and how the systems are technically equipped. However, these calculations do not reflect how water resources are used for producing agricultural crops.

The approach of the assessment of water use trough “delivery efficiency coefficient” calculations was fitting very well into the environment of economic system of the former Soviet Union (FSU). As in all socialistic economies, the approach to natural resources, including scarce water resources, was unfrugal. In such economic environment the water use in all sectors of economy was not related with the end product of the sector. However, in municipal and industrial sectors there were legally pending nominal fees for water supply and severe penalties for unregistered and untreated discharge of sewage water. Again, all industrial sectors were state owned, and the regulations were hardly implemented. The few attempts to introduce water fees in the irrigated agriculture failed after 1-2 years of experiments.

In the irrigated agriculture, the main aim of water management units at all levels was to deliver water according to the users’ demands. The demands for water in the irrigated agriculture were collected by district water management organization in the beginning of each irrigation season (there are 2 irrigation seasons in Central Asia: vegetation - April-September, and non-vegetation - October-March). The demands for water were determined according to climatic zones, size of irrigated area, crop type, and soil and groundwater conditions. There are so called “hydromodule districts” within the irrigated zones of Central Asia. For each type of crop, within each hydromodule district recommended water demand norms are calculated. The collected demand for water included all losses above the on-farm level (in main and secondary canals) by dividing the demand by the “delivery efficiency coefficient” of the higher systems. However, the delivery efficiency coefficients of the systems were not monitored, and only “normative” values were used.
used for the calculations. The water allocation principles applied in the FSU had no incentive for conserving and saving water. In many cases the real water supply rates were 2-3 times higher than recommended water demands. The absence of incentives for conserving water resources led to overexploitation of irrigation water.

In the late 1980s, the limitation of water demand was introduced in Central Asia, because the demand for water almost equalized with available water resources of the region. Under the water demand limitation the demands of users were adjusted in accordance with water availability in the sources (rivers, reservoirs, etc.).

After the collapse of the Soviet Union, the Central Asian states did not change at all the water allocation principles. Only in Kyrgyzstan, an upper reach country, the limits were abolished, and in fact water has been delivered according to the users' demand. In the water-scarce states of the region (Uzbekistan, Kazakhstan and Turkmenistan) the limited demand principle of water allocation is still operational.

The principle of limited demand made the process of water allocation more complicated. In reality there are two separate processes of planning and allocating water in irrigated agriculture. The first process consists in collecting the demand from water users, collective/cooperative and private farms, or from users' associations towards higher water management levels (district-province-state). The second process includes the preparation of limits for users; it comes from higher hierarchy of water management (Ministries of Agriculture and Water Management) to lower units (district water management organizations). The "limiting" demands and the collected demands are translated into water use plans at the district level, according to which water is allocated to the users.

### 3.2 Water Accounting and Water Productivity

In many irrigation systems all around the world, the question "how water resources are used" is answered by assessing "how much crop (yield) is produced per unit of water" (Molden, D.; Sakthivadivel, R.; Habib, Z., 2001). However, physical productivity (kg/m³) calculations are very difficult. For project area, physical (kg/m³) water productivity was calculated using the following formula (1).

\[
WP = \frac{Yield}{Water \, Supply}
\]

where: WP is the productivity of water (kg/m³ or $/m³), Output is the output of irrigated agriculture, crop yields (t/ha).

### 4 Calculation of Water Productivity for Syrdarya River Basin

In the research paper physical (kg/m³, kg/ha) water productivities were calculated for 3 years (1999-2001), and for 4 levels of water management (field-farm-district-province).

In all monitored areas the following productivity of irrigation water was calculated:

#### 4.1 Productivity of total surface water supplied to a unit:

In the water management units (farm-rayvodkhoz-oblvodkhoz) higher than the research sites, water accounting is performed to measure total water inflow to the unit. It makes very difficult to calculate physical productivity of irrigation water (kg/m³). The water requirements of different crops are different, rice, cotton, and wheat being the crops with the highest water requirements in the overall cropping pattern of Central Asia. Therefore, physical productivity (kg/m³) calculations are very difficult. In Central Asia, where the share of cotton in the crop pattern varies from 95.9% (South Kazakhstan province) to 40.4% (Osh province), the water requirements of different crops are different, rice, cotton, and wheat being the crops with the highest water requirements in the overall cropping pattern of Central Asia. The high share in the cropping pattern and in water requirement allows us to calculate economical water productivity ($/m³), SGVP is applied. However, physical productivity (kg/m³) calculations are very difficult. For the project area, physical (kg/m³) water productivity was calculated using the following formula (1).

The accurate water accounting requires recording incoming and out flowing water of the area. For accurate water accounting, Pilot Plots (PP) was selected in each district, where all inflows and outflows were measured. Agronomic data (crop development stages), agricultural inputs (agrochemicals, fertilizers etc.) and water supply are the main monitored indicators. The farmers were hired as observers, and they were paid for data submission.

The water measurement was organized using measurement devices. The measurement devices were installed at the inlet and outlet of each PP. The measurement devices (water) are tooled up with a ruler, which shows the depth of water in the ditch. In some PPs, the ruler shows directly the discharge of water in the ditch. The farmer-observer takes records of the readings of the ruler (depth or discharge of water). The monitoring is organized according to the irrigation schedule. At each irrigation a farmer-observer takes records of water depth or discharge. The monitoring of irrigation water supply is organized on hourly basis. The monitoring records of water inflow-outflow were taken using special monitoring forms developed by the SIC ICWC research team. All recorded data were entered into the database for further analysis.

For the project area, physical (kg/m³) water productivity was calculated using the following formula (1).

\[
WP = \frac{Yield}{Water \, Supply}
\]

where: WP is the productivity of water (kg/m³ or $/m³), Output is the output of irrigated agriculture, crop yields (t/ha).

### 4.2 Productivity of supplied surface water and precipitation occurred during irrigation:

In the irrigated areas of the Syr-Darya Basin the precipitation during the irrigation season is very rare, and the efficiency of its use is lower than 15-20%. The precipitation rates vary through years. For taking account of the precipitation impact the water productivity formula (2) is used for calculations:

\[
WP = \frac{Yield}{Water \, Supply + \text{Precipitation}}
\]

where: WP₂ - Water Productivity of Total Water Supply + Precipitation, m3/ton; Precipitation- precipitation during the irrigation season, m3/ha
4.2.1 Per unit productivity of evapo-transpiration:
Biologically crops consume water for evapotranspiration (ET), and the rest of supplied water does not participate in the yield formation. In order to assess the productivity of ET, the following formula (5) is used:

\[ WP_3 - \text{productivity of evapotranspiration, m}^3/\text{tonn} \]

where: \( WP_3 \) - productivity of evapotranspiration, m\(^3\)/tonn; \( ET \) - crop evapotranspiration, m\(^3\)/ha. 

ET for different crops was calculated using the Alpatev method (Kashkarov A.K, et al., 1984), with the following formula:

\[ ET = \text{ref (5a)} \]

where: \( ET_{\text{ref}} = 0.0018 \times 0.8 \times (25 + t)^2 \times (100 - a) \); \( a \)- monthly average of relative air humidity, %; 0.8-coefficient of Molchanov (?); \( t \)- monthly average of air temperature, °C.

\( K_b \)- biological coefficient for different crops (Khasankhonova, 1999).

4.2.2 Field level water productivity:
The water supplied to irrigation system is not fully committed to the irrigation, and a part of it lost during the conveyance to the field. For field level water productivity calculations the following formula (6) is applied:

\[ WP_4 = \text{Productivity of Supplied Water} - \text{Losses, m}^3/\text{tonn} \]

where: \( WP_4 \) - Productivity of Supplied Water - Losses, m\(^3\)/tonn; \( W_{\text{Loses}} \) - total losses of irrigation water (in the irrigation canals +in the field), m\(^3\)/ha;

The losses of irrigation water are classified into several categories, such as losses in the main canal, losses in the interfarm canal, losses in the on-farm canals, infiltration losses in the field, evaporation losses from the soil in the field. Total losses were acquired from the reports of field observers (SIC-ICWC, 2002).

4.2.3 Productivity of irrigation water for “normative” irrigation water supply:
All the above mentioned water productivities are calculated for real water supply rates. However, in the Syr-Darya basin, “normative” irrigation requirements of different crops in different irrigation zones have were designed (Sredazgiprovodkhlopok, 1979), and in theory it is possible to calculate water productivity for “normative” water supply rates.

\[ WP_5 - \text{productivity of evapotranspiration, m}^3/\text{tonn} \]

where: \( WP_5 \) - theoretical productivity of irrigation water for a given crop, m\(^3\)/tonn. \( N_{\text{crop}} \) - “normative” irrigation requirement of given crop (cotton, wheat or rice), m\(^3\)/ha. The “normative” irrigation requirements for cotton are acquired from “Calculated irrigation norms for agricultural crops in the Syr-Darya and Amu-Darya river basins” (Sredazgiprovodkhlopok, 1979), and for wheat and rice from “Meliorative districtifcation (zoning)” (Legostaev M.V., 1951).

4.2.4 Productivity of irrigation water supplied to production units:
Water allocated to different types of farms (collective and cooperative and private) also includes a share of so called “family plots”. The sizes of the family plots are not large (<2 ha), but the number of families in rural areas is high. To exclude the water share of family plots from the production units’ (kolkhoz, cooperative, or private farms) water shares, or, in other words, to calculate “actual” water productivity, the following formula (8) is used:

\[ WP_6 - \text{water productivity, m}^3/\text{ha} \]

where: \( WP_6 \) - water productivity of the total water supplied into the field, m\(^3\)/ha; \( A_{\text{family plots}} \) - total area of family plots, ha; \( N_{\text{family plots}} \) - water requirements for family plots, m\(^3\)/ha.

The sizes of family plots were provided by the report on “Best Practices” project (SIC-ICWC, 2002), while the water requirements were acquired from “Meliorative districtifcation (zoning)” (Legostaev M.V, et. al., 1951).

4.3 Temporal and spatial analysis of water productivity
For a total of 18 collective/cooperative and 24 private farms the water inflow-outflow, crop yields, and agro-economic (prices, inputs, outputs, etc.) indices were monitored. The average size of the CCFs is 15.89 ha, and of PPFs - 128.2 ha.

The productivity of total surface water supplied to a unit (WP1) is the productivity of the total water supplied into the irrigation system (unit), and does not take account for the delivery losses and water supply to family plots. The highest of the WP1 for cotton (0.60 kg/1000 m\(^3\)) was reached in 2001 at the upper reach (PPFs), while the lowest (0.31 kg/1000 m\(^3\)) WP1 was two times less, and it occurred at the upper reach in 2001 (CCFs). The difference in the WP1s is related to water supply rates, sizes of units, and crop yields. In 2001, water supply rates were 13-15% higher, than in 2000, and 16-17% higher, than in 1999; in the crop yields were 3-5% less than in 2000 and 7-8% less than in 1999 (average of CCF-PPF).

The productivity of supplied surface water and precipitation occurred during irrigation (WP2): this shows the productivity of surface water and precipitations, occurred during the vegetation season (April-September). The maximum WP2 (0.55 kg/kilo m\(^3\)) was observed at the upper reach in 2000 (PPFs), there is very small difference between WP1 and WP2 (0.05 kg/m\(^3\)). It is because the precipitation during the vegetation season was very low, and it really did not have a true impact on the water use. The lowest WP2 (0.30 kg/1000 m\(^3\)) was at the upper reach in 2001 (CCFs).

The productivity of per unit of evapotranspiration (WP3): it shows the productivity of the water, which the crops used for evapotranspiration. It is very difficult to distinguish difference between evaporation from the field and transpiration from the crops. WP3 presents the productivity of both, water evaporated from the field and transpired by the crops. The highest (0.43 kg/1000 m\(^3\)) and lowest (0.23 kg/m\(^3\)) WP3 were at the upper reach in 2000 and 2001 respectively. The big differences between WP1 and WP3 may be explained by higher ET levels; on all pilot areas the ET was much higher, than water supply. It shows that in many parts of the SRB deficit irrigation was practiced, and demonstrates the importance of ground waters in the ET.
The field level water productivity (WP4): it shows the productivity of water, excluding the delivery losses, and it has the highest values. The WP4 varies from 0.67 kg/1000 to 0.38 kg/1000 m³ for cotton and 0.31 kg/1000 m³ to 0.19 kg/1000 m³. The highest and lowest values of WP1 and WP4 for cotton did not show a big difference (0.07 kg/1000 m³ only). This result contradicts to the widely accepted theory of huge losses at the on-farm level. According to the research sources (SIC, IWMI 2001) the losses at the on-farm (former) level are averaging 20 to 25%. The difference between WP4 and WP1 is less than 10%, or the productivity of water (including losses) is 10% less, than the one, which excludes such losses. It means the losses at the on-farm level are not higher, than 10%.

The productivity of irrigation water for “normative” irrigation water supply (WP5): it shows what would have been the productivity of water, if water users had followed the established irrigation water supply rates for specific areas. The WP5 varies from 0.64 kg/1000 m³ at the middle reach (PPFs) in year 2000, to 0.28 kg/1000 m³ at the upper reach (CCFs) in 2001. The highest water productivity (WP5) was observed in the areas where the actual water supply rate was the highest (8100 m³/ha and 8000 m³/ha, respectively). The productivity of irrigation water supplied to production units (WP6): it shows the real productivity of water supplied to the area under a specific crop. In the calculation of WP6 all losses, as well as the water supply to the neighboring family plots are excluded. The WP6 has the highest value among the other types of water productivity calculations. The highest water productivity (WP6) was calculated at the upper reach (PPFs) in 2000, and the lowest value of the WP6 was observed at the upper reach (CCFs) in 2001.

In 1999, the highest water productivity occurred at the middle reach (0.47 kg/1000 m³) at the private farm level (PPF), while the lowest was (0.13 kg/1000 m³) at the collective/cooperative farm level (CCF) at the tail reach.

In 2000, the maximum water productivity (0.60 kg/1000 m³) was at the middle reach at the private farm level, and the minimum (0.17 kg/1000 m³) was at the tail reach at the CCF level.

In year 2001, the highest water productivity was again at the middle reach (0.52 kg/1000 m³) at the CCF level, and the lowest water productivity (0.07 kg/1000 m³) was at the tail reach at the CCF level.

**Table 1  Productivity of Water at Farm Level (1999-2001)**

<table>
<thead>
<tr>
<th>Reach</th>
<th>Type of unit</th>
<th>Year</th>
<th>Number of Monitored Farms</th>
<th>Average Size, ha</th>
<th>Average water supply rate, m³/ha</th>
<th>WP1 kg/m³ of water supply</th>
<th>WP2 kg/m³ of water supply + precipitation</th>
<th>WP3 kg/ET</th>
<th>WP4 Kg/water supply-losses +precipitation</th>
<th>WP5 Kg/irrigation requirement</th>
<th>WP6 Kg/water supply to the field</th>
<th>WP average</th>
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<td>4</td>
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<td>0.36</td>
<td>0.35</td>
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<tr>
<td></td>
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<td>2001</td>
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<td>0.42</td>
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<td></td>
<td>2000</td>
<td></td>
<td></td>
<td>20000</td>
<td>0.24</td>
<td>0.24</td>
<td>0.26</td>
<td>0.31</td>
<td>0.19</td>
<td>0.33</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2001</td>
<td></td>
<td></td>
<td>24000</td>
<td>0.18</td>
<td>0.18</td>
<td>0.22</td>
<td>0.23</td>
<td>0.17</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td></td>
<td>PPF</td>
<td>1999</td>
<td>4</td>
<td>293.5</td>
<td>19000</td>
<td>0.15</td>
<td>0.15</td>
<td>0.16</td>
<td>0.19</td>
<td>0.12</td>
<td>0.19</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2000</td>
<td></td>
<td></td>
<td>19500</td>
<td>0.26</td>
<td>0.25</td>
<td>0.28</td>
<td>0.31</td>
<td>0.20</td>
<td>0.31</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2001</td>
<td></td>
<td></td>
<td>21400</td>
<td>0.16</td>
<td>0.16</td>
<td>0.18</td>
<td>0.20</td>
<td>0.14</td>
<td>0.16</td>
<td>0.17</td>
</tr>
<tr>
<td>Average</td>
<td>CCF</td>
<td>1999</td>
<td>18</td>
<td>1558.9</td>
<td>10800</td>
<td>0.35</td>
<td>0.34</td>
<td>0.27</td>
<td>0.42</td>
<td>0.35</td>
<td>0.42</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2000</td>
<td></td>
<td></td>
<td>11100</td>
<td>0.35</td>
<td>0.34</td>
<td>0.28</td>
<td>0.42</td>
<td>0.36</td>
<td>0.42</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2001</td>
<td></td>
<td></td>
<td>13000</td>
<td>0.31</td>
<td>0.31</td>
<td>0.24</td>
<td>0.38</td>
<td>0.34</td>
<td>0.37</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>PPF</td>
<td>1999</td>
<td>24</td>
<td>128.2</td>
<td>11200</td>
<td>0.34</td>
<td>0.33</td>
<td>0.25</td>
<td>0.39</td>
<td>0.34</td>
<td>0.38</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2000</td>
<td></td>
<td></td>
<td>11200</td>
<td>0.47</td>
<td>0.46</td>
<td>0.34</td>
<td>0.55</td>
<td>0.43</td>
<td>0.53</td>
<td>0.47</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2001</td>
<td></td>
<td></td>
<td>12000</td>
<td>0.36</td>
<td>0.36</td>
<td>0.26</td>
<td>0.43</td>
<td>0.39</td>
<td>0.41</td>
<td>0.37</td>
</tr>
</tbody>
</table>
Temporally, the highest water productivity during 1999-2001 was observed at the middle reach (0.60 kg/1000 m³) in 2000. It can be explained by very low water availability during this year. In 2001, the lowest water productivity (0.07 kg/1000 m³) occurred. The water productivity fluctuations in time are mostly related to water availability of the specific year: the lowest water productivity (in 2001) at the highest water availability and vice versa.

Territorially (spatially), the lowest water productivity was at the tail reach of the basin, at the CCF level. It may be explained by natural conditions of area (saline and low fertile soils), and by the size of agricultural units (200-2500 ha). The crop yields (cotton) in tail reach of Syr Darya (South Kazakhstan) 50-60% less than in middle reach and 30-40% less than in upper reach. It may be caused by high salinity of tail irrigated areas and impact of speedy land fragmentation in South Kazakhstan. Also, tail reach farmers have difficulties on receiving fertilizers, good quality seeds of cotton. In the middle reach (Tajikistan and Uzbekistan) still centralized supplies of seeds, fertilizers exist. In the upper reach (Kyrgyzstan) thanks to cooperation farmers were able to easy problems with supplies.

However, not only supplies are the major problem of tail farmers. Irrigated area of tail (South Kazakhstan) located in the tail of “Dustlik” canal, which takes water of Syr Darya in Tajikistan, flows through Uzbekistan, while supplying water to around 60,000-70,000 ha irrigated area and only then flowing into South Kazakhstan (tail). Farmers in tail were able irrigated their cotton in 1999 only one time and only two times in 2000.

In rice growing tail (Kzylorda) situation is reverse. Area has several water withdrawing points from Syr Darya. The rice growing tail has highest water supply rates 18,000 to 21,000 m³/ha, highest ET values (15,000-20,000 m³/ha) and low rice yields. ET is high, because of high ground water tables, 0.5-0.6 meters from soil surface in irrigated season and 1.0-1.5 meters during winter season. The role of evaporation (E) in total ET almost 60-65%.

Water productivity at the Pilot Plots. A total of 42 pilot plots (PP) were observed for water and all other inputs. The water inflowing and out flowing from the PPs was strictly measured with the water measuring devices during each irrigation. The crop yields were observed and recorded according to the methodology developed by scientists for crop development monitoring (phenological monitoring).

In the table 2 there are presented the results of water productivity analysis at the PPs. Again, the analysis was made for the 3 reaches of the SRB and for 2 types of the farm units (CCF and PPF). The water productivity was calculated for 2001, because the monitoring of the PPs was introduced only that year. The water productivity for cotton was calculated for upper and middle reaches, and for rice - only for the tail reach.

<table>
<thead>
<tr>
<th>Reach</th>
<th>Type of unit</th>
<th>Number of Pilot plots</th>
<th>Water Productivity for Cotton, kg/1000 m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head CCF</td>
<td>4</td>
<td>WP1: 0.42, WP2: 0.28, WP3: 0.50, Wpaverage: 0.40</td>
<td></td>
</tr>
<tr>
<td>PPF</td>
<td>3</td>
<td>WP1: 0.41, WP2: 0.32, WP3: 0.48, Wpaverage: 0.40</td>
<td></td>
</tr>
<tr>
<td>Middle CCF</td>
<td>10</td>
<td>WP1: 0.53, WP2: 0.32, WP3: 0.57, Wpaverage: 0.47</td>
<td></td>
</tr>
<tr>
<td>PPF</td>
<td>12</td>
<td>WP1: 0.65, WP2: 0.30, WP3: 0.63, Wpaverage: 0.51</td>
<td></td>
</tr>
<tr>
<td>Average CCF</td>
<td>14</td>
<td>WP1: 0.48, WP2: 0.30, WP3: 0.54, Wpaverage: 0.44</td>
<td></td>
</tr>
<tr>
<td>PPF</td>
<td>20</td>
<td>WP1: 0.53, WP2: 0.31, WP3: 0.56, Wpaverage: 0.46</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Reach</th>
<th>Type of unit</th>
<th>Water Productivity for Rice (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tail CCF</td>
<td>4</td>
<td>WP1: 0.25, WP2: 0.26, WP3: 0.30, Wpaverage: 0.27</td>
</tr>
<tr>
<td>PPF</td>
<td>4</td>
<td>WP1: 0.18, WP2: 0.18, WP3: 0.21, Wpaverage: 0.19</td>
</tr>
</tbody>
</table>

There are calculated 3 types of water productivity (WP1, WP2 and WP3), because there are no delivery losses, and no water is supplied to neighboring family plots. The average water productivity on the PPs varies from 0.30 to 0.54 kg/1000 m³ at the CCF level,
and from 0.31 to 0.56 kg/1000 m³ at the PPF level. The highest water productivity (WP1) for cotton was observed (0.65 kg/1000 m³- WP1) at the middle reach at the PPF level, and for rice - 0.25 kg/1000 m³, at the tail reach at the CCF level. The highest water productivity was mainly due to high crop yields.

The 3 types of the calculated water productivity were plotted in a descending order, from the highest to the lowest (see figure 3). The WP3 (productivity of evapo-transpiration) is higher, than WP1 and WP2. It means irrigation water supply at the PPs was sufficient to cover biological requirements of crops, and soil evaporation.

The WP2 (productivity of irrigation water + precipitation) is less than average water productivity (average of WP1, WP2 and WP3), and it shows, that in 2001 precipitation rates were high, and their share in the crop irrigation was also high.

5 Conclusions

- Analysis of the water productivity in Syr Darya basin temporally and spatially showed, that in the drier year (1999) water productivity higher, than in normal water availability year (2001).
- Physical water productivity in Syr Darya basin (wp1, kg/m³) 20% higher, when delivery losses are excluded from water supply (wp4) or water delivered to family plots are ignored (wp6). The elimination of delivery losses or tighter control of water use for non-crop production may be potential for increasing productivity of irrigation water in Syr Darya basin;
- Et productivity is lowest among all other versions of water productivity in Syr Darya basin. Evaporation (e) portion of et is very high, because of very high ground water tables in the irrigated areas of basin. It is very good approach on improving water management and productivity of water use in Syr Darya basin.

Figure 3 Water productivity on Cotton at the Pilot Plots

6 References


ABSTRACT
The field experimental carried out during winter season 1999-2000 in Zankloun research station, Water management research institute, (NWRC), Sharkia Governorate, to study the effect of different irrigation water amounts (100, 90, 85, 80 and 75%) of field capacity on yield production and water use efficiency to maximize both production and water use efficiency, Randomize block design with four replicates was used in this study.

The results showed that there was no significant difference between the effect of levels 100% of field capacity (F.C) and 90% F.C. for plant roots volume and roots weight. The seasonal irrigation water applied were (2334, 2179, 2122, 1979 and 1947 m3/fed) under different irrigation water treatments (100, 90, 85, 80 and 75%) of F.C. respectively and the roots yield production under aforementioned treatments were 21.35, 22.23, 18.20, 17.67 and 17.17 (tone/fed.) respectively, also the obtained results shown that water use efficiency (WUE) at different treatments were (9.15, 10.20, 9.0, 8.93 and 8.82) Kg/m3 for (100, 90, 85, 80 and 75%) of field capacity, so the 90 % F.C treatment is highly recommended for Sugar Beet irrigation for water saving.

The result obtained that the treatment of 90 % of filed capacity seemed to be better adopted to product a high crop yield with acceptable yield quality coupling with water use efficiency at Eastern Delta region.

1 INTRODUCTION
Sugar beet has become one of the major winter field crops in Egypt due to its high income to the farmers. Sugar beet can be irrigated with about one-fourth the water utilized by sugar cane, the other source of sugar around the world. Production and water relations of sugar beet has been widely investigated by many researchers; Howell et al (1987), Bailey (1990), Emara (1990), Ibrahim et al (1992) and 1993 showed that irrigating every two or three weeks, especially for the second half of the growing season of the sugar beet resulted in high yield. The values of water consumptive use were 58.06, 55.04 and 49.86 cm /fed. for the 2, 3 and 4 weeks intervals, respectively.

The water use efficiency of 8.66 kg for sugar beet root could be obtained from each cubic meter of water consumed. Eid (1994) studied the effect of irrigation depths (4, 6 and 8 cm) and intervals (7, 14 and 21 days) on sugar beet at Sakha. He found that with increasing the irrigation interval, soil moisture content decreased clearly especially when accompanied with the least water applied of 4 cm and the longest period of 21 days. Dawlatz et al (1995) showed that the highest sugar beet yield and sugar production were obtained from 37.8 m2 plot area.

Actual evapo-transpiration (ET) values of the average two seasons were 41.51, 42.26, 45.01, 48.19 and 50.85 cm for 25.2, 37.8, 50.4, 58.8 and 67.2 m2 plot area treatments respectively. Shams (2000) showed that the treatment irrigated at field capacity plus 5% recorded the highest values of water consumptive use (2479.4 and 2563.34 m3/fed.) for the 1st and 2nd seasons, respectively. The lowest value of water applied was recorded by irrigation at field capacity minus 5% and soil moisture depth of 30 cm, which achieved the highest value of water use efficiency.

Sugar beat production could be increased through cultivation of high yield varieties and appropriate agronomic practices. Among the most important practices is water management. The increased emphasis on crop water relation can be attributed to its role as a controlling factor in crop production. It would be obviously valuable to know these relation for crop because much can be concluded in regard to water policy and optimizing of water use.

The present investigation was initiated to study the effect of irrigation system and water stress on sugar beet yield and its water relations.

2 MATERIALS AND METHODS
The field experimental carried out in a clay soil in Zankloun research station, Water management research institute, (NWRC), Sharkia Governorate, Egypt. Some physical and chemical proprieties of soil were determined according to FAO (1976) and Black (1965) and presented in Tables (2 & 3) respectively.
Table 1  Some physical properties of the experiment soil.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>FC (%) w/w</th>
<th>WP (%) w/w</th>
<th>AW (%)</th>
<th>Bd (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>46.02</td>
<td>25.43</td>
<td>20.59</td>
<td>1.19</td>
</tr>
<tr>
<td>10-20</td>
<td>41.00</td>
<td>21.67</td>
<td>19.23</td>
<td>1.25</td>
</tr>
<tr>
<td>20-30</td>
<td>38.50</td>
<td>18.82</td>
<td>19.68</td>
<td>1.32</td>
</tr>
<tr>
<td>30-40</td>
<td>37.50</td>
<td>18.29</td>
<td>19.21</td>
<td>1.33</td>
</tr>
<tr>
<td>40-55</td>
<td>36.50</td>
<td>17.21</td>
<td>19.29</td>
<td>1.33</td>
</tr>
<tr>
<td>50-60</td>
<td>36.00</td>
<td>16.03</td>
<td>19.97</td>
<td>1.34</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Particles</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>42.60</td>
<td>30.50</td>
<td>26.90</td>
</tr>
</tbody>
</table>

The average of permeability rate at soil depth of (1m) = 0.025 mm/day
The average of permeability rate at soil depth of (2m) = 0.044 mm/day

Table 2  Some chemical properties of the experiment soil.

<table>
<thead>
<tr>
<th>PH</th>
<th>EC (dS/m)</th>
<th>TDS (ppm)</th>
<th>Na⁺ (meq/100g soil)</th>
<th>Ca⁺⁺ (meq/100g soil)</th>
<th>Mg⁺⁺ (meq/100g soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>1.23</td>
<td>787.2</td>
<td>1.98</td>
<td>0.79</td>
<td>0.04</td>
</tr>
</tbody>
</table>

2.1  Irrigation water:
The irrigation water used for the experiment was from mouis canal with average electrical conductivity of (0.23 dS/m).

2.2  Plots areas:
As shown in fig (1) each plot has area of 375 square meters and it was irrigated using a raised lined irrigation network with controlled gates.

2.3  Sowing proceeding:
Sugar beet was sown on the 15 of Nov.1999 of the growing successive season. Fertilizers were added at the recommended rate of Ministry of Agriculture (70 kg N, 15kg P₂O₅, and 100kg k₂SO₄) per feddan. The data were statistically analyzed (sedeor and Cochran 1980). The following characters were studied:

2.4  Sugar beet yield:
- Root yield was recorded in ton/fed.
Sucrose percentage was determined polarly metrically in lead acetate.

Extract of fresh roots according to method described by le – Decote (1927).

Amount of irrigation water applied was measured by cut-throat flume (20 x 90 cm) and calculated as m³/ fed. (Early 1975).

2.5 Water consumptive use:
-Water consumptive use computed as the difference in the soil moisture content after and before irrigation according to the following equation by Israel son and Hansen (1962).

\[ Cu = D \times Bd \times \frac{(\partial_2 - \partial_1)}{100} \]  

Where:

- \( Cu \) = Water consumptive use m³/ fed.
- \( D \) = soil depth
- \( Bd \) = soil bulk density (g/cm³)
- \( \partial_1 \) = soil moisture content before irrigation (% by weight).
- \( \partial_2 \) = soil moisture content after irrigation or after 48 hours (% by weight).

- Seasonal water consumptive use is the sum of the figures computed for each irrigation application.
- Reference evapo-transpiration and crop coefficient it was estimated using meteorological data measured at Zankloun research station (Table 3). Planey-Criddle method are used.

\[ ETO = a + b \times (p \times (0.46T + 8.13)) \]  

Where

- \( ETO \) - reference crop evapo-transpiration (mm/day)
- \( a \) & \( b \) – Two coefficient which depend on minimum relative humidity (RH min), sunshine hours (n/N) and day time wind speed (Uz)
- \( P \) – Mean daily percentage of total annual day time hours for given month latitude.
- \( T \) – Mean daily temperature in °C.

Accordingly the crop coefficient \( K_c \) was calculated under the prevailing condition as follows:

\[ K_c = \frac{Cu}{ETO} \]  

2.6 Meteorological Data:
Meteorological data collected through weathering station, this data utilized for evapotranspiration calculation, the average of meteorological data of cropping period are presented in table (3).

<table>
<thead>
<tr>
<th>Month</th>
<th>Temperature (°C)</th>
<th>Class pan (mm/day)</th>
<th>Wind speed (m/sec)</th>
<th>Rainfall mm</th>
<th>RH (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Max.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov. 1999</td>
<td>8.1</td>
<td>23.4</td>
<td>2.55</td>
<td>1.51</td>
<td>2.30</td>
</tr>
<tr>
<td>Dec. 1999</td>
<td>7.3</td>
<td>21.8</td>
<td>2.58</td>
<td>1.42</td>
<td>1.42</td>
</tr>
<tr>
<td>Jan. 2000</td>
<td>4.2</td>
<td>18.1</td>
<td>2.08</td>
<td>1.72</td>
<td>14.4</td>
</tr>
<tr>
<td>Feb. 2000</td>
<td>4.3</td>
<td>19.3</td>
<td>2.56</td>
<td>1.11</td>
<td>0</td>
</tr>
<tr>
<td>Mar. 2000</td>
<td>5.9</td>
<td>20.6</td>
<td>3.29</td>
<td>1.30</td>
<td>4.6</td>
</tr>
<tr>
<td>Apr. 2000</td>
<td>11.3</td>
<td>27.2</td>
<td>5.24</td>
<td>1.35</td>
<td>0</td>
</tr>
<tr>
<td>May 2000</td>
<td>13.2</td>
<td>32.0</td>
<td>8.45</td>
<td>1.66</td>
<td>0</td>
</tr>
</tbody>
</table>

2.7 Crop water use efficiency:
It was calculated according to Michael (1978):

\[ CWU.E = \frac{Y}{Cu} \]
Where:
- $CWU.E = \text{crop water use efficiency (kg/m}^3\text{)}$
- $Y = \text{root yield (kg/fed.)}$
- $CU = \text{water consumptive use (m}^3\text{fed.).}$

**Field water use efficiency:**
The field water use efficiency was calculated as reported by Michael (1978).

$$FWUE = \frac{Y}{WR} \quad \ldots(5)$$

Where:
- $FWUE = \text{field water use efficiency (kg/m}^3\text{)}$
- $Y = \text{root yield (kg/fed.)}$
- $WR = \text{water delivered to the field (m}^3\text{fed.).}$

### 3 RESULT AND DISCUSSION

#### 3.1 Effect of different irrigation water amounts on sugar beet roots yield:
Data presented in table (4) and fig (4) showed the effect of different irrigation water amounts on sugar beet yield. The statistical analysis of data using f test indicated that, the different irrigation water treatments had no significant effect on the productivity of root yield. Treatment field capacity of –10% achieved the highest value (22.225 ton/fed) while treatment field capacity of –25% recorded the lowest value of (17.175 ton/fed.)

#### 3.2 Crop water use efficiency:
It was calculated according to Michael (1978):

$$CWU.E = \frac{Y}{CU} \quad \ldots(4)$$

Where:
- $CWU.E = \text{crop water use efficiency (kg/m}^3\text{)}$
- $Y = \text{root yield (kg/fed.)}$
- $CU = \text{water consumptive use (m}^3\text{fed.).}$

#### 3.3 Field water use efficiency:
The field water use efficiency was calculated as reported by Michael (1978).

$$FWUE = \frac{Y}{WR} \quad (5)$$

Where:
- $FWUE = \text{field water use efficiency (kg/m}^3\text{)}$
- $Y = \text{root yield (kg/fed.)}$
- $WR = \text{water delivered to the field (m}^3\text{fed.).}$

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Figure 2 shows the evolution of maximum and minimum temperature.

Figure 3 shows the evolution of Class pan and rainfall.

Table 4 shows Sugar beet Root yield as affected by different irrigation water amount.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Sugar beet yield (ton/fed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F.C.</td>
<td>21.35</td>
</tr>
<tr>
<td>-10% of F.C.</td>
<td>22.225</td>
</tr>
<tr>
<td>-15% of F.C.</td>
<td>18.2</td>
</tr>
<tr>
<td>-20% of F.C.</td>
<td>17.675</td>
</tr>
<tr>
<td>-25% of F.C.</td>
<td>17.175</td>
</tr>
<tr>
<td>Mean</td>
<td>19.325</td>
</tr>
<tr>
<td>t test</td>
<td>N.S</td>
</tr>
</tbody>
</table>
4.2 Effect of different irrigation water amounts on water applied:
The amount of irrigation water applied is presented in table (5) and fig (5). It is clear from the data obtained that, the water requirements for sugar beet plant ranged between 1947 and 2334 m³/fed. The highest value is recorded from field capacity treatment, while the lowest value is obtained from field capacity of –25% treatment.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Amount of water applied (m³/fed)</th>
<th>Water consumptive use (m³/fed)</th>
<th>Crop WUE (kg/m³)</th>
<th>Field WUE (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F.C.</td>
<td>2334</td>
<td>2100</td>
<td>10.17</td>
<td>9.15</td>
</tr>
<tr>
<td>-10 of F.C.</td>
<td>2179</td>
<td>1934</td>
<td>11.49</td>
<td>10.20</td>
</tr>
<tr>
<td>-15 % of F.C.</td>
<td>2122</td>
<td>1922</td>
<td>9.47</td>
<td>9.00</td>
</tr>
<tr>
<td>-20 % of F.C.</td>
<td>1979</td>
<td>1890</td>
<td>9.35</td>
<td>8.93</td>
</tr>
<tr>
<td>-25 % of F.C.</td>
<td>1947</td>
<td>1840</td>
<td>9.33</td>
<td>8.82</td>
</tr>
</tbody>
</table>
4.3 Water use efficiency:

The term of water use efficiency has been widely used in irrigation crop production to describe the efficiency of irrigation with respect to crop yield production from the standpoint of water conservation and production cost. Water use efficiency as used in this discussion is defined as kg of sugar beet roots yield per cubic meter of water consumed or water applied. Values of crop and yield water use efficiency are presented in table (5) and graphically presented in fig (6).
The data showed that, the irrigation with field capacity of –10 % treatment recorded the highest values of crop and field water use efficiency (11.49 – 10.20 kg/m³) followed by treatment with field capacity of 100 % (10.17 – 9.15 kg/m³), while the lowest value was obtained from treatment with field capacity of –25 %.

4.4 Determination of sugar beet crop coefficient:
Effect of crop characteristics on crop water requirements is indicated by the crop coefficient ($K_C$) which represents the relationship between reference potential ($E_T$) and actual evapo-transpiration ($E_T^c$).

<table>
<thead>
<tr>
<th>Months</th>
<th>Average of ETc (mm/day)</th>
<th>$E_T$ (mm/day)</th>
<th>Blany-Criddle</th>
<th>Hargraves</th>
<th>Class A Pan</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec.</td>
<td>0.86</td>
<td>2.30</td>
<td>2.20</td>
<td>1.90</td>
<td>2.13</td>
<td></td>
</tr>
<tr>
<td>Jan.</td>
<td>1.75</td>
<td>1.80</td>
<td>2.00</td>
<td>1.60</td>
<td>1.80</td>
<td></td>
</tr>
<tr>
<td>Feb.</td>
<td>2.65</td>
<td>2.00</td>
<td>2.70</td>
<td>1.90</td>
<td>2.20</td>
<td></td>
</tr>
<tr>
<td>Mar.</td>
<td>4.55</td>
<td>2.50</td>
<td>3.50</td>
<td>2.50</td>
<td>2.83</td>
<td></td>
</tr>
<tr>
<td>Apr.</td>
<td>5.50</td>
<td>4.10</td>
<td>5.10</td>
<td>3.80</td>
<td>4.33</td>
<td></td>
</tr>
<tr>
<td>May.</td>
<td>2.65</td>
<td>5.40</td>
<td>6.60</td>
<td>5.90</td>
<td>5.97</td>
<td></td>
</tr>
</tbody>
</table>

Regarding the effect of different methods for calculating the potential evapo-transpiration in comparison with the actual consumptive use, the data in table (6) show monthly parallel agreement between the average of actual consumptive use and potential evapo-transpiration calculated by using methods of Blany-criddle, Hargraves and Class A Pan.

From the result obtained evapo-transpiration values as an overall methods are 2.133, 1.80, 2.20, 2.83, 4.33 and 5.97 mm/day for Dec., Jan., Feb., Mar., Apr., May respectively.

<table>
<thead>
<tr>
<th>Months</th>
<th>$K_C$ Blany-Criddle</th>
<th>Hargraves</th>
<th>Class A Pan</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feb.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mar.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Values of crop coefficient of sugar beet are listed in table (7) and graphically presented in fig (8), the average of crop coefficient are 0.41, 0.98, 1.23, 1.65, 1.28 and 0.44 for Dec., Jan., Feb., Mar., Apr., May respectively. The average value for the whole season is 0.99. It can be noticed that, the crop coefficient is low at the begging of the growing season, then the value increase and reaches its maximum Value in March and declines to reach its minimum value at maturity stage.

It can be concluded that, the calculated crop coefficient value of 0.84 can be used in calculation the consumptive use of sugar beet in Eastern Delta, also the treatment of –10% of field capacity seemed to be better adopted for sugar beet irrigation without any adverse impacts on roots yield so water can be saved.

5 REFERENCES


[2] Researcher on Water Management and irrigation systems research Institute, (NWRC), Cairo, Egypt.
[3] Associate Prof., on Water Management and irrigation systems research Institute, (NWRC), Cairo, Egypt.
[4] Researcher Associate on Water Management and irrigation systems research Institute, (NWRC), Cairo, Egypt.
EXPERT SYSTEM FOR MANAGEMENT OF HEAVY CLAY SOILS IN EGYPT

Eng. Gehan A. H. Sallam, Prof. Dr. Talaat M. Owais, Prof. Dr. Osama W. El Din, and Dr. Mohamed B. Abdel Ghany

ABSTRACT
In Egypt, the increasing demands for food production requires reclamation and cultivation of more agricultural areas. More attention should be given to increase the productivity of heavy clay salt affected soils since they are potentially productive and require less investment, effort and time for restoring their productivity in comparison with new land reclamation. The management of problematic heavy clay areas is a multi-disciplinary strategy and joint efforts between key persons who involved in this process. The transfer of the knowledge from consultants & scientists to landowners and farmers represents the bottleneck for the development of heavy clay soil on the national level. Therefore, there is a need for an unconventional method to collect and transfer the knowledge and expertise in the problematic heavy clay management domain to the general responsible persons who involved in this process. It promise great prospects for application and great economic value to adopt Expert System (ES) as a management tool in accordance with the research results achieved by the problematic heavy clay soil ameliorating experts and their successful experiences. A user-friendly expert system computer program was developed for management of problematic heavy clay soils. Heavy Clay Management Expert System (HCMEXS) can help users to make appropriate decisions on heavy clay management so that the goal of improvement of heavy clay soil can be achieved, it also helps farmer to make correct decisions on agricultural practice.

Keywords: Drainage, Expert system, Heavy clay soils, Knowledge acquisition, Management

1 INTRODUCTION
The Nile Delta and the Nile valley of Egypt, is one of the oldest agricultural areas in the world, having been under continuous cultivation for at least 5000 years. The Delta of the Nile is one of the most fertile and intensively cultivated regions in the world (Abu El-Azz, 1971). The total Egyptian agricultural land is about 7.8 million feddans (1 feddan = 0.42 hectares) that is almost entirely depended on irrigation. The majority of the delta is occupied by heavy clay soils. Heavy clay soils represent approximately 260,000 feddans.

Saline and sodic problems are in many instances associated with heavy clay soils (FAO, 1970). To face the increasing demands for food production, increased attention has been given to solve problems of saline and sodic heavy clay soils to increase their productivity since they are potentially productive and require less investment, effort and time for restoring their productivity in comparison with new land reclamation. The risks of soil salinization are particularly acute in clay soils, because there is no economically viable method of draining them and of controlling salinity (Rycroft and Amer, 1995). Therefore, there is an urgent need to establish the limits for sustainable farming on heavy clay soils and to devise economical types of drainage systems. It was obvious that the drainage management for problematic heavy clay soils is a multi-disciplinary process concern crop variety, water management, soil improvement, drainage management and socio-economic aspects. Hence, the management of problematic heavy clay areas should be a multi-disciplinary strategy and joint efforts between key persons who involved in this process.
Since the mid eighties advances have been made with draining and reclaiming most of the problematic heavy clay areas to maximize the food production (DRI, 2001). After these years of comprehensive progress, there has been a lot of data on the research and practical experiences and formation of a comprehensive management system for heavy clay soils. The transfer of this knowledge from consultants and scientists to the responsible persons in the field scale, landowners and farmers represents the bottleneck for the development of heavy clay soil on the national level.

Therefore, it was necessary to develop a comprehensive multidisciplinary strategy for management of problematic heavy clay soils and develop a tool to transfer it to the general public of farms and the responsible persons in the field scale.

Under such conditions, a Heavy Clay Management Expert System (HCMEXS) has been developed to help users to make appropriate decisions on heavy clay management so that the goal of improvement of heavy clay soil can be achieved, it also helps farmer to make correct decisions on agricultural practice.

2 EXPERT SYSTEMS

Management of water resources is becoming increasingly complex. Emerging computer based decision support systems, and technologies such as expert systems, geographical information system, and decision analysis methodologies are being used to enhance decision-making in this complex environment (Fontane, 1992).

Expert systems are computer programs that manipulate knowledge to solve a specific problem in the same manner as the human experts using common sense, logic and experience. However, an expert system must achieve the same levels of performance in the domain of interest that human experts can achieve. Once an expert system is developed, we can see the advantages of this “Artificial Expertise”; it is permanent, easy to transfer and document, consistent and inexpensive to use (Jones, 1992).

Expert System application to drainage and irrigation management is a new subject. Unfortunately there has been little published on expert systems for water management that are being used routinely and therefore most of the applications of artificial intelligence concepts would be most appropriately classified as still in the prototype development phase (Fontane, 1992).

During the past years, there were some related expert systems applications that have been developed. In China an expert system for the comprehensive amelioration of the saline-sodic soil of Huang-Huai-Hai plain was developed (Wang Wansen, 1992). An expert system for Border Irrigation Management (ESBIM) model was developed. The system is a knowledge-based expert system for improved irrigation management of freely draining graded borders (Muhammad et al, 1994). An Expert Geographical Information System, (EXGIS), was developed for the evaluation of natural resources (Yialouris et al, 1995). Crop Information Management System (CIMS) was developed in 1997 (Brennan et al, 1998). The Work Efficiency Institute in Finland had developed two knowledge-based computer programs for planning plant production (Palonen, 1994).

In Egypt, an Expert System Model for Generating Water Policies (ESMGWP) has been developed in the Ministry of Water Resources and Irrigation to guide the decision maker (DM) to generate realistic water policies (Mohamed Rami, 2001). In 1989, the Egyptian Ministry for Agriculture (MOA) initiated the Expert Systems for Improved Crop Management (ESICM) project with main objectives of building an expert system laboratory within MOA that has the capacity to identify, develop, and maintain expert systems. Since that time several expert systems were developed. The first expert system has been developed for cucumber seedling production under plastic tunnels (El-Dessouki et al, 1992). Another expert system for the technical feasibility of Citrus cultivation (CITEX/feasibility) was developed (Salah et al, 1992). In 1995, an expert system was developed for tomato disorders (El-Shishtawy et al, 1995). In 1995, an integrated system for irrigated wheat crop management in Egypt (NEPER WHEAT) was also developed (Schroeder et al, 1995). In 2000, Grapes Production Management Expert System (GRAPEX) was developed to give advice to the grapes growers in Egypt to improve grape productivity quality and quantity (Edrees et al, 2000).

The task of building an expert system involves: information gathering, domain familiarization, analysis, design, and
implementation efforts. The adapted methodology of knowledge engineering includes three main activities to produce successive versions of expert system. These activities are (Rafea and Shaalan, 2001):

- Knowledge acquisition;
- Knowledge analysis & modelling, and;
- Knowledge verification and validation.

3 KNOWLEDGE ACQUISITION

Knowledge Acquisition is considered the bottleneck of the expert system building process. In fact, it has been said that knowledge acquisition is probably the most important task in the development of an expert system. Traditionally, human experts have been the source of knowledge for expert systems. Before developing the system, qualified experts must be located. Those experts must have the expertise and also have time to work with knowledge engineers.

The term ‘expertise’ is used to mean all of the expert system’s knowledge before it is reduced to the formal rule sets of a knowledge base. Three different activities were planned to acquire expertise and knowledge base required to develop the Heavy Clay Management Expert System (HCMEXS). Each of these activities has a role in acquiring knowledge about heavy clay management domain. The first activity was reviewing literature in several related fields to study and analyze previous experiences in the field of drainage of problematic heavy clay soils and gather the available knowledge from textbooks and research publications. The second activity was acquiring knowledge through the measurements program in the case studies areas to obtain and evaluate the existent experiences in these areas and through interviewing leading experts. The third activity was a questionnaire comprising Drainage and Reclamation and Improvement experts. The questionnaire was the final and the main source of knowledge acquisition. The objectives of the questionnaire were to bring together local expertise of the experts in the field of land reclamation and improvement and drainage and arrive at a final assessment of the state of drainage and crop production in the heavy clay areas. This questionnaire aims at bringing all information together and defines how to proceed with work in the reclaimed heavy clay areas.

Drainage and Reclamation and Improvement experts in Egypt were contributed in this study. The expertise of the experts were collected through the questionnaire that provides knowledge for the different factors that affect the drainage management of problematic heavy clay soils such as the; irrigation system performance, crop data, soil improvement including leveling, leaching, ploughing, sub-soiling and gypsum application and drainage system. Two sets of questionnaires were sent out to 20 different experts. Questionnaire I was designed to provide knowledge of the experts of drainage of problematic heavy clay soils such as their approach, and their decision process regarding different alternatives in management and planning of drainage. Questionnaire II is specific to the experts of reclamation and improvement of heavy clay soils. Out of the 20 experts who the questionnaires were sent to, 13 Drainage experts replied to questionnaire 1, and 7 reclamation and improvement experts replied to questionnaire II. Finally, the collected expertise of the experts who contributed in this study was combined in one copy to form the database of the expert system.

4 CONCEPTUAL MODEL AND KNOWLEDGE BASE

The acquired data was analysed according to Knowledge Acquisition Development System (KADS) approach to get the required database for the expert system and define the main concepts and properties of the system. The documented knowledge was analysed aiming at identifying concepts, properties of these concepts, and relations. The relations are either relations between concepts or relation between expressions. Concepts and relations found to be used by more than one subsystem were identified and grouped in a common knowledge base. The Heavy Clay Management Expert System (HCMEXS) is divided into eight subsystem: irrigation system performance; crop management; soil improvement; levelling; sub-soiling; gypsum application; drainage and economic.
For every subsystem, the main concepts and properties were defined. The type of every properties were defined as following:

- If it is nominal or numerical;
- If it has single value or multiple value (S/M);
- If the source of value would be the user or it would be derived from the model;
- The expected value for each property;
- The prompt that would to be used to define the value of the property in case of the source of the value is the user.

Consequently the system rules were generated from the acquired concepts properties for each subsystem in the base that the "Right Hand Side" is the rule conclusions part and the "Left Hand Side" is the conditions part. HCMEXS Expert System comprises 461 rules. The flow chart of HCMEXS is shown in Figure 2. This flow chart shows the main inputs and outputs for every subsystem and the interrelation between the different subsystems.

5 EXPERT SYSTEM IMPLEMENTATION

The Expert System HCMEXS was implemented using SICStus Objects and KROL programming language. The user interface was implemented using Tcl/Tk/Tix packages. The main screen of the developed expert system is shown in Figure 1. It consists of eleven buttons, the about button gives a brief description for the system, the new session button is used to run the system for new case without needing to restart the system, the Exit button is used to end the system and each one of the others eight buttons is considered with a different subsystem of the expert system.

![Main screen of HCMEXS](image)

6 EXPERT SYSTEM VERIFICATION AND VALIDATION
Verification and Validation is the demonstration of the consistency, completeness and correctness of the software. An incorrect system can make costly errors or may not perform up to expectations. In either case, the decisions generated may be wrong or inappropriate.

Verification can and should be done at the end of each of phase of the life cycle. Simply, it is building the system right. The verification techniques include two phases, the first one during the development stage and the second one after the development stage. During the development stage of the expert system HCMEXS, the non case-based techniques include tracing, spying and other traditional debugging techniques were applied. Tracing and debugging techniques were applied using dummy data, to test the correctness of the developed rules, and the expected behavior of the inference engine.

The ‘after development stage’ which is called ‘testing’ or ‘examination’ stage was aimed to find the discrepancies between the design and requirements specifications against implementation and finding the discrepancies between expected behavior of the system against the actual behavior. Any encountered differences were documented so that system maintenance was accomplished by walking through both of the design and the requirement specification documents and making the required correctness to clear any discrepancies.

After the development of the expert system HCMEXS, the case testing Validation technique was applied by preparing "Typical Cases". The developed expert system was tested with two typical cases. These cases were selected to serve requirements satisfaction as spelled out in the requirements specification document. This Validation technique aims at testing the developed expert system and finding the discrepancies between expected behaviors of the system according to the knowledge of the experts against the actual behavior.

7 CONCLUSIONS AND RECOMMENDATIONS

It was clear that, the problems in the heavy clay soils are not a single factor. Problems concern crop variety, water management, soil improvement, drainage management and socio-economic aspects. Hence, the management of problematic heavy clay areas should be a multi-disciplinary strategy and joint efforts between key persons who involved in this process. Therefore, it was of great prospects for application and great economic value to adopt Expert System (ES) as a management tool in accordance with the research results and experience of consultants and scientists. The developed user-friendly expert system computer program HCMEXS can help users to make appropriate decisions on heavy clay management, it also helps farmer to make correct decisions on agricultural practice.

It is also recommended to involve the Geographical Information System (GIS) technology within the developed expert system (HCMEXS) as GIS provide new tools to collect, store retrieve, analyze, and display spatial data in a timely manner and at low cost.
Figure 2   HCMEXS Flow Chart.

8 REFERENCES


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EXPERT SYSTEM FOR MANAGEMENT OF HEAVY CLAY SOILS IN EGYPT


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ABSTRACT
A two dimensional model has been developed to investigate the water table variations and design of subsurface drains within polders. The basic equation in this model was a combination of continuity and Darcy equations by considering two terms for ground water discharge and recharge. This equation was solved by numerical control volume method using appropriate initial and boundary conditions. The model can be used to simulate both steady and unsteady flow conditions in addition to isotrope and unisotrope porous media. The variations of water table for different depths and distances of subsurface drains can be investigated and the best case can be selected. The capability of the newly developed model was confirmed by real data from previous investigations. The sensitivity analysis of the model showed that the model was very sensitive to the size of calculation grids. The results also show that the vertical flow is important only above the drains while the horizontal flow is important above and under the drains plan.

1 INTRODUCTION

In many parts of the world irrigation is a key factor for agricultural products. It is well known that sustainable agriculture mostly depends on management of water and salt in the root zone. Drainage is a way to keep the water and salt balance in a desired level in agricultural lands. For drainage systems, the depth, distance, slope and diameter of subsurface tubes are the parameters which determine how the system should work. In other words, for a certain expected situation after installing the drains, these parameters must be selected or determined correctly.

Darcy's Law is the most common and well-known equation for water flow in soil. There are several equations aiming to design and evaluate subsurface drains based on Darcy's Law with some assumptions more or less. Important among them are Hooghoudt (1906), Donnan (1940), Kirkham (1958) and Dagan (1964) equations. Hooghoudt considered only horizontal flow and DF (Dupuit & Forcheheimer) assumptions were considered to be valid. Some of drainage models such as “DRAINMOD”, presented by Skaggs (1990), are based on the Hogout’s equation. They applied water balance technique by using the relationship between soil-water content and matrix potential to take into account the effect of flow in the unsaturated layer above the water table. It means that these methods are based on several assumptions. For achieving more realistic results Darcy's and continuity equations must be considered together (Richard's equation) with representative terms for discharge and recharge. Cooley (1983) and Huyakorn (1986) presented the numerical solution of Richard's equation for two and three-dimensional flow. Different researchers such as Chaung & Astin(1986), Marino & Tracy (1988), Celia (1990), Garcia (1995), Manguerra & Garcia (1995) and Pen (1996) presented the numerical solution of Richard's equation for unsaturated one-dimensional (vertical) flow. Simunek (1994) developed "SWMS-SD" model to simulate water and salt flow in saturated soils. Ayers (1997) used this model to design drainage systems. Guitgens (2002) suggested a method based on Hooghoudt and Richard's equations to analyze the performance of drainage systems. Das (2000) developed a non-linear optimization model (MINOS) to design and analyze of subsurface drains. Finally the work of Das & Datta (2003) can be mentioned here in which the solution of Richard's equation for three-dimensional flow of seawater towards coastal zone by adding the terms for salt concentration has been presented. In this research a differential equation which consists of Richard's equation and the terms for recharge of water table and discharge from drains for subsurface drains has been developed. Numerical solution of this differential equation by control volume method, and appropriate boundary and initial conditions results into a two-dimensional model which is able to simulate the flow towards subsurface drains. The method presented here has the following advantages:

- It is easy to use
- It is based on physical and mathematical facts and there isn't any empirical relation.
- The radial flow can be considered.
- It can be used in both saturated and unsaturated conditions.
- It can be used in both steady and unsteady flows.
- It will be easy to apply different grid size over the required domains.
- Piezometric head and velocity vectors can be computed.

2 MODEL DEVELOPMENT

http://library.wur.nl/ebooks/drainage/drainage_cd/1.3%20fatahi%20nafchi%20and%20shayannejad%20bm.html (1 of 9)26-4-2010 12:11:12
Numerical simulation of water table variations in the drains within polders

To derive basic equation, a control volume with dimension of $\Delta x$, $\Delta y$, $w$ (perpendicular to the page) was considered. The flow in the other sections on $w$ direction is similar, therefore it can be assumed that the flow is a two-dimensional flow within X-Y plan.

\[ \begin{align*}
\text{Figure 1} & \quad \text{Schematic vertical cross section of porous media with finite flow element} \\
\text{The upper boundary acts as a linear source and the layer contains drains acts as a linear sink (see Fig. 1.). The mass balance for each control volume can be written as follows:} \\
& \quad \begin{cases}
M_i \quad \text{input mass per unit time} \\
M_o \quad \text{output mass per unit time}
\end{cases} \\
& \quad \begin{cases}
u \quad \text{flow velocity in } X \\
v \quad \text{flow velocity in } Y
\end{cases} \\
& \quad \begin{cases}
\Delta x \quad \text{dimensions of control volume in } X \\
\Delta y \quad \text{dimensions of control volume in } Y
\end{cases} \\
& \quad \begin{cases}
\rho_w \quad \text{specific mass of water} \\
W \quad \text{dimension of control volume perpendicular to the page}
\end{cases} \\
& \quad \begin{cases}
q_r \quad \text{discharge to control volume per unit volume} \\
q_p \quad \text{discharge from control volume per unit volume}
\end{cases} \\
\text{Where:} \\
M_i \text{ and } M_o = \text{input and output mass per unit time respectively} \\
u \text{ and } v = \text{flow velocity in } X \text{ and } Y \text{ directions respectively} \\
\Delta x \text{ and } \Delta y = \text{dimensions of control volume in } X \text{ and } Y \text{ directions respectively(grid size)} \\
\rho_w = \text{specific mass of water} \\
W = \text{dimension of control volume perpendicular to the page} \\
q_r \text{ and } q_p = \text{discharge to and from control volume per unit volume respectively}
\end{align*} \]

From the overall recharge, the $q_r$ can be expressed as:

\[ q_r = \text{overall recharge} \]

The right hand part of Eq. 5 is the change in stored water per unit time which is in fact the specific storagre of ground water aquifer and can be expressed as:
Where \( H \) is the piezometric head and \( S_s \) is the specific storage. For unconfined aquifers the specific storage can be determined as:

\[
H = H_0 + \frac{L}{S_s} \tag{6}
\]

In Eq. 7, \( S_y \) is the specific yield and \( D \) is the average thickness of aquifer. Hereunder \( D \) is considered to be the initial thickness of aquifers before drainage. Combining Eqs. 5, 6, and 7 by considering that water is incompressible fluid, the basic equation describing flow should be:

\[
\sum_{n} \left[ \frac{D}{2} \right]^2 \left( S_y - \frac{1}{3} S_s \right) = 0 \tag{8}
\]

Figure 2 Representative control volume element

Considering a control volume and applying finite difference method Eq. 8 can be solved. Fig. 2 shows a representative control volume:

The coordinates of \( W, E, N, S, \) and \( P \) points in accordance with \( I \) and \( J \), can be written as \((I,J), (I,J+1), (I,J-1), (I+1,J), (I-1,J)\). Now the Eq. 8 for the control volume, can be rewritten as:

\[
\sum_{n} \left[ \frac{D}{2} \right]^2 \left( S_y - \frac{1}{3} S_s \right) = 0 \tag{9}
\]

Where the integrals bands are as defined in Fig. 2 and \( k \) and \( k+1 \) are two sequential time steps (\( \Delta t \)). Each terms of Eq. 9 can be rearranged as follows:

\[
\sum_{n} \left[ \frac{D}{2} \right]^2 \left( S_y - \frac{1}{3} S_s \right) = 0 \tag{10}
\]

\[
\sum_{n} \left[ \frac{D}{2} \right]^2 \left( S_y - \frac{1}{3} S_s \right) = 0 \tag{11}
\]

By substituting expressions 10 to 12 in Eq. 9:

\[
\sum_{n} \left[ \frac{D}{2} \right]^2 \left( S_y - \frac{1}{3} S_s \right) = 0 \tag{12}
\]

The seepage velocity can be determined by Darcy's law. Hence,

\[
\frac{K_x}{K_y} \left( \frac{D}{2} \right)^2 = \frac{1}{2} \left( S_y - \frac{1}{3} S_s \right) \tag{13}
\]

Where \( K_x \) and \( K_y \) are the hydraulic conductivity of porous media in \( X \) and \( Y \) directions respectively. Substituting Eqs. 14 to 17 within the Eq. 13 and solving for
Numerical simulation of water table variations in the drains within polders

\[
\begin{align*}
\text{Where: } & \left\{ \begin{array}{l}
A_4 \\
W, N, S, E
\end{array} \right. \\
& \left\{ \begin{array}{l}
(18) \\
(19) \\
(20) \\
(21) \\
(22) \\
(23)
\end{array} \right.
\end{align*}
\]

The term \(A_4\) is zero everywhere except the upper boundary and in the position of drain tubes. Therefore the potential for each nod can be determined by the potential for four nods around it \((W, N, S, E)\). The Gauss-Seidel iteration is a suitable approximation method for this situation. To show the practical application of the Eq. 8 the boundary and initial conditions, as explained hereunder, must be known.

\(\zeta\)

\[\text{Figure 3 Schematic sketch of drains within a polder and representative boundaries}\]

A polder as shown in Fig.3 was considered. Where the initial water table elevation from impermeable layer is \(D\). The drains were installed within polder to pull down the water table. The left boundary is a boundary with known potential and the distance of the first and last drains from near boundaries were considered to be half of the drain space.

3 MODEL VERIFICATION

3.1 Steady Conditions

Data from reference 6 were used to confirm the performance of the model. The required input data are summarized in Table 1.

\[\text{Table 1 Input data to evaluate the performance of the model}\]

<table>
<thead>
<tr>
<th>DD (m)</th>
<th>D (m)</th>
<th>L (m)</th>
<th>(mm/day)</th>
<th>(m/day)</th>
<th>(m/day)</th>
<th>(m)</th>
<th>(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>0.1</td>
<td>1</td>
<td>0.2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Note that data in Table (1) refer to steady condition and “DD” is the depth of drain tubes under the ground surface. Model outputs concerning the above input data are shown in Fig.4 and 5. For each point of the interested domain the pressure head were calculated as piezometric head minus gravitational head. The water table is the location of a set of points with zero pressure head.
To evaluate the model performance the Root Mean Square (RMS) was calculated as follows:

\[ \text{RMS} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (H_m - H_s)^2} \]  

(24)

Where \( n \) is the number of data, \( H_m \) and \( H_s \) are measured and simulated values for water table elevation within polder.

The comparison of predicted and observed values for the case presented in table (1) shows that the RMS is about 0.084 and it is not significant within 5 percent confident level. Fig.4 and the calculated RMS show that the two dimensional model can be used to simulate the water table within polders with high accuracy. The equipotential lines are presented on Fig.5.

**Figure 4  Comparison of predicted and observed water table location within polders**
Numerical simulation of water table variations in the drains within polders

**Figure 5** Equipotential lines for the case study

The results of study cases show that the model accuracy is related to grid size. As an example using data in Table(1), (where $\Delta x=0.5$ and $\Delta y=0.2$) if we use $\Delta x=2$ and $\Delta y=2$ then the RMS should be increased up to 0.45. The same results and analysis show that the best grid size is when $\Delta x=(\quad) L$ and $\Delta y=(\quad) D$.

**Figure 6** Model output for Water table elevation with two drain depths

To study the effect of drains depth data from Table (1) were used for two depths of 2 and 1.6 meter. Fig.6 shows the location of water table between drains for the two mentioned depths. As expected the smaller the depth, the lower water table is in agreement with real observations.
Vertical and horizontal velocity distribution can be calculated using Darcy's law when the piezometric heads and hydraulic conductivity in x and y directions ($K_x$ and $K_y$) are known. The results show that distribution of horizontal velocity are different for each location within drains but the distribution of vertical velocity is identical everywhere. Moreover the magnitude of horizontal velocities are bigger than vertical ones. It shows the importance of horizontal flow in comparison to vertical flow in subsurface drainage. Fig.7 shows a sample of vertical velocity distribution calculated by the model using data on Table (1), for a section located 18 meters from left boundary in Fig.1. It can be realized from Fig.7 that the most vertical flow is located above the drain plan, therefore in this region the vertical flow is more important that anywhere in the domain. The average horizontal velocity for this section was 0.34 m/h.

3.2 Unsteady Conditions

In this section the recharge of water table was considered to be unsteady. The input data are shown in Table (2). The temporal variations of recharge is shown in Fig. 8. For the first try the drains space was considered to be 20 meters. The variation of water table for a section located 20 meters from left boundary has been calculated and presented in Fig.8. If assumes that the impermeable layer is 11 meters below the ground surface and the minimum allowed depth for water table is 1.4 meters under the ground, then with this drain space the water table should reach above the desirable level and the drain space must be decreased. In the second try the drain space was considered to be 10 meters. With this drain space the results show that the goal has been achieved.

![Figure 7 A sample of Vertical velocity distribution calculated by model.](image)

**Table 2  Input data for unsteady case study**

<table>
<thead>
<tr>
<th>(m/day)</th>
<th>(m/day)</th>
<th>DD(m)</th>
<th>D(m)</th>
<th>(m)</th>
<th>(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>1.2</td>
<td>0.1</td>
<td>2</td>
<td>10</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The diameter of the drain tubes depends on the maximum influx from the soil layers and longitudinal slope. The discharge per unit length of drain tubes or specific discharge can be determined by the model. Fig. 9 shows the predicted specific discharge and its variations, based on input data from Table (2) when the drain space is 10 meters. It can be seen that the maximum specific discharge for this case is about 8.33 l/s. For example, if the drain length considered to be 300 meters with 0.001 longitudinal slope then the required tube diameter should be 60 mm.
Figure 8 Model output as water table variation for an unsteady recharge and two different drain depths

Figure 9 Model output for specific discharge in unsteady condition
CONCLUSION
A two dimensional model to analyze the flow toward subsurface drains within polders has been developed. The basic equation in this model was a combination of continuity and Darcy equations, by considering two terms for ground water discharge and recharge. This equation was solved by numerical control volume method using appropriate initial and boundary conditions. The model is easy to use and the predictions of model for both steady and unsteady flow conditions are in agreement with real data. The variations of water table for different depths and distances of subsurface drains can be investigated and the best combination can be selected. The study of seepage velocity by considering vertical and horizontal velocity components shows that the vertical velocity component is important above the drains plan while under this plan the horizontal component is more important. These all are not new concepts but show the capability of newly developed model to investigate the performance of a drainage system numerically. The variations of water table and specific discharge for unsteady condition depend highly on the recharge pattern. More investigation is needed to combine the time series of recharge with the model in order to predict the variations according to real conditions.

REFERENCES
A MODEL FOR OPTIMIZATION OF WATER MANAGEMENT IN RICE POLDERS IN THAILAND

Preecha Wandee

ABSTRACT
This paper presents a mathematical model for the optimization of the main components of the water management system in rice polders in Thailand. The aim of the water management system in a rice area is to create good growing conditions for the crops. In the hydrological conditions of Thailand, the average rainfall during the rainy season is more than enough for growing rice or other crops. On the other hand, during the dry season, there is a very small amount of rainfall. Thus the farmers are confronted with two extreme conditions. Hence water management has to deal with irrigation and drainage conditions. The main components of the water management system in a rice polder are the water level in the canals, the percentage of open water, and discharge capacity from the field and discharge capacity of the pumping station or sluice. A model has been developed that takes into account damage cost due to flooding and drought as well as construction and maintenance cost based on the hydrological conditions. Optimizing of such a system means to determine the main components in such a way that the whole system has minimum annual equivalent cost. A case study for a polder in Thailand is presented.

1 Introduction
Rice forms a staple part of the Thai diet (35% of GDP), while it is still the basis of the rural economy of Thailand. As the population increased lowland rice growing expanded in downstream direction, eventually into the lowland parts of river basins. The young delta of the Chao Phraya River was brought under cultivation between the middle of the 19th century and the beginning of the 20th century. Later, particularly after the Second World War, new fields were opened on relatively higher level with less favorable conditions. Polders were formed by constructing dikes along the rivers to prevent inundation of the cultivated land where the major crop is rice. Normally in the polders the irrigation water is coming from a diversion or storage dam, barrage and weir, which divert water from the river and feed to the main canals, sub main canals and lateral canals. Rainfed lowland is the predominant rice ecology in Thailand. In the crop year 1997/1998, rainfed lowland accounted for about 75% of the wet season rice area and contributed 49% of the annual rice production (Kupkanchanakul, 1999). Under rainfed conditions rice is usually grown only once a year in the wet season, where the monsoon rain is the single source of water supply for the rice cultivation. Average yield in the rainfed lowland was extremely low, about 1.9 ton/ha, in the crop year 1997/1998 (Kupkanchanakul, 1999). Major production constraints in this area are the rainfall variability, drought, submergence and inherent low soil fertility.

Lowland rice is usually grown in a layer of ponded water on the surface of the field. This water is supplied by rainfall and may be supplemented by irrigation. The water layer on the surface of the ground is usually kept at various depths dependent on the crop stage and the agricultural practice, the so called “preferred water level”.

Thailand has a humid tropical climate. The seasons in Thailand can be divided into the rainy season and the dry season. In general in the rainy season the average rainfall is more than enough for the growing of rice or other crops in polders. In fact farmers often experience flooding, resulting in the ruin of crops. On the other hand, during the dry season there is a very small amount of rainfall. Thus the farmers are confronted with two extreme conditions.

In practice when there is a dry spell the farmers will pump water from the canal by trying to keep the water level in the field at the preferred water level. On the other hand the farmers will drain the excess water into the collector drain if the water level in the rice field is higher than the maximum water level that rice can tolerate.
Due to unreliable rainfall and agricultural practices in Thailand, farmers always grow two or three crops if irrigation water is available. The water for irrigation is stored in the main canal before the dry season. In the dry season the farmers usually pump the water from the main canal to the lateral canal and finally pump it to the field (see Figure 1). On the other hand in the wet or rainy season the water level in the main canal cannot be kept so high to prevent damage due to unexpected storms, which may be caused by heavy rainfall in the area. In the wet period the farmers usually drain the water from to lateral canals through a gate or through a culvert and or a pump dependent on the water level in the lateral canal and the field. In case of heavy rainfall farmers let water flow to the lateral canal by a pump or through a culvert dependent on the water level in the lateral drain canal and the field. In case of harvesting this is always at the time when the water level in the main canal is high owing to storing water for the second crop in the dry season, farmers always drain water by pumping.

2.1 Soils
Due to the mineral composition of the clay the soil, which has a small amount of montmorillonite, there is a very small tendency to swell when the soil moisture increases. Therefore the soil permeability will not change so much when the soil moisture increases. In this case the soil still has a high permeability because the water can flow through the cracks even if the soil is saturated.

2.2 Rice cultivation
There are two main methods of growing rice in rainfed lowland ecosystems in Thailand, which are transplanting and direct seedling. Recently the traditional transplanting method has been increasingly replaced by direct seedling, especially dry-seed broadcasting. The reason for the change in the growing method is the increasing labor costs. The broadcasting requires only a fraction of the labor required for transplanting. Moreover direct seeding can also avoid the risk of transplanting failure due to a lack of standing water at the time of transplanting. As soon as rainfall has moistened the soil enough to make ploughing possible, the land is ploughed (late of April, May or June). Hence, in the model developed the starting date of the land preparation is computed for certain boundary conditions based on the following parameters:

- soil moisture tension of pF <= 2.0;
- start ploughing in mid June and harvest in early November.
2.3 Physical aspects of main components of the water management system in rice polders

The main components of the water management system in the rice polders are as follows:

- water level in the canals;
- percentage of open water;
- discharge capacity from the field;
- discharge capacity of the pumping station or sluice.

The water level in case of rainfed cultivation the water level in the lateral canals, sub main canals and main canals is considered as only one level.

It can be seen from Figures 2 and 3 that in both irrigation and drainage if there is an appropriate water level in the lateral canal, the water can be irrigated or drained by gravity. In reality there are many factors involved in the water level in the lateral canal such as cropping pattern, storage volume of the main canal, hydrological conditions, etc.

2.3.1 Percentage of open water area

Excess water will be stored in the canal system before draining the volume of water that is stored in the polder area for irrigation, dependent on the percentage of open water.

2.3.2 Water level in the canals

The water level in the canals can be affected in both irrigation and drainage in rice polder systems as shown in Figure 2 and 3.
A MODEL FOR OPTIMIZATION OF WATER MANAGEMENT IN RICE POLDERS IN THAILAND

PL = water level in lateral canal in m-MSL
PPL = polder water level in m-MSL
BL_L = bed level of the lateral canal in m-MSL
BL_M = bed level of main canal in m-MSL
H_b = bund height of the rice field in m
GL = ground level of the rice field in m-MSL
W_LM = maximum allowable of water layer in the field for rice growth stage in mm

**Figure 2**  Schematic presentation of the drainage from a rice field in a rice polder
Pumping from the lateral canal when the water level is low

**Figure 3**  Schematic presentation of irrigation in a rice field in a rice polder

2.3.3 Discharge capacity from the field
The discharge capacity from the field is the amount of water that can be drained out from the field. This is called drainage modulus in mm/day. If the surface drainage system at field level has less discharge capacity the possibility of inundation of the crop will increase.

### 2.3.4 Discharge capacity of the pumping station or sluice

The lower the discharge capacity of the pumping station or sluice the more susceptible to inundation the rice field in a polder area will be.

### 3 the method

The four main components of the water management system in rice polders can be optimized in such a way that the equivalent annual costs of the system are a minimum (Schultz, 1982 and Schultz and Saiful Alum, 1997). In the equivalent annual costs of the system, the cost of construction, operation and maintenance of the water management components, as well as the crop damage due to drought, water logging or inundation are present. Decrease in rice yield can be caused by an improper water level in the field, drought and inundation. It can be calculated depending upon the growth stages of the crops. To determine the components the method consists of three main parts namely:

- hydrological computation;
- economical computation;
- optimisation.

With the hydrological computation the effect of non-steady rainfall on the water level is simulated for a series of years. In the economical computation, the costs of construction, operation and maintenance of water management system, investment for crops, the value of crops, buildings, infrastructure and damage are calculated. With the optimization routine, the optimal values for the main components of the systems are determined.

#### 3.1 Hydrological Computation

The hydrological computation consists of two parts. Firstly the parameters of the hydrological model are determined based on measured time series of rainfall, evaporation, discharge from the plots and pumping into plot. The parameters to be determined are mostly soil physical constants. Secondly with the verified parameters the optimal values for the main components of the water management in rice polders are determined. The latter calculations are made with the program OWAR3.

To be able to simulate the hydrological situation the soil profile is schematized according to the soil profile of a rice field at the Samchuk Irrigation Water Use Research station in Thailand. The top layer consists of clay where cracks occur when it is dry (see Figure 4). The soil may be very permeable when cracks occur. In this situation the hydraulic conductivity of a cracked soil was calculated by using a slit model presented by Bouma and Anderson (1973).
Within the hydrological computation the two states of a rice field will be considered: submerged and non-submerged.

In the non-submerged condition the following elements are taken into account:

- interception;
- unsaturated groundwater flow in Zone I;
- unsaturated and saturated groundwater flow in Zone II;
- capillary rise from Zone III.

In the submerged condition the following elements are taken into account:

- interception;
- saturated groundwater flow in Zone I and II.

In the non-submerged condition the model calculates the moisture deficit in the three layers and discharge through the lateral canal from Zone II by the Glover Dumm Equation. In the submerged condition the model calculates the discharge to the lateral canal by applying the Dupuit’s formula and calculates seepage through the dike if there is no water in the lateral canal. The time step can be chosen, normally two hour is taken.

### 3.2 Economical Computation

The economical computation consists of three parts namely:

- determination of the costs for construction;
- operation and maintenance of the water management systems;
- determination of the value of the crops, buildings and infrastructure;
• determination of the damage on crops, buildings and infrastructure.

All computations are made with the program OWAR3.

The cost for construction and maintenance of the water management system are derived from unit prices per m, m², m³, etc. By determination of the necessary quantities the total cost can be found. These cost are dependent on the sizes of the four main components of the water management system in the rice polders.

The calculation of damage to the crops is mainly to the water layer depth on the field and evapotranspiration during the year. For buildings and infrastructure, damage is dependent on the height of the exceedance of specific groundwater tables (US Army Corps of engineers, 1996-2000).

3.3 The Optimization

The optimal values for the water management components are obtained according to the optimization method of Rosenbrock (Kuester and Mize, 1973). The process starts with assumed values of the water level in the canals, the percentage of open water, the discharge capacity from the field and the discharge capacity of the pumping station. The economical model computes the costs of construction, operation and maintenance of the water management system. Using the hydrological and the economical models together, the expectable damages can be computed. The sum of costs and damages is calculated and transferred to equivalent annual costs. During the optimization the water level in the canals, the percentage of open water area, the discharge capacity from the field and the discharge capacity of the pumping station are increased or decreased with a certain value. If a good result is obtained, this value is stored for the next calculation. If not, then the original value is stored and in the next cycle a search is made in the opposite direction. This process is repeated until the total of cost and damage is at the minimum. The Rosenbrock routine contains possibilities to accelerate the process.

4 preLIMINARY results of the field experimentS

The aim of the experiments in Thailand is to collect data of discharge, corresponding with rainfall and cropping pattern in rainfed conditions. Based on these data the hydrological model can be calibrated in order to determine the hydrological parameters.

4.1 Field Lay-out

The experiments were carried out at the experimental station of the Samchuk Irrigation Water Use Research station, Suphanburi province, Thailand. An area for rainfed rice cultivation was selected in the high part of the experimental area because in rainfed conditions a deep groundwater table was normally found in this area. The total experimental area for rice is 7.30 X 21.00 m. The lay out and cross-section of the experiment is shown in Figure 5. In the rainfed condition it is assumed that only a drainage system is available. The excess water, which is related to the maximum water level that crops can tolerate during the growth stage, will be drained by pumping to the lateral canal. KDML105 rice, which is normally grown in rainfed areas, was used in this study.

4.2 Primary investigation and discussion

4.2.1 Primary investigation

• The ground water level in the experimental area during the dry period is about 1.2 to 1.3 m-surface. The small amount of rainfall in the dry period has no effect on groundwater level in the study area;
• Soil at the study area is clay, which is composed of about 38% clay in the layer I, 42% in layer II and 32 % in layer III;
• The clay mineral analysis has shown that the clay in the study area is composed of Kaolinite 42.4%, Illite 48.3%, and montmorillonite 9.3%;
• Average saturated permeability at 0.30 m-surface is 7.6*10⁻⁶ m/day, at 0.60 m-surface it is 5.89*10⁻⁶ m/day. The
permeability of the cracked clay soil is about 2-20 m/day except for the plough pan it is much lower, about 0.001 m/day (Hendriks, et. al, 1998)

4.2.2 First simulation results
The simulation of rainfall and evaporation data from year 1991 to 1999 for the rainfed rice area of 10,000 ha, the optimal water management components as shown in Table 1.

Table 1 The four main components of the optimal condition in rainfed rice condition in Thailand

<table>
<thead>
<tr>
<th>Items</th>
<th>Polder level in m-s.</th>
<th>Open water in %</th>
<th>Surface drainage in mm/day</th>
<th>Pumping capacity in mm/day</th>
<th>Annual costs in Euro x10^6</th>
<th>Annual damage in Euro x10^6</th>
</tr>
</thead>
<tbody>
<tr>
<td>optimal</td>
<td>-0.03</td>
<td>0.63</td>
<td>53</td>
<td>17.11</td>
<td>0.79</td>
<td>1.45</td>
</tr>
<tr>
<td>practical</td>
<td>-0.60</td>
<td>1.50</td>
<td>46</td>
<td>26.00</td>
<td>2.12</td>
<td>1.17</td>
</tr>
</tbody>
</table>

The sensitivity of the cost for rainfed the rice cultivation is shown in Figure 6.
4.2.3 Discussions

The water level in lateral canal is the most sensitive factor to damage from inundation of rice in polder area as shown in Figure 6. The possibility to inundation of crops is high when the water level in the lateral canal is kept higher than the ground level in the field. Because the water cannot drain from the field through a culvert when the water level in the lateral canal is high. The simulation showed that the optimal water level would be 0.03 m-surface. But this damage may be depending on the diameter of the culvert in the rice field as well.

The drainage modulus of the field drain system at the optimal condition is 53 mm/day. This value is more or less the same as the design practice in Thailand, which is about 46 mm/day. The values at optimal condition is different from the practical may be due to maintenance problem and management in the area such as water weed problem, garbage and obstruction of some structures in canals such as house invasion to the canal. Moreover safety has to be considered in practice.

The lateral canal water level in a rainfed rice field may be kept high to prevent loss of water from the rice field and get benefit for irrigation water that will flow through culvert to the rice field when water level in the rice field is low. However this will create more risk to inundation of the rice field due to heavy rainfall during storms. In practical the water in polder will be drained before a storm comes.
Appropriate lateral canal spacing may reduce the loss of ponded water in the field, which can pass through the cracks when the water level in the lateral canal is lower than water level in the field.

In reality the water level in the canals may be affected by topography and the gradient of water flow when the pumping is working, but the model is a zero dimensional model, which determines the water level of open water by the volume of water that is stored in the canal. This may be reason as well why the water level in practical and in the simulation is different.

5 Conclusions and recommendations
Although the sowing time in rainfed lowland rice cultivation is determined by one set of wet season rainfall data, it may be concluded that due to the unreliability of rainfall, there, may be risk because there is a high probability of unfavorable water depth in the field or

Figure 6 Deviation of the main components in % and deviation of annual equivalent cost in % in rainfed rice conditions
no water standing at the right time of planting which is almost normal for rainfed conditions in Thailand. Besides the selection of time of sowing in rainfed rice conditions, the other important factor in rainfed rice can be the suitable drainage system. From this study it is shown that the optimal water management condition can be found by mathematical model simulations as described.

6 References


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GUIDELINES FOR REHABILITATION PLANNING OF SUBSURFACE DRAINAGE SYSTEMS IN EGYPT

M.A. Ragab

ABSTRACT
The increase in irrigated agriculture and intensive cropping has resulted in waterlogging and salinity. In response to this challenge, the Government of Egypt gave high priority for installing subsurface drainage systems to overcome the problem of waterlogging and conserve the productivity of agricultural areas. About 90% of the areas under subsurface drainage system were constructed before the past two decades and are in need for rehabilitation. There are some indicators for defining the need of subsurface drainage for rehabilitation e.g. water table depth; soil salinity; crop degradation; complaints and the age of the system.

The study of these indicators was implemented in two stages through 3 years. The result showed that the water table draw down curve after irrigation is a most important indicator for rehabilitation. Rehabilitation decisions taken based on the number of complaint is rather misleading since not all the drainage centres with a high number of complaints do necessarily have the oldest installed systems.

It is recommended to use multi-indicators integrally to determine the need for rehabilitation instead of depending on one or two indicators only (age, number of complaints). Based on the integrated evaluation system proposed, the following areas should be selected as a first guideline: South Ibrahemia, Zagazig, Meet Ghamr, South Aga, Sheben el Kom, and South Kafr el Zayyat.

Keywords: Drainage, Maintenance, Rehabilitation

1 INTRODUCTION
Subsurface drainage systems were installed in Egypt to lower the water table, and remove salts from the plant root zone. Installation rates for subsurface drainage system by Egyptian Public Authority for Drainage Projects (EPADP) vary from 63 000 to 71 400 ha per year. Many of the areas which have been provided with subsurface drainage system since the sixties have problems which are related to sedimentation; water logging and salinity. These systems have passed their technical and economical lifetime, which is estimated between 25 and 40 years (Van Leeuwen and Ali 1999). The problems of those areas resulted from the fact that maintenance is not helping any more. Considering, the time life of those areas, the materials and tools used for implementation by that time and the concepts and criteria of both planning and design, then, rehabilitation may be the only option (Rady 1993 and Salman 1995). Rehabilitation is defined as the new construction done to bring back existing system to its former good functional state (DRI 1996). Rehabilitation works are always implemented by contractors.

Smedema and Vlotman (1996) mentioned that in order to assess the need for rehabilitation two main parameters need to be considered: the water table depth as function of time and area to certain percentage and the soil salinity. That is in addition to complaints and maintenance costs. Van Leeuwen and Mohamed Ali (1999) stated that the lifetime of the subsurface drainage systems depend on the quality of used material, quality of the construction, design factors and external factors, such as vandalism, penetration of root growth in pipes, rodents, etc. Normally a drainage system has to be renewed when:
1. Water table is rising to unacceptable levels;
2. Soil salinity is increasing;
3. Cost to maintain the hydraulic performance of the system become unacceptably high.

Decisions to rehabilitate a drainage system should be based on actual information about the lifetime and the performance of the system. The EPADP Monitoring and Evaluation System, collects data and prepares evaluated information with respect to Physical and Operational Performance of Drainage Systems. The information that is obtained from the system performance monitoring and the required maintenance is essential feed-back for preparation of priority plans for areas in need of rehabilitation and to ensure an effective and efficient distribution of maintenance equipment and funds.

EPADP and DRI cooperated through the Monitoring & Evaluation Project and the Drainage Research Project to arrive at a common set of rehabilitation criteria. These two project carried out a preliminary joint study in the Santa Drainage Centre in Middle. The objective of this paper is to develop guidelines for rehabilitation planning of subsurface drainage systems in Egypt.

1.1 Indicators for rehabilitation
There is an urgent need to precisely identify the areas currently requiring rehabilitation. Four strategies are recommended for this process (DRI, 1993) as
GUIDELINES FOR REHABILITATION PLANNING OF SUBSURFACE DRAINAGE SYSTEMS IN EGYPT

follows:

1. Complaints by farmers should be investigated with field observation.
2. Areas with any failure in the network should be identified.
3. Pipes which demonstrate permanent over pressure, or are continually blocked with sediment should be investigated.
4. Long term monitoring program of water tables, drain discharges, crop yields, and soil and water salinity needs to be developed.

The National Drainage Programme identified general indicators and criteria for the selection of new areas in need of subsurface drainage and gives some additional indicators and criteria for areas in need for rehabilitation (DRP,1995) as:

1. A water table less than 100 cm depth below soil surface in at least 75% of the area.
2. Soil salinity (EC) exceeding 4 dS/m at 25 and 50 cm depth below soil surface.
3. Areas where decline in agricultural production (about 20-30%) is reported due to high water table and/or saline conditions.
4. Effect of maintenance: cases where intensive maintenance and flushing do not result in an improvement of the existing situation.
5. Farmers' views and willingness to pay with respect to rehabilitation (complaints)
6. Age of the system.
7. Design and installation history

A joint EPAD/DRI workshop was held on March 1996. It became clear during the workshop on performance assessment, that in order to assess the need for rehabilitation, the following indicators should be used:

1. The age of the systems;
2. The number of farmers' complaints;
3. Level of water table;
4. Soil salinity;
5. Maintenance cost.

2 Materials and methods

In the first stage of rehabilitation study (DRP-1) three indicators were tested in Santa area (central part of the middle Delta) as one of the old design areas. Considering, those areas completed their economical lifetime, especially if we considered the tools and materials used for implementing such areas 25 years ago. These indicators are farmer's complaints, water table depth and salinity. The farmer's complaints were collected at Santa areas (16800 ha.) for period five years before the study. At the same time the measurements of water table depth and salinity were done for two period of irrigation at midway between two laterals and in the middle of each collector at both right and left sides.

The research programme for rehabilitation in the second stage was implemented at large-scale. DRI focused on studying two indicators: age of the drainage system and farmer's complaints. The current farmer's complaints procedure, can be explained as follow:

1. The farmers who have complaints go to the drainage sub centers and write the complaints on papers.
2. Submit them to the drainage engineer. The complaint contains the farmer's name, the location of the problem (the village's name, the number of the collector), and the complaint's reason.
3. The drainage engineer collects the complaints and sends them to the drainage centre as soon as possible to be studied and solved.
4. The drainage centres put the complaints in files and send a standard complaints summery form to the drainage Directorate General.

In the second stage of rehabilitation study (DRP II) special arrangements have been followed to be able to collect complaint data by DRI staff from different drainage centers. A complaint survey form for the overview of drainage complaints was sent by fax or submitted by hand to the Directorate to fill it. The data from the survey forms was tabulated and is shown as example in Table 1. The number of complaints for collectors, laterals and open drains was collected on a monthly basis from drainage centres in the West, Middle, and East Delta, and Middle Egypt. Data on the year of installation of each sub surface drainage system and the reasons for complaints during 1993, 1994, 1995, and 1996 were recorded.

The location of the Drainage Centers is shown in Figure 1. The complete coding system of the M&E project (EPADP) used in the Figure and Table 1 and its summary Table 2.

3 Results

3.1 Complaints frequency

It was observed from the analysis of complaints in Santa area that 40% of collectors under monitoring were working without any problems. The main problems
observed were caused by high water level and problems of weed growth in the open drains. 
Table 3, shows the frequency of complaints for the different Sub-Centers under study. It was noticed that the majority of the collectors do not exceed the first class (less than 10 complaints). This means that there was no serious problems that can lead to rehabilitation of the network. Less number of the collectors lie in the other classes that have more than 10 complaints. According to Table 3 most the sub centers were not in need for rehabilitation; even though, all these areas were planned for rehabilitation by EPADP depending only on the age as indicator.
GUIDELINES FOR REHABILITATION PLANNING OF SUBSURFACE DRAINAGE SYSTEMS IN EGYPT

Figure 1  Drainage Centres in the Nile Delta

Table 1  Complaints

Table 2  Complaints summary
Table 3  Frequency analysis of complaints numbers

<table>
<thead>
<tr>
<th>Class of Complaints Number</th>
<th>Number of collector for different Sub Centers</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mahallet Rouh</td>
<td>Shenrak</td>
</tr>
<tr>
<td>1-10</td>
<td>22</td>
<td>28</td>
</tr>
<tr>
<td>11-20</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21-30</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>31-40</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

3.2 Water Table Depth and Salinity

From the study of water table recession in different Sub centers of Santa Area during irrigation cycle. It is observed that:

- For Belkeem; Tukh Mazyed, Eknaway and Shubraks sub Centers, the average water table depth through the whole irrigation cycle was 84; 63; 68; and 92 cm below soil surface respectively. At the same time it was observed that the average water table depth 6 days after irrigation was 87.5, 47, 60.5 and 59 cm below soil surface for the same sub centers, respectively. This means that these collectors were not functioning well actually according to the criteria defined for Egyptian soils (100 cm below soil surface).

- For Mahallet Rouh Sub Center, it is observed that the average water table depth for the whole irrigation cycle is 103 cm below soil surface. This means that the water table depth coincides with the criteria defined for Egyptian soils because is more than 100 cm below soil surface. At the same time the average water table depth was 103 cm below soil surface “6 days after irrigation” and this also coincides with the desirable watertable depth according to DRI procedure (DRI 1997), which stated that the desirable water table depth of 1 m as an average should be reached 6 days after irrigation. Consequently, the collectors under that sub center were functioning well and were not in need for rehabilitation.

The electrical conductivity (EC) in dS/m was measured simultaneously with the water table depths. It was observed that salinity has been increased with the time progress after irrigation. This comes from the fact that the receding of the water table with time makes the concentration of salts in the water table increase. The average salinity of ground water during the study was about 2.0 dS/m in all sub centers.

3.3 Spatial distribution of age and complaints

West Delta
According to the data collected from drainage centres in the West Nile Delta, the subsurface drainage system installation started in 1970. Shobrakhiet Drainage Centre has the most complaints, which is evaluated as 34. The average number of complaints for the West Delta Central Drainage Department is low, of 14 complaints (Figure 2).

Middle Delta
In the Middle Delta the Desouk Drainage Centre had a large number of complaints, where it is reached 55 complaints. The second area is for Sedi Ghazi (46 complaints) and the third area for the South Kafr El Zayyat Drainage Centre (43 complaints). The average number of complaints for Middle Delta is 26, almost double the one of West Delta. Installation started as early as 1962 and is still ongoing.

East Nile Delta
The East Nile Delta has the same average number of complaints for ‘93-’96 period as Middle Delta: 26 (Figure 2). The Drainage Centers with the highest number of complaints are South Senbellawain (64), South Ibrahimia (60) and North Senbellawain together with El Saniya/Hosania (54). Construction in the East Delta started in 1964.
Middle Egypt

The average number of complaints of Middle Egypt is exceptionally low, with only 2 complaints. Most complaints are found in Etsa Fayoum Governorate (11), the oldest system where construction started in 1965. The extreme low values for Middle Egypt are mainly due to the relatively recent installation of most of the subsurface drainage systems.

The distribution of complaints in the period 1993-1996, per 10,000 fed (Fig 3) shows that for 75% of the observations the yearly number of complaints of the Drainage Centers is 35 or less. The 90% cumulative frequency occurs at approx. 45 complaints per year.

3.4 Complaints related to the year of installation

The Drainage Centers were arranged according to their average installation year in five groups: 1960-1977 (areas more than 20 years old), 1978-1982, 1983-1987, 1988-1992, and 1993-1997. An age of 20 years has been chosen because it is the period that economic life time in Egypt. Farmers have to pay the instalments for their subsurface drainage system over this period. For each group the average number of complaints in the period 1993-1996 was calculated and visualised in Figure 4. From this figure it is clear that the Drainage Centers more recently constructed have less complaints than the older ones. The oldest areas, constructed between 1960-1977, seem to have a similar number of complaints as the construction period of 1983-1987. The reason for this could be that those areas are located in the south of the Nile Delta, the highest part, with stable clay soils, where less problems with waterlogging and salinity are to be expected and where no filters are needed.

4 Conclusions and recommendations

The results obtained from the Santa area revealed that the number of complaints collected through five years were few compared to the served area. Most of these complaints were solved by the sub centers. The total number of complaints does not give a real picture about the need for rehabilitation in an area. In addition one needs to know the total collectors served by the sub center and the number of complaints per collector.
The water table drawdown curve after irrigation is a very important tool for defining to what extent recession takes place. If the water table was still high 6 days after irrigation this means that the system was in need of rehabilitation (main open drainage system is performing well). At the same time the open drainage system must be maintained because if there were any backward flow to the subsurface drainage system it would create many problems.

Not all the Drainage Centers with a high number of complaints do necessarily have the oldest Design Areas. The farmers in Egypt are paying for the installation of the subsurface drainage systems. During 20 years after the construction instalments are paid by the farmers to the government through taxes levied by the agricultural co-operatives. The maintenance departments of EPADP stay responsible for the maintenance of systems during their lifetime. It would be difficult to rehabilitate (i.e. construct a new drainage system) in areas that haven't been repaid completely by the farmers, unless EPADP recognises that the original drainage system was not designed, installed, or maintained well enough and waives the farmers the remaining instalments.

The complaint information from EPADP used for this study was available only per Drainage Center. Each Drainage Center contains older and newer Design Areas and it is not clear which Design Areas generated the complaints listed for the Drainage Center. A more accurate complaint assessment can only be made when for each recorded complaint the associated Design Area is known as well. In that case pre-drainage investigation could start at specific Design Areas instead of in the whole Drainage Center.

The future transfer of ownership and responsibility for subsurface drainage systems to Water Boards will allow for a completely different approach towards rehabilitation. Instead of a preventive total rehabilitation, a responsive, piecemeal rehabilitation could be applied.
The following recommendations for drainage complaint assessment can be made:

- Start a rapid appraisal in the Drainage Centers, which have an average age of more than 20 year. It is clear that that 75% of the yearly complaints observations of the Drainage Centers have an average number of complaints of 35 or less. Therefore, as a first guideline, the following areas should be selected: South Ibrahemia, Zagazeg, Meet Ghamr, South Aga, Sheben el Kom, and South Kafr el Zayyat. The rapid appraisal should include the visual inspection of the open drains (waterlevel, weed, blockage), manholes (waterlevel, sediment, damage), fields (waterlogged, crop condition, salt) and interviews with the farmers who logged most of the complaints;

- Based on the rapid appraisal select the areas where the problems can not be solved with (improved) maintenance;

- Start a standard pre-drainage investigation in the selected areas in order to determine the need for a subsurface drainage system. The decision should be based on the same criteria, used in new areas (without a drainage system). If needed, install new drainage systems as needed;

- Implement the M&E improved complaint assessment system in all the areas, provided with subsurface drainage systems in Egypt. The complaint assessment system developed by the M&E project includes detailed information on the location of the complaint source and the reason for the complaint. The results are stored in the M&E database.

- Implement the proposed priority ranking and planning procedure for rehabilitation, developed by the Monitoring and Evaluation Project.

- Repeat the exercise, made in this paper with the improved complaints data from the M&E database. Show the spatial distribution of the complaints from the Design Areas instead of the Drainage Centers.

5 REFERENCES


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[2] Senior Researcher, Drainage Research Institute (DRI), National Water Research Center (NWRC), Delta Barrage, Cairo, Egypt
ABSTRACT
The main objective of this paper is modeling of the nitrate load in the river outlet of a dominantly rural catchment using the simulation models DRAINMOD and MIKE 11 in combination with a regional GIS, containing major data layers of the catchment. In addition to describing the DRAINMOD-GIS approach in combination with the MIKE 11 model, for simulating the NO3-N fluxes in the land phase and the river draining the catchment, the methodology is tested using data of the Molenbeek river catchment situated in the Flemish region of Belgium. The comparative analysis reveals that the combination model (GIS-DRAINMOD-MIKE 11) is able to predict fairly accurate the nutrient load at any location in the catchment as well as the catchment outlet, resulting in a more precise modeling of the nutrient load transport and transformation in the land phase and the river of catchments. As such the approach can be used to derive for the study area the fertilizer practice that will result in a NO3-N load at the river outlet that does not exceed the limits, as specified by environmental considerations. The sensitivity analysis indicates that the nutrient load at the catchment outlet is most sensitive to the nitrification rate (K4) and mildly sensitive to the denitrification rate (K6) in the nitrification process and insensitive to the dispersion coefficient (D) in the one-dimensional advection-dispersion equation.

Keywords: DRAINMOD-GIS, MIKE 11 software code, rural catchment, catchment scale, nutrient loading, nitrate leaching

1 Introduction
The aim of this article is to upscale the outflow and nutrient load from individual fields to the outflow and nutrient load at catchment outlet through a combination of DRAINMOD (Skaggs, 1981), DRAINMOD-N (Brevé et al., 1997) with the MIKE 11 model (DHI, 1998). DRAINMOD and DRAINMOD-N simulate the drainage flux and the NO3-N concentration of the drainage water, respectively, whereas MIKE 11 is a hydraulic model simulating the flow and particle transport in rivers. The integrated modeling approach was evaluated simulating the nutrient load in a 5744 ha large catchment, the Molenbeek river basin. The model results were tested against field observations. The study presented in this paper was carried out to quantify in a rural catchment the contribution from organic and inorganic nitrogen fertilizers to the nitrate load found in the surface water. To model the transfer of nitrogen from the soil-crop system to the river use was made of a quasi two-dimensional mechanistic flow model, DRAINMOD, in combination with DRAINMOD-N, a GIS and MIKE 11.

The DRAINMOD and DRAINMOD-N models allow calculating at the scale of an individual field the daily nitrate leaching for a given soil, crop, climate, geo-hydrological and farming condition. The nitrate model covers the entire land phase of the hydrological cycle from the source on the soil surface, through the soil profile and the shallow drainage system to the river. The GIS pre-processes the river basin data in field specific data in a format suitable for the simulation models, and summarizes the main simulation results in tables and maps. The DRAINMOD and DRAINMOD-N results from each field are integrated at sub-catchment level. The time series of water and nitrogen load at sub-catchment level or river node are used as input in the MIKE 11 model to simulate the transfer and transformation of the discharge and the NO3-N flux in the river. The model results were tested versus the NO3-N load in the river water measured at the basin outlet.

2 Study area
The study area chosen to test the modeling-GIS approach was the Molenbeek catchment, being a tributary of the Dender basin. The catchment is situated north of the linguistic border, which divides Belgium in a northern and southern part. The river Dender is a tributary of the river Scheldt and has its springs in the Walloon region. The Dender basin has a total area of 1384 km² and the Flemish part of the river Dender catchment is divided into 12 hydrographic sub-catchments (zones), of which the Molenbeek is one, as shown in Fig. 1.
Methods

The DRAINMOD/DRAINMOD-N & GIS modeling approach as described in El-Sadek et al. (2000a) is coupled with the MIKE 11 river hydraulic model to calculate the nitrate load at the catchment outlet. The combined modeling-GIS system enables to upscale the discharge and nitrate load at field scale up to the scale of an entire basin. In the following a brief description is given of the DRAINMOD, DRAINMOD-N and the MIKE 11 modeling codes. The three models are combined as to be able to simulate not only the flow of water, but also the transport and transfer of nitrogen in the land-river phase of the hydrological cycle.

3.1 DRAINMOD & DRAINMOD-N Models

DRAINMOD simulates the water flow in a drained field. The simulation output gives the time series of the elevation of the water table and the drain outlet, including the net recharge to the underlying aquifer. DRAINMOD-N is in fact an add-on module to DRAINMOD, designed for simulating the nitrogen dynamics in artificially drained soils. The DRAINMOD/DRAINMOD-N model is a quasi two-dimensional model because the model considers only vertical transport in the unsaturated zone and both vertical and lateral transport in the saturated zone. The controlling processes considered by the model are rainfall deposition, fertilizer dissolution, net mineralization of organic nitrogen, denitrification, plant uptake, and surface runoff and subsurface drainage losses. Nitrate-nitrogen (NO₃-N) is the main N pool considered and the processes in the variable saturated zone of the soil profile can be represented by the advective-dispersive reactive (ADR) equation (Brevé et al., 1997).

3.2 MIKE 11 Model

The MIKE 11 model consists of different modules. In this study only the hydrodynamic (HD) and water quality (WQ) modules were used. The MIKE 11 hydrodynamic module uses an implicit, finite difference scheme for the computation of the flow in the rivers. The module can describe sub-critical as well as super-critical flow conditions through a numerical scheme that adapts in time and space according to the local flow conditions. Advanced computational modules are included for the description of flow over hydraulic structures, including possibilities to describe structure operation. The formulations can be applied to looped networks and quasi-two-dimensional flow simulation on flood plains.

The water quality module in MIKE 11 was developed by the VKI (Water Quality Institute, Denmark). It describes the basic processes of river water quality in areas influenced by human activities: e.g. oxygen depletion and ammonia levels as a result of organic matter loads. The WQ module solves the system of coupled differential equations describing the physical, chemical and biological interactions in the river.

Concentrations of nitrate are calculated in MIKE 11 by taking into consideration advection, dispersion and the most important biological, chemical and physical processes. The one-dimensional (vertical and lateral variation integrated) equation for the conservation of mass of a substance in solution, i.e., the one-dimensional advection-dispersion equation, reads as follows:

\[
\frac{\partial C}{\partial t} + \frac{\partial (AC)}{\partial x} = D \frac{\partial^2 C}{\partial x^2} - KC + qC_2
\]

where \( C \) is the concentration (arbitrary unit), \( D \) is the dispersion coefficient \([L^2 T^{-1}]\), \( A \) is the cross-sectional area \([L^2]\), \( K \) is the linear decay coefficient \([T^{-1}]\), \( C_2 \) is the source/sink concentration, \( q \) is the lateral inflow, \( x \) is the space co-ordinate \([L]\) and \( t \) is the time co-ordinate \([T]\). The equation reflects two transport mechanisms: advective (or convective) transport with the mean flow and dispersive transport due to concentration gradients.
The main assumptions underlying the advection-dispersion equation are that the chemical component is instantaneously mixed over the cross-sections, and the substance is conservative or subject to a first order reaction (linear decay). Fick's diffusion law applies, i.e., the dispersive transport is proportional to the concentration gradient. The reactions influencing the nitrate concentration are given by:

\[
\begin{align*}
\text{Nitrification} & \quad \text{(nitrification)} \\
\text{Denitrification} & \quad \text{(denitrification)}
\end{align*}
\]

where \( \text{NO}_3 \) is the concentration of nitrate \([\text{M L}^{-3}]\), \( \text{NH}_3 \) is the concentration of ammonia \([\text{M L}^{-3}]\), \( K_4 \) is the nitrification rate at 20°C \([\text{T}^{-1}]\), \( K_6 \) is the denitrification rate \([\text{T}^{-1}] \) or \([\text{M L}^{-3} \text{T}^{-1}]\), \( T \) is the water temperature \([\circC]\), \( a \) is the Arrhenius temperature coefficient for nitrification \([-]\), and \( b \) is the Arrhenius temperature coefficient for denitrification \([-]\) and \( t \) is the time \([\text{T}]\).

### Materials

The 5744 ha large catchment was subdivided into 24 sub-catchments based on the soil type and land use, as shown in Table 1. This table lists the area of each sub-catchment, the distance to the outlet, the land use and the main soil type. The code of the soil type is according to the Belgian Soil Mapping system. The main river, with a total length of 23.043 km, was divided into reaches with 31 nodal points, including the points of lateral inflows from each sub-catchment or block of fields and the hydraulic structures. Input data files were created for each of the sub-catchments (soil hydraulic properties, land use and other parameters). Most of the data on sub-catchment areas and river dimensions could be derived from existing database. The drain spacing and drain depth were assumed constant for the entire region equal to 25 m and 1.25 m below the surface, respectively. The measured cumulative load at the outlet is equal to 107.5 kg ha\(^{-1}\). Table 2 gives the explanation of the codes used for the soil types.

Daily flows and nutrient concentrations at sub-catchment level were simulated using the for Belgium agricultural conditions validated DRAINMOD and DRAINMOD-N models (El-Sadek et al., 1999; El-Sadek et al., 2000b). The daily flows are multiplied with the nutrient concentration to obtain daily nutrient loading at the outlet of the field blocks. Daily flow and nutrient loads from each of the 24 field blocks is used as input to the MIKE 11 modeling code. The MIKE 11 code was run with the water quality option for a period of four years, 1990-1993.

### Table 1  Number, area, distance to the river outlet, land use and soil type of the 24 sub-catchments in which the study basin was divided

<table>
<thead>
<tr>
<th>#</th>
<th>Area (ha)</th>
<th>Distance to outlet (km)</th>
<th>Land use</th>
<th>Soil type(^{(1)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>179</td>
<td>22.675</td>
<td>Sugar beet</td>
<td>Aba</td>
</tr>
<tr>
<td>2</td>
<td>195</td>
<td>22.306</td>
<td>Maize</td>
<td>Aba</td>
</tr>
<tr>
<td>3</td>
<td>226</td>
<td>20.647</td>
<td>Maize</td>
<td>Aba</td>
</tr>
<tr>
<td>4</td>
<td>234</td>
<td>19.910</td>
<td>Maize</td>
<td>Aba+Lca</td>
</tr>
<tr>
<td>5</td>
<td>244</td>
<td>19.173</td>
<td>Sugar beet</td>
<td>Aba</td>
</tr>
<tr>
<td>6</td>
<td>241</td>
<td>17.883</td>
<td>Maize</td>
<td>Aba</td>
</tr>
<tr>
<td>7</td>
<td>245</td>
<td>17.514</td>
<td>Maize + Sugar beet</td>
<td>Aba</td>
</tr>
<tr>
<td>8</td>
<td>233</td>
<td>15.671</td>
<td>Maize + Sugar beet</td>
<td>Aba</td>
</tr>
<tr>
<td>9</td>
<td>247</td>
<td>15.302</td>
<td>Maize + Sugar beet + Vegetables</td>
<td>Aba</td>
</tr>
<tr>
<td>10</td>
<td>232</td>
<td>14.380</td>
<td>Maize + Pasture + Sugar beet</td>
<td>Aba</td>
</tr>
<tr>
<td>11</td>
<td>248</td>
<td>13.643</td>
<td>Maize + Pasture + Sugar beet + Vegetables</td>
<td>Aba</td>
</tr>
<tr>
<td>12</td>
<td>250</td>
<td>12.537</td>
<td>Maize + Pasture + Sugar beet</td>
<td>Aba</td>
</tr>
<tr>
<td>13</td>
<td>250</td>
<td>12.168</td>
<td>Maize + Pasture + Sugar beet + Vegetables</td>
<td>Aba</td>
</tr>
<tr>
<td>14</td>
<td>250</td>
<td>10.325</td>
<td>Maize + Pasture + Sugar beet</td>
<td>Aba</td>
</tr>
<tr>
<td>15</td>
<td>250</td>
<td>9.219</td>
<td>Maize + Pasture</td>
<td>Aba</td>
</tr>
<tr>
<td>16</td>
<td>250</td>
<td>8.482</td>
<td>Pasture + Sugar beet + Vegetables</td>
<td>Aba</td>
</tr>
<tr>
<td>17</td>
<td>238</td>
<td>7.265</td>
<td>Maize + Sugar beet + Vegetables</td>
<td>Aba</td>
</tr>
<tr>
<td>18</td>
<td>232</td>
<td>5.790</td>
<td>Maize + Sugar beet</td>
<td>Aba+Ada</td>
</tr>
<tr>
<td>19</td>
<td>250</td>
<td>5.237</td>
<td>Maize + Sugar beet</td>
<td>Aba+Ada</td>
</tr>
<tr>
<td>20</td>
<td>250</td>
<td>4.776</td>
<td>Vegetables</td>
<td>Aba</td>
</tr>
<tr>
<td>21</td>
<td>250</td>
<td>3.670</td>
<td>Maize + Sugar beet</td>
<td>Aba+Ada</td>
</tr>
<tr>
<td>22</td>
<td>250</td>
<td>2.011</td>
<td>Maize + Sugar beet</td>
<td>Aba+Ada+Ldc</td>
</tr>
</tbody>
</table>
USE OF THE DRAINMOD AND MIKE 11 MODELS IN COMBINATION...IS FOR SIMULATING THE NITRATE LOAD AT CATCHMENT SCALE

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>250</td>
<td>1.289</td>
<td>Sugar beet + Vegetables</td>
</tr>
<tr>
<td>24</td>
<td>250</td>
<td>0.243</td>
<td>Maize</td>
</tr>
</tbody>
</table>

(1) the explanation of the codes used for the soil types is given in Table 2

Table 2 Definition of the codes of the soil types (Belgian Soil Map system)

<table>
<thead>
<tr>
<th>Code</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aba</td>
<td>Loam, well to medium drained</td>
</tr>
<tr>
<td>Ada</td>
<td>Loam, moderately to insufficiently drained</td>
</tr>
<tr>
<td>Lca</td>
<td>Silt loam, medium drainage condition</td>
</tr>
<tr>
<td>Ldc</td>
<td>Silt loam, moderately to insufficiently drained</td>
</tr>
</tbody>
</table>

4.1 Statistical Analysis

The qualitative judgement of when the model performance is good is a subjective matter (Anderson and Woessner 1992). Therefore statistical criteria are used for the quantitative judgement (Vázquez et al. 2002). Statistical based criteria provide a more objective method for evaluation of the performance of the models (Ducheyne 2000). In this study the following statistical criteria were used to evaluate the performance of the model:

4.1.1 Mean Absolute Error (MAE)

\[
MAE = \frac{1}{n} \sum_{i=1}^{n} |O_i - P_i|
\]

where \( O_i \) is the observation at time \( i \), \( P_i \) is the prediction at time \( i \). The MAE has a minimum value of 0.0.

4.1.2 Relative Root Mean Square Error (RRMSE)

\[
RRMSE = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (O_i - P_i)^2}
\]

where \( \bar{O} \) is the mean of the observed values over the time period (1 to \( n \)). The RRMSE has a minimum value of 0.0, with a better agreement close to 0.0.

4.1.3 Model Efficiency (EF)

\[
EF = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2}
\]

EF ranges from minus infinity to 1.0, with higher values indicating better agreement. If EF is negative, the model prediction is worse than the mean observation.

4.1.4 Coefficient of Residual Mass (CRM)

\[
CRM = \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (P_i - \bar{O})^2}
\]

The CRM has a maximum value is 1.0. If CRM is negative the model overestimates and vice versa.

4.1.5 Coefficient of Determination (CD)

\[
CD = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2}
\]

The CD describes the ratio of the scatter of the simulated values and the observed values around the average of the observations. A CD value of one indicates to what extent the simulated and observed values match perfectly. It is positive defined without upper limit and with zero as a minimum.

4.1.6 Goodness of Fit (R²)

\[
R² = 1 - \frac{SS_{res}}{SS_{tot}}
\]

where \( SS_{res} \) is the sum of the squared residuals and \( SS_{tot} \) is the total sum of squares.
where \( \hat{Y} \) is the mean of the predicted values over the time period (1 to \( n \)). \( R^2 \) is ranging from 0.0 to 1.0 indicating a better agreement for values close to 1.0 and it is known as the goodness of fit (Shahin et al. 1993; Legates and McCabe 1999; Vázquez et al. 2002). The characteristic of the different statistical criteria is given in Table 3.

### Table 3  The characteristic of the different statistical criteria

<table>
<thead>
<tr>
<th>RRMSE</th>
<th>MAE</th>
<th>CD</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRMSE=0 model is perfect</td>
<td>MAE=0 model is perfect</td>
<td>CD=0 no prediction capability</td>
</tr>
<tr>
<td>RRMSE=min optimal</td>
<td>MAE=min optimal</td>
<td>CD&lt;0 some at least prediction capability</td>
</tr>
<tr>
<td>0&lt;MAE model is less perfect</td>
<td>CD=max optimal</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EF</th>
<th>CRM</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF=1 model is perfect</td>
<td>CRM=1 no prediction capability</td>
<td>( R^2=1 ) perfect</td>
</tr>
<tr>
<td>EF=max optimal</td>
<td>CRM=1 some at least prediction capability</td>
<td>( R^2=max ) optimal</td>
</tr>
<tr>
<td>EF&lt;1 less perfect</td>
<td>CRM closes to 0 capability</td>
<td>( R^2=0 ) no prediction capability</td>
</tr>
<tr>
<td>EF= no prediction capability</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 5 Sensitivity analysis

The sensitivity analysis was performed for the most sensitive parameters of the water quality module of the MIKE 11 modeling code. The sensitivity of the model to the most sensitive parameters was conducted on a one to one basis, i.e., when considering the sensitivity of one parameter, all other parameters were held at their base value. The sensitivity analysis was conducted for the parameter base value (\( P \)) and four parameter values equally spread at both sides of the base value, \( P+P \), \( P-P \), \( P+2P \) and \( P-P \), respectively. The sensitivity analysis was performed for the dispersion coefficient (\( D \)) in the one-dimensional advection-dispersion equation and the nitrification rate (\( K_4 \)) and the denitrification rate (\( K_6 \)) in the nitrification and denitrification process, respectively.

### 6 Results and discussions

#### 6.1 Hydrology and Hydrodynamic Modeling

MIKE 11 calibration was done in a previous study for two different parameter groups (Radwan et al., 2000). In a first step the parameters of the routing model (the recession constants or time constants for base, inter and overland flow) were calibrated, and in a second step the water balance parameters (maximum water content in the lower zone storage, maximum water content in the surface storage, and overland flow runoff coefficient). After calibration of the recession constants, the water balance parameters were calibrated by trial and error. The procedure was repeated until the best match is obtained between the measured and modeled peak discharges and the total cumulative discharge.

For the Molenbeek case study the full hydrodynamic MIKE 11 model was implemented. The total length of the Molenbeek brook is 23.043 km. For the first 5.650 km no detailed data about cross-sections and hydraulic structures are available, but for the next 17.393 km, detailed data about cross-sections and all significant hydraulic structures are available. Data of 440 cross sections are available over the distance of 17.393 km. The variation in channel shape along the model branches could be described adequately.

MIKE 11 output of daily discharge rates at Mere station in the Molenbeek catchment were verified using measured data as shown in Fig. 2. The comparative analysis indicates that, the flow discharge obtained by using MIKE 11 are very similar. The foregoing indicates that the simulated flow rates derived by the DRAINMOD model at sub-catchment level and routing of the hydrographs of the 24 sub-catchments, using MIKE 11, given satisfactory results.
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6.2 Water Quality Modeling

The nutrient loading or concentration at the outlet of a field block is simulated using DRAINMOD-N. The predicted discharge outflows are used with a flow-weighted concentration to obtain the N loading at the outlet of the sub-catchments. Instead also the relationship of flow versus concentration could be used for each field block with a specific land management practice to determine the N load at the outlet of the field block. The procedures for calculating the nitrate load at the outlet of the catchment are explained schematically in Fig. 3. A comparison of total cumulative load using the DRAINMOD/DRAINMOD-N model in combination with the MIKE 11 modeling code versus measured data is shown in Fig. 4. Table 4 gives the annual load measured and simulated using the DRAINMOD/DRAINMOD-N & MIKE 11 approach. The comparative analysis reveals that DRAINMOD-GIS in combination with MIKE 11 model is able to simulate with acceptable accuracy the monthly NO3-N load at the catchment outlet for the period 1990-1993. The results of the statistical analysis, presented in the Table 5, clearly illustrate that on average the combination model performs good results in the prediction of the NO3-N load at the catchment outlet.

<table>
<thead>
<tr>
<th>Year</th>
<th>Measured NO3-N load in kg ha⁻¹</th>
<th>Simulated NO3-N load in kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>2.6</td>
<td>8.8</td>
</tr>
<tr>
<td>1991</td>
<td>40.1</td>
<td>31.7</td>
</tr>
<tr>
<td>1992</td>
<td>17.8</td>
<td>17.1</td>
</tr>
<tr>
<td>1993</td>
<td>47.0</td>
<td>36.8</td>
</tr>
</tbody>
</table>

6.3 Sensitivity Analysis Results

The sensitivity analysis results, as presented in Table 6, reveal that the nutrient load is most sensitive to the nitrification rate (K₄) and mildly sensitive to the denitrification rate (K₆) and insensitive to the dispersion coefficient (D) in the one-dimensional advection-dispersion equation. The statistical criterion used in this study to characterize the sensitivity is the coefficient of determination between the simulated and observed NO₃-N load at the basin outlet, using 5 different values of the parameter for which the sensitivity analysis is performed. The middle or base value (P) for the parameter, for which the analysis is performed, is the value found after calibration. The value of Δ was taken as 25% of the P-value.

<table>
<thead>
<tr>
<th>Year</th>
<th>Measured NO3-N load in kg ha⁻¹</th>
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<td>17.8</td>
<td>17.1</td>
</tr>
<tr>
<td>1993</td>
<td>47.0</td>
<td>36.8</td>
</tr>
</tbody>
</table>

Table 4 Annual measured and simulated NO₃-N load, in kg ha⁻¹, at the river outlet, for the period 1990-1993

Table 5 Statistical performance analyzers calculated for the simulation period 1990-1993
USE OF THE DRAINMOD AND MIKE 11 MODELS IN COMBINATION...IS FOR SIMULATING THE NITRATE LOAD AT CATCHMENT SCALE

Based on the measured and simulation results of the combined modeling approach, the performance metrics are as follows:

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAE</td>
<td>0.457</td>
</tr>
<tr>
<td>RRMSE</td>
<td>0.803</td>
</tr>
<tr>
<td>CD</td>
<td>0.87</td>
</tr>
<tr>
<td>EF</td>
<td>0.877</td>
</tr>
<tr>
<td>CRM</td>
<td>-0.081</td>
</tr>
<tr>
<td>R²</td>
<td>0.896</td>
</tr>
</tbody>
</table>

MAE: mean absolute error; RRMSE: relative root mean square error; CD: coefficient of determination; EF: model efficiency; CRM: coefficient of residual mass; R²: goodness of fit

Table 6  Results of the sensitivity analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitivity criterion(^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-2ΔP</td>
<td>P-ΔP</td>
</tr>
<tr>
<td>P</td>
<td>P+ΔP</td>
</tr>
<tr>
<td>P+2ΔP</td>
<td></td>
</tr>
</tbody>
</table>

\(^{(2)}\) Sensitivity criterion = coefficient of determination

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sensitivity criterion(^{(2)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>K₄</td>
<td>0.758</td>
</tr>
<tr>
<td>K₆</td>
<td>0.807</td>
</tr>
<tr>
<td>Dispersion coef.</td>
<td>0.896</td>
</tr>
</tbody>
</table>

http://library.wur.nl/ebooks/drainage/drainage_cd/1.7%20alaas,%20shaden%20et%20al.html (7 of 9)26-4-2010 12:11:18
7 Conclusions

The combination GIS-DRAINMOD-MIKE 11 model was tested using four years of measured data of the river Molenbeek basin in Belgium. The modeling approach was applied in a distributed way and used to model the river flow and nutrient load in the Molenbeek River. The statistical analysis indicated that the approach is able to reconstruct quite accurately the river discharge and the nitrate load of a primarily agricultural catchment with heterogeneous land management practice. For the analysis the catchment was subdivided in 24, more or less homogeneous, sub-basins with a particular soil-land use-management practice. The sensitivity analysis results indicated that the nutrient load is most sensitive to the nitrification rate ($K_4$) and mildly sensitive to the denitrification rate ($K_6$) in the nitrification process and insensitive to the dispersion coefficient ($D$) in the one-dimensional advection-dispersion equation. The comparative analysis revealed that the combination model (GIS-DRAINMOD-MIKE 11) is able to predict fairly accurate the nutrient load at any location in the catchment as well as the catchment outlet, resulting in a more precise modeling of the nutrient load transport and transformation in the land phase and the river of catchments. As such the approach can be used to derive for the study area the fertilizer practice that will result in a NO$_3$-N load at the river outlet that does not exceed the limits, as specified by environmental considerations.

8 References

USE OF THE DRAINMOD AND MIKE 11 MODELS IN COMBINATION...IS FOR SIMULATING THE NITRATE LOAD AT CATCHMENT SCALE


Skaggs, R.W., 1981. Methods for design and evaluation of drainage water management systems for soils with high water tables, DRAINMOD. North Carolina State University, Raleigh, North Carolina, USA.


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ABSTRACT
A two dimensional saturated-unsaturated Galerkin finite element numerical model was used to predict water table height between parallel drains. A user-friendly software (DRENAFEM) was developed to allow for the calculation of the distance between drains and the water table height at middle space between drains. It also allows for determination of variations of the total head throughout the entire geometric space considered in the model. Such facts lead to the design of flow nets with stream lines and equipotentials. The numerical drain outflow is also obtained by using the radial flow equation, conservation of mass and finite element analysis.

The results obtained with the model agree well with Khirkam’s and Hooghoudt analytical solution for the distribution of total head in ideal drains and for the total head calculations midway between drains.

Keywords: Subsuperficial drainage, numerical simulation.

1 INTRODUCTION
The movement of the water and solutes in the vadose zone has had an increasing interest in diverse areas of science as the hydrology, agricultural and soil engineering. The knowledge of the processes of transfer of water in the soil and ways to foresee, predict and control water movement in the soil are important in the simulation of the behaviour of water table and dispersion of solutes, in particular for the subsurface drainage., From the solution of transient saturated/unsaturated flow equation of Richards the oscillation of the water table levels and drain flow rate can be simulated between two parallel drains in response to a recharge due precipitation and/or irrigation, as well as its variation in time.

Numerous solutions for the considered problem are found in the literature. The majority of the proposed solutions are based on the hypotheses of Dupuit-Forchheimer which, when certain initial and boundary conditions are established, allow for an exact analytical solution of the steady state saturated flow equation of Laplace (Yeh, 1999). The mathematical solutions are usually of two dimensions (Kirkham, 1966; Gureghian and Youngs, 1975) and well suited for a variety of applications and well defined for particular cases, but they do not comply very well when more complex problems arise, for instance when the heterogeneity and anisotropy of the soil are to be taken into consideration, when the unsaturated flow is also to be considered, and when there exist complex and irregular boundary conditions for drain boundary. Only way to solve the problem is to use numerical methods.

The finite element method is a numerical method that is used as a numerical approach of the transient saturate/unsaturated flow, especially in the search of solutions for the water table level between two ditches or in a riverbank. FRANCE et al (1971); DESAI
(1972); Gureghian and Youngs (1975) had applied the method to solve the problem in two dimensions for steady state and saturated flow, to determine the position of the water table surface, subject to different boundary conditions. Neuman (1973) solved the same type of problem considering the contribution of the flow in the unsaturated zone. The application of the same numerical approach solution to subsurface drainage by drain pipes is described in Zaradny and Feddes (1979). The method suffered further improvements to allow it to represent drains in the numerical mesh (Tarboton et al., 2000) and also suffered further numerical refinements to diminish the loss of mass and the numerical oscillation in the computation (Pan et al., 1996).

There are several finite element computer codes to numerically solve the water flow in soil, like the HYDRUS2D (Simunek et al., 1999), SWMS_3D (SIMUNEK et al., 1995) Aquifem-N (TOWNLEY, 1990), however they all need a relatively complex set of initial and boundary conditions.

The objective of this work is to propose a friendly computer software which solves the transient vertical unsaturated flow in a subsuperficial drainage situation, drained by parallel pipe drains set at the same depth. Numerical approach is compared with the analytical solution for a well-defined situation. In the case, from the well known Hooghoudt equation and Kirkham potential theory calculations. The results of our proposed model are also compared with the results generated by Hydrus2D model of Simukey et al. (1999).

The model allows also for the simulation of drain flow rate from the concept of the mass conservation. The solutions were also compared with the approximate solution in steady state simulation.

2 MATERIALS AND METHODS

2.1 The theory

With water flowing into an elementary prism of soil with unit dimensions, the flow leaving the soil is equal to that which enters it, deduced of the variation of volume of stored water. This fact translates the principle of the mass conservation that, applied jointly with the dynamic equation of Darcy, allows for the generalized flow equation into the soil.

Without great margin of error for the type of problem considered, that the water and the soil are incompressible and they do not change mass between themselves, that thermal gradients do not exist in the soil and the law of Darcy is valid in all the domain of the flow, the general flow equation - Richards equation - can be written as

\[ \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left( \frac{1}{K(\psi^e)} \frac{\partial \psi^e}{\partial z} \right) \]

\[ \text{where } K(\psi^e) \text{ is the unsaturated hydraulic conductivity (m.day}^{-1}), C(\psi^e) \text{ the soil water capacity (m}^{-1}), \text{ representing the slop of the moisture retention curve in the soil, } \psi^e \text{ the pressure water potential related to the weight of water (m), } z \text{ the gravitational potential (m) and } t \text{ the time (days).} \]

Applying the Galerkin finite element approach to the generalized flow equation, transforming the resulting integrals into matrices and adding all the elements of the domain a global matrix is obtained, for where the formulation of the weighed residuals for steady state and transient flow is written as:

\[ \frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z} \left( \frac{1}{K(\psi^e)} \frac{\partial \psi^e}{\partial z} \right) \]

\[ \text{where} \]

\[ \text{(2a)} \]

\[ \text{(2b)} \]

\[ \text{(2c)} \]
Ni, Nj are the element interpolation functions, $\Omega$ the flow domain and $\Gamma$ the boundary segment. The matrix $[C(\psi\bullet)]$ is a diagonal matrix carrying the coefficients of specific capacity and the matrix $[K(\psi\bullet)]$ is a symmetrical matrix, with a positive dominant diagonal line with coefficients of the hydraulic conductivity. The vector $\{F\}$ is the summation of all flows that enter or leave the system with the flow gravitational component. Accordingly, the value of the flows is equal to zero when no water enter or exit the system, negative when it exits and positive when it enters the system. $r_n$ is the component of flux normal to the soil surface.

### 2.2 The numerical model

Placing the drains to the same depth between the horizontal soil surface and a deeper impermeable layer, the space between any two drains becomes symmetrical and the problem can be represented as in Figure 1.

![Figure 1 The flow domain in steady state regime.](image_url)

The boundary conditions for the solution of a problem of this kind can be classified in two categories of the essential type, also known as the Dirichlet boundary condition and 2) the natural type or Neumann boundary condition. Boundary AB is of the natural type, therefore to each node of the segment it is possible to apply one flux lower of the soil infiltration capacity. The remaining borders are taken as having zero flow, that is, without entrance or exit of water. The drain, it is represented by only one node in the point, with a border of the type essential, since the total potential will equal there the gravitational potential, allowing for the potential of pressure in the drain to become zero (atmospheric pressure).

Mathematically terms the boundary and initial conditions are written as:

- **AED:**
- **DC:**
- **BC:**
- **AB:**
- **E:** (drain node) $\psi=0$, $t \geq 0$;

A computer program (DRENAFEM) was designed to solve Equation 1, subjected to boundary an initial conditions where the drain is represented as one node and the surrounding elements have the values of hydraulic conductivity adjusted from one factor, according to the VIMOKE and TAYLOR (1962) approach, also described by in FIPPS and SKAGGS (1986). Anisotropy in the hydraulic conductivity anisotropy on vertical and horizontal directions, two soil layers and the Brooks and Corey and van GENUCTHEN (1980) retention models were included into the model. The final software makes space discretization of 1520
triangles and 820 nodes, with larger mesh density in the unsaturated zone and near the drain.

Figure 2 shows the program main window where the geometry problem is defined, as well as the soil physics parameters such as hydraulic conductivity, soil-water retention and the steady drainage flux. The model has the capability to simulate ideal and non-ideal drains, and by assigning backpressure to the drain controlled drainage problems can also be simulated. In the absence of real values, the model suggests values for use with soil-water retention curves as well as saturated hydraulic conductivity values, all based in the soil texture considered for the problem. It also automatically builds up the finite element mesh and in the transient state mode it chooses the ideal time step to prevent numerical difficulties and run-time errors. The time spent to obtain a solution depends on the computer performance, with about 1 minute time spent to find a steady state solution in a Pentium IV at 800 Mhz. In a transient state simulation mode the run time depends on the total time of the period simulation, with several minutes expected for the described above Pentium machine.

Figure 2  The main window of software.

2.3  Analytical solutions of the problem

For testing the reliability of a numerical model the usual procedure is to compare the obtained results with well know solutions. We chose two analytical solutions based on different theory, and one numerical solution offered by a commercial software. KIRKHAM et al (1974), based in the theory of potentials considered the analytical determination of our same problem. In their approach they did not consider the effect of the unsaturated zone in the flow in solving the Laplace’s equation, is consequently, different from the approach used in this work. Kirkham et al. assume that the head loss in the zone between the water table surface and the horizontal plan of the drains is small when compared to the head loss in the remaining region of the flow. They also consider that the soil f above the plan of drains is replaced by fictitious membranes and gravel with infinite hydraulic conductivity, so that the standard equipotential lines in that zone of flow above the horizontal drains plan has no solution with their method.
Figure 3 The steady state window result

Figure 3 shows the results of a steady state run where the water table shape is presented as well as the head distribution from the drain to midpoint between drains, and the numerical drain flow.

The drains also are dealt with thickness zero and equal width to the radius. The model of Kirkham also assumes that the flow above of the horizontal plan of the drains is vertical in the unsaturated zone and that in the saturated zone it obeys the conventional way of looking at the flow, that is a horizontal flow.

The model results were compared with the widely used equation for drain spacing calculation based in the Boussinesq equation, known as the Hooghoudt equation

\[(3)\]

where \(d_e\) is the depth of the equivalent depth layer, used to correct the convergence of the radial flow near the drain, \(h_m\) the water table above the drain at the midpoint between drains and \(K_s\) the saturated hydraulic conductivity, \(L\) the space between two drains and \(q\) the steady drainage flux, numerically the same at \(r_n\) in the steady state regime.

### 3 RESULTS AND DISCUSSIONS

Several calculations were performed to test the numerical results obtained. One compared the elevation of the water table above the drain at the midpoint between drains with the Hooghoudt analytical solution.

Hooghoudt in his expression for the shape of the water table as an ellipse assumes that the constant value of the flow \(q\) that crosses the water table surface is equally removed between the drains. In steady state this is true for the numerical approach. The steady drainage flux in the surface of soil has the same value as that the one that crosses the water table surface. Figure 4 shows the good agreement obtained between our numerical approach and the Hooghoudt equation, for several geometric conditions. The exception is when the water table is near or above the surface. In this case the midpoint head value obtained with the numerical simulation is larger above the drains possibly due of the effect of capillary fringe in the vadose zone. As observed,
the Hooghoudt equation results are no longer valid for pounded water table. Figure 4 also shows the effect of drain radius on the obtained results, and the need for a numerical model that simulates well the behaviour of the drain hole as a single mesh node. For higher values of \(q/K_s\) ratio, the drain radius effects have influence in the results, with the need to adjust the elements surrounding the drain node to best simulate drainage flow. For lower \(q/K_s\) ratio that need is no longer so evident.

**Figure 4** Variations of the \(h_m/L\) ratio with \(d/L\) ratio for different \(q/K_s\) ratio and real drain radius. Simulations are made for a clay soil in a homogeneous and isotropic medium.

**Figure 5** Comparison of the equipotential lines and the position of the water table according to Kirkham (solid line) and of the numerical model (doted line). Simulation made for \(L=20\) m, \(K_s = 1.5\) m day\(^{-1}\), imperme barrier at the depth of 3 m, drain at depth of 1 m, VG parameters: \(n=1.09, \theta_s = 0.36\) m\(^3\) m\(^{-3}\), \(\theta_r = 0.07\) m\(^3\) m\(^{-3}\) e \(\lambda = 0.5\) m\(^{-1}\), \(q=0.002\) m day\(^{-1}\) and \(r = 0.05\) m (A) and \(r=0.005\) m (C).
Figure 5 shows the potential patterns computed with the finite element method (doted lines) and the Kirkham solution (solid lines), and also the water table configuration from the drain to the midpoint of drains.

The difference in equipotentials between the two methods explains the observed differences for the different position of the water table. The drain radius influences greatly the distribution of the potentials and the position and shape of the water table. Drain radius must be reduced in the Kirkham approach to obtain satisfactory agreement of the equipotential lines for the two methods, as seen in Fig. 5B. The values of the drain radius used are respectively 0.05 m and 0.005 m. In the first case, the level of the water table was lower than the level obtained with the numerical analysis simulation and, as a result the hydraulic potential is lower for all the flow points. The variations correspond to the difference observed between the positions of the two free surfaces. So, to obtain the same values of water table level it is necessary to attribute an abnormally small value to the drain radius, inducing a radial flow or an entrance resistance in the case of the Kirkham analysis. Figure 5C) In doing so, the agreement between the water table shape and equipotential lines is satisfactory in both methods, especially at the mid point between the drains. However, near the drain the potential distribution estimates higher values for the hydraulic potential. This aspect of the problem leads us to believe that a sole analysis of the head at the half distance of the drains is not able to inform in absolute of the adjustment between different methods of calculation. Some differences, however less evident that the above, also exist in the way drainage occurs. The analysis using Kirkham method practically considers a vertical flow in the corresponding zone more significantly at the half distance of the drains and also shows a trend of if becoming horizontal for distances close to the drains. The confluence of the flows for the drain (radial flow), also starts at lesser distances of the drain when compared to the numerical analysis solution. The smaller level of water table obtained with the Kirkham approach, beyond the value attributed to the drain radius can be explanation in the fact of the flow above of the plan of the drains being considered vertical and the Kirkham analysis considering not important loss of head in this region. However, the resultant equipotentials of the numerical analysis show that the flow is practically horizontal, being the simplification made by Kirkham partially responsibly the difference in the results. Also below of the plan level of the drains a zone there is a definite horizontal drain flow what does not happen when the solution of Kirkham To analyse the weight of the restrictions in the observed differences, as well as the precision of the numerical method, the HYDRUS2D (Simunek et al, 1999), which uses a finite element method was compared to our model. HYDRUS2D was used for simulations with a mesh of regular space and 4640 triangles that correspond to 3042 nodes. The drain in the HYDRUS2D is also represented by only one node adjusted to the mesh by using the Vimoke adjustment. Several calculations were performed in the unsteady state mode, for a period of 5 days, considering as the initial condition the soil a profile fully water saturated and a recharge q of 0 m day⁻¹. Despite the denser mesh of triangles of HYDRUS2D when compared to our model, the regular mesh did not allow to greater density next to the drain where larger values of hydraulic gradients were expected. The results are obtained directly in the model DRENAFEM, while for the HYDRUS2D model the solution is obtained by inspection of the hydraulic head in the node situated in the impermeable barrier, exactly half distance between the drains, deduced of the distance of the drain to the impermeable layer. The obtained results are shown in the following figure
Figure 6  
**Time variation of the $h_m$ in two software programs**

During the 24 hours simulation period the values of $h_m$ diverge slightly, due to the large space discretization resources of the HYDRUS2D model, and more important, due to the use of lesser intervals of time as verified for the smaller distances of the points of the line. However, it is in the numerical method used in the two models to solve the system of equations that they are, in essence, different. While the DRENAFEM model uses the direct method of LU decomposition for solving the system of equations the HYDRUS2D uses the indirect method of preconditioning conjugate gradient method, for faster and relatively little expected problems with the round off of errors. These aspects contribute for the differences observed in the obtained results. The execution time was the same. Taking into account differences in the dimension of the matrices set up for the problem, the HYDRUS2D model is very fast.

4  
**CONCLUSION**

The DRENAFEM numerical model presented good agreement in results when compared to the Hooghoudt analytical solution for a homogeneous and isotropic soil, assuring that the hydraulic head at the mid point between the drains can be obtained numerically with a friendly software. All what is required is a few soil and geometric parameters to obtain steady state solutions.

When compared to Kirkham method of evaluation the results show that the drain radius influences the shape of the water table and as result a different flow pattern is obtained with the DRENAFEM model, especially in what concerns the calculation of the head above the vertical plain of drain. So, despite the inherent differences of the two methods, the representation of a drain in a mesh as a one single node must suffer improvements to handle the simulated problem. Also differences were observed for the field potential distribution due to differences in the drain radius and in the initial assumptions made for both models.

Despite differences in the nature of the used numerical method to solve the system of equations and the required speed a reasonable agreement was obtained between the results of the DRENAFEM model and the results obtained with the Hydrus2D model simulating an unsteady flow regime.

5  
**Acknowledgements**

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6  
**REFERENCES**

A FINITE ELEMENT SOFTWARE FOR PREDICTING WATER TABLE HEIGHT BETWEEN PARALLEL DRAINS


THE DECISION-SUPPORT SYSTEM FOR THE FEDERAL INVESTMENT'S PLANNING AT DRAINAGE OPERATION[1]

Dr.Sc. I.Yurchenko[2]

ABSTRACT
The development of drainage systems operation related to the elaboration of their supervision, analyzing of their functioning as well as both environmental control and efficiency estimation. Such a development needs data systematization, sequencing, storing, processing and interpretation.

Justification and planning of the federal investments on the reclamation systems preparing to the crops planting period is the chief task at the tactical scale of the governing. At this stage the estimation of available resources on the regional, local or total (country) scale are made to increase the ecology-economical efficiency of reclamation systems operation. To raise the efficiency of the governing decisions the computerized decision support sustainable system has been created in vniigim. At decision support sustained system development method based on the optimizing and heuristic has been approached. The practical application of the decision support sustained system (dss) in the field of land reclamation has shown it high efficiency and great opportunities.

Keywords: Drainage, Dss, Planning, Optimization, Alternative

1 Introduction
Management improving at maintenance depends on control and analysis of economic and ecological efficiency of reclamation system (operation). Systematization of data at their selection, collating, storage, processing, interpretation is required.

Justification and planning of budgetary financing at reclamation system preparation to the crop planting period is the chief problem at the tactical level of management. Supervision of resources employment at the region and country level is done to improve management efficiency. The last task is determined as the strategic purpose of reclamation (Program 2001...2010 “Reproduction of arable lands fertility).

As a rule volume of financing is lower than demanded. Ecological and economic efficiency of the possible variants can be different. Order of budgetary funds distribution requires many factors to be taken to the account Being unavailable today special models of limited capital investment distribution need for analytical estimation of decision acceptance. At the lack of both time and tools manager chooses reasonably obvious alternative, the results of accepted decisions rarely analyzing.

Decision support sustainable system (DSS) gives opportunity to implement uninterrupted training of the stuff and to solve the following problems:

- analyses of results at hydraulic structure survey; estimation of technical conditions of reclamation system; cost structure of fund; ecological characteristics;

- information composition forming concerning budgetary financing requirements in different regions of Russia is formed according to the sort of activity and object features;
• creating of alternative version of budgetary financing plan;
• searching of efficient version of budgetary financing plan as a result of optimization program.

2 DSS architecture
DSS architecture “THE PLAN” packs three systems: analyzing; informative, decision acceptance. (Fig.1)

Figure 1 DSS architecture “PLAN”

System of analysis includes the database and model of conditions, control and estimation used for version of budgetary financing development. Both special data input and output data is stored in semantic database. Database is organised and supported with DBMS “Access” facilities. Analytical input data presented characteristics of modern technical, ecological and economic condition of the reclamation system were obtained: on the base of irrigation and drainage systems description realising on the regional, republic and other federal levels; on the base of the cadastre data.

System of solutions includes: models of optimization, models of efficient candidate solution searching at specified characteristics; algorithm of automation and enhancement of traditional techniques at budgetary financing planning; planning procedure
according to subscriber tend. Informative system combines the following methods: problem definition using database; information processing for decision acceptance, input and output data at technological process modelling; report formation according to inquiries of users.

On the first stage two levels of DSS application with feedback are supposed. The first stage named “Finance distributor” – the chief of subdivision who conventionally provides plan of financing. The second stage named “Departments” – the departments of the subdivision. Information received from the workstations storing in the corresponding database. Using application programs manager can request necessary information and get it in convenient and demonstrable form (as a table, as a text report). Service of departments provides information obtaining and so new input data forms in the SADS database. This service carries out report preparation etc.

3 System components

**Figure 2** Components of DSS “Plan” (The main Form)

Components of DSS “PLAN” and functional structure of system is shown in the Figs. 2, 3. Manipulation with separate subsystem, task, database etc. is implemented using menu “The main form” – DSS (Fig.3). Description of the next problem and short-form recommendation are given.

3.1 Analysis of hydraulic structures and reclamation systems inspection

Actual problems of maintenance service are the following: testing and estimation of technical characteristics of hydraulic structures; capital ratio estimation; ecological and economic settlement. The above mentioned problems determine efficiency of management solutions on financing planning of maintenance and repair service.

DSS “Plan” provides information obtaining in the convenient form to analyze existing convenient situation; to support solution of decisions; to make plans; to form forecast etc. Reference and reports preparation simplifies analysis and improves final result.

Maintenance organizations obtain input data as the result of object’s inspections, instrumental measurement, official report data etc. DSS using include several stages: input and storing of information in the computer database, analytical data processing, analytical information preparing for solution accepting person (SAP). Analytical information for technical and economic estimation
is prepared by input data aggregation, iconic representation of information, special references forming according to the DSS’s inquiry etc.

DSS provides high functionality at documents forming by different information packing and new knowledge obtaining on the base of input data. Ecological estimations are made by DSS for Russian Federation subjects using suggested criterions for reclamation systems: actual water delivery derivation from normative value and the corresponding irrigation water application efficiency [Mikhailov, 2000].

**Figure 3  Functional Structure of DSS**

Normative water delivery gross-value is water capacity necessary to provide required crop irrigation depending on the agrometeorological conditions during rated period.

Normative water delivery for the irrigation period is calculated as:

\[ E_{o}^n \times X_{n} \times \eta \]  

where \( E_{o}^n \) is the optimum evapotranspiration value; \( X_{n} \) - the precipitation value; \( \eta \) - irrigation efficiency.

Factual water delivery derivation from normative value (%) is determined as:
The corresponding irrigation water application efficiency (CIWE) is determined considering soil moisture variation. Productive water value is the difference between evapotranspiration and precipitation value. Productive water value is directly used by plant to provide crop yield.

Actual CIWE value is calculated for the irrigation season using formula:

\[ \text{CIWE} = \frac{\text{Productive water value}}{\text{Total water application}} \]

Derivation of CIWE actual value (%) from conditional normative value is determined as:

At actual data accumulation and customer needs growth the list of service is enlarged both for the settled task and for DSS as a whole.

### 3.2 Composition of information about financing requirement at maintenance

The problem of financing requirement is the chief task at budgetary facilities distribution. To plan budgetary backing at reclamation systems preparation for the crop planting period is done considering facilities requirement. Target at budgetary financing requirement of repair-maintenance works is determined on the base of:

- the declared needs. Subordinated enterprises present the declared needs according to the actual situation. Data processing is implemented at the subsystem level;
- the rated demand determining at the subsystem level using branch-wise standards on the repair and maintenance works;
- declared and standard financing and resources needs analysis using the derivations values. According to the results of analysis the solution of decision is made on the schedule budgetary financing (using additional data).

DSS “Plan” allows determining the financing needs according to subscriber enquiry. Repair maintenance works are divided as followed: capital repair, current repair and technical service. Calculation is made at the following levels: country; budget recipients; types of hydraulic structure: canals, drainage network, escape canals, pumping stations, dams, water intakes, protective banks and dams, roads, etc.; different combination of financed subject, repair complexion and objects of repairing.

### 3.3 Forming of alternative version at budgetary financing plan making

Alternative version at budgetary financing at plan making can be formed on the base of the gate: using optimization system (paragraph 3.4) or using traditional technology of finance distribution. The last technology is used to settle the following problem: This settlement provides automation of plan formation at budgetary financing.

- preference of the decision accepting person;
- limit distribution among recipients pro rata planned demand value.

Problem solution is realized using procedures “Irrigation computing”, “Drainage design”, menu “The main form”. (Fig.3). To
support decision solution about concrete budgetary allocation of funds according to the corresponding recipient information about the declared and the calculating cost of repair and maintenance works is rendered. Using as default the column “Appropriated for” is corresponded to the column “Rated needs”. Adjustment lines in column “Appropriated for” is made by the subscriber with data input by the keyboard. The summarized data of planned financing is automatically varied according to the individual recipient (district, region and country). The summarized data displayed on the screen is served for decision solution support.

Distribution of available financing limit among recipients is realized pro rata planned demand at window “The appropriated funds” belong to the form named “Budgetary financing”. Output document is printed at key button “Report” activation in the form named “Planing”.

3.4 Solver finder of efficient solution for technical maintenance as the result of optimization task

Problem definition and its solution at optimum decision acceptance are the general problems at DSS development. Optimum decision acceptance allows distributing financial resources so that the ecologo-ecomonical efficiency of repair within the select criterion would be the maximum. To develop a decision acceptance support system the approach combining methods of optimization and heuristic estimation has been suggested. Budgetary facilities distribution is realized in two stages. At the first stage the “n-th” part of facilities appropriated for financing is distributed. The “n-th” part is the financial support required providing of reclamation systems viability. Subscriber determines the list of criterions using at budget funds distribution. According to traditional order of financing facilities distribution the criterions are determined as following:

- availability of irrigated and drained lands, served by reclamation systems belong to the federal ownership;
- book value of state operated reclamation systems (main canals and pipes, pumping stations, hydraulic structures);
- pattern of reclamation funds (earth canals, canals with concrete lining; flumes, regulating structures, pumping stations, vertical drainage, etc.)
- actual technical condition on reclamation facilities and funds belong to federal ownership (according to reclamation cadastre data);
- network extend, amount and type of hydraulic structures and their location, maintenance difficulties;
- regional factors;
- operational organizations availability;
- general staff.

All recipients are given numerical estimation on every criterion. Each criterion is given entity ratios denoting its significance. Ratios are multiplied on criterion estimations and the resulting values are summarized. So to distribute financial facilities the value of each recipient is obtained. Procedures are implemented in the on-line regime at maximum possible user-friendly interface.

The remained financial facility is appropriated according to the results of optimizing task solution. Maximum high efficiency is provided at reclamation systems operation. Constraints are the financial facility on separate recipient and on the reclamation as the whole. The discrete model on optimizing task solution at budgetary funds distribution is looked as following (3-5):

\[
\text{(3)}
\]
\[ \sum_{i}^{\text{declared}} \leq \sum_{i} \text{delivery} \]

\[ \sum + \sum \leq \sum \text{remaining} \]

where \( W_i \) – is the water delivery for irrigation by the system of recipient \( i \); \( \sum_{i}^{\text{declared}} \) – the budgetary financing facility for the repair and maintenance works (passive and active); \( \sum_{i}^{\text{regular}} \) – includes permanent repair expenditure of network with structures at the reclamation system and permanent repair of civil and industrial buildings, flood protecting works, forestations and other measures independent on water delivery; \( \sum_{i}^{\text{structure}} \) – includes expenditure of hydraulic structure maintenance and repairing (protective dams and canals, pumping stations, wells, power use, fuel, canals and drainage network cleaning, buffer stock of materials and other expenditure depending on water delivery); \( \sum_{i}^{\text{declared}} \) – budgetary financing facility declared by recipient \( i \) on maintenance. \( \sum, \sum, \sum \) – federal financing facilities value on maintenance respectively total for the branch, passive funds of objects, active funds of objects. According to expert estimation expenditure on maintenance of passive funds equal not less than 60% of the total expenditure. This proportion has been taken into account at algorithm realizing: \( \sum = 0.6 \times \sum \); \( \sum = 0.4 \times \sum \); \( I = 1 \ldots N \) – recipient index; \( N \) – amount of recipients; \( X_i = 1 \) in the case of recipient \( i \) receives financial facility, \( X = 0 \) if recipient \( i \) does not receives financial facility.

### 4 Decisions and conclusions

DSS “Plan” includes specialized complex of techniques and proprietary designed software to create database, to modeling, to control, to represent results of solution, to accept and to analyze decisions.

DSS is designed for maintenance staff and for federal management and suggests two-level circuit: chief level and department level to plan financial backing. DSS “Plan” uses input data according to actual maintenance practice without additional material expenditure.

DSS provides wide possibility on document forming by information form different tables combination.

At DSS application automation level rising is 20%, information support is 15% higher; decision acceptance person possibilities are increased by 10%. DSS application in reclamation has shown their high efficiency and wide opportunities. At the same time DSS application is not widespread now. One reason of their slow application is low recipient request by reclamation system managers. Subscribers reverse traditional techniques of decision support unwillingly and prefer to spend additional money, labor and intelligence. This additional expenditure is necessary to spend now to obtain unsecured benefit in the future. Obviously it is necessary to expand DSS capabilities to make it more attractive for the subscribers. The same situation was at computer application several decades ago. However managers can’t imagine their work without computers now.

### 5 References

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ABSTRACT
Large areas of globally important tropical peatland in Southeast Asia are threatened by land clearance, degradation and fire, jeopardising their natural functions as reservoirs of biodiversity, carbon stores and hydrological buffers. Many development projects on tropical peatlands have failed because of lack of understanding of the landscape functions of these ecosystems. Utilisation of these peatland resources for agriculture or other land use requires drainage which, unavoidably, leads to irreversible loss of peat through subsidence, resulting in severe disturbance of the substrate, CO₂-emissions and problems for cultivation.

To assist planners and managers in wise use of these tropical peatlands a decision support system (DSS) has been developed. This DSS, which is based on a GIS application, combines the Groundwater Modelling Computer Programme PMWIN with expert knowledge on subsidence, land use and water management. The DSS can be used to predict the long-term effects of different types of land use, e.g. peat swamp forest, sago or oil palm plantations, on the lifetime and associated CO₂ release of these tropical peatlands. The type of land use dictates the required depth of the groundwater table, which on its turn has a significant effect on the sustainability of the peatland. Therefore, special attention should be paid when deciding which type of land use to pursue. The Decision Support System (DSS) will help to improve the decision-making process.

The groundwater model PMWIN was selected because it maintains a good balance between the complexity of the model (esp. regarding to its input data requirements) and the availability of input data. The groundwater model was calibrated using data from the Balingian Area, Central Sarawak, Malaysia. The model was used to predict, based on a given land use scenario, the ratio between surface and groundwater runoff, the depth of the groundwater table and recharge and discharge zones of the peat dome. Various land use scenarios, each with its own specific water management requirements, were developed and used to predict the long-term changes in ground level and associated CO₂ release. For each scenario the following outcome was generated: time span after which the water management systems have to be deepened, time span after which gravity drainage is no longer possible, time span for peat disappearance. Final results are presented in the form of maps generated by the GIS application. These maps serve as a communication tool with stakeholders to demonstrate what the hydrological effects are on for instance a certain land use type and drainage system lay-out.

Keywords: Water Management, Tropical Peat, Management, Borneo, Stakeholder Communication

1 INTRODUCTION
The majority of the world’s tropical peatlands (11 million hectares) occur in South-east Asia, mainly in the coastal regions. Many of these coastal regions are identified as major regions for development with agriculture as its driving force. Agricultural development includes oil palm, sago and forest plantations, aquaculture, paddy and miscellaneous crops including pineapple and vegetables. The peatlands in these coastal regions have global ecological significance, being some of the largest remaining areas of lowland rainforest in SE Asia that provide the habitat of many endangered species. In addition, they are large stores of carbon and water and also play an important regional economic role, providing forest products and land for settlement. Owing to a lack of awareness and understanding about sustainable land management practices, however, many peatland development projects fail, resulting in serious environmental degradation and impoverishment of local communities (Diemont et al 2002).
Tropical peatlands consist of waterlogged organic soils that have formed from dead organic materials from plants and trees. According to the common definition of peat, these lands have at least 0.5 m of organic soil materials that consist of more than 35% of organic matter in various stages of decomposition. Peatlands are waterlogged most of the year and need drainage to make them suitable from agriculture or other land use (Alan Tan and Ritzema 2003). Compared to mineral soils, peat has a much higher infiltration capacity, drainable pore space and hydraulic conductivity, but a lower capillary rise, bulk density and plant-available water (Wösten and Ritzema 2001). Another major difference is the subsidence behaviour of peat: it is never-ending and partly caused by oxidation. This oxidation leads to CO$_2$ emissions, which under Borneo conditions, is estimated to be in the order of 26 tonnes per hectare per year.

Beside the loss of peat by oxidation, the excessive subsidence rates result in a pronounced drop in the elevation of the land reducing the efficiency of the drainage system (Ritzema et al 2001). To avoid flooding and waterlogging problems during the monsoon season, frequent deepening of the system is required (Fig. 1). This never-ending process threatens the sustainable use of peat areas (Rieley et al 2002). Controlled drainage can reduce subsidence but never arrest it (Ritzema and Wösten 2002a). The rate of subsidence depends on the design depth of the watertable, which in its turn is prescribed by the type of agricultural use: e.g. oil palm requires a water table in the range of 0.60 to 0.80 m compare to sago which only needs a water table in the range of 0.20 to 0.40 m. Thus the type of agricultural development has a direct effect on the sustainability of the peat.

![Figure 1](http://library.wur.nl/ebooks/drainage/drainage_cd/1.7%20ritzema%20et%20al.html (2 of 10)26-4-2010 12:11:24)

Figure 1 The everlasting subsidence of peat results in a continuously lowering of the land surface (after Eggelsmann 1982).

To assist planners and managers in wise use of these tropical peatlands a decision support system (DSS) has been developed. This DSS, which is based on a GIS application, combines the Groundwater Modelling Computer Programme PMWIN with expert knowledge on subsidence, land use and water management. The DSS consists of three components:

- A groundwater model to simulate the impact of reclamation on groundwater levels;
- A model to calculate the corresponding soil subsidence, and
- A GIS component to visualise the results.
As (ground) water is the driven force in peat formation and destruction, the groundwater model is the core of the DSS. The DSS can be used to predict the long-term effects of different types of land use, e.g. peat swamp forest, sago or oil palm plantations, on the lifetime and associated CO₂ release of these tropical peatlands. As the DSS is based on a GIS application other expert knowledge, for example on water quality, social interactions and economics can be relatively easy incorporated in the future. This paper discusses the development of the three DSS components and its calibration in the Balingian area, a tropical peat dome of about 10,000 ha in the Central Region of Sarawak, Malaysia (latitude 3° 00' N, longitude 112° 36' E).

2 GROUNDWATER MODELLING

2.1 PMWIN Package
To simulate the flow of groundwater the PWWIN 5.0-79 simulation package was selected (Grobbe 2003). PMWIN is based on Modflow: a public-domain, three-dimensional, finite-difference, saturated groundwater flow model (www.modflow.com). Modflow was selected because it offers good pre- and post-processing options, requires not too much input data, is well documented and can easily be extended with additional modules.

Geometry of the peat domes

The peat domes in the study area are purely rainfed with a lens-shaped domed surface. Because of the coastal and alluvial geomorphology, they are often elongated and irregular rather than having the 'ideal' round shape that is characteristic of peat domes (Figure 2). Surface slopes vary between 1 and 2m/km at the edges near adjacent rivers to less than 0.5 m/km at the centre of the domes. The depth of the peat varies from less than 1 meter near the coast to more than 20 m inland with a surface level of some 4 m above the adjacent river levels near the coast to some 9 m above these levels in the swamps that are more inland. The subsoil is either sulphidic in nature, or consists of a mixture of marine and riverine deposits, especially along river courses. Because of the dome-shaped surface (ground) water flow takes places in different directions.

Figure 2 Cross-section of a peat dome in the Balingian area (PS Konsultant 1998)

In the model, the peat domes were schematized as a one-layered, unconfined aquifer with the mineral subsoil at mean sea level as the bottom boundary. The mineral subsoil was considered to be impervious. The top boundary was the soil elevation of the peat layer, which in the waterlogged peat soils, is also the elevation of the groundwater level.

2.2 Hydraulic conductivity
Hydraulic conductivity of the peat domes is very high, but varies considerably with the type of peat and the degree of humification (Wösten & Ritzema 2001). For the model simulation the horizontal hydraulic conductivity in the peat layer was assumed at 30 m/d, based on long-duration pumping test data (Ong and Yogeswaren 1991).
2.3 Recharge and discharge
The peat domes are purely rainfed with a total annual rainfall of about 3700 mm. Although the rainfall is not evenly distributed over the year, the average rainfall in the dry season (March –November), about 200-300 mm/month, still exceeds the rate of evaporation, about 120-130 mm/month (Ritzema and Wösten 2002b). For the model, the peat dome was divided in a recharge and discharge zone with the 2.5 m contour-line as the boundary (Figure 3). This 2.5 m contour was identified as boundary because it marks a change in peat soil types and slope of the soil surface (Grobbe 2003). The amount of recharge was deduced from the water balance study in the nearby Kut catchment (SWRC 1997):

Rainfall (100%) = Evapo-transpiration (45%) + Surface Runoff (37%) + Interflow (12%) + Groundwater Recharge (6%)

For the Balingian area, with a total rainfall of about 3700 mm/year, this results in a recharge of 222 mm/year.

2.4 Model calibration
The model was calibrated using the recharge as input and the elevation of the groundwater table as output. Using the above mentioned values of the hydraulic conductivity and recharge the simulated groundwater levels were far too high. A sensitivity analysis conducted for the horizontal hydraulic conductivity showed that the hydraulic conductivity had to be increased to unrealistic high values (> 180 m/d) to obtain acceptable groundwater levels, thus the value of the hydraulic conductivity was left unchanged. Subsequently, a value of the recharge was determined using the inverse modeling package PEST, which is part of the PMWIN programme. This resulted in a recharge of about 40 mm/year (or only 1.1% of the total rainfall), considerably lower than the recharge of the SWRC water balance study, but in agreement with hydraulic studies in European peat domes (van der Schaaf 1999). The subsequent model simulations were run with a value of 30 m/d for the hydraulic conductivity and 40 mm/year recharge.

Figure 3 Model schematization of the recharge and discharge zones (not to scale).

3 Subsidence modelling
The outcome of the groundwater modeling was used to calculate the subsequent subsidence using the following relation:

Subsidence (m/year) = 0.1 x groundwater depth (m – ground level)

This relation is based on data of peat subsidence in Western Johore, Peninsular Malaysia, (Wösten et al 1997) and corrected for the conditions in Sarawak (Wösten and Ritzema 2001). To overcome local disturbances in the actual elevation of the ground level, the initial ground (water) level has been smoothened and made equal to the initial groundwater level. The resulting simulated levels are in good agreement with the measured data (Figure 4).
The groundwater model was used to simulate the effect of the reclamation of part of the peat dome on the depth of the watertable, subsequent subsidence and the elevation of the ground surface in the surrounding part of the dome. Changes were calculated after 1, 2, 5, 10, 20 and 50 years. The simulations were done for two land use options, i.e. oil palm plantations with a required depth of the water table of 0.8 m below ground surface and sago plantations with a required depth of the water table of 0.4 m. The plantations were situated either on top of the peat dome or along the edges (Figure 5), resulting in the following scenarios:

1. Deep drainage (0.8 m below ground surface) on the top of the peat dome;
2. Shallow drainage (0.4 m below ground surface) on the top of the peat dome;
3. Deep drainage (0.8 m below ground surface) along the edges of the peat dome;
4. Shallow drainage (0.4 m below ground surface) along the edges of the peat dome.

Figure 4  Simulation results of the subsidence modelling: initial ground(water) level and calculated subsidence after $t = 4$ years,
5. Combination of scenario 2 and 3

Despite the subsidence and the resulting lowering of the ground surface, the depth of the drainage base was left unchanged during the simulation runs. Consequently the depth of the groundwater (= difference between the groundwater level and the ground surface) reduced over time ultimately resulting in an equilibrium condition in which the groundwater level was again at the ground surface. Under normal operation conditions, the drains should have been deepened every so many years and an equilibrium conditions should only have been reached when all peat had disappeared (= oxidized).

![Diagram showing plantations on top (A) and along the edge (B) of the peat dome.](image)

**Figure 5**  *In the scenarios the plantations were either situated on top (A) or along the edge (B) of the peat dome.*

4.1 Visualization of the Results of the Simulations

The results of the simulations confirm the hypotheses formulated in the previous studies (e.g. DID 2001), namely that:

- Locating a plantation on top of the peat dome results in a higher overall subsidence over the peat dome than locating a plantation along the edges (Figure 6).
- The deeper the drainage the higher the rate of subsidence.
Figure 6  Drawdown of the ground level after 1, 2, 5, 10, 20 and 50 years for a plantation on top
The DSS was also used to visualize the differences the various scenarios have on e.g. the groundwater elevation over the peat dome (Figure 7), soil subsidence and the time it takes for the peat layer above the groundwater to disappear.

**Figure 7** Effect of the installation of a drainage system on the groundwater levels surrounding the plantations (top left - scenario 1; top right – scenario 2; middle – scenario 3; bottom left – scenario 4 and bottom right – scenario 5).

### 5 CONCLUSIONS

In this study a decision support system (DSS) for peatland management in the humid tropics was developed. This DSS, which is based on a GIS application, combines the Groundwater Modeling Computer Programme PMWIN with expert knowledge on subsidence, land use and water management. The groundwater model (Modflow in the PMWIM 5.0-79 version) was used to simulate the groundwater flow inside a tropical peat dome. The groundwater model was calibrated for the Balingian area, a tropical peat dome of about 10,000 ha in the Central Region of Sarawak, Malaysia. Although actual field data was scarce, the initial results are rather promising: the model was calibrated by simulating groundwater table fluctuations based on actual rainfall data. Inverse modeling was used to access the recharge to the groundwater. Results indicate that the total amount of recharge, i.e. around 40 mm/year or about 1% of the total rainfall, is considerably lower than found in previous studies (around 220 mm/year or 6% of the total rainfall), but more in agreement with results found in European peat domes. Sensitivity analysis of the horizontal hydraulic conductivity shows that the assumed value (30 m/d) is quite realistic.
The groundwater model was combined with expert knowledge on subsidence in a GIS to compare the effect of various land use options. The resulting Decision Support System (DSS) made it possible to visualize the effect caused by certain land uses options, e.g. the effect of reclaiming part of the peat dome for (oil palm or sago) plantation development on the groundwater levels, subsequent subsidence and ultimate elevation of the ground surface. The GIS structure of the DSS allows the incorporation of other model parameters such as water quality, crop yields, etc.) in future versions. Final results are presented in the form of maps generated by the GIS application. These maps can also serve as a communication tool with stakeholders to demonstrate what the hydrological effects are on for instance a certain land use type and drainage system lay-out. This makes the DSS a useful tool for planners and designers to optimize the sustainable use of these valuable peat domes.

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EVALUATION OF SWAP-MANIMEA MODELS FOR PREDICTING NO$_3$-N LEACHING FROM HOG MANURED PLOTS

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ABSTRACT
The Manurial Nitrogen Management: Environmental Aspects (MANIMEA) model was coupled with Soil-Water-Atmosphere-Plant (SWAP) model, and evaluated to simulate NO$_3$-N transport to subsurface drainage from hog manured plots. SWAP was used to simulate the vertical transport of water flow, the outputs of which were used as inputs of MANIMEA. The field data obtained from 1999 and 2000 in Truro, Nova Scotia, Canada, on four test plots receiving liquid hog manure, were used to test the models. The simulated daily drainage flows and NO$_3$-N losses in the subsurface drainage were compared with the observed values. The simulated daily drainage flows followed the pattern of observed drainage flows with correlation coefficient 0.71–0.81 in 1999 and 0.29–0.79 in 2000. The simulated results were in good agreement with observed results in 1999, but not in 2000 due to possible malfunction of measuring equipment. The simulated NO$_3$-N losses closely followed the pattern of drainage flows. Total simulated NO$_3$-N losses for four plots in 1999 were within –7.9% and 59.9% of observed values with correlation coefficient 0.55–0.65. The mean of difference ranged from –0.084 kg ha$^{-1}$ to 0.023 kg ha$^{-1}$. The absolute mean error ranged from 0.155 kg ha$^{-1}$ to 0.174 kg ha$^{-1}$. The agreement between the simulated and observed results in 2000 was not too reasonable due to large difference existed in the simulation of drainage flows. Overall, the results showed that MANIMEA has the potential of predicting nitrate leaching. However, this study was only a preliminary test of model ability to predict nitrate leaching. The model needs to be tested widely for longer simulation periods and with extensive field data.

Keyword: MANIMEA, Drainage flow, Nitrate-nitrogen, Hog manure

1 INTRODUCTION
Animal manure applied to agricultural land is a valuable source of nutrients for crop production and also enhances long-term productivity of soils. However, extensive amounts of manure application on agricultural land can be potential source of pollution for the atmosphere, groundwater, and surface water bodies. A number of studies have shown that if manure is applied at excessive rates to cropland, then instead of nourishing the crops, the nutrients in the manure become sources of pollution (Edwards and Daniel, 1992; Giddens and Barnett, 1980).

One of the main concerns is the risk of nitrate leaching to groundwater (Bakhsh et al., 2000; Marchetti et al., 2001). Manure constituents can be transported by infiltrating water from the soil surface to subsurface drainage and ultimately to surface waters, which may lead to the potential contamination of drinking water sources as well as recreational waters (Cook et al., 2001). Environmental concerns resulting from excessive manure applications have prompted researchers to investigate and study the fate and transport of manure-nutrients in agricultural fields through extensive efforts, field and laboratory experiments, and modeling techniques (Angle et al., 1993; Hubbard et al., 1987; Kumar et al., 1998; Bakhsh et al., 1999). The increasing reliance on models as tools for evaluating the environmental impact of various manure management practices under field conditions makes model development and validation an important issue.

The MANIMEA (MANurial Nitrogen Management: Environmental Aspects) model was developed to simulate the environmental conditions of the manure-soil system, the biological and chemical processes affecting nitrogenous components in the manure and soil, and the transport of nitrogenous compounds through the system (Hengnirun, 1996). The model considers the manure as a separate component prior to its incorporation into the soil. The transformations and transport processes in the applied manure layer before it is incorporated were simulated separately and simultaneously with the processes occurring in the soil component. This approach provides a realistic simulation of the manure-soil system by taking into account the losses due to ammonia volatilization and surface runoff from the applied manure layer at the soil surface. Although the sub-models for nitrogen processes that formed the MANIMEA model have been tested and verified individually, the model has not been tested under field conditions. Therefore, this study was conducted to evaluate MANIMEA for predicting and validating NO$_3$-N losses from subsurface drainage for barley-carrot rotation production system receiving liquid hog manure for an experimental site in Nova Scotia, Canada. The goal of this study was a preliminary test of model ability to simulate nitrate leaching after the spreading of liquid hog manure.

In this study, MANIMEA was coupled with SWAP model, which has already been successfully used by many researchers, to simulate water and nitrogen transport (Kroes et al., 2000; Sarwar et al., 2000; EI-Sadek et al., 2001). SWAP outputs describing water flow are used as inputs of MANIMEA. Two years of field data, namely 1999 and 2000, obtained from four plots in Truro, Nova Scotia, Canada that were receiving liquid hog manure, were used to evaluate the MANIMEA. The specific objectives of the study were (1) to calibrate SWAP based on simulated and measured daily drainage flow; (2) to evaluate the performance of MANIMEA for predicting NO$_3$-N losses in the subsurface drainage.

http://library.wur.nl/ebooks/drainage/drainage_cd/1.3%20wang%20s%20et%20al%20.html (1 of 7)26-4-2010 12:11:26
2 OVERVIEW OF MODELS

2.1 SWAP
SWAP (Soil-Water-Atmosphere-Plant) is a one-dimensional transient model that simulates vertical transport of water, solutes and heat flow in unsaturated-saturated soils (Van Dam et al.; 1997). The model calculates the soil water flow by using Richards equation based on Darcy's law. The soil hydraulic functions are described by the analytical expressions of Van Genuchten and Mualem or by tabular values. System boundaries at the top are defined by the soil surface with or without crop and the atmospheric conditions. The lateral boundary simulates the interaction with surface water systems. The boundary conditions can be described with various options, e.g. water table depth, flux to/from semi-confined aquifer, flux to/from open surface drain, an exponential relationship between bottom flux and watertable, or zero flux, free drainage and free outflow.

The upper boundary conditions of the system are determined by the potential evapo-transpiration rate \( ET_p \), rainfall, and irrigation. SWAP uses daily meteorological data, including air temperature, net radiation, wind speed and air humidity, to calculate \( ET_p \) according to the Penman-Monteith equation. Because the meteorological data might not be available in most cases, SWAP also allows the use of a reference potential evaporation-transpiration rate \( ET_{ref} \), which can be determined in several ways, such as pan evaporation, the Penman open water evaporation. SWAP firstly separate \( ET_p \) into potential soil evaporation rate \( E_p \) and potential plant transpiration rate \( T_p \) according to the leaf area index or soil cover fraction as a function of crop development, and subsequently calculates the reduction of potential soil evaporation rate and potential plant transpiration rate. \( E_p \) is reduced to be equal to the minimum of \( E_p \) and \( E_{max} \) in which \( E_{max} \) is the maximum soil water flux in the topsoil based on Darcy’s law. Actual transpiration rate is equal to the root water uptake rate as a function of potential transpiration, root length density and possible reductions due to wet, dry, or saline conditions.

SWAP makes a distinction between local drainage flux to drains (drain discharge rate), and the regional groundwater flux at the bottom of the simulated soil profile (Sarwar et al., 2000). The drain discharge rate is computed with the steady-state drainage equations of Hooghoudt and Ernst. The difference in hydraulic properties of the layered soil profile determines whether the Hooghoudt or Ernst equation should be used. With Hooghoudt’s equation, the water flow to drains in a homogeneous profile with the drains above or on top of an impervious layer or a two-layered profile with the drains at the interfere of the two layers can be described. On the other hand, with Ernst’s equation, the water flow to the drains in a two-layered profile when the drains are situated in either the top or the bottom layer can be analyzed (Van Dam et al., 1997). Because of the lateral outflow from the one-dimensional column, SWAP is sometimes referred to as a quasi two-dimensional model.

2.2 MANIMEA
The MANIMEA model is a nitrogen management-oriented computer simulation model developed mainly for use with manural nitrogen (Hengnirun, 1996). It was designed to describe the simultaneous nitrogen processes occurring in both the applied manure layer and in the soil component. The process involved include nitrogen partition in surface runoff, ammonia volatilization, and net mineralization-immobilization in the applied manure layer, and ammonia volatilization, net mineralization-immobilization, denitrification, plant uptake, adsorption and leaching in the soil component. Three major forms of N, organic N, ammonium N \( (\text{NH}_4^+ \) ), and nitrate \( (\text{NO}_3^- \) were considered in this model. The model includes two kinds of manure application methods: (1) the manure was surface applied and left for a period before incorporation into the soil; (2) The manure was injected into the soil.

The MANIMEA includes 10 sub-models, namely CONVERT, HEAT, RUNOFF, VOLAT, MINER, DENITRI, UPTAKE, ADSORP, LEACH and NMOL. First, the CONVERT was executed to convert the profiles of soil moisture tension, plant water uptake, and soil volumetric moisture distribution generated by SWAP model to be able to use in the HEAT sub-model. The HEAT sub-model was executed to generate the soil temperature profile using the nodal moisture information and the average air temperature data. Subsequently, sub-models RUNOFF, VOLAT, and MINER were run simultaneously to generate the upper boundary condition for nitrogen levels at the soil surface by partitioning nitrogen into nitrogen losses in surface runoff and nitrogen in percolation water. After the upper boundary condition was generated, the VOLAT, MINER, DENITRI, and UPTAKE sub-models were executed to simulate nitrogen volatilization, mineralization, denitrification, and plant uptake in the soil component, and used as sink/source terms in the following governing equation (1) of nitrogen transport.

The ADSORP and LEACH sub-models were coupled and developed to simulate leaching processes and adsorption. The effects of micropores and macropores on the transport of nitrogenous compounds in the soil were taken into account. Of three major forms of N, nitrate is the only one that is known to be transported significantly by the leaching process and does not exist in the gaseous state. Therefore, only nitrate leaching was considered in this model. The integration of results from nitrogen transformation processes in the manure-soil-water-plant system yields transient profiles of nitrate concentration, which can be evaluated by the following governing equation (Hengnirun 1999):

\[
\frac{dC}{dt} = \frac{F}{\rho} \left( K_d s_2 - \theta C \right)
\]

Where \( C \) is concentration of nitrate (g/mm^3); \( \theta \) is volumetric water content (mm^3/mm^3); \( \rho \) is bulk density of dry soil (g/mm^3); \( F \) is fraction of micropores; \( K_d \) is sorption coefficient (mm^3/g); \( s_2 \) is concentration of adsorbed...
Based on the non-equilibrium adsorption concept, the adsorption was assumed to be time-dependent (van Genuchten and Wagenet, 1989) and the adsorption term $s_2$ in equation (1) can then be written as:

$$s_2 = \frac{\alpha}{\rho} \cdot \frac{1}{\rho} \cdot \frac{1}{\rho}$$

where $\alpha$ is the first-order rate coefficient for mass transfer (d$^{-1}$).

Equation (1) was used as the governing equation for nitrate leaching in this model, and Numerical Method of Lines (NMOL) technique was adopted to solve this equation. A detailed description of nitrogen transformation and transport processes was given by Hengnirun (1996).

3 MATERIALS AND METHODS

3.1 Experimental site

The experimental site for this study was located at the Atlantic Agri-Tech Park of the Nova Scotia Agricultural College in Truro, Nova Scotia, Canada. It consists of 8 subsurface drainage plots, each 24m wide by 48m long with an area of 1152 m$^2$. Each plot contained two 100mm diameter tile drains. The drains were installed at 0.80m depth and 12m spacing. Experimental plots were isolated by buffer drains to prevent lateral water movement between the plots. The liquid hog manure was applied to plots 1, 3, 5, and 7 while inorganic fertilizer was applied to plots 2, 4, 6, and 8.

The soil type is predominantly Pugwash sand loam with Debert loam to sandy loam soil. There were three types of soil groups, namely, Pugwash82 (plots 1 and 7), Pugwash52 (plot 5), and Debert 22 (plot 3). The physical properties of the soil profile are shown in table 1.

Field experiments were conducted in 1999 and 2000. Crops grown in the field were barley in 1999 and carrots in 2000. The barley was planted on May 17th, 1999 and harvested on August 24th, 1999. The Carrots were seeded at a rate of 40 seed m$^{-1}$ on May 22nd, 2000 and harvested on October 8th, 2000. Manure samples prior to and during the application of manure to the field were collected and analyzed by the Nova Scotia Department of Agriculture and Fisheries (NSDAF) Quality Evaluation Laboratory to determine their nutrient content. The three liquid hog manure samples collected in 1999 had an average of 2.11 kg N Mg$^{-1}$, while in 2000 the average was 3.08 kg N Mg$^{-1}$. In 1999, the manure was obtained from an open pit that had no roof, allowing rain and snow to dilute the manure. In 2000, the manure came from covered hog storage at the Nova Scotia Agricultural College (NSAC) Farm. Table 2 presents the characteristics of the liquid hog manure used for the experiment.

The drain outflows from each plot flowed directly into a water sampling room in the adjacent facility. Hourly flow rates were continuously recorded using tipping buckets, wired to a Campbell Scientific CR10X data logger. Water samples for NO$_3$-N analysis were collected from flowing water discharging from the tipping buckets. Samples were immediately frozen and stored, prior to transport to the Charlottetown Research Station of Agriculture and Agri-Food Canada in Prince Edward Island for analysis. The midspan water table fluctuations and the surface runoff were not observed in this study.

3.2 Input Data For Models

3.2.1 Meteorological data

The reference potential evapo-transpiration rate $ET_{ref}$ determined by pan evaporation and daily rainfall were used as input to the SWAP model. The daily average air temperature was used as input to sub-model HEAT of MANIMEA model to simulate soil temperature. The potential evapo-transpiration $ET_{p0}$ is calculated by:

$$ET_{p0} = \frac{ET_{ref}}{ET_{ref0}}$$
3.2.2 Soil data
A 1-m deep soil profile above the impermeable layer was considered for model simulations. The soil profile was divided into four horizons for three types of soil, and soil properties in these horizons were specified according to Table 1. Based on soil hydraulic function and saturated hydraulic conductivity from Table 1, the tabular forms, in which the corresponding soil water pressure head and hydraulic conductivity were given for each water content increments by 0.01, were calculated from soil preparation routine of DRAINMOD model (Skaggs, 1978), and used as inputs of SWAP model.

Table 1 Soil physical properties

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Plot No.</th>
<th>Depth (cm)</th>
<th>Ksat* (mm/hr)</th>
<th>Volumetric Soil Moisture retention (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0 5 10 33 kPa 100 300 1500</td>
</tr>
<tr>
<td>Pugwash82</td>
<td>1 and 7</td>
<td>0-25</td>
<td>20</td>
<td>46.4 38.3 37.3 34.9 33.0 16.8 11.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25-44</td>
<td>10</td>
<td>35.8 30.8 29.6 27.6 25.6 16.6 11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>44-76</td>
<td>7</td>
<td>35.6 30.8 29.3 27.2 25.6 16.1 10.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>76-100</td>
<td>5</td>
<td>34.3 29.4 27.1 24.3 21.7 11.6 7.7</td>
</tr>
<tr>
<td>Pugwash52</td>
<td>5</td>
<td>0-25</td>
<td>20</td>
<td>53.5 42.8 41.2 38.4 35.6 15.2 12.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25-44</td>
<td>9</td>
<td>34.5 29.4 28.5 26.1 23.3 16.8 11.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>44-76</td>
<td>6</td>
<td>34.0 29.0 28.4 26.6 24.8 17.7 11.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>76-100</td>
<td>4</td>
<td>36.1 27.6 25.1 22.7 20.7 15.5 8.3</td>
</tr>
<tr>
<td>Debert22</td>
<td>3</td>
<td>0-24</td>
<td>20</td>
<td>50.0 39.1 38.3 35.3 31.3 15.1 9.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24-38</td>
<td>8</td>
<td>33.1 27.2 26.7 24.7 20.9 17.0 11.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>38-80</td>
<td>5</td>
<td>35.3 31.6 31.2 28.4 24.8 17.3 13.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80-100</td>
<td>4</td>
<td>38.4 33.0 32.1 28.3 23.0 18.9 11.7</td>
</tr>
</tbody>
</table>

*Lateral saturated hydraulic conductivity

3.2.3 Crop data
For SWAP model, leaf area index (LAI) or soil cover fraction (SCF), crop height (CH) or crop factor (CF), rooting depth and yield response as a function of crop development stage need to be specified. In this study, leaf area index, crop factor, root depth and yield response as a function of crop development stage were used as inputs. The leaf area index was used to obtain potential plant transpiration rate and potential soil evaporation rate from potential evapotranspiration rate. The crop factor was used as stated in equation (3). The rooting depth will be used to calculate actual plant transpiration. Since these data were not available from the field measurement, the estimated data were taken from literature sources.

3.2.4 Chemical properties and nitrogen-related parameters
The chemical properties of manure and soil, and nitrogen-related parameters were obtained either from direct field or laboratory measurements or through a calibration process (see Table 2). Various rate constants were calibrated using observed and simulated NO₃-N losses in the subsurface drainage. The major chemical properties and nitrogen-related parameters used in MANIMEA were listed in Table 3. Due to lack of data, same parameters about soil and nitrogen dynamics were used for two years of simulation.

4 MODEL EVALUATION
The model evaluation included both graphical display and statistical comparison of observed and simulated data. Firstly, the daily subsurface drainage flow simulations in 1999 and 2000 were conducted with SWAP model. Model simulations were compared to measured results for daily and total drainage flow. The input parameters required for SWAP simulations were obtained from direct field measurements (Table 1) as well as literature sources (such as crop parameters). Nitrogen simulations were conducted with MANIMEA to calibrate nitrogen component of the model using NO₃-N losses in the subsurface drainage. Total NO₃-N losses in the subsurface drainage were estimated by adding the lateral transport from each incremental layer in the saturated zone. The lateral transport from each incremental layer i in the saturated zone was calculated by multiplying nitrate concentration in layer i by water volume contributed from layer i to subsurface drainage flow.

The model performance was quantified by calculating percentage difference, correlation coefficient (R), Mean of the Difference (MD), and the Mean Absolute Error (MAE). The percentage difference between observed and simulated data was calculated as [(simulated-observed)/observed]*100. The equations for MD and MAE are shown below:
EVALUATION OF SWAP-MANIMEA MODELS FOR PREDICTING NO3-N LEACHING FROM HOG MANURED PLOTS

RESULTS AND DISCUSSION

Table 3. Main input parameters in SWAP-MANIMEA

<table>
<thead>
<tr>
<th>Parameters</th>
<th>1999</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Nitrogen (TN) (%)</td>
<td>0.211</td>
<td>0.308</td>
</tr>
<tr>
<td>NO3-N/TN</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>TAN/TN</td>
<td>0.8</td>
<td>0.5</td>
</tr>
<tr>
<td>NH4-N/TAN</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>pH</td>
<td>5.8</td>
<td>5.9</td>
</tr>
<tr>
<td>C/N ratio</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>Soil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk density (g/cm³)</td>
<td>1.3</td>
<td></td>
</tr>
<tr>
<td>Depth of root zone (mm)</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>TN in root zone (µg/g of soil)</td>
<td>1700</td>
<td></td>
</tr>
<tr>
<td>TN beyond root zone (µg/g of soil)</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>NO3-N/TN</td>
<td>0.007</td>
<td></td>
</tr>
<tr>
<td>TAN/TN</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>NH4-N/TAN</td>
<td>0.93</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>CEC (meq/100g)</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Nitrogen dynamics in soil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st-order rate constant for mineralization (d⁻¹)</td>
<td>Fast pool: 0.5</td>
<td>Slow pool: 0.015</td>
</tr>
<tr>
<td>1st-order rate constant for denitrification (d⁻¹)</td>
<td>0.05</td>
<td>10</td>
</tr>
<tr>
<td>Diffusion coefficient (cm²·d⁻¹)</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

In accordance with the requirements of the models, the simulations were started on 17 May (Julian day 137) when manure was applied. The rainfall pattern in 2000 possibly tends to storm pattern, i.e., there was higher rainfall intensity and larger runoff. The major reason resulting in larger differences can be attributed to the malfunctioning of the measuring equipment. Obviously, there were quite a few larger rainfall events in November, but there was little rainfall in middle-later period of September, there were larger subsurface drainage flow under continuous rainfall events, especially in plot 1 and plot 7, while the observed drainage flow was low still. The main reasons may be attributed to higher evapo-transpiration estimation or higher soil effective porosity. The main input parameters in SWAP-MANIMEA are summarized in Table 3.

Table 4. Statistics of observed and simulated daily and total subsurface drainage flow for the simulation period from 17 May to 12 December

<table>
<thead>
<tr>
<th>Plot</th>
<th>MD (mm)</th>
<th>MAE (mm)</th>
<th>R²</th>
<th>Percentage difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>0.43</td>
<td>0.51</td>
<td>0.73</td>
<td>6.3%</td>
</tr>
<tr>
<td>No.2</td>
<td>0.50</td>
<td>0.54</td>
<td>0.78</td>
<td>3.5%</td>
</tr>
<tr>
<td>No.3</td>
<td>0.50</td>
<td>0.50</td>
<td>0.79</td>
<td>2.5%</td>
</tr>
<tr>
<td>No.4</td>
<td>0.45</td>
<td>0.52</td>
<td>0.77</td>
<td>4.2%</td>
</tr>
<tr>
<td>No.5</td>
<td>0.43</td>
<td>0.47</td>
<td>0.77</td>
<td>2.9%</td>
</tr>
<tr>
<td>No.6</td>
<td>0.47</td>
<td>0.57</td>
<td>0.77</td>
<td>4.2%</td>
</tr>
<tr>
<td>No.7</td>
<td>0.37</td>
<td>0.41</td>
<td>0.77</td>
<td>2.9%</td>
</tr>
</tbody>
</table>

The mean of difference (MD) ranged from –0.30 mm/day to 0.5 mm/day. The correlation coefficient for each plot was larger than 0.7, except for plot 3, the MD was positive for all three plots. This indicated that the model underestimated the observed flow. The smallest MD value in plot 5 was predicted value at time - observed value at time -1/2, i.e., 0.43 mm/day. The rainfalls in 2000 were generally larger than those in 1999, total rainfall was 626.7 mm in 1999 and 607.3 mm in 2000. But, total observed drainage flow in 1999 was about 6-7 times larger than that in 2000. Due to the storm pattern, there were larger drainage flow in 1999 than in 2000. In 2000, although simulated subsurface drainage flow followed the observed trend, there were larger differences between simulated and observed flows. The correlation coefficient for each plot was larger than 0.7, the values of MD ranged from –0.30 mm/day to 0.5 mm/day. The percentage difference between total simulated and observed flows was very large. In 1999, the correlation coefficient for each plot was larger than 0.7, and the values of MD ranged from –0.30 mm/day to 0.5 mm/day. The mean of difference (MD) ranged from –0.30 mm/day to 0.5 mm/day. The results indicate that SWAP can simulate drainage flows accurately.
EVALUATION OF SWAP-MANIMEA MODELS FOR PREDICTING NO$_3$-N LEACHING FROM HOG MANURED PLOTS

The simulated losses were different from the measured values by 0.10 kg ha$^{-1}$ to 0.14 kg ha$^{-1}$ on either side of the mean value. The mean of difference ranged from –0.084 kg ha$^{-1}$ to 0.023 kg ha$^{-1}$. Except for plot 1, the model underestimated NO$_3$-N losses for the remaining three plots. The correlation coefficients were between 0.55 and 0.65, which is slightly worse than the results of 1999. Although the mean of difference and %Difference of NO$_3$-N losses were much small as compared to that in 1999. Although the mean of difference and %Difference of NO$_3$-N losses were much small as compared to that in 1999. However, the correlation coefficient increased from 0.55 in 1999 to 0.60 in 2000. This indicates that the total simulated flow was very close to total observed flow. The mean absolute error ranged from 0.63 mm/day to 0.91 mm/day, indicating that the simulated results were different from the measured values by 0.63 mm/day to 0.91 mm/day on either side of the mean value. The statistical indexes, calculated for the simulated and observed daily and total NO$_3$-N losses, are listed in Table 5. Generally, the results indicated that the model underestimated peak subsurface drainage flow and the fluctuation range of observed subsurface drainage flows agrees well. The lateral saturated hydraulic conductivity was major factor affecting peak subsurface drainage flow. Under the simulation condition, the simulated subsurface drainage flow only reaches about 5 mm/day when the water table rose to the ground surface. This indicates that the unsaturated soil domain, which was not considered in the simulation, so that has a large effect on the subsurface drainage flow, especially for peak flow. Compared with the drainage pattern, it is obvious that the simulated results were different from the measured values by 0.63 mm/day to 0.91 mm/day on either side of the mean value. The negative MD ranged from –0.28 mm/day to –0.67 mm/day. The negative MD for four plots indicated that the model overestimated the observed values. The correlation coefficients were between 0.29 and 0.79. The MAE ranged from 0.40 mm/day to 0.68 mm/day. Actually, the magnitude of MD and MAE indexes in 2000 was similar to that in 1999, but due to smaller observed drainage flow, the percentage difference statistics would be very sensitive to the difference between simulated and observed flows so that results in 2000 were poor due to possible malfunctioning of measuring equipment, or missing data. The correlation efficient was between 0.29 and 0.79. Table 5. Generally, the results indicated that the model underestimated peak subsurface drainage flow and the fluctuation range of observed subsurface drainage flows agrees well. The lateral saturated hydraulic conductivity was major factor affecting peak subsurface drainage flow. Under the simulation condition, the simulated subsurface drainage flow only reaches about 5 mm/day when the water table rose to the ground surface. This indicates that the unsaturated soil domain, which was not considered in the simulation, so that has a large effect on the subsurface drainage flow, especially for peak flow. Compared with the drainage pattern, it is obvious that the simulated results were different from the measured values by 0.63 mm/day to 0.91 mm/day on either side of the mean value. The negative MD ranged from –0.28 mm/day to –0.67 mm/day. The negative MD for four plots indicated that the model overestimated the observed values. The correlation coefficients were between 0.29 and 0.79. The MAE ranged from 0.40 mm/day to 0.68 mm/day. Actually, the magnitude of MD and MAE indexes in 2000 was similar to that in 1999, but due to smaller observed drainage flow, the percentage difference statistics would be very sensitive to the difference between simulated and observed flows so that results in 2000 were poor due to possible malfunctioning of measuring equipment, or missing data. The correlation efficient was between 0.29 and 0.79.

### Table 5: Statistics of observed and simulated daily total NO$_3$-N losses for the simulation period from 1 May to 12 December

<table>
<thead>
<tr>
<th>Year</th>
<th>Plot</th>
<th>Total observed (kg ha$^{-1}$)</th>
<th>Total simulated (kg ha$^{-1}$)</th>
<th>MD (kg ha$^{-1}$)</th>
<th>MAE (kg ha$^{-1}$)</th>
<th>R</th>
<th>%Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>No.1</td>
<td>19.9</td>
<td>18.3</td>
<td>0.023</td>
<td>0.155</td>
<td>0.60</td>
<td>-7.9</td>
</tr>
<tr>
<td></td>
<td>No.3</td>
<td>13.1</td>
<td>20.9</td>
<td>-0.084</td>
<td>0.163</td>
<td>0.60</td>
<td>59.9</td>
</tr>
<tr>
<td></td>
<td>No.5</td>
<td>16.0</td>
<td>19.8</td>
<td>-0.039</td>
<td>0.165</td>
<td>0.60</td>
<td>23.4</td>
</tr>
<tr>
<td></td>
<td>No.7</td>
<td>18.2</td>
<td>18.3</td>
<td>-0.002</td>
<td>0.174</td>
<td>0.60</td>
<td>0.8</td>
</tr>
<tr>
<td>2000</td>
<td>No.1</td>
<td>18.3</td>
<td>19.8</td>
<td>-0.07</td>
<td>0.11</td>
<td>0.55</td>
<td>-10.27</td>
</tr>
<tr>
<td></td>
<td>No.3</td>
<td>20.9</td>
<td>23.4</td>
<td>-0.14</td>
<td>0.14</td>
<td>0.53</td>
<td>38.9</td>
</tr>
<tr>
<td></td>
<td>No.5</td>
<td>19.8</td>
<td>21.0</td>
<td>-0.10</td>
<td>0.10</td>
<td>0.51</td>
<td>10.27</td>
</tr>
<tr>
<td></td>
<td>No.7</td>
<td>18.2</td>
<td>21.0</td>
<td>-0.08</td>
<td>0.10</td>
<td>0.55</td>
<td>8.94</td>
</tr>
</tbody>
</table>

The results of daily NO$_3$-N losses, Mean of the Difference (MD), and the Mean Absolute Error (MAE) are shown in Figs. 4, 5 and 6 respectively. The statistical indexes, calculated for the simulated and observed daily and total NO$_3$-N losses, that the simulated losses after the peak value in the end of October were overestimated, i.e., the mean of difference ranged from –0.14 kg ha$^{-1}$ to –0.07 kg ha$^{-1}$. The negative MD showed that the model overestimated the losses. The mean of difference ranged from –0.084 kg ha$^{-1}$ to 0.023 kg ha$^{-1}$. Except for plot 1, the model overestimated. And, the simulated losses in later stage of simulation period have small variation than drainage flow. The results in 2000 were poor due to possible malfunctioning of measuring equipment, or missing data. The correlation efficient was between 0.29 and 0.79. The lateral saturated hydraulic conductivity was major factor affecting peak subsurface drainage flow. Under the simulation condition, the simulated subsurface drainage flow only reaches about 5 mm/day when the water table rose to the ground surface. This indicates that the unsaturated soil domain, which was not considered in the simulation, so that has a large effect on the subsurface drainage flow, especially for peak flow. Compared with the drainage pattern, it is obvious that the simulated results were different from the measured values by 0.63 mm/day to 0.91 mm/day on either side of the mean value. The statistical indexes, calculated for the simulated and observed daily and total NO$_3$-N losses, are shown in Figs. 4, 5 and 6 respectively. The statistical indexes, calculated for the simulated and observed daily and total NO$_3$-N losses, that the simulated losses after the peak value in the end of October were overestimated, i.e., the mean of difference ranged from –0.14 kg ha$^{-1}$ to –0.07 kg ha$^{-1}$. The negative MD showed that the model overestimated the losses. The mean of difference ranged from –0.084 kg ha$^{-1}$ to 0.023 kg ha$^{-1}$. Except for plot 1, the model overestimated. And, the simulated losses in later stage of simulation period have small variation than drainage flow. The results in 2000 were poor due to possible malfunctioning of measuring equipment, or missing data. The correlation efficient was between 0.29 and 0.79. The lateral saturated hydraulic conductivity was major factor affecting peak subsurface drainage flow. Under the simulation condition, the simulated subsurface drainage flow only reaches about 5 mm/day when the water table rose to the ground surface. This indicates that the unsaturated soil domain, which was not considered in the simulation, so that has a large effect on the subsurface drainage flow, especially for peak flow. Compared with the drainage pattern, it is obvious that the simulated results were different from the measured values by 0.63 mm/day to 0.91 mm/day on either side of the mean value. The negative MD ranged from –0.28 mm/day to –0.67 mm/day. The negative MD for four plots indicated that the model overestimated the observed values. The correlation coefficients were between 0.29 and 0.79. The MAE ranged from 0.40 mm/day to 0.68 mm/day. Actually, the magnitude of MD and MAE indexes in 2000 was similar to that in 1999, but due to smaller observed drainage flow, the percentage difference statistics would be very sensitive to the difference between simulated and observed flows so that results in 2000 were poor due to possible malfunctioning of measuring equipment, or missing data. The correlation efficient was between 0.29 and 0.79.
EVALUATION OF SWAP-MANIMEA MODELS FOR PREDICTING NO3-N LEACHING FROM HOG MANURED PLOTS

The results indicate that the daily NO3-N losses simulated by the MANIMEA model closely follow the pattern of actual drainage flows. The Mean of Difference (MD) ranged from –0.084 kg ha\(^{-1}\) to 0.023 kg ha\(^{-1}\) between the simulated and observed NO3-N losses in 1999. In 2000, the difference was very large, with a MD of 2.82 kg ha\(^{-1}\). The Mean Absolute Error (MAE) was between 0.63 mm/day and 0.91 mm/day for the simulated NO3-N transport process following manure application. The correlation coefficient was larger than 0.79 for these simulations.

The sensitivity to possible malfunctioning of measuring equipment, or missing data in field conditions. This study was a preliminary test of the model's ability to simulate nitrate leaching after spreading liquid hog manure.

The MANIMEA model was calibrated based on field data in different regions, especially measured data for the attempt to calibrate the MANIMEA model. The model performance in simulating every nitrogen transformation and transport process needs to be widely tested and modified to reflect the initial condition at different depths in the soil profile, and allow longer simulation transport need to be validated further. The effect reflecting preferential flow in the simulation of water flow should be considered. The model also needs to be used to simulate the water movement and used as inputs of MANIMEA. MANIMEA is a computer simulation model of nitrogen management fertilized plots using GLEAMS. Transaction of the ASAE 43(1): 69–77.

The Mean of Difference ranged from –0.084 kg ha\(^{-1}\) to 0.023 kg ha\(^{-1}\). In 2000, the difference between the simulated and observed results was very large, with a MD of 2.82 kg ha\(^{-1}\). The correlation coefficient was between 0.29 and 0.79.

The observed NO3-N data contained daily drainage flow and nitrate losses in 1999 and 2000, and nitrate concentrations in the soil profile. The four plots receiving hog manure were used to test the models. The simulations started on 17 May (days 137) when manure was applied, and ended on 12 December (days 346) when the soil might be frozen. The observed daily drainage flows and NO3-N losses in 2000 were greater than that (0.40 kg ha\(^{-1}\)) in 2000 due to a greater amount of water being drained. Similar to drainage flow observed results due to possible malfunctioning of measuring equipment, or missing data. The correlation coefficient was between 0.29 and 0.79.

The observed daily simulated vs. observed NO3-N loss in plot 5
A PROPOSED COUPLED FINITE ELEMENT MODEL FOR WATER AND HEAT FLOW IN POROUS MEDIA

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ABSTRACT

A coupled mathematical model was exploited to simulate the two dimensional water flow in saturated-unsaturated porous media under thermal effects. The coupled model consists of two sub-models that simulate water and heat flow in porous media under the unsteady state conditions. The two sub-models are coupled by few coupling terms. Due to high non-linearity of the governing differential equations of the sub-models, they had to be solved numerically. Therefore, the numerical solution for the coupled mathematical model was proposed following the Galerkin finite element method. In which the two partial differential equations were transformed into a set of ordinary differential equations. Then the derived ordinary differential equations are transformed into a set of algebraic equations by using the implicit finite difference method. The proposed numerical model had to be verified to achieve the certainty of the proposed solution. The verification process was based upon a collected field data. Correlating the numerical solution and the field results shows an acceptable norm of errors. Having been verified, the proposed coupled finite element model can be used in solving the problems of water flow to drains and water flow in porous media under thermal effects.

Keywords: Water flow, Heat, Model, Finite Element, Porous Media

1 INTRODUCTION

At the beginning of the sixties there had been much interest in the physics of water flow in porous media under thermal effects. The analysis of the problems of the heat and water balance during evaporation from soils requires understanding of influence of thermal effect on soil water movement. A quantitative treatment of the combined flow of heat and water in porous media is very complicated. Philip and de Vries (1957) proposed some aspects of this theory. The theory of combined heat and water flow leads to two simultaneous differential equations with two dependent variables, viz. The temperature T(x, z, t) and the moisture content, expressed for instance as the volume of liquid water per unit volume of soil, θ(x, z, t). The first of these equations follows the conservation of energy, the second follows the conservation of mass. The produced differential equations should be coupled based on the dependent variable to study the thermal effect on soil water movement. The boundary conditions belonging to these equations describe conditions of temperature or heat flux, and of volumetric water content, moisture flux, or water potential at the boundaries of the porous medium.

Most of the models proposed to deal with the coupled water and heat flow in porous media as described in Collin et al. (2001) and Mendes et al. (2002) did not study the effect of evaporation on the water table drawdown and the design of subsurface drainage systems. However, the proposed models that deals with effect of evaporation on the water table drawdown did not take the effect of the temperature distribution on varying the soil hydraulic properties as in Gupta et al, (1995), Pandey et al, (1997) and Hathoot (2002).

A coupled mathematical model that includes two coupled mathematical sub-models is exploited to study the water and heat flow in porous media. The governing flow equation of the water flow sub-model is based on the modified form of the Richards’ equation. Considering two-dimensional isothermal Darcian flow of water in a variably saturated porous medium. However, The governing flow equation of the heat flow sub-model is based on the Sophocleous equation. Considering the movement of heat in the porous media due to conduction as well as convection by flowing water. To study the effect of the heat flow in the soil on the water flow in it, the coupling of the two sub-models was essential. The two sub-models are coupled through coupling terms that are unsaturated hydraulic conductivity (K) and Darcian fluid flux density (q) (Abdel-Fattah, 2003).

Furthermore, due to high non-linearity of the governing differential equation of the exploited models the difficulty of the solution would be multiplied. Therefore, the analytical solution could not be used for this type of the problems. Consequently, the numerical solution has to be used to solve such problems. Herein, the exploited sub-model is spatially discretised by Galerkin finite element method and temporally discretised by the central difference method.

Several computational experiments were carried out for the sake of the verification based on actual field data.

The objective of this paper is to propose a coupled finite element model to introduce the numerical solution for water flow through porous media under thermal effects. It simulates the two-dimensional water and heat flow in variably saturated porous media using Galerkin method. Then, The proposed
finite element model is used to predict the water table drawdown between parallel drains considering the effect of evaporation and root water uptake.

The next sections provide a formulation for the water and heat flow sub-models as well as variational formulation of the sub-models. In addition, verification of the numerical solution based on field data is discussed.

2 STATEMENT OF THE PROBLEM

Studying the water flow in porous media under thermal effects is important for a more accurate calculation of the water table drawdown and consequently a more accurate design of the subsurface drainage systems. To achieve that, a coupled mathematical models of water and heat flow in porous media is exploited. The mathematical model consists of two sub-models. The two sub-models are coupled through coupling terms. The two sub-models are presented as follows.

2.1 Water Flow Sub-Model

The mathematical model for simulating two dimensional movement of water in saturated-unsaturated porous media was presented by Simunek and van Genuchten (1994).

2.1.1 Governing flow equation

The governing flow equation of the water flow sub-model is based on the modified form of the Richards’ equation. Considering two-dimensional isothermal Darcian flow of water in a saturated-unsaturated porous medium and assuming that the air phase plays an insignificant role in the liquid flow process the equation is given by the following form:

\[
\frac{\partial h}{\partial t} = \frac{\partial}{\partial x_i} \left( K^{ij} A_{ij} \frac{\partial h}{\partial x_j} \right) - S
\]

Where, \( \theta \) is the volumetric water content \([L^3L^{-3}]\), \( h \) is the pressure head \([L]\), \( S \) is a sink term, represents the volume of water removed per unit time from a unit volume of soil due to plant root uptake \([t^{-1}]\), \( x_i \) \((i = 1, 2)\) are the spatial coordinates \([L]\), \( t \) is time \([t]\), \( K^{ij}_{A} \) are components of a dimensionless anisotropy tensor \( K^A \), and \( K \) is the unsaturated hydraulic conductivity \([Lt^{-1}]\).

The diagonal entries of \( K^{ij}_{A} \) equal one and the off-diagonal entries equal zero for an isotropic medium, Simunek and Van Genuchten (1999). For planer flow in a vertical cross-section, \( x_2 = x \) is the horizontal coordinate and \( x_3 \) is the vertical coordinate, the latter taken to be positive upward.

2.1.2 Initial and boundary conditions

Assume that the flow domain has the general form as shown in Fig. (1). The symbol \( \Omega \) represents the domain, however the symbol \( \Gamma \) represents the boundary.

- Initial conditions

  The initial condition required for solving the water flow equation is represented by the distribution of the pressure head within the flow domain, \( \Omega \) at time zero.

\[
\begin{cases}
\end{cases}
\]

Where, \( h_0 \) is a prescribed initial pressure head function of \( x \) and \( z \) and \( t \) is the time.

- Boundary conditions

  For describing system-independent interactions along the boundaries of the flow region, two types of conditions were implemented. These conditions are Dirichlet type boundary conditions and Neumann type boundary conditions as shown in Fig. (1).

Dirichlet (pressure head) boundary conditions

Dirichlet boundary conditions specifies the pressure head along the boundary segment \( \Gamma_D \) as follows:

\[
\begin{cases}
\end{cases}
\]

Where, \( \psi \) \([L]\) is the pressure head functions of \( x \), \( z \) and \( t \), and \( \Gamma_D \) indicates Dirichlet boundary segment.

Neumann (flux) boundary conditions
Neumann type boundary conditions specifies flux along the boundary segment $\Gamma_N$ as follows:

$$\sigma_{1} \ [Lt^{-1}]$$

Where, $\sigma_{1} \ [Lt^{-1}]$ is the specified flux functions of x, z and t and $\Gamma_N$ indicates Neumann boundary segment.

2.2 Heat Flow Sub-Model

The mathematical model for simulating two-dimensional heat flow through porous media was developed by Sophocleous, (1979).

2.2.1 Governing flow equation

The heat flow equation considers the movement of heat through the porous media by conduction as well as convection by flowing water.

Neglecting the effects of water vapor diffusion, two-dimensional heat flow can be described as follows

$$\lambda_{ij}(\theta) \ [ML^{-3}oC^{-1}] e.g. [W/m^oC] and C(\theta) and C_w are the volumetric heat capacities [ML^{-2}oC^{-1}] \ [e.g. J/m^3oC] \ of \ the \ porous \ medium \ and \ the \ liquid \ phase \ respectively. \ The \ first \ term \ on \ the \ right-hand \ side \ of \ equation \ (5) \ represents \ heat \ flow \ due \ to \ conduction \ and \ the \ second \ term \ accounts \ for \ heat \ being \ transported \ by \ flowing \ water. \ We \ do \ not \ consider \ the \ transfer \ of \ latent \ heat \ by \ vapor \ movement.

2.2.2 Initial and boundary conditions

Assume that the flow domain has the general form as shown in figure (2). The symbol $\Omega$ represents the domain, however the symbol $\Gamma$ represents the boundary.
• **Initial conditions**
The initial condition required for solving the heat flow equation is represented by the distribution of the temperature through the flow domain, $\Omega$ at time zero.

$$
\begin{align*}
\text{Initial conditions} \\
\end{align*}
$$

Where $T_i$ is a prescribed initial temperature function of $x$, $z$ and $t$ ($t$ is the time).

• **Boundary conditions**
In the case of the heat flow, Three types of boundary conditions (Dirichlet, Cauchy and Neumann type boundary conditions) are specified along the boundary of $\Omega$ as described in Fig. (2).

- **Dirichlet boundary conditions**
Dirichlet type boundary conditions prescribe the temperature distribution along a boundary segment $\Gamma_D$:

$$
\begin{align*}
\text{Dirichlet boundary conditions} \\
(7)
\end{align*}
$$

Where, $T_0[T]$ is the temperature functions of $x$, $z$ and $t$ along the boundary $\Gamma_D$, and $\Gamma_D$ indicates Dirichlet boundary segment.

- **Cauchy boundary conditions**
Cauchy type boundary conditions prescribe the heat flux along a boundary segment $\Gamma_C$ as follows

$$
\begin{align*}
\text{Cauchy boundary conditions} \\
(8)
\end{align*}
$$

Where, $q_i$ represents the outward fluid flux [L/t], $n_i$ is the outward unit normal vector and $T_w$ is the temperature of the incoming fluid [T]. $\Gamma_C$ indicates Cauchy boundary segment.

- **Neumann boundary conditions**
When $\Gamma_C$ is an impermeable boundary ($q_i n_i=0$) or when water flow is directed out of the region, Cauchy type boundary condition reduces to a third Neumann type boundary condition of the form:

$$
\begin{align*}
\text{Neumann boundary conditions} \\
(9)
\end{align*}
$$

Where, $\Gamma_N$ indicates Neumann boundary segment.

2.3 **Coupling of the Water Flow and Heat Flow Sub-Models**
The heat flow through the soil due to conduction affects on the change of the moisture content in the soil domain under atmospheric condition. Therefore, to study the effect of the heat flow through the porous media (soil) on the water flow, coupling the water and heat flow sub-models was essential. Coupling of the two sub-models achieved through a couple of terms. These terms are the unsaturated hydraulic conductivity ($K$) in the water flow sub-
model and Darcian fluid flux $q_i$ in the heat flow sub-model (Abdel-Fattah, 2003).

### 2.3.1 Unsaturated hydraulic conductivity ($K$)
The unsaturated hydraulic conductivity ($K$) in the water flow sub-model is recalculated as temperature dependent. That helps in the coupling process through studying the effect of the temperature movement on changing soil hydraulic property as follows (Simunek and Van Genuchten, 1999).

\[
\frac{K_{\text{ref}}}{K} = \left(\frac{\mu_{\text{ref}}}{\mu_T}\right) \left(\frac{\rho_{\text{ref}}}{\rho_T}\right)
\]

(10)

Where $K_{\text{ref}}$ and $K$ denote hydraulic conductivities at the reference temperature $T_{\text{ref}}$ and soil temperature $T$, respectively; $\mu_{\text{ref}}$ and $\mu_T$ ($\rho_{\text{ref}}$ and $\rho_T$) similarly represent the dynamic viscosity [ML$^{-1}$t$^{-1}$] (density of soil water [ML$^{-3}$]) at temperatures $T_{\text{ref}}$ and $T$, respectively.

### 2.3.2 Darcian fluid flux $q_i$
$q_i$ in heat flow sub-model is a function of the pressure head, ILRI (1994):

\[
q_i = \eta T_{i,0}
\]

(11)

Also, $q_i$ is used in calculating apparent thermal conductivity $\lambda_{ij}$ of the porous media in case of the presence of the liquid flow as shown in the following equation:

\[
\lambda_{ij} = \frac{\lambda_L}{\delta_{ij}} + \lambda_T
\]

(12)

Where, $|q_i|$ is the absolute value of the Darcian fluid flux density [L/t], $\delta_{ij}$ is the Kronecker delta function and $\lambda_L$ and $\lambda_T$ are the longitudinal and transverse thermal dispersivities [L] and $\lambda_0(\theta)$ is the apparent thermal conductivity of the porous media in absence of flow respectively [ML/(t*L)], Simunek and van Genuchten (1994).

### 3 THE PROPOSED FINITE ELEMENT MODEL

#### 3.1 Space Discretization
The proposed finite element model introduces the numerical solution for the coupled mathematical model to simplify the solution of the nonlinear differential equations of the sub-models. The two sub-models of water and heat flow are spatially discretized using Galerkin finite element method. Herein, the governing differential equations are transformed into sets of time-dependent ordinary differential equations. They could be written in matrix form for the water and heat flow as follows (Abdel-Fattah, 2003):

\[
W\{\phi\} = \{F\}
\]

(13)

In which, $W$ is the global stiffness matrix, $\{\phi\}$ is the dependent variable (pressure head or temperature) vector over the complete domain and $\{F\}$ is the global force vector.

#### 3.2 Time Discretization
The integration of equation (14) in time is achieved by discretizing the time domain into a sequence of finite intervals and replacing the time derivatives by finite differences. In which, the set of ordinary differential equations is transformed into a set of algebraic equations. Herein, an implicit finite difference scheme is used for the time discretization as follows (Bathe and Wilson, 1976):

\[
W_{j+1}\{\phi_{j+1}\} = W_{j}\{\phi_j\} + \Delta t J_{j+1}^{-1}\{F\}
\]

(14)

Where $j+1$ denotes the current time step level at which the solution is considered, $j$ refers to the previous time level and $\Delta t = t_{j+1} - t_j$.

#### 3.3 Simulation of the Tile Drain in Finite Elements
The tile drain is treated as a single node in the finite element mesh as a boundary condition, (Fipps et. al, 1986). The approach assumed that the node representing a drain must be surrounded by finite elements, which form a square whose hydraulic conductivity is adjusted according to equation (15). The effective drain diameter is taken to be 1.08 cm according to Fipps et al, (1986).

\[
K_{\text{drain}} = K_S C_d
\]

(15)

Where $K_{\text{drain}}$ is the adjusted conductivity [L/t], $K_S$ is the saturated hydraulic conductivity and $C_d$ is the resistance adjustment factor.
4 VERIFICATION OF THE PROPOSED COUPLED MODEL

Verification of the proposed coupled model was essential to achieve the certainty of the numerical model solutions and to check the capability of the exploited coupled model to predict the effect of the evaporation and root water uptake on the water table drawdown. The verification of the numerical model is based on actual field data collected from two pilot areas of the Drainage Research Institute (DRI) of Egypt that have different soil types and different drain spacing. The data was collected during winter and summer seasons to achieve the verification under different atmospheric conditions. The typical domain of the field problems with the applied initial and boundary conditions are shown in Fig. (3).

4.1 Case 1: Model Verification Based On The Field Data Of Winter Season

The first simulation is applied based on data collected from Zankalon pilot area (ZPA) during winter season.

The collected data are water table depth midway lateral drains, cultivated crop and its potential transpiration, Moursy (1998). Soil moisture characteristics are determined based on collected undisturbed samples analyzed at DRI laboratory and shown in Fig. (4), soil thermal properties are given in table 1 as mentioned in Chung and Horton, (1987). The atmospheric data are temperature degrees, potential evaporation rate for an irrigation of 8 days cycle in winter season.

These data are collected from the meteorological station of ZPA, as shown in table 2. The area was cultivated with wheat crop. The location from which the data is collected in ZPA has a heavy clay soil texture with a saturated hydraulic conductivity of 4.03 cm/d. The drainage system in ZPA consists of field drains of 8 cm outside diameter at 1.2 m depth below soil surface, 20 m spacing as reported in El-Refaie (1994).

Initial and Boundary conditions

The initial and boundary conditions for the case study, shown in Fig. (3), are as follows.

The initial conditions

\[
\begin{align*}
    h(x,z,t) &= h_0(x,z,t_0) = 0 \text{ at soil surface for initial time } t_0=0 \\
    T(x,z,t) &= T_i(x,z,t_0) = 10 \degree C \text{ for initial time } t_0=0
\end{align*}
\]

The boundary conditions

\[
\begin{align*}
    h(x,z,t) &= h(x,z,t>0) = 0 \text{ at drain position for } t=1 \text{ to } 8 \text{ days of winter season (January, 2001)}; \\
    (x,y) &= (0,500) \text{ and } (2000,500) \text{ in meter for the left and right drain respectively.} \\
    T(x, z, t) &= T(x, z, t>0) \text{ for } t=1 \text{ to } 8 \text{ days.} \\
    T_i &= \text{initial soil temperature, } h_0 \text{ is the initial pressure head, } h \text{ [L] is the pressure head functions of } x, z \text{ and } t. \text{ While } K \text{ is the unsaturated hydraulic conductivity, } q \text{ is the flux, } E \text{ is the maximum potential evaporation rate and } T(t) \text{ is the time dependent temperature degree. The values of } E(t), T_p \text{ (t) maximum potential transpiration, used in evaluating the sink term that represents root water and } T(t) \text{ are shown in table 2.}
\end{align*}
\]

Where, \(T_i\) is the initial soil temperature, \(h_0\) is the initial pressure head, \(h\) [L] is the pressure head functions of \(x, z\) and \(t\). While \(K\) is the unsaturated hydraulic conductivity, \(q\) is the flux, \(E\) is the maximum potential evaporation rate and \(T(t)\) is the time dependent temperature degree. The values of \(E(t), T_p\) (t) maximum potential transpiration, used in evaluating the sink term that represents root water and \(T(t)\) are shown in table 2.

The numerical solution gives a reasonable pressure head values correlating to the measured pressure head midway between the drains with an error norm of 4.4% as shown in Fig. (5).
4.2 Case 2: Model verification based on the field data of summer season

The second field simulation is applied based on data collected from Haress pilot area (HPA) during summer season. The collected data are water table depth midway lateral drains, the cultivated crop type and its potential transpiration, Moursy (1998). Soil moisture characteristics are detected based on collected un-disturbed samples analyzed at DRI laboratory, as shown in Fig. (6), soil thermal properties are taken from table 1 as mentioned in Chung and Horton, (1987). The atmospheric data are temperature degrees, potential evaporation rate for an irrigation of 6 days cycle in summer season as shown in table 3. These records are collected from the meteorological station of HPA. The area was cultivated with Maize crop. The location from which data is collected in HPA has Loam soil texture with a hydraulic conductivity of 40.7 cm/d. The drainage system in HPA consists of field drains at 1.40 m depth below soil surface, 40 m spacing and 8 cm outside diameter, DRI (1992).

<table>
<thead>
<tr>
<th></th>
<th>1st day</th>
<th>2nd day</th>
<th>3rd day</th>
<th>4th day</th>
<th>5th day</th>
<th>6th day</th>
</tr>
</thead>
<tbody>
<tr>
<td>E [cm]</td>
<td>0.593</td>
<td>0.593</td>
<td>0.585</td>
<td>0.585</td>
<td>0.555</td>
<td>0.615</td>
</tr>
<tr>
<td>Tp[cm]</td>
<td>0.368</td>
<td>0.368</td>
<td>0.375</td>
<td>0.375</td>
<td>0.405</td>
<td>0.13</td>
</tr>
<tr>
<td>T [°C]</td>
<td>32</td>
<td>31</td>
<td>30</td>
<td>29</td>
<td>29</td>
<td>29</td>
</tr>
</tbody>
</table>

Initial and Boundary conditions

The initial and boundary conditions for the second case, shown in Fig. (3), are introduced as follows.

The initial conditions

\[ h(x,z,t) = h_0(x,z,t_0) = 0 \quad \text{at soil surface for initial time } t_0=0 \]

\[ T(x,z,t) = T_i(x,z,t_0) = 20 \quad \text{°C for initial time } t_0=0 \]

The boundary conditions

\[ h(x,z,t) = h(x,z,t>0) = 0 \quad \text{at drain position through the time period of the problem.} \]

for \( t=1 \) to 6 days during summer season (June, 2001);

\( (x,y) \) equal (0,500) and (5000,500) in cm for the left and right drain respectively.

\[ T(x,z,t) = T(x,z,t>0) \quad \text{for } t=1 \text{ to 6 days.} \quad \text{(18)} \]

\[ \text{for } t=1 \text{ to 6 days.} \quad \text{(19)} \]
Where, $T_i$ is the initial soil temperature, $h_0$ is the initial pressure head, $h \ [L]$ is the pressure head functions of $x$, $z$ and $t$, $K$ is the unsaturated hydraulic conductivity, $q$ is the flux and $E$ is the maximum potential evaporation rate and $T(t)$ is the time dependent temperature degree. The saturated hydraulic

**Figure 4  Soil moisture characteristic curve for the soil of Zankalon Pilot Area**

**Figure 5  Model verification based on Zankalon field data**
conductivity $K_s$ equals 40.7 cm/d. The values of $E(t)$, $T_p(t)$ maximum potential transpiration, used in evaluating the sink term that represents root water and $T(t)$ are described in table 3.

The numerical solution outputs gave a reasonable pressure head values correlating to the measured pressure head midway between the drains with an error norm of 4.7% as shown in Fig. (7).

5 CONCLUSION
A coupled finite element model is proposed to simulate the highly nonlinear two-dimensional water and heat flow in saturated-unsaturated porous media. The numerical solution of the coupled finite element model is based on the Galerkin method for the space discretization and backward implicit finite difference method for time discretization. The numerical solution composed of two components, the first concerns with the solution of the transient water flow in porous media, and the second concerns with the transient heat flow in porous media. The proposed finite element model is verified depending on two sets of field data for winter and summer seasons to cover different atmospheric conditions. The numerical solution gives a reasonable pressure head values correlating to the measured pressure head midway between the drains with an error norm of 4.4% for the data of winter and 4.7% for the data of summer. Since the proposed model verified and introduced an acceptable error norm, it can be used for evaluation the water table and design of subsurface drainage systems considering the effects of the heat flow on the soil hydraulic properties.

![Soil moisture characteristic curve for the soil of Haress Pilot Area](http://library.wur.nl/ebooks/drainage/drainage_cd/1.3%20abdel-fattah%20mm%20et%20al.html)
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A PROPOSED COUPLED FINITE ELEMENT MODEL FOR WATER AND HEAT FLOW IN POROUS MEDIA

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ABSTRACT
This paper describes the method of hydraulic calculations of the drainage discharge rate from the internal landfill drainage system, placed at the bottom of the sanitary communal waste landfill, based on the drainage theory of De Zeeuw-Hellinga, under the non-steady saturated drainage flow conditions. The results were verified and compared with the actual data measured in the sanitary landfill of domestic waste in Osecna location, situated in Northern Bohemia, Czech Republic.

Keywords: Drainage, Leakage, Drainage Discharge Rate, Landfill, Communal and Domestic Waste, Sanitary Landfill.

INTRODUCTION
The drainage system at the bottom of the landfills of the communal and domestic waste are used to secure conservation of the environment. The design of drainage system placed at the bottom of the sanitary landfills of communal waste should proceed from a water management project based on mathematical and physical description of the hydraulic processes inside the landfill body (Stibinger, 1994), hydrological conditions of the particular locality, the amount and physical properties of incoming communal and domestic waste as well as on the way of landfilling.

The hydraulic calculations of the landfill leakage rate, resp. drainage discharge rate from the internal landfill drainage system, placed at the bottom of the sanitary communal and domestic waste landfill, are, in this case, based on the drainage theory of De Zeeuw-Hellinga, under non-steady saturated drainage flow conditions (Ritzema, 1994). The results were verified and compared by the actual data from the sanitary landfill of domestic waste in Osecna location, situated in Northern Bohemia.

THEORETICAL

2.1 De Zeeuw-Hellinga Equation
To simulate the drainage rate, in this case the landfill leakage rate q (M/T), during a period with a non-uniform distribution of landfill recharge R (M), the period was divided into time intervals of equal length (day, month, year).

De Zeeuw and Hellinga discovered that the change in the drainage rate is proportional to the excess drainage rate (R-q) (M/T) if the recharge R (M) in each time-interval is assumed to be constant. De Zeeuw-Hellinga drainage intensity factor a (T⁻¹) represents the constant of proportionality and depends on the parameters of pipe drainage system and on the position of the impervious layer (Dieleman and Trafford, 1976).

In this case, drainage intensity factors also express the hydraulic efficiency of the landfill internal drainage system, which is situated at the bottom of landfill body. The basic equation can be formed as:

\[
\frac{dq}{dt} = -Aq + R
\]

After integration between the limits \( t=t_1 \), \( q=q_1 \) and \( t=t_2 \), \( q=q_2 \), can be written:

\[
q(t) = \frac{R}{A} + q_1 - A \int_{t_1}^{t} q_2 dt
\]

where:
- q landfill drainage discharge rate (M/T)
- change in the landfill drainage discharge rate (M/T)
- \( q_t, q_{t-1} \) landfill drainage discharge rate in time-interval t, t-1 (M/T)
- time interval (T)
- R recharge of percolation water of landfill, constant in time interval (M)
- A De Zeeuw-Hellinga drainage intensity factor (T⁻¹)
- t time (T)
- M, T length, time unit

2.2 Water balance equation for landfills
The recharge of the percolation water of landfill R (M) to the internal drainage system at the bottom of the landfill body, can be derived from the series of the

\[
\frac{dR}{dt} = q - R
\]
HYDRAULIC ESTIMATION OF DRAINAGE DISCHARGE RATE AT ...DFILL OF COMMUNAL WASTE IN OSECNA, NORTHERN BOHEMIA

(3)

where:

- \( i \) interval in the tested period
- \( n \) total number of intervals in the tested period
- \( \sum_{i=1}^{n} M_i \) series of the cumulative values of recharges in tested period (M)
- \( \sum_{i=1}^{n} M_{\text{tot}} \) series of the total precipitation amounts in tested period (M)
- \( \sum_{i=1}^{n} M_{\text{irr}} \) series of the total landfill irrigation amounts in the tested period (M)
- \( \sum_{i=1}^{n} M_{\text{evap}} \) series of the total landfill evaporation amounts in tested period (M)
- \( \sum_{i=1}^{n} M_{\text{run-off}} \) series of the total quantity of the landfill surface run-off in tested period (M)
- \( V \) series of the total wastewater retention capacity amounts in tested periods (M)
- \( V \) water storage capacity or drainable pore space of the domestic waste (% of volume)

Parameter \( W \) (M) represents the amount of waste in length units and can be approximated by expression \( W = \frac{(N \cdot G - 1)}{S} \) where \( N \) is the amount of waste in tons, \( G \) represents the density of waste in ton per volume and \( S \) (M²) is area delimited for waste landfilling. Because the series of the cumulative values of recharges \( \sum_{i=1}^{n} M_i \) represents in reality cumulative curve, the values of the recharges of the percolation water of landfill \( R \) (M) for individual corresponding time interval \( \sum_{i=1}^{n} M_i \) can be derived by equation (4).

\[ R = 0 \]

If the expression \( R = 0 \). From the known values of the recharges \( R \) (M) and by the application of the De Zeeuw-Hellinga drainage theory, the landfill leakage rate \( \frac{\text{M}}{\text{T}} \) was estimated according to equation (4) in the each time interval .

3 EXPERIMENTAL STUDY OF THE LANDFILL

3.1 Elemental input data of the landfill Osecna

All the data, which are necessary for calculation of the parameters of equation (3), (4) and for an approximation of the De Zeeuw-Hellinga drainage intensity factor \( a \) (T^{-1}) and finally for the estimation of the landfill leakage rate \( \frac{\text{M}}{\text{T}} \) according to equation (2), were taken from the monthly hydrological records of the location Osecna, region Liberec and from the landfill Osecna working records (monthly data) and from the monitoring of the landfill Osecna. In accordance with the De Zeeuw-Hellinga drainage theory, it is assumed, that all values in a selected time-interval (month) are constant.

The sanitary landfill of the solid domestic waste Osecna, situated near the location Osecna, region Liberec, Northern Bohemia, opened running in December 1995. It is supposed the landfill running will be finished at the end of the year 2003. The landfill location is situated in the Luzicke Mountains with altitude 770 – 800 meters above the sea level, in the forested territory of the Sierra Ještěd base. Long-term annual average of precipitation amounts to 910 mm, long-term annual average of temperature amounts to about 7.3

The effective area \( S \) (M²), delimited for waste landfilling during the years 1997 and 1998, amounted to about 2.14 hectares (21 400 m²). The landfill internal drainage system, placed at the bottom of landfill body, comprises the drain spacing \( L \) (m) = 30, average of the thickness of the gravel drainage layer \( D \) (m) = 0.3 and diameter of the lateral drains \( r_0 \) (m) = 0.1. Plastic perforated drainage pipes are placed under the drainage layer on the approximately horizontal landfill base liner. Hydraulic saturated conductivity of the gravel-sand material of drainage layer \( K = 3.0 \text{ m.day}^{-1} \), drainable pore space \( P_d = 0.25 \) (-), (Figure 1).

The results of the initial hydraulic calculations indicate the value of the average depth of aquifer \( H \) (m) = 0.14 (lateral drains are placed almost to an impervious sealing system), and indicate the value of the De Zeeuw-Hellinga drainage intensity factor \( a \) (day^{-1}) = \( \left( \frac{v^2 \cdot K}{L^2 \cdot P_d} \right) \) = 0.0184.

The base liner of the sanitary landfill Osecna is approximately horizontal. The slope of the base with plastic sealing foil is neglected. This fact is corresponding with premises of the De Zeeuw-Hellinga drainage theory, which is based, besides others, on a present of the approximately horizontal impervious layer. In a case of the strongly sloped landfill base liner system, other models and other methods have to be applied (D’Antonio and Pirozzi, 1991, McEnroe, 1992, Upadhyaya and Chauhan, 2001).

3.2 Results of hydraulic calculations

For description of the hydraulic behaviour of leakage at the bottom of sanitary landfill Osecna by De Zeeuw-Hellinga drainage theory was chosen year 1998, the third year of the landfill running. The actual hydrological and working data from landfill Osecna during the year 1998 are presented in Table 1 and viewed on Figure 2.
The water storage capacity $V$ (% of volume) of the domestic waste and the waste density $G$ (ton.m$^{-3}$) in the conditions of the landfill Osecna, were approximated by the field experimental measurement, laboratory testing (Kutílek and Nielsen, 1994, Genuchten and Nielsen, 1985) and from the landfill working records as $V$ (% of volume) = 25.0 and $G$ (ton.m$^{-3}$) = 0.85.

The specific hydrological conditions of the territory of the Sierra Ještěd base, the way of landfilling of the communal waste and the handling of percolation waters from landfill (landfill irrigation) in the landfill Osecna, allowed to reduced the water balance equation (3) in the tested period in to following form:

$$ \text{(5)} $$

By the reduced water balance equation (5), the cumulative values of the landfill recharges (mm) from the landfill Osecna, which in reality form cumulative curve (see Table 2) were approximated. In Table 2 are also presented the cumulative values of precipitation, total amounts of the incoming domestic waste and cumulative values of the waste water retention capacity (see Figure 3). All these data create the input parameters of the reduced water balance equation (5) for approximation of the cumulative values of the landfill recharges.

On the basis of known constant values of the landfill recharge curve $R$ (mm) in the monthly time interval (see Figure 3 and Table 3) and the known value of the De Zeeuw-Hellinga drainage intensity factor $a$ (day$^{-1}$) = ($\sqrt{K_{\alpha}}$) (L$^2$.P$_d$) = 0.0184 = 0.552 (month$^{-1}$), according to equation (2), the values of the drainage discharge rate $q_t$ (mm/month) for every month (time-interval t) of the year 1998, were calculated. In accordance with De Zeeuw-Hellinga drainage theory, it is supposed, that the drainage discharge rate in the corresponding time interval (month) will be constant.

$$ \text{(5)} $$

Table 1  Measured characteristics from the landfill Osecna (solid communal waste), location Osecna, Northern Bohemia, 1998.

<table>
<thead>
<tr>
<th>1998 (month)</th>
<th>Precipitation (mm)</th>
<th>Solid waste (tons)</th>
<th>Leakage (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54.0</td>
<td>15 014</td>
<td>4.5</td>
</tr>
<tr>
<td>2</td>
<td>53.5</td>
<td>11 718</td>
<td>13.0</td>
</tr>
<tr>
<td>3</td>
<td>102.0</td>
<td>17 162</td>
<td>24.0</td>
</tr>
</tbody>
</table>

The water storage capacity $V$ (% of volume) of the domestic waste and the waste density $G$ (ton.m$^{-3}$) in the conditions of the landfill Osecna, were approximated by the field experimental measurement, laboratory testing (Kutílek and Nielsen, 1994, Genuchten and Nielsen, 1985) and from the landfill working records as $V$ (% of volume) = 25.0 and $G$ (ton.m$^{-3}$) = 0.85.

Figure 1 A scheme of the internal landfill drainage system inclusive of the drainage discharge and recharge processes at the Landfill Osecna, Northern Bohemia, Czech Republic, 1998

Table 1 Measured characteristics from the landfill Osecna (solid communal waste), location Osecna, Northern Bohemia, 1998.

<table>
<thead>
<tr>
<th>1998 (month)</th>
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<th>Solid waste (tons)</th>
<th>Leakage (mm)</th>
</tr>
</thead>
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<tr>
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<td>15 014</td>
<td>4.5</td>
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<tr>
<td>2</td>
<td>53.5</td>
<td>11 718</td>
<td>13.0</td>
</tr>
<tr>
<td>3</td>
<td>102.0</td>
<td>17 162</td>
<td>24.0</td>
</tr>
</tbody>
</table>
HYDRAULIC ESTIMATION OF DRAINAGE DISCHARGE RATE AT ...DFILL OF COMMUNAL WASTE IN OSECNA, NORTHERN BOHEMIA

<table>
<thead>
<tr>
<th></th>
<th>19.5</th>
<th>23 815</th>
<th>15.0</th>
</tr>
</thead>
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<tr>
<td>5</td>
<td>22.5</td>
<td>23 626</td>
<td>5.6</td>
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<td>73.0</td>
<td>23 758</td>
<td>4.0</td>
</tr>
<tr>
<td>7</td>
<td>69.0</td>
<td>104 138</td>
<td>9.0</td>
</tr>
<tr>
<td>8</td>
<td>36.5</td>
<td>23 266</td>
<td>2.3</td>
</tr>
<tr>
<td>9</td>
<td>100.0</td>
<td>21 405</td>
<td>32.5</td>
</tr>
<tr>
<td>10</td>
<td>80.3</td>
<td>18 457</td>
<td>25.4</td>
</tr>
<tr>
<td>11</td>
<td>66.1</td>
<td>17 823</td>
<td>26.6</td>
</tr>
<tr>
<td>12</td>
<td>24.4</td>
<td>12 924</td>
<td>2.3</td>
</tr>
<tr>
<td>Total</td>
<td>700.8</td>
<td>313 100</td>
<td>164.2</td>
</tr>
</tbody>
</table>

Figure 2  Measured data from the landfill Osecna (solid waste), Northern Bohemia, 1998.

Table 2  Measured and calculated cumulative values from the landfill Osecna, Northern Bohemia, 1998 (* measured values, + calculated values)

<table>
<thead>
<tr>
<th>cumulative values from 12. 1995 to 1997</th>
<th>precipitation (mm)</th>
<th>Communal waste (tons)</th>
<th>wastewater retention (mm)</th>
<th>Landfill recharge (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>1640.0</td>
<td>118313.6</td>
<td>1626.0</td>
<td>13.9</td>
</tr>
<tr>
<td>1998 (month) 1</td>
<td>1694.0</td>
<td>119815.0</td>
<td>1646.7</td>
<td>47.2</td>
</tr>
<tr>
<td>2</td>
<td>1747.5</td>
<td>120986.8</td>
<td>1662.8</td>
<td>84.6</td>
</tr>
<tr>
<td>3</td>
<td>1849.5</td>
<td>122703.1</td>
<td>1686.4</td>
<td>163.0</td>
</tr>
<tr>
<td>4</td>
<td>1869.0</td>
<td>125084.6</td>
<td>1719.1</td>
<td>149.8</td>
</tr>
<tr>
<td>5</td>
<td>1891.5</td>
<td>127447.2</td>
<td>1751.6</td>
<td>139.8</td>
</tr>
<tr>
<td>6</td>
<td>1964.5</td>
<td>129823.0</td>
<td>1784.2</td>
<td>180.2</td>
</tr>
<tr>
<td>7</td>
<td>2033.5</td>
<td>140236.8</td>
<td>1927.3</td>
<td>106.1</td>
</tr>
<tr>
<td>8</td>
<td>2070.0</td>
<td>142563.5</td>
<td>1959.3</td>
<td>110.6</td>
</tr>
<tr>
<td>9</td>
<td>2170.0</td>
<td>144704.0</td>
<td>1988.7</td>
<td>181.2</td>
</tr>
<tr>
<td>10</td>
<td>2250.3</td>
<td>146549.8</td>
<td>2014.1</td>
<td>236.1</td>
</tr>
<tr>
<td>11</td>
<td>2316.4</td>
<td>148332.1</td>
<td>2038.6</td>
<td>277.7</td>
</tr>
<tr>
<td>12</td>
<td>2340.8</td>
<td>149624.5</td>
<td>2056.4</td>
<td>284.3</td>
</tr>
</tbody>
</table>

If, for example, \( q_6 = 26.5 \text{ (mm/month)} \), it means, that the total landfill leakage in the June (at 1 month) will be 26.5 mm. The calculated values of the landfill leakage \( q_t \) are expressed in mm per corresponding month (time-interval \( t \)). The results of the estimations (together with actual monthly measured values of the landfill leakage) are presented in Table 3 and graphically demonstrated in Figure 4.

The values of the recharges of the landfill percolation water \( R \) (mm) in the corresponding time intervals with constant length (months) were derived according
to equation (4). The results, landfill recharge curve $R$ (mm), are graphically symbolized in Figure 3 and presented in Table

### 4 RESULTS AND DISCUSSION

From the comparison of monthly values of the landfill leachate $q_l$ calculated according to equation (2) for the landfill Osecna conditions and the factual measured monthly values of the landfill leakage from the same field (see Figure 4 and Table 3) it is obvious, that the shape of the curve of equations (2) and the shape of the curve of the actual measured monthly values is identical, even though the certain difference between the curves is apparent.

It seems that the maximum difference affects at the maximum of the precipitation. It means, that the De Zeeuw-Hellinga drainage model reacts for precipitation much more better then for an incoming amount of domestic waste, which creates the wastewater retention capacity of the landfill body and reduces the direct precipitation effects.

The use of the De Zeeuw-Hellinga way of estimation will be probably more effective at the beginning of landfilling, where the impact of precipitation is strong and the landfills are, especially in this period, more unstable during the precipitation and heavy rains action. De Zeeuw-Hellinga drainage theory also supposes, the relatively large distance between drain pipe level and impervious layer and this requirement, in a case of the landfill Osecna, was not completely carried out.

On the other hand, it should be noted that the modeling of time series of the landfill leakage during the landfilling is very difficult and complicated. The mathematical and physical description of the incoming waste compacting and increasing in connection with hydrological processes can be exact, especially for a long period of landfilling.

And from this point of view, the De Zeeuw-Hellinga drainage model can be applied as a suitable tool for landfill leakage approximation in a certain selected (critical) time period of the landfilling. It also appears, that the De Zeeuw-Hellinga drainage model approximation, yields the slightly higher values of the landfill leachates then the experimental data, so that is why, the application of its results, can guarantee the more effective probability of the internal landfill drainage system design.

![Figure 3](http://library.wur.nl/ebooks/drainage/drainage_cd/2.2%20stibinger.html)  
**Figure 3** Total amounts of precipitation, incoming waste and total values of wastewater retention capacity with course of the landfill recharge $R$, Landfill Osecna, Northern Bohemia, 1998.

<table>
<thead>
<tr>
<th>1998 (month)</th>
<th>Precipitation (mm)</th>
<th>Landfill recharge $R$ (mm)</th>
<th>Landfill leakage measured values (mm)</th>
<th>Landfill leakage $q_l$, calculated values (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54.0</td>
<td>33.4</td>
<td>4.5</td>
<td>20.0</td>
</tr>
<tr>
<td>2</td>
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<td>37.4</td>
<td>13.0</td>
<td>27.4</td>
</tr>
<tr>
<td>3</td>
<td>102.0</td>
<td>78.4</td>
<td>24.0</td>
<td>49.1</td>
</tr>
<tr>
<td>4</td>
<td>19.5</td>
<td>0.0</td>
<td>15.0</td>
<td>28.2</td>
</tr>
<tr>
<td>5</td>
<td>22.5</td>
<td>0.0</td>
<td>5.6</td>
<td>16.2</td>
</tr>
<tr>
<td>6</td>
<td>73.0</td>
<td>40.3</td>
<td>4.0</td>
<td>26.5</td>
</tr>
<tr>
<td>7</td>
<td>69.0</td>
<td>0.0</td>
<td>9.0</td>
<td>15.2</td>
</tr>
</tbody>
</table>
HYDRAULIC ESTIMATION OF DRAINAGE DISCHARGE RATE AT ...DFILL OF COMMUNAL WASTE IN OSECNA, NORTHERN BOHEMIA

<table>
<thead>
<tr>
<th></th>
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<th>4.5</th>
<th>2.3</th>
<th>10.7</th>
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<tr>
<td>8</td>
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<td></td>
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</tr>
<tr>
<td>9</td>
<td>100.0</td>
<td>70.6</td>
<td>32.5</td>
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</tr>
<tr>
<td>10</td>
<td>80.3</td>
<td>55.0</td>
<td>25.4</td>
<td>44.2</td>
</tr>
<tr>
<td>11</td>
<td>66.1</td>
<td>41.6</td>
<td>26.6</td>
<td>42.8</td>
</tr>
<tr>
<td>12</td>
<td>24.4</td>
<td>6.6</td>
<td>2.3</td>
<td>27.4</td>
</tr>
<tr>
<td>Total</td>
<td>700.8</td>
<td>367.8</td>
<td>164.2</td>
<td>343.9</td>
</tr>
</tbody>
</table>

Figure 4  Comparison between the measured and calculated values of the landfill leakage Landfill Osecna, Northern Bohemia, 1989.

5 CONCLUSIONS
The correct estimation of landfill drainage recharge rate during the landfilling has a key role in landfill hydrology and landfill drainage policy. It is vital for the impact evaluation of the existing internal landfill drainage systems or for the calculation of parameters of the new ones.

Verification of simple analytical De Zeeuv-Hellinga solution as application to estimate the landfill drainage recharge from the internal drainage landfill system at the bottom of landfill, formed in equation (1) and (2), showed a good conformity between calculations and measured data under the unsteady state saturated landfill drainage flow (leakage) in the bottom of landfill body.

At the Department of Land Use and Improvement, Faculty of Forestry, Czech University of Agricultural Prague, research of the landfill leakage at the beginning of landfilling is carried out. The partial results of this investigation entitle to apply the De Zeeuv-Hellinga drainage model of landfill leakage, expressed by equation (2), especially in the initial period of the landfilling on conditions that the complex software products like DRAINMOD (Skaggs, 1999), SWAP (Dam, 2000), MODFLOW are used, or the other available models of similar type should be tested or adjusted for the landfill hydrology. This introduced De Zeeuv-Hellinga landfill leakage approximation should be used as a simple tool for immediate estimation of the values of landfill leakage for certain selected time intervals, further can be corrected and specified. It should serve as a tool what requires only minimum amount of information (the basic hydrology data, working data of the waste collecting and landfill bottom drainage system basic design parameters).

The verification of the field test results and measurements reflects, that the possibilities of application and their benefits user, mentioned above, can be fulfilled.

6 ACKNOWLEDGEMENTS
The authors thank Mrs. Jiřina Suvova for her careful documentation of all data. We would like to acknowledge in particular help of Mrs. Marta Medlikova from GESTA Rynoltice a. s., Landfill Osecna, during the operation on the landfill site Osecna.

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PROBABILISTIC ANALYSIS OF DRAINAGE WATER QUALITY FOR SUSTAINABLE REUSE IN AGRICULTURE

Dr. Maha M. Tawfik

Abstract
Scarcity of freshwater resources globally is fast becoming a major factor in limiting the development in arid and semi-arid regions. The security and development of a nation is fundamentally tied to the development and management of water resources. Yet, planning for water resources utilization is not merely a question of ensuring the right quantity of water at the right place at the right time, but also is related to ensuring the proper quality for the use in view.

As most developing countries, the demand on Egypt’s water is expected to exceed available renewable freshwater resources. Thus, the country has adopted the reuse of agricultural drainage water in irrigation as a national policy since the late seventies. The drainage reuse policy is currently threatened by increasing pollution due to different socio-economic activities dumping their wastes into the various water bodies. Such policy cannot be sustainable unless information on the impact of using this quality water on the surrounding environment is available. Therefore, water quality monitoring programs and monitoring networks have been established long time ago. Samples are collected, analyzed for major pollutants, and stored in well-documented database systems. Currently, there is a wealth of data on many quality parameters that may help to better inform the decision makers and make them work towards sustainable use of drainage water. Nevertheless, this data is of no use unless appropriate analysis is performed to identify temporal and spatial trends of the parameters of major concerns when planning for future reuse projects. It is also important to investigate relationships among the different parameters to be able to predict their impacts on the environment.

This paper investigates the sustainability of drainage water reuse through using a simple probabilistic analysis approach. BESTFIT statistical software is used to fit the proper probability distribution for monthly data of some selected water quality parameters. The deviation between the levels of water quality concentrations and the standards for reuse are checked through the analysis of exceedance probability for each parameter. Few water quality parameters are included in this analysis according to their environmental impacts on crop production, soil salinity, groundwater quality, etc. Based on the results of this analysis, specific recommendations can be drawn with respect to permission of drainage reuse for irrigation purposes during certain periods.

The catchment of Umoum Drain in Western Delta region has been selected as the study area where several drainage pump stations lift water from branch drains into Umoum principal drain and one mixing pump station for lifting drainage water into an irrigation canal for reuse in irrigation. The results of the analysis show that in general there is not any significant change in drainage water quality concentrations from one month to the other and also between concentrations of parameters at some selected pump stations. The potential for use of the drainage water could not be concluded as some pollutants have safe levels of concentration throughout the whole year, while other pollutants have varying concentrations from one month to the other.

Keywords: Reuse, Probabilistic Analysis, Probability Distribution

1 Introduction
Water is an essential element for socio-economic development of every society. Thus, scarcity of freshwater resources globally has been recognized as a major factor in limiting the development of countries and regions as well as in causing conflicts between regions sharing the same water resource. Moreover, sustainable development of water resources is highly correlated with an ecological matrix that includes soil, water, fauna, flora, and human beings. Several environmental problems are associated with this development including scarcity of water resources, water quality deterioration, and the uncertainty about the impacts of climatic changes and possible conflicts over shared water resources (Attia and Tawfik, 2002). With the increasing population growth on one hand and environmental degradation on the other, there is an urgent pressure on fresh water resources for direct consumption as well as for productive use.

Egypt is an arid country with limited fresh water resources seeking sustainable economic development. The Egyptian water resources system is characterized by its dynamic and uncertain nature. It is a large system composed of many interacting components and interfaces with social, economic and environmental systems. Egypt has relied for centuries on the Nile River to satisfy almost all of its water requirements. Currently, the country is approaching a situation where water requirements are expected to significantly exceed the available fresh water resources (Tawfik at al., 2001).

Consequently, efficient use of water resources in both time and space requires the formulation and implementation of appropriate water sector policies. The main objectives of the current water policy are to develop water resources in a sustainable manner to meet socio-economic and environmental needs of the country as well as augment non-conventional resources and resources of marginal quality into the water sector plans. Drainage water has emerged as an important resource to complement the water required to meet the demands on short-term basis.

Nevertheless, there is an ever-increasing threat to the quality of drainage water due to increase in population, urbanization and industrialization, and intensified use of agro-chemical. As in most developing countries, Egypt suffers from water pollution generally because of domestic, industrial and agricultural activities. Water quality deterioration results in various impacts varying from human health hazards, due to direct and indirect contact, loss of biodiversity, irreversible pollution of groundwater, in addition to less water available for different uses. Therefore, water quality monitoring has emerged as an important task in water management where the environment is a vital dimension.

The paper presents the reuse of drainage water for irrigation purposes as an important water supply in many parts of the Nile Delta. It introduces a new simple probabilistic approach for the analysis of drainage water quality data. This approach can be used in order to check the appropriateness and suitability for reuse in irrigation. It provides simple probabilistic analysis that was performed on the water quality data of one of the main drains in the Western Delta region. This paper is intended to advocate this approach for the analysis and demonstrate it functionality in evaluating drainage water quality to ensure sustainable national development.
2 Drainage reuse in Egypt

Drainage water reuse projects in the Nile Delta started as early as 1930s alongside the construction of drainage projects (Amer and de Ridder, 1989). Nevertheless, Egypt has adopted the reuse of agricultural drainage water in irrigation as a national policy since the late seventies. The MWRI is undertaking major projects for horizontal land expansion to divert considerable amounts of drainage water to newly reclaimed areas after being blended with fresh water (Abdel-Gawad, 1993 and 2001). Table 1 reports the quantities of reused drainage water in the three Delta regions from the period of 1984/85 to 1999/2000 in million cubic meters per year. The table also shows the average salinity represented by the electric conductivity (EC) in deci Siemens per meter (dS/m) of the reused water.

<table>
<thead>
<tr>
<th>Year</th>
<th>Eastern Delta</th>
<th>Middle Delta</th>
<th>Western Delta</th>
<th>Total Reuse</th>
</tr>
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<tbody>
<tr>
<td>Q</td>
<td>EC</td>
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<td>(dS/m)</td>
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<td>84/85</td>
<td>1301</td>
<td>1.28</td>
<td>763</td>
<td>1.29</td>
</tr>
<tr>
<td>85/86</td>
<td>1253</td>
<td>1.30</td>
<td>748</td>
<td>1.21</td>
</tr>
<tr>
<td>86/87</td>
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<td>87/88</td>
<td>1381</td>
<td>1.44</td>
<td>693</td>
<td>1.41</td>
</tr>
<tr>
<td>88/89</td>
<td>1400</td>
<td>1.53</td>
<td>704</td>
<td>1.46</td>
</tr>
<tr>
<td>89/90</td>
<td>1504</td>
<td>1.57</td>
<td>1506</td>
<td>2.24</td>
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<tr>
<td>90/91</td>
<td>1585</td>
<td>1.59</td>
<td>1999</td>
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<td>91/92</td>
<td>1445</td>
<td>1.46</td>
<td>2058</td>
<td>1.90</td>
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<td>92/93</td>
<td>1460</td>
<td>1.41</td>
<td>1841</td>
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<td>93/94</td>
<td>1120</td>
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<td>1691</td>
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<td>94/95</td>
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<td>1843</td>
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<td>1746</td>
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<td>1815</td>
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<td>1843</td>
<td>1.94</td>
<td>1946</td>
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<tr>
<td>97/98</td>
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<td>98/99</td>
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At present about 14 bcm of drainage water of reasonable quality flow to the Mediterranean and the northern lakes with salinity 3 to 5 dS/m. The drainage reuse policy is currently threatened by increasing loads of pollution due to various socio-economic activities dumping their wastes into different water bodies, especially agricultural drains. Such policy cannot be sustainable unless information on the impact of using this low quality water on the environment is available. During the past decades considerable attention has been given to the monitoring of water quality. Therefore, water quality monitoring programs and monitoring networks have been established long time ago. Samples are collected, analyzed for major pollutants and stored in well-documented database systems. Currently, there is a wealth of data on many water quality parameters that may help in achieving the goal of sustainable use of drainage water.

Agricultural drainage water in Upper Egypt is discharge back to the Nile. Thus, it is mixed with Nile water and becomes part of the flow to the Delta. This slightly affects the quality of the Nile water as its salinity increases from 250 ppm at Aswan to 350 ppm near Cairo. The quantity of drainage water from Upper Egypt is relatively small and is estimated by about 2 billion m3 per year. On the other hand, the drainage system in the Delta is rather intensive. It serves a gross area of 4.72 million acres out of the 7.2 million acres of agricultural lands in Egypt. The main open drains dispose their water into the Mediterranean and the coastal lakes. However, there is a few numbers of drains that still discharge into the two Nile branches (Rosetta and Damietta branches).

A network of fixed measuring stations on the key points of the drainage system was established in the late 1970s (Amer and de Ridder, 1989). Since then the system has been continuously maintained and upgraded to furnish reliable measurements. The measuring sites are located at the outlets of drainage catchments whether it is a pumping station which lifts water from a secondary drain into a main drain, or from a branch drain into a secondary drain, intermediate check point along the open main drains and at reuse pumping stations.

2.1 Existing monitoring program for water quality

The specific objectives of drains monitoring are to quantify the seasonal variation of drainage water quality in relation to water reuse. It is also intended to identify changes in water quality due to contamination by different human activities including domestic, industrial and agricultural activities. In addition, identification and quantification of contaminants and their temporal and spatial distribution are required to consider proper mitigation measures for quality improvement.

The Drainage Research Institute (DRI) of the National Water Research Center (NWRC) has been entrusted with all activities related to water quality monitoring of the drainage network since the 1980s. Comprehensive work has been carried out to identify the significant pollutants of drainage water and their concentrations. The spatial distribution of pollutants is also considered when selecting the network of monitoring locations in addition to determination of a proper monitoring frequency for the effective management of water quality. The monitoring locations were determined at all reuse pump stations, at drain outfalls into the northern lakes and the Mediterranean, as well as locations related to critical waste dumping. The monitoring frequency was selected to be on monthly basis. The monitored parameters are categorized into six categories representing the physical characteristics, oxygen budget, nutrients, major ions, heavy and trace metals, and biocides. The parameters within each category are displayed in Table 2.

Table 2 Categories of monitored parameters

<table>
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<tr>
<th>Category</th>
<th>Parameters</th>
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</table>

http://library.wur.nl/ebooks/drainage/drainage_cd/1.3%20aw%20%20m_i.html (2 of 9) 26-4-2010 12:11:33
Physical | temperature, ph, turbidity, color, odor
---|---
Oxygen budget | DO, BOD, COD
Nutrients | nitrogen, phosphorus, organic carbon
Major ions | anions and cations: Na, K, Ca, Mg, CO3, HCO3, SO4, Cl
Heavy and trace metals | Fe, Cu, Mn, Zn, Cd, B, Pb
Biocides | herbicides, pesticides, anionic detergents

Analyzing previously collected water quality data, we can conclude that:

- Data and information on the state of water quality is very limited and does not provide an overall coherent picture,
- There are gaps in geographic coverage of water quality monitoring,
- Data on conventional pollutants are available but are extremely sparse for the more toxic pollutants, and
- The monitoring efforts are fragmented among several agencies following different ministries.

3 Case study description

The Umoum drain catchment in Western Delta was selected as the case study for the application of the proposed probabilistic approach. Figure 1 illustrates the schematic representation of Umoum Drain system. The Umoum main drain system consists of several small catchments served by seven drainage lifting pump stations. There is currently one reuse pump station (Mariout Khalt Pump Station, P.S.) diverting water from the drain into Nubaria canal. The eight pump stations are exhibited in Figure 1.

Figure 1 Schematic representation of Umoum Drain System

This paper aims at identifying the potential of drainage water reuse at Mariout Khalt P.S. by analyzing the water quality data of Shersheira and Truga pump stations located upstream Mariout Khalt P.S. Shersheira pump station serves an irrigated area of 56,730 ha, while Truga pump station serves 43,080 ha. The data available at these two stations are the monthly discharge, electric conductivity, major cations and anions concentrations for the period from 1980 till 2000. The data also included EC and TDS concentrations for the same period. Figure 2 shows the average monthly concentrations of cations in milligram per liter (mg/l) at Shersheira pump station for the month of July during the period 1980 to 2000. The figure shows wide variations for the different concentrations of cations from one year to the other. However, it is clear that sulphates and chlorides have the highest concentrations among the other cations during the month of July, while carbonates have the lowest concentrations.
4 Proposed statistical analysis approach

Ross (1987) stated that the science of statistics deals with drawing conclusions from observed data. This means that by selecting a suitable number of samples from a certain population and analyzing them, some conclusions can be drawn. Statistics plays a significant role by providing rules and guidelines for planning and management of water resources. As mentioned before, water quality data has been collected through an extensive network of monitoring locations in the Nile Delta. Nevertheless, this data is of no use unless appropriate analysis is performed to identify temporal and spatial trends for the parameters of major concern when planning for reuse. It is also important to investigate relationships among different parameters to be able to predict the different impacts on the environment.

Table 3 lists some of the basic monthly statistics for four selected parameters at Shersheira pump station. The selected statistics are the maximum value, minimum value, average, standard deviation and skewness. The parameters considered are the total dissolved solids, Sodium, Chloride, and Bicarbonate.
PROBABILISTIC ANALYSIS OF DRAINAGE WATER QUALITY FOR SUSTAINABLE REUSE IN AGRICULTURE

The software provides the distribution to water quality time series. Therefore, the time series of the selected parameters were imported into the software and the "AUTOFIT" was applied to the monthly water quality data at the two locations. The goodness of fit of the distribution was examined using the Chi-square test and the Kolmogorov-Smirnov test. It was found out that the lognormal distribution performed better with respect to the calculated test values at 95% confidence level. The software calculates a test value in each case and examines it against a specified value under assumption of a certain confidence level and ranks the different distributions for their appropriateness accordingly.

Water quality variables have been classified as stochastic process as any water quality variable exhibits random behavior in both time and space (Sanders et al., 1990). In addition, Sanders et al. (1990) also stated that water quality time series have been identified among the most complex time series. A useful approach to data analysis is to analyze and establish probability distribution functions for the various water quality variables. Yet, one has to select a limited number of water quality random variables in order to appropriately describe the water quality aspects of a particular water body.

In order to analyze a set of data, a probability distribution is chosen to fit the data and represent the population from which the data arose (Wadsworth, 1989). When water quality data are interpreted in terms of a probability of a location being in violation of its standards with respect to concentration of a certain parameter, the uncertainty of the chosen distribution is incorporated. Using this procedure one can determine the probability of violating water quality standards for appropriate reuse at a specific location in a certain month instead of plotting the time series and checking their deviation from these standards.

Ayer and Westcot (FAO, 1985) reported ranges of values of concentration for some water quality parameters for the water to be used for agricultural purposes. They classified three groups of irrigation water based on salinity, sodicity, toxicity and miscellaneous hazards. These general water quality classification guidelines help in identifying potential crop production problems associated with the use of non-conventional water resources. For example, high sodium content in irrigation water may also affect certain crop physio-chemical properties that reduce soil permeability and aeration creating unsuitable environment for plant growth (Abdel-Dayem, 1999). The guidelines define three degrees of restriction on irrigation water use: none, slight to moderate, and severe restrictions. Table 4 shows the levels of some parameters including the concentration of electric conductivity (EC), total dissolved solids (TDS), Sodium (Na), Chloride (Cl), Boron (B), Nitrate-nitrogen (NO3-N), and Bicarbonate (HCO3).

| Avg. | 8.77 | 7.40 | 6.02 | 6.84 | 6.87 | 6.57 | 1.04 | 7.65 | 6.39 | 5.97 | 6.28 | 11.74 | 8.37 |
| Skew. | 3.60 | 8.73 | 3.96 | 3.02 | 2.78 | 2.88 | 5.13 | 3.60 | 2.62 | 3.71 | 2.29 | 3.10 |
| Bicarbonate | Max. | 8.37 | 9.11 | 7.37 | 6.63 | 7.17 | 7.32 | 7.84 | 6.43 | 6.08 | 7.24 | 6.60 | 6.74 |
| Min. | 0.91 | 0.93 | 1.09 | 0.86 | 0.84 | 1.02 | 1.04 | 1.12 | 1.08 | 1.10 | 1.10 | 1.18 |
| Avg. | 3.71 | 4.37 | 3.86 | 3.57 | 3.70 | 3.78 | 4.07 | 3.92 | 3.68 | 3.83 | 3.65 | 3.65 |
| Std. Dev. | 1.87 | 1.81 | 1.61 | 1.26 | 1.42 | 1.61 | 1.87 | 1.56 | 1.41 | 1.59 | 1.46 | 1.18 |
| Skew. | 0.85 | 0.69 | 0.35 | 0.37 | 0.48 | 0.48 | 0.32 | 1.15 | 0.05 | 1.56 | 0.50 |

| Table 4 Guidelines for interpretation of water quality for irrigation (FAO, 1985) |
|---|---|---|---|
| Potential irrigation problem | Units | Degree of restriction on use |
| | | None | Slight to moderate | Severe |
| Salinity | EC | dSm/m | <0.7 | 0.7-3.0 | >3.0 |
| | TDS | mg/l | <450 | 450-2000 | >2000 |
| Specific ion toxicity | Na | meq/l | <3 | 3-9 | >9 |
| | Cl | meq/l | <4 | 4-10 | >10 |
| Miscellaneous effects | NO3-N | mg/l | <5 | 5-30 | >30 |
| | HCO3 | meq/l | <1.5 | 1.5-8.5 | >8.5 |

5 Analysis and discussion

BESTFIT is simple statistical software that has been selected to be applied in the current analysis. The software is used to fit a probability distribution to the water quality data of each parameter for every month at each pump station. The software allows for the identification and fitting of more than 20 recognized probability distributions and investigates all of them with respect to the available data.

BESTFIT examines the goodness of fit for each probability distribution by three tests; the Chi-square test, Kolmogorov-Smirnov test, and Anderson-Darling test. The Chi-square test is typically used to test whether or not the data fit a particular distribution without specifying the parameters of this distribution, while Kolmogorov-Smirnov test, which is a more powerful test, requires the specification of the distribution parameters. The software calculates a test value in each case and examines it against a specified value under assumption of a certain confidence level and ranks the different distributions for their appropriateness accordingly.

The software also determines the basic statistics for each of the water quality parameters as well as estimates the parameters of each probability distribution. The software also provides a capability for splitting the data into 10 categories and determines the non-exceedance probability for each category. Thus, it allows for the identification of specific values that corresponds to a given percentiles.

The analysis starts by calculating the basic statistics of some selected water quality parameters to indicate a set of probability distributions that may be applicable. It has been recommended to fit either a normal or a lognormal probability distribution to water quality time series. Therefore, the time series of the selected parameters were imported into the software and the "AUTOFIT" was applied to the monthly water quality data at the two locations. The goodness of fit of the distribution was examined using the Chi-square test and the Kolmogorov-Smirnov test. It was found out that the lognormal distribution performed better with respect to the calculated test values at 95% confidence level. The software provides the...
non-exceedance probabilities corresponding to the water quality standards provided in FAO (1985). The exceedance probability was determined.

Figure 3 exhibits the non-exceedance cumulative probability for the selected lognormal distribution applied to the data on the concentration of Chloride for the month of December. The figure also allows for the evaluation of the non-exceedance probability corresponding to the standard level of concentration of Chloride of 10 mg/l. Concentrations greater than this value may cause severe negative impacts in agriculture when the drainage water is used for irrigation. The non-exceedance probability corresponding to that level is 15.5%.

The exceedance probability of the concentration of a certain parameter to exceed the standard is determined for each month. For this exceedance probability to be high means that irrigation with this type of water would have high risk for negative impacts on crop production and soil conditions. The process is repeated for all months and for the selected parameters. It was found out that the exceedance probability of the sodium to violate the standard level is always greater than 95%.

Figure 4 presents the monthly exceedance probability of three water quality parameters; Total dissolved solids (TDS), Chloride, and Bicarbonate at Shersheira Pump Station for the 12 months. It is clear from the figure that Chloride has the highest exceedance probability throughout the year. Nevertheless, it drops in the summer months of May and July. Bicarbonate has the lowest exceedance probability of standards violation meaning low threat to crop production. The exceedance probability of TDS has a wider range of variation between 10% and 70%.
Figure 4  Monthly exceedance probability of total dissolved solids (TDS), Chloride (Cl), and bicarbonate (HCO3) at Shersheira Pump Station

Figure 5 displays the exceedance probabilities of the same three parameters at Truga Pump Station. The same pattern can be seen with Chloride having the highest exceedance probability, Bicarbonate having the lowest exceedance probability, and TDS having exceedance probabilities between 50% and 70%.

Figure 5  Monthly exceedance probability of total dissolved solids (TDS), Chloride (Cl), and bicarbonate (HCO3) at Truga Pump Station

Figure 6 exhibits a comparison between exceedance probabilities of TDS at both Shersheira and Truga pump stations where TDS concentrations at Truga are expected to violate the standards more often than TDS concentrations at Shersheira. It is also clear that in February and due to the low water requirement period, both parameters have the highest exceedance probability. This is the consequence of serving a larger irrigated area.

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Conclusion

The scarcity of water supplies, which are badly needed to meet the demands of the growing population, has given cause for innovative actions on the formulation of national development plan. Water planners and decision makers are being increasingly involved in devising ways to optimize the use of available water resources as well as augmenting the available supplies with non-conventional resources. In Egypt, the reuse of drainage water in irrigation has been adopted as a national policy since 1980s. However, due to the dumping of different types of wastes into the open drainage system, hazards associated with the reuse of drainage water have to be frequently monitored and accurately evaluated.

Agriculture has been recognized as a widespread non-point source of pollution. Even though irrigation systems in general are beneficial, they are also responsible for certain environmental hazard including water logging, soil degradation, contamination of surface and groundwater due to return flows, and spread of water borne diseases. The major effect of agricultural activities on water quality can be considered to be changes in salinity, deterioration of water quality due to agro-chemical use, and eutrophication of water bodies due to increase in nutrient loads.

In the case of water quality data and due to its high variability, one has to rely on long time series rather than one or two snap shots. Not only that but also a good deep analysis of such series is a must to draw proper conclusions on water quality status. Enhancing the field and lab investigation process by increasing the number of samples and the frequency of sampling may not eliminate the uncertainty associated with the potential of drainage water reuse. The suggested probabilistic approach accounts explicitly for this uncertainty related to wastewater quality resulting from various human activities rather than ignoring it. Based on the probability theory, all available information on concentration of various parameters has been utilized with almost no pre assumptions for their probability distribution functions (pdfs).

Seasonal variations in water quality are clear during some distinct time intervals year. The most identifiable periods are the winter closure, the winter and summer cropping periods and the intercrops fallow periods. The least drainage water flows into the system is during the closure period. On the other hand, the largest quantity is available during the summer, which includes the period of maximum irrigation water demands.

This paper has presented a new probabilistic approach for analysis of monthly water quality data. In this approach the probability of violating the allowable quality standards is identified rather than plotting water quality time series and checking their deviations from these standards. The standards used in this application are FAO standards for water reuse in irrigation. Building decisions on this probabilistic approach should be more convenient to decision makers and should eliminate their reluctance to adopt the deterministic estimates for potential reuse since water quality are highly variable. It should be noted that when Sodium data was fitted to both normal and lognormal probability distributions, the Sodium concentrations violated the standards 95% of the time. This approach allows that when the probability of standards violation is estimated very high, a decision of no reuse should be adopted.

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ABSTRACT

Recharge to the aquifer through seepage from irrigation canals is often quoted as one of the main causes for waterlogging in Pakistan. In the design of drainage systems to control this waterlogging, rules-of-thumb are often used to quantify the seepage from canals. This paper presents the option to use a groundwater model for a more detailed assessment. Groundwater models may assist in evaluating the effect of recharge reducing measures such as interceptor drains along irrigation canals and lining. These measures are commonly aimed at reducing the drainage requirement of adjacent agricultural lands.

In this paper an example is given of the application of a numerical groundwater model, aimed at assessing the effect of interceptor drainage and canal lining in the Fordwah Eastern Sadiqia project, being a typical and well-monitored location in Pakistan. The paper also presents references to other conditions.

The model was used to obtain a better insight in the key hydraulic parameters, such as the infiltration resistance of the bed and slopes of irrigation canals, the drain entry resistance of interceptor drains and the hydraulic conductivity of soil layers. The model was applied to assess the effectiveness and efficiency of interceptor drains under various conditions.

The results of the study show that the net percentage of intercepted seepage is too low to have a significant effect on the drainage requirement of the adjacent agricultural lands. Besides, the operation of the system, with pumping required, is often an added headache for the institution responsible for operation of the system. The marginal effect of interceptor drains and lining on the drainage requirement of adjacent agricultural land does not always justify the large investments involved.

It can be concluded that:

• Use of rules-of-thumb to estimate components of the water balance of irrigation systems in designing drainage can be very misleading;
• Interceptor drainage may cause induced seepage from irrigation canals, which is often an order of magnitude more than the net intercepted seepage;
• Interceptor drains and canal lining do not significantly reduce the drainage requirements, or in other words, cannot prevent the need for the installation of a drainage system.
• A numerical model can aid to evaluate proposed measures and strategies to alleviate water losses and drainage problems.

Relevant hydrological concepts and modelling parameters with respect to leakage from irrigation canals and interception by interceptor drains are presented in a separate paper.
1.1 Waterlogging and Salinization

In many countries, the introduction of irrigated agriculture has also resulted in negative side effects, such as increased water tables, waterlogging and salinization. These side effects are caused by a change in the local hydrology. Waterlogging and salinization are the result of altered water and salt balances in the root zone and subsoil.

Surface irrigation systems, generally, cause an increase of recharge to the subsoil. If this water is not adequately discharged by a natural or man-made drainage system, the water tables will rise and salts may accumulate. In irrigated areas, the following recharge sources require attention:

- (excess) precipitation;
- irrigation application surplus;
- leakage from irrigation canals;
- losses in the field distribution system and operational spills.

Obviously, the irrigation application should be narrowly matched with the climatic and crop requirements. The amount of excess irrigation water can be minimised, or rather optimised, through efficient irrigation methods, appropriate crop selection and -rotation, and good operational management. In the case of optimum irrigation practices, any occurring irrigation application surplus can be considered as an intentional recharge source, necessary for the leaching of salts. A man-made drainage system may be required to discharge the excess irrigation water (and salts).

The leakage from irrigation canals and losses in the field distribution system are an unintentional recharge source. They result in reduced irrigation efficiencies and increased operational costs, possibly with waterlogging in the irrigated areas and water shortages downstream.

The losses from the field distribution system and losses through spills can often be countered by using the appropriate irrigation equipment, and the proper installation and operation of the system. Leakage from canals involves –sometimes poorly understood– hydrological concepts, more complicated design aspects and, often, elevated cost for measures. This paper will, therefore, focus on leakage from irrigation canals.

1.2 Canal Leakage

In Pakistan, the recharge to the aquifer through leakage from irrigation canals is often quoted as one of the main causes for waterlogging. Various measures to control canal leakage have been proposed or implemented. These measures are either aimed at the prevention of leakage or at the mitigation of the negative impacts of leakage.

The main preventive measure against water losses through canal leakage is the lining of irrigation canals, which is, however, a costly measure. A possible mitigation measure is the installation of interceptor drains.

In Pakistan, interceptor drains have been installed in various systems. In addition to mitigating seepage from the irrigation canals, they were also aimed at reducing the drainage requirement in the irrigated fields served by the canals. The effectiveness of interceptor drains has, however, been subject of discussion. The objective of this paper is to provide a more accurate (and more decisive) assessment method to evaluate interceptor drainage and canal lining.

1.3 Assessment Methods

Several methods exist to assess the leakage from irrigation canals and the effectiveness of interceptor drains:

- Water balance studies;
- Field tests;
• Hydraulic calculations.

A constraint of canal leakage assessments through water balances is the (absolute) accuracy of the measuring devices. Measuring inaccuracies in the (generally large) inflow and outflow terms often result in a large relative error in the (relatively small) canal leakage component, although both the inflow and outflow may have been measured accurately (visualised in Figure 1).

Field tests mainly refer to infiltration tests, such as the "ponding test", in which the decrease of the water level in a controlled section of the canal is measured. As the groundwater flow pattern during the test is different from the flow pattern during normal operation, this method is, generally, rather tentative. Constant level ponding tests are more reliable, but they have the same disadvantages as water balance studies.

Hydraulic calculations can provide good results, if they are based on reliable data. For simple cases (or as a first estimate), infiltration from irrigation canals and interception by interceptor drains can be calculated with analytical methods. However, numerical methods have become more popular, given the broad availability of easy-to-use numerical modelling packages and their capacity to assess more complicated situations (incorporating spatial and temporal variability of parameters, heterogeneity, etc.).

1.4 Numerical Modeling
This paper presents the application of a numerical model to assess preventive and mitigating measures with respect to canal lining and interceptor drainage at the Interceptor Drainage Trial Site along the Malik Branch Canal in the Fordwah Eastern Sadiqia project, Pakistan. Advantages of numerical modelling are the possibility to quickly evaluate various measures or water management options, under different physical and hydrological conditions, which enables the selection of the most feasible measures and strategies to alleviate water losses and drainage problems.
Groundwater modelling to assess the effect of interception in the Fordwah Eastern Sadiqia project, Pakistan

Section 2 (“Methods and Materials”) presents a brief description of the area and a summary of the collected data. The most important details on the applied groundwater modelling package are given and, finally, the methodology to evaluate measures and scenarios is presented.

The model calculations have been conducted with the modelling package MODFLOW, being one of the most widely used groundwater modelling packages. The presented methodology is, however, in principle independent of the modelling software and can, therefore, also be applied with other modelling packages.

Background information on the hydrological concepts involved and the conversion of these concepts to model parameters (parameterisation) are presented in a separate paper (Jansen, 2003).

Section 3 presents the model calculations, which includes the implementation and calibration of the model and the simulation of various measures. Additional model calculations were made for other physical conditions (soil properties).

An evaluation and discussion of the results is presented in Section 4. Conclusions follow in Section 5.

2 METHODS AND MATERIALS

2.1 Brief Area Characterisation

The Fordwah Eastern Sadiqia (South) Project was the third major project in Pakistan in which interceptor drainage was installed. Pilot interceptor drains were installed along three main canals: Malik Branch, Hakra Branch and 3-R Khatan Distributary. Along with the interceptor drainage an extensive performance monitoring system was installed.

The numerical model has been applied for a section along the Malik Branch where a pilot interceptor drain had been installed. The area is representative in terms of physical setting and drainage problems, while extensive monitoring data allow for the verification of calculation results.

Figure 2 presents the layout of the Malik Branch Canal, the interceptor drain with the measuring points (manholes) and the groundwater observation wells. The Malik Branch Canal has a width of approximately 35 metres and a (design) water depth of approximately 2.5 metres. The average (long-term) water level in the canal outside the closure period ranges from (downstream) 163.4 to (upstream) 163.7 m. +MSL (=Mean Sea Level).

The interceptor drain was installed between October 1995 and March 1996. The drain has a total length of 1828 metres, divided in a northern section (upstream of the canal) of 685 m, and a southern section of 1143 m. Both sections discharge into a sump. The distance to the canal edge varies from approximately 45 to 60 m (60 to 80 m. to the canal centre line). The drain diameter varies from 20 centimetres (8 inch) to 25 centimetres (10 inch) at the sump. The average installation depth is (approximately) 2.7 metres (Niazi et al.; IWASRI, 1998).

The area is characterised by a thick phreatic aquifer, consisting of fine sands and loams. The hydraulic conductivity is in the order of 1 m/day (IWASRI, 1998).

2.2 Performance Monitoring

From 1994 to 1997 an extensive monitoring programme was executed. During 4 years the following data were measured on a regular basis:

- water levels in the irrigation canal (upstream and downstream);
- groundwater levels in the observation wells and some piezometers;
- drain discharges and water quality (13 times after drain installation; from March 1996 to June 1997);
In addition, a seepage measurement was executed by means of a ponding test during the closure period of January 1998 (IWASRI, 1998). The data were analysed to determine the relation between the irrigation canal, the groundwater and the interceptor drain. Special attention was paid to temporal trends, particularly the situation before and after the installation of the interceptor drains.

The data analysis showed that:

- The water level in the canal is very constant over the year (except for the closure period; see also Jansen, 2003);
- The response of the groundwater to changes in the water level of the canal is very direct;
- The average observed discharge of the interceptor drain is in the order 4.5 l/s. This is much less than the design discharge of 14 l/s (the difference is explained in [Jansen, 2003]).
- The installation of the interceptor drain did not cause significant changes in groundwater levels (see also Niazi et al.).

Figure 2  General location map with monitoring points

http://library.wur.nl/ebooks/drainage/drainage_cd/1.3%20jansen%20et%20al.html (5 of 17) 26-4-2010 12:11:35
Special attention was paid to investigate the temporal trends of the groundwater levels. For each East-West running profile and for each observation well both the monthly and the long-term averages were calculated for the periods before and after the drain installation (the data collected during the drain installation were not used for this assessment). No significant impact of the interceptor drain on the regional groundwater levels was observed. As an example, Figure 3 shows the average groundwater levels before and after drain installation at the central profile.

Figure 3 Impact of interceptor drain on long-term average groundwater table

2.3 Numerical Modeling

The model calculations have been conducted with the (pseudo-)3D groundwater modelling package MODFLOW\[^5\]. MODFLOW was developed by the U.S. Geological Survey and is nowadays one of the most widely used packages. The model is based on the finite-difference calculation technique and is capable to simulate the effects of wells, rivers, drains, and other groundwater recharge (or discharge) functions.

Various software packages are available, which integrate MODFLOW with tools that can simulate a specific feature of the hydrological system. Most of the available packages include an easy-to-use graphical user-interface and a wide variety of pre-and post-processing tools, which facilitate an efficient model implementation and easy analysis of results. Examples are PMWIN, GMS, GWVistas, Visual MODFLOW and numerous others. MODFLOW is public domain, but the supporting interface programs, generally, require a software license.

To assess the situation at the interceptor drainage trial site along the Malik Branch Canal no complicated model is required and any of the MODFLOW-based packages can serve. The modelling work included the following activities:

- Set-up of the model (schematisation, parameter definition);
- Calibration;
2.4 Measures & Scenarios
A properly calibrated and validated model can be used to evaluate all kind of measures and scenarios. For this assessment the effect of interceptor drainage and canal lining at the trial site along the Malik Branch Canal were evaluated. In addition, an assessment was made for interceptor drainage in areas with different soil characteristics, as the soil hydraulic properties are one of the most determining factors in drain design.

Three situations have been simulated:

- The existing situation. The phenomenon of induced seepage and the effect of interceptor drainage on the drainage requirement of the adjacent agricultural lands were also assessed.
- Canal lining. It was investigated whether canal lining would significantly reduce the drainage requirement of the adjacent agricultural lands.
- The existing layout of interceptor drainage in the case of other hydraulic properties of the soil.

2.5 Evaluation of Measures
In order to evaluate and compare the preventive and mitigating measures with respect to canal lining and interceptor drainage, it is required that logic and clear evaluation criteria ("indicators") be defined. Both the effectiveness and efficiency should be addressed.

The effectiveness of a measure refers to the degree that the objectives are met. The effectiveness is, therefore, mostly an engineering criterion: desired impacts of a measure should be maximised.

The efficiency of a measure refers to the ratio between the desired impacts of the measure and the required input (i.e. desired impact per cost unit). Efficiency, therefore, involves both engineering and financial criteria.

In this paper the effectiveness of measures will be assessed through the "net intercepted seepage". Figure 4 shows details on this concept (Bhutta et. al., 2000). The relative effectiveness is the net intercepted seepage as a percentage of the initial seepage.

It is noted that the drain discharge is not a suitable indicator, as a huge drain discharge does not necessarily imply that the seepage from the canal to the land decreases significantly. The introduction of interceptor drains will, generally, cause induced seepage from the canal (see also Bhutta et al., 2000; Jansen, 2003). This induced seepage should be subtracted from the drain discharge to obtain the net intercepted seepage (Figure 4).
The efficiency of the measure can be expressed as the ratio between the net intercepted seepage and the total canal seepage. This indicator thus incorporates the most important (unwanted) side effect of the measure (induced seepage).

Hence, an efficiency (and effectiveness) of 0 % means that all intercepted water is induced seepage and that the net seepage rates do not decrease. An efficiency of 100 % means that all initial seepage is intercepted. To illustrate the concepts effectiveness and efficiency, some hypothetical examples are given in Table 1.

Table 1 Calculation examples effectiveness and efficiency.

<table>
<thead>
<tr>
<th>Initial canal seepage (m$^2$/day)</th>
<th>Canal seepage after drain installation (m$^2$/day)</th>
<th>Drain discharge (m$^2$/day)</th>
<th>Effectiveness (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>0.1</td>
<td>1.0</td>
<td>1.0</td>
<td>100</td>
<td>10</td>
</tr>
<tr>
<td>0.1</td>
<td>0.5</td>
<td>0.45</td>
<td>50</td>
<td>10</td>
</tr>
<tr>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

3 APPLICATION OF NUMERICAL MODEL IN FORDWAH EASTERN SADIQIA (PAKISTAN)

3.1 Set-Up and Parameters

3.1.1 Geometry and schematisation
A regional numerical model was constructed, which included the entire area with the interceptor drain and the observation wells,
shown in Figure 2. Figure 5 presents the (lateral) boundaries.

The numerical model is a one-layer, phreatic model, covering an area of 18 km² (4.5 x 4.0 km) with 90000 grid elements. The size of the grid elements varies from 5 x 20 m. along the canal and drain (where steep hydraulic gradients can be expected, perpendicular to the canal) to 20 x 20 m near the edges of the model (Figure 5).

The impermeable base is assumed at approximately 12 metres below the ground surface, which is the bottom boundary of the model. As phreatic conditions were simulated, the upper boundary of the model consists of the (calculated) phreatic water table.

### 3.1.2 Hydraulic conductivity aquifer

In the model, a constant value of 1.0 m/day was used for the hydraulic conductivity of the aquifer, as no spatial variability was observed (see also IWASRI, 1998).

### 3.1.3 Canal hydraulic conductance \( (C_{CANAL}) \)

On the basis of the data from the monitoring programme, it could be concluded that the canal infiltration resistance, \( C_{CANAL} \), is very low; probably less than 1 day. The model calculations were made with \( C_{CANAL} = 0.1 \) days, which means that the canal hydraulic conductance, \( C_{CANAL} \), is 1000 m²/day (see also Jansen, 2003). Rather than trying to determine the exact value, a sensitivity analysis was executed, which showed that the calculation results are not sensitive for the canal infiltration resistance, if this parameter is less than approximately 10 days (see also Section 3.2).

Figure 6 (horizontal logarithmic scale) shows that both the canal leakage rate and the interceptor drain discharge are not very much influenced by (uncertainties in) the canal infiltration resistance (below approximately 10 days).
Figure 5  Model lay-out
3.1.4 Drain hydraulic conductance ($C_{\text{DRAIN}}$)

The hydraulic losses due to partial penetration of the drains were incorporated in the drain entry resistance. This means that the drain entry resistance is at least (see Jansen, 2003):

$$R_{\text{DRAIN}} = \frac{h}{Kd}$$

where:
- $h$ = Piezometric level in the aquifer [L]
- $H_{\text{DRAIN}}$ = Drain level (elevation of the drain) [L]
- $H_{\text{CANAL}}$ = Hydraulic head (water level) in the canal [L]
- $P_{\text{DRAIN}}$ = Wetted perimeter of drain [L]
- $L$ = Distance between the canal and drain [L]
- $K$ = Hydraulic conductivity of the aquifer [LT⁻¹]
- $d$ = Equivalent depth of groundwater flow [L]
- $C_{\text{DRAIN}}$ = Drain hydraulic conductance [L²T⁻¹]
- $L_{\text{DRAIN}}$ = Length of the drain segment (in model node) [L]

The drain entry resistance and drain hydraulic conductance (considering partial penetration) can be estimated from the layout of the canal and drain system, the monitoring data, and the model geometry, which are summarised in Table 2.
Table 2 Parameters for estimation of drain entry resistance

<table>
<thead>
<tr>
<th>Parameter:</th>
<th>Value:</th>
</tr>
</thead>
<tbody>
<tr>
<td>h - H\text{DRAIN}</td>
<td>≈ 2 m (on average)</td>
</tr>
<tr>
<td>L</td>
<td>≈ 45 m</td>
</tr>
<tr>
<td>K</td>
<td>≈ 1 m/day</td>
</tr>
<tr>
<td>H\text{CANAL} - H\text{DRAIN}</td>
<td>≈ 2.7 m</td>
</tr>
<tr>
<td>d</td>
<td>≈ 3.4 m. (calculated)</td>
</tr>
<tr>
<td>L\text{DRAIN}</td>
<td>20 m. (model grid length)</td>
</tr>
</tbody>
</table>

Substitution of these values in the equations gives:

\[ c_{\text{DRAIN}} \geq 7 \cdot P_{\text{DRAIN}} \text{ days}. \]
\[ c_{\text{DRAIN}} \leq 2.9 \text{ m}^2/\text{day}. \]

These values are first estimates. As other hydraulic losses than partial penetration losses occur in and near the interceptor drain, the actual value of \( c_{\text{DRAIN}} \) will be less than 2.9 \( \text{m}^2/\text{day} \).

3.2 Calibration and Sensitivity Analysis

The objective of the model calibration was to quantify the parameters that were not well known, yet having significant impact on the modelling results. During the calibration procedure, also the sensitivity of parameters was investigated.

3.2.1 Calibration method and parameters

Given the low sensitivity of the canal hydraulic conductance, not much attention was paid to this parameter (see also Section 3.1). The hydraulic conductivity of the aquifer was much better known than the drain hydraulic conductance and the groundwater recharge. Moreover, the role of the hydraulic conductivity of the aquifer was further investigated during the scenario calculations.

The calibration, therefore, focussed on:

- Drain entry resistance (incl. the effect of partial penetration);
- Net groundwater recharge from irrigated areas.

Given the constant water level in the canal (the closure period excepted) and the direct relation between the canal water level and the groundwater level, the groundwater system can be considered in steady-state (see also Jansen, 2003). The model was, therefore, calibrated for a steady-state situation, based on the following historical data:

- Drain discharge measurements (the average discharge being 4.445 l/s = 384 m\(^3\)/day; see Section 2.2);
- Groundwater levels of 38 observation wells. Only the data recorded after the installation of the interceptor drain were used (i.e. weekly groundwater measurements from April 1996 to November 1997).

3.2.2 Calibration results

The main results are:

- The drain hydraulic conductance is approximately 1.5 \( \text{m}^2/\text{day} \);
- The net groundwater recharge from irrigated fields is very low (in the order of only 0.02 mm/day, hence almost nil);
- Calculation results are very much influenced by the hydraulic conductivity of the aquifer, the drain hydraulic conductivity.
conductance and the groundwater recharge from irrigated areas;

- In the expected range of magnitude, the canal hydraulic conductance is not a sensitive parameter (See also Section 3.1).

The very low value of the (average) net groundwater recharge was also reported by (Saleem Bashir, 1995), who found that the recharge to groundwater did more or less equal the capillary rise. This might imply that the irrigated lands be subject to salinization. This issue has not been investigated, nevertheless requires further attention.

The drain discharge simulated by the calibrated model was 387 m$^3$/day.

### 3.3 Simulation of Measures and Scenarios

Once a groundwater model is properly calibrated, a further analysis of the hydrological system can be made, while also all kind of management scenarios can be evaluated. In this section, a few examples are given.

#### 3.4 Assessment of the Existing Situation (“Reference Situation”)

To allow for an easy evaluation of measures, the reference situation was defined, being the calibrated situation without any groundwater recharge from the adjacent fields.

##### 3.4.1 Net intercepted seepage

In the reference situation, the simulated infiltration from the irrigation canal amounted to 413 m$^3$/day (from the section along the interceptor drain). Without interceptor drain, the (calculated) leakage from the canal would be 60 m$^3$/day. This means that the net intercepted seepage is 34 m$^3$/day (namely: 60 − [413-387]), which is 57 % of the initial seepage. This means that the effectiveness of the drain is 57 %.

However, the efficiency of the system is only 8 %. This means that for each cubic meter seepage reduction, also more than 10 cubic meter of induced seepage need to be pumped. This is also shown in Figure 7.

##### 3.4.2 Use of interceptor drain for field drainage

The idea to use the interceptor drains to both intercept the canal leakage and to drain the adjacent irrigated land can easily be assessed by investigating the impact of increased groundwater recharge from irrigated fields (irrigation water excess). Table 3 presents the simulated relation between the irrigation water excess from the cultivated lands, the discharge of the interceptor drain and the canal leakage.
Figure 7  Simulated induced and net intercepted seepage; reference situation. [6]

Table 3  Relation between the irrigation water excess, drain discharge and canal leakage.

<table>
<thead>
<tr>
<th>Irrigation water excess (recharge) *) (mm/day)</th>
<th>Canal infiltration (m²/day) **)</th>
<th>Drain discharge (m²/day) **)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (= present situation)</td>
<td>0.29</td>
<td>0.22</td>
</tr>
<tr>
<td>0.1</td>
<td>0.16</td>
<td>0.24</td>
</tr>
<tr>
<td>0.2</td>
<td>0.10</td>
<td>0.27</td>
</tr>
<tr>
<td>0.3</td>
<td>0.03</td>
<td>0.30</td>
</tr>
</tbody>
</table>

*) Only applied on (cultivated) west bank of the canal, west of the interceptor drain.
**) Volumes per stretching meter of drain / canal (specific volumes).

The drain discharge does not increase proportionally with the groundwater recharge. In addition, the reduced canal leakage indicates that the drain cannot discharge all water originating from the irrigated lands and water tables between the canal and drain are also influenced. This indicates that the capacity of the aquifer is too small to discharge all excess irrigation water to the drain. The model indeed simulates elevated water tables, if the recharge increases to 0.1 mm/day or more.

Interceptor drains, therefore, do not significantly reduce the drainage requirements, or in other words, cannot prevent the need for the installation of a drainage system.

3.5  Lining of Irrigation Canal

For the investigated Fordwah Eastern Sadiqia (South) Project, the model calculations showed that the lining of the irrigation canal obviously reduces the leakage, but does not eliminate the need of a field drainage system.
It was investigated whether a single drain along the edge of the cultivated land would suffice. Table 4 shows that the discharge by such a drain corresponds to the drainage requirements of a strip of cultivated land of approximately 1400 metres (along the drain). However, the model calculations also show that elevated water tables can be expected in the cultivated lands, away from the drain, if the recharge increases to 0.1 mm/day or more. It can, therefore be concluded, that neither canal lining alone, nor canal lining with a single drain along the fields will significantly reduce the drainage requirement of the agricultural lands.

**Table 4  Simulated drain discharge with canal lining and significant irrigation water excess.**

<table>
<thead>
<tr>
<th>Lining:</th>
<th>Irrigation water excess (recharge) (mm/day)</th>
<th>Canal infiltration (m²/day)</th>
<th>Drain discharge (m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No canal lining</td>
<td>0 (= present situation)</td>
<td>0.29</td>
<td>0.22</td>
</tr>
<tr>
<td>Canal lining</td>
<td>0.1</td>
<td>0</td>
<td>0.14</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>0</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>0</td>
<td>0.41</td>
</tr>
</tbody>
</table>

### 3.6 Effect of Aquifer Hydraulic Properties

The simulation of the impact of the hydraulic properties of the aquifer requires some attention, as the hydraulic resistance due to partial penetration is dependent of the hydraulic conductivity of the aquifer. The methodologically correct approach would be to split the value of the drain hydraulic resistance into a portion that accounts for the partial penetration losses and a portion that accounts for all other drain hydraulic losses. Note that the latter are (in principle,) not dependent of the aquifer properties, but merely on the drain properties, whereas the hydraulic resistance due to partial penetration is inversely proportional to the hydraulic conductivity of the aquifer, \( K \) (see Jansen, 2003).

For the assessment of the impact of the aquifer properties it was assumed that the drain entry resistance was entirely determined by the partial penetration losses (hence the drain design and installation were optimum).

Table 5 presents the simulated relation between the hydraulic properties of the aquifer, the effectiveness and efficiency of the interceptor drainage system.

It can be concluded that for the applied drain design (in terms of depth, diameter and distance from the canal), the effectiveness is in the order of 60 %, almost irrespective of the aquifer properties. This means that the net intercepted seepage is approximately 60 % of the original seepage.

The efficiency of the interceptor drain is, however, low for all situations. Less than 10 % of the discharged water is net intercepted seepage water, the rest is induced seepage.

**Table 5  Relation between aquifer hydraulic conductivity, effectiveness and efficiency of interceptor drains.**

<table>
<thead>
<tr>
<th>K (m/day)</th>
<th>Canal infiltration (m²/day)</th>
<th>Induced canal seepage (m²/day)</th>
<th>Net intercepted seepage (m²/day)</th>
<th>Drain discharge (m²/day)</th>
<th>Effectiveness (%)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.04</td>
<td>0.009</td>
<td>0.001</td>
<td>0.001</td>
<td>0.009</td>
<td>60</td>
<td>8.2</td>
</tr>
<tr>
<td>0.1</td>
<td>0.023</td>
<td>0.002</td>
<td>0.002</td>
<td>0.021</td>
<td>55</td>
<td>7.8</td>
</tr>
<tr>
<td>0.2</td>
<td>0.046</td>
<td>0.004</td>
<td>0.004</td>
<td>0.043</td>
<td>55</td>
<td>7.9</td>
</tr>
</tbody>
</table>
4 DISCUSSION AND CONCLUSIONS

A numerical model can aid to evaluate the effectiveness and efficiency of measures and strategies to alleviate water losses and drainage problems. A numerical model can also be used to better quantify the components of the water balance, as the use of rules-of-thumb can be very misleading.

The effectiveness of a system of interceptor drains can be improved by an optimum design, in terms of distance to the irrigation canal, drain depth and, to a lesser extent, diameter. The depth and distance to the canal are the most critical design parameters (see also Jansen, 2003).

The costs of increased effectiveness are, however, often elevated. For the Fordwah Eastern Sadiqia (South) Project, more than 10 cubic meter of induced seepage need to be pumped for each cubic meter of net intercepted seepage. An optimum design may improve the efficiency, however interceptor drains in thick phreatic aquifers (with direct hydraulic contact with the aquifers) will always cause large volumes of induced seepage from the irrigation canal, up to an order of magnitude more than the net intercepted seepage. Under such conditions, it will be very difficult to realise more acceptable efficiencies.

In flat areas, generally, pumping is required, which is an added headache for the institution responsible for operation of the system. In the flat areas of the Gangetic Plain (Pakistan and Northern India) a system with pumps and sumps (that need to be operated 24 hours per day) is unavoidable.

It can finally be concluded that interceptor drains and canal lining do not significantly reduce the drainage requirements, or in other words, cannot prevent the need for the installation of a drainage system.

5 REFERENCES


[2] H.C. Jansen and W. Wolters, Alterra-ILRI: International Institute for Land Reclamation and Improvement/ILRI, PO Box 47, 6700 AA Wageningen, The Netherlands, Tel. + 31 317 495549, Fax. + 31 317 495590, e-mail: ilri@ilri.nl

[3] M.N. Bhutta and I. Javed, IWASRI: International Waterlogging and Salinity Research Institute, Near Muhammadpura Village, PO Thokar Niaz Beg,
In a pseudo-3 dimensional model, the groundwater flow is strictly horizontal in aquifers, while the exchange of groundwater between aquifers at various depths occurs by (strictly) vertical flow through semi-confined layers.

The volumes refer to the canal section along the interceptor drain (1828 metres).
GROUNDWATER MODELLING TO ASSESS THE EFFECT OF INTERCEPTOR DRAINAGE AND LINING

HYDROLOGICAL AND MODELLING CONCEPTS

H.C. Jansen

ABSTRACT

Recharge to the aquifer through seepage from irrigation canals is often quoted as one of the main causes for waterlogging in Pakistan. In the design of drainage systems to control this waterlogging, rules-of-thumb are often used to quantify the seepage from canals. This paper presents the option to use a groundwater model for a more detailed assessment. Groundwater models can assist in evaluating the effect of recharge reducing measures such as interceptor drains along irrigation canals and lining. These measures are commonly aimed at reducing the drainage requirement of adjacent agricultural lands.

In this paper the hydrological concepts with respect to leakage from irrigation canals and interception by interceptor drains are presented. A good understanding of these concepts is critical for the proper application of numerical groundwater models and for the correct quantification of model parameters. Key hydraulic parameters are the infiltration resistance of the bed and slopes of irrigation canals, the drain entry resistance of interceptor drains, hydraulic conductivity and hydraulic resistance of soil layers and equivalent depth of groundwater flow.

The paper shows how the hydrological concepts can be transferred into model parameters for the widely used groundwater modelling package MODFLOW. Most concepts, however, can also be applied in other modelling packages.

The presented hydrological and modelling concepts have been applied in a numerical model for the Fordwah Eastern Sadiqia project, Pakistan. This model application is reported in a separate paper.

1 Introduction

1.1 Canal leakage

In Pakistan, the recharge to the aquifer through leakage from irrigation canals is often quoted as one of the main causes for waterlogging. Various measures to control canal leakage have been proposed or implemented. These measures are either aimed at the prevention of leakage or at the mitigation of the negative impacts of leakage.

The main preventive measure against water losses through canal leakage is the lining of irrigation canals. A possible mitigation measure is the installation of interceptor drains. Interceptor drains have been installed in various projects. In addition to mitigating seepage from the irrigation canals, they were also aimed at reducing the drainage requirement in the irrigated fields served by the canals.

The effectiveness of interceptor drains has, however, been subject of many discussions. In the design of these drainage systems, rules-of-thumb are often used to quantify the seepage from canals. In previous studies it was recommended that a groundwater model be used for a more detailed assessment (Saleem Bashir et al., 1995). Groundwater models can assist in evaluating the effect of recharge reducing measures such as interceptor drains along irrigation canals and lining.
1.2 Groundwater model

In this paper the hydrological and modelling concepts with respect to leakage from irrigation canals and interception by interceptor drains are presented. A good understanding of these concepts is critical for the proper application of numerical groundwater flow models and for the correct quantification of model parameters.

Reference is made to the use of MODFLOW, however, the presented hydrological and modelling concepts are also applicable for other modelling packages.

The application of a numerical model to assess preventive and mitigating measures with respect to canal lining and interceptor drainage in a selected (pilot) area in Pakistan is presented in a separate paper (Jansen et al, 2003).

In this paper, interceptor drainage in flat areas with phreatic aquifers is addressed, which are common in the Indo Gangetic Plain (Pakistan and Northern India). Section 2 deals with some theoretical concepts on the hydrology of interceptor drains and canal lining. The application of these concepts in a numerical model (i.e. the parameterisation = conversion of concepts to model parameters) is presented in Section 3.

An example of the application of the theoretical concepts and field data to obtain model parameters is presented in Section 4. Conclusions follow in Section 5.

2 HYDROLOGICAL CONCEPTS OF CANAL LEAKAGE AND INTERCEPTOR DRAINS

2.1 Hydraulic Resistance

Water leaking from an irrigation canal into the aquifer, from where it subsequently flows to an interceptor drain, which eventually discharges the water, encounters hydraulic resistance on its way. The hydraulic resistance results in a loss of hydraulic head between the water level in the canal and the water level inside the drain.

The total hydraulic resistance between the canal and the drain can be subdivided in:

- canal infiltration resistance (aquifer entry resistance) (resulting in head loss $\Delta_1$);

- aquifer resistance (resulting in $\Delta_2$);

- drain entry resistance (resulting in $\Delta_3$).

These three components together determine the canal leakage and the flow of groundwater to the interceptor drain. This is schematically shown in Figure 1. Note that this scheme assumes direct hydraulic contact between the canal and the saturated aquifer. The case of an (easier to assess) unsaturated zone below the canal bed is discussed below.
Not only the hydraulic resistances and head losses determine the groundwater flow, but also the “wetted surfaces”. This can be represented by the following equations (assuming 2-dimensional groundwater flow, i.e. the flow direction is perpendicular to the canal and drain):

\[ q = P_{\text{CANAL}} \times \Delta_1 / c_{\text{CANAL}} \]  
\[ q = D_{\text{AQ}} \times \Delta_2 / c_{\text{AQ}} \]  
\[ q = P_{\text{DRAIN}} \times \Delta_3 / c_{\text{DRAIN}} \]

where:  
- \( q \) = Groundwater flow \([L^2T^{-1}]\);  
- \( P_{\text{CANAL}} \) = Wetted perimeter of the canal (portion that causes flow to the drain) \([L]\);  
- \( P_{\text{DRAIN}} \) = Wetted perimeter of the drain \([L]\);  
- \( D_{\text{AQ}} \) = Average thickness of the aquifer, which contributes to groundwater flow to the drain \([L]\) (further details will be given below);  
- \( \Delta_1 \) = Loss of hydraulic head in the canal bed \([L]\);  
- \( \Delta_2 \) = Loss of hydraulic head in the aquifer \([L]\);  
- \( \Delta_3 \) = Loss of hydraulic head in (and near) the drain \([L]\);  
- \( c_{\text{CANAL}} \) = Canal infiltration resistance \([T]\);  
- \( c_{\text{AQ}} \) = Hydraulic resistance aquifer \([T]\);  
- \( c_{\text{DRAIN}} \) = Drain entry resistance \([T]\).

The canal infiltration resistance is caused by a thin layer of fines accumulated on the canal bed and by any soil compaction, for example due to reed growth. The aquifer resistance is dependent on the hydraulic conductivity (permeability) of the aquifer material and the distance between the canal and the drain. The drain entry resistance is caused by various factors, which will be addressed in the following section.

### 2.2 Drain entry Resistance
Groundwater approaching a drain will encounter hydraulic resistance before entering the pipe (or open drain). The drain entry resistance, $c_{\text{DRAIN}}$, can be considered as the cumulative effect of various hydraulic losses, being the result of:

- Flowline contraction (as pipe drains have limited open area to ensure sufficient structural strength. Flowline contraction can be aggravated by clogging);
- Drain envelope resistance;
- Soil compaction occurred during installation;
- Turbulent flow in and near the drain openings;
- Friction in drain openings;
- Limited discharge capacity.

In addition, the drain entry resistance may account for reduced groundwater flow to the drain due to *partial penetration*, i.e. if the drains are installed well above the base of the aquifer. The partial penetration of drains results that the groundwater flow to the drains is confined to a limited portion of the aquifer (further details are given below). It may be argued whether the partial penetration of drains should be accounted for by the drain entry resistance or by the aquifer resistance, as the partial penetration losses are both determined by the drain design and the aquifer properties (see below). For modelling purposes it is, however, more practical to consider the partial penetration losses as drain hydraulic losses.

If the drains have been properly designed and installed, the drain hydraulic losses should be small, except for the partial penetration losses, which are to a large extent determined by the physical environment. Especially in the case of a thick aquifer, the effect of partial penetration can be considerable.

### 2.3 Partial Penetrating Drains (Thick Aquifers)

In the case that an interceptor drain is installed in a thick aquifer, it should be realised that the (average) thickness of the aquifer contributing to groundwater flow to the drain ($D_{\text{AQ}}$ in Equation (2)) can significantly differ from the aquifer thickness (see Figure 2). In such a situation, the Dupuit-Forchheimer Equation for groundwater flow in phreatic aquifers (often applied in numerical models) is not valid.

*Figure 2  Groundwater flow to interceptor drain in thick aquifer.*
The groundwater flow should be calculated considering only the aquifer thickness that contributes to the groundwater flow to the drain (in Figure 2 indicated by $D'$, being the difference between the lower dotted line = bottom limit of flow- and the phreatic groundwater level = upper limit of flow-).

In the case of negligible canal infiltration and drain entry resistances, the following equation may be used:

$$ q = \frac{K \cdot (H_{\text{CANAL}} - H_{\text{DRAIN}})^2 + 2 \cdot K \cdot d \cdot (H_{\text{CANAL}} - H_{\text{DRAIN}})}{2 \cdot L} $$  \hspace{1cm} (4)

where

- $q$ = Specific groundwater flow \ [L$^{2}$T$^{-1}$]
- $K$ = Hydraulic conductivity of the aquifer \ [LT$^{-1}$]
- $H_{\text{CANAL}}$ = Hydraulic head (water level) in the canal \ [L]
- $H_{\text{DRAIN}}$ = Drain level (elevation of the drain) \ [L]
- $d$ = Equivalent depth of groundwater flow \ [L]
- $L$ = Distance between the canal and drain \ [L]

This equation adds the phreatic groundwater flow above the drain (according to the Dupuit-Forchheimer Equation) to confined groundwater flow below the drain down to the equivalent depth of groundwater flow (Darcy Equation). This equation is similar to the Hooghoudt Equation for parallel, partial penetrating drains (drains well above the base of the aquifer) with an infinite extension.

The equivalent depth according to Hooghoudt can be calculated as (Ritzema et al, 1994):

$$ r_0 = \frac{r_0}{D} $$ \hspace{1cm} (5)

where

- $r_0$ = Drain radius \ [L]
- $D$ = Thickness of aquifer below drain level \ [L]

This Hooghoudt Equation is valid for groundwater flow to drains with recharge from the top (precipitation or irrigation) or bottom.
(deep upward seepage) over a distance \( L \). Given the analogous phreatic surface and groundwater flow pattern, it is assumed that the same equivalent depth can be used for groundwater flow with lateral recharge from leaking canals. The distance \( L \) may not be the exact physical distance between the canal and drain, but should rather be referred to as “hydraulic distance”. The canal infiltration resistance \( c_{\text{CANAL}} \) can be accounted for by simply increasing the hydraulic distance \( L \) between the canal and drain.

2.4 Unsaturated flow

If there is no direct hydraulic contact between the canal and aquifer, i.e. in the case of an unsaturated zone below the canal bed, Equation (1) can still be applied, but the meaning of the symbol \( \Delta_1 \) changes slightly (see Figure 3):

\[
q = P_{\text{CANAL}} \times \frac{\Delta_1}{c_{\text{CANAL}}}
\]  

(1a)

where \( \Delta_1 \) = Water level in the canal above the canal bed [L].

It is also noted that the canal infiltration resistance \( c_{\text{CANAL}} \) is calculated in a different way:

Saturated zone below canal bed: \( c_{\text{CANAL}} = \frac{D_{\text{CANAL}}}{K_{\text{CANAL}}} \)  
(6)

Unsaturated zone below canal bed: \( c_{\text{CANAL}} = \frac{\Delta_1}{K_{\text{CANAL}}} \)  
(7)

where: \( D_{\text{CANAL}} \) = Thickness of confining layer on the canal bed [L];  
\( K_{\text{CANAL}} \) = Hydraulic conductivity of confining layer on the canal bed [LT\(^{-1}\)].

In the case of an unsaturated zone under the canal bed, the infiltration from the canal is a process that is hydraulically isolated from the groundwater flow towards the drain. This implies that the impact of canal lining is independent of the aquifer
characteristics. For the same reason, the installation of an interceptor drain will not cause an increase of canal leakage.

The existence of an unsaturated zone under the canal bed does not impose restrictions to the application of most numerical groundwater models, including MODFLOW. Obviously, a modelling package that cannot simulate an unsaturated zone under the canal should be avoided.

### 2.5 Impact of Canal Lining and Interceptor Drains

It is obvious that the maximum flow to the interceptor drain occurs if the canal infiltration resistance and the drain entry resistance are both minimal. The groundwater gradient is then maximal and the volume of groundwater flow is principally determined by the hydraulic conductivity and thickness of the aquifer, the distance between the canal and drain and the water levels in the canal and drain (according to Equation (4)).

The lining of the canal will result in a large canal infiltration resistance ($c_{\text{CANAL}}$) and, therefore, a decrease of groundwater flow through canal leakage. However, whether or not the lining of the canal will indeed have the desired impact, depends on the relative contributions of the distinctive hydraulic resistances $c_{\text{CANAL}}$ and $c_{\text{AQ}}$ (together with the "wetted surfaces" $P_{\text{CANAL}}$ and $D_{\text{AQ}}$) to the total hydraulic resistance between the canal and the drain. For example, in the case that the aquifer is composed of material with a relatively low hydraulic conductivity, $c_{\text{AQ}}$ is large and canal lining may not have much effect, as in such a situation the aquifer will be the limiting factor for groundwater flow, not the canal bed.

Another implication is that the installation of an interceptor drain will always induce additional canal leakage, as the hydraulic gradients between the canal and drain increase. Whether this induced canal leakage is significant or not, also depends on the relative contributions of the distinctive hydraulic resistances to the total hydraulic resistance. Especially in the case of a permeable aquifer, the induced leakage may be large. In such a situation the canal infiltration resistance is, often, also low.

Finally, it can be seen that a poor-functioning drain (large $c_{\text{DRAIN}}$) may result that infiltrated groundwater moves across the drain (if the groundwater gradient expands further land inward), causing waterlogging inland.

It can be concluded that all three components of the hydraulic resistance between the canal and the drain have to be assessed before the most feasible solution for waterlogging problems can be identified. A numerical model can aid in this assessment. The numerical model should be able to incorporate the canal infiltration resistance, the drain entry resistance and the aquifer. In Section 3 further details are presented on the well-known MODFLOW modelling package.

### 3 THE USE OF A Numerical model

For the assessment of canal leakage and interceptor drainage, the MODFLOW-based (finite difference) groundwater modelling package PMWIN can be used. Advantages of this package are the relatively easy applicability and its common use (MODFLOW is used world-wide). The MODFLOW calculation routine is public domain. PMWIN (and other MODFLOW based packages) can simulate canals and drains, although some conversion is needed to transfer the hydrological concepts (presented in Section 2) into the model parameters. This parameterisation process is shown in the following.

#### 3.1 Simulation of canal infiltration resistance

Most groundwater modelling packages are provided with tools to simulate the interaction between the aquifer and surface water. This interaction can be simulated through individual watercourses or by "lumped (infiltration or drainage) systems", which principally simulate q-h relations for a certain area (relations between the piezometric level and the aquifer discharge to the surface water system). The lumped approach is not suitable for interceptor drains and will, therefore, not be discussed.
The infiltration and drainage by individual surface watercourses can be simulated by applying the principles laid down in Equations (1) and / or (3). However, various methods exist to convert these equations into the model parameters. A correct and easy-to-use method would be to prescribe the wetted perimeters and the infiltration and drainage resistances in the model. In MODFLOW, however, these parameters have been lumped to the "hydraulic conductance of the canal bed" and the "drain hydraulic conductance". These parameters have no clear, explicit physical meaning and cannot be measured or determined in the field. To obtain the proper model parameter values, a conversion from (quantifiable) hydraulic parameters is, therefore, required.

In MODFLOW, the canal leakage is simulated as:

\[
Q_{\text{CANAL}} = C_{\text{CANAL}} \cdot (H_{\text{CANAL}} - h) \quad h > H_{\text{BOT}} \\
Q_{\text{CANAL}} = C_{\text{CANAL}} \cdot (H_{\text{CANAL}} - H_{\text{BOT}}) \quad h \leq H_{\text{BOT}}
\]

where:
- \( Q_{\text{CANAL}} \) = Canal leakage (can also be negative) \([L^3T^{-1}]\)
- \( C_{\text{CANAL}} \) = Hydraulic conductance of canal bed \([L^2T^{-1}]\)
- \( H_{\text{CANAL}} \) = Hydraulic head (water level) in the canal \([L]\)
- \( h \) = Piezometric level in the aquifer \([L]\)
- \( H_{\text{BOT}} \) = Elevation of canal bed \([L]\)

With the aid of Equation (1), the hydraulic conductance of the canal bed can be determined as follows:

\[
C_{\text{CANAL}} = \frac{L_{\text{CANAL}} \cdot P_{\text{CANAL}}}{c_{\text{CANAL}}} = \frac{L_{\text{CANAL}} \cdot P_{\text{CANAL}} \cdot K_{\text{CANAL}}}{D_{\text{CANAL}}}
\]

where:
- \( L_{\text{CANAL}} \) = Length of the canal segment \([L]\)
- \( P_{\text{CANAL}} \) = Wetted perimeter of canal \([L]\)
- \( c_{\text{CANAL}} \) = Canal infiltration resistance \([T]\)
- \( K_{\text{CANAL}} \) = Hydraulic conductivity (permeability) of the river bed \([LT^{-1}]\)
- \( D_{\text{CANAL}} \) = Thickness of the river bed \([L]\)

Generally, the hydraulic conductance of the canal bed has to be further quantified through model calibration, as not all the involved parameters may be known in detail.

### 3.2 Simulation of drain entry resistance

If 2-dimensional groundwater models (or pseudo-3-dimensional[3] models such as MODFLOW) are used, one must take care that groundwater flow to drains can only occur in the aquifer section above the equivalent depth (see Figure 2). This may be achieved by reducing the depth of the aquifer (with the drain), or by introducing an additional drain entry resistance to account for the impacts of partial penetration, the latter option being more practical (see Section 2).

The conversion of (quantifiable) drain parameters to the drain hydraulic conductance is similar to the conversion of the above-described canal parameters. Analogously to canal leakage, the discharge by the interceptor drain is simulated by MODFLOW as:
where: \( Q_{DRAIN} \) = Drain discharge (can only be positive) \([L^3T^{-1}]\)

\( C_{DRAIN} \) = Drain hydraulic conductance \([L^2T^{-1}]\)

\( h \) = Piezometric level in the aquifer \([L]\)

\( H_{DRAIN} \) = Drain level (elevation of drain) \([L]\)

With the aid of Equation (3), the drain hydraulic conductance can be calculated as follows:

\[
C_{DRAIN} = \frac{L_{DRAIN} \cdot P_{DRAIN}}{c_{DRAIN}} \tag{9}
\]

where: \( L_{DRAIN} \) = Length of the drain segment \([L]\)

\( P_{DRAIN} \) = Wetted perimeter of drain \([L]\)

\( c_{DRAIN} \) = Drain entry resistance \([T]\)

These equations imply that the differences between a canal and drain are:

A canal can both infiltrate and drain (depending on the groundwater level in relation to the water level in the canal), whereas a drain can only discharge water;

If the groundwater level drops to below the level of the canal bed, the canal will continue to infiltrate (at its maximum rate). If the groundwater level drops to below the drain level (level of the drain bed), the drain will stop to discharge water.

Generally, the drain hydraulic conductance has to be further quantified through model calibration, as not all involved parameters may be known in detail.

4 EXAMPLE OF CANAL AND DRAIN PARAMETER ASSESSMENT

4.1 General Outline

As stated in Section 3, the hydraulic conductance of the canal bed and the drain hydraulic conductance, generally, need to be quantified through model calibration. A first assessment of these parameters can be obtained from field data. Thereafter, the parameters can be further quantified through numerical modelling (“fitting”). Numerical models are based on closed water balances, hence the hydraulic conductance of the canal bed and the drain hydraulic conductance need to be calibrated (“fitted”) simultaneously.

An example of how to assess the canal infiltration resistance and the drain entry resistance from field data is shown in the following paragraphs. Paragraph 4.2 presents a summary of the field data that were used. The applied methods and materials are presented in Paragraph 4.3. The calculation results follow in Paragraph 4.4. The application of the numerical model is presented in a separate paper (Jansen et al, 2003).

4.2 Field Data

The data used for this example were retrieved from the monitoring system of the Fordwah Eastern Sadiqia (South) Project, Pakistan. A pilot (subsurface) interceptor drain was installed at a distance varying from approximately 45 to 60 metres from a
main (unlined) irrigation canal (the Malik Branch Canal). The area is characterised by a thick phreatic aquifer, consisting of fine sands and loams (Euroconsult, 1994; IWASRI, 1998; Niazi et al.).

From 1994 to 1997 an extensive monitoring programme was executed. During 4 years the following data were monitored on a regular basis:
- Water levels in the irrigation canal (upstream and downstream);
- Groundwater levels in a dense network of observation wells and some piezometers (nested).

In addition, drain discharges (and water quality) were measured 13 times in the period from March 1996 to June 1997 (shortly after drain installation). Also a seepage measurement was executed by means of a ponding test during the closure period of January 1998. Finally the hydraulic conductivity was determined at 17 locations along the Malik Branch Canal. The distances between these conductivity measurements were 500 metres.

### 4.2.1 Interceptor drain

The interceptor drain has a total length of 1828 metres, divided in a northern section of 685 m (in the upstream direction of the irrigation canal), and a southern section of 1143 m. Both sections discharge into a sump, which is permanently pumped. The drain diameter varies from 8 inch (≈ 20 centimetres), upstream, to 10 inch (≈ 25 centimetres) at the outlet to the sump. The average installation depth is approximately 2.7 metres (below the topographic surface). The design discharge was 14 l/s (Euroconsult, 1994; IWASRI, 1998; Niazi et al).

The northern section is equipped with 2 manholes (Manhole 1 and 2) which allow for monitoring the drain (discharge and water quality) over various sections. Only Manhole 1 had been monitored. The southern section is also equipped with 2 manholes (Manhole 3 and 4), which had both been monitored. The discharges from the drain sections were measured in the period from March 1996 to June 1997. The average measured discharges are presented in Table 1.

<table>
<thead>
<tr>
<th>Drain section</th>
<th>Length (m)</th>
<th>Discharge (l/s)</th>
<th>Specific discharge (m²/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upstream of Manhole 1</td>
<td>≈ 258</td>
<td>0.70</td>
<td>0.23</td>
</tr>
<tr>
<td>Entire section north of sump</td>
<td>≈ 685</td>
<td>1.62</td>
<td>0.20</td>
</tr>
<tr>
<td>Southern Section</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upstream of Manhole 4</td>
<td>457</td>
<td>1.4</td>
<td>0.26</td>
</tr>
<tr>
<td>Between Manhole 4 and Manhole 3</td>
<td>376</td>
<td>0.4</td>
<td>0.09</td>
</tr>
<tr>
<td>Between Manhole 3 and the sump</td>
<td>310</td>
<td>1.14</td>
<td>0.32</td>
</tr>
<tr>
<td>Entire section south of sump</td>
<td>1143</td>
<td>2.94</td>
<td>0.22</td>
</tr>
</tbody>
</table>

The average specific discharge of the interceptor drains is in the order of 0.21 (m²/day). The discharge of the interceptor drains is much lower than the design capacity.

### 4.2.2 Irrigation Canal

The Malik Branch Canal is one of the main irrigation canals in the Fordwah Eastern Sadiqia (South) Project. The canal has a width of approximately 35 metres and a (design) water depth of approximately 2.5 metres.

Figure 4 shows that the water level in the canal is rather constant over the year (except for the closure period).
Groundwater levels were monitored to assess the effectiveness of the interceptor drains and to determine the relation between the surface water and the groundwater. The results of the groundwater monitoring programme showed:

- No significant change of the groundwater levels occurred after the installation of the interceptor drain;
- The response of the groundwater to changes in the water level in the canal (e.g. the lowering during the closure period) is very direct.

Given the constant canal water level (the closure period excepted) and the direct relation between the canal water level and the groundwater level, the groundwater system can be considered as a steady-state.

Hydraulic conductivity

The hydraulic conductivity of the shallow soil layers was determined by testing 17 boreholes having a depth of 3 metres (10 feet). The lithology was further investigated by drilling 13 boreholes with a depth of 12 metres (40 feet). The average hydraulic...
conductivity (used for the drain design) amounted to 0.75 m/day (Euroconsult, 1994). No spatial trend was observed.

5 Methods and Materials
No other materials have been used than an EXCEL spreadsheet, in which the Equations (4) and (5) were programmed. Equation (4) was split in two components in order to calculate both the flow above the drain level and the flow below the drains. The Dupuit Formula was also programmed in the spreadsheet, to allow for the evaluation of the concept of equivalent depth.

The calculation results can be represented tabularly and graphically.

- The spreadsheet requires the following data:
  - Distance between the irrigation canal and interceptor drain;
  - Drain internal diameter (ID);
  - Depth of aquifer below the drain;
  - Hydraulic conductivity of the aquifer;
  - Drain depth.

The equivalent depth (according to Equation (5)) and the specific drain discharge (according to Equation (4)) are calculated by the spreadsheet.

6 Results and Analysis

6.1 Partial Penetration Losses
The following data were used for the assessment of the canal and drain parameters (based on the situation of the Malik Branch Canal):

<table>
<thead>
<tr>
<th>Parameter:</th>
<th>Value:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance between the irrigation canal and interceptor drain</td>
<td>Variable</td>
</tr>
<tr>
<td>Drain internal diameter (ID)</td>
<td>0.2032 m. (8 inch)</td>
</tr>
<tr>
<td>Depth of aquifer below the drain</td>
<td>9.5 m. (value used for the drain design)</td>
</tr>
<tr>
<td>Hydraulic conductivity of the aquifer</td>
<td>0.75 m/day</td>
</tr>
<tr>
<td>Drain depth</td>
<td>2.7 m. (average value)</td>
</tr>
</tbody>
</table>

At first, the effect of partial penetration of the interceptor drain was evaluated.

Figure 5 presents the calculated specific groundwater flow to the interceptor drain, as a function of the distance between the irrigation canal and the interceptor drain. It is noted that the (topographic) distance between the canal and drain varies from 45 m. (in most of the area) to 60 metres. The calculated specific discharge for these distances is, respectively, 0.21 and 0.18 m²/day. This specific discharge would, theoretically, occur if no other hydraulic losses than the partial penetration losses and aquifer losses would exist.
Figure 5 Reduced flow to drain due to partial penetration.

Figure 5 also presents the calculated specific groundwater flow to the interceptor drain in the case that no partial penetration losses exist (Dupuit flow; no converging flow lines). It can thus be concluded that the partial penetration of the interceptor drain results in a flow reduction with a factor 2 – 2.5 in comparison with a fully penetrating drain.

It seems that the partial penetration losses of the drain were not considered in the design procedure, as the reported design discharge (14 l/s) is considerably higher than the theoretical maximum discharge shown in Figure 5 (0.21 m²/day corresponds with approximately 4.4 l/s). The calculated maximum drain discharge in Figure 5 is very well in line with the observed drain discharge (on average 0.20–0.22 m²/day; see Table 1).

6.2 Canal Infiltration Losses

As the observed drain discharge is approximately equal to the theoretical maximum drain discharge, this indicates that there are hardly any other hydraulic losses than the aquifer losses and partial penetration losses (some additional drain entry losses may, however, still be involved, which will be explained below).

This implies that the canal infiltration resistance, $c_{\text{CANAL}}$, is very small. Other facts confirming the small canal infiltration resistance are:

The observed direct response of the groundwater levels to the lowering of the water level in the canal (see Section 4.2). A significant hydraulic resistance would cause a time lag in the response;

The ponding test, which showed that the canal can infiltrate at a much higher rate, if the groundwater levels are lowered. During the ponding test an infiltration rate in the order of 25–35 mm/day was measured (see Section 4.2), which corresponds with
approximately 1 m²/day (the wetted perimeter of the canal is approximately 30-35 m.). In other words: the canal is not the limiting factor.

The canal infiltration resistance is expected to be a few days at maximum (which is common for sandy soils). The infiltration resistance cannot be further quantified with the available data. For a more detailed assessment, a numerical model could be applied (see Jansen et al., 2003). However, the canal infiltration resistance is, most probably, not a very sensitive parameter for the presented case, as this parameter is not the limiting factor for groundwater flow.

### 6.3 Drain Entry Losses

Although the observed drain discharge is approximately equal to the theoretical maximum drain discharge, some additional drain entry losses may occur, in addition to the partial penetration losses, as the theoretical maximum discharge in Figure 5 assumed only leakage from the irrigation canal. In reality also some groundwater from the adjacent irrigated lands will be discharged. The observed gradient between the groundwater level and the drain level (at the drain location) also indicates drain entry resistance.

In the case that the hydraulic losses due to partial penetration of the drains are incorporated in the drain entry resistance (see also Section 2), the drain entry resistance should be at least (see also Equation 3 and 4):

$$ c_{\text{DRAIN}} \geq \frac{(h - H_{\text{DRAIN}}) * P_{\text{DRAIN}}}{q} $$

or:

$$ c_{\text{DRAIN}} \geq 2 * \frac{(h - H_{\text{DRAIN}}) * P_{\text{DRAIN}} * L}{K * (H_{\text{CANAL}} - H_{\text{DRAIN}})^2} + 2 * K * d * (H_{\text{CANAL}} - H_{\text{DRAIN}}) $$

(10)

With Equation (10) the minimum drain entry resistance can be determined. The parameters can be estimated from the layout of the canal and drain system and the monitoring data:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(h - H_{\text{DRAIN}})</td>
<td>(\approx 2) m (on average)</td>
</tr>
<tr>
<td>(L)</td>
<td>(\approx 45) m</td>
</tr>
<tr>
<td>(K)</td>
<td>(\approx 0.75) m/day</td>
</tr>
<tr>
<td>(H_{\text{CANAL}} - H_{\text{DRAIN}})</td>
<td>(\approx 2.7) m</td>
</tr>
<tr>
<td>(d)</td>
<td>(\approx 3.4) m (calculated)</td>
</tr>
</tbody>
</table>

By substituting these values in Equation (10), we obtain \(c_{\text{DRAIN}} \geq (\approx 9.4 * P_{\text{DRAIN}})\) days. The wetted perimeter, \(P_{\text{DRAIN}}\), is sometimes difficult to determine, as any envelope, gravel pack or high permeable backfill must also be taken into account.

This calculation is only a first estimate of the drain entry resistance. As other hydraulic losses than partial penetration losses occur in and near the interceptor drain, the actual value of \(c_{\text{DRAIN}}\) should be more than \((9.4 * P_{\text{DRAIN}})\) days. The drain entry resistance cannot be further quantified with the available data. For a more detailed assessment, a numerical model could be used (see Jansen et al., 2003).
It is noted that the wetted perimeter, $P_{\text{DRAIN}}$, is not directly required for modelling with MODFLOW: Substituting $c_{\text{DRAIN}} \geq (9.4 \times P_{\text{DRAIN}})$ in Equation (9) gives:

$$c_{\text{DRAIN}} \leq \frac{L_{\text{DRAIN}}}{9.4}.$$ 

The value of $L_{\text{DRAIN}}$ merely depends on the geometry of the applied model (grid size; see also Jansen et al., 2003), which confirms that $C_{\text{DRAIN}}$ has no explicit physical meaning (Section 3). For example, if the length of the grid node that contains a drain segment is 20 metres, $C_{\text{DRAIN}}$ will be less than 2.1 m$^2$/day. If the grid note has a length of 50 metres, $C_{\text{DRAIN}}$ will be less than 5.3 m$^2$/day (hence $C_{\text{DRAIN}}$ is not merely determined by the hydraulic properties of the drain).

### 6.4 Synthesis

The above assessment shows that the canal infiltration and drain entry resistances can sometimes be estimated from monitoring data. In addition to (separate) calculations of the individual parameters, the entire system can also be looked upon.

From the Equations (1), (2) and (3), it follows that

$$q = \frac{P_{\text{CANAL}} \times \Delta_1}{c_{\text{CANAL}}} = \frac{D_{\text{AQ}} \times \Delta_2}{c_{\text{AQ}}} = \frac{P_{\text{DRAIN}} \times \Delta_3}{c_{\text{DRAIN}}}$$

If the canal infiltration resistance is not more than a few days, $P_{\text{CANAL}} / c_{\text{CANAL}}$ is an order of magnitude larger than $P_{\text{DRAIN}} / c_{\text{DRAIN}}$ (at least a factor 100). This means that $\Delta_1$ is negligible in comparison with $\Delta_3$. With $q = 0.21$ m$^2$/day and $P_{\text{DRAIN}} / c_{\text{DRAIN}} \leq 1/9.4$ m/day, $\Delta_3$ is at least (in the order of) 2 m. Similarly $\Delta_2$ can be estimated at (in the order of) 1 m. The sum of $\Delta_2$ and $\Delta_3$ is indeed close to the observed value of $(H_{\text{CANAL}} - H_{\text{DRAIN}})$ of 2.7 m.

As the hydraulic head losses in the aquifer and the losses due to partial penetration of the drain are both an order of magnitude more than the hydraulic losses in the canal bed, any increase of the drain discharge capacity (higher $P_{\text{DRAIN}} / c_{\text{DRAIN}}$) will result in more canal leakage. The process of induced leakage will only stop when, finally, an unsaturated zone appears under the canal bed.

The process of induced leakage is further detailed, for various conditions, with a numerical model (see Jansen et al., 2003).

### 6.5 Final Remarks

It can be seen in Figure 5, that the existence of canal infiltration resistance and/or drain entry resistance has the same hydraulic effect as an increased (topographical) distance between the canal and drain. To account for these losses, the concept “hydraulic distance” was introduced in Figure 5. Obviously, the hydraulic distance is at least the topographic distance.

It is, finally, noted that the use of larger diameter drains will result in a relatively small decrease of partial penetration losses. Large-diameter drains are, therefore, not very effective to reduce these losses (they may, of course, have other benefits).

### 7 CONCLUSIONS
An assessment of all components of the hydraulic losses between the canal and the interceptor drain has to be made before feasible solutions for waterlogging problems can be identified. The hydraulic losses are a result of canal infiltration resistance, hydraulic resistance in the aquifer and drain entry resistances.

With this regard, it is critical to assess the hydraulic losses due to partial penetration of the interceptor drain. Especially in thick aquifers, these losses can be considerable. The partial penetration losses can be assessed with the concept of “equivalent depth”, which was also used by Hooghoudt. The example from Pakistan shows that partial penetration losses may reduce the groundwater flow by a factor of 2 to 2.5.

The introduction of interceptor drains will cause induced leakage from the canals, which, therefore, reduces the effectiveness of the drain.

Only in the case of an unsaturated zone under the canal bed, the installation of an interceptor drain will not cause an increase of canal leakage. In such a case, also the impact of canal lining is independent of the aquifer characteristics.

A detailed quantitative assessment, generally, requires numerical modelling, as the canal infiltration and drain entry resistances are often difficult to determine directly by monitoring. The hydrological concepts of canal leakage and interceptor drains can, relatively, easily be converted to model parameters. Further details on the application of a numerical model to assess the impact of interceptor drainage and lining are presented in a separate paper (Jansen et al., 2003).

8 ACKNOWLEDGEMENTS
The author wants to thank Dr. M.N. Bhutta and Eng. I. Javed of the International Waterlogging and Salinity Research Institute at Lahore, Pakistan, and Dr. W. Wolters of Alterra-ILRI, Wageningen, The Netherlands, for providing valuable data that could be used to illustrate and support the presented concepts, and for their constructive remarks and contributions to this paper.

9 REFERENCES

[2] H.C. Jansen, Alterra-ILRI: International Institute for Land Reclamation and Improvement/ILRI, PO Box 47, 6700 AA Wageningen, The Netherlands, Tel. + 31 317 495549, Fax. + 31 317 495590, e-mail: ilri@ilri.nl
[3] In a pseudo-3 dimensional model, the groundwater flow is strictly horizontal in aquifers, while the exchange of groundwater between aquifers at various depths occurs by (strictly) vertical flow through semi-confined layers.
[4] Assuming that only canal leakage needs to be intercepted.
SALINITY CONTROL. IS IT EFFICIENT? IS IT FAIR?[1]

Evan Christen[2]

1 The issue

The long term sustainability of irrigated agriculture depends upon controlling the salinity levels in the crop root zone and to do this, maintaining the ability to dispose of drainage water. This requires that subsurface drainage systems are efficient in terms of removing the minimum amount of water of the lowest salinity possible whilst still maintaining crop productivity and the drainage disposal option minimises risks to water quality and downstream users.

However, many irrigated areas have reached the limits for salt disposal limit to river systems and are being pressured to reduce salt loads in return flows to rivers. Much of the salt load from irrigated regions is due to disposal of saline drainage water from subsurface drainage (SSD) systems. This raises the questions of a) is the current drainage undertaken effective and efficient, b) is the current drainage disposal practice well managed, c) what is the future for SSD.

Within most irrigated regions there is a lot of reuse of drainage water. This is driven by water scarcity and policy signals that encourage reuse in order to minimise return flows to rivers. This reuse can occur on-site by those draining and then conjunctively reusing the drainage water with channel irrigation supplies or downstream where drainage water is disposed of into irrigation channels and surface drains. On-site reuse is self-implemented and so could be considered as a case of irrigators controlling their own destiny. However, those using irrigation water degraded by upstream disposal are of greater concern as their destiny is being altered by increased irrigation water salinity and policy signals to reuse drainage water. Drainage disposal policy that increases salinity within irrigation channels and surface drains is of concern unless it is sure that the downstream users are aware of the elevated salinity, aware of the consequences of use, have good management practices and are in locations that can sustain use of that water. This is especially of concern in areas that already have poor drainage characteristics. In the end the drainage and “salvation” of one area can lead to the degradation of another.

2 The research questions

To address these concerns the aspects of SSD that I believe we should investigate fall into two areas:

1) Is the current drainage practice efficient, effective and equitable?
   - Providing adequate crop protection
   - Minimising salt mobilisation
   - Protecting aquifer quality
   - Has sufficient effort been given to providing SSD options to those in areas which are difficult to drain, e.g. no pumpable aquifers, heavy clay soils

2) Is the current drainage disposal practice efficient, effective and equitable?
   - Is the “salt balance” concept, often used to justify disposal, adequately proven?
   - Is the disposal adequate or more than necessary?
   - Is the disposal adequately managed to ensure that the sustainability of downstream users is not being compromised?
   - Is the salt management/disposal adequately managed at the regional scale both spatially and temporally?

Are these the right questions? How do we research and implement them? How do we provide an integrated approach to deal with these concerns?
3 Is the current drainage practice efficient, effective and equitable?

3.1 Providing adequate crop protection
It would appear that much of the drainage practice is implemented with very generalised objectives based on previous work and regional “rules of thumb”. This can lead to more intensive drainage than is actually required. This leads to greater expense, reduced water use efficiency and increased salt mobilisation.

3.2 Minimising salt mobilisation
This is becoming crucial as available salt disposal ceilings are met. Much of the groundwater pumping is not critically targeted or managed to maintaining a root zone salt balance. Tile drainage systems are not managed and design considerations are not given to avoidance of draining highly saline waters.

3.3 Protecting aquifer quality
The shallow aquifers with low salinity that can be pumped are a high value asset in terms of the long-term sustainability of irrigation in the region. In many situations the low salinity of these aquifers can be assumed as a “single use” commodity. This commodity can be expended rapidly (to provide supplemental irrigation water) or used conservatively to provide root zone salinity control over an extended period. To allow rapid increase in salinity of these shallow aquifers raises serious questions regarding the care given to long term sustainability issues.

Pumping of deep lead aquifers is also an important tool in providing a strategic complementary tool to other salinity control measures. Care should also be given to ensuring that the deep leads can continue to provide this area wide benefit, this means ensuring salinity does not increase rapidly. This tool although not a cure for salinity is important as it provides one of the only widely applicable measures and thus can be seen to benefit everyone.

3.4 Has sufficient effort been given to providing SSD options to those in areas with non-pumpable aquifers?
In many areas there are no aquifers suitable for groundwater pumping. At present the salinity control measures for these areas are limited and expensive. In this case that there are not easy solutions available, all other efforts need to be applied to these areas in the short term, including: provision of lowest available quality irrigation water, implementation of surface drainage, control of deep lead pressures, effective source control – irrigation, channels, drains, rainfall.

In the longer term solutions need to be found and strategic management plans prepared for these areas. There may be required additional funding for these areas and some proactive implementation.

4 Is the current drainage disposal practice efficient, effective and equitable?

4.1 Is the “salt balance” concept used to justify disposal adequately proven?
The current justification for salt disposal is to maintain a long term salt balance. However, the justification for this approach is unclear. The salt balance needs to be specified in time and space, also the concept of a requirement for an absolute balance is questionable. Salt accumulation is quite safe if it does not occur in the root zone, or it occurs in the root zone up to a crop threshold level.

The salt that needs to be managed is that which is accumulating within the root zone. The root zone should be the space/volume for which salt management is targeted. Currently it appears to be some mix of the root zone and the general aquifer system. Salt extracted from an aquifer system only has a limited relationship with salts actually in the root zone.

The time frame for salt management needs to be carefully considered. Irrigation areas often act as salt sinks. This is not
worrisome if this does not affect crop production. Salt export to balance incoming salt actually only needs to occur when the capacity of the irrigation area to safely store the salt has been exhausted.

4.2 Is the disposal adequate or more than necessary?
Much of the drainage disposal is based on salt balance as discussed above. This may well be unnecessary in many areas. SSD is often installed for waterlogging control, this then also provides salinity control, or SSD is installed for reclamation of salinised land or SSD is installed for supplemental water supply that also provides a drainage function. In all these situations there is potential for salt mobilisation as a side effect. As discussed above salinity control for the root zone is useful, however salt mobilised from below the root zone serves no useful purpose, it is an unfortunate byproduct of the drainage process that creates disposal problems. SSD design and management needs to be reappraised to minimise this byproduct.

4.3 Is the disposal adequately managed to ensure that the sustainability of downstream users within the irrigation area is not being compromised?
Note: This relates to reuse within the SIR.
When salt disposal occurs by addition to irrigation channels and surface drains which is then used downstream then there is a special duty of care upon those disposing of the salt. When disposal is permitted to increase salinity in downstream users supply has this been planned considering all the physical/economic constraints of those users. Does it safeguard their future sustainability and flexibility to produce a variety of products economically and of high quality? The use of generalised rules of thumb for the region is easy to implement but do these address issues that may arise at the local scale within the SIR?

4.4 Is the salt management/disposal adequately managed at the regional scale both spatially and temporally?
Salt management for the SIR is complex. There are large variations in the physical conditions spatially and temporally and the boundary conditions upstream and downstream are varying.
This complexity and continuing variability requires a careful planned approach at a regional scale to ensure that actions do not lead to adverse consequences elsewhere. This requires a robust framework to manage salt levels within the irrigation system and within the surface drainage system. Also required is a plan to manage salt levels within the root zone, to include areas that have shallow aquifers, and areas of non-pumpable aquifers. Once this plan is available then some proactive education and implementation may be required rather than relying on grower approaches. This should provide a more optimal ($ terms) implementation of SSD. Also equitable distribution of resources needs to occur to ensure sustainability of as large an area as possible.
A regional salt disposal framework is required that allows optimal implementation of salt disposal options.

1 The issue
Traditionally, land drainage is a tool to improve crop growth conditions for agriculture. This is done through optimising crop root zone soil moisture conditions to prevent crop damage. By removing excess water from the crop root zone, water-soluble constituents are removed as well. Solute removal may be beneficial for the crops grown (removal of salts), non-beneficial for the crop (leaching of nutrients) or resulting in negative impacts elsewhere (transport of agro-chemicals).

When examining drainage as a tool for integrated water management we have to consider effects of drainage on other functions of the land as well. These other functions should not be restricted to the agricultural fields where drainage is practised, but also neighbouring field influenced by drainage or downstream areas where the effluent is used as water source.

2 Drainage in the context of integrated water management
Improving land drainage conditions locally, to improve crop production, does not necessarily mean that interests of other actors and stakeholders in the region are safeguarded. On the contrary, if those interests are not considered during drainage implementation, it is more likely that these interests will be damaged.

Based on the above considerations, this leads us to the conclusion that the benefits of land drainage for agriculture should be weighted against the interests of other actors and stakeholders.

3 Solute transport
Based on the assigned subtopic, we should discuss the influence of solute transport by drainage in the framework of integrated water management. Discussing solute transport, we can approach the issues from two sides. The conventional approach is to look at adverse impacts of solute transport, which need to be mitigated or at least addressed to fit in the integrated water management concept. An alternative approach could be to discuss (potential) positive effects of drainage induced solute transport processes (the other side of the same coin).

4 Drainage to change the pathways of solutes
By land drainage the pathway of soil water fluxes changes. A deeper groundwater table may reduce surface run-off and thereby reduce phosphorous leaching to surface waters. A shallow groundwater table may promote denitrification processes in the soil and reduce nitrogen leaching to surface waters. I would like to open the discussion (case studies, experience, and thoughts) on this subject.

5 Purification of water through drainage
Polluted water streams may be cleaned by treatment in wetlands or by passage through the soil system. Drainage is part of such cleaning activities and recovers the cleaned water resource. I would like to open the discussion (case studies, experience, and thoughts) on this subject.

6 Other examples
Any other examples of drainage as a tool for integrated water management are welcomed here. Please submit your case studies, experience or thoughts on this subject.
SOLUTE TRANSPORT


ESTIMATING BOD POLLUTION RATES ALONG EL-SALAM CANAL USING MONITORED WATER QUALITY DATA (1998-2001)

Dr. Ayman M. Mostafa El-Degwi, Eng. Faten M. Ewida, and Prof. Sameh M. Gawad

ABSTRACT
A study has been conducted to investigate the BOD pollution rates from Non-Point Sources (NPS) along various zones of El-Salam canal as well as estimating the BOD variation along the canal. This study employs the water quality data measured in the period of 1997-2001 by the Drainage Research Institute (DRI) of Egypt. The canal has been divided into three zones bounded by monitoring stations located along the canal. An estimation technique and a numerical model QUAL2E have been adopted to estimate the BOD pollution rate from NPS along the various zones of the canal. The estimation of BOD from NPS has been made considering mass balance and matching the measured values of BOD at downstream monitoring stations. Statistical analysis has been conducted to compute the maximum, the average, the minimum and the upper/lower limits of BOD either measured at monitoring stations of El-Serw and Hadous drains or estimated along various zones (NPS). Results from the statistical analysis of water quality either measured or estimated are of good help for the prediction of possible water quality along the canal when it comes into full operation.

Moreover, water from El-Serw and Hadous drains, and occasionally from the Nile River, have been found to violate the Egyptian law 48/1982 concerned with the protection of waterways. However, water quality has been found to improve and a room still exists for improvement. Furthermore, it has been found that significant NPS and high BOD concentration exist along the middle zone, i.e., between pump station No.1 (PS1) and pump stations No.2 (PS2) along El-Salam canal.

Keywords: BOD, El-Salam Canal, Non-Point Sources and Water Quality.
presented and discussed and, finally, conclusions and recommendations are given.

1.1 Governing Equations and Model Description

To enable understanding the problem investigated in this work, a review has been made on the governing equations and the numerical model adopted. The mass balance equation is used to keep track of water quality constituents and is written as:

\[ \text{Accumulation} \]
\[ \text{Dispersion} \]
\[ \text{Advection} \]
\[ \text{Kinetics} \]
\[ \text{External sources/sinks} \]

It can be realized that the transport equation consists of two components; i.e., advection and dispersion. The QUAL2E model, employed in the current work, considers the flow in the stream to be steady, even if dynamic calculations are used. Therefore, the flow from one element to the next is thus the net flow across the element. Thus, the water balance at an element is expressed as follows:

\[ Q_i \] is the outflow from an element, \( Q_{i-1} \) is the flow from the upstream element; \( Q_{xi} \) is the inflow/outflow for elements in this reach (if \( Q_{xi} > 0 \), the flow is in, if \( Q_{xi} < 0 \) the flow is out). Source is the inflow rate from a point source and Sink is the outflow rate through a point. The inflow to the first element in the computational domain is specified as the headwater flow and is input in a separate screen in the model.

Any element may be the location of either a point source or a point sink. Uniform flows or outflows can be specified for all the elements in a particular reach on the “Incremental flow Screen” of the model. Additional point sources or sinks may also be added to particular elements.

Once the flow is calculated for an element, the mean stream velocity and depth can be determined based upon the flow equation selected. On the other hand, Biological Oxygen Demand (BOD) is determined by integrating the following equation:

\[ BOD_t \]

where \( L \) is the ultimate BOD, \( K_d \) is the de-oxygenation rate coefficient, \( K_s \) is the settling rate of inorganic matter.

The previous equation integrates to the following form:

\[ BOD_t \]

where BOD\(_t\) is the BOD after \( t \) days.

On the other hand, Oxygen flows into water due to re-aeration or consumed during other oxidation processes. Thus, the Oxygen balance can be written as follows:

\[ O \]

Where \( A \) is algal biomass concentration, \( N_{NH3} \) is ammonia nitrogen concentration, \( N_{NO2} \) is nitrite nitrogen concentration, \( O \) is the dissolved Oxygen concentration, \( O_S \) is saturation oxygen concentration, \( P_P \) is the net oxygen contribution from periphyton, \( a_3 \) is rate of oxygen production per unit of algal photosynthesis, \( a_4 \) is rate of oxygen uptake per unit of algae respiration, \( a_5 \) is rate of oxygen uptake per unit of ammonia nitrogen oxidation, \( a_6 \) is rate of oxygen uptake per unit of nitrite nitrogen oxidation, \( a_1 \) is temperature dependent ammonia oxidation rate, \( a_2 \) is temperature dependent nitrite oxidation coefficient, \( a_1 \) is temperature dependent algal growth rate, \( K_{SOD} \) is sediment oxygen demand, and \( K_a \) is the oxygen re-aeration rate.

The coefficients are corrected for temperature using the following equation:

\[ K_T \]

Where \( K_T \) is rate at temperature \( T \), \( K_{20} \) is the rate at 20°C, and \( \tau \) is a temperature correction factor.

Constituents may enter or leave the element by ordinary convection or dispersion as well as through sources/sinks. Finally, they can be consumed or generated as a result of the activity of algae and periphyton. These effects are included in a one dimensional mass transport equation with dispersion. This equation includes transport by convection and by dispersion. Additional terms are added to the classical transport equation to allow for local sources, sinks and local generation and consumption of a constituent within the element. For any constituent, \( C \), the transport equation is:

\[ C \]

where \( C \) is constituent concentration, \( A_c \) is the element cross-sectional area, \( M \) is mass of constituent in water in the element, \( U_c \) is average velocity in element, \( s \) is any external source or sink of the constituent, and \( dx \) is the incremental distance. Recalling that \( M = CV \)

where \( V \) is the volume of water in the element.
Because the flow is considered to be steady in this study, $V$ is constant and $V = A_c \frac{dx}{dt}$. Thus, substituting and rearranging, the transport equation is written as follows:

\[ V = \frac{dC}{dt} = A_c \frac{dx}{dt} \]  

(9)

The derivative term ($\frac{dC}{dt}$) represents the generation or consumption of the constituent within the element, which can be non-zero. The partial derivative represents the change in constituent concentration over time and is set zero in the steady state calculation. In the dynamic calculation, the partial derivative is used to compute dynamic changes in the basin.

Attention has been given here to the BOD and DO parameters since most of the pollution load in El-Salam canal is expected to be caused by domestic/agricultural wastewater sources. This is also consistent with earlier investigations concerned with pollution sources along Egyptian drains (e.g., DRI, 1997, Mostafa, 2001).

2 Case Study:

The project of North Sinai Development for land reclamation of 400,000 feddans is one of the leading reuse projects in Egypt. The project will be supplied by water from El-Salam canal which utilizes 2.3 milliard m$^3$/year of agricultural drainage water, i.e., 1.9 milliard m$^3$ from Hadous drain and 0.4 milliard m$^3$ from El-Serw Drain, and mixing it with about 2.1 milliard m$^3$/year from Domietta branch. El-Salam canal runs from its intake at km219 of Domietta branch to El-Salam siphon for 89.40km and its area served is about 220,000 feddans.

Among forty-six monitoring stations located in the Eastern Delta drains of Egypt, only four stations are positioned along El-Salam canal and two others are located on the feeding drains. Layout of monitoring stations and the location of canals withdrawing water from El-Salam canal are shown in Figure 1. Table 1 lists the name and location of monitoring stations as relevant to El-Salam canal. EI21 measures water quality flowing from the Nile into El-Salam canal, while EH17 and ES02 monitors water quality going from Hadous and El-Serw drains into El-Salam canal, respectively. EH20, EH21 and EH24 are located and used as check points for water quality along the canal.

![Layout of monitoring stations and withdrawal points along El-Salam canal](image)

Table 1 Monitoring stations along El-Salam canal and feeding drains

<table>
<thead>
<tr>
<th>Station Type</th>
<th>Code</th>
<th>Name</th>
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<tbody>
<tr>
<td>Pump station</td>
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<tr>
<td>Monitoring station</td>
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<tr>
<td>El-Salam canal</td>
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<tr>
<td>Small canals</td>
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</table>

Figure 1 Layout of monitoring stations and withdrawal points along El-Salam canal
The measured concentrations of BOD, DO and discharges at various monitoring stations along El-Salam canal have been used in this study to investigate the characteristics of various pollution sources affecting the canal. Table 2 shows the monthly records in year 2001 as an example. It is evident that the measured BOD concentrations from Hadous drain violate the limiting value of 40mg/lit set by Law 48/1982 in several months except in February and July-October 2001. On the other hand, BOD measured at ES02 sometimes violates the law, i.e., February, July, September and November 2001. Furthermore, the measured BOD at PS2 (EH20) is generally higher than that measured at PS1 (EH20) except in October 2001 and, hence, serious pollution sources are anticipated to exist along this zone. Additionally, BOD values measured at El-Salam siphon (EH24) are usually less than or almost equal to those measured at the upstream monitoring station (EH21) except in December 2001. This may be attributed to the less rates of pollution along the zone from PS2 and El-Salam siphon as well as the effect of self-purification along the canal as the water flows toward the siphon. It is noteworthy that BOD values measured in 2001 are generally less than those measured in earlier years. Temporal analysis and seasonal fluctuations have been studied and it has been found that the average values of BOD from various pollution sources as well as the measured ones at monitoring stations along the canal generally decrease slightly over the period 1998-2001. Several canals are located along El-Salam canal and withdraw their water duties from it. List of the canals and their flows during the study period have been quoted from the North Sinai Development project Organization. The canal is lined over some sections while others are not. It is, hence, expected to have inflow to the canal along the unlined sections, caused by drainage water carrying organic loads. Dumping of liquid (and accidentally solid) wastes along El-Salam canal is sometimes practiced by residents.

### Table 2  Measured BOD and discharges at monitoring stations in year 2001

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<tbody>
<tr>
<td>Nile River (EI21)</td>
<td>Qm³/sec</td>
<td>37.5</td>
<td>41.3</td>
<td>45.6</td>
<td>51.96</td>
<td>72.33</td>
<td>87.03</td>
<td>88.54</td>
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<td></td>
<td>BOD (mg/lit)</td>
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<td>10.3</td>
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<td>31.7</td>
<td>28.46</td>
<td>10</td>
<td>13.8</td>
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<tr>
<td>Serw drain (ES02)</td>
<td>Qm³/sec</td>
<td>23.53</td>
<td>21</td>
<td>7.46</td>
<td>22.46</td>
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<td>42</td>
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<td>49</td>
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<td>PS 1 (EH20)</td>
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<td>33</td>
<td>33</td>
<td>33.5</td>
<td>33</td>
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<td></td>
<td>BOD (mg/lit)</td>
<td>14</td>
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<td>29</td>
<td>22</td>
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<td>37</td>
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<td>34</td>
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<tr>
<td>PS 2 (EH21)</td>
<td>Qm³/sec</td>
<td>16.5</td>
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<td>16.5</td>
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<td>BOD (mg/lit)</td>
<td>28</td>
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<td>37</td>
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<td>40</td>
<td>52</td>
<td>25</td>
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<tr>
<td>Hadous drain (EH17)</td>
<td>Qm³/sec</td>
<td>16.5</td>
<td>16.5</td>
<td>16.5</td>
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<tr>
<td></td>
<td>BOD (mg/lit)</td>
<td>52</td>
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<td>67</td>
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<td>43</td>
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<tr>
<td>Siphon (EH24)</td>
<td>Qm³/sec</td>
<td>20.5</td>
<td>20.5</td>
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<td>20.5</td>
<td>41.5</td>
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<td>BOD (mg/lit)</td>
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<td>26</td>
<td>30</td>
<td>44</td>
</tr>
</tbody>
</table>

### 3 Study approach

This paper aims at studying the variation of BOD concentrations along El-Salam canal and estimating the equivalent NPS of BOD pollution along it. The measured BOD values within the study area have been used as well as the estimation technique developed by Mostafa et al. (2003) to estimate the NPS rates of BOD pollution along various zones of El-Salam canal. The canal is, thus, divided into three zones, i.e., the first one is bounded by EI21 and EH20, the second is from EH20 to EH21 and the third goes from EH21 to El-Salam Siphon (EH24).

Several canals exist along various zones of El-Salam canal and withdraw their water duties from it. Runs have been made considering the exact location of the canals, but it has been found a tedious job. Sensitivity analysis has been conducted to investigate the effect of replacing the small canals by equivalent ones having the same total flow withdrawn but at a single point. The results have been compared with the case when the exact locations are used in computations. It has been found that the effect of this simplification is quite insignificant on the simulation results of BOD variation along El-Salam canal. This may be attributed to the small discharges withdrawn by the canals along El-Salam canal. Moreover, it is intuitive that the flow out of a canal does not affect the concentration of BOD at the withdrawal point(s), but it rather reduces the flow velocity and slightly increases the travel time between two sections along the canal. Thus, equivalent withdrawal points along El-Salam canal (Figures 2-5) have replaced the small canals shown in Figure 1 and the values are shown in units of m³/s (Figures 2-5).

The estimation technique utilized considers mass balance between various sources and sinks within each zone to estimate an equivalent flow from NPS, uniformly distributed along the zone, and is named as the equivalent discharge (m³/sec/Km) from NPS. Either inflow or outflow from NPS is possible depending on the balance...
between various known sources/sinks within the zone. The concentration of BOD from NPS, case of inflow only, is thus assumed in a trial and error computations using QUAL2E model until matching is reached between measured and computed values of BOD at the respective downstream monitoring station. If the equivalent NPS discharge corresponds to the outflow case, the model can automatically compute the equivalent BOD of NPS. In some cases, outflow has been estimated especially along zone 1, while the introduction of an equivalent point source/sink has been found unavoidable to match the measured value of BOD at a downstream monitoring station in some records. Since, no significant point source of pollution has been observed by the authors during site visits or reported by other others, it is suggested that some errors may be encountered in the BOD samples or accidental conditions took place at the time water samples were taken, e.g., dumping of wastewater by tankers, …etc. Less attention has been given here to the results obtained from such cases. Further details of the estimation technique are found in Mostafa et al. (2003).

4 Results and analysis

Graphical presentations have been prepared to show the estimated variation of BOD along El-Salam canal during various months in 2001. Results from investigating earlier dates (1998-2000) are also available, but not presented graphically in this paper. However, statistical analysis has been applied to the results of all the available records from 1998 to 2001, i.e., 48 records. Both graphical and tabular forms are used to analyze the study results. The results presented in the following graphs are those for the case when matching between the measured and estimated values of BOD is achieved. The annual records are also grouped into four seasons starting from August (flood season in Egypt) and each season has three consecutive months. Each season is presented in a single graph (Figures 2-5).

It can be seen that BOD commonly decreases along zone 1 until El-Serw drain is reached (Figures 2-5). In October and December 2001, BOD decreases in El-Salam canal downstream its mixing section with El-Serw drain implying that El-Serw drain has surprisingly lower BOD in these months than that the upstream section of El-Salam canal (Figures 2 and 3). However, the opposite is true in other months (Figures 2-5). Results in other years have shown that El-Serw drain has higher BOD than that in El-Salam canal at their meeting section in most seasons, but exceptions have been found. The same is true for Hadous drain which usually has higher BOD than at the section of El-Salam canal upstream their mixing section except in September and November 2001 (Figures 2 and 3).

It can be observed that BOD generally decreases downstream mixing sections with drainage waters except for some zones in some months, e.g., Zone 2 in September 2001 (Figure 2). The increase in BOD downstream mixing sections is attributed to the significant BOD load flowing from the equivalent NPS along El-Salam canal in zone 2, e.g., September 2001 in Figure 2, November and January 2001 in Figure 3, February-May in Figures 4 and 5. The reach between EH21 and the mixing section with Hadous drain usually has the highest BOD along El-Salam canal (Figures 2-5).

According to the Egyptian law 48/1982 for the protection of waterways, the BOD concentration along El-Salam canal sometimes violate the law over some sections in 2001. It is worthwhile that the highest BOD is sometimes located at an unmonitored section by the virtue of the estimation technique used. Thus, the worst location along El-Salam canal is not always a monitoring station. The concentration of BOD is as high as 80mg/lit in November and May 2001 (Figures 3 and 5). On the other hand, BOD concentration along El-Salam canal is almost invariant at a section in zones 2 and 3 for the period of February to April 2001 (Figure 4). It can be observed that the BOD at El-Salam siphon almost complies with the Egyptian law 48/1982 in 2001. However, earlier records have shown higher BOD values along El-Salam canal and its feeding drains. Statistical analysis of BOD concentration and discharge values are presented in Tables 3-10. The maximum, the average and the minimum values of BOD are listed as well as the standard deviation and the upper/lower limits. The average discharge (Q) from various sources/sinks and at monitoring stations is listed in Tables 3-10, where +ve values of Q from NPS indicate inflow and –ve ones are for the outflow case (Tables 8-10).
Figure 2  BOD variation along El-Salam canal (August-October 2001)

Figure 3  BOD variation along El-Salam canal (November-January 2001)
It can be seen that the maximum and average BOD values at EI21 reaches 63 and 31.5 mg/lit, respectively, in November-January season (1998-2001) and correspond to the low flow season (Table 3). The latter season has the highest BOD from El-Serw drain as well (Table 4). Although, Hadous drain has high BOD during the low flow season, the highest occurs during May-July season (Table 7). The highest BOD value among various monitoring stations occurs during May-July season at EH17 (Hadous drain) and amounts to 375.2 mg/lit. Moreover the highest standard variation of all monitoring stations has been computed at ES02 (El-Serw drain) and EH17 (Hadous drain) and has values of 96.63 and 91.89 mg/lit, respectively (Tables 4 and 7). The highest BOD variation occurs in November-January at ES02 and in May-July at EH17 (Tables 4 and 7).

Tables 5 and 6 show that the average BOD at pump station 2 (EH21) is higher than that at pump station 1 (EH20) during the period August-January, but the opposite is true during the rest of the year. The highest maximum and average BOD values at EH20 and EH21 have been found to occur during May-July in the examined records (Tables 5 and 6). The highest standard deviation of BOD also occurs during the latter period. Maximum BOD values of 256.4 and 177.2 mg/lit were measured at EH20 and EH21, respectively, in May-July season.

Tables 8-10 present the estimated values of BOD and discharge from the equivalent NPS along zones 1, 2 and 3 of El-Salam canal. It has been found that zone 1 always experiences outflow (-ve discharge) and, hence, the value of BOD varies along the zone as the value of BOD in the adjacent section of El-Salam canal. Thus, Not Applicable (NA) is assigned to the BOD values (Table 8). On the other hand, zones 2 and 3 usually experience inflow into El-Salam canal at an average seasonal rate that varies from 0.26 to 0.48 m³/sec/Km in zone 2 and it varies from 0.31 to 0.76 m³/sec/Km in zone 3 (Tables 9 and 10). The concentration of equivalent BOD from NPS along zone 2 is higher than the corresponding value along zone 3 during the period August-January, while the situation reverses during February-July period. It should be noted that the inflow along zone 3 is generally two or three times the value along zone 2 except in the period August-October. The variation in the equivalent BOD is very high in zone 3 and the lower limit was taken as zero if its value is computed and found to have negative value (Table 10), i.e., meaningless.

**Table 3** Statistical analysis of BOD (mg/lit)/discharge data from the Nile (EI21)

<table>
<thead>
<tr>
<th>Season</th>
<th>Max.</th>
<th>Upper limit</th>
<th>Average</th>
<th>Lower limit</th>
<th>Min.</th>
<th>Standard deviation</th>
<th>Q, m³/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug.-Oct</td>
<td>50</td>
<td>39.5</td>
<td>26.67</td>
<td>13.82</td>
<td>10</td>
<td>12.84</td>
<td>62.496</td>
</tr>
<tr>
<td>Nov.-Jan</td>
<td>63</td>
<td>46.26</td>
<td>31.51</td>
<td>16.76</td>
<td>13.8</td>
<td>14.75</td>
<td>41.64</td>
</tr>
<tr>
<td>Feb.-April</td>
<td>44</td>
<td>37.079</td>
<td>25.77</td>
<td>14.461</td>
<td>10.3</td>
<td>11.309</td>
<td>72.912</td>
</tr>
<tr>
<td>May-July</td>
<td>49</td>
<td>35.71</td>
<td>25.27</td>
<td>14.83</td>
<td>10</td>
<td>10.442</td>
<td>104.16</td>
</tr>
</tbody>
</table>
### Table 4 Statistical analysis of BOD (mg/lit)/discharge data from El-Serw drain (ES02)

<table>
<thead>
<tr>
<th>Season</th>
<th>Max.</th>
<th>Upper limit</th>
<th>Average</th>
<th>Lower limit</th>
<th>Mini.</th>
<th>Standard deviation</th>
<th>Q m³/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug.–Oct.</td>
<td>119.7</td>
<td>95.69</td>
<td>62.87</td>
<td>30.05</td>
<td>24</td>
<td>32.82</td>
<td>21.88</td>
</tr>
<tr>
<td>Nov.–Jan.</td>
<td>379</td>
<td>175.38</td>
<td>78.74</td>
<td>0</td>
<td>21</td>
<td>96.63</td>
<td>19.97</td>
</tr>
<tr>
<td>Feb.–April</td>
<td>126</td>
<td>100.04</td>
<td>69.92</td>
<td>39.8</td>
<td>34</td>
<td>30.12</td>
<td>14.84</td>
</tr>
<tr>
<td>May–July</td>
<td>162.3</td>
<td>135</td>
<td>96.39</td>
<td>37.78</td>
<td>30</td>
<td>48.61</td>
<td>29.29</td>
</tr>
</tbody>
</table>

### Table 5 Statistical analysis of BOD (mg/lit)/discharge data measured at pump station No.1 (EH20)

<table>
<thead>
<tr>
<th>Season</th>
<th>Max.</th>
<th>Upper limit</th>
<th>Average</th>
<th>Lower limit</th>
<th>Mini.</th>
<th>Standard deviation</th>
<th>Q m³/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug.–Oct.</td>
<td>124.7</td>
<td>85.73</td>
<td>52.64</td>
<td>19.55</td>
<td>21</td>
<td>33.09</td>
<td>29.45</td>
</tr>
<tr>
<td>Nov.–Jan.</td>
<td>81</td>
<td>43.95</td>
<td>34.36</td>
<td>24.77</td>
<td>22.1</td>
<td>17.44</td>
<td>19.25</td>
</tr>
<tr>
<td>Feb.–April</td>
<td>134</td>
<td>93.6</td>
<td>63.8</td>
<td>34</td>
<td>35</td>
<td>29.8</td>
<td>19.25</td>
</tr>
<tr>
<td>May–July</td>
<td>177.2</td>
<td>113.74</td>
<td>64.35</td>
<td>14.96</td>
<td>17</td>
<td>49.39</td>
<td>26.29</td>
</tr>
</tbody>
</table>

### Table 6 Statistical analysis of BOD (mg/lit)/discharge data measured at pump station No.2 (EH21)

<table>
<thead>
<tr>
<th>Season</th>
<th>Max.</th>
<th>Upper limit</th>
<th>Average</th>
<th>Lower limit</th>
<th>Mini.</th>
<th>Standard deviation</th>
<th>Q m³/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug.–Oct.</td>
<td>129</td>
<td>91.37</td>
<td>57.3</td>
<td>23.23</td>
<td>12</td>
<td>34.07</td>
<td>27.5</td>
</tr>
<tr>
<td>Nov.–Jan.</td>
<td>81</td>
<td>56.36</td>
<td>38.9</td>
<td>21.44</td>
<td>12</td>
<td>17.46</td>
<td>19.25</td>
</tr>
<tr>
<td>Feb.–April</td>
<td>134</td>
<td>93.6</td>
<td>63.8</td>
<td>34</td>
<td>35</td>
<td>29.8</td>
<td>19.25</td>
</tr>
<tr>
<td>May–July</td>
<td>177.2</td>
<td>113.74</td>
<td>64.35</td>
<td>14.96</td>
<td>17</td>
<td>49.39</td>
<td>26.29</td>
</tr>
</tbody>
</table>

### Table 7 Statistical analysis of BOD (mg/lit)/discharge data from Bahr Hadous drain (EH17)

<table>
<thead>
<tr>
<th>Season</th>
<th>Max.</th>
<th>Upper limit</th>
<th>Average</th>
<th>Lower limit</th>
<th>Mini.</th>
<th>Standard deviation</th>
<th>Q m³/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug.–Oct.</td>
<td>109.8</td>
<td>79.99</td>
<td>54.29</td>
<td>28.59</td>
<td>30</td>
<td>25.7</td>
<td>54.92</td>
</tr>
<tr>
<td>Nov.–Jan.</td>
<td>338.9</td>
<td>158.26</td>
<td>74.4</td>
<td>9.4</td>
<td>34.5</td>
<td>83.85</td>
<td>50.11</td>
</tr>
<tr>
<td>Feb.–April</td>
<td>216.4</td>
<td>128.32</td>
<td>77.55</td>
<td>26.77</td>
<td>40</td>
<td>50.77</td>
<td>37.2</td>
</tr>
<tr>
<td>May–July</td>
<td>375.2</td>
<td>199.73</td>
<td>107.84</td>
<td>15.94</td>
<td>40</td>
<td>91.89</td>
<td>73.55</td>
</tr>
</tbody>
</table>

### Table 8 Statistical analysis of BOD (mg/lit)/discharge data from NPS along zone 1

<table>
<thead>
<tr>
<th>Season</th>
<th>Max.</th>
<th>Upper limit</th>
<th>Average</th>
<th>Lower limit</th>
<th>Mini.</th>
<th>Standard deviation</th>
<th>Q m³/secKm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug.–Oct.</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>-2.718</td>
</tr>
<tr>
<td>Nov.–Jan.</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>-1.54531</td>
</tr>
<tr>
<td>Feb.–April</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>-1.686</td>
</tr>
<tr>
<td>May–July</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>-2.64</td>
</tr>
</tbody>
</table>

### Table 9 Statistical analysis of BOD (mg/lit)/discharge data from NPS along Zone 2

<table>
<thead>
<tr>
<th>Season</th>
<th>Max.</th>
<th>Upper limit</th>
<th>Average</th>
<th>Lower limit</th>
<th>Mini.</th>
<th>Standard deviation</th>
<th>Q m³/secKm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug.–Oct.</td>
<td>278</td>
<td>229.9</td>
<td>138</td>
<td>46.1</td>
<td>10</td>
<td>81.9</td>
<td>0.475</td>
</tr>
<tr>
<td>Nov.–Jan.</td>
<td>367</td>
<td>269.23</td>
<td>156.84</td>
<td>44.45</td>
<td>51</td>
<td>112.39</td>
<td>0.2595</td>
</tr>
<tr>
<td>Feb.–April</td>
<td>308</td>
<td>173.54</td>
<td>86.43</td>
<td>0</td>
<td>15</td>
<td>87.11</td>
<td>0.322</td>
</tr>
</tbody>
</table>
Table 10  Statistical analysis of BOD (mg/lit)/discharge data from NPS along Zone 3

<table>
<thead>
<tr>
<th>Season</th>
<th>Max.</th>
<th>Upper limit</th>
<th>Average</th>
<th>Lower limit</th>
<th>Mini.</th>
<th>Standard deviation</th>
<th>Q m³/sec/Km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug.–Oct.</td>
<td>277</td>
<td>176.62</td>
<td>87.67</td>
<td>0</td>
<td>10</td>
<td>88.95</td>
<td>0.3108</td>
</tr>
<tr>
<td>Nov.–Jan.</td>
<td>239</td>
<td>116.09</td>
<td>54.29</td>
<td>0</td>
<td>10</td>
<td>61.8</td>
<td>0.7643</td>
</tr>
<tr>
<td>Feb.–April</td>
<td>467</td>
<td>294.25</td>
<td>139.75</td>
<td>0</td>
<td>10</td>
<td>154.5</td>
<td>0.7117</td>
</tr>
<tr>
<td>May–July</td>
<td>445</td>
<td>216.58</td>
<td>98.79</td>
<td>0</td>
<td>10</td>
<td>117.79</td>
<td>0.6585</td>
</tr>
</tbody>
</table>

5  Conclusions

A study has been conducted to investigate the BOD variation along El-Salam canal using the monitored water quality data in the period 1998-2001. Estimation has been made for the equivalent BOD from NPS along the canal. Statistical analysis has also been conducted for the BOD values either measured at monitoring stations or estimated from NPS. The following can be concluded:

- The estimation technique could successfully estimate the BOD variation along El-Salam canal and find out sections having BOD concentration higher than that measured at the existing monitoring stations.
- BOD concentration along El-Salam canal generally decreases downstream zone 1, i.e., between the Nile and El-Serw drain outfall. The latter zone has been found to experience outflow most of the time (1998-2001).
- The zones downstream pump station 2 along El-Salam canal experience inflow carrying significant BOD loads into the canal.
- The highest BOD concentrations in 2001 have been found to generally occur in the reach between pump station 2 and Hadous drain.
- Drainage water from El-Serw and Hadous drains generally has BOD values higher than those at their mixing sections along El-Salam canal. Unexpectedly, it has been found that the BOD values measured at ES02 and EH17, i.e., El-Serw and Hadous drains, may be less than the values at the sections upstream their mixing sections with El-Salam canal in some seasons.
- Although the measured and estimated values of BOD along El-Salam canal in 2001 almost comply with the Egyptian law 48/1982 most of the time in 2001, earlier records have shown significant high values of BOD along the canal that violate the Egyptian law. It can be stated that water quality in terms of BOD is slightly improving during the past few years.
- The concentration of equivalent BOD from NPS along zone 2 has been found to be higher than the corresponding value along zone 3 during the period August-January, while the situation reverses during February-July (1998-2001). It should be noted that the inflow along zone 3 is generally two or three times the corresponding values (1998-2001 data) along zone 2 except in the period August-October.
- High values of the standard deviation of BOD have been found to occur at monitoring stations and from the equivalent NPS along El-Salam canal.

5.1  Recommendations

It is recommended to pursue the current investigations and the authors are currently performing the following:

- Studying the possible future operational scenarios of El-Salam canal.
- Predicting BOD variation along El-Salam canal under its possible future operational scenarios employing the statistical characteristics of the canal computed in this study.
- Investigating and analyzing problems with BOD concentrations as predicted by the current technique under various operational scenarios.
- Developing possible enhancement scenarios/techniques of BOD concentrations along El-Salam canal.
- Introducing on-site treatment technologies of drainage water to help improve water quality along El-Salam canal.
- Lining the rest of the canal would help limit the inflow of polluted water into El-Salam canal.
- Investigating the existence of non-point sources of pollution along El-Salam canal.
- Studying other water quality parameters along El-Salam canal.

6  REFERENCES


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[4] Professor, Ph.D., Dept. of Irrig. & Hydr., Faculty of Eng., Cairo University, Giza, Egypt
ABSTRACT

Irrigation development throughout Australia has seen a significant change in the natural hydrological cycle and groundwater systems over the past 50 –100 years. A significant part of all irrigation areas in Australia now have watertables within 2m of the soil surface creating waterlogging and salinisation problems.

In many cases the problems associated with shallow watertables have been controlled by the installation of subsurface drainage systems. Already within the Murray Darling Basin there is approximately 90 000 ha of subsurface drainage, mostly in irrigated perennial horticulture and pasture. The existing subsurface drainage has a significant impact on the salt load in streams and rivers. For example, in the Murrumbidgee Irrigation Area only 7% of the area has subsurface drainage but this contributes 30% of the salt load leaving the area. In today’s social climate the search to manage our natural resource base sustainably and allow equity for future generations dictates that exporting environmental problems is no longer acceptable and we must aim to minimize off site environmental impacts as much as possible.

This paper describes a multi-level drainage system, which aims to improve drainage water quality, presenting results from a field scale land reclamation experiment implemented in the Murrumbidgee Irrigation Area of New South Wales. The multi-level drainage system consisted of shallow closely spaced drains (3.3m spacing at 0.85m depth) underlain by deeper widely spaced drains (20m at 1.75m depth).

Comparisons of water and solute movement between the multi-level drainage system and a single level drainage system are presented in the paper. Significant differences in the performance of the multi-level and single level drainage systems have been found in the watertable regime, drain water salinity and soil salinity.

Keywords: Drainage Design, Multi-Level Drainage, Drainage Salinity, Semi-Arid Drainage

1 INTRODUCTION

In a review of subsurface drainage systems (Christen, Ayars and Hornbuckle, 2001), in irrigation areas in Australia, it was shown that in many cases the drainage salt loads are 5-10 times greater than that applied through the irrigation, even after reclamation of the rootzone was completed, indicating that such systems typically remove stored geologic salt as well as that applied with the irrigation water, Figure 1. Often this stored salt may be from below the root zone and its removal offers little benefit to the crop.
Hornbuckle and Christen (1999) reviewed assessments of salinity in irrigated soils for the Murrumbidgee Irrigation Area (MIA) in SE Australia. They found that soil salinity showed a general increase with depth. Figure 2 shows a typical soil salinity profile for horticultural soils found in the MIA. This shows that generally within the MIA there is considerably less salt stored in the upper soil layers.

For the soil profile shown in Figure 2 the approximate amount of salt stored in the upper soil profile (0-1m) and lower soil profile (1-2m) is 25 and 91 t/ha respectively, hence it can be seen that at
depths greater than 1m there is considerably more salt stored than at shallower depths.

Flow paths to drains have been shown to have a large effect on the quality of drainage water (Jury 1975a,b) and flow path depths are a function of the drain depth and spacing. The shallower and more closely spaced the drain the shallower the depth of flow paths. Considering this, shallow drains placed in areas with soil salinity profiles such as those found in the MIA, should have much reduced drain water salinities and hence present less of a drainage water disposal problem.

The use of a shallow drainage system, has been show in the past to be effective in waterlogging protection, but controlling soil salinisation is less certain (Christen and Skehan 2001, Hermsmeier 1973 & Ghaemi and Willardson 1992). Resalinisation from capillary rise can occur from considerable depths (Talsma 1963) hence if shallow drainage systems are used there is the potential for salinisation from capillary upflow. Considering this a multi-level drainage system is proposed to control soil salinisation while still having the benefits associated with reduced salinity drainage water and effective waterlogging control.

2 Objectives
The aim of this experiment was to compare a Single-Level (SL) and Multi-Level (ML) drainage system in a field situation. The objectives were to:

1. Compare drainage volumes and salinity, and hence salt loads
2. Compare the effectiveness of salt leaching in relation to root zone removal of salts
3. Determine the effectiveness of water table and waterlogging control

3 Methods and Materials
3.1 Site Description
The experimental site was situated in the Murrumbidgee Irrigation Area of New South Wales, Australia. The site had not been previously irrigated for several decades, whilst surrounding areas had been continuously irrigated. This led to severe salinisation of the area. Figure 3 shows the average soil salinity at the site before drainage installation.

It can be seen that the site was saline, well above the recommended salinity levels for grapes for no yield loss of 1.5 dS/m (Rhoades and Loveday, 1990). It was also apparent that the salt content of the deeper soil layers was higher than the surface layers (0-0.5m).

The soil at the study site was an Alfisol, known as a Red – Brown Earth of the Australian Great Soil Groups (Stace et al., 1968). The surface soil is shallow and passes quickly through a clay loam to a light clay. A grey subsoil develops below a depth of 0.75m and continues to a depth of 7m becoming heavier with depth. Soft and hard carbonates are found at depths below 0.5m.

3.2 Experimental Design
Two treatments were installed at the site. These being a Multi-Level (ML) subsurface drainage treatment and a Single-Level (SL) subsurface drainage treatment. The deep drains on the multi-level drainage system were at the same spacing as the SL treatment. This allowed a direct comparison to be made between the systems, with any effects on the salt load of the system being directly attributed to the presence of the shallow drainage system. The ML treatment was placed in the highest salinity area of the field. This was done to provide a thorough assessment of the ML treatment in highly saline conditions.

Drain spacings of the deeper drains were calculated from the methodologies developed by Talsma and Haskew (1959), which led to a design spacing of 20m. Shallow drains were spaced at 3.3m to align with the center of each vine row. Deep drains were laid at a 0.2% gradient and the shallower drains at a 0.1% gradient. A plan view of the drainage system and treatment layout is shown in Figure 4. Surrounding fields were already drained at the same depth and spacing as the deep drains providing a continuous array of parallel drains. A cross-section of each of the drainage treatments is shown in Figure 5.
Figure 3 Average soil salinity at the experimental site, based on 22 cores. Horizontal bars show standard deviation

Drainage water and salt loads were monitored continuously from sumps 2 and 4 using tipping buckets and TPS electrical conductivity sensors (TPS Pty Ltd) interfaced to GPSE dataloggers (Harris Pty Ltd). A total of 42 testwells and piezometers installed at various depths were used to monitor groundwater movement in the treatments. Positioning of the instrumentation is shown in Figure 4.
4 RESULTS

4.1 Drain Flows and Salinity
The salt and water balance data for the treatments during the 2001/2002 irrigation season are shown in Table 1.
Table 1 Irrigation and drainage volumes and salt applied and removed in the ML and SL treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Irrigation (mm)</th>
<th>Total</th>
<th>Draining (mm)</th>
<th>Total</th>
<th>Leaching Fraction</th>
<th>Total</th>
<th>Drainage (mm)</th>
<th>Shallow Drains</th>
<th>Total</th>
<th>Drainage (mm)</th>
<th>Deep Drain</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>541</td>
<td></td>
<td>139</td>
<td></td>
<td>0.26</td>
<td></td>
<td>36</td>
<td></td>
<td></td>
<td>103</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Salt Applied (kg/ha)</td>
<td>433</td>
<td>Salt Removed (kg/ha)</td>
<td>21868</td>
<td>Total</td>
<td>Salt Removed (kg/ha)</td>
<td>1367</td>
<td>Salt Removed (kg/ha)</td>
<td>20500</td>
<td>Total</td>
<td>Average EC (dS/m)</td>
<td>Shallow Drains</td>
</tr>
<tr>
<td>SL</td>
<td></td>
<td>551</td>
<td></td>
<td>120</td>
<td></td>
<td>0.22</td>
<td></td>
<td>493</td>
<td></td>
<td></td>
<td>22541</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Average EC (dS/m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The ML treatment drained 15% more water than the SL treatment, due to the shallow drains. The shallow drains contributed 26% of the total discharge from the ML treatment and the deep drains in the ML treatment drained 15% less than the deep drains in the SL treatment. This indicates that the shallow drains are effective in removing water from the soil profile and reducing the hydraulic load on the deeper drains.

The average salinity of the shallow drains was 4.7 dS/m. This is significantly lower than in the deep drains that averaged 31.7 dS/m and 29.5 dS/m for the ML and SL treatments respectively. This reflects the increasing soil salinity with depth. These results show that by having shallow drains the aggregate salinity of the drainage water can be reduced. Also, the drainage volumes show that by having shallow drains the flows from the deeper drains can be reduced.

In comparing the total salt removed by each of the treatments it can be seen that the ML and SL treatments were comparable at 21868 kg/ha and 22541 kg/ha respectively. However the ML treatment was more saline than the SL treatment (Figure 8). In the ML treatment the shallow drain salt load was 6% of the total, reflecting the lower drainage volumes and salinities than the deep drains. An important issue is where in the soil profile salt removal is occurring, i.e. in or below the root zone. This is discussed in a later section.

In this trial the deep drain spacing in the ML treatment was identical to the SL treatment. Due to the increased drainage rates provided by the addition of shallow drains a sensible design step would be to increase the spacing of the deep drains. With an increased spacing the volumes of drainage from the deep drains in the ML treatment would be reduced and hence salt loads.

Considering these results it can be seen that the multi-level drainage system has the potential to reduce drainage water salt loads over single-level drainage systems.

4.2 Waterlogging And Water Tables

Water tables measured at mid-spacing of the deep drains in the ML and SL treatments with continuous data recorders are shown in Figure 6. It can be seen from the hydrographs that the two...
treatments only differed greatly during periods of high recharge. This occurred during the first irrigation of the 2000/2001-irrigation season and after the 3rd and 4th irrigations and rain event, which occurred in the 2001/2002 irrigation season.

Figure 6 Water table depths under the ML and SL treatments over the experimental period

It is evident that during these high recharge events the ML treatment was more effective in controlling the water table below rootzone depth. During the high recharge periods the water table in the SL treatment reached levels within the rootzone that could be considered detrimental to the plants. At other periods the water table regime in the ML and SL treatments were similar, although water table depths were slightly higher in the ML treatment than the SL treatment. This may have been due to the slightly lower hydraulic conductivity of the ML treatment.

Table 2 shows the number of hours the water table remained above given depths during both irrigation seasons as measured in the seven testwells located in each treatment. It can be clearly seen that the ML treatment is significantly more effective in keeping the water table below the rootzone.

Table 2 Total time water table levels above specified depths (hours)

<table>
<thead>
<tr>
<th>Depth</th>
<th>Treatment</th>
<th>ML</th>
<th>SL</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 500 mm</td>
<td></td>
<td>84</td>
<td>526</td>
</tr>
<tr>
<td>&lt; 750 mm</td>
<td></td>
<td>248</td>
<td>764</td>
</tr>
<tr>
<td>&lt; 1000 mm</td>
<td></td>
<td>784</td>
<td>1330</td>
</tr>
</tbody>
</table>

Based on the water table data the ML treatment can be seen to be more effective in preventing waterlogging than the SL treatment. Water table levels after high recharge events are rapidly reduced due to the presence of the shallow drains, which are extremely effective in preventing waterlogging of the rootzone.
4.3 SOIL SALINITY

Soil salinity changes were monitored over the experimental period using EM38 ground conductivity surveying and soil coring. Six cores were taken in each treatment during each sampling event at cross-sectional positions on the drain and at mid-drain spacing of the deep drains. This cross-section sampling was undertaken at ¼, ½ and ¾ lengths down the field in each treatment. The ESAP software package (Lesch, Rhoades and Corwin, 2000) was used to construct calibrated soil salinity maps. These are shown as 9 layers for before drainage and after two irrigation seasons, Figure 8.

It can be seen that there was significant reductions in soil salinity in both treatments. The higher initial soil salinity levels in the ML treatment have been reduced to levels similar to the SL treatment. The shallow soil layers (<0.5m) have been more effectively leached in the ML treatment. The effect of the deep drains in both treatments can clearly be seen in the 1.05, 1.35 and 1.65m depths where salt leaching close to the drain has been much greater than at mid drain spacing.

To investigate the zone of salt removal the percentage reduction in soil salinity for each soil layer was calculated, Figure 7.

![Figure 7 Percentage change in soil salinity (EC1.5) over two irrigation seasons](image)

It can be seen that the ML treatment has been more effective in removing salts from the upper soil layers (<0.5m) compared to the SL treatment. This is useful as this is the main root zone which requires leaching to be as rapid and uniform as possible. Between 0.5 and 1.0m the two treatments performed similarly, however below 1.0m the SL treatment removed more salt. This is not a great advantage to the crop as this is well below the main root zone. For the Semillon vines grown during the experiment it appeared root depth was no deeper than 0.4m based on soil moisture monitoring. For mature vines the rooting depth would be greater. Cox (1995) in studying root distributions in well water furrow irrigated vineyards with mature vines in the region found maximum rooting depths of 0.6-0.8m. Therefore, leaching of salts is only essential to a 0.8m depth to maintain vine health. Leaching below these depths is essentially non-beneficial to the plant, also resulting in higher salinity water requiring disposal.
A NEW APPROACH TO OVERCOME THE WATERLOGGING AND SALINITY PROBLEMS IN THE ARAL SEA BASIN

A.S.Kapoor

ABSTRACT
The annual irrigated area from the water of the rivers Amu Darya and Syr Darya in the Aral Sea Basin has increased from 2.5 million hectares (1900) to 8.0 m ha (2000). The estimated average available annual water resource is about 120 billion cubic metres (bcm). The volume or return water is about 30 bcm, a major part of which is disposed off into the rivers.

The water logging and salinity conditions have caused decline in agriculture produce. It is estimated that out of an irrigated area of 8 m.ha, 5.7 m.ha area needs drainage. The drainage measures have so far been carried out over a total area of about 4.5 m ha, an area of 1.0 m.ha is provided with sub surface horizontal drainage, 0.8 m.ha with vertical drainage and rest with open drains. The results of the practised drainage measures are far from satisfactory on account of many reasons.

The reported levels of salinity in the drainage return waters for the period 1990-97 are as follows:

<table>
<thead>
<tr>
<th>Reaches</th>
<th>Salinity in mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper reaches</td>
<td>1500-3000</td>
</tr>
<tr>
<td>Middle reaches</td>
<td>3500-6000</td>
</tr>
<tr>
<td>Lower reaches</td>
<td>5000-7000</td>
</tr>
</tbody>
</table>

The salinity of the natural water of the rivers, in the beginning of the century used to be about 250 mg/l in the upper water shed and 1000 mg/l in the low lands. It has been progressively increasing everywhere. The major cause of this increase is the discharge of saline drainage water from irrigated lands into the rivers.

The scenario of discharge of drainage water into the river thereby increasing river water salinity, then using greater volumes of saline river water for irrigation and again discharging back salts into the river results in a vicious cycle in which the demand for irrigation water keeps on growing and the salinity of river water keeps on increasing. The Aral Sea Basin, unfortunately, is caught in this vicious cycle.

The discharge of saline drainage water from irrigated lands into the rivers is the major cause of the problem. The drainage measures such as the horizontal sub-surface or open drains that are contributing to the problem can be a part of the solution, only if the drainage water can be conveyed to the sea through out fall drains without ever getting into the rivers and/or disposed off in evaporation tanks with safe disposal of accumulated salts. Another way could be to demineralise drainage water before it is discharged into the rivers. None of these seems to be feasible.

The right approach, therefore, would be to reduce and ultimately stop altogether the discharge of drainage water into the rivers. Biodrainage in which excess groundwater is removed from the soils by tree plantations by transpiration can be a feasible option. This can prevent the flow of saline drainage water into the river thereby helping to restore the salinity levels in the river water, to the original natural levels of less than 250 mg/l.

Water logging/salinity problem in irrigated lands in the Aral Basin cannot be overcome by traditional drainage measures. There is a threat of its getting worse and worse with passage of time. Biodrainage, by itself or in combination with other drainage measures, can be of great help.

Keywords: Aral Basin, Waterlogging, Salinity, Biodrainage

1 INTRODUCTION

1.1 Irrigation and Drainage Development
A programme to utilise the waters of rivers Amu Darya and Syr Darya for irrigation on a large scale to transform barren desert into productive farm
A NEW APPROACH TO OVERCOME THE WATERLOGGING AND SALINITY PROBLEMS IN THE ARAL SEA BASIN

Land covering an area of about 8 million hectares was undertaken in the Central Asia in the 1960’s. The growth of irrigated area according to Dukhovny and Umarov (2000) was as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual Irrigated area (m. ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>2.5</td>
</tr>
<tr>
<td>1960</td>
<td>4.5</td>
</tr>
<tr>
<td>1970</td>
<td>5.2</td>
</tr>
<tr>
<td>1980</td>
<td>6.9</td>
</tr>
<tr>
<td>1990</td>
<td>7.5</td>
</tr>
<tr>
<td>2000</td>
<td>80</td>
</tr>
</tbody>
</table>

The five Sea Basin States are Turkmenistan, Uzbekistan, Tajikistan, Kirgizistan and Kazakhstan. The average annual water resource of the basin is estimated as 120 billion cubic metres (bcm). Dukhovny and Yaku Bov (2000) give annual water use figures as follows:

<table>
<thead>
<tr>
<th>Water Use in Cubic km (or bcm) in Aral Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>Water resource</td>
</tr>
<tr>
<td>Return water</td>
</tr>
</tbody>
</table>

From the total volume of return water (30-36 cu Km.), 55-60% is used for irrigation. The total irrigated area has expanded up to 8 m. ha.

The withdrawal of water from the rivers resulted in progressively reduced inflow into the Aral Sea into which the rivers were ultimately discharging. As a result, the Aral Sea started shrinking in the 1970’s; salinity of the Aral Sea rose and several phenomena of environmental degradation such as the destruction of the eco-systems around the sea, extinction of many fish species, and pollution of ground water were discovered. The occurrence of illness among the residents rose because of salty dust sprays in the surrounding areas as high winds picked up salts from the drying bed of the sea. Takano.Y (1994) stated that the cause of the Aral Sea crisis is the same one that destructed the Mesopotamia and Mohenjo-Daro civilizations. The same catastrophic phenomena that mankind experienced those days are recurring today due to inadequate counter measures against salinization and other failures of arid region irrigation. If we fail today to solve the environmental crisis because of our ignorance and arrogance, the next generation will lose their place to live and suffer. The cause of the Aral Sea crisis is apparent and its counter measures technically attainable. We must solve the crisis since it is a crisis universal to us, the human beings.

The ill effects of the extensive irrigation cum drainage programme are not confined to the Aral Sea alone. The ground water table in the irrigated areas is rising progressively along with an increase in the salinity of soils. Dukhovny and Umarov (1990) give the following picture:

<table>
<thead>
<tr>
<th>Year</th>
<th>Irrigated area (m.ha.)</th>
<th>Depth of ground water level (per cent area)</th>
<th>Degree of soil salinity (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;2 m</td>
<td>from 2 to 3 m</td>
</tr>
<tr>
<td>1990</td>
<td>7.47</td>
<td>24.8</td>
<td>32.7</td>
</tr>
<tr>
<td>1994</td>
<td>7.96</td>
<td>31.1</td>
<td>29.9</td>
</tr>
</tbody>
</table>

The waterlogging and salinity conditions have caused decline in agriculture produce. As an illustration, Dukhovny and Umarov give the example of Makpaaral zone of South Kazakhstan in the middle reach of Syr darya river, where an irrigated area of 40.6 thousand hectare was a fertile land with cotton yields of 3.2 to 3.5 tons per hectare upto the year 1985 which progressively declined to the low level of 1.9 ton per ha. by the year 1996.

It is estimated that out of an irrigated area of 8 m.ha., 5.7 m.ha. area needs drainage. The drainage measures have so far been carried out over a total area of about 4.5 m ha; an area of 1.0 m ha is provided with sub-surface horizontal drainage, 0.8 m ha with vertical drainage and the rest with “mufriga” and “zauras” which are open drains and canals. It has not been possible to maintain and operate the drainage systems properly as a result of which these have deteriorated and do not provide the intended relief. The main reasons of neglect of drainage systems are high costs, shortage of electric power (for pumping), lack of participation by water users, low land productivity and unavailability of investment funds. Most existing drainage facilities now require reconstruction.

Dukhovny and Umarov (2000) describe to approach the problem in the following three principal directions:
• completion of drainage facilities, where they have not been, as required by design;
• reconstruction of the existing drainage facilities;
• proper maintenance of the existing drainage facilities.

To start these it is necessary to:

• work up a more complete understanding of the present structure of land use;
• improve the methods and assessment criteria of the state of land melioration and fertility, considering the following: condition of irrigation and drainage networks, shortage of water resources and deteriorating quality of irrigation water. Assess lands in Central Asia using the new criteria and methods;
• develop a system to assess the state of drainage. Identify the operational state of existing drainage facilities and necessary rehabilitation measures;
• determine standards for drainage system design with consideration for on-farm irrigation demands, water quality and the transition to new regulations on water and lands use;
• design standards for the operation of drainage systems that will allow responsibility for operation and maintenance to be transferred to Water User Associations.

In principle, the proposed actions will minimize water loss in irrigation network, but require a great capital investments. It will require the following steps:

• implementation of crop irrigation regimes in accordance with planned yields;
• a sharp improvement in the scale of leaching regimes by adoption of intensive methods of crop cultivation (deep soil loosening, chemical ameliorants and organic fertilizers, deep ploughing, crop rotation);
• to secure uniform moistening and desalinization of soil and minimization of groundwater infiltration through optimization of the size of irrigated plots and land leveling;
• revision of crop selection with regard for the environmental, economic and social conditions in the region;
• exclusion of strongly saline lands from cropping;
• raising the efficiency of inter-farm and on-farm irrigation network by anti-filtration lining;
• organizing of the manufacture and large scale introduction of better drainage machinery and improved irrigation technology to achieve a inform supply of water along furrows and consistent moistening of the root zone;
• organization of regular cleaning and maintenance of inter-farm and on-farm collectors and water intakes, to prevent further deterioration of technical conditions of primary drains and the appropriate drainage of irrigated lands;
• to initiate repair and rehabilitation works of on-farm drains, drainage collectors and tube wells, as well as expansion of the modern drainage technologies;
• to definite proper government support to drainage network, especially for vertical drainage and inter-farm collectors;
• to organize local base for maintenance and repair of drainage system on contract base;
• to rehabilitate the local production of tubes and drainage techniques;
• to create the training and education of young specialists in drainage (construction, operation, maintenance).

It would be an uphill task to carry out the proposed measures successfully. A fresh look is needed on the two vital aspects, of water management and drainage methodology to search alternative approaches and methods that may be effective.

2 Water Resource Management

Assuming that 96 bcm (80 per cent of the available annual water resource of 120 bcm) is used for irrigation and an additional quantity of return water, 18 bcm (55-60% of 30-36 bcm) is also so used, the total water volume of 114 bcm is presently used to irrigate an area of 8 m ha annually. This gives the overall irrigation water use figure of 1.45 m. This is far too excessive and is an important cause of the prevailing problems.
Dukhovny and Umarov mention that in the Makpaaral zone of South Kazakhstan, cotton yields of 3.2 to 3.5 tons/ha were being obtained up to 1970', with irrigation water use (including leaching requirement) of 650 mm. In the Hunger Steppe area, the recommended water delivery for optional reclamative regime is 895 mm against the old practice of delivering water at the rate of 1344 mm.

In the Indus basin in India and Pakistan, irrigation over an area of 26 m ha is based on a water delivery of about 600-mm.

The reasons for the use of excessive water for irrigation appear to be (i) liberal availability of water to the water users particularly in upper reaches; (ii) increasing salinity in the irrigation water as well as in the soils requiring greater fractions of leaching water. The remedial measures should aim to control and regulate irrigation water supply at rates no more than actually needed by the crops.

In case the rate of water application for irrigation is restricted and regulated to 650 mm, then the water use for irrigating 8.0 m ha area would be about 52 bcm (against 114 bcm as at present) resulting in a possible saving of 62 bcm. The volume of return water may reduce to about 10 bcm (20% of 52 bcm), that is 26 bcm less than at present (which is 36 bcm). The net saving in water use would work out to 62-26 = 36 bcm. This quantity of water can then be used for irrigating additional lands or allowed to flow into the Aral Sea or shared between the two options. This arrangement would help to:

- overcome the environmental and other problems being faced due to shrinking of Aral Sea.
- reduce the problem of water-logging and salinity in irrigated areas.
- improve the quality of water in the rivers.
- save water for additional productive use.

### 3 Salinity Management

It is reported (Dukhovny & Yayubov) that 55 to 70 per cent of return water in Syr Darya basin and 40-48 per cent of that in Amu Darya basin is discharged into the rivers. The total annual return water volume being 30-36 cu.Km., the net volume of return water being discharged into the rivers is therefore about 18 cu.Kms.

The reported levels of salinity in the return waters for period 1990-97 are as follows:

<table>
<thead>
<tr>
<th>Reaches</th>
<th>Salinity in mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper reaches</td>
<td>1500-3000</td>
</tr>
<tr>
<td>Middle reaches</td>
<td>3500-6000</td>
</tr>
<tr>
<td>Lower reaches</td>
<td>5000-7000</td>
</tr>
</tbody>
</table>

Taking the overall average salinity of the return water discharge into the river as 3500 mg/l, the total salt load discharged into the river annually by the return waters, works out to about 63 million tons.

The volume of drainage water from one hectare of irrigated land in Hunger steppe under the old zone of irrigation (unoptimal reclamative regime) was 7877 cu.m containing 27.57 tons of salt. Under the new zone of irrigation (optimal reclamative regime) the volume of drainage water from one hectare of irrigated land reduced to 2130 cu.m containing 10.22 tons of salt. It was concluded that if irrigation in Central Asia is practised in accordance with the recommended optimal reclamative regime, the salt discharge into the rivers due to return waters would reduce to 40 per cent of the present value. But even under the recommended optimal reclamative regime, discharge of 10 tons of salt from one hectare of irrigated land would result in a total annual discharge of 80 million tons from 8 m.ha. and if 60 per cent of this finds its way into the rivers, the net annual discharge of salts into the river would still amount to 48 m. tons.

Dukhovny and Yayubov mention that in the Syr Darya basins the salt content in the return water in the upper reaches is 1500 to 3000 mg/l and in the lower reaches 3500-7000 mg/l. Similar picture is found in the Amu darya basin. The collector drainage water salinity is 1500-4800 mg/l. While discussing the re-use of drainage water for irrigation they classify the water with salinity 600-1090 mg/l as good (I Class), that with salinity 1000-2500 mg/l as satisfactory (II class), that with salinity 2500-6000 mg/l as weakly satisfactory (III class) and that above 6000 mg/l as bad (IV class).

In the Aral Sea basin an annual river flow of 120 bcm of salinity 250 mg/l and return flow of 18 bcm with average salinity of 3500 mg/l would give total annual salt contribution of 93 million tons. When drainage water is discharged into the rivers, the salinity of the mix water in the river increases. The
quantity of increase would depend upon the salinity of drainage water and its volume. The following table shows the average salinity of mix-water in the river corresponding to different salinity levels of the return water and different mix ratios. It is seen that there is manifold increase in river water salinity due to the discharge of saline drainage water into the rivers.

<table>
<thead>
<tr>
<th>Salinity of natural river water (mg/l)</th>
<th>Salinity of return water (mg/l)</th>
<th>Average resultant salinity of mix water of ratio (natural: return) (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>1500</td>
<td>4:1 5:1 6:1 7:1</td>
</tr>
<tr>
<td>2000</td>
<td>800</td>
<td>643 594</td>
</tr>
<tr>
<td>3000</td>
<td>1200</td>
<td>1042 1029</td>
</tr>
<tr>
<td>4000</td>
<td>1600</td>
<td>1375 1357</td>
</tr>
<tr>
<td>5000</td>
<td>2000</td>
<td>875 844</td>
</tr>
<tr>
<td>6000</td>
<td>2400</td>
<td>1208 1174</td>
</tr>
<tr>
<td>7000</td>
<td>2800</td>
<td>1214 1188</td>
</tr>
</tbody>
</table>

When mix-water from the river is used for irrigation, the need for leaching fraction increases with increase in salinity in the irrigation water. The direct use of saline drainage water for irrigation results in even greater requirement of water for leaching and irrigation. The volume of net drainage water discharged into the river may be reduced but not the quantity of salts. Therefore, the salinity in river water is not reduced. Discharge of drainage water from irrigated fields into the river, can provide relief from salinity to the drained areas on regional or local basis, but in the overall terms it creates more problems than it solves. Horizontal sub-surface or open drainage systems can be no solution to the overall problem being faced in the Aral Sea Basin, unless the drainage water can be safely disposed off into evaporation tanks or discharged into the oceans through dedicated outfall drains without being put into the rivers. The experience on evaporation tanks, so far is not very encouraging. The outfall drains are very expensive and difficult to construct and maintain.

The scenario of discharge of drainage water into the river thereby increasing river water salinity, then using greater volumes of saline river water for irrigation and again discharging back salts into the river results in a vicious cycle in which the demand for irrigation water keeps on growing and the salinity of river water keeps on increasing. The Aral Sea Basin, unfortunately, is caught in this vicious cycle. The traditional drainage measures, the horizontal sub-surface or open drainage systems or the vertical drainage systems cannot solve the problem of the Aral Sea Basin area, in the long term on a sustainable basis. The viable solution can be only that in which the salts from irrigated areas do not find their way into the rivers.

### 4 Bio-drainage

Dukhovny and Umarov classify reclamative regimes as follows:

- **automorphous regime** - irrigation water not connected with ground water. Infiltration is free.
- **semi automorphous regime** - ground water backs up irrigation water but almost doesn't feed plants
- **semi hydromorphous** - ground water feeds plants prevailing over irrigation water
- **hydromorphous** - plants are mainly fed by ground water

Under the bio-drainage scheme, the irrigated crops (cotton etc.) would grow under automorphous regime while the tree plantations to provide drainage would be under the hydromorphous regime. The tree plantations are to be raised in blocks and strips adjacent but outside the blocks of irrigated areas.

#### 4.1 Water balance

Dukhovny and Umarov, for the optimal reclamative regime in respect of Hunger Steppe estimate the volume of drainage water as 2130 cubic metres corresponding to total water application of 11530 cubic metres. The volume of drainage or recharge water is approximately 20 per cent of the applied water. They give the figure of annual potential evaporation as 1200-1700 mm.

Kapoor (2001) suggests that tree plantations can transpire quite large volumes of ground water at shallow depth. To estimate the area required for tree plantations for transpiring as much quantity of ground water as is added in the form of recharge from irrigated area, he gives the following relationship:

\[
P/C = \frac{R_c \times A_c \times I_i}{R_c}
\]
A NEW APPROACH TO OVERCOME THE WATERLOGGING AND SALINITY PROBLEMS IN THE ARAL SEA BASIN

Where \( P/C \) represents the fraction of culturable area that must be under afforestation

\[ R_F \]

is the recharge factor i.e. ratio of net recharge (to ground water) to total irrigation water supply

\[ A_F \]

is the area intensity factor of irrigated agriculture

\[ A_{Apan} \]

is surface evaporation from a standard pan

\( k \)

is adjustment 'factor' to account for canopy cover, tree species and salinity of ground water.

\[ k \times A_{Apan} \]

represents the quantity of Tree Water Use

For the Aral Sea Basin, if \( R_F = 0.2 \), \( A_F = 1.0 \), \( l_R = 660 \text{ mm} \) and \( k \times A_{Apan} = 1300 \text{ mm} \), then \( P/C = 0.10 \), that is, tree plantations over 10 per cent of the area can provide the needed bio-drainage to check the rise of ground water table and stabilise it at safe deep level. Tree plantation in blocks or strips, suitably distanced and dispersed in the irrigated area can help achieve a water balance to overcome the threat of water logging.

Kapoor (2001) recommends the use of Donnan equation to decide on the spacing of plantations:

\[
L^2 = \frac{8K Y_o h}{R} + \frac{4Kh^2}{R}
\]

Where

\( L \)

is distance between plantations

\( R \)

is rate of recharge

\( Y_o \)

is height of water level above barrier layer underneath plantations

\( K \)

is hydraulic conductivity

\( h \)

is head difference

4.2 Salt balance

The annual salt input with 650 mm of irrigation water containing 250 mg/l salts would be 1.65 tons/ha/yr.

The harvested raw cotton produce of 3 tons/ha along with 7 tons/ha of foliage containing 3.33 per cent average minerals (cations – Na + Ca + K + Mg), would enable extraction and removal of salt compounds to an extent of 1.0 ton/ha/year (The weight of salt compounds of sodium, calcium etc. is on average about three times the weight of cation elements found in the plant by ash analysis). The data of cotton/foliage produce and mineral content in them is to be checked for the relevant site and if it is different from the figures given above, then the actual field data should be used to estimate mineral removal by harvested agriculture crops.

Tree plantations over 10 per cent area with utilizable bio-mass produce of 30 tons/ha/year, containing 2.5 per cent minerals (cations), would enable evacuation of another 0.2 tons of salt compound per ha per year.

Total extraction and removal of salts by crops and plants would be about 1.2 tons/ha/year. This would be 0.45 tons/ha/year less than the salt input of 1.65 tons/ha/year. This would result in an increase in the salinity of ground water. Kapoor (2001) describes a method of estimating the rate at which the ground water salinity may be expected to increase and shows that this rate while using irrigation water of low salinity is likely to be too slow to be a matter of concern.

There can be methods to achieve full salt balance. Cervinka et al (2001) describe experiment on growing Salicornia plant giving a bio mass produce of 10.5 tons/ha with as much as 43.5 per cent mineral content. Growing of Salicornia plants on one hectare area by irrigating from pumped ground water can help remove about 4.5 tons of salts from the ground water. Such plantations over relatively small areas can help in achieving a total salt balance.

An acceptable salt balance is feasible with the help of crops and plantations so long as the irrigation water is of good quality. Therefore, a feasible approach, for overcoming the problem being faced in the Aral Sea Basin, is to prevent the pollution and increase in salinity of the river water. If the discharge of drainage water from irrigated lands is totally stopped along with elimination of discharge from other polluting sources, the salinity level in the river waters can be restored to the original natural level of 250 mg/l or even lower. Bio-drainage can help to achieve this.
5 Other benefits:
In addition to providing drainage, the tree plantations would give economic and environmental benefits of great value, so much so that the net cost of providing drainage may be near zero. Good deal of data is available on suitable plantations for different conditions of soils and climates. A start can be made on the basis of available information and experience. Further research for improvements and finding answers to gaps in knowledge may be needed.

6 Conclusion:
In the Aral Sea Basin the annual irrigated area has increased from 2.5 m.ha at the beginning of the century to 8 m. ha by the year 2000. The salinity of the water of the rivers Amu Darya and Syr Darya, which earlier used to be about 250 mg/l in the upper watershed has been progressively increasing. The salinity levels in the lower reaches of the rivers are much higher. The major contributory source to the progressively increasing salinity is the discharge of saline drainage water from irrigated lands into the rivers. The water salinity of return water in the upper reaches is 1500-3000 mg/l, in the middle reaches 3500-6000 mg/l and in the lower reaches 5000-7000 mg/l.

The waterlogging and salinity are on the increase in the irrigated land causing loss in agriculture productivity. The problem is proposed to be overcome by cutting down on the volume of water that is excessively used for irrigation and by extension and reconstruction of the horizontal sub-surface and open drainage systems.

There is no doubt that better water management to reduce the quantity of water being used for irrigation would help and is a step in the right direction. But it is doubtful whether horizontal sub-surface and open drainage systems can be sustainable in the long term for the entire basin taken as a whole. The discharge of saline drainage water from irrigated lands into the rivers is the major cause of the problem. How can then it be a part of the solution? The right approach should be to reduce and ultimately stop altogether the discharge of saline drainage water into the rivers. This cannot be achieved by reconstructing and extending the horizontal sub-surface and open drainage systems. This may further aggravate the situation.

The vertical drainage systems can be effective where the ground water is of good quality and where assured electric power is available for pumping. But in this system the salts are merely recycled and not removed from the system.

Bio-drainage, in which excess groundwater is removed from the soils by tree plantations by transpiration can be a feasible option. They can prevent the flow of saline drainage water into the river and restore the salinity levels in the river waters to the original natural levels of less than 250 mg/l. This in turn can help in achieving salt balance by removal of enough salts through the harvested crops and foliage.

7 REFERENCES

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ABSTRACT

Technical solutions are developed for the structures at the irrigation-drainage systems to improve drainage efficiency and drainage and escape water quality under reconstruction. The original technical solutions are suggested to purify drainage flow with natural sorbents using the following structures and techniques: drain spacing decrease, drainage pipes joining using the prism of filtering fill, local purification plant on the base of filtering well, filtering dam in the idle canal.

Some technical solutions have got the licenses of Russian federation and have been applied at drainage flow purification in Russia.

Technical solutions are carried out for the different elements of drainage network and can be chosen appropriate to natural conditions and drainage flow purification.

The developed technical solutions provides drainage efficiency increase by 20%, allows to reduce pollution of water resources by 20%, to raise economical benefit and to reduce the ecological failure costs.

1 Introduction

To raise the efficiency of irrigated lands the reclamation conditions of the territory are to improve, the drainage operation being one of the most important measure. By the turn of the centuries irrigated area in Russia has been decreased from 6 to 4,65 mln. Hectares, 15 per cent of above mentioned area being in unsatisfactory conditions now. The major reason of irrigated lands failure is lack of drainage or it’s inefficiency. Recently drainage systems have extended on the 1,2 mln. Hectares in the south of Russia (25% of the irrigated area), 15 per cent have being required drainage facilities yet. The lack of proper financial support for the drainage maintenance last decade has been deteriorated situation.

2 Results of drainage systems survey in the south of Russia

Recently the most widespread type of drainage construction at the irrigated lands in the south of Russia is the subsurface horizontal drainage. The prevalent drain depth is 2,5-3,0 m, the drain spacing is 120-150m. At heavy soils the drain spacing is reduced up to 80-100m. Surface drainage is used primary at rise planting and at soil leaching measures. The main canals are usually surface when discharge is more than 1 m³/c.

Our research allows making decision about reconstruction of drainage systems on the irrigated lands to develop new techniques for its application in practice.

New techniques proposed for drainage systems reconstruction provide their secure operation within the ecological standards and improve their efficiency during at the maintenance.

Last years many new drainage techniques have been developed according to the modern landscape conception of drainage application. The main statement of this conception is to create drainage system as a part of landscape and to use drainage for water resources management. Major aim of drainage systems creation at the irrigated land is to provide stable crop yield.

To carry out new techniques analyzes of drainage systems efficiency for the irrigated lands in the south of Russia have been fulfilled. The total area covered at the analyzes equal 141364 hectares, more than 53 per cent of mentioned territory being at inadequate efficiency. The results of survey of drainage systems in the south of Russia being carried out during the last two decades shows that drainage facilities exist on the area – 191721 hectares including: 44946 hectares - surface drainage; 142823 hectares – subsurface drainage; 3952 hectares – vertical drainage. The carried out analyzes of the drainage systems operation at the irrigated lands for 3 regions of south Russia (Stavropolskii kray, Povoljie, Rostovskaya obl.) shows:

The operation conditions on the irrigated lands in the south of Russia depend on the technical conditions of drainage network. To raise the efficiency of the irrigated lands we have to improve drainage system operation.
Recently drainage network on the irrigated lands in the south of Russia has been occupied 1,2 million hectares (25% of the whole-irrigated area) and 15% of above mentioned land needs drainage measures.

The total square of analyzed territories for the above mentioned region equal 141364 hectares, the total area with failure in drainage network operation equal 74527 hectares (53% of the total). The differentiated information on the reasons of drainage network failure according to these three regions is shown on the diagram. (Fig.1).

Inadequate operation condition on the irrigated land have been caused by the failure in drainage network operation in 53% of land has been observed. The main reasons at drainage system operation failure are the following:

2.1 **Stavropolskii Kray**
The main reason of the drainage network failure (up to 54% of the territory) was the shallow drainage and small drain spacing.

2.2 **Povoljie**
Vertical drainage (17347 hectares) needs new pumps and electro-technical equipment and proper maintenance. Horizontal drainage needs reconstruction to deepen drains and to decrease drain spacing.

2.3 **Rostovskaya obl**
The main reason for the drainage network failure here is damage of some intersystem structures (drain mouth, wells, pipes).

The survey has been fulfilled using data of the regional institutes (StavNIIGiM, VolgNIIGiM, Yugmelioratsiya, Volgoproekt, Astrakhangiprovodkhoz) under the direction of Proff. Kireycheva L.V. (VNIIGiM).

### 3 NEW TECHNIQUES TO RAISE DRAINAGE EFFICIENCY AT IT’S RECONSTRUCTION

The main recommendations for the future researches were to carry out new techniques for drainage network reconstruction on the irrigated lands, providing their higher efficiency, drainage flow purification and it’s reusing and utilization.

One of the main direction at drainage network reconstruction for the irrigated lands in the south Russia are therefor to deepen drain, to decrease drain spacing and to provide drainage flow purification. According to these main directions the follow technical decisions have been carried out:

3.1 **Drain spacing decrease**
To decrease drain spacing new techniques are proposed in our institute. This techniques are based on the operation of mobile drainage machine created in VNIGiM: drainage machine ETC-1607 has the wheel driving. It allows pipes at the diameter up to 100 mm to be laid at the depth up to 1.6m. Such drain may be laid both along the existing drains and across them. This technique provides to raise drainage efficiency and to below the subsurface water table at the area served.

3.2 **Drainage pipes joining using the prism of filtering fill**
Technical solutions at drain deepening and drain spacing decreasing (Fig.2). At drain deepening and drain spacing decreasing the existed shallow drainage main drain have to be joined to the new drainage network. The careful joining is shown on the Fig.2.
We suggest to join the exist drain to the new drain or main drain (using the prism of filtering fill). To purify drain flow we suggest to use grained sorbing instead of gravel package as the material of filtering fill for this technical solutions.

At exist drain joining to the new deeper main drain the slots are maid in upper part of the main drain. After that the main drain are enveloped with geotextile and then the backfill are maid of grained sorbing (for example grained sapropel). At drain spacing diminishing new drains are joined to new main drains with overlap joint or with the triangle joint.

![Figure 2: Junction of existing main to new main drain (A) and existing main drain to the new drain (B):](image)

1 – the existing drain; 2- new main drain; 3- geotextile envelope; 4 – backfill of grained sapropel; 5- ground backfill; 6 – new drain; 7 – the existing main drain.

New drains are joined to the new main drains with the help of inspection wells. To purify drainage flow we suggested to use grained sorbing as the fill in the well. So we carried out the structure of the local purification plant for intersystem drainage flow purification.

3.3 Local purification plant on the base of filtering well

Local purification plant are made on the base of standard filtering well being equipped with additional removable filtering package consisting of the geotextile envelope fill with grained sorbing material SORBEX. SORBEX is a sorbing material being developed in VNIIGiM on the base of sapropel mixture with mineral substances. The well is provided with bottom filter up to 1 m wide made of gravel, broken stone or other filtering material.

Local purification plant is installed at the main drain mouth or at the drain mouth. At the well size equal 1,5 x1,5 m it is required about 1 ton of sorbing material SORBEX to absorb 100 kg pollutants from drainage flow. The absorbing capacity of SORBEX is 250 mg-equ per 100g dry substance. The results of SORBEX efficiency testing showed: 90-98% at heavy metals absorbing and 98 –100% at pesticides absorbing.

Filtering well application is very perspective measure at every stage of water purification and water preparation. The well depth depends on the hydrogeologic conditions of the plot and the water level in water receiver. The most rational place for the filtering well location is at drainage flow escape outside the drainage system. Sometimes at the favorable conditions it is possible to escape drainage water having been purified to the subsurface water.

Sorbents’ application in the filtering wells together with supplement bio-purification allows to provide intersystem drainage flow purification at every structure of drainage network: at the drain mouth; at the main drain; at the water receiver.

Filtering well capacity is up to 100 m$^3$/day. At rate of drainage flow equal 0,05 l/day per hectare it is necessary to install one filtering well per 50 hectares of area drained.

To regenerate sorbents after their removing from the filtering well the liquid ammonia solution is used (5-10% by the mass of sorbent). The leaching water can be used as fertilizer so we’ve obtained the recycling technique for drainage flow re-using at drainage system reconstruction.

3.4 Filtering dam in the idle canal

When the idle canal is rather long we carried out the filtering dam to purified drainage flow. The filtering dam is maid of gravel package. On the upstream face of the dam the sacks (bags) maid of filtering materials, filled with grained sorbing are located.

The filtering dam is installed at the main drain inflow to the flow regulating structure. Its utilization is to purified drainage flow from heavy metals and pesticides forming the proper filtration rates. Hydraulic conductivity of gravel package forming the dam is not less than 40 m/day. Sacks with grained sorbing material
located on the upstream face of the dam are removable. To construct the dam the filtering calculations are to be provided and the necessary amount of sorbing material are to be determined.

Filtering calculations include filtering flow velocity determination and its further comparison to the standards of low filtration values at water purification measures. The computer program for these purposes using the system of equations by Pavlovskii is being elaborated.

In VNIIGiN different types of filtering dam have been developed respectively to the drainage flow pollution, economical and natural condition of irrigated lands and the type of sorbent being used.

Filtering dam installing in the idle canal of drainage network provides the ecologically safe escape of drainage flow to the water receiver. The filtering dam can be complexioned with the structures of bio-purification or with the structures for supplemental conditioning of drainage flow.

4 Discussions and conclusions
Using the results of numerous investigations on the drainage at irrigated lands carried out on the large territory in the south of Russia (Volgogradskii region, Stavropolskii region, Rostovskaya obl.). The up-to-date drainage systems were analyzed and the historic experience of the drainage development was considered. New technical solutions at drainage systems' reconstruction basing on the latest ecological principals were suggested. The ecological principles include: the optimization of the drainage systems parameters and its constructions, the minimization of the water-salt process within the drainage area, the possibilities of the drainage water management, the drainage flow cleaning with the re-use purpose. New techniques proposed in the article allow to raise drainage efficiency at drainage system reconstruction and to ensure the minimization of drainage influence on the nature.

5 References

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CONTRIBUTION OF SUBSURFACE DRAINAGE AND SURFACE RUNOFF ON NUTRIENT LOSSES IN A CLAY SOIL

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ABSTRACT
Water flow and transport of nitrogen, phosphorus and suspended soil were studied on an agricultural hillslope in southern Finland. Seasonal and short-term variation of runoff components and concentrations were investigated to find out the main characteristics of flow and transport pathways. Subsurface drainage flow accounted for 45-55 % of the annual total runoff, 54-91 % of the total N loss and 25-43 % of the total loss of suspended solids in the study years 1995, 1996 and 1998. The share of the total P transport via tile drains was 23 % and of the dissolved orthophosphate P 45 % in 1998 when the runoff volume was highest. The peak losses via tile drains were attributed to heavy rainfalls which followed immediately fertilizer application and soil tillage. The transport of nutrients and eroded soil into the drain lines was mainly explained by preferential flow via macropores. The study revealed that more emphasis should be paid on reduction of nutrient losses via subsurface drainage when field scale measures in water protection management are planned.

Keywords: Clay, Tile Drain, Macropores, Nitrogen, Phosphorus

1 INTRODUCTION
Clay soils (>30 % clay fraction) form major part of the arable land in southern and south-western Finland where the main crop cultivation areas are located. In this region 70-80 % of the agricultural fields are subsurface drained. Efficient drainage is needed during sowing in spring and during harvest and soil tillage in autumn. The risk of soil compaction also reduces in drier soils.

In heavy textured soils, good macroporosity is crucial for both drainage and gas exchange. On the other hand, lowering of groundwater table by using drainage is expected to be important for formation of macropores in clay soils. Subsurface drainage has altered the hydrological cycle in the fields by reducing overland flow and increasing the flow component from the unsaturated zone. Water flow and transport of agrochemicals in these soils are complicated processes where preferential flow via macropores is likely of great importance.

One of the main objectives in the Finnish Agri-Environmental Programme is a significant reduction of nutrient losses to rivers, lakes and coastal waters from cultivated areas. Accordingly, profound knowledge on nitrogen and phosphorus transport is needed for design efficient abatement measures. Experimental research on runoff and nutrient losses from agricultural areas in Finland has focused on clay soils (e.g. Seuna and Kauppi 1981; Puustinen 1999; Turtola 1999; Uusi-Kämppä and Kilpinen 2000; Koskiaho et al. 2002). In these studies impact of subsurface drainage, soil tillage methods, crop type etc. on nutrient losses have been investigated. It is evident that the nutrient losses vary according to the soil characteristics, topography, drainage system, cultivation practice and weather conditions.

In this research project, runoff and nutrient transport were studied by using on-farm monitoring system in a subsurface drained clay field. The measurements covered the periods from January 1994 to December 1996, and from September 1997 to April 1999. In the field, comprehensive field and laboratory measurements on macroporosity and other soil physical properties and earthworm abundance were carried out in 2001 and 2002 by MTT Agrifood Research Finland. Objective of the study was to...
investigate interactions of macroporosity and subsurface drainage (Alakukku et al. 2003). Water flow in the field has also been studied with MACRO-model (Hintikka et al. 2003).

The aim of the present study was to describe and quantify the importance of field drains and surface runoff as a source of nitrogen, phosphorus and sediment entering surface waters. Seasonal and short-term losses have been evaluated on the basis of the experimental data from the years 1995, 1996 and 1998. Characteristics of the flow and transport components have been studied under various weather and cultivation conditions. Need of practices to reduce nutrient losses is discussed.

2 EXPERIMENTAL SITE AND MEASUREMENTS

2.1 Soil Characteristics, Drainage System and Cultivation Practice

The experimental site was a field section of about 3 ha at the Sjökulla farm in southern Finland. The soil is classified (Soil Survey Staff 1998) as very fine Aeric Cryaquept (Peltovuori et al. 2002). The clay content of the soil was high especially in the subsoil. Some properties of the soil profile are given in Table 1.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Clay (≤ 0.002 mm) g g⁻¹</th>
<th>Silt (0.002-0.02 mm)</th>
<th>Organic carbon (0.017-0.044)</th>
<th>pH (water) (6.2-6.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-0.25</td>
<td>0.47 (0.38-0.59)</td>
<td>0.28 (0.22-0.33)</td>
<td>0.026 (0.06-0.31)</td>
<td>6.4 (6.2-6.5)</td>
</tr>
<tr>
<td>0.25-0.45</td>
<td>0.60 (0.46-0.83)</td>
<td>0.24 (0.09-0.33)</td>
<td>0.009 (0.004-0.019)</td>
<td>6.9 (6.5-7.2)</td>
</tr>
<tr>
<td>0.45-0.65</td>
<td>0.73 (0.52-0.90)</td>
<td>0.18 (0.07-0.33)</td>
<td>0.003 (0.002-0.009)</td>
<td>7.2 (6.3-7.6)</td>
</tr>
<tr>
<td>0.65-0.80</td>
<td>0.78 (0.46-0.89)</td>
<td>0.16 (0.06-0.39)</td>
<td>0.004 (0.002-0.009)</td>
<td>7.4 (6.7-7.8)</td>
</tr>
</tbody>
</table>

The field is undulating with slopes of 2-4.7 % towards a drainage ditch (partly piped) which is buffered by a 1.0-m vegetation strip. The slope decreases in the lower part of the hillslope. The drainage system was installed in 1951, the drains being comprised of clay tiles. The distance between the drains is about 13 m and the drain depth 0.7-1.5 m. The tiles discharge into a main collector pipe which drains to the drainage ditch. Layout of the drainage network is shown in Fig. 1.

Small grain crops (barley 1995, autumn rye 1995-1996, spring wheat 1998) with conventional rates of mineral fertilizers (95-120 kg N/ha, 9-20 kg P/ha) were grown in the field. The fertilizer was applied by placement technique. Ploughing (depth 23-25 cm) or stubble cultivation (depth 15 cm) was used in autumn and seedbed preparation (depth 5 cm) in spring.

Investigation of soil macroporosity and hydraulic conductivity at the Sjökulla site was conducted in relation to location of the tile drains. The spatial variability of macroporosity (diameter 0.300-0.450 mm) was large in all horizons. The macroporosity was clearly larger in the topsoil than in the layers beneath it. The range of variation in the topsoil layer (0-0.23 m) was 2.9-8.1 vol-% and 0.7-2.3 vol-% at the depth of 0.38-0.50 m. The median number of root channels at the depth of 0.5 m was greater above the drain than between the drains. The median number and biomass of earthworms were highest above the drains but the variation in the measurements was very large. Saturated hydraulic conductivity decreased rapidly with depth. The mean of the saturated hydraulic conductivity in the topsoil layer varied from 21 mm/h to 212 mm/h in the different sampling locations. The range was 1-125 mm/h at the depth of 0.23-0.38 m and 0.05-23 mm/h at the depth of 0.38-0.50 m. (Alakukku et al. 2003).
2.2 Hydrometeorological Measurements
The outflow from the subsurface drainage system was measured at a well with a v-notched weir intercepting the collector pipe. Surface runoff was measured at the lowest point of an individual field section using a v-notched weir, too. The areas draining through the subsurface drainage weir and the surface runoff weir were 3.14 ha and 0.63 ha, respectively. Water level on the v-notched weirs was measured every 15-30 minute using a pressure transducer or an ultrasonic sensor. Manual measurements of water level was carried out in connection with water sampling. A micrometeorological station recorded basic meteorological variables at the site using 15-minute measurement frequency.

Mean hourly values of surface and subsurface drainage runoff were calculated using a basic head-discharge calibration formula for each of the two weirs. No automatic measurements of surface runoff were obtained from January 1 to February 24 1995 and of precipitation from January 1 to May 15 1995 because of technical problems. There were also some shorter breaks of the automatic data due to failure of the equipments. Corrections of the runoff data were made by using the manual measurements. The missing measurements of precipitation were replaced by precipitation data from the Vihti climate station run by the Finnish Meteorological Institute. The station located 20 km to the north of the experimental site.

2.3 Water Sampling and Analyses
Water samples were collected manually at the weir outlets. The sampling frequency varied depending on the flow event. During peak flow periods samples were taken 2-4 times per week, whereas, during low flow the sampling was less frequent. An automatic sampler was used to study quality of the drainage water during non-freezing period in 1995 and 1998. A predetermined value of water level (20 mm) initiated a special storm-sampling schedule with of sampling interval of 2 or 4 hours.
The samples were analysed for total nitrogen (total N), nitrite+nitrate nitrogen (NO2+NO3-N), nitrite nitrogen (NO2-N), ammonium nitrogen (NH4-N) in 1995 and 1996, total phosphorus (total P), dissolved orthophosphate phosphorus (DP) and total suspended solids (TSS). Concentrations of total N and P and TSS were measured in unfiltered water samples. NO2+NO3-N, NH4-N and NO2-N were determined using a FIA autoanalyser and Tecator Application Notes (ASN 62-01/83, ASN 50-01/84 and ASN 62-04/84). Nitrate nitrogen was calculated as the difference between NO2+NO3-N and NO2-N. Total N was determined by oxidation a subsample to NO3-N with K2S2O8 and NaOH. Total P was determined by converting a subsample to orthophosphate by oxidation with K2S2O8 and H2SO4. DP was determined with the FIA autoanalyser by the method of Tecator Application Note (ASN 60-05/90). For the DP analysis the sample water was passed through a Nuclepore filter with a pore size of 0.4 µm. The concentration of TSS was estimated in 1995 and 1996 by using the mass of dried (105 °C) matter retained on the 1 µm fibreglass filter. In 1998, the concentration of TSS was determined by weighing the evaporation residue of a subsample.

When calculating the estimates of nutrient and TSS losses at Sjökulla, the daily runoff volumes were multiplied by the measured or estimated concentrations. The estimated concentration values were obtained by linear interpolation between sampling dates. Thus it was relied on the assumption that the measured or estimated nutrient concentrations of the sample approximated the daily averages.

2.4 Measurement of soil mineral nitrogen

Soil samples were taken in 20-30 cm increments down to the depth of 120 cm using a Ø 20 mm drill in 1995-1996. The number of the sampling points was 8-12. Nitrate (NO3-N) and ammonium (NH4-N) nitrogen were determined by extracting 10 g fresh soil in 50 ml of 2 M KCl. Concentrations of NO3-N and NH4-N in the filtered extract were measured by the FIA autoanalyser (Tecator Application Notes ASN 65-31/84 and ASN 65-32/84). Soil moisture was determined gravimetrically by oven drying at 105 °C. NO3-N concentration in the soil water was calculated assuming that all the nitrate nitrogen in the soil was dissolved in the soil water.

3 RESULTS AND DISCUSSION

3.1 Seasonal Variation of Runoff and Nutrient Losses

Annual precipitation in the study years 1995, 1996 and 1998 was 675 mm, 620 mm and 819 mm, respectively. The long-term average (1961-1990) from the Vihti meteorological station was 617 mm. The seasonal distribution of rainfall differed clearly between the years (Fig. 2). The wettest season was May-August 1998 when the rainfall was 74 % higher than the long-term average. Heavy rainfalls also occurred in May 1995 and November 1996 and October 1996 which had a prominent influence on nutrient losses.
CONTRIBUTION OF SUBSURFACE DRAINAGE AND SURFACE RUNOFF ON NUTRIENT LOSSES IN A CLAY SOIL

Figure 2   Monthly precipitation in the study years and the long-term average values from the period 1961-1990. The values in 1995 and the long-term averages are from the Vihti meteorological station.

Seasonal runoff and losses of total nitrogen and eroded soil are shown in Fig. 3. Subsurface drainage flow constituted 45% in 1995, 57% in 1996 and 45% in 1998 of the annual total runoff (drainage+surface runoff). The highest amounts of runoff were measured during snowmelt and in the late autumn. Sporadic rainfalls and snowmelt occurred throughout the winter 1995 and 1998. On the contrary in 1996, snow steadily accumulated until the end of March and melted in only two weeks in April.
Surface runoff clearly dominated in the winter-spring season (January-April). The structure of soil frost and occurrence of freezing and thawing events obviously had an effect on the distribution of runoff components in this season. Relatively high volumes of subsurface drainage flow were measured in January and February 1998 when simultaneous snowmelt and rainfalls occurred. In the growing season (May-August) surface runoff appeared only occasionally and remained low even in the rainy summer 1998. Almost all runoff in summer discharged through the tile drains. The subsurface drainage in summer 1998 accounted for 15 % of the annual total runoff (333-mm). Proportion of surface runoff and subsurface drainage flow varied in autumn depending obviously on the antecedent soil moisture conditions in the previous summer. In autumn 1995, precipitation was about the average, but runoff remained low due to crop cover (winter rye) and early winter. The highest monthly runoff volumes were measured in November 1996 (113 mm) and in October 1998 (80 mm). Subsurface drainage flow formed 55 % of the total runoff in November 1996 and 31 % in October 1998. August-October 1996 was exceptionally dry, whereas in summer 1998 the soil remained relatively moist and was only slightly cracking.

Annual loss of total nitrogen was 14.9 kg/ha in 1995, 11.9 kg/ha in 1996 and 23.2 kg/ha in 1998. From these losses subsurface drainage flow accounted for 91, 68 and 54 %, respectively. Total N concentration in the subsurface drainage water varied from 1.9 to 63 mg/L. The range of concentration in the surface runoff water was 0.5-14 mg/L. The concentrations in the subsurface and surface runoff waters were relatively similar during the snowmelt and in the late autumn. The seasonal losses of total N via tile drains showed partly a different pattern than drainage flow. The peak losses in the study period occurred in the early growing season in 1995 and 1998. Fertilizer leaching induced high N concentrations in the drainage water (see Fig. 5). In autumn, high losses were measured both via surface runoff and subsurface drainage depending on the weather conditions. During snowmelt a significant part of the nitrogen load came with surface runoff. Nitrate nitrogen formed 69-81 % of the annual total N load via subsurface drainage and 32-53 % via surface runoff.

The annual total loss of eroded soil was 420 kg/ha in 1995, 6325 kg/ha in 1996 and 5615 kg/ha in 1998. Subsurface drainage flow accounted for 28 %, 43 % and 27 % of the annual loss, respectively. Range of the measured concentrations of suspended solids was 0.006-6 g/L in the subsurface drainage water and 0.016-7 g/L in the surface runoff water. The peak losses with the both flow components occurred in autumn. Heavy rains after soil tillage induced lot of erosion in a relatively short time period.
Losses of different P fractions from the year 1998 in Fig. 4 give an indication of the seasonal transport pattern. Subsurface drainage flow accounted for 23% of the annual total P loss and 42% of the annual dissolved orthophosphate phosphorus (DP) loss. The concentration of total P varied from 0.04 to 6.6 mg/L in the subsurface drainage water and from 0.14 to 6.7 mg/L in the surface runoff water. The maximum DP concentration was 0.15 mg/L both in the subsurface drainage and surface runoff. The loss of eroded soil at the Sjökulla site reflected well the loss of particulate phosphorus via both runoff components because major part of total P was transported as adsorbed on soil particles (Uusitalo et al. 2001, 2003).

The share of subsurface drainage flow of the annual total runoff has varied in the Finnish field experiments in clay soils. A clear reason is the age of the subsurface drainage system, but naturally the weather conditions and cultivation practices also have impact. At the Jokioinen site in southwestern Finland, drainage water constituted 10-40% of the total runoff but after the renewal of the drainage system 50-90% (Turtola and Paajanen 1995). The drainage system was 29 year old before the renewal. Subsurface drainage accounted for on average 77% of the total annual runoff in an agricultural small basin in southern Finland (Seuna and Kauppi 1981). The study period covered seven years after the installation of the drain lines. During the snowmelt period 59% of the total runoff came from drain pipes, on average. However, the percentage of surface runoff increased during springs with deep soil frost. It seems evident that the permeability of soil decreases in the course of time especially at the sites of the drain lines.

Figure 4  Monthly loss of (a) total phosphorus (total P) and (b) dissolved orthophosphate phosphorus (DP) via surface runoff and subsurface drainage in 1998.
The annual losses of total N at the Sjökulla site corresponded the range measured in the other Finnish experimental fields in clayey soils (e.g. Seuna and Kauppi 1981; Turtola and Paajanen 1995; Puustinen 1999; Koskiaho et al. 2002). Annual erosion varied greatly in the study years, but the amounts had the same order of magnitude as in the other studies. However, the erosion via subsurface drainage system was exceptionally high. The measured losses of total P in 1998 were clearly higher both via surface runoff and subsurface drainage runoff compared to the other experimental fields (Turtola and Jaakkola 1995; Turtola and Paajanen 1995; Puustinen 1999; Koskiaho et al. 2002). Significant losses of eroded soil and total P via drain pipes have also been at the Jokioinen site (Turtola and Jaakkola 1995; Turtola and Paajanen 1995). P associated with eroded soil can form a significant loss of bioavailable P both in surface and subsurface runoff in tile-drained clayey soils (Uusitalo et al. 2003). It has been observed that heavy rainstorms, as in autumn 1996 and 1998, induce major part of erosion in a relatively short time period (e.g. Grant et al. 1996; Ulén and Persson 1999; Djodjic et al. 2000).

One reason for the high losses in the Sjökulla field might be the water-sampling schedule. The losses via surface runoff were estimated by using continuous runoff measurements and instantaneous manual water samples. The losses via subsurface drainage flow were based on instantaneous manual samples and samples taken with an interval of 2 or 4 hours by an automatic sampler. It is well known that loads are strongly dependent on the timing of observations because concentrations vary considerably depending on runoff (e.g. Rekolainen et al. 1991; Grant et al. 1996; Ulén and Persson 1999). It is expected that the highest uncertainties are involved in the losses of suspended solids and total P because the concentrations change most prominently with the flow volume.

Both the rainfall-runoff patterns and nutrient concentrations in the drainage water revealed that preferential flow via macropores is of great importance in subsurface water flow and nutrient transport in the Sjökulla field. The data analysis by Al-Soufi (1998) and the modeling study by Hintikka et al. (2003) also showed the dominant role of macropores in drain flow generation. Preferential flow clearly enhanced nutrient losses via subsurface drainage under conditions when heavy rainfalls followed fertilizer application or soil tillage. Characteristics of this transport are illustrated in the following sections.

### 3.2 Nitrogen Transport in Subsurface Drainage Water

Total N concentration in the drainage water varied clearly between the seasons. Nitrogen concentrations shown in Fig. 5 reflect the general pattern of variation in the early growing season and in the late autumn when the highest losses occurred. A sharp increase of total N concentration after fertilization indicated a rapid transport of fertilizer N to the tile drains. Over 95 % of total N concentration in the drainage outflow was as nitrate after fertilization. The proportion in the other seasons varied from 45 % to 82 %. The lowest values were measured in winter and in the late autumn.
Part of the fertilizer nitrogen leached from the surface soil into the drains bypassing the soil matrix. The NO$_3$-N concentration in the drainage water was in the same order of magnitude as the concentrations in the soil water at the depth of 0-40 cm, but the concentrations deeper in the profile remained relatively low and stable throughout the spring (Fig. 6). In May-June 1995 the N loss via drainage system reached 11 kg/ha accounting for 73 % of the total annual N load (14.9 kg/ha). In May-June 1998, the N loss was also high (4.8 kg/ha). In 1995 most of the rains fell immediately after fertilization, whereas in 1998 the heaviest storms occurred in the middle of June one month after fertilization.

### 3.3 Transport of Phosphorus and Suspended Solids in Subsurface Drainage Water

High concentrations of suspended solids (TSS) and total P were measured in the drainage outflow especially in autumn after ploughing. The characteristic development in the concentration of TSS, total P and DP is illustrated for an autumn storm in Fig. 7. The drainage runoff hydrograph showed a rapid response to the precipitation event.
The concentrations reached the highest values during peak runoff and were almost as high as in the surface runoff waters. The close relationship between TSS and total P concentrations could also be seen in the other rainfall-runoff events. According to $^{137}$Cs measurements conducted in Sjökulla, the soil particles in the drainage water mainly originated from the topsoil (Uusitalo et al. 2001).

It is assumed that the transport of TSS and total P at Sjökulla mainly occurs via macropores, but probably the drainage system itself (e.g. drain envelop, back-filled trench) also has impact. At the Jokioinen site, drainflow sediment derived from either topsoil or the backfill of drainage trenches (Turtola and Paajanen 1995, Uusitalo et al. 2001). Ulén and Matsson (2003) assumed that some of the soil particles and thus particulate P has an ability to accumulate and, later, to be mobilised from the vicinity of the drains or inside the drainage tiles. Øygarden et al. (1997) assumed in the lysimeter studies that particulate P transport may take place via back-filled trenches.

4 CONCLUSION
The data collected from the field site under relatively old subsurface drainage system suggest that both subsurface drainage and surface runoff are important components in nitrogen and phosphorus transport. Pathways of water flow and nutrient transport vary according to the season and short-term weather conditions. The measurements showed that subsurface drainage could lead to high N losses if heavy rainfalls occur soon after fertilization. From these losses almost all is as nitrate nitrogen which is readily available for algae growth. Significant loss of particulate P is evident via tile drains after autumn ploughing although surface runoff is clearly the main source of the particulate P and total P load. Particulate P can make a prominent contribution to bioavailable P loss in both runoff components. Leaching of dissolved orthophosphate P into the drainage system is also an important factor in the load of bioavailable P.

Preferential flow via macropores plays the key role in nutrient transport into the drain lines in this experimental field as in many other clayey areas. On the other hand, good macroporosity is needed for efficient drainage and gas exchange in clay soils. Subsurface drainage generally reduces P losses but it might be less than expected in macroporous clayey fields. Buffer strips and zones, reduced tillage and winter cover crops, which are commonly used as on-site abatement measures, mainly have impact on losses via surface runoff. The challenge in the future is to find out measures which reduce nitrogen and phosphorus losses via drainage system, too. Emphasis should be paid e.g. on new drainage techniques and materials and on improvement of cultivation practices and their timing.

5 Acknowledgements
The authors thank the technical and laboratory staff of the two participating institutions for water and soil sampling and measurements. Financial support for the study was received from the Finnish Field Drainage Foundation and Ministry of Agriculture and Forestry and in the early stages of the work also by Maa- ja vesitekniikan tuki ry.

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http://library.wur.nl/ebooks/drainage/drainage_cd/2.4%20paasonen%20etal.html (12 of 12)26-4-2010 12:11:48
ABSTRACT
A field study at PARS (UAF) was carried out to compare the effectiveness of sulfurous acid generator (SAG) with other traditional amendments in a sandy loam field (BD = 1.58 Mg m⁻³, IR = 1.1 cm h⁻¹, pH₅ = 6.11–8.90, ECₑ = 0.88-6.10 dS m⁻¹, SAR = 5.42-25.12) at 00-15 cm depth. The treatments were: T₀) Brackish tube well water without any amendment, T₁) All irrigations with water passed through SAG, T₂) Alternate irrigation—one irrigation of SAG treated and one of tube well water, T₃) One irrigation with SAG treated water and two with untreated tube well water, T₄) FYM @ 15 t/ha/yr, T₅) Gypsum @ WGR equivalent to reduction in RSC of water treated with SAG, T₆) H₂SO₄-fertigation equivalent to decrease in RSC by SAG treatment. Rice CV. Basmati-2000 - wheat CV. Aqab-2000 - rice CV.

Basmati-2000 were planted in rotation during the 1st and 2nd year of experimentation. Tube well water used had EC = 3.24 dS m⁻¹, SAR = 17.23 and RSC = 5.44 mmolc L⁻¹. Water analysis after treatment with SAG showed that SAG decreased only the RSC from 5.44 to 3.55, but had no beneficial effect on SARₑ. While ECₑ slightly increased. For rice 2001, maximum paddy yield was obtained with T₄ (2660 kg ha⁻¹) followed by T₃, T₂, T₆, T₅, T₂ and T₀ (1357 kg ha⁻¹). For 2nd wheat 2001-02, maximum grain yield was obtained with T₅ (3630 kg ha⁻¹) followed by T₂, T₆, T₃, T₄, T₁ and T₀ (2570 kg ha⁻¹). For 3rd rice 2002, maximum paddy yield was obtained with T₄ (3203 kg ha⁻¹) followed by T₀, T₂, T₃, T₆, T₁ and T₅ (2726 kg ha⁻¹). After three crops, for 0-15 cm depth, maximum increase in pHₑ (1.62%) was noted in T₃ plots while maximum decrease (2.56%) in FYM treated plots although statistically non-significant difference with control. At 0-15 cm depth, all the treatments decreased soil ECₑ except T₄ where an increase of 27% was noted but having non-significant difference with control. For soil SAR at 0-15 cm depth, all the treatments decreased soil SAR but with non-significant differences. The highest net benefit from 1st rice 2001 was realized from T₄ (Rs. 28126 / ha) followed by T₃) One irrigation with SAG treated water and two with untreated tube well water, T₄) FYM @ 15 t/ha/yr, T₅) Gypsum @ WGR equivalent to reduction in RSC of water treated with SAG, T₆) H₂SO₄-fertigation equivalent to decrease in RSC by SAG treatment. Rice CV. Basmati-2000 - wheat CV. Aqab-2000 - rice CV.

INTRODUCTION
Under agro-climatic conditions of Pakistan evapo-transpiration is several times higher than rainfall (2025 mm Vs. 150 mm) which is responsible for net upward movement of salts. In Pakistan shortfall in water supply is likely to reach 107 MAF by 2013. To supplement canal water availability at farm gate (43.00 MAF), more than 531,000 tubewells are pumping 55 MAF in Pakistan, of which = 60-70 % is hazardous due to high EC, RSC and/or SAR. In judging the quality of irrigation water, the primary consideration is usually made to its total salt contents and sodium ion hazards involved during its use. The bicarbonate contents of irrigation water in relation to Ca+Mg also influence the sodium hazards. In Pakistan, for water RSC the safe limit of 2.5 mmolcL⁻¹ has been proposed by Directorate of Land reclamation while limit 5.0 mmolcL⁻¹ by WAPD. The poor quality water can be improved considering the sodicity hazard, by increasing calcium through addition of chemical amendment rich in calcium or by decreasing its carbonate and bicarbonate contents with the addition of acids/acid formers, either to soil or water. Thus for irrigation purpose, neutralization of water RSC with the use of proper amount of gypsum or acid is widely recommended to take care of its sodium hazards. Although use of gypsum is economical but, has low solubility (0.24-0.30 g/100 mL water at 25 °C) which on the other hand is also an added advantage for sustained availability of calcium. On the other side, use of pure acids is about 5-7 times costly than gypsum and handling is also difficult. As an alternate Sulfurous Acid Generator (SAG) is a recently introduced technology to treat saline-sodic/sodic waters. Sulfur (S) is burnt to produce SO₂ in a chamber which gets dissolved in a fraction (1/15th – 1/20th) of tubewell water to form sulfuric acid (H₂SO₄) although solubility in water is limited. This H₂SO₄ neutralizes CO₃⁻ and HCO₃⁻ ions of water so RSC of such a water is reduced while there might not be any added benefit regarding the amelioration of water EC and SAR.

Keeping above facts in view, an experiment was planned to study/compare the economics and effectiveness of SAG treatment of brackish water and other amendments for rice-wheat production on a normal soil using high EC, SAR and RSC tubewell water under the supervision of multidisciplinary team of experts including soil scientists, agri. Economist and water management experts.

3 Materials and Methods
A field experiment was conducted at Post-Graduate Agricultural Research Station (PARS, UAF) on normal, calcareous soil, using brackish tube-well water (EC = 3.24 dS m⁻¹, SAR = 17.23, RSC = 5.44 meq/l, pH 7.6) with the following treatments:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₀</td>
<td>Control (all irrigations with untreated tubewell water – T/W)</td>
</tr>
<tr>
<td>T₁</td>
<td>All irrigations with water passed through SAG</td>
</tr>
<tr>
<td>T₂</td>
<td>Alternate irrigation—one irrigation of SAG treated and one of tube well water</td>
</tr>
<tr>
<td>T₃</td>
<td>One irrigation with SAG treated water and two with untreated tube well water</td>
</tr>
<tr>
<td>T₄</td>
<td>FYM @ 15 t/ha/yr</td>
</tr>
<tr>
<td>T₅</td>
<td>Gypsum @ WGR equivalent to reduction in RSC of water treated with SAG</td>
</tr>
<tr>
<td>T₆</td>
<td>H₂SO₄-fertigation equivalent to decrease in RSC by SAG treatment</td>
</tr>
</tbody>
</table>

For rice-wheat production on a normal soil using high EC, SAR and RSC tubewell water under the supervision of multidisciplinary team of experts including soil scientists, agri. Economist and water management experts.
The experiment was laid out in RCBD with three replications. In rice-wheat rotation rice cv. *Basmati 2000* (2001) was sown as a first test crop, followed by wheat cv. *Aqab 2000* (2001-02), and rice cv. *Basmati 2000* (2002). A total of 54 treated and 8 untreated irrigations (each of 3 acre inch) were made to the three crops. Soil analysis was made at start of experiment and at the harvest of each crop from 00-15 cm and 15-30 cm depths. Physical properties of soil like soil texture, bulk density and infiltration rate were recorded at start (Table 1). The soil from each experimental plot was analyzed at start of experiment, and at harvest of each crop for pHs, ECe, water soluble cations (Ca$^{+2}$, Mg$^{+2}$, Na$^{+}$ and K$^{+}$) and anions (CO$_3^{-2}$, HCO$_3^{-}$, Cl$^{-}$ and SO$_4^{2-}$) following methods of the U.S. Salinity Laboratory Staff (1954). The crops were harvested at biological maturity to record biomass and economic yields. The data were subjected to statistical analysis following the DMR test (Steel and Torrie, 1980).

### 4 Results and Discussions

#### 4.1 Water Quality

As an average of 25 analysis events (Table 2) the SAG slightly increases EC$_{iw}$, with out any beneficial effect on SAR$_{iw}$. However, SAG treatment of brackish water could not decrease RSC to safe limit of 2.5 mmolc L$^{-1}$.

#### 4.2 Crops Yield

The yield data is given in Table 3 for all three crops. For 1st rice crop (2001), maximum paddy yield was obtained from T$_4$ (2660 kg/ha) treatment plots where farmyard manure was applied @ 15 ton/ha/year. However T$_1$, T$_3$, T$_5$ and T$_6$, also produced statistically similar yields when compared to T$_4$. Minimum yield was noted in control plots (1357 kg/ha). Maximum yield in T$_4$ may be due to beneficial effects of organic matter on soil physical and chemical properties as reported by a number of researchers. The statistically better but similar yields as obtained in T$_4$, T$_1$, T$_3$, T$_5$ and T$_6$ may be correlated with statistically similar EC$_e$ at 0-15 cm depth. Minimum yield in control plots may be attributed to maximum EC$_e$ noted in control plots. For 2nd wheat crop, maximum grain yield was noted for gypsum treated plots (3630 kg/ha). However rest of all the treatments except control also produced statistically similar yields to T$_5$ while minimum yield was noted in control plots (2570 kg/ha). For 3rd rice crop all the treatments produced statistically similar yields with non-significant differences which is strongly correlated with SAR which did not differ statistically at 0-15 and 15-30 cm depths.

<table>
<thead>
<tr>
<th>Soil depth (cm)</th>
<th>Property</th>
<th>R$_1$</th>
<th>R$_2$</th>
<th>R$_3$</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>00-15</td>
<td>pH$_s$</td>
<td>8.40</td>
<td>8.57</td>
<td>8.49</td>
<td>8.49</td>
</tr>
<tr>
<td></td>
<td>EC$_e$ (dSm$^{-1}$)</td>
<td>3.54</td>
<td>2.19</td>
<td>3.60</td>
<td>3.11</td>
</tr>
<tr>
<td></td>
<td>SAR</td>
<td>19.5</td>
<td>10.4</td>
<td>19.0</td>
<td>16.3</td>
</tr>
<tr>
<td>15-30</td>
<td>pH$_s$</td>
<td>8.20</td>
<td>8.61</td>
<td>8.52</td>
<td>8.45</td>
</tr>
<tr>
<td></td>
<td>EC$_e$ (dSm$^{-1}$)</td>
<td>5.41</td>
<td>2.28</td>
<td>3.74</td>
<td>3.81</td>
</tr>
<tr>
<td></td>
<td>SAR</td>
<td>21.2</td>
<td>13.9</td>
<td>23.0</td>
<td>19.4</td>
</tr>
<tr>
<td>00-30</td>
<td>Texture</td>
<td>sandy loam</td>
<td>loamy sand</td>
<td>sandy loam</td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td>B.D (Mg m$^{-3}$)</td>
<td>1.59</td>
<td>1.54</td>
<td>1.67</td>
<td>1.60</td>
</tr>
</tbody>
</table>
### Table 2  SAG treatment of brackish tube well water

<table>
<thead>
<tr>
<th>Treatment</th>
<th>EC (dSm⁻¹)</th>
<th>SAR</th>
<th>RSC (mmolcL⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated tubewell water</td>
<td>3.24</td>
<td>17.23</td>
<td>5.44</td>
</tr>
<tr>
<td>All water SAG treated</td>
<td>8.96</td>
<td>16.98</td>
<td>0.00</td>
</tr>
<tr>
<td>SAG water after mix with T/W</td>
<td>3.31</td>
<td>17.14</td>
<td>3.55</td>
</tr>
</tbody>
</table>

### 4.3 pHs, ECe and SAR of Soil

The data about experimental soil pH is given in Table 4. Before start of experiment soil pHs was statistically similar in all the plots at both the depths. After three crops, for 0-15 cm depth maximum decrease in pHs (2.56%) was noted for farmyard manure treated plots which may be attributed to the formation of carbonic acid through decomposition of organic mater in the soil while maximum increase was noted for T3 plots (1.62%) where one SAG treated and two untreated tubewell irrigations were made continuously to grow all the three crops. For 15-30 cm depth, all the treatments increased soil pHs except gypsum treatment where a decrease of 0.31% was noted.

### Table 3  Effect of different treatments on straw and paddy/grain yields (kg ha⁻¹) of rice (2001), wheat (2001-02) and rice (2002) crops

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1st rice</th>
<th>2nd wheat</th>
<th>3rd rice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Straw yield</td>
<td>Paddy yield</td>
<td>Straw yield</td>
</tr>
<tr>
<td>T₀</td>
<td>2845</td>
<td>1357 c</td>
<td>4486</td>
</tr>
<tr>
<td>T₁</td>
<td>4647</td>
<td>2354 ab</td>
<td>5175</td>
</tr>
<tr>
<td>T₂</td>
<td>3913</td>
<td>2048 b</td>
<td>5001</td>
</tr>
<tr>
<td>T₃</td>
<td>4723</td>
<td>2434 ab</td>
<td>4949</td>
</tr>
<tr>
<td>T₄</td>
<td>5136</td>
<td>2660 a</td>
<td>5231</td>
</tr>
<tr>
<td>T₅</td>
<td>4115</td>
<td>2237 ab</td>
<td>5060</td>
</tr>
<tr>
<td>T₆</td>
<td>4708</td>
<td>2339 ab</td>
<td>5218</td>
</tr>
</tbody>
</table>

LSD at 5% probability = 532.1, 282.6, 1076

Data for soil ECe is given in table 5. Before the start of experiment soil ECe was statistically similar in all the experimental plots. After three crops for 0-15 cm depth maximum ECe was noted in control treatment (3.15 dSm⁻¹) which had non-significant difference with all the other treatments except T₁ (3.10 dSm⁻¹) and T₄ (3.0 dS m⁻¹). For 15-30 cm depth, maximum ECe was noted in control treatment (1.84 dSm⁻¹). Minimum ECe was noted for T₃ plots at both the soil depths. For both the soil depths over a period of three crops, minimum decrease in ECe was noted for gypsum treated plots followed by control plots while maximum decrease was noted for T₃ plots.

Data for soil SAR is given in table 6. During the growing period of three crops there were almost no significant differences noted among all the treatments for soil SAR. Over a period of three years , maximum decrease in soil SAR was noted in control plots (98.3%) followed by T₁ plots (97.0%) for 0-15 cm depth; and in farmyard manure treated plots (136.5%) followed by gypsum treated plots (112.2%) for 15-30 cm depth.

### 4.4 Economic analysis of the treatments

Data about different parameters considered for economic analysis is given in table 7. It is depicted from the data that after growing three crops maximum income was received from farmyard manure treatment plots (96931 Rs/ha) followed by T₃ and T₆ while minimum income was received from control plots (74336 Rs/ha).
Maximum expenses were noted for T1 (39106 Rs/ha) where continuous SAG treated water was applied followed by T6 where sulfuric acid fertigation was made through drip method. The treatment of brackish water with either SAG or acid fertigation was found to be about 5-6 times costlier than gypsum treatment. Maximum net benefit (93181 Rs/ha) was obtained from farmyard manure treated plots followed by gypsum treated plots (81110 Rs/ha) while minimum net benefit was received from T1 (49472 Rs/ha) where all the SAG treated water was applied.

Table 4  Average variation in Soil pHs during SAG Experiment at PARS before start of Experiment (2001) up to after 3rd Rice Crop –2002

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Before 1st rice</th>
<th>After 1st rice</th>
<th>After 1st wheat</th>
<th>After 3rd rice</th>
<th>% Variation after 3 crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>8.47 a</td>
<td>8.60 a</td>
<td>8.34 ab</td>
<td>8.37 c</td>
<td>-1.15</td>
</tr>
<tr>
<td>T1</td>
<td>8.37 a</td>
<td>8.61 a</td>
<td>8.30 ab</td>
<td>8.42 bc</td>
<td>0.55</td>
</tr>
<tr>
<td>T2</td>
<td>8.50 a</td>
<td>8.69 a</td>
<td>8.21 b</td>
<td>8.59 ab</td>
<td>1.01</td>
</tr>
<tr>
<td>T3</td>
<td>8.48 a</td>
<td>8.68 a</td>
<td>8.30 ab</td>
<td>8.62 a</td>
<td>1.62</td>
</tr>
<tr>
<td>T4</td>
<td>8.55 a</td>
<td>8.57 a</td>
<td>8.33 ab</td>
<td>8.34 c</td>
<td>-2.56</td>
</tr>
<tr>
<td>T5</td>
<td>8.56 a</td>
<td>8.58 a</td>
<td>8.38 a</td>
<td>8.47 abc</td>
<td>-1.10</td>
</tr>
<tr>
<td>T6</td>
<td>8.48 a</td>
<td>8.62 a</td>
<td>8.26 ab</td>
<td>8.41 bc</td>
<td>-0.87</td>
</tr>
<tr>
<td>LSD</td>
<td>0.360</td>
<td>0.149</td>
<td>0.169</td>
<td>0.187</td>
<td></td>
</tr>
</tbody>
</table>

Table 5  Average variation in Soil ECe during SAG Experiment at PARS before start of Experiment (2001) up to after 3rd Rice Crop –2002

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Before 1st rice</th>
<th>After 1st rice</th>
<th>After 1st wheat</th>
<th>After 3rd rice</th>
<th>% Variation after 3 crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>3.29 a</td>
<td>2.76 a</td>
<td>5.31 a</td>
<td>3.15 a</td>
<td>-4.33</td>
</tr>
<tr>
<td>T1</td>
<td>3.93 a</td>
<td>2.27 ab</td>
<td>4.49 a</td>
<td>3.10 a</td>
<td>-26.8</td>
</tr>
<tr>
<td>T2</td>
<td>3.21 a</td>
<td>1.93 b</td>
<td>4.85 a</td>
<td>1.94 b</td>
<td>-65.8</td>
</tr>
<tr>
<td>T3</td>
<td>3.41 a</td>
<td>2.16 ab</td>
<td>6.46 a</td>
<td>1.85 b</td>
<td>-83.9</td>
</tr>
<tr>
<td>T4</td>
<td>2.19 a</td>
<td>2.32 ab</td>
<td>5.42 a</td>
<td>3.00 a</td>
<td>27.0</td>
</tr>
<tr>
<td>T5</td>
<td>2.47 a</td>
<td>2.60 ab</td>
<td>4.65 a</td>
<td>2.43 ab</td>
<td>-1.7</td>
</tr>
<tr>
<td>T6</td>
<td>3.28 a</td>
<td>2.52 ab</td>
<td>6.29 a</td>
<td>2.70 ab</td>
<td>-21.5</td>
</tr>
<tr>
<td>LSD</td>
<td>2.42</td>
<td>0.83</td>
<td>2.12</td>
<td>0.91</td>
<td></td>
</tr>
</tbody>
</table>
### Table 6  Average variation in Soil SAR during SAG Experiment at PARS before start of Experiment (2001) up to after 3rd Rice Crop –2002

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Before 1st rice</th>
<th>After 1st rice</th>
<th>After 1st wheat</th>
<th>After 3rd rice</th>
<th>% Variation after 3 crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>16.64 a</td>
<td>18.82 a</td>
<td>25.58 a</td>
<td>8.39 a</td>
<td>-98.3</td>
</tr>
<tr>
<td>T1</td>
<td>21.07 a</td>
<td>17.88 a</td>
<td>22.38 a</td>
<td>10.69 a</td>
<td>-97.0</td>
</tr>
<tr>
<td>T2</td>
<td>15.21 ab</td>
<td>15.68 a</td>
<td>23.03 a</td>
<td>10.87 a</td>
<td>-39.9</td>
</tr>
<tr>
<td>T3</td>
<td>14.59 ab</td>
<td>17.25 a</td>
<td>25.07 a</td>
<td>10.96 a</td>
<td>-33.1</td>
</tr>
<tr>
<td>T4</td>
<td>16.11 ab</td>
<td>16.43 a</td>
<td>23.04 a</td>
<td>10.68 a</td>
<td>-50.9</td>
</tr>
<tr>
<td>T5</td>
<td>13.49 b</td>
<td>18.04 a</td>
<td>22.91 a</td>
<td>12.72 a</td>
<td>-6.0</td>
</tr>
<tr>
<td>T6</td>
<td>17.09 ab</td>
<td>19.22 a</td>
<td>24.52 a</td>
<td>10.36 a</td>
<td>-65.0</td>
</tr>
<tr>
<td>LSD</td>
<td>6.56</td>
<td>5.72</td>
<td>3.37</td>
<td>5.02</td>
<td></td>
</tr>
</tbody>
</table>

### Table 7 Economic analysis (Rs ha⁻¹) of SAG and other treatments of brackish water on rice (2001), wheat (2001-02) and rice (2002) crops at PARS, UAF

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total Income Rice</th>
<th>Total Income Wheat</th>
<th>Total Income Rice</th>
<th>Variable Expenses Rice</th>
<th>Variable Expenses Wheat</th>
<th>Total expenses</th>
<th>Net Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>15668</td>
<td>23761</td>
<td>34907</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>74336</td>
</tr>
<tr>
<td>T1</td>
<td>26635</td>
<td>30435</td>
<td>31508</td>
<td>88578</td>
<td>19570</td>
<td>2256</td>
<td>17278</td>
</tr>
<tr>
<td>T2</td>
<td>23269</td>
<td>31368</td>
<td>32465</td>
<td>87102</td>
<td>9784</td>
<td>1331</td>
<td>8774</td>
</tr>
<tr>
<td>T3</td>
<td>27515</td>
<td>30704</td>
<td>32047</td>
<td>90266</td>
<td>6523</td>
<td>753</td>
<td>5849</td>
</tr>
<tr>
<td>T4</td>
<td>30001</td>
<td>30956</td>
<td>35974</td>
<td>96931</td>
<td>1875</td>
<td>--</td>
<td>1875</td>
</tr>
<tr>
<td>T5</td>
<td>25348</td>
<td>32285</td>
<td>30727</td>
<td>88360</td>
<td>3482</td>
<td>401</td>
<td>3367</td>
</tr>
<tr>
<td>T6</td>
<td>26470</td>
<td>31596</td>
<td>31574</td>
<td>89640</td>
<td>18286</td>
<td>2110</td>
<td>17583</td>
</tr>
</tbody>
</table>
Note: Costs of inputs were considered as per market rates and through produce the support prices

5 Conclusions and Recommendations
As all the treatments kept soil ECe and SAR within threshold limits which may be attributed to high irrigation frequency required for rice crop as well as sandy loam texture and good infiltration rate (1.1 cm/h) of the experimental field. There was no significant difference for soil SAR at both the depths for all treatments so recommendations will purely follow net benefit findings. As per table 7, it is clear that maximum net benefit was obtained by farmyard manure treatment followed by gypsum treated plots while minimum from SAG treated plots. Moreover gypsum treatment was found 5-6 times cheaper than acid treatments of brackish water so farmers can adopt gypsum application to combat brackish water ill effects on soil in rice-wheat rotation on normal soils.

[2] Department of Soil Science, University of Agriculture, Faisalabad, Pakistan
ABSTRACT
Irrigated agriculture is expected to play a major role in reaching the broader development objectives of achieving food security and improvements in the quality of life, while conserving the environment, in both the developed and developing countries, especially in the prospect of global population growth from almost 6 billion today to, at least, 8 billion by 2025. In this context, the constraints posed by land and water scarcity and the associated need to increase the carrying capacity of the land in a sustainable manner will require significant enhancements in efficiency and flexibility of irrigation and drainage systems in the next few decades.

In most of the world’s irrigated and rainfed lands drainage facilities were developed on a step by step basis over the centuries. In many of the systems structures have aged or are deteriorating and, consequently, they need to be renewed or even replaced and thus, redesigned and rebuilt. Drainage systems, in the past, were conceived for a long life, on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to the global warming and the greenhouse effect. Therefore, designers and managers need to systematically re-examine planning principles, design criteria, operating rules and management policies for new drainage systems.

With reference to these issues, the report, on the basis of the available information, gives an overview of current and future (time horizon 2025s) drainage development and drainage needs around the world. Moreover, the paper analyses the latest results of four of the most advanced General Circulation Models (the Geophysical Fluid Dynamic Laboratory, Princeton, USA, the Goddard Institute of Space Sciences, USA, the Oregon State University, USA, the United Kingdom Meteorological Office, UK ) to assess the hydrological impacts of global warming, due to the greenhouse effect, on the drainage planning and design process. Finally, a five-step planning and design procedure able to integrate and factor, within the drainage development process, the hydrological consequences of climate change, is proposed.

1 INTRODUCTION
Both surface and subsurface drainage have expanded rapidly in developed countries over the last two centuries. It was not until late in the nineteenth century that emphasis began to be placed on drainage in the developing world. Nowadays, in many cases the structures are aging or deteriorating. So, they need to be renewed or even replaced and thus redesigned and rebuilt, in order to achieve improved sustainable production. Moreover, the environmental conditions have changed dramatically in the last half century. In the older irrigated lands of the temperate zone groundwater levels have risen to produce waterlogging in many areas. In arid climates this process has caused excessive salinity buildup in crop root zones and created yield reductions or caused land abandonment in severe cases. In humid and sub-humid tropics, population pressures and the need to adopt more intensive and higher input crop husbandry have led to a sharper focus on flood control and flood alleviation measures. Most of these factors are well known and linked to uncertainties associated with climate change, world market prices and international trade. These uncertainties call for continued attention and suitable action on many fronts, if productivity and flexibility in agricultural systems are to be improved. In this context, the effects of climate change may play an important role in may regions. Availability of reliable hydrological data is an essential prerequisite for the rational planning, design and management of water resources.

Drainage systems were designed for a long life, on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to the global warming and the greenhouse effect. Although an anthropogenically-induced
climate change is expected to have significant impacts on drainage systems, the range of uncertainty as to how these climate impacts, at the geographic scales of interest, affect the drainage development process is still great. Moreover, the absence of a uniform understanding makes it difficult to assess the adequacy of existing planning principles and design criteria, in the light of these potential changes. Therefore, planners, designers and decision-makers need to review the strengths and weaknesses of current trends in drainage development and rethink technology, institutional and financial patterns, research thrust and manpower policy, so that service level and system efficiency can be improved in a sustainable manner.

2 DRAINAGE AND AGRICULTURE

Drainage is a crucial instrument for achieving sustainable development of both irrigated and rainfed agriculture throughout the world.

Figure 1 Development of cultivated area in the world without a water management system and under irrigation and the presently drained area (Schultz, 2001).

In Figure 1 the development of the cultivated area, irrigation and drainage since the beginning of the nineteenth century is given (Schultz, 2001). The total cultivated area on earth is about 1,500 ha. At about 1,100 million ha agricultural exploitation takes place without a water management system. However, in a certain part of these areas methods like water harvesting, or soil treatment may be applied. From these areas 45% of crop output is being obtained. Presently irrigation covers more than 270 million ha and is responsible for 40% of crop output. It uses about 70% of water, withdrawn from global river systems. Drainage of rainfed crops covers about 130 million ha and contributes to about 15% of crop output. In about 60 million ha of the irrigated lands there is a drainage system as well (Smedema, 1995). Some key figures of the 10 countries with the largest drained areas are given in Table 1.

With respect to agricultural production, the role of drainage is considered in three major agro-climatologic zones (Schultz and De Wrachien, 2002):

- arid and semi-arid regions
DRAINAGE DEVELOPMENT IN A CHANGING ENVIRONMENT: OVERVIEW AND CHALLENGES

- humid tropical zone
- temperate zone

Dependent on the local conditions, different types of drainage systems with different levels of service will be appropriate (Schultz, 1993).

Table 1  Indicative key figures for the 10 countries with the largest drained area (international Commission on Irrigation and Drainage, 2001, and database CEMAGREF)

<table>
<thead>
<tr>
<th>Country</th>
<th>Population (x10^6)</th>
<th>% of population in agriculture</th>
<th>Total area (10^6 ha)</th>
<th>Arable land (10^6 ha)</th>
<th>Drained area (10^6 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>168</td>
<td>19</td>
<td>851</td>
<td>66</td>
<td>8</td>
</tr>
<tr>
<td>Canada</td>
<td>31</td>
<td>3</td>
<td>997</td>
<td>46</td>
<td>10</td>
</tr>
<tr>
<td>China</td>
<td>1267</td>
<td>68</td>
<td>960</td>
<td>96</td>
<td>29</td>
</tr>
<tr>
<td>Germany</td>
<td>82</td>
<td>3</td>
<td>36</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>India</td>
<td>998</td>
<td>61</td>
<td>329</td>
<td>170</td>
<td>13</td>
</tr>
<tr>
<td>Indonesia</td>
<td>209</td>
<td>50</td>
<td>190</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Japan</td>
<td>127</td>
<td>4</td>
<td>38</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Pakistan</td>
<td>152</td>
<td>48</td>
<td>80</td>
<td>22</td>
<td>6</td>
</tr>
<tr>
<td>Poland</td>
<td>39</td>
<td>23</td>
<td>32</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>USA</td>
<td>276</td>
<td>2</td>
<td>936</td>
<td>188</td>
<td>47</td>
</tr>
<tr>
<td>Total</td>
<td>3349</td>
<td></td>
<td>4449</td>
<td>650</td>
<td>142</td>
</tr>
<tr>
<td>World</td>
<td>6000</td>
<td></td>
<td>13000</td>
<td>1512</td>
<td>190</td>
</tr>
</tbody>
</table>

2.1     Arid and semi-arid regions

The prospects of increasing the gross cultivated area in these regions are limited by the dwindling number of economically attractive sites for large-scale irrigation and drainage projects. Moreover, the threat of waterlogging and salinization hangs over nearly every irrigation scheme; apparently irrigation systems have failed because of lack of adequate drainage. Intensification of agriculture relies upon irrigation, but the poor efficiency of many irrigation systems pledges for significant improvements in agricultural water use and management. Therefore, the required increase in agricultural production will necessarily rely largely on major improvements in the construction, operation, management and performance of existing irrigation and drainage systems (De Wrachien, 2001). Some excellent agriculture is practiced today in some semi-arid and arid areas, such as the Indus Valley in Pakistan, the Nile delta and central and southern California. The physical constraint that threatens sustainable agricultural development is limited drainage capacity. This requires dealing effectively with the twin menaces of waterlogging and salinization.

The extent of agricultural areas suffering from waterlogging and salinization on a global scale has not been well documented. It is estimated that these phenomena are a serious threat to some 100-120 million ha of irrigated land in arid and semi-arid regions. The available data suggest that some 20-30 million ha of irrigated land in this zone are already significantly affected and that the problem is growing by 0.5-1.0 million ha per year (Smedema, 2000).

2.2     Humid tropical zone

In the humid tropical zone agriculture is practiced mainly in lowland plains. It is severely constrained by flooding and submergence caused by monsoons. The consequences are low yields, limited crop choices and constraints to introduction of mechanization and other modern farming techniques. A distinction is generally made in cultivation during the wet and the dry monsoon. During the wet monsoon cultivation is, normally, possible only with a drainage system, although quite often irrigation is also applied to overcome dry spells. In the dry monsoon irrigation is required to make possible good yields. When systems are well coordinated and their efficiency improved to enable the cultivation of crops during both the wet and the dry seasons, irrigation and drainage systems are generally applied. Open drainage canals are used where the rainfall intensity is so high that pipe drainage will almost
always have insufficient capacity or become very expensive. In some countries, as in Japan, experience shows the combination of open and pipe drainage systems in order to achieve a better control of surface and groundwater for the cultivation of mixed crops—rice followed by dry crops.

Large lowland areas along coasts and in the river flood plains often need to be reclaimed. Reclamation includes water management measures based on balanced drainage and equilibrium with the environment, in line with national and international nature-conservation policies.

Another increasing problem is the pollution of drainage systems due to the uncontrolled discharge of urban and industrial wastewater and the uncontrolled application of fertilizers and pesticides in agriculture. On the whole, heavy rainfall, overflowing rivers and flooding from upstream areas represent the major constraints to agricultural development in the humid and sub-humid tropics. This zone is estimated to cover 100-200 million ha (IPTRID, 2001). The area is not expanding, but with higher demands put on agricultural production systems, more farmers increasingly require better flood protection and drainage.

### 2.3 Temperate Zone

Agriculture in the Temperate Zone is to a large extent rainfed. Crops evapo-transpirate water taken directly from rainfall and use soil moisture in dry spells. To maintain groundwater table levels within desired limits drainage systems were installed. A major effect of the drainage systems is to allow for timely land preparation: agricultural machinery can access to land early in the season, cultivate and prepare it for sowing. The cultivation period is thus extended, which is of importance because the daily sunlight periods in parts of the Temperate Zone represent the crucial production factor. As rainfall is unevenly spread, supplementary irrigation may be required depending on location and production systems. Groundwater of generally good quality is often used for irrigation. The field drainage system is generally of subsurface type, but in soils with a low permeability surface drainage systems may be applied. In clay soils pipe drains and, sometimes, mole drains may be used, while the peat soils are generally drained with open field drains. Flood control has been achieved virtually everywhere in the Temperate Zone by dykes along rivers and the sea.

In several countries environmental laws and regulations have been, or are being made to control the application of fertilizes and pesticides in such a way that the drainage effluents are acceptable for the receiving water bodies. Many of the world's current drainage systems have been installed in the developed countries of the temperate humid zone, especially in Europe and North America. Two hundred years ago, drainage programs focused on bringing waterlogged and low-lying areas into production; more recently, up to the 1980s, they have been carried out on a widespread intensive basis. The present situation is that, with 25-30 % of agricultural land drained, the installation rate is falling.

### 3 CURRENT STATE OF DRAINAGE DEVELOPMENT

Both surface and subsurface drainage have expanded rapidly in developed countries over the last two centuries. It was not until late in the nineteenth century that emphasis began to be placed in the developing countries. The early works were in the deltas of Asia and other newly developed irrigated areas. There were reasons why early irrigators were slow to introduce drainage into irrigation systems. In the arid zones, the planned cropping intensities were often low and groundwater tables were situated far below the crop root zones. In the humid zone, crops that would tolerate periodic inundations were selected. It was logical to defer expenditure on drainage until the need for it arose. The conditions in the older irrigated areas have changed dramatically in the second half of the last century. Water tables have risen to produce waterlogging in many areas. In arid climates, this process caused excessive salinity buildup in crop root zones and created yield reductions or caused land abandonment in severe cases. In humid zones, there were economic pressure to diversify cropping away from what was almost a rice monoculture. Due to the above-mentioned pressures agricultural drainage developed differently with various features in different countries. The salient aspects of drainage development in a few significant countries are herewith described (Framji and Mahaja, 1969, Field, 1990, Chauhan, 2000, Dam, 2000, Sarwar, 2000, Ahmad, 2002, Jhorar, 2002).
3.1 Canada

Drainage and reclamation were carried out in Canada, to protect coastal marshlands by tide waters and floods, starting from the seventeenth century. During 1940s, the reclamation structures fell into disrepair and large areas of good marsh land were again flooded by tides. Later on, the provincial and federal governments, in pursuance of the marsh land rehabilitation act, passed in 1948, took up programs of further reclamation measures.

Currently, the most serious problems in irrigation districts is the presence of saline soils. Seepage from irrigation canals causes the water table to rise and salts to appear in the surface. This is overcome by lining of canal, surface and subsurface drainage and land levelling.

3.2 China

A large proportion of China’s low-lying lands are under the threat of submersion under water due to poor drainage. Since 1949 efforts have been made on regulation of several low-lying areas going under inundation. For the ameliorations of these lands different methods are used in different situations. In mountainous areas of upper valleys, reservoirs are constructed and soil and water conservation measures undertaken. For hill-lands in middle valleys, terraces are built to let rain water seep into subsoil. For the low-lying lands subject to submergence ditches are systematically dug for drainage in areas wherever outlets for gravity drainage are available. Where drainage is not practical the land is protected with earth dykes or bottom lands are levelled to act as flood detention basins. In coastal plains dykes are built for the prevention of tidal flows and sluices are provided for stoppage of tidal inflows.

3.3 India

Waterlogging and salinity were first noticed in the upper region of Rechana Doab soon afterward the opening of lower Chenab canal in 1892. Later on, in 1925 the Punjab government constituted a committee to study and report on the extent and cause of waterlogging. Since independence the Land Reclamation Irrigation and Power Research Institute of Amritsar had taken up this work. Research and investigation programs have been carried out up today in this field, the most significant of which are listed beneath:

- Drainage studies at Baramati experimental plot with deep drains to release subsurface water into the drain;
- Pilot polder project, in Saurashtra with the co-operation of The Netherlands, for reclamation of saline lands in coastal plains;
- Investigations carried out at Central Soil Salinity Research Institute of Karnal on the reclamation of alkali soils, using both tile drains and open ditches;
- Studies on the reclamation of saline soils in heavy textured clay loam soils using subsurface drainage systems in the Bidaj District;
- Studies carried out by the Harayana Agricultural University on vertical tube wells;
- Investigations on the effectiveness of subsurface drainage systems in removing toxic acidic substances and improving the crop productivity in the Kerala command area.
- Studies on the effects of enhanced conjunctive use of surface and groundwater on soil salinity in the Sirsa Irrigation Circle, in cooperation with The Netherlands.

3.4 Italy

A number of drainage projects were carried out before sixteenth century. In 1896 a national survey reveled that, at that time, Italy had 1 million ha of swampy lands. The innovation of the mechanical drainage system allowed the reclamation of these lands. The main aim of the reclamation at that time, was to control water-related vector-borne diseases and reduce the incidence of malaria in the agricultural areas. In Emilia from 1869 to 1950, the Central Authority reclaimed more than 0.2 million ha of swampy areas.
and made cultivation possible in additional 0.2 million ha under natural meadows and pastures which were periodically flooded. More recently, in the Po Valley, farmers responded to the introduction of improved drainage by shifting from arable crops to orchards.

### 3.5 Pakistan

In Pakistan the potential need of drainage was realized since the time large scale diversion works were constructed. Starting from unsuccessful attempts on lining the canals, steps were taken to provide for seepage drains along the main canals. Surface drains were also constructed to remove storm water and reduce groundwater recharge. In 1954, a comprehensive hydrological ground water and soil research was carried out in Indus plains. The survey indicated that more than 4.5 million ha were poorly drained or waterlogged and 6.5 million ha were affected by salinity. After this investigation drainage and reclamation were implemented through projects known as Salinity Control and Reclamation Projects (SCARP). The main aims of the SCARP projects were to combat waterlogging and salinity through lowering of the groundwater table and increase in the irrigation supplies by using the pumped groundwater directly of mixed with canal water. As a result, in fresh groundwater areas, about 14,000 tubewells (covering about 2.6 million ha of irrigated land) were constructed in the 1960s and 1970s. Initially, the implementation of the SCARPs was moderately successful and the problems of waterlogging and salinity were somewhat arrested and reserved.

In the last ten years five SCARP have been carried out in an area of 2 million ha. Besides, surface drainage was taken up for more than 1.0 million ha in Gulum Mohammad Command area and 0.25 million ha in other projects. Within the fourth project an important study has been realized, in cooperation with The Netherlands, to develop a transient model approach to improve design procedures for subsurface drainage systems in relation to adopted irrigation techniques for improving crop yields in the Rechna Doab Command area.

### 3.6 United States of America

Drainage is used in basically two connotations. The first is in the context of reclamation of swamplands and marsh regions, by removing excess surface and groundwater from the soil to make waterlogged lands suitable for cultivation. The second connotation is applied to irrigation practices. In this case, drainage is necessary to maintain the watertable below the plant root zone to provide a favorable salt balance.

The history of drainage development in the USA can roughly be divided in two periods, before and after the 1960s, respectively. During the first period, which substantially started in the eighteenth century, much drainage development took place, driven almost exclusively by agricultural interest and strongly promoted and supported by government policies. Initially, most of the drainage was for reclamation of waterlogged lands, while later on it became more a mixture of surface and subsurface drainage development. Much of the country’s current drainage infrastructure dates from this period.

After the 1960s, the drainage systems became more influenced by the changing environmental ethics. A number of laws and policies were adopted to protect the remaining wetlands and to constrain environmentally undesirable drainage developments. The rate of drainage development slowed down and became much more selective.

Going into statistics, it may be indicated that in 1920 there were 25 million ha in drainage projects which increased: in 1940 to 35 million ha, in 1960 to 41 million ha, and in 2000 to 47 million ha.

### 3.7 The Netherlands

The installation of flood control and drainage systems has a long history in the Netherlands. The primary function was to provide safe and habitable country with optimum growing conditions for crops. Most drainage systems are subsurface, evacuating excess water towards open drains. In the past, windmills lifted the water from these to secondary and main drains, from where it was finally disposed of in rivers and the sea. The unending struggle with the water formed the landscape, which consists of polders, drained lakes, innumerable canals, pumping stations and small and large hydraulic structures.
Valuable experience was obtained as drainage development went through a continuous process of technological innovations. Windmills were replaced by pumping stations and clay drain pipes were substituted by perforated plastic pipes. Institutions and policies on drainage and flood control evolved accordingly. The 3000 Water Boards that existed in the middle Ages were merged into fewer than 100 existing today. The driving forces behind the establishment of an integrated water quantity and quality management policy, were concerns about salinity intrusion, point-source pollution from municipalities, industries and upstream international sources, agricultural pollution, groundwater depletion and nature conservation and navigation requirements.

4 PROSPECTS OF MEDIUM TERM DEVELOPMENT

The above salient aspects give a brief history of development of drainage in different countries. It has not been possible to cover all the countries. Nonetheless, the picture indicates that drainage has a culture to travel from material of stones, ditches, clay tiles, to plastics pipes and from reclamation of flooded areas and marshes to drainage of waterlogged irrigated lands and that the process has taken a long time to develop to this stage and has been fruitfully utilized and practiced by developing countries. On the basis of the above-presented figures and the available recent database on the world’s total cropped area and the areas irrigated and drained, a rough compilation of the state of drainage development of the world’s cropland may be made as in Table 2.

Table 2 State of drainage development of the World’s cropland (Smedema 2000, modified)

<table>
<thead>
<tr>
<th></th>
<th>Not drained (without drainage facilities)</th>
<th>Drained (with drainage facilities)</th>
<th>Total World Cropland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated</td>
<td>200</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Rainfed</td>
<td>1100</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1300</td>
<td>190</td>
<td>1500</td>
</tr>
</tbody>
</table>

The currently drained area of 190 million ha has been developed over a period of roughly two centuries. The current rate of drainage development is unknown but estimated to be in the order of 0.5 – 1.0 million ha for year (including upgrading and rehabilitation). Considering that the continuing agricultural development will make improved drainage increasingly needed, as well as affordable, for the 2025s time horizon, the following projection can be made (Smedema, 2000):

4.1 Irrigated Land

In irrigated agriculture drainage is essential under most conditions. It is essential to combat water logging and salinity. Pilot projects in waterlogged and salinized areas need to be established in order to verify available technologies and provide training for personnel. Groundwater monitoring, water balance studies and conjunctive use of surface and groundwater should be encouraged as well. The above-described issues tackle the root cause of the major drainage problems encountered in irrigated agriculture. To be effective they have to be translated into actions through the formulation of appropriate programs. In this context, a realistic medium term drainage program is conceived to involve the development of 10-15 million surface drainage and 2-3 million ha of subsurface drainage, almost all located in the developing countries. The contribution of the world’s food production of such a program would roughly be equivalent to that of some 3-4 million ha of irrigated land.

4.2 Rainfed Land

In rainfed agriculture, drainage is required to increase and sustain agricultural production by preventing any temporary waterlogging and flooding of lowlands. It is estimated that about one-third of the world’s rainfed cropland is naturally not well enough drained and would benefit from investment in improved drainage. This suggests that some 250-300 million ha of rainfed cropland are still in need of improved drainage of which 25-30 million ha would seem to be a reasonable target for a medium term program. Most of this land would be located in the humid tropical zone of southeastern Asia, as it is, mainly, in this area that drainage has remained under-developed (with only some 4% of the land being provided with drainage facilities) and, therefore,
4.3 Challenges for Drainage Systems in a Changing Environment

The above assessment of future drainage needs suggests that the contribution of drainage development to the world’s food supply would be rather modest in the medium term perspective. Implementation of an envisioned program of improved drainage for the 2025s time horizon is predicted to increase the food production of the irrigated area by some 1.0-1.5 % and of the rainfed area by some 0.5-1.0%, while the global weighted average would be only in the order of 1%. Although the absolute values of these figures may be disputed, there should be no doubt that drainage no longer plays the important role in the food production process that it played in the past. Drainage, however, plays and will play an important role in maintaining present levels of food production. This applies to rainfed land, the productivity of much of which would fall substantially without the provided drainage, but especially to the irrigated land. Without drainage, a large part of the irrigated land in the arid and sub-arid zones (probably up to one third) would not be sustainable and would be doomed to degrade into waterlogged and/or salinized wasteland. Added to this, the systems have to withstand the pressure of changing needs, demands and social and economic evolution. Consequently, the infrastructure of most drained areas needs to be renewed or even replaced and, thus, redesigned and rebuilt, in order to achieve improved sustainable production. This process depends on a number of common and well-coordinated factors, such as a new and advanced technology, environmental protection, institutional strengthening, economic and financial assessment, research thrust and human resource development. Most of these factors are well known, and linked to uncertainties associated with climate change, world market prices and international trade. In this context, the effects of climate change may play an important role (Schultz and De Wrachien, 2002). Availability of reliable hydroclimatic data is an essential prerequisite for the rational planning, design and management of drainage systems. These systems were designed for a long life on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to the global warming and the greenhouse effect. Therefore, designers and managers need to systematically re-examine planning principles design criteria, operation rules, contingency plans and water management policies. All the above factors and constraints compel engineers and decision-makers to review the strengths and weaknesses of current and future trends in drainage and rethink technology, institutional and financial patterns, research thrust and manpower policy so that service levels and system efficiency can be improved in a sustainable manner.

5 THE CHANGING ENVIRONMENT: CLIMATE TRENDS, HYDROLOGY AND WATER RESOURCES

Global climate change has become an important area of investigation in natural sciences and engineering, and water resources has often been cited as an area in which climate change may be particularly important for decision-making. A change in the global climate would have major impacts on both the quantity and quality of water available for human use. According to the Intergovernmental Panel on Climate Change (IPCC, 1996a) a greenhouse warming would affect precipitation patterns, evapotranspiration rates, the timing and magnitude of runoff and the frequency and intensity of storms. A rise in sea level associated with such a warming could affect flooding of coastal lands and related drainage and reclamation measures. In addition, temperature and precipitation changes would affect demands for water for irrigation and other purposes. Although a climate change is expected to have significant impacts on water resources, the range of uncertainty as to these climate impacts, at the geographic scales of particular interest, would affect the water resources planning and management process, is great. In contrast to the considerable work that has been devoted to examining the potential impacts of global climate change on water resources systems, relatively little has been done to review the adequacy of existing water planning principles and evaluation criteria in the light of these potential changes.

In this context, and with reference to the agricultural sector, the absence of a uniform understanding and application of basic evaluation principles, has hindered, up to now, the prospects for developing an integrated assessment to account for the linkages between climate change and planning and design criteria of irrigation and drainage systems. The challenge today is to identify short-term strategies, in planning and design procedures, in the face of long-term uncertainty. The question is not, what is the best
irrigation and drainage development over the next fifty or hundred years, but rather, what is the best development for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course.

5.1 Trends in Climate Change

5.1.1 The greenhouse effect
Over the long-term, the Earth’s climate has been changing due to a number of natural processes, such as gradual variation in solar radiation, meteorite impacts and, more importantly, sudden volcanic eruptions in which solid matter, aerosols and gases are ejected into the atmosphere. Ecosystems have adapted continuously to these natural changes in climate, and flora and fauna have evolved in response to the gradual modifications of their physical surroundings, or have become extinct. Human beings have also been affected by and have adapted to changes in local climate, which, in general terms, have occurred very slowly. Over the past century, however, human activities have begun to affect the global climate. These effects are due not only to population growth, but also to the introduction of technologies developed to improve the standard of living. Human-induced changes have taken place much more rapidly than natural changes. The scale of current climate forcing is unprecedented and can be attributed to greenhouse gas emissions, deforestation, urbanization, and changing land use and agricultural practices. The increase in greenhouse gas emissions into the atmosphere is responsible for the increased air temperature, and this, in turn, induces changes in the different components making up the hydrological cycle such as evapo-transpiration rate, intensity and frequency of precipitation, river flows, soil moisture and groundwater recharge. Mankind will certainly respond to these changing conditions by taking adaptive measures such as changing patterns in land use. However, it is difficult to predict what adaptive measures will be chosen, and their socio-economic consequences (De Wrachien, Ragab and Giordano, 2002).

5.1.2 Climate change scenarios
Current scientific research is focused on the enhanced greenhouse effect as the most likely cause of climate change in the short-term. Until recently, forecasts of anthropogenic climate change have been unreliable, so that scenarios of future climatic conditions have been developed to provide quantitative assessments of the hydrological consequences in some regions and/or river basins. Scenarios are “internally-consistent pictures of a plausible future climate” (Wigley, et al., 1986). These scenarios can be classified into three groups:

- hypothetical scenarios;
- climate scenarios based on General Circulation Models (GCMs);
- scenarios based on reconstruction of warm periods in the past (paleoclimatic reconstruction).
- The plethora of literature on this topic has been thoroughly summarized by IPCC (IPCC, 1992).

The scenarios of the second group have been widely utilized to reconstruct seasonal conditions of the change in temperature, precipitation and potential evapo-traspiration at basin scale over the next century. GCMs are complex three-dimensional computer-based models of the atmospheric circulation, which provide details of changes in regional climates for any part of the earth. Until recently, the standard approach has been to run the model with a nominal “pre-industrial” atmospheric carbon dioxide (CO₂) concentration (the control run) and then to rerun the model with doubled (or sometimes quadrupled) CO₂ (the perturbed run). This approach is known as “the equilibrium response prediction”. The more recent and advanced GCMs are, nowadays, able to take into account the gradual increase in the CO₂ concentration through the perturbed run.

To examine climate change over the three major agro climatic zones, due to the enhanced greenhouse effect, the most recent results of the following GCMs have been mainly used in the present report (in alphabetical order):

- the Geophysical Fluid Dynamic Laboratory (GFDL), Princeton, USA (Weatherald and Manabe 1986);
- the Goddard Institute of Space Sciences (GISS), USA (Hansen and Takahashi, 1984);
- the Oregon State University (OSU), USA (Schlesinger and Zhas, 1989);
The models differ as to the way in which they handle the physical equations describing atmospheric behaviour. The important elements are the interactions between land and water surfaces and the fluxes of energy, water and CO\textsubscript{2}. The description of these processes, for large areas, is often based on small-scale field data or models that cannot be valid for the large grid cells that subdivide the areas modelled (of the order of 300x300 to 1000x1000x km\textsuperscript{2}). The upscaling problem is one of the main reasons for the different results of the models. All the scenarios are for time horizons ranging from 2040s to 2050s.

### 5.1.3 Arid and semiarid regions

The arid and semiarid regions are particularly vulnerable to climate change, such that any changes in precipitation patterns will have significant impacts on hydrological regimes and water resource systems (Leavesley et al., 1992, Shiklomanov 1994). For example, an increase in mean annual air temperature by 1-2\textdegree C and a 10% decrease in precipitation could reduce annual river runoff by up to 40-70%. These conclusions were based on estimates for river basins in areas of water deficit in the USA, Canada, Australia, Russia, Africa and South America (Table 3).

#### Table 3 Results of assessments of impacts of climate change on annual river runoff (basins and areas of water deficit) (Shiklomanov, 1999)

<table>
<thead>
<tr>
<th>Climate change scenario</th>
<th>Temperature (°C)</th>
<th>Precipitation (%)</th>
<th>Change in annual runoff (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean for seven large basins in the western USA</td>
<td>+2</td>
<td>-10</td>
<td>-40 to -76</td>
</tr>
<tr>
<td>Colorado River, USA</td>
<td>+1</td>
<td>-10</td>
<td>-50</td>
</tr>
<tr>
<td>Peace River, USA</td>
<td>+1</td>
<td>-10</td>
<td>-50</td>
</tr>
<tr>
<td>River basins in Utah and Nevada, USA</td>
<td>+2</td>
<td>-10</td>
<td>-60</td>
</tr>
<tr>
<td>River basins in the steppe zones of European Russia</td>
<td>+1</td>
<td>-10</td>
<td>-60</td>
</tr>
</tbody>
</table>

In analyses of the hydrological consequences of global warming in arid regions, particular attention has been paid to the Sahel, where the severe droughts of recent decades have already caused critical situations and highlighted the inadequacy of most water management systems.

The greenhouse effect, due to higher CO\textsubscript{2} concentrations, affects strongly plant physiology and transpiration capacity (at higher CO\textsubscript{2} concentrations, transpiration tends to decrease). Such factors have been stressed for river basins in Arizona (Idso and Brazel, 1984), and for watersheds in Australia (Aston, 1984) and in Pakistan (Ahmad, 2002).

With regard to irrigation and drainage practices, Easterlin, et al. (1991) found that the direct effect of higher CO\textsubscript{2} concentration would be to increase rainfall, leading to a reduction in crop water requirements, but this depends to a large extent on the type of vegetation. For example, Kimball et al. (1993) found that an increase in CO\textsubscript{2} of up to 550 parts per million would reduce the evapotranspiration of winter wheat by about 11%.

### 5.1.4 Humid tropical zone

The impacts of global warming on water resources in humid tropical regions have been assessed mainly on the basis of studies and investigations carried out on river basins of the following countries: India, Indonesia, Sri Lanka, Uruguay, Venezuela, Vietnam.
GCMs were used in each case where river basin responses were estimated from hypothetical scenarios. The quantitative conclusions differ somewhat. For example, in a study of the Uruguay River, Tucci and Damiani (1991) compared the results of GISS, GFDL and UKNO GCMs for the case of double CO₂ concentration. The Authors concluded that all three models underestimated the amounts of precipitation, but that GISS model better reflected the historical situation. Nonetheless, with global warming of 1-2°C, the total runoff in likely to increase.

5.1.5  Temperate zone
The most significant changes in hydrological regimes are likely to occur in the seasonal distribution of runoff, rather than in mean annual values. There is a general consensus that the greatest increases in runoff would occur in winter, due to the combined effects of higher temperatures reducing snow cover, and increases in the frequency of occurrence and the intensity of storms (Leavesley, et al., 1992, and Arnell 1995). Such effects would be most acute in regions where at present river regimes are dominated by spring snowmelt. Thus, there would be a shift in the frequency of floods and low flows, with such extreme occurring more often in winter and summer, respectively.

For the former Soviet Union, for example, Shiklomanov and Lins (1991) showed that with a temperature increase of 1°C, the total annual river runoff could increase by about 7%, and with an increase of 2°C the runoff of large river systems could increase by 10-20%. Similar conclusion have been drawn for regions with comparable physiographic conditions such as Belgium, Canada, Poland, Scotland.

In summary, the materials submitted to the IPCC for temperate humid regions indicate that global warming will tend to increase mean annual runoff. In regions where runoff is derived mainly from spring snowmelt significant changes in seasonal and monthly runoff can be expected. In this case the streamflow distribution throughout the year would be more vulnerable to changes in air temperature than in annual precipitation.

5.2  Impacts of Climate Change in the Hydrological Cycle
Under warmer conditions the hydrological cycle will become more intense, stimulating rainfall of greater intensity and longer duration, causing longer prolonged periods of floods and droughts. Increases in maximum floods are likely to occur in north-western USA and northeaster Canada. Significant increases in runoff maxima may be expected in north-western Europe, and increases in winter runoff minima and reduced spring snowmelt in eastern Europe. The global warming is likely to intensity the variability of the Asian monsoon region, increasing the frequency of floods and droughts. In Australia there would be greater variability in the extreme parameters of precipitation and river runoff (Australian Bureau of Meteorology, 1991).

The hydrological consequences of global warming include changes in river runoff and the water balance, as well as in other parameters such as the total water availability, water levels, and maximum and minimum discharges, which, in turn, would affect planning, design and management of water resource systems.

Sea level rise and changes in river runoff will cause the flooding of many low-lying coastal areas. Changes in the processes of delta formation would also contribute to the salinization of irrigated lands near the lower reaches of rivers and estuaries, due to the saltwater intrusion.

These problems have not been adequately addressed yet in the available literature. Such assessments require multidisciplinary research that takes into account detailed forecast of changes in regional climate characteristics and water regimes under various environmental conditions.

5.3  Impacts of Climate Change on Water Resources
In assessing the hydrological impacts of global warming, the issue of water resources represents an important component of the process. Global warming could result in changes in water availability and demand, as well as in the redistribution of water resources, in the structure and in the nature of water consumption, and more intense disputes among different water uses. These impacts may be positive or negative, depending on the climate scenario adopted, the water management sector concerned and the environmental conditions.
In summary, for all developing countries with high population growth rates, the per capita water availability tends to decrease irrespective of the climate scenario (Dam, 1999). However, for many countries the various model results are inconsistent; this highlights the difficulty in formulating appropriate adaptive water management strategies if they are to be based on current predictions of the effects of climate change. The results of assessments of possible changes in irrigation and drainage water requirements for various world regions are, also, ambiguous and depend on the scenarios applied, on the methods of computation and on physiographic conditions. All this stresses the fact that factors other than climate will stimulate projects to ensure the availability of reliable water supplies in many parts of the world and that climate change may introduce still greater uncertainty in the development of methods for water resources management and control.

6 PLANNING AND DESIGN OF DRAINAGE SYSTEMS UNDER CLIMATE CHANGE

Impacts of a greenhouse warming that are likely to affect planning and design of water systems include changes in precipitation and runoff patterns, sea level rise, land use and changes in water demand and allocation. Drainage systems are particularly sensitive to change in precipitation, temperature and carbon dioxide levels. Despite recent advances in climate change science, great uncertainty remains as to how and when climate will change and how these changes will affect planning design and management of drainage systems at both the watershed and field levels. So, water authorities should begin to re-examine design criteria for the present and future planned drainage systems under a wide range of climatic conditions and explore the vulnerability of both structural and non-structural components of the systems to possible future climate change. Water authorities have relied in the past on the assumption that the future climatic conditions will not be different from the past ones. Drainage systems have been designed using historical information on temperature, precipitation and crop water requirements and expected to last 50 years or even longer. Past records of hydrological conditions may no longer be a reliable guide for the future. New planning principles, design criteria, operating rules, contingency plans and evaluation procedures are needed able to respond to new information with midcourse corrections and to include hedging strategies along with the option value of alternative courses of action. The challenge today is to identify short-term strategies to face long-term uncertainties. The question is not, what is the best course, for a drainage project over the next fifty years, but rather, what is the best scheme for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course (IPCC, 1996b).

6.1 Current Planning Principles and Design Criteria

The planning and design of a drainage system should be viewed as an aspect of agricultural development concerning the private sector as well as the national economy. So, particular attention should be paid to:

- the importance of water for agricultural production in relation to national water use;
- historical water use practices;
- effect on the local hydrological environment;
- maintenance of water quality and quantity.

In this context, the process of determination of design parameters, selection of systems and materials, construction methods, operational and maintenance aspects has to proceed in a balanced way, in order to optimize designs and to take into account the interactions among land use, agricultural practices and the layout and characteristics of drainage networks (Storsbergen, 1993).

The choice of a drainage technique will depend on the environmental conditions. The available methods include deep and shallow tube wells, skimming wells, wide-spaced and narrow-spaced drain pipes, deep and shallow ditches, surface drainage or mole drains. Planners and designers have to incorporate sufficient flexibility into the networks to be able to cope with changes in the objectives of the schemes. These may be due to alteration of cropping patterns, agrarian structures, urbanization, infrastructure, agricultural practices, mechanization, hydrological regime, water management and water use trends.
Research on the planning and design of drainage systems has to deal with different aspects such as: design criteria and design methods, materials, construction, maintenance, control and inspection equipment, institutional and financial aspects of system construction, operation and maintenance. Because of the increasing scarcity of usable water resources, special attention should be focused on the control of disposal water. The objective of this process is to optimize the efficiency of available land and water resources use with the ultimate goal of enhancing crop yield and production. For a well planned and controlled drainage scheme, the following aspects need to be taken into account at the design stage:

- data on climate, cropping pattern, stream flow, surface and subsurface water regime, water demand for agricultural, industrial and municipal purposes;
- existing facilities (dams, canal systems and associated structures);
- design parameters for drainage works and all associated structures;
- future operational, maintenance and management procedures including monitoring, financial and administrative facilities.

Standardization of design procedures is necessary to allow for possible decentralization of the design process. This will facilitate construction supervision and establish the basis for a more rational and sustainable drainage scheme, with consequent benefits for its operation and maintenance. Design standards should be simple and precise, so as to provide designers with clear choices as to type of structure to be used and procedures to be followed.

In operational terms, the design of a drainage system may be divided in two phases: the selection of type and layout of the system and the determination of its hydraulics characteristics (discharge rates, pumping capacity, pipe cross-sections and so). Two design criteria can be followed: the traditional empirical method and the optimization procedure (ICID, 1999).

### 6.2 Climate Change Impacts on Planning and Design

As stated above, greenhouse warming is likely to have major impacts on drainage systems. Possible impacts that may especially affect planning principles and design criteria include changes in precipitation and runoff patterns, sea level rise, flooding of coastal irrigated lands and land use. Warmer temperatures will accelerate the hydrologic cycle, altering rainfall, the magnitude and timing of runoff, and the intensity and frequency of floods and droughts. Higher temperatures will also increase evapo-transpiration rates and alter soil moisture and infiltration rates.

Uncertainties as to how the climate will change and how drainage systems will have to adapt to these changes, are challenges that planners and designers are compelled to cope with. In view of these uncertainties, planners and designers need guidance as to when the prospect of climate change should be embodied and factored into the planning and design process. An initial question is whether, based on GCM results or other analysis, there is reason to expect that a region's climate is likely to change significantly during the life of a drainage system. If significant climate change is thought to be likely, the next question is whether there is a basis for forming an expectation about the likelihood and nature of the change and its impacts on the system. For example, in arid and semiarid areas, where runoff is particularly sensitive to temperature and precipitation changes, planners should pay special attention to potential climate impacts. The suitability and robustness of a system can be assessed by either running what if scenarios that incorporate alternative climates or through synthetic hydrology by translating apparent trends into enhanced persistence. In the absence of an improved basis for forming expectations as to the magnitude, timing and the direction of shifts in an irrigated area's climate and hydrology, it may be difficult to evaluate the suitability of further investments in drainage development, based on the prospects of climate change.

When there is ground for featuring reasonable expectations about the likelihood of climate changes, the relevance of these changes will depend on the nature of the project under consideration. Climate changes that are likely to occur several decades in the future will have little relevance for decisions involving drainage development or incremental expansions in present systems capacity. Under these circumstances planners and designers should evaluate the options under one or more climate change scenarios.
scenarios to determine the impacts on the project’s net benefits. If the climate significantly alters the net benefits, the costs of proceeding with a decision assuming no change can be estimated. If these costs are significant, a decision tree can be constructed for evaluating the alternatives under two or more climate scenarios (Hobbs, et al., 1997). Delaying an expensive and irreversible project may be a competitive option, especially in view of the prospect that the delay will result in a better understanding as to how the climate is likely to change and impact the effectiveness and performance of the system.

Even in the absence of concerns about climatic change, the high costs of and limited opportunities for developing new large drainage projects, have brought a shift away from the traditional quite unbending planning principles and design criteria to meeting changing water needs and dealing with hydrologic variability and uncertainty. Efficient, flexible drainage systems designed for current climatic trends would be expected to perform efficiently under different environmental conditions. Thus, institutional flexibility that might complement or substitute for infrastructure investments is likely to play an important role in drainage system development under the prospect of global climatic change. Frederick et al. (1997) proposed a subsequent five-step planning and design process for water resource systems, to deal with uncertain climate and hydrologic events, that is likely to fit the development of large drainage schemes.

If climate change is identified as a significant planning issue (first step), the second step in the process would include a forecast of the impacts of climate change on the region’s irrigated area. The third step involves the formulation of alternative plans, consisting of a system of structural and/or non-structural measures and hedging strategies that address, among other concerns, the projected consequences of climate change. Non-structural measures that might be considered include modification in management practices, regulatory and pricing policies. Evaluation of the alternatives, in the fourth step, would be based on the most likely conditions expected to exist in the future with and without the plan. The final step in the process involves comparing the alternatives and selecting a recommended development plan.

The planning and design process needs to be sufficiently flexible to incorporate consideration of and responses to many possible climate impacts. Introducing the potential impacts of and appropriate responses to climate change in planning and design of drainage systems can be both expensive and time consuming. The main factors that might influence the worth of incorporating climate change into the analysis are the level of planning, (local, national, international) the reliability of GCMs, the hydrologic conditions, the time horizon of the plan or life of the project. The development of a comprehensive multi-objective decision-making approach that integrates and appropriately considers all these issues, within the drainage project selection process, warrants further research on:

- understanding the processes governing global and regional climates and the links between the climate and hydrology;
- the impacts of increased atmospheric CO₂ on vegetation and runoff;
- the effect of climate variables, such as temperature and precipitation, on the demand of water especially for agricultural and landscape irrigation

7 CONCLUDING REMARKS

- Drainage is a crucial measure for achieving sustainable development of both irrigated and rain fed agriculture throughout the world.
- In irrigated agriculture, drainage is essential to combat waterlogging and salinity. Groundwater monitoring, water balance studies and investigations and conjunctive use of surface and groundwater should be encouraged. Pilot projects in waterlogged and salinized areas need to be established in order to verify and test available technologies and provide training for personnel.
- In rainfed agriculture drainage is required to increase and sustain agricultural production by preventing any temporary
waterlogging and flooding of lowlands. It is estimated that about one-third of the world's rainfed cropland would benefit from investments in improved drainage.

- It is estimated that by 2025s, drainage development would increase the world's food production by some 1.0%. This, compared to a projected 50% increase due to irrigation development, means that drainage no longer will play the important role, in the food production process, that it played in the past.

- Drainage, however, remains of critical importance to the maintenance of the present food production levels as without this measure, yields from much of the most productive rainfed land would fall drastically, while an estimated one third of the irrigated land in the arid zone is predicted to turn into waterlogged/salinized wasteland.

- Most of the world's drainage facilities were developed on a step-by-step basis over the centuries and were designed for a long life (50 years or more), on the assumption that climatic conditions would not change in the future. This will not be so in the years to come, due to the global warming and the greenhouse effect. Therefore, engineers and decision-makers need to systematically re-examine planning principles, design criteria, operating rules, contingency plans and water management policies.

- Possible impacts of climate variability that may affect planning principles and designs criteria includes changes in temperature, precipitation and runoff patterns, sea level rise, flooding of coastal irrigated and rainfed lands.

- Uncertainties as to how the climate will change and how drainage systems will have to adapt to these changes are issues that water authorities are compelled to cope with. The challenge is to identify short-term strategies to face long-term uncertainties. The question is not what is the best course for a drainage project over the next fifty years or more, but rather, what is the best scheme for the next few years, knowing that a prudent hedging strategy will allow time to learn and change course.

- The planning and design process needs to be sufficiently flexible to incorporate consideration of and responses to many possible climate impacts. The main factors that will influence the worth of incorporating climate change into the process are the level of the planning, the reliability of the forecasting models, the hydrological conditions and the time horizon of the plan or the life of the project.

- The development of a comprehensive approach that integrates all these factors within the drainage project selection, warrants further research on the processes governing climate changes, the impacts of increased atmospheric carbon dioxide on vegetation and runoff, the effect of climate variables on water demand for irrigation and the impacts of climate on drainage systems performance.

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DRAINAGE DEVELOPMENT IN A CHANGING ENVIRONMENT: OVERVIEW AND CHALLENGES

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ABSTRACT

Under the arid conditions prevailing in the Lower Indus Basin, crop production is only possible under irrigated agriculture. The irrigation system of Pakistan is largely unlined, which means that seepage losses from canals and watercourses reduce the water available for crop production. Farmers installed shallow tubewells to increase their irrigation water supplies. Over the past years rainfall has been minimal in Pakistan and this has reduced the availability of canal water. As a result the need for tubewell water increased and the number of private tubewells increased exponentially. This caused the watertable to fall dramatically and farmers are pumping groundwater from greater depth. However, in the Indus Basin ground water salinity is increasing with depth and farmers are pumping more and more saline water, which they use to irrigate their fields. This development has reached alarming dimensions. Current estimates put the number of tubewells in Pakistan at around 600,000. Under the National Drainage Program the Lower Indus Water Management and Reclamation Research (LIM) Project at Hyderabad is conducting experiments on farmers fields for dissemination of technologies to grow crops with saline water without destroying soil structure so that the practice remains sustainable. The experimental work involves the application of amendments, use of proper fertilizers, water management technology using laser-controlled precision land leveling as well as lining of watercourses to reduce seepage losses. This will increase availability of good quality water for crop production. This paper reports on preliminary results. Farmers meetings and field days are being held in the area to disseminate findings and farmers show great interest in the results.

Tentative findings indicate that groundwater of poor quality containing up to 2,000 ppm total salts can be used for crop production on these soils, provided amendments like farm yard manure and sugar mill filter cake (Press mud) are used. Without the use of amendments, irrigation with this saline water will deteriorate soil structure and reduce crop yields. Experiments and dissemination to farmers continue and this project will be completed by mid 2004.

1 INTRODUCTION

Agriculture depends upon irrigation and most of crop production is attributed to irrigated agriculture. Due to arid and semi-arid climatic conditions, irrigation is central to irrigated agriculture. Pakistan has developed one of the largest contiguous irrigation systems of the world which is confronted with problems of waterlogging and salinity and water shortages. The irrigated agriculture in Pakistan offers conducive environment for occurrence of waterlogging and salinity due to flat topography and arid to semi-arid conditions. The evaporation rates vary between 2.5 mm/day to 13 mm/day with an annual average of 2400 mm. These climatic conditions are favourable for capillary salinization. The irrigation system without adequate drainage facilities has resulted in rising water tables. The rise in water tables has been followed by salinization and sodification of the surface soils. In the country vast areas have been affected by moderate to strong salinity and sodicity problems. This has led to a decrease in national agricultural output to meet the population needs growing at the rate of about 2.15% per annum (Anonymous, 2000).

Further due to scarcity of canal water supplies, dependence on ground water use has increased rapidly. In many canal water shortage areas, farmers often supplement it with ground water resources of which the quality varies from useable to hazardous. Generally farmers give little attention towards the quality of underground water being used and as such its discriminate use without adopting proper management practices deteriorates the physical and chemical properties of the soil. The available ground water resources in the Indus Plain are in general of inferior quality and deteriorate the physical and chemical status of the soil as well as crop growth. About 50% of the underground resources can be used for crop production by adopting appropriate technology, while remaining 50% is hazardous (Malik, et al; 1984).

The magnitude of problem warrants all out efforts for improvement, management and reclamation of salinized soil. The role of appropriate technology in agriculture and allied sectors is more crucial in SAARC countries as more than half of the national income derived from agriculture (Kabir, 1998). Hence an integrated package of fertilizer and amendments use to avert the deleterious effects of soil and water salinity need to be developed and disseminated to farmers. The use of fertilizers with proper dose and combination play an important role in increasing crop yields (Braun et al; 1983). Soil condition is an important consideration especially for the selection of fertilizers materials and results in higher efficiency (Saleem, 1992).

Plants are generally inefficient in uptake of soil N due to losses from NH3 volatilization, leaching and de-nitrification. Efficiency can be improved by properly time fertilization or by enhancing plant absorption of N. Ammonium toxicity is particularly deleterious to young seedling and can limit plant yields (Fenn et al; 1991). Plant yields in calcareous soils where Ca2+ was applied with Urea were increased compared to yields with Urea alone, NH4NO3 or other common N fertilizers (Fenn, 1986; Fenn et al; 1987).

Organic matter (FYM, green manure or natural manure) aid in reclamation process by releasing Ca from CaCO3 present in calcareous soils (Ahmed and Chaudhry, 1997). Various researchers reported that addition of organic matter as FYM/ green manure could facilitate the hydraulic conductivity which can prolong the appearance of adverse effects of high ECw on soil and crops (Ghaofer et al; 1997 a.b). The application of press mud to a saline sodic soil significantly reduce soil SAR and increase water infiltration and crop yields of Wheat and Cotton with use of high SAR water (Haider and Hussain, 1976 and Chaud et al; 1977).

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The objectives of the study are to:

http://library.wur.nl/ebooks/drainage/drainage_cd/2.1%20azad%20h.%20and%20vos%20j.html (1 of 12)26-4-2010 12:11:56
2 Material and Methods

2.1 Location of Study Area

The study is being carried out in the Dhoro Naro Minor command located in the east of Nawabshah City in Nawabsahah Component of LBOD Stage-I. The total Gross Command Area (GCA) is about 6098 hectares (15067 acres) out of which Culturable Command Area (CCA) is 5416 hectares (13382 acres). It off takes from the Gajrah Branch of Nasrat Branch that off takes from Rohri Canal. The total length of the minor is 10.39 km. The designed, discharge of the minor is 51.62 cusecs with 25 watercourses off taking from both the sides of the minor. The Dhoro Naro Minor command area is a nondescript stretch of land, about 17 kilometers long and roughly 7 kilometers wide. As this area is situated at the intersection of Nawabshah and Sanghar Districts, therefore, from an administrative point of view, it is divided into two districts; but, from an irrigation point of view, it falls in the Nawabshah Division. The salient features of the study area are presented in Table 1.

Table 1 Salient Features of the Dhoro Naro Minor

<table>
<thead>
<tr>
<th>Irrigation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Off take RD</td>
<td>91.4 (Gajrah Branch)</td>
</tr>
<tr>
<td>Designed Discharge at Head-Regulator</td>
<td>51.62 cusecs</td>
</tr>
<tr>
<td>Length of Minor</td>
<td>10.4 km</td>
</tr>
<tr>
<td>Total Length of Watercourses</td>
<td>77.8 km</td>
</tr>
<tr>
<td>Number of outlets</td>
<td>25</td>
</tr>
<tr>
<td>Number of lined Watercourses</td>
<td>16</td>
</tr>
<tr>
<td>Number of unlined Watercourses</td>
<td>09</td>
</tr>
<tr>
<td>Culturable Command Area (CCA)</td>
<td>13,382 acres</td>
</tr>
<tr>
<td>Gross Command Area (GCA)</td>
<td>15,067 acres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Drainage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of saline Tubewells</td>
<td>07</td>
</tr>
<tr>
<td>Number of private Tubewells</td>
<td>more than 153</td>
</tr>
<tr>
<td>Total Length of Disposal Channel</td>
<td>km</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>19822</td>
</tr>
<tr>
<td>Number of potential Water Users</td>
<td>504</td>
</tr>
<tr>
<td>Tenants (Share Croppers)</td>
<td>594</td>
</tr>
<tr>
<td>Number of Villages</td>
<td>147</td>
</tr>
<tr>
<td>Number of Households</td>
<td>2468</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Major Communities</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jamali, Khakheli, Syed, Zaradi, Brohi, Arain,</td>
<td>Shar, Mughari,</td>
</tr>
<tr>
<td>Gupchani, Shar, Mughari, Keerio, etc.</td>
<td>Keerio, etc.</td>
</tr>
</tbody>
</table>
## Languages of the area

<table>
<thead>
<tr>
<th>Languages of the area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sindhi, Siraiki, Punjabi, Balochi &amp; Brahvi</td>
</tr>
</tbody>
</table>

## Cropping Pattern

<table>
<thead>
<tr>
<th>Season</th>
<th>Crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kharif</td>
<td>Cotton, Sugarcane, Fodder</td>
</tr>
<tr>
<td>Rabi</td>
<td>Wheat, Sugarcane, Oil Seed, Vegetables, Fodder</td>
</tr>
</tbody>
</table>

### 2.2 Climate

The climate of the command area is extremely hot in the summer season, mostly in June and July, but is cold during winter. In the summer season, days remain very hot, sometimes temperatures pass 50 degrees centigrade, but in the night, mostly fast winds blow from the South; hence, nights are charming in the open air, while inside the house the atmosphere remains hot. The climate is suitable for all major crops such as cotton, wheat, chilies, sugarcane, oil seeds, bananas, etc.

Monthly rainfall during summer is between 45 and 55 millimeters, which is slightly more than in the northern part of the Sindh Province, while the winter season is particularly dry (IIMI, 1997).

### 2.3 Irrigation Resources

The main source of irrigation water is canal. But at the same time, there are more than 153 private tubewells which are being used during periods of water shortage. The tubewell water is being used by mixing with canal water when available because tubewell water contains salt concentrations ranging between 371 ppm and 8857 ppm. otherwise they use it as such just to save their standing crop.

There are water shortages at the tail of the minor, as well as at the ends of the watercourses. Despite the fact that there is water shortage, canal water is also wasted. The water wastage is mainly due to unreliable water supply, seepage losses, field application losses, deep percolation, evaporation due to an arid and hot climate, unlined watercourses, over and frequent irrigation.

### 2.4 Experimental Work

The experimental work was started during April, 2001 on farmer’s fields in the command of Dhoro Naro Minor. The experimental work involves the application of amendments on two plots with size of 0.4 hectares on two watercourses, use of proper fertilizers on size of 0.4 hectares plots each on normal and saline soil on two separate watercourses and water management technology on separate watercourse. For experimental and demonstration purpose 5 out of 25 watercourses were selected. The soils were sandy loam with moderate salinity. Crop rotation used was Cotton-Wheat-Cotton. The following amendment treatments were tested with three replications and Randomized Complete Block Design:

- **Treatment 1**: No amendment and irrigation with canal water (control)
- **Treatment 2**: Farm Yard Manure @ 25 tons/ha and irrigation with tubewell water (up to 2000 ppm).
- **Treatment 3**: Press Mud (Sugar mill filter cake) @ 25 tons/ha and irrigation with tubewell water (up to 2000 ppm).
- **Treatment 4**: No amendment and irrigation with tubewell water (up to 2000 ppm).

The fertilizer treatments tested were Urea+DAP (control), Ammonium Nitrate + DAP and Ammonium Sulphate + Nitrophos. The parameters studied were soil characteristics (ECe, SAR & pH) at 0-15, 15-30, 30-60, 60-90 and 90-120, soil infiltration rates by using Standard Ring Method (Aronovici, 1955) and crop yields at various stages. ECe, SAR and pH were measured according to the method described by US Salinity Laboratory Staff (1954). About 10 hectare plot was precisely leveled with laser controlled equipment and about 325 meter section of watercourse was lined to reduce water losses and increase water availability.

Dissemination plan has been framed for the end users which includes demonstration of experiments, individual/group farmers meetings and discussion, farmer’s day and preparation and distribution of leaflets, pamphlets, and brochures regarding tested technologies. At regular intervals the process of dissemination is underway and farmers are showing keen interest in the various interventions for saline water use.

### 3 Results and Discussion

#### 3.1 Role of Amendments Experiment

##### 3.1.1 Changes in Infiltration Rate of Soil

The Calcium Bicarbonates in solution form in irrigation waters tends to form relatively insoluble Calcium Carbonates which produces cement like calcite deposits in the soil. Consequently, Calcium is progressively lost in water while the Sodium remains in solution due to which Sodium to Calcium ratio increases in the water moving in the soil. The dominance of Sodium decreases the porosity of soil resulting in the reduction in soil infiltration rate, soil aeration and leaching capability of irrigation water. These reductions in soil permeability due to use of poor quality water can lead to salt accumulation unless otherwise managed through amendments.

The changes in infiltration rate of soil over the seasons are given in Table 2 & 3. The initial average infiltration rate of experimental plots at start of Kharif (season 15 April to 15 October) 2001 was 13.7 cm/6 hours at watercourse 3R and 12.0 cm/6 hours at watercourse 1BL.
At the end of the season (Kharif 2002), the 51 percent highest increase in infiltration rate over 2 years period was recorded in the plots where press mud was applied and irrigation were given with tubewell water at watercourse 3R whereas at watercourse 1BL, highest increase of 79% infiltration rate was recorded in treatment plot where Farm Yard Manure @ 25 tons/ha was applied with tubewell water. The results are in conformity with Ghafoor et al; (1997a, b) and Haider and Hussain (1976). The infiltration rates recorded at the harvest of Wheat crop Rabi (15 October to 15 April) 2001-02 are lower at both sites as compared to Kharif crop. The increase in infiltration rates seems to be attributed to addition of Cotton crop residue in the soil and due to low soil moisture contents. The post Rabi 2002-2003 infiltration measurement may further support this hypothesis.

Table 2  Soil infiltration rate (cm/6 hrs) as affected by different treatments at watercourse 3R.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Initial Pre-Cotton 2001</th>
<th>Post Cotton 2001</th>
<th>Post Wheat 2001-02</th>
<th>Post Cotton 2002</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Amendments and irrigations with canal water</td>
<td>13.7</td>
<td>19.2</td>
<td>6.4</td>
<td>14.0</td>
<td>+2</td>
</tr>
<tr>
<td>(control).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm Yard Manure @ 25tons/ha and irrigation with</td>
<td>13.7</td>
<td>19.8</td>
<td>11.7</td>
<td>20.0</td>
<td>+46</td>
</tr>
<tr>
<td>tubewell water.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press Mud @ 25 tons/ha and irrigation with tubewell</td>
<td>13.7</td>
<td>18.7</td>
<td>9.8</td>
<td>20.7</td>
<td>+51</td>
</tr>
<tr>
<td>water.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Amendments and irrigation with tubewell water.</td>
<td>13.7</td>
<td>17.0</td>
<td>8.5</td>
<td>18.4</td>
<td>+34</td>
</tr>
<tr>
<td>(T-4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3  Soil infiltration rate (cm/6 hrs) as affected by different treatments at watercourse 1BL.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Initial Pre-Cotton 2001</th>
<th>Post Cotton 2001</th>
<th>Post Wheat 2001-02</th>
<th>Post Cotton 2002</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Amendments and irrigations with canal water</td>
<td>12.0</td>
<td>14.3</td>
<td>6.7</td>
<td>14.4</td>
<td>+20</td>
</tr>
<tr>
<td>(control).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm Yard Manure @ 25tons/ha and irrigation with</td>
<td>12.0</td>
<td>16.0</td>
<td>7.4</td>
<td>21.5</td>
<td>+79</td>
</tr>
<tr>
<td>tubewell water.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Press Mud @ 25 tons/ha and irrigation with tubewell</td>
<td>12.0</td>
<td>13.3</td>
<td>7.1</td>
<td>14.2</td>
<td>+18</td>
</tr>
<tr>
<td>water.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Amendments and irrigation with tubewell water.</td>
<td>12.0</td>
<td>13.3</td>
<td>5.8</td>
<td>14.1</td>
<td>+17</td>
</tr>
<tr>
<td>(T-4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.1.2 Changes in Electrical Conductivity (ECe) of Soil

The ECe of soil profile is based on the movement of soluble salts with water in the soil matrix. If the movement of water is restricted by soil crusting, hardening of soil layers, inadequate drainage etc. the soil salinity is developed and as such ECe is increased and vice versa. On the other hand if the soil environment facilitates proper leaching, the ECe could be managed even with marginal quality irrigation water.

The bench mark ECe of study was determined before sowing of Cotton crop during Kharif 2001 and it was higher at upper depths than the lower depths. Depending on the quality of water used (tubewell and canal) and different amendments, the different treatments showed variable behaviour in the trend of ECe during the study (Table 4 & 5). The depth-wise trend of initial ECe at watercourse 3R shows gradual decrease up to 30-60 cm depth where it is almost of the same level as in 60-90 cm depth. At watercourse 1BL, the initial ECe is highest at 0-15 cm depth, followed by 60-90 cm depth and almost equal for 15-30 cm and 30-60 cm depth.

The data shows trend of increase in ECe at the end of Post Wheat 2001-02 at almost all the depths in all treatments at both the sites except T-3, where there is 34% decrease at 0-15 cm depth at watercourse 3R. The increase of ECe at treatment where canal water has been applied seems to be due to canal water shortages. In the absence of canal supplies some time tubewell water has to be applied for survival of crop.
Table 4  Electrical conductivity (Ece dS/m) of soil as affected by different treatments at watercourse 3R.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depth (cm)</th>
<th>Initial Pre-Cotton 2001</th>
<th>Post Cotton 2001</th>
<th>Post Wheat 2001-02</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Amendments and irrigations with canal water (control). (T-1)</td>
<td>0-15</td>
<td>4.7</td>
<td>11.3</td>
<td>5.4</td>
<td>+14.9</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>2.9</td>
<td>10.8</td>
<td>3.6</td>
<td>+24.1</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>1.7</td>
<td>3.6</td>
<td>2.7</td>
<td>+58.8</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>1.7</td>
<td>2.7</td>
<td>2.2</td>
<td>+29.4</td>
</tr>
<tr>
<td>Farm Yard Manure @ 25tons/ha and irrigation with tubewell water. (T-2)</td>
<td>0-15</td>
<td>4.7</td>
<td>8.4</td>
<td>6.4</td>
<td>+36.2</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>2.9</td>
<td>7.9</td>
<td>4.5</td>
<td>+55.2</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>1.7</td>
<td>5.5</td>
<td>3.4</td>
<td>+100.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>1.7</td>
<td>3.5</td>
<td>2.6</td>
<td>+52.9</td>
</tr>
<tr>
<td>Press Mud @ 25 tons/ha and irrigation with tubewell water. (T-3)</td>
<td>0-15</td>
<td>4.7</td>
<td>7.5</td>
<td>3.1</td>
<td>34.0</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>2.9</td>
<td>5.6</td>
<td>2.9</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>1.7</td>
<td>4.2</td>
<td>2.5</td>
<td>+47.1</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>1.7</td>
<td>4.1</td>
<td>2.1</td>
<td>+23.5</td>
</tr>
<tr>
<td>No Amendments and irrigation with tubewell water. (T-4)</td>
<td>0-15</td>
<td>4.7</td>
<td>7.8</td>
<td>5.2</td>
<td>+10.6</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>2.9</td>
<td>10.6</td>
<td>5.4</td>
<td>+86.2</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>1.7</td>
<td>5.3</td>
<td>2.9</td>
<td>+70.6</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>1.7</td>
<td>2.3</td>
<td>2.3</td>
<td>+35.3</td>
</tr>
</tbody>
</table>

Table 5  Electrical conductivity (Ece dS/m) of soil as affected by different treatments at watercourse 1BL.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depth (cm)</th>
<th>Initial Pre-Cotton 2001</th>
<th>Post Cotton 2001</th>
<th>Post Wheat 2001-02</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Amendments and irrigations with canal water (control). (T-1)</td>
<td>0-15</td>
<td>2.9</td>
<td>5.4</td>
<td>4.5</td>
<td>+55.2</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.9</td>
<td>5.0</td>
<td>5.3</td>
<td>+178.9</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>2.0</td>
<td>4.3</td>
<td>3.7</td>
<td>+85.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>2.3</td>
<td>3.6</td>
<td>2.2</td>
<td>-4.3</td>
</tr>
<tr>
<td>Farm Yard Manure @ 25tons/ha and irrigation with tubewell water. (T-2)</td>
<td>0-15</td>
<td>2.9</td>
<td>4.7</td>
<td>4.1</td>
<td>+41.4</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.9</td>
<td>5.7</td>
<td>4.9</td>
<td>+157.9</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>2.0</td>
<td>4.0</td>
<td>4.1</td>
<td>+105.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>2.3</td>
<td>4.2</td>
<td>2.5</td>
<td>+8.7</td>
</tr>
<tr>
<td>Press Mud @ 25 tons/ha and irrigation with tubewell water. (T-3)</td>
<td>0-15</td>
<td>2.9</td>
<td>4.5</td>
<td>3.8</td>
<td>+31.0</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.9</td>
<td>3.9</td>
<td>4.2</td>
<td>+121.1</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>2.0</td>
<td>4.6</td>
<td>4.3</td>
<td>+115.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>2.3</td>
<td>4.1</td>
<td>3.1</td>
<td>+34.8</td>
</tr>
<tr>
<td>No Amendments and irrigation with tubewell water. (T-4)</td>
<td>0-15</td>
<td>2.9</td>
<td>5.5</td>
<td>3.9</td>
<td>+34.5</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>1.9</td>
<td>4.0</td>
<td>5.6</td>
<td>+194.7</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>2.0</td>
<td>8.1</td>
<td>4.7</td>
<td>+135.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>2.3</td>
<td>3.6</td>
<td>2.9</td>
<td>+26.1</td>
</tr>
</tbody>
</table>

3.1.3  Changes in Sodium Adsorption Ratio of Soil

The soil SAR values for different periods as affected by different treatments are given in Table 6 & 7. At the initial stage the SAR in 15-30 cm depth at watercourse 3R were higher in almost all the plots whereas it lowered with increasing depth. At the end of Wheat 2001-02 crop the SAR values have been decreased in the upper layer in all the treatments except T-3. The highest decrease was recorded in the 0-15 cm depth in T-1. At watercourse 1BL the SAR in the upper layer 0-15 cm depth has increased in all the treatments. The SAR level is well below the critical level and there are no signs of sodicity.
### Table 6  Sar of soil as affected by different treatments at watercourse 3r.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depth (cm)</th>
<th>Initial Pre-Cotton 2001</th>
<th>Post Cotton 2001</th>
<th>Post Wheat 2001-02</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Amendments and irrigations with canal water (control). (T-1)</td>
<td>0-15</td>
<td>3.8</td>
<td>8.0</td>
<td>2.2</td>
<td>-42.1</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>4.6</td>
<td>8.2</td>
<td>3.6</td>
<td>-21.7</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>3.4</td>
<td>4.5</td>
<td>3.9</td>
<td>+14.7</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>3.6</td>
<td>4.8</td>
<td>2.1</td>
<td>-41.7</td>
</tr>
<tr>
<td>Farm Yard Manure @ 25tons/ha and irrigation with tubewell water. (T-2)</td>
<td>0-15</td>
<td>3.8</td>
<td>7.0</td>
<td>4.2</td>
<td>+10.5</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>4.6</td>
<td>7.3</td>
<td>3.8</td>
<td>-17.4</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>3.4</td>
<td>5.2</td>
<td>4.0</td>
<td>+17.6</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>3.6</td>
<td>3.8</td>
<td>3.3</td>
<td>-8.3</td>
</tr>
<tr>
<td>Press Mud @ 25 tons/ha and irrigation with tubewell water. (T-3)</td>
<td>0-15</td>
<td>3.8</td>
<td>8.4</td>
<td>4.8</td>
<td>+26.3</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>4.6</td>
<td>5.9</td>
<td>5.7</td>
<td>+23.9</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>3.4</td>
<td>5.2</td>
<td>3.3</td>
<td>-11.8</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>3.6</td>
<td>4.2</td>
<td>3.2</td>
<td>-11.1</td>
</tr>
<tr>
<td>No Amendments and irrigation with tubewell water. (T-4)</td>
<td>0-15</td>
<td>3.8</td>
<td>7.1</td>
<td>2.9</td>
<td>-23.7</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>4.6</td>
<td>8.9</td>
<td>3.9</td>
<td>-15.2</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>3.4</td>
<td>5.1</td>
<td>5.0</td>
<td>+47.1</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>3.6</td>
<td>3.5</td>
<td>3.3</td>
<td>+47.2</td>
</tr>
</tbody>
</table>

### Table 7  Sar of soil as affected by different treatments at watercourse 1bl.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depth (cm)</th>
<th>Initial Pre-Cotton 2001</th>
<th>Post Cotton 2001</th>
<th>Post Wheat 2001-02</th>
<th>Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Amendments and irrigations with canal water (control). (T-1)</td>
<td>0-15</td>
<td>2.3</td>
<td>4.7</td>
<td>4.2</td>
<td>+82.6</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>3.1</td>
<td>3.4</td>
<td>2.8</td>
<td>-9.7</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>2.0</td>
<td>3.2</td>
<td>2.5</td>
<td>+25.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>7.4</td>
<td>3.3</td>
<td>3.5</td>
<td>-52.7</td>
</tr>
<tr>
<td>Farm Yard Manure @ 25tons/ha and irrigation with tubewell water. (T-2)</td>
<td>0-15</td>
<td>2.3</td>
<td>4.9</td>
<td>3.6</td>
<td>+56.5</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>3.1</td>
<td>5.0</td>
<td>3.4</td>
<td>+9.7</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>2.0</td>
<td>4.3</td>
<td>1.9</td>
<td>-5.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>7.4</td>
<td>3.5</td>
<td>2.1</td>
<td>-71.6</td>
</tr>
<tr>
<td>Press Mud @ 25 tons/ha and irrigation with tubewell water. (T-3)</td>
<td>0-15</td>
<td>2.3</td>
<td>4.8</td>
<td>2.9</td>
<td>+26.1</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>3.1</td>
<td>4.0</td>
<td>3.0</td>
<td>-3.2</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>2.0</td>
<td>4.9</td>
<td>2.2</td>
<td>+10.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>7.4</td>
<td>6.3</td>
<td>2.8</td>
<td>-62.2</td>
</tr>
<tr>
<td>No Amendments and irrigation with tubewell water. (T-4)</td>
<td>0-15</td>
<td>2.3</td>
<td>6.1</td>
<td>3.6</td>
<td>+56.5</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>3.1</td>
<td>4.2</td>
<td>3.9</td>
<td>+25.8</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>2.0</td>
<td>3.6</td>
<td>2.7</td>
<td>+35.0</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>7.4</td>
<td>4.2</td>
<td>4.0</td>
<td>-46.9</td>
</tr>
</tbody>
</table>

### 3.1.4 Tubewell Water Quality

Tubewell water is being used for irrigation in all the treatments except control. The determination of its quality is important to know the effects on crop response. The quality of tubewell water is changing over time depending on the running time, as most of the tubewells are shallow. The tubewell water EC ranges from safe limits less than 1000 ppm and over the season it sometimes reach up to 4000 ppm which becomes hazardous and mixing with canal water becomes essential. The results of water quality are given in Table 8 to 10.
### Table 8 Quality of tubewell water used for irrigation (Kharif 2001)

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>Date</th>
<th>pH</th>
<th>ECw Micromhos/cm</th>
<th>TDS (ppm)</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watercourse 3R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 15.06.2001</td>
<td>7.8</td>
<td>2900</td>
<td>1856</td>
<td>3.7</td>
<td></td>
</tr>
<tr>
<td>II 22.06.2001</td>
<td>7.8</td>
<td>4600</td>
<td>2944</td>
<td>6.7</td>
<td></td>
</tr>
<tr>
<td>III 06.07.2001</td>
<td>8.0</td>
<td>5000</td>
<td>3200</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>IV 20.07.2001</td>
<td>8.0</td>
<td>6000</td>
<td>3840</td>
<td>6.0</td>
<td></td>
</tr>
<tr>
<td>Watercourse 1BL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 01.07.2001</td>
<td>7.9</td>
<td>4200</td>
<td>2688</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>II 22.07.2001</td>
<td>7.8</td>
<td>4200</td>
<td>2687</td>
<td>4.9</td>
<td></td>
</tr>
</tbody>
</table>

### Table 9 Quality of tubewell water used for irrigation during rabi 2001-02.

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>Date</th>
<th>pH</th>
<th>ECw Micromhos/cm</th>
<th>TDS (ppm)</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watercourse 3R</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 06.12.2001</td>
<td>8.0</td>
<td>550</td>
<td>352</td>
<td>1.06</td>
<td></td>
</tr>
<tr>
<td>II 16.01.2002</td>
<td>8.0</td>
<td>3700</td>
<td>2368</td>
<td>3.57</td>
<td></td>
</tr>
<tr>
<td>III 30.01.2002</td>
<td>8.0</td>
<td>4300</td>
<td>2752</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>IV 15.02.2002</td>
<td>8.0</td>
<td>1100</td>
<td>704</td>
<td>1.81</td>
<td></td>
</tr>
<tr>
<td>Watercourse 1BL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I 11.12.2001</td>
<td>7.8</td>
<td>4800</td>
<td>9072</td>
<td>3.10</td>
<td></td>
</tr>
<tr>
<td>II 06.01.2002</td>
<td>7.8</td>
<td>6500</td>
<td>4160</td>
<td>4.89</td>
<td></td>
</tr>
<tr>
<td>III 09.02.2002</td>
<td>7.8</td>
<td>6800</td>
<td>4352</td>
<td>5.11</td>
<td></td>
</tr>
</tbody>
</table>

### Table 10 Quality of tubewell water used for irrigation during Kharif 2002.

http://library.wur.nl/ebooks/drainage/drainage Ced2.1%20azad%20h.%20and%20vos%20j.html (7 of 12)
### Effect of Treatments on Crop Yields

The yield data for two season Cotton crop (Kharif 2001 & 2002) and one season Wheat crop for Rabi 2001-02 is given in Table 11 & 12. The data of Seed Cotton yield (Kharif 2001) at watercourse 3R indicate that the highest Seed Cotton yield of 1239 kg/ha was obtained from T-2 where Farm Yard Manure @ 25 tons/ha was applied with tubewell water which is followed by T-1. Seed Cotton yield of 1197 kg/ha was achieved where only canal water was applied. The Seed Cotton yield of 1062 kg/ha was noted from T-3 where Press Mud was used with tubewell water irrigations. The lowest Seed Cotton yield of 767 kg/ha was produced from T-4 where all irrigations were made by tubewell water. It is further added that 4% increase has been noticed in Seed Cotton yield in T-2 which is followed by T-1 whereas 11% and 36% yield decrease has been observed in T-3 and T-4 respectively as compared to T-1.

The yield data of Seed Cotton at watercourse 1BL indicate that the maximum Seed Cotton yield of 1074 kg/ha was obtained from T-2 where Farm Yard Manure @ 25 tons/ha was applied with tubewell water which is followed by T-1. Seed Cotton yield of 1060 kg/ha was achieved where only canal water was applied. The Seed Cotton yield of 950 kg/ha was noted from T-3 where Press Mud was used with tubewell water irrigations. The lowest Seed Cotton yield of 759 kg/ha was produced from T-4 where all irrigations were applied with tubewell water. It is further added that 1% yield has been increased in T-2 which is followed by T-1 where all irrigations were applied with canal water (control). 10% and 28% yield was decreased in T-3 and T-4 respectively when compared with T-1.

During Kharif 2002, at watercourse 3R highest Cotton yield was obtained from T-2 plot followed by T-1 whereas at watercourse 1BL, control plot gave highest yield followed by T-2.

The highest Wheat grain yields of 5345 and 5525 kg/ha were obtained during Rabi 2000-01 at watercourse 1BL and 3R respectively from the treatment T-1 where canal water was applied. The next higher yields were 4815 and 4630 kg/ha at watercourse 1BL and 3R, respectively from the treatment T-2 where FarmYard Manure was applied. The lowest yields were obtained from the treatment T-4 where tubewell water was applied.

### Table 11 Crop yield (kg ha⁻¹) as affected by different treatments at watercourse 3R.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cotton Kharif 2001</th>
<th>Change over control (%)</th>
<th>Cotton Kharif 2002</th>
<th>Change over control (%)</th>
<th>Wheat Rabi 2001-02</th>
<th>Change over control (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Amendments and irrigations with canal water (control). (T-1)</td>
<td>1197</td>
<td>-</td>
<td>1100</td>
<td>-</td>
<td>5525</td>
<td>-</td>
</tr>
<tr>
<td>Farm Yard Manure @ 25 tons/ha and irrigation with tubewell water. (T-2)</td>
<td>1239</td>
<td>+4</td>
<td>1268</td>
<td>+15</td>
<td>4630</td>
<td>-16.2</td>
</tr>
<tr>
<td>Press Mud @ 25 tons/ha and irrigation with tubewell water. (T-3)</td>
<td>1062</td>
<td>-11</td>
<td>1041</td>
<td>-5</td>
<td>4340</td>
<td>-22.2</td>
</tr>
<tr>
<td>No Amendments and irrigation with tubewell water. (T-4)</td>
<td>767</td>
<td>-36</td>
<td>953</td>
<td>-13</td>
<td>3800</td>
<td>-31.2</td>
</tr>
</tbody>
</table>

### Table 12 Crop yield (kg ha⁻¹) as affected by different treatments at watercourse 1BL.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cotton Kharif 2001</th>
<th>Change over control (%)</th>
<th>Cotton Kharif 2002</th>
<th>Change over control (%)</th>
<th>Wheat Rabi 2001-02</th>
<th>Change over control (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Amendments and irrigations with canal water (control). (T-1)</td>
<td>1197</td>
<td>-</td>
<td>1100</td>
<td>-</td>
<td>5525</td>
<td>-</td>
</tr>
<tr>
<td>Farm Yard Manure @ 25 tons/ha and irrigation with tubewell water. (T-2)</td>
<td>1239</td>
<td>+4</td>
<td>1268</td>
<td>+15</td>
<td>4630</td>
<td>-16.2</td>
</tr>
<tr>
<td>Press Mud @ 25 tons/ha and irrigation with tubewell water. (T-3)</td>
<td>1062</td>
<td>-11</td>
<td>1041</td>
<td>-5</td>
<td>4340</td>
<td>-22.2</td>
</tr>
<tr>
<td>No Amendments and irrigation with tubewell water. (T-4)</td>
<td>767</td>
<td>-36</td>
<td>953</td>
<td>-13</td>
<td>3800</td>
<td>-31.2</td>
</tr>
</tbody>
</table>
3.2 Use of Proper Fertilizers Experiment

3.2.1 Changes in Electrical Conductivity (ECe) of Soil
The Electrical Conductivity values for five depths ranging from 0-15 to 90-120 cm during pre Kharif 2001 are given in Table 13. The changes at the end of study will be recorded and compared.

3.2.2 Changes in Sodium Adsorption Ratio of Soil
The soil SAR values for different periods as affected by different treatments are given in Table 14. The SAR values range between 2.3 (normal soil at 60-90 cm depth) to 10.5 (saline soil at 30-60 cm depth) and fall within safe limit of sodicity. The changes in SAR due to various fertilizer treatments will be recorded at the end of study i.e. Rabi 2002-2003.

3.2.3 Tubewell Water Quality
Tubewell water is being used for irrigation in all the treatments. The determination of its quality is important to know the effects on crop response. The quality of tubewell water is changing over time depending on the running time as most of the tubewells are shallow. The tubewell water EC values range from 1800 to 8300 micromhos/cm during different times over the season. Similarly SAR values show variation ranging from 1.7 to 8.0 and needs careful management for its application.

Table 13 Electrical conductivity (dS/m) of soil as affected by different treatments pre-Kharif 2001.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depths (cm)</th>
<th>Watercourse 6R</th>
<th>Watercourse 7L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Normal Soil</td>
<td>Saline Soil</td>
</tr>
<tr>
<td>T-1 = Urea + DAP (Control)</td>
<td>0-15</td>
<td>4.3</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>6.8</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>6.0</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>5.3</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>90-120</td>
<td>4.8</td>
<td>4.7</td>
</tr>
<tr>
<td>T-2 = Ammonium Nitrate + DAP</td>
<td>0-15</td>
<td>3.8</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>5.8</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>6.5</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>6.0</td>
<td>6.6</td>
</tr>
<tr>
<td></td>
<td>90-120</td>
<td>4.8</td>
<td>4.5</td>
</tr>
<tr>
<td>T-3 = Ammonium Sulphate + Nitrophos</td>
<td>0-15</td>
<td>3.9</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>15-30</td>
<td>5.9</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>6.1</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>6.0</td>
<td>5.8</td>
</tr>
<tr>
<td></td>
<td>90-120</td>
<td>4.0</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Table 14 Sar of soil as affected by different treatments pre-Kharif 2001.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Watercourse 6R</th>
<th>Watercourse 7L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Saline</td>
</tr>
<tr>
<td>T-1 = Urea + DAP (Control)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-2 = Ammonium Nitrate + DAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T-3 = Ammonium Sulphate + Nitrophos</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


3.2.4 Effect of Treatments on Crop Yields

The yield data for two Cotton crop (Kharif 2001 & 2002) and one Wheat crop for Rabi 2001-02 is given in Table 15 & 16.

The data of Seed Cotton during Kharif 2001 at Watercourse # 6-R normal soil indicate that highest Seed Cotton yield of 1255 kg/ha was obtained from T-3 where Ammonium Sulphate and Nitrophos was applied which is followed by T-2 (Ammonium Nitrate+DAP) and T-3 (Urea+DAP). The same trend is observed on saline soil with maximum yield of Seed Cotton of 1092 kg/ha from T-3 (Ammonium Sulphate+Nitrophos) followed by T-2 and T-1.

The yield data of Seed Cotton given in Table 15 indicates that maximum Seed Cotton yield of 1649 kg/ha was obtained from T-3 on normal soil which is followed by T-2 and T-1. The lowest yield of 1240 kg/ha was obtained from T-1 where Ammonium Nitrate and Urea were applied.

Almost similar trend was observed on saline soil with maximum Seed Cotton yield of 1143 kg/ha followed by 998 kg/ha from T-2 and 935 from T-1.

The highest Wheat grain yield of 5470 kg/ha (Table 16) was obtained during Rabi 2001-02 from Treatment T-3 where Ammonium Sulphate and Nitrophos were applied at normal soil on Watercourse 7-L. The next maximum yield of 5130 kg/ha was obtained from Treatment T-2 where Ammonium Nitrate and DAP were used. T-3 gave 11.35% higher yield over control.

Similarly normal soil site at watercourse 6R gave higher yields than saline soils irrespective of treatment. Among the treatments, T-3 gave highest yield of 5321 and 4227 kg/ha at normal and saline soil site at watercourse 6-R, respectively.

The lowest yields were recorded from control where Urea+DAP was applied. The increase in T-3 plots over control ranges from 2.9% to 18.7%.

3.3 Water Management Technologies

A block of 10 hectares land has been precisely leveled using laser controlled equipment which was provided by Water Management Training Institute, Sakrand. The block consisted of 62 fields before leveling and after leveling it was divided into 12 equal size fields measuring 100 m x 72 m each with 4 meter access road in the middle of the farm. Similarly two field channels have been constructed in the middle of the area on either side of the main access road. About 5600 cubic meters volume of earth was removed during cut and fill process on this block. The losses on 1000 feet length of selected watercourse before improvement were found as 46% (WAPDA, 2003). The designing and lining of this length is in progress and results of water saving will be recorded during course of study and disseminated to farmers.

3.3.1 Dissemination Plan

For farmers motivation and participation in the development and transfer of technology, farmers day and group meetings were arranged. Local Agriculture Extension staff and farmers organization are also participating in dissemination plan. In the light of the interactions and discussions held during the last two years, it is felt that there is strong need to create awareness about the productive utilization of low quality water use of proper fertilizer and amendments. Groundwater quality and soil testing facilities are being extended to study area farmers and they are accordingly advised to use proper intervention to get maximum crop production.

Table 15 Crop yield (kg ha⁻¹) as affected by various treatments at watercourse 6R.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Normal Soil Cotton 2001 Yield</th>
<th>% increase over control</th>
<th>Normal Soil Wheat 2001-02 Yield</th>
<th>% increase over control</th>
<th>Normal Soil Cotton 2002 * Yield</th>
<th>% increase over control</th>
<th>Saline Soil Cotton 2001 Yield</th>
<th>% increase over control</th>
<th>Saline Soil Wheat 2001-02 Yield</th>
<th>% increase over control</th>
<th>Saline Soil Cotton 2002 * Yield</th>
<th>% increase over control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea + DAP (Control) (T-1)</td>
<td>1085</td>
<td></td>
<td></td>
<td></td>
<td>910</td>
<td></td>
<td></td>
<td></td>
<td>3560</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...
Table 16  Crop yields (kg ha⁻¹) as affected by various treatments at watercourse 7I

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
<td>% increase</td>
<td>Yield</td>
<td>% increase</td>
<td>Yield</td>
<td>% increase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>over control</td>
<td></td>
<td>over control</td>
<td></td>
<td>over control</td>
</tr>
<tr>
<td>Urea + DAP (Control) (T-1)</td>
<td>1240</td>
<td>-</td>
<td>4912</td>
<td>-</td>
<td>1120</td>
<td>-</td>
</tr>
<tr>
<td>Ammonium Nitrate + DAP (T-2)</td>
<td>1509</td>
<td>+21.7</td>
<td>5130</td>
<td>+4.4</td>
<td>1388</td>
<td>+23.9</td>
</tr>
<tr>
<td>Ammonium Sulphate + Nitrophos (T-3)</td>
<td>1649</td>
<td>+32.9</td>
<td>5470</td>
<td>+11.3</td>
<td>1505</td>
<td>+34.4</td>
</tr>
</tbody>
</table>

4 Conclusions

- Awareness has been increased among the farmers regarding use of shallow groundwater as a result of dissemination efforts. They often approach LIM field staff for advice regarding use of tubewell water and fertilizer application.
- Participation of large number of farmers on Farmer’s Day shows interest to adopt technologies being disseminated in the area.
- Among the fertilizer type and combinations Ammonium Sulphate+Nitrophos was significantly found better resulting higher Seed Cotton and Wheat grain yield than other combination.
- Poor quality groundwater up to 2000 should not be used for Wheat and Cotton without any amendment (Farm Yard Manure or Press Mud).
- Due to drought conditions, increasing trend of installation of shallow tubewells in the Dhoro Naro Minor Command area, has necessitated further to disseminate the proper use of low quality tubewell water adopting use of amendment such as Gypsum/Press Mud and Farm Yard Manure and use of low pH fertilizer combination (Ammonium Sulphate + Nitrophos) to minimize deleterious effects of its use.
- About equal Seed Cotton and Wheat grain yield were obtained by applying Farm Yard Manure and irrigation with tubewell water when compared with the yield obtained by applying canal irrigation with no Farm Yard Manure.
- Huge amount of irrigation water loss at watercourse level, farm ditches and field level are taking place due to poor maintenance of watercourses, improper land leveling and farm layout.
- Demonstration of studies are the main tools/approaches to motivate the beneficiaries for saving/conserving irrigation water.
- Further research is required to study the effect of amendments and fertilizers using saline water of inferior quality above 2000 ppm on soil properties and crop yields on long term basis.

5 Acknowledgements

The research presented was funded by National Drainage Programme. The authors wish to thank Dr. Ir. Th. M. Boers, Chief Research Advisor, NDP and LIM Project for encouraging, assisting and providing opportunity to prepare this paper for IDW9. Special thanks are for Mr. Muhammad Suleman Khan, Stenographer Grade-I for typing and composing the draft of the manuscript.

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ABSTRACT
The World's irrigated area is 255 million hectares (m.ha) of which about 20 per cent is affected by waterlogging and salinity. Where the ground water is of good quality, its use by pumping (vertical drainage) can check the rise of ground water table. Horizontal sub-surface drainage in which the saline ground water is drained away through pipes and drains, is the other commonly practised anti waterlogging measure. It is claimed that bio-drainage, in which the characteristic of the trees to transpire water is harnessed to control the rise of ground water table can be an alternative drainage measure, which would be most economical and eco-friendly. But there are doubts and reservations on the long-term sustainability of biodrainage, because of the apprehension that no salts would be removed. The paper describes why this apprehension is not wholly valid and how a sustainable ‘salt balance’ is achievable, when natural river water is used for irrigation. The ‘potential’ and ‘limitations’ of bio-drainage are discussed.

Keywords: Waterlogging, Salinity, Biodrainage

1 INTRODUCTION
The total irrigated area in the world is 255 million hectares (m.ha) of which more than two-third lies in Asia. About 20 per cent of the irrigated land has been rendered saline due to waterlogging. Each year, an additional area of about 1.5 million ha. of irrigated land gets affected by secondary salinisation due to waterlogging, and thereby loses its productivity.

In areas receiving good precipitation, the ground water is generally non-saline and is often used for irrigation. The infiltrating water from precipitation leaches the topsoil and pumping of ground water checks the rise of ground water table into the root zone of crops. Such regions in tropical or temperate climatic zones therefore rarely face the problem of waterlogging and salinisation. On the other hand, in arid and semi-arid zones natural precipitation is inadequate, ground water is saline, and agriculture is practised by surface irrigation by bringing water from sources outside the region. This disturbs the previously existing water balance in the region resulting in rise of ground water table, which if unchecked causes waterlogging and salinisation. The most common method of overcoming the problem is to provide horizontal sub-surface drainage to drain away the excess water through under ground pipelines, and open drains. Another practice is to make conjunctive use of saline ground water along with fresh canal water for irrigation. Vertical drainage by pumping helps to check the rise of ground water table.

The horizontal sub-surface drainage measure is quite effective and is widely practised. The disposal of saline drainage water poses pollution and environmental problems where the saline drainage water cannot be safely disposed off into the sea without polluting natural surface water bodies. The high cost of construction, maintenance and operation of the drainage system is another draw back. The vertical drainage measure has limitation because of the saline nature of the ground water. There is need of finding alternative methods of providing drainage. Biodrainage, in which the characteristic of trees to transpire water is harnessed, can be one such measure. There are differing views on whether ‘bio-drainage’ can or cannot be an effective measure and whether it is sustainable in the long run. A careful study of the potential and limitations of bio-drainage is needed. This paper is an attempt to do so.

2 Requirements to be met by bio-drainage
For biodrainage to be effectively adaptable, the following requirements must be met:

(a) Water balance : The quantity of water removed from the ground water annually should equal the quantity of recharge.
(b) Salt balance : The quantity of minerals removed annually should be nearly equal to the quantity of mineral import.
(c) Area under plantation : Irrigation is practised primarily to promote agriculture, horticulture, dairy etc. Therefore in term of economic returns afforestation or agro-forestry should be comparable with that from other alternative uses of land. If it is not so, afforestation may still be justified, on considerations of the environmental and drainage benefits.
(d) Water for plantations: Under ideal situation, trees in afforestation area on full development should be able to draw most of their requirement of water from the ground water table, so that surface irrigation water can be put to other productive uses. If, and so long it is not possible, plantation trees would need some irrigation water. They may also need some water periodically to leach down salts from the root zone, if and when the salinity levels approach threshold limits.

(e) Ground water quality: The quality of ground water, when the water table approaches the root-zone of trees, should be such as can be tolerated by the plant species, otherwise the trees would need to be supplied irrigation water.

(f) Effect on lowering ground water table: Trees can lower the ground water table directly underneath the plantation area, to a depth up to which the tree roots can extend. This can be up to 15 m from ground surface or even more. To be effective as a drainage measure, the ground water table must be lowered in the irrigated area to a minimum critical depth (say 2 m below ground level), at the farthest point from the edge of the plantation area.

Whether and to what extent the above requirements can be met, would depend upon the prevailing field conditions. Kapoor (2001) has described methods of estimating these. IPTRID (2002) has presented a knowledge synthesis report describing principles, experiences and applications of biodrainage. The Indian National Committee on Irrigation and Drainage (INCID) (2003) has brought out a status report on bio-drainage.

3 Common apprehensions and doubts regarding biodrainage

The ‘apprehensions’ and ‘doubts’ that are often expressed on the feasibility of biodrainage are described in sub paras 3.1 to 3.5.

3.1 Salt Evacuation in Irrigated Agriculture

All plants and vegetation contain some minerals, notably Calcium (Ca++), sodium (Na+), Magnesium (Mg+) as cations and sulfate (SO4), chlorides (Cl-) etc. as anions. The composition and quantity of mineral content in biomass depends on the plant species and characteristics of the soil where the plant grows. The plant analysis results show that the weight of Ca++, Mg++ and Na+ cations in dry biomass of a plant is about 3.3 percent of the weight of the dry biomass. When biomass is harvested and removed from the field, minerals to this extent are also evacuated from the field along with the biomass. Therefore, if the dry biomass produce (grain + foliage) be 10 tons/ha, the weight of cations of minerals evacuated along with the biomass of harvested crop would be at the rate of 0.33 tons/ha.

The commonly found soluble salts in soil solutions are salts of calcium, sodium and magnesium. The percentage gravimetric weight of the respective elements in the salt compounds are as shown in Table 1.

<table>
<thead>
<tr>
<th>Calcium Sulphate (CaSO4)</th>
<th>Sodium Chloride (NaCl)</th>
<th>Magnesium Chloride (MgCl2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.4</td>
<td>39.3</td>
<td>25.5</td>
</tr>
<tr>
<td>Calcium Chloride (Ca Cl2)</td>
<td>Sodium bicarbonate (NAHCO3)</td>
<td>Magnesium sulphate (Mg SO4)</td>
</tr>
<tr>
<td>36.1</td>
<td>27.4</td>
<td>20.2</td>
</tr>
<tr>
<td>Sodium Sulphate (Na2 SO4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

On an overall average basis, the gravimetric weight of mineral elements (Ca, Na, Mg...) in the mineral salt compounds may be taken as about 33 percent. In other words, the total weight of mineral salts absorbed by a plant or evacuated from the soil solution is about three times the total weight of mineral elements (cations) found in the plant. The total weight of mineral compounds evacuated would be about 1.0 ton/ha, corresponding to a harvested crop biomass weight of 10 tons/ha.

The main input of salts in agriculture is through irrigation water, whose source is either rivers or ground water. James (1982) gives the composition of average river waters of the world as shown in the following table 2:

<table>
<thead>
<tr>
<th>Region</th>
<th>Ecb (mhos/cm at 25°C)</th>
<th>Total Concentration B (mg/l)</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>Alkali</th>
<th>So4</th>
<th>Cl</th>
<th>No3</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

http://library.wur.nl/ebooks/drainage/drainage_cd/2.2%20kapoor%20as.html (2 of 6) 26-4-2010 12:11:58
**3.2 Survival of Trees Under Saline Conditions**

Different species of trees have different capacity to survive and grow under saline conditions. Salt tolerant species like Tamarix Troupii, Prosopis jaliflora, Acacia farnesiana give satisfactory growth upto salinity level of 35 dS/m. Acacia nilotica, A. tortilis, Eucalyptus camaldulensis etc. give satisfactory growth upto salinity level of 25 dS/m.

When trees transpire water, salts are left behind in the soil. It is apprehended that if this continues to happen continuously for many years, the salt content in the soil may exceed the tolerance limit of the trees and plantations may not survive.

The concentration of salts in the soil in this manner occurs in the 'capillary zone' which may be about 1.0 m thick. When ground water table is shallow and within the reach of the roots of the trees, they would be able to draw their water requirement from the ground water table. The trees would survive so long as the salinity of ground water (below the ground water table) does not increase beyond the threshold limit. The rise of salinity in the capillary zone does not mean that it would also necessarily increase correspondingly under the ground water table. Survival of trees would be threatened only when the salinity level in the capillary zone as well as in the ground water table both exceed the tolerance limits.

**3.3 Ground Water Salinity**

Ground water salinity under irrigated agriculture lands may or may not increase with passage of time. In the early years, after irrigation is introduced the ground water salinity gets diluted due to recharge from relatively less saline water that infiltrates down from the fields and the conveyance system. This continues to be so with the rise in ground water table until the ground water table stabilises under the new equilibrium conditions. Thereafter, the ground water salinity would not increase if natural river water (unpolluted) is used for irrigation. It would also not increase if ground water is used for irrigation, regardless of whether it is saline or non-saline.

However, if polluted river water (containing salts, say more than 200 mg/l) is used for irrigation, the salinity of ground water may show an increasing trend. The rate at which ground water salinity may increase would depend upon the salinity level and quantity of recharge water, the depth to the barrier layer under the ground water table and the porosity of the sub-strata. Kapoor (2001) estimates that the rate of rise of ground water salinity is likely to be too slow to be a matter of concern in most situations. Transpiration rate from tree plantations decreases with increase in ground water salinity. In case of Eucalyptus plantations the rate may reduce to about one-half of that under non-saline conditions, when the ground water salinity reaches a level of 12 dS/m.

**3.4 Impact of Bio-Drainage on Depressing the Ground Water Table**

Bio-drainage would lower down the ground water table underneath the plantation area. But the objective is not to lower down the ground water table only underneath the plantation area, but to do so under the entire irrigated area. The lowering down of ground water table underneath the plantation area should be to such depth, that the draw down effect extends up to the farthest point from the plantation area, and the ground water table, no where under the irrigated area rises above the critical depth (say 2.0 m) to cause waterlogging. Besides achieving water balance and salt balance, the plantations should be able to generate effective ground water movement from all around under the irrigated area towards the plantation area. The quantity of subsurface water drainage towards the plantations should be adequate to prevent rise of water table above the critical depth any where and everywhere under the irrigated area. To achieve this, the plantation areas would have to be suitably planned and dispersely located over the irrigated area.

If plantation areas are separated by distance L, the depression of water table underneath them would result in ground water flow behaviour similar to that as in case of flow towards parallel ditches penetrating a unconfined aquifer. On equilibrium, the position would be as shown in Figure-1 and the relationship between depression of ground water table, rate of recharge, hydraulic conductivity, depth to barrier layer and distance between plantations can be expressed by

| North America | 220 | 142 | 1.89 | - | 1.05 | 0.41 | 0.39 | 0.04 | 1.11 | 0.42 | 0.23 | 0.02 | 0.96 | 0.23 | 0.22 | 0.02 | 0.4 |
| Europe | 270 | 182 | 2.28 | - | 1.55 | 0.46 | 0.23 | 0.04 | 1.56 | 0.50 | 0.19 | 0.06 | 0.2 |
| Australia | 95 | 59 | 0.58 | - | 0.19 | 0.22 | 0.13 | 0.04 | 0.52 | 0.50 | 0.28 | trace | 0.3 |
| World | 190 | 120 | 1.42 | - | 0.75 | 0.34 | 0.27 | 0.06 | 0.96 | 0.23 | 0.22 | 0.02 | 0.4 |

- Adopted from Rhodes and Bernstein, 1971
- Electrical conductivity
- Alkalinity is titrable bases made up mostly of $\text{HCO}_3^-$, with small amounts of $\text{CO}_3^{2-}$ and OH

When such natural river water (world average) is used for irrigation, the salt import on the field is at the rate of 120 mg/l in which the total cation content (Ca+Mg +Na+K) is about 28 mg/l. If 500 mm of this water were used for irrigation, the import of salt would be 0.6 ton/ha.

Therefore, when natural river water is used for irrigation, there should be no adverse salt balance. When ground water is used for irrigation the salts are merely recycled and there is no change in the overall salt balance status. Salt imbalance would occur only when saline surface water is used for irrigation.
BIO DRAINAGE - POTENTIAL AND LIMITATIONS

Donnan equation:

Donnan Equation

\[ L^2 = \frac{8KYh}{R} + \frac{4K^2h^2}{R} \]

With \( R = 0.5 \text{ mm/day} \), \( h = 10.0 \text{ m} \), \( Y_0 = 10.0 \text{ m} \), and \( K = 100 \text{ mm/day} \), \( L \) works out to 500 m.

**Figure 1  Flow towards depressed ground water table.**

It is seen that plantations would be able to provide effective bio-drainage to farther distances in permeable soils (in comparison to impermeable soils) and when barrier layers are sufficiently deep. With a rate of recharge (R) equal to 0.5 mm/day, head difference (h) of 10.0 m, depth to barrier layer under plantations (Yo) as 10.0 m and hydraulic conductivity value of 100 mm/day, plantations can be spaced 500 m apart. With hydraulic conductivity values of 1000 mm/day and 10 mm/day, the distance between plantations would work out to 1500 m and 150 m respectively.

3.5  Land required for bio-drainage plantations

Land under command in irrigation projects is generally used for agriculture by farmers who own the lands or hold tenancy rights. Sometimes these holdings are quite small in densely populated countries and regions like in India. It is feared that it may not be possible to persuade the farmers to part with their lands or to change its use from agriculture to forestry.

Land is no doubt scarce in densely populated areas. But fresh water is even scarcer. Leaving aside a few exceptional cases, water is relatively much more scarce than land. In dry and regions, the disparity is so marked that land without water has little value. With limited quantity of available water, it is rarely possible to make full productive use of all land. It is very common to leave part of land fallow every season because there is not enough water to irrigate the whole land. In large tracts of irrigated commands in India and Pakistan, irrigation water is available to hardly meet the crop water requirement over half area during each of the winter and summer season. The rest of the land either remains fallow or produces much less than its potential. Therefore, it would not be right to say that land cannot be made available for forestry.

Generally, farmers receive their share of irrigation water on some rationing basis. The returns to a farmer depend more on the volume of his share of water rather than on the size of his land holding. That being the position, it should not be very difficult to persuade the farmers to divert a part of their lands for tree plantations by assuring them that there would be no reduction in their share of water.

In any case, loosing a part of land for tree plantations should be a much better proposition than allowing the land to be destroyed by waterlogging and salinity.

4  Potential and limitations of bio-drainage

Bio-drainage, like other drainage measures, has potential and limitations. All irrigation regions are not alike. They differ in physiographic and climatic conditions. Bio-drainage may be very suitable, partly by suitable or unsuitable depending upon the prevailing conditions. The important characteristics of a region that would govern whether bio-drainage is appropriate or not are whether the region is humid or dry and what is the salinity level of the ground water. Brief description on four possible regional scenarios follows:

4.1  Humid region with ground water of good quality

Generally, humid regions have soils and ground water of good quality. The natural precipitation washes down the salts in soils which are drained away naturally. The top soils and ground water are of a reasonably good quality to enable irrigated agriculture. Natural precipitation may not occur uniformly throughout the year to match with the crop water requirements and therefore supplemental irrigation may be needed. This can be done by storing surface water and making it available for irrigation when needed or by pumping ground water and using it.
In case, use of stored surface water for irrigation results in rise of ground water table and there is a threat of waterlogging the best course would be to make conjunctive use of ground and surface water. This would enable best possible use of the water resource and at the same time check the rise of the ground water table. However, if this is not possible for some reasons, like abundance of surface water or non-availability of dependable power for pumping ground water (a situation that is common in developing countries), then plantation of trees on part area can provide the needed drainage.

4.2 Humid regions with saline ground water
There are very few regions which receive good precipitation and yet have saline ground water. This condition can occur in localised pockets where the ground sub-strata has salt incrustations. The infiltrating water dissolves and carries the salts to the ground water table. In a situation like this, it should be possible to make conjunctive use of surface and ground water. Bio-drainage through tree plantations can also be a viable option.

4.3 Semi-arid and arid regions with ground water of good quality
In dry regions, water is generally scarce and irrigation is often practised by bringing surface water from outside regions. Recharge from irrigation disturbs the previously existing ground water balance and the ground water table (often perched water table) starts rising. The ground water can be pumped and put to conjunctive use along with the surface water for irrigation. This should be the best way to prevent waterlogging. However, there are many examples of excessive use of surface water for irrigation and little use of ground water inspite of its good quality. The reasons of this anomalous position are surplus availability of surface water during early operative years of a project or low cost of surface water to the farmer in comparison to the cost of ground water. The situation should be remedied by appropriate management measures.

The second best alternative to prevent or overcome the threat of waterlogging should be to plant trees on part area to provide bio-drainage.

4.4 Semi-arid and arid region with saline ground water
This is the commonly prevailing situation in most semi-arid and arid regions. The need of irrigation water is maximum in such regions. Water is the scarce resource. Land, mostly waste land, is in abundance.

Waterlogging and secondary salinisation is a common problem when lands are brought under irrigation by bringing water from outside sources. Horizontal sub-surface drainage would be the most suitable and effective measure, where saline drainage water can be safely disposed off into the sea or in evaporation tanks at affordable cost without polluting natural water bodies and/or causing environmental problems. Conjunctive use of ground water can be possible to a limited extent.

Bio-drainage can be a feasible option. Availability of land should not be a problem. Transpiration rates are quite high. The limitation would be the salinity level of the ground water. Where the salinity in ground water at shallow depths reaches 12 dS/m, the transpiration rate falls down to about one-half. If and when it reaches to a level of say 25 dS/m, the tree plantations may become ineffective.

The position of potential and limitations of bio-drainage and relative suitability with other drainage measures is summarised in the following table:

<table>
<thead>
<tr>
<th>Characteristics of the region</th>
<th>Potential and limitation of bio-drainage</th>
<th>Relative ranking of drainage measures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feasibility</td>
<td>Merits</td>
</tr>
<tr>
<td>Humid region with ground water of good quality</td>
<td>Feasible</td>
<td>Least cost, environment friendly</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humid region with ground water of poor quality</td>
<td>Feasible where salinity of ground water is not excessive (say, more than 12 dS/m)</td>
<td>Least cost, environment friendly</td>
</tr>
<tr>
<td>Semi arid and arid regions with</td>
<td>Feasible</td>
<td>Least cost, environmental</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Potential and limitations of biodrainage and relative suitability of drainage measures.
5 Summary and conclusions

Bio-drainage can be a feasible option for controlling waterlogging and salinity in irrigated lands. Its main merits are economy in cost and environment improvement. The limitations are requirement of land for tree plantations, limited evacuation of salts from the system and vulnerability of trees to high saline conditions.

The requirement of land for tree plantations may be about 10 per cent of the area, which should be no problem, particularly in semi-arid and arid zones.

All biomass contain some minerals which are evacuated, when the crops are harvested and removed from the field. When natural river water (unpolluted) is used for irrigation, the mineral evacuation by biomass may equal the net import of minerals with the irrigation water, enabling a reasonable salt balance.

Tree growth and transpiration rate is affected by ground water salinity. There are many species of trees that are salt tolerant and grow satisfactorily upto salinity levels of 12 dS/m or more. There are quite large irrigated areas, that have ground water salinity of less than 12 dS/m, Bio-drainage should be feasible in such areas.

6 REFERENCES

INCID (2003) "Bio-drainage - Status in India and other countries" Publication of the Indian National Committee on Irrigation and Drainage, New Delhi, India.
MANAGING SALINITY FOR SUSTAINABILITY OF IRRIGATION IN AREAS WITH
SHALLOW SALINE GROUND WATER

Dr. James E. Ayars, Dr. Ir. Richard W. Soppe, Dr. Evan W. Christen

ABSTRACT
Irrigation will be required to meet the demands of the world population for food. Water will also be needed to meet the municipal, industrial, and environmental demands of the growing population. As a result irrigation water supplies will be reduced and irrigators will probably be forced into using degraded water as part of the supply and the possibility for increased salinity in the soil profile will occur. Drainage will be required to assist in the management of the water needed for leaching to prevent soil salinisation. Drainage water containing salt and other contaminants creates a water quality problem for the water body receiving the drainage water. The paper presents the results of three cases studies that address the issue of disposal of saline drainage water through reuse for supplemental irrigation, water table control, and changing the design criteria for subsurface drainage as methods to reduce the drainage volume. The first study demonstrated that over 50% of the crop water requirement can be met with saline drainage water and that salinity in the soil profile can be managed to not adversely affect yields. This is not the case if the drainage water contains high levels of boron. The second study demonstrated that the water table can effectively be manipulated if the drainage system is properly installed. The third study showed the reduction in salt load as a result of implementing drainage control on deep drains or installing shallow drains. The results from these studies demonstrate that irrigated agriculture is sustainable in arid and semi-arid areas through improved management of the subsurface drainage system.

Keywords: Shallow ground water, salinity, crop selection, controlled drainage.

1. INTRODUCTION
Irrigation supplies approximately 35% of the world food supply on less than 20% of the arable land and has a significant future role in meeting the projected world food demand. Currently, irrigation uses approximately 80% of the developed water supply worldwide, and this water will be a logical source for meeting other demands for water i.e., municipal, industrial, and environmental. The alternative to new irrigation development will be to increase water use efficiency through improved irrigation technology, improved crops, improved productivity of lands impacted by high water tables and salinity. Surface irrigation is the major form of irrigation throughout the world and as a result the world wide irrigation efficiency is in the range of 30 to 50%. This poor efficiency provides opportunities for improvement that will result in water for other uses without having a negative impact on production. Low irrigation efficiency is also responsible for extensive areas of water logging and shallow ground water in irrigated agriculture that continue to require subsurface drainage. Improvements in irrigation management will reduce water logging and deep percolation. However, there is still a need for deep percolation to manage salinity in the root zone, thus resulting in areas of shallow ground water that have to be managed.

In the past shallow ground water was viewed as a waste product of irrigation that required disposal. Recently, shallow ground water is viewed as a resource to meet crop water demands either through in-situ use or by using drainage water for supplemental irrigation (Ayars and Schoneman, 1986; Ayars et al., 1986, 1993, 1998; Ayars, 1996, 1999). Each of these techniques has been used to supplement irrigation supplies with varying degrees of success depending on the crop, shallow ground water quality, and irrigation management. When drainage water is used for supplemental irrigation or in-situ, it has to be stored for future use. If it is to applied by an irrigation system it must be stored in a surface pond for use during the irrigation season which requires an additional irrigation infrastructure. For in-situ use it must be stored in place in the ground by maintaining the water table position and preventing drainage. In-situ use is a more complicated system because there are limited data on the potential crop water use...
from shallow ground water and how to achieve the full potential. Even though there has been extensive research on in-situ crop water use by a wide variety of crops over the past 50 years, the full potential of this resource has not been quantified. This lack of quantification is the result of the complexity of the system, the limited equipment, and the wide variety of objectives being met in the research. Subsurface drainage is a necessary component of irrigated agriculture in arid and semi-arid areas of the world. In the past, drainage systems were designed to prevent salt accumulation using criteria that resulted in deep placement of drainage laterals with wide spacings that insured a mid-point water table depth of 1.2 m. Also, drainage systems were not managed but left to run continuously resulting in a maximum drainage flow and disposal of salt, pesticide, and nitrate without consideration of the water quality consequences for the receiving water body. It is no longer acceptable for a drainage system design not to include a consideration of the impact of drainage water on surface water quality (Ayars et al, 1997; Guitjens et al, 1997). Future drainage design will require that a subsurface drainage system be part of a water management system that includes both irrigation and drainage. The drainage system will contain structures that permit active control of the water table position and discharge (Ayars, 1999; Ayars et al, 2000) (Christen and Ayars, 2001).

Active management of subsurface drainage systems is a new concept for arid and semi-arid areas even though it has been a common practice in humid areas of the world (Fouss et al, 1990). A major limitation in arid areas is the need to manage salinity in soil profile to insure that yield and soil quality are not negatively impacted. The emphasis on drainage management has been for water quality reasons. In humid areas there has been a need to reduce the nitrate level in shallow ground water. In arid areas, salt, toxic elements, and nutrients are the components that affect drainage water quality. In arid and semi-arid areas it is not possible to remove most water quality contaminants through a chemical process so the emphasis has been on methods that reduce the total load delivered to the receiving water body. The approaches taken include source control, the reduction of deep percolation through improved irrigation management, reusing the drainage water for supplemental irrigation, and managing shallow groundwater position for in-situ use by crops. Each of these approaches presents differing opportunities and challenges for managing the salt load in the drainage water and the salt in the soil profile.

The objective of this paper is to use data from case studies in the United States and Australia to discuss the impact of practices and approaches developed to manage the total drainage flow from saline soils in arid and semi-arid areas world on the sustainability of irrigated agriculture.

2. REUSE OF SALINE DRAINAGE WATER

When developing best management practices for subsurface drainage system design, Christen and Ayars (2001) assumed that the irrigation management on a field was developed to the highest practical economic level prior to implementing practices such as reusing drainage water or in-situ use by crops. The first step in solving the drainage water disposal problem in the Central Valley of California (San Joaquin Valley Drainage Program, 1990) was improving irrigation management and was dubbed source control. The next step was reusing saline drainage water for supplemental irrigation, followed by land retirement because there were limited options for discharging water into any surface water supply or evaporation basins. As a result, there were several studies conducted in California to evaluate using saline water for irrigation to reduce the total drainage volume and salt load (Rhoades, 1989; Rhoades et al, 1989) (Ayars et al, 1993). Rhoades et al. 1989 demonstrated cyclic use of saline (3-4 dS/m) and low salinity (1 dS/m) water to alternately grow sensitive and moderately salt sensitive crops with out a loss in crop productivity while maintaining soil salinity at low levels. The study by Ayars et al. (1993) detailed in the following sections used saline water and salt tolerant crops. The essential elements in both studies were the matching of the crop to the water quality and providing leaching at appropriate intervals during the crop rotation.

2.1 Murrieta Farms

This research/demonstration project evaluated irrigation and salinity management on saline soils using either or both low salinity and saline water in the presence of an operating subsurface drainage system. The site was located on the west side of the San Joaquin Valley of California in an area containing naturally occurring saline soils, a product of the weathering of the Coast Range of California. The experiment was conducted for six years (1982 -1987) on a 60 ha field site at Murrieta Farms located near Mendota, California, USA. The soil in the experimental field was classified as an Oxalis silty clay loam (fine, montmorillonitic, thermic Pachic haploxerolls) with a well-developed salinity profile. The salinity development in the profile is typical of many
irrigated areas throughout the world with salinity increasing with depth in the profile. This means that deep drain placement will result in high concentrations of salt in the drainage water and high salt loads. The field was underlain by a shallow (1 to 1.9 m deep), saline ground water having an electrical conductivity (EC_w) of 7 - 10 dS m⁻¹, high concentrations of boron (B), selenium (Se), sodium (Na), calcium (Ca), sulfate (SO₄), chloride (Cl), and nitrate (NO₃). The entire field was drained by subsurface 100 mm diameter plastic drains installed at depths ranging from 1.5 to 1.7 m with lateral spacings of 80 to 90 m. The field was divided into six experimental plots of approximately 10 ha each, four of which were used in this experiment.

Furrow irrigation (F) was used on two plots and surface drip irrigation (T) was used on the remaining two plots. The drip irrigation treatments T1 and T2 were irrigated with saline drainage water collected from the experimental site and adjacent fields (EC_w = 7 dS m⁻¹, B = 5 mg L⁻¹) and stored in a pond adjacent to the site. A separate pumping system was used to move water from the storage pond to the field and to pressurize the drip irrigation system.

Two plots furrow irrigated with low salinity water were used for comparison with plots trickle irrigated with saline water. These plots were adjacent to drip irrigated plots T1 and T2. The treatment F1 was furrow irrigated with low salinity (0.3 to 0.5 dS m⁻¹) water during the 1982 to 1987 period, while treatment F2 received low salinity water from 1982 to 1985 and both saline and low salinity water in 1986 and 1987. The saline water in F2 generally consisted of a 1:1 mix of the saline drainage water (used in treatments T1 and T2) and the low salinity water supplied by the Westlands Water District.

<table>
<thead>
<tr>
<th>Year</th>
<th>Irrigation Treatment</th>
<th>EC_w dS/m</th>
<th>Cl meq/L</th>
<th>B mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>T1 and T2</td>
<td>7.2⁸</td>
<td>28.3</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>F1 and F2</td>
<td>0.3</td>
<td>1.2</td>
<td>0.5</td>
</tr>
<tr>
<td>1984</td>
<td>T1 and T2</td>
<td>7.4</td>
<td>27.4</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td>F1 and F2</td>
<td>0.5</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>1985</td>
<td>T1 and T2</td>
<td>0.6</td>
<td>1.3</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>F1 and F2</td>
<td>0.5</td>
<td>1.3</td>
<td>0.5</td>
</tr>
<tr>
<td>1986</td>
<td>T1 and T2</td>
<td>7.9</td>
<td>27.5</td>
<td>6.4</td>
</tr>
<tr>
<td></td>
<td>F2</td>
<td>3.8</td>
<td>14.3</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>F1</td>
<td>0.3</td>
<td>2.3</td>
<td>0.3</td>
</tr>
<tr>
<td>1987</td>
<td>T1 and T2</td>
<td>7.7</td>
<td>34.4</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>F2</td>
<td>3.5</td>
<td>15.3</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>F1</td>
<td>0.5</td>
<td>3.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

⁸ After 7/15 of 1983, this quality water was used in T1/T2 plots, prior to the data water comparable of F1 plot was used.

Values shown represent the mean of 3 to 7 measurement dates per year at approximately 3 to 5 week intervals.
Table 2. Rainfall and applied water (low-salinity water (NS) EC₆ = 0.3 to 0.5 dS/m and saline EC₆ = 3.5 to 3.8 dS/m in F1 and F2 treatments.

<table>
<thead>
<tr>
<th>Year</th>
<th>Crop</th>
<th>Rainfall (mm)</th>
<th>Applied water (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Between planting and harvest</td>
<td>Total (planting to planting)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F1 NS S</td>
<td>F1 NS S</td>
</tr>
<tr>
<td>1982</td>
<td>cotton</td>
<td>42</td>
<td>287</td>
</tr>
<tr>
<td>1983</td>
<td>cotton</td>
<td>64</td>
<td>126</td>
</tr>
<tr>
<td>1984</td>
<td>cotton</td>
<td>29</td>
<td>128</td>
</tr>
<tr>
<td>1984/85</td>
<td>wheat</td>
<td>60</td>
<td>64</td>
</tr>
<tr>
<td>1985/86</td>
<td>sugar beet</td>
<td>245</td>
<td>349</td>
</tr>
<tr>
<td>1987</td>
<td>cotton</td>
<td>68</td>
<td>68</td>
</tr>
<tr>
<td>Total - 1982 (planting) through 1987 (harvest)</td>
<td>508</td>
<td>1022</td>
<td>3631 0</td>
</tr>
</tbody>
</table>

*Represents total rainfall received from planting time for the year shown in the column of table to planting time of the subsequent crop (in either the same, or the next calendar year - see table for planting dates). The 1987 data are for period of planting to harvest.*
MANAGING SALINITY FOR SUSTAINABILITY OF IRRIGATION IN AREAS WITH SHALLOW SALINE GROUND WATER

Depth of applied water in the furrow irrigated plots was determined by apportioning total applied water measured from the Westlands Water Districts meters based on the plot area, then subtracting tailwater from each area measured using cutthroat flumes equipped with water stage recorders. Depth to shallow ground water was determined in treatments F2, T1, and T2 using shallow wells. Average irrigation water qualities (EC_w, Cl, B) are shown in Table 1. Rainfall and total water applications are shown in Table 2 for the furrow irrigation and Table 3 for the drip irrigation.

The crop rotation used was cotton (Gossypium hirsutum L.), cotton, cotton, wheat (Triticum aestivum), sugar beet (Beta vulgaris), and cotton during the 1982 to 1987 experiment. With the exception of the wheat seed, which was broadcast, all other crops were planted on a 0.76 m row spacing. Pre-plant irrigation with approximately 150 mm of low salinity water was done in a fallow period each year prior to planting. The wheat crop, which was planted approximately 30 days after cotton harvest and was sprinkled with 50 mm of low salinity water for germination. The wheat was irrigated with only low salinity water. After germination, saline water was used exclusively in treatments T1 and T2 to meet crop water requirements for the sugar beet and cotton crops in all years, and after 1986 in treatment F2. Soil sampling for chemical analysis was done in the Spring each year prior to planting but after pre-plant irrigation and in the Fall after harvest but prior to most rainfall and pre-plant irrigation. The soil profile was sampled in 0.3 m increments to a depth of 1.8 m at three to eight locations within each plot using either a machine-driven or 51 mm diameter manual sampling auger. Saturation extracts were made from each sample and a complete analysis of anions and cations was run on the extract. The EC_e, Cl, and B analyses will be used to demonstrate the irrigation management needed for salinity control.

2.1.1 Results

2.1.1.1 Applied water
The total applied water (NS, S) ranged from 3475 mm for treatment T1 to 4196 mm in Treatment T2 (Table 3). In the six crop rotation, 51% and 59% of the total water applied in the T1 and T2 treatments, respectively, was supplied by saline water, while 34% of total applied water was saline in treatment F2. In treatment T1, analysis of the crop water requirements based on ET:crop production functions (Ayars et al, 1986) indicated that crop water use from shallow ground water for the different crops ranged from 15 to 40% of total crop water use. This indicated that most of the applied saline water in T1 was used in evapotranspiration and did not result in net deep percolation losses. This was not true for treatment T2 where applied water in 1986 and 1987 was equal to 1.4 and 1.3 times the estimated Etc. Throughout the experiment the furrow irrigation applications (F1, F2) exceeded the calculated crop water requirement based on Eto and the Etc:crop production functions (Table 2). The shallow ground water was not actively managed during this experiment but there was some passive control on the system that was exerted by the water meters used to measure flow from the individual plots. The water meters were 19 mm residential type water meters that restricted the flow and sustained the water table for a longer period than would normally have been expected with the design. This enabled the cotton and sugar beet to use water from the shallow ground water that would otherwise have been removed by the drainage system.

2.1.1.2 Soil Chemistry

Managing these plots for long term sustainability using saline water of qualities shown in Table 1 requires considering both the short and long term responses of the soil to salinity and specific ion accumulations in response to the application of saline water. The data in Tables 4 and 5 and Figs 1 and 2 will be used to demonstrate the responses and problems associated with using only a good quality water, using degraded quality water, and a combination of degraded and good quality water. By the Fall of 1984 following the cotton crop and the application of 536 mm of saline water in T1 and 747mm in T2, the EC data in Table 4 show that the salinity in the surface layers of the soil profile in Treatments T1 and T2 had exceeded levels recommended as being safe for germination of moderately or even salt tolerant crops in successive years if leaching did not occur (Maas, 1986). The 1984 cotton crop was followed by wheat, which was irrigated with 526 to 535 mm of low salinity water (Table 2) in addition to 64 mm of rain. the ECe data for the top meter of the soil profile in the Fall of 1985 indicate that leaching had occurred over the Fall 1984 to Fall 1985 period. By the Spring of 1986 the average salinity in the top 90 cm of the soil in both T1 and T2 had been reduced further by leaching due to rainfall (245 mm) and pre-plant irrigation (114 m) with low salinity water. The Fall 1986 salinity levels in the top meter of the soil profile had increased to about the previous levels of Fall 1984 after irrigating the sugar beets with 666 mm and 973 mm of saline water in T1 and T2, respectively.

In treatment F1, irrigated with low-salinity water, the average salinity levels in the upper 120 cm profile varied between 4.2 dS m\(^{-1}\) and 5.6 dS m\(^{-1}\) in the period from Fall 1984 to Fall 1986, with ECe in treatment F2, which received 720 mm of saline water (ECw .3.5 dS m\(^{-1}\)) in 1986, the average salinity levels in the top 120 cm of soil increased from 6.4 dS m\(^{-1}\) by 1984 to 9.3 dS m\(^{-1}\) by the Fall of 1986. The salinity data for treatments T1 and T2 show that in the short term (individual seasons) the surface soil salinity levels in the top 60 cm of soil can be controlled by leaching during pre-plant irrigation and rainfall. The ECe data for the upper 30 cm of the soil profile of the F1 treatment show that the salinity at planting was never at a level which would negatively impact germination and plant growth.
The data in Fig. 1 and 2 show the levels of ECe and Cl at the initiation of the experiment (Spring 1982), the beginning of the final season (Spring 1987, after rainfall and low salinity pre-plant irrigation) and at the end of the final season (Fall 1987), respectively. The Cl data are presented to characterize salt transport and ground water uptake. The shallow ground water represented a potential source of degraded water which could move up in the soil profile due to plant uptake and evaporation. Comparison between Spring 82 and Spring 87 shows that the ECe levels and Cl concentrations of had increased throughout the profile in treatments (T1 and F2) receiving saline irrigation water (Figs. 1, 2). The amount of the increase was related to the total depth of applied water, with a larger increase occurring in T1 than in F2 in the top 90 cm of the profile. Comparing between the Spring 87, and Fall 87 data show that within a season there were increases in ECe and Cl concentrations in treatments T1 and F2. In general, pre-plant leaching was adequate to return the profiles to nearly the original condition but the data taken at the end of the experiment indicate that there is still some accumulation of salt occurring within the profile. T2 received the largest amount of saline water, approximately 40% more than T1, during the experiment. In addition, the water was much more saline than that applied to treatment F2 as a result of the differences in total application and salinity amounts, the ECe and Cl profile responses were quite

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Depth in Profile (cm)</th>
<th>Fall 1984</th>
<th>Fall 1985</th>
<th>Spring 1986</th>
<th>Fall 1986</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>0 - 30</td>
<td>1.6 (0.2)*</td>
<td>1.4 (0.2)</td>
<td>1.4 (0.2)</td>
<td>2.2 (0.2)</td>
</tr>
<tr>
<td></td>
<td>30 - 60</td>
<td>4.7 (0.6)</td>
<td>1.3 (0.2)</td>
<td>3.2 (0.4)</td>
<td>3.4 (0.3)</td>
</tr>
<tr>
<td></td>
<td>60 - 90</td>
<td>7.1 (0.6)</td>
<td>5.3 (0.7)</td>
<td>6.6 (0.7)</td>
<td>6.3 (0.5)</td>
</tr>
<tr>
<td></td>
<td>90 - 120</td>
<td>9.0 (0.5)</td>
<td>8.8 (0.7)</td>
<td>8.8 (0.7)</td>
<td>9.0 (0.6)</td>
</tr>
<tr>
<td>F2</td>
<td>0 - 30</td>
<td>1.3 (0.1)</td>
<td>1.5 (0.3)</td>
<td>1.2 (0.1)</td>
<td>5.9 (0.5)</td>
</tr>
<tr>
<td></td>
<td>30 - 60</td>
<td>5.1 (0.3)</td>
<td>4.2 (0.3)</td>
<td>2.1 (0.3)</td>
<td>8.8 (0.6)</td>
</tr>
<tr>
<td></td>
<td>60 - 90</td>
<td>8.0 (0.6)</td>
<td>9.3 (0.6)</td>
<td>7.8 (0.2)</td>
<td>11.2 (1.1)</td>
</tr>
<tr>
<td></td>
<td>90 - 120</td>
<td>11.5 (0.4)</td>
<td>12.8 (0.7)</td>
<td>11.4 (0.7)</td>
<td>11.6 (1.2)</td>
</tr>
<tr>
<td>T1</td>
<td>0 - 30</td>
<td>7.6 (0.2)</td>
<td>3.0 (0.4)</td>
<td>3.2 (0.3)</td>
<td>7.8 (0.5)</td>
</tr>
<tr>
<td></td>
<td>30 - 60</td>
<td>9.0 (0.8)</td>
<td>7.7 (0.4)</td>
<td>6.7 (0.6)</td>
<td>10.7 (0.3)</td>
</tr>
<tr>
<td></td>
<td>60 - 90</td>
<td>13.8 (1.3)</td>
<td>14.3 (1.6)</td>
<td>12.1 (0.2)</td>
<td>11.3 (1.3)</td>
</tr>
<tr>
<td></td>
<td>90 - 120</td>
<td>12.9 (0.6)</td>
<td>14.5 (0.5)</td>
<td>14.0 (1.2)</td>
<td>12.7 (0.9)</td>
</tr>
<tr>
<td>T2</td>
<td>0 - 30</td>
<td>10.9 (0.6)</td>
<td>3.2 (0.4)</td>
<td>3.1 (0.3)</td>
<td>7.6 (0.8)</td>
</tr>
<tr>
<td></td>
<td>30 - 60</td>
<td>11.8 (0.5)</td>
<td>8.1 (1.0)</td>
<td>6.8 (0.2)</td>
<td>11.4 (0.8)</td>
</tr>
<tr>
<td></td>
<td>60 - 90</td>
<td>11.6 (0.2)</td>
<td>11.6 (1.1)</td>
<td>11.4 (0.9)</td>
<td>13.3 (1.7)</td>
</tr>
<tr>
<td></td>
<td>90 - 120</td>
<td>13.5 (0.9)</td>
<td>13.7 (0.6)</td>
<td>14.2 (1.6)</td>
<td>15.6 (0.9)</td>
</tr>
</tbody>
</table>

Day of year corresponding to Fall (1984), Fall (1985), Spring (1986), and Fall (1986) were 315, 310, 98, and 272, respectively.
Standard error of the mean is given in parenthesis.
different between T2, T1, and F2. Below approximately 45 cm the ECe and Cl concentrations in the T2 profile were reduced between Spring 1982 and Spring 1987 rather than increased as in T1 and F2. This is an indication of a large leaching occurring in T2 and not in T1 and F2.

The boron data in Table 5 and Fig. 3 show a different response than observed in the EC and Cl data. In treatments T1 and T2 (Table 5) there was a gradual increase in the B concentration in the top 90 cm with no observed reductions associated with within year leaching as was observed with the ECe values. This is particularly evident in the data in Table 6. The B concentrations increased throughout the profile in the drip treatments T1 and T2 and in the furrow treatment F2 which received saline water in 1986, while remaining constant in the furrow irrigation treatment irrigated with only low salinity water (F1). Over the 6 year study, the B concentration in treatment T2 increased from an average of 2.2 mg B kg⁻¹ in the top meter of the soil profile to and average of 6.8 mg B kg⁻¹. The increased concentration was due to the application of saline irrigation water with a B concentration which ranged from 4 to 7 mg B L⁻¹ during the study.

The data in Figure 3 show the increases in B from the beginning of the experiment. The data in F1 remained constant over the years. In the remaining treatments the B concentrations with depth showed a steady increase with the time which directly related to the depth of applied water. The data in T2 showed the largest increases compared to F2 and T1. It is possible that T2 had reached the maximum concentration of adsorbed B by 1987, since there was no increase in the B concentration with depth as was experienced in T1 and F2.

Table 5. Boron (B) in soil saturation extract as a function of depth, time of season, and irrigation treatment in 1984, 1985, and 1986.
a Day of year corresponding to Fall (1984), Fall (1985), Spring (1986), and Fall (1986) were 315, 310, 98, and 272, respectively.

b Standard error of the mean is given in parenthesis.

c No data.

Using the reclamation guidelines in Hoffman (1990) it would take approximately 130 to 200 mm of low salinity water to restore the average ECe profile in the top one meter of T1 to previous levels using intermittent applications of low salinity water. If reclamation were attempted by ponding, it would take almost 600 mm of water. It would take almost 1800 mm of boron free low salinity water to restore the first meter of the soil profile in treatment T1 to the original B levels using intermittent leaching. It is apparent that salinity can be managed in the profile and that large quantities of water can be use without detrimental effects on the soil structure. However, this is not the case if the drainage water contains high concentrations of boron.

2.1.3 Yields

The yield data for each treatment and each year are summarized in Table 6. With the exception of the wheat crop grown in 1984/85, the yields were not affected by using saline water to meet part of the crop water requirement during the 6 years of the study. Recall that only low salinity water was used to irrigate the wheat in all the treatments. The yield loss in the wheat crop in T1
and T2 was a result of the use of saline water for irrigation of cotton prior to planting the crop. The residual effects of the salt in the soil profile reduced the yield. The lower lint yields in 1983 in all treatments compared to 1982 and 1984 was a result of a shortened growing season in 1983. The cotton yields were comparable in 1982, 1984 and 1987 for all treatments and across all years and are typical of this area.

3. **CONTROLLING SHALLOW GROUND WATER**

In-situ use of shallow ground water as an aid to drainage water disposal is being studied in the Untited States, Australia, Egypt, and Pakistan. For this practice to be effective, the ground water position will have to be controlled during the growing season. Ideally, the water table position will be capable of being controlled at different depths from the soil surface in response to the plant development. The effectiveness of in-situ use will depend on the source of the water, the quality of the ground water, the salt tolerance of the crop, the depth to ground water, and the configuration of the drainage system. If the shallow ground water is solely a result of poor irrigation practice, then improving the irrigation management will result in reduced availability of water for crop use and in the extreme might eliminate the need for drainage. If improved irrigation efficiency doesn't eliminate the need for drainage then drainage control and in-situ use should be considered. If the excess water is due to lateral inflow from regional flows due to climate or poor irrigation management then ground water control should be considered.
Salt tolerance of the crop and ground water quality are a concern when considering the potential for crop water use from the shallow ground water. The Maas-Hoffman (M-H) (Maas, 1986) salt tolerance data and thresholds offer a good starting point for consideration of the potential use from shallow ground water. Previous work (Ayars et al, 1993; Ayars and Hutmacher, 1994; Hutmacher et al, 1996) has shown that crops will use water from the shallow ground water with salinity in excess of twice the M-H threshold value at the same rate as low salinity water. This means that there is considerable potential for crop water use even for salt sensitive crops. A list of crops that have reportedly used water from shallow ground water is given in Table 7.
Table 7. Crops reported to have successfully used water from shallow ground water and references.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>alfalfa</td>
<td>Benz et al., 1983, 1987; Grimes and Henderson, 1984; Kruse et al., 1993; Meyer et al., 1996; Meyer, 1996; Smith et al., 1996; Zhang et al., 1999</td>
</tr>
<tr>
<td>carrot</td>
<td>Schmidhalter et al., 1994</td>
</tr>
</tbody>
</table>
MANAGING SALINITY FOR SUSTAINABILITY OF IRRIGATION IN AREAS WITH SHALLOW SALINE GROUND WATER

The depth to ground water has a significant impact on the potential for crop water use as does the soil type. Water use by a plant from the ground water requires that water move through the unsaturated zone of the soil from the water table to the root system. The potential flux is controlled by the unsaturated hydraulic conductivity function which is highly variable across soil types and as the distance increases between the plant and water table the sustainable flux decreases rapidly. The net result is that the water table in a sandy soil has to be considerably closer to the plant than in a loam soil to maintain the same flux. The effect of soil type and depth to water table on average contribution to cotton water use can be seen in Figure 4. The percentage of water use by cotton increased as the depth to water table decreased and as the soil went from a clay to a loam soil. One problem is how to enable the control of shallow ground water without creating problems with waterlogging in a portion of the field. This will be a significant consideration for systems designed with laterals parallel the surface grade of the field. In this case restricting flow at the outlet or on each lateral will result in waterlogging a portion of the field without providing much control on the remainder of the field. Therefore, a design change will be required such that the laterals are installed perpendicular to the surface grade and the submain collector is run parallel to the surface grade. This will enable control along the submain to extend to large portions of the field and will prevent waterlogging at the low end of the field. In cases with extremely low grade on the surface it might be possible to control the water table at only the outlet (Fouss et al, 1990).

<table>
<thead>
<tr>
<th>Plant</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>corn (maize)</td>
<td>Follett et al., 1974; Benz et al., 1984; Kruse et al., 1985, 1993; Kang et al., 2001; Sepaskhah et al., 2003</td>
</tr>
<tr>
<td>cotton</td>
<td>Namken et al., 1969; Williamson and Carreker, 1970; Williamson and Kriz, 1970; Wallender et al., 1979; Grimes and Henderson, 1984; Ayars and Schoneeman, 1986; Ayars and Hutmacher, 1994; Cohen et al., 1995; Hutmacher et al., 1996</td>
</tr>
<tr>
<td>eucalyptus</td>
<td>Thorburn et al., 1995</td>
</tr>
<tr>
<td>pasture</td>
<td>Shih and Snyder, 1984</td>
</tr>
<tr>
<td>peach</td>
<td>Boland et al., 1996</td>
</tr>
<tr>
<td>sorghum</td>
<td>Mason et al., 1983; Shih, 1984; Robertson et al., 1993; Sepaskhah et al., 2003</td>
</tr>
<tr>
<td>soybean</td>
<td>Dugas et al., 1990; Meyer et al., 1990; Meyer, 1996</td>
</tr>
<tr>
<td>string bean</td>
<td>Williamson and Carreker, 1970; Williamson and Kriz, 1970</td>
</tr>
<tr>
<td>sugar beet</td>
<td>Follett et al., 1974; Benz et al., 1984, 1987</td>
</tr>
<tr>
<td>sugar cane</td>
<td>Escolar et al., 1971; Omary and Izuno, 1995; Sweeney et al., 2001</td>
</tr>
<tr>
<td>sunflower</td>
<td>Mason et al., 1983</td>
</tr>
<tr>
<td>tomato</td>
<td>Hutmacher and Ayars, unpublished data</td>
</tr>
<tr>
<td>wheat</td>
<td>Chaudary et al., 1974; Meyer et al., 1987; Kruse et al., 1993; Kang et al., 2001</td>
</tr>
</tbody>
</table>
The following sections describe a drainage control system tested in the San Joaquin Valley of California (Ayars, 1996).

### 3.1 Cilker Farms

A subsurface drain system of corrugated plastic tubing, which had previously been installed on 65 ha of land located in the Broadview Water District, was used for this research. The system is laid out in a gridiron pattern with a total of seven laterals spaced approximately 123 m apart. The lateral length is 670 m and the depth of installation is 2.4 m. Butterfly valves were installed on each lateral at the juncture of the lateral and main collector line. Manholes with weir structures were installed at three locations along the main collector line. Figure 5 gives a schematic of the site showing the subsurface drain laterals, the location of the manholes, lateral valves, and observation wells. The installation of the control system was completed in April 1994. The site was sprinkle irrigated on 2/1, 3/1, and 3/14/94 and was planted to processing tomatoes (Lycopersicon esculentum var. APEX 1000) on February 14-16, 1994. Furrow irrigation using gated pipe occurred on 4/17, 5/25, 6/9, 6/17, and 6/25/94. Observation
wells constructed of three m long 38 mm diameter PVC pipe, which had slits cut into the bottom meter, were installed at each valve installation and across the field between several laterals (Figure 5). The depth to the water table was measured weekly and used to plot water surface elevations and responses to the valves opening and closing. Three areas in the field were identified to characterize the vegetative response to the water table depth. These were labeled shallow (S), medium (M), and deep (D). The drain laterals were installed on grade from west to east with the outlet on the east side of the field. The shallow area close to the control structures had a water table fluctuation from 1.5 to 2.2 m below the soil surface. The medium depth area had a water table depth of 1.8 to 2.6 m during the experimental period and the deep area had a water table depth of 2.2 to 2.6 m during the project. The tomato rows were in a north-south orientation, perpendicular to the drain laterals. The individual sites were located such that the shallow site was on the east side of the field with the deep site on the west side and the medium site located between the two. LWP was determined two to three times a week at each of these sites. These sites were also used to determine crop yield. Yields were determined both by hand harvest and machine harvest.

3.1.1 Results
The water table response to valve operation is shown in Figure 6 for the period between the irrigations on 4/17/94 and 5/25/94. In Figure 6, the control structures are located at 670 m on the x-axis. The soil surface is shown as the upper surface grid and the water table as the lower surface grid in Figure 6. After the valves were closed on each lateral, the water table rose to within a meter of the soil surface. The valves were opened and the water level receded to approximately 2 m below the soil surface (Figure 6). The valves were opened because the ranch manager was concerned about drying the soil profile in preparation for
Figure 6. Water table position for the period between 4/17/94 and 5/25/94 in field with drainage system control.
Figure 7. Leaf water potential in tomato crop grown on field with water table control and three depths to water table, shallow (S), medium (M), and deep (D).

The plant response was measured in three areas in the field. The LWP is given in Figure 7 for plants growing in each experimental area. The data show that the plants were progressively more stressed as the initial depth to the water table increased. A potential of -0.9 to -1.1 MPa is considered a stress level for tomatoes that will not negatively impact yield. This level of stress was not attained in the shallow water table area and was only slightly exceeded in the medium water table depth areas. During the entire time of measurement, the plants in the deep water table area were stressed at a much higher level than in the other areas.

The objectives of the drain control project were to reduce the volume of drain water by using shallow groundwater to meet the crop water requirement, to reduce depth of each irrigation application, and determine if it was possible to control the water table. The results indicate that these objectives were met. The EC of the shallow groundwater ranged from 3 to 8 dS m⁻¹ which is usable by a tomato crop. Hutmacher et al. (1989) demonstrated that tomatoes could extract up to 45% of the water requirement from 5 dS m⁻¹ water when the water table was within 1.2 m of the soil surface. The improved plant vigor and reduced stress levels in the shallow and medium depth areas indicated that the crop was using shallow groundwater. Maintaining the shallow groundwater reduced the crop water requirement by 141 mm. A companion field which did not have water table control required 829 mm of irrigation and the test field needed only 688 mm. This resulted in a savings of 6.5 x 10⁵ m³ of water.

4. DESIGN CRITERIA

Another method to reduce drainage flow is to install the drains at a shallower depth. Doering (1982) proposed a shallow drainage concept to reduce over-drainage of soils. They found that shallow placement of the drains reduced the total flow and increased the amount of water used from the shallow ground water by the crop. Soil and water salinity were not a significant problems in the region where that research was conducted. The effect of shallow drainage placement on the drainage water quality and soil salinity is a significant concern and needs to be evaluated before this type of change can be recommended. Christen and Skehan (2001) reported on a replicated field trial in a vineyard in the Murrumbidgee Irrigation Area (MIA) that evaluated improved drainage design and management strategies. The new strategies were tested against current design and management practice, and a no drainage scenario, and are summarized in Table 8. Measurements were taken over three years from 1996 to the end of the 1998 season, this period included three irrigation seasons. Measurement on individual drainage treatments involved; irrigation and rainfall, run-off, drain flow, drainage salinity, water table depth, and soil salinity.
4.1 Results
The different drainage treatments resulted in markedly different drainage volumes and salinities, and hence salt loads, Table 9. The differences in flow resulted from the drain position in the soil profile and the management of the drains. The Deep Drains flowed continuously during the irrigation seasons, a small saline flow being sustained between irrigations and a large flow during and just after irrigation, Figure 8. The Deep Drains continued to flow long after an irrigation had ceased because they were draining a larger soil volume, down to 1.6-1.8 m, and they were influenced by regional groundwater pressures. This was despite the area having no significant shallow aquifer systems and being in a fairly flat area so that hydraulic gradients from neighbouring farms and channels were small. That there were some regional effects was demonstrated by the rise in piezometric levels at the beginning of the irrigation season in the experimental area before any irrigations had been applied. The Managed Deep Drains were less influenced by these regional effects and the Shallow Drains were completely isolated from them.

<table>
<thead>
<tr>
<th>Treatment name</th>
<th>Deep Drains</th>
<th>Shallow Drains</th>
<th>Managed Deep Drains</th>
<th>Undrained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drain type</td>
<td>slotted PVC pipe</td>
<td>Unlined soil channel (mole)</td>
<td>slotted PVC pipe</td>
<td>none</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>1.8</td>
<td>0.7</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>100</td>
<td>65</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Spacing (m)</td>
<td>20</td>
<td>3.65</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Length (m)</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Management</td>
<td>unrestricted flow</td>
<td>unrestricted flow</td>
<td>flow only when water table is above 1.2m, and not during irrigation events</td>
<td></td>
</tr>
</tbody>
</table>
The Deep Drains removed the most water and at the highest salinity, about 11dS/m, and hence had the highest salt load, Table 9. The Managed Deep Drains had 33% less flow than the Deep Drains and a lower salinity, 7-8 dS/m, resulting in a 49% reduction in salt load. The Shallow Drains removed 78% less water than the Deep Drains at a significantly lower salinity, about 2 dS/m, resulting in a 95% reduction in salt load. The large amounts of water removed by the Deep Drains leads to reduced overall water use efficiency and increased farm costs in terms of increased pumping and nutrient loss. The extra salt removed by the Deep Drains compared to the Shallow Drains and even the Managed Deep Drains doesn’t have a negative impact on the drained area but will adversely affect the receiving waters. If in the future farmers are charged for the amount of salt they export off farm then this extra salt export will have a negative effect upon farm income. Where farms are denied the option of off farm disposal of drainage water, then the use of shallower drains will be advantageous in reducing the overall volume requiring disposal and also the lower salinity of the drainage water will leave more options open for reuse.

Table 9. Drainage treatment volume, salinity and salt load.

<table>
<thead>
<tr>
<th>Drainage Treatment</th>
<th>Total drainage volume (mm)</th>
<th>Average drainage salinity (dS/m)</th>
<th>Total salt load (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep drains</td>
<td>70</td>
<td>11</td>
<td>5867</td>
</tr>
<tr>
<td>Managed deep drains</td>
<td>47</td>
<td>7-8</td>
<td>2978</td>
</tr>
<tr>
<td>Shallow Drains</td>
<td>15</td>
<td>2</td>
<td>319</td>
</tr>
</tbody>
</table>

The three drainage treatments tested only the Shallow Drains came close to a salt balance with the irrigation water, removing 0.7 of the salt applied in the irrigation water. This is actually a small accumulation of salt, but this was in absolute terms a very small
amount 170 kg/ha, and was not accumulated in the root zone. The Deep Drains removed 11 times more salt than was applied, a large net leaching of salt. This leaching was not reflected in the soil salinity in the top 2 m, thus this salt was from below drain depth. The managed treatment exported 5 times more than the salt applied, still a large net export. This shows that drains placed deep in the soil profile will export large quantities of salt over and above that applied in the irrigation water. Assessment of the drainage water salinity with depth of water table confirms this. When the water table was at one meter below the surface the drainage water salinity from the Deep Drains was around 8 dS/m; as the water table fell to 1.6 m below the surface the salinity increased to around 11 dS/m, Figure 9. This is consistent with the suggestion that deeper drainage intercepts deeper water flow paths that move through much more saline portions of the soil profile.

![Diagram](http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20ayars,%20soppe%20et%20aal.html)

In terms of water table and waterlogging control the Deep Drains were adequate in reducing the periods of high water tables and waterlogging to a negligible amount, Table 10. The management changes used to control water flow from deep drains had only a small effect on waterlogging, about an extra day of waterlogging during the irrigation event itself. This minimal increase in waterlogging is a small trade off for the benefits of less water drained resulting in greater water use efficiency, lower operating costs and improved downstream water quality. At this stage in the development of the vineyard this small increase in waterlogging had no effect on vine leaf chlorides or yield. The Shallow Drains as expected gave the best control of root zone waterlogging, the watertable did build up beneath this treatment but was controlled at mole depth.

These varying water table regimes resulted in some differences in the root zone soil salinity trends over the two seasons monitored, Figure 10 and Figure 11. The Undrained treatment soil salinity remained static, whereas all the drained treatments showed a decrease in salinity after the first season. In both the Shallow Drains and Managed Deep Drains there was a rise after the second season resulting in no net change. For the average salinity down to two metres this picture was similar except the Deep Drains showed a fall in salinity after both the first and second seasons. These results are somewhat unclear in terms of the possible effects of the different treatments on long-term soil salinities especially since the undrained treatment did not show any change in salinity over the experimental period. However, there is an important outcome from this analysis in that, the drainage...
treatments had only small effects on the root zone salinity, no measurable effect on vine health over the experimental period, but still drained water and salt from the area. So over this particular time the water drained, salt removed, costs incurred and downstream impacts of drainage water resulted in little benefit to the farm. Under these circumstances of small benefit from a drainage system, which can occur due to site factors, dry climatic conditions and plants not highly susceptible to waterlogging, it is even more important that the drainage system incurs the least downstream impacts and least costs to the farmer.

4.2 Discussion
This field trial was conducted in a drier than average year, the relatively low drainage flows and static soil salinities reflect this. During wetter conditions it is likely that the drainage water reduction would be greater than measured here and that there would be more soil leaching due to rainfall, both of which are positive. However, there may be negative effects due to the design and management suggested, such as increased waterlogging. These negative effects are unlikely to be great and with good management could be monitored and controlled. For instance if the water table was remaining high for too long on the Managed Deep Drains then the drainage depth could be increased to provide a greater soil buffer to store rainfall. The main negative effect of a prolonged wet period on the Shallow Drains would be an increased rate of collapse in the mole drains. At this site, the soil was quite stable and as such it is unlikely that the moles would collapse to the point of being ineffective within a single season. Obviously if a shallow pipe system was installed this would not be a concern.

<table>
<thead>
<tr>
<th>Table 10. Duration of water tables above specified depths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water table depth (mm)</td>
</tr>
<tr>
<td>Treatment</td>
</tr>
<tr>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td>Number of hours</td>
</tr>
<tr>
<td>Deep Drains</td>
</tr>
<tr>
<td>Managed Deep Drains</td>
</tr>
<tr>
<td>Shallow Drains</td>
</tr>
<tr>
<td>Undrained</td>
</tr>
<tr>
<td>Percentage of time</td>
</tr>
<tr>
<td>Deep Drains</td>
</tr>
<tr>
<td>Managed Deep Drains</td>
</tr>
<tr>
<td>Shallow Drains</td>
</tr>
<tr>
<td>Undrained</td>
</tr>
</tbody>
</table>
Predicting the effects of wetter periods on the results of drainage design and management tested here is possible. The likely drain flow under wet conditions can be considered by analysing single high input irrigation events. Figure 12 and Figure 13 show the proportion of water applied that drained through the different drainage treatments at a particular event. During wet periods when...
the soil has a small storage a lot of the water applied that does not run off will be drained out, similar to irrigations 3 and 4 in Figure 12 and the highest ranked drainage events in Figure 13. This gives an indication that under wet conditions it is likely that up to 25% of water applied may be drained by a deep pipe drainage system, whether managed or not.

![Graph showing irrigation and rainfall amounts](http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20ayars,%20soppe%20et%20al.html)

The rate of drainage can be predicted by considering the drain hydrographs such as in Figure 8. The peak flow rates shown here are unlikely to be greatly exceeded, but the duration of the peak flows will be prolonged under wet conditions with high inputs of water. The effect of wetter conditions on drain water salinity can be considered using the drainage water salinity as a function of water table depth results. Since water tables are likely to be high during wet conditions the drain water salinity will be lower than dry periods when the water tables are deeper. The height and duration of water tables during wetter periods is harder to predict. Water table depth is a function of the time from the last recharge event, the drainage rate of the system and the combination of deep leakage and plant water use. If recharge events are larger, and at shorter intervals, then water tables will remain higher.
MANAGING SALINITY FOR SUSTAINABILITY OF IRRIGATION IN AREAS WITH SHALLOW SALINE GROUND WATER

An indication of the impact of a drainage system on water use efficiency and hence total water costs is shown by the Deep Drains that drained 20% or more of the water applied in 23% of plot drainage events and drained 10% or more in 65% of plot drainage events. This is a considerable proportion of the water applied that was intended for use by the plant. Management of deep drains cut the proportion of plot drainage events draining more than 10% of water applied to 37% and events draining more than 20% to 6%. This is a significant improvement but does not match the Shallow Drains, which drained less than 5% of the water applied in 90% of plot drainage events. Drainage systems for irrigated areas on clay soils in south eastern Australia can be designed and managed better than the currently accepted practices, so that detrimental downstream environmental effects due to excessive salt export are reduced, without affecting the productivity of the farm.

CONCLUSIONS

The objective of the study was to evaluate the potential for sustaining irrigated agriculture in arid and semiarid areas that are impacted by salt in the soil and the shallow ground water. Accumulation of salinity in the soil profile, the inability to dispose of saline ground water, and the reduction in the available water supply were considered to be the primary factors affecting the sustainability. Drainage will always be a component in irrigated agriculture and is the system that is needed to manage the salinity in the profile. It is also the system that generates the saline water that has to be managed and requires responsible disposal. The ability to manage the drainage system and the salt load will be central to sustaining irrigated agriculture.

The results from these studies lead to the following conclusions:

Reuse of saline water for supplemental irrigation is a viable alternative for extending existing water supplies, particularly if the area is affected by lateral ground water flows that need to be controlled. Salt in the profile can be managed through the use of rainfall and pre-plant irrigation with good quality water during fallow periods.

Total drainage flow will be reduced when drainage water is used for supplemental irrigation.

Water containing high levels of boron should not be used.

The water table can be controlled over a wide range of depths using either individual control on the laterals or control along the submain collector. Irrigation water requirements are reduced when the water table is controlled.

New configurations of the subsurface drain laterals will be required to effectively manage shallow ground water. Drainage lateral...
design criteria need to be changed to consider shallow drain lateral placement and control structures. Shallow drains remove less irrigation water than deep drains, thus reducing irrigation losses. Compared to deep drains in this trial, shallow drains have low drainage water salinity and remove smaller drainage volumes, thus reducing the salt load, with up to 95% reduction. Shallow drains control waterlogging better than deep drains. Managing deep drains by preventing discharge during irrigation and whenever the water table was below 1.2 m deep reduced irrigation water losses compared to unmanaged deep drains. Managing drains reduces flow and drainage water salinity compared to unmanaged drainage, resulting in a reduction in drainage salt load of 50% in the third study.

A more rapid decline in drainage water salinity can be achieved by managing deep drains. In the third study a deep pipe irrigation system, without major groundwater inflow from surrounding areas, only needed to be run for 2 to 7 days after an irrigation to control the water table below the root zone.

Best management practices for subsurface drainage system design and management are needed for drainage systems being constructed and operated in arid and semi-arid areas throughout the world.

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ENVIROMENTAL IMPACT OF DISPOSAL OF DRAINAGE EFULLENT TO EVAPORATION PONDS

Muhammad Nawaz Bhutta, M.F.K. Niazi, and Nazir Ahmed

ABSTRACT
Evaporations ponds were developed to dispose off the drainage effluent of 514 drainage tubewells, installed to alleviate waterlogging in Salinity Control and Reclamation Project (SCARP) VI area. Lateral movement of seepage water from evaporation ponds affected the adjacent agricultural lands. A lot of agricultural land around the ponds became waterlogged and gone out of production. Initially the designed pond area was more than the existing which was reduced on hue and cry of the down slope riparian. The management measures were taken to reduce the pond levels and also move the ponds away from agricultural lands.

Field data for the period 1998 to 2002 were collected to study the impact of these ponds on the environment. The change in the health, occurrence of benthic macro invertebrates, phytoplankton's, hydrophytes, terrestrial vegetation and wildlife was noted during monitoring. It was found that the lands, which initially affected with waterlogging and salinity due to seepage from these ponds are being recovered slowly after management measures taken. The pond area is very sensitive issue for the biological and environmental changes in the adjacent areas.

Field data indicated that the saline water can be used for saline agro-forestry, fisheries and salt mining. If the drainage technology is changed from tubewells to subsurface pipe drainage not only the quantity of effluent can be reduced significantly but also ponds will be more sustainable due to reduced salinity levels. It is recommended that the data for longer period should be collected.

Water balance indicates that ponds are not sustainable. Therefore, there is a need to replace tubewells with pipe drains to reduce the effluent. Otherwise a link to outfall drains has to be made in near future.

1 \textbf{The Study Area}

The area of SCARP-VI is located in the districts of Rahim Yar Khan and Bahawalpur of Punjab province of Pakistan. The gross area of the project is 1.46 million acres (Mac) out of which 1.267 Mac are cultureable commanded by Punjnad and Abbasiya Canals. The project falls in arid sub-tropical zone. High temperature and low rainfalls are the main features of the climate. Mean annual precipitation is 156 mm of which more than half falls in the months of July and August. The area had been suffering from waterlogging and salinity since early nineteen sixties NESPAK-ILACO (1981).

514 deep drainage tubewells were installed to control waterlogging in the area. In most of the drainage system in Pakistan drainage effluent is mainly disposed off into rivers. In future there will be danger of deterioration of the river water quality especially during low flow periods. Due to lack of natural outfall to the Indus river, the option of saline water disposal through evaporation ponds was adopted in SCARP-VI Project.

The evaporation ponds are a series of interdunal depressions along the fringe of Cholistan Desert, which are remnants of old Hakra River. These are comprised of interdunal valleys, separated by longitudinal sand ridges. The sand ridges are about 3 to 10 meter high. The area is barren and without irrigation. The subsoil water is saline. Dykes are provided at saddle and in between the dunes to form ponds embankments. The channels have been made by cutting the concerned dunes to interlink the adjacent ponds, which have converted them in to a contiguous series of ponds.

The operation of 514 tubewells of SCARP-VI started in 1989. Effluent of salinity level in the range of 18000 to 25000 ppm has been put into these evaporation ponds for disposal through seepage and evaporation. The lateral seepage from these ponds caused serious environmental problems for the adjacent population (Alam et al., 2000a).

2 \textbf{OBJECTIVES}

The objectives of the study are:

- Assessment of the environmental impact of the drainage effluent disposal in the evaporation ponds, with reference to their long term sustainability;
- Identify the beneficial uses of evaporation ponds with respect to fish culture, agro-forestry, and salt mining; and
- Prepare recommendations for the sustainability of these ponds.

3 \textbf{Design of Evaporation Ponds}

To accommodate the effluent of 514 drainage tubewells two series of ponds i.e. Stage-I, with an initially designed area of 8400 acres and Stage-II having an area of 24,600 acres were finalized by the design engineers of SCARP-VI Project. Drainage tubewells effluents drained into Pattan Munara Drain after lifting. Khanpur-Trukri Drainage System were joined together and discharged into ponds of Stage-I by gravity flow, and those drained into Manthar Drainage System discharged into ponds of Stage-II through pumping station. A spillway structure was provided for spill over of water from Stage-I to Stage-II. The design level for Stage-I and Stage-II...
The capacity of tubewells varied from 1.5 to 3.0 cusec. Tubewells effluent was discharged, through a network of 444 kilometer of surface drains, in the evaporation pond. Assuming 10% seepage and evaporation losses, the quantum of water entering the ponds was assessed as 0.438 MAF per year. This effluent in the ponds was disposed mainly through evaporation and seepage, as per design criteria.

4 Review of Literature

In the past a number of studies were carried out by WAPDA and various consultants to review the design and feasibility of the project. The idea of disposal of saline effluent was first given by M/S T&K (Tipton and Kalambach, 1968). The effluent of 304 drainage tubewells was proposed to be disposed off into evaporation ponds having gross area of 160,000 acres with storage capacity of 1.32 MAF in the Cholistan desert.

World Bank (1977) proposed that five evaporation ponds would be needed for the drainable surplus of about 380,000 acre feet. The ponds would be formed by closing the gaps between the sand dunes with earth fill to be taken from nearby clay pans to minimize seepage losses. The ponds would have interconnecting overflow spillways, while the lower most pond would discharge into the Thar desert. It was estimated that the ponds would have a minimum surface area of 57,000 acres.

NESPAK-ILACO (1981) proposed the minimum required ponds area to be about 67500 acres. Total pumpage from 514 drainage tubewells would amount to 0.487 MAF per year. Assuming 10% seepage and evaporation losses, the total quantity of water entering the evaporation ponds would be 0.438 MAF per year. The deep percolation rate into the ground would be 11 inches per year. The annual evaporation from the saline effluent in the ponds was estimated as 67 inches per year. The storage loss from the ponds both from seepage and evaporation would be 79 inches per year.

World Bank (1989) suggested that WAPDA should proceed with construction of ponds on 56,000 acres identified. WAPDA should investigate further in the North East to make up the shortfall of 4,000 acres as well as another 7,000 acres as reserve for the future due to the fact that the seepage rates may fall below the assumed rate of 1.5 mm per day after the ponds are sealed with crystallized salts. Evaporation ponds would be technically sound and the best interim method of...
disposing saline drainage water under the circumstances, until replaced by LBOD Stage-II which hopefully would reach the project area in the next 15 to 20 years.

Nasir (1991) reported that before operation of the Khanpur ponds in September 1989 water table in the irrigated area in June 1989 was from 10-20 feet below the NSL. In February 1991, 15 villages were affected with depth to water table ranging from 0.5 feet above the ground surface to 7 feet. The affected area was 1935 acres.

WAPDA (1991) gave the reasons for inundation of the area. These were due to the higher pond levels resulting from reduction in pond area from 67000 acres to 33,000 acres. The saline effluent had spread over about 12,000 acres against the total pond area of 33,000 acres. The effected area may increase to 9,900 acres. It was proposed that connecting channels between the ponds be deepened and difference in the water level between upstream and downstream of the spillway be reduced by providing a bypass channel. Additional dikes be provided to keep the saline water away from the cultivable land.

IWASRI and NRAP engaged two groups of consultants (Mian M. Alim, T.V. Remmen, Trehella and Badrudin, 1991) to prepare reports on feasibility study, data collection and guidelines for monitoring, evaluation and research on evaporation ponds for disposal of saline effluent in Pakistan. They suggested that Possibilities of fish-culture in the evaporation ponds be explored particularly in the pond. The possibility of salt mining in the newly developed ponds might become feasible in future like the salts being produced in a natural pond near Pattan Minara.

Euroconsult (1992) conducted the groundwater model study. The purpose of the groundwater model study was to simulate the groundwater situation around the evaporation ponds and to delineate the present and future extent of areas effected by waterlogging caused by seepage from the ponds and also to test remedial measures for reclaiming the affected areas and to find possible solutions.

### 4.1 Effluent Quantity and Pond Area

The evaporation ponds were designed over an area of 33,000 acres. Basic stage-volume curves for each pond were based on the topographic survey. Gauges were installed in Stage-1 ponds; near the inlet at Khanpur outfall in Pond No.1, outlet channel and Spillway-1, whereas, gauges were also installed at Manthar Pond-1, Gath Beri and Spillway-2 in Stage-2 ponds. The inflows and pond levels were monitored. The quantity of effluent of tubewells carried through surface drains to the evaporation ponds at their outfall points was recorded. Table 1 shows year-wise aggregate volume of effluent entering the ponds. On average annually 0.166 MAF effluent was entering in the ponds as compared to the estimated quantity of 0.438 MAF. This could be due to reduced pumping capacity of tubewells with the passage of time.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>Khanpur Drain</th>
<th>Pattan Munara Drain</th>
<th>Total Stage-1</th>
<th>Stage-2 Manthar Drain</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>18,908</td>
<td>9,641</td>
<td>28,549</td>
<td>8,617</td>
<td>37,166</td>
</tr>
<tr>
<td>1991</td>
<td>54,144</td>
<td>18,947</td>
<td>73,091</td>
<td>51,073</td>
<td>124,164</td>
</tr>
<tr>
<td>1992</td>
<td>70,331</td>
<td>29,519</td>
<td>99,849</td>
<td>53,943</td>
<td>152,793</td>
</tr>
<tr>
<td>1993</td>
<td>82,423</td>
<td>30,420</td>
<td>112,844</td>
<td>56,871</td>
<td>169,714</td>
</tr>
<tr>
<td>1994</td>
<td>79,219</td>
<td>34,372</td>
<td>113,591</td>
<td>65,956</td>
<td>179,547</td>
</tr>
<tr>
<td>1995</td>
<td>73,346</td>
<td>34,372</td>
<td>107,718</td>
<td>75,347</td>
<td>182,065</td>
</tr>
<tr>
<td>1996</td>
<td>58,267</td>
<td>30,003</td>
<td>88,269</td>
<td>67,073</td>
<td>155,342</td>
</tr>
<tr>
<td>1997</td>
<td>50,073</td>
<td>22,820</td>
<td>72,893</td>
<td>75,887</td>
<td>148,780</td>
</tr>
<tr>
<td>1998</td>
<td>88,165</td>
<td>38,877</td>
<td>127,043</td>
<td>96,091</td>
<td>223,134</td>
</tr>
<tr>
<td>1999</td>
<td>98,204</td>
<td>42,376</td>
<td>140,580</td>
<td>102,574</td>
<td>243,154</td>
</tr>
<tr>
<td>2000</td>
<td>105,807</td>
<td>27,403</td>
<td>133,210</td>
<td>84,597</td>
<td>217,807</td>
</tr>
<tr>
<td>Average</td>
<td>70,808</td>
<td>28,557</td>
<td>99,365</td>
<td>67,094</td>
<td>166,458</td>
</tr>
</tbody>
</table>

The actual spread area of evaporation ponds was also reduced due to shifting of ponds away from the agricultural areas, construction of bypass channels, Spillway-2 for reducing the flood levels of the ponds. Currently active pond area was in the range of 13000 acres (Alam et al., 2000a).

### 4.2 Effluent Quality and Mining Potential of Sodium Chloride

The quantity of salts and other biomass, entering the ponds, depends upon the volume and quality of the drainage effluent. Water samples were collected for routine chemical analysis from the selected locations namely, Khanpur Pond-1, Manthar Pond-1, Spillway-1, Gath Beri bridge and Spillway-2 (Exit Channel). The spatial change in the effluent water quality is given in Figure 2. The quality of water entering the ponds was variable. It was probably due to the fact that different tubewells having different water quality might be operated at different times. In addition changes in water quality occur due to rainfall or irrigation return flows/canal escapes. Some effluent was pumped up to raise the flow elevation in Pattan Munara Drain and Manthar Drain. The upstream drain water was held up for some time to attain its level for pumping. This stagnated water also causes accumulation of salts, which ultimately caused the variation of water quality at the outfall of drains.

The rate of accumulation of salts deposit in different years could also be due to variations quality and quantity of the effluent. The data of the 10 years, after operation of the evaporation ponds as given in Table 1 shows that on the average 0.166 maf/year of saline effluent with an average quality of 24500 ppm was
entering the ponds. Maximum flows to the tune of 243,154 acre feet were received during the year 1999. Based on the three years data of average yearly aggregate volumes of effluent, the total bulk of salts entering the ponds was calculated in Table 2. The average annual accumulation of salts was found 7.18 million tons, however, even after 10 years of operation of the ponds, there were no signs of crystallization of salts in the evaporation ponds (Alam et al., 2000a). The precipitation of salts occurs at concentration level of above 130,000 ppm., As the release of water from Spillway 2 was continued the water had never been stagnant to come up to a concentration level of 130,000 ppm.

Table 2  Summary of Total Salts Entered in Evaporation Ponds (SCARP-VI).

<table>
<thead>
<tr>
<th>Year</th>
<th>Khanpur Outfall</th>
<th>Manthar Outfall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Water</td>
<td>Average Water</td>
</tr>
<tr>
<td></td>
<td>Quality (ppm)</td>
<td>Inflow Acr.ft</td>
</tr>
<tr>
<td></td>
<td>KPR Drain Inflow Acr.ft</td>
<td>PM Drain Inflow Acr.ft</td>
</tr>
<tr>
<td>1999</td>
<td>20144</td>
<td>98204</td>
</tr>
<tr>
<td>2000</td>
<td>20550</td>
<td>105807</td>
</tr>
<tr>
<td>2001</td>
<td>23356</td>
<td>91452</td>
</tr>
<tr>
<td>Average</td>
<td>22701.3</td>
<td>106337</td>
</tr>
</tbody>
</table>

SCARP Monitoring Organization WAPDA carried out analysis of water samples of Khanpur and Manthar ponds and determined the sodium chloride by theoretical procedure. On the basis of supplied results, the desired potential of sodium chloride was calculated keeping in view the principle that one mole of sodium combines with one mole of chloride to form one mole of sodium chloride being strongly electropositive and electronegative elements, the quantity of sodium chloride in water samples of Khanpur pond was 8.828 g/l and that of Manthar pond was 16.064 g/l. It is clear that sodium chloride of Manthar pond was almost double than that of Khanpur pond. The commercial scale salt mining potential of evaporation ponds depends on the operation of saline drainage tubewells, as the rate of accumulation of salts was different in different years.

From the past history there are two examples of salt mining activity in this area. Mr. Ghulam Muhammad aged 59 years got land on lease for Salt mining near Chaks # 113-P and 114-P in Rahim Yar Khan District. He remained engaged in salt mining from 1973 to 1990 from a natural pond developed due to waterlogging, spreading over an area of 18-20 acres. The activity was discontinued after the operation of SCARP tubewells. The salt was produced as a result of crystallization of the heavily saline standing water of about 2 feet deep. This salt was mainly used in leather industry and also for domestic animals use. The price of 100 kg was Rs.80. Main extraction period of maximum yield was summer due to higher evaporation rate (Awan et al., 2002).

Another site near Pattan Minara at village Jam Khuda Bakhsh has also the history of salt mining. A person named Ghaus Bakhsh aged 72 years was interviewed for information regarding salt mining. According to the information gathered from him the site for salt mining was comprised of 100 acres, where the extraction was resulted mainly from the stagnant seepage water. This remained in practice from 1963 to 1991 which finished with the operation of saline tubewells. The main extraction period was summer and normally no formation of salts crystal used to take place in winter. The extracted salt was mainly used for leather industry in Multan and adjacent areas (Akhtar, 1993).

### 4.3 Heavy Metals

The analysis of samples from Khanpur Pond, Spillway II and Gath Beri indicate absence of Selenium, Lead and Cadmium except 0.032 ppm of Cadmium at Khanpur Pond, which was also within permissible limits. This shows that ponds water was free of heavy metals (Alam et al., 2000a).
4.4 Agro-socio-Economic Impact

The aftereffects of the ponds started a disturbance among nearby population soon after their operation and several complaints were received to the projects executing agencies. Lateral movement of seepage water from evaporation ponds affected the adjacent agricultural land. Agro-socio-economic survey was conducted by interviewing 118 villagers living in the nearby vicinity of ponds. The major source of their living was from cultivated land and livestock. Some of these work as labourers. Area affected due to waterlogging and salinity was 67% in surrounding areas of ponds. Reported loss of live stock varied from 43 to 100 percent. Camels and horses were the worse affected. Small land holders were 56% whose livelihood was affected adversely. Sugarcane crop is affected badly as compared to other crops. In general cropping intensity and yield were considerably decreased. Two out of 12 affected villages were completely abandoned and a large number of families were dislocated. Forty nine percent resident of these villages had to move out due to waterlogging and salinity (Alam et al., 2000).

4.5 Potential for Saline Agro-Forestry

Agro-forestry is an important factor of human life on this planet. Human being is essentially required trees since his birth on this planet. It is a proven fact that thousand years ago in the era of un-civilization human being on the face of the earth used leaves of the trees as clothes ate its roots and fruits as food and used its shadow as shelter. This ancient relationship between human being and tree has not been weakened even with the dawn of the civilization because, human being still needs trees for furniture, fuel, paper industry, match boxes, chip board, pulp, chemical and food for their animals. The plants/trees also act as wind breaks in plains and anti erosion element for landslides in watershed and mountains.

Forestry can also function as bio-drainage for the area. It is low cost technology with a little O&M cost and environment friendly as well. A survey was conducted in the vicinity of SCARP-VI evaporation ponds by IWASRI staff for various parameters of the agro-forestry study. It was disclosed that the culture of growing Eucalyptus trees in the area already existed. It needs little guidance to more people about its benefits in addition to its survival in the severe saline conditions. In addition to one of the best tree species for waterlogged and saline area recovery, Eucalyptus has three special uses for Pakistan, i.e. at the age of 5 years it can be a pulp wood, at 10 years age it produces top class polls for telephone and electricity transmission lines and at 15-18 years it produces high class timbre for furniture.

Reconnaissance survey of the evaporation ponds indicated that there is a potential for agro-forestry, which can briefly be defined as species of suitable trees planted as agricultural crops particularly in saline and waterlogged lands where crops production has almost ceased. As there are a large number of species, which are grown naturally in that environment at the periphery of evaporation ponds having water quality of more than 25,000 ppm. The generally found species are given in Table 3. These trees and shrubs can be used for firewood and other domestic purposes. Quite a few species can be utilized for grazing of animals. Wild Mushroom was also found which is used for human consumption. Planned-efforts of growing specific nature plants by using pond water have not been done. Socio-economic survey of affected area was carried-out to explore the farmers’ interest in agro-forestry. The farmers were told that growing salt tolerant grasses and eucalyptus trees could reclaim their abandoned land and 68% of the farmers showed their willingness (Alam et al., 2000b).

Table 3 Species of Agro-Forestry found in Pond Area of SCARP-VI

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Local Name</th>
<th>Botanical Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Akk</td>
<td>Calotropis procera</td>
</tr>
<tr>
<td>2</td>
<td>Desi Kikar</td>
<td>Acacia nilotica</td>
</tr>
<tr>
<td>3</td>
<td>Farash</td>
<td>Tamarix aphylla</td>
</tr>
<tr>
<td>4</td>
<td>Jand</td>
<td>Prosopis cineraria</td>
</tr>
<tr>
<td>5</td>
<td>Jawanah</td>
<td>Alhaji maurorum</td>
</tr>
<tr>
<td>6</td>
<td>Karir</td>
<td>Capparis deciduas</td>
</tr>
<tr>
<td>7</td>
<td>Khip</td>
<td>Liptadenia pyrotechnica</td>
</tr>
<tr>
<td>8</td>
<td>Lana</td>
<td>Haloxylon salicornicum</td>
</tr>
<tr>
<td>9</td>
<td>Phog</td>
<td>Colligonum polygonoides</td>
</tr>
<tr>
<td>10</td>
<td>Walaiti Kikar</td>
<td>Acacia jacquemontii</td>
</tr>
</tbody>
</table>

4.6 Environment and Health

Impact of concentration changes in various chemicals in pond water and bed soils; vector borne disease, air pollution, reduction in flora and fauna and other environmental variables was determined. Water sampling and its detailed analysis for toxic elements and nutrients was made.

Some of the important factors effective in preserving or improving human health are housing, sanitation, control of epidemic diseases, provision of good quality food and water and medical care. Health hazards like poor housing condition; ill planned village building, inadequate and bad quality water supply and medical care were prevalent all over the Cholistan desert area. Generally speaking the housing conditions were mostly poor, composed of mud houses and temporary shelters; small and congested; lacking proper ventilation. Pure and fresh drinking water, which plays a vital role in human health, was not even dreamed in this area. There was no concept of sanitation amongst most of the respondents, medical services like dispensaries, health unit, are not existent for these people. However, in case of emergent cases medical care from the nearby village was utilized both for human beings and livestock (Awan et al., 2002).

4.7 Sediment Deposition and Useful Life of Ponds

The Cholistan area comprises series of unstable sand dunes. During summer the sand drifting with the wind blowing is almost in one direction. Large quantity of sand is surly be trapped in pond water every year. This quantity was expected to be much more than anything brought into the ponds by all other factors put
As no such previous study was available, it was difficult to estimate correctly the impact of this factor. In order to determine the sediment deposit and useful life of the ponds, the volume of water and the masses of salts held in the ponds were measured along with the bottom height of the ponds at different points. Climatic data including wind speed was also collected to determine the effect of sand deposition in the ponds. Its effect could be mitigated by plantation along the windward periphery of the pond as a part of environmental improvement (Awan et al., 2002).

### 4.8 Potential for Fish Culture

Evaporation ponds of SCARP-VI are spread over an area of more than 13,000 acres. It is a large water body of 12,000 to 15,000 acre feet average storage and provides a natural site for fish production. Change in water quality at different locations within ponds are shown in Figure 2. The salinity at Khanpur Pond-1 has an average value of 18515 ppm whereas the average salinity of Manthar Pond was 20975 ppm. Table 4 shows the water balance of ponds.

Meetings and field visits were conducted along with the local farmers to collect the relevant information for the existing fish culture in the ponds. A hopeful fishery potential was discovered. No doubt the prawn species of Tiger and Giant can survive and thrive up to the salinity range shown in Figure 2. But due to the non-fulfillment of other parameters for raring of prawn or fresh water prawn, the prawn culture in these ponds cannot survive. However, other species of fish such as Tilapia Mozambica can flourish and thrive well in these ponds’ salinity levels, provided the scarcity of food in these ponds is compensated. The common size of Tilapia Mozambica ranges from 500 to 1500 gms. Fisheries Department of Punjab Government made stocking of fish seed of ‘Tilapia Mosambica’ species in the drain in the year 1989-90.

It was informed that the experiment of fish seed stocking of Mosambiqa, was encouraging and satisfactory. The experiment was successful and the department in the year of 1992 and 1993 put to auction the catches and sale of the species, through contractor in the open market as auction of fish rights of Manthar pond.

<p>| Table 4 Water Balance in Ponds (AF) |
|-------------------------------|-------------------------------------------------|---------------------------------|-----------------|-----------------|------------------|-----------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>YEAR</th>
<th>Previous Storage</th>
<th>INFLOWS</th>
<th>SURFACE Drains</th>
<th>Rain</th>
<th>TOTAL</th>
<th>OUTFLOWS</th>
<th>Spillway-2</th>
<th>Seepage</th>
<th>Evapo-ration</th>
<th>TOTAL</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>0</td>
<td>37166</td>
<td>135</td>
<td>37301</td>
<td>0</td>
<td>17400</td>
<td>4142</td>
<td>21542</td>
<td>15759</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>15759</td>
<td>124164</td>
<td>3157</td>
<td>13405</td>
<td>0</td>
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<td>41334</td>
<td>130134</td>
<td>12946</td>
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<td></td>
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<tr>
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<td>4663</td>
<td>170402</td>
<td>0</td>
<td>105000</td>
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<td>0</td>
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<td>5092</td>
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<td>223134</td>
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<td>239260</td>
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<td>99900</td>
<td>61354</td>
<td>212361</td>
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<td>1999</td>
<td>26899</td>
<td>243154</td>
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<td>66360</td>
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<td>78579</td>
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<td>215353</td>
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</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>15,047</td>
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</tr>
</tbody>
</table>

During the meeting, it was also discovered, that there is no need of any further fish seed stocking, for the reason that the breeding of Mozambique species is very fast and it breeds 3 to 4 times, in a year. However, at some places it was found that the species could not attain maximum weight, due to paucity of desired fish feed in the evaporation pond. That can be remedied, provided the catches are encouraged through local contractors.

The change in water quality of tubewells in SCARP-VI regarding drainage system of Khanpur, Manthar and Pattan Minara are shown in Table 5 below. It is evident from the contents of the table that as a whole, the average salt concentration initially in the year 1989, is on higher side as compared to the year 1999 and is showing a decreasing trend in salt concentration of the SCARP tubewells which can provide a better atmosphere and surrounding for fish culture regarding species of ‘Tilapia Mosambica’ and ‘Tilapia Nobila’ (Alam et al., 2000).

| Table 5 Changes in Water Quality of Tubewells in SCARP-VI. |
|-----------------|-------------------------------------------------|-----------------|-----------------|-----------------|-----------------|
| Khanpur         | 25371                                           | 20085           |
| Pattan Minara   | 20768                                           | 17373           |
| Manthar         | 22177                                           | 18717           |
| Average         | 22772                                           | 18725           |

### 4.9 Water Balance

The storage in the ponds is fluctuating. Average outflow from spillway 2 in 4-5 times of the storage in the ponds. Spillway 2 outflow necessitate its link to an outfall
5 Conclusions

- After operation of the ponds in general the life of the people living in the vicinity of ponds was badly affected.
- Two out of 12 affected villages were completely abandoned and a large number of families were dislocated. 49% resident of these villages had to move out due to waterlogging and salinity.
- A combined approach of surface, sub-surface and bio-drainage is most suitable for the problems of waterlogging and salinity in the project area.
- Environmental degradation can be balanced through agro-forestry in areas affected from salinity and waterlogging. Eucalyptus tree, is the best species for waterlogged and saline areas. Most of the farmers were willing to grow Eucalyptus trees.
- The rate of accumulation of salts deposit was different in different years. The salt mining potential of evaporation ponds is dependent on the operation of saline drainage tubewells. Anyhow, it is limited to 3 million tons of sodium chloride per year.
- Heavy metals were not found in the ponds water.
- The present salinity of the pond water is suitable for Fish species particularly Tilapia Mosambiqa and Tilapia Nolitica. However, the food required for prawn culture in existing saline ponds is not available.
- Water balance indicates that ponds are not sustainable and outflow is 4-5 times the ponded water.

6 Recommendations

- In general salt contents in all the three drains are very high. These deep drainage tubewells may be replaced with horizontal pipe drainage system which will not only generate less quantity of effluent but of better quality as well.
- In future ponds should be made only after the consultation with the residents of the area.
- Saline agro-forestry should be encouraged around the ponds to manage the saline lands. Forestry can also function as a good bio-drainage alternative, being low cost technology with a little O&M cost and environment friendly as well.
- The potential regarding fish culture exists but it requires more exploitation and strengthening on scientific grounds. The participation of local community must be encouraged in fish culture through Punjab Fisheries Department.
- More concentrated research by the respective Departments like Fisheries, Forest and Mineral Department is needed to explore the beneficial uses on scientific grounds.
- Long-term policies should be framed to accrue the benefits from the evaporation ponds on sustained basis.
- Study should be conducted to link these ponds to an outfall drain.

7 References


ABSTRACT
Agriculture in Pakistan is confronted with the problems of waterlogging and salinity. To tackle these problems, a programme was initiated in the shape of SCARPs. As a result of this programme, huge amount of drainage effluent is being produced which needs to be disposed off or used for irrigation purpose. The quality of this effluent is generally not good and its use as such will deteriorate soil properties resulting low crops yield. For this purpose, a study was conducted in Fordwah Eastern Sadiaq South (FESS) project Bahawalnagar with the broad objective to develop appropriate technology for the use of brackish drainage water on sustainable basis. About 1.2 ha non-saline non-sodic loam land. The soil pH ECc and SAR at the time of site selection was 7.9-8.1, 2.8-4.5 dS m-1 and SAR 3.5-5.6 respectively. Wheat-cotton crop rotation was followed. Treatments were: all irrigations with canal water(T1), irrigation with canal water during Rabi and drainage water during Kharif season(T2), irrigation with drainage water for two years and canal water for one season(T3) and drainage water for three years + gypsum @ 25% of CWR and canal water for one season(T4). Soaking and first irrigation after germination were applied with canal water to facilitate emergence and initial establishment of crop. Soil salinity increased invariably in all the treatments where drainage water was applied. Salinity built up was generally proportional to the quantity of drainage water received by the experimental treatment. Percent increase in ECc was 187 in the treatment(T3) receiving year-round drainage water lacking gypsum application. However, increase in ECc was 142% in case of treatment receiving gypsum as water conditioner. SAR did not visualize much increase as observed in case of ECc. Canal water irrigation and irrigation with drainage water involving gypsum application resulted 54 and 4%, respectively reduction in the original sodicity of the soil. In case of year-round application of drainage water, salinity deposition was the highest. However, application of canal water during Rabi and drainage water during Kharif season had a nominal increase in soil SAR. Increase in ECc due to the effect of capillary rise into the crop root zone from the brackish groundwater aquifer was also a source of addition to this parameter. Yields were fairly higher with canal water irrigation and receded with drainage water application. Drainage water treatment with gypsum sub-sidled the ill-effect of brackish water on crop yields to some extent. Effect of gypsum was slightly more conducive for wheat than cotton crop. Crops irrigation with pure drainage water and lacking gypsum application gave the lowest yield of both the crops. Drainage water application on alternate season basis with canal water was slightly less injurious for irrigation purposes. Irrigation with canal water had higher soil infiltration rate whereas drainage water alone or in combination with canal water had some adverse effect on soil permeability. Use of gypsum lessened the deleterious impact of brackish water and improved soil conditions and crop yields. The drainage water may be used for crop production provided it is used on short-term basis and amended with gypsum on 25% crop water requirement or by adopting cyclic use.

1 INTRODUCTION
The Pakistan is basically an agricultural country and its economy largely depends on agriculture. Occurrence of waterlogging, salinity and sodicity problems has become the major constraints of agriculture sector. In the areas where these problems exist jointly, the first strategy involves to provide drainage facility to control the depth of groundwater. In most of the problematic areas of the country, the drainage facilities are being provided through vertical drainage by tubewells and horizontal drainage through open drains as well as by sub-surface drains (tiles/pipes). These redressal measures drain out a huge amount of water which can either be utilized for irrigation purposes or disposed off into the sea. Mostly the quality of the drainage water is poor and cannot be used directly for growing commercial crops on sustainable basis without adopting necessary management techniques (Chaudhry et al. 2000, 2001a and 2001b).

The drainage water can be utilized for crops by following certain site specific technologies. Addition of F.Y.M. helped in reducing the adverse effects of brackish water on crops (Haider and Hussain, 1981) for medium textured soils. Similarly soil applied H2SO4, CaSO4, S, CaCl2 or HCl at rates equivalent to 50% water GR of the total applied water were helpful to sustain the crop production (Cheema et al., 1988). Application of chemical and biological amendments can reclaim the salt affected soil even with the use of brackish water (Ghafoor et al., 1986, 1985a and b; Haider and Hussain, 1976; Haq and Dabin, 1981 and Bhatti, 1986). Cyclic or conjunctive use of such type of water can be used for growing crops (Chaudhry and Bhutta, 2002). Similary hazardous water can be used for salt tolerant trees (Subhani et al. 2003; Chaudhry et al.2002).

The main objective of the study was to find out the possible and appropriate technology for the use of saline drainage effluent for agriculture under the actual field conditions. The specific objectives were:

- Testing of promising crop varieties under real production environment.
- Monitor the effects of use of brackish water on the physical and chemical properties of soil, crops yield and environment
- Reduce the disposal requirement of drainage effluent.

2 MATERIALS AND METHODS
The research was carried out during the period 1998-2002 on farmer's field in Fordwah Eastern Sadiaq South (FESS) Project, Bahawalnagar on wheat and cotton crops. Wheat was generally planted during the first week of December and cotton during the second half of May after vacation of the field by the respective crop. Soil samples were taken from 0-15 and 15-30 cm depths before sowing and at harvesting of each crop to monitor changes in soil salinity/sodicity. The initial physical and chemical characteristics of soil are presented in Table 1. Since wheat and cotton crops were rotated in the same field, therefore, soil samples collected at harvesting of cotton were considered as samples at sowing of wheat and samples taken at wheat harvesting were envisaged as salinity status before cotton crop.

Wartetable fluctuations were noted from the piezometer installed at the research site on weekly interval and averaged on monthly basis. During five years (1998-99 to 2002-03) study period, it ranged between 0.74 to 2.95 m. The treatments tried were:

http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20chaudhry%20iqbal%20and%20subhani%20v2.html (1 of 7)26-4-2010 12:12:07
USE OF BRACKISH DRAINAGE WATER EFFLUENT FOR CROP PRODUCTION

T1: Canal water (control).
T2: Canal water during Rabi and drainage water during Kharif season.
T3: Drainage water for two years and then canal water for one season.
T4: Drainage water for three years + gypsum @ 25% of CWR and then canal water for one season.

Soaking and first crop irrigation was applied with canal water for seed germination and initial crop establishment. The subsequent irrigations, each of about 7.5 cm, were applied as per treatmental schedule.

Table 1 Initial physical and chemical characteristics of the soil (0-30 cm)

<table>
<thead>
<tr>
<th>Physical analysis</th>
<th>Percent content</th>
<th>Textural class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sand</td>
<td>Silt</td>
</tr>
<tr>
<td></td>
<td>44</td>
<td>36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chemical analysis</th>
<th>ECe (dS m⁻¹)</th>
<th>SAR (mmolc L⁻¹)½</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.8-4.5</td>
<td>3.5-5.6</td>
<td>7.9-8.1</td>
</tr>
</tbody>
</table>

Initially drainage water collected in the sump from the sub-surface drainage system of the project and later on tubewell installed for the study was used for brackish water irrigation. The quality of drainage water used for irrigation during the study period had ECe from 2.55 to 3.35, SAR from 7.00 to 8.20, and RSC from 0.70 to 0.82.

Gypsum @ 25% of CWR was applied to the respective treatment at sowing during preparatory tillage.

Nitrogen, phosphorus and potash were applied @ 120, 60 and 50 kg ha⁻¹ in the form of urea, di-ammonium phosphate and sulphate of potash. Full dose of phosphorus and potash and half of nitrogen were applied as basal during preparatory tillage while half nitrogen was top-dressed during the growth period of the crop.

3 RESULTS AND DISCUSSION

The study was carried out to determine the possibility of using drainage water for crop production. Impact of different irrigation treatments on soil ECe, SAR, infiltration rate and crops yield was studied and is discussed as under:

3.1 Soil Salinity (ECe dS m⁻¹)

Time to time soil analysis indicates that ECe was almost static with a slight decrease of 16% over baseline salinity level in case of canal water application while drainage water application showed rise in soil salinity depending upon the amount of brackish water received by any particular treatment (Table 2). Maximum increase of 232% was observed in case of two year continuous irrigation with drainage water without gypsum application. However, almost same irrigation treatment involving gypsum application @ 25% of CWR, reduced salinity buildup to 52%. Increase in soil ECe with drainage water lacking gypsum application, could have even higher level if this treatment had not canal water irrigation during wheat season of 2000-01. Interception of canal water during Rabi season, further reduced the salinity deposition to 100%. The effect of different treatments after about five years on ECe is clearly shown in Figure-1 indicating that ill-effects of brackish water can be minimized with the application of gypsum or cyclic use of such type of water.

3.2 Soil Sodicity (SAR)

Data presented in Table 3 displayed a fair reduction in SAR with canal water irrigation and even with drainage water involving gypsum application @ 25% of CWR. Since baseline SAR was fairly high, therefore, the subsequent analysis could not visualize prominent differences with poor quality water irrigation as observed in study-1. Maximum reduction in SAR (68%) was observed with canal water followed by brackish water irrigation having application of gypsum (27%). Contrary to this, some increase in soil sodicity was observed in case of brackish water application without any amendment indicating that there was accumulation of sodium salts in the soil. It can easily be deduced that gypsum application @ 25% of CWR has helped in reducing the soil SAR. The impact difference amongst treatments after about five years is fairly visible in Figure-2.

Table 2 Impact of irrigation treatments on ECe of soil

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>ECe (dS m⁻¹)</th>
<th>Increase or decrease in S10 over S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1: Canal water</td>
<td>S1: 3.1</td>
<td>S2: 2.9</td>
</tr>
</tbody>
</table>
3.3 Infiltration Rate

Infiltration rate of soil was monitored after harvesting of each crop to evaluate the impact of different irrigations on soil permeability. Canal water application showed some improvement in the soil permeability and there was 9% increase in soil infiltration at the end of the experimental period. Addition of gypsum @ 25% of CWR and cyclic use of canal water during Rabi and drainage water during Kharif season did not allow the brackish water to exert much its negativity on soil permeability. However, year-round application of drainage water without gypsum displayed a gradual reduction of 43% in soil infiltration by the end of fifth year as shown in Table 4.

### Table 3 Impact of irrigation treatments on SAR of soil (0-30 cm depth)

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>SAR (mmol_(\text{c L}^{-1}))</th>
<th>Increase or decrease in S_{10} over S_{1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1. Canal water</td>
<td>S_{1} 11.1  S_{2} 6.7  S_{3} 5.6  S_{4} 6.2  S_{5} 6.7  S_{6} 5.7  S_{7} 6.1  S_{8} 6.8  S_{9} 6.2</td>
<td>-68%</td>
</tr>
<tr>
<td>T2. Canal water during Rabi and drainage water during Kharif season</td>
<td>S_{1} 11.1  S_{2} 5.8  S_{3} 7.0  S_{4} 10.0  S_{5} 12.5  S_{6} 9.9  S_{7} 12.3  S_{8} 10.7  S_{9} 11.9  S_{10} 12.1</td>
<td>+9%</td>
</tr>
<tr>
<td>T3. Drain water for two years and the canal water for one season</td>
<td>S_{1} 11.1  S_{2} 5.6  S_{3} 8.0  S_{4} 15.0  S_{5} 17.0  S_{6} 14.8  S_{7} 16.2  S_{8} 17.7  S_{9} 18.1  S_{10} 15.2</td>
<td>+40%</td>
</tr>
</tbody>
</table>

Figure 1  Impact of irrigation treatments on EC_e of soil
**Table 4 Impact of irrigation treatments on infiltration rate of soil**

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>Infiltration rate of soil (cm/hour)</th>
<th>Increase or decrease in S₁₀ over S₁</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T1. Canal water</strong></td>
<td>S₁  S₂  S₃  S₄  S₅  S₆  S₇  S₈  S₉  S₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3  2.3  2.4  2.4  2.3  2.4  2.3  2.3  2.5  +9%</td>
<td></td>
</tr>
<tr>
<td><strong>T2. Canal water during Rabi and drainage water during Kharif season</strong></td>
<td>S₁  S₂  S₃  S₄  S₅  S₆  S₇  S₈  S₉  S₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3  2.3  2.3  2.2  2.2  2.2  2.2  1.8  2.0  -13%</td>
<td></td>
</tr>
<tr>
<td><strong>T3. Drainage water for two years and the canal water for one season</strong></td>
<td>S₁  S₂  S₃  S₄  S₅  S₆  S₇  S₈  S₉  S₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3  2.3  2.3  2.2  2.0  1.9  1.8  1.8  1.6  1.3  -43%</td>
<td></td>
</tr>
<tr>
<td><strong>T4. Drainage water for three years + 25% gypsum on CWR basis and then canal water for one season</strong></td>
<td>S₁  S₂  S₃  S₄  S₅  S₆  S₇  S₈  S₉  S₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3  2.3  2.5  2.4  2.3  2.4  2.3  2.1  2.0  -13%</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2** Impact of irrigation treatments on SAR of soil

**Table 4 Impact of irrigation treatments on infiltration rate of soil**

<table>
<thead>
<tr>
<th>Irrigation treatment</th>
<th>Infiltration rate of soil (cm/hour)</th>
<th>Increase or decrease in S₁₀ over S₁</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>T1. Canal water</strong></td>
<td>S₁  S₂  S₃  S₄  S₅  S₆  S₇  S₈  S₉  S₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3  2.3  2.4  2.4  2.3  2.4  2.3  2.3  2.5  +9%</td>
<td></td>
</tr>
<tr>
<td><strong>T2. Canal water during Rabi and drainage water during Kharif season</strong></td>
<td>S₁  S₂  S₃  S₄  S₅  S₆  S₇  S₈  S₉  S₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3  2.3  2.3  2.2  2.2  2.2  2.2  1.8  2.0  -13%</td>
<td></td>
</tr>
<tr>
<td><strong>T3. Drainage water for two years and the canal water for one season</strong></td>
<td>S₁  S₂  S₃  S₄  S₅  S₆  S₇  S₈  S₉  S₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3  2.3  2.3  2.2  2.0  1.9  1.8  1.8  1.6  1.3  -43%</td>
<td></td>
</tr>
<tr>
<td><strong>T4. Drainage water for three years + 25% gypsum on CWR basis and then canal water for one season</strong></td>
<td>S₁  S₂  S₃  S₄  S₅  S₆  S₇  S₈  S₉  S₁₀</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.3  2.3  2.5  2.4  2.3  2.4  2.3  2.1  2.0  -13%</td>
<td></td>
</tr>
</tbody>
</table>
3.4 Crops Yield

The wheat grains and seed cotton yields were evaluated on whole plot basis to avoid any field variation and are presented as under:

3.4.1 Wheat grain yield

Data given in Table indicate that maximum wheat grain yield of 3652 kg ha⁻¹ was obtained in case of canal water irrigation followed by (2972 kg ha⁻¹) canal water during Rabi and drainage water during Kharif seasons. These yields were fairly higher than the rest of the treatments. Yield penalty consequent to brackish water irrigation was well recognized and was directly related to the share of water received by the crop. Inclusion of drainage water during summer season resulted in a yield loss of 680 kg ha⁻¹ than full season canal water irrigation but was higher than exclusive year-round drainage water application. Pure drainage water irrigation without any amendment reduced wheat grain yield by 1433 kg ha⁻¹ (39%). Amendment of drainage water with gypsum @ 25% gypsum requirement of irrigation water reduced the yield loss to 972 kg ha⁻¹ (27%) while application of canal water during Rabi and drainage water during Kharif further reduced the yield penalty to 680 kg ha⁻¹(19%) depicting that use of brackish water had deleterious effect on wheat grain yield depending upon the mode of application. Wheat season of 1998-99 was the first year of the experiment and had no carried over adverse effect of poor quality water on soil but proved inferior in respect of wheat grain yield due to prevailing of fog for long period. The rest of years were quite favorable for wheat crop. The impact of different irrigation treatments, on an average, is presented in Figure 3.

3.4.2 Seed cotton yield

Table 6 indicates, on an average, maximum yield of 2387 kg ha⁻¹ with canal water irrigation in identity to wheat yield discussed above. Likewise minimum yield of 1417 kg ha⁻¹ was obtained with drainage water irrigation without any amendment. Adverse effect of drainage water on seed cotton yield was relatively more compared to the wheat grain yield perhaps due to higher evapo-transpiration and more absorption of the saline water. Application of gypsum exerted a little bit positive effect on crop yield and gave a slightly higher seed cotton yield over the comparable treatment (Figure-4). Data further reveal that difference in crop yield obtained with canal water and drainage effluent is increasing with the advancement of the study. During the first year, yield reduction resultant to poor quality irrigation water, was <500 kg ha⁻¹ while during the subsequent years, the loss sustained by the crop multiplied to almost double. It can be clearly identified that with the passage of time, the use of pure drainage water has resulted in increased accumulation of salts and consequent reduction in yield. But this reduction in yield was, in general, related to the amount of brackish water used or application of gypsum @ 25% on CWR basis.

Table 5 Impact of different irrigation treatments on wheat grain yield (kg ha⁻¹)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁. Canal water(control)</td>
<td>2172</td>
<td>3947</td>
<td>3896</td>
<td>3914</td>
<td>4331</td>
<td>3652</td>
<td>-</td>
</tr>
<tr>
<td>T₂. Canal water during Rabi and drain water during Kharif season</td>
<td>2191</td>
<td>3187</td>
<td>3061</td>
<td>3079</td>
<td>3341</td>
<td>2972</td>
<td>-680 kg (19%)</td>
</tr>
<tr>
<td>T₃. Drain water for two years and the canal water for one season</td>
<td>1885</td>
<td>2628</td>
<td>1999</td>
<td>2017</td>
<td>2566</td>
<td>2219</td>
<td>-1433 kg (39%)</td>
</tr>
<tr>
<td>T₄. Drain water for three years + 25% gypsum on CWR basis and then canal water for one season</td>
<td>1875</td>
<td>2688</td>
<td>2834</td>
<td>2852</td>
<td>3150</td>
<td>2680</td>
<td>-972 kg (27%)</td>
</tr>
</tbody>
</table>
USE OF BRACKISH DRAINAGE WATER EFFLUENT FOR CROP PRODUCTION

4 CONCLUSIONS AND RECOMMENDATIONS

Based on the experimental data, the conclusions and recommendations drawn are as under:-

4.1 Conclusions

- Maximum increase of 232% in ECe was observed in T3 followed by T2 (100%) and T4 (52%) within about 5 years period.
- Soil SAR was reduced in T4 by 27 % whereas it increased 40 % in T3 and 9 % in T2 generally in proportional to the quantity of drainage water used.
- Two years continuous use of drainage water then one season canal water and again drainage water irrigation reduced the infiltration rate by 43%. However, application of gypsum @ 25% CWR reduced this effect to only 13%.
- Maximum wheat grains yield was in T1 followed by T2, T4 and T3 respectively indicating effectiveness of different treatments.
- Similar yield trend was also observed in case of seed cotton yield i.e. maximum yield in T1 followed by T2, T4 and T3 respectively.

4.2 Recommendations

- If need prevails, the brackish water should be used as cyclic or with some amendments.
- If brackish water has sodicity problem, gypsum should be applied to minimize its deleterious effect.
- Leaching fraction, if applied, will maintain soil productivity, so it should be applied.

4.3 Message For Farmers

- In using brackish water, it should be amended with suitable amendment.

---

Figure 3: Average impact of different irrigation treatments on wheat grain yield

Table 4: Impact of different irrigation treatments on seed cotton yields (kg ha⁻¹)

<table>
<thead>
<tr>
<th>Irrigation Treatment</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>Avg.</th>
<th>Decrease over control</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁. Canal water (Control)</td>
<td>1847</td>
<td>2604</td>
<td>2282</td>
<td>2816</td>
<td>2387</td>
<td>-</td>
</tr>
<tr>
<td>T₂. Canal water during Rabi and drainage water during Kharif season</td>
<td>1572</td>
<td>1757</td>
<td>1508</td>
<td>2124</td>
<td>1740</td>
<td>-647 kg (27%)</td>
</tr>
<tr>
<td>T₃. Drainage water for two years and the canal water for one season</td>
<td>1327</td>
<td>1493</td>
<td>1356</td>
<td>1492</td>
<td>1417</td>
<td>-970 kg (41%)</td>
</tr>
<tr>
<td>T₄. Drainage water for three years + 25% gypsum on CWR basis and then canal water for one season</td>
<td>1354</td>
<td>1541</td>
<td>1496</td>
<td>1766</td>
<td>1539</td>
<td>-848 kg (36%)</td>
</tr>
</tbody>
</table>

Figure 5: Average impact of irrigation treatments on seed cotton yield.
During the availability of good quality water, it should be applied to leach the accumulated salts due to brackish water irrigation.

Salt tolerant crop cultivators be planted during brackish water use to have better crop production.

5 REFERENCE

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[3] Senior Agronomist, IWASRI
[4] Research Officer, IWASRI
ABSTRACT
Sustainability of irrigated agriculture in the arid and semi-arid regions of the country has faced the challenge because alkalinity/salinity problems associated with soils and irrigation waters. Many problems of the irrigated agriculture arise from inefficient management of irrigation water especially when it carries high salt concentrations. One of the major problems confronting present day agriculture is decreasing availability of good quality irrigation water. With increasing demand and decreasing availability of good quality waters, there is growing tendency among the farmers to use these poor quality waters for crop production. Indiscriminate use of poor quality waters in the absence of proper soil-water-crop management practices pose grave risks to soil health and environment. In India about 36 percent of irrigated lands have been damaged at different levels due to such type of practices. In arid zone, even a good quality water supply will add two tons of salt per hectare every year.

This disappointing picture caused due to faulty irrigation development has now resulted in the planners giving greater attention right at the planning stage to include irrigation improvement intervention as a preventive strategy. However failure of institutional aspects of implementing the improvement strategies, lack of provision of drainage coupled with social aspects relating to ineffective communication between farmers and the agencies have all contributed to failure of our efforts to prevent the growing problem of water logging and salinity. For example, increase in area under canal irrigation during the last three decades was only 19 percent; increase through tube wells has been of the order of 160 and 189 percent in Haryana and Punjab, respectively. Whereas, the scenario on ground water utilisation is not the same in several other states or they're specific areas disadvantaged either with poor quality aquifer yields or their quality. Surveys rate 32-84 per cent of the presently 'running' wells of different states to be of poor quality.

Technological options like vertical drainage where ground water quality is poor but water table is at a reasonable level, skimming well/ *doruvu* technology where shallow ground water management is needed and where water table is high and quality of ground water is poor, subsurface drainage (SSD) is suggested along with different management practices. Different strategically approaches were adopted of in different period. In the seventies and eighties the major emphasis was system (canal) improvement, on farm development (OFP) and farmers participation. But each of these prescribed strategies remedies enjoyed the status of a 'privileged solution' at one time or other. There was no effort to harness the synergetic benefits of those options, with the result that no progress was achieved in testing these strategies together. It does not stimulate testing and modification and does not promote a 'learning process' strategy. From 1990's onward the emphasis shifted on transfer of irrigation management, operation and maintenance from government to the water users through some short of institutional set-ups. Concern about the proper utilisation of poor quality waters for crop production in areas, where their use is inevitable, is not new. Efforts have been made for the development of management practices for using poor quality waters. Although it is widely acknowledged that preventive strategies like irrigation improvement intervention have only a limited scope for immediate benefits to the farmers and that curative measures like subsurface drainage (SSD) are needed to tackle the problem of water logging and salinity. Yet SSD development was neglected both at the national, state and at the farm. Since subsurface drainage technology is indivisible in nature, it needs collective action, which calls for new institutional set up to tackle the problem. Keeping the above in view, this paper will suggest the scope and prospects of different technological options and the form of institutional set up which is needed to promote equity among all stakeholders and devolves power and autonomy to local institutions with effective regulation backed by legislation and enforcement for sustainable development of agriculture in the saline environment.
Keywords: Privileged Solution, Learning Process, Synergetic Benefits, Preventive Strategies,

1 Introduction

In the seventies irrigation enjoyed a favoured status in terms of investment in agricultural sector. More than 75 percent World Bank assistant is on irrigation. The resultant outcome is the unprecedented rise in agricultural productivity. Afterwards there is a decline trend of investment on irrigation. One reason of such type of disillusionment is due to its economic performance. The poor performance is mainly due to poorly managed operations; inadequate supplies in the tail ends and untimely and unreliable water deliveries. In the fresh ground water zone there is a threat of serious water scarcity due to over use of ground water and consequent decline in water table. On the other hand farmers are generally disliked towards the use of saline ground water. Due to non-exploitation of poor quality ground water and mismanagement of surface canal water creates the problem of water logging and secondary Stalinization. As a result about 15-20 percent command area have become afflicted with the menace of water logging and salinity. These areas are mostly underlain with marginal and poor quality underground water. In the northwest states of India like Haryana, Punjab, Rajasthan and Gujarat are facing greater problems of water logging and salinity. In Gujarat about 9 percent of the total geographical area is affected by salinity and sodicity. About 20-30 percent of the area in the Chambal Command of Madhya Pradesh has gone out of cultivation because of water logging and salinity.

Acquifers surveyed in different states have been indicated that about 32-84 percent of the ground water is of poor quality in nature. Central Ground water Board (1994) reported that about 4 percent area in Haryana is under saline ground water whereas for Punjab it is about 3 percent for Rajasthan it is about 82 percent for Gujarat it is about 10 percent and for Uttar Pradesh it is about 1 percent area. The document of Eighth Five Year Plan has reported 17.61 million ha area affected by the problem of waterlogging (8.53 million ha), alkalinity (3.58 million ha), and salinity and sandy area (5.50 million ha) (GOI 1991). Recent estimate shows that the extent of salt affected soils in India was 8.6 mha and 4.5 mha is waterlogged (Singh 1994).

Keeping the above in view, this paper will suggest the scope and prospects of different technological options and the form of institutional set up which is needed to promote equity among all stakeholders and devolves power and autonomy to local institutions with effective regulation backed by legislation and enforcement for sustainable development of agriculture in the saline environment.

1.1 Technological Options:

Various remedial measure such as better water management, conjunctive use of canal and ground waters, improvement of surface drainage, on-farm development, introduction of forestry, amendment of soils and shallow ground water management were suggested. Out of those it has been suggested to adopt the technologies like vertical drainage where ground water quality is good and water table is at a reasonable level, skimming well/ doruvu technology where shallow ground water management is needed and where water table is high and quality of ground water is poor, subsurface drainage (SSD) is suggested along with different management practices. Similarly for reclamation or to make productive of alkali soils, gypsum base reclamation strategies were suggested where resource base of the farming community is sound. In the poor resource base-farming situation, adoption of salt resistant varieties like CSR10 and KLR1-4 for paddy-wheat cropping sequence is recommended in the first year of the reclamation programme. It was also suggested that for quick encasement small doses of gypsum along with salt resistant varieties fetched higher returns. Different strategically approaches were adopted in different period and it was observed that all the above-mentioned approach fetched good returns, which is financially and economically viable in the farmers’ field.

1.2 Case studies of different technological adoptions:

1.2.1 Sub subsurface drainage at Haryana:

In Haryana, subsurface drainage was installed in 589 ha at thirteen different locations in order to prevent, or enable the
TECHNOLOGICAL OPTIONS FOR POOR QUALITY SALINE WATER MANAGEMENT IN AGRICULTURE: SCOPE & PROSPECTS

reclamation of areas which were already affected by water logging and soil salinity and about 2000 ha in two different location has been selected for SSD under Indo-Dutch collaboration. in the Chambal Command area in Rajasthan where SSD were installed on 10 thousand under Canadian Funded Project. In collaboration with CSSRI, WALMI in Gujarat installed SSD in 200ha in four different location. The cost of installation of SSD mainly depends on soil type, depth and spacing of drains, location under drainage and the type of the drainage material used. At present (1994-95 prices) the cost of manually installed SSD varies from RS.22,310 to RS. 18,525 per ha in Haryana (Datta & de Jong, 1998).

The installation of a subsurface drainage system enables the control of the watertable level and the desalinisation of the soils by leaching, either with irrigation water or with the monsoon rains. Operational research on Sampla Farm showed that salinity in the topsoil decreased rapidly after drainage, from about 50 dSm⁻¹ in June 1984 to about 5 dSm⁻¹ in November 1985, in spite of low rainfall in these years (Rao et al. 1991). In all small-scale pilot projects in Haryana, most of which are run by the farmers, the short-term effects of subsurface drainage were:

- A considerable increase in cropping intensity;
- A shift in the cropping pattern towards more remunerative crops;
- A remarkable increase in crop yields.
- An increase in the efficiency, or productivity of fertilizers.
- Increase in gainful employment
- Timeliness of planting and harvesting;
- Increase the land value.

The combined result of these changes was a substantial increase in farm incomes.

It is well documented that subsurface drainage sustains or restores the productivity of the agricultural land (Datta & de Jong 1997). The cost of installation of SSD is about Rs 35,000 per ha at 1997-98 prices. It needs collective action for which institutional set up is needed. An attempt has already taken in Hiragana, Rajasthan and Gujarat. An positive co-ordination were observed in some of the small scale SSD area (Datta & Joshi, 1993, Datta, 1998).

1.2.2 Doruvu technology in coastal Andhra Pradesh:

Due to lack of availability of canal water, poor recharging rate and occurrence of clayey soils in deeper layers are the major constraints for installation of tubewell. The source of irrigation are mainly from rain water and use of shallow depth of good quality ground water. Though the coastal area received high rainfall but with very high permeability of coastal sands, almost all the rainwater percolates in to the soil. The infiltrated rainwater having lesser density floats over the subsurface saline water itself is underlain by impervious soil layer. To tap and use the shallow ground water farmers forced to draw shallow ground water that collects in dug-out conical pits locally called “Doruvus” in Andhra Pradesh. Due to wastage of 20 percent productive land, unproductive evaporation and high maintenance costs, the ACRIP-Saline Water, Bapatla centre improved the traditional “Doruvus” into improved subsurface water harvesting system (SSWHHS). The immediate impact of it:

- change the cropping sequence from rainfed ground nuts to paddy;
- fallow land due to lack of irrigation reduces;
- cropping intensity increases due to sufficient quantity of good quality water;
- it can irrigate 3 ha of area during rabi;
- it can irrigate 4-5 ha by using sprinklers or drip method irrigation system for plantation crops.

http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20datta.html (3 of 7)26-4-2010 12:12:08
The cost of installation of SSWHS system at 1997-98 prices is about 48,000, which can irrigate about 3-4 ha of land. Consolidation of land holdings is essential to take the full advantage of above-mentioned technology. Individual farmers can install but due to poor resource base and poor economic condition of the coastal farmers it needs government intervention.

### 1.2.3 Management practices for saline water use in Uttar Pradesh:
The AICRIP-Agra center adopted Karanpur village in Uttar Pradesh under ORP programme since 1993-94. Recommended doses of gypsum (1.25 t/ha) along with 2 t/ha FYM were applied where alkali waters were used for irrigation. Conjunctive use of canal and saline waters, used gypsum, conservation of rain water and use of sprinkler and drip method of irrigation were suggested as the management strategies for saline water for irrigation. The effects of the above-mentioned strategies are:

- fallow lands during kharif season is drastically reduced;
- average yield both in kharif and rabi season increases;
- crop stability both the seasons increases;
- requirement of man days per ha increases;
- annual income of the farm families increases.

Economic studies for using saline drainage water for irrigation shows that if the share of good quality irrigation water is limited, it is possible to produce the wheat by using saline drainage water and the yield will be higher than the break even level of output (Datta et.al, 2000).

To promote the adoption of the technology, the effective supply price of the technology to the farmer will be reduced, which will increase the quantity demand (along with demand curve) as driven by private net returns. Such a demand shift increases the technology prices, *ceteris paribus*, and thus stimulates competition to provide new technologies. Subsidy is needed for encouraging the comparatively dis-advantages farmers, subsidy is an essential component to make their production frontier stronger (Datta, 1998).

Policy intervention in the form of availability of canal water during the time of sowing is an essential component in the saline environment. The irrigation authority should take care, that canal water must be available in the saline ground water zone at least during sowing season, in time. If timely canal water is available it will encourage the farmers to bring more and more area for crop production and will use their saline ground water either through conjunctive use (if canal water is provide by the agency one or two) or subsequent irrigation afterwards as per the crop’s requirement.

### 1.2.4 Technology for alkali soil:
Several management options have been advocated by the CSSRI for reclamation of alkali soils, such as (i) reclamation for crop production with rice based cropping system, (ii) afforestation activity singly and/or in conjunction with appropriate crops in between, and (iii) cultivation of forage and grasses without application of any soil amendment, etc. For the option of reclamation for crop production again management strategies could be adopted such as amelioration through soil amendment and appropriate cropping practices and in poor resource endowment situations, through biological amelioration-growing salt resistance varieties of paddy and wheat.

#### 1.2.4.1 Chemical amendment technology in Haryana, Punjab & Uttar Pradesh:
Over the past few years, chemical amelioration of alkali soils in Punjab, Haryana and Uttar Pradesh has been fairly standardised. It involves land grading and bunding, assured irrigation, soil test based application of an amendment (mainly gypsum). Different technological options for reclamation of alkali soils demand different amount of capital investment during the initial stages in the form of land leveling, land shaping, application of water, installation of tubewells, applications of gypsum. The success of the
Economic studies of chemical amendment technology (with subsidy) for reclamation of salt affected alkali soils were highlighted by several scholars. Operational Research Project at Kapurthala in the Punjab showed that the benefit cost (B•C) ratio was as high as 2.25 (Khalon and Singh 1980). In different set of situations in Punjab the benefit•cost ratio varied from 1.15 to 1.20 (Bajwa et al 1983). The benefit•cost ratio in different situations under farmers' resource constraints in Haryana ranged from 1.34 to 1.42 (Joshi,1985). The pay•back period was about 2 and 3 years in Haryana and Punjab. Few studies in Uttar Pradesh showed that the performance of technology is encouraging and paying (Singh and Bajaj 1988).The benefit cost•ratio was about 1.21 in Rai Barailly under a government sponsored program in Uttar Pradesh (Government of U.P., 1989). Most of the studies under ORP adopted farmers and those in periphery and also at several distantly located situations showed that there exists a wide gap between the level of package of practices recommended by the CSSRI and its actual adoption level by the farmers. If the yield gap between recommended and farmers' level of technology could be narrowed, the alkali soils after reclamation have great potential in increasing the much-needed production of rice and wheat in the country. It is, therefore, necessary that potential of the land reclamation technology must be exploited to bridge the untapped yield reservoir. The gap can be minimize if proper network for gypsum base infrastructure can be evolved and it may be link with easy rural credit facilities at the village level.

1.2.4.2 Adoption of biological base technology in Uttar Pradesh:

The scope of alternative technological option like growing salt resistant paddy-wheat varieties. It has been observed, from the demonstration plots in the farmers fields at Mandanpur (in Aligarh) during 1991-92 under adoptive research trials of CSSRI, that without putting gypsum, the productivity of CSR 10 and KRL 1-4 in the marginally affected land (A-class) is about 34 qt/ha for paddy and 8.23 qt/ha for wheat. In moderately (B-class land) affected land, it was 28 and 7.71 qt/ha and for severely (C-class) affected land it was 20 and 5 qt/ha respectively. Financial analysis shows that those salt resistant paddy•wheat varieties fetched higher B•C ratio (5.56) in the marginally affected. In the moderately affected area (B-class) the internal rate of returns is about 68 percent and for severely affected it is about 24 percent, which are much higher than the opportunity cost of capital. It indicates, that even if the amount of subsidy which is given at present on gypsum ( Rs 9900/ha on an average level) can be withdrawn in the context of our new economic policy, the biological amelioration technology, i.e., salt resistance paddy-wheat varieties (CSR 10 & KRL 1-4) will be financially and economically feasible for producing the food grain in soils with different level of degradation (Datta et. al.,1996). In order to induce the farmers to adopt the reclamation technology at a fast rate, it may be suggested to use 25 percent gypsum (instead of 50 percent on GR as a recommended dose) along with salt resistant paddy (CSR 10) and wheat (KRL1-4) varieties. It will not only reduce the investment cost but also help to increase the productivity of salt affected soils. However to judge the technical viability of the above alternative, it calls for further research. If it is technically feasible, then may be salt resistant varieties along with 25 percent gypsum amendment is the appropriate low cost technology for resource constraint farmers located in Uttar Pradesh. It has been observed that the adoption of chemical amendment technology for reclamation is more where productivity in normal soils are high i.e. resource rich environment. Whereas dissemination of gypsum base technology has been slow in the resource poor areas (Datta & Joshi 1992).

2 Constraints & policy needs

In the institutional aspects, the poor performance of irrigation arises mainly due to larger systems, lack of reliable and responsive management, no management in terms of deliberate water allocation in response to actual circumstance The inherent lacuna of the institutional set-up in irrigation systems is promoting irregularity, uncertainty, favoritism, exploitation and corruption. To overcome some of the problems, during seventies and eighties major emphasis was shifted towards improvement of irrigation performance through on-farm development (OFD), participation in the form of involving water users and strengthening of irrigation agencies. But there was no effort to harness the synergetic benefits of those options, with the result that no progress was achieved in testing these strategies together. From 90's onward rethinking is going on to transfer of responsibility and authority for irrigation management from government to non-governmental authority. Keeping in mind, such transfer will help the water users to
maintain transparency, accountability and supporting incentives to the users by managing, operating and maintaining of irrigation system. In the approach paper of the Ninth Five Year plan (1997-2001), it is proposed to improve the efficiency of end-use of water through adoption of water-efficient devices and promote conjunctive use of surface and ground water. The entire attempt, which was mentioned, was present and initiative was taken for a long time, but all of a sudden calls for an organised solution by means of public intervention. Those solutions are not thought to require testing and modification for sustainability in long term. And attempt is always in terms of diverting fund from one specific scheme to another alternative options. Where the surface layers are not too saline; dry drainage where the management system allowed, indeed encouraged, salt to be leached from intensively cultivated land and to accumulate on the surface of abandoned fallow land; and further development of salt tolerant varieties. However as a preventive measure for short run, those solutions may be effective but for long term, subsurface drainage (SSD) has been proved to be the only option to reclaim the waterlogged saline lands, where salts are accumulated both in soil and ground water.

The main draw back in the system that it assumes free market mechanism will work implicitly i.e., well-capitalised and market-oriented farmers will take care the operation and maintenance. But in reality it is difficult because the inherent drawback of unsatisfactory performance of irrigation system is due to non-fulfillment of the target, incompatible rational action with collective rationality and finally quantity-constrained behaviour compelled the individual to adjust his or her own private decisions. It is not easy to see a system of subdividing the benefits into purchasable units that can be competitively sold separately to different individuals. In other words, property rights, the basis of all markets cannot be easily be established at regional scale. Even if the market fully reflected the values for individual goods and services, the market would still allocate less than a socially optimum amount because farms are unable to fully appropriate the gains from R&D. Without internalisation of environmental externality and holistic approach, only shifting the power will not improve the system.

3 References
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PADDY RICE CULTIVATION IN IRRIGATED WATER MANAGED SALINE SODIC LANDS UNDER RECLAMATION, EGYPT

A. A. Rashed, E. Khalifa, and H. S. Fahmy

ABSTRACT
Several mega-projects are undertaken by the Government of Egypt to divert considerable amounts of drainage water to newly reclaimed areas after blending with the Nile water. One of those projects is El-Salaam Canal, which will put 620,000 feddans (650,000 acres) of new lands in the northeastern Nile Delta and northern Sinai Peninsula, under irrigation. Establishment of guidelines for drainage water reuse in agriculture and land reclamation to avoid risk on the soil-plant system, and human health is required. Accordingly, three pilot areas of approximately 1200 Feddan were selected in the El-Salam Canal command area, west of Suez Canal: which are El Rowad, Tarek Ibn Ziad, and al Eman villages to establish these guidelines.

Soils of the study areas are saline sodic soils, which need special reclamation strategies. Average soil salinity and sodicity values are 20 dS/m and 25 respectively. Infiltration rate is small and water table depth is less than 0.75 m below ground. These conditions are not ideally suitable for paddy rice cultivation or at least may decrease crop yield by 75%. But a well controlled water management system including daily surface irrigation followed by rapped field drainage could lead to high paddy rice crop yield, compared with the average rice yield in Egypt which is the highest in the world. Land reclamation experience suggested two years of salt leaching and soil amendments are required to manage crop cultivation and get positive income. The objective of this study is to describe the monitoring program, the water management and the cultivation steps which are set up to derive the guidelines that should lead to high production of paddy rice yield in such saline sodic soils.

1 Background
El-Salaam Canal Project aims at mixing drainage water with fresh water from Damietta Branch of Nile River Delta. Equal volumes of fresh and drainage water will be mixed to irrigate an area of 620,000 acre of newly reclaimed lands (NAWQAM, 1999). Salinity of El-Salam Canal irrigation water is in a range of 0.8 to 2 dS m⁻¹. Irrigation water sodicity expressed in sodium adsorption ratio (SAR) is ranged between 8 and 11.

1.1 Study Area
The study area is El-Rowad reclamation village, which lies within the south El-Hussania plain of El-Salam Canal project area. The geodesic coordinates are 31 02 49 N Latitude and 32 00 06 E Longitude. Total reclamation area is 2000 acres. Annual rainfall approximately 33 mm. Maximum temperatures during July-August are 41-to 46 °C and minimum temperature during December–January is 8 to 19 °C. The land is slightly above the level of Lake Manzala (M.S.L.). Field survey was conducted in years 1999 and 2000 to establish a baseline data for the study area as a part of the National Availability and Water Quality Management project, (NAWQAM). Twenty monitoring and sampling locations were selected to make soil, water and crop surveys.

Soils are described as saline sodic soils since salinity of the top 1.0 m is more than 4 dS.m⁻¹ and the SAR is greater than 15-mil eq. L⁻¹. There is a clay cap, which is sometimes near to the ground surface. The soil texture in the area is loamy clay-to-clay extending to more than 2.0m. The calcium carbonate content is low and the high sodicity leads to wetness of the soil profiled at some locations. (Khalifa and Rashed, 2001). A Summery of the soil chemical analysis data is presented in Table 1.

Table 1  Summary of the soil samples chemical analysis El-Rowad area in 1999.

<table>
<thead>
<tr>
<th>pH</th>
<th>EC (dS/m)</th>
<th>Cations (mg/liter)</th>
<th>Anions (mg/liter)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ca</td>
<td>Mg</td>
</tr>
<tr>
<td>Min</td>
<td>7.10</td>
<td>3.64</td>
<td>9.1</td>
</tr>
<tr>
<td>Avg</td>
<td>7.47</td>
<td>25.9</td>
<td>26.8</td>
</tr>
<tr>
<td>Max</td>
<td>7.80</td>
<td>71.04</td>
<td>89.7</td>
</tr>
<tr>
<td>SD</td>
<td>0.16</td>
<td>11.50</td>
<td>17.4</td>
</tr>
</tbody>
</table>

(Source: Khalifa, and Rashed, 2001)
Salinity and chemical analysis of irrigation, drainage and ground waters in winter 1999 and summer 2000 are presented in Tables 2, 3 and 4. The groundwater table depth is shallow at some locations (varies from 0.0-1.05m) with an average of 0.47 m below ground surface.

Land use of El-Rowad reclamation area during 1999 shows nearly fallow lands in winter season except few spots of barley and wheat while paddy rice cultivation was abundant in the summer. It is used during reclamation and salt leaching stages. The average rice crop yield during 1999 was 2.9 ton / acre, (Khalifa, and Rashed, 2001). The yield is not so much less than the average rice crop yield in the old lands of Nile Delta.

### Table 2 Chemical parameters for El-Rowad pilot area irrigation water on 1999.

<table>
<thead>
<tr>
<th>Season</th>
<th>pH</th>
<th>EC</th>
<th>TDS</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>HCO₃</th>
<th>SO₄</th>
<th>Cl</th>
<th>SAR</th>
<th>SAR_adj</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>7.2</td>
<td>1.8</td>
<td>1455.7</td>
<td>5.7</td>
<td>5.6</td>
<td>10.0</td>
<td>0.3</td>
<td>5.4</td>
<td>10.3</td>
<td>6.9</td>
<td>4.2</td>
<td>10.8</td>
</tr>
<tr>
<td>Summer</td>
<td>7.5</td>
<td>1.5</td>
<td>940.8</td>
<td>3.0</td>
<td>2.4</td>
<td>8.4</td>
<td>0.3</td>
<td>4.9</td>
<td>4.2</td>
<td>5.1</td>
<td>5.1</td>
<td>13.0</td>
</tr>
</tbody>
</table>

(Source: Khalifa, and Rashed, 2001)

### Table 3 Chemical parameters of El-Rowad pilot area drainage water on 1999.

<table>
<thead>
<tr>
<th>Season</th>
<th>pH</th>
<th>EC</th>
<th>TDS</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>HCO₃</th>
<th>SO₄</th>
<th>Cl</th>
<th>SAR</th>
<th>SAR_adj</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>7.3</td>
<td>10.3</td>
<td>6431.6</td>
<td>10.4</td>
<td>22.4</td>
<td>71.5</td>
<td>1.0</td>
<td>5.0</td>
<td>32.9</td>
<td>67.3</td>
<td>17.7</td>
<td>47.6</td>
</tr>
<tr>
<td>Summer</td>
<td>7.3</td>
<td>5.9</td>
<td>3776.0</td>
<td>11.4</td>
<td>7.5</td>
<td>35.0</td>
<td>0.7</td>
<td>5.0</td>
<td>13.8</td>
<td>35.8</td>
<td>11.4</td>
<td>32.2</td>
</tr>
</tbody>
</table>

(Source: Khalifa, and Rashed, 2001)

### Table 4 Chemical parameters of El-Rowad pilot area groundwater on 1999.

<table>
<thead>
<tr>
<th>pH</th>
<th>EC</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K</th>
<th>HCO₃</th>
<th>SO₄</th>
<th>Cl</th>
<th>SAR</th>
<th>SAR_adj</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min.</td>
<td>6.4</td>
<td>30.7</td>
<td>28.9</td>
<td>67.4</td>
<td>115.5</td>
<td>0.2</td>
<td>4.0</td>
<td>46.6</td>
<td>77.5</td>
<td>6.8</td>
</tr>
<tr>
<td>Avg.</td>
<td>6.8</td>
<td>72.8</td>
<td>90.9</td>
<td>245.1</td>
<td>872.1</td>
<td>0.7</td>
<td>6.8</td>
<td>387.7</td>
<td>813.9</td>
<td>68.8</td>
</tr>
<tr>
<td>Max.</td>
<td>7.3</td>
<td>109.4</td>
<td>148.0</td>
<td>488.7</td>
<td>1387.5</td>
<td>3.8</td>
<td>8.6</td>
<td>707.7</td>
<td>1462.5</td>
<td>95.3</td>
</tr>
<tr>
<td>S D</td>
<td>0.2</td>
<td>26.9</td>
<td>31.4</td>
<td>129.4</td>
<td>370.4</td>
<td>0.8</td>
<td>1.37</td>
<td>209.4</td>
<td>372.1</td>
<td>22.1</td>
</tr>
</tbody>
</table>

(Source: Khalifa, and Rashed, 2001)

### 1.2 Paddy Rice Culture

#### 1.2.1 Climate

Paddy rice (*Oryza sativa*) needs optimum climate conditions to grow during its different growing stages. However, different varieties of rice can grow along a wide climatic range from tropical regions, subtropical to slightly moderate tempered regions (Yun, 2001). Temperature, solar radiation and precipitation influence rice yield by directly influencing the physiological processes involved in grain production.

#### 1.2.2 Soil

Rice is growing in a soil that has a variety of water content ranging from waterlogged, poorly drained to well drained. The term, rice soil or paddy soil are not precise enough to be used to indicate the type of soil group, (USDA, 1975). Most types of soil can be used to grow rice if water conditions are favorable. For rice cultivation soils of fine to medium texture are most commonly used. Clays of floodplains and deltas and sandy textured soil are suitable for rice cultivation.

### 1.3 Effects of Salinity and Sodicity on Soils

The suitability of soils for rice cropping depends heavily on the readiness with which they conduct water and air (permeability) and on aggregate properties, which control the friability of the seedbed (tilth). Poor permeability and tilth are often major problems in irrigated lands (FAO, 1992). Contrary, sodic soils may have greatly reduced permeability and poor tilth. Rhoades, 1982 made a relation between the SAR of the topsoil and the salinity of the irrigation water that infiltrate this topsoil. He found that there is a threshold values for SAR of topsoil and salinity of irrigation water above, which the irrigated lands may in unlikely permeability hazard (Rhoads,1982). Comparing his findings with El Salam Canal situation (EC irrigation water = 1.5 dS m⁻¹ and SAR of top soil, the area is generally may suffer from permeability hazards.

#### 1.3.1 Effects of salinity and sodicity on Rice as a plant

http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20rashed%20khalifa%20and%20fahmy.html (2 of 8)26-4-2010 12:12:10
Excess salinity with the plant root zone has a general deleterious effect on plant growth since it causes reduction in transpiration and growth rates. Each crop has a tolerance limit in growth against salinity. Ayers and Westcot, 1976 summarized soil salinity tolerance levels for different crops including paddy rice. The salt tolerances of various crops are expressed in terms of relative yield ($Y_r$), (threshold salinity value ($a$), and percentage decrement value per unit increase in excess of the threshold ($b$), where soil salinity is expressed in terms of $EC_e$ in dS/m$^{-1}$ as in eqn (1) (Maas and Hoffman [8]). Table 4 shows Salt tolerance and relative crop yield for paddy rice.

\[ Y_r = 100 - b \left( EC_e - a \right) \]  

### Table 5: Some Referenced Salt tolerance and relative crop yield for paddy rice.

<table>
<thead>
<tr>
<th>Soil Salinity $EC_e$ dS/m</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Crop Yield %</td>
<td>100</td>
<td>88</td>
<td>78</td>
<td>45</td>
<td>35</td>
<td>25</td>
<td>16</td>
<td>5</td>
</tr>
<tr>
<td>(Maas and Hoffman [8])</td>
<td>100</td>
<td>90</td>
<td>75</td>
<td>45</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>10</td>
</tr>
<tr>
<td>Relative Crop Yield %</td>
<td>100</td>
<td>90</td>
<td>75</td>
<td>45</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>10</td>
</tr>
<tr>
<td>(Ayers and Westcot [7])</td>
<td>100</td>
<td>90</td>
<td>75</td>
<td>45</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>10</td>
</tr>
</tbody>
</table>

Mass, 1986 reported salt tolerance values for rice at emergence and during growth to maturity classifying rice as a sensitive crop. The $EC_e$ values of 3.6 dS m$^{-1}$ is the tolerant soil salinity value for 100 % relative crop yield while it is 18 dS m$^{-1}$ in emergent stage for 50 % relative crop yield. The soil salinity values were measured at the submerged soil in paddy rice fields which is less saline the same soil if it is dry or even partially saturated.

As for sodicity, sodic soil conditions may include calcium as well as other nutrients, deficiencies because the associated high pH and bicarbonate conditions repress the solubility of many soil minerals, hence limiting nutrient concentration solutions and, thus, availability the plant. Tolerance of paddy rice to Exchangeable-Sodium Percentage (ESP) may reach 20-40 % describing rice as a moderate sensitive crop against sodicity (James et al.,1982).

Rice does not tolerate excess salinity: rice yield is halved at 6–7 dS/m salinity in saturated soil paste extract (Mass and Hoffman [8]). However, a satisfactory yield of rice can be achieved even with 20–25 dS/m in topsoil saturated extract, if submergence is maintained throughout the crop growing season (van Alphen, 1975).

## 1.4 Rice Cultivation at El Salam Canal Reclamation Area

Rice is the main summer crop in El Salam Canal project area. It is the most favorable crop all the Egyptian North Delta due to several reasons. First, rice is the best summer serial crop in the local market. Second, paddy rice is efficient in salt build up protection in the arid water logged soils located at the relatively low lands in the Nile Delta and the surrounding areas. Third, rice is easier for farmers in agricultural activities such as land preparation, adding fertilizers, best management practices comparing with the other summer crops such as cotton and corn.

### 1.4.1 Land preparation for rice cultivation

The following steps were practiced in order to prepare farms for rice cultivation as well as salts leaching:

- Land leveling is practiced at the very beginning using either non-leaser tractors or leaser-equipped tractors. The leveling time was 5 to 8 tractor hours per acre.

- Each farm was divided laterally into 12 to 14 sections each section has dimensions of 100 * 15 to 100 * 12 meters. These sections are separated by field canals or field open drains which have about 0.9-m depth. The field open drains helps in the drainage of the poor permeable sodic soils.

- Gypsum is added as amendment tool for sodicity problems. Small gypsum dozing rate is practiced (not more than 1 ton/acre) since gypsum is expensive for poor farmers. The required dozing rate is about 2 to 3 tons/acre for 3 years period according to the SAR and ESP of the soil. Deep bloughing is practiced after gypsum adding to introduce it at the deeper soil layers where the sodicity is dominant and forming a hard pan at the plants root zone.

- Alternate or cycling salt leaching is practiced two months prior to rice cultivation. Flooding farms with 10 to 20 cm of water and leave it on farm for 2 to 5 days while the drainage outlets are blocked. Draining the field water rapidly to the field open drains and consequently to the collector drain and leaving the drainage system opened for 2 to 3 weeks. Deep wide cracks are observed at the drained fields and those cracks are developed with time passed after drainage. Repeating the leaching cycle on the coming month and leaving the field for complete drying in order to prepare for rice planting.
Rice water seeding is started on mid April, one month earlier than the transplanted rice in the Nile Delta. Precise water control must be achieved and more seeds are required than the transplanting method.

Alternate daily irrigation and drainage for rice field is practiced. Water is irrigated on the early mornings for 2 to 3 hours filed filling time. Field water is left 10 cm above ground for the whole daytime. After sunset, filed drains are opened to get rid of the field water and drainage is continued until the next morning. A new irrigation cycle started on the net day. The cyclic paddy rice irrigation continued for the 110 days of rice cultivation period.

On mid August, the irrigation-drainage cycling is stopped leaving farms to dry as a preparation for mechanical or manual rice harvesting.

2 Materials and methods
Twenty farms of 100 acres total area were selected of the total 2000 acres in El Rowad village to monitor rice cultivation practices. Irrigation water was measured at each plot irrigation inlet using both current meters and volume and time methods. The measurements were taken daily at noontime. Current meters were used at the irrigation inlet pipes while bucket and stopwatch was used directly with the lifting irrigation pumps. Each measurement was repeated 3 times and the average was taken in order to minimize human error. For each plot, collective irrigation quantities were calculated from multiplying the average discharge value times the irrigation period. A field survey was done at each farm in order to measure the net cultivated area which is the total farm area subtracted from the area of filed irrigation and drains canals. Water consumption (m³/acre) was obtained by dividing total field irrigation quantities by farm net area.

The physical and chemical measurements were made for soil and irrigation water as well. Soil sampling was done just before rice seeding and just after its harvesting. Soil samples were collected from the selected 20 locations at four depths; 0-25, 25-50, 50-75, and, 70-100 cm.

Rice crop productivity measurements are used to determine the level of soil reclamation and the economics of crop production. Crop productivity parameters measured in the field include cropping pattern or the distribution of crops grown in the pilot areas is assessed during each cropping season. Yield samples are taken in the field at harvest time. Three crop samples were selected randomly at each monitoring site. An area of 3.0 * 3.5 m was harvested and fresh and oven dried weighted and then manually rice crop obtained. This area forms 1/400 of acre. Two kg of the harvested rice samples was analyzed for moisture content estimation. The fresh samples were weighted directly after harvesting, then dried at 105 C electrical oven for 24 hours to obtain the dry weight ant the moisture content.

3 Results and discussions

3.1 Water management at rice fields
Paddy rice water consumptions at 20 farms at El Rowad reclamation area are shown in Table 5. In addition, farm irrigation water quantities are presented. The irrigation was done daily for about 2 hours per acre for the 110 days of rice growing stages. The mean rice water consumption at El Rowad area is 5215 m³/acre that is almost equal to the average rice water consumption at Nile Delta matured agricultural lands (5000 m³/acre). This is attributed to using a shorter age rice variety at El Rowad area that lasts 120 days comparing with the 150 days rice variety at the Delta lands. In addition the new lands has only surface on farm drainage while the Delta lands are provided with subsurface drainage in addition to some field surface drains. Daily irrigation and drainage cycles with efficient field water management consume the same irrigation quantities in rice fields of old lands in Nile Delta. Efficient field water management is done by surrounding the field with earth ridges 10 cm higher than pounding rice water that stops surface runoff. Also well controlled drainage outlets help in water saving by preventing surface drainage. The short period between field draining and re-irrigating keeps soil in saturation phase and prevent water evaporation from field surface.

Table 5. Some Statistics parameters for farm irrigation water quantity of El-Rowad reclamation area.

<table>
<thead>
<tr>
<th>N</th>
<th>Minimum</th>
<th>Average</th>
<th>Maximum</th>
<th>Standard Deviation</th>
<th>SD/Avg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>4231</td>
<td>5215</td>
<td>6583</td>
<td>719</td>
<td>0.138</td>
</tr>
</tbody>
</table>

3.2 Effects of Irrigation Water on soil and plant
Referring to Table 1, irrigation water salinity is 1.8 and 1.5 during winter and summer seasons respectively which classified as a permissibly irrigation water but with considered leaching fraction. Several imperial equations were used to estimate leaching fraction of planted root zone in different soil types depending mainly on irrigation salinity values. FAO, (1992) mentioned examples such as;

\[ LF = \frac{EC_i}{(2.2 \times EC_e)} \]
Where LF is irrigation leaching fraction of plant root zone, \( EC_i \) and \( EC_e \) are salinity of irrigation water and average root zone soil salinity in dS/m respectively.

Applying this equation for farm 347 in El Rowad area as an example gives that required LF for 1999, 2000, and 2001 is 4, 7, and 11% respectively while the referenced values for leaching root zone of loamy clay soil is 30% as reported by Hoffman et al. (1983). Accordingly these equations are not suitable for estimating LF of such severe saline soils. These equations were adopted for leaching accumulated salts within plant root zone resulted from evaporation that occurred after irrigation activities (Hoffman et al. 1983). Meanwhile, our case is leaching huge mount of salts accumulated at the root zone and 1 m layer beneath affected with severely shallow saline groundwater.

Water sodicity may described as low sodic irrigation water during winter season (adjustable sodium absorption Ratio, (SAR_{adj} = 10) while it has medium sodic during summer season (SAR_{adj} = 13). The summer irrigation water needs both soil amendments such as gypsum and to increase salts leaching fraction.

### 3.3 Soil salinity and Sodicity Improvement

Continuous paddy rice cultivation as a summer reclamation practices in addition to the alternate winter salt leaching was practiced since 1999. Figure 1 shows arithmetic average soil salinity of the selected monitoring locations of El Rowad area in 1999, 2000 and 2001. The results are by layers (25 cm apart) as well as an average of the top 50 cm and the top 100 cm of soil.

*Figure 1* Average rice crop yield for El Rowad reclamation area and the corresponding soil salinity of different layers (referenced threshold salinity values and the % rice yield reduction is mentioned on top).

It is clear that there is a big improvement in the soil salinity during the past 3 years. In 2000, after the second rice season, the salinity of all layers significantly decreased comparing with the 1999 values. The salinity decrease in 0-25 and 25-50 cm layers is 93% and 45% in 2000 comparing with 1999 respectively. In 2001, after the third rice season, the salinity decreasing continued in all layers comparing with the 1999 values. The salinity decrease in 0-25 and 25-50 cm layers by 222% and 236% in 2000 comparing with 1999 respectively and by 63% and 136% in 2001 comparing with 2000 respectively.

Rice tolerates exchangeable sodium because it grows well in standing water, but the infiltration rate needs to be sufficient to leach out toxic substances (USDA, 1975). In addition, as rice has a shallow root system, it can grow well if sodicity is reduced in only the top few centimeters of soil. Excessive uptake of elemental sodium can be toxic at high ESP.

### 3.4 Rice crop yield
Results of crop yield of 11 farms of El Rowad reclamation area is shown in table 6 during three summer seasons, 1999 -2001. The corresponding soil salinity ($EC_e$) that was measured just after rice harvesting values is also presented against each crop yield. Results show that in 1999, rice crop yield is almost zero or rice was failed to be cultivated or to complete its growing stages. When soil salinity excesses 20 dS/m, rice seeding faced high salinity stresses during the germination stage and 2 farms of 11 manage to get rice grain at the season end.

Observations showed that about 70 % of rice seeds was died after 10 to 15 days from planting and first germination. Some farmers attempted to re-seed the died spots 3 weeks later but useless. Other farmers transplant rice at the failed spots from the dense well germinated adjacent spots and about 50 % manage to grow up. The whole rice field including the dead rice spots was continued for irrigation and drainage daily as a tool for salts leaching.

On the second season (2000), soil salinity levels decreased significantly as shown in Table 6 due to continues leaching during winter season. Eight farms of eleven manage to cultivate paddy rice with a crop yield ranged from 1.5 to 3 tons/acre with a soil salinity ranging from 7 to 18 dS/m in the top 25 cm soil layer. The other 3 farms failed to complete the growing season and rice died during germination stage and even after a rice-transplanting trail. It is obvious since soil salinity of the topsoil is still above 20 dS/m in those farms. On the third growing season (2001) all the 11 farms managed to cultivate paddy rice. The rice crop yield increased significantly comparing with the 2nd season of 2000 by a range of 40% to 270%. Some farms reach the national rice production (3.8 tons/acre) while the others have yield values of 75% of the national rice yield records. Rice yield at El Roawd reclamation area and the corresponding soil salinity measures was not comparable with the referenced threshold soil salinity limits for paddy rice.

<table>
<thead>
<tr>
<th>Plot No.</th>
<th>$EC_e$ (0-25 cm)</th>
<th>$EC_e$ (0-50 cm)</th>
<th>$EC_e$ (0-50 cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>319</td>
<td>14 (2.5)</td>
<td>6 (3.4)</td>
<td>14 (2.5)</td>
</tr>
<tr>
<td>328</td>
<td>23 (0.0)</td>
<td>7 (3.0)</td>
<td>6 (3.8)</td>
</tr>
<tr>
<td>330</td>
<td>30 (0.5)</td>
<td>13 (1.5)</td>
<td>13 (2.7)</td>
</tr>
<tr>
<td>332</td>
<td>20 (1.5)</td>
<td>14 (2.5)</td>
<td>10 (3.6)</td>
</tr>
<tr>
<td>336</td>
<td>26 (0.0)</td>
<td>14 (0.0)</td>
<td>7 (2.7)</td>
</tr>
<tr>
<td>347</td>
<td>20 (0.0)</td>
<td>18 (2.8)</td>
<td>6 (3.8)</td>
</tr>
<tr>
<td>349</td>
<td>15 (0.0)</td>
<td>12 (2.0)</td>
<td>10 (3.8)</td>
</tr>
<tr>
<td>351</td>
<td>18 (0.0)</td>
<td>12 (3.0)</td>
<td>6 (4.0)</td>
</tr>
<tr>
<td>355</td>
<td>20 (0.0)</td>
<td>9 (4.6)</td>
<td>8 (3.6)</td>
</tr>
<tr>
<td>370</td>
<td>17 (0.0)</td>
<td>11 (2.0)</td>
<td>9 (2.8)</td>
</tr>
<tr>
<td>392</td>
<td>89 (0.0)</td>
<td>20 (0.0)</td>
<td>21 (1.5)</td>
</tr>
</tbody>
</table>

A 100% relative rice yield (3.8 ton/acre) is obtained at salinity values of 6 to 9 dS/m or three times the referenced values. Also a 55 % reduction in rice yield (1.9 ton/acre) was obtained at salinity levels of a 9-17 dS/m comparing with the reference tolerance value of 7dS/m. Average rice crop yield for El Rowad reclamation area and the corresponding soil salinity of different layers are shown at Figure 1. Reduction in rice yield comparing with the national rice production is 92%, 54%, and, 12% during 1999, 2000 and 2001 respectively. This reduction is accepted since the soil salinity measures are much more the threshold values of paddy rice. Comparisons between relative rice crop yield at El Rowad area and some referenced data against soil salinity is shown in figure 2. Logarithmic trend of the percentage relative rice yield and the soil salinity shows that 60 to 70 % relative yield was achieved at 15 to 20 dS/m soil salinity comparing with 6 dS/m for both references (Ayres, and Westcot, 1976) and (Maas and Hoffmann, 1976). The relation between rice crop yield and soil salinity at El Rowad Area is:
Figure 2  Comparisons between Relative Rice Crop Yield at El Rowad Area and Some Referenced Data Against Soil Salinity.

Relative Rice Yield = -38.99 Ln (EC_e) + 167.06 \hspace{1cm} (n=20, R^2 = 0.61) \hspace{1cm} (3)

The high rice yield at high salinity and sodicity levels may be attributed to many reasons. The main reason is the daily irrigation and drainage practicing for the growing period of the plant. There has been little good systematic research on the thermal properties of lowland fields and their effect on rice. The available information indicates that throughout the crop season in temperate regions of India, the ponded water in a rice field maintains soil temperature at 7.5 cm depth at about 5 ° C higher than the continuously flowing water and significantly increases the grain yield of rice (Kanwar et al, 1978).

Field preparation or puddling process is the second factor of planting rice in saline sodic soil. Puddling influences pore size distribution and thus water retention and transmission. Puddling also explains how the water consumption of paddy rice of El Rowad area is very close to the average rice water consumption of the Nile Delta old lands. In a silty clay loam soil (El Rowad area), puddling decreased transmission pores by 50%, increased storage pores by only 23% and decreased residual pores by 3% over non-puddled soil. Compaction resulted in a drastic decrease in transmission pores (95%), an increase in storage pores (48%), and a further decrease in residual pores (8%) (Acharya and Sood, 1992). This may help in decreasing water consumption by reducing vertical drainage but it has negative impact on leaching deeper soil layers below rice root zone.

4 Conclusions

Paddy rice is a suitable crop for land reclamation is saline sodic soil that has salinity values less than 20 dS/m. the crop yield is comparable with the yield of the matured lands of Nile Delta. Rice planting is not economic during reclamation stages when thee average soil salinity of root zone exceeds 20 dS/m. Alternate salt leaching is preferable up to reaching the 20 dS/m soil salinity. The obtained relation between relative rice crop yield and soil salinity of El Rowad reclamation area may be used to at similar saline sodic soil types with similar agricultural practices.

Daily irrigation-drainage cycles with controlled field water management helps to protect rice from severe saline soil especially during early growing stages. Good field preparation such as puddling, leveling and smoothing as well as maintaining farm ridges is essential for rice cultivation in saline under reclamation soils. Condensed field drainage with 10 to 15 m spacing is essential for rapid leaching of ponded water in paddy rice fields. The referenced threshold rice crop yield values with soil salinity are not applicable of the cases of cultivation in high saline under reclamation soils.

5 REFERENCES

PADDY RICE CULTIVATION IN IRRIGATED WATER MANAGED SALINE SODIC LANDS UNDER RECLAMATION, EGYPT


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ABSTRACT
On the west side of the San Joaquin Valley, California, groundwater tables have risen after several decades of irrigation. A regional semi-permeable layer at 100 m depth (Corcoran Clay) combined with over-irrigation and leaching is the major cause of the groundwater rise. Subsurface drain systems were installed from the 60's to the 80's to remove excess water and maintain an aerated root zone. However, drainage water resulting from these subsurface systems contained trace elements like selenium, which were determined at toxic levels to fish and waterfowl. To maintain healthy levels of salt and selenium in the San Joaquin River, the natural drain out of the San Joaquin Valley, outflow of drainage water from farms was severely restricted or completely eliminated. Several on-farm management methods are being investigated to maintain agricultural production without off-farm drainage. One method is drainage water reuse through blending with irrigation water. Another method is to reuse drainage water consecutively, where drainage water from one field is used as irrigation water for another field. Progressively more salt tolerant crops need to be grown in such a system along the reuse path, and salts can eventually be harvested using solar evaporators. A method described in this paper aims to reduce the volume of drainage water during the growing season by increasing shallow groundwater use by crops before it is drained from the field.

Five years of crops were grown on two weighing lysimeters using drip irrigation. Two years of cotton were grown under high frequency drip irrigation (applications up to 10 times a day), followed by two years of safflower (early season crop) and one year of alfalfa (perennial) under low frequency drip irrigation (twice a week). One lysimeter maintained a shallow groundwater table at 1.0-m below soil surface, while the other lysimeter was freely drained at the bottom (3.0-m below soil surface). High frequency irrigation requires more irrigation water over a season than low frequency irrigation in the presence of shallow groundwater, since low frequency irrigation induces more shallow groundwater use by crops. Groundwater use for cotton was measured as 8% of total seasonal crop water use, while measurements under safflower showed that 25% of seasonal crop water use came from groundwater. Measurements under alfalfa, in its first year of establishment, showed 15% of seasonal crop water use coming from the groundwater.

To maintain a sustainable system, leaching of salts need to occur. Leaching under the proposed irrigation/drainage management system would occur in the early growing season with winter precipitation, pre-plant irrigation and the first irrigation of the growing season, when the water table can be maintained at shallower depths through restriction of the outflow of the subsurface drainage system (groundwater control).

Keywords: Shallow Groundwater Use, Controlled Drainage, Irrigation Management, Crop Selection, Soil Salinity.
On the east of the river, soils are generally light and orchards and vineyards can be found there. On the west, soils are generally heavy, and mainly row crops are grown there. Average reference evapo-transpiration rates in the valley vary between 1-2 mm/day during the winter months (Nov-Feb) and 7-8 mm/day during the summer months (Jun-Aug). On average, the rain falls during the winter months (summer precipitation is generally negligible for crop production), and average annual precipitation is approximately 300 mm. In general, more rain falls in the north of the valley than in the south, and less rain falls in the west than in the east of the valley.

From the 30's to the 70's, large irrigation systems were developed, importing water from north of Sacramento to the San Joaquin Valley, and from constructed reservoirs in the Sierra Nevada. On the west side of the San Joaquin Valley groundwater has risen after several decades of irrigation. A regional semi-permeable layer at 100 m depth (Corcoran Clay) combined with over-irrigation and leaching is the major cause of the groundwater rise. With shallow groundwater, salinity is a problem as well. Salts, naturally occurring in the soil, as well as imported into the Valley with irrigation water accumulate in the root zone and must be leached to maintain crop production levels.

Subsurface drain systems were installed from the 60's to the 80's to remove excess water and salts, and maintain an aerated root zone. However, drainage water resulting from these subsurface systems contained trace elements like selenium. High concentrations of selenium were determined at toxic levels to fish and waterfowl in drainage water collection ponds, especially the Kesterson Reservoir. To maintain ecologically healthy levels of salt and selenium in the San Joaquin River, the natural drain out of the San Joaquin Valley, outflow of drainage water from farms was severely restricted or completely eliminated, and collection ponds were closed and reclaimed.

Several on-farm management methods are being investigated to maintain agricultural production without off-farm drainage. One method is drainage water reuse through blending with irrigation water. Another method is to reuse drainage water consecutively, where drainage water from one field is used as irrigation water for another field. Progressively more salt tolerant crops need to be grown in such a system along the reuse path, and salts can eventually be harvested using solar evaporators.

Another method, discussed further in this paper, is through the use of controlled drainage. Controlled drainage usually restricts the outflow of drainage, either partial or complete, for periods of time when drainage water production is high. This will result in a higher water table in the field. The shallower groundwater can be seen as a source of water to the crop.

2 Methods and materials

2.1 Weighing lysimeters

Two weighing lysimeters were installed at the research farm of the USDA in Parlier, California. The lysimeters were each 4-m x 2-m on the surface and 3-m deep. The top 2-m of the soil profile was taken as an undisturbed soil monolith from the west side of the Valley, approximately 15 km south of the town of Mendota. The soil type was classified as an Oxalis silty clay loam soil (Harradine et al. 1956). The soil consists of approximately 30% clay, 55% silt and 15% sand. The salinity of the soil profile (ECe) was approximately 5 dS/m over the root zone.

One of the two lysimeters was free draining at the bottom (RefTank), while in the other lysimeters a water table was maintained at 0.9-m depth (GWTank). The salinity of the groundwater was stable over the five years of this study between 14 and 16 dS/m.

Over a period of 5 years, 3 different crops were grown. The first two years, cotton was grown, followed by two years of safflower, and the fifth year was an establishing year for alfalfa. Drip irrigation management was different for the cotton crop than for the following safflower and alfalfa crop. The cotton was irrigated using high frequency (up to 10 applications a day) subsurface drip irrigation, while the other crops were grown using low frequency (2 applications a week) surface drip irrigation.
A Mariotte bottle maintained the groundwater level in the GWTank at a constant level. However, several times during peak demand in the summer, the water table measurements showed a decline of the groundwater level, thus indicating that the Mariotte bottle could not keep up with groundwater use. The level in the Mariotte bottle was measured hourly, thus hourly contributions to the groundwater were measured.

The weight of the lysimeters was recorded hourly. Groundwater levels were initially measured manually, approximately once a week, while later an automated inverted PVC cup and a pressure transducer were used to automatically record the groundwater level hourly.

### 2.2 Field Research

During a four-year period, two field plots where controlled drainage was applied were studied. In one field (BV), the land user managed all farming practices, including irrigation. The other field (WL) both the drainage control structure and the irrigation scheduling were managed specifically for research.

The field called BV was located approximately 10 km west of Firebaugh, CA. The drainage system in the field was installed at 2.0-m below field level, and the tiles were installed 95 m apart. Tile drains were installed along the elevation lines, with the collector drain perpendicular to the elevation lines. The field under one drainage system was 120 ha, with the field divided in two equal sections of 60 ha (Fld01 and Fld03) for farming purposes. Soil type was a Ciervo clay (Fine, smectitic, thermic Haplocambids) (SSURGO, 2002), which exists of 50% clay, 30% silt and 20% sand. Cropping pattern over five years is shown in Table 1. Irrigation was applied during the season through furrow irrigation, but often pre-plant irrigation and the first irrigation of the season was applied using sprinkler sets. Furrows for irrigation purposes were not longer than 400 m.

### Table 1: Cropping pattern on field BV from 1996-2002

<table>
<thead>
<tr>
<th>Year</th>
<th>Fld 01</th>
<th>Fld 03</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>Cotton</td>
<td>Melons</td>
</tr>
<tr>
<td>1997</td>
<td>Cotton</td>
<td>Cotton</td>
</tr>
<tr>
<td>1998</td>
<td>Cotton</td>
<td>Cotton</td>
</tr>
<tr>
<td>1999</td>
<td>Alfalfa (new)</td>
<td>Melons</td>
</tr>
<tr>
<td>2000</td>
<td>Alfalfa (est)</td>
<td>Cotton</td>
</tr>
</tbody>
</table>

The field called WL was located approximately 5 km east of Kettleman City, CA. The soil type is classified as a Tulare Clay (Fine, montmorillonitic, calcareous, thermic Vertic Haplaquoll) (USDA-SCS, 1986), which contains approximately 60% clay, 30% silt and 10% sand. The drainage system in this field was installed at 1.3-m depth with a distance between the tile drains of 28 m. Tile drains were also installed parallel to the elevation lines, and the collector line ran perpendicular to the elevation lines. The field under a single drainage system was 110 ha, and all three years (1996, 1997 and 1998) a cotton crop was grown. The whole field was managed as a single unit. The field was divided into basins of 75 m wide and 1600 m long for irrigation purposes. Irrigation water was applied through the use of a “sideboom”; a high-volume low-head pump mounted on a track-laying tractor that pumped water directly from a main canal into one of the basins, using a flow rate of 1.0 m³/s. Irrigation was terminated once water reached 2/3rds the length of the field (1100 m), and after 24 hour, the water still remaining in the field was surface drained. The field was sampled three times between 1996 and 1998. Each time, the same 42 locations were sampled in 30 cm intervals to a depth of 120 cm.

Collector drains at the lowest point in each field were excavated, and a manhole was located in the line, thus making access to drainage water possible. At both locations, a structure was inserted that allowed for control of drainage water outflow. The level at which drainage water flow would occur could be manually adjusted by adjusting the height of the structure (Schoneman and Ayars, 2000).
3 Results AND DISCUSSION

3.1 Groundwater Use by Crop

Measurements in the lysimeters showed that groundwater use for cotton was 8% of total seasonal crop water use (Soppe and Ayars, 2000), while measurements under safflower showed that 25% of seasonal crop water use came from groundwater (Soppe and Ayars, 2003). Measurements under alfalfa, in its first year of establishment, showed 15% of seasonal crop water use coming from the groundwater.

Groundwater contribution for cotton was well below the expected potential of the crop to extract water from groundwater. The most important reason for this low contribution was irrigation management. Since high frequency irrigation was used (water application several times a day) and the available water to the plant was kept constant, most of the active root water uptake was around the drip emitters (Soppe et al, 2002).

Over the next two years, when safflower was grown, irrigation scheduling was adjusted to a water application twice a week. Not only did this increase the fluctuation in total available water in the root zone on a weekly basis, but during peak water demand in the season it also depleted stored soil water, since the total irrigation application was less than the crop water use between irrigation applications. This was a result of the capacity of the storage tanks for irrigation water, but did not result in visual stress of the crop, or apparent yield loss.

The same irrigation schedule was applied on the establishing alfalfa. However, this crop did show visual signs of water stress, and irrigation had to start early in the season, maintaining the total available water in the root zone higher than the safflower crop. This resulted in lower groundwater contribution to crop water use than when the safflower was grown.

3.2 Drain Water Volume

Figure 1 shows the drainage outflow from field WL for three growing seasons. No controlled drainage was applied in 1996, the initial year of the project, while in the subsequent two years, drainage water outflow was restricted. Note how the first irrigation of the season produces the largest volume of drainage water, while the last irrigation of the season creates the least amount of drainage water. Reduction of drainage water volume in 1997 and 1998 was a result of less irrigation applications. Irrigation was scheduled in 1997 and 1998 on a combination of leaf water potential and soil water deficit, while in 1996 irrigation was scheduled based only on leaf water potential. Applied irrigation depths are shown in Table 2. Scheduling based on soil water deficit in the root zone automatically incorporates shallow groundwater use by the crop (Ayars and Soppe, 2002).

<table>
<thead>
<tr>
<th>Year</th>
<th>Applied seasonal irrigation depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>750 mm</td>
</tr>
<tr>
<td>1997</td>
<td>330 mm</td>
</tr>
<tr>
<td>1998</td>
<td>220 mm</td>
</tr>
<tr>
<td>1999</td>
<td>390 mm</td>
</tr>
</tbody>
</table>

Although drainage water production was lower in growing seasons 1997 and 1998, Figure 2 shows that most drainage water was produced outside the growing season. This is the result of a combination of precipitation and pre-plant irrigation. Pre-plant irrigation is needed on this clay soil to facilitate land preparation. Without pre-plant irrigation, it is not possible to obtain the correct water content for a good seedbed.
In field BV, drainage water outflow over the three years has a more constant flow (Figure 3). In 1996, half of the drainage area was cultivated with melons, requiring a different irrigation application, resulting in a lower drainage outflow than in 1997 and 1998.
Drainage water production in field BV is much higher than drainage water production in field WL. This is a result of several differences between the fields. The drains are installed at a greater depth in BV than in WL, regional groundwater flow is higher in BV (thus, more interception) than in WL, the soil has a higher conductivity and lower water holding capacity in BV than in WL, thus resulting in higher irrigation frequency and higher irrigation losses in BV. Seasonal applications for field BV are shown in Table 3.

Controlled drainage in field BV does not seem to affect the volume of drainage water. This is a result of irrigation scheduling, which was not integrated with drainage management during the growing season. For controlled drainage to have a positive effect on the overall water management on the field, irrigation management needs to be adjusted at the same time that active drainage management is practiced. The salinity of drainage water between the years does not show large fluctuations, and follows measurements by Ayars and Meek (19xx).

Figure 3: Seasonal drainage flow (June-Oct) for field BV from 1996-2000

Table 3: Applied depth of water during irrigation season for field BV

<table>
<thead>
<tr>
<th>Year</th>
<th>Applied seasonal irrigation depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>409 mm</td>
</tr>
<tr>
<td>1997</td>
<td>526 mm</td>
</tr>
<tr>
<td>1998</td>
<td>480 mm</td>
</tr>
<tr>
<td>1999</td>
<td>364 mm</td>
</tr>
<tr>
<td>2000</td>
<td>449 mm</td>
</tr>
</tbody>
</table>

Figure 4 shows a different cumulative annual drainage flow for field BV than was shown for field WL. Most drainage water is produced during the growing season, while the winter period shows no or low flow. The seasonal drain water flow shows two increases: The start of pre-plant irrigation, between February and April, and the start of the seasonal irrigation, between the end of June and the beginning of July. The low flow periods during the winter are in part the result of controlled drainage, namely turning off the sump pumps. The water district that this field is part of has restrictions on the salt and selenium load that they can dispose of outside the district. To prevent exceeding these limits, drainage pumps are sometimes turned off when no crop is grown on the
field. Another reason is that since irrigation halted, the regional groundwater levels decreased, and less regional groundwater was intercepted by the drains.

### 3.3 Salinity profile

Adjusted irrigation management (reduction of application) combined with controlled drainage in a saline environment must be adjusted for root zone salinity control as well. Figure 5 shows that in May 1997 the total salt mass in the root zone for field WL was higher than in subsequent years. Soil salinity measurements in 1998 and 1999 (both years had controlled drainage) show less salt mass, despite small seasonal irrigation applications (Table 2).

No major salt mass fluctuations were expected for field BV, since irrigation management had not been adjusted to controlled drainage. Figure 6 shows the salt mass distribution in the root zone for field BV. The lowest salt mass was measured in April 2000. This follows a year with a high drainage outflow (Figure 3) but low seasonal irrigation applications (Table 3), indicating high off-season leaching out of the root zone. This leached salt is not removed from the field (winter drainage practically zero (Figure 4)) but stored below the root zone.

*Figure 4: Cumulative 5-year drainage volume for field BV from 1996-1998*
Growing season 2000 shows a low total drainage outflow for the season and an increase in salt mass in the root zone. This was the first full year of established alfalfa on half of field BV. The difference between an establishing alfalfa crop and an established alfalfa crop is that the root system of an established crop is already fully developed. The potential of shallow groundwater use is therefore larger than for an establishing crop. The reason that salt mass does not increase largely compared to seasons with an establishing crop could be that groundwater is used at the bottom of the root zone (as suggested in Soppe and Ayars, 2003), where salts will accumulate, but not at shallower depths in the root zone. The salts at the bottom of the root zone can be leached fairly easy since regional groundwater fluctuation allows for high mobility of the salts.
Conclusions

Irrigation management can induce crops to use larger amounts of groundwater for their water demand. However, irrigation management is limited by crop tolerance for water and salt stress. Keeping available soil water in the root zone high will reduce groundwater uptake by a crop. Larger irrigation intervals, or lower irrigation applications will increase groundwater uptake.

Controlled drainage can reduce drainage volume if it occurs together with adjusted irrigation management to increase crop water use from the groundwater. Controlled drainage without adjusted irrigation management does not necessarily result in reduced drainage water volume. Controlled drainage is a good tool to focus attention on irrigation management.

The effect of controlled drainage during the season might be small if large drainage volumes are produced during the off-season, as is the case for field WL. Controlled drainage during the off-season (in field BV through turning off the drainage pumps) does not necessarily result in an increase in salinity in the root zone.

Increased groundwater use during the season does not necessarily result in long-term salinization of the root zone. Off-season leaching appears enough to maintain a root zone salinity sufficient to grow a crop.

It is likely that the described systems are not long-term sustainable without removal of salt from the root zone – groundwater system (for example through salt harvesting). The storage capacity of the groundwater for salts is limited. However, comparing the volume of salt stored in the root zone and groundwater with the volume of salt added by irrigation water and removed from the system by drainage water shows that it will take a long time (several hundreds of years) before the storage capacity of groundwater is exceeded.

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REUSE OF DRAINAGE WATER FOR RICE AND WHEAT GROWTH DURING RECLAMATION OF SALINE-SODIC SOILS IN PAKISTAN UNDER THE NATIONAL DRAINAGE PROGRAM (NDP)

A. Ghafoor and Th. M. Boers

ABSTRACT
Pakistan is facing scarcity of canal water for irrigated agriculture on 16 mha land. This problem is caused, among others, by the loss of surface storage capacity and by the current prolonged dry spell lasting over the several past years. Siltation of Mangla, Tarbela and Chashma Dams have caused a loss of .5 km³ which is 25 % of the designed capacity. Since this problem is increasing, there may be a gradual decrease of food production for a population of 140 million, which is expected to have doubled by 2025. Water shortage is the most serious for the provinces of Punjab and Sindh, where ground water is of hazardous quality and about 75 % of pumped ground water is not safe for irrigation without amendments. In this scenario, it appears wise and timely to study the prospects of growing food grains during reclamation of salt-affected soils using ground water to save good quality canal water for irrigating good soils. Under arid and semi-arid conditions of Pakistan with scarce and irregular rainfall, limited leaching of salts promotes soil salinization followed by sodication, induced by irrigation with ground water of high EC, SAR and RSC without amendments or other agronomic management practices. In this way, 6 mha of soils have become salt-affected, of which 60 % are saline-sodic and needs a source of calcium for amelioration. For initial reclamation of salt-affected soils, low quality irrigation waters are generally useful and some times even better than canal water, due to favorable effects of electrolytes on infiltration rate and hydraulic conductivity. For a variety of reasons, farmers are not properly applying the technologies for reclamation and management of saline-sodic soils. To improve this situation on sustainable basis, Univ. Agri., Faisalabad has launched a three-year research study on reclamation of saline-sodic soils by using drainage water, in which farmers are participating. The experiments were started in June 2001 in the Fourth Drainage Project Area located in the Central Punjab and are funded by the National Drainage Programme. The reclamation technologies include split application of gypsum @ soil or water GR alone and in combination with FYM or green manure, and on-farm wheat seed priming. This paper will present preliminary results and recommendations pertaining to economical as well as sustainable reuse of drainage water on saline-sodic soils, farmers’ constraints and limitations for adapting the required technologies in this regard on the basis of the on-going experiments.

1 INTRODUCTION
Pakistan is facing scarcity of canal water for irrigated agriculture on 16 mha land. This problem is caused, among others, by the loss of surface storage capacity and by the current prolonged dry spell lasting over the several past years. Siltation of Mangla, Tarbela and Chashma Dams have caused a loss of .5 km³ which is 25 % of the designed capacity (Mojadullah, 1993). Since this problem is increasing, there may be a gradual decrease of food production for a population of 140 million, which is expected to have doubled by 2025. Water shortage is the most serious for the provinces of Punjab and Sindh, where ground water is of hazardous quality and about 75-80 % of pumped ground water is not safe for irrigation without amendments (Ahmad, 1993). In this scenario, it appears wise and timely to study the prospects of growing food grains during reclamation of salt-affected soils using ground water to save good quality canal water for irrigating good soils. Under arid and semi-arid conditions of Pakistan with scarce and irregular rainfall, limited leaching of salts promotes soil salinization followed by sodication, induced by irrigation with ground water of high EC, SAR and/or RSC without amendments or other agronomic management practices. In this way, 6.3 mha of soils have become salt-affected (Khan, 1993), of which 60 % are saline-sodic (Muhammed, 1983) and needs a source of calcium for amelioration (Qadir et al., 2000; Ghafoor et al., 1998; Shainberg et al, 1989).

Problem of salination and sodication is expected to increase at alarming rate in the days to come because of prevailing drought and voluminous input of brackish tube well waters for irrigation. The ground water with high EC, SAR and/or RSC is used by the Pakistani farmers without amendments which is inducing sodication of soils. For initial reclamation of salt-affected soils, low quality irrigation waters are generally useful and sometimes even better than canal water owing to favourable effect of their electrolytes on soil infiltration rate and hydraulic conductivity (Shainberg and Letey, 1984; Rhoades, 1988). Relatively higher ratios of EC : SAR in such drainage and ground waters have been found to improve water conducting properties of soils which resulted in better and rapid amelioration of saline-sodic soils (Ghafoor et al., 2000 and 2001).

It is generally agreed that farmers are not properly and effectively adapting the technologies regarding the reclamation and management of saline-sodic soils and waters. This is assumed, in general, because of (a) inability of the extension experts to contact and advise all the farmers of area assigned to him, (b) farmers’ lack interest in such a stress land agriculture for want of financial resources, (c) farmers seldom approach the extension staff for advice, (d) technologies developed at farms of Agricultural Universities and Research Institutes are seldom available in time and space even to interested farmers, (e) lack of interaction between the farmers and research workers, (f) adulteration of agricultural inputs, (g) small farmers do not possess produce storing capacity which compel them for rapid disposal without realizing even the support prices and (h) lack of socio-political will of the society. Keeping the above in view, saline-sodic soils and water management investigations with the participation of farmers were initiated in June 2001 in the Fourth Drainage Project Area, Faisalabad, Punjab, Pakistan.

Objectives

1. Evaluation of different strategies for the reclamation of saline sodic soils using low quality ground water for irrigation following rice-wheat crop rotation.

http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20ghafoor%20a.%20and%20boers%20th_ab073.html (1 of 9)26-4-2010 12:12:15
2 MATERIALS AND METHODS

2.1 Description of Project Area:
During the seventies, soils of the lower Rachna Doab were highly waterlogged and salt-affected and consequently the crop yields were dwindling rapidly. For controlling these problems, area of this Doab was divided into units named Kharwala, Gojra-Khewra, Shorkot-Kamalia etc. to launch development projects. Among the remedial measures, provision of surface and subsurface drainage systems was on the priority in the Remaining Rachna Doab and has been named as the Fourth Drainage Project Area (FDPA). It covers an area of 143,437 ha but subsurface pipe drainage has been laid in badly affected area of 30,364 ha. Construction of 79 sumps and pipe drains were completed by June 1994 while its commissioning was completed by December 1995. Soils are deep, poorly drained, moderately fine textured, calcareous, have structured B horizon (Typic Aquisalid subgroup) developed in alluvium derived from Himalayas and deposited during early Pleistocene.

2.1.1 Rice (Oryza sativa):
The experiments have been permanently laid out following Randomized Complete Block Design with three replications at two sites in the FDPA. Each experiment was laid out on about 1.5 ha of land. Rice-wheat crop rotation is being followed. Transplanting of rice (2-3 seedlings per hill of about 40 days age with 22 cm row to row and plant to plant distance) was accomplished in July each year without puddling the soils. Puddling is commonly practiced to induce submergence which is the ecological requirement of rice. The NPK was applied at the rate of 100, 68 and 25 kg ha⁻¹, respectively as urea, single super-phosphate and potassium chloride. Crops were harvested (whole plot measuring 10 m by 31 m) and threshed manually during the month of November each year to record the paddy yield.

2.1.2 Wheat (Triticum aestivum):
With the help of tractor driven drill, wheat was planted during the last week of November/first week of December each year after the harvest of rice in "Wattar" condition of soils using 100 kg ha⁻¹ seed rate. Row to row distance was kept as 22 cm. The NPK was applied at the rate of 100 and 68 kg ha⁻¹, respectively as urea, single super-phosphate and KCl. Crops were harvested manually and threshed mechanically during May each year to record grain yield.

2.1.3 Junter (Sesbania aculeata):
In the treatment (T6), junter was planted in mid-May 2002 by broadcast method using 30 kg seed per hectare. Crop was grown for about 45 days with 18 cm of tube well water irrigation. During this period plants thinly populated attained height of about 80 cm which were rotavated 10-15 days before transplanting rice. There was negligible rainfall during this period.

Treatments: The experiment was planned at two sites in the FDPA with the following treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
</tr>
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<tbody>
<tr>
<td>T1</td>
</tr>
<tr>
<td>T2</td>
</tr>
<tr>
<td>T3</td>
</tr>
<tr>
<td>T4</td>
</tr>
<tr>
<td>T5</td>
</tr>
<tr>
<td>T6</td>
</tr>
<tr>
<td>T7</td>
</tr>
</tbody>
</table>

Table 1 Quality of tube well waters used for irrigating rice-wheat crops during reclamation of soils

<table>
<thead>
<tr>
<th>Location</th>
<th>Parameters of Water Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>EC, dS/m</td>
<td>SAR</td>
</tr>
</tbody>
</table>

To grow each rice crop up to maturity, 70-75 cm and 20 cm of canal and tube well water (Table 1), respectively was applied. The corresponding amount of irrigation water was 40 cm and 10 cm for wheat. The studies were initiated in June 2001 and by June 2003, two crops each of rice and wheat have been harvested. Before laying out the experiments and after the harvest of each crop, composite soil samples were drawn from 0-15 cm and 15-30 cm soil depths and were analyzed for pH, EC, soluble ions, SAR etc. following the methods described by Page et al. (1982).
3 RESULTS AND DISCUSSION

The present studies were initiated in July 2001 at two different sites in the FDPA and by now four crops (two wheat and two rice) have been harvested. The changes in pHs, ECe and SAR of soils are presented as per cent decrease (-) or increase (+) over the initial values.

3.1 Soil Reaction (pHs):
Response of pHs was mixed one (Tables 2 a & b) at both the sites to the tested treatments. In general, there was a small increase in pHs values after rice crops because of the rapid leaching of soluble salts but slow rate of Na+ desorption as well as the irrigation with high SAR and/or RSC ground water. But there was a decrease in pHs after the harvest of wheat crops as this crop received much smaller amount of irrigation water than rice and thus less leaching of soluble salts (Tables 3 a & b), i.e. an increase in ECe to SAR ratio. As a consequence of which, ECe to SAR ratio decreased after every crop compared to that of the initial soils in July 2001. It is known that increasing values of ECe tend to decrease while that of the SAR tend to increase the pHs (Quirk and Schofield, 1955; Ghafoor et al., 1997b; Quirk, 2001). However, mostly the pHs values are still around 8.4 which is the critical limit for sodic condition of soils (US Salinity Lab. Staff, 1954). Low rate of changes in the pHs also could be due to moderate calcareousness of soils since lime buffers the pHs. Also there is no big difference in pHs values so far (after two years of the initiation of studies) among the two sites at both the soil depths.

3.2 Electrical Conductivity (ECe):
There was a decrease in ECe during the study period at both the sites and both the soil depths except T8 at 0-15 cm after harvest of rice 2002 at site 1 (Tables 3 a & b). However, decrease in EC was more after rice than that after wheat crops mostly because of high input of irrigation water to rice which helped maintain leaching fraction (LF) more than that during wheat and high LF is necessary for reclamation and management of poor quality irrigation water.

At site 1 after the harvest of rice 2002, decrease in ECe was the highest with T2 followed by T3, T1, T5 and T4 at 0-15 cm soil depth while the treatment order was T3, T1, T5, T2 and T4 at 15-30 cm soil depth. At site 2 after the harvest of rice 2002, decrease in ECe was the highest with T2 followed by T1, T4, T7, T5 and T3 but increased with T8 at 0-15 cm soil depth while the treatment order was T1, T2, T4, T3, T5, T7 and T8 at 15-30 cm soil depth. In general, the gypsum application resulted in relatively less decrease in ECe because of its low solubility which is useful to sustain the electrolyte concentration in soil solution to favourably affect the hydraulic conducting (HC) soil properties (Ghafoor et al., 1997a; Rhoades, 1993) and better HC is an asset for the reclamation of saline and/or sodic soils. Overall, by the time of harvest of rice 2002 in November 2002, with almost all the treatments, ECe was still higher than 4 dS m⁻¹ which is mostly considered the critical limit for saline soils (US Salinity Lab. Staff, 1954).

The auger hole treatment (T6) caused less leaching of salts against expectation because visually it was observed that free water on the soil surface used to disappear much earlier in this treatment than the others. It is opined that applied irrigation water infiltrated better through these auger holes without interacting with soil to get enriched with salts. This phenomenon proved helpful for wheat (Table 5 a) which can not tolerate submergence but detrimental to rice which is a crop of submerged ecology.

3.3 Sodium Adsorption Ratio (SAR):
It is a measure of sodicity problem of soils and indirectly indicates gypsum requirement of soils and deterioration status of soil physical properties. The soils under this study at both the sites have SAR much higher than 13 (Tables 4 a & b), a limit for sodic soils prescribed by the US Salinity Lab. Staff (1954) and commonly is followed in several other countries. It was relatively higher at site 2 than that at site 1. It was higher in the surface 15 cm soil layer compared to that at 15-30 cm soil depth. Since soils were lying barren for the last many decades during which soils were salinated followed by sodication (Muhammed, 1983) due to formation of CaCO₃ (Ghafoor et al., 1990; 1997 a, b). The sodicity indicator natural plants like Nara (Arundo donax), Saji (Sueda fruticosa), Lani (Salsola foetida) and Sarkanda (Saccharum manja) were sparsely growing at both the sites. The decrease in SAR remained much higher after rice compared to that after wheat crops at both the sites except post-rice 2002 at site 1. The rate of decrease in SAR was more in 0-15 cm than that at 15-30 cm soil depth because as the water/soil solution moves down into soil, its osmotic pressure decreases to affect a decrease in its salt carrying capacity. The decrease in SAR was generally higher at site 2 compared to site 1 most probably due to initially high SAR values at site 2. As the SAR decreases, there is a decreasing probability of Na - Ca exchange which has to slow down the rate of decrease in SAR as appears for site 1.

At site 1 after the harvest of rice 2002, decrease in SAR was the highest with T2 followed by T3, T1, T5 and T4 at 0-15 cm soil layer, while the treatment order was T5, T3, T1, T2 and T4 at 15-30 cm soil depth. At site 2, after the harvest of rice 2002, the decrease in SAR was the highest with T7 followed by T5, T2, T4, T1, T2 and T8 at 0-15 cm soil layer, while the treatment order was T4, T1, T2, T7, T5 and T8 at 15-30 cm soil depth. The results indicate that application of commercial
grade gypsum (75-80 % pure and passed through 30 mesh sieve) @ of 50 % in two equal splits to the first two crops with or without organic matter (FYM or GM) could successfully reclaim saline-sodic soils even when rice-wheat crops are irrigated with saline-sodic ground water as is the case with T4 and T5. Even the simple irrigation with brackish water has decreased SAR of calcareous soils considerably through valence dilution (Eaton and Sokoloff, 1935), dissolution of native lime which was promoted by the activities of the living roots of crops (Robbins, 1986), Ca²⁺ supplied in irrigation water and in-situ mineral weathering (Rhoades et al., 1968).

It is reported (Ahmad and Riaz, 1986) that soils under investigation are dominated by the illite type (low CEC) clay minerals for which 6-10 mmol_c L⁻¹ Ca²⁺ in irrigation water or soil solution is the most efficient to promote Na-Ca exchange (Ghafoor, 1999; Ghafoor and Salam, 1993). As a result of brackish water irrigation with or without OM (T1, T3), the observed decrease in SAR had been possible. However, since the soil amelioration is still in progress, treatment effectiveness and spatially variable soils Oresponses to treatments are tentative and still changing and are likely to continue to change by the time soils attain steady-state most probably by the end of third year of studies.

3.4 Growth Response of Rice and Wheat Crops

There is a gradual improvement in crop yields at both the sites (Tables 5 a & b). Growth performance of rice and wheat was better at site 1 than at site 2 (Tables 5 a & b) because of initially low soil EC_e and SAR (Tables 3 a & b, 4 a & b) as well as skillful management by the farmer at site 1. Yields of wheat were consistently better than that of rice at both the sites owing to high EC tolerance of wheat (Ayers and Westcot, 1985).

Grain yield of wheat 2002-03 was the highest with T6 followed by T4, T2, T5, T7, T3, T8 and T1 at site 1. At site 2, the treatment effectiveness to produce wheat 2002-03 grain yield was T8, T2, T7, T4, T1, T3, and T5. At site 1, auger hole treatment (T6) performed the best as the soil was dense and was in need of immediate drainage improvement that was provided by auger holes. However, wheat seed soaking (T7, T8) was less effective at this site as the soil was near to normal and germination was almost sufficient without seed treatment. But at site 2, wheat seed soaking (T7, T8) proved the best as the soil has SAR high enough to disturb germination that was countered by seed soaking. Overall, soil-applied gypsum @ 50 % soil GR in one (T7, T8) or two splits (T2, T4) proved better.

The effectiveness of T5 (gypsum @ water GR on the basis of SAR) proved better at site 1 than at site 2 because soil was less saline-sodic but received more sodic irrigation water than that of site 2 soil. Hence the applied quantity of gypsum proved enough to reclaim the saline–sodic soil at site 1 but remained small at site 2. As a result crop yields with T5 remained higher at site 1 than those at site 2. This indicates that treatment(s) has to be devised more specifically to exploit saline-sodic soils using brackish water for the irrigation of rice-wheat crops through soil characterization.

3.5 Evaluation of Economics of Soil and Water Amelioration Treatments

Economical gains are the ultimate objective of any industry including agriculture. The stress-land agriculture is generally discouraged because of initial cost of treatments of soils or irrigation waters. Although in the long run, stress-land agriculture is always in favour of farmers and country. Economics of the on-going experiments has been computed using the market cost of variable items and support prices of the paddy and wheat grains. The appreciation in the value of land and the cost of constant items have not been considered.

Expenditures are lower at site 2 than those at site 1 (Table 6). At site, net benefit was the highest with T2 followed by T4, T3, T1, T5, T7, T8 and T6. The treatment effectiveness was in the decreasing order of T8, T7, T5, T4, T2, T1 and T3 at site 2. The wheat seed soaking treatments (T8, T7) remained the best at site 2 because of high problem of soil salinity/sodicity where seed soaking helped better germination and subsequently better crop stand and growth to result high income because once plants are established, then can withstand hazards of salinity/sodicity in a better way (Ayers and Westcot, 1985). While this was not required at site 1 as the soil has become just normal. Gypsum application @ 50 soil GR in two equal splits with and without FYM (T2 and T4, respectively) have edge over the others, i.e. both treatments not only successfully reclaimed saline-sodic soil but also countered the adverse effects of high SAR and RSC tube well water used for the irrigation of rice and wheat crops.

In addition, there is great appreciation in the land value, e.g. at site 1 common value of one hectare salt-affected field was US$ 1450 to 2050 in 2000 which now has increased to US$ 6175 to 7500 per hectare. Secondly, there is considerable friendly effect of reclaimed soils on the environment through the sequestration of CO₂ from the atmosphere as well as through a better aesthetic value. Farm employment to help decrease migration from rural to urban areas is another added benefit of amelioration of salt-affected soils using poor quality water, otherwise disposal of brackish was is an environment risk.

Further, the salt balance in the Indus Basin is positive and area under salt-affected soils is increasing every year while canal water supplies are decreasing. In this scenario, amelioration of salt-affected soils even become more and more imperative and attractive. Because further loss in cultivated lands due to salination/sodication could not be tolerable since population is on the increase in most of the countries which will need food, fiber and shelter. These are the long term benefits those have not been included in the present economic evaluation.

3.6 Farmers motivation and their initiatives

Sign boards explaining treatments both in English and Urdu were permanently displayed at each site and for each experiment. Farmers are being encouraged as shown by their active participation and with the project staff during meetings and their visits to the experimental sites. Because of good growth of crops, they are considerably motivated and encouraged to initiate reclamation of their salt-affected soils using tube well brackish waters. However, project staff has to approach them, and provided them only the facility of soil testing for gypsum requirement and tube well waters for irrigation quality along with technical advice. This fact has been realized further from the participation and quaries raised by farmers in our Farmer Focus Group meetings and Field Days convened at each site. Major constraint of farmers is the shortage of finances to purchase soil and/or water amendments. Secondly the availability of quality gypsum in time and space is the limitation to their initiative of reclaiming salt-affected soils. Overall, it is felt that Research cum Demonstration of technologies is the best to motivate the farmers.
4 CONCLUSIONS
On the basis of 2-year results from soil reclamation studies using brackish water, it is concluded that:

- Low quality ground water could successfully reclaim saline-sodic soil provided agricultural grade gypsum passed through 30 mesh sieve is split applied (25% and 25% of the 0-15 cm soil GR each to the first and second crop). Addition of FYM did improved crop growth.
- The application of gypsum @ water SAR to reduce it to 10 with green manuring reclaimed saline-sodic soils to reasonable extent.
- For dense saline-sodic soils, in general, one auger hole per 50 sq. m. filled with rice husk, gypsum and soil proved better both for wheat which could not tolerate prolonged submergence and O₂ stress.
- Wheat seed priming, i.e. soaking in 15 mmolc L⁻¹ gypsum solution for 3 or 6 hours soaking produced better crop on a saline-sodic soil receiving agricultural grade gypsum @ 50% soil GR for 0-15 cm layer soil-applied once before the start of studies.
- Research-cum-demonstration, Focus Group Farmers meetings and on-site excursion proved very good and effective method of farmer as well as extension workers’ education.
- Farmers’ need technical and in-kind financial assistance.
- Visits and discussions with farmers by different Expert Missions proved helpful to build farmer confidence in the research project.

5 RECOMMENDATIONS
- Gypsum should be made available to farmer in time and space at subsidized rates.
- The activities of the on-going project need replication at more sites.
- In-service training of the Extension worker’s in reclamation technologies is imperative.
- Reclamation of salt-affected soils using poor quality irrigation water is worth investment under agro-climatic and socio-economic conditions of arid regions.

6 LITERATURE CITED
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http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20ghafoor%20a.%20and%20boers%20th_ab073.html (5 of 9)26-4-2010 12:12:15
Table 2  Percent decrease (-) or increase (+) in pHs of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 1, FDPA

<table>
<thead>
<tr>
<th>Treatment</th>
<th>0-15 cm</th>
<th>15-30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>8.0</td>
<td>4.7</td>
</tr>
<tr>
<td>T2</td>
<td>8.3</td>
<td>4.0</td>
</tr>
<tr>
<td>T3</td>
<td>8.5</td>
<td>5.2</td>
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<tr>
<td>T4</td>
<td>8.3</td>
<td>-1.9</td>
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<td>T5</td>
<td>8.4</td>
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<td>0.2</td>
</tr>
<tr>
<td>T8</td>
<td>8.4</td>
<td>-1.3</td>
</tr>
</tbody>
</table>

* P stands for post.

Table 3  Percent decrease (-) or increase (+) in pHs of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 2, FDPA

<table>
<thead>
<tr>
<th>Treatment</th>
<th>0-15 cm</th>
<th>15-30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
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<td>T2</td>
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<td>1.66</td>
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<tr>
<td>T3</td>
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<td>Treatment not tested</td>
<td></td>
</tr>
<tr>
<td>T8</td>
<td>8.70</td>
<td>-7.24</td>
</tr>
</tbody>
</table>

Table 4  Percent decrease (-) or increase (+) in $EC_e$ (dS m$^{-1}$) of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 1, FDPA

<table>
<thead>
<tr>
<th>Treatment</th>
<th>0-15 cm</th>
<th>15-30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>8.44</td>
<td>3.20</td>
</tr>
<tr>
<td>T2</td>
<td>8.42</td>
<td>1.66</td>
</tr>
<tr>
<td>T3</td>
<td>8.52</td>
<td>1.41</td>
</tr>
<tr>
<td>T4</td>
<td>8.47</td>
<td>1.89</td>
</tr>
<tr>
<td>T5</td>
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<td>1.63</td>
</tr>
<tr>
<td>T6</td>
<td>Treatment not tested</td>
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</tr>
<tr>
<td>T8</td>
<td>8.70</td>
<td>-7.24</td>
</tr>
</tbody>
</table>
Table 5  Percent decrease (-) or increase (+) in ECe (dS m⁻¹) of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 2, FDPA

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<th>Treatment</th>
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<td>T5</td>
<td>6.73</td>
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<td>T6</td>
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<tr>
<td>T7</td>
<td>5.01</td>
<td>+04</td>
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<tr>
<td>T8</td>
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<td>-14</td>
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Table 6  Percent decrease (-) or increase (+) in SAR of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 1, FDPA

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
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<td>T3</td>
<td>24.2</td>
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<tr>
<td>T4</td>
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<td>28.3</td>
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</tr>
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<td>T7</td>
<td>18.2</td>
<td>Crop not planted</td>
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<tr>
<td>T8</td>
<td>04.5</td>
<td>+437</td>
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</table>

Table 7  Percent decrease (-) or increase (+) in SAR of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 2, FDPA

<table>
<thead>
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<th>Treatment</th>
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</thead>
<tbody>
<tr>
<td>T1</td>
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<td>-30</td>
</tr>
<tr>
<td>T3</td>
<td>54.1</td>
<td>-26</td>
</tr>
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</table>
**Table 7** Percent decrease (-) or increase (+) in SAR of saline-sodic soil receiving poor quality ground water for irrigation of rice and wheat crops at site 2, FDPA

<table>
<thead>
<tr>
<th>Treatment</th>
<th>0-15 cm</th>
<th>15-30 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
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<td>T2</td>
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<td>T3</td>
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<td>T4</td>
<td>109.2</td>
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<td>T5</td>
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<td>-79</td>
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<tr>
<td>T6</td>
<td>Treatment not tested</td>
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</tr>
<tr>
<td>T7</td>
<td>143.7</td>
<td>Crop not planted</td>
</tr>
<tr>
<td>T8</td>
<td>36.0</td>
<td>+75</td>
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**Table 8** Crop yields (kg ha⁻¹) at sites 1 during reclamation of saline-sodic soils using poor quality ground water for the irrigation of rice and wheat crops, FDPA

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rice 2001</th>
<th>Wheat 2001-02</th>
<th>Rice 2001</th>
<th>Wheat 2002-03</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>3532</td>
<td>2569</td>
<td>1141</td>
<td>3900</td>
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<tr>
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<td>3730</td>
<td>3433</td>
<td>1761</td>
<td>4518</td>
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<td>T3</td>
<td>2692</td>
<td>2618</td>
<td>1566</td>
<td>4182</td>
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<td>T4</td>
<td>3409</td>
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<td>4562</td>
</tr>
<tr>
<td>T5</td>
<td>3656</td>
<td>2668</td>
<td>1176</td>
<td>4419</td>
</tr>
<tr>
<td>T6</td>
<td>1062</td>
<td>3705</td>
<td>Crop could not be planted</td>
<td>4629</td>
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<tr>
<td>T7</td>
<td>2890</td>
<td>3984</td>
<td>4306</td>
<td></td>
</tr>
<tr>
<td>T8</td>
<td>1951</td>
<td>2766</td>
<td>4113</td>
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### Table 9  Crop yields (kg ha\(^{-1}\)) at sites 2 during reclamation of saline-sodic soils using poor quality ground water for the irrigation of rice and wheat crops, FDPA

<table>
<thead>
<tr>
<th>Treatment</th>
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<th>Wheat 2001-02</th>
<th>Rice 2001</th>
<th>Wheat 2002-03</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>148</td>
<td>1507</td>
<td>1393</td>
<td>2835</td>
</tr>
<tr>
<td>T2</td>
<td>445</td>
<td>2248</td>
<td>1472</td>
<td>3214</td>
</tr>
<tr>
<td>T3</td>
<td>198</td>
<td>1877</td>
<td>1265</td>
<td>2732</td>
</tr>
<tr>
<td>T4</td>
<td>222</td>
<td>2445</td>
<td>1899</td>
<td>2860</td>
</tr>
<tr>
<td>T5</td>
<td>395</td>
<td>1433</td>
<td>1376</td>
<td>2714</td>
</tr>
<tr>
<td>T6</td>
<td>Treatment not tested</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T7</td>
<td>Crop could not be planted</td>
<td>2766</td>
<td>2720</td>
<td>3776</td>
</tr>
<tr>
<td>T8</td>
<td></td>
<td>2717</td>
<td>2497</td>
<td>3846</td>
</tr>
</tbody>
</table>

### Table 10  Economics (US$ ha\(^{-1}\)) of treatments for the reclamation of saline-sodic soils receiving poor quality ground water for irrigation of rice and wheat crops (data from 4 crops, i.e. 2 years), FDPA

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Site 1</th>
<th>Site 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Expenditure</td>
<td>Benefit</td>
</tr>
<tr>
<td></td>
<td>Gross</td>
<td>Net</td>
</tr>
<tr>
<td>T1</td>
<td>192</td>
<td>1705</td>
</tr>
<tr>
<td>T2</td>
<td>317</td>
<td>1980</td>
</tr>
<tr>
<td>T3</td>
<td>268</td>
<td>1762</td>
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<tr>
<td>T4</td>
<td>367</td>
<td>1871</td>
</tr>
<tr>
<td>T5</td>
<td>357</td>
<td>1821</td>
</tr>
<tr>
<td>T6*</td>
<td>332</td>
<td>1145</td>
</tr>
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<td>T7*</td>
<td>298</td>
<td>1600</td>
</tr>
<tr>
<td>T8*</td>
<td>327</td>
<td>1367</td>
</tr>
</tbody>
</table>

*Prices: Actual variable costs and support prices of the produce.* Data from 3 crops.

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[2] Professor, Inst. of Soil & Environ. Sciences, University of Agriculture, Faisalabad, Pakistan
TIDAL AREAS OF SRI LANKA

Eng. Lakshamane W. Seneviratne

ABSTRACT

Sri Lanka is an island in the Indian Ocean of 65519sqkm land area and 103 river basins. Highest annual precipitation is 5500mm in the central highlands. The wet zone is demarcated by 2000mm isohyet covering southwestern and central regions. Nearly 2/3 area of the country is dry and the annual precipitation lies between 1100-2000mm. The northeast, north central, northwestern and southeastern areas are in the dry zone. It supported 3000 years of agricultural civilization continuously. 1200km long coastal zone supports nearly 33% of the population about six million. Wet zone areas are increasingly getting populated due to prevailing conditions in Sri Lanka. The coastal zone is a tidal area.

Wet zone population increased from 1300AD due to international impacts and spice trade. Tidal zones always had paddy cultivation in the periphery of lagoons. Mangroves dominated in the coastal wetlands.

Negombo Lagoon, Koggala Lake and Madampe Lake are large water bodies formed due to faults of the region. The basin has a high precipitation of 2200mm and rice farms are cultivated for a longer period. Low humic gley soils are suitable for paddy and not suitable for any other crop. But the brackish water of the lake is harmful to paddy. Tidal flows take up saline water up to 0.6m and salinity barriers are constructed across the canals to control the high tides. Irrigation Department maintained these barriers. The lagoon bed is possessing (beru) carbonic compounds but life is not flourishing in that layer. Lagoon water supports predators such as prawns and crabs. Prawns come from the sea and again go back to sea for reproduction. Hence a passage to the sea is open. Sand bars always block this passage, which is due to accretion. Irrigation department is cutting sand bar for a longer time but later groynes were laid to clear the passage. Sand budget has a balance in rivers and beaches. Presently sand mining in rivers in excessive quantities has reduced the beach formation. The accretion is on the southern side of the groynes in the western beach. It is on the western side of the groynes of the southern beach.

Ben River basin has a large area of tidal action. Water transport in the 19th century used the up tides for the boating up to Hattaka. Down tides are used to reach the coastline at Bentara. These boat ways are now limited to marshy areas only. Motor transport is used elsewhere. Railway and highway are laid across the mouth of the lagoon preferably on the suitable rock base. Many mangroves are now cut for land clearing and buildings were erected. Tourism is the main reason for the wanton destruction of mangroves. Regosol soils in the coastal region are suitable for coconut plants.

Lagoons in the dry zone were developed for prawn ponds. Artificial ponds were constructed along the periphery and brackish water was pumped into it. Effluent was released back to the lagoon. This changed the biodiversity of the salt marshes.

Tidal swamps are under environmental degradation due to industrial pollution. This is aggravated due to the ignorance of farmers as many fields are abandoned. Environmental management is necessary to preserve link between the sea and control excessive pollution. Industries, houses, roads, reclamation work and recreation activities destroy the natural habitats of salt marshes and reduce lagoon area. Commercialization of lands needs national awareness. Case studies are interesting for future plans. Coastal engineers criticize groynes.

1 INTRODUCTION

Sri Lanka’s economic and coastal management challenges are clearly set out in the published Coastal 2000: Recommendations
for a Resource Management Strategy for Sri Lanka's coastal region. The identified basic facts are,

1. There are more people per square kilometer in the coastal region than in the rest of the country—people who want to achieve a better quality of life (good health, a way to support their family, education, a healthful environment), and who in turn put additional demands on the coastal eco system.

2. The traditional coastal resource base cannot support the number of people already utilizing these resources for agriculture, fisheries, industry and tourism, and there are indications that the resource base itself is getting poorer.

The potential economic developments that can provide jobs for this growing population either depend on a healthy natural eco system for their success and sustainability—for example tourism, aquaculture or expanded fisheries—or have the potential—as with industrial estates, ports, energy facilities—of further degrading this resource base if improperly sited, constructed or operated.

Hence the challenges of coastal eco system management and of economic development are inextricably intertwined. The basic problem that coastal management programs should be attempting to address is that of altering current patterns in the utilization of coastal ecosystems, which are reducing the capacity of these eco systems to produce wealth and sustain human quality of life over the long-term. To put it another way in classic economic terms, the economic “rent” that can be obtained from coastal ecosystems to benefit people is being reduced. We are living off capital rather than the interest that such capital can produce.

2. COASTAL MANAGEMENT AND DEVELOPMENT

2.1 Coastal Management

Tidal areas are divided into coastal zone and upstream areas. First we must define coastal management, which has several definitions. There are three that are of concern: (a) coastal zone management, which typically means managing or regulating all that occurs in a defined narrow strip -300 meters-at the land sea interface; (b) Coastal resources management—managing renewable and non-renewable resources such as coral reefs, mangroves, fish etc., either separately or in an integrated fashion; and (c) coastal area or eco system management, where one considers a geographic area or eco system and tries to chart a course for its over all sustainable development. In Sri Lanka as elsewhere, all three are essential to economic development.

Much of what coastal programs do can be characterized as coastal zone management. This is expressed as trying to bring order to the development process, avoiding site selection and construction mistakes, directing development away from critical ecological or high hazard areas, minimizing adverse environmental impacts of development and reducing foreseeable use conflicts. This is classic coastal zone management. It is both pragmatic and conceptually simple. It also makes good an obvious economic sense.

2.2 History

In Sri Lanka expressions of avoidable mistakes are well known. How much better off we could be today if the British had built the Colombo-Galle road and the coastal railway 100 meters further inland? The enormous expenditures that have recently been made in shoreline structures to protect this important infrastructure are testament to the economic costs of such simple miscalculations. Electrical transmission and distribution network and the telecommunication link network also found its base along the same road. A super highway is now planned to link Colombo and Matara along a new route about 15 km interior from the coastline. This highway is planned to reduce the bulk of traffic presently undertaken by the Galle Road.

In 1796 when the British regiment captured Colombo and Galle fortresses this road was in existence. A road was running right round the island and it was the only free route, which communicated with Arab and Indian traders. The Dutch controlled coastal provinces and the common trade items were collected along the rivers. Boats were in use than carts. Coastal settlers were foreign due to continuous migration and emigration took place before 1800. They wanted a good road for their free communication. The central kingdom eliminated all the routes due to foreign invasion. Armed guards controlled key entrance points and the tax officers...
maintained custom offices in the coastal side. This basic operation resulted in linking high grounds along the coastal belt at suitable locations of estuaries. Water drainage courses were subjected to tides from the sea. At the same time floods gather and drain to the sea during rainy season. Timber bridges were constructed across the river.

### 2.3 Human Activity

Southwest coastal area had a line of mountains, which had sloping sides to the lagoons on one side and it paved the way to restrict the shifting the road to interior due to its base rock formation. These estuaries functioned as flood buffer zones. The adjoining area was developed for paddy cultivation. Mangroves developed along the low-lying marshy lands. Clean water was visible during fair weather. Turbidity was visible during floods. Fishing was continued in the coastal zone using big nets. About 50 men pulled this big net. They stand on the beach and pull the two ends gradually so that it coincides at one point. The set back area is defined to allow this operation without any obstruction. Coconut trees and houses shall not be in this set back area. It was recorded that the beach is encroaching private owned lands. The net fishing operation continues for one season from October to April where the sea is calm and the sand is collecting towards the coast. This beach collection is eroded in the rough season from April to September due to monsoon winds. The tourist season also ends due to rough winds. If a coral rock is available as in Hikkaduwa it acts as a pool. But fishing net operation is not possible due to the rock. Pooled areas are safe for bathing as the under currents are not dragging the swimmers into the deep sea as in open area. The under sea currents are capable in dragging the bodies in to the deep sea and take away about 10 kilometers. The dead bodies are landed to locations about five to sixty km north of the dragging point. Skilled swimmers are also found drowned as the under currents are not allowing to breathe from the initial upright position. One boy found unconscious and not dead after five days and floated nearly 120kms and landed near Negombo.

The open currents are visible to the beach users. Surface currents very rarely caused a death. Investors deploy fishing boats. Fishermen hire a boat and sail to deep sea to catch fish by nets. Their experience and the favorable weather confirm the safe return with a good catch. Bad weather takes them away from the prominent area and finally land in India or Africa. Indian coast guards arrest many fishermen for the encroachment of national fishing area. Motorboats are now in use as against the wind driven boats. Sea wind is used to drive into the deep sea. Then anchor in the sea in the night and fish until the sea breeze begins at 4 a.m. Then the anchor is lifted. The boat is sailed towards the land. Landing points are necessary to unload the fish catch and tie the boats for safe vacation period. Harbors are developed by tradition. Fishermen are not developing any harbor but insist on governing bodies to do so. The shore is a source of income to the local authority. It is auctioned for the season for the highest bidder. The prospective bidder earns the income by allowing fishing in traditional manner. When season is over boats and nets are nicely packed and kept in near shore huts for the reuse after six months.

Many fishermen move to east coast in the rough season. But this traditional move is now not possible due to the civil war. Disabled fishermen refuse to go to sea but used to lagoon fishing. Lagoon fishing is continued through out the year but it has limits in the drought season. The drought reduces the fish growth and diseases spread due to various reasons. The estuaries are the breeding grounds for some fish varieties. Prawns breed in sea but migrate to lagoons for maturity and again go back to the sea for mating. This cycle continues using brackish water and nutrients in the lagoons. If the lagoon is separated from the sea by a sand bar this natural growth of prawns is disturbed. It also happens due to loss of mangroves.

### 3 EROSION AND CONTINENTAL SHELF

Sri Lanka has a sedimentary rock formation, which can resist sea erosion due to wave action. The northern part has limestone bed- rock, which is soluble and breaks due to sea waves. The islands presently withstand the erosion but the weaker material has already left its neighborhood to form the strait. Coral islands formed under the sea level had now emerged up due to land rise. Sea level drop is another possibility. Transported soil is available in some areas over the limestone.

In the south gneiss rocks resist the wave action and the present coastline has carved from a high land mass. From time to time sea level change is recorded. Nearly three miles of shallow shelf is the result of wind driven waves. Hikkaduwa area has lost more
than one square mile in the recent past. The only stable area was identified as a sacred shrine at Sinigama. The beach eroded coconut lands and lost lands were compensated to residents by providing new residential areas. Coral rock was survived in the lost land bed. This provides stability against further erosion.

The growth of coral provides pure calcium carbonate, which is used for plastering. The colorful corals attracted tourists and breaking of it was prohibited. However, the chemicals in seawater kill part of corals. This is the result of urbanization in the coastal area. Estuaries develop limestone under the ground due to deposition. This was extracted and sold for building construction. The continental shelf is widening in the southwest coastal belt by erosion and the sediments gather along the northwest coast. The sediment budget is strengthened by the sand and silt brought by river flow. Agriculture in the river basins continuously supplies silt to the coastal belt. The large dams in the Kelani basin trap the sediment load in the reservoirs. Sand bars are formed along the southern coast blocking the estuary sea confluence. Sand bars are periodically cut and remove to facilitate the drainage of storm water in the estuary basin. Sand mining in rivers during the past 15 years has reduced the natural budget and it has caused the riverbank erosion and reduced water table, which allowed salinity intrusion in to estuaries.

River sand is best suitable for cement mortar than coastal sand, which is finer. Thus much of the riverbeds in the Matara to Chillaw region in the southwest coast are affected. Hence regulations are laid to control the extraction from rivers using permits during restricted days in the week. The bridges, dams and flood bunds are under a threat due to bank erosion. As traditional brick making was expensive it is difficult to control sand mining from rivers in the near future. The natural making and breaking of seacoast is likely to disturb due to sand mining. Employment due to traditional lime industry in Akurala is reduced by legal action but it continues.

4 SEA LEVEL RISE AND SALINITY INTRUSION
Global warming is well documented in Sri Lanka and it was observed that the daily mean temperature of the coastal areas has risen by one degree C during the past sixty years.

Jungles of 20% of the country area were converted into agricultural lands, which increased the day and night temperature difference in this period. The reduction of trees in the coastal zone increases the salinity intrusion. Revetments along the coast prevent spilling of seawater at improved locations. Aquaculture projects in Puttalam District went beyond the target planned and encroached Mundel Lake area completely. It brings fresh water lands, which had coconut trees into salinity forever. It is necessary to promote mangroves to reduce salinity effects. Biodiversity of the lake is affected due to nutrients and effluents released from prawn ponds. Coastal engineers oppose erection of groynes, revetments and salinity gates as it affects the beauty. Changes in the high and low tides coupled with sediment deposition in the lagoons are leading factors of cropping and aquaculture.

5 RELEASE OF EFFLUENT

5.1 Effluent Release
New industries are releasing the effluent to the sea as the final dumping ground. Quality standards are given before the commencement under EIA procedure. Sewerage effluent is pumped under ground to sufficient distance so that the near shore is not affected. The proposed coal power plant can have an effect on water quality. Dwellers damage the seashore by various means but the hotel projects are maintaining the necessary quality. Hotels built close to the sea are to be demolished as the setback limit is 50 meters.

Coast Conservation Department controls the release of effluents by issuing permits. The most dangerous hazard is landing through the newly installed industries, which receives state security under the name of investment. The next is due to the increase of dwellers along the coast. Increase of roof area reduces the use of nutrients brought by the rain. How ever the river basins have to be more protected from industries as it provides drinking water. Beira Lake in Colombo is already polluted by sewage. Flood
bunds and reclamation work increases local pollution. Very nice beaches are seen in Kalpitiya and in the East. Floating parcels of carbonic matter provide occasional dirtying of beaches. Lakes possess more reddish floating matter due to iron soil drains from upstream basin. Greenish floating belt is due to plankton growth using nitrates and phosphates from drainage water.

5.2 **Salvinia**

Salvinia is a floating asexual bush growth due to excessive nutrients. Rich salvinia growth is fully controlled using a weevil if nitrogen content is about 3% in the leaves. This method was introduced by CISIR and it cleared the water bodies in three days using this imported weevil from South America. The method of introduction was to cut a square meter size patch of salvinia and replace that with a same size portion cut from a tank with the living weevil colony on salvinia. The new buds of salvinia formed on the new water body develop the starting point and the weevil continues the eating procedure until it vanishes. If the nitrogen content is less it is not fully successful. Green water bodies of salvinia controlled by this method need frequent care as these will again catch salvinia. The danger of salvinia is loss of water and prevention of sunlight reaching bottom of water body. Only selected fish is thriving under salvinia. Boat travel and human use of the water body is restricted as the plants occupy nearly half a meter. Reptiles live under the bush and myco-bacteria grow in water. This is not the case of eutrophication as the dissolved oxygen is maintained at good level. Lotus growth from the bottom of a freshwater tank has more transpiration.

Salt marshes of arid areas possess more thorny plants and provide breeding grounds for crabs and birds. Tides bring necessary nutrients while making surface drainage up and down on the sandy beaches.

6 **GROYNES AND REVETMENTS**

People express opposition to the formation of groynes generally but it is better than revetments to form some type of beach. Northern line of the beach is getting less sand due the obstruction caused by Thoduwawa groyne. Groyne is laid to clean the passage of estuaries from sand bars as in Kathaluwa, Mahamodera, Thoduwawa, Hikkaduwa, and Dewata by Irrigation Department. Sand bars are cut five times of the year and that sand is allowed to remove. Galle harbor is dredged near the jetties. Revetments along the heavily eroded sections were systematically laid under the program in Moratuwa, Bentara and Beruwala. Some places the revetment level was higher than the road. Tourism has low attraction in such areas. It was seen in recent years that the erosion in free areas are worse.

7 **DEVELOPMENT OF HARBOURS**

This is the most important development industry, which can bring employment to people. Small ports are suitable for fisheries improvement through motorboats. Major harbors may attract the ships traveling across Indian Ocean. Galle, Colombo, Hambanthota and Trincomalee are natural harbors, which can be improved to international requirements to accommodate all the modern techniques. This needs improvement to jetties, new breakwaters and connected road network for industrial development. However degradation of social values are very serious as it was noticed through the contraband passed through various entry points. The social unrest, growth of narcotics trade, induction of low quality literature, increased crime rate are features of present day exchange activities. Investors are responsible for the development but they usually practice harmful activities purely for the gain in profits. As a developing country the imposed conditions on the investor is not mandatory. Investors are ready to get profits by items like ship breaking which is harmful to the environment. Employment opportunities are needed due to growth of population.

8 **PADDY CULTIVATION**

Koggala Lake, Madu Ganga, Negombo Lake and many upstream tidal areas of rivers are earlier trained for paddy cultivation. Economically high income is recorded by paddy up to 1980. Salinity intrusion was controlled using wooden gates operated at the time of the high tides. Drainage gates are opened in normal hours. Salinity wedge rising with high tides damages paddy tracts. Many paddy tracts are abandoned due to losses. Irrigation Department maintained these projects. Reeds grow in saline soils and
farmers prefer to cultivate it. Bolgoda Lake area is now used by so many industrialists. Moratuwa is a furniture making populace city. Timber dust is gradually polluting Panadura Moratuwa River draining from Bolgoda Lake but still some fishermen catch fish in protected areas of the riverbed. Great lakes in the eastern coast are very good fishing grounds and pollution is least affected this part of the country due to civil war.

9 DRINKING WATER SUPPLY
Coastal areas are supporting nearly half of the population and the Kelani, Kalu, Gin, Nilwala and other rivers are presently using water in the tidal areas of rivers. During low base flows salinity enters the intakes and it becomes a problem to solve in future. Freshwater reservoirs are proposed using rubber dams in rivers. Upstream reservoirs are proposed but some villages are inundated. Salinity barriers are proposed as another method. Tidal flows are to be reduced by this weir laid across the low riverbed. But tidal flow jumps over the weir.

10 CONCLUSIONS
Coastal zone management needs proper physical planning to protect the ecosystems. Tourism, ports development, local industries, population distribution, water quality management, internal security and above all the peace among people are main features of a coastal zone management in Sri Lanka. These are the unending challenges we face in a coastal country.

Industrial pollution due to promoted zones is creating a new threat leading to pollution of tidal areas. Ports development increased the facility to fishermen to land the boats and keep it anchored. Small motorboats are now used for fishing but safe anchor places are less in number.

Mangroves are cut for various uses but reforestation is necessary for the reduction in salinity intrusion resulting in sea level rise. Trees can bring down the water level through transpiration.

New ports are planned for Oluwil and Hambanthota to serve international ships in future. Sand collections fill the constructed harbours and it needs a high cost of maintenance. Water transport activities of rivers using tides are limited to marshy areas and it is not economical.

Salinity barriers are now planned to construct near the mouth of major rivers as it is a continuing nuisance during low flows for water supply projects.

11 Acknowledgements
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OPEN DRAINAGE AND MOILING FOR DESALINIZATION of Salty Clay Soils of Northeastern Egypt

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ABSTRACT
This work is a part of composite studies dealing with problem marine clay salty lands of low level (0 m MSL), underlain by a permanent saline groundwater, and which had not yet been provided with subsurface drainage system. The study was conducted in the experimental drainage field at El-Serw Research Station, Northeastern Delta, near Lake Manzala with open field drains involving 2 spacing treatments 20 and 40. Later, moiling was executed perpendicular to the field drains. The objective of this article is to follow the extent of soil desalinization obtained with the above drainage practices, along 5 cropping seasons.

A slow, gradual, non-uniform decrease is observed in the salinity of the profiles of the test plots up to 120 cm. The decrease depends on the initial salinity of the profile layers. The degree of reduction is higher in 20m treatment. Compared to the initial state, highly significant reduction in the mean salinity of the profiles occurred in both spacing treatments at the last cropping season after moiling. Subsurface layers remained slightly saline. The reduction is realized in spite of the persisting high salinity of the groundwater. Moiling could be considered in conjunction with open drainage when dealing with similar soil conditions, which need special water management to raise productivity.

Key Words: Mole drainage, Open drains, Clay soil, saline groundwater table

1 INTRODUCTION
In Egypt, northern part of the Nile Delta represents large area of heavy clay soils with low permeability that might have a potential production. These soils are always threatened by a sallow saline groundwater. In the irrigated area, saline groundwater is a permanent source of soil salinization that causes poor productivity. The groundwater contribution in soil salinization is governed, to a large extent, by its fluctuation and solute movement through soil profile, whether in saturated or unsaturated state. This behavior is a function of different complicated factors of climatic and soils environmental conditions interacting together. Many investigators such as Simedema and Rycroft (1983), Ritsema (1994), Moukhtar et al, 1995 and 1998) mentioned that heavy soils of low hydraulic conductivity often require very closely spaced drainage systems for satisfactory water control. With conventional pipes, the cost of such systems is usually uneconomic and hence alternative techniques are required. Surface drainage is one possibility; the other is mole drainage.

The limited flow of water in salty clay soils restricts salt removal. This situation is aggravated if the shallow groundwater is highly saline; only shallow rooted crop can be grown. On the other hand, Moukhtar et al, (1995) decide that field drainage with open ditches alone is not quite satisfactory for a good crop production. Mole drainage, in combination with open drain ditches overcomes the slow water movement. A fast recession of water table upon irrigation is realized through fissure and cracks above the mole line. This is reflected satisfactory on soil salinity in the rootzone and leads to good and uniform vegetation. Moukhtar et al, (1995), (2002) and (2003) concluded that moiling combined with field drains could be highly recommended as an auxiliary drainage treatment in clay salty soils of low level with a saline water table to raise the soil productivity. It is a low cost measure...
needing no advanced machinery and small farmers instead of using narrow drain spacing, which wastes the area of agricultural land, can adopt it. In addition, this type of soil should not be left fallow even for a short period otherwise salinization quickly arises. Also, shallow root crops are preferred. Water submerged crops i.e. rice, amshout should be included in agricultural rotation.

The management of such soils depends essentially on providing efficient drainage conditions beside regular irrigation to preserve the rootzone from salinity in the cropping season and to restrict capillary rise from the saline groundwater between cropping seasons. The objective of this article is to follow the extent of soil desalinization obtained with the above drainage practices, along 5 cropping seasons.

## 2 MATERIALS AND METHODS

The site of the field under study (0 m MSL) is representative of northern low lands, fluviomarine clay salt affected soils of low productivity (mean clay content: 63.5% up to 90 cm soil depth with hydraulic conductivity: 0.0669 m/day). Moreover, they are assumed to lie in the zone of hydrostatic pressure. A main controversial factor is the extreme salinity of the groundwater table, which renders the desalinization process of the soil profile rather difficult. The mean EC: of soil profile is 25 dS/m, dominant salt: sodium chloride and magnesium exceeds calcium. (Moukhtar et al 1990). Crop rotation comprises in winter wheat, barley, clover, and sorghum, in summer corn, rise and sometimes cotton. Also in highly saline parts, submerged permanent forage crops (amshout) are grown and last several years in the land.

Drainage testing was monitored in replicate plots in an experimental field with open drain ditches involving 2 spacing treatments 20 and 40 m. Later and recently in 2000, moling was executed perpendicular to field drains, two meter apart and 50 cm depth. Water table depth was measured in observation well in the test plots; Calculated mean water table depth during 7 and then 13 days period of the irrigation intervals (about 2 weeks) was studied. Soil salinity was determined as EC in soil saturation extract. Soil desalinization obtained with the above drainage practices was recorded through 5 cropping seasons, three before moling and two after installation.

## 3 RESULTS

Monitoring water table fluctuation and drawdown rates were observed. In general, water table fluctuation differs among the test plots due to soil variability. The data shows that the mole drains were effective at the beginning of the irrigation interval. Five days after irrigation, the water table depth recedes deeper in the second and third season of years 2001 and 2002 (after moling was executed) than in the first season with open drains alone. The recession of water table after moling was faster in 20m spacing treatment. The effect of moling was not visible beyond 60 cm soil depth. Statistical analysis shows a highly significant difference between water table depth before and after moling in the fifth day after irrigation. In each period, the watertable depths in all the irrigation's are deeper under 20m than under 40m spacing treatment. On the other hand, the difference between values 20 m spacing treatment before and after moling is highly significant and significant in the first and second periods, respectively; whereas, in 40 m treatment, it was significant in the first period only. Concerning rate of water table drawdown, with drain alone, it was very low at the fifth day and then increased slightly (6.5cm/day) by one week. This increase might be due to existing bio-pores channels. Moling in conjunction with open drains realized a high rate of water table drawdown in almost all the irrigation's. Five days after irrigation, the rate of water table drawdown was deeper in 20m spacing treatment 12cm/day than in 40m treatment about 8 cm/day. This tendency demonstrates the beneficial effect of moling combined with open drains to prevent water logging in the rootzone.

In General, Results showed a gradual, non-uniform decrease in soil salinity of the different profile layers through the studied seasons. In the topsoil up to 60 cm, the decrease was quite obvious after moling where the EC of the soil saturation extract dropped to the convenient values around 4 dS/m or less. However, of the subsurface layers, still remained saline, although conceivable reduction is realized (Figure 1,2). Regarding monitoring soil desalinization and desodification, in general, the desalinization of the profiles occurred as a result of the decrease in salinity of the different soil layers. Another important beneficial
effect of the standing fresh water that keep the saline groundwater faraway enough from the rootzone and dilutes the upper part of it (El Hakim et al, 1990). Compared to the electric conductivity values, a decrease is realized in the topsoil up to 60 cm, especially in the surface layer (0-30 cm), the electric conductivity values decreased below 4 dS/m in both spacing treatments. There is invisible decrease in electrical conductivity values in subsurface layers (60-120 cm). These results might be explained by the effect of moling on water table recession, which occurred only around mole depth and thus contributing to an active salt transfer during the falling water table. It could be concluded that in heavy textured soils, the ponding conditions under rice culture, realizes desalinization of the surface soil layers and partly of the subsurface layers. Whereas, moling is effective in removing salts from the upper layers only. Salt transfer from deeper layers depends on the drainage efficiency.

Regarding average profile salinity in each treatment, statistical analysis showed significant and highly significant reduction after rice cultivation and after moling, respectively, compared to the initial salinity. The average salinity of the profiles in 20m spacing treatment dropped from an initial value of 8.7 dS/m to 5.3 dS/m after rice and to 4.8 dS/m after moling, whereas in the 40m spacing treatment, it dropped from 7.1 dS/m to 4.8 dS/m after rice and to 4.4 dS/m after moling.

![Figure 1](http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20open%20drainage%20and%20moling.html)  
*Figure 1  Mean salinity in the profile layers in successive years for 20 m spacing treatment.*
Figure 2  Mean salinity in the profile layers in successive years for 40 m spacing treatment

Figure 3  Mean groundwater depth (cm) and salinity in the successive years for both drainage
Regarding soil desodification after rice and gypsum addition, the decrease in exchangeable sodium percentage ESP was confined only in the upper 30 cm soil depth, where the ESP decreased from values of 20 and 25 to around 10 and 15 in 20 m and 40 m spacing treatment, respectively.

The reduction occurred in spite of the persisting salinity of the groundwater table till the last season. Initial average groundwater EC of the profile plots in each treatment at the first season was 34.0 dS/m at 69 cm depth and 26.0 dS/m at 66 cm depth in 20 and 40 m spacing treatment, respectively (Figure 3). At the last season (year of 2002) after moling, the average EC was still high but at a deeper depth; EC being 28.6 dS/m and 20.9 dS/m at 85.3 cm and 75.5 cm depth in 20 and 40 m spacing treatments, respectively.

With respect to crop growth conditions, during the first summer season (1989), sorghum growth was not uniform; many barren patches were found in the field. Whereas in the season where moling was executed, and in the following season, sorghum growth became normal and the barren patches totally disappeared. This is due to the improvement that occurred in the rootzone conditions, as a direct effect of soil desalinization and to the faster water table recession upon irrigation as a result of moling.

It may be concluded that, moling combined with field drains is an adequate auxiliary drainage treatment in clay salty soils of low level with a saline water table top reserve the rootzone from water logging and salinity.

4 REFERENCES


DRAINAGE AND ROLE OF MOLE DRAINS FOR HEAVY CLAY SOILS UNDER SALINE WATERTABLE, EGYPT


ABSTRACT
In Egypt, northern part of the Nile Delta represents large area of heavy clay soils with low permeability that might have a potential production. These soils are always threatened by a sallow saline groundwater. In the irrigated area, saline groundwater is a permanent source of soil salinization that causes poor productivity. The groundwater contribution in soil salinization is governed, to a large extent, by its fluctuation and solute movement through soil profile, whether in saturated or unsaturated state. This behavior is a function of different complicated factors of climatic and soil environmental conditions interacting together. The present study is conducted in drainage experimental field, northeastern Nile Delta, representative of this land. The aim is how to sustain clay soil management under saline ground water table for a good crop production. Also to represent local Egyptian experiences for maintaining the soil at its high productivity. The results, obtained through ten years in consecutive research phase, could be summarized as follows: (i) Water table depths and its salinity play an important role in the root zone activity by affecting soil salinization, morphological feature, chemical process and most of hydro physical characteristics. (ii) At the first stage of study, open drains at narrow spacing and shallow depth encouraged the reduction of topsoil salinity. (iii) Gypsum with open drains lowered exchangeable sodium percentage in the upper soil layer. (iv) Mole drains perpendicular to open drains accelerated downward water movement to the depth of mole plow. Soil salinity and alkalinity in the root zone was maintained under the permissible level to sustain a convenient production. (v) Introducing tile drainage system, the average water table depth increased. (vi) After tile drainage further desalinization is realized in topsoil and also in deeper layers. Alkalinity is somewhat still higher than required in subsurface soil. The gained improvement water table behavior was reflected on the morphological features of water table fluctuation zone. (vii) To complete the picture of soil conservation, under good drainage conditions, irrigation management is an essential practice for soil productivity. Reducing irrigation intervals and increasing leaching requirement will build a permanent film of fresh water above the saline groundwater. Capillary rise is reduced; soil profile salinization and degradation are prevented.

Key Words: Heavy Clay Soil, Shallow Saline Groundwater, Role of Drainage, Mole drainage.

1 INTRODUCTION
The Nile Delta and the Nile valley of Egypt, is one of the oldest agricultural areas in the world, having been under continuous cultivation for at least 5000 years. The arid climate of Egypt, characterized by high evaporation rates (1500 - 2400 mm/ year), and little rainfall (5-200 mm/year), leaves the River Nile as the main fresh water supply. The Delta of the Nile appears as a triangle broader at its base than the sides. The area of the Nile Delta is 22000 square Kilometers, with length and maximum width of 170 and 220 Kilometers, respectively. The drainage problem areas are defined as those areas with unusual conditions, which require unconventional design and/or a different implementation technique. Unusual conditions may be related to crops, soils or hydrology in the area. Low coastal lands in the northeastern periphery of the Nile Delta are considered problem soils due to composite controversial factors: (i) They are salt affected soils, (ii) the presence of a saline groundwater constitutes source and permanent threat for soil salinization, (iii) they are heavy clay soils salt removal is difficult, (iv) They are assumed to lie in the zone of upward movement of water flow and (v) Groundwater is shallow and highly saline. These are huge areas which representing clay salt-affected soils of poor productivity. Water management in such lands needs much attention, especially in countries with limited land resources and continuous increasing population. Heavy clay soils posses a high inherent fertility that gives them excellent potential for agricultural production. Clayey soils with shallow and highly saline ground water in the northern part of the Delta, lying in the zone of upward movement, are subject to severe salinity problems. For these reasons, water table depth plays an important role in soil properties and crop productivity. Unfortunately, in many semi arid and arid areas under irrigation, poor internal drainage in similar soils has led to salt accumulation that resulting insignificantly reduced yields and/or abandonment of the land. Local experience is very important to deal with the problem. The most important feature is the highly saline shallow ground water, which creates Procedures for soil desalination through leaching and drainage showed successful in some areas but were disappointing in other areas. As mentioned by FAO consultants (1980), local experience is rarely transferable to other locations. The difficulty of desalination in clay soils might arise from the preferential type of water flow. Since leaching water may pass only through macropores and not within clay peds. Consequently improving leaching efficiency through artificial reconstruction would be a possible solution (Moustafa, 1984; Tanton et al, 1990).

The need for a new approach to reclamation of saline soils had become evident during a project carried out at El-Zawia Reclamation Project, near Kafr-
El-Sheikh in the northern Nile Delta (Pearce, 1984). This project had focused on the lake of success of standard reclamation procedures in desalinating the heavy, saline-sodic, montmorillonitic clay soil. Existing field-ditch drainage was initially identified as inadequate for the very low permeability soil. Also the lack of initial gypsum application was shown to have a detrimental effect on the infiltration of leaching water. The project investigated whether improved drainage methods, which included gypsum addition, would provide a new, economically viable reclamation success. The drainage methods tested were: (1) Tile-drains (1.5m depth at 12.5m spacing), (2) fabric-wrapped gravel tubes (1.5m depth at 12.5 m spacing), (3) shallow, close-spaced ditches (0.5m depth at 8m spacing), (4) mole drains (0.75m depth at 1.8m spacing), (5) well-points (A grid of 5m deep well points penetrating to the bottom of underlying silt, at 25m spacing, connected to a single pump), and (6) control (Existing field-ditches at 0.8m depth and 25m spacing). The methods were designed for a water-table depth of 1.0m and a drain discharge rate of 5mm/day. Both intermittent and continuous leaching was carried out. At the end of trials, only the tile-drains had shown any significant reduction in salinity profile. However, the rate of removal was still too slow for economically valuable reclamation. After 15 months of ponding, the salt content of the soil had only decreased from 6.5 % to 4.5% (of dry weight) and the rate of reduction was leveling off. Furthermore, only 27% of the removed salt had left via drains the remainder had been lost by deep percolation down to a side specific underlying silt layer, and ignored the presence of the drains. The project concluded that conventional drainage by itself was in sufficient for reclamation to succeed in this type of soil. It also identified a number of further complicating factors, such as the decrease in observed drain water Ec over the course of the tile-drain trial due to the establishment of preferential routs between clay peds. Laboratory and field studies have identified the reasons why these fields’ methods have failed, and have pointed to the need for greatly improved permeability within the soil. (Pearce, 1984)

The rapid swelling of the soil matrix on wetting causes closure of cracks and macro-pores, rendering the soil virtually impermeable (Tanton et al, 1990). In this state the high intensity of land drains needed for effective leaching of salts make reclamation projects economically unviable. Tanton et al, (1990), working in Turkey on restructured heavy saline montmorillonite clay in a polythene lined trench, 25m long and 0.75m deep, have shown that it is possible to remove 85% of leachable saline from the soil in 16 days. Most of the salt was released in the first eight days. The method of leaching was to apply water to one end of the trench and allow it to pass through the soil profile to a drain at the opposite end. The hydraulic conductivity (K), which prior to restructuring was <0.1 m/day, always exceeded 25 m/day. This experiment clearly demonstrated that it is possible to leach a heavy clay saline to a depth of 0.7m by artificially restructuring the soil and establishing a horizontal flow of water through the restructured soil. Armstrong et al (1990) constructed field that was subsoiled to a depth of 0.7m at 0.6 m spacing in three directions (longitudinally, laterally and diagonally). They found that during field trial described large hydraulic conductivity were maintained and 58% of leachable salts were removed in a four-week leaching period. Adaptations of the technique to improve leaching efficiently were suggested restructuring and leaching was found to prevent soil structural deterioration.

Secondary drainage treatments might be moling which a technique of moling seeks to place inexpensive “drain” at close spacing, intercepted by permanent laterals at wider spacing. Moling is the best suited to clay soils with a minimum clay content of about 30%. When during installation the moisture content at mole depth is near the lower plastic limit. Subsoiling in the drainage mode seeks to lift and shatter the soil peds to induce improved structure and so improve the water movement to the permanent pipe system.

1.1 The Objectives

The above conditions of heavy clay water logged soils associated with highly saline ground water constitute a challenging problem. The solution must achieve lowering the water table at the end of the irrigation interval and accelerating the downward movement in the surface layers. Thus irrigation water constitutes a temporary front separating the saline ground water from the root zone. Also, it aims to reclaim deteriorated clay-salty low permeable soil threaten with shallow saline groundwater table during agricultural processing for improving weaken rootzone layer and sustainable lands for good productivity. To achieve this goal, consecutive trials have followed and mentoring.

1.2 General Description of El-Serw Farm

The present work is conducted in El-Serw Farm, Ministry of Agriculture, north of El-Dakahlia governorate. It is representative area of northern lands. El-Serw farm has an area of 1100 feddans (1 feddan=4200 m²). It is about 200 km north of Cairo, 60 km west of Port Said Province and 40 km east of River Nile (Damiatta branch). The northeastern boundary is about 1 km far from El-Manzala Lake. The area is situated at latitude of 31° 14’N and the longitude is 29° 15’ E. Therefore, it lies in the coast area according to the agroclimatologically division made by Rijetema and Abokhaled (1975). The farm boundaries are at north El-Harrana main drain, at east and south El-Serw main drain, both meeting at the drainage pumping station, El-Serw Lower station. The land surface of the area can be described as plain. It has an approximate elevation of “0 m” above sea level. Meteorological data over more than 30 years are available from the nearest two stations to El-Serw farm, Port Said and Sakha stations. The main characteristics of the climate are long dry summer and rarely winter rainfall. The annual rainfall is about 80 mm/year. The main annual temperature is around 20.1 °C. The daily maximum temperature rises occasionally over 32.2 °C in summer and the minimum night temperature in winter falls to about 8.7 °C. Vapor pressure is around 17.0 mill-bars as mean value. The mean annual wind velocity is around 2.2 m/sec. The percentage of sunshine is around 77%. El-Shoka main irrigation canal, 11 Km long, takes its source from El-Sarouk Ganabia at the right bank of Damiatta branch, runs from east to west and ends in El-Harrana main drain. It crosses the lands of the El-Serw farm in the last 3 Km of its course. Two main drains from the boundaries of the area are at the end of their course. El-Harrana drain bounds the area on the north and El-Serw main drain on the south and east. The two drains end in El-Serw farm has an area of 1100 feddans (1 feddan=4200 m²). It is about 200 km north of Cairo, 60 km west of Port Said Province and 40 km east of El-Manzala Lake. Since the area lies on the tail of the irrigation canal, irrigation water is not always enough to face the demand of the area; water of the main drains is used occasionally for irrigation. Crop rotations...
comprises in winter wheat, barley, clover, and sorghum, in summer corn, rice and sometimes cotton. Also in highly saline parts, submerged permanent forage crops (amshout) are grown and last several years in the land.

2 MATERIALS AND METHODS

(i). In late 1987, a pre-investigation of hydropedological studies were conducted in El-Serw Research Experimental Farm, near lake Manzala northeastern Delta.

(ii). In 1988, an experimental drainage field of 20 feddans, was conducted in El-Serw Research Station Farm. The field involves open field drains with 2 spacing treatments 20m and 40m, since subsurface drainage did not cover the area at the time of this study. Later in 1991, moling was executed perpendicular to field drains, 2m apart and 50 cm depth. Gypsum doses (5 Tons/feddan; 1 feddan= 42000m²) were added to the field in different seasons. Sorghum for animal grazing was cultivated in the summer of 1989, 1991 and 1992 and rice in 1990. Like most of the northern lands, the field lies on the tail of the main canal, irrigation water is frequently insufficient. Drainage water from El-Serw main drain (year EC ranges from 1.1 - 2.3 dS/m, average EC 1.5 dS/m), is pumped to feed the canal. Water entering the field irrigation ditch had an EC ranging from 0.7 - 2.2 dS/m with an average of 1.2 dS/m (800 ppm). In every sorghum season, watertable position was measured at several days after some irrigation's in watertable observation wells placed midway drain spacing. Also soil samples were collected from profile layers every 30 cm up to 120 cm depth. Salinity was determined in soil saturation extract according to Black(1965). ESP was determined using modified Hissink’s method. Moreover, rice grain was determined in each plot.

Drainage testing was monitored in replicate plots in an experimental field with open drain ditches involving 2 spacing treatments 20 and 40 m (Fig. 1) without moling in 4 cropping seasons, and in conjunction with moling in the following 3 cropping seasons. Water table depth was measured in observation well in the test plots and soil salinity was determined as EC in soil saturation extract.

3 RESULTS AND DISCUSSIONS

3.1 Hydropedological Features for Deteriorated Soils and classification

In late 1987, a pre-investigation of hydropedological studies were conducted in El-Serw Research Experimental Farm. The clay content reaches 63.5% up to 90 cm depth. The soil is low permeable, average hydraulic conductivity is 0.0669 m/day. A permanent saline groundwater table (average 25 dS/m mainly sodium chloride) is the main source of soil salinization and alkalinization due either to its direct contact with the subsurface soil or by capillary rise in the topsoil. Soil salinity increases with soil depth since salts in the topsoil are more or less effectively leached upon irrigation. But severe soil salinization occurs even in the topsoil under fallow conditions. The topsoil salinity reached a value of 40 dS/m in a field left fallow for several seasons, with a groundwater salinity of 59 dS/m at 102 cm depth. Obviously if brought back for cultivation, its desalinization will be difficult. The main ions are sodium and magnesium chloride. The soil salinity is strongly related to the watertable depth and its salinity. Watertable depth varied between 53 cm and 100 cm, the deepest depth is always found adjacent to the main drain and the shallowest value adjacent to the main irrigation canal.

<table>
<thead>
<tr>
<th>Profile</th>
<th>Adjacent to the Main Canal</th>
<th>Adjacent to the Main Drain</th>
<th>In Between</th>
<th>Fallow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Layer (cm)</td>
<td>0-30</td>
<td>5.5</td>
<td>3.7</td>
<td>5.6</td>
</tr>
<tr>
<td></td>
<td>30-60</td>
<td>5.9</td>
<td>4.7</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>60-90</td>
<td>15.0</td>
<td>6.1</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>90-120</td>
<td>22.6</td>
<td>6.7</td>
<td>21.1</td>
</tr>
<tr>
<td>Water Table:</td>
<td>Salinity</td>
<td>22.3</td>
<td>15.4</td>
<td>18.1</td>
</tr>
<tr>
<td></td>
<td>Depth (cm)</td>
<td>53</td>
<td>100</td>
<td>78</td>
</tr>
</tbody>
</table>

If returned to cultivation, its desalinization will be difficult (Moustafa et al., 1990; Michaelsen et al., 1993). It is worthy to mention that soil adjacent to the main drain is protected from degradation as shown from the relative low salinity especially in the upper 60 cm. Generally, salt content in the soil is strongly related to the watertable depth and its salinity (Moukhtar et al., 1990a,b; Ismail, 1996). The dominant salt either in groundwater or in soil is sodium chloride, magnesium ions exceed calcium. On the other hand, the deepest water table is always found adjacent to the main drain and the shallowest adjacent to the main irrigation canal.
Moukhtar et al. (1990) attempted to set a required water table depth for salinity control. For the area under study, it is given by the highly significant regression equation relating the mean EC soil profiles to their corresponding water table depth:

\[ EC_s = 20.0439 - 0.1385 \times wt \]

Here, \( EC_s \) : Mean soil profile EC (dS/m) and \( wt \) : watertable depth (cm).

If a mean soil profile EC has to be maintained at 5 dS/m or 3 dS/m, the above equation gives a required water table depth of 109 and 123 cm, respectively. These depths are close to the value of 120 cm suggested by FAO consultants (1980) in the drainage design for fine textured plow permeable soils, during irrigation season. On the other hand, the design water table criteria of 1.0 m adopted in the Nile Delta might be slightly increased when dealing with northern heavy lands underlain by saline groundwater. On the other hand, relating the mean profile \( EC_s \) to both groundwater depth and salinity, a highly significant multiple regression equation is obtained:

\[ EC_s = 16.738 - 0.124 \times wt + 0.089 \times EC_w \]

Here, \( EC_w \) : Water table EC, dS/m.

Substituting the mean soil profile EC value which has to be maintained (5 or 3 dS/m) and the corresponding groundwater depth (109 or 123 cm), obtained in the first equation, the respective groundwater EC which may prevail in each case is found to be 21.8 and 19.3 dS/m. They concluded that lowering water table by means of drainage is of primordial importance, so that saline groundwater is not able to link with the upper soil layers. Depth of 110 - 120 cm seems to be adequate. Soils should not be left without irrigation to avoid capillary salinization. Gypsum amendment is needed to treat soil sodicity, which leads to collapse of soil structure.

### Table 2  Mean Ec soil profile (\( EC_s \)), water table Ec (\( EC_w \) and drawdown rate relationship(DDR)).

| Parameters | \( r \) | Regression equation | DDR cm/m
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( EC_w ) and DDR vs ( EC_s ) (30cm)</td>
<td>0.88</td>
<td>( EC_s = 4.023 + 0.126 \times EC_w - 0.347 \times DDR )</td>
<td>3.70 7.33 10.96</td>
</tr>
<tr>
<td>( EC_w ) and DDR vs ( EC_s ) (60cm)</td>
<td>0.94</td>
<td>( EC_s = 5.125 + 0.100 \times EC_w - 0.411 \times DDR )</td>
<td>5.17 7.60 10.04</td>
</tr>
</tbody>
</table>

El-Hakim et al. (1990) studied groundwater table variations during irrigation intervals in the same area. They show that highly significant correlation is found between both the groundwater EC (\( EC_w \)) and the rate of drawdown DDR, and soil EC (\( EC_s \)). Also, the interaction of both factors on soil EC can be described by the significant and highly significant multiple regression equations respectively (table 2).

As is expected, the equations show that as the groundwater salinity increases and/or deeper desalinization the soil profile is required, the rate of drawdown should be increased. Assuming that a soil EC of 4 dS/m is required up to 60-cm soil depth, and if the groundwater EC is 10, 20, or 30 dS/m, the second equation gives a respective rate of drawdown of 5.2, 7.6 or 10 cm/day. This means that water table depth should drop to 60 cm in a maximum period of 11, 8 or 6 days, respectively in the early months of the growing season.

If the drainage conditions cannot meet these requirements in a certain period, supplementary practices to improve drainage efficiency such as subsoliling can be used periodically (Moukhtar et al, 1990). Moling or subsoliling will enhance downward movement of irrigation water carrying off excess salts from surface layers. After wards, regular subsequent irrigations will gradually reduce the salt content in groundwater at least when close to soil surface. The percolating water will constitute a temporary front preventing the saline groundwater in subsurface soil layers from linking with the upper ones.

### 3.2 Design Proposal

Regarding the ground water depth to be maintained in order to reduce capillary salinization for heavy soils as recommended by FAO (1980) is 1.4 m during the fallow season and 1.2 m for drain spacing design for the irrigation season using steady state formula. In a previous, Moukhtar et al (1990) found by statistical computation under the conditions of the studied area, that the water table depth should be maintained at a level of 110 cm or 125 cm to keep the mean soil profile salinity at 5 or 3 dS/m, respectively. These depths are close enough to the water table depth of 120 cm, suggested by FAO (1980) to be used in drain spacing for heavy textured soils. The drainage discharge criteria used in the Delta is 1 mm/day; in such problem lands, it is recommended that a discharge of 1.5 mm/day might be useful to face leaching process. Accordingly, drainage parameters for the area under study.

http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20moukhtar%20-drainage%20and%20role%20of%20mole.html (4 of 9) 26-4-2010 12:12:19
for spacing design calculations using Houghoudt formula (1940): \( L^2 = \frac{(8 \times k \times d \times h)}{q} + \frac{(4 \times k \times h^2)}{q} \)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic conductivity K</td>
<td>0.0669 m/day</td>
</tr>
<tr>
<td>Depth of field drain</td>
<td>1.5 m</td>
</tr>
<tr>
<td>Pipe diameter</td>
<td>0.08 m</td>
</tr>
<tr>
<td>Depth of dewatering zone</td>
<td>1.2 m</td>
</tr>
<tr>
<td>Design of hydraulic head h</td>
<td>0.3 m</td>
</tr>
<tr>
<td>Discharge rate q</td>
<td>0.0015 m/day</td>
</tr>
<tr>
<td>Equivalent depth “Moody, 1966) d</td>
<td>0.9 m</td>
</tr>
<tr>
<td>Calculated drain spacing L</td>
<td>10.6 m</td>
</tr>
</tbody>
</table>

It should be said that spacing less than 20 meter is uneconomic. Therefore, wider spacing accompanied with auxiliary treatments should be tested. Moleing is to raise the efficiency of subsurface drainage (Spoor et al, 1990) and Moukhtar et al (1998). In one of the areas representing northern lands (an experimental field with open field drains under consideration in this work), Moukhtar et al, (1990) and El-Hakim et al, (1990) pointed to the need of increasing the rate of water table drawdown after irrigation, through auxiliary drainage measures, in order to restrict detrimental effect of the saline groundwater around the rootzone.

### 3.3 Soil Morphological and Classification:

Recently, the soil morphology and classification for the El-Serw Farm were studied by Abdel-Aal (1995). The soil classification of the study area is Aquic chromuderts, fine, montmorillontic, thermic.

#### 3.3.1 Drainage and Soil Conservation

The main purpose of drainage is not only to remove of excess water but to prevent soil degradation. Local experience showed that the salinity of the falling water table varied according to its position during the irrigation intervals. For the soils under study, the saline groundwater table should first be considered as to its effect on the upper soil profile until 50-60 cm depth, which includes the rootzone and which must be preserved from water logging and salinity. Through enhancing the downward water movement in the first days after irrigation, excess salts could be removed from the rootzone and the fresh irrigation water will constitute a temporary front separating the saline groundwater from the rootzone. On the other hand, the saline groundwater increases the drainage requirements that mean that the rate of water table drawdown should increase.

### 3.4 Monitoring Water Table fluctuation and drawdown rates

In general, water table fluctuation differs among the test plots due to soil variability. The data shows that the mole drains were effective at the beginning of the irrigation interval. Five days after irrigation, the water table depth recedes deeper in the second and third season years 1991 and 1992 (after moleing was executed) than in the first season with open drains alone. The recession of water table after moleing was faster in 20m spacing treatment. The effect of moleing was not visible beyond 60 cm soil depth. Statistical analysis shows a highly significant difference between water table depth before and after moleing in the fifth day after irrigation. The water table recession (Moukhtar et al, 1995, 1998a) after irrigation was rather slow both for 20 or 40 m spacing in the experimental field. As shown in Fig. 2, the rate of water table drawdown in the rootzone did not exceed 6 cm/day in the first season. However, much improvement in water table recession occurred when moleing was introduced. Water table dropped to about 50 and 40 cm in 5 days in treatments with 20 and 40 m spacing respectively. The rate of water table drawdown values were around that required (8 - 10 cm/day), values being higher in 20 m spacing treatment. Previous studies by El-Hakim et al (1990) showed that a rate of water table drawdown of 8-10 cm /day under a saline groundwater of 20-30 dS/m must be obtained in the upper 60 cm. The beneficial effect of moleing is to avoid the harmful stagnation of irrigation water and dissolved salts around the rootzone. The downward water movement is enhanced through cracks and fissures developed by the mole plough blade and water is evacuated partly through the mole drains (Moukhtar et al, 1998a).

Calculated mean water table depth during 9 and then 13 days period of the irrigation intervals (about 2 weeks) is illustrated in table (3). In each period, the values in all the irrigation’s are higher under 20m than under 40m spacing treatment. On the other hand, the difference between values 20 m spacing treatment before and after moleing is highly significant and significant in the first and second periods, respectively; whereas, in 40m treatment, it was significant in the first period only.

### Table 3 Mean watertable depth (cm) during 9 and 13 days periods of the irrigation interval.

<table>
<thead>
<tr>
<th>Spacing Treatments</th>
<th>Days after irrigation</th>
<th>Dates of Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1989 1991 1992</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/8 16/8 1/9 16/9 13/8 3/9</td>
</tr>
<tr>
<td>20 m</td>
<td>9</td>
<td>47.0 53.0 55.3 54.5 53.9 59.3</td>
</tr>
</tbody>
</table>
Computed rates of water table drawdown (DDR) at the fifth, ninth and thirteenth days in the irrigations prior and after moling indicated that, with drain alone, the rate of water table drawdown was very low at the fifth day and increased slightly (6.5 cm/day) at the ninth day. This increase might be due to existing biopores channels. Moling in conjunction with open drains realized a high rate of water table drawdown in almost all the irrigations. Five days after irrigation, the rate of water table drawdown was higher in 20m spacing treatment (DDR about 10 cm/day) than in 40m treatment (DDR about 8 cm/day) in 20m and 40m spacing treatment, respectively (fig.2). This demonstrates the beneficial effect of moling combined with open drains to prevent waterlogging in the rootzone.

### 3.5 Monitoring Soil Desalinization and Desodification

The desalinization of the profiles occurred as a result of the decrease in salinity of the different soil layers. The average EC values of the consecutive soil layers in each spacing treatment, in the different seasons, are shown in figure (2). Data shows that prior to rice, the mean initial salinity in 20 m spacing treatment was higher than that in 40m treatment, whereas after rice the salinity decrease obtained was more pronounced in the narrower spacing treatment. After rice, EC values decreased to values around 4 dS/m in both treatments, in the surface 60 cm layers (the effective rootzone). Also EC values decreased in the subsurface layers, however they remained still saline. During the growing season, water increments are supplied every few days to the rice field to bring the level of the ponded water to about 6 cm.

![Figure 1](http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20moukhtar%20-drainage%20and%20role%20of%20mole.html)  
**Figure 1** Rate of drawdown after irrigation in the consecutive seasons in 20 and 40 m spacing treatments before and after moling (above and below mole depth).

![Figure 2](http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20moukhtar%20-drainage%20and%20role%20of%20mole.html)  
**Figure 2** Mean EC (dS/m) in upper layer (0-60 cm) and deeper layer (60-120 cm) in season before and after moling under 20 m and 40 m drain spacing treatments
Thus a pressure head is always present and consequently a downward flux of water takes place. Some of the standing water infiltrates and percolates through the rootzone dissolving and carrying off soluble salts. Another important beneficial effect of the standing fresh water, specific of the soil under study, is that it keeps the saline groundwater far enough from the rootzone and dilutes the upper part of it (El Hakim et al, 1990).

One year after moling execution, at the end of the cropping season 1992, the mean salinity EC of the different soil layers of the profiles representing each treatment is shown in figure (3). Compared to the EC values after rice, a decrease is realized in the topsoil up to 60 cm, especially in the surface layer (0-30 cm), the EC values decreased below 4 dS/m in both spacing treatments. No EC decrease was shown in subsurface layers 60-90 and 90-120 cm. These results might be explained by the effect of moling on water table recession, which occurred only around mole depth (figure 3), and thus contributing to an active salt transfer during the falling water table. It could be concluded that in heavy soils, the ponding conditions under rice culture, realizes desalinization of the surface soil layers and partly of the subsurface layers. Whereas, moling is effective in removing salts from the upper layers only. Salt transfer from deeper layers depends on the efficiency of drainage. On the other hand, a highly significant difference exists between the mean EC values of the soil layers in both treatments prior to and after rice, while no significance is found between EC values after moling and that after rice. Regarding average profile salinity in each treatment, statistical analysis showed significant and highly significant reduction after rice cultivation and after moling, respectively, compared to the initial salinity. The average salinity of the profiles in 20m spacing treatment dropped from an initial value of 8.7 dS/m to 5.3 dS/m after rice and to 4.8 dS/m after moling, whereas in the 40m spacing treatment, it dropped from 7.1 dS/m to 4.8 dS/m after rice and to 4.4 dS/m after moling. The obtained data of soil desalination after rice and gypsum addition indicated that the decrease in exchangeable sodium percentage ESP was confined only in the upper 30 cm soil depth, where the ESP decreased from values of 20 or 25 to around 10 and 15 in 20 m and 40 m spacing treatment respectively.

In (1994 -1995), subsurface tile drainage was constructed after improved technique and substitute open drains. Tile drainage was mechanically installed; corrugated plastic laterals are 100 m in length and 150 cm depth at the field end. The collector line is 600 m long and its outlet is in the main drain El-Serw. The experimental field was designed with three drain spacing treatments separated by buffer zones: 15 m spacing (calculated spacing according to the steady state formula, Houghd, 1940); 30 m spacing (conventional spacing adopted in the surrounding areas) and (iii) 60 m spacing (double of the conventional spacing for future drainage treatments). The drain spacing treatment highly affects the water table depth. Water table affected layers have been increased with depths; these become more evident with narrow spacing. Deeper desalinization occurred. The fiber yield of cotton (deep root crop) also show variations in the different treatments; the yield increased from less than 4 to about 8 Quantar/feddan as the drain spacing decreased from 60 m to 15 m (1 Quantar = 157.5 kg; 1 feddan =4200 m²). Full detail is presented by (Moukhtar et al, 1998b,c).

In (1999 -2000), mole drainage was constructed in separated experiment. The aim is to develop suitable local techniques for land improvement in rootzone and sustainable agriculture. An experimental field was designed with different treatments of mole drain spacing 0, 3.0, 2.0 and 1.5 m combined without or with gypsum addition. Rice was cultivated in the summer of 1999 and 2000. All agricultural practices are similar to that in neighbour fields. Irrigation water salinity ranges from 1.5 to 2.0 dS/m. In the first year, results revealed that only negligible reduction in salinity occurred in the plots under 3 m mole spacing with or without gypsum. Better desalinization is obtained in plots under 2 m and 1.5 m without gypsum up to 60 cm soil depth. Salinity reduction is clear enough under the same spacing with gypsum, since the EC dropped to values around 6 and 5 dS/m, respectively. For exchangeable sodium percentage, ESP, the soil at all depths is initially highly sodic ESP>40. The sodicity almost persists in the different treatments, even in plots under 2 and 1.5 m mole spacing either without or with gypsum, the sodicity is still high (ESP~26). The rice yield in the control being 1 Ton/feddan reached 2.6 and 1.75 Ton/feddan under 1.5 m treatment with and without gypsum, respectively. Almost the same yield is obtained with 2 m spacing. In the second year, there is a progressive improvement in soil conditions. In general, salinity decreased with decreasing mole drain spacing; EC dropped to less than 4 dS/m in 1.5 m mole drain spacing with gypsum treatments comparing to the other treatments. Regarding exchangeable sodium percentage, there is a relative reduction in ESP at the soil surface than in the deeper depth especially with gypsum and narrow drain spacing. The ESP is still high. Concerning plant growth and production, there is a good cover plant for mole drain spacing especially with gypsum treatments compared to that without gypsum addition. The best treatment is 1.5 m mole drain spacing with gypsum. Data of rice yield follows the same trend to that in the first year with a relative increase in all treatments. A full detail is found in published paper by Moukhtar et al (2003).

### 3.6 Crop Growth Conditions

During the first summer season (1989), sorghum growth was not uniform; many barren patches were found in the field. Whereas in the season 1991 where moling was executed, and in the following season 1992, sorghum growth became normal and the barren patches totally disappeared. This is due to the improvement that occurred in the rootzone conditions, as a direct effect of soil desalinization and to the faster water table recession upon irrigation as a result of moling.

In the summer of 1990, rice culture showed a well uniform stand in the whole field. During the growing season, the layer of ponded water, renewed every few days, had a depth of about 6 cm. Its average salinity was 2.1 dS/m. A high grain yield was obtained, the average being 3.4 tons/feddan and 3.8 tons/feddan in 20 and 40m spacing treatments respectively. Whereas, under the same agricultural practices the average grain yield in the neighboring fields in El-Serw farm was 1.870 Tons/feddan. No significant difference in the grain yield was found between the two spacing treatments. The relatively high grain yield realized in the experimental field may be due to the gypsum addition and to the good maintenance of the field drain...
ditches.

The limited flow of water in salty clay soils restricts salt removal. This situation is aggravated if the shallow groundwater is highly saline; only shallow rooted crop can be grown. Although rice tolerates soil salinity (only moderately), it can tolerate exchangeable sodium in appreciable amounts. The standing water layer realizes a dilution in the topsoil solution and in addition displaces down the saline groundwater in the subsurface soil layers. Thus, conceivable desalinization may take place in the whole soil profile. Rice crop should be included in any crop rotation in salty clay soils, whenever irrigation water is sufficient.

On the other hand, field drainage with open ditches alone is not quite satisfactory for a good crop production. Mole drainage, in combination with open drain ditches overcomes the slow water movement. A fast recession of watertable upon irrigation is realized through fissure and cracks above the mole line. This is reflected satisfactory on soil salinity in the rootzone and leads to a good and uniform vegetation.

4 Conclusion and Recommendation

- Moling combined with field drains is an adequate auxiliary drainage treatment in clay salty soils of low level with a saline water table top reserve the rootzone from water logging and salinity.
- It is a low cost measure needing no advanced machinery and small farmers instead of using narrow drain spacing that is highly costly and wastes the area of agricultural land can adopt it.
- This type of soil should not be left fallow even for a short period and dalled irrigation should be avoided, otherwise salinization quickly arises.
- Shallow root crops are preferred.
- Water submerged crops i.e. rice, amshout should be included in agricultural rotation. Care for tillage operations should be followed.

5 REFERENCES

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http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20moukhtar%20-drainage%20and%20role%20of%20mole.html (8 of 9)26-4-2010 12:12:19

ABSTRACT

Most of deteriorated salty clay soils are found throughout the northern periphery of the Nile Delta. The clay cap is about 40 meters. It is the highly saline shallow ground water, which creates soil water logging, salinity and/or alkalinity associated with severe decline in soil structure and soil aeration. Since leaching water may pass only through macro-pores and not within clay peds. Consequently improving leaching efficiency through artificial re-structure would be a possible solution. The aim is to improve water table condition in deteriorated soil by drainage technique. The experimental drainage field constitutes a main treatment of subsurface drains at 15 m, 30 m and 60 m spacing. The sub main is subsoiling at control, one direction perpendicular on tile drains and two directions as net structure.

The maximum water table depth reached depends mainly on drain spacing and subsoiling treatments for wheat, sorghum and clover. The drain spacing and subsoiling type as well as interaction between them is highly affected on water table depth. They are following: 15 m > 30 m > 60 m drain spacing and net > parallel > no subsoiling. The best treatment for dropping water table is 15 m spacing combined with net subsoiling for three seasons. These types of drainage especially in heavy clay low permeable soil the flow of water is highly accelerated drawdown as a result of loosening and fissuring up to the depth of subsoiling plow. Afterwards, watertable drown rate depends on the distance of drain spacing. The configuration of water table shape for 15 m spacing made a hump especially with net subsoiling treatment but it was a curve for 30 m spacing and a flat for 60 m spacing. It means that the drained area followed the order of 15 m > 30 m > 60 m, drain spacing treatments.

1 INTRODUCTION

Drainage technology has developed around two basic needs: (i) to ensure aeration and trafficability for agricultural soils, and (ii) to provide for salinity control. As a consequence, the goal usually has been to design systems that provide as much drainage as possible. Land drainage, as a tool to manage ground water levels, plays an important role in maintaining and improving crop yields: (i) It prevents a decrease in the productivity of arable land due to rising water tables and the accumulation of salts in the root zone. And (ii) A large portion of the land that is currently not being cultivated has problems of water logging and salinity. Drainage is the only way to reclaim such land. Various crops respond differently to specific soil-water environments; so the key element of the shallow water table concept is the drainage requirement of the crop being grown.

Heavy clays are considered impervious and consequently unsuitable for drainage by a subsurface drainage system. This opinion however, is not always justified. Draining such soils poses special problems, reasonable solutions can be sometimes being found. The traditional drainage system on heavy clay soils is surface drainage by parallel furrows or shallow ditches. Yet it has recently been proved that subsurface drainage can be very successful in situations where an under lying layer with a hydraulic conductivity occurs. In order that secondary drainage treatments may persist and function efficiently, it is necessary that they shall be drawn in a layer of the subsoil at least moderately high in clay.

In the agricultural lands of Egypt, the water table has a fluctuating nature. It rises due to recharge by irrigation water losses and falls due to evapo-transpiration or lateral and deep seepage. When the rate of recharge exceeds the rate of seepage, there is always a rising trend in water table levels. In this case, artificial drainage becomes necessary to control the water table and maintain a suitable aerated root zone throughout the season. The rate of rise and fall depends on many factors such as the irrigation and
infiltration rates, moisture content of the soil before irrigation, soil physical properties, climatic conditions, root depth, hydrological boundary conditions, size of area irrigated, irrigation conditions in the neighboring fields and depth and spacing of drains Moukhtar et al, 1990). The hydraulic conductivity in the North Delta is different (Abdel-Aal, 1995), depending on the predominant properties in this area; in general it is a low permeable soils. Subsoiling is technique used in combination with tile drainage, because it enables economic drain spacing to be applied. Since little is known about the best time of the year that subsoiling can be performed, or about its durability or costs and benefits, local field trials are required to decide the technique can be applied.

The present work plan has been setup to study combined tile drainage with subsoiling on improving watertable conditions in deteriorated salty clay soil in order to sustain resource management.

2 MATERIALS AND METHODS

The experimental field has been carried out in the farm of Agricultural Research Station, which belongs to Agriculture Research Centre. The area is situated at the end of El-Dakhlia Governorate between two main drains, El-Serw drain and El-Harana drain, which they are, meets at a city called El-Alexandria El-Gadeidh. The two drains end in El-Serw pumping drainage station, which lifts the drainage water to El-Manzala Lake. The area of the field under study is representative of northern low lands, fluvio-marine clay salt affected soils of low productivity. Moreover, they are assumed to lie in the zone of hydrostatic pressure. A main controversial factor is the extreme salinity of the groundwater table. The main treatments are subsurface drainage. The tile drainage system was mechanically installed four years ago. Corrugated plastic laterals are 100 m. length and 150 cm. depths at the tile end. The collector line is 600 m. long and its outlet (2.5 m. depth) is in the main drain El-Serw. The experimental field was designed with three drain spacing treatments separated by buffer zones (Dielman and Trafford, 1976): (i) 15 m. spacing (calculated spacing according to the steady state formula, (Houghoudt, 1940)); (ii) 30 m. spacing (conventional spacing adopted in the surrounding areas); and (iii) 60 m. spacing (double of the conventional spacing for future secondary drainage treatments). The sub-treatments are two types of subsoiling; the distance between plowing two metere and the depth is 50 cm. There are: (i) One direction: Parallel orientation subsoiling type and perpendicular on tile drains, and (ii). Two directions: Net structure-subsoiling type.

To monitor the fluctuation of water table, the plane work was designed to install observation wells in different treatments. They fitted to the depth of 150 cm. An intensive observation wells were situated between tile drain in two sides for each investigated tile drain. There were designed to place on one line perpendicular to tile drain, it was located at distance of 1/2 L, 1/4 L, 1/8 L 1/16 L and 1/32 L (L = distance between drains which are 15 m, 30 m or 60 m spacing). The neighbor fields were provided with tile drainage system at 30 m spacing. Water table was measured in observation wells (25-mm. Diameter and 2 m. length) during the irrigation interval over a wheat, sorghum and clover seasons. The wells were placed between two laterals and distributed according to Dielman and Trafford (1976). Water table depth was measured with a sounder consisting of a 1.25 cm diameter copper tube and 5.0 cm in length connected with a calibrated steel tape. The data were measured daily and directly after irrigation during the growing season. The soil was cultivated by wheat followed sorghm and clover. All the data collected were subjected to the statistical analysis using statistical computer program.

3 RESULTS AND DISCUSSIONS

3.1 During Wheat Winter Season

3.1.1 Water table fluctuations in midway between drain:
Results of water table fluctuations as affected by drain spacing and combined with subsoiling type treatments are shown in figure 1 and 2. In general, upon irrigation, water table level rises close to soil surface and then recedes gradually. Maximum depth reached depends mainly on drain spacing and subsoiling types. The water table level at the midway between drains at the end of the considered interval irrigation reached to 89, 71 and 64 cm in drainage treatments without subsoiling for 15, 30 and 60 meters spacing, respectively.
For treatments with tile drains combined with subsoiling types, they reached to 98, 79 and 72 cm for parallel subsoiling type and 123, 92 and 78 cm for net subsoiling type treatments of corresponding drain spacing treatments, respectively, before the next day of irrigation. The difference among drainage type treatments could be noticed when considering the water table level reached after a certain length of time during the different irrigation intervals. For instance, five days after irrigation, water table level drops to 42, 39 and 30 cm in treatments having no subsoiling but having drain at 15, 30 and 60 meters spacing, respectively. For treatments combined with subsoiling types, they lowered to 45, 41 and 32 cm for parallel subsoiling orientation and 83, 43 and 33 cm for net structure treatment for drain spacing at 15m, 30m and 60m, respectively. Also, 10 days after irrigation, the water table is found at levels of 75, 53 and 46 cm for drainage without subsoiling treatments and 80, 57 and 50 cm for parallel subsoiling and 109, 64 and 51 for net treatment, respectively, in the same corresponding drain spacing treatments.

The results of statistical analysis for water table depths as affected by drain spacing and subsoiling treatments are shown in table (1) and fig. (3). The data indicate that both drain spacing and subsoiling type as well as interaction between them is highly affected on water table depths. The closed drain spacing is highly significant on lowering the water table depths, also net subsoiling gives the same trend comparing to the other treatments. The highly significant effect of the interaction treatments between drain spacing and subsoiling on lowering the water table depth is obvious for the combined treatments drain spacing with net subsoiling. The best treatment is drain spacing at 15 m combined with net subsoiling while the worst treatment on lowering water table is drain spacing at 60m only without subsoiling. Also, there are highly significant interactions between daily watertable drawdown and drain distance, subsoiling types and also among three of them.

Figure 1 Watertable depth at midway drains spacing between two-interval irrigation, winter season 96/97: (a). Parallel subsoiling (b). Net Subsoiling
Figure 2  Watertable depth at midway drains spacing and subsoiling types between two-interval irrigation, winter season 96/97: (a) 15m  (b) 30m (c) 60m

Figure 3  Average watertable depth as affected by drain spacing and subsoiling types, in winter season 96/97 (wheat).

Table 1  Analysis of variance for water table depths between two interval irrigations as affected by drainage and subsoiling types.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Degree of Freedom</th>
<th>Water table depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicates (R)</td>
<td>1</td>
<td>**</td>
</tr>
<tr>
<td>Drainage (D)</td>
<td>2</td>
<td>**</td>
</tr>
<tr>
<td>Error (a)</td>
<td>2</td>
<td>**</td>
</tr>
<tr>
<td>Time(T)</td>
<td>17</td>
<td>**</td>
</tr>
<tr>
<td>Subsoiling (S)</td>
<td>2</td>
<td>**</td>
</tr>
<tr>
<td>T X S</td>
<td>34</td>
<td>**</td>
</tr>
<tr>
<td>D X T</td>
<td>34</td>
<td>**</td>
</tr>
<tr>
<td>D X S</td>
<td>4</td>
<td>**</td>
</tr>
<tr>
<td>D X T X S</td>
<td>68</td>
<td>**</td>
</tr>
</tbody>
</table>
In general, both drainage and subsoiling types have great influence on lowering water table depths (table 1 and fig. 3). They are following the order: 15 m > 30 m > 60 m drain spacing and Net > parallel > no subsoiling types. The best treatment for dropping water table is 15 m spacing combined with net subsoiling structure. Result could be explained on the basis that net subsoiling increased the physical quality of soil by broken any hard pan or hard clods and loosen and created fissuring.

3.1.2 Water table fluctuations at L/8 from drain

For water table depth at L/8 from drain spacing, data are shown in figure 4. In general, results indicate that drainage treatments are highly affected on water table depth. For drains combined with net subsoiling type is more effective than parallel treatment. The difference between treatments is obviously shown with 15m-combined net subsoiling type.

(a). Parallel Subsoiling  
(b). Net Subsoiling

![Figure 4](http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20moukhtar-improving%20watertable.html)

**Figure 4** Watertable depths at L/8 drain spacing and subsoiling type between two-interval irrigation. (a). Parallel Subsoiling (b). Net Subsoiling

3.1.3 Water table fluctuations at L/32 from drain (closed to drain)

Regarding water table depths at L/32 from drain (nearest to drain), results (figure 5) indicate that water table depths are highly effective with all treatments under drain spacing and subsoiling types. The difference between treatments is not significantly for parallel subsoiling but they are highly significant for net type.
3.1.4 Water table shape

The fluctuation of water table is highly affected by different drain spacing combined with subsoiling type treatments in relation to time. The water table flow pattern is shown in figure 6 for 15 m spacing, fig. 7 for 30 m spacing and fig. 8 for 60 m spacing. It is very clear that directly after irrigation, the configuration of water table for 15 m spacing made a hump especially with net subsoiling type treatment but it was a curve for 30 m spacing and a flat for 60 m spacing. It means that the drained area followed the order of: 15m > 30 m > 60 m drain spacing treatments. The shape of water table showed a sharp gradient increases towards the drains for most treatments. Results could be attributed to the nature of permeability at each layer of soil profile. Close spacing leads to better soil aeration and soil structure compared to a wider spacing. These results are good agreement with those obtained by Moukhtar et al (1990) and Abdel-Mawgoud (1999).

Figure 5 Watertable depths at L/32 drain spacing (closed to drain) and subsoiling type between two-interval irrigation: (a). Parallel Subsoiling (b). Net Subsoiling.

(a). Parallel Subsoiling (b). Net Subsoiling

Figure 6 Watertable shape between two-irrigation intervals as affected by drain spacing (15m) combined subsoiling treatment: (a). Parallel Subsoiling (b). Net Subsoiling.
3.2 Sorghum Summer Season

3.2.1 Water table fluctuations in midway between drain

Results of water table fluctuations as affected by drain spacing combined with subsoiling type treatments are shown in figure 9 and 10. In general, upon irrigation, water table level rises close to soil surface and then recedes gradually. Maximum depth reached depends mainly on drain spacing and subsoiling treatments. The water table level at the midway between drains at the end of the considered interval reached to 100, 75 and 67 cm in drainage treatments without subsoiling for 15, 30 and 60 meters spacing, respectively. For treatments combined with subsoiling, they reached to 114, 89 and 77 cm for parallel subsoiling and 123, 100 and 84 cm for net subsoiling treatments of corresponding drain spacing treatments, respectively. The difference among drainage type treatments could be noticed when considering the water table level reached after a certain length of time during the different irrigation intervals. For instance, five days after irrigation, water table level drops to 42, 36 and 30 cm in treatments having no subsoiling but having drain at 15, 30 and 60 meters spacing, respectively. For treatments combined with subsoiling, they lowered to 67, 47 and 32 cm for parallel subsoiling and 90, 58 and 36 cm for net treatment for drain spacing at 15m, 30m and 60 cm, respectively. Also, 10 days after irrigation, the water table is found at levels of 76, 55 and 48 cm for drainage without subsoiling treatments and 99, 80 and 65 cm for parallel subsoiling and 112, 68 and 70 cm for net treatment, respectively, in the same corresponding drain spacing treatments.
The results of statistical analysis for water table depths as affected by drain spacing and subsoiling treatments are shown in table (2). The data indicate that both drain spacing and subsoiling type as well as interaction between them is highly affected on water table depths. The closed drain spacing is highly significant on lowering the water table depths, also net subsoiling gives the same trend comparing to the other treatments. The highly significant effect of the interaction treatments between drain spacing and subsoiling on lowering the water table depth is obvious for the combined treatments drain spacing with net subsoiling. The best treatment is drain spacing at 15 m combined with net subsoiling while the worst treatment on lowering water table is drain spacing at 60m only without subsoiling. Also, there are highly significant interactions between daily watertable drawdown and drain distance, subsoiling types and also among three of them.

![Figure 9](image1.png)  
**Figure 9**  Watertable depth at midway drains spacing as affected by drain spacing combined subsoiling between two-interval irrigations, summer 1997: (a). Parallel Subsoiling (b). Net Subsoiling

![Figure 10](image2.png)  
**Figure 10**  Watertable depth at midway drains spacing as affected by drains spacing at 15 m and subsoiling treatments between two-interval irrigations, Summer 1997: (a).15m (b). 30m (c) 60m.

**Table 2**  Analysis of variance for water table depths (cm), between two interval irrigations.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Degree of Freedom</th>
<th>Water table depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicates (R)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Drainage (D)</td>
<td>2</td>
<td>**</td>
</tr>
<tr>
<td>Error (a)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Time(T)</td>
<td>17</td>
<td>**</td>
</tr>
</tbody>
</table>
In general, both drainage spacing and subsoiling type have great influence on lowering water table depths; They are following the order: 15 m > 30 m > 60 m drain spacing and Net > parallel > no subsoiling. The best treatment for dropping water table is 15 m spacing combined with net subsoiling (table 2 and fig. 11). Result could be explained on the basis that net subsoiling increased the physical quality of soil by broken any hard pan or hard clods.

Water table fluctuations at L/8 from drain: For water table depth at L/8 from drain spacing, data are shown in figure 12. In general, results indicate that drainage treatments are highly affected on water table depth. For drains combined with net subsoiling is more effective than parallel treatment. The difference between treatments is obviously shown with 15 m combined net subsoiling.
3.2.2  Water table fluctuations at L/32 from drain (closed to drain)
Regarding water table depths at L/32 from drain (nearest to drain), results (figure 13) indicate that water table depths are highly effective with all treatments under drain spacing and subsoiling. The difference between treatments is not significantly for parallel subsoiling but they are highly significant for net treatments.

Figure 13  Watertable depth at L/32 close to drain spacing as affected by drain spacing combined subsoiling type between two-interval irrigations: (a). Parallel Subsoiling  (b). Net Subsoiling

3.2.3  Water table shape
The fluctuation of water table is highly affected by different drain spacing combined with subsoiling treatments in relation to time. The water table flow pattern is shown in fig. 14 for 15 m spacing, Fig. 15 for 30 m spacing, Fig. 16 for 60 m spacing). It is very clear that directly after irrigation, the configuration of water table for 15 m spacing made a hump especially with net subsoiling treatment more than parallel treatment. For the soil treatment with 30 m drain spacing, the shape of water table formed curve shape for both parallel and subsoiling treatments. Concerning soil treated with 60 m spacing. The shape pattern looks mostly flat, except the water table nearest to drains. In general, results indicate that the drained area followed the order of: 15m > 30 m > 60 m drain spacing for both parallel and net subsoiling treatments. The shape of water table showed a sharp gradient increases towards the drains for most treatments. Results could be attributed to the nature of permeability at each layer of soil profile. Close spacing leads to better soil aeration and soil structure compared to a wider spacing (Moukhtar et al, 1990).

Figure 14  Watertable shape between two-irrigation intervals as affected by drain spacing (15m) combined subsoiling treatment:  (a). Parallel Subsoiling  (b). Net Subsoiling.
3.3 Clover Winter Season

3.3.1 Water table fluctuations in midway between drain

Results of water table fluctuations as affected by drain spacing combined with subsoiling type treatments are shown in figure 17 and 18. In general, upon irrigation, water table level rises close to soil surface and then recedes gradually. Maximum depth reached depends mainly on drain spacing and subsoiling treatments. The water table level at the midway between drains at the end of the considered interval reached to 99, 70 and 62 cm in drainage treatments without subsoiling for 15, 30 and 60 meters spacing, respectively. For treatments combined with subsoiling, they reached to 106, 76 and 68 cm for parallel subsoiling and 119, 92 and 79 cm for net subsoiling treatments of corresponding drain spacing treatments, respectively. The difference among drainage type treatments could be noticed when considering the water table level reached after a certain length of time during the different irrigation intervals. For instance, five days after irrigation, water table level drops to 35, 25 and 16 cm in treatments having no subsoiling but having drain at 15, 30 and 60 meters spacing, respectively. For treatments combined with subsoiling, they lowered to 39, 27 and 18 cm for parallel subsoiling and 67, 28 and 26 cm for net treatment for drain spacing at 15m, 30m and 60 cm, respectively. Also, 10 days after irrigation, the water table is found at levels of 77, 44 and 29 cm for drainage without subsoiling treatments and 82, 47 and 32 cm for parallel subsoiling and 105, 60 and 41 cm for net treatment, respectively, in the same corresponding drain spacing treatments.

The data of watertable depths as affected by drain spacing and subsoiling type treatment and daily watertable drawdown treatments
are statistical analyzed. The results indicate that both drain spacing and subsoiling types as well as interaction between them are highly affected on lowering watertable depth. Also, there are highly significant interactions among daily watertable drawdown and drain distance, subsoiling types and also among three of them on lowering watertable depths between two-interval irrigations; as shown in table (3).

![Figure 17](image1.png)  
Figure 17  Watertable depth at midway drains spacing as affected by drain spacing combined subsoiling between two-interval irrigations, winter 1997/98: (a). Parallel Subsoiling (b). Net Subsoiling

![Figure 18](image2.png)  
Figure 18  Watertable depth at midway drains spacing as affected by drains spacing at 15 m and subsoiling treatments between two-interval irrigations, winter 1997/98: (a) 15m  (b) 30m  (c) 60m.

![Table 3](image3.png)  
Table 3  Analysis of variance for water table depths cm, between two interval irrigations.

<table>
<thead>
<tr>
<th>Source of Variance</th>
<th>Degree of Freedom</th>
<th>Water table depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicates (R)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Drainage (D)</td>
<td>2 **</td>
<td></td>
</tr>
<tr>
<td>Error (a)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Time(T)</td>
<td>17 **</td>
<td></td>
</tr>
<tr>
<td>Subsoiling (S)</td>
<td>2 **</td>
<td></td>
</tr>
<tr>
<td>T X S</td>
<td>34 **</td>
<td></td>
</tr>
<tr>
<td>D X T</td>
<td>34 **</td>
<td></td>
</tr>
<tr>
<td>D X S</td>
<td>4 **</td>
<td></td>
</tr>
<tr>
<td>D X T X S</td>
<td>68 **</td>
<td></td>
</tr>
<tr>
<td>Error (b)</td>
<td>159</td>
<td></td>
</tr>
</tbody>
</table>
In general, both drainage spacing and subsoiling types have great influence on lowering water table depths; They are falling the order: 15 m > 30 m > 60 m drain spacing and Net > parallel > no subsoiling. The best treatment for dropping water table is 15 m spacing combined with net subsoiling structure type (table, 3 and fig.19). Again, result could be explained on the basis that net subsoiling increased the physical quality of soil by broken any hard pan or hard clods.

### 3.3.2 Water table fluctuations at L/8 from drain

For water table depth at L/8 from drain spacing, data are shown in figure 20. In general, results indicate that drainage treatments are highly affected on water table depth. For drains combined with net subsoiling is more effective than parallel treatment. The difference between treatments is obviously shown with 15 m combined net subsoiling.

![Figure 20](http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20moukhtar-improving%20watertable.html)

**Figure 20**  Watertable depth at L/8 drain spacing as affected by drain spacing combined subsoiling type between two-interval irrigations, winter season 79/98: (a). Parallel Subsoiling (b). Net Subsoiling

### 3.3.3 Water table fluctuations at L/32 from drain (closed to drain)

Regarding water table depths at L/32 from drain (closed to drain), results (figure 21) indicate that water table depths are highly effective with all treatments under drain spacing and subsoiling. The difference between treatments is not significantly for parallel...
subsoiling but they are highly significant for net treatments.

Figure 21  Watertable depth at L/32 drain spacing as affected by drain spacing combined subsoiling type between two-interval irrigations, winter season 79/98: (a). Parallel Subsoiling  (b). Net Subsoiling

3.3.4 Water table shape

The fluctuation of water table is highly affected by different drain spacing and subsoiling types treatments in relation to time. The water table flow pattern is shown in fig. 22 for 15 m spacing, fig. 23 for 30 m spacing, fig. 24 for 60 m drain spacing. It is very clear that directly after irrigation, the configuration of water table for 15 m spacing made a hump especially with net subsoiling treatment but it was a curve for 30 m spacing and a flat for 60 m spacing. It means that the drained area followed the order of: 15m > 30 m > 60 m drain spacing treatments. The shape of water table showed a sharp gradient increases towards the drains for most treatments. Results could be attributed to the nature of permeability at each layer of soil profile. Close spacing leads to better soil aeration and soil structure compared to a wider spacing (Moukhtar et al, 1990).

Figure 22  Watertable shape between two-irrigation intervals as affected by drain spacing (15m) combined subsoiling treatment, winter season 97/98: (a). Parallel Subsoiling  (b). Net Subsoiling
The impact of drain spacing treatments on the improvement of drainage conditions is illustrated by the rate of water table. The importance of the different water table depths is the positions of them midway between drains during two-interval irrigations. In general, it could be said that an improvement in drainage conditions is realized progressively as time proceeds, especially in the treatment having 15 m spacing combined with net subsoiling (fig. 25). For this spacing treatment, the improvement is continuous with a fast rate. It may worthwhile to mention that the drawdown changes irregularly from day to another. It might be attributed to preferential flow through macro-pores “bypass” flow (Moustafa, 1984 and Moukhtar and Moustafa. 1985). Generally, results indicate that drainage treatments have an enhancing effect on lowering the water table, particularly under narrow spacing between drains combined with subsoiling especially net treatment. Increasing downward water movement after irrigation gives the chance for the effective root zone to dry, shrink and form water pathways. It is worthy to mention that the drying process and its consequent plays an important role in the drainage of heavy clay soils since it improves the soil structure and permeability.
It may worthy to mention that these types of drainage especially in heavy clay low permeable soil the flow of water is highly accelerated drawdown as a result of loosening and fissuring up to the depth of subsoiling plow. Afterwards, watertable drowdown rate depends on the distance of drain spacing.

Figure 25  The watertable depth during different seasons as affected by drain spacing and subsoiling type treatments.

Figure 26  Average salinity in the surface soil layer as affected by drain spacing in the year of 96/97-97/98

Figure 27  Average salinity in the surface soil layer as affected by subsoiling in the year of 96/97-97/98.

Figure 28  Average ESP (alkalinity) in the surface soil layer as affected by drain spacing in
Improving Watertable Conditions in Deteriorated Salty Clay Soil in Egypt

The year of 96/97-97/98.

Soil desalinization in relation to drain spacing combined with subsoiling treatments shows a reduction in soil salinity following the order of: 15 m > 30 m > 60 m drain spacing. The net subsoiling is more effective on salinity reduction than parallel subsoiling in all treatments. It could be concluded that in such soils, the closer drain spacing with net subsoiling realizes desalinization of the surface soil layers. There is also a highly significant effect on lowering soil surface salinity by drain spacing (fig. 26) and subsoiling (fig. 27) in the year of 97/98 than 96/97. A presentation of the ionic composition of soluble salts in soil saturation extract, through soil profiles in relation to drain spacing and subsoiling treatments Chloride and sodium are the major ions of the soil saturation extract in all treatments. They are increasing in the subsequent layers as the total soluble salts values increase. Magnesium ions exceed calcium ions as the total soluble salts values increase.

The extent of desalinization obtained along the soil profile in different treatments, results indicate that it is obvious that 15-m drain spacing with net subsoiling realizes high efficiency in leaching soluble salts up to 150 cm. While the other treatments leached the salts out the soil profile down to 90 cm soil depth only.

The sodification phenomenon constitutes highly complicated problems in clay soils, which hinder its productivity. The obtained data of soil desodification expressed by exchangeable sodium percentage (ESP) as affected by drain spacing and combined subsoiling type treatments, the decrease in the ESP value was confined in the upper layer soil depth (fig. 28). As previously mentioned, the ESP values increase with soil depth to reach higher values in all treatments. This may be due to the effect of highly saline groundwater on the soil complex (Moukhtar et al., 1990). Again, it could be concluded that the closer drain spacing (15 m combined with net subsoiling) shows relatively higher effectiveness in soil desodification.

In general, it should be mentioned that low coastal lands in Northeastern Delta are considered problem soils due to composite controversial factors. They are heavy clay low permeable and salt affected soils. The presence of a saline ground water constitutes a source and permanent threat for soil salinization. It is very apparent that water control in these heavy soils by means of subsurface drainage is primordial. However, a narrow spacing could be expressive and not practical. To overcome this situation modifying the profile loosening and fissures will accelerate water movement. Modification in these cases through deeper loosening and fissuring will increase the depth of more permeable soil allowing either a small increase in drain spacing or more rapid water table drawdown to reduce plant stress (Spoor, 1999). El-Hakim et al (1990), Moukhtar et al (1995) and Moukhtar et al (2002) stated for such situation of heavy clay water logged salty soils associated with highly saline groundwater, which constitute a challenging problem that the solution must achieve lowering water table at the end of the irrigation intervals, accelerating the downward movement in the surface layers, so that irrigation water constitutes a temporary front separating the saline ground water table from the rootzone. The soil must not be left fallow for a long time.

Therefore, it may worth to mention that the main prime objective and principle goal to overcome these complicated situation is to increase hydraulic conductivity in critical areas through loosening and fissuring operations, as a means of increasing drainage rates and/or drain spacing to: (i) improve drainage efficiency, (ii) reduce costs, (iii) prevent rootzone layer from deterioration and to be suitable for optimal growth, and (iv) sustainable land use.

It can be concluded that the best treatment is drain spacing at 15 m combined with net subsoiling. However, it is worthy to mention that treatment of wider drain spacing (30 m) combined with net subsoiling gives satisfactory results in lowering watertable and reducing salinity and alkalinity with improving soil physical properties. It is also reduce drainage costs. Auxiliary treatments must be combined with any drainage system in the management of heavy clay low permeable soil.

On the other hand, Moukhtar et al, 1995 and 1998 decide that field drainage with open ditches alone is not quite satisfactory for a good crop production. Mole drainage, in combination with open drain ditches overcome the slow water movement. A fast recession of water table upon irrigation is realized through fissure and cracks above the mole line. This is reflected satisfactory on soil salinity in the rootzone and leads to good and uniform vegetation. Moukhtar et al, 1995 concluded that moling combined with field drains could be highly recommended as an auxiliary drainage treatment in clay salty soils of low level with a saline water table to raise the
soil productivity. It is a low cost measure needing no advanced machinery and small farmers instead of using narrow drain spacing, which wastes the area of agricultural land, can adopt it. In addition, this type of soil should not be left fallow even for a short period otherwise salinization quickly arises. Also, shallow root crops are preferred. Water submerged crops i.e. rice, amshout should be included in agricultural rotation. Care for tillage operations should be followed.

4 REFERENCES

SUSTAINABLE UTILIZATION OF WATER RESOURCES IN EASTERN PART OF NORTH CHINA PLAIN

ABSTRACT

The eastern part of North China Plain is short of water resources, the deep groundwater has been overdrawn seriously and the eco-environment has deteriorated. For sustainable utilization of water resources, the systems of well irrigation with well drainage and canal irrigation with ditch drainage should be developed. The exploitation and utilization of shallow groundwater including brackish water and saline water should be regarded as the major water source, and the diversion of available surface water as the supplementary water source. To regulate the groundwater according to a critical dynamics of groundwater depth as the core, take the stratum space of soil and phreatic aquifer as the underground reservoir for regulating atmospheric water, soil water, groundwater and surface water, to transform the natural rainfall unevenly distributed in time and space into sustainable utilized water resources to a maximum.

Keywords: Exploitation and utilization of saline groundwater, Regulation of groundwater depth, Increase of rainfall infiltration, Sustainable utilization of water resources, North China plain.

1 Introduction

The North China Plain located to the north of Yellow River belongs to a seasonal arid semi-humid continental monsoon climate. The average annual precipitation is 500 – 600 mm. The precipitation varies considerably from year to year, it is unreliable for timely irrigation, it has even been less than 400 mm in a dry year, showing the characteristics of a semi-arid region and even arid region. The precipitation in a wet year has even more than 800 mm, showing the characteristics of humid region. Besides, the precipitation is concentrated in summer and mainly in July and August, the other months are the dry season. The average annual precipitation is 550 mm in Nanpi County, its summer (June - August) precipitation accounts for 74% of the total annual precipitation. Spring (March – May) and Autumn (September – November) accounts for 11 % and 13% respectively, winter (December–next February) accounts for only 2 %. That causes drought in spring and waterlogging in summer, and then drought in autumn and winter again; drought and waterlogging occurred alternately. In North China Plain – the precipitation reaching the ground interacts with the underlying surface in North China Plain, it forms a part of surface water (accounted for 8 %) and a part is infiltrated. Under the action of gravity, a part (accounts for 20.6 %) of water infiltrated becomes groundwater, but most of it (accounts for 71.4 %) is stored in soil as soil water. In the process of the transformation of atmospheric precipitation, the salt in the soil is leached out and moves with water. In the region where with low-lying land and the runoff of surface and groundwater slowly has formed saline-alkali land and mineralized groundwater. In the period of geological history, under the influence of salinization of the continent in dry climate and sea water intrusion, there had formed saline groundwater region of large area in the eastern part of North China Plain. Its total area is 83.9 thousand km², in which the area with shallow thin layer of fresh groundwater is 12.8 thousand km², the area with wholly saline groundwater is 71.1 thousand km² which accounts for 51.1 % of North China Plain. The eastern part of the North China Plain become a region with minimum fresh water resources and the maximum saline groundwater region, a region with the lowest water resources per capita (160 – 190 m³) and the most serious overdrawn of deep groundwater in nation – wide, and the eco-environment there has been seriously deteriorated.

Drought, waterlogging, salinity and saline groundwater are the restraint factors of sustainable development of agriculture, and influenced for each other, caused damage to crops alternatively, caused poorness and backwardness in long term in this region. Till 1985, there were still exist saline-alkali land of 0.47 million km² in Haihe and Luohne River Plain, the unit yield was only 4050 kg/ha-m³ in the eastern part area (Hailonggang region ), which was 2400 kg/ha-m³ lower than that of the piedmont plain. In order to explore the effective approach of comprehensive control of drought, waterlogging, salinity and saline groundwater and utilization and reclamation of saline-alkali land, in large area, in 1984, the Ministry of Agriculture, livestock and Fishery had introduced the IFAD Loan by applying the research results of Hebei Institute of Hydrotechnics on using saline groundwater for irrigation to establish Nanpi Agricultural Development Project Area (NADPA), starting exploitation and utilization of saline groundwater and carrying out comprehensive control. Till 1987, the well irrigation area is increased from that accounted for 22.5 % to 44 %. The groundwater depth before rainy season was kept at 4 – 5 m, when daily rainfall was 189 mm no waterlogging occurred, due to increased of the recharge to groundwater. Utilizing summer rainwater to leach and drain off soil salt, the saline-alkali land had decreased 57 % than that in 1984, the groundwater has been somewhat freshened. Remarkable social-economic and eco-environmental benefits have also been obtained. The grain occupation per capita increased to 521 kg from 294 kg before the project, cotton yields increased by 9- fold. The total agricultural production value was increased by 3.6-fold. The income per capita increased by 3-fold. The forest coverage rate increased from 3 % to 9 %. The research results and experience of NADPA had been applied and popularized extensively in the eastern part of North China Plain. The cycling and blending of saline water with sodic fresh water for irrigation have been widely used in Cangzhou, Hengshui, Xingtai and Tianjin Cities. Now the total volume of brackish water utilized has achieved 0.66 billion m³ in North China Plain, in which 0.32 billion m³ was used in Hebei Plain. Scientific experiment and production practice have provided relative technology and scientific accordance on comprehensive control of drought, waterlogging, salinity and saline groundwater and sustainable utilization of water resource in North China Plain.

2 Distribution of water resource in time and space

2.1 Shallow fresh and saline groundwater

The agricultural water application is takes the local water resources, especially the groundwater resources, as the principal water source. The Hebei Plain belongs to a part of North China subsidence zone. In the Quaternary system, according to the groundwater with mineralization less than 2 g/L is regarded as the fresh water, the boundary of fresh and saline groundwater is approximately located at the line of piedmont plain meeting with alluvial plain, the fresh groundwater region in the west and the saline groundwater region in the east. The area of fresh groundwater and shallow thin layer fresh groundwater in the region with saline groundwater occupies 67.6 % and the various saline groundwater occupies 32.4 % of the total plain area. But the saline groundwater had not yet been used in the past, it occupies the stratum of shallow groundwater and influences the rainfall and surface fresh water storage. As a result, the water evaporated and the salt accumulated which caused soil salinity. Especially in Hailonggang region and the region to the east of South Grand Canal in Hebei Plain, are short of fresh water and saline groundwater is extensively distributed. Their area and amount of exploitable fresh water account only for 18 % and 14 % respectively, but the area and amount of exploitable brackish water (2 – 3 g/L) all occupy one half in Hebei Plain (Table 1). The saline groundwater region in Hebei Plain is 39471 km², the area of brackish water (2 – 3 g/L) and semi-saline water (3 – 5 g/L) accounts for one half of Hebei Plain (Table 2). In NADPA, due to exploiting and utilizing shallow groundwater including brackish water and semi-saline water, the groundwater depth can be kept at 3 m ( in dry season) – 6 m ( before rainy season), the modulus of exploitable resources is 68 – 73 thousand m³/km² a, it can meet the irrigation requirement for 43 % of farmland.

Table 1 Resources and exploitable resources of fresh and brackish groundwater in Hebei Plain

<table>
<thead>
<tr>
<th>Region</th>
<th>Fresh water (2 g/L)</th>
<th>Brackish Water (2–3 g/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (km²)</td>
<td>Resources (10⁹m³/a)</td>
<td>Exp. res. (10⁹m³/a)</td>
</tr>
<tr>
<td>Hebei Plain</td>
<td>49486.6</td>
<td>90.45</td>
</tr>
<tr>
<td></td>
<td>14118.1</td>
<td>21.04</td>
</tr>
</tbody>
</table>

http://library.wur.nl/ebooks/drainage_cd/2.3%20sheng%2020%2Chen%20and%20boers%20theo%20mod.html (1 of 9) 26-4-2010 12:12:25
SUSTAINABLE UTILIZATION OF WATER RESOURCES IN EASTERN PART OF NORTH CHINA PLAIN

2.2 Deep fresh groundwater

The deep fresh groundwater distributed in the 3rd group of aquifers (Q2, 160 – 360 m) and 4th group of aquifers (Q1, 360 – 500 m), its mineralization is less than 1 g/L, pH about 8.5, mostly HCO3 – Na type. The deep groundwater is confined aquifer by overlying and underlying weak permeable layer or water resistance layer (aquitards or aquicludes), that can't receive the supplement from rainfall infiltration, canal seepage and irrigation water. Besides side recharging and cross-flow supplement from neighboring aquifers all the exploited deep groundwater is extracted from unsustainable groundwater storage capacity. From rough estimate, the exploitable deep groundwater is only 0.77 billion m³ in Heihe River Plain, but the average annual overdrawn amount was 2.6 billion m³. Due to overdraft an extensive regional cone depression of deep groundwater table in large area in Tianjin, Cangzhou, Henshui, Dezhou and Langfang Cities has been developed. It has caused serious eco-environmental problems, such as: land subsidence, downward movement of the salt-fresh water interface, the worsening of the water quality of deep groundwater etc. For the protection of water resources and rehabilitation of eco-environment, the water supply by the deep confined aquifers it should be gradually replaced by other available water resources and deep groundwater should be strictly forbidden or rigorously controlled. The groundwater in deep confined aquifers should be retained as reserve water source for use in extraordinary year of water shortage.

Table 2 Area of groundwater with different mineralization in saline groundwater region of North China Plain

<table>
<thead>
<tr>
<th>Mineralization of Groundwater (g/L)</th>
<th>Area (km²)</th>
<th>Account (%)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2</td>
<td>15829</td>
<td>40</td>
<td>Fresh water</td>
</tr>
<tr>
<td>2 – 3</td>
<td>14118</td>
<td>36</td>
<td>Brackish water</td>
</tr>
<tr>
<td>3 – 5</td>
<td>5154</td>
<td>13</td>
<td>Semi-saline water</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>4370</td>
<td>11</td>
<td>Saline water</td>
</tr>
<tr>
<td>5</td>
<td>59471</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

2.3 Surface water

There was river flow coming from upper stream to the eastern part of North China Plain from the South Grand Canal in the past, but owing to the water application increased due to the increase of population and the development of economy and society, the river flow of South Grand Canal had been cutoff since 1965. For the supplement of water source to Haihe River Plain, Weilin Canal (from Weishan, Shandong Province to Linqing, Hebei Province) was built for Yellow River Diverion, the water flow diverted in the non irrigation period, i.e. every winter from November to next February, the allowable water diversion amount is 500 million m³ per year given for Cangzhou, Hengshui and Xintai Cities since 1994. 1997 – 2002, the average annual water diversion was 100 million m³ to Cangzhou City. Yellow River flow was diverted in winter, stored in canal and ditches, applied for irrigation in spring, and recharging groundwater.

3 Infrastructure of Water Management and Control of Water and Salt

3.1 Well irrigation and drainage combining with canal irrigation

Establishment of well system to exploit and utilize shallow groundwater including brackish water and saline water is the key measure for the regulation of water-salt management. According to the local hydrogeological conditions, and the layout of the farm canal, well spacing is 200 – 300 m, well depth is 10 – 20 m, output of unit well is 10 – 20 m³/h, irrigated area served by each well is 2 ha². In the place with clay layer above the thin sandy aquifer vacuum well can be used, the well depth is 10 m, the irrigated area per well is 0.6 ha². The well water is conveyed by PVC hose pipe to farm canal for irrigation by gravity. The farm canal can also receive the surface water lifted from lateral or branch ditch for irrigation.

Exploiting and utilizing shallow groundwater including brackish water and saline water for irrigation, that enable to regulate water and salt, has also a series of advantages: (a) To meet the water requirement for crops in proper quantity and in time for drought combat and yield increasing. (b) To lift water for irrigation in the mean time to lowered the groundwater table, cutoff or decrease the water-salt of groundwater supplement to surface soil by capillary raise, therefore the salt accumulation can be prevented effectively. (c) To increase water infiltration that changes the process of salt accumulation due to strong evaporation in spring, and has the functions of salt leaching and restricting salt accumulation. (d) Pumping a lot of groundwater for irrigation in spring enable to lowered groundwater table and vacate underground capacity before rainy season, with the benefits of not only reducing the evaporation of phreatic water, capturing available water resources, but also increasing rainfall infiltration, reducing surface runoff, preventing waterlogging and reclaiming fresh water resources, strengthening the functions of salt leaching by summer rainwater and groundwater freshening.

3.2 Drain off excessive rainwater and salt to the sea by deep drainage ditches

For removing excessive storm water and salt from farmland to main drainage river course and direct to the sea, the NADPA takes the Dalongdian Main Drainage Ditch as the general main drainage ditch and outlet to the sea. The old No. 4 Main Ditch and No.2, No.3, No.4 main ditches (Attached Figure 1) as the main drainage systems (ditch depth 4 – 5 m), are connected together with the newly excavated branch, lateral, farm and field ditches and form a complete farm drainage systems.

The deep ditch drainage system turned the unfavorable factors of inundated farmland by excessive rainwater and salt accumulation after waterlogging in semi-humid monsoon climate region into favorable condition of salt leaching and saline water drainage. In rainy season, when the excessive rainwater is drained off, simultaneously a lot of salt is drained out with drainage water. The increased salt in soil due to irrigation with saline water can be leached and drained off in rainy season. The situation of regional water-salt balance had changed by the deep ditch drainage system, which enables the merging of the local small cycling of water-salt movement into the large cycling of continent and sea. That made the process of desalinization by rainfall leaching stronger than the process of salinization due to evaporation by drought, which lays a foundation for permanent control of soil salinization.

3.3 Water diversion and storage by deep canal and lifting irrigation

The NADPA take Xiaquan Canal (canal depth 4 – 5 m) as the general main canal to convey diverted water flow of Yellow River by South Grand Canal. The Xiaquan general main canal is connected with the main ditches (depth 3 – 4 m), irrigation canals and drainage ditches merges into one system. Water is lifted from branch and lateral ditches to farm canal for irrigation. Yellow River water flow is diverted and stored in canals and ditches in November to next February, and is lifted for irrigation in spring. For regulating surface water, there were built 14 controlling gates, 4 pumping stations and 346 bridges.

The advantages of deep canal for water diversion, storage and irrigation are: (a) Water can be diverted at any time whenever it is available. (b) All canals and ditches are connected with each other, water flow can be diverted to any where in the controlled range of canals and ditches. (c) The canals and ditches can be taken as regulating reservoir, water stored in winter is used in spring for lifting irrigation with proper water quantity and in time. (d) Through the control of water level in deep canals and ditches, the water table can be controlled below the critical depth of groundwater for prevention of salt accumulation due to water storage. (e) Increase of Groundwater recharge by water storage, it enables to keep the balance between exploitation and supplement of groundwater and freshening of groundwater quality.

http://library.wur.nl/books/drainage/drainage_cd/2%20cheng%20f%282%29%20xiuling%20chen%20boers%20theo%20mod.html (2 of 9)26-4-2010 12:12:25
4 Using saline groundwater for irrigation

4.1 Using brackish and semi-saline groundwater for irrigation

When the crops are irrigated with saline water in dry season, the soil moisture increases and the concentration and osmotic pressure of soil solution decreases which is beneficial to the moisture and nutrient absorption by crops. Since in dry season, the soil moisture during the growing stage of non-irrigated wheat is always less than 10 %, it is a severe limitation to crops growth. The soil moisture content when irrigating with saline water generally is 15 – 20 %, which corresponds to 60 – 80 % of the field moisture capacity and which is conducive to crops growth. During the seedling stage of wheat, soil evaporation is strong and the soil solution becomes concentrated (it may increase from 6 g/L to 14 g/L). However, after the seedling stage, when the wheat is irrigated with saline water, the concentration of soil solution may fall to 6 – 10 g/L. According to experimental results, the physiological tolerance of soil solution should not exceed 10 g/L in turn green stage and 20 g/L in jointing stage. Because the concentration of soil solution is kept below their limit, the wheat can grow well.

According to the research in Nanpi Pilot Area by the Hebei Institute of Hydrotechnics during the 1980 – 1989 decade, the crops yield increased significantly by irrigating with saline water as compared with non-irrigation. The yield of wheat irrigated with semi-saline water of 4 – 6 g/L was 2925 kg/hm², and for summer corn it was 4036.5 kg/hm², so the total was 6961.5 kg/hm², which is 1.2 times more than when non-irrigated. The yield of wheat irrigated with brackish water of 2 – 4 g/L was 3630 kg/hm² and for summer corn it was 4725 kg/hm², the sum being 8355 kg/hm² which is an increase of 1.6 times compared with non-irrigation (Table 3).

<table>
<thead>
<tr>
<th>Crops</th>
<th>1 g/L</th>
<th>2-4 g/L</th>
<th>4-6 g/L</th>
<th>Non-irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) wheat</td>
<td>4848.0</td>
<td>3630.0</td>
<td>2925.0</td>
<td>840.0</td>
</tr>
<tr>
<td>(2) summer corn</td>
<td>5542.5</td>
<td>4725.0</td>
<td>4036.5</td>
<td>2340.0</td>
</tr>
<tr>
<td>(1)+(2)</td>
<td>10390.5</td>
<td>8355.0</td>
<td>6961.5</td>
<td>3180.0</td>
</tr>
<tr>
<td>(3) spring corn</td>
<td>5883.0</td>
<td>5332.5</td>
<td>4797.0</td>
<td>4882.5</td>
</tr>
<tr>
<td>(4) soybean</td>
<td>1704.0</td>
<td>1252.5</td>
<td>960.0</td>
<td>915.0</td>
</tr>
</tbody>
</table>

4.2 Cycling of saline and fresh water

The alternative use of saline water and fresh water, according to the salt tolerance of different crops and salt tolerance in different growth stage, allows to optimize the role and benefits of saline water and fresh water respectively. Saline water is used when irrigating salt tolerant crops in the rotation or when irrigating a salt sensitive crop during a salt tolerant growth stage. The fresh water is used at all other times. Whatever salt build-up occurs in the soil from irrigating with saline water, is leached in a subsequent cropping period when fresh water is applied. The cyclic irrigation scheduling is formulated on basis of the different crops salt tolerances and different salt tolerant stages of the crops. In Nanpi Pilot Area, saline water of 5 – 6 g/L and fresh water of < 1 g/L was used in cyclic irrigation for wheat. Fresh water was used during the seedling stage and saline water was used after the jointing stage, which achieved good harvest. The yield of wheat was 4549.5 kg/hm², only 2.2 % less than when irrigating with fresh water (Table 4).

<table>
<thead>
<tr>
<th>Type of water</th>
<th>PH</th>
<th>Mineralization (g/L)</th>
<th>Composition of salt</th>
<th>SSP(%)</th>
<th>SAR</th>
<th>RSC (meq/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep fresh groundwater</td>
<td>8.3</td>
<td>1.0</td>
<td>HCO₃⁻-Na</td>
<td>90.4</td>
<td>15.2</td>
<td>5.04</td>
</tr>
<tr>
<td>Shallow saline groundwater</td>
<td>7.7</td>
<td>5.6</td>
<td>Cl,SO₄²⁻-Na,Mg</td>
<td>51.2</td>
<td>9.7</td>
<td>-</td>
</tr>
<tr>
<td>Mixture (two kinds as above)</td>
<td>8.1</td>
<td>3.0</td>
<td>Cl,SO₄²⁻-Na,Mg</td>
<td>46.4</td>
<td>9.0</td>
<td>-</td>
</tr>
<tr>
<td>Shallow fresh groundwater</td>
<td>8.2</td>
<td>1.9</td>
<td>Cl,SO₄²⁻-Na,Mg</td>
<td>46.0</td>
<td>4.7</td>
<td>-</td>
</tr>
<tr>
<td>River water</td>
<td>8.2</td>
<td>0.3</td>
<td>HCO₃⁻SO₄²⁻-Na,Mg</td>
<td>16.95</td>
<td>0.57</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3 Crop yield (kg/hm²) irrigated with various qualities of water

<table>
<thead>
<tr>
<th>Crops</th>
<th>1 g/L</th>
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</table>

4.3 Blending of saline and fresh water

Blending saline water with fresh water for irrigation, enables to improve the water quality, to enlarge available water resources and to increase the benefits of irrigation. The blending of saline water with sodic fresh water decreases the salinity and sodicity due to the mutual dilution of the two types water, and decreases the residual sodium carbonate (RSC) by the chemical combination of ions in the two types water (Table 5). When the sodic water which contains more Na⁺ is blended with saline water which contains more Ca⁺⁺, Mg⁺⁺, the chemical combination of CO₃⁻, HCO₃⁻ and Ca⁺⁺, Mg⁺⁺ forms harmless salts CaCO₃, MgCO₃, Ca(HCO₃)₂ and Mg(HCO₃)₂. Also, Na⁺ is chemical combined with Cl⁻, SO₄²⁻ to form NaCl and Na₂SO₄, which are far less harmful than Na₂CO₃ and NaHCO₃ and are easy leached by the concentrated rainfall or by irrigating with fresh water. In Nanpi Pilot Area, double cropped wheat and corn was irrigated with shallow saline groundwater (5 – 6 g/L) blended with deep sodic fresh water (< 1 g/L, pH = 8.5). The average yield during 1980 – 1989 was 8355 kg/hm², which was an increase of respectively 163 % and 20 % over non-irrigated with saline water of 4 – 6 g/L (Table 3).

<table>
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<tr>
<th>Type of water</th>
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<td>3.0</td>
<td>Cl,SO₄²⁻-Na,Mg</td>
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<td>9.0</td>
<td>-</td>
</tr>
<tr>
<td>Shallow fresh groundwater</td>
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<td>1.9</td>
<td>Cl,SO₄²⁻-Na,Mg</td>
<td>46.0</td>
<td>4.7</td>
<td>-</td>
</tr>
<tr>
<td>River water</td>
<td>8.2</td>
<td>0.3</td>
<td>HCO₃⁻SO₄²⁻-Na,Mg</td>
<td>16.95</td>
<td>0.57</td>
<td>-</td>
</tr>
</tbody>
</table>
### Soil salt control in the root zone

Using saline water for irrigation differs from irrigation with fresh water, because it not only should meet the requirement of moisture of the crops but also control the damage by salt. The principles of salinity control for irrigation with saline water are: (a) The salt accumulated in the soil should not exceed the crops salt tolerance limits. (b) The salt added to the soil by irrigating with saline water should be leached by rain or irrigation water so that the long term balance of soil salinity is maintained. (c) The salt accumulation should not occurred in root zone of soil. The salt balance relationship can be expressed as follow:

\[
S_0 + S_i - S_d \leq T_c
\]

Where:
- \(S_0\) = original salt content in the soil before irrigation;
- \(S_i\) = addition of salt to the soil due to irrigation with saline water;
- \(S_d\) = salt leached from soil by rain water or irrigation water;
- \(T_c\) = threshold value of crops salt tolerance.

Research results indicate that soil salinity does not reduce crop yield measurably until a threshold level is exceeded. Beyond the threshold, yield decrease approximately linearly as salinity increases. The salt tolerance index of crops is expressed as the ratio in yield under saline and non-saline conditions. The crop salt tolerance is evaluated by correlating crop yield and the total amount of soluble salts in the root zone. The equation of crops salt tolerance index can be expressed as follows:

\[
Y_r = \begin{cases} 
100 & \text{for } 0 < C < C_t \\
100 - S(C - C_t) & \text{for } C_t < C < C_0 \\
0 & \text{for } C > C_0 
\end{cases}
\]

Where:
- \(Y_r\) = relative yield;
- \(C\) = the average root zone salinity;
- \(C_0\) = the level of soil salinity above which the yield is zero;
- \(C_t\) = threshold, the maximum soil salinity without yield reduction;
- \(S\) = slope i.e. the percent yield decrease per unit of salinity above the threshold.

For the Nanpi Pilot Area where saline water is used for irrigation (taking the yields of non-saline soil irrigated with fresh water as 100) the relation between the salinity of root zone (0 – 40 cm) and the relative yield of crops can be expressed by the following equation (see also Figure 1):

\[
Y_{\text{wheat}} = 100 - 25.038(C - 1.20) \\
Y_{\text{summer corn}} = 100 - 16.232(C - 1.38) \\
Y_{\text{spring corn}} = 100 - 11.87(C - 1.72)
\]
Exploiting and utilizing shallow groundwater including brackish and saline water in eastern part of North China Plain may be used as the criteria of water table regulation for keeping water balance between exploitation and sustainable utilization of water resources. The required critical dynamics of groundwater depth in different seasons are:

**5.1 Critical depth of groundwater for soil salinity control in dry season (2 – 3 m)**

That is the shallowest groundwater depth that wouldn’t be accumulated salt in soil and not harmed crops by salt in dry season. This is the groundwater index to judge whether salt accumulation occurred in soil or not. Regulating groundwater table at critical depth, can be reduced evaporation of phreatic water as far as possible and prevent salt accumulation. In the region of light loam with different groundwater qualities which salt easily accumulated their critical depth are 1.8 – 2.8 m (Table 7). So that is proper to regulate the groundwater depth at 2 – 3 m in dry season.

**5.2 The depth for waterlogging prevention and rainwater storage before rainy season (4 – 6 m)**

Regulating the groundwater depth before rainy season should beneficial to increase the supplement to groundwater by rainfall infiltration. The precipitation in rainy season from June to September was 434 mm in normal year in Heilonggang region and east to South Grand Canal in North China Plain, the maximum supplement to groundwater by rainfall infiltration, its response groundwater depth was about 4.5 m before rainy season. In the range of groundwater depth at 2.5 – 4.5 m, the water table lowered 1 m, the supplement to groundwater increased 22 – 6 m. When the groundwater depth was more than 4.5 m, the rainfall infiltration decreases with the depth increased. When the groundwater depth at 5.5 and 4 m in wet year and dry year respectively, the supplement of rainfall infiltration is the maximum (Table 8). The proper groundwater depth is at 4 – 6 m before rainy season.

**5.3 The depth for subsurface waterlogging control of crops in rainy season (0.5–1m)**

The rainy season is the period of soil desalinization, the main disaster to crops is waterlogging.

<table>
<thead>
<tr>
<th>Mineralization of groundwater (g/L)</th>
<th>Light loam</th>
<th>Light loam sandwich clay</th>
<th>clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 3</td>
<td>1.8 – 2.1</td>
<td>1.5 – 1.8</td>
<td>1.0 – 1.2</td>
</tr>
<tr>
<td>3 - 5</td>
<td>2.1 – 2.3</td>
<td>1.8 – 2.0</td>
<td>1.0 – 1.2</td>
</tr>
<tr>
<td>5 - 8</td>
<td>2.3 – 2.6</td>
<td>2.0 – 2.2</td>
<td>1.2 – 1.4</td>
</tr>
<tr>
<td>8 - 10</td>
<td>2.6 – 2.8</td>
<td>2.2 – 2.4</td>
<td>1.2 – 1.4</td>
</tr>
</tbody>
</table>

When ponded water that is drain off, and the groundwater table raised by rainfall infiltration should be lowered to a depth for subsurface waterlogging control (wet resistance depth) in a required time (Table 9). In consideration of the main crops are corn and cotton in rainy season in the area of North China Plain, the proper groundwater depth should be kept at 0.5 – 1 m in rainy season. Summarizing the critical depth of groundwater required in various seasons, the critical dynamics of groundwater depth is as given in Figure 2. This figure can be used as the criteria of water table regulation for keeping water balance between exploitation and sustainable utilization of water resources. Transforming natural precipitation distributed unevenly in time and space into sustainable utilized water resources.

Exploiting and utilizing shallow groundwater including brackish and saline water in eastern part of North China Plain have the benefits of lowering groundwater table, vacating underground capacity, regulating groundwater depth at critical dynamics, transforming the natural precipitation distributed unevenly in time and space into sustainable utilized water resources. The exploited amount of groundwater was 6 million m³ before the establishment of NADPA, and reached 13.8 million m³ in 1987. The groundwater depths all dropped below 3 m before rainy season (June) in 1988, as compared with the same stage in 1985, the area with depths of 2 – 3 m was reduced by 77 %, the area with depths of 4 – 6 m increased by 53 %. The groundwater depths in 1986 – 1988 were 2.78 – 3.73 m in spring (March), 4.48 – 5.03 m before rainy season (June) and 1.15 – 2.95 m after rainy season (September), which were in accordance to the indices of critical dynamics of groundwater depth (Figure 3). It shows that the project has created the condition for enhance the control and utilization of rainwater.
<table>
<thead>
<tr>
<th>Plant</th>
<th>Milkage</th>
<th>Milky ripeness</th>
</tr>
</thead>
<tbody>
<tr>
<td>corn</td>
<td>Heading</td>
<td>3 - 4</td>
</tr>
<tr>
<td></td>
<td>Heading, milkage</td>
<td>50 - 60</td>
</tr>
<tr>
<td>Soybean</td>
<td>Blooming</td>
<td>10 - 12</td>
</tr>
<tr>
<td>cotton</td>
<td>Blooming, ball forming</td>
<td>3 - 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>60 - 70</td>
</tr>
</tbody>
</table>

**Figure 2  Critical dynamics of groundwater**

### 5.4 To Reduce phreatic water evaporation

The amount of phreatic water evaporation is closely related to the groundwater depth. In the area of light sandy loam, when the groundwater depth is at 1 m, the amount of phreatic water evaporation is 6-times that of the groundwater depth at 2.5 m (Figure 4). In the NADPA according to the average groundwater depth in 1984 – 1986, the calculated exploitable amount of phreatic water was 4.3 million m³. The groundwater depths in 1986 – 1988, which were regulated at critical dynamics (2.5 – 5 m), the calculated exploitable amount was 13.2 million m³, that means a total of 8.9 million m³ of available water resources was taken from phreatic water evaporation.

### 5.5 To increase rainfall infiltration

After the rainwater has infiltrated into soil, some part of it is stored as soil water, but most is transformed into groundwater and become available water resources. The groundwater depth was in critical dynamic state in NADPA, the rainfall infiltration recharged to groundwater was increased. In October 1986 – September 1987 and October 1987 – September 1988, the coefficient of rainfall infiltration reached 25 % and 21 % respectively. Though in 1986 – 1987, drought and a lot of groundwater had been exploited and used, due to the rainwater supplement in rainy season, the groundwater table rose by 1.75 m. After deducting the exploited amount and phreatic water evaporation in that year, the modulus of exploitable amount increased by 85.2 thousand m³/km² per annum, which supplied the groundwater source for combating drought in autumn and next spring.
5.6 To Reduce loss of runoff

While combating drought by irrigation in spring, a lot of shallow groundwater including brackish water had been exploited, that increased the underground reservoir capacity, increased the rainfall infiltration, reduced the surface runoff, and prevented the occurrence of waterlogging. Simultaneously the natural rainfall was transformed into available water resources as far as possible. The observation and research have shown that the runoff decreased with the drop of groundwater table. The groundwater depth was at 1.1 – 2.5 m before rainy season in 1974 – 1977, the individual rainstorm and the proceeding rainfall (P + Pa) was 156 – 244 mm, the depth of runoff was 18 – 47 mm. In 1984 – 1987, P + Pa= 88 – 236 mm, the runoff was 0 – 30 mm. As compared with 1980’s and 1970’s, the groundwater depth increased by 1.6 – 2.0 m, under the condition of P + Pa = 150 – 230 mm, the runoff was reduced by 17 – 24 mm. The groundwater depth was in the range of 1 – 5 m, when it dropped by every 1 m, the runoff decreased by 12 – 25 mm. 1987 was a sub-wet year with a precipitation of 736 mm, in which 509 mm fell down in rainy season, but no waterlogging occurred. The precipitation was 149 mm in Nanpi Pilot Area on August 3, 1987, the runoff was only 4 mm, most of the rainfall supplied to groundwater. The individual rainstorm lasting 6 hours was 189 mm on August 26, the depth of runoff was 30 mm, the excessive rainwater was accumulated on surface ground, but the groundwater depth was about 3 m before rainfall. As there are facilities of drainage, the accumulated water was drained off rapidly and infiltrated to underground, the groundwater depth was at 1.73 m 2 days after the rainfall, no waterlogging occurred. In the northern part of Nanpi Pilot Area, the groundwater depth was at 4.62 m before the occurrence of individual rainstorm (189 mm), no runoff occurred (Table 10).

5.7 Salt leaching and drainage by summer rainwater

The precipitation is concentrated in rainy season, mainly in July and August in North China plain. The rainfall is 434 mm in June to September in normal year, which accounts for 73% of the annual precipitation, with a stronger function for leaching salt of soil. Under the condition of deep drainage, the unfavorable factors of inundated by excessive rainwater and salt accumulation after waterlogging can be turned into favorable condition for salt leaching and saline groundwater drainage. Under the situation of groundwater depth regulated at the critical dynamics, the desalinization of soil in large area, mainly depend upon the salt leaching and drainage by summer rainwater. There were 7 times of water and salt drainage in Nanpi Pilot Area from 1974 to 1987, the total salt drainage was 1394.5 t/km² (Table 11). Owing to a lot of salt of soil was drained off, the saline-alkali land has reclaimed gradually. The saline-alkali land had reduced by 57 % from 1984 – 1987, till 2001 there was only remained 8 % (Table 12, Attached Figure 1). Owing to a lot of salt of soil was drained off, the soil salt supplement to groundwater was also reduced, which promoted the groundwater freshening gradually.

Table 10 Influence of water table depth on infiltration and runoff of rainfall.

<table>
<thead>
<tr>
<th>Observed section</th>
<th>Area (km²)</th>
<th>Date</th>
<th>H (m)</th>
<th>P (mm)</th>
<th>Pa (mm)</th>
<th>P+Pa (mm)</th>
<th>R (mm)</th>
<th>groundwater depth 2 days after the rain (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South branch ditch</td>
<td>4.51</td>
<td>1977/7/23</td>
<td>1.10</td>
<td>102.0</td>
<td>54.5</td>
<td>156.4</td>
<td>47.2</td>
<td>0.01</td>
</tr>
<tr>
<td>South branch ditch</td>
<td>4.53</td>
<td>1977/5/20</td>
<td>2.05</td>
<td>123.0</td>
<td>121.0</td>
<td>244.0</td>
<td>44.7</td>
<td>0.15</td>
</tr>
<tr>
<td>North branch ditch</td>
<td>15.05</td>
<td>1975/7/29</td>
<td>2.36</td>
<td>186.3</td>
<td>8.2</td>
<td>194.5</td>
<td>24.5</td>
<td>0.65</td>
</tr>
<tr>
<td>South branch ditch</td>
<td>4.51</td>
<td>1987/8/3</td>
<td>3.20</td>
<td>149.0</td>
<td>12.0</td>
<td>171.0</td>
<td>4.0</td>
<td>1.73</td>
</tr>
<tr>
<td>North branch ditch</td>
<td>15.05</td>
<td>1987/8/26</td>
<td>4.62</td>
<td>189.1</td>
<td>47.7</td>
<td>236.8</td>
<td>0</td>
<td>1.92</td>
</tr>
</tbody>
</table>

Note: H=groundwater depth, P=individual rainstorm, Pa=preceding rainfall, R=depth of runoff

Table 11 Amount of rainfall, water and salt drainage in Nanpi Pilot Area

<table>
<thead>
<tr>
<th>Duration</th>
<th>Drainage area(km²)</th>
<th>Rainfall (mm)</th>
<th>Water drained 1000 m³</th>
<th>Average mineral. (g/L)</th>
<th>Salt drained (l)</th>
<th>Unit area salt drained (t/km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974.7.22-8.30</td>
<td>4.53</td>
<td>570</td>
<td>365.0</td>
<td>3.83</td>
<td>1397.0</td>
<td>308.1</td>
</tr>
<tr>
<td>1975.7.29-8.20</td>
<td>4.53</td>
<td>284.5</td>
<td>75.0</td>
<td>4.17</td>
<td>312.5</td>
<td>68.7</td>
</tr>
</tbody>
</table>
5.8 Saline groundwater freshening

Under the monsoon climate and drainage conditions, pumping saline groundwater for irrigation over a long period of time, together with the supplement by rainwater and fresh water, has enhanced the cycling and replacement of saline water and freshwater, and promoted the saline groundwater freshening. Since 1980, the Nanpi experimental field began to pump saline groundwater (5 – 6 g/L) for irrigation by siphon wells. After 8 years, the mineralization of groundwater decreased to 1 – 2 g/L. The mineralization of groundwater at the depth of 5 m decreased to 2.3 – 2.8 g/L, from 5.1 – 5.3 g/L, the mineralization of sub-layer (about 10 m) groundwater decreased to 3.06 – 3.83 g/L from 5.2 – 7.8 g/L. (Table 13). In Nanpi groundwater monitoring area, the groundwater was freshened obviously in the 15 years from 1974 – 1989. The area of fresh water (<2 g/L) has increased from 20 % to 50 % at the groundwater surface. In some area the groundwater has become fresh water from original saline water surface from the depth of 8 m (Attached figure 2). The freshwater body increased by 639000 m³, the modulus of exploitable amount increased by 15000 m³/km²/a. The rainfall infiltration is the main factor to promote saline groundwater freshening. The precipitation was 736 mm in 1987, in the groundwater layer was all freshened as compared with the same stage (June and September) of the preceding year. 1985 was a normal year, as compared with the preceding year the groundwater freshened accounted for 72 %. But 1986 was a dry year, as compared with the preceding year, the groundwater mineralized accounted for 78 %. But the general trend was freshening, which accounted for 56 – 72 %, and the mineralized accounted for 23 – 44 %. The key measure for increasing rainfall infiltration is regulating groundwater depth in an appropriate state. The precipitation was 1185 mm in 1977, but the groundwater depth was 1 – 2 m, under such conditions the total rainwater could not be stored, a lot of fresh water was drained off. While in 1987, the groundwater depth was 4.26 m, when an individual rain storm was P+Pa = 236 mm occurred, no runoff drained off, all infiltrated into underground, the groundwater was freshened more obviously.

### Table 12 Variation of area (hm²) of salt-affected soils (SAS) in Nanpi Project Area (1984-2001)

<table>
<thead>
<tr>
<th>Year</th>
<th>Light SAS</th>
<th>Medium SAS</th>
<th>Heavy SAS</th>
<th>Saline waste land</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 1984</td>
<td>959</td>
<td>1011</td>
<td>1866</td>
<td>446</td>
<td>4282</td>
</tr>
<tr>
<td>June 1987</td>
<td>1060</td>
<td>472</td>
<td>203</td>
<td>91</td>
<td>1826</td>
</tr>
<tr>
<td>June 2001</td>
<td>208</td>
<td>60</td>
<td>72</td>
<td>-</td>
<td>340</td>
</tr>
</tbody>
</table>

### Table 13 Variation of mineralization (g/L) of groundwater (1982 – 1988) Nanpi experimental field of Hebei Institute of Hydrotechnics

<table>
<thead>
<tr>
<th>Date</th>
<th>Ground Water Depth M</th>
<th>Surface</th>
<th>No.12</th>
<th>Bottom</th>
<th>Surface</th>
<th>No.14</th>
<th>Bottom</th>
<th>Surface</th>
<th>No.15</th>
<th>Bottom</th>
<th>Precipitation (Mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982/3</td>
<td>2.9</td>
<td>10.03</td>
<td>5.30</td>
<td>5.70</td>
<td>3.80</td>
<td>3.60</td>
<td>5.70</td>
<td>4.80</td>
<td>5.20</td>
<td>6.40</td>
<td>380.4</td>
</tr>
<tr>
<td>1982/9</td>
<td>2.0</td>
<td>7.60</td>
<td>7.80</td>
<td>11.5</td>
<td>4.80</td>
<td>3.60</td>
<td>5.70</td>
<td>4.80</td>
<td>5.20</td>
<td>6.40</td>
<td>380.4</td>
</tr>
<tr>
<td>1983/6</td>
<td>2.7</td>
<td>6.62</td>
<td>5.06</td>
<td>7.11</td>
<td>3.27</td>
<td>4.24</td>
<td>5.78</td>
<td>6.26</td>
<td>6.52</td>
<td>405.3</td>
<td></td>
</tr>
<tr>
<td>1983/9</td>
<td>2.2</td>
<td>4.05</td>
<td>5.77</td>
<td>6.98</td>
<td>3.66</td>
<td>3.92</td>
<td>4.09</td>
<td>3.67</td>
<td>4.50</td>
<td>11.95</td>
<td></td>
</tr>
<tr>
<td>1984/6</td>
<td>3.0</td>
<td>3.77</td>
<td>3.83</td>
<td>7.25</td>
<td>3.38</td>
<td>3.87</td>
<td>4.05</td>
<td>1.35</td>
<td>4.19</td>
<td>11.73</td>
<td></td>
</tr>
<tr>
<td>1984/9</td>
<td>1.5</td>
<td>3.51</td>
<td>3.23</td>
<td>6.07</td>
<td>1.98</td>
<td>3.77</td>
<td>4.92</td>
<td>2.65</td>
<td>4.00</td>
<td>11.32</td>
<td></td>
</tr>
<tr>
<td>1985/7</td>
<td>1.8</td>
<td>1.98</td>
<td>2.08</td>
<td>2.90</td>
<td>1.98</td>
<td>2.25</td>
<td>4.73</td>
<td>4.98</td>
<td>5.01</td>
<td>10.60</td>
<td></td>
</tr>
<tr>
<td>1985/9</td>
<td>1.0</td>
<td>2.43</td>
<td>3.34</td>
<td>4.05</td>
<td>2.65</td>
<td>3.34</td>
<td>5.05</td>
<td>2.75</td>
<td>3.86</td>
<td>9.06</td>
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</tr>
<tr>
<td>1986/6</td>
<td>2.9</td>
<td>4.03</td>
<td>3.93</td>
<td>5.79</td>
<td>2.95</td>
<td>3.23</td>
<td>3.98</td>
<td>4.75</td>
<td>4.81</td>
<td>396.8</td>
<td></td>
</tr>
<tr>
<td>1986/10</td>
<td>3.9</td>
<td>2.98</td>
<td>3.25</td>
<td>5.21</td>
<td>2.71</td>
<td>3.42</td>
<td>4.58</td>
<td>3.78</td>
<td>4.47</td>
<td>12.13</td>
<td></td>
</tr>
<tr>
<td>1987/3</td>
<td>3.5</td>
<td>2.63</td>
<td>3.21</td>
<td>3.93</td>
<td>1.40</td>
<td>2.39</td>
<td>2.38</td>
<td>3.31</td>
<td>3.21</td>
<td>8.56</td>
<td></td>
</tr>
<tr>
<td>1987/8</td>
<td>2.5</td>
<td>0.38</td>
<td>0.57</td>
<td>2.22</td>
<td>1.20</td>
<td>1.44</td>
<td>1.62</td>
<td>0.31</td>
<td>1.01</td>
<td>1.56</td>
<td></td>
</tr>
<tr>
<td>1988/3</td>
<td>2.5</td>
<td>2.46</td>
<td>2.38</td>
<td>3.32</td>
<td>1.19</td>
<td>1.23</td>
<td>2.56</td>
<td>2.12</td>
<td>2.12</td>
<td>2.84</td>
<td></td>
</tr>
<tr>
<td>1988/11</td>
<td>1.5</td>
<td>3.47</td>
<td>3.43</td>
<td>3.83</td>
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<td>1.83</td>
<td>3.83</td>
<td>1.06</td>
<td>1.26</td>
<td>3.06</td>
<td></td>
</tr>
</tbody>
</table>

The Yellow River diversion for water source supplement is also the important condition for promoting the balance between exploitation and supplement of groundwater and groundwater freshening. The average annual Yellow River diversion was 100 million m³ in Cangzhou City in which water diverted to Nanpi County was 20.5 million m³, the area of water storage and irrigation was 6000 hm². The annual precipitation was 521 mm in 2001, and from January to May in 2002, the precipitation was only 32 mm, but due to diversion of Yellow River water the groundwater depth still maintained at 4 – 4.5 m in June 2002 after spring irrigation (Attached figure 2), that is it just at critical depth of groundwater before rainy season.

The premise condition to enhance the control and utilization of rainwater is exploiting and utilizing shallow groundwater including brackish and saline water. Owing to exploitation of the storage amount of groundwater, the groundwater table goes down, the underground capacity of groundwater aquifer is vacated, so that the rainwater can be infiltrated to replenish the groundwater, and the irrigation water extracted from the aquifer can be compensated by rainfall recharge, the salt in the soil can be dispersed to a deeper layer and saline water can be desalinated and becomes exploitable resources. The area of brackish and saline water of less than 5 g/L is 36.3 thousand km² in North China Plain, in which 20 thousand km² is in Hebei Plain. According to rough estimates of the average annual rainfall infiltration 100 mm (100 thousand m³), the supplement resources of groundwater in North China Plain and in Hebei Plain are 3.63 and 2 billion m³ respectively, if exploitation coefficient is 0.8, then the increased exploitable resources due to utilization of saline water will be 2.9 and 1.6 billion m³ respectively.

### 6 Conclusion

Drought, waterlogging, salinity and saline groundwater are the main restraining factors for sustainable development of agriculture in the eastern part of North China Plain. The area is the region with minimum water resources per capita in nation-wide, most extensive distribution of saline groundwater, and the serious overdrawn of deep groundwater and the eco-environmental deterioration. For the sustainable utilization of water resources should be taken the local shallow groundwater including brackish and saline water as the basic water source, and diverting available surface water resources as the supplementary water source. Setting up infrastructure of wells, canals and ditches, developing well irrigation and drainage in combination with canal irrigation, construction of ditch drainage systems, using deep ditches to drain off excessive rainwater and salt to the sea, diverting and storing surface water by deep canal for irrigation are the comprehensive measures for combating drought, waterlogging, salinity and saline groundwater in this area. Exploiting and utilizing shallow groundwater including brackish and saline groundwater for irrigation can help to increase yield by providing some key waterings for wheat which is the crop that requires most water in dry season, the seeding of corn and cotton may reach full stand by irrigating before seeding in dry spring in every year. It enables to provide one half of farmland with irrigation water, replace the continuous overdrawn of deep groundwater.

http://library.wur.nl/ebooks/drainage/drainage_cd/2.3%20sheng%20W%20s%20%26%20chen%20%26%20boers%20theo%20mod.html (8 of 9)26-4-2010 12:12:25
depth at critical dynamics. The stratum space of soil and phreatic water aquifers can be used as the underground reservoir for regulating atmospheric water, soil water, groundwater and surface water, reduce phreatic water evaporation, increase rainfall infiltration, reduce loss of surface runoff, promote salt leaching and drainage by summer rainwater and freshening saline groundwater, thus to transform the natural rainfall unevenly distributed in time and space into available water resources to a maximum. So as to achieve the comprehensive control of drought, waterlogging, salinity and saline groundwater, and the sustainable utilization of water resources as well as the sustainable development of economy and society, and the good cycling of eco-environment can be realized.

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[3] International Institute for Land Reclamation and Improvement The Netherlands
Lack of drainage and inadequate protection of agricultural lands from inundation are major constraints to agricultural development in many humid tropic areas. Existing hydraulic infrastructure cannot cope with hydrological regimes and as a result, land use cannot reach its full potential. There are three drainage problems that are characteristic of humid regions, namely:

- Submergence of agricultural lands caused by surface runoff from the catchment area.
- Water logging inundation of agricultural lands caused by local rainfall.
- Water logging and associated physio-chemical problems in low-lying areas.

Drainage system includes river bunds, earth drains, drainage gate and crossing were constructed to overcome the problems. These systems require proper operation and regular maintenance for the system to be functioning well. To enhance the implementation of a drainage system, farmers’ participation must be further exploited since they are the user and beneficiaries of the system.

Users can be divided into two categories, ie individual or group. Individual user can be a company/private sector or anybody that have the overall responsibility in operation and maintenance of the facilities provided. Individual users can also form a group to take certain responsibility and become a group user.

**Current Role / Contribution**

There are a lot of drainage projects initiated by government department/agency to solve problems faced by the farmers. Most of the farmers are normally an individual user who has their own problems which need to be look into. For private company, they have their own expertise and financial to address the problems but for individual farmers they needs support from the government.

Currently users are sometime participate during the planning stage where they are consulted through dialog, meeting or local course in determining the required infrastructure because they are more familiar with the site condition since they have been working on their land for so many years. Their comments or suggestions are mostly based on their experience and individual requirement such as crossing, farm road and offtake. In the era of IT, their contribution will be more meaningful if they can acquire more knowledge and technical know-how related to crop requirement and best agricultural practices.

**Farmers Organization**

Although farmers as a user of a drainage and irrigation facilities can be a member of a body which is called farmer's Organization (FO), but their role in operation and maintenance of the facilities is still lacking. To them, the operation and maintenance is government responsibility since all the infrastructures were provided by the government. The role of the FOs' in the implementation and management of a drainage system is also very little accept in maintenance works where some of the contract works was given to them. To the users, the FOs' role is to give them assistance in agricultural input and financial.

Director, Asian Drainage Programme for the Humid Tropics, Kuala Lumpur, Malaysia.
MANAGERIAL ASPECTS OF INTEGRATED WATER MANAGEMENT (IWM)[1]

Prof. V. Dukhovny[2]

IWRM supposes observance of several main principles:

- Basin management along hydrographical boundaries;
- Conjunction of hierarchic levels and their connection;
- Inter-sector approach;
- Public participation in management, operation and maintenance – two approaches: “bottom-up” and “top-down”;
- Providing ecological requirements;
- Sustainable functioning.

Functional tasks of the management of drainage systems are sharply differing between rain fed and irrigated areas. In rain fed areas, drainage of excessive water from precipitation, ground inflow or melting snow is needed to prevent ground water table rise which otherwise will result in unfavourable conditions for crops, buildings and structures, etc. In irrigated agriculture, the drainage network within a basin is a part of reclamation system, including both drainage and irrigation, which should create favourable conditions for crops growing. Here drainage serves to regulate the soil water-salt regime, to prevent soil salinisation, to decrease salt stock and for certain areas to minimize specific water discharges for irrigation at the expense of the irrigation regime and the joint ground water management.

For both rain fed and irrigated areas, drainage includes the removal of excess water and dissolved salts and the release in recipient water bodies (rivers, lakes, closed depressions). To maintain biodiversity and bio productivity in the recipient water bodies water qualitative indicators are needed to regulate and limit both the amount of water to be released as well as the quality in order to provide sustainability. From this point of view, large collectors and water withdrawal tracts should be included into the basin part of the water system and managed in connection with the requirements of the regional basin water bodies (Basin Water Organisation, Basin Commission, etc.). To manage drainage systems within an irrigation system and especially the parts served by Water Users Associations is more difficult because the boundaries of the irrigation and drainage systems do not always coincide. This should be taken into account in organizing the management of the systems. Points for discussion are:

- How to provide links between the main water withdrawal system at river basin level and the irrigation and drainage systems with their two-level hierarchy, i.e. systems governed by State Bodies and systems governed by WUA (release and withdrawal limits, pollutants limits, water withdrawal regime and its planning)?

- How to provide sustainability for recipient water bodies and how to meet the requirements for the amount and quality of the water in these systems especially in closed water bodies with regard to natural flow, anthropogenic fluctuations, water diversion and drainage management (here ecological requirements appear)?

- How to create favourable reclamation conditions on irrigation massifs with regard for all these fluctuations and the necessity to use saline water for irrigation?

Taking into account that inter-sector approaches and public participation issues are considered in detail in some other sub-topics of the workshop program (sub-topic 3.1, 3.2, 3.3), we will concentrate on the sustainable management of drainage under current, modern conditions.
The sustainability of the functioning of drainage system depends on:

- Fluctuation, irregularity and variability of natural factors determining impact on drainage (precipitation, ground inflow, evaporation);
- Changes of anthropogenic load on drainage (irrigation norm, irrigation technique, water losses from canals);
- Performance (workability) of the drainage system: decrease due to ageing by siltation, colmatation of screens and openings, well destruction, over-drain stripes compaction);
- Intensity and order of repair-operation works; Indisputably the latter two factors themselves depend on the capital investments available for the design and construction of the drainage system: the higher these investments the lower repair and maintenance costs. In this respect, rational water use, drainage maintenance and water-salt regime regulation require certain main tools.
- Dynamic account of variability and forecast of unsaturated zone and groundwater water & salt balances;
- Anthropogenic impact on drainage management;
- Optimal planning and implementing repair-operation works.

Questions for discussion:

- What are the experiences of sustainable drainage system operation in irrigated and rain fed areas?
- What are the main obstacles for sustainable management in the interrelation “irrigation-nature-drainage” and what measure are there to overcome these obstacles?
- How to predict the performance (workability) of drainage systems and what maintenance is needed?
- How to select the optimal ratio “capital investment (drainage reserve) – rational regime of repair-operation works”;
- Which mechanism for the financing of the operation of the drainage system is needed?

[2] Director SIC ICWC, ICID member, Uzbekistan.
My name is Bert Smedema and I have been asked by the organising committee of the 9th IDW to initiate and facilitate an Internet discussion on the theme of “cost recovery” of land drainage projects.

For those of you who are preparing a workshop paper or are otherwise considering making a workshop contribution to this theme, below please find for your guidance some thoughts on how such a contribution might be approached and which aspects of cost recovery might be highlighted.

These thoughts are merely meant as an opening of this (Internet) discussion. I am certainly not an expert on this theme, just your humble facilitator. I would very much appreciate your comments and suggestions and will respond accordingly. In due time, when the workshop papers come in, I will also try to incorporate the substance of these papers in our discussions.

Hope we will have fruitful but also enjoyable exchange and that we will succeed in ending up with increased understanding of the involved factors and with some sensible and tangible conclusions.

1 Development models

Current thinking on the recovery of the costs of drainage projects should be seen against the backdrop of the shift in development thinking which occurred during the 1970/80’s when the central planning model was largely replaced by the market model. While in the first model, the initiative and the management and financing responsibilities of development projects rested primarily with the governments, the new model reserves a much greater role for the users and other stakeholders. Environmental protection/enhancement, long term sustainability, participatory development and ownership are the key elements of the new model.

It may be noted that almost all drainage development in the developed countries was completed before the 1980’s under the old central planning model. Almost all existing drainage infrastructure in Europe and North America was in fact developed with strong governmental support.

Discuss:

- appropriateness of the market model for drainage development
- drainage in developed vs developing countries
- specific cases of positive and/or negative policy environments
- role of international donor and financing agencies

2 Public vs private good

A leading principle of public finance is that (based on efficiency and equity considerations), the financing of activities from public resources should be restricted to public goods and that private goods should be financed from private resources. In drainage,
this public/private goods distinction is closely linked to the typical three level hydrological and institutional ordering of the drainage activities within a drainage basin (basin level, district level and farm level). For proper application of the above enunciated public finance principle, the public/private goods content of the drainage activities needs to be established at each of these three levels.

In the most developed countries, the drainage activities at the basin level were traditionally considered to a public good, a mixture at the district level and a private good at the farm level. Most developing countries also adhere in principle to this division. In practice, however, drainage activities at the farm level were considered to have a considerable public good content and as such entitled to public financial support. The above described shift in development thinking has in many countries led to a limitation the public financing of drainage activities at the on-farm and also at the district level

Discuss:

• appropriateness of the public/private goods distinction to drainage development
• appropriateness to subsistence farming in developing countries
• public/private good content of various drainage activities
• appropriate classification criteria

3 Capital vs O&M costs
In cost recovery consideration and practices, often a distinction is made between the capital costs and the O&M costs. Apart from the fact that the capital needs to be available as a sum to finance the planned development, financially the two costs are quite similar, both posing recurrent annual burdens (although administratively treated separately).

The commonly made cost recovery distinction, therefore, is based on other, non-financial, considerations. The distinction is usually that capital costs are not recovered from the direct beneficiaries. This holds for much of the main drainage infrastructure but in many cases also fully or partly for the on-farm investments. The main consideration is usually that recovery of the invested capital from the direct beneficiaries is beyond their means while development as such is desirably, justifying it to be considered a public good. The O&M costs of drainage projects at the other hand are as a rule born by the direct beneficiaries, because it is considered to be affordable but also on principle, to promote responsibility, ownership and sustainability.

Discuss:

• justification of non-recovery of capital costs of drainage project; specific cases requiring special consideration (recovery/non-recovery)
• capital cost recovery justification for main vs on-farm systems
• cost recovery of rehabilitation projects
• cost recovery of replacement/improvement investments

4 Special cost recovery considerations
It may plausibly be argued that some drainage activities should be given special cost recovery consideration. This applies e.g. to drainage development project which demonstrably contribute to poverty alleviation, social development, rural development, combat of public health, improvement of residential living conditions, environmental protection, natural resource conservation and other objectives with a high public good content.
COST RECOVERY

It may even be argued that much of the drainage development for salinity control of irrigated areas in the arid fall in this category, the arguments being that such projects are environmental protection projects, national resource conservation projects. An additional argument for special cost recovery consideration may be that in many cases the water logging and salinization of the land is not (solely) caused by the farmer.

Discuss:

- extension, elaboration, articulation of the mentioned cases justifying special cost recovery consideration.
- justification of special cost recovery consideration of drainage for salinity control

5 Beneficiary identification, Assessment base and Affordability

Almost all those residing and/or economically engaged in the drainage basin have in one way or other an interest in the quality of the drainage conditions and drainage services in that basins. This applies first of all to the landowners and the farmers but also to homeowners, businesses and industries. The level of interest between these various may however differ greatly and this should be properly accounted in the cost recovery. Interest may also greatly at the different hierarchical levels. Proper identification of these various categories of beneficiaries and the establishment of a solid basis for assessing these derived benefits is therefore an essential requirement for a fair and equitable system of costs recovery.

Rates may be simply determined by dividing the annual costs to be recovered by the total assessed interest of the beneficiaries. Other systems also prevail. In some cases it is also justified to take into account the financial positions of the beneficiaries. In some countries, upper limits are set on the contribution which can be demanded from farmers (say not more than 20-30 % of their net crop based income).

Discuss:

- descriptions and analyses of various beneficiary identification and assessment systems followed in different countries
- identification of best cost recovery practices
- overviews of actual and relative cost recovery rates (expressed in term of derived drainage benefits, net income or otherwise)
- merits and justification of affordability considerations

6 Analogies with other Water Sectors

Although each sector is unique and specific, view may be developed and lessons may be learned by comparing and analysing principles, considerations and experiences with cost recovery in other water sectors.

First of all comparison with the irrigation sector comes to mind although the provided service is technically clearly quite different (water supply vs water removal). In the public/government/official view, the provision of irrigation services has often a much higher public good content than the provision of drainage services and cost recovery in treated accordingly.

Technically, land drainage systems are much closer to sewerage systems and quite similar cost recovery principles are followed. As with drainage, different beneficiary groups are usually identified for the different hierarchical system component (in-house facilities, lateral, sub-main and main lines, treatment and disposal facilities). Affordability considerations quite similar to those discussed above, have also been advanced in many developing country cases to justify lower or otherwise adapted cost recovery policies.
COST RECOVERY

Discuss:

• analogies and lessons to be learned from irrigation projects
• analogies and lessons to be learned from sewerage projects
• other analogies

7 Recovery Mechanisms
Various modes of cost recovery are applied: crop based (higher rates for higher value crops), area based (with possible differentiation between higher and lower land), incorporated in other fees (general or local taxes, part of a land tax, part of an irrigation fee), collected by local/regional/central government or by public drainage organization or water user organizations, allocation and use of the collected funds. Various combinations of each of these elements are found in different countries and for different projects

Discuss:

• pro's and con's of the possible alternatives
• detailed descriptions and analyses of specific cost recovery practices or combinations of specific cost recovery practices in specific countries or on specific projects
• suggested judgement criteria, suggested best practices.

8 Other subjects
The above subjects are suggestions, not restrictions. All relevant subjects are welcome. Case studies, descriptions and analyses of successes and failures, factual/anecdotic information, all this is particularly welcome.

PARTICIPATION OF DRAINAGE USERS IN INTEGRATED WATER MANAGEMENT

Hussein El-Atfy and Samir Abbas

ABSTRACT
The River Nile forms the main water resource in Egypt and provides a natural flow at 55.5 billion cum/annum. Water demand is rapidly overtaking the supply from the available water resources. About 85% of the demand is consumed in irrigation. The use of irrigation water under the perennial irrigation increased after the construction of the Aswan Dam and the Aswan High Dam, which has resulted in drainage problems such as waterlogging and soil salinization. So far, an area of about 5 million feddans has already been covered with tile drainage.

Realizing the importance of subsurface drainage, the Egyptian Public Authority for Drainage Projects (EPADP) has established since 1992 nearly 4,700 stand-alone Collector Users’ Associations (CUAs) in around 8% of the agricultural lands planned to be served by subsurface drainage in the framework of involving farmers in O&M of drainage. Meanwhile, the Irrigation Improvement Sector (IIS) has established about 6000 Water Users’ Associations (WUAs) on the mesqa tertiary level and federated some of them on the Branch Canal level (BCWUAs). Moreover, by the end of 2002 a total over 50 Water Board-like institutions have been established covering more than 150,000 feddans.

However, in the context of the agricultural development in Egypt, the necessary maximization of water use efficiency and minimization of drainage problems have been achieved by the water sector via technical solutions for which the feasible options are about to be exhausted. Introducing the concept of participatory and integrated water management (PIWM) becomes obviously the next step. Exploration of alternative institutions, legislations and regulations to efficiently introduce drainage users and other stakeholders to this concept becomes an important issue.

This paper illustrates the importance of farmers participation in drainage, the constraints encountered and identifies the current CUAs, WUAs/BCWUAs, Water Boards and the Integrated Water Management Districts being piloted by the Ministry of Water Resources and Irrigation (MWRI). The paper explores and analyses integrated alternatives to present a future overview for a proposed institutional model of users participation in drainage aspects nationwide on the basis of the aforementioned concept.

1 THE IMPORTANCE OF USERS’ PARTICIPATION IN DRAINAGE ISSUES

1.1 The Existing Services Rendered by EPADP to Users

Being a service oriented authority, EPADP provides different drainage services to farmers. A brief for these services will be given in the following paragraphs.

A comprehensive program covering 7.2 million feddans (1 feddan= 4200 m² i.e. around 1 acre) and including construction of new surface drains, remodeling, deepening and widening of existing open drains was initiated in the early seventies. In 1978, EPADP introduced long term planning for flexible construction of subsurface drainage in an area of 6.4 million feddans, which widely enabled the use of mechanized pip-laying, plastic pipes and synthetic envelope materials by public and private contractors.
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(average 150,000 feddans/ year).

EPADP is intensifying the efforts to rehabilitate the old subsurface drains in an area of 1.6 million feddans by year 2012.

Maintenance is very important because it guarantees high efficiency during lifetime of open and covered drainage networks. Some 18,000 km of weed harvesting in addition to 21 million m³ of earthmoving costing about L.E 55 million are annually necessary for maintaining the open main drains. Cleaning is done manually by EPADP’s laborers in small drains and mechanically by contractors awarded by EPADP for the rest. Maintenance of subsurface drains (6 times for manholes and twice for pipes) in some 5 million feddans is financed (around LE 25 million/year) and done annually by EPADP.

1.2 Priorities of Users’ Participation in Drainage Issues

Taking into consideration the commitment of the national plans and relevant technicalities such as use of costly equipment, supply of drainage plastic pipes and envelop materials … etc, the construction and rehabilitation activities of drainage systems cannot be practically subject to transfer from EPADP to the users. Moreover, this is against the responsibilities to be undertaken by EPADP according to the prevailing laws. However, in addition to the existing cost recovery system, users’ participation in these activities will likely include information exchange, quality control, operation of the modified system of subsurface drainage, monitoring, evaluation and complaint management. As a matter of fact, users’ participation in maintenance activities will have high priority.

With respect to open drainage maintenance, the Land Taxes Department considers an incremental increase for the areas supplied with open main drains that partially includes maintenance costs. However, as properties of less than 3 feddans –which are the prevailing properties– have been recently exempted from land taxes, the land tax may not be the proper solution. Accordingly, farmers’ participation in maintenance of open main drains will require amendments in the prevailing legislation.

To perform maintenance of subsurface drainage in old lands and new lands, forming CUA’s is allowed if they are in accordance with law no. 213/1994 and if they do not violate the authority of MWRI. Some of these CUA’s are located within the area of Irrigation Improvement Project (IIP) which gives a probability of integrated approach in water management and extension services as far as the prevailing laws allow.

From practical point of view, farmers’ participation in maintenance of open main drains is advisable to take place in a second stage after setting successful procedures of the most appropriate mechanism for farmers’ participation in maintenance of subsurface field drainage.

Therefore, farmers’ participation in maintenance of subsurface field drainage could have first priority to start with.

1.3 Importance of Farmers’ Participation in the Operation and Maintenance of Subsurface Drainage

Farmers’ participation in operation and maintenance of subsurface drainage and consequently recovery of the maintenance costs are important for the following reasons:

- Subsurface drainage networks are in land possessions of farmers.
- These networks are private properties owned by farmers who pay the construction costs.
- Farmers often cause blockage of the network elements and they should be responsible for protecting it against such defaults to attain its lifetime.
- Drainage directorates presently have heavy administrative, financial and technical burden. Shift of
maintenance responsibilities to farmers will enable staff to achieve the progressive rehabilitation plans of subsurface drainage of EPADP.

- Farmers’ complaints will be minimal.
- Farmers will realize compatibility between operation of the network and a voluntary cropping pattern.
- Integrated management of irrigation and drainage systems on the tertiary level will be easier.

2 THE PRESENT USERS’ INVOLVEMENT IN INTEGRATED WATER MANAGEMENT

2.1 Collector Users’ Associations (CAUs)
Open main drains are considered to be common property and their construction, remodeling and maintenance are consequently done and paid by EPADP. Maintenance of open field drains is done and paid by farmers as private properties. But maintenance of subsurface field drains is still done and paid by EPADP. Land taxes is the only revenue for funding the government drainage services while sufficient financial resources are required to accomplish the national plans. Since 1992 EPADP has aimed at giving greater role to drainage users in operation and maintenance of drainage through CUAs which has been established so far in around 500,000 feddan i.e. 8% of the objected subsurface drainage area.

The following paragraphs present an idea on the roles of both of EPADP and CUAs and the constraints encountered for involving the CUAs in Integrated water management.

Belonging to EPADP, there are 162 maintenance centers (40,000 feddans each) and 450 drainage sub-centers (5,000 feddans each) at 29 general directorates of drainage in 5 drainage sectors. Through their centers and sub-centers, these directorates currently undertake the following responsibilities:

- Periodic maintenance of subsurface drainage.
- Periodic desilting and weed-control of open main-drains.
- Unperiodic maintenance of drainage networks that have sudden defaults and farmers complain from.
- Enforcement of irrigation and drainage law (law 12/1984) and law of watercourses’ protection from pollution (law 48/1982).
- Monitoring the performance of drainage pumping stations.
- Lately, rehabilitation of subsurface drainage networks which forms additional burden on maintenance directorates.

The CUA is made up of a group of farmers located in the command area (serviced by subsurface drainage) of a specific collector. The CUAs are designated to cover the following functions:

- To undertake the responsibility of subsurface-drainage ownership and release the burden of its maintenance from EPADP.
- To address farmers’ problems and enhance communication between farmers and engineers of EPADP during the field investigation, design and implementation activities required for rehabilitation of the drainage network.
- To encourage trained farmers to extend their experience to neighbors who are receiving new drainage
PARTICIPATION OF DRAINAGE USERS IN INTEGRATED WATER MANAGEMENT

• To ensure co-operation with the Ministry of Health on its public awareness campaigns dealing with the impact of reuse of contaminated drainage water on the environment and public health.

The effective performance and involvement of stand-alone CUAs in water management issues are hindered by many constraints that can be attributed to the following factors:

2.1  

2.1.1 Legal framework
CUAs lack any legal identity and there is no official authorization to buttress their existence. Furthermore, CUAs cannot receive ownership rights (on behalf of users) to the appropriate section of subsurface drainage system. This situation conflicts with the ultimate objective of transferring O&M of drainage to farmers.

2.1.2 Financial limitations
The absence of a legal identity for a CUA has several financial implications:

• The CUA is not authorized to collect fees from its members.
• It lacks a mechanism for cost recovery/sharing of drainage maintenance.

2.1.3 Institutional obstacles
Some of these obstacles are:

• Coordination between the irrigation/drainage directorates and CUAs is insufficient.
• Insufficient capacity of the Drainage Advisory Services (DAS) directorates such as: shortage of trained staff and shortage in extension facilities.
• Lack of In-Service Training in drainage maintenance for the CUAs' members.

2.1.4 Technical shortcoming
The CUAs are restrained by the following:

• Farmers do not possess maintenance and inspection equipment. Moreover, the equipment for specialized maintenance is too expensive for a CUA to own, even rental of the equipment would require more than one CUA to optimally substantiate the overhead of using it in the area.
• Crop pattern in the collector's command-area highly diverse. To optimally benefit from the drainage system, a CUA would require organization of cropping pattern beyond its area.
• The nature of the drainage-maintenance work is twofold. One, the bulk of work necessitates usage of heavy, sophisticated machines; and is to be carried out by contractors. Two, Some maintenance tasks that require manual labor; and is being so light that farmers can, and often, do without assistance from an association.
• Establishing CUAs comes after implementing the collector network that will be handed over to them for doing O&M. This means that the CUA will not participate in the field investigation, design and implementation for this network and consequently weakens the sense of ownership and adoption.
• Drainage users' involvement in the construction; operation; and maintenance of open drainage is beyond the role of a CUA and needs another vehicle.

2.2 Water Users' Associations (WUAs)
A WUA is composed of a group of farmers whose lands are serviced by a certain improved mesqa. The objective of a WUA is to
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ensure the farmers’ involvement in O&M of the tertiary (or mesqa) irrigation devices.

The following paragraphs present a brief on the establishment of WUAs, their roles and their involvement in drainage issues.

According to the recommendations of the Egypt Water Use & Management Project (EWUP 1977-1984), The Irrigation Management System project (IMS) had started in 1981 with USAID funding. In 1987 the Irrigation Improvement Project (IIP) launched the establishment of formal WUAs. The IIP has evolved into the organizational set-up of the Irrigation Improvement Sector (IIS) in the ministry. The IIP included an Irrigation Advisory Services (IAS) component, which was assigned to organize farmers into WUAs.

The amendment of Law 12/1984 known as Law 213/1994 gives the WUAs and the Water Users’ Unions (WUUs) the legal status at the mesqa level in the irrigation systems of the old lands and new lands respectively. Since then some 6000 WUAs and hundreds of WUUs have been established together with the major infra structure development.

The function of the WUAs can be summarized as follows:

- To participate in the planning, design and implementation of mesqa system.
- To operate and maintain WUA pumps and regularly undertake mesqa maintenance and its financial management.
- To improve mesqa water delivery, water use management through improved irrigation scheduling and practices.
- To develop a functional linkage with Irrigation Directorate (ID) through branch canal federations (BC WUAs).
- To develop good communication with field staff and all organization concerned with irrigation.

Although WUAs and WUUs work at the tertiary level where field drainage is constructed but they are entirely oriented to irrigation issues such as irrigation scheduling, operation of irrigation pumps, collection of dues from irrigators and depositing the collected money in bank accounts to finance irrigation activities. Therefore, the involvement of WUAs and WUUs in drainage issues is not practically existing.

2.3 Branch Canal Water Users’ Associations (BCWUAs)
The following paragraphs present a brief on the establishment of BCWUAs and their involvement in integrated water management.

In 1999, under the USAID sponsored Water Policy Program, 3 BCWUAs were formed at the secondary level in the Nile Delta. This activity was followed up by an experiment in Irrigation Management Transfer (IMT), under which 5 BCWUAs were set up. With assistance from the IIP a further 4 BCWUAs were established.

The established BCWUAs have been constrained by the lack of a legal personality and mandate to effectively perform water management functions including drainage issues. Furthermore, the absence of a mechanism at the tertiary level has also hindered the involvement of BCWUAs in the subsurface drainage activities.

2.4 Water Boards (WBs)
The following summarizes the establishment of WBs and their involvement in drainage issues.

In 1995, the first WB was established in Egypt and called a Local Water Board (LWB) under the Dutch supported Fayum Water Management Project (FWMP). The developed LWBs could participate in decision making by recommending maintenance and repairs priorities to MWRI engineers.
The consultative and informal nature in addition to the lack of budget or source of income made (and still) the presence of these LWBs fully dependent on the presence of FWMP which challenged the possibility of sustainable involvement in drainage aspects.

The need to address all the constraints mentioned before led MWRI to the formulation of the Water Boards’ Project (WBP) in 1999 with a support from the Dutch government and the German KFW bank.

Under the ministerial decree no. 33/2001 and through a step-wise transfer process, the WBP established 10 pilot WBs at secondary canal level representing the Egyptian diversity conditions with an objective to develop a viable national policy and legal framework for Participatory Water Management (PWM) improvement at secondary level.

Fifty-three WBs have been established nation-wide covering a total area of some 150,000 feddans to date.

Definitely, a WB is a user-managed water management organization, responsible for both irrigation and drainage as well as water quality in a specific command area. Consequently, in its executive body the WB has a Drainage Committee to be the mechanism representing the drainage users’ interests. Moreover, members of the Base Units and the Representative Assembly in the composition of the WB reflect the drainage users’ interests too at tertiary and secondary levels respectively. This makes field drainage and public open drainage aspects highly introduced to the WB activities.

On the other hand, MWRI has set-up permanent Regional Management Committee (RMCs) including in its membership the top-management in charge of irrigation and drainage systems in the command area of the WB. Moreover, a protocol has been already signed between MWRI and WBP according to which the Central Directorate of Water Advisory Services (CD-WAS) will replace the WBP after its expiration. Both of RMCs and CD-WAS guarantee the following:

1. sustaining two-way communication between WBs and MWRI;
2. supporting the development of an integrated transfer process; and;
3. availing a wider involvement for drainage users in PIWM.

2.5 Integrated Water Management Districts (IWMDs)

Egypt’s Water Policy of 2017 is a response to several challenges facing the water sector such as water scarcity, competition of water use by different sectors, declining water quality. This policy estimates water requirements to be around 87.7 billion m³ by year 2017 and assumes that the additional water needed is to be met partly by: i) improving the water use efficiency, ii) increasing the reuse of drainage water on environment sound basis, iii) optimizing ground water use, iv) improving water harvesting, v) changing the cropping pattern to introduce new varieties that consume less water, and, vi) expanding users’ participation in water management.

Accordingly, MWRI has developed a vision for institutional reform including decentralization of water management via (IWMDs) which emphasizes the integration of water resources functions. In years 2001 and 2002, two ministerial decrees were issued to launch the establishment of 2 IWMDs in Monoufia and Sharkia governorates.

In order that the composition of IWMDs is ‘best-fit’ for its functions and tasks, a size of 30-50,000 feddan each is considered to be relevant size. Also, the boundaries of drains and canals were amended to satisfactorily form natural boundaries for each IWMD. Consequently, IWMD acts as one hydraulic unit able to manage an entire drain or canal while Directorates manage larger ones.

3 FUTURE OVERVIEW FOR ALTERNATIVE MODELS TO INVOLVE DRAINAGE USERS IN INTEGRATED WATER MANAGEMENT
3.1 The First Alternative-Model: Stand-Alone CUAs Participating in Drainage with Drainage Department

Involvement of Drainage Users, via stand-alone CUAs, in each of drainage issues and integrated water management is inapplicable as explained below.

- The involvement of drainage users in drainage issues via CUAs is hindered by many constraints previously mentioned in this paper.

The involvement of drainage users in water management via CUAs is inapplicable. Important reasons are:

- CUAs have drainage-oriented roles regardless other water resources.
- CUA cannot perform its role in areas where irrigation system is existing while subsurface-drainage collector has not yet been entirely implemented.
- The water management issue relevant to CUAs is restricted to the operation of manholes’ gates of subsurface drainage in areas covered with the modified system to manage water demands for summer crops including rice.
- CUAs have no legal status and not authorized to collect costs of water management.

Thus, this cannot be considered a viable alternative model.

3.2 The Second Alternative-Model: Integrated ‘Irrigation & Drainage’ Users Associations Participating in Drainage with Drainage Department

Involvement of drainage users in integrated water management, via integrating CUAs and WUAs, necessitates addressing insurmountable obstacles. This can be attributed to the following:

- Mismatch of command areas of the two associations. CUAs and WUAs service command areas of collectors and mesqas, respectively. This means that the two associations have different field boundaries.
- Mismatch of the corresponding administrative units. CUAs and WUAs are affiliated with different administrative organizations while farmers want to address their problems to a unique body.
- The CUAs outnumber the WUAs. In Egypt, 6.4 Million Feddan (MF) is planned to be provided with subsurface drainage and while 5.3 MF of which has finished and become ready for establishing CUAs (which has already been established in some 0.5 MF), only some 0.6 MF has improved irrigation and consequently WUAs. Moreover, the rate of establishing WUAs could by no means equal that of CUAs. So, most of CUAs will lack WUAs to integrate with.

Thus, this cannot be considered a viable alternative model.

3.3 The Third Alternative-Model: Water Boards Participating in Drainage with Integrated Water Management District

It became clear during the National Conference on Water Boards of January 2002 held in Egypt that it is not realistic to expect that WBs at secondary canal level will sustain on their own. Economics of scale and hydraulic/operational factors require WBs at District level to become sustainable and actually contribute to the reduction of MWRI involvement in water management, both financially and personnel-wise. The ongoing proposed amendment in the Water Law is in-line with this reform via allowing the establishment of District WBs. On the other hand, the vision on institutional reform of MWRI foresees that:

- District Water Boards (DWBs) will take over all the operational tasks in water management (WM) of MWRI.
- Integrated Water Management Districts (IWMDs) will take on a supervisory and regulatory role.

Thus, this cannot be considered a viable alternative model.
Thus, this alternative model can be considered viable.

The features of this model are proposed to be as follows:

- Water Boards at the Branch Canals level (BCWBs) will be integrated into one DWB responsible for O&M of both irrigation and drainage systems in the District. DWB will have mandate, responsibility and funding for O&M of the WM infrastructure to the District level. DWB will be assigned the broader mandate of Integrated WM including ground water, water quality, environmental issues, etc.

- BCWBs will be responsible for the implementation of specific WM tasks and to ensure optimal communication between the DWBs and the users.

- To resolve the obstacles of integration in lower levels, CUAs and WUAs can be integrated into one BCWB because it susmes their command areas.

- MWRI will be regionally represented by IWMDs responsible for supervising quantitative and qualitative aspects of WM. The IWMDs will also ensure compliance with norms in O&M of WM infrastructure, and planning and contracting for O&M of the main infrastructure.

- This model needs to be piloted with support from all concerned MWRI’s sectors. The piloting feedback will determine the appropriate framework for the institutional reform required in Egypt’s water sector.

4 CONCLUSIONS AND RECOMMENDATIONS

The review given by this paper illustrates the current status of various participatory models under consideration in the irrigation and drainage sectors in Egypt. From such review, it is clear that the suggested model composed of ‘Integrated Water Management District’ and ‘District Water Board’ needs to be coordinated in order to ensure proper institutionalization. This is practically true as the two components of the suggested model will work on the same level ‘District Level’. The line of authority need to be clear to avoid redundancy and unnecessary conflict of interest. On the other hand, the Irrigation and Drainage Law and Legislations that are currently under review in Egypt need to take this model into consideration.

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Public Works and Water Resources (Irrigation Improvement Sector), Alexandria, Egypt.

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ABSTRACT

Fresh water is a finite resource for many countries around the globe. Its availability is decreasing both in quantity and quality, while the competition for water is increasing due to growing world population and demand for food and attempts to improve living standard. The management of scarce water resources, the need for water conservation and restoration of the environment, damaged due to ineffective water management require changes in the water managing policies and institutions.

The way water resources in FSU were managed in the second half of the past century had both positive and negative effect and contributed to the existing situation. On one hand, extensive development of water resources led to transformation of millions of hectares of virgin lands into agricultural production, providing millions of people with food and livelihoods. On the other hand, the over-exploitation of water resources led to drastic changes of the environment: many water bodies, such as lakes, small rivers, and delta wetlands had dried up. The Aral Sea basin is one of the dramatic examples of the negative impacts of large-scale irrigation interventions.

The state-controlled era of development in the Soviet period has a legacy of standardized procedures and rules formulated at the top. The shortcomings of such a water management included fragmentation, duplication and highly administrative approach, without considering the needs of the environment and input of water users into planning, allocating, and managing of water resources.

Presently, in most parts of the world water users play a growing role in water resources management and water conservation programs, in all water sub-sectors. Especially in irrigated agriculture, which in some countries is using over 90% of the available water resources, the input of water users into water management is essential. This paper presents an analytical view of the role and importance of water users organizations/associations (WUOs /WUAs) in the irrigated agriculture and under irrigation management transfer (IMT) in Central Asia region.

Water Users Associations are an excellent vehicle to promote participatory irrigation management (PIM) and water conservation in agriculture, offering many water and economic advantages to the farmers who become WUA members. Besides securing water and providing for its equitable distribution, WUAs can purchase a variety of agricultural inputs and machinery, as well assist to obtain a credit. The WUAs can serve as wholesome units for improving water and land productivity at a basin-scale and institutionalize integrated water natural resources management. Other advantage of WUAs is that structurally, they can form a basic unit for water management in the basin and facilitate conjunctive water management, consider protection of groundwater and use of drainage water, as well as sustainability of the environment.

Keywords: Integrated Water resources Management, Water Users, Water Users Associations, Irrigation Management Transfer, Participatory Irrigation Management

Background

The world’s population may not be growing at the rate projected by different organizations; however, the need for the natural resources in some countries exceeds the reserves of these resources. Amongst the resources, water is the one for which the need is rapidly growing, as most sectors of the countries economies are expanding. Industry and agriculture are two sectors for which the...
water need is rising. The need for water is predicted to grow from 25 to 100 percent of the level of 1990 in 2025.

At present, water scarcity, either permanent or seasonal, exists when the country water resources base cannot satisfy the multiple needs of the population for domestic use, industry, agriculture, and the needs of the environment. To secure adequate amount of water of good quality for human needs, food production and the environment presents the greatest water problem of our time. Already about 60 % of the natural ecosystems (lakes, wetlands, forests, etc.) have deteriorated due to water supply problems during the 20th century. The key problem is that water resources are being mismanaged, and a serious water crisis is looming. Some elemental reasons may be: i) insufficient time to act, ii) limited tools and measures available for conserving essential water supplies; iii) competing water demands; iv) inadequate ability to deal with and manage water shortages and droughts.

Access to drinking and irrigation water has always been a political issue. Power and politics ultimately are about access to resources, whether they are natural, human or imaginary. Any society needs to find ways of regulating resource ownership, modes of production and human relationships. The main differences between societies can be defined in terms relating to some of the political issues: decision-making power, law enforcement, access to production factors such as labor, land and water, gender relations. Notably, the awareness that water is not the least important in this series is growing. History is full of examples of wars fought about land and water. While today the access and control over markets have become more important than the territory, policy makers are looking at water as a strategic commodity like oil, steel or rubber. Increasingly, water shortages in some industrialized countries and competition and struggle over the access to water sources by the growing populations in the developing countries, are leading to better awareness about the need for more efficient use of water. However, in developing countries, productivity of water in the irrigated agriculture is approximately 2-3 times lower than in developed countries. It is possible, that many users have not yet developed a proper appreciation for the real value of water, because they are isolated from the planning, distributing and managing of water resources, or just simply not aware. However, it is peculiar hat in many developed countries; the use of agricultural water supply is subsidized.

The most suitable response to the growing water crisis would seem to be a preservation of crucially important water resources and sources and conservation of water resources that are used to produce food and other goods, along the principle quoted by Kofi Anan – getting more ‘crop per drop’, as well as improving water management through introducing principles of integrated water resources management and participatory irrigation management.

1 New Water Management Principles

In the past, the term ‘water resources management’ was used by technicians and engineers, who attended to the issues of access, construction, and maintenance of dams, canals and water reservoirs. But dams and reservoirs, or even laws for water resources, do not guarantee equal and fair access to water. Nor do they automatically result in equal distribution (World Bank, 2002). The key issues in water resources management today are largely institutional. Nevertheless, it is very important to understand that some of the more difficult areas for the strengthening of institutional arrangements or capacity building have often physical or other limitations. The main reasons for poor performance in the state governed water resources management maybe:

- Lack of innovative thinking or understanding to apply the proper soil and water management concepts (including design) for the different environmental conditions. Therefore, yields may remain low and various upgrades may have a little effect, thus not providing enough incentives for improvement of soil and water productivity.
- Improper or lack of budget for maintenance of infrastructure and distributing facilities, as well as preventive maintenance and asset management

In the past, many governments, especially those across the countries of the Former Soviet Union and Eastern Europe, were responsible for irrigation system investment planning, policy making, as well as construction, O&M and control of water use. Farmers had practically no involvement. The maintenance that was carried out was marginal, and as a result, the system infrastructure found itself after the states’ independence in need of high investments and major rehabilitation. The above mentioned water management shortcomings are now being well recognized and new trend towards integrated,
comprehensive, or holistic water resources management is propagated. Three new principles, issued by the International Conference on Water and the Environment, held in Dublin in 1992 were:

- The "Ecological Principle" requiring holistic water management,
- The "Institutional Principle" requiring participatory water management including devolution of responsibility "to the lowest appropriate level" and greater involvement of NGOs, the private sector, and women, and
- The "Instrument Principle" requiring that water is managed as an economic resource.

There is a consensus among all major technical assistance, research, lending and donor organizations that integrated water resources management (IWRM) is the essential concept within which most solutions to the world's water problems must be found. The concept promotes coordinated development and management of all water resources and sources in a conjunctive manner to maximize the resultant economic and social welfare equitably, without compromising the sustainability of vital ecosystems (adapted from GWP 2000).

IWRM, in contrast to the conventional sectoral management (that maybe fragmented and uncoordinated), aims to integrate at least the following aspects:

- demands for water of different sectors of the economy
- interests of all water and land users and other stakeholders, with attention to upstream and downstream users;
- physical, biological, and human components of needs for water;
- political or administrative levels or units;
- policy, legal, institutional, managerial, technological, financial, research, and development aspects of water resources;
- Management functions of water acquisition, allocation, distribution, conveyance, application, use, and disposal (or drainage).

Integration occurs through a common process of analysis, negotiation, consensus building, decision-making, and management. The objective of IWRM is to find an optimal balance between water use for livelihoods and conservation of the ecosystem within which water resources are used and replenished (Vermillion, 2002).

The IWRM principle is similar to the decentralization of water resources management. Three main trends in decentralization of water services have emerged: private sector participation (PSP), delegation, and devolution. PSP is a spectrum ranging from full privatization to contracting out for services such as irrigation to the private companies. Under the delegation model, governments transfer water management to public or semi-private water companies and to water users. The third trend considers transfer of small-scale irrigation, rural and urban water supply/sanitation to local governments.

The new thrust towards participatory management processes has enabled decentralization to user groups. This comprises the intended beneficiaries, who weigh all technically feasible options, consider capital and recurrent cost implications, make choices, and then manage systems. The approach pays dividends for both governments and communities: communities receive what they need and governments are relieved of the long-term operation and maintenance (O&M) burden.

Where irrigation uses the majority of water in a river basin, without viable participatory management of irrigation systems, effective IWRM will not be possible. Participatory irrigation management means that water users take over primary responsibility and authority for:
• Water delivery and drainage within irrigation systems,
• Maintenance and repair of irrigation infrastructure, and
• Upgrading and extension of irrigation systems.

1.1 World Experience on Implementing Water Management
The attempts to improve performances of government owned and operated irrigation systems have compelled a number of countries to transfer rights and responsibilities for management of irrigation systems from government agencies to users. The Philippines (Wijayaratna and Vermillion 1994, Svendsen 1992), Indonesia (Soenarno 1995), China (Xu Zhifang 1995) and Sri Lanka (Ratnayake 1995) in Asia, Mexico (Gorriz et al 1995) and Colombia (Garcia-Betancourt 1994) in Latin America, and others such as New Zealand (Farley 1994) and Turkey (Devlet su Isleri et al 1996), have made major efforts in this direction. Transferring responsibilities has become seen as a way to reduce pressures on thinly stretched government finances while at the same time improving irrigated agricultural production and ensuring the long term sustainability of irrigation systems (Geijer et al 1996, Vermillion 1991). A number of management options ranging from full agency control to full users control, used in water management systems are shown below. Forms of shared management (agency-users) are the most popular.

Table 1 The Options of Water Management (World Bank, 1996).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Full Agency Control</th>
<th>Agency O&amp;M (user input)</th>
<th>Shared Management</th>
<th>Users O&amp;M</th>
<th>Users own (agency regulation)</th>
<th>Full control users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td>Agency</td>
<td>Agency</td>
<td>Agency</td>
<td>Agency</td>
<td>Agency</td>
<td>Users</td>
</tr>
<tr>
<td>Ownership of structures, water</td>
<td>Agency</td>
<td>Agency</td>
<td>Agency</td>
<td>Agency</td>
<td>Users</td>
<td>Users</td>
</tr>
<tr>
<td>O&amp;M responsibility</td>
<td>Agency</td>
<td>Users</td>
<td>Users</td>
<td>Users</td>
<td>Users</td>
<td>Users</td>
</tr>
<tr>
<td>User Representation</td>
<td>Agency</td>
<td>Users</td>
<td>Users</td>
<td>Users</td>
<td>Users</td>
<td>Users</td>
</tr>
</tbody>
</table>

1.1.1 Intermediate and Central Government Functions
In most cases, regulatory functions remain the domain of national level agencies, while operating functions are more likely to be devolved in some way. Central government agencies often have a primary role in establishing legal and regulatory frameworks for water rights, pricing policies, and environment standards. These regulatory functions are the most susceptible to capture the attention of local interest groups and the concerns that they address – potential for environmental degradation and disputes over the distribution of water - often affecting multiple sub-national jurisdictions. Central governments’ broader perspective gives them a comparative advantage as authority in disputes between communities as well as various broad user groups (such as agricultural, residential, etc.)

Central and provincial governments also have a financial and technical comparative advantage in managing and financing capital-intensive main systems. End-users are better able to manage smaller, feeder systems that require local knowledge and ingenuity, local resource mobilization, and enforcement of contracts among secondary and tertiary users (e.g. irrigation channels).

1.1.2 Role of Water User Groups
Water user groups are usually formed around a group of potential users, farmers or rural/urban households, for the purpose of accessing water sources. These groups usually have some sort of legal character (e.g. are legally registered, have elected leadership and a constitution, etc.) and are held together by common interests of members, the public good characteristics of the service, and the expected gains from collective action. User groups work well and fully internalize costs and benefits of schemes when they are certain that they will not be rescued by public agencies if they fail to mobilize the required funds for operation and maintenance.
2.1 Brief Historical Development

In the Soviet era, different ministries and institutions were responsible for water management. The Ministry of Melioration and Water Management of the FSU were in charge of Central Asian water resources management. The water resources of Central Asia were considered as water resources of the entire Soviet Union. The water management policy and water allocation between the Central Asian States were based on the maximum economic benefit to the Soviet Union as a whole [Jochen Renger, 1998].

Under the FSU, the Central Asia region had a rather unique water management policy and institutions, based on interdependency of the republic. After independence, the Central Asian states put into place different arrangements for regional cooperation in water management, primarily with the establishment of the Inter-state Commission for Water Coordination (ICWC). During the ten years of independence the water management institutions and policies of Central Asian countries had changed and the countries are proceeding in different land and water reforms at their own pace. Kazakhstan and Kyrgyzstan are reforming its institutions and policies faster than the other neighbors are, while Turkmenistan may be the slowest, just now embarking on the road towards reforms. Uzbekistan and Tajikistan seem to be somewhere in between.

In all five states of Central Asia, agriculture is gradually changing from a sector composed of large-scale state farms to a mixture of agricultural cooperatives, joint stock companies, associations of peasant farms, and private independent farms. This transformation has created maintenance problems resulting in an institutional vacuum, posing additional financial burden on the governments. The O&M of canals, which, in the past were maintained by the large cooperative farms, has been gradually transferred under a system of land and water reforms either to the newly created WUAs (in Kazakhstan and Kyrgyzstan), or to shirkats (Uzbekistan) and joint stock companies (Tajikistan).

At present, private farms are becoming quickly members of the newly created WUAs - approximately 80% in Kyrgyzstan, 65% in Kazakhstan, 25% in Uzbekistan, and 10% in Tajikistan. In the irrigation systems that are managed by WUAs, some progress in O&M and water conservation can be seen (an example of “Best Practices” project executed in a partnership of IWMI-SIC below).

2.2 Water Users Organizations and Participatory Irrigation Management

Within the PIM terminology, water users associations are comparable to water user groups, from the point of view of the size and level of responsibility that corresponds to the tertiary or secondary system units (or parts thereof) within the irrigation schemes, depending pretty much on the size and layout of the schemes. In most countries the WUAs at the tertiary level are informal, and not necessarily legally constituted. Nevertheless, WUAs can also be formed at the tertiary level and established as formal legal entities to assume irrigation management responsibilities for a hydraulic unit, however, mostly at the secondary system level. WUAs can then federate to create a WUF for primary (or secondary) system management that will assume responsibilities typical of a large WUA as legal entity.

What is generally proposed under well-developed legal framework, are WUAs of suitable size (from around 3,000 to 5,000 ha; definitely over 2,500 ha to be financially sustainable), the WUFs formed at the sub–scheme or scheme level, again, depending on the size of the scheme and its layout. Such an organizational set up enhances chances for sustainability of the irrigation system. There are different models for the organizational set up of WUAs and WUFs, however, the principles and practices remain the same, generally evolving under the country specific conditions.

The basic progression of steps for the WUA to function as a management unit is the following:

- Creation of WUAs at a minor canal level
- Transformation of basic O&M responsibilities for the minor and smaller channels to the WUA, with farmers participation in the O&M
- Allocation of water and delivery of water to the WUAs by the water providing entity, accordingly with annual agreements
- Applying water charge to WUA for water service on the basis of the volume actually delivered (volumetric pricing).
2.3 PIM/ WUAs and Water Conservation – as viewed under the 'Best Practices' project

Participatory irrigation management can lead to significant increases in the efficiency of water use and the value of irrigated agricultural production. In countries, where PIM and IWRM principles were applied, generally, positive results have been achieved. Amongst those are: improved availability and reliability of water supply, flexibility in cropping pattern enabling farmers to make shifts in cropping pattern towards high value crops; and more efficient use of water.

Farmers in the Syr-Darya basin (H.Murray-Rust et. al., 2002) have reported general improvement in yields. Another noticeable benefit to farmers was the time saved for receiving water without having to apply for it and apply separate payments. Additionally, more equitable water distribution resulting in reduction in conflicts is also visible. This in turn has led to improved understanding and goodwill in the farming community. Farmers are spending more time on repair and maintenance, and as a result, the field systems are in a good condition. Improvements in irrigation efficiency and reduction in seepage losses are noticeable. Willful damage to the infrastructure has been considerably reduced, because farmers are watchful for each other, and start developing a different sense of collective action. WUAs have adopted new water distribution rules suitable to local conditions. These rules are pragmatic and ensure equity.

The PIM also serves well to the water providing entity. The irrigation agencies have had to make additional investments in improving the physical system condition before handing over to farmers for water distribution. They have also had to provide management subsidy and repair and maintenance grants to the WUAs. Significant benefits to the agencies have been marked in the increased recovery of water charges, and reduction in time spent in water distribution, conflict resolutions and recovery of water charges.

The concept of Irrigation Management Transfer (IMT), handing over the O&M and control over water related resources to the water users, with the implied expectation that they now have to live with the consequences of their management, appears to be the key to make users effectively manage their resources. Users maintain the physical structure of the system better when substantial responsibilities are transferred to them. The equity in water distribution also improves when WUAs distribute water amongst the water users.

Some preliminary indications are that the shift to volumetric pricing of water is beginning to make farmers think more seriously about conservation and about the value of water. Therefore, volumetric pricing coupled with improved physical conditions of the systems and increased reliability of water supply will help in increasing the value of agricultural production and the efficiency of water use.

Water saving competitions conducted earlier under the Best Practices predecessor - the A2 component of the GEF (World Bank project) combined the need to increase productivity of irrigation water under the increasingly worsening conditions of water scarcity. The competition was to stimulate wider circle of water users and involve them into water savings. Its primary strategy was to propagate application of inexpensive technical and managerial methods and measures to save water by users themselves. The first year of the 'Best Practices' project accomplished broader involvement of water users into the water conserving methods, therefore continuing of good water management practices. It also continued to involve the water supplying organizations and various groups of water users (collective farms, farmers, and water users' associations) that participated under the A2 component. In total, some 144 water saving initiatives participated in the original competition: 30 district water management organizations (DWMO), 8 WUAs, 58 collective farms (CCF) and 61 private farms (PPF) from 8 oblasts of the Aral Sea Basin.

When IWMI had decided to build on the previous work and continue the monitoring and evaluation of the applied water saving practices, the initiative focused on reaching wider public to adopt basin wide water conservation practices. The overarching goal of the project is to forge a gradual change of attitude of water users and water managers at all levels of hierarchy towards water as a limited resource and prepare indicative recommendations for policy makers regarding water allocations of irrigation water within the region. The strategy is to select the best objects from the previous competition, monitor the water use, productivity and salinity situation, and encourage the other water users through demonstration to conserve water. In this process, the local NGOs are to be involved to promote water savings campaign in irrigated agriculture and disseminate water conservation results to public at large.

The organization of the second year of the Best Practices is slightly different, due to financial limitations. The number of the
participants has decreased to: 12 DWMOs, 9 WUAs, 15 CCFs and 24 PPFs, including 6 oblasts of the Syr-Darya Basin and 3 oblasts of the Amu-Darya basin. The project outcomes from general data collection is now oriented towards the data on water productivity. Also, attitude for water saving had changed from competition into participation (Murray Rust, et.al. 2002). The WUAs mainly cover the territory of former kolkhozes and sovkhozes, the cultivable command area is similar, but crops grown have slightly changed, however, the main crops still remaining cotton and wheat, occupying 60% of the land.

The water delivery changes in the project sites are given in Table 2, showing that in all reaches of the Syr-Darya basin, the WUAs have lowest water supply rates, among all other types of water users/units. This proves that best results in water conservation can be achieved under the collective arrangement and PIM principles of WUAs. In all reaches, WUAs have two times lower water supply rates, in comparison with collective/cooperative farms, in spite of their similar sizes and cropping pattern.

### Table 2  Water Deliveries to Different Types of Unit, and Different Locations (mm/season) (Hammond Murray Rust, et.al.2002)

<table>
<thead>
<tr>
<th>Type</th>
<th>Head</th>
<th>Middle</th>
<th>Tail</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCF*</td>
<td>986</td>
<td>862</td>
<td>1883</td>
<td>966</td>
</tr>
<tr>
<td>PPF**</td>
<td>498</td>
<td>949</td>
<td>870</td>
<td>831</td>
</tr>
<tr>
<td>DWMO***</td>
<td>934</td>
<td>1123</td>
<td>1122</td>
<td>1080</td>
</tr>
<tr>
<td>WUA</td>
<td>483</td>
<td>482</td>
<td>782</td>
<td>525</td>
</tr>
<tr>
<td>Average</td>
<td>831</td>
<td>961</td>
<td>974</td>
<td>913</td>
</tr>
</tbody>
</table>

Note: CCF- collective/cooperative farms, PPF- private/peasant farms, DWMO- district water management organizations.

The key indicator in assessing performance of different water users/management organizations is considered water productivity. For the different types of users/organizations and for different oblasts of the Syr-Darya Basin the water productivity ($/m^3) is calculated and the results are presented in the Table 3. Again, it shows, that WUAs have the highest water productivity amongst all users/organizations.

### Table 3  Productivity of Water by Oblast and Type of Unit ($/m^3), all lands (Hammond Murray Rust, et.al.2002)

<table>
<thead>
<tr>
<th>Type</th>
<th>Djalalabad</th>
<th>Osh</th>
<th>Fergana</th>
<th>Sogd</th>
<th>South Kazakhstan</th>
<th>Kzylorda</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCF</td>
<td>0.12</td>
<td>0.12</td>
<td>0.21</td>
<td>0.10</td>
<td>0.15</td>
<td>0.03</td>
<td>0.11</td>
</tr>
<tr>
<td>PPF</td>
<td>0.10</td>
<td>0.11</td>
<td>0.23</td>
<td>0.16</td>
<td>0.22</td>
<td>0.04</td>
<td>0.14</td>
</tr>
<tr>
<td>DWMO</td>
<td>0.05</td>
<td>0.06</td>
<td>0.13</td>
<td>0.03</td>
<td>0.14</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>WUA</td>
<td>0.13</td>
<td>0.15</td>
<td>N/A</td>
<td>N/A</td>
<td>0.24</td>
<td>N/A</td>
<td>0.17</td>
</tr>
</tbody>
</table>

N/A- WUAs are not represented among the project sites.

The following may be the main reasons for highest water productivity in the newly created WUAs of Central Asia:

- Agriculture production responsibilities are divorced from water resources management, which makes it easier for WUAs, in comparison to the CCFs;
- Involvement of water users in O&M and water management within the WUA organization leads to more efficient water allocation and reduced water losses;
- Introduction of water fees makes it possible to conserve more water, leading to the increase of its productivity

### Conclusions

The major response to the growing water crisis would be conservation of critical water resources or “crop per drop” principle, improving of water management through the implementation of principles of integrated water resources and participatory irrigation management.
Some preliminary indications are that the shift to volumetric pricing of water is beginning to make farmers think more seriously about water conservation and the value of water. Therefore, volumetric pricing coupled with improved physical conditions and increased reliability of water supply will enhance the increase of agricultural production and the efficiency of water use.

Irrigation management transfer of the O&M and/or the systems to Water Users Associations, as well as a specific involvement of farmers in a participatory process to develop and manage the land and water resources may lead to a substantial increase of land/water productivity in the many parts of the world.

4 References


The ‘Best Practices’ project was initiated in a partnership of the International Water Management Institute (IWMI) and the Scientific Information Center (SIC) of the ICWC in 2001, funded by the IWMI, as a follow up to the A2 component of the Global Environment Facility (GEF) project, in four countries of Central Asia: Kyrgyzstan, Kazakhstan, Uzbekistan and Tajikistan.
ACTION RESEARCH: AN APPROPRIATE RESEARCH METHODOLOGY TO DEVELOP ON-FARM DRAINAGE SYSTEMS WITH FARMERS WITH REFERENCE TO THE NRAP PROJECT, PAKISTAN

Dr Aart Schrevel and Dr Mohammed N. Bhutta

ABSTRACT
In the period up till 2000 the Netherlands Research Assistance Project (NRAP) ran an Action Research programme to develop a drainage system together with farmers in an area suffering from salinity and waterlogging. Executing parties of NRAP were the International Waterlogging and Salinity Research Institute (IWASRI), Pakistan's main research institute in salinity and waterlogging research, and International Institute for Land Reclamation and Improvement (Alterra-ILRI), based in the The Netherlands. The Action Research was an approach to establish an on-farm collective drainage system together with farmers, while at the same time learning how this is done best. This latter aim is achieved by systematically analysing the actions taken by all involved in the drainage development process. Action Research is unique in the sense that conclusions from the analyses are fed back into, and can lead to changes in, the process. The experiences with Action Research in case of the NRAP project lead to the conclusion that the approach has potential for other irrigation and drainage development projects as well.

Keywords: drainage, participatory, research methodology, action research

1 Why action research was needed (introduction)
The Netherlands Research Assistance Project (NRAP) was a collaboration between the International Waterlogging and Salinity Research Institute (IWASRI), Pakistan, and the International Institute for Land Reclamation and Improvement (Alterra-ILRI), The Netherlands. The project was funded by the Governments of Pakistan and The Netherlands. NRAP embarked on an Action Research in the period 1995-2000. The aim of the Action Research was to realise a drainage system in a research area (112 ha) and to systematically analyse how this was achieved with maximum participation by the farmers concerned.

To undertake an Action Research was seen as the most appropriate method of working. For decades Pakistan had worked on the development of drainage systems to combat the related problems of waterlogging and salinization. Initially the emphasis had been on the design and construction of drainage systems by the government without much consultation with the farmers, but gradually a shift in focus occurred into the direction of more participatory drainage development. This was visible in a change in policy to involve farmers in drainage design and construction and to delegate management responsibilities to them. The multi-year National Drainage Programme, which was started in 1997, intensified this trend. The NRAP research programmes evolved along the same path (NRAP existed from 1988 till 2000). So it happened that the NRAP project decided to study the mechanisms of working with farmers in the development of drainage. However, examples of farmers actually participating in drainage development did not yet exist. The issue was entirely new to Pakistan at the time. The best way for the research project NRAP to proceed was to self-initiate the implementation of a drainage system, to invite and encourage farmers to participate, and to study the process of participatory drainage development simultaneously.

This method of working – running a process of change and analysing the process at the same time – is known as Action Research (see below for a more comprehensive account on the method). For NRAP to work in this way had several advantages:
as examples on farmers’ participation in drainage development did not yet exist, it was practically the only way to quickly improve understanding on the issue, not only research results would be acquired, but also a drainage system would be constructed, the method is not expensive and good value for money.

As can be seen, the advantages serve the interests of both the researchers (NRAP) as well as the research objects (the farmers). The latter are provided with a drainage system, which will help them to solve acute problems of waterlogging and salinization. This was important to the researchers as well, as they wanted to do research that would have immediate practical value. Also the donors – Government of Pakistan and Government of The Netherlands – were pleased with the approach. For comparatively little money results in the field were achieved, as well as improved understanding on how to do things. It is for such reasons as these that donor institutions today also increasingly ask for the Action Research approach in their programmes.

2 Agricultural production, waterlogging and salinization: a few facts

For a better understanding of the background of the Action Research a short introduction to agricultural production and the problems of waterlogging and salinization in Pakistan is in place.

The agricultural sector is one of the main pillars of Pakistan's national economy. In 1992-1993, the sector contributed 24 percent to the Gross Domestic Product, making it the largest contributing sector (Economic Adviser’s Wing, 1993). Today, ten years later, this is not much different. (Economic Survey 2002-03). Undoubtedly agriculture will continue to play an important role in the future, as the other sectors - industry and services – show little evidence of growing disproportional. In absolute figures 48.4 percent people are directly employed in agriculture (Economic Survey 2002-03).

Without irrigation agricultural production would not be as important. Great canal systems cover 18 million hectares of Pakistan’s part of the Indus Basin. At the same time they are a cause of concern. Seepage of water from canals, watercourses and irrigated fields, in combination with lack of natural and artificial drainage and the semi-arid climate, are at the root of waterlogging and salinity problems that are said to compromise production on roughly one-seventh of all irrigated land (Planning Commission, 1997a/b). Loss of production can range from 25 to 60%; in severe cases there is no production at all (Planning Commission, 1997a).

Installing proper drainage is essential to combat waterlogging and salinization. In the past decades huge investments have been done in drainage development. Lately policies have been formulated that require the farmers who are to benefit from the drainage systems to be more directly involved in the management of the systems.

3 Action research: what is it?

According to the literature, Action Oriented Research, or Action Research, stands for a theoretical and methodological approach to the understanding of social processes. The guiding analytical concepts are the human agency and social actor; notion of multiple realities and arenas of struggle; and the idea of interface, relating discontinuities of interests, negotiation, values, knowledge and power (Long and Long, 1992). Farmer Participatory Research stands for a people centred process of purposeful and creative interplay between communities and outsiders with formal knowledge. It is about empowerment, local knowledge, interface between formal and informal knowledge systems, rural livelihood systems and sustainable land and water resources utilisation (Okali et al, 1994).

Action Research in case of NRAP is somewhat different. It did not solely serve the purpose to understand social processes, but also to realise exactly the thing that triggered the Action Research in the first place: a drainage system. This was a well-
functioning, tertiary drainage system, installed with the users of the system playing their role in design, construction and management of the system. Keywords like empowerment, arenas of struggle, values, knowledge and power do not describe adequately the Action Research as it took place in the case of NRAP. And for that matter, the Action Research that appears to be asked for today in land and water development projects.

The Action Research as it was undertaken by NRAP has different qualities. Most important is that while the ‘process’ (of installing drainage) was ongoing it was documented what was exactly happening. In NRAP terminology this is called ‘process documentation’. It was the task of a person who was especially appointed for the purpose. This person was also involved in the drainage development itself, but stood as it were at some distance from this when occupied with the process documentation task.

A further characteristic of the Action Research by NRAP is that it was highly flexible. It worked with a set of objectives, a team of professionals, an office and means of transport, a budget and a final date at which the project would have to be completed. The research did not start with a hypothesis, a set of research questions, a detailed research methodology plan, formats to record all kind of data, etc. A detailed action plan was never written, hence, money was not allocated to activities described in detail beforehand. Only a simple list of steps to be taken was produced. This allowed the researchers to take the best decision given the circumstances each time that a decision had to be taken, while at the same time forcing them to think and convene. We will come back to this later.

### Selection of the study area

To further focus the discussion, we give the objectives that NRAP wanted to realise through the activities in the field:

- to develop and implement a well-functioning on-farm drainage system with full participation of the beneficiary farmers
- to ensure that the beneficiary farmers fully operate and maintain the drainage system upon termination of the action research
- to develop guidelines for the replication of the pilot study at a much wider scale (IWASRI, 1995; IWASRI, 1997).

Fieldwork was started up in an area near Bahawalnagar, Province of Punjab. The study area is one of the most poverty stricken areas in the Punjab, with a high incidence of land degradation caused by waterlogging and salinity. The research area is located at about one day drive from Lahore, near to the Indian border. It concerns an area of 112 ha between two watercourses: watercourse 18 and 20 on Yarwah Distributary. Farmers of three adjacent villages, Rehman Toghera, Nikka Bair and Khawja Buksh Bodla, cultivate land in the area. Ninety-two farmers belong to Rehman Toghera, four to Nikka Bair and three to Khawja Buksh Bodla.

The area was selected out of several because of a number of qualities that improved chances on success:

- the occurrence of severe problems of waterlogging and salinity, which were local problems in the sense that they could be addressed in a geographically restricted area small enough for NRAP to be feasible
- existing possibilities to evacuate excess drainage water from the area (an outfall drain was planned that would make this even better possible)
- availability of irrigation water for land reclamation purposes
- drainage solutions to be manageable by the farmers
- land tenure situation of small landholders without dominating feudal families
- expected co-operation of local community and line agencies
As can be seen the selection criteria were a mix between geo-physical, sociological and cultural qualities.

5 Socio-economic and cultural conditions
In the course of the project NRAP collected socio-economic data, and data on the social fabric and culture of the villages. The aim was to better understand:

- differences in access to land (the most important asset in the villages)
- other sources of income and absolute levels of income, also in comparison to poverty levels
- distribution of power, and social build-up of the villages
- cultural characteristics, in particular the relations between groups and the role and position of men and women

A summary of the main findings is presented here. One conclusion from the socio-economic analyses was that the average farmer owns 12.1 acre of land and only 2.7 acre of this land is situated within the research area. It follows that the activities of the project were of interest to the farmers, but a positive result would increase their income with one-fourth at best. This conclusion may add to other explanations (discussed below) why farmers were not all participating fully in the project.

Landlessness does not seem to occur much in the villages. About half of the population has less than 8 acre. Although exact figures are not available, the project assumed that 12 acre – the average area of land owned by households – would be sufficiently productive to provide the average family with enough income to live from. The conclusion was drawn that generally the households in the area earn enough to contribute with cash to the operation and maintenance costs of the drainage system. Another interesting finding concerned the location of plots affected by waterlogging and salinity and their owner’s willingness to contribute to the project. It showed that owners of land suffering more from these problems were actually contributing more. Analyses of this kind helped the researchers to understand farmers’ reactions to propositions from the project.

In rural Punjabi society conflicts are endemic and, as a result, co-operation on a long-term basis is rare (Merrey, 1979). The project needed to understand this phenomenon better, as obviously it would have implications for the drainage institutions that were needed to manage the drainage system to be constructed. It drew a diagram depicting existing conflicts between potential beneficiaries of the project. It could be concluded that conflicts existed within villages, rather than between villages, and occurred between as well as within kinship groups. The sociological data also provided insight into the castes and kinship groups that prevail in the villages. Notwithstanding the endemic occurrence of conflicts, examples of villagers from different castes and kinship groups working together on activities of mutual importance also exist. For example, a mosque has been built and villages cooperated in cleaning watercourses.

A further important conclusion was that the village did not have one leader, in the sense that there was not one person who could be trusted to speak in the name of all villagers, or who could instruct villages what to do. The Numberdar[5] of Rehman Toghera is the only formal leader in this village. Nevertheless, he has hardly succeeded to mobilise the beneficiaries to contribute towards the drainage system. Initially, this could have been caused by the Numberdar doubting himself that the drainage system would really be implemented, as a result of which he did not try very hard. After the installation of the drainage system however, he was very eager to get the system functioning, but still did not really manage to motivate the other beneficiaries to cooperate and contribute. The informal leaders of the different caste and kinship groups have not shown to have much influence over their people when contribution towards drainage is concerned. Also these conclusions were important to the project. They were acknowledged when efforts were made to set up an effective Farmers’ Drainage Organisation.
6 How it was done: the ‘process’

It was already said that the Action Research by NRAP was characterised by the ‘process’ on the one hand and ‘process documentation’ on the other.

With process is meant all actions related to the realisation, with the farmers concerned, of a drainage system in a previously selected area. It includes setting up drainage management institutions. A simple list of the actions taken followed by a short explanation may suffice to provide the reader with insight on how this was done (Table 1).

NRAP started working with a NGO. The idea was that all work with farmers could better be contracted out to an organisation specialised in this type of work, rather than the project doing it itself. After some time the contract with the NGO was terminated. The NGO appeared to operate with an agenda that was not only broader in scope – community development – but that also asked for more time than was available. As alternatives were not available NRAP decided to charge the tasks involved to its own staff, which was trained for the purpose as intensively as possible. In the table, it can be seen that an NRAP Social Organiser was appointed in September 1997. The table further speaks of a FDO; this is the Farmers' Drainage Organisation.

An interesting detail is further that the project organised a number of formal trainings for the farmers of the research area. The training subjects were decided upon with the farmers and concerned many practical issues related to both implementation and management of the drainage system. All trainings took place in the villages. Also important is that the project took special efforts to involve the women from the villages in the project. They were approached by female researchers, as the culture of the villagers does not allow men who are not family to communicate directly with women.

Important to remark is that the sequence of activities and the activities themselves do not deviate essentially from those in other drainage or irrigation projects that work in a similar intensive way with farmers. These approaches are known under the term ‘participatory irrigation development’ or ‘participatory drainage development’. Those involved in those kinds of projects will recognise many if not all of the activities described in the table. Depending on the circumstances, things may be organised just a little bit different or the order in which they occur deviates. In other words, there is nothing special about this side of Action Research.

7 How it was done: ‘process documentation’

The process was documented at all those moments that activities were being planned or implemented. Thus, it consisted of

- the preparation of minutes of the NRAP Progress Meetings
- the preparation of minutes of other meetings concerning the action research
- monitoring of the contribution (cash, kind, or labour) of individual beneficiary farmers towards the installation and operation and management of the drainage system
- monitoring of the attendance of individual beneficiary farmers in Farmers’ Drainage Organisation (FDO) meetings and FDO Executive Body meetings
- monitoring of the participation of individual beneficiary farmers in training sessions
- recording of information and experiences by field staff
- preparation of field reports, and
- preparation of reports on training conducted
### Table 1 Actions taken in the course of the development of the Bahalwanager drainage system

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>June '95</td>
<td>Selection of area with potential sites for implementation of the action research</td>
</tr>
<tr>
<td>Dec. '95/Jan. '96</td>
<td>Participatory Rural Appraisal in 6 <em>mozahs</em> in selected area</td>
</tr>
<tr>
<td>March '96</td>
<td>Selection of action research area: area between watercourse 17 and 20 on Yarwah Distributary</td>
</tr>
<tr>
<td>March '96</td>
<td>First meetings with farmers cultivating land in the research area</td>
</tr>
<tr>
<td>March '96</td>
<td>Establishment of a Community Management Structure</td>
</tr>
<tr>
<td>1st quarter '96</td>
<td>Technical surveys</td>
</tr>
<tr>
<td>April/May '96</td>
<td>Redefinition of research area as the area between watercourse 18 and 20 on Yarwah Distributary</td>
</tr>
<tr>
<td>3rd quarter '96</td>
<td>Preparation of preliminary design (surface drainage)</td>
</tr>
<tr>
<td>October '96</td>
<td>Exposure visit for farmers to Malik Branch</td>
</tr>
<tr>
<td>2nd half '96</td>
<td>Construction of sump</td>
</tr>
<tr>
<td>Dec. '96/Jan. '97</td>
<td>Acknowledgement that installation surface drains is not possible and that the system has to be installed by machine</td>
</tr>
<tr>
<td>March '97</td>
<td>Technical training for staff of the NGO and line agencies</td>
</tr>
<tr>
<td>April '97</td>
<td>Preparation of a new design for the drainage system, with 6 additional laterals</td>
</tr>
<tr>
<td>2nd half of '97</td>
<td>Termination of the formal partnership between NRAP/IWASRI and the NGO</td>
</tr>
<tr>
<td>June '97</td>
<td>Technical training for staff of the NGO and line agencies</td>
</tr>
<tr>
<td>July '97</td>
<td>Transportation of drainage pipes to the study area and purchase of pump by farmers</td>
</tr>
<tr>
<td>3rd quarter '97</td>
<td>Appointment of NRAP Social Organiser</td>
</tr>
<tr>
<td>September '97</td>
<td>Establishment of FDO and FDO Executive Body</td>
</tr>
<tr>
<td>October '97</td>
<td>Discussion of draft agreement between project, farmers and the NGO with farmers</td>
</tr>
<tr>
<td>October '97</td>
<td>Exposure visit for farmers to Trail Site 1</td>
</tr>
<tr>
<td>October '97</td>
<td>Installation of drainage system</td>
</tr>
<tr>
<td>March '98</td>
<td>Assessment of farmers’ training needs</td>
</tr>
<tr>
<td>March '98</td>
<td>Opening of FDO bank account</td>
</tr>
<tr>
<td>March '98</td>
<td>Training of Trainers for staff of NRAP/IWASRI, the NGO and line agencies</td>
</tr>
<tr>
<td>April/May '98</td>
<td>Farmers’ training on Pump Operation and Maintenance</td>
</tr>
<tr>
<td>June '98</td>
<td>Project does not allow the pump to be operated as it is of the opinion that the farmers should first fulfill their promises</td>
</tr>
<tr>
<td>June '98</td>
<td>Implementation of Gender Program</td>
</tr>
<tr>
<td>June '98</td>
<td>Operation of pump for irrigation purposes by farmers</td>
</tr>
<tr>
<td>June '98</td>
<td>Farmers’ training on Project Approach and Government Policy</td>
</tr>
<tr>
<td>June/July '98</td>
<td>Operation of pump for drainage purposes and appointment of pump operator</td>
</tr>
<tr>
<td>June- Dec. '98</td>
<td>Construction of pump house</td>
</tr>
<tr>
<td>July- Sept. '98</td>
<td>Farmers’ training on Financial Management of the System</td>
</tr>
<tr>
<td>Aug./ Sept. '98</td>
<td>Farmers’ training on Functioning of the Drainage System</td>
</tr>
<tr>
<td>October '98</td>
<td>Farmers’ training on Social Organisation</td>
</tr>
<tr>
<td>Oct./Nov. '98</td>
<td>Farmers’ training on Irrigation and Drainage Management</td>
</tr>
<tr>
<td>November '98</td>
<td>Project does not allow the pump to be operated due to non-co-operation from the side of the farmers</td>
</tr>
<tr>
<td>February '99</td>
<td>Pumping is not required due to a low water table</td>
</tr>
<tr>
<td>February '99</td>
<td></td>
</tr>
<tr>
<td>Feb./ Mar. '99</td>
<td></td>
</tr>
<tr>
<td>April/May '99</td>
<td></td>
</tr>
</tbody>
</table>
Yet, process documentation was more than only registering the details of each separate activity. In fact, process documentation by NRAP entailed two far more essential tasks: systematically analysing of what is happening, and ploughing back the conclusions of the analyses into the process. It is in these two ways that Action Research is different from participatory drainage system development.

As was said, the information on the process that was collected in the systematic way described above was analysed by a specially appointed staff member. This person also set up a socio-economic Base Line Survey and at other occasions collected information on different aspects of life in the villages. Thus data was collected on:

- farmers' landholdings, both in total and outside the research area
- the extent of waterlogging and salinity on plots within the research area
- the possibility for each farmer to use drainage effluent for irrigation purposes
- farmers' occupations other than agriculture
- conflicts between farmers
- leadership among farmers, and
- farmers' attitude of dependence

These data served not only to make more rational choices about the direction that NRAP should take (see above). The data also helped in demystifying ideas why farmers sometimes did not respond to challenges or to beneficial propositions by the project. To give an example, based on the data collected it could be established that the farmers who were most interested in cooperation and most willing to actively participate were those with large holdings and with land that would benefit most from the drainage system constructed by the project. The project had always been worried about the low number of farmers who participated and who were willing to contribute with cash, other inputs, or their labour. Farmers' landholding, the extent of waterlogging and salinity on their plots, and the possibility to use drainage effluent for irrigation were put forward as reasons to explain the response of the farmers. The in-depth researches that were organised helped to create clarity on this matter.

The conclusions of the analyses of the process itself and of the data collected were brought in the meetings that regularly took place. They became part of the data sets that the NRAP project staff used to decide on further steps. And not even NRAP staff only. The conclusions were also shared with the farmers of the research area.

To sum it all up, process documentation consisted of the following four elements:

- systematically recording what was actually happening
- setting up supportive research into socio-economic, social and cultural conditions in the field
- analysing the findings of these two previous steps
- feeding the conclusions of these analyses back into the process

In the NRAP experience these four elements are at the core of the Action Research approach.

8 Conditions for success

At a number of occasions NRAP staff had to make conscious decisions in order to secure the success of the Action Research. These will be explained below, albeit in more general terms.
The success of Action Research depends to a large degree on the understanding of the method by all involved. This is true for the farmers, but also for the staff of the project. If not, the success of the Action Research itself is at stake. For example, if project staff starts to question the conclusions from process documentation and are reluctant to integrate them into decision-making, the very reason to do Action Research is compromised.

Special care must be taken to direct the communication with the farmers. Preferably this is done by, or on the advice of, experts with training in rural sociology and with an intimate knowledge of social relations in the villages concerned. Keywords in communications with the farmers are ‘consistency’ and ‘transparency’. Consistency is necessary in order to avoid confusion among farmers and to avoid that earlier decisions are being questioned again or can be re-negotiated. NRAP also learned that it is essential that all project staff speak the same language that the same messages are passed to the farmers. If this is not the case three problems arise: i) farmers will be confused, ii) the negotiation position of the project vis-à-vis the farmers will be weakened, and iii) tensions may arise among the project staff. Transparency increases the possibility that farmers and all project staff know, or are in the position to acquire information, about what is actually going on and decided in the project. These are all common sense management techniques. The point is that they apply to working with farmers as well, and more importantly, that special actions must be taken to realise them.

Also farmers need to understand how Action Research works. At the very least Action Research requires continuous communication and co-ordination between farmers as the clients and the researchers and project as the suppliers of a service. If the question is asked whether the client or the supplier determines the dimensions of the service that is rendered, the answer is that it must be the client. This implies that many of the major decisions are to be taken by the farmers.

By definition Action Research is a flexible way of working. Directions of the project can change because of new facts or conditions. This disadvantage of flexibility is that it creates uncertainty. For example, initially a surface drainage was envisaged. Later a sub-surface drainage system appeared to be the only technical possibility. This was not understood by the NGO and as a result created confusion. All partners participating in an Action Research have to understand that this is all in the nature of the approach, and in fact special efforts have to be made to make them accept this.

A serious problem that NRAP experienced, which is not unique to the NRAP research area, is that the farmers are not one group. As we have seen above, farmers in the project area belong to different fractions and castes. They are not joined in a type of organisation or institution that binds them. To further complicate matters there appeared not to be one or a group of leaders who had sufficient authority to make farmers cooperate. To set up Farmers’ Drainage Organisations under these conditions is difficult, as the NRAP researchers experienced. NRAP began to have the Farmers’ Drainage Organisations formally registered. This meant that the authority that was lacking in the village was sought for at other levels. NRAP came to this solution after having analysed the situation in the field. This serves to explain that in-depth studies are important in projects or this kind and indeed are a condition to success.

The attentive reader will have noted in Table 1 that the farmers did not always act as NRAP expected. Sometimes the farmers did not do what they had promised to do at an earlier occasion. In the table it says that the ‘project does not allow the pump to be operated as it is of the opinion that the farmers should first fulfil their promises’, and later ‘project does not allow the pump to be operated due to non-co-operation from the side of the farmers’. In both cases the argument was about the money and other contributions that the farmers were expected to rise in order to operate the pump and pay for the operator. Apparently this way of dealing with farmers worked, because later the farmers did arrange for the inputs for the pump to be available. Such tensions did exist in the project. They must be seen as part of the process, and not as prove of strained relations, because that certainly was not the case.
The Action Research approach certainly proved its worth in the case of the NRAP project. The farmers received the drainage system which they themselves helped to develop. In the process they learned to understand the technical qualities of the system, which is essential for proper operation and maintenance, and organised their forces to run the system. An evaluation carried out in 2002 by the Government of Pakistan and The Netherlands established that yields in the project area had increased as a result of improved drainage. The project, thus IWASRI and ILRI, collected valuable information and experience on how to develop on-farm drainage systems with the active participation of farmers. Much of this information was disseminated during national workshops organised by NRAP. And the governments of Pakistan and The Netherlands gained insight in how to set up participatory drainage development projects.

Action Research essentially consisted of two parallel activities: the development of the drainage system together with farmers, which is called the ‘process’, and the systematic collection and analysing of data on how this is done, called ‘process documentation. The ‘process’ is much similar to other participatory irrigation and drainage development activities. ‘Process documentation’ is more unique. In NRAP it consisted of:

- systematically recording what was actually happening
- setting up supportive research into socio-economic, social and cultural conditions in the field
- analysing the findings of these two previous steps
- feeding the conclusions of these analyses back into the process

Action research is an approach that needs to be carefully managed. Its success depends among others of the understanding of the approach by all parties involved (senior and junior project staff, farmers, government agencies, and other partners, like NGO’s). This includes accepting that sometimes fundamental changes of previously agreed lines of action are possible. Such changes are of course taken together. Good communication is essential to keep everyone on board. This requires transparency and consistency of speech towards farmers.

Sometimes reality forces one to accept less than optimal results. The NRAP project faced the problems that the Farmers’ Drainage Organisations appeared not to be functioning as successful as expected, and not all farmers appeared to participate in the process. The Action Research approach contains the element to study the reasons of such unexpected developments and to feed back the conclusions of these studies into the process.

Undoubtedly Action Research is an appropriate approach to use in irrigation and drainage development projects. It is especially useful in all those situations that the active participation of farmers is required and the ways in which this is best achieved are not yet fully understood. Many will agree that this is still the case in the majority of the participatory irrigation and drainage development situations.

10 References and suggested reading


Economic Survey 2002-03, Pakistan Economic Survey (unofficial title), Government of Pakistan


[2] Alterra-ILRI, Postbox 47, 6700 AA Wageningen, The Netherlands, email: aart.schrevel@wur.nl

[3] IWASRI, Lahore, Pakistan, email: mbhutta@net.brain.pk

[4] This paragraph is copied from an unpublished NRAP report: Ruiter (2001). The present paper draws on much of the material written in this report.

[5] The Numberdar collects the land revenue and irrigation fees for the government and acts as the intermediary between villagers and the government officials.
ABSTRACT

In the last decades (1946-1989) in Poland there was a conviction that "each hectare must give crop" the consequence of which was a duty of an agricultural use of farmland. That opinion grew in the period when the quantity of food production depended straight and directly on the amount of the possessed agricultural land. In those times it was forbidden to afforest agricultural land freely. Contemporarily it is assumed that not only the amount of the land but its quality and the way of their use decide upon the size of food production. Such a situation creates favourable conditions for afforestation. The proof of the claim is that each agricultural land can be afforested no matter what quality it has while, at the same time, there is no free putting forest area into agriculture.

The main thesis of this paper is that afforestation of the right agricultural land in Poland influences not only the protection of this land positively but the water management and agricultural production on adequate and sufficient resources of agricultural areas.

The aim of this paper is to develop an algorithm of keeping valuable agricultural lands while afforesting those lands in the aspect of bettering water management.

The article understands afforestation of agricultural land as starting forest farming on lands, which have been out of forest cultivation (not included in the forest area).

Keywords: Afforest, water management, agricultural production.

1 INTRODUCTION

A continuous development of industrialisation and urbanisation processes influences the natural environment negatively, including the agricultural lands, which are an important factor of the biosphere. That negative influence on agricultural lands may be observed both in the quantity aspect (a systematic decrease of agricultural lands surface) and in the quality one (worsening of the agricultural and forest production value). Agricultural lands in the aspect of shaping farming production space should be taken under protection consisting in their preservation, restitution and which is most important - ensuring the permanence of their use. The more so, their protection and shaping is justified as they are a basic means of production in agriculture and they are characterised by, among other, non-transferability, non-enlargeability and they have been irreplaceable so far and, what is more, we have less and less of them in Poland each year. [see table 1, chart 1].

Proper management of agricultural lands in Poland is connected with their optimal use for farming, forest and other purposes. Transferring lands into non-agricultural purposes is practically irreversible. So while taking a decision on that subject one should bear in mind an economical management of farmland as it is a non-multiplicable resource.

Table 1 The surface area of agricultural lands per one Polish inhabitant in the years 1983-1997

<table>
<thead>
<tr>
<th>Year</th>
<th>General surface area of the country [ha]</th>
<th>Agricultural lands Total [ha]</th>
<th>The share in the total surface area in the country [%]</th>
<th>Population [thousands]</th>
<th>The surface of agricultural lands for one inhabitant [ha]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31.268.330</td>
<td>18.878.650</td>
<td>60,38</td>
<td>36.745,0</td>
<td>0,51</td>
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<td>31.268.330</td>
<td>18.875.673</td>
<td>60,37</td>
<td>37.063,3</td>
<td>0,51</td>
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<td>31.268.330</td>
<td>18.843.685</td>
<td>60,26</td>
<td>37.341,0</td>
<td>0,50</td>
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</tbody>
</table>
### AFFORESTATION OF AGRICULTURAL LAND AND WATER MANAGEMENT ON THE EXAMPLE OF POLAND

<table>
<thead>
<tr>
<th>Year</th>
<th>Farmland Area (ha)</th>
<th>Water Area (ha)</th>
<th>Percentage</th>
<th>Water Area Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>31,268,330</td>
<td>18,803,856</td>
<td>60,14</td>
<td>37,571,7</td>
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<td>60,14</td>
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<td>18,783,800</td>
<td>60,07</td>
<td>38,183,2</td>
</tr>
<tr>
<td>1991</td>
<td>31,268,500</td>
<td>18,759,564</td>
<td>60,00</td>
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<td>31,268,500</td>
<td>18,740,884</td>
<td>59,94</td>
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</tr>
<tr>
<td>1993</td>
<td>31,268,500</td>
<td>18,712,799</td>
<td>59,85</td>
<td>38,504,7</td>
</tr>
<tr>
<td>1994</td>
<td>31,268,500</td>
<td>18,689,685</td>
<td>59,77</td>
<td>38,580,6</td>
</tr>
<tr>
<td>1995</td>
<td>31,268,500</td>
<td>18,663,821</td>
<td>59,69</td>
<td>38,609,4</td>
</tr>
<tr>
<td>1996</td>
<td>31,268,500</td>
<td>18,632,581</td>
<td>59,59</td>
<td>38,639,0</td>
</tr>
<tr>
<td>1997</td>
<td>31,268,500</td>
<td>18,607,762</td>
<td>59,51</td>
<td>38,660,0</td>
</tr>
</tbody>
</table>

Total in the years 1993 - 1997: 270,888 - 0,87 +1.915,0 -0,03

Source: own calculations on the basis of source materials

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### 2 MATERIALS AND METHODS

The subject of the paper places itself within the widely understood set of problems connected with shaping the agricultural-forest production space. It concerns the extremely important issue appearing in shaping the natural environment and in planning and arranging work, which is protection and shaping farm and forest land in the aspect of bettering water management.

Empirical studies gave the basis for developing an algorithm that would be important while afforesting farmland in the aspect of water management. That is why my own quality analysis is prevailing in the whole article. The method of double cross information was used. The data received from one source were confronted with the data from other sources. The method used in the study is based upon logical and comparative analyses while using statistical and descriptive techniques.

The main thesis of the work is that afforestation of the adequate land in Poland influences not only the protection of this land but the water management and the agricultural production on adequate and sufficient resources of agricultural land.

The objective of this work is developing an algorithm of agricultural land afforestation in the aspect of bettering water management. That algorithm, which a general one, was developed assuming that the land fulfills its main function of running agricultural production on it. The developed algorithm concerns...
AFFORESTATION OF AGRICULTURAL LAND AND WATER MANAGEMENT

The research held concerned the data for Poland from the years 1983-1997. The choice of data from those years was purposeful. The accepted period is characteristic both for the whole national economy of Poland and for agriculture and protection of natural environment with water management within. The events enumerated below were important taking into consideration their influence on protection and shaping farm- and forestland in the aspect of water management:

- two acts of Parliament come from that period of time: from 1983 (annulled) and from 1985 (valid) on protection of agricultural and forest land;
- development of market economy in the place of already not functioning system of command-distributive economy;
- from the shortage of food supplies to their abundance on the market;
- from a compulsory use of all agricultural lands for the purpose of agricultural production (sanctioned by their loss or relevant penalties) to their voluntary use for the same purpose;
- from the period when agricultural land was protected more than forest area to the time when forest land is protected more than the agricultural one;
- future Polish membership in the European Union.

The work refers to the rule sustained development, which is the aim to be reached (it is rather the realisation of the rule of sustained development, which is talked about now).

The work uses the published and unpublished data concerning the widely understood issue of protection and shaping agricultural land. The data on the above issue is published in various sources, but it is not always comparable. This fact made collecting and selecting it difficult additionally. So, to achieve the objective of the study, while collecting the data I selected it on the basis of obtaining unanimous and comparable data. The data included in this work come from various available sources: The Main Statistical Office, Voivodship Statistical Offices, The Ministry of Agriculture and Rural Development, The Ministry of Environment, The Main Land Surveyor's Office and from The Institute of Forestry Research.

3 AFFORESTATION OF AGRICULTURAL LAND AND WATER MANAGEMENT

Until 1989 there was a common belief in Poland that "each hectare must give crop" [Wos, 1992], the consequence of which was, among other, the duty of agricultural use of farmland. The conviction was consolidated in the period when the quantity of food production depended directly on the amount of the possessed farmland. Nowadays it is supposed that not only the quantity of farmland but also its quality and the way of its use decide about the quantity of food production. After 1990 new social and economy conditions appeared in Poland favouring afforestation of agricultural land.

For the sake of this paper afforestation is understood as setting forest farms on the land which were out of forest farming before, that is on the land not included to the surface of forests.

Afforestations of farmland in Poland play a limited role in bettering water management while running agricultural production correctly at the same time. Moreover, they influence farmland protection positively as well. The positive influence on water management appears when we afforest the land of the lowest bonitation classes, i.e. farmland of the 6th and 7th classes and more rarely of the class 5. It does not mean that as a result of afforestation the surface area of land used for farming decreases because there are about 1.8mln hectares of uncultivated and fallow land in Poland [see table 2] and the next 1.5mln hectares should not be used for food production because of various reasons [Szot, 1997].

Table 2 Selected data on agricultural land in Poland in the years 1995-1996

<table>
<thead>
<tr>
<th>Uncultivated and fallow land within agricultural area in thousands of hectares</th>
<th>Agricultural land % from the general %</th>
<th>Plough individual</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Afforestation of Agricultural Land and Water Management

#### Table

<table>
<thead>
<tr>
<th></th>
<th>of hectares</th>
<th>area</th>
<th>farms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Poland</strong></td>
<td>1799,2</td>
<td>12,8</td>
<td>76,7</td>
</tr>
<tr>
<td></td>
<td>18622,2</td>
<td>81,7</td>
<td></td>
</tr>
</tbody>
</table>

Source: own calculations on the basis of source materials

About 10 years ago it was estimated, however, that about 800-900 thousand hectares of farmed land not giving profitable production at that time should be assigned for afforestation [Grochowski, 1988]. The above data shows that during the last decade the area of land predestined for setting forest farms was increased.

There is a positive influence on water management when we afforest the poorest plough land created from loose sands and loam belonging to soil-farming complexes no7 and 6. Moreover, it is positive when we afforest agricultural land on which there are advanced processes of soil erosion and its considerable overdrying. Such a situation exists mainly in Polish central belt and in the belt of the mountains and foothills where forests limit the flow of ground waters [Szot, 1997].

Afforestation has a positive influence on economy through:

- bettering the water balance, mainly by the increase of retention and alleviation the extensive states of river flows,
- preventing the phenomena of soil erosion,
- purifying the air, water and soils from chemical substances,
- the influence of forests as a soil creating and a soil degradation preventive factor,
- a beneficial modification of microclimatic system on the adhering agricultural land.

The above analysis of establishing forest farms takes the process in its potential dimension. They are only the agricultural lands, which are predestined for afforestation because of their low farming use effectiveness or because of soil erosion and its high degree of overdrying. As the data of The Institute of Forestry Research until 2020 show the area of forests in Poland is to increase by about 700 thousand hectares and until 2050 by the next 1200 thousand hectares [Szot, 1997]. It is supposed, that enlarging the area of forests including the voluntary afforestation will take place at the cost of the agricultural land area.

The actual taking of agricultural land for the above purposes must consider some important organisational and spatial conditions, ecology and landscape factors, etc. To describe the afforestation process of agricultural land on a given area one should consider the following conditions of the given area:

- the up-to-date state of afforestation,
- the quality of agricultural production space,
- danger of erosion

Because of the procedure of starting forest farms one may enumerate two categories of land afforestation [Hernik, 1997]:

1. obligatory,
2. voluntary.

### 3.1 Obligatory afforestations

Obligatory afforestations are carried out in the situations, when:

1. forests were deprived of tree-stand - then the National Forests and the owners of those forests are obliged to introduce forest woodland vegetation (forest farms) in those forests again within two years - art. 13 pass. 1 point 2 of the act on woods. [Ustawa, 1991];

2. agricultural land was assigned for afforestation according to the plan of spatial development which is in force in a given community. Such afforestation, according to art. 14 pass. 2 of the act on woods may take wasteland, agricultural land that is useless for agricultural production and other land suitable for afforestation (including agricultural land), with especially:

- grounds situated at water-heads of rivers and streams, on watersheds, along river banks and on the shores of lakes and water bodies,
- quick sands and sand dunes,
• steep slopes, hillsides, precipices and hollows,
• heaps and the area after sand, gravel, peat and clay excavation.

The obligation of afforesting such area lies on forest inspectors - in relation to the grounds owned by State Tresury taken by National Forests - and on owners of those grounds (art. 14 pass. 4 of the act on woods) [Ustawa, 1991].

### 3.2 Voluntary afforestation

Voluntary afforestation takes place on the basis of the articles present in the Parliamentary act on agricultural and woodland protection. Nowadays each agricultural land, no matter of its agricultural and natural value, might be afforested. Then there is no need of obtaining a decision allowing its exclusion from agricultural production. Farmland afforestation causes a change in the way of using the agricultural land. The land loses its agricultural character and becomes woodland or a wooded area. It is worth noticing that according to the parliamentary act, afforestation of agricultural land does not mean its assignment for non-agricultural or non-forest purposes because there is no other use of land as agricultural or forestlike. It was implied by the obligation of agricultural use of farmland and by a simplified procedure allowing assigning woodland for agricultural land. After 1991 there have been serious changes in legal solutions concerning the protection of those lands. As a result of those changes woodland area is protected more than farmland. Nowadays farmland can be freely afforested while woodland can be transformed into farmland only in a justified and exceptional situation. The legislator gives the priority to woodland before farmland in this field of protection.

### 4 AFFORESTATIONS AND AGRICULTURAL PRODUCTION

The institution of agricultural land afforestation is included in modern concepts of rural areas development. Those concepts stress ecoforestry, which is a specific symbiosis of agriculture and forestry [Wos, 1992]. The act from 1995 on protection of agricultural and forestlands should facilitate the development of rural areas, especially on the land of poor bonitation classes, by, among other, transferring them for forest area. It should be noticed, however, that afforestations (apart from the given above positive characteristics) add to the decrease of the area of agricultural land. According to Wos [1992], although afforestations diminish the amount of land used by agriculture but they do not decrease the agriculture production potential [see table 3, chart 2]. On the contrary, the potential increases as a result of a cumulative action of two factors:

• beneficial influence of forests on biocenotic balance, which favours the increase of agricultural land productivity,
• running agricultural production on a smaller area of agricultural land but on good and average land, which influences its increase in comparison with running a bigger area with a smaller productivity potential.

### 5 THE DEGREE OF EFFICIENCY OF VALUABLE AGRICULTURAL LAND PROTECTION

It should be stressed, that the problem of protection and shaping agricultural land still remains the issue of a social meaning because of the need to ensure an adequate area of land for food production. It requires rational management of the best land.

The act on protection of agricultural and forestland allows free afforestation of each agricultural land, even of class 1-3. Such a solution may be supposed as too liberal because there is little land of classes 1-3 in Poland and, what is more, they are characterised by a high environmental value apart from their agricultural worth. One may suggest freedom while assigning agricultural land with classes 4-6 to afforestation but not all agricultural lands.

In order to preserve the best agricultural lands for their main objective, i.e. agricultural production and having in mind the betterment of water management an algorithm of determining the degree of efficiency of valuable agricultural land protection (preservation). It allows to determine the tendency to protect valuable agricultural land for agricultural production.

Calculations of valuable agricultural land protection efficiency for Poland for the analysed period of 1983-1997 were carried out. The publications concern the analysed period in reference to the amount of agricultural land within particular bonitation classes in Poland from the years 1980, 1985 and 1990 [see table 4].

Table 3: The change in the surface area of agricultural land in Poland in the years 1983-1997

<table>
<thead>
<tr>
<th>Year</th>
<th>Total surface area of farmland</th>
<th>Loss of farmland in compared with the previous year</th>
<th>Excluded farmland and forest lands¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Surface area %</td>
<td>Farmland</td>
</tr>
<tr>
<td></td>
<td>Surface area</td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>% of the total area of farmland</td>
<td></td>
<td>Surface area %</td>
</tr>
</tbody>
</table>

http://library.wur.nl/ebooks/drainage/drainage_cd/2.5%20fernak.html (5 of 9)26-4-2010 12:12:33
AFFORESTATION OF AGRICULTURAL LAND AND WATER MANAGEMENT FOR AGRICULTURAL PRODUCTION ON THE EXAMPLE OF POLAND

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>18.878.650</td>
<td>38.238</td>
<td>0,2</td>
<td>9.428</td>
<td>8.409</td>
<td>0,0499</td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>18.875.673</td>
<td>40.266</td>
<td>0,21</td>
<td>8.557</td>
<td>7.484</td>
<td>0,0453</td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>18.843.685</td>
<td>31.070</td>
<td>0,17</td>
<td>7.686</td>
<td>6.676</td>
<td>0,0354</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>18.803.856</td>
<td>29.309</td>
<td>0,16</td>
<td>7.710</td>
<td>6.376</td>
<td>0,0339</td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>18.791.257</td>
<td>27.354</td>
<td>0,15</td>
<td>8.926</td>
<td>7.538</td>
<td>0,0401</td>
<td></td>
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<tr>
<td>1988</td>
<td>18.797.979</td>
<td>28.669</td>
<td>0,15</td>
<td>8.486</td>
<td>7.436</td>
<td>0,0396</td>
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<tr>
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<td>29.984</td>
<td>0,16</td>
<td>8.045</td>
<td>7.334</td>
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<td>18.783.800</td>
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<td>6.630</td>
<td>5.936</td>
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<tr>
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<td>18.680</td>
<td>0,01</td>
<td>6.243</td>
<td>5.707</td>
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</tr>
<tr>
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<td>28.085</td>
<td>0,15</td>
<td>7.683</td>
<td>7.079</td>
<td>0,0378</td>
<td></td>
</tr>
<tr>
<td>1994</td>
<td>18.689.685</td>
<td>23.114</td>
<td>0,12</td>
<td>6.074</td>
<td>5.360</td>
<td>0,0287</td>
<td></td>
</tr>
<tr>
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<td>18.663.821</td>
<td>25.864</td>
<td>0,14</td>
<td>2.287</td>
<td>1.419</td>
<td>0,0076</td>
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<td>18.632.581</td>
<td>31.240</td>
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<td>1.693</td>
<td>1.211</td>
<td>0,0107</td>
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<td>24.819</td>
<td>0,13</td>
<td>1.183</td>
<td>0,0053</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For the years 1983 - 1997 - 270.888 - 1,43 95.207 83.140   0,44 **

Source: own calculations on the basis of source materials

1 – following the procedure of farmland and woodland protection
* - without woodland
** - compared to 1983

Figure 2  The change of the area of agricultural land excluded from agricultural production in comparison to their total area in Poland in the years 1983-1997

Table 4  Bonitation classes of agricultural lands in Poland and in five voivodships in the years 1980-1990

<table>
<thead>
<tr>
<th>Year</th>
<th>Bonitation classes of agricultural lands [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>1980</td>
<td>POLAND</td>
</tr>
</tbody>
</table>
In those years there were no considerable changes in bonitation classes of agricultural land. While calculating of the above degree of efficiency for Poland for the years 1983-1984 the data on the amount of agricultural land of classes 1-3 from the year 1980 was taken and for the next calculations for the years 1985-1989 the data from the year 1985. The calculations of the degree of efficiency of valuable agricultural land protection for Poland for the years 1990-1997 was carried out on the basis of the data for 1990. Moreover, a simulation of the amount of agricultural land of classes 1-3 for the years not covered by the above bonitation statistics was carried out with the use of Microsoft Excel computer software. It appeared, however, that there is only a small difference between the calculations of the efficiency of valuable agricultural land protection carried out on the basis of the published data on the amount of agricultural land according to bonitation classes and the calculations on the basis of the simulation data. That is why the calculations were performed on the basis of the published data on the amount of agricultural land according to bonitation classes.

Table 5 presents the amount of agricultural lands of classes 1-3 excluded for non-agricultural purposes in Poland for the analysed period 1983-1997. The table shows the data of those excluded areas together for all three classes (1-3) which is caused by its presentation in statistical publications.

<table>
<thead>
<tr>
<th>Years</th>
<th>Poland</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>909</td>
</tr>
<tr>
<td>1984</td>
<td>1039</td>
</tr>
<tr>
<td>1985</td>
<td>920</td>
</tr>
<tr>
<td>1986</td>
<td>1065</td>
</tr>
<tr>
<td>1987</td>
<td>1374</td>
</tr>
<tr>
<td>1988</td>
<td>1217</td>
</tr>
<tr>
<td>1989</td>
<td>1210</td>
</tr>
<tr>
<td>1990</td>
<td>1196</td>
</tr>
<tr>
<td>1991</td>
<td>678</td>
</tr>
<tr>
<td>1992</td>
<td>1377</td>
</tr>
<tr>
<td>1993</td>
<td>1854</td>
</tr>
<tr>
<td>1994</td>
<td>1248</td>
</tr>
<tr>
<td>1995</td>
<td>876</td>
</tr>
<tr>
<td>1996</td>
<td>812</td>
</tr>
<tr>
<td>1997</td>
<td>760</td>
</tr>
</tbody>
</table>

Source: own calculations on the basis of source materials [81].

Next the calculations determining the efficiency of valuable agricultural land protection were carried out [see table 6] with the use of own coefficient of the efficiency of agricultural land protection (W_sour), according to the formula below:

\[ W_{sour} = \frac{P_w}{P}, \]

where

- \( W_{sour} \) - the coefficient of the efficiency of valuable agricultural land protection in the surveyed region (Poland);
- \( P_w \) - the % of the excluded valuable agricultural land area in the surveyed region (Poland);
- \( P \) - the % of valuable agricultural land area in the surveyed region (Poland).
AFFORESTATION OF AGRICULTURAL LAND AND WATER MANAGEMENT ON THE EXAMPLE OF POLAND

Figure 3  The tendency of valuable agricultural land protection efficiency (Wsour) for Poland in the years 1983-1997

Table 6  The coefficient of the efficiency of valuable agricultural land protection (Wsour) for Poland in the years 1983-1997

<table>
<thead>
<tr>
<th>Years</th>
<th>Poland</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>0.1926</td>
</tr>
<tr>
<td>1984</td>
<td>0.2202</td>
</tr>
<tr>
<td>1985</td>
<td>0.1915</td>
</tr>
<tr>
<td>1986</td>
<td>0.2221</td>
</tr>
<tr>
<td>1987</td>
<td>0.2867</td>
</tr>
<tr>
<td>1988</td>
<td>0.2539</td>
</tr>
<tr>
<td>1989</td>
<td>0.2524</td>
</tr>
<tr>
<td>1990</td>
<td>0.2487</td>
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<td>1991</td>
<td>0.1412</td>
</tr>
<tr>
<td>1992</td>
<td>0.287</td>
</tr>
<tr>
<td>1993</td>
<td>0.387</td>
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<tr>
<td>1994</td>
<td>0.2608</td>
</tr>
<tr>
<td>1995</td>
<td>0.1834</td>
</tr>
<tr>
<td>1996</td>
<td>0.1702</td>
</tr>
<tr>
<td>1997</td>
<td>0.1595</td>
</tr>
</tbody>
</table>

Source: own calculations on the basis of source materials

A general interpretation of Wsour coefficient for the sake of this article is as follows: the lower the value of this indicator the more efficiently the valuable agricultural land is protected.

The calculations imply that in the years 1983-1997, in Poland, there is generally a slow increasing tendency within the efficiency of valuable agricultural land protection and within shaping of those lands (see chart 4). In the case of Poland the value of the agricultural land protection efficiency coefficient in 1997 was almost three times smaller compared with 1983.

6  CONCLUSIONS

It was shown that afforestation of the suitable agricultural lands in Poland influences not only the protection of those lands but the water management and agricultural production on adequate and sufficient resources of agricultural land as well.

Afforestations of agricultural lands, as it was proved, influence water management positively as well. Besides positive results afforestations cause
decreasing the area used for agricultural production. However, it should be mentioned, that afforestations do not decrease the productive potential of agriculture in Poland. On the contrary, the potential increases. In such a context it was shown that afforestation of suitable agricultural lands in Poland, with preservation of the valuable agricultural lands, may add to two positive results:

- bettering of water management and
- bettering of running agricultural production on good and average lands in better environmental conditions.

Such objectives would find it beneficial to use the algorithm of preserving the best agricultural lands for their main purpose, i.e. agricultural production considering betterment of water management. It makes it possible to determine the tendency in valuable agricultural lands protection for agricultural production. The carried out calculations imply that in the analysed period of 1983-1997 in Poland there is a general tendency of a slow increase within the efficiency of valuable agricultural land protection.

7 REFERENCES


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Ustawa from 28 September 1991 r. on woods. 1991. (Dz. U. Nr 101, poz. 444 z po. zm.).
Ustawa from 3 February 1995 r. on protection of agricultural and forest land 1995. (Dz. U. Nr 16, poz. 78, z po. zm.).
ROLE OF FARMER’S PARTICIPATION IN OPERATING MODIFIED DRAINAGE SYSTEM

M. Akmal Omara, M. A. Qenawy, Ibrahim Lashine, and M. A. Ragab

ABSTRACT

Modified drainage system is applied in some areas in the Nile Delta of Egypt cultivated with rice crop during summer season in order to manage and rationalize irrigation water application. About 700 000 feddan is planned yearly to be cultivated with rice in Egypt. Balaker area located in western delta is selected to identify and define the role of farmer participation in operating modified drainage system.

Participatory Rapid Appraisal (PRA) technique is used to evaluate the feasibility of application of modified drainage concept and to identify the expected constraints and suggested suitable solutions. A flap gate is used at the outlets of sub-collector drains to be operated by the farmers during summer season in the areas cultivated with rice. A multidisciplinary team is established before starting the study to co-ordinate the PRA tasks among them. This team is consisted of representatives from Drainage Research Institute (DRI), Egyptian Public Authority for Drainage Projects (EPADP), Agricultural co-operatives at Balaker area, Agricultural Extension Services (AES), and Irrigation Improvement Project (IIP). Application of PRA technique and its tools showed that, the challenge facing the application of modified drainage system on a large scale can be related to the following constraints: Un-consolidation of rice cultivation on collector or sub-collector drains, Insufficient convincing among the interdisciplinary team of modified drainage concept, Lack of sufficient financial and administrative possibilities for multidisciplinary team, Difficulty in the formation of an efficient multidisciplinary team, Defects in irrigation and drainage systems, and Weakness of institutional relationships between farmers and local institutional services.

The wider application of modified drainage concept needs as a first priority more co-operations between different responsible organizations and farmers. Then, the role of farmer participation and awareness in the application and operation of modified drainage system will increase.

Keywords: Drainage, Participation, Water, Rice, Organization

1 INTRODUCTION

The irrigation water play an important role in agricultural and economical development, and also the availability of water for the old land and new reclaimed land is a main target. Therefore, rationalisation of irrigation water used is one of the very important issues to overcome the limitation of irrigation water in the future. As a result of economical liberalisation and free agriculture, the agricultural rotation was cancelled and the farmers created a major disturbance for water distribution on the canal level. In summer season they are willing to cultivate big areas of rice crop more than permitted by the government, depending on the big return and competitive advantages of this crop. This unorganised performance from the farmer’s side created negative impact on irrigation water management.

For this situation, The Drainage Research Institute (DRI) tried to manage and rationalise the water use of rice in the studied area. In order to apply the agricultural development on a large scale, it is necessary to change the traditional practices of farmers, and also increase farmer participation in rationalisation of water use. In addition, an Extension Service Sector for water rationalisation is needed in different sectors of the Ministry of Water resources and Irrigation. The role of this sector is to convince the farmers by the importance of irrigation water and the necessity of water saving for cultivating new reclaimed areas in order to increase the crop production. One of the main contributions of saving irrigation water is to reduce the water losses from rice areas without restricting the subsurface drainage system for “dry-foot” crop.

Several methods were tested to get farmers familiar with the idea of controlled drainage in rice fields, and to encourage them to consolidate their crops on the same collector / sub-collector and partly close the drainage system by using small flap gates. The efforts of the MWRI and MALR should combine to enhance integrated water management in general, an effective control of the drainage system in particular, an advisory services towards the farmers and organising them. New modified design for this system based on crop consolidation scheme was tested and applied at several areas in the Nile Delta with the participation of the farmers as the end users. One of these areas was Balaker area (11500 feddan) in Beheira Governorate. The Participatory Rapid Appraisal (PRA) was used as a new technique and also as a tool at Balaker area to create the awareness among farmers. Also, several organising committees to guide the introduction and implementation of controlled drainage for rice cultivation were established as following: Rice Committee (RC) including a high level staff from the different Ministries represented by EPADP, IIP and MALR to organize integrated water management policy in irrigation, drainage and agriculture, sectors. Central Contract Integrated water management (CCI) on Beheira governorate to select the field staff and define their role during the study period. Contract Integrated water management (CI) to introduce the concept of controlled drainage during rice season through scheduled meetings with the farmers. These committees met 10 times and they aimed at selecting Balaker area (11500 feddan) in Beheira Governorate for introducing the controlled drainage on large scale; installing 80 gates on the sub-collectors under study, helping awareness meetings for governmental staff and farmers, and encouraging farmers for consolidating rice fields on sub-collectors.

2 OBJECTIVES

The main objectives of this study are to:

- Evaluate the work of the interdisciplinary team that is responsible for spreading and application of controlled drainage in rice fields in Balaker area (Rice
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season 2000) by achieving following secondary objectives;

- Evaluate the skillfulness of the interdisciplinary team with working group;
- Evaluate the interdisciplinary team towards the concept of controlled drainage;
- Evaluate the positive aspects towards the application of controlled drainage and the interdisciplinary team attitudes;
- Evaluate the farmers' awareness and their participation in application of controlled drainage by achieving following secondary objectives;
- Evaluate the farmers' skill in application of the controlled drainage;
- Evaluate the knowledge of farmers about the concept of controlled drainage;
- Evaluate the farmers' awareness for water rationalisation through consolidation of the rice field;
- Evaluate the farmers' acceptability towards applying the controlled drainage.

3 METHODOLOGY

3.1 Description of the Study area
The Balakter area (Figure 1) under study has two types of the co-operatives, credit co-operatives and reform co-operatives. The farmers of credit co-operatives are free to cultivate the crops they need, while the farmers of reform co-operatives are still follow the agrarian reform law and the traditional cropping pattern of the crop rotation system.

The tools used with PRA technique are divide into three groups as following:

- The first group is used for collecting information;
- The second group is used for analysing information;
- The third group is used for collecting and analysing information.

For any PRA study some of these tools are used. The most appropriate and useful set of tools were selected to be applied during this study as following:
CONTROLLED DRAINAGE

Agreed and did not apply

REJECTED THE CONTROLLED DRAINAGE.

FIVE SEPARATED KEY QUESTIONS WERE FORMULATED TO COVER THE ITEMS RELATED TO THE

PRA METHOD. SEVERAL METHODS WERE USED FOR COLLECTING BOTH QUANTITATIVE AND QUALITATIVE DATA.

THE APPRAISAL AND ASSIGNED TASKS TO THE MEMBERS OF THE PRA TEAM WAS PREPARED. THE FIELDWORK IS AN IMPORTANT INDICATOR FOR THE THEORETICAL AND PRACTICAL QUALITY OF THE

ACCOMMODATION AND MATERIALS TO COLLECT AND ANALYSE THE OBTAINED INFORMATION. COPIES OF EVERY DESIGNED TOOL ARE MADE FOR ALL MEMBERS OF THE PRA TEAM. A SCHEDULE FOR

A BLANK FORMS WERE DESIGNED, INCLUDES LIST OF TOPICS FOR SEMI-STRUCTURE INTERVIEWS (SSI), LIST OF SPECIFIC KEY QUESTIONS FOR DISCUSSION GROUP, INTERVIEW GUIDE, INDICATORS AND KEY QUESTIONS, IDENTIFYING SOURCES OF INFORMATION FOR EACH SUB-TOPIC, AND SELECTING TOOLS TO GATHER AND ANALYSE INFORMATION.

THE FOLLOWING STEPS WERE FOLLOWED TO DESIGN THE WORK PLAN OF THE FIELD WORK: CLARIFYING GOALS AND OBJECTIVES OF THE STUDY, CHOOSING MAIN TOPICS, PREPARING LIST OF SUBTOPICS, INDICATORS AND KEY QUESTIONS, IDENTIFYING SOURCES OF INFORMATION FOR EACH SUB-TOPIC, AND SELECTING TOOLS TO GATHER AND ANALYSE INFORMATION.

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following main topics: The concept of conventional drainage system; the concept of controlled drainage system; the acceptance and sustainability the idea of controlled drainage, the application skills of controlled drainage; and the constraints related to the application of controlled drainage. Also, fourteen focus group discussions were held in the study locations. The number of attendance was varied. The new policies of agricultural liberation and its effect on the crop rotation and consolidation of rice crop was the specific topic discussed in detail.

In the case of individual interviews as one of the Semi-Structure Interviews. Case studies were designed to capture the farmer interaction with the concept of controlled drainage, their awareness with controlled drainage, the benefits of controlled drainage and their constraints with application of the controlled drainage. Many individual interviews were held with the key persons from the farmers of Balakter area. In addition, at the multi-disciplinary level, many individual interviews were held with senior staff and field staff from EPADP, IIP and AES. Three question groups were formulated covering the following topics: The multi-disciplinary team importance and constraints; the application capability of controlled drainage and its complaints; and farmers' participation in carrying out and sustainability of the controlled drainage on a large scale.

The collected data were analyzed, reviewed and summarized. Also the findings and the method used were evaluated. Then, sorting and shifting the information and looked for patterns, differences, variations and contradictions. At the end, weighted the relative importance of the information without partiality.

The agriculture Co-operatives in Balakter area fabricated in total 80 gates. In addition 5 gates were installed in 1996 and 1997 during DRI's study. Sixty gates out of Eighty gates were installed in both areas that have rice consolidation and mixed crops while 20 gates left in store to be used if needed. The reason for installation of gates in mixed crop areas is to create awareness amongst farmers concerning application of controlled drainage in the coming years.

4 RESULTS AND DISCUSSIONS

Three credit co-operatives are considered in this study are including El Roda Khairi, Balakter El Sharkia, and Balakter El Gharbia. While the three other reform co-operatives considered in the study are including El Wakeel, El Brince , and El Nomairy. The total population of the previous co-operatives boundaries is about 94,255 inhabitants, it is distributed between the six co-operatives as shown in Figure 2.

Figure 2 Population of the co-operatives boundaries

The boundaries of the co-operatives at Balakter area are classified into cultivated area, and utilities area for each co-operative (Figure 3). Different utility services are offered for the society of the co-operatives of Balakter study area. The services include health, education, religion, veterinary, credit and agricultural consumptive. Inside the boundaries of the credit co-operatives, there are many general utilities like hospitals, health clinic, integrated clinic, primary and preparatory schools, religious institute, municipality (local unit), and Public co-operative. Within the boundaries of the reform co-operatives, there are limited number of utilities like hospitals, health clinic, primary schools and Koran office. There are also agricultural services like agricultural co-operatives and development bank.

In general the percentage of educated persons (in different educational levels) was about 75% from the total population belongs to the co-operatives under study, while the rest (25%) were suffering from illiteracy.
Figure 3  Total boundaries of the co-operatives at Balakter area

Figure 4 shows that, the credit co-operatives have the bigger number of the owned tenures than the reform co-operatives. It is observed also that the reform co-operatives have the bigger number of the rented lands according to the tenured fragmentation of the agrarian reform system. Figures 5 shows the number of tenures at the cultivated area of each co-operative, which classified to owned and rented. Also, Figure 6 shows that the bigger number of the tenures is noticed at Balakter El Sharkia co-operative, while the smallest number of tenures is at El Prince co-operative. The cultivated major crops in Balakter area were cotton, rice and maize and limited area was cultivated with vegetables and orchard. The Figure shows that the most important crops at the cultivated area of all co-operatives were cotton, rice and orchard as the marketable crops and the last crop in importance as subsistence crop like maize and vegetables. Figure 7 shows that the size of the tenure groups was classified to different classes from less than 3 feddan to greater than 10 feddan. It is noticed also that, the bigger number of tenures is (between less than one feddan and three feddan) situated in the area of credit co-operatives, while the small number of tenures is situated in the reform co-operatives. It is also noticed that most of the big area which represented by more than three feddan is belongs to the credit co-operatives.
Figure 5  The number of tenures at the cultivated area of each co-operative at Balakter area

Figure 6  Cropping pattern of co-operatives at Balakter area
4.1 Assessment of Farmer Awareness

The results show that farmer’s knowledge about the concept of conventional drainage system; and the concept of controlled drainage system and their awareness for water rationalisation through consolidation of the rice field, is too low. This is due to the following reasons:

The study area consists of six co-operatives with average of 13 villages, the distance between the villages is considerably long; therefore it is very difficult to visit the whole villages.

Twenty meetings were held in only 4 months to give awareness about the controlled drainage concept to the farmers. The average available time for each meeting was 2 hours. These meetings were started in November 1999 and continued until March 2000 (according to the seasonal calendar). It is also noticed that (November, December, January and February) are the best months for the awareness meetings.

There was only one interdisciplinary team to carry out the awareness meetings with this number of villages and limited time. The number of participants in interdisciplinary team were few to carry out the awareness meetings with this number of villages and limited time. Many constrains faced the interdisciplinary team during the course of the study. The most suitable months for awareness meetings are Nov, Dec, Jan, and Feb. The weekly routine tools showed also that there are four available days for awareness meetings (Saturday, Monday, Thursday, and Friday). The daily routine tools show that there are two available time for awareness meetings the first is from 13 PM to 15.30 PM, while the second is from 19 PM to 21 PM.

In spite of holding 20 awareness meetings, the number of attendance from farmers per meeting ranged from 4-10 farmers, this is due to the miss arrangement.

The controlled drainage system were carried out on 75 sub-collectors which serve about 2250 feddan and represent about 22 % of the total cultivated area in the study area. The total land owners, where the controlled drainage was applied is about 1550 farmers represent about 4% of the total farmers in the study area (about 42450 farmers). During the period between Nov 1999 and March 2000, the interdisciplinary team tried to convince the farmers with the idea of controlled drainage rice fields, and to encourage them to consolidate their crops, (the convincing had carried out with 110 farmers represent about 7 % of the farmers in the area served by the controlled drainage system, and about 0.26 % of the total farmers in the study area).

The item of farmer awareness is including knowledge of the controlled drainage concept. The results, obtained from the 12 Semi-structure interviews and 22 individual interviews, show that only 0.82 % of the farmers in the study area had knowledge about the concept of controlled drainage and 0.56 % of them get their Knowledge during the experimental phase from1996 to 1998 while 0.26 % of them during the experimental phase from 1999 to 2000. The maps and the transact which the farmers drew by themselves about their village and the collector and sub-collector, showed that their knowledge about the concept of controlled drainage is not sufficient.

Farmers’ skill in the application of controlled drainage:

Preliminary results were extracted from direct observation and interviews with the representatives of various farmers groups during the study period. About 0.56% of the total farmers in the study area have good skills in the application of the controlled drainage such as closing device (gates) in their manholes.

The primary results about water rationalisation through consolidation of the rice field reveal that most of the farmers are quite aware of water rationalisation through consolidation of the rice field. The source of information about water rationalisation by the direct contact through consolidation of the rice field took place from1996 to 1998.
Farmers belong to reform co-operatives suggested that the consolidation of the rice field could be applied by law, while the farmers belong to credit co-operative are preferring the free cropping where they can cultivate what they want and consolidation of the rice field is harmful for them.

According to the analysis of the Semi-Structure interviews which were carried out with the framers of the pilot area, the results show that 2.25% of the farmers were agreed to apply the controlled drainage and about 1.4% of them rejected the concept, while about 96.35% were ignored the idea (no agreed and no rejected). Generally, from above mentioned results, it can be concluded that farmer awareness about the concept of controlled drainage was very low and not enough. Based on the analysis of PRA tools, the farmers of the study area are divided into the following categories, (Figure 8):

**4.2 Agreeable and applied controlled drainage category**
The farmers belong to this category had a good idea about the concept of conventional drainage system; and the concept of controlled drainage system. Also their application skills of controlled drainage are high. This is due to the advisory services towards the farmers during the experimental phase from 1996 to 1998 by DRI. These farmers considered first pioneers (adopters)

![Figure 8 Farmers classification according to their desire for applying C.D.](http://library.wur.nl/ebooks/drainage/drainage_cd/3.3%...a,%20lashine%20i,%20omara%20am%20and%20ragab%20ma.html (8 of 12)26-4-2010 12:12:35)

First pioneers (adopters) are about 0.56% of the farmers in the study area agreed and applied the controlled drainage after DRI trails to get them more awareness about the concept. Moreover, 0.18% from those farmers in El-Wakeel Co-operative manufactured the gates (for controlled drainage) using their own money. These farmers are distinguished with some characters such as: Most of them can read and write, IIP have been applied in their land (the success of this project encourages them to investigate any new technology), landowner ship of farms ranged from 1 to 3 feddan, age of farmers ranged between 20 to 65 years, farmers belong to Reform co-operative (so they haven't consolidation crop problems). They observed that the application of the controlled drainage is saving money which could help them to buy spare irrigation pump. They applied controlled drainage by themselves, without any help from the drainage maintenance. In addition, by the direct contact no constrains faced controlled drainage in Reform co-operative. The controlled drainage was applied in their lands but they were ignored.

**4.3 Rejected Farmers**
This farmers group is characterized by the following: About 70% of them belong to credit co-operative, where the free cropping law was applied, farm size ranged from 1 to more than 40 feddan, area suffered from irrigation and drainage problems, about 50% of the farmers have their area as one unit, and want to cultivate more than two crops in their units, the small farm owners (1-3 feddans) in co-operative catchment select the crops according to their demand such as maize and vegetables for food or expenditures. Therefore they refused the consolidation of the rice crop.

The triple checking is one of the important characteristics of PRA. It depends on accuracy and correct information. The formation of multi-disciplinary team is one of the main elements of the triple checking.

Multi-disciplinary team was formed from members of different specialists, with different skills and experience to use different techniques of farmers' awareness about the controlled drainage. The different specialists are: Key individuals (local leaders), Drainage maintenance engineer, Agricultural extension engineer, Irrigation Improvement engineers, and Agricultural co-operative engineer.

The results of the different interviews with different rural individuals at Balakter area show the order of magnitude of the multi-disciplinary team. For achieving that order, ranking tool of PRA was used by defining importance and giving voting role for each of them, (Table 1). This order started by agricultural extension engineer, agricultural co-operative engineer, drainage maintenance engineer, key individuals (local leaders), and at the end irrigation improvement engineers.

**Table 1 Importance of the multi-disciplinary team**
Through semi-structured interviews with multi-disciplinary team using special prepared questions and application of ranking tool with them, it was known that the different respondent (member) in the ranking faced some constraints. These constraints due to:

- Poor management between the teamwork;
- Lack of monetary incentives and administrative expenses.

It is difficult to work with controlled drainage during the period of workloads from April to October. It was suggested that the members of this team should be available to carry out this work and for perfect awareness especially during these months.

The importance of multi-disciplinary team role during the application of controlled drainage system was clear. The role of farmer during preparation and fabrication of the controlled drainage gates is important. In addition, the role is very important during the installation of gates without loading the farmer with extra cost for fabrication of gates.

In order to apply the controlled drainage system on a large scale, awareness of farmers should be strengthen by solving the vital problems and constraints of the work team. The main constraints and problems are as follows:

- Consolidation of rice cultivation, which can solve through perfect awareness of rice consolidation and reviewing the law of agriculture release especially for rice cultivated area by Agricultural Extension Service and Ministry of Agriculture.
- Irrigation and Drainage Problems, which can be solved through the farmers associations (i.e. Water Boards) and water council on secondary canal.
- Difficulty of interdisciplinary team’s formation, which can form under supervision of Advisory Water Department.
- Unconvincing of interdisciplinary team, which can be solved through workshops and lectures about controlled drainage.
- Overload of interdisciplinary team on the basic work, which can be solved by complete legation in the work of controlled drainage for the first application year and for 4 months in the next four years (from Nov. to Feb. as a part time).
- Shortage in financial and administrative possibilities of interdisciplinary team, which can be solved through available budget to provide these possibilities by Water Advisory Department.

Table 2 shows the ordering of the constraints during the execution of controlled drainage. It is clear that the sequence of these constraints started by the most important one according to this score as following:

- Difficulty in consolidation of rice cultivation on one sub-collector,
- Disputes may rise between farmers on one sub-collector,
- Irrigation and drainage problems in the area,
- Diversification of administrative authorities within the work team,
- Difficulty of formation of multi-disciplinary team,

The least important one at the end referred to the team members where some of them are not convinced with the feasibility of controlled drainage. Then, the important and the preferred procedures in this situation is the consolidation of rice crop on the same collector / sub-collector to solve the disputes between the farmers and any irrigation / drainage problems.
The institutional relationships were assessed on the two levels of PRA as following:

a. Farmer's level
The relationships between the farmer and the institution were very weak except the relationships between him and the co-operatives.

b. Multi-disciplinary team level
It is mentioned before that the structure of the multi-disciplinary team was formed from members of different specialists (economist, socialist, drainage engineer and agronomist). Therefore, good arrangements were carried out among the different institutions where the team members come from.

Figure 9 shows the relationship between the farmer and the agricultural serves. It was observed that there are some closed agricultural serves to the farmers with strong relation like agricultural extension serves and the co-operatives, while other services are semi-closed and are not interfere enough with the farmers like IIP, Irrigation Department and EPADP. It is clear also that the agricultural serves are not closed to the other irrigation serves.

4.4 Adopting and Displaying the Controlled Drainage Concept

Adopting is the mental process of the individual, starts with the farmers' awareness for new technology till accept or reject adopting and finally the decision fixation. Adopting and display of the controlled drainage concept were started at Balakter area during the period from 1996 to 2001. It was not so easy for the farmers and key individuals to apply the controlled drainage concept, although lot of workshops and lectures were given to them. Figure 10 shows the adopting curve for the farmers who applied controlled drainage concept. The curve is classified into five classes where the percentage of each class during the period (from 1996 to 2001) is shown. These classes are nominated as following:

a. Early adopters
Early adopters are persons who, adopted and displayed immediately the controlled drainage concept without any problems. Their personal characteristics are younger, having social positions and wealth specialised in their work, close relationship with innovators, have an enterprising spirit and a great tendency for new experiences and open-minded. Besides, their willing for being leader for their local communities.

b. Early majority
Early majority are persons who adopted the controlled drainage concept and take longer time. Their personal characteristics are high standard of living, large tenure possession, having tendency to specialise, close relationship with innovators, and are respected by others as a models to be looked up to them and leaders within their community's limits.

c. Late majority
Late majority are persons who take the adoption's decision of the controlled drainage concept after relatively shorter time. Their personal characteristics are considered having middle standard of living, medium land ownership, some specialised works, close relationship with innovators for change, close relationship with those in the first two categories, persevering and willing to apply after ensuring success of the experiment and are skilful in their communities.

d. Late adopters
They are persons who take the adoption's decision after relatively late time. Their personal characteristics are less than middle standard of living, small land ownership, simple works that do not need specialisation, receive their information from those in the first three categories, less prone to receive information from public sources and
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not take a part as a leader.

**e- Laggards**

Laggards are persons who takes the adoption's decision after too late to apply the any new idea. Their personal characteristics are low social status, small land ownership, small income, low educational status.

![Adopting curve](image)

**Figure 10 Adopting curve**

5 CONCLUSIONS

The most important conclusions of this study are:

- The most suitable months for awareness meetings are November and December after the end of rice season and January and February before the beginning of the rice season.
- The market days of village, neighbouring village and downtown should be considered before choosing the most suitable days for farmer's awareness.
- The most suitable time for awareness meetings are from 1.00 to 3 .30 o'clock P.M and from 7 to 9 o'clock P.M in the aforementioned four months. Before starting the awareness for farmers, the irrigation and drainage problems should be solved, because it take much time for discussion during the meetings. *(The farmers said, “why we install new button for the ragged clothes”)*
- The application of rice consolidation in credit co-operative, (free cropping) is very difficult *(The farmers said, “we need bread (Maize) along the year and crops give fast return (vegetables)”)*.
- The relationship between the farmers and the Institutions of services are not good except the co-operative and IIP. Although the relationship between different members of Institutions was good, there were some problems faced them such as financing and transportation. The members in the multi-disciplinary team were different in their importance due to their relationships with farmers and the methods of their convincing. It was found that the most important member (very closed to the farmer ) is the agricultural extension engineer, and the least important one is the irrigation improvement engineer (IIP). There are some months are not permitted for working with controlled drainage from April to October because the farmers have a lot of work during this period.
- The role of farmer during preparation and fabrication of controlled drainage gates is not important, while it is very important during the installation of gates.

6 RECOMMENDATIONS

From the study results, the recommendations are:

- The number of workshops and lectures about controlled drainage should be increased.
- Strengthen awareness and review to the law of release agriculture.
- Sufficient legation and time for teamwork of controlled drainage.
- The teamwork have to be well management and increasing the incentives for them.
- Forming water council or water boards on the secondary canals.

7 REFERENCES

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[2] Senior researchers, Director, Drainage Research Institute (DRI), National Water Research Center, Delta Barrages, P.O Box 1362/5, Cairo Egypt.
Sustainability of irrigated agriculture is under threat due to waterlogging and soil salinity. In India, about 36 percent of irrigated lands have been damaged due to waterlogging and salinity whereas world over it is about 24 percent. This disappointing picture caused due to faulty irrigation development has now resulted in the planners giving greater attention right at the planning stage to include irrigation improvement intervention as a preventive strategy. However, failure of institutional aspects of implementing the improvement strategies, lack of provision of drainage coupled with social aspects relating to ineffective communication between farmers and the agencies have all contributed to failure of our efforts to prevent the growing problem of waterlogging and salinity. Despite the widespread acknowledgement the preventive strategies like irrigation improvement intervention have only a limited scope for immediate benefits to the farmers whereas curative measures like subsurface drainage (SSD) are needed to tackle the problem of waterlogging and salinity. The results from small scale as well as large drainage area from Harayana, Gujarat and Rajasthan showed that it is possible to obtain several farm-level benefits through installation of subsurface drainage. These include (i) substantial increase in farm income, (ii) crop intensification and diversification towards high value crops, (iii) generation of employment opportunities, (iv) high internal rate of return justified investment in subsurface drainage and (v) Narrowing of income inequalities across farm producers. In spite of economic, social and environmental benefits, the sustainability of the subsurface drainage technology is always questioned due to absence of appropriate institutional arrangements. The specific reasons may be classified into two broad aspects viz., (a) technical reasons and (b) social reasons. Technical reasons are mainly due to (i) indivisible nature of the technology, (ii) unforeseen nature of weather, (iii) unpredictable uprise of watertable. Social reasons are (i) lukewarm collective action by the beneficiaries, (ii) conflicting objectives among beneficiaries, (iii) growing numbers of free riders and (iv) fickle efforts for institutional support. To minimize those problems, institutional arrangement in the form of collective action has taken place to facilitate the conduit. Lessons from such type of organization were highlighted. The analysis revealed that the technology without institutional arrangement might not yield desired results. A technology with high potential benefits may not make a difference and can be abandoned in the absence of required institutional arrangements.

Key words: Free riders, Indivisibility, Conflicting Objectives, Fickle efforts, and Sustainability

1 Introduction

Now a day, there is a fashion to talk about farmer’s “participation” in irrigation and drainage management. However, what is wrong with the traditional system? Most of the traditional system failed to deliver the goods effectively and efficiently. May be second defense is needed for efficient system management through participatory approach. Participatory approach may help to run the system more effectively and efficiently, reduce the O & M cost and reduces the conflict.

Keeping in mind, that participatory approach will help the users to maintain transparency, accountability and supporting incentives to the users by managing, operating and maintaining of drainage system. The main draw back in the system that it assumes free market mechanism will work implicitly i.e., well-capitalized and market-oriented farmers will take care the operation and maintenance. However, in reality it is difficult because the inherent drawback of unsatisfactory performance of irrigation and drainage system. It is mainly due to non-fulfillment of the target, incompatible rational action with collective rationality and finally quantity-constrained behaviour compelled the individual to adjust his or her own private decisions. Even if the market fully reflects the values for individual goods and services, the market would still allocate less than a socially optimum amount, as the farms are unable to fully appropriate the gains from it. Without internalization of environmental externality and holistic approach, only shifting the power will not improve the system. Recent study (Brewer, 1997) from five Indian states about irrigation management transfer concluded, “Irrigation Management Transfer (IMT) has not proceeded very far in India. Even in those states that have formulated a clear policy such as Maharashtra, there has been little progress of actual transfer to group of farmers. There is not yet clear-cut evidence to prove that IMT will achieve these goals. However, the indications are that IMT can achieve these goals completely or in part. To do so IMT policies and programs must be designed to provide clear benefits to farmers as well as to the state, and the policies and programs must actually be implemented as designed”. The focus of this paper is on farmer’s participation for the reclaimation/prevention the waterlogged saline soil by involving farmers in the building up institutional set-up. Hardly any evidence of evaluation yet on participatory drainage development. In India, Haryana state was selected for our study area where subsurface drainage (SSD) was installed in 1000 ha in Gohana and 500 ha in Kalayat area in Sonepat and Jind districts under Indo-Dutch Collaborative funds.

2 Extent of the losses

Several scholars have highlighted the extent of water logging and secondary salinisation due to mismanagement of irrigation. Worldwide the extent of damage
due to salinisation is ranging from 36 to 12 percents. In India, the damage of irrigated area due to salinisation is more as compared to top five world wide irrigated countries (Rydzewski, 1992). In the global level, the annual loss from 45.4 mha salt affected lands in irrigated area has been estimated as US $ 11.4 billion (Ghassem et al., 1995). In India, estimated loss varies in different command areas. Cropwise the pure effect of soil salinity in declining yield ranged from low level of about 3 to 1 percent for sugarcane and wheat in parts of western Yamuna canal and the Bhakra system. An high level of about 74 to 64 percent was noticed for paddy and all crops in the Sharda Sahayak Irrigation Projects (Joshi et al 1995). In the Chambal irrigated command area it was about 21,000 ha (Ajmera, 1997). In Western Yamuna Canal and Bhakra system the annual income losses due to water logging and salinity ranges from Rs. 2550 to 8300/ha (Datta, 1996). Recent estimate shows that the annual economic loss from the waterlogged saline area in Harayyan in the tune of Rs 1640 million (Datta and De jong, 2002). The variation of losses mainly depends on the degree of degradation of land. It is interesting to mention that farming community is still not worried about the dimension of the problem, because the severity of the problem is not uniform. Major losses due to waterlogging and soil salinity at farm level threats the sustainability of land resources, decrease the farm production by abandoning of crop production; decline in resource productivity and cut-back in resource use. At the regional level, the consequences are displacement of labour from agriculture, wider income disparities and affect the sustainability of secondary and tertiary sectors. At national level the negative effect of waterlogging and salinity are in the form of decline in agricultural production, affect the gross domestic product, bring down export of important crops and increase import bill (Joshi et al, 1995).

3 Technological Options
Various remedial measures such as better water management, consumptive use of canal and ground waters, improvement of surface drainage, on-farm development, forestry and shallow ground water management were suggested. Increasing the ground water discharge and controlling the water table can be effective by vertical (skimming well) or horizontal drainage. In the Tenth five-year plan (2002-2007) in India, it is proposed to improve the efficiency of end-use of water through adoption of water-efficient devices and promote consumptive use of surface and ground water. The entire attempt, which was mentioned, was present and initiative was taken for a long time, but all of a sudden calls for an organized solution by means of public intervention. Those solutions are not thought to require testing and modification for sustainability in long term. An attempt is always required in terms of diverting fund from one specific scheme to another alternative options. However as a preventive measure for short run, those solutions may be effective but for long term, subsurface drainage (SSD) has been proved to be the only option to reclaim the waterlogged saline lands, where salts are accumulated both in soil and ground water. In Egypt SSD has been provided in 1.75 million ha of its irrigated area and in Western U.S.A 25-30 percent irrigated area was covered under SSD. Pakistan also has embarked on a big programme of providing SSD in its irrigated area. Although the history of horizontal drainage in India started in 1925 at Chakanwali (now in Pakistan) and in 1928 at Baramani in Maharashtra, the concept of SSD is new. It is now been realised that SSD is most important component of irrigation system management to maximize the benefits from irrigation investment. The cost of installation of SSD mainly depends on soil type, depth and spacing of drains, location under drainage and the type of the drainage material used. At present (1994-95 prices) the cost of manually installed SSD varies from Rs.22, 310 to Rs. 18, 525 per ha in Haryana (Datta and De Jong, 1997).

4 Constraints of the technology
In the saline environment, due to fragility, low accessibility, internal resource heterogeneity and marginality of biophysical resources, the farm families' sustain themselves through adaptation to harsh biophysical environments without dependable and effective external links on extensive scale. The people have to live with limited, high risk, low productivity options. To evolve their sustenance strategies through adaptations of limited natural resources, they included seasonally and spatially diversified land base activities. Despite internal inequities and occupational specific differences in gains, everybody’s close dependence on local resources created an integrated collective stake in their activities. Despite yielding high dividends, collective action is required to realise the potential benefits from SSD due to indivisible nature of the technology. The study from several small scale as well as large scale (SSD) area in Haryana and Gujarat visualises several constraints in its adoption levels (Datta & Joshi, 1993). These are (i) indivisible nature of the SSD technology, (ii) no attraction to an individual farm household on investment to prevent or cure the degraded lands, (iii) increased economic differentiation and socio-political factionalism and (iv) internal heterogeneity and inequities. The technical and economic issues relating to curative or rehabilitation of land in the saline environment depends on its productivity. Evidence shows that people care more about more productive unit than unproductive unit. Reconciliation of interests of diverge groups is foremost for the success of SSD. Major improvements could readily be achieved by rehabilitating the existing degraded lands. However, the benefits would be rapidly vanishing when they are subsequently not well maintained.

In the technical side, farmers realized that SSD creates a problem by quickly removing water before plant had an opportunity to use any water from shallow ground water and made irrigation less efficient. Farmers opine that SSD systems should help to manage the watertable at a potential level by holding water in the profile for plant use so that it may make irrigation practices more efficient. Secondly, in Indian condition the pumping of drain water is required during wet (rainy) season. Since most of the farmers grow paddy in the wet season, they require stagnant water in their paddy field. But SSD system remove the stagnant water quickly and hence frequent irrigation is needed for the paddy field which is more cost intensive and hence make effective irrigation less efficient. Thirdly, field investigation tells us that the paddy grown farmers frequently pump the drain water from the 'manholes' as and when needed for irrigating their near by fields as well as distant fields also. This practice automatically created a conflict between head and tail ender of the drainage boundary. As pumping the 'manholes' water reduces the watertable of the nearby fields and creates additional demand of irrigation for protecting the paddy field. For instance, in the Gohana area of Haryana, majority of the farmers wanted to grow paddy whereas the small or marginal farm size groups prefer to produce jowar for their livestock. Rice growing farmers blocked the lateral for maintaining the moisture in the paddy field. On the other hand, the tail-ender of the lateral block of SSD deprived to maintain such moisture in their field. For such reason, a differential crop-mix in a drainage area lead to conflicts amongst the beneficiaries. Thus, major problem arises when not all villagers subscribe to similar use or same product from SSD. Differential resource endowments mainly created the incompatibility of rational individual actions with collective rationality. Any kind of formal or informal group approach to manage problem soils will have to
assure each individual participant that decisions of other individuals will not cause any negative eternality.

Participation of beneficiaries is widely accepted as the key for successful management of the drainage activity. It has been realised that mere planning and executing the drainage systems to manage saline and water logged soils by government agency may not yield the desired results unless there is a positive attitude and strong will of the beneficiaries to participate in the programme. If the conception, design and implementation of external intervention like SSD is not clear at the grass root levels, then such intervention will finally lead to disempowerment of the communities, disintegration the community stakes and marginalised the local knowledge system and institutional arrangement. From the study in Haryana and Gujarat, it was revealed that persuasion, education and demonstration of the beneficial role of farmers’ participation is crucial for the successful operation in managing such type of problem soils (Datta and Joshi, 1993). Problems, lessons and prospects of setting up the organisation structure for drainage society in Gohana area will be discussed in details in the subsequent section.

5 Options for drainage organization

The process of transformation through technology has a strong interface with the existing as well as emerging institutional structures. Institutions are formed in order to bring an aggregate change in the use of factors and facilitate the production process. For the management of SSD, focus on bottom-up approach, sensitization of the decision-makers to local people’s participation through participatory approach, identification and incorporation of rationale of traditional practices into new technological and institutional measures planned should be encouraged. Three interrelated concepts, viz. common goods, the SSD technology and empowerment of people's organization are the focal points from the inception of the organization. The centrality of common good, therefore, is expected to trigger off new processes that are self-balancing, both socially as well as environmentally. State should work as a promotional role to support the SSD developments. Each SSD blocks should compete for better service provision and production. It should neither the state promoted co-operatives nor the state-owned collectives. It should be self-governance where values like freedom, autonomy and dignity matter a lot along with material well being. The question may be raised that who will will organise farmers to come together to manage their problem soils. The task may be taken-up by the government as well as non-government agencies. A preliminary review of the institutional options for creation of drainage organisation capable of implementing large scale SSD in Haryana reveals at least five distinct possibilities.

• The recognition/ restructuring of the Soil Conservation Office and incorporating the operational pilot drainage project nucleus organization to undertake large scale SSD.
• Incorporating operational drainage project into an existing Haryana Land Reclamation Development Corporation (HLRDC) or with Haryana State Minor Irrigation Tubewell Corporation (HSMITC).
• Creation totally new non-governmental organization exclusively for the implementation and monitoring the SSD.
• Creation of new department of agriculture, which will solely, charged with reclamation of wastelands where operational drainage project will work as a nodal organisational unit.
• Creation of drainage co-operative like Pani panchayats in Maharashtra may be the another form.

In brief, three general directions for long-term establishment of a drainage organization appear possible, placing it in a governmental context or a non-governmental organization or a corporatised public enterprise environment. To recognise government agency seems pragmatic because of the pressures to minimize expansion of the public sector generally. But scaling up the existing drainage staff from department of agriculture, to a level sufficient to meet the challenges of large scale SSD could be accepted since this would be a budget neutral solution, consistent with the policy of restraining growth in the public sector.

Involving of some Non-Government Organisation (NGO) was recommended in order to mobilise and participation of farmers with a view to cover larger drainage area. The major constraints of NGO’s is non-existing of such system in Haryana, out-siders NGO has its own problem of communication, lack of accountability on the part of NGO. Lack of knowledge of SSD, understanding the nature of the problem, and getting access to different interests groups for developing strategies to evolve solutions.

Other alternative is in the form of drainage co-operative like in Gujarat, which was registered as ‘Saline land agricultural development Co-operative’ in 1989-90 under the Gujarat Co-operative registration Act of 1860. The main activity of this co-operative was to share O&M cost. Widen the activities of drainage co-operative is essential for its sustainability. As the need for soil improvement will not be uniform in the entire drainage area, it varies across farms. The farmers located in disadvantageous position may not be enthusiastic to participate in such co-operatives in the long run (Datta and Joshi, 1993). Place the Haryana Operational Pilot Project (HOPP) in the semi-governmental corporation. This could be accomplished by either creating a new organization with exclusive mandate for large-scale mechanized SSD works or to integrate the same into existing corporate entity as HLRDC or HSMITC. A move in this direction would potentially have advantages over the government locus. However, its success mainly depends on commitment and motivation of the staff.

6 Approach to involve the farmers

How farmers’ involvement can contribute in SSD and thereby to improve their farm income in a sustainable way is the major issue, which rise in this section.
Collective action was taken care (since collectors link and serve several farm units) to describe the process and consequences of individual decisions to voluntary coordinated behaviour. In reality, individuals associate themselves for a collective action with an objective to face the uncertainties and to search for solutions wherever possible. The individual not only gets an identity but also security in the process of collective action. Since individuals face a number of problems, unsolvable on their own they tend to assessable together to find solutions and this becomes an immediate necessity rather than a choice. The major issues that were addressed for setting up drainage society in the drainage areas of Haryana are:

1. Motivation and organization of farmers and preparing them for the selected activities;
2. Identification of activities and tasks where there seems to be scope for farmers’ involvement and the nature of this involvement;
3. Assessment of the actual effects and benefits of the increased involvement and lessons learned for future similar projects.

It must be realized that the boosting of farmers involvement to irrigation is already a problem in many instances. The problem may be even bigger for drainage, because usually farmers do not attach much importance to drainage, let alone to maintenance of drainage systems. Ample attention must be paid to the factors involved in stimulating or jeopardizing the success of such an undertaking. Farmers’ involvement can refer to different activities and levels, namely:

- Co-operation during installation of drainage,
- Maintenance of link and filed drains,
- Disposal the drain water as and when it is required and
- Maintenance of the structures at various levels in the system.

In the Gohana HOPP project area, it is assumed that farmers will not ask any compensation during the installation stage of SSD and they will allow as and when machine will move for installing the drainage. Cleaning and maintenance of collector drain will require at long interval say at 10-15 years interval and needs technical guideline. The main responsibility should be with the drainage and irrigation department and farmers’ involvement on it to arrange labour as and when it requires. Pump the drain water as and when it requires is the main activity for which farmers have to organize and collect the fees for running the pump. Generally, it is needed during monsoon (wet) season. Participation of all drainage stack holders may reuse the drain water as and when they required it.

Since participation, power and well being are the key factors for the success of any technological intervention, from the beginning bottom-up and countervailing actions by the farmers to influence decision making through direct and informal means has given priority in Haryana Operational Pilot Project area. Participatory approach besides co-lateral relations and linkages at all level has been emphasised. The most distinguishing and striking part of SSD in Haryana is its vibrant and constant interaction with farmers, or rather all stakeholders. A full scale farmers’ participation section (FPS) was created just to ensure that farmers and other stakeholders developed a basic awareness about SSD, what are waterlogging and salinity, what are their pernicious influences and how to design the works. Aim of the FPS was to bring the potential of farmers in a group who knows each other and band together to manage community resources.

In FPS, there are community Organizers (CO’s). Their main task is to help the farmers to analyze their resources, and organize themselves into drainage society. A very well defined system of mass awareness coupled with gender focus was developed through FPS section. Farmers have been sensitized and enlightened about SSD. This section is always in touch with the village Pradhan (village head man). FPS section also developed good rapport with the progressive farmers, key and effective persons in the villages in order to settle any disputes arising during the process of installation of drainage who has good rapport with the villagers. Parallel Women’s informal organization emphasized.

Farmer’s participation is based upon bottom up, de-centralized, democratic, strategy in which farmers have the sense of owners of the drainage system. Flexible and learning approach to inculcate their maximum participation and interaction at every stage, consensus and co-operation of farmers is also essential to keep the construction process smoothly. Their co-operation also contributes to reduce the conflict during construction. To keep in such spirit it was decided consciously that the component of crop compensation need not be persuaded in view of the large-scale implementation of similar projects in the state. This policy decision helps to monitor the farmer’s opinions about the involvement in the scheme. In the FPS section, the important role of the Community Organiser and Women mutilators in conflict resolution, when drainage block farmers are resistant during field construction activities. It also works as a second-line defense for Farmers’ Drainage Society (FDS). In the course of installation of drainage, it was observed that neither a single farmer raised the issue of its compensation.

7 Approach towards Organization of farmers

FPS section acts as an interface between farmers and the project. In the beginning, FPS section start the sessions to familiarize the local people in the area with the project objectives and activities. FPS section also selects those local people who are interested and sensitive to participate in the process. To motivate and for mobilization a written agreement is with all farmers on a drainage block basis. Farmers realize that major beneficiaries would be whose lands are covered under SSD. Drainage Block of about 50 ha was made in order to maintain optimum group of persons. Since larger groups, higher the transaction costs of bringing them together, and hence the higher the tendency to free rider. In order to avoid it, the number of farm families kept in a group is quite small.
The number of farm families in FDS blocks ranges between 30-35. Detail of it given in Table 1. The societies are registered under Societies Registration Act 1860 under Section 21. Profile of the drainage society of Gohana is given in Table 2. The main objective of the FDS is to take care of operation and maintenance of the SSD system. There are about 22 FDS blocks planned in 1000 hectare (of saline waterlogged area) in Gohana. The preliminary task of each block of the FDS is to pump the initial drainage saline water (effluent) from the sump. Accordingly, they have created their own by laws so that the group’s activities address the felt needs of the group members. The group has enough solidarity in compelling other people and organization to cooperate with them in addressing the common needs of the group members. FDS tends to be strongest when (i) it collects members’ monthly or yearly fees in order to strengthen the financial position of the society (ii) the members of the society should give time as and when it is needed for the success of the group (FDS) and (iii) it provides credit facilities to their members through a carefully planned, mutually accountable credit programme.

Already most of the societies are registered and made functional. Most of the societies operated smoothly for initial pumping. Several review committees of the project observed that participatory aspect is encouraging and turnover of the operation and maintenance responsibilities to farmer’s societies. In fact, the efforts are mainly to break down the old culture of dependence on public sector subsidies. FDS require common fund to prolong the O & M works on a sustainable basis. The effectiveness of first drainage Block is precedent for the subsequent efforts made in this direction. It is a learning process and must be stepped up systematically. An apex body of all the FDS was established to co-ordinate and pulls the experiences at the project level. The vitality of the FDS’s will mainly depend upon considerable follow up required by the FPS with each FDS. Since the actual status of the turnover in different drainage block was unclear in the beginning, it is imperative that a clearly defined system has to be formulated before handing over to FDS. For instance in FDS block 12, even though installation of SSD was over for a long time, still the pump set for the pump is in unfunctional and no clear cut guidelines for disposing the drainage effluent. Similarly, in FDS block 13, the surface drainage through which effluent passes has not enough capacity. Overflowing of the saline effluent drainage water spoiled the paddy crops during 1998 to the nearby farmers’ field. In FDS block 14, due to negligence of supervising role and management, pumping activity was neglected. Even then, record shows that the expenses for pumping are going on. But there are lot of malpractices going on since the beginning, even though the village Pradhan who is also the president of FDS block 14 appoints pump operator. Like that, there were lot of seepage of canal water directly to the sump and reducing the confidence of SSD technology to the farmers. In due course, all such types of problems were taken care properly. Success of FDS primarily depends on the strong determination and commitment of the personnel of the project authority to demonstrate exceptionally good performance and to solve farmers’ problems regarding waterlogging and soil salinity in their field and that was the lesson we derived after taking care of all those problems.

Alternative to Farmers’ Drainage Societies, it was recommended to involve some of the Non- Government Organisation (NGO) in order to mobilise and participation of farmers with a view to cover larger drainage area. In the process, NGOs may not only focus on selling their own perspectives and approaches but tend to build their own space and indispensability that will help the state, which neither understands the rural communities well enough nor can deliver promised goods and services.

8 Lessons learned

Since drainage technology is indivisible in nature, to an individual farmer adopting the technology in isolation is financially non-viable. It requires certain institutional arrangement. Whatever may be the form and its nature, drainage by its very nature requires huge investment. In addition to that, additional cost for its O & M is needed. Unless such costs are recovered from beneficiaries, the state has to incur large subsidies. In the study area, farmers are willing to pay for the drainage service, at least for the operation and maintenance costs. This is the more positive, because they are only becoming slowly aware of the fact that they have a serious problem, which they cannot tackle individually.

Secondly, the issue is whether drainage will be treated as public or private goods. It should be mentioned here that under Indian conditions, it should be public goods and should be linked with irrigation. It is clear that the farmer cannot bear the full burden of the cost of drainage. However, since the deterioration of valuable agricultural land has to be controlled for the sake of the farmer and society as a whole, land drainage is a joint responsibility of the Government and the farmers. In India, irrigated lands in the arid and semi-arid area should be drained as soon as the need arises. Finally, in conclusion it may be mentioned that though the process of salinisation is very slow, its intervention in terms of drainage investment must be needed from the beginning instead of it makes no sense to let the farmers suffer great losses over long periods before an unsustainable situation is corrected.

DRAINAGE investment in this case will be treated as conservation of natural resources. In that case, subsurface drainage projects would become economically feasible before the land is seriously affected and farmer suffers great income losses. Because as conservationists all over the world advocate, the required return on the invested capital for conservation and environmental protection should be lower than for other investments, say 6 per cent.

<table>
<thead>
<tr>
<th>Block No</th>
<th>Area in hectare</th>
<th>Male</th>
<th>Female</th>
<th>Total</th>
<th>Medium &lt;0-1ha</th>
<th>Small 1-2ha</th>
<th>Large 2-3ha</th>
<th>Medium &gt;3ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>G - 1</td>
<td>35.45</td>
<td>22</td>
<td>6</td>
<td>28</td>
<td>15</td>
<td>9</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>G - 2</td>
<td>51.47</td>
<td>25</td>
<td>1</td>
<td>26</td>
<td>12</td>
<td>5</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>G - 3</td>
<td>66.31</td>
<td>35</td>
<td>3</td>
<td>38</td>
<td>16</td>
<td>11</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>G - 4</td>
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<td>1</td>
<td>39</td>
<td>20</td>
<td>10</td>
<td>6</td>
<td>3</td>
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<tr>
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<td>42.83</td>
<td>36</td>
<td>1</td>
<td>37</td>
<td>16</td>
<td>12</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 1 Detail profile of Farm families in the Drainage Society HOPP Gohana, Haryana, India

http://library.wur.nl/ebooks/drainage/drainage_cd/3.3%20datta.html (5 of 7)26-4-2010 12:12:38
Table 2  Profile of the drainage Society in Gohana area of Haryana, India

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of the Society</td>
<td>Farmers Drainage Society</td>
</tr>
<tr>
<td>Registration Act</td>
<td>State co-op Registration Act, 1860</td>
</tr>
<tr>
<td>Area of Operation</td>
<td>Saline and waterlogged area belonging to the farmers of the Farmers Drainage Society Block</td>
</tr>
<tr>
<td>Objective</td>
<td>i) To regulate the pumping of the saline water and discharge the effluent from the outlet to the main drain; ii) To operate and maintain SSD system iii) To raise resources through collection from the members for meeting the O&amp; M cost iv) To arrange loans, subsidies, grants etc. for the society towards reinvestment in the development of SSD, agricultural productivity and reclamation of saline soils v) To take any official and legal action deemed necessary to achieve the above mentioned objectives</td>
</tr>
<tr>
<td>Aims</td>
<td>1. Increasing agricultural production and reclamation of saline land, 2. Adoption of improved methods of water and land management, 3. Monitoring the ground water level, quality of land and water and crop yields, 4. Reuse of the effluent for irrigation, 5. Involving women of the member households in the management and functions of the society,</td>
</tr>
<tr>
<td>Membership</td>
<td>Farmers both men and women who own or have land under their control under the jurisdiction of the Society and their spouse, above 18 years of age and sound of mind are eligible for membership. Members have to pay non refundable fee of Rs. 21/-, Farmers and their spouses who lose possession of land automatically ceases to be members</td>
</tr>
<tr>
<td>General Body</td>
<td>All members together constitute the General Body and any decision of the General Body is binding and final. The General Body has the power to prepare and amend the bylaws,</td>
</tr>
</tbody>
</table>

An annual meeting of the Society will be conducted during September every year. Special meetings can be convened whenever need arises. At least seven days notice will be given for holding the meeting. To pass proposal for amendment of the bylaws, vote of at least sixty percent of all members present is required.
### Executive Committee

The general Body will elect at least seven members to the Executive Committee for each financial year, The ADO from APO office will be ex-official member of the society who will be responsible to check the registers and other records maintained by the society. The ADO (Soil Conservation) of the respective area shall be the ex-officio member of the society.

### Funds

Funds can be raised by the Society for its functioning in several ways, such as: Membership fee, annual fee, or land fee; Proportion of crops; Fines; Donations from well wishers; Loans from banking institutions, etc. Funds from HOPP, Govt. and other agencies

The Functioning of the society will be on a no-loss and no-profit basis.

### Relation to HOPP and Government

HOPP-Dept of Agriculture Haryana officials shall have the right to verify the records and accounts of the society at any point. On the dissolution of the society, all its assets and liabilities shall vest with HOPP-Dept of Agriculture Haryana. The society is registered under the societies registration Act, 1860 and all provisions of the said act are applicable to the society.

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INSTITUTIONAL REFORMS IN IRRIGATION SECTOR OF PAKISTAN: AN APPROACH TOWARDS INTEGRATED WATER RESOURCE MANAGEMENT

Bakhshal Lashari, Yameen Memon and Nazeer Ahmed Memon

ABSTRACT

The introduction of irrigation network in Pakistan resulted in large area under cultivation on one hand and waterlogging and salinity problem emerged on the other hand. Several interventions (Physical and Institutional) emerged to enhance agriculture production. But the targeted achievements could not be obtained until now. All interventions emerged without considering the participation of end users.

Since 1995 the Government of Pakistan has been making efforts to restructuring the century old irrigation system by involving beneficiaries (water users) at various units of the irrigation system management. The main purposes of reforms are: to improve operation and maintenance (O&M) of irrigation system, to make balance in expenditure and revenue, to improve crop production through efficient use of water, maintain affordable drainage system and develop an integrated water resource management (IWRM) approach.

In these reforms, the Irrigation Department has been transferred to an autonomous body – Provincial Irrigation and Drainage Authority (PIDA). Under PIDA, Canal Area Water Board at each canal command area and Farmer Organizations at each secondary canal (Distributary/Minor) command area being formed. These all units are now responsible for irrigation, drainage and environment in their jurisdiction. However, some of the drainage and environment aspects would be jointly managed if the boundaries crossing to their jurisdiction.

Because of culture, political influence, social and economic set up of Sindh Province of Pakistan; it was argued that the formation of Farmer Organizations would be hard and challenging part of institutional reforms in irrigation sector for any organization. But the International Water Management Institute (IWMI) successfully completed the experience of formation of Farmer Organizations on thirteen distributaries at the time of project. This experience has further resulted in continuous formation of FOs. Until now more than 190 FOs have been formed on Nara Canal Command Area and some other canal area water boards by various organizations.

As part of the program, the capacity building activities for members of the organizations being carried out through training and awareness which has subsequently proved that the FOs are holding regular meetings and discussing the issues relating to irrigation and drainage, organization set up, and resource mobilization. The participation of farmer members and management committee members in all events organized at various time and purposes has proved successful as 70-75 percent attendance was observed.

Joint efforts of maintenance by FOs have significantly improved the tail water conditions and reduced the cost of maintenance. In a one-week period, water users contributed over 7,800 man-days of labor and 582 hours of tractor operation in eight secondary canals, and removed over 43,000 cubic meters of sediment. The imputed cost of these contributions exceeded over Rs.900,000 ($15,000) or almost Rs.30 per hectare ($0.50).

The hydraulic benefits were substantial. Comparing water deliveries into the head and tail reach of eleven canals before maintenance, head end areas were receiving roughly 68% more water than tail enders. After maintenance the head end areas only able to receive 14% more water, and in six of the eleven canals where water measurements were taken, tail end areas actually received more water than head end areas.
Further, when the farmers are grouped and are aware then they are eager to learn more from interactions and coordination. Farmers are capable in improving water distribution among the users by proper maintenance of the channel, and utilizing the drainage facilities for the conjunctive use and stabilizing water table depth at required level.

Paper concludes that the participation of beneficiaries (Water users) is one of the best tools to ensure as well as gauge the reliability in water delivery, equity in water distribution, efficient use of resources for improvement of the irrigated-agriculture and effective working of drainage units.

Based on the results it is also concluded that the institutional reforms as envisaged by ensuring the participation of farmers in irrigation sector is the only option towards an integrated water resource management where irrigation and drainage function simultaneously under the umbrella of one institution and active involvement of beneficiaries.

1 INTRODUCTION

Pakistan possesses one of the largest irrigation networks in the world, which supplies water to 16 million hectares providing income for about 4 million private farmers. The introduction of gravity flow irrigation system in the Indus Basin, resulted in large area under cultivation on one hand and created waterlogging and salinity problem on the other hand. When water logging and salinity seriously affected agricultural productivity then the government responded with introducing several interventions (Physical and Institutional) to enhance agriculture production. But the targeted achievements could not be obtained until now. All interventions emerged without considering the participation of end users.

Issue of distribution and access are also critical in understanding the role of water in rural livelihoods. In many cases, formal legal frameworks usually guarantee equitable distribution of water; however, in practice they are not enforced, and the powerful monopolize access. Further, some claims to water are based on informal or customary rights that may be more difficult to defend, especially in the face of social changes such as significant in/out- migration or increased market integration. Ensuring access to water quality is similarly problematic.

The developing countries have the challenges as increasing population; increasing demand for food and other crops; poverty and famine; human resources constraints: health, education, and training; women in development; natural climate constraints: land and water; market competition from industrial and other countries and global warming. These all are possible irrigated agriculture is given priority and integrated approaches are developed. [John Hennessy 1990].

The foremost factor is the expected population growth in developing countries. Under the most optimistic scenario, which assumes successful population programs, world population will grow from 6.2 billion in the year 2000 to at least 8 billion by the year 2025. This growth will increase the demand for food supplies and thus the demand for irrigated agriculture production necessary to produce sufficient food worldwide. This demand will in turn create serious water management challenges in countries where additional supplies of arable land and water at reasonable costs are almost exhausted. These problems are especially serious in countries where waterlogging and salinity are causing a reduction in the irrigated area [Guy Le Moigne 1990].

To improve the sustainability of irrigated agriculture is the urgent need to review current practices and standards and formulate new criteria for various aspects of drainage system design, and incorporating environmental safeguards. Further, the waterlogging and salinity control must be linked to sound irrigation water management, including water saving techniques and the proper maintenance of irrigation and drainage systems [Tom Brabben, etal 1991].

Literature and world experiences on irrigated agriculture have clearly indicated that without integrated approach of water resources that includes irrigation, drainage and environment, the agriculture productivity and sustainability of different interventions in water resources will not be possible in the developing countries. The linkages and coordination among all stakeholders of irrigated agriculture is the most important intuitional intervention. Pakistan has many institutes who are working on irrigated agriculture, but the coordination among all is very much lacking.
One way to ensure that the poor and marginalized groups are considered is to include them in the decision-making process about watershed management and research. It is increasingly recognized that the watershed management and research conducted in an open, participatory way can be more effective than top-down approaches (Kerr et al. 1996; Hinchcliffe et al. 1999; Johnson et al. 2001). User participation is critical in identifying relevant research problems and priorities. Many issues that are important to the poor, such as the impact on water availability of burning fields for land preparation (Ravnborg and Ashbly 1996), or appropriate methods for maintaining secondary water resources in watersheds, have not received significant attention from research in the past.

Water is life. It is a precious resource. Only 2.5% of the world's water is not salty, and of that two-thirds is locked up in the ice caps and glaciers. Of the remaining amount, subject to the continuous hydrological cycle, some two-thirds is "lost" to evapotranspiration. Of the remaining amount of potentially useable water, some 20% is in areas too remote for human access, and of the remaining 8%, about three-quarters comes at the wrong time and place in monsoons and floods and is only partially captured for use by people. We actually get to use less than 0.08% of the total water on the planet (Serageldin, 1998).

This water is used predominantly in agriculture to grow the food and fiber on which human society depends. In Pakistan, more than 70 percent of the rural populace depends on agriculture and mostly they irrigate their lands through one of the world's largest and century old contiguous irrigation systems. With the passage of time, this system has deteriorated and now faces several problems. These are: less recovery of water charges, over expenditure on operation and maintenance, poor operation and maintenance, inequitable distribution of water and unreliable supply and rent seeking. To overcome these problems institutional reforms were identified and suggested for implementation in the system that will support water conservation, food security, poverty alleviation and sustainable agriculture.

It is widely assumed that irrigation management transfer (IMT) to the farmers through institutional reforms will reduce the cost of irrigation to governments; since, the farmers are compelled more than government to improve the efficiency, productivity, and sustainability of irrigation (Vermilion, 1991). Several countries have experienced the positive results of the IMT, such as USA, Turkey, Mexico, Australia, Sri Lanka and Nepal. Other countries are in the process to adopt their model, like Pakistan and India. For example the IMT from the US Bureau of Reclamation to irrigation districts in the Columbia Basin Project (Svendsen and Nott, 1997), showed the gains in the form of increased irrigation efficiency, gross returns to irrigation agriculture, and reduced operation and maintenance cost to the government and farmers. A farmer-controlled community irrigation system was found to have led to better design of the irrigation system and to have increased the problem-solving capabilities of local farmers (Alfonso, 1981).

2 BACKGROUND

Since the mid 1990s, Pakistan has been seeking to reform its irrigation sector. The primary motivation behind this effort is to create financially sustainable irrigation agencies and improved operation and maintenance of the infrastructure. A history of inadequate management, combined with an increasing demand for water by irrigators and other water users, has resulted in low, inequitable, and unreliable water supplies. This water scarcity situation has given birth to a hidden economy, where users illegally tapped irrigation systems to generate a black market in water (IWMI 2002).

The entry into force of the 1997 Provincial Irrigation and Drainage Authority Acts, paved the way for the creation of three new institutions. Irrigation Departments will become semiautonomous Provincial Irrigation and Drainage Authorities (PIDA). Area Water Boards will be formed, through which farmers and personnel of PIDAs will jointly manage irrigation and drainage networks at the canal command level. Management responsibilities at the distribution level will be transferred to Farmer Organizations (FOs).

Open and frequent dialogue is the central strategy of these reforms. Through these new structures, agency personnel and farmers will cooperate in the joint-management of irrigation resources.

But there is a major practical obstacle to this well-laid plan. Currently, farmers are neither organized to become effective partners in managing the irrigation and drainage infrastructure nor sufficiently skilled to take responsibility for operation and maintenance. To build these skills, international donor agencies and the Government of Pakistan launched social mobilization pilot projects, to
organize farmers into water users organizations, provide them with training in essential skills, and involve them in operation and maintenance activities at distributaries level.

Beginning in 1995, IWMI Pakistan ran three pilot projects at Bareji and Heran Distributaries and Dhoro Naro Minor in the Sindh Province of Pakistan, later in 1999 other ten distributaries were included in the pilot project. The objective of this work was to test the viability of FOs and their capacity to participate in the management of their irrigation and drainage systems at the local level. This study specifically focuses on the pilot projects in particular and institutional progress in general in the Sindh Province of Pakistan. The pilot area is shown in Figure 1 and salient features are shown in Table 1.

### Table 1 Salient features of the pilot distributaries.

<table>
<thead>
<tr>
<th>Distributary/Minor</th>
<th>Command Area (ha)</th>
<th>Design Discharge (m³/sec)</th>
<th>Canal Length (m)</th>
<th>Number of Outlets</th>
<th>Canal Length/ha of command area (m/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heran</td>
<td>4994</td>
<td>1.77</td>
<td>9754</td>
<td>31</td>
<td>1.95</td>
</tr>
<tr>
<td>Rawtiani</td>
<td>3658</td>
<td>0.83</td>
<td>8382</td>
<td>19</td>
<td>2.29</td>
</tr>
<tr>
<td>Bareji</td>
<td>5797</td>
<td>1.18</td>
<td>11979</td>
<td>24</td>
<td>2.07</td>
</tr>
<tr>
<td>Mirpur</td>
<td>6566</td>
<td>1.74</td>
<td>14630</td>
<td>53</td>
<td>2.23</td>
</tr>
<tr>
<td>Potho</td>
<td>3264</td>
<td>0.82</td>
<td>10058</td>
<td>19</td>
<td>3.08</td>
</tr>
<tr>
<td>Dhoro Naro</td>
<td>5418</td>
<td>1.46</td>
<td>9836</td>
<td>25</td>
<td>1.82</td>
</tr>
<tr>
<td>Mohd Ali</td>
<td>1552</td>
<td>0.31</td>
<td>5182</td>
<td>10</td>
<td>3.34</td>
</tr>
</tbody>
</table>

3 IMPACTS OF PARTICIPATORY MANAGEMENT OF IRRIGATION AND DRAINAGE SYSTEM

3.1 Creating Farmer Organisations

The formation of FOs on 14 distributaries on Nara Canal Command Area was publicly recognized by oath-taking and handing over ceremony of thousands of water users from hundreds of villages, farmer members, leaders representing all watercourse associations and farmer organizations and politicians in the command area of all distributaries and civil society representatives. The Honorable Governor of Sindh Province chaired the Ceremony in April 2001.
3.2 Capacity Building

The team of researchers assessed the training need through intensive interaction and participatory rapid appraisal. The need for capacity building program was assessed in the field of organizational, financial and technical aspects in order to undertake the activities of operation and maintenance of distributaries, assessment and collection of abiyana (water charges), conflict resolution and leadership to run the organization. The training programs arranged were: Social Organizer Volunteers (SOVs) workshop, Awareness on institutional reforms, Discharge measurement and walk through survey (O&M), Organizational and financial
management, FO rules, regulations, bylaws, action plan and Irrigation and Drainage Management Transfer agreement, Crop assessment and abiyana (Water charges) collection, and Workshops on agricultural production practices. In all 2,206 water users were trained.

The characteristics of the participants are: Office bearers (Chairman, Secretary and Treasurer) of WCAs and FOs; 90% literate; 23% post graduate having masters degree in various fields; 29% primary education. Participants: 35% from head reach, 31% from middle reach and 34% from tail reach of the distributaries. Mean age 42 years; majority of farmers well experienced in farming; on average participants had at least 20 years of farming experience; most of the participants were landowners and owner cultivators; smaller number of managers, lessees and tenants participated and most of the members participated in more than one training programs.

### 3.3 Imputed and Actual Costs on maintenance

The imputed cost of this activity is calculated on the typical labor and machinery hire rates prevailing at the time of the survey. Based on an average of Rs. 100 per day per person and between Rs.150-175 per tractor-hour, the grand total is just over Rs. 800,000. On an average basis the cost is almost Rs.25 per ha ($0.45) which represents about 40% of the typical irrigation water fee or abiyana that farmers are expected to pay. This is a substantial saving for the government who would otherwise have had to pay those labor rates to accomplish the amount of work done. If the inputs were typical for all of Sindh then the total cost of maintenance for the Province would something on the order of Rs.125 m or $2.25 m. The details are given in table 2.

<table>
<thead>
<tr>
<th>Distributary</th>
<th>Man-days</th>
<th>Tractor-hours</th>
<th>Imputed Cost (Rs)</th>
<th>Earthwork (m³)</th>
<th>Work (man-days per ha)</th>
<th>Cost (Rs/ha)</th>
<th>Cost (Rs/ m³)</th>
<th>Volume (m³ per Man-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heran</td>
<td>1157</td>
<td>58</td>
<td>124100</td>
<td>7411</td>
<td>0.23</td>
<td>24.85</td>
<td>16.74</td>
<td>6.41</td>
</tr>
<tr>
<td>Rawtiani</td>
<td>586</td>
<td>35</td>
<td>64025</td>
<td>1351</td>
<td>0.16</td>
<td>17.50</td>
<td>47.40</td>
<td>2.31</td>
</tr>
<tr>
<td>Bareji</td>
<td>1020</td>
<td>14</td>
<td>105700</td>
<td>5601</td>
<td>0.18</td>
<td>18.23</td>
<td>18.87</td>
<td>5.49</td>
</tr>
<tr>
<td>Mirpur</td>
<td>1311</td>
<td>120</td>
<td>172650</td>
<td>9993</td>
<td>0.20</td>
<td>26.29</td>
<td>17.28</td>
<td>7.62</td>
</tr>
<tr>
<td>Potho</td>
<td>979</td>
<td>17</td>
<td>113611</td>
<td>8138</td>
<td>0.30</td>
<td>34.80</td>
<td>13.96</td>
<td>8.31</td>
</tr>
<tr>
<td>MAW</td>
<td>427</td>
<td>30</td>
<td>44625</td>
<td>3806</td>
<td>0.28</td>
<td>28.76</td>
<td>11.72</td>
<td>8.91</td>
</tr>
<tr>
<td>Khadwari</td>
<td>301</td>
<td>16</td>
<td>49275</td>
<td>n/a</td>
<td>0.24</td>
<td>39.59</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Dhor Naro</td>
<td>2055</td>
<td>292</td>
<td>249375</td>
<td>7376</td>
<td>0.38</td>
<td>46.03</td>
<td>33.81</td>
<td>3.59</td>
</tr>
<tr>
<td>Total</td>
<td>7836</td>
<td>582</td>
<td>923361</td>
<td>43678</td>
<td>0.25</td>
<td>29.51</td>
<td>22.83</td>
<td>6.09</td>
</tr>
</tbody>
</table>

### 3.4 Hydraulic Impact of Desilting

Before desilting the average DPR at the head of the eleven canals was 1.29 (i.e. 29% above design), ranging from 213% of design at Bareji which had been remodeled in 1995 and could cope with much larger than designed discharge to 58% of design at Bagi. However, the DPR at the head of the tail sections averaged only 97% of design indicating that in most canals all of the extra water was being captured by the head and middle sections of the canal (Table 4).

Looking at the ratio between head and tail DPR values the degree of inequity can be clearly seen. In only two canals (Potho and Bagi) were tail end DPR values higher than the head: in all other canals head end values were higher than tail end and on averaged were 68% higher. At Heran and Belharo head end values were over three times as high as tail end values, showing gross inequity between head and tail.
After desilting the picture changed considerably. Average discharges into canals were only 20% above design: overall in the area discharges are low after desilting because it is the coolest season of the year and wheat in some areas is beginning to mature. However, tail end DPR values were, on average, also at 120% of design indicating almost uniform distribution. Data demonstrate that the inequity between head and tail was substantially reduced. However, many tail end areas got more water than the head, but in reality this will slowly be reversed as canals silt up again during the year.

### Table 3  Hydraulic condition of the distributaries before and after maintenance

<table>
<thead>
<tr>
<th>Distributary</th>
<th>Before Desilting</th>
<th>After Desilting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Head:Tail</td>
<td>Head:Tail</td>
</tr>
<tr>
<td>Heran</td>
<td>1.36</td>
<td>0.38</td>
</tr>
<tr>
<td>Rawtiani</td>
<td>1.71</td>
<td>1.71</td>
</tr>
<tr>
<td>Tail</td>
<td>1.49</td>
<td>1.20</td>
</tr>
<tr>
<td>Mirpur</td>
<td>1.02</td>
<td>0.39</td>
</tr>
<tr>
<td>Bareji</td>
<td>2.13</td>
<td>1.63</td>
</tr>
<tr>
<td>Sanrhao</td>
<td>1.29</td>
<td>1.11</td>
</tr>
<tr>
<td>Belharo</td>
<td>1.11</td>
<td>0.36</td>
</tr>
<tr>
<td>Digri</td>
<td>1.17</td>
<td>1.12</td>
</tr>
<tr>
<td>Potho</td>
<td>1.02</td>
<td>1.28</td>
</tr>
<tr>
<td>Khatian</td>
<td>1.31</td>
<td>0.65</td>
</tr>
<tr>
<td>Bagi</td>
<td>0.58</td>
<td>0.80</td>
</tr>
<tr>
<td>Average</td>
<td>1.29</td>
<td>0.97</td>
</tr>
</tbody>
</table>

### 3.5  Reform progress in Sindh

Experience of pilot project has lead to the formation of new canal area water boards and farmer organizations in the province of Sindh, Pakistan. The newly established AWB and FOs are given in the table 4 and 5 respectively. (Figure 2. shows the canal commands in Sindh).

### Table 4  Newly established canal area water boards under institutional reforms in Sindh.

<table>
<thead>
<tr>
<th>Area water Board</th>
<th>Barrage</th>
<th>CCA (Acres)</th>
<th>Designed Discharge (cusec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nara Nara Canal</td>
<td>Sukkur</td>
<td>2493,029</td>
<td>13,600</td>
</tr>
<tr>
<td>Year of Establishment: 1999</td>
<td>Total FOs to be formed: 165</td>
<td>Total FOs so far registered: 142</td>
<td></td>
</tr>
<tr>
<td>Left Bank Canal Circle</td>
<td>Kotri</td>
<td>1,533,935</td>
<td>18,956</td>
</tr>
<tr>
<td>Year of Establishment: 2002</td>
<td>Total FOs to be formed: 123</td>
<td>Total FOs so far registered: 05</td>
<td></td>
</tr>
<tr>
<td>Ghotki Feeder Canal</td>
<td>Guddu</td>
<td>855,231</td>
<td>8,490</td>
</tr>
<tr>
<td>Year of Establishment: 2002</td>
<td>Total FOs to be formed: 64</td>
<td>Total FOs so far registered: 06</td>
<td></td>
</tr>
</tbody>
</table>
Table 5 Newly established farmer organizations under institutional reforms in Sindh.

<table>
<thead>
<tr>
<th>Area water Boards/Canal</th>
<th>Total FOs to be Registered (Tentative)</th>
<th>Registered FOs</th>
<th>Management Transferred to FOs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guddu Barrage</td>
<td>85</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Begari Sindh Feeder Canal AWB</td>
<td>45</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Desert Pat Feeder</td>
<td>45</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Ghotki Feeder Canal AWB</td>
<td>94</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Nara Canal AWB</td>
<td>166</td>
<td>162</td>
<td>82</td>
</tr>
<tr>
<td>Sukkur Barrage</td>
<td>183</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Western Canal AWB (Dadu 111+ Rice 72)</td>
<td>183</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Khairpur Irrigation Circle (East and west feeder canal)</td>
<td>123</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Rohi Canal Circle</td>
<td>283</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Kotri Barrage</td>
<td>105</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Left Bank Canal AWB (Phuleli 66+ Akram Wah 39)</td>
<td>105</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Kalri Beghar feeder circle</td>
<td>110</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Pinyari circle</td>
<td>113</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total (14 Canals)</td>
<td>1308</td>
<td>190</td>
<td>82</td>
</tr>
</tbody>
</table>

4 LESSONS LEARNED

The ability of Farmer Organizations to take substantial responsibility for running the organization and handle the problems of operation and maintenance at secondary in Pakistan is a relatively recent phenomenon. It has paved the way forward and hence more FOs has been established. In fact, ten years ago it has been viewed that this is more or less impossible. However, the process is still in its infancy and there remains a lot of work still to be done to develop a systematic and sustainable approach to run the organization in a sustainable manner and take the responsibilities of Drainage and Irrigation management.

It is also clear that in a comparatively short period of time, and certainly in no more than two or three days if people work hard, it is possible to completely desilt secondary canals and restore them to some measure of their original design condition. This level of input does not seem unreasonable and we can speculate that if other conditions remain in place then it will be possible to expect similar inputs into the future.

http://library.wur.nl/ebooks/drainage/drainage_cd/3.3%20lasheri%20memon%20and%20memon.html (8 of 12)26-4-2010 12:12:40
There were substantial hydraulic benefits. In virtually all locations the inequity of water distribution between head and tail was reduced, and in several cases previous inequities were reversed with tail end water users getting a slightly higher proportion of available water than head enders.

![Canal command of the Lower Indus basin Irrigation System in Sindh, Pakistan](image)

**Figure 2** Canal command of the Lower Indus basin Irrigation System in Sindh, Pakistan

5 CONCERNS FOR THE FUTURE
It would, however, be unwise to be complacent about the situation that was measured and observed during the January 2000 maintenance period. A number of issues remain that continue to cast doubt on the ability of Farmer Organizations to maintain their facilities now that management transfer has occurred.

Even on those canals where IWMI had undertaken physical surveys of cross-sections and longitudinal sections desilting remained more a matter of eyeballing than of systematic and controlled establishment of design sections. The desilting was done up to a point where the profile looked more or less smooth, banks were shaped to look correct, weak sections were strengthened, and in a limited number of places, the cross-section was made narrower. Yet at no time were physical measurements taken to determine whether widths, depth or slopes were consistent with what should be required to provide effective water levels at each outlet when the canal operates at design discharge.

Although hydraulic conditions improved in most canals, these results did not become inculcated into the daily actions of water users or the Irrigation Department, instead remaining more or less as a separate and unrelated measurement exercise. So the link between maintenance and performance remains weak or non-existent, and there is no sign of any major effort to try to link them again.

The maintenance efforts described here only dealt with the issue of desilting and repair of canal banks. There was no attention paid to physical infrastructure such as regulator, bridges and outlet structures which are controlling the discharge of water. To some extent this reflected the continuing stand-off between the Farmer Organizations and the Irrigation Department that prevailed at that time.

Collecting water charges from the water users and giving the agreed portion (60%) to the canal area water board and rest (40%) keep with FO to maintain the channel and run the organization is another task that farmer organizations have to take. Until end of the project this exercise was not carried over.

Based on these concerns it would be premature to suggest that the Farmer Organizations can undertake all aspects of maintenance and organizational matters and water conflicts into the future. There is still a long way to go before they develop the technical skills and the managerial capacity to maintain canals, repair infrastructure, and upgrade it as and when the need arises.

On the other hand, the Irrigation Department has been unable to do this for many years despite technical training, manuals and guidelines, and financial resources. So the result may be one that is no worse than previous conditions but one that does hold out some hope for the future that the current water users have the responsibility for looking after their own affairs.

6 CONCLUSIONS

The institutional reforms in irrigation sector are in progress. The impact of pilot project has indicated that the FOs jointly discusses the irrigation and drainage issues in their meetings which were not held before in any formal or informal way. A good number of water users have received technical, social and financial training, which has resulted in better management of the system.

In systems with a high degree of control over water there is some opportunity for a trade-off between operation and maintenance in order to achieve the desired water distribution pattern. In the supply-based systems of the Indus Basin and northwest India this option is not available: if canals are not maintained so that their physical condition approximates the original design, it is impossible to achieve a reasonable degree of equity of water distribution.

Irrespective of who is given operation and maintenance responsibility, be it the Irrigation Department, Farmer Organizations or private companies, the basic maintenance requirements remain the same in these supply-based systems. If ownership or management responsibility changes, there is no hydraulic basis for altering the rules of operation and maintenance unless there is a change in design.
There is no shortage of information on performance parameters, their values and tolerances, that should form the basis of an integrated operation and maintenance program that achieves the desired levels of water distribution equity and predictability that are the hallmarks of a well-managed supply-based irrigation system.

The joint efforts of farmer organizations insured the proper operation of the drainage system in the three pilot distributaries (Dhoro Naro Minor, Heran and Bareji Distributaries) and consequently the water table gone significantly down that controlled the water logging problem in the area. For this farmers were quite happy (Figure 3).

The pilot project has resulted in further formation of canal area water boards and farmer organizations in Sindh, Pakistan. The management of distributary channels has been given to many other FOs, who are managing the system.

Figure 3  Water table situation in three distributaries command area.

7  References

INSTITUTIONAL REFORMS IN IRRIGATION SECTOR OF PAKISTAN: PROSPECT TOWARDS INTEGRATED WATER RESOURCE MANAGEMENT

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ABSTRACT
Sri Lanka is an island with 2000mm average annual rainfall and maximum rainfall of 5500mm. Land area of 65519Mm² is divided into a wet zone of 22000Mm² by 2000mm isohyet. Heavy rainfall dropped into central mountains is drained to many reservoirs and hence it provides electricity in hilly areas. But the water drained to wet zone is not stored to produce electricity, other than in Kelani, Walawe river basins. A series of wet zone rivers are drained to sea with devastating floods. Lower Kelani, Kalu, Gin, Ben, Nilwala are the river basins with flood control projects. Gin and Nilwala basins were protected by specially designed flood control systems to protect drainage basins. Unprotected areas of the river basins need disaster control equipment. Upstream tanks are necessary for each stream. Integrated effort is needed to get the benefits from these protected areas. The protected area predominantly meant for paddy cultivation. Hence farmers are instructed to use the available opportunity to cultivate the protected basins.

Quite contrary the paddy cultivation is not successful during the last 10 years. Drop in rice yields when compared with dry areas is one reason for the abandoning of cultivation. Rice price also drops due to government efforts to import rice and to bring down the cost of living of residents. The rice variety selected for these lands are traditional and not changed to high yielding hybrids. Bush growth is also not effective and one plant has only one shoot. But dry zone area develops nearly 32 shoots from one plant. The problems associated with the flood control projects are discussed in the paper. It is useful to develop awareness program and to integrate the use of protected lands. Pumping is necessary to protect the houses and roads of the protected basin. It is useful to avoid housing in low levels.

It is useful to organize farmers and reduce pumping costs by planned farming. Breakdown in individual pumps is a serious trouble for the engineers. Electric pumps as well as diesel pumps develop faults, which are costly. Salinity gates are not durable. Low productive lands need crop rotation to recover the cost of pumping. Large areas suffering with floods and salinity problems are easily cultivated with polder techniques as in Indonesia. Many areas are abandoned due to largeness of the tract. Abandoned areas of drainage basins needed a farming approach to recover the cost of maintenance as well as the use of the land. Relaxing state imposed rules to safeguard tenant ownership for cultivation is a best way of renovating cultivation.

1 INTRODUCTION
Sri Lanka is an island with 2000mm average annual rainfall and maximum rainfall of 5500mm. Land area of 65519Mm² is divided into a wet zone of 22000Mm² by 2000mm isohyet. Heavy rainfall dropped into central mountains is drained to many reservoirs and hence it provides power in hilly areas. But in wet zone only Kelani and Walawe rivers had reservoirs. Kelani and Kukule rivers are partly dammed.

Flood control measures were done by state agencies since 1919 with the flood control ordinance empowering the Irrigation Department for prompt action. A heavy flood affected Colombo City in 1916 and the then governor realized the need for an effective control of incoming floods. Kelani flood protection scheme was commenced under Irrigation Department. Major flood bunds with lock gates were constructed. River gauging at Hanwella and a flood warning system was
organized. Rain gauging and flood forecasting was planned. Temporary closure of railway and main road at Kelaniya was designed to prevent spillage over the flood bund under heavy floods.

Kalu River in Western and Sabaragamuwa Provinces is another basin, which experience heavy floods. It has a flood control project at Ratnapura. Due to its narrow passage at Ellagawa the stagnation of floods lasted many hours. This fact led to take preventive measures for the urban area in the upstream. Kalutara is at a higher level and Horana, Matugama towns were developed at the periphery of flood basin. Gin River in Southern Province had a traditional development with floods. People harnessed the elevated flood level for transportation. Cultivation was planned to avoid onset of floods. Necessity of flood control was finally made into action in 1976. This plan provided flood bunds with a series of pump houses and low lift pumps. Drainage basins are separated to reduce flood accumulation. Nilwala flood protection scheme in the Southern Province was completed in 1988. This was in line with Gin basin plan. The pumps were operated by diesel engines. A section of the plan to protect Matara City was not completed.

Ben River, which flows to West Coast with a low-level catchment, had flood protection bunds to protect paddy areas in Dedduwa Ranthotuwila with a control gate. Also it had saltwater exclusion gates. Coastal areas had salinity exclusion works in addition to flood control. Many gates were closed to prevent high tides and opened to release fresh water to the sea. Kothmale multi purpose reservoir in the Mahaweli basin was planned to reduce flood threat in the down stream area. Major reservoirs can reduce the flood volume and water potential can be effectively used for irrigation and power generation. The downstream control measures are cheaper than upstream reservoir controls. Water transport methods were adopted in 1770 and it was necessary to cut canals and link with the sea. Salinity intrusion was improved but the floodwater was taken into cut canals for improved travel. Paddy lands in the vicinity were badly affected by salinity. It is said that Muthurajawela in Western Province was badly affected by the excavation of Hamilton-Dutch canal. Fresh water is a resource, which can be harnessed by agriculture. Upstream reservoirs were constructed where possible to detain water but failing that drainage options were taken. Ancient rulers advocated reuse of water after detaining in the dry zone. Excess of water in the wet zone could not be utilized in the nature of its destructive properties. Coastal area in addition possessed tidal erosion and sediment loss as a disaster.

Mitigating measures taken against floods in the ancient days were preventive and houses were not erected in the flood basin. Agricultural activities were planned to avoid high floods in most area and one season was used for cultivation. Temples were constructed over elevated platforms because of floods. Flood Control Ordinance in Ceylon (Sri Lanka) was passed in 1919 and the duty was assigned to Irrigation Department. Kelani flood protection scheme using flood bunds and lock gates was constructed. People settled over the bunds after constructing unauthorized houses.

Flood bunds become barriers against lateral flow from local storm water discharges. Many environmental hazards are created by flood control actions. Proper designs in hydrology and hydraulics shall make the efficient plan. Economic conditions and sustainability of the system leads to further problems in time to time.

In many cases the environmental factors are not effectively considered in controlling floods. Cost benefit analysis mainly looked at agricultural productivity. Environmental Impact Assessment (EIA) was introduced recently for water resources projects. Therefore environmental assessment for flood control projects is not widely practiced as yet in Sri Lanka. The Gin Ganga project was completed in the year 1983 and has passed a significant time period to adequately reflect the changes due to the project. Nilwala project needs further development.

1.1 Gin Basin

Gin Ganga is a river situated in the South Western Region of Sri Lanka. It drains an area of 960Mm² at the sea out fall, which is Ginthota. The river is 112.5km long, with its source reaching Abbey Rock (Elevation 1293m MSL). The river drains part of Southern Province and passes Udugama, Mapalagama, Agaliya, and Baddegama, Dodangoda and flows into the sea at Ginthota. The last stretch of Mapalagama to Gintota of the river is through flat lands. During rainy season floodwater inundates the Gangaboda Pattuwa and Galle Four Gravets (Bope-Poddala, Akimina DS Divisions) in Galle District. The disaster caused by...
floods menaced 6200ha of paddy lands and 33000 people living in 6000 houses and affected transportation and communication in
the lower basin. Nearly 216 000 people lived in the basin and 60000 people lived in the vicinity of floods in lower basin (PDR, GRP, 1975).

The Government of Sri Lanka in 1972 invited the Government of People’s Republic of China to recommend a plan to control the
flooding in the river basin. Chinese Engineers designed the flood control project. The Gin Ganga Regulation Project (GRP) was
completed in 1983 by the joint assistance of Chinese and Sri Lanka Governments. Irrigation Department of Sri Lanka commenced
operation and maintenance work in 1983. In 1972, about 22000 people living in 4000 houses occupied the project area below
Agaliya. Gin Ganga project declared an unprotected area of 2540ha with 830 houses with 4000 inhabitants. Backwater effect
inundates 78ha in upstream of Agaliya. Project occupies about 225 ha of paddy lands, which is 45% of the total. Electric pumps were provided to dispose
drainage water from 3188ha of paddy lands. Another 1000ha of rainfed paddy lands in the upstream sub basins were unaffected
and were taken as free from high scale flooding. 1740ha of Holuwagoda basin was drained by gravity. 800ha of marshy lands
were reclaimed and converted as paddy fields in Diviturai.

1.2 Hydrology
Gin Ganga basin mainly experiences southwest monsoon rains and floods are usually experienced during May - June. Floods
also occur during the inter-monsoon period of October - November but to a lesser degree than the May-June monsoons. Average
annual flow into the sea is about 1600 million cubic meters and the mean annual rainfall is 3048mm at Neluwa-Tawalama in mid
catchment. Available records show that maximum stagnation of floods was for 30 days in May 1940 with a maximum discharge of
1400cumec at Agaliya (IDGaunging, 1940). Rainfall and river stage records are available from year 1928 onwards (PDR, GRP,
1975). The Irrigation Department maintains Agaliya, Bopagoda, Ratnapura and Tawalama gauging stations. Department of
Meteorology maintains Galle meteorology station.

Table 1 gives average annual values of data at respective locations in the vicinity.

Table 1 Average Annual Values of Rainfall, Evaporation, Specific Yield of Flow, Run Off, Peak
Flow, Water Quality.

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>STATION</th>
<th>ANNUAL VALUE</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>Tawalama</td>
<td>3048mm</td>
<td>1901/65 Average</td>
</tr>
<tr>
<td></td>
<td>Galle</td>
<td>2380mm</td>
<td>1901/65 Average</td>
</tr>
<tr>
<td>Pan evaporation</td>
<td>Ratnapura</td>
<td>1210mm</td>
<td>95/96</td>
</tr>
<tr>
<td></td>
<td>Ratnapura</td>
<td>1140mm</td>
<td>65/96 Average</td>
</tr>
<tr>
<td>Run off</td>
<td>Tawalama</td>
<td>911MCM</td>
<td>Run off 95/6</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Tawalama</td>
<td>3580mm</td>
<td>Rain fall 95/96</td>
</tr>
<tr>
<td>Specific yield</td>
<td>Tawalama</td>
<td>0.68</td>
<td>1995/6</td>
</tr>
<tr>
<td>Volume estimated</td>
<td>Ginthota</td>
<td>1600MCM</td>
<td>1901-1965 average</td>
</tr>
<tr>
<td>Peak flow</td>
<td>Agaliya</td>
<td>1400cumec</td>
<td>Peak flow May 1940</td>
</tr>
<tr>
<td>River water quality</td>
<td>Wakwella</td>
<td>Salinity, iron</td>
<td>River water quality</td>
</tr>
</tbody>
</table>

1.3 Development
Gin Ganga basin is fairly well developed in agricultural pursuits excepting Singharaja forest in the mid-basin. The upper reaches
are planted with tea, rubber, coconut and cinnamon. Rubber predominates in the lower areas. Paddy lands are in lowland
pockets, all along the river amounting to about 14,133ha (PDR, GRP, 1975). About half of paddy lands, situated in the low lands,
suffer from periodical floods (ECIR, 1968). The tea plantations are said to contribute to the sediment in water currents. Paddy
fields lose finer sediments. Mountains in mid basin also said to have low vegetation due to erosion. The new short rooted bud tea
plantations with high foliage reduced the erosion after 1970 (Soil, 1994). Low- lands in the basin are about 15% and most are
paddy lands, which were concentrated in the lower basin. The cash crop plantations in high lands are about 34 % cultivated with
tea, cinnamon and rubber. Domestic areas are cultivated with coconuts and vegetables. About 25 % of the basin is under jungles.
Project area had 40% paddy, 20% rubber, 10% tea and others in the lowest section. In the upper project area 31% paddy, 30% tea, 30% rubber, 5% gardens and 4% scrubland are available (ECIR, 1968). The soil map of Sri Lanka shows red yellow podzolic soils from Udugama to Kimbi ela and red yellow podzolic soils with well-developed laterites and their drainage associates from Kimbi ela to Galle (Panabokke, 1967).

Gin Ganga flood plains possess clay deposits, which are used for pottery, brick and tile making while using the same land for paddy cultivation. Sugarcane was also cultivated in the low lands. Vegetables and green leaves are cultivated mostly near Labuduwa, Ukwatte villages. Sand mining from the riverbed was a long time practice among the villagers. This was accelerated due to cement mortar brick production. Though bamboo plants are found along banks the erosion can be observed during high flows.

Problem of Gin Ganga flooding was considered as the first and foremost environmental hazard of the district. Government budget allocations for flood relief activities included food and lodging services for the displaced persons. Daily river flow gauging at Agaliya was commenced in 1940 by the Hydrology Division of Irrigation Department. River stage was recorded from 1928 onwards. Since then the highest flood had been the one recorded in May 1940, which amounted to 1400 cumecs. This storm was widespread in the wet zone of Sri Lanka. Heavy rainfall in the basin initially creates flooding in Mapalagama area. Then it moves down to Agaliya area in a significant stagnation due to narrowness of the section. Wakwella area is then affected by heavy flooding, which usually lasts for more than a week. People make use of boats for urgent travel and transport needs. Social and economic damages were very high as the people face enormous difficulties including loss of life and property. Schools remained closed during floods. A significant effect was the rejection of entire area for future development. Flood basins are used for paddy cultivation but fertilizer is not added due to high risk of flooding in many areas. As a result the crop is not thriving to a maximum level. Average yield is 1-2 tons/ha for paddy.

The land closer to important places like roadways, markets, schools, temples are in demand for building construction but could not be utilized solely due to flood inundation. The area produced tea, rubber, and coconut products for export market in British period but now demanding more space for village expansion due to high population. Two storied houses were constructed in flood plains to escape from wetting in ground floor. After various investigation studies, (ECIR, 1968 & PDR, GRP, 1975) the plan proposed by the Government of China was executed to control the Gin Ganga flooding which was completed in year 1983. Agaliya to Mapalagama section of the basin was excluded for the final design and took as a buffer zone.

2 NILWALA GANNA BASIN

Nilwala river basin lies mainly in the Matara District. The river flows south and the drainage area is 975 Mm². The longest path of the basin begins near to Deniyaya of Gin basin. Paninkanda hill is in this basin and a solar battery rain gauge station was mounted there to transmit precipitation records directly to Matara office, which controls the flood protection in the lower basin. This was now withdrawn due to terrorist activities. The northern part of the basin is mountainous and possesses high rainfall of 3000mm annual average but the lowest point of Matara has only 1990mm. The 2000mm isohyet, which defines the wet zone limit passes through the basin.

The basin comprises Hulanda oya, which joins at Akuressa with the Nilwala River. Kirama Ara in the left bank joins the river below Akuressa. Part of the Nilwala catchment is augmented to Urubokka oya, which drains to Tangalla. This augmentation is relieving the burden of a high flood and it feeds the Muruthawela reservoir. Part of Kirama Ara is augmented to Kirama Oya. Digili Oya and Kadawedduwa oya are left bank streams joining in the last 7mile stretch of the river. Kirala kele is in the right bank of the basin, which is boggy and marshy and the land is in the same level with the sea. Several attempts were made to develop Kiralakele area during the last 100 years but only in 1988 the area was isolated by flood bunds and a pump house was provided to evacuate drainage water into the river at Thudawa. A large area was separated as the unprotected area including the road from Thudawa to Bandattara. New Bridges were erected to clear the passage of the river and the river- bed is lowered by dredging. Old gravity drainage canals were closed.
2.1 Development

Kadawedduwa oya in the left bank was protected by flood bunds along the bank. A pump house is provided to evacuate storm water from the protected basin. This area protects 1500ha from floods. This sub basin is in arid sector and it was successful in paddy cultivation. The drought in 2001 provided necessary heat to the crop and it yielded more than 5T/ha. Kiralakele area protects 3000ha of paddylands. This Kiralakele is a big marshy area. Several canals were cut to direct the drainage water to the pump house but the water is stagnating due to low head. Area closer to the Matara city is now protected from flooding due to the flood bunds and hence the scheme was successful in the city limits. 2000ha of paddylands in the Kiralakele is now abandoned due to acidity development in exposed half bog soils.

Seasonal variation of rainfall also creates difficulties in drainage. Shortage of water in the second half of crop season becomes a major problem for farmers. The drought situation in 2001 reduced the water availability without giving a higher crop yield. They demand supply from upstream of river in to paddy tracts. This will automatically increase the pumping hours of drainage water through the pumps. To reduce the drainage volume a large gravity outlet is planned with a new gate. Acidity development is due to exposed half bog soils, which contains iron and aluminium and receives sulphate from trapped seawater and finally forms acid sulphate called jarosite. This acidic water is harmful to animals equally. Acid sulphate situation reported first time in Sri Lanka only after the creation of flood bunds in 1990. The project protected 650 houses in the protected area. It also declared an unprotected area of 2800ha. Farmers in this open land cultivate their paddylands at a risk of getting destroyed. However there is no drainage problem for them.

2.2 Disasters

The design of main line of flood bunds was planned for 1969 flood but the flood came in May 2003 became more serious and it inundated all the upstream towns and villages. Kirama Ara basin drainage reached the river at first and it overtopped the spills of BR7 and released water to Kiralakeke area. The villagers of threatened areas made use of the opportunity to breach the spill and heavy flood entered the area inundating all the paddylands. Pumping was not sufficient to remedy the situation and at two places the bunds were cut open to drain stagnant water. This breach of peace caused damages in the protected basin. Protected areas were subjected to additional threat after 13 years and it collected dead cattle and other creatures in the highly turbid drained water, which remained at 2.5 m level when the river dropped to 1.5m after 7 days of the flood. 250 lives were lost in this disaster and about 90 lives were lost due to earth slips in the residential hill slopes. The sudden soil wetness, developed in the jungle cleared and bared tea lands, could not resist sliding forces of the slip circles in 30 hours of rain which was 338mm intensity showered in the full moon Wesak day as a result of monsoons developing into a cyclone over the southwest corner of Sri Lanka. The resulting overland flow drained along Gin Ganga, Nilwala Ganga, Kalu Ganga, Kukule Ganga, Kirama oya, Urubokka oya, Walawe Ganga creating a flow stage of 12 meters. The damages caused to wipe out towns and villages destroying the infrastructure facilities of roads, telecom, houses, offices, drinking water supply, electrical distribution net work, bridges in the valleys. Displaced citizens were accounted to 150,000 families. Rescue parties safe landed 155 people who were hung on to trees. Medical attention and food was given to the needy with international aid at this hour of disaster. Gin basin recorded 16 deaths and 3 of them were in Niyagama in the unprotected area of Gin Project. Overland flow filled few reservoirs in Hambanthota District including Muruthawela and Walawe. Ratnapura recorded 227mm rainfall in 3hours, which was the cause of major break down in communication.

Gin Ganga flood bunds were designed for 1967 flood at Agaliya. May 2003 flood was bigger than that but it was nicely controlled with in the flood bunds with the action of spreading half the volume in the mid way unprotected area of Nagoda Gonalagoda area. Gravity drainage in Holuwagoda canal was controlled by opening the sea out fall.

3 BEN RIVER BASIN

This river is situated in between the heavily flooding Kalu and Gin basins. The length of the river is 45km and its catchment is touching the middle of Gin basin. The area drains Bentara Walallawita Korale and flows west to meet the sea at Bentara. Its lower
basin is mostly suffering from floods. Lowlands of the basin are cropped with traditional paddy. The common problem of these paddylands is the salinity entering from sea with tides. The river-bed is full of marshes. The tributaries are blocked by salt water gates. Dedduwa gates are operated to prevent influx of seawater while allowing the drainage of basin storm water. It also prevents floods. The lands in Dedduwa Ranthotuwila are abandoned for long periods except few upstream reaches. Anicuts in upstream areas irrigate some lands in Mattaka. Economic problems lead to crop abandoning. 2003 May flood was controlled with less damage.

4 KALU-KUKULE RIVER BASIN

Kalu basin is a large area in between central mountains and western coast. It covers Ratnapura and Kalutara Districts. The river basin covers Matugama, Horana and Kalutara towns. Ratnapura is in the upper part of Kalu basin. Storm water quickly drains to Ratnapura town and inundates it. It joins Wey Ganga and passes through a narrow section at Ellagawa. Next it joins Kukule Ganga from Sinharaja forest in the left bank. Maguru Ganga comes from Neluwa and joins it lastly. All branches are rich water sources but it carries low driving head. As a result the area is populated and there is an opposition to form a dam. The river had flood bunds and gates in the lower basin to protect the paddy tracts. Kukule power project is now nearing completion. This water freely joins the sea at Kalutara and it needs development as a drinking water source. Ratnapura has a head for power generation. Vegetation is same as the Gin basin. Maguru- Gin reservoir has a head for power generation as a combined tank.

Elapatha earth slip caused 40 deaths in May 2003. Ratnapura city was heavily damaged inundating all houses and isolating many areas from rest of the island caused delay in rescue operations. Ratnapura area was famous for gem mining for the last millennium and it has open mines in weak foundations for roads and houses. Many hill slopes are identified as slipping. Tea plantations are weak in earth slip resistance and hence not suitable for permanent residence. Environmentalists opposed the reservoir construction with optimum capacity and Kukule was designed as run of the river project to protect few villages. These protected villages got fully inundated and perished due to heavy floods. It is better to evacuate people and construct a reservoir to store valuable fresh water for the use in dry spells. Due to global warming we experience high floods as well as long droughts.

The lower basin of Kalu is served with flood protection schemes with controlled gates. But clayey soils and frequent flooding does not give high yield in Moronthuduwa area. Only one season is well cropped. The other season suffers with water stress. The yield is more than that of Galle district but less than the dry zone. Rerouting the Kalu River is planned.

5 DRAINAGE SCHEMES

Koggala Lake and Maduganga are drainage projects maintained for paddy cultivation. Saltwater exclusion gates are provided in time to time to improve the yield. Most areas are abandoned due to low income from paddy. The lakes are open water bodies, which allow prawns and other migratory fish to develop in brackish water. The sand bars formed due to tides at the mouth of wet zone rivers are cut to allow the drainage of fresh water. Usually it takes a period of 2 months to build up but the mouth was opened only when the upstream head is more than the sea high tide. The stagnant water in the upstream paddy tracts of Lower Gin Holuwagoda, Koggala, Ambalangoda, Balapitiya locations suffer if it cannot build up a sufficient head before cutting the sand bar. Polder developments are helpful for these areas if it is planned in future to provide a pump. Kirama Oya takes part of Kirama Ara water and has 19 anicut schemes on the way and finally drains to Rekawa Lagoon in South. Coastal tourism development in lagoons demands more fresh water which was used for irrigation. On the other hand many anicut project cultivations are abandoned due to lack of water, low income from paddy and salinity build up. Land fertility is gradually dropping and hence it depends on imported fertilizers and pesticides. Small industries using reeds are successful in saline affected tracts. Attanagalu oya tracts are developed by a series of anicuts.

6 KELANI RIVER BASIN

Colombo and Kegalla Districts belong to this basin. This river is a source for power production in the upper reaches under Maskeliya and Kehelgamuoya. A reservoir is planned at Broadlands in the midway for power generation. Below this point it
serves as a drinking water source to distribute to major cities. Colombo flood protection project operates from Hanwella and it maintains 22 gates in the left bank. The flood bunds are on both banks. There is a large unprotected area, which is partly occupied by encroachers. Due to upstream tanks the flood menace is reduced. The RB flood bund is occupied by people for their permanent residence. Colombo city limits are improved by several aid projects. The major threat is given by local storm water as it happened in 1992. Groynes are introduced with beach making to control sand bars. Heavily populated areas create flow blocks due to polythene bags.

7 DISCUSSION
Flood protection in the drainage basins is the most important activity. Awareness programs can control deaths due to high flow. Skill in swimming is a necessity for all ages to recover the life in case of drowning. Life saving ability is needed to rescue others. Teaching classes are needed for children in the wet zone. Monsoons are receiving in May with heavy floods lasting 10 days and the people are ready to deploy timber boats for transporting. Sudden rise of water levels are due to intense precipitation, which is unexpected as in 2003, which had 100 year return period. Life vests, climbing towers, hanging ropes, emergency boats are necessary for each house in the unprotected area. Villagers are keeping electronic and electric goods and books and many other valuable items in the modern society at a risk of getting wet. Rich persons possess more perishable goods than poor. Upstream reservoirs are now proposed in the wet zone to store water for future use. Trans-basin diversion is suggested for long time but due to lack of financial aid it was not realized. Stored water is used to generate power and the fresh water is an invaluable resource in the dry period. Sri Lanka drains half of wet zone water directly to the sea.

Long-term flood protection projects are maintained by Irrigation Department. In addition anicut projects supply water to paddy tracts by control gates. The gate is manually operated to close to store water for diversion. Excess water is spilled down the stream. When the devastating floods are expected due to heavy precipitation it is the practice to open all the anicut gates to prevent damage to the paddy tract. This will result in heavy floods in the down stream areas. Usually floods are coming in the middle of the cropping season. It is the duty to protect the crop. Warning signals are necessary to avoid damage. Many anicut schemes are unproductive due to lack of water, salinity, rat attack, crab damage, poor soil quality and weeds. Rekawa Lagoon is receiving low inflows and hence proposed recreational activity is reduced.

7.1 Gin Basin Protected Areas
Electric pumps are operated to evacuate storm water during flood hours and high base flows in the river-side. 3044ha are protected successfully. Some farmers face drainage problems due to soil subsidence. Some areas are abandoned due to low base flows. Some farmers willingly do not crop. Poor farmers abandon due to economic reasons. Cattle damage paddy tracts. Canal blocks cause water-logging. Farmers assure yala and maha crops with high yield after 1983.

7.1.1 Gin gravity drainage areas.
Holuwagoda basin 1000ha is abandoned from 1992 due to subsidence and poor drainage. Widened Kepu ela provides drainage path but it is controlled by salinity intrusion.

7.2 Nilwala Project
Kadawedduwa sector is well cropped but Kiralakele 1800ha is abandoned. Poor drainage, soil subsidence, acidity development, water stress due to low base flows and lack of funds to run diesel pumps frequently, are the negative factors.

7.2.1 Nilwala unprotected area
May 2003 devastating flood has caused submergence of Hulandawa, Akuressa, Malimboda areas by 10m and the death toll is 40. Residents never expected this height of flood lift as they were living for the last century. Residents feel that damaging Kiralakele protected basin by cutting bunds is a measure to reduce floods as it happened before 1990. Three times they tried to cut flood bunds. This property damage can be avoided by a proposed Binhamara reservoir in the upstream of the project. Inundated lands will be compensated. Storing valuable freshwater is useful for 4500ha paddylands and providing drinking water to
Matara and to generate power. Part of Kiralakele marshes also can be used for a storage tank. Residents in unprotected area oppose replacement for a tank bed but at last they drowned by heavy floods.

8 SOCIAL ISSUES

8.1 Land Issues
Galle paddy landowner gets 20% crop yield but Matara owner gets 50% as the yield was high in Matara. In 1958 Paddy lands act reserved the tenant ownership and owner got only 25% of the crop yield. This is a benefit to the Matara tenant. But the aim of the act was to improve productivity. Some landowners dropped the possibility of tenant farming. In the Agrarian services act the commissioner has the power to allocate barren lands to tenants for a definite period. Shortage of base flows damage the running crop but as a result further increase in land use cannot be guaranteed. Banana introduction is also considered for some areas. Cattle damage is not prevented. Cattle owners live in the same village. Acid water is harmful to cattle. Low income from paddy is due to rising cost of labour, machinery, fertilizer and chemicals. Cheap rice is imported from India. Younger generation is not willing to continue farming as the diseases like lepto-spirosis is spreading. Wet zone crop yield is around 2T/ha where as dry zone gets 6T/ha. This is due to high bushing in the plant with more heat. Water stress and iron toxicity reduces yield. Yield was good after flood controlling for five years. Soil nourishment was reduced after flood control (Seneviratne, 2000).

8.2 Polder Development
Abandoned drainage basins are fairly large in size. Holuwagoda and Kiralakele are protected areas of 2500ha size. Large areas are best to fight insects, pests and weeds but inundation and low water conditions damage the area. Hence poldering smaller areas using a small pump to evacuate excess water, is a better solution. A ring of bunds can protect the area with a surrounding canal to drain storm water. Such areas can be cropped with rice, reeds and banana. Reeds withstand salinity in coastal areas.

Lack of funds for repair of existing structures and machinery is a reason for failure of maintenance. Diesel pumps in Nilwala very often damage due to wear and tear. Life span of a machine expires needing new machines. But there is no replacement. Diesel is a fuel imported at a rising cost.

9 FARMER ORGANIZATIONS
Branch canals of all schemes are controlled by farmer organizations. Many farmers reside closer to the tracts but as the lands are not profitable to sustain a living, farmers migrate to towns and Colombo city to get better facility and opportunities. Farmers need incentives to continue cropping. Strict controlling in water issues under irrigation tanks depends on farmers do not waste water and maximize the use of rainwater. Hence timing of land preparation and seed broadcasting is very important in saving water. Any farmer who delays land preparation needs more time at the end of the season and hence requests more water or more pumping hours. Hence control activities in pumping are dependent on farmers. At the same time houses constructed near the pump houses are frequently subjected to inundation. They always request pumping, which is costly and could be avoided. Construction of houses near low water line has to be prohibited. Maintenance of drainage canals with the help of farmers shall be done annually. If it is neglected poor drainage is the ultimate result. At present drainage canals are the responsibility of farmers.

10 CROP ROTATION
Crop rotation is recommended for those areas, which satisfies the conditions for new crops. Lack of water is a reason for crop abandoning and hence paddylands can be converted to tea, rubber and banana. Many farmers are thus benefited.

11 RE-USE OF DRAINAGE WATER
Kirindi oya project, Kala oya basin drain brown water in the dry spells but this water can be reused by pumping in to tanks if the power is abundant. Growing population needs these projects in future.

12 CONCLUSION

1 Rejuvenation of drainage activity needs sustainability of flood control activities. Kelani, Gin, Nilwala projects need continuous-financing as they are already maintained. It is the duty of the farmer and the state to attend to day to day needs to make the task simpler without allowing it to aggravate into a big problem.

2 Unprotected areas are highly populated and hence needed preventive measures. Possible storage tanks are necessary to store water for future use and for possible augmentation. The body of a drowned person reaches the sea if there is no reservoir in the way. This is very harmful and many lives can be recovered otherwise. Tanks can solve wet zone problems of low fresh water in dry spells for drinking and agriculture. Rubber dams are some times useful in low elevations.

3 Unused lands can be used as storage tanks. Kiralakele acidity development can be reduced by a new tank storage.

4 Farmer organizations need to integrate to increase cropping intensity and reduce cropping time to reduce pumping hours. Early farming practice reduces damage to the crop.

5 Legislation changes are necessary not to discourage landowners for farming.

6 Crop rotation and using high yielding varieties are suggested.

7 Electric pumps are better than diesel pumps. Nilwala pumps need conversion to electricity. Additional pumps are needed to Kiralakele and Holuwagoda to avoid water-logging. Polder development can be introduced to abandoned areas.

8 Awareness programs are necessary to train swimming and life saving. Boats have to be ready in all villages. Life vests are needed for every house.

9 Augmentation of rivers to send excess water to dry areas is necessary. Upstream reservoirs satisfy the need of drinking water and irrigation. Reuse of brown water drained to sea from reservoir projects can be used by pumping in to another tank.

13 Acknowledgements

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Some practical aspects of the new policy on water management in the Netherlands polders

Bart Schultz2 and Preecha Wandee3

ABSTRACT

After two river floods in respectively 1993 and 1995 and several local heavy rainfalls in the past decade in The Netherlands there is reconsideration concerning effective strategies and approaches on flood protection and water management. The general feeling is that we have to try to live more with the water than to fight against it. As far as flood protection is concerned a policy has been developed to give more room for the rivers.

As far as water management is concerned a basic distinction can be made between the low part and the relatively high part of The Netherlands. In the low part the polder systems dominate, where the water levels are basically controlled with drainage systems and where the surplus rainwater is pumped out into surrounding watercourses and lakes. Here the focus is on an increase in storage capacity for surplus water during wet periods, instead of on the increase the capacities of the pumping stations. In the relatively high part an improved water management is envisaged where due attention is being given to the water management requirements of the various types of land use.

This paper deals with water management in the polder areas. Some aspects of the application of the new policy in practice will be illustrated. With respect to this a distinction has been made into rural and urban areas. Special attention has been given to the impact of the increase of urban areas in polders and the effects of vertical differences between urban and rural areas.

1 INTRODUCTION

After two river floods in respectively 1993 and 1995 and several local heavy rainfalls in the past decade in The Netherlands there is a reconsideration concerning effective strategies and approaches on flood protection and water management. The general feeling is that we have to try to live more with the water than to fight against it. As far as flood protection is concerned a policy has been developed to give more room for the rivers.

As far as water management is concerned a basic distinction can be made between the low part and the relatively high part of The Netherlands. In the low part the polder systems dominate, where the water levels are basically controlled with drainage systems and where the surplus rainwater is pumped out into surrounding watercourses and lakes. Here the focus is on an increase in storage capacity for surplus water during wet periods, instead of on the increase the capacities of the pumping stations. In the relatively high part an improved water management is envisaged where due attention is being given to the water management requirements of the various types of land use.

This paper deals with water management in the polder areas. Some aspects of the application of the new policy in practice will be illustrated. With respect to this a distinction will be made into rural and urban areas. Special attention will be given to the impact of the increase of urban areas in polders and the effects of vertical differences between urban and rural areas.

2 PHYSICAL CONDITIONS OF THE NETHERLANDS

2.1 Scope

The Netherlands is a low lying, densely populated country bordering the North Sea. The major part of the country consists of lagoon and delta type areas, originating from the deltas of the Rhine, Meuse and Scheldt rivers. The Dutch have made this area inhabitable by reclamation and protection against the water. But for this creation of their country the Dutch had to fight for centuries against water coming from the North Sea, the rivers, rainfall, or from waves on the lakes during storm surges. The present land area comprises 3.4 million ha. As a result of land reclamation and subsidence about one third is situated below mean sea level, whereas about 60% of the land is protected against flooding.

The history of water management shows how the original natural landscape was transformed into a man-made landscape in a never-ending struggle with the water. At present the low part of the Netherlands in particular, virtually constitutes one hydraulic work, mainly created by man: a patchwork of lands gained on the sea, polders and drained lakes, crossed by innumerable ditches and canals. The fight against water that resulted in the present situation of The Netherlands started in the ninth century on a minor scale involving a small number of inhabitants with modest demands. People were faced with technical problems that required solutions. However, the provisions that had been made entailed new problems all the time. In the ninth century people started to move into the huge peat areas, which were situated a few metres above mean sea level, in many places. They lowered the groundwater table of these lands by digging a system of ditches or watercourses to the lower situated adjacent waters. This cultivation process was rounded off in the fourteenth century. The expansion of these, at first massive, interventions in the hydrological situation repeatedly stagnated in the course of the twelfth and thirteenth centuries as a result of a series of severe storm surges, swallowing up large parts of the cultivated land. In this period local communities that were located in the first danger zone started to connect their local dikes. This was the start of collective dike construction. This second radical intervention in the natural hydrological system caused a chain reaction that is still going on (De Bruin and Schultz, 2002).

The cultivation of the peat lands caused a considerable drop of the surface due to subsidence and oxidation. The subsidence of the deeper situated layers, due to natural causes, continued as well. These processes resulted in a drop of the ground level, amounting to two to three metres in the course of the centuries. This made it necessary to impolder the old cultivated grounds, initially by means of small sluices that could be opened at low outside water. In the course of the fifteenth century windmills were to bring help. During the nineteenth century these windmills, in their turn, were to be replaced by steam-driven pumping engines and in the twentieth century by electric and diesel pumping engines. Thus, one simple intervention in the natural condition of the delta has had far-reaching consequences.
2.2 Meteorological aspects

The Netherlands has a temperate maritime climate with a rather even distribution of rainfall over the year. The mean annual rainfall is about 785 mm. The mean annual reference evapo-transpiration is about 550 mm. Owing to the relatively even distribution of precipitation over the year, the intense evapo-transpiration during summer and low evapo-transpiration during winter, the Netherlands has under average conditions a rainfall deficit during summer amounting to 60 mm and a rainfall surplus of 300 mm during winter (Figure 1).

If we look closer to the development of annual rainfall over the years, then the longest time series that is available is the series of station Hoofddorp. Sound daily data are available for the period from 1867 to present. The annual figures are given in Figure 2.

If we screen the data series for consistency based on Spearman's rank correlation method, then we find that during the periods 1867 - 1934 and 1960 - 2001 no trend can be observed (Table 1). In this table T is the calculated value according to Spearman's formulae, T tab 0.025,(n-2) is the value for the Student T distribution at the two sided significance level of 2.5%. Based on these results the data from 1960 - 2001 have been used in the simulations.

![Average monthly rainfall and reference crop evapotranspiration](http://library.wur.nl/ebooks/drainage/drainage_cd/3.5%20schultz.html (2 of 10)26-4-2010 12:12:43)
Figure 2  Annual rainfall data for station Hoofddorp, The Netherlands, period 1867 - 2001

Table 1  Test for trend at 95% confidence level

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of data</th>
<th>T Spearman's</th>
<th>T tab 0.025,(n-2)</th>
<th>Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>1867 - 2001</td>
<td>2001</td>
<td>2.745</td>
<td>1.960</td>
<td>Yes</td>
</tr>
<tr>
<td>1867 - 1934</td>
<td>68</td>
<td>-2.058</td>
<td>2.000</td>
<td>no</td>
</tr>
<tr>
<td>1935 - 2001</td>
<td>67</td>
<td>3.399</td>
<td>2.000</td>
<td>yes</td>
</tr>
<tr>
<td>1956 - 2001</td>
<td>46</td>
<td>2.064</td>
<td>2.004</td>
<td>yes</td>
</tr>
<tr>
<td>1960 - 2001</td>
<td>42</td>
<td>1.880</td>
<td>2.021</td>
<td>no</td>
</tr>
<tr>
<td>1959 - 2001</td>
<td>43</td>
<td>2.333</td>
<td>2.020</td>
<td>yes</td>
</tr>
</tbody>
</table>

Extreme rainfalls are quite moderate. In Figure 3 the rainfall duration frequency curves based on the data of station Hoofddorp for return periods of 2, 10 and 100 year are given.
**2.3 The polder concept**

A polder can be defined as a level area, in its original state subject to high water levels (permanently or seasonally, originating from either ground water or surface water), but which through impoldering is separated from its surrounding hydrological regime in such a way that a certain level of independent control of its water table can be realized (Segeren, 1983). The polders have primarily facilities for flood protection (dikes) and drainage. The drainage system caters for removing surplus rainwater and seepage water, and consists of a field drainage system to control the groundwater table, a main drainage system or hydraulic transport system to transport the water from the field drains to the outlet, and an outlet structure to evacuate the water from the area (Figure 4) (Schultz, 1982).

---

**Figure 3** Rainfall duration frequency curves for station Hoofddorp (1960 – 2001)

**Figure 4** Schematic presentation of a drainage system in a Dutch polder (Schultz, 1982)
Three principle field drainage systems may be distinguished in the polders:

- **subsurface drain pipes**, which are generally applied in the clay soils;
- **open field drains**, which are generally applied in peat soils;
- **collector drains**, which are locally applied in sandy clay soils.

In the main drainage systems collector drains and main drains can be distinguished. Collector drains receive the drain water from field drains and transport it to the main drains, which on their turn transport the surplus water to the outlet. Several flow control structures, like weirs and culverts, may be installed in the main drainage system.

The outlet of the drainage systems in the polders may be a discharge sluice or a pumping station. The water level at the outlet constitutes the drainage base for the area concerned. This level, relative to the surface level, governs the amount of hydraulic head available for the drainage flow, as it determines to which extent the water levels may be lowered below the surface. It also determines whether the area can be drained by gravity or requires pumping. At present by far the majority of the polders require drainage by pumping. Therefore only drainage by pumping will be analysed in this paper.

The drainage systems have to convey and store the drainage water from the fields in such a way that the water levels in the polders remain at acceptable levels. The design criteria for drainage systems have generally been developed as follows:

- **preferred normal conditions.** These are the conditions one would like to maintain in the polder area. They result in a preferred water level, or water levels and operation rules for the pumping stations. The criteria are strongly linked to the soil type, or other land uses like urban, industrial, recreation and nature conservation;
- **design conditions.** These are the conditions on which the design of the drains and pumping stations is based. In general they are formulated as:
  - exceedance of the preferred water levels;
  - duration of the exceedance;
  - return period for which the prescribed exceedance occurs;
- **extreme conditions.** Although this is generally not a design criterion, control computations can be made for extreme situations. In these situations bankfull storage is generally accepted. When the results are unacceptable, the design criteria may be modified.

The above principles and considerations have resulted in the characteristic dimensions of different types of polders as shown in Table 2 (Luijendijk and Schultz, 1982).

<table>
<thead>
<tr>
<th>Type of polder</th>
<th>Percentage of open water</th>
<th>Polder water level in m-surface</th>
<th>Pumping capacity in mm/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat polder</td>
<td>5 - 10</td>
<td>0.20 - 0.50</td>
<td>8 - 12</td>
</tr>
<tr>
<td>Old clay polder</td>
<td>3 - 10</td>
<td>0.40 - 0.70</td>
<td>8 - 12</td>
</tr>
<tr>
<td>meadows</td>
<td>5 - 10</td>
<td>0.80 - 1.00</td>
<td>8 - 12</td>
</tr>
<tr>
<td>arable land</td>
<td>1 - 2</td>
<td>1.40 - 1.50</td>
<td>11 - 14</td>
</tr>
<tr>
<td>IJsselmeerpolders</td>
<td>3 - 8</td>
<td>1.50 - 1.80</td>
<td>15 - 30</td>
</tr>
<tr>
<td>Urban polder</td>
<td>3 - 10</td>
<td>0.80 - 1.00</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Greenhouse polder</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Most of the polders in The Netherlands were originally reclaimed for agricultural purposes. Since the last decades more and more other forms of land use are developed in the existing polders, like: industry, urban areas, recreation, and nature conservation. This implied that the original designs had to be reviewed and adjusted.

### 3 WATER MANAGEMENT POLICY IN THE NETHERLANDS

In 1968 the 1st Policy Document on Water Management was published. It concentrated mainly on the item: ‘water managers should cover the enormous water need of the future for agriculture, for flushing of salt, for drinking water and for other purposes’. The water situation in The Netherlands, with problems of salinization and pollution on one hand and an increasing demand for drinking, irrigation, cooling and processing water on the other, made it necessary to pay special attention to the main water infrastructure. An intensive study named ‘Policy Analysis of Water Management in The Netherlands (PAWN)’ was made by the Ministry of Transport, Public Works and Water Management and the Rand Corporation (Blumenthal, 1982). The primary objectives of this study were to:

- develop a methodology for assessing the multiple consequences of water management policies;
Some practical aspects of the new policy on water management in the Netherlands polders

- develop various water management policies and compare their consequences;
- create a capability in The Netherlands for further analyses.

The 2nd National Policy Document on Water Management (1984) was supported by the policy analysis as developed by PAWN. This document was based on the cost-benefit relation of the water development and on the multiple use of water. The document elaborated on the need for water, whereas it also emphasised the relation between the uses of surface and ground water.

The 3rd National Policy Document on Water Management (1989) was based on 'integrated water management', and related ground water with surface water and water quantity with water quality. Water systems were identified, and the document specified that 'the water systems had to be managed and developed so that they satisfy their ecological objectives and functions'. The 4th National Policy Document on Water Management (1999) took the different water systems as the basis for decision making. It therefore went one step further than the 3rd Policy Document. Since then The Netherlands focused on integrated water management. During the last decades the whole legal and organizational structure has been reorganized and modernized, anticipating on this approach.

After two river floods in respectively 1993 and 1995 and several local heavy rainfalls in the past decade there developed, however, a reconsideration concerning effective strategies and approaches on flood protection and water management. Since then for the water management systems in the polder areas the focus is on an increase in storage capacity for surplus water during wet periods, instead of on the increase the capacities of the pumping stations. In addition more safety was considered to be required to prevent to a large extent that valuable elements likes buildings, infrastructure and greenhouses in polder areas would be inundated. These problems are to a large extent caused by the rapid expansion of urban areas, infrastructure and greenhouses in polder areas, especially in the densely populated western part of The Netherlands. With this expansion the specific conditions of water management in polder areas has not always been adequately taken into account.

4 ANALYSES OF THE WATER MANAGEMENT CONDITIONS IN POLDER AREAS

In addition to the temporary storage of surplus rainwater in the unsaturated groundwater zone, which may be quite significant (Saiful Alam and Schultz, 1987), temporary storage occurs especially in the collector and main drains. The question is to what extent the present systems are already working at their capacity, or if there is still room in these systems. In order to get an impression of the present conditions and to analyse the effects of urbanisation and vertical differences between urban and rural areas on the water management in polder areas the following items were analysed:

- actual pumping data of the Northeast polder;
- fluctuations in the open water level in a theoretical polder under different percentages of urban area and different vertical levels of the urban and the rural area.

4.1 Analyses of the actual pumping data of the Northeast polder

The Northeast polder is one of the IJsselmeerpolders in the former Zuiderzee (Schultz and Verhoeven, 1987). The polder fell dry in 1945. It is provided with three drainage pumping stations. The installed capacity of the pumping stations enables to remove a water layer of 14 - 15 mm/day counted over the total area of the polder, which is 480 km². Daily data of the discharge by the pumping stations are available for the period 1945 - 2001. In figure 5 the frequency distribution of the pumped amounts of water during the said period is shown.
From Figure 5 some characteristics can be derived. It is shown that 89% of the time 3 mm/day or less have been pumped out, which is less than one fifth of the installed capacity. 98% of the time 7 mm/day or less have been pumped out which is about 50% of the installed pumping capacity. With respect to these figures it has to be realised that the seepage in the Northeast polder is almost 1 mm/day (Schultz and Verhoeven, 1987) and that the additional water is due to surplus rainfall.

Only two days in the total period the installed capacity of 15 mm/day has been used and 14 days a capacity of 14 mm/day. Although water levels are only available for part of the period, these data show that exceedances of more than 0.30 m above the preferred water level of 5.70 m-MSL almost never have occurred (Van de Ven, 1996). While the preferred water level in this polder, with predominantly clay soil, is at least 1.2 m-surface, an exceedance of the preferred polder water level with 0.30 m under extreme conditions will not do any harm. Only in very exceptional periods some local inundations have occurred, which were generally not caused by insufficient pumping capacity, but by insufficient infiltration capacity of the soil, or discharge capacity by the local drainage system.

Although the Northeast polder is not representative for all the polder systems, the results show that there may be quite some room in the drainage systems of the polders under extreme conditions. It is therefore of importance that representative water management systems are carefully analysed on their performance before generally costly measures to increase the storage capacity in a polder area are being taken.

4.2 Analyses of fluctuations in polder water levels

In polder areas the value of property per unit area is much higher in the urban areas compared to the rural areas. For the polder Flevoland, which is one of the IJsselmeerpolders, it was found in 1990 for example that the total value of public and private property was about €3 million per ha, while the total value in the rural area was only about €15,000 per ha (Schultz, 1992). Since then the difference became even more pronounced. In order to keep the damage due to excessive rainfall under extreme conditions as low as possible it is therefore advisable to situate the urban areas at a certain level above the surrounding rural area.

In order to analyse the effects of urbanisation in a polder area some theoretical examples have been analysed for respectively a clay polder and a peat polder. The polder areas are considered to be completely flat. The analyses have been made with the relatively simple model POLDER, which is basically a water balance model. In this model the hydraulic gradients in the watercourses are neglected, which in polder areas due to the relatively low flow velocities generally doesn’t result in significant differences with the results of hydrodynamic models. For both the clay polder and the peat polder the chances for inundation of the respective surfaces have been investigated in number of days during the total period, as well as in percentages. It has to be realised that these percentages refer to the days of occurrence and not to the years in which such events have occurred. The following data have been used in the analyses:

- **Both the clay and the peat polder:**
  - polder area 50 km²;
  - daily rainfall series of station Hoofddorp 1960 - 2001;
  - percentages of urban area in the polder of 5, 10 and 50%;
  - vertical surface level distribution in the urban area: streets 0, footpath and squares +0.10 m, ground floor in houses +0.20 m, green areas +0.15 m and preferred water level in the urban canals –1.00 m (reference level) (Figure 6);
  - horizontal surface distribution: streets 10%, footpath and squares 10%, houses and buildings 40%, green areas 37%, urban canals 3%;
  - vertical differences between the preferred water level in the urban canals and the water level in the surrounding rural area of 0, 0.25 and 0.50 m;
  - in the rural area the computation of the runoff is based on the daily soil water balance. For the urban area a runoff coefficient of 80% is used for the paved area and for the green areas a similar computation as for the rural area;
  - it is supposed that the urban area discharges its surplus water over a weir into the watercourses in the rural area. The theoretical length of the weir is determined in such a way that under free overflow the water level rise in the urban canals is not more than 0.40 m at a return period of ten years (Figure 3). The surplus water from the total polder area is removed with a pumping station from the water courses in the rural area;

- **Clay polder:**
  - open water 5%;
  - polder water level 0.90 m-surface, road level 0.1 m-surface, ground floor level of farm houses 0.10 m+surface
  - pumping capacity 11 mm/day;

- **Peat polder:**
  - open water 7%;
  - polder water level 0.40 m-surface, road level 0.1 m-surface, farm level 0.10 m+surface
  - pumping capacity 11 mm/day.
In Table 3 the results of the simulations for the clay polder are given and in Table 4 the results of the simulations for the peat polder.

### Table 3  Results of the simulations for the clay polder

| Item                      | Width of the urban weir in m | Percentage of urban area (%) | Difference in level in m | Days/frequency n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| Streets                   | 36                           | 5                             | 0                        | 7                | 0.05 | 2 | 0.01 | 8 | 0.05 | 3 | 0.02 | 3 | 0.02 | 36 | 0.23 | 23 | 0.15 | 17 | 0.11 |
| Footpath and squares      | 36                           | 5                             | 0                        | 3                | 0.02 | 0 | 0.00 | 0 | 0.00 | 5 | 0.03 | 2 | 0.01 | 1 | 0.01 | 25 | 0.16 | 18 | 0.12 | 15 | 0.10 |
| Houses and buildings      | 36                           | 5                             | 0                        | 1                | 0.01 | 0 | 0.00 | 0 | 0.00 | 2 | 0.01 | 2 | 0.01 | 0 | 0.00 | 24 | 0.16 | 17 | 0.11 | 12 | 0.08 |
| Green areas               | 36                           | 5                             | 0                        | 1                | 0.01 | 0 | 0.00 | 0 | 0.00 | 2 | 0.01 | 2 | 0.01 | 0 | 0.00 | 20 | 0.13 | 15 | 0.10 | 10 | 0.07 |
| Rural area                |                              |                               |                          |                  |                |   |     |   |     |   |     |   |     |   |     |   |     |   |     |   |     |   |     |   |     |   |     |
| Road                      | 36                           | 5                             | 0                        | 6                | 0.04 | 6 | 0.04 | 9 | 0.06 | 8 | 0.05 | 8 | 0.05 | 57 | 0.37 | 70 | 0.46 | 89 | 0.58 |
| Agricultural area         | 36                           | 5                             | 0                        | 4                | 0.03 | 4 | 0.03 | 4 | 0.03 | 4 | 0.03 | 4 | 0.03 | 44 | 0.29 | 50 | 0.33 | 61 | 0.40 |
| Farm house                | 36                           | 5                             | 0                        | 1                | 0.01 | 1 | 0.01 | 3 | 0.02 | 3 | 0.02 | 3 | 0.02 | 25 | 0.16 | 35 | 0.23 | 36 | 0.23 |

Total number of days of simulation from 1960 to 2001 = 15341 days

n = number of days of inundation

% = frequency in %

### Table 4  Results of the simulations for the peat polder

| Item                      | Width of the urban weir in m | Percentage of urban area (%) | Difference in level in m | Days/frequency n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| Streets                   | 36                           | 5                             | 0                        | 4                | 0.03 | 2 | 0.01 | 8 | 0.04 | 3 | 0.02 | 3 | 0.02 | 21 | 0.14 | 15 | 0.10 | 7 | 0.05 |
| Footpath and squares      | 36                           | 5                             | 0                        | 3                | 0.02 | 0 | 0.00 | 0 | 0.00 | 4 | 0.03 | 1 | 0.01 | 1 | 0.01 | 17 | 0.11 | 8 | 0.05 | 4 | 0.03 |
| Houses and buildings      | 36                           | 5                             | 0                        | 1                | 0.01 | 0 | 0.00 | 0 | 0.00 | 3 | 0.02 | 0 | 0.00 | 0 | 0.00 | 14 | 0.09 | 6 | 0.04 | 3 | 0.02 |
| Green areas               | 36                           | 5                             | 0                        | 0                | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 9 | 0.06 | 4 | 0.03 | 2 | 0.01 |
| Rural area                |                              |                               |                          |                  |                |   |     |   |     |   |     |   |     |   |     |   |     |   |     |   |     |   |     |   |     |   |     |
| Road                      | 36                           | 5                             | 0                        | 25               | 0.16 | 24 | 0.16 | 24 | 0.16 | 30 | 0.20 | 28 | 0.18 | 29 | 0.19 | 217 | 1.41 | 241 | 1.57 | 247 | 1.61 |
| Agricultural area         | 36                           | 5                             | 0                        | 14               | 0.09 | 14 | 0.09 | 14 | 0.09 | 20 | 0.13 | 18 | 0.12 | 18 | 0.12 | 150 | 0.98 | 173 | 1.13 | 179 | 1.17 |
| Farm house                | 36                           | 5                             | 0                        | 4                | 0.03 | 4 | 0.03 | 4 | 0.03 | 7 | 0.05 | 7 | 0.05 | 7 | 0.05 | 63 | 0.41 | 77 | 0.50 | 86 | 0.56 |

Total number of days of simulation from 1960 to 2001 = 15341 days

n = number of days of inundation

% = frequency in %
It has to be stressed that the results of this analyses are indicative, while the simulations have been done in a quite simplified manner and possible soil storage during extremely wet periods has been neglected. For the urban area possible insufficient discharge capacity of the sewers has been neglected. However, the trends in the results are clear.

For the clay polder the results show that, under the conditions as specified above, when the preferred water level in the urban area is 0.25 m above the preferred water level in the rural area, which implies that the street level in the urban area is 0.35 m above the surface level in the rural area, in fact no inundations have to be expected in the urban area, when the percentage of urban area in the polder is up to 10%. In these conditions occasionally an inundation of the rural area could be expected, but only in exceptional cases an inundation of the ground floor of the farmhouses. When this ground floor would be situated a little higher, say 0.10, or 0.20 m no inundation would have to be expected.

For the peat polder more frequent inundations in the rural area may be expected with little difference in the urban area, as long as this area doesn’t take more than 10% of the total area. This increase in possible inundations in the rural area is primarily caused by the relatively high polder water level, which is required to prevent a too rapid subsidence of the peat soil.

5 CONCLUDING REMARKS

In this paper some practical aspects of the new policy on water management in the Netherlands polders have been analysed. A distinction has been made into rural and urban areas. Special attention has been given to the impact of the increase of urban areas in polders and the effects of vertical differences between urban and rural areas.

Although the simulations as used in the preparation of this paper are of a general nature the results show that there is in general still quite some room in the existing water management systems. In addition it is shown that it is advisable to locate urban areas higher than the surrounding rural areas. As a consequence of such an approach possible inundations will primarily occur in the lower parts of the polder area where the value of property is relatively low. When proper vertical differences between land use components are being realised within the polder area damage due to extreme wet conditions can be kept relatively low. It will be clear that such measures cannot be taken overnight, but they could be a basis for new developments in polder areas.

6 ACKNOWLEDGEMENT

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SOME PRACTICAL ASPECTS OF THE NEW POLICY ON WATER MANAGEMENT IN THE NETHERLANDS POLDERs


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SOCIO ECONOMIC IMPACTS OF AGRICULTURAL LAND DRAINAGE – A STUDY FROM NORTH WEST INDIA

K.K.Datta, C. De Jong, B.C.Roy and S.B.Singh

ABSTRACT

To combat waterlogging and soil salinity, subsurface drainage/SSD has been recommended. Drainage needs have developed in 10-15 million hectares in arid and semi-arid regions and in some 45 million hectares in irrigated areas throughout the world. Due to long neglect of the drainage problem, at the global level annual losses in the order of US $11 billion have been reported from the waterlogged saline area. Also in India, waterlogging and soil salinity take their toll. Diverse statistics show that the twin problem is threatening agricultural production on 5.5 million to 13 million ha. Roughly one million hectares are so seriously affected, that agricultural production had to be abandoned completely. To control and manage the problem in the most fertile, irrigated areas, investment in drainage was initiated in the Northwest region of India. This paper attempts to assess the benefits of installing subsurface drainage for salinity control. Specific objectives of the paper are: (i) to assess the impact of subsurface drainage on efficiency, equity and sustainability of agricultural production, and (ii) to examine the factors affecting the sustainability of the technology.

Decomposition analyses were made to assess the absolute contribution of drainage to farm income. Gini concentration ratios were computed in comparable areas with and without subsurface drainage systems to measure differences with respect to equity as a result of drainage. In the drained area, also a before and after comparison was made. Lorenz curves were used to visualise the inequalities between the drained and non-drained area, and in the drained area before and after drainage installation. The result of the calculations reveals several farm-level benefits of subsurface drainage. These include (i) substantial increase in farm income, (ii) crop intensification, and diversification towards high value crops, and (iii) generation of employment opportunities. Apart from that, the results also show that subsurface drainage will result in a reduction of income inequalities across farm producers. The decomposition analyses show that in the Gohana area drainage resulted in a 40 to 70 per cent yield increase. However, in spite of its economic, social and environmental benefits, the acceptance of the subsurface drainage technology is always questioned. Some specific reasons for this are discussed in the present paper. These are: (i) indivisible nature of the technology, (ii) lukewarm attitude with respect to collective action by the potential beneficiaries, (iii) conflicting objectives among beneficiaries, and (iv) growing numbers of free riders. This occurs due to the absence of appropriate institutional arrangements. The analysis showed that, in spite of its high potential, the subsurface drainage technology might not yield the desired results in the absence of proper institutional arrangements.

Keywords: Economic effect of subsurface drainage, decomposition analysis, Cobb-Douglas analysis, Gini-concentration, institutional arrangements, sustainability, free riders

1 Introduction

Agricultural land drainage has been practised for millennia. Although it is recognised that under various conditions drainage is an important means to secure sustainable agriculture, it is nevertheless a highly neglected factor. Only researchers and environmentalist are paying increasing attention to the drainage needs. Nevertheless, there are few reliable estimates on the effect of waterlogging and soil salinity on agricultural production at farm level, regional level, or at global scale. Since land degradation is location specific and spatial in nature, the magnitude of the losses varies from area to area. World-wide, the extent of the damage due to salinisation is ranging between 12 to 36 percent of the annual gross production value. It has been estimated that, at the global level, the annual loss from 45.4 million ha of salt affected lands in irrigated areas may amount to US $11.4 billion (Ghassem et al., 1995). Unfortunately, in India, data on the occurrence and spread of waterlogging and soil salinity in the country are varied and sketchy. The existing estimates range from 5.5 million to 13 million ha (Joshi et al. 1992).

There are some more recent estimates. It has been reported that in Northwest India an area of 0.7 to 1.0 million ha is already seriously affected by waterlogging and soil salinity. Recent estimates pointed out that the damage due to water logging and soil salinity in this area is in the order of 10 to 15 per cent of the annual gross production per hectare as compared to the yields obtained in the non-affected land. The total annual loss in Haryana is about Rs 1670 million (about US $37 million) (Datta & De Jong, 2002).

There are basically three reasons for installing agricultural land drainage systems: (1) for trafficability, so that seedbed preparation, planting, harvesting, and other field operations can be conducted in a timely manner, (2) for protection of crops from excessive soil water conditions, and (3) for salinity control. This paper attempts to assess the impact of the installation of subsurface drainage for salinity control. Specific objectives of the paper are: (i) to assess the economic effect of subsurface drainage on crop production, income level, efficiency, equity, and the environment; (ii) to quantify the contribution of drainage by comparing the productivity of drained areas with the productivity of comparable non-drained areas; (iii) to highlight the factors which are affecting the adoption of drainage by the farming community.

2 Database & analytical tools used

The socio-economic survey was conducted in the Gohana area, situated in the Gohana Sub-Division of the Sonipat District of Haryana. The district was selected with a view to the extent of the waterlogged, saline area. In Haryana, about 207,000 ha, or 54 percent of the geographical area, is affected by waterlogging and soil salinity. For the study, five villages, constituting the Gohana area, were selected. Together, these villages cover an area of about 4,600 ha. In the area, there
are about 2,150 households and the population is some 14,000.

In this area, about 250 sample plots were selected with the help of a grid system. Subsequently, the owners of the sample plots were identified with the help of revenue records and maps. In the selected sample plots, soil samples, crop cuttings, and water table measurements were done. Apart from this, socio-economic surveys were carried out amongst the owners and/or cultivators of the sample plots. Since some of the farmers possessed two selected sample plots, the plot and farm surveys were conducted among some 225 farmers’ families. The monitoring and evaluation programme of the project aimed at assessing the potential contribution of drainage technology for salinity management to crop production.

To determine the absolute effect of drainage on gross crop income decomposition analysis was used. Decomposition analysis is a mathematical technique that can disaggregate and quantify a difference in an observable quantitative variable into its components. More simply, the technique provides a method to quantify the intervening factors of a difference such as before and after or with and without situation. Bisaliah (1977) and Joshi et al. (1992, 1994) used a similar technique for wheat and other crops.

Since paddy and wheat are the main crops in the wet and dry season, respectively, these two crops were chosen for the analysis. The approach assumes that in the non-drained area, salinity build-up will directly influence the crop yields. To establish the relationship, a Cobb-Douglas (C-D) form of production function was employed. Several explanatory variables, defined in different ways, were included to estimate the production function. The following functional form and variables were selected for further analysis:

\[ Y = A S^b F^c I^d K^e L^f e^u \] ................................. (1)

Where, \( Y \) is the gross income from paddy or wheat (Rs/Acre); \( S \) is cost of seeds (Rs/Acre); \( F \) is cost of fertiliser (Rs/Acre); \( I \) is cost of irrigation (Rs/Acre); \( K \) is cost of capital (includes cost of chemicals and machinery use, Rs/Acre) and \( L \) is the cost of labour (Rs/Acre). Since fertiliser application has a direct effect on salinity, it was considered separately and not added into capital. The coefficient \( a \) refers to any kind of shift in the production function as a result of technological change. The exponents \( b, c, d, e, \) and \( f \) are the regression coefficients of the respective variables (\( u \) is the error term and \( e \) is the base of the natural log).

The change in gross income between drained and non-drained, salt-affected soils was decomposed into (i) changes due to drainage effect and (ii) changes due to reallocation of inputs.

### 2.1 Drained area:

\[ \log Y_d = \log A_d + b_d \log S_d + c_d \log F_d + d_d \log I_d + e_d \log K_d + f_d \log L_d \] ..............(2)

### 2.2 Non-drained area:

\[ \log Y_{ud} = \log A_{ud} + b_{ud} \log S_{ud} + c_{ud} \log F_{ud} + d_{ud} \log I_{ud} + e_{ud} \log K_{ud} + f_{ud} \log L_{ud} \] ..............(3)

Taking the difference between (2) and (3), adding some terms, and subtracting the same terms yield the following:

\[ \log Y_d - \log Y_{ud} = (\log A_d - \log A_{ud}) + (b_d \log S_d - b_{ud} \log S_{ud}) + (c_d \log F_d - c_{ud} \log F_{ud}) + (d_d \log I_d - d_{ud} \log I_{ud}) + (e_d \log K_d - e_{ud} \log K_{ud}) + (f_d \log L_d - f_{ud} \log L_{ud}) \] ..............(4)

Rearranging terms in equation (4) yields the following:

\[ \log (Y_d/Y_{ud}) = \log (A_d/A_{ud}) + [(b_d-b_{ud}) \log S_{ud} + (c_d-c_{ud}) \log F_{ud} + (d_d-d_{ud}) \log I_{ud} + (e_d-e_{ud}) \log K_{ud} + (f_d-f_{ud}) \log L_{ud}] + \log (S_d/S_{ud}) + \log (F_d/F_{ud}) + \log (I_d/I_{ud}) + \log (K_d/K_{ud}) + \log (L_d/L_{ud}) \] ..............(5)

Equation (5) apportions approximately the differences in gross income per hectare between drained (salinity-free) and non-drained (salt-affected soils) into two components. The sum of the first two bracketed components on the right hand side indicates the drainage effect. The third bracketed term measures the contribution of changes in input levels between the two situations.

Lorenz curves were used to depict the inequalities in income on land with and without drainage, and on the same land before and after drainage. Since the studied drained and non-drained areas are ‘comparable’, the differences between before and after and with and without are small. Gini concentration ratios (GCR) were also computed in the study areas with and without subsurface drainage to measure difference in inequalities in income in the salt-affected and non-affected lands.

Finally, issues related to large-scale adoption of drainage are discussed based on the experience gained in different drainage projects.

### 3 Results and Discussion

#### 3.1 Drainage Investment

Given the present scarcity of financial resources, priority setting for investment in resource development is strongly guided by the demand driven forces. Land augmentation or ‘horizontal development’ through reclamation will be needed for feeding the rural masses only when the potential productivity levels of the non-
affected (normal) lands will have been realised, in other words, when the 'saturation point' has been reached. Then, there is no more scope for investment in 'vertical development'.

At this 'threshold level', investment in 'horizontal development' will be needed to break the stagnant level of production. However, at 'threshold level' returns to investment in 'horizontal development' will be a big question mark because it will be difficult to show its financial feasibility at farm, regional, and at national level. Therefore, investment at 'threshold level' will rather be guided on the ground of scope for further diversification and long-term sustainability through conservation of the natural resources. The financing of such type of investment may be feasible for the developed countries where the scope for 'horizontal development' is more or less limited and increasing of production is only possible through 'vertical development'.

In the Indian context, past experience shows that investment in land reclamation was done only after the production potential of the non-affected (normal) soils was reached (Datta & Joshi, 1990).

Recently Smedema (2002) observed rightly that “The ‘saturation point’ and the ‘threshold level’ are useful concepts for the opportunity driven drainage development of rain-fed land, but less for drainage for salinity control of irrigated land. In the latter case, drainage is often not a choice, but a dire necessity to salvage a valuable natural resource from degradation”

3.2 Drainage Costs and Economic Feasibility

To control the water table in areas underlain by groundwater of poor quality, subsurface field drainage systems will have to be installed and to be connected with the main surface drainage system. Earlier research in Haryana has sown (Datta et al., 2000) that drainage will be economically feasible, if manually installed systems can be implemented at the cost of Rs. 25,000/ha. Mechanically-installed drainage systems would also be justified at the same cost level (Datta et al., 2002). However, mechanised installation of subsurface drainage systems at the rate of Rs. 43,000-45,000 per ha, as was recently done in the framework of the Haryana Operational Pilot Project/HOPP, is much less cost-effective and not economically feasible under the circumstances in the area. Hereby, we have to make the reservation that, in an irrigated area, cost-benefit analysis for drainage alone is not correct. The benefits obtained earlier, as a result of the shift from rain-fed to irrigated agriculture, must be taken into account in assessing the feasibility of drainage. For, in arid and semi-arid regions, irrigation development without drainage is, in principle, unsustainable.

Therefore, now agricultural development in Haryana has reached the ‘threshold level’ at which drainage becomes a critical constraint for further advancement, and investment in drainage is essential, one should look beyond the momentary economic feasibility of drainage development alone. Moreover, in view of the threat of losing very scarce and highly valuable agricultural land, drainage development is a must. It may also be observed that, although the process of salinisation is mostly slow, intervention in terms of drainage development should be started as soon as the salinisation process starts, because it makes no sense to let the farmers suffer great losses over long periods before installing the long overdue drainage system. In the problem areas, only drainage development will make an end to the stagnation of agricultural production and the decrease in welfare of the rural society.

3.3 Drainage Impacts

3.3.1 Direct impact on water table

To monitor the depth of the water table, 40 observation wells were installed in an area of 2,000 ha in the Gohana Block of Sonepat District. Twenty-seven observation wells are located in the area of 1,000 ha, where in the meantime, drainage systems have been installed, and 13 points in are in the non-drained area.

At 500-m grid points, the depth of the water table was measured monthly and analysed. The water table levels were monitored during 3 years. In the study area, depths of the water table fluctuated from zero to 3.95 m in the study area.

After the installation of subsurface drainage systems the water table levels went down. In the non-drained area, the water table remained shallower, as compared to the levels in the drained area (Table 1). Where the pumps were operated properly, the depth of the water table in the drained area remained below 1.00 m during the whole growing season of the rabi (winter) crops.

Farmers reported that the 20 to 50 per cent crop losses during kharif (summer season) were mainly due to heavy rainfall in combination with local storms, which cracked the rice stems causing the nearly matured grains to rot in standing water. After the installation of subsurface drainage, the positive impact is not only an improvement in crop yield in the kharif season, but also that the following rabi crop can be sown in time. Another observation of the farmers in the drained area was that most of the waterlogged, saline fallow lands were reclaimed and brought back into crop production.

3.3.2 Direct impact on soil salinity

Monitoring of soil salinity and crop yields before and after drainage is convenient for an impact assessment of installing a subsurface drainage system in waterlogged, saline lands. To this end, soil and crop samples were collected at a large number of sample plots, at the harvest of the rabi crops. Hereby the same grid pattern was used as in the years before drainage development, and the results of the analyses were compared with the initial values of 1995-96 in the drained, as well as in the non-drained area. The installation of subsurface drainage systems was started in 1997 and completed in June 1999. At the harvest of the rabi crop 1999-2000, the average salinity levels in the drained and in the non-drained control area were 4.6 and 9.2 dS/m, respectively. At the harvest of the rabi crop 1995-96, the average salinity level was 7.1 dS/m in the whole non-drained area, indicating a 35 per cent decrease in salt content after the installation of subsurface drainage in part of the area. Block wise analysis in the drained area also shows the same picture. In some of the SSD blocks, average soil salinity was reduced.
increased from 9.7 to 66.3%, whereas in the non-drained area the average salinity level increased from 9.0 (1995-96) to 9.2 (1999-00) indicating a small increase within two years.

### 3.3.3 Indirect impact on cropping pattern and intensity

During the period 1986-90, the major kharif crops were paddy, jowar, and sorghum. Respective percentages of those crops were 11, 7, and 7. But after the installation of drainage the cropping intensity increased dramatically and the respective shares of the above-mentioned crops changed to 61, 14, and 3 per cent, respectively. The area under paddy increased tremendously, due to a spectacular increase in the number of shallow wells for irrigation.

In rabi, wheat is the most important crop, covering 81 percent of the area in the post drainage period. This is an increase of about one-third over the 60% during 1986-1990. A number of other crops are grown as well, but each of them occupies only a few per cent of the land. The perennial crop grown in the area is sugar cane. There were no changes in area. The crop still occupies about 5 per cent of the cultivable area.

In the study area, the cropping intensity has drastically increased. It was reported that, in the period 1986-90, the cropping intensity in kharif was 35 per cent only; whilst in the rabi season it was 82 per cent. The annual cropping intensity was thus 117 per cent. In the post drainage period (1999-2000), the cropping intensity during kharif was 83 per cent and in rabi season it was 92 per cent. Thus, annual cropping intensity increased to 175 per cent.

### 3.3.4 Impact on crop yield:

Wheat is the most important crop grown in the Gohana area. In 1994-95, wheat yield was as high as 3.7 ton/ha. It was higher than the district and state averages for that year, which were 2.6 and 2.7 ton/ha respectively. The yields are, generally, far below potential yield levels and show a declining trend as can be seen from district statistics. The reason for this is most probably the deterioration of the agricultural resource base because of aggravated problems of waterlogging and salinity.

During 1995-96, paddy and wheat yields in Gohana area were about 1.8 and 3.1 ton per ha respectively. The average wheat yields in the drained and non-drained areas were 3.6 and 2.4 ton/ha, respectively (Table 2), indicating a significant increase in wheat yield due to the subsurface drainage system. (Drainage) block wise increase in wheat yield ranged from 9.7 to 54.0 per cent, as compared to the rabi 1995-96 wheat yield. The overall net yield increase due to subsurface drainage was about 49 percent.

From the above analysis it is clear that on-farm direct benefits of subsurface drainage, which controls the water table and enables the process of desalination through leaching of the salts, are substantial. This is a combined result of the following changes: (i) a considerable increase in cropping intensity; (ii) a shift in cropping pattern towards more remunerative crops; (iii) a significant increase in crop yields; (iv) an increase in gainful employment, and (v) a conversion of abandoned, marginal lands into agricultural use. In other words, subsurface drainage helps to improve farm incomes by creating proper conditions for crop intensification and crop diversification, for overcoming crop calendar constraints, for allowing mechanisation of farm operations, for enhancing the impact of fertilisers and other inputs, for lowering production costs, and for mitigating adverse environmental impacts.

In general, SSD will make the agricultural sector more competitive, efficient and sustainable.

### 3.4 Contribution of Drainage

To quantify the absolute contribution of drainage to the increase in farm income, a regression analysis was carried out. The estimated regression equations (equation nos. 2 & 3) for drained and non-drained areas in Gohana are presented in Table 4a and 4b for paddy, and in Table 5a and 5b for wheat. Most of the selected variables, namely seed, fertiliser, labour and capital were statistically significant at different probability levels, except labour, both in the drained and non-drained areas, and irrigation for paddy in the non-drained area. The value of $R^2$ ranged from 33% to 68% for wheat, whereas for paddy it was about 57% both in the drained and non-drained area. The F values were high for both cases. May be, including different salinity levels as one of the variables in our production function will improve the $R^2$ value for wheat. The expected positive production elasticities of different factors indicated the response on gross (paddy and wheat) income. As an example, a 1% increase in fertiliser expenditure at mean level (6.4468, see Table 3b) increased the income from wheat in the drained area with 0.43% and in the non-drained area with 0.22% only. Similarly, in the case of paddy, the effect of increasing fertiliser expenditure by 1% (where the mean level is 2.8564, see Table 3a) will yield an increase of 0.54% in paddy income in the drained area, and 0.47% in the non-drained area. From these observations, we may conclude that drainage helps to make fertiliser use more efficient, thus reducing the cost of production.

The results of the decomposition exercise, derived from the results shown in Table 4a and 4b, and in Table 5a and 5b, are reported in Table 6. The figures in Table 6 indicate that the drainage technology accounted for about 40% of the increase in income in paddy areas. In wheat areas, the corresponding figure for drained areas was 72%. These values indicate that with the same level of resource use in the drained and in the non-drained, salt-affected areas, gross income would increase by 40% in paddy the areas and by 72% in the wheat areas of Gohana. It is important to note that seeds, fertilisers, irrigation and capital cost were positively related and statistically significant at different probability levels. It is interesting to note that in the non-drained areas none of the factors was negatively related with income. This may be due to the fact that there is still scope to enhance income through those inputs also in the non-drained areas. However, field observations indicated that farmers are reluctant to use best agricultural practices in the salt-affected areas. They are giving less priority to these areas, as compared to their non-affected areas. Smedema (2000) reported a 10-15% contribution of drainage in the total world food production.

### 3.4.1 Reducing Income Disparity:

It is generally argued that in canal irrigation systems, there is always a ‘head’ versus ‘tail’ problem related to the distribution of the available irrigation water. By the very nature of the canal system, the higher-lying, better-drained land is in the head-end and the lower lying, naturally poorer drained lands, in the tail end. Generally, the head-end farmers had earlier and better access to water and better opportunities for development than tail-end farmers. This situation is often
reinforced over time as much of the progress and development bypasses the poor or can not be beneficially used by them, due to the poor drainage conditions of the land. The naturally poorer drainage conditions, together with the inadequate and unreliable irrigation water supply, have often resulted in severe waterlogging and salinisation problems in the tail-end land. Crop yields are often low and part of the land has become fully unproductive. Improved drainage, in combination with improved irrigation water management, can under these conditions be an effective instrument for combating poverty (Smedema, 2002).

To show that drainage technology helps to reduce income disparities, Lorenz curves were derived from the income data of the drained Gohana HOPP area and from the non-drained Control area (Figure 1 & 2). With the same data also Gini Concentration Ratios (GCR) were calculated for the situation before and after drainage, and for the situation with and without drainage. Before drainage, the GCR in the project area was about 23 percent (Table 7), but after drainage it was only 3 percent. This is a clear indication that drainage technology maximises the distribution of welfare gains (also to the weaker sections of society) by conserving the land and water resources. The resulting reduction in income inequality is about 20 per cent. The Lorenz curves (Figure 1 & 2) also support this by clearly depicting the disparity between drained and non-drained area. The inequality curve is more prominent in case of the non-drained area (Figure 2), whereas in the drained area the disparity is less.

In terms of employment generation, drainage helps to create additional gainful employment during the installation stage, and subsequently for intensified crop production. About 85 additional labour days per hectare were created.

Apart from this, drainage development it helps to create additional work and income in the industrial sector. About 60 to 70 per cent of the investment in drainage go to the industrial sector, which delivers drainpipes and other drainage materials.

Improved drainage also produces a number of social and environmental benefits like, improved public health, improved sanitation, safe water supply, improved animal health, protection of rural infrastructure, which enhance rural welfare.

Recent research findings from Pakistan indicate that the derived additional benefits can be quite substantial, and do significantly contribute to the feasibility of investment in improved drainage (IPTRID 1999; Scheumann and Freisem 2001).

Agricultural drainage projects in Japan always include the provision of improved village sanitation. Drainage Boards in the Netherlands not only deal with the control of excess water, but also with water quality control.

It is highly relevant to recognise that much of the early drainage developments were not for agricultural, but for public health purposes, in order to reduce the prevalence of marshy conditions in populated areas to combat malaria and other water related diseases. Subsurface drainage not only improved land for agricultural production, but is also helped to control diseases carried by the mosquitoes and black flies leaving in the wet areas. It is also reported that the drainage facilitated the settlement of immigrants in North America (USDA, 1955). In spite of the manifold economic, social and environmental benefits, the adoption of subsurface drainage is always questioned. The reasons for this will be discussed in the following section.

3.4.2 Constraints towards the Adoption of the Technology

Constraints towards large-scale adoption of drainage are discussed on the basis of the experience gained in various drainage projects. The study of small-scale subsurface drainage projects in Haryana and Gujarat revealed a number of serious constraints towards the adoption of the technology (Datta & Joshi, 1992). The most important are: (i) the indivisible nature of the SSD technology, (ii) increased economic differentiation and socio-political factionalism and (iii) internal heterogeneity and inequities.

In order to overcome such type of problems a participatory approach in project development is generally advocated. But there are several serious constraints, which may hamper the success of people's participation in implementing drainage projects. Some of these are: (i) the problem of free riders, (ii) the lukewarm attitude of potential beneficiaries to participate, (iii) conflicting objectives of different (groups of) beneficiaries, (iv) poor perception of the objectives of the project, (v) factionalism in the village, (vi) strong dependence on governmental patronage, and (vii) a completely eroded culture of group action and sharing systems (Datta & Joshi, 1992).

No attraction to an individual farm household on investment to prevent or cure the degraded lands

Despite yielding high dividends, collective action is required to realise the potential benefits from SSD due to indivisible nature of the technology. Our analysis concluded that the technology without institutional arrangement might not yield desired results. A technology with high potential benefits may not make a difference and can be abandoned in the absence of required institutional arrangements.

4 Conclusions

In spite of the high potential economic, social, and environmental benefits, the adoption of the subsurface drainage technology is always questioned. Our study in the Gohana Pilot Area revealed substantial farm-level benefits as a result of installing subsurface drainage. This is a combined result of the following changes: (i) a considerable increase in cropping intensity; (ii) a shift in cropping pattern towards more remunerative crops; (iii) a significant increase in crop yields; (iv) an increase in gainful employment, and (v) a conversion of abandoned, marginal lands into agricultural use.

In other words, subsurface drainage helps to improve farm incomes by creating proper conditions for crop intensification and crop diversification, for overcoming crop calendar constraints, for allowing mechanisation of farm operations, for enhancing the impact of fertilisers and other inputs, for lowering production costs, and for mitigating adverse environmental impacts.

In general, SSD will make the agricultural sector more competitive, efficient and sustainable.

Apart from this, subsurface drainage proved to contribute greatly to the mitigation of income inequalities across farmers. And, drainage development triggers
forward and backward linking activities, such as the production of drainpipes and other drainage materials, increased trade in fertilisers and other farm inputs, and in farm outputs (multiplier effect).

The decomposition analyses show that in the Gohana Pilot Area the installation of subsurface drainage resulted in a 40 per cent increase in gross income of the paddy crop and a 70 per cent increase in gross income of the wheat crop. However, technology alone is not sufficient. A technology with high potential benefits may not make a difference in the absence of proper institutional arrangements. Therefore, technical development must go hand in hand with institutional development to realise the potential of the drainage technology.

Given the fact that agriculture in Haryana has reached the ‘threshold level’ at which drainage becomes a critical constraint for further advancement, and investment in drainage is essential, one should look beyond the momentary economic feasibility of drainage development alone. Moreover, in view of the threat of losing very scarce and highly valuable agricultural land, drainage development is a must. The Government should take its responsibility for saving the scarce, high potential agricultural lands and preventing affected rural communities from total impoverishment. Therefore, one-quarter or one-third of the annual budget for irrigation development should be reserved for large-scale drainage to prevent valuable irrigated land from complete deterioration.

Although the process of salinisation is mostly slow, drainage development should start as soon as the problem arises, because it makes no sense to let the farmers suffer great losses over long periods before installing the long overdue drainage system.

In the problem areas, only drainage development will make an end to the stagnation of agricultural production and the decrease in welfare of the rural society.

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Table 1 Water table depth in the Gohana area before (1995-96) and after (1999-00) SSD (in m)

<table>
<thead>
<tr>
<th>Area</th>
<th>Before SSD</th>
<th>After SSD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>March</td>
<td>June</td>
</tr>
<tr>
<td>Range</td>
<td>0.42-1.24</td>
<td>1.23-2.79</td>
</tr>
<tr>
<td>Average in the drained area</td>
<td>0.79</td>
<td>1.91</td>
</tr>
<tr>
<td>Average in the non-drained area</td>
<td>0.63</td>
<td>1.24</td>
</tr>
</tbody>
</table>

Table 2 Effect of subsurface drainage system on crop yield (ton/ha)

<table>
<thead>
<tr>
<th>Crops</th>
<th>Area</th>
<th>Before SSD (1995-96)</th>
<th>After SSD (1999-00)</th>
<th>Percentage of yield increase (+)/ decrease (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>Without drained</td>
<td>2.94</td>
<td>2.43</td>
<td>-17.3</td>
</tr>
<tr>
<td></td>
<td>With drained</td>
<td>3.07</td>
<td>3.61</td>
<td>+17.6</td>
</tr>
<tr>
<td>Paddy</td>
<td>Without drained</td>
<td>1.3</td>
<td>1.2</td>
<td>-7.69</td>
</tr>
<tr>
<td></td>
<td>With drained</td>
<td>1.4</td>
<td>1.7</td>
<td>+21.43</td>
</tr>
</tbody>
</table>
Table 3a Average log values of the selected input-output parameters for paddy in Gohana during 2000.

<table>
<thead>
<tr>
<th></th>
<th>Gross income</th>
<th>Seed cost</th>
<th>Fertiliser cost</th>
<th>Irrigation cost</th>
<th>Capital cost</th>
<th>Labour cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drained area</td>
<td>3.792947</td>
<td>2.041648</td>
<td>2.856421</td>
<td>2.816473</td>
<td>3.169412</td>
<td>3.014069</td>
</tr>
<tr>
<td>Non-drained area</td>
<td>3.730641</td>
<td>2.060694</td>
<td>2.82138</td>
<td>2.803338</td>
<td>3.136155</td>
<td>3.006405</td>
</tr>
</tbody>
</table>

Table 3(b) Average log value of the selected input-output parameters for wheat in Gohana during 1999-00

<table>
<thead>
<tr>
<th></th>
<th>Gross income</th>
<th>Seed cost</th>
<th>Fertiliser cost</th>
<th>Irrigation cost</th>
<th>Capital cost</th>
<th>Labour cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drained area</td>
<td>2.7067</td>
<td>5.72008</td>
<td>6.44685</td>
<td>5.11053</td>
<td>7.31951</td>
<td>7.29875</td>
</tr>
<tr>
<td>Non-drained area</td>
<td>2.55098</td>
<td>5.63450</td>
<td>6.43431</td>
<td>5.13869</td>
<td>7.30254</td>
<td>7.31686</td>
</tr>
</tbody>
</table>

Table 4a C-D production function of paddy in the drained area of Gohana during 2000

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.753438</td>
</tr>
<tr>
<td>R Square</td>
<td>0.567668</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.535405</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.164021</td>
</tr>
<tr>
<td>F value</td>
<td>17.59472</td>
</tr>
<tr>
<td>Observations</td>
<td>73</td>
</tr>
</tbody>
</table>

Factors

<table>
<thead>
<tr>
<th>Factors</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interception</td>
<td>2.71976*</td>
</tr>
<tr>
<td>Seeds</td>
<td>0.864683*</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>0.544942*</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.365422**</td>
</tr>
<tr>
<td>Capital costs</td>
<td>0.983354*</td>
</tr>
<tr>
<td>Labour</td>
<td>-0.31688</td>
</tr>
</tbody>
</table>

Table 4(b). Production function of paddy crop (C-D) in the non-drained area of Gohana during 2000.

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.755929</td>
</tr>
<tr>
<td>R Square</td>
<td>0.571428</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.529411</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.161566</td>
</tr>
<tr>
<td>F-value</td>
<td>13.59996</td>
</tr>
<tr>
<td>Observations</td>
<td>57</td>
</tr>
</tbody>
</table>

Factors

<table>
<thead>
<tr>
<th>Factors</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interception</td>
<td>2.82005**</td>
</tr>
<tr>
<td>Seeds</td>
<td>0.164698</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>0.472837*</td>
</tr>
<tr>
<td>Irrigation</td>
<td>-0.19751</td>
</tr>
<tr>
<td>Capital costs</td>
<td>1.330303*</td>
</tr>
<tr>
<td>Labour</td>
<td>0.418737***</td>
</tr>
</tbody>
</table>

*, **, *** Significant at 1%; 5% and 10% probability level.

Table 5a C-D production function of wheat in the drained area of Gohana during 1999-00

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Regression</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factors</td>
<td>Standard Error</td>
<td></td>
</tr>
<tr>
<td>---------------</td>
<td>---------------</td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>2.065399***</td>
<td></td>
</tr>
<tr>
<td>Seeds</td>
<td>0.238736**</td>
<td></td>
</tr>
<tr>
<td>Fertiliser</td>
<td>0.427158**</td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.341752*</td>
<td></td>
</tr>
<tr>
<td>Variable costs</td>
<td>0.10439</td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>0.072175**</td>
<td></td>
</tr>
</tbody>
</table>

Table 5(b). C-D production function of wheat in the non-drained area of Gohana during 1999-00

<table>
<thead>
<tr>
<th>Regression Statistics</th>
<th>Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple R</td>
<td>0.576962</td>
</tr>
<tr>
<td>R Square</td>
<td>0.322885</td>
</tr>
<tr>
<td>Adjusted R Square</td>
<td>0.298139</td>
</tr>
<tr>
<td>Standard Error</td>
<td>0.195159</td>
</tr>
<tr>
<td>Observations</td>
<td>102</td>
</tr>
<tr>
<td>Factors</td>
<td>Standard Error</td>
</tr>
<tr>
<td>Intercept</td>
<td>4.579794*</td>
</tr>
<tr>
<td>Seeds</td>
<td>0.098951*</td>
</tr>
<tr>
<td>Fertiliser</td>
<td>0.220497**</td>
</tr>
<tr>
<td>Irrigation</td>
<td>0.096959**</td>
</tr>
<tr>
<td>Variable costs</td>
<td>0.322056*</td>
</tr>
<tr>
<td>Labour</td>
<td>0.037118</td>
</tr>
</tbody>
</table>

*, **, *** Significant at 1%; 5% and 10% probability level.

Table 6  Decomposition of factors contributing to yield and income differences between the drained and non-drained area of Gohana during 1999-0.

<table>
<thead>
<tr>
<th>Items</th>
<th>Percentage attributable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sources of change</td>
<td></td>
</tr>
<tr>
<td>Technological</td>
<td>39.49</td>
</tr>
<tr>
<td>Changes of input</td>
<td>60.51</td>
</tr>
<tr>
<td>(i) Seed</td>
<td>-3.90</td>
</tr>
<tr>
<td>(ii) Fertilisers</td>
<td>-26.43</td>
</tr>
<tr>
<td>(iii) Irrigation</td>
<td>30.65</td>
</tr>
<tr>
<td>(iv) Capital</td>
<td>52.49</td>
</tr>
<tr>
<td>(v) Labour</td>
<td>7.70</td>
</tr>
</tbody>
</table>

Table 7  Impact of drainage on income inequality in the Gohana area

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Control area</th>
<th>Project area</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.18878</td>
<td></td>
<td>0.2263</td>
</tr>
<tr>
<td></td>
<td>0.0313</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1

Figure 2

[2] ICAR Research Complex for NEH, Umroi Road, Umiam 793103, Meghalaya, India.
ADAPTABILITY CONSTRAINTS OF A TECHNICALLY AND ECONOMICALLY FEASIBLE SUBSURFACE DRAINAGE SYSTEM IN THE LOW-LYING ACID SULPHATE SOILS OF KERALA, INDIA

Dr. E.K. Mathew

ABSTRACT
The state of Kerala supports over 3.43% of India's population within 1.18% of the geographical area of the whole country. Increased population pressure and sub division and fragmentation of farming area have made sustainable agriculture a difficult task for the farming communities. Rice in Kerala is cultivated in distinct macro environments ranging from 2-3 m below mean sea level as in coastal lowlands of Kuttanad to near temperate situations at 2,500 m height in the high ranges. Owing to its innate adaptation to waterlogged environment, rice can be the only food crop grown in the coastal tracts. High rainfall coupled with undulating topography subject the low land rice fields to environmental vagaries of flash floods in the monsoon and tidal saline incursions during the summer. Impeded by poor drainage, excess water and poor water management, the potential of high yielding rice varieties is hardly realized in this region. The situation is further aggravated in acid sulphate problem soils owing to high acidity, salinity and accumulation of toxic salts etc inherent to these soils. As a result, the cropping intensity in coastal low lands is the lowest (100% as against 161% of the state). The present trend of conversion of low productive rice lands for alternate enterprises have created serious environmental problems altering the unique ecological functions of these wetlands.

This paper discusses the introduction of subsurface drainage as a tool to improve rice production in low land areas of acid sulphate soils. Pipe drains with 15 and 30 m spacing were installed in farmers' fields. Soil conditions improved within two years after the introduction of the subsurface drainage and significantly improved the crop yield. Data collected over a period of 14 years, showed a yield increase of 1.1 t/ha (43%) compared to non-drained areas. An economic analysis indicated that subsurface drainage is feasible with a benefit-cost ratio of 2.45, an internal rate of return of 47% and a net present value of Rs 5.17 million. The poor financial status of the farmers, however, is the main constraint for the large-scale adoption of the comparatively capital-intensive subsurface drainage systems in the acid sulphate soils of Kerala.

Keywords: Subsurface drainage, Drainage Adaptability, Drainage Economics

1 INTRODUCTION
The state of Kerala supports over 3.43% of India's population within 1.18% of the geographical area of the whole country. Increased population pressure and sub division and fragmentation of farming area have made sustainable agriculture a difficult task for the farming communities.

1.1 Rice Cultivation in Kerala
Owing to its innate adaptation to waterlogged environment, rice can be the only food crop grown in the coastal tracts of Kerala. Rice in Kerala is cultivated in distinct macro environments ranging from 2-3 m below mean sea level as in coastal lowlands of Kuttanad to near temperate situations at 2,500 m height in the high ranges. The high rainfall coupled with undulating topography subject the low land rice fields to environmental vagaries of flash floods in the monsoon and tidal saline incursions during the summer. The low-land situations constitute 25% of the total rice area of the state contributing over 37% of the rice output. Impeded by poor drainage, excess water and poor water management, the potential of high yielding rice varieties is hardly realized in this region. The situation is further aggravated in acid sulphate problem soils owing to high acidity, salinity and accumulation of toxic salts etc inherent to these soils.

For the past two decades, rice production in the State has come under tremendous pressure from more remunerative, high-value crops like coconut, banana, plantain and pineapple. As a result, the area of production under paddy has shrunk from a peak of 881,000 ha in the mid-1970s to 431,000 ha in 1996-97. The area currently hovers around 450,000 ha. Each year, the area under paddy dwindles by around
22,000 ha, though the rate of annual decline has been marginally checked in the last three years. Even at the height of production, 1,400,000 tonnes in the mid-1970s, there existed a demand-supply gap and Kerala had to import almost half of its requirements from other States. During 2000-01, Kerala's rice production was 751,000 tonnes far below the decade's opening level of 1,060,000 tonnes.

1.2 Area of study
The area selected for the study is in the Karumady village of the Kuttanad tract in Kerala, India (Figure 1 and 2).

---

Figure 1  Map of India showing location of Kuttanad
The total population of Kuttanad is 1.4 million. The rural population alone constitutes one million with a population density of 800 persons per m². Forty per cent of the population is engaged in agriculture, the major economic activity in the area. Fishery is another important primary activity of the region. The total number of operational holdings in the zone is 888,000, which accounts for 16.57% of the total holdings in the state. Around 94.45% of the total operational holdings are marginal in size (less than 1.0 ha) against the State's figure of 92.5%. Small holdings (1.0 to 2.0 ha) constitute 3.94% of the region. Only 0.04% holdings in the zone are large (above 10 ha). The area where experiments were conducted is a true and representative tract of acid sulphate soil lying 1.0 - 1.5 m below Mean Sea Level (MSL).

1.3 Reasons for low production
The soil is extremely acidic when dry with pH ranging from 3.0 to 4.5 and EC as high as 6.0 dSm⁻¹ during summer. The ionic concentration of Fe, SO₄, Ca, Mg and Cl are found to be present in toxic concentrations for paddy, rendering the soil poor in productivity. The soil cracks during summer on drying. This makes the subsoil more acidic due to the oxidation of sulphur compounds and later with inundation forming free sulphuric acid. In summer, the intrusion of saline water in the water bodies surrounding the farming area brings down the quality of irrigation water. Symptoms of iron toxicity on the leaves are predominant. The roots are also found to decay due to the sulphide injury. The high water table condition in the field inhibits the downward percolation of the water to create the desired leaching effect. All these factors result in patchy crop growth and poor grain yield approximately 1.5 tons/ha even after 100% adoption of high yielding paddy varieties.
1.4 Present farming practice

Farming is done in contiguous stretches of lowlands, reclaimed as polders for rice cultivation by constructing earthen bunds around, which is a homogeneous entity. The size of polders varies from 10 ha to nearly 500 ha. Individual farming concept is not feasible in this peculiar hydrologic condition where the field is below MSL and hence group farming is practiced. Farmers, after every harvest, flood their fields with water to contain the acidity which otherwise would be formed due to oxidation. As the area is below MSL, the impounded water has to be drained from the entire area to make it suitable for cultivation. During cultivation, the field is washed with water very frequently to leach the salts and acidity. The present method of intermittent washing is not found to be successful enough to boost the yield because of the high water table conditions. The leaching effect extends only up to a few centimetres depth, below which, the salt concentration is very high.

There are two cropping seasons namely, puncha (November•March) and additional (June•September). In between the seasons the lands are kept under water fallow. The puncha crop is sown after the flood season is over while the additional crop is taken with the risk of floods during the South-West monsoon. Presently, paddy is the only crop grown extensively. High yielding varieties are being used throughout the area.

The present infrastructure in the area supports a cropping intensity of about 120%. The main crop is still the puncha crop grown on about 80% of the land. The scope for developing more land by reclamations is virtually exhausted. Therefore, the increased crop
production will have to come from higher cropping intensities and yields. This calls for flood protection measures and sub-surface drainage so that an overall increase in production can be obtained.

2 METHODOLOGY

Keeping the problems in mind, a pilot study was conducted by the Kerala Agricultural University to explore the influence of subsurface drainage in improving crop performance and soil quality.

2.1 Subsurface drainage design layout

The layout of the drainage system is given in Figure 3. Considering the shape of the field and availability of farmers' field for in situ experimentation, nine lines of parallel lateral drains were installed.

Figure 3 Layout of the subsurface drainage system

The first six lines close to the main collection sump were at 15m spacing and the remaining at 30m spacing. The length of first five lines was 75m and the remaining was of 100m. In order to offset the hydrologic interference between adjacent plots as much as possible, buffer lines were introduced between test spacings and at boundaries. Thus the first line, designated as 1B15, is a buffer line and so are the 6th and the 9th designated as 6B_{15/30} and 9B_{30} respectively. The lines 2E_{15}, 3E_{15}, 4E_{15}, and 5E_{15} are experimental lines of 15m spacing and the lines 7E_{30}, and 8E_{30} are experimental lines of 30m spacing. Further replication for 30-m spacing or some other spacing was not possible because of the shape of the field.

Baked clay pipes were used as drains. These drain pipes were of 60 cm length with an outer diameter of 125 mm and inner diameter of 100 mm, having bell mouth at one end. They were provided with fifteen 6-mm holes on 1/3rd of its peripheral area. These holes were arranged in three bands of 5 holes each. River sand was used as filter material. The tiles were placed at an average depth of 0.87 m. The tail end of each pipe was connected to the bell mouth of the succeeding. The tiles were placed with the holes facing the trench bottom. The main water entry is through the annular space at the joints between the bell mouth and tail end of the pipes. The average total annular space was 53 cm² per m of the drain line. Rigid PVC pipes were used as collector drains to carry the drainage water into the main sump. The collector pipes were laid at 0.4% slope.

2.2 Technical feasibility of subsurface drainage

Technical feasibility of the system in the problematic acid sulphate soil was mainly assessed through the systems capacity to achieve sustainable crop growth though the improvement of soil quality.
2.2.1 Crop performance under drainage

Paddy crop was grown in the subsurface-drained area to evaluate the effect of subsurface drainage on the crop performance. The effect of drainage at any point was considered to depend on the perpendicular distance of that point from the drain. Randomized Complete Block Design (RCBD) was used to find the effect of drainage on crop in relation to the proximity to drains.

The standing crop was divided into strips of 2.5 m widths parallel to the tile lines. Thus, within the area of influence of a 15 m spaced drain line (7.5 m on either side), there were three strips each on either side. These strips were named T1 (0-2.5 m), T2 (2.5 m-5.0 m), and T3 (5.0 m- 7.5 m). There were 4 experimental lines in 15 m spacing and the total number of replications was eight. In order to compare the crop performance for each replication, eight control plots also were taken from areas where there was no influence of subsurface drainage, i.e. normal farmers’ practice. Thus for a 15 m tile line, there were four treatments [T1, T2, T3 and T4 (control)] and eight replications. Similarly, the 30 m drain line also was divided into strips of 2.5 m within its area of drainage influence (15 m on either side). There were six strips on either side of the 30 m spaced drain. These strips were named T1 (0-2.5 m), T2 (2.5-5.0 m), T3 (5.0- 7.5 m), T4 (7.5-10 m), T5 (10.0-12.5 m), and T6 (12.5-15.0 m). There were two experimental lines for 30 m spacing and the total number of replications was four. Control plots (T7) were taken in a similar way as for the 15 m spaced drains. Thus for a 30 m tile line, there were 7 treatments [T1, T2, T3, T4, T5, T6, and T7 (control)] and four replications.

The treatment and control plots were influenced by the usual surface drainage practiced by the farmers. The control plots were adjacent to the subsurface drained area and had no influence of the subsurface drainage. The treatment plots were drained every day for eight hours throughout the cropping period except for a few days during which fertilizers were applied. All non-labour inputs were supplied to the farmers so as to obtain a similar package of practice. The observations on growth parameters like height at maturity, number of plants/m², number of panicles/m², number of grains per panicle, grain yield, 100 grain weight, straw yield and chaff percentage were recorded.

2.2.2 Soil improvement under drainage

Drain out-flow from each drain was collected during cropping season for the first two years after the installation of the system to study the effect of drainage on improving the general soil condition. The parameters monitored were pH and EC of the leachate samples collected.

In order to assess the variation brought out by drainage on soil chemical properties, another experiment with three treatments, namely, 15 m spaced subsurface drainage, 30 m spaced subsurface drainage, and control where there was no subsurface drainage, was considered. In all the treatments, four locations were fixed for soil sampling. Wet soil samples at a depth of 0.5 m were drawn at four critical stages of crop growth, namely, germination, active tillering, panicle initiation, and after harvest, to assess the effect of drainage on different soil chemical parameters. The sampling locations were kept the same throughout the cropping season. The chemical parameters monitored were pH and EC of wet soil samples and Fe, SO₄, Ca, Mg, Na, K, and Cl concentrations after drying the same samples. Standard chemical analysis procedures were followed for estimating different ionic concentrations. The concentrations of different elements/radicle were worked out in ppm. Leachate samples were also collected during the same time from the drains. Mean values for each treatment was used to interpret the changes taking place in the field due to drainage and its resulting effect on crop growth.

2.3 Financial feasibility of subsurface drainage

The proposed layout of subsurface drainage for finding financial feasibility of a typical polder is shown in Figure 4. Baked clay pipes of 110 mm diameter and 60 cm length were considered as drain pipes and river sand as filter material. The drains are to be installed at an average depth of 1 m with 30 m spacing. The system consists of parallel subsurface drains of 100 m length each discharging into a secondary open drain. All secondary open drains are connected to a main open drain, which have their outlets at the periphery of the field and adjacent to the main water body outside. The drained water is pumped into these main water bodies with the help of two suitable pumping units located at the outlets of the main open drain.
Figure 4 Proposed layout of a subsurface drainage system suitable to the area

Based on the prevailing material and labour cost, the capital investment of the subsurface drainage system is worked out for a polder of 100 ha. The field experience obtained while installing the pilot system was the base in identifying the different cost and benefit components. The costs are worked out based on the actual expenditure incurred while installing the pilot system. The benefits are worked in terms of additional yield actually obtained during the experiment of paddy crop under subsurface drainage system.

2.3.1 Economic analysis
The economic analysis was done using discounting measures commonly applied to agricultural projects, namely, benefit-cost ratio, net present worth, and internal rate of return. The procedures given by Gittinger (1976) were used for the purpose.

2.3.1.1 Benefit-cost ratio (B-C Ratio)
The benefit-cost ratio is used almost exclusively as a measure of social benefit and most commonly for water resource projects. The important assumption to be made in computing the benefit-cost ratio is the discounting rate. The most appropriate rate is the opportunity cost of capital- the rate that will yield the most if all the capital were invested in all the possible projects. In most developing countries it is assumed to be between 8 and 15 per cent (Gittinger, 1976). In the present case, an opportunity cost of 12% was taken as the discounting rate. When the benefit-cost ratio is used to evaluate projects, the formal decision criterion is to accept all projects with a ratio of one or greater.

2.3.1.2 Net present worth (NPW)
Another way to estimate the worth of a project is to subtract the costs from the benefits on a year-to-year basis to arrive at the incremental net benefit and then to discount that. The net present worth can be determined by adding up the discounted incremental net benefit for the life span of the project. The same problem of choice of discount rate mentioned in connection with the B-C ratio arises also in connection with the NPW criterion. The formal selection criterion for the net present worth of a project is to accept all projects with a positive NPW when discounted at the opportunity cost of capital.
2.3.1.3  **Internal rate of return (IRR)**

The third way of measuring the worth of a project is to find the discount rate that makes the NPW equal to zero and the BC-ratio equal to one. This discount rate is termed the IRR and represents the average earning power of the money used in the project over the project life. Internal rate of return turns out to be a very useful measure of project worth. It is the measure, which the World Bank uses for practically in all its economic and financial analyses of projects, as do most other international financing agencies (Gittinger, 1976). The formal selection criteria for the IRR measure of a project is to accept all projects having an IRR above the opportunity cost of capital.

3  **RESULTS**

3.1  **Technical feasibility of the system**

Crop performance and soil improvement were considered to be the impact indicators for the technical feasibility of the sub surface drainage in the acid sulphate soils.

3.1.1  **Crop performance**

Many of the crop (paddy) growth parameters in the experimental area, particularly the grain yield and 100-grain weight were significantly superior to that of the control plot when subsurface drainage was provided. Spacing up to 30 m was found to significantly improve the productivity of the area (Mathew *et al*, 2001).

3.1.1.1  **Yield consistency**

Though all the crop growth parameters are equally important in assessing the efficiency of a subsurface drainage system, yield becomes the most important parameter when one has to assess the financial feasibility of the system. The yield data collected for 14 years after the installation of the system in the experimental polder is shown in Figure 5. The yield increase was consistent all through the years when subsurface drainage was practiced. The average increase in yield due to subsurface drainage was 1.10 t/ha equivalent to 42.52% over control.

3.1.1.2  **Soil improvement**

The study also revealed that the soil became uniform within two years of the installation of subsurface drainage, which could guarantee a uniform crop contributing to significant increase in grain yield. The study concluded that subsurface drainage was very effective in alleviating the deleterious effects of acidity, salinity and other toxic concentration of both cations and anions (Mathew *et al*, 2001). Thus it is concluded that subsurface drainage could effectively control the deleterious effect of acidity, salinity, and toxicity of various elements. The crop yield could be considerably and significantly increased after the introduction of subsurface drainage.

3.2  **Financial feasibility of the system**

On the basis of results of crop performance under drainage and also based on the actual cost involved in the installation of the pilot subsurface drainage system, an economic analysis was done for a hypothetic subsurface drainage system for a polder of 100 ha, assuming the area to be rectangular in shape. The layout of the proposed drainage system is given in Figure 4. The system proposed is an ideal one that can be installed in a polder in this region. The study on the crop performance under subsurface drainage in the acid sulphate soils of Kuttanad revealed that a drain spacing of up to 30 m could significantly increase the yield. A minimum increase in yield of 1.0 t/ha was expected when the crop is grown under subsurface drainage system. This assumption is based on the experimental results where an average increase in yield of 1.10 t/ha (based on 14 years data) was obtained when paddy crop was taken in farmers’ field with the additional input of subsurface drainage. It is assumed that the area can go for double cropping after the introduction of subsurface drainage system since each polder can be better managed through the proper network of drainage systems. Based on the actual cost incurred in installing the pilot system, an estimate of cost for the subsurface drainage system for a 100 ha polder was worked out and an economic analysis was made to assess its financial viability. It has been assumed that when the system is working properly, farmers can go for double cropping. The life expectancy of the system is taken as 20 years with no salvage value. Since the labour is costly in Kerala, the annual growth rate of cost was taken as 5% while that of benefit was 2%. All the costs and benefits were discounted at 12% to the present worth for each year during the life span of the project. An abstract of the analysis is given in Table-1. The B-C ratio was calculated by dividing the sum of the discounted benefits of each year during the life span of the project by the sum of the discounted costs for each year during the corresponding period. The NPW was calculated by adding the discounted net benefits for each year during the project period. Trial and error method was used to find IRR, the discount rate that makes the NPW equal to zero. Figure 6 shows the
The analysis showed that the project is economically feasible because a B-C ratio of 2.45 was obtained. Since the NPW is positive, Rs 5.17 million in this case, the project is acceptable on that measure too. Similarly, the IRR, which is 47% is far beyond the opportunity cost and hence the project is economically feasible.

### 3.2.1 Sensitivity analysis

There is a tendency in agricultural projects to be optimistic about potential yields especially when the information is based mainly on experimental trials. A test to determine how sensitive the project’s internal economic and financial returns are to lower yields may not only provide information useful in deciding whether to implement the project, but may also emphasize the need to assure proper extension services if the project is to yield as high a return as could reasonably be expected. Hence a sensitivity analysis was done to see how the IRR varies with the errors in yield-estimates. The discounting criteria were calculated for incremental yield increases of 0.1 t/ha starting from 0 to 1.4 t/ha. The expected variations are depicted in Figure 7. The relationship established between the IRR and the variations in the yield is:

\[
\text{IRR} = \frac{\text{increase in yield (t/ha)}}{x} \times (1)
\]

It could be seen that when the yield increase due to drainage falls to 0.41 t/ha, the IRR becomes the opportunity cost (Figure 7). It could be concluded that the subsurface drainage system is economically feasible in Kari lands if it can increase the yield by 0.41 t/ha from the present level. The analysis could also be sensitive to the price variations in rice, delay in implementation of the project and subsequent cost overrun. Since the prevailing market rates are used in evaluating costs and benefits, and the annual growth rate (2%) of benefits is kept less than the annual growth rate (5%) of costs, the analysis presented above is reasonable and could be used by policy makers, entrepreneurs, and private and public sector financial entities as a stepping stone for further critical consideration of subsurface drainage projects in Kuttanad.

### Table 1 Abstract of the economic analysis
Assumptions
Expected life of subsurface drainage system = 20 years
Annual growth rate of costs = 5 %
Annual growth rate of benefits = 2 %
Additional yield expected on introduction of subsurface drainage = 1 t/ha
Discount rate = 12 %

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<th>Capital Cost</th>
<th>O &amp; M Cost</th>
<th>Total Cost</th>
<th>Benefits</th>
<th>Discount Factor</th>
<th>Present Worth of Costs</th>
<th>Present Worth of Benefits</th>
<th>Cash Flow</th>
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<td>177674</td>
<td>1280704</td>
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<td>5497021</td>
<td>27408670</td>
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<td>8902011</td>
<td>19661650</td>
<td>5270777</td>
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Discount Rate: 0.12
Benefit Cost Ratio (B/C Ratio): 2.45
Net Present Worth (NPW): Rs 5,270,777/-
3.3 Production Constraints

High cost of cultivation, small size of land holdings, vagaries of the nature and migration of farm labourers to urban areas are the main production constraints in the region.

3.3.1 High cost of cultivation

The major items of expenditure required for the cultivation of rice in the study area for one hectare is given in Table 2 and the abstract of the cost is given in Table 3. On an average the rice cultivation in the study area is not profitable as seen from the tables. There is no other option except to cultivate, as the farmers are fully dependent on the produce from their small farms. The physical labour that the farmers’ put into cultivation (shown as farmer’s share in the form of job opportunity and security) is considered the major indirect income for the cultivation and is the solitary benefit they get through farming. Introduction of technologies not only for improving the productivity of the soil but also to decrease the cost of production is highly warranted in this situation.

3.3.2 Other constraints
Individual farming concept is not possible in this area as cultivation is done in polders and more than 90% of the holdings are marginal in size (<1.0 ha). Cooperative farming is the only option in which active participation and cooperation of all farmers are of prime importance for sustainable crop production. Paddy cultivation in the present set up is a gambling and most of the farmers do not have any alternate option except to cultivate. Crop failures are a common phenomenon. The cooperative set up is almost bankrupt and often fails to raise the minimum funds required for the infrastructure development for cultivation. The farmers are economically so poor to make the compulsory contributions required for farming activities in time and often fail to contribute. Financial shortcomings always lead to delay in farming operations. The best cropping period may lag behind or get advanced in the meantime and the crop suffers.

Migration of labour class into urban areas and to Gulf countries for better prospects is also seriously affecting the labour requirements in the area. The problem gets aggravated during the peak periods. Labour costs are also very high compared to the corresponding rates in other states. Marketing of paddy has also become a problem in the recent years. Organized marketing facilities are lacking and the monopoly of modern rice mills and the activities of their brokers are a hindrance for getting a fair price for the produce.

Table 2  Cost of cultivation per hectare of rice in Kari lands

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Item</th>
<th>Cost/ha (Rs)</th>
<th>Category of Expenditure (Rs)</th>
<th>Farmer’s share of labour (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Initial pumping &amp; outer bund consolidation</td>
<td>500</td>
<td>LP</td>
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<tr>
<td>2</td>
<td>Ploughing - Power tiller</td>
<td>1250</td>
<td>LP</td>
<td></td>
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<tr>
<td>3</td>
<td>Land Levelling</td>
<td>938</td>
<td>LP</td>
<td>150</td>
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<tr>
<td>4</td>
<td>Making interior bunds(@ Rs.150/- for man labourer)</td>
<td>750</td>
<td>LP</td>
<td>750</td>
</tr>
<tr>
<td>5</td>
<td>Seed (@ 50kg/acre)</td>
<td>1500</td>
<td>SD</td>
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<tr>
<td>6</td>
<td>Sowing</td>
<td>250</td>
<td>OT</td>
<td>250</td>
</tr>
<tr>
<td>7</td>
<td>Dewatering during cultivation</td>
<td>375</td>
<td>OT</td>
<td>375</td>
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<td>8</td>
<td>Weedicide (2-4 D) (@ 1kg/ha)</td>
<td>160</td>
<td>WD</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Weedicide -Application charge</td>
<td>250</td>
<td>WD</td>
<td>250</td>
</tr>
<tr>
<td>10</td>
<td>Quick Lime (@ 250kg/ha)</td>
<td>825</td>
<td>FT</td>
<td></td>
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<tr>
<td>11</td>
<td>Quick Lime - Application charge</td>
<td>150</td>
<td>FT</td>
<td>150</td>
</tr>
<tr>
<td>12</td>
<td>Fertilizer (90:45:45 N:P:K) kg/ha</td>
<td>1900</td>
<td>FT</td>
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<tr>
<td>13</td>
<td>Fertilizer - Application charge</td>
<td>200</td>
<td>FT</td>
<td>200</td>
</tr>
<tr>
<td>14</td>
<td>Hand weeding &amp; Gap filling</td>
<td>1125</td>
<td>OT</td>
<td>150</td>
</tr>
<tr>
<td>15</td>
<td>Threshing charge</td>
<td>875</td>
<td>HT</td>
<td></td>
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<tr>
<td>16</td>
<td>Labour charge during harvest</td>
<td>750</td>
<td>HT</td>
<td>375</td>
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<tr>
<td>17</td>
<td>Insecticide (if necessary)</td>
<td>400</td>
<td>PP</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Insecticide - Application charge</td>
<td>500</td>
<td>PP</td>
<td>500</td>
</tr>
<tr>
<td>19</td>
<td>TOTAL</td>
<td>12698</td>
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<td>3150</td>
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</table>

LP: Land Preparation; WD: Weed Control; SD: Seed; OT: Other Charges; FT: Fertilizer; HT: Harvest; PP: Plant Protection

Table 3  Abstract of cost of cultivation of paddy (per ha)

<table>
<thead>
<tr>
<th>Item</th>
<th>Expenditure, Rs</th>
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<tr>
<td>Land Preparation (LP)</td>
<td>3438</td>
</tr>
<tr>
<td>Seed (SD)</td>
<td>1500</td>
</tr>
<tr>
<td>Fertilizer (FT)</td>
<td>3075</td>
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</table>
3.4 Poor adaptability of subsurface drainage

Poor financial status of the farmers is the main adaptability constraint for the large-scale adoption of the comparatively capital-intensive subsurface drainage systems in the acid sulphate soils of Kerala. When 95% of farm-holding size is marginal (<1.0 ha), the question of individual farmer adopting subsurface drainage is remote. The benefits of drainage like soil improvement and improvement in the crop growth parameters like better grain weight are largely invisible. The increase in grain yield, though attributed to the overall improvement of soil due to drainage, is seldom realized as an outcome of drainage, as the total yield is nowhere near the yields obtained from elsewhere in Kuttanad where the acidity and salinity problems are non-existent. Moreover, drainage is not an essential input like irrigation for crop production and its benefits are often overlooked and not quantified. Cultivation is done against the vagaries of nature, which often becomes a gamble and further investments is a too much asking for these poor farmers.

Above reasons cannot be treated as negative for the adoption of subsurface drainage in these areas as rice can be the only crop that can be raised here. Population pressure and the inability to find alternate enterprises compel the farmers to cultivate. Hence there is a dire need to introduce technologies not only for improving the productivity of the soil but also to decrease the cost of production. Since it has been proved beyond doubt that subsurface drainage is technically and financially a viable proposition, governmental and financial institutions can play a major role in providing the infrastructure for the development of this region.

4 Conclusion

Rice is the staple food of the people of Kerala in India. Owing to its innate adaptation to waterlogged environment, rice can be the only food crop grown in the coastal tracts of Kerala. In the acid sulphate region of these coastal tracts, the potential of high yielding rice varieties is hardly realized due to poor drainage and inherent problems of the soils like high acidity and salinity. Introduction of subsurface drainage at 30 m spacing was found to significantly improve the productivity of the area. The yield increase was consistent for the last fourteen years after the subsurface drainage introduction. The average increase in the yield of paddy was 1100 kg/ha. Subsurface drainage was also very effective in alleviating the deleterious effects of acidity, salinity and other toxic concentration of both cations and anions. An economic analysis has shown that subsurface drainage is financially feasible with an Internal Rate of Return (IRR) of 47%. A sensitivity analysis done on the variation in the IRR due to the errors in yield estimates has shown that even an additional increase in the yield to the tune of 410 kg/ha could make the subsurface drainage a financially feasible proposition.

High cost of cultivation, low productivity due to inherent problems of the soil, small size of land holdings, vagaries of the nature and migration of farm labourers to urban areas are the main production constraints in the region. Though introduction of subsurface drainage can improve the productivity of the area, its large-scale adoption is not found to be forthcoming. Poor financial status of the farmers is the main constraint for the large-scale adoption of the comparatively capital-intensive subsurface drainage systems in the acid sulphate soils of Kerala. Since it has been proved beyond doubt that subsurface drainage is technically and financially a viable proposition, governmental and financial institutions can play a major role in providing the infrastructure for the development of this region. A polder wise demonstration of the system could be a prerequisite in the right direction.

5 References


[2] AICRP on Agricultural Drainage, Kerala Agricultural University, Karumady, Alleppey, Kerala 688 564, India. email: ekmathew@yahoo.com
ABSTRACT
Studies on cost effectiveness of subsurface drainage systems in controlling waterlogging and salinity were conducted by the Indo-Dutch Network Project at Konanki and Uppugunduru Pilot areas of Prakasam district, Andhra Pradesh, India. The study compared both the situations of before and after drainage covering sample sizes of 76 farmers and equal number of spouses of farmers to carryout analysis on Socio-Economic and Gender aspects respectively at each pilot area. The study focused on Socio-Economic changes which took place after installation of subsurface drainage systems. Gender issues were also documented for post drainage period. The post drainage data reflect the average of three years data from June 1999 – May 2002. The studies conclude that subsurface drainage system changes the land quality, increases cropping intensity and assets value and increases agricultural production. Women have developed positive attitude towards the subsurface drainage system and are encouraged by the direct and indirect benefits of the subsurface system which prompted them to venture investment on dairy enterprise. The economic analysis of system satisfied all the economic criteria, which are the B: C ratio to be greater than one, NPW to be greater than zero and IRR to be greater than opportunity cost. The benefits cost ratios, NPW and IRR are found to be 2.82 and 2.54, and Rs.36655 and Rs.50872 and 32 and 36 at Konanki and Uppugunduru respectively. The study concludes that subsurface drainage technology which proves to be a boon to the marginal and small farmers is cost effective under Indian conditions too.

Keywords: Cost, Socio-Economic, Benefit Cost Ratio, Gender, Drainage.

1 INTRODUCTION
Land is a limited factor of production which is responsible for prosperity of the country as it provides variety of services to the population. This limited factor of production has to be properly managed for sustainable agricultural production. The irrigation water enhances the land capacity to increase agricultural production by increasing the land use intensity. The cropping intensity boosts the agricultural production, provides more employment generation and increases the scope for more income generation directly. The indirect benefits from agricultural production are seen with development of agro-based industry in the countries, which contributes for the prosperity of nation that indirectly depends on agricultural production.

The first task of any government would be to make the valuable land into more productive by increasing the investments on irrigation sector. The irrigation brings prosperity to the farming community without any doubt especially in developing countries like India where 70% of population depends upon agriculture. Among the people who depend on agriculture, small (1-2 ha) and marginal (<1.0 ha) farmers constitute 80% of farming community in the Indian context. The irrigation water has to be managed more efficiently by the farming community for increasing agricultural production. The water management if not properly carried out by the farmers could bring untoward consequences to land quality. The twin problem which is interwoven is Water Logging and Salinity problems. This twin problem severely hampers irrigation investments in canal commands. This is mainly due to unplanned drainage system prevailing in many of the commands in India. The solution to overcome the problems of water logging and salinity lies with subsurface drainage system which is a proven technology to improve land quality and thus helps to sustain agricultural production.

The subsurface drainage technology is very important in Indian context as the valuable limited factor of production i.e. land, if damaged due to improper management of irrigation water would severely effect the socio-economic conditions of the farmers and consequently the standard of living of the farmers. Women are the first to be exposed to the consequences of the low agricultural production and the effect on women would ultimately affect the entire farm families.
Keeping this in view, the present study was conducted at two pilot areas of Indo–Dutch Network Project operated at Konanki and Uppugunduru in Prakasam district of Andhra Pradesh, India with the following objectives.

1. To study the Socio-Economic aspects of the pilot areas farmers both under pre and post drainage scenario.
2. To document the data on women perception towards subsurface drainage technology.
3. To evaluate economic feasibility of subsurface drainage technology.

2 METHODOLOGY

All the farmers of the pilot areas, thirty and forty farmers from Konanki and Uppugunduru respectively, were taken as sample units for the socio-economic study. The spouses of the farmers were taken for studies on gender aspects. The information on costs of the subsurface drainage system installation collected from the records of the project and benefits derived from the system were analysed to study the economic feasibility of subsurface drainage system.

Pre-tested designed schedules were used to collect primary data from the pilot areas farmers and as well as spouses of farmers for both pre and post drainage periods. The sample units were subjected to personal interview method to elicit the primary data. Simple tabular analysis technique was used for the purpose of analysis of the data. The pre drainage data refer to the 1997-98 year and post drainage data refer to the average of three crop years from June 1999 to May 2002.

3 RESULTS AND DISCUSSION

The results and discussions of the present study were presented under different appropriate heads for easy presentation and understanding.

3.1 Socio-Economic Characteristics

The socio-economic aspects of both Konanki and Uppugunduru pilot areas were presented parameter wise, in Table 1.

3.2 Number of Farmers

The information on number of farmers under pre and post drainage (Table 1) indicated that the farmer’s number increased under post drainage condition. The reasons mainly attributed were the increase in pressure on the land which led to abandoned land claimed by the legal heirs due to change in the land quality and the increase in Paddy yields. Accordingly average farm size was also decreased. This was the first social impact noticed which was mainly due to subsurface drainage system that changed the land quality favourably.

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<td>Number of farmers</td>
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<td>36</td>
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<td>44</td>
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<td>Average farm size</td>
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<td>Land value (Rs/ha)</td>
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<td>93.1</td>
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<td>176.3</td>
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</table>
### 3.3 Land Value

This economic parameter indicated that the land value would increase once the quality of land changed favourably for agricultural production. The land value on per ha basis in both the pilot areas has increased ranging from 100 to 125 per cent over pre drainage period. This is quite logical that subsurface drainage system brought radical changes in the land quality that helped the farmers to reap more farm produce than previously before the installation of subsurface drainage system. The same fact was endorsed by the farmers (Table 1) of pilot areas.

### 3.4 Cropping Intensity

The cropping intensity has also changed in both the pilot areas as the land quality changed favourably for agricultural operations and also the Paddy crop has established well during post drainage period. In some parts of both the pilot areas farmers have grown second minor important crop. The land quality improvement made it possible for the farmers to increase the cropping intensity. During the slack season the change in the land quality helped them to graze milch animals, as it was not the situation earlier as there was limited or no grazing land before installation of subsurface drainage system.

### 3.5 Returns

The information on returns from the pilot areas were recorded both under physical and monetary terms under pre and post drainage periods.

#### 3.5.1 Physical returns

The physical returns of the paddy on per ha basis (Table 1) have indicated that the yields of Paddy have increased by 52 and 48 per cent over pre drainage periods at Konanki and Uppugunduru pilot areas respectively. The interesting phenomenon noticed was that the yields under post drainage period were sustained over three years periods at the both pilot areas. The yield levels of pilot area farmers were compared to that of control area farmers whose lands were not treated with subsurface drainage system and normal area farmers where soils were not affected by water logging and salinity.

The results (Fig 1&2) indicated that the yields of pilot area farmers have increased over period of time and there was no change in yield levels of farmers the remaining two categories of farmers. The yields from pilot areas have crossed over the control fields and nearing to paddy yield levels of normal areas. The same trend was noticed at both the pilot areas.

The discussions with the farmers especially with marginal farmers revealed an interesting feature. The marginal incremental paddy yields of 10-15 bags in their farms brought a psychological happiness and it indirectly made them to develop a confidence in the life leading to some sort of social security.

Further discussions with the marginal farmers especially whose annual paddy returns from their marginal land was only 5 bags and which later improved to 10-12 paddy bags with reclamation of soils by subsurface drainage system technology, revealed that the additional paddy yields made them to plan alternative investment plans as their labour is saved and the additional farm produce created food security. Some farmers made additional investments in dairy enterprise as the green fodder availability increased from the fields and the farm families were very happy due to comfortable food security.
3.5.2 By-product
The By-product yields (Table 1) has also increased at both the pilot areas by 3 tons/ha between pre and post drainage conditions. There was change in fodder quality which was first noticed by the women and according to them the dry fodder became palatable to cattle with installation of the drainage system. The farmers are relieved from excess dependence on outside sources for dry fodder as their own fodder was sufficient enough to maintain dairy enterprise.

The indirect benefit derived by farm family with change in quality of fodder mainly is that the spouses of farmers got additional employment opportunities which increased their economic activity profile. This brought them a sort of individuality psychologically in the life.

3.5.3 Monetary returns
Monetary returns obtained by farmers in paddy production (Fig. 3&4) for both the pilot areas indicated that at Konanki the farmers were losing the money in paddy production before system installation and the returns realization has increased positively after system installation with reclamation of soils and the returns sustained over 3 years with little price risks. The results of Uppugunduru have also
indicated positive trend and benefit cost ratio of paddy cultivation has also indicated a favourable trend.

Figure 3  Monetary returns pattern in Paddy production under Pre and Post- drainage conditions at Konanki pilot area

Figure 4  Monetary returns pattern in Paddy production under Pre and Post-drainage conditions at Uppugunduru pilot area

3.6  Factor sharing
Information on factor sharing was analysed in production of Paddy (Fig.5). The expenditure on fertilizers and chemicals has increased by 9% at Konanki between pre and post drainage conditions while it was 3% at Uppugunduru (Fig.6). The labour contribution has indicated reduction by 6% at Konanki while it increased by 3% at Uppugunduru.

The fertilizer consumption has increased at both the pilot areas due to the reason that lands responded positively with reclamation of soils. The reduction in labour at Konanki was mainly due to the savings in paddy transplanting. Thus it can be concluded that subsurface drainage system also affects the cultivation expenses pattern with improvement in land quality to the farmers advantage.
1.1.1.3 Post-drainage

Figure 5  Factor sharing pattern in Paddy production at Konanki pilot area

1.1.1.1 Pre-drainage
3.7 Labour Utilisation

Labour utilization under pre and post drainage situation for men and women requirement were analysed for both the pilot areas (Fig. 7 & 8). The results indicated that men and women utilization reduced by 25% at Konanki respectively. The reason mainly attributed for reduction in labour utilization was the improvement in land quality and this helped the farmers to reduce the labour use in production of paddy on per ha basis. The Uppugunduru information indicated that men requirement was reduced marginally by 2 units while the women requirement was reduced by 13 in absolute terms. In terms of percentage the reduction was noticed by 5 and 11 for men and women respectively.
3.8 Gender aspects

Women’s perception towards subsurface drainage system on selected parameters were collected in view of the importance of women's role in agricultural economy. Women’s perception is very important for success of any technology. Hence due care was taken to analyze women’s involvement also in project implementation.

During the personal interview by the project staff, the women were appraised about the subsurface drainage system and probable benefits the farming community might derive in due course. There was spectacular positive change in the women perception during the period of project implementation towards subsurface drainage system.

3.8.1 Opinion on variation of income

The farm women opinion on selected parameters was obtained under post drainage period and the data indicated that the increase in variation of income was attributed by farm women mainly to Sub-Surface Drainage (SSD) system installation (60%) followed by weather (27%) and crop management (13%) at Konanki pilot area and similar trend was noticed at Uppugunduru pilot area (Table 2).

Table 2 Attributions to income variations on selected parameters (%)

<table>
<thead>
<tr>
<th>Situation</th>
<th>Konanki Pre-drainage</th>
<th>Konanki Post-drainage</th>
<th>Uppugunduru Pre-drainage</th>
<th>Uppugunduru Post-drainage</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSD</td>
<td>0</td>
<td>60</td>
<td>0</td>
<td>65</td>
</tr>
<tr>
<td>Crop management</td>
<td>60</td>
<td>13</td>
<td>55</td>
<td>15</td>
</tr>
<tr>
<td>Weather</td>
<td>40</td>
<td>27</td>
<td>45</td>
<td>20</td>
</tr>
</tbody>
</table>

3.8.2 Opinion on influence of Drainage System

The opinion of women on the influence of drainage systems on selected parameters was also obtained under post drainage situations (Table 3) at both the pilot areas. The analysis of the Konanki data indicated that drainage directly influences the incomes of the farm families (90%) followed by the influence on yield levels (70%), fodder quality improvement (80%) and land quality (50%).

The positive influence of drainage systems at Uppugunduru pilot area was also seen and the influence on yields were felt by 74% of farmwomen followed by income (70%), fodder quality (70%) and land (56%).

Table 3 Women’s opinion on influence of Drainage system on selected parameters at Konanki and Uppugunduru pilot areas (%)
3.9 Economic Analysis

The economic analysis of project for its economic viability is very important especially when the project is a long duration project with sizeable investments. The economic viability is viewed from the probable benefits that may be derived from the project and actual costs that are to be incurred in project implementation.

The economic viability is associated with satisfying the economic criteria namely discounted flow of benefits and discounted flow of costs, NPW of project at stipulated period and Internal rate of return. The B:C ratio should be greater than one, the NPW should be greater than zero and the IRR should be greater than the opportunity costs of the capital. The economic analysis of the drainage system for the recommended spacing of 60 m for both Konanki and Uppugunduru pilot areas was analysed and verified the economic criteria for the rehabilitating water logged saline soils. The analysis indicated that the system was viable economically at both the pilot areas as it satisfied all the criteria (Table 4).

The B: C ratio was arrived as 2.8 at Konanki and as 2.54 at Uppugunduru. The information on NPW was indicated as Rs. 36,655 at Konanki and Rs. 50,872 at Uppugunduru. The IRR was more than 32% at both the pilot areas with a pay back period of 3 years.

Table 4 Economic analysis of Drainage system with 60 m spacing at 10 % discount rate for 30 years life of the system

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Konanki</th>
<th>Uppugunduru</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-C Ratio</td>
<td>2.82</td>
<td>2.54</td>
</tr>
<tr>
<td>NPW (Rs.)</td>
<td>36655</td>
<td>50872</td>
</tr>
<tr>
<td>IRR (%)</td>
<td>32</td>
<td>36</td>
</tr>
<tr>
<td>Payback period (Years)</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

4 SUMMARY

The Subsurface drainage system installed at Konanki and Uppugunduru pilot area has brought in favourable socio-economic changes in the lives of the pilot area farmers. There was an increase in the land value and pressure on land with reclamation of waterlogged saline lands.

The Paddy yields have increased by 1.41 t/ha and 1.74 t/ha at Konanki and Uppugunduru respectively and the monetary returns are also increased.

Women’s perception towards subsurface drainage system has been observed to be positive at both the pilot areas.

The economic analysis of the system has satisfied the economic criteria at both the pilot areas.

5 CONCLUSIONS

The Subsurface drainage system is effective in reclamation of water logged saline soils.

The increase in crop productivity has brought favourable changes in socio-economic characteristics of farmers at both the pilot areas.
Subsurface drainage system has brought positive changes in women attitude.

The system satisfied all the economic criteria.

6 REFERENCES


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ABSTRACT

International Waterlogging and Salinity Research Institute (IWASRI) was created with the broad objective to conduct, manage and coordinate research on waterlogging and salinity. The Dutch Government, through its bilateral cooperation programme, provided support to IWASRI. With a long twelve years (1988-2000) cooperation, IWASRI research was carried out with the collaboration of International Land Reclamation and Improvement (ILRI) of The Netherlands. During this period IWASRI staff carried out many studies with the technical and financial assistance of ILRI staff. Shallow drainage can reduce the drainable surplus, reduce the need for irrigation supply and cost of installation. Evaluation of Pipe Drainage Systems showed that the field drainage design could be decreased from initial 3.5 mm/d to the value of 1.5 mm/d. Field experiments showed that geo-synthetic as drain envelope material could safely replace the usual gravel envelope materials. Use of synthetic envelopes were much more economical compared with the granular envelopes. Spatially varying drainage needs can be detected through application of groundwater modeling approach.

Due to O&M problems drainage benefits as expected at the time of design cannot be fully achieved. Farmers might be ready to pump from pipe drainage sump for irrigation, but they will not pump continuously for drainage. Good communication with the farming community throughout the project is essential for project success. There is lack of understanding to involve small farmers in the planning, design and O&M of system.

Interceptor drains and canal lining cannot prevent the need of installation of drainage system. Due to excessive operational cost, the interceptors do not justify the large investments.

Marginal and hazardous water can be used for reclamation of salt-affected soils with the application of gypsum/organic matter and leaching. The joint research conducted by IWASRI/NRAP Engineers/Scientists has improved knowledge and capabilities significantly. IWASRI research shows its value for money.

1 Introduction

The mandate of IWASRI is to conduct, manage, and coordinate research on the control of waterlogging and salinity. This includes work on related water management. In 1988 the Dutch Government, through its bilateral cooperation program started support to IWASRI. In the years 1988 through 2000, part of IWASRI's research was conducted in collaboration with the ILRI under the Netherlands Research Assistance Project (NRAP).

IWASRI is involved in many ongoing and planned drainage and irrigation projects. The range of subjects that are studied by IWASRI is wider than just the technical issues; such as: (i) Studies on drainage design criterion and operation and maintenance issues are carried out. Model studies are being done to save on expensive fieldwork and to be able to predict the effects of contemplated measures; (ii) Work on water quality and environment is being done which is increasingly important, because of the negative effects of pollution on agricultural production and health; (iii) Action research on farmer's participatory drainage is being conducted; and (iv) Farmers are also helped with the cultivation of salt tolerant vegetation and crops. In areas where reclamation is not feasible, the 'bio-saline' approach to impede waterlogging and salinity is being applied.
In 1995, the formation of the autonomous Provincial Irrigation and Drainage Authorities (PIDA's) was approved. This ultimately lead to the involvement of the water users in the management and operation of irrigation and drainage system of Pakistan.

An important goal of IWASRI is to ensure that all end-users, particularly the farmers, are informed on the practical use of the research results being generated. This involves conducting programmes of technology transfer, with inputs from a wide range of disciplines and the rural communities themselves. The concrete outputs of a research Institute are reports, papers, and published recommendations, and IWASRI started, from the early beginning, a series of publications. IWASRI Internal Report 2003/01 presents the impressive list of published material: about 191 Publications ('blue cover'), almost 363 Internal reports ('yellow cover'), and about 320 papers published in national and international Journals and Conferences Proceedings.

2 IWASRI-NRAP Joint Research and Lessons Learned

2.1 Drain Envelope Work

The drain envelope research originated from the initial construction problems in Fourth Drainage Project. It appeared that although the standard design specifications had been followed, the crushed rock used as envelopes did not satisfy the requirements in the field and lines became choked. Upon these problems research in both the field and laboratory was started, including work on the use of synthetic envelopes. After IWASRI research the use of synthetic envelopes is now accepted by designers and contractors. Lessons for future use are; (a) The earlier standard design rules for granular (gravel) envelopes did not apply for the very fine soils of the Indus Basin; (b) The subsequent IWASRI-NRAP research led to refinement of the design standards for the soils encountered in large parts of Pakistan; (c) Field experiments showed that geo-synthetic envelope materials could safely replace the usual gravel envelope materials for the prevailing soil conditions when properly designed and installed; and (d) Use of synthetic envelopes results in: (1) Less material cost in comparison to gravel envelopes; (2) Reduced construction cost because installation is faster; (3) Less logistic problems; (4) Easier quality control of pipe-laying.

The use of synthetic envelopes is expected to result in savings. In the project, about 800 km (500 miles) of drains have been laid, with 15% collectors and 85% laterals. The applied envelope material was gravel, with an assumed 0.15 m thickness around the laterals, and a thickness of 0.20 m around the collectors, in a 0.45 m and 0.6 m wide trench, respectively. This worked out, with a unit cost of gravel of US$ 19.7 per m$^3$ (FDP Design Memorandum) to US$ 3.25 M. The estimated cost for the synthetic is US$ 1.8 M. The savings to be obtained when using synthetics would be about US$ 1.4 M. Installation will speed up with synthetics as well by 25%: the trench box will be less wide, which implies a smaller excavation area. Quality control of pipe-laying is also easier with synthetic envelopes and this helps in improving construction quality.

2.2 Evaluation of pipe drainage systems

The cost of pipe drainage is high, and any possible savings should be realised. The evaluations of pipe drainage systems conducted by IWASRI have shown that the field drainage design discharge could be lower than its initial value. Two decades ago, the initial field drainage design discharge in Pakistan was chosen as 3.5 mm/d (East Khairpur), as there was no experience at all with pipe drainage. Now, research experience has advanced to the stage where 1.5 mm/d is acceptable as a starting point for design. FESS project was initially (early 1990s) designed for 2.7 mm/d, but IWASRI-NRAP could reduce it to 1.5 mm/d (IWASRI, 92/6). The Khushab SCARP drainage system, the last one before FESS, was designed at 1.8 mm/d, mentioning IWASRI work in its design report (EUROCONSULT-NESPAK, 1990). Similarly, Mardan SCARP was designed for a field drainage design discharge of 3 mm/d, but nearby Swabi SCARP, subject to similar climatic and other conditions, was designed at 2 mm/d, also referring IWASRI.

The savings that result from a lower drainage design discharge cannot be directly proportional to that reduction, but nevertheless an estimated indication of savings can be given. Assume that, for a certain area, two designs are made, one based on 3 mm/d and the other on basis of 1.5 mm/d: if the system designed for 3 mm/d has a drain spacing of 300 m, a system designed for 1.5
RESEARCH ASSISTANCE FOR IWASRI CAPACITY BUILDING

mm/d will have a drain spacing of over 500 m. This implies that taking a drainage design discharge of half the initial value will result in a construction cost that will be about one-third lower. Taking into account the investments in drainage during the last decade, this results in hundreds of millions of Rupees have been saved already. Pipe drainage systems, although more expensive, are better for the environment than tubewell drainage systems. Generally, the shallow groundwater quality in pipe drainage systems improves (or at least remains constant) whereas the deep groundwater quality does not improve. In areas drained by tubewells the trend is that effluent quality deteriorates, except near canals.

Pipe drainage systems have been evaluated to show both ‘technical’ and ‘socio-economic’ benefits, including: (1) Controlled the water table; (2) Decreased soil salinity; (3) Increased crop yield (wheat and sugarcane); (4) Decreased abandoned land area; (5) Increased cropping intensity; (6) Increased income, with households in non-saline areas better off in terms of assets; (7) Improved situation for women, landless and tenants (livestock conditions also improved); (8) Decreased workload for women; (9) Enrolment of children (aged 5-15 years) is significantly higher in non-saline area than in saline area, with boys better educated than girls; (10) Improved drinking water quality in the villages where the drainage system is working continuously; (11) Re-immigration towards the farms after reduction of waterlogging and salinity. There is an urgent need for better maintenance of drainage as well as farmers’ participation and co-operation to own it.

2.3 Operation and Maintenance (O&M point of view)

Most of the systems require pumping due to flat areas. The O&M of such systems remains difficult because of financial and technological difficulties. The Government of Pakistan cannot continue to fund the O&M of the entire irrigation and drainage system, in conditions where, for instance, in the fiscal year 1992, the operation of tubewells in the Punjab absorbed more than 50% of the available O&M funding, even though the wells were operated on a very limited basis. Also, in Sindh, the cost of operation of the LBOD drainage system is more than the Government can budget: the annual cost for O&M amounts to Rs.600 million (1993 prices, equivalent to about US$ 20 M), with a construction cost of Rs.24,000 million (US$ 800 M).

Formally, operation and maintenance of drainage systems is to be taken care of by the Provincial Irrigation Departments, a few years after completion of the systems. However, these Departments do not receive additional funds when they are handed over the additional charge of O&M of the drainage systems, and therefore, the systems could not be operated and maintained as necessary. This is among the main problems of drainage management in Pakistan where the surface drainage system is not functioning properly due to poor maintenance. Similarly, operation and maintenance of drainage tubewells and pipe drainage systems (where pumping is needed) is not done as per design criteria. The main reasons include lack of sufficient funds; power failure; mechanical problems; lack of farmers’ cooperation. Due to this very often the drainage benefits expected at the time of design cannot fully be achieved.

The role of the surface drainage system in groundwater drainage is neglected in Pakistan. One of the first actions (during 1994/5) in the construction of Fourth Drainage Project was the cleaning (desilting) of the open drainage system. The subsequent groundwater table drop indicates the enormous influence that surface drains have for groundwater drainage, provided at proper depth and with design capacity.

The Government cannot continue to inject funds into irrigation and drainage projects forever and the users will have to pay their share as well. Preferably, and that seems to be a growing consensus now in Pakistan, should the both main systems of irrigation and of drainage be managed by the Government. Somewhere in between, the users of the system should become involved in the management. The GOP has plans and policies ready in this direction (NESPAK/MMI, 1995). PIDA's, Provincial Irrigation and Drainage Authorities, are becoming autonomous bodies to manage the system.

However, we cannot expect too much of this 'social approach' in a short time. Farmers might be ready to pump for irrigation, but they will not pump ‘continuously’ for drainage. The resource base of the small farmers is very narrow. Small farmers cultivate about 45% of the land in Pakistan. They typically have a farm size of less than 5 acres and they have virtually no own resources. Moreover, they are even offered lower than market prices of Pakistan for some of their produce, or have to pay water cess when
not even receiving canal water. Pakistan market prices are much lower than the international market. Sincere involvement of farmers takes time. This is what we experience in the recent IWASRI/NRAP 'Participative Approach to Drainage' work. Several current, hurried, attempts to promote 'participative' approaches in on-farm drainage have little chance of real success quickly. Even with a functioning main drainage system, and a favourable attitude of users and bureaucracy, it would be time-consuming. There seems to be, at decision-taking level, a lack of understanding of what it takes to involve farmers, especially with the objective to involve farmers in the planning, implementation, and O&M of drainage systems.

2.4 Interceptor Drains

Seepage from the irrigation canals is considered the major cause of waterlogging in Pakistan. And because of this, seepage reduction measures as interceptor drains and canal lining have been proposed and installed in several systems in Pakistan. An interceptor drain is a drain (either an open ditch or a buried pipe) to intercept seepage from a neighbouring parallel canal or stream. Such drains can be installed on one side (as often in sloping land) or on both sides of the canal (as usually in flat areas).

The reasoning behind recharge reduction measures is that if seepage is the main cause of waterlogging, prevention or reduction of that seepage should eliminate or reduce the waterlogging. The purpose of the IWASRI-NRAP research into interceptor drains was to investigate those for their effectiveness in reducing drainage requirement. The effect of interceptor drains was studied at several locations in three irrigation systems in Pakistan: along the Chashma Right Bank Canal, in the Fordwah Eastern Sadiqia South Project, and in the Left Bank Outfall Drain project.

Interceptor drains were installed for one or more of the reasons: (a) To intercept a significant part of canal seepage to reduce drainage requirement of adjacent lands; (b) To relieve an area from waterlogging due to a canal; (c) To provide supplemental water for irrigation; and (d) To have a beneficial effect on the stability of side-slopes of a canal. Interceptor drains are usually the upstream and downstream lines (parallel to the canal) connected to a sump from where the water is pumped. The idea is that the pumped water is the seepage from the canal and the most important performance parameter for an interceptor drain from the viewpoint of seepage interception is the percentage net interception:

A review of literature gave a percentage of net interception of about 30% (including both flat and sloping lands). In 1977, WAPDA electric analog model study to test the feasibility of interceptor drains for the FESS area gave a percentage net interception of 34%. The results of that study showed that the seepage were more than double due to the construction of the interceptor drains. This implied that to recover 0.5 cusec net, 2.7 cusec had to be pumped, which would be very inefficient. Moreover, there will only be a net recovery of seepage when more water than the induced seepage is pumped back into the canal. However, when the farmers locally use all discharge of the interceptor drain sump, we actually have increased the seepage from the canal, which implies even greater suffering for tail-end farmers. To prevent any decrease of water availability to tail end farmers, at least the quantity of induced seepage should be pumped back. For the study discussed here, this implied that only half of what would be pumped could be used for supplemental irrigation. In FESS, the estimate of net intercepted seepage of the trial drain along the Malik branch (FESS) was 19%, on the basis of a seepage measurement (by ponding test) and the measured discharge of the drain.

In the design of a drainage system often rules-of-thumb are applied to estimate the values of components of the water balance of the system to be drained, in the absence of measurements. An example of such estimations for the Fourth Drainage Project (FDP) near Faisalabad in the Punjab, Pakistan. The rules-of-thumb estimates a contribution of canal and distributary losses of 0.45 mm/d. The expected relative contribution of the various components of the need for drainage: the losses of canals and distributaries are a part of the total recharge to groundwater. The data arrive at an overall 0.45 mm/d "seepage contribution" to the recharge.

The decades-long record from an automatic water level recorder in Dunga Bunga (FESS) shows that the rise of the groundwater table in FESS has been highest in the period of 1950 to 1960. That rise is about 6000 mm in 10 years, which is an average of 1.6
mm/d. With an assumed specific yield of 10% this actually implies an average total net recharge (from the entire irrigation system and rainfall) of 0.16 mm/d. Also the measurement of seepage by IWASRI in the FESS area points to far less seepage than the rules-of-thumb seem to suggest, that the average seepage value for the smaller canals is about 3% of their inflow. For the Malik Branch canal it was 1% of the inflow. Let us assume that the average for all canals is 2% of the inflow. The initially planned water duty for the area was 3 cusec/1000 acres (1.8 mm/d), but may have increased since the commissioning of the Mangla Dam to 5 cusec/1000 acres (3 mm/d). If the seepage from the canals is about 2% of the inflow, and we take the higher value of 3 mm/d for the inflow, the ‘seepage contribution’ to the recharge will be 0.06 mm/d.

Both the values of 0.16 and 0.06 mm/d are lower than the assumed 0.45 mm/d. But let us, nevertheless, assume that the seepage conditions in the FESS area are the same as in the FDP area and that the canal seepage contributes 0.45 mm/d to the ‘drainage requirement’ of the area. The chosen field drainage design discharge for FESS is 1.5 mm/d of which the 0.45 mm/d is about 30%. It could then be argued that, if all seepage could be recovered, the drainage requirement could be taken 30% lower. If, however, only a part of the seepage can be recovered, the possible reduction will be less. If the net interception of seepage would be 33%, the possible reduction in the field drainage design discharge could only be 10%, from 1.5 mm/d to 1.35 mm/d. Because drain spacing is proportionate to the square root of the design discharge, the spacing could then only be increased by 5%. This implies that if the net interception of seepage is about 30% in real-life practice, the influence of interceptor drains on the drainage requirement of adjacent agricultural land would be marginal. However, because the seepage is far lower than the rules-of-thumb suggest the influence of interceptor drains on the reduction of drainage requirement in FESS will be negligible.

The results of the studies show that the net percentage of intercepted seepage was too low to have a significant effect on the drainage requirement. Besides, the operation of the system, with pumping required, is an added headache for the institution responsible for operation of the system. The total cost budgeted for interceptors in FESS was about US$ 20 M. The IWASRI research results point out that interceptors should not be used as a standard measure to recover seepage from canals.

The research results on interceptor drains came, in fact, just in time to have a bearing upon the thinking on their use for reduction of drainage requirement in FESS. The interceptor drainage studies have shown that in conditions of deep, permeable, aquifers and flat lands, as in the Indus plain of Pakistan (and similar conditions elsewhere), their effectiveness in intercepting seepage is low, less than 30%. To expect that operation of one or two drain lines parallel to a canal would at least partly solve the drainage problem of an entire area would indeed be expecting too much. Another important factor is that due to the Indus plains being very flat, drainage has to be pumped. Installation of interceptor drains in FESS as planned, would have led to enormous recurrent operation cost, in conditions when the cost of operating tubewells in the Punjab absorbs more than 50% of the available O&M funding.

Ponding tests on the Malik Branch canal were carried out because a high seepage volume was expected from the canal. The result, however, shows low seepage rates: 0.27 m/d (0.9 ft/d) in the head reach to 0.04 m/d (0.13 ft/d) for a downstream reach, commensurate with about 1% of the inflow at the head. Based on these results, the plans to line a part of the Malik branch were abandoned.

2.5 Groundwater Modelling Approach to Drainage Design

It appeared to be impossible to make a water balance of a sump in FDP. The area of influence of a sump turned out to be beyond its physical limits. The reason for this was the highly permeable, phreatic, aquifer. Upon this observation the joint IWASRI-NRAP groundwater study started. The developed approach is a combination of ‘inverse’ modelling (finding recharge from known water table elevations) and the ‘decomposition’ approach (finding recharge from deduction of losses from rainfall and head deliveries). The seasonal net recharge values based on the decomposition approach were ‘tuned’ with the inverse modelling results. This has an advantage that all recharge and discharge components are looked at in an integrated way.

Application of the groundwater model approach as an addendum to drainage design, enables the detection of spatially varying drainage needs, which was previously impossible. For FDP, such a study was carried out. The model operates on basis of 32
nodal areas, selected on basis of groundwater level observations. The size of these nodal areas varies from 0.3 to 3.0 km², with an average size of 1.6 km². The total model area extended over some 66 km². In the actually implemented drainage system for FDP, drainage is installed in 21 nodal areas. The IWASRI results show that only 11 of those areas are in urgent need of drainage. Such results indicate that the application of this approach has enormous savings potential. Application of the groundwater approach, as an addendum to drainage design, enables the detection of spatially varying drainage needs. The ‘tuning’ procedure that is part of the developed approach gives the advantage to check on the rules-of-thumb used for estimation recharge from rainfall and the irrigation water supply system.

2.6 Participatory Drainage Pilot Study
IWASRI-NRAP entered into a partnership with an NGO with a long-term perspective and probable sources for long-term funding for farmers', participatory drainage. Good and clear communication with the farming community is essential. This includes training on drainage. The benefits of the participatory drainage system include higher yields (except for rice) and a larger area cultivated. The farmers seem ready to pump for irrigation but they will not pump ‘continuously’ for drainage. The outlook of IWASRI staff on the participatory approach to drainage has been significantly influenced. Even with a well-functioning main drainage system and a favourable attitude of users and bureaucracy, application of the participatory approach to drainage would be time-consuming. There is, at decision-taking level, a lack of understanding of what it takes to involve small farmers in the planning, implementation, and O&M of drainage systems.

The cost of the system was Rs.3,180,863 for 112 ha. This is equal to a very reasonable Rs.28,400 per ha (with 1 US$ equal to Rs.54, this implies US$ 526 per ha). The contribution of the farmers, including e.g. labour and foregone crop compensation, amounts to Rs.212,100.

3 Capacity Building of IWASRI
NRAP provided assistance for human resources development, provision of office and laboratory/field equipment and upgradation of IWASRI Library.

3.1 Training
Higher Education
NRAP funded for 49 participants for training/short courses in national/international institutes, such as: (i) Short courses=34 (ICID=20, Others=14); (ii) MSc/M.Phil=13 (National=8, International=5); (iii) Ph.D.=2 (National=1, International=1).

Participation in Seminar/Workshops/Symposia
NRAP also funded 76 participants for seminar/workshops, 20 for national and 56 for international participation in various events.

GIS training
NRAP also funded for 7 participants in GIS Training 4 participants in National and 3 in International Institutes.

3.2 Computers, Equipment (Laboratory and Field)
NRAP provided funds for 8 computers and laboratory and field equipment, like drain envelop testing equipment and material, watertable recorders, tensio-meters, silicon kit etc.

3.3 Library
A local training on library management was sponsored by NRAP and Software “DRAIN” was also provided for cataloguing and quick reference and maintenance of record. Technical books/reports/journals were sponsored by NRAP.

4 Conclusions
4.1 Research not disseminated is research not done
If there is one overall Lesson learned, it is that research not published is research not done, and likewise, research not disseminated is research not done. It appears necessary to continuously discuss the findings of research and field trials. The country has invested billions of Rupees to manage and improve land and water. The experience at IWASRI has made it very clear that a modest investment in research could yield large benefits. We should also not forget that lessons are also learned at several other places as, for instance, in ongoing implementation projects. The lessons learned there are often also valuable. The fact that research has considerable benefits does not automatically imply that research will make the required efforts cheaper. But, the investments will be more effective, more sustainable and directly targeting whatever areas are in need of investment.

4.2 Capacity building with joint research
The joint research of the last 12 years (1988-2000) has significantly increased the knowledge and capabilities of every engineer and scientist involved. The Project Purpose of the later phases of IWASRI-NRAP was enhanced technical and social research capacity to combat waterlogging and salinity. Without doubt this has been achieved to a great extent.

4.3 Benefits of research
It will always be difficult to quantify the direct benefit of research in monetary terms. Realizing that potential savings, in hindsight, as well as actually saved expenditure by a better design, is not cash in hand, but we are confident that the IWASRI research shows that it is value for money. The cost of having a partner like IWASRI is more than justified.

4.4 Impact of a research phase in an ongoing implementation project (FESS)
The Fordwah Eastern Sadiqia South Irrigation and Drainage project is unique because it is the first-ever project that started with a research phase in which obvious improvements were implemented in the area, but in which also the effectiveness of certain measures, and the necessity for these measures could be investigated. This led to great advantages because it prevented ineffective or unnecessary investment. The research results on the benefits of interceptor drainage for reduction of drainage requirement have, for instance, been achieved within the framework of the first phase of the FESS project. The impact of the FESS research results include the considerably adjustment of the plans for the lining and interceptor drainage component. The areas in urgent need of drainage have been identified. The approach chosen for the FESS project is extremely useful because it makes a project more flexible. Issues not considered during the planning of the project, for whichever reason, can be accommodated relatively easy.

5 Recommendations
It is further suggested to study; (1) Model runs to replay conditions at already installed interceptor drains, for investigation of: (i) seepage from canals; (ii) net interception of seepage at interceptor drainage sites; (iii) possibility to control the water table adjacent to the canal; (2) Continued monitoring of pilot areas and existing systems for possible refinement of the design discharge; (3) Social impact assessment of drainage; (4) Width of influence of large open drains; (5) Influence of maintenance of open drains on groundwater table; (6) Improved methods of maintenance of surface drains; (7) Quantification of the impact of the choked surface drainage system on waterlogging.

6 REFERENCES
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Abstract

Over the last fifty years, numerous efforts have been made to alleviate poverty in Pakistan through investments in drainage sector for restoring the waterlogged and salt-affected lands. These investments include construction of 15,000 kilometers long surface drains, installation of 14,000 deep public tubewells and more than nine pipe drainage projects. The total investments made in these projects were over half a billion US dollar. In the past, the impact evaluation studies of these projects were focused on the estimation of areas where ground water tables were lowered and salt-affected lands were reclaimed. However no serious attempt has been made to evaluate the impact of these drainage projects on socio-economic conditions of the farmers and to alleviate poverty in these areas. As a result, social benefits of these investments remained undiscovered.

This paper aims at analyzing the impact of these drainage projects on socio-economic conditions and the role these projects have played in improving livelihoods of the rural poor. The results revealed that these projects have contributed substantially in improving land conditions, which in turn has enhanced the agricultural productivity; thereby increasing farm incomes. Resultantly, in the previously waterlogged areas, head count poverty has decreased from 20% to 14%. The reduction in head count poverty in previously saline areas is noted at 10%. The study suggests that for the true evaluation of the impacts of these drainage investments, all physical, technical, social and environmental benefits should be taken into consideration.

Keywords: Drainage, Poverty, Waterlogging, Salinity, Socio-Economics, Environment, Health, Farmers, Pakistan

1 Introduction

Presently, the escalating pressure on land and water resources for providing food and fiber to the ever-increasing population is of main concern for policymakers. Both the water resources and the land base supporting irrigated agriculture are becoming scarce and degraded. Improper irrigation methods and practices are causing waterlogging, soil salinity, soil erosion, and water pollution problems. UNEP (1992) recently reported that the rate of loss of irrigated lands from waterlogging and salinity is 1.5 million ha per year. Millions of hectares of irrigated land, from Morocco to Bangladesh and from northwestern China to central Asia, suffer from this progressive condition. Salt-affected lands, as a percentage of total irrigated area, is estimated to be 10 percent in Mexico, 11 percent in India, 23 percent in China and 28 percent in the United States (Umali, 1993). The best estimates indicate that roughly one third of the irrigated land in the major irrigation countries is already badly affected by salinity or is expected to become so in near future (Gleick, 1993 and Ghassemi et al. 1995).

The total land area of Pakistan is nearly 197 million acres, while the population growth rate is 3.1 per cent annually. However, due to non-agricultural uses, waterlogging, and salinity, our current and potential agricultural land is reducing and shrinking tremendously, thereby increasing poverty in irrigated agricultural areas. It has also been estimated that throughout the country, everyday approximately 202 hectares of farmland is taken out of agriculture by the expansion of settlements, roads, factories and other non-agricultural activities. It is predicted that if this trend continues then after every decade approximately 0.4 million hectares or more of cropland would be taken out of agriculture in our country (Alam and Khan, 1999).

Over the years, about forty percent of the irrigated cropping land in Pakistan, which produces around 90 per cent of the total agricultural output of the country, has come under waterlogging and salinity. In Pakistan, before the start of weir controlled irrigation system, the agriculture was practiced on inundation irrigation system. Watertable in irrigated areas was below 15m from ground surface. Later on, with
introduction of weir controlled irrigation, which at present consist of 4230 km main canals, 6835 km branches, 25874 km distributaries, 19189 km minors and 110,000 km watercourses, the seepage from this huge conveyance system and the field application loses resulted in waterlogging and salinity problems (Mirbahar, 2000). Figure 1 shows that the changes in areas from 1978 to 1998 with depth to watertable above 1.5 meter ranged from 9.0 to 18.3 percent –waterlogged area (adopted from Kahloun and Majeed, 2002).

Figure 1  Historical trend of waterlogging in Pakistan.

About 6.17 million hectares of lands (about 28 percent of CCA) are salt-affected in Pakistan. Province-wise salt-affected lands are 2.66 million hectare in Punjab, 2.11 in Sindh, 0.048 in NWFP & FATA and 1.35 million hectare in Balochistan, out of which about 1.96 million hectare is very severely saline, 2.38 million hectare is severely saline, 1.23 million hectare is moderately saline and 0.598 million hectare is slightly saline in nature (Alam and Khan, 1999). Figure 2 shows the historical trend of the extent of surface salinity soils in Pakistan (WAPDA, 1981 and GOP, 1999). The magnitude of the problem can be gauged from the fact that the area of productive land was being damaged by the salinity at the rate of about 40,000 hectares annually (Alam et al., 2000).

Over the last fifty years, numerous efforts have been made to alleviate poverty in Pakistan through investments in drainage sector for restoring the waterlogged and salt-affect lands to start agricultural activities. These investments include construction of 15,000 kilometers long surface drains, installation of 14,000 deep public tubewells and more than nine pipe drainage projects. The total investments made in these projects were over half a billion US dollar. In the past, the impact evaluation studies of these projects were focused on the estimation of areas where ground water tables were lowered and salt-affect soils were reclaimed. However no serious attempt has been made to evaluate the impact of these drainage projects on socio-economic conditions of the farmers and to alleviate poverty in these areas. As a result, social benefits of these investments remained undiscovered. Therefore, this study was conducted at analyzing the impact of these drainage projects on socio-economic conditions and the role these projects have played in improving livelihoods of the rural poor.
Effects of Waterlogging and Salinity

2.1 Social and health effects

Social, cultural and economic aspects of a community are adversely affected, due to waterlogging and salinity conditions. A survey in the Satiana area near Faisalabad, in the Pakistan Punjab (Ijaz and Davidson, 1997), showed that in salt-affected villages 56% of men and 91% of women were illiterate, compared to 51% and 77% in normal villages (Figure 3).

Health problems for human and cattle occur, as a result of salinity. Some species of mosquitoes thrive on saline ponds. Water quality in salt-affect villages is generally poor with high salinity levels (greater than 1,000 mg/l TDS). Consumption of such water for drinking cause
stomach-relates diseased. Skin rash is also related to the usage of saline water. People in salt-affected villages had worse access to basic health-care, with only 1 out of 8 villages in the area having access to basic health facilities. The ownership of household goods like refrigerators, televisions, radios and fans was substantially less in salt-affected villages. Crumbling of houses is common. Female population comes under greater stress, due to the pressures of salinity. It has also been reported that, salinity has severe impact on communities and decreases the health and life expectancy of females (Mughal, 2002).

2.2 Economical effects
The share of the agricultural sector in the Gross Domestic Product (GDP) of Pakistan is about 24 percent (Kahlown and Majeed, 2002). Waterlogging and salinity rob Pakistani farmers by exerting 25 percent reductions of major crops (Shah et al., 2001). In Sindh province, these reductions are closer to 40 – 60 percent (World Bank, 1996). Agricultural losses in Pakistan due to waterlogging and salinity are around US$28.5 million annually, while annual economic damage is estimated at US$300 million (Haider, 2000). Based on a 1995 estimate, the annual economic cost of water pollution related health issues ranged from US$460 million to US$1.25 billion, while air pollution related health costs ranged from $250 million to $369 million (ADB, 2003).

Since 1950s, Pakistan began to sink wells to pump out groundwater. The initial capital costs were high and operating costs have been increasing constantly. Between 1971 and 1985, the cost of managing the wells and drains rose fivefold. Today, Pakistan spends more on reclaiming land than on irrigation. The cost of maintaining drains is five times the recurrent costs of supplying water and most farmers pay only half the costs of delivering irrigation. Policymakers are now arguing that with the rise in value of irrigation water, the management will improve and much of the wastage, which creates unhealthy conditions as well as increased drainage requirements, will also be reduced. Farmers may then be willing to pay for a drainage service that makes their investments sustainable (FAO, 2003).

3 Investment in Drainage sector
To arrest and reverse the process of waterlogging and accompanying salinity problem, the Salinity Control and Reclamation Projects (SCARP) was launched in 1960. At present, the total drainage area in the country is estimated at 5.17 Mha (IEPSAC, 2001). In addition to SCARP tubewells, there are surface drainage systems and horizontal subsurface drainage systems in the country, as well. Surface drainage system is now covering 15476 kilometers length in the country, of which 7326 kilometers are in Punjab, 5980 kilometers in Sindh, 1990 kilometers in NWFP and only 160 kilometers in Balochistan (Zahra, 2000). Main surface drainage system include: (i) Left Bank Outfall Drain (LBOD), (ii) Right Bank Outfall Drain (RBOD), and Fordwah Eastern Sadiqia South (FESS). Eight horizontal subsurface drainage systems have been completed at: (i) East Khairpur, (ii) Mardan, (iii) Faisalabad, (iv) Chasma, (v) Bahawalnagar, (vi) Swabi (Farooq et al., 2000).

Under SCARP, some 15,000 large deep tubewells (of 60 – 150 l/s capacity) were installed to control waterlogging, and to supplement canal water supplies to about 9.3 Mha area of gross command area of 16.85 Mha. Figure 4 shows the distribution of SCARP tubewells in various provinces of Pakistan (IWASRI, 1991). About 75 percent of all SCARP tubewells were installed in Punjab. These SCARP tubewells were pumping about 12.33 BCM annually (Shah et al., 2001 & Haider, 2000). These wells were constructed at a cost of Rs. 70 billion.

The scheme brought a green revolution and ushered to an era of prosperity till 1980s. The area under cultivation became more than doubled during this period and per hectare yield of all major crops registered a marked increase, giving a boost to the financial condition of farmers. The scheme was extremely economical as the farmers had to pay only the usual abiana (water charges) and no electricity bill. But the things started deteriorating in the late 1980s due to inadequate funding and subsequent deferred maintenance by the public sector.
Figure 4. Number of SCARP tubewells in various provinces in Pakistan.

Figure 5. The historical trend shows O&M expenditures on public tubewells in Pakistan (adopted from IWASRI, 1991).

Additionally, many SCARP tubewells have to close due to pumping hazardous quality groundwater that exacerbated salinity and sodicity.
problems. Therefore, with declining performance of SCARP tubewells, depth to watertable started to rise again. In 1996, in the Indus Basin, the depth watertable was within 1.5 meters –waterlogged, on 5.3 Mha (12.9% of GCA), and around 0.32 Mha (2% of GCA) was having depth to watertable within 1 meter from the ground surface –severely waterlogged (Haider, 2000). Most recent estimates showed that about 30 percent of the GCA in the Indus basin was waterlogged, and 13 percent was severely waterlogged (Shah et al., 2001).

Pakistan used the SCARP strategy to deal with the crisis but it was an expensive option. Attacking the twin menace is a massive undertaking and the international donor agencies have made 27 irrigation loans or credits to Pakistan for a total of US$ 1305 million. Nine of these, having worth of US$ 457 million, were principally for drainage systems. Nevertheless, the problem is far from having been solved, and Pakistan continuous to lose almost as much irrigated land each year as it gains from drainage investment (World Bank, 1997).

Impact of Drainage Investment on Poverty Alleviation

4.1 Reducing waterlogging and salinity
Figures 6 & 7 show the some success stories of these SCARP tubewells of selected SCARP projects (IWASRI, 1991). It lowered the water table to below 1.5 meters in 2.02 Mha, and below 3 meters in 4.05 Mha and thus alleviated the problem of waterlogging significantly. It also reduced the salt-affected lands from 7.0 Mha to 4.5 Mha.

4.2 Increasing cropping intensity
Drainage investment did not only reduce the waterlogging and salinity in the area but also improved the agronomic condition of the area. For example, Figure 8 shows a significant increase (from 60 % to 170 %) in the cropping intensity as a result of SCARP projects (IWASRI, 1991).

4.3 Reduction in overall poverty status
Although, poverty considerations were not given a high priority in the SCARP projects, however, these projects helped in alleviating poverty through their effects on farm production by reducing waterlogging and salinity in the project areas (GOP, 2002; Ahmad, 1994; Kahlown and Mujeeb, 2002). Figure 9 and 10 show the relationship of head count poverty (rural poverty) with the waterlogging and salinity. There is a clear trend of poverty reduction with decreasing waterlogging and salinity trends.
Conclusions and suggestions

It is unfair to criticize drainage investment for failing to achieve their designed objectives. Drainage projects have contributed substantially in improving land conditions, which in turn has enhanced the agricultural productivity; thereby increasing farm incomes. Resultantly, in the previously waterlogged and salt-affected areas, head count poverty has decreased significantly. Therefore, it is suggested that for the true evaluation of the impacts of these drainage investments, all physical, technical, social and environmental benefits should be taken into consideration.
Throughout the human history men had learned lessons from their mistakes. In the past, the farming communities were not involved at any stage of the drainage projects, and therefore they did not play any physical, financial or management role. This put pressure on the public sector in providing continuing support for operation and maintenance of these projects. Thus, the transition of SCARP projects from public sector to the farming community was the right decision. However, the concern regarding the implementation of this policy is how well this transfer may take place so that any possible losses in terms of equity, sustainability and productivity can be minimized.

Figure 9. Salinity and head count poverty (rural poverty) trend in Pakistan.

Figure 10. Waterlogging and head count poverty (rural poverty) trend in Pakistan.
The Provincial Irrigation Departments (PIDs) should divert some of their resources into promoting networking activities among various stakeholders of irrigation and drainage systems. With the implementation of the National Drainage Program (NDP), it is expected to bring enormous benefits to irrigated agriculture in Pakistan by taking measures in improving irrigation and drainage management, thereby increasing agricultural production even in the tail-end areas. The NDP can play a vital role as a catalyst for such networking, and it has already taken steps in that direction by transforming the PIDs into the Provincial Irrigation and Drainage Authorities (PIDAs). These authorities are responsible to establish Area Water Boards at the main canal level and Farmer Organizations (FOs) at the secondary canal level for effective management of irrigation and drainage systems. Therefore, it is now the responsibility of farming community to come forward and play their role in increasing the irrigation and groundwater economy of the Pakistan. However, the projected benefits of these FOs will only be reaped if all environmental, social and administrative issues are resolved satisfactorily.

The nation cannot afford the luxury of taking loans after loans indefinitely for the control of this twin menace. Indigenous, cost-effective, technical feasible, and environmental friendly ways and means should be used, and saline agriculture provides such options. The main purpose of this approach is to use simple interventions to leach salt out of the surface soils. These interventions include the use of: (i) leaching measure, (ii) gypsum, (iii) acids and acidic wastes, (v) mechanical methods, and (vi) biological means. The use of gypsum is economical for the amelioration of salt-affected soil and water, and it has been a time-tested for over 50 years at the national and international levels for the amelioration of salt-affected soils and waters. Similarly, the use of biological means offer considerable potential as an alternative measures where the drainage cost is high and the disposal of drainage effluent poses economic and environmental concerns. Efforts should be made to make the use of such cost-effective measures in the country.

5 REFERENCES


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ABSTRACT
In recent years Dutch aid projects have focused more on institutional strengthening. The overall impact of this type of aid has been limited. This paper explores possible reasons for this. In Egypt, it appeared to be difficult to make significant changes in the institutional setting. Main constraints were the low salaries, recruitment and personnel policies and the organisational culture within the government. Another factor that may have played a role is inadequate recognition of cultural backgrounds of the international consultants advising in Egypt. This is explored using Hofstede’s and Trompenaar’s typologies of culture and their effects on management. Maslow’s Hierarchy of Needs, as applied to the environment of institutional strengthening, is also considered. Adjusting an organisational culture to improve efficiency and sustainability of the organisation is a long and difficult process and should not be seen as an extension of tradition technical assistance aid projects, but rather it should be implemented as a dedicated long-term project. A major finding is that short-term consultancies may only be effective for idea generation, and not as instruments for implementing change management. Managerial capacity building should be a long-term activity with gradual change, particularly in government settings. Recognition of organisation culture in light of trans-national cultural typologies by Hofstede and Trompenaars, as well as, acceptance of the most pressing needs of the target group as the responsibility of one and the same financing agency are found lacking in traditional Development Aid.

Keywords: Institutional Strengthening, Organisational Development, Capacity Building, Development Aid, Technical Assistance, Human Resources Management, Culture, Hofstede, Trompenaars, Maslow.

1 Introduction
Egypt is one of the biggest recipients of foreign aid. Net disbursements of Official Development Assistance (ODA) have averaged more than US$ 2200 million per annum during the past 20 years. Bilateral aid is the most important aid category, accounting for two-thirds of the total aid flow over the period 1970-94. It increased steeply from the middle of the 1970s, after Egypt severed its ties with the Soviet Union and started its Open Door Policy, strengthening relations with the United States and other western countries.

The Netherlands is one of the smaller bilateral donors to Egypt, contributing about Dfl. 960 million between 1975 and 1996, somewhat less than 1 per cent of all aid to Egypt (NEDA, 1998). The Netherlands started its development assistance to Egypt in the mid-1970s with the initial focus on improving the infrastructure. During the 1980s, the attention concentrated on technical assistance in the drinking water, sanitation and health sectors. Eighty percent of the total disbursements during 1975 - 85 involved the supply of commodities, while the remaining twenty percent was for technical assistance. The technical assistance component increased to half of all aid in the mid 1980s and to roughly two-thirds in the 1990s (NEDA, 1998). At first technical assistance was merely technical on-the-job training, assuming that the improvement of technical expertise of key institutions would result in organisations that functioned more efficiently. Gradually, projects gave more attention to structural problems in operations and maintenance and to general organisational and management issues. This type of aid can be characterised by greater participation by the recipients, a concern with process, institutional development and capacity building. The idea was that when the donor withdraws, the organisation is able to maintain a high standard independently.

Typical of these latter type of projects are the Drainage Research Projects; DRP1 (1994- 1998) and DRP2 (1998 – 2001) which had respectively a 50-50 and 75-25 division of institutional strengthening versus technical assistance components (Walbeek et al. 2001).
The technical assistance components concerned guidance for research at drainage pilot projects in the Nile Delta. The institutional strengthening activities concerned strengthening of the operation and management of the Drainage Research Institute (DRI). Although the enhanced technical capabilities acquired were substantial and appreciated (Soussan, 2000), the same could not be said of the institutional strengthening and organisational development aspects. What may have been the possible reasons for this is explored in this paper.

Before going into details, typical terms such as “Institutional Strengthening”, “Organisational Development”, “Technical Assistance” and “Capacity Building” are put in perspective. Institutional Strengthening (IS) can be defined as the introduction of new methods and methodologies to an existing organisation with the purpose of improving functioning of the organisation. Organisational Development (OD) is the enhancement and strengthening of an existing management structure to operate more effectively. OD is defined as an intervention strategy, using group processes to focus on the whole organisation to bring about planned changes. Technical Assistance (TA) is seen as the whole range of activities designed to develop human resources through improving the level of skills, know-how and productive aptitudes of the target population (NEDA, 1998). Capacity Building is a fashionable term with international NGO’s but each organisation, and each person within those organisations seems to have his or her own interpretation as to what the term entails. In this paper we consider it as an all-encompassing term for training of, and education in, both technical and managerial competences.

2 Institutional Strengthening and Organisational Development at DRP1 and DRP2

One of the first goals of DRP1 was to map the existing organisational structure of DRI with the help of various consultancies, and to discuss the desirable future structure with the staff. The expatriate consultants on the team came from Belgium and the Netherlands, and staff of the local consultancy firm had received extensive training in Germany. The initial input of the consultants and the implementation of their advice ultimately resulted in the DRI Handbook, which contained a brief description of the old DRI organisational structure, an extensive description of the desired (partially) new structure, and job descriptions. The desired organisational structure included DRI’s mission statement as mandated by various Presidential Decrees. For each department and unit the mission, tasks and responsibilities were elaborated, based upon group exercises.

After completion of strategy (mission statements) and theoretical structure of the institute, the project concentrated on creating the enabling environment to meet the mission of DRI and the objectives of the project. This was done with the help of local consultants, and an Arabic version of the Handbook was used for on-site training. Establishment of new departments and staffing them was found to be very difficult due to financial and government hiring policy constraints. The project found itself limited to development of primarily electronic tools for a Management Information System as well as a Data Information System (Gamal El Din 2001).

A manual for a Staff Performance Appraisal System followed. This was the result of a year of intensive consultation with DRI staff on the criteria to be considered. The system was rather unique in that it is the first documented effort of establishing a fair and comprehensive staff performance appraisal system in the Egyptian context. It considered 90% of the concerns brought forward by the staff (Walbeek et al., 2001). However, this made the system rather complex and it was considered a challenge for DRI to simplify the system for quarterly use without loosing the ability to consider all aspects raised by the staff. Several areas were identified as requiring further development: guidelines for peer review of technical publications; guidelines to judge research standards; and, guidelines for progress reports. The appraisal system was only partially implemented during the course of the project. The reasons for this were the difficulty in establishing the Human Resources Department that could manage the appraisal system and handle the data requirement of the appraisal system.

One of the main achievements of the institutional strengthening and organisational development activities was that a broad section of the DRI staff has become aware of institutional, management and personal considerations in day-to-day management of DRI. The project was completed with a final workshop specifically on the Institutional Strengthening and Organisational Development (IS&OD) aspects (Abdel Gawad et al. 2001). At the time of project completion there was a sense of under achievement of IS&OD aspects by the expatriate staff and, to some extent, the local staff as well. This may have been caused by the complexity of transforming the
Institution as outlined in the Handbook, as well as frustration with the restraints put on the execution by external influences. The external factors were primarily those imposed by the government system within which DRI has to operate. A fallback to, and preference for, old routines was evident. Another finding was the limited usefulness of short-term consultancies (whether by local or expatriate consultants) and the need for continuous long-term on-the-job training. Advice and recommendations were extensive but short on practical application and implementation options. The consultancies served as appropriate focal points and generated strategies for change, but proposed strategies were so far beyond the local staff experience and competences that adequate implementation was not possible. Constraints included limited finances for change and an inadequate number of staff qualified in the identified new management tasks. It may also be that there was an inadequate recognition of cultural backgrounds of the various project team staff. Therefore in Section 4 the theories of Hofstede and Trompenaars are explored.

It should be noted that a recent visit to the Institute two years after completion of the DRP projects showed a marked change in the atmosphere at DRI. Although DRI is still faced with low salaries and few externally funded projects, there was a sense of optimism and pride in the Institute. DRI seemed reborn; people appeared content in the environment in which they were working. They had new air conditioners, smart looking sun blinds, walls were painted, offices clean, and probably a range of other small improvements not apparent at first glance. This improvement is attributed to satisfaction of small but important basic needs as is described in Section 4 under Maslow's theory on Hierarchy of Needs.

### 3 The Egyptian Public sector and Institutional strengthening

The most obvious characteristic of the Egyptian public sector is its immense size compared with other countries (see Table 1). The government has grown tremendously in the past four decades. On the eve of the 1952 Revolution, there were roughly a quarter of a million civil employees among all the ministries and agencies of the Egyptian government. By 1972 this number had jumped to 1.2 million, and in 1980 slightly over 3 million people were working for the government (Mayfield, 1996). In the beginning, this expansion could be explained by an extension of the government functions into areas unknown under the monarchy. However, the continued growth of the bureaucracy was a clear sign of the failure of the Open Door Policy to solve the country's economic problems (El-Sayyid, 1996). Even now, despite the liberalisation, the public sector still plays a dominant role in the economy, accounting for over one-third of total Gross Domestic Product (GDP) (EIU, 1999) and employing about one third of the labour force (World Bank, 2000).

This large number of government employees is an attempt of the government to absorb the unemployed, particularly the youth (El-Sayyid, 1996). The government has been committed to placing all college graduates in some type of government position regardless of background, interest or need. This policy was amended and a three to four year waiting list was introduced, and usually such jobs were only made available in the rural areas (Mayfield, 1996). By 1999, the waiting list had increased to 11 years (EIU, 1999). The government has plans to reduce government employment by some 2% per year, but maintain the size of education and health ministries (World Bank, 2000). Especially public enterprises will be made to downsize. It was initially estimated that labour redundancies in public enterprises was around 10%, but in practice this figure proved to be closer to 35% (Abrahart et al., 2002). This puts pressure on the creation of private sector jobs, especially in the tertiary sector, including activities such as trade, banking, services related to production, state administration and social services. (Hoodfar, 1999). More than half of all of new employment has come from an expansion of the informal sector (Abrahart et al., 2002).

<table>
<thead>
<tr>
<th>Government employment, early 1990s</th>
<th>Percentage of total population</th>
<th>Percentage of total employment</th>
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<tbody>
<tr>
<td>Africa</td>
<td>2.0</td>
<td>6.3</td>
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<tr>
<td>Asia</td>
<td>2.6</td>
<td>6.7</td>
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<td>Eastern Europe and former USSR</td>
<td>6.9</td>
<td>16.0</td>
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<td>Latin America and Caribbean</td>
<td>3.0</td>
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Despite the planned downsizing, Egypt's public sector employment continued to grow at an annual rate of 3.7% in 1986-95, but the private sector grew by only 1.9%. Overall employment growth in Egypt was only 2.6% annually, slightly below the annual growth rate of the total labour force (2.7%, Tzannatos, 2002). In 1999 Egypt's rate of job creation was 400,000 a year, showing a deficit of 100,000 jobs (EIU, 1999). In 1996/97, the national unemployment rate was officially at 8.8%, but independent estimates were considerably higher, at about 11-15%, with the majority of unemployed under 20 years of age. Under-employment is estimated to affect one third to half of all workers.

3.1 Low salaries
The majority of low and middle ranks of employees in government and the majority of the public sector workers have a monthly income not exceeding US$ 175 (Amin, 1997). A junior engineer in the Drainage Research Institute can expect to take home between US$ 60 and US$ 150 per month as salary, including allowances and incentives or bonuses. Even compared to countries whose per capita income is significantly lower than Egypt's, compensation is low (Table 2, Merrey, 1998).

To overcome the low salaries, many civil servants have a second job. Palmer et al. (1988) found 89 percent of their sample of government employees admitted holding second jobs, and 84 percent of those with second jobs worked three to five hours per day in these supplemental positions. These positions are running a small local shop; selling vegetables in the local market; operating a taxi; or working as a doorman or domestic servant. Workers often earned more from these extra economic activities than from their primary occupation (Hoodfar, 1999). A few lucky ones found a second job in the same field of expertise and competence as their main job.

Staff working for aid projects often made longer hours than their colleagues not working on projects, resulting in some cases of loss of the second income. Dutch Aid projects started using incentives in lieu of the loss of the second job and this became the norm rather than the exception. Other countries used different modalities of compensation but with the same effect. To avoid too much interference in personnel issues, generally a lump sum was paid to the management of the organisation for distribution as incentives. As a result, these incentives were seen as an integral part of the salary and not as a reward for extra performance. Over time working hours for local staff were more according local standards, and many of the local staff had second jobs in the evening.

3.2 Human Resource Policies
Aside from the low compensation, there was no observable link between compensation and performance. Staff evaluation is generally highly subjective, based principally on the attitude of the boss toward the subordinate. It tends to be personality-oriented, in that the identification of poor performance is apt to be associated with those things the superior believes are negative qualities,
such as bad attitude, lack of initiative, poor relationships with others, etc. (Mayfield, 1996).

Promotion is based on seniority rather than on performance. In order to ensure that promotions are given in a fair and impartial way, the administrative system is divided into several categories (Figure 1).

![Figure 1 Categories and grades in the Egyptian Civil Service.](After: Mayfield (1996); DRI Human Resource Database (Gamal El Din 2001).

All individuals within the category are subject to the same procedures and sequences for promotions, salary increases, transfers and changes. Once an individual is assigned to a category it is not possible to shift to the next category until all individuals ranked higher have first been promoted (Mayfield, 1996). Of course this system has clear disadvantages. In more recent years, experience and performance received more consideration in promotions, especially for senior engineers. Promotions from Level 3 to Level 2 are based 75% on seniority and for Level 2 to Level 1 seniority counts 50% (Merrey, 1995).

Palmer (1988) found that educational level had a greater impact on productivity, innovation and flexibility than either foreign or local training programs in the Egyptian civil service. When education was held constant, training programs were found to contribute only modestly to the productivity of less educated officials, and not all to those who are better educated. Also in the Dutch Development Aid it appeared that training did not make a significant difference. Instead, tailored, in-country, human resource development activities were generally found to be more effective (NEDA, 2000).

The educational background of the employee is a determining factor for promotion and recruitment policies. For example, in the Ministry of Water Resources and Irrigation, top positions are only available to civil engineers. As a result other engineers and specialists feel little loyalty to the Ministry/Minister and this relates to issues of family structure (Hofstede 1991 and Trompenaars 1993, see Section 4). Many of these professionals complain about their lack of career prospects, lack of influence and prestige, and are bitter about not being invited to the large number of workshops held under donor-funded projects (Merrey, 1998).

Our experience in the Drainage Research Institute showed that it was extremely difficult, if not impossible, to attract personnel in the field of human resources and marketing, due to government regulations and the large difference in remuneration between government and private industry. Rather (civil) engineers already in government service with an interest in these fields received additional training (Walbeek et al. 2001). Their additional qualifications did not necessarily result in immediate benefits to the participants of the training, but potential advancement was used as incentive to participate.
Theories of Culture and Institutional Strengthening

National and organisational cultures have a major effect on the management of organisations. This has been accepted since the early work of Hofstede in the seventies. Trompenaars developed a more elaborate model of cultural effects on management. Both models have applicability to project management in Development Aid. In addition to the two models on culture characterisation, also Maslow's Hierarchy of Needs is thought to have a bearing on the functioning of staff on aid projects.

4.1 Hofstede’s Five Dimensions of Culture.
Hofstede and others derived a 5D model to describe cultural difference at national level based on a survey held amongst IBM staff at its worldwide subsidiaries (Hofstede 1991, Hofstede and Bond 1988). Initially the study involved 40 countries and had four dimensions. Others have replicated the popular study and data are based on additional research and on estimates using correlated phenomena now covers 90 countries and 5 regions (ITIM 1993). A fifth dimension (CDI) was added by Hofstede in the mid 80’s. The five dimensions are:

1. **Power Distance (PDI)**: extent to which the less powerful members of institutions and organisations accept that power is and should be distributed unequally. In other words people in high power distance cultures are much more comfortable with a larger status differential than low power distance cultures;

2. **Uncertainty Avoidance Index (UAI)**: degree to which members of a society feel uncomfortable with uncertainty and ambiguity, and support beliefs promising certainty and institutions protecting conformity. Cultures which ranked low (compared to other cultures), feel much more comfortable with the unknown. As a result, high uncertainty avoidance cultures prefer formal rules and any uncertainty can express itself in higher anxiety than those from low uncertainty avoidance cultures;

3. **Individualism Index (IDV)**: degree of preference for loosely knit social framework in which individuals are supposed to take care of themselves and their immediate family only. Individualist versus collectivist cultures are also characterised by respectively high vs. low per capita GNP, restrained vs dominant role of government in the economy, identity based on individual vs. group, and education increases economic worth vs. education gains entry to status groups (Hofstede 1991 paraphrased in Smotherman and Kooros 2001);

4. **Masculinity Index (MAS)**: degree of preference for achievement, heroism, assertiveness and material success. This dimension tends to draw (unwarranted) criticism for its name alone. It basically refers to expected gender roles in a culture. The cultures that scored towards what Hofstede referred to as "masculine" tend to have very distinct expectations of male and female roles in society. The more "feminine" cultures have a greater ambiguity in what is expected of each gender;

5. **Confucian Dynamism Index (CDI)**: degree of importance attached to perseverance, ordering relationship by status, thrift and a sense of shame rather than to personal steadiness and stability, protecting face, respect for tradition and reciprocation of greeting, favours and gifts. Also referred to as Long-/Short-Term Orientation of Cultures (Hofstede 1991 paraphrased in Smotherman and Kooros 2001).

Nationals from numerous nations have been intimately involved in Egypt over the years. Influences of the French, British and Russians have shaped the government organisations. Since the Open Door Policy, nationals from the USA and many of the European countries have impacted to some extent the way organisations operate. Personal experience of staff working on projects also determines the modus operandi of projects. The selection of countries in Table 3 reflects the nations that have relevance, from cultural point of view, in the DRP projects.

It is interesting to observe that some of the major donors since Egypt’s Open Door Policy (Germany, Great Britain, USA, and the Netherlands) have scores that are on the opposite end of the scale in almost each category. Egypt and France have a high score in Power Distance (80 and 68), while the others score 35 – 40, implying a much greater acceptance of the top down authoritative style of management in Egypt and France than in the other countries, where performance is much more important and organisational structures are much flatter. Hence consultants from these countries will tend to recommend structures with delegation of authority. Egypt has a low individualism Index of 35, while the other countries range between 67 and 91. This is also confirmed by Trompenaars typology of a family style culture (see section 4.2).
Table 3  Hofstede’s values of dimension describing national (group) culture based on IBM study.

<table>
<thead>
<tr>
<th>Country or Region</th>
<th>PDI Score</th>
<th>IDV Score</th>
<th>MAS Index</th>
<th>UAI Score</th>
<th>CDI Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>REGIONS ORIGINAL IBM STUDY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arab Countries</td>
<td>80</td>
<td>38</td>
<td>53</td>
<td>68</td>
<td>-</td>
</tr>
<tr>
<td>East Africa</td>
<td>64</td>
<td>27</td>
<td>41</td>
<td>52</td>
<td>-</td>
</tr>
<tr>
<td>West Africa</td>
<td>77</td>
<td>20</td>
<td>46</td>
<td>54</td>
<td>-</td>
</tr>
<tr>
<td>COUNTRIES FROM THE ORIGINAL IBM STUDY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>65</td>
<td>75</td>
<td>54</td>
<td>94</td>
<td>-</td>
</tr>
<tr>
<td>Canada</td>
<td>39</td>
<td>80</td>
<td>52</td>
<td>48</td>
<td>23</td>
</tr>
<tr>
<td>France</td>
<td>68</td>
<td>71</td>
<td>43</td>
<td>86</td>
<td>-</td>
</tr>
<tr>
<td>Germany FR</td>
<td>35</td>
<td>67</td>
<td>66</td>
<td>65</td>
<td>31</td>
</tr>
<tr>
<td>Great Britain</td>
<td>35</td>
<td>89</td>
<td>66</td>
<td>35</td>
<td>25</td>
</tr>
<tr>
<td>Netherlands</td>
<td>38</td>
<td>80</td>
<td>14</td>
<td>53</td>
<td>44</td>
</tr>
<tr>
<td>Pakistan</td>
<td>55</td>
<td>14</td>
<td>50</td>
<td>70</td>
<td>0</td>
</tr>
<tr>
<td>USA</td>
<td>40</td>
<td>11</td>
<td>62</td>
<td>46</td>
<td>29</td>
</tr>
<tr>
<td>COUNTRIES FROM LATER STUDIES AND ESTIMATES (ITIM 1993)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arab Emirates*</td>
<td>90</td>
<td>25</td>
<td>50</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>Egypt</td>
<td>80</td>
<td>35</td>
<td>40</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>Poland*</td>
<td>55</td>
<td>55</td>
<td>70</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Russia &amp; Ukraine</td>
<td>95</td>
<td>47</td>
<td>40</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>95</td>
<td>25</td>
<td>60</td>
<td>80</td>
<td></td>
</tr>
</tbody>
</table>

* - numbers are pure estimates based on correlated phenomena; the others numbers have some research base.
Sources: Hofstede (1991); ITIM 1993.

The masculinity factor shows more variation amongst the five countries considered in this paragraph, with the Netherlands being exceptionally feminine oriented, implying great emphasis on gender, ecological and social issues. Incidentally, these issues are high up on Maslow's Hierarchy of Needs described below. The Dutch feminine score is clearly reflected in Dutch Development Aid policies of "for the poorest of the poor and women in development". Germany, USA and Great Britain on the other hand score higher than Egypt and this may be evident in higher emphasis on project oriented working (Logic Framework approaches, benchmark performance, etc). As far as risk taking and uncertainty avoidance Egypt scores highest, implying perhaps a tendency for slower decision making at various management levels.

4.2  Trompenaars Seven Dimensions of Culture.

Another benchmarking typology of cultural difference that needs to be considered in cross-cultural business management and to some extent is seen as an extension of Hofstede’s work is presented by Trompenaars (1993, Trompenaars and Hampden-Turner 2003). Trompenaars considers seven dimensions of culture:

1. **Universalistic/Particularistic cultures**: Universalism vs. particularism relates to judgement. On the one end of the spectrum lie cultures that adhere to universally agreed upon standards. At the other end are cultures whose obligations lie in the people they know. People in universalistic cultures share the belief that general rules, codes, values and standards take precedence over particular needs and claims of friends and relations. In a universalistic society, the rules apply equally to the whole "universe" of members. Any exception weakens the rule;

2. **Individualist/Collectivist cultures**: Individualism vs. Communitarianism. An individualist’s primary focus is on self and any contribution to the group is their choice. A collectivist places emphasis on duties and obligations to their in-group. Therefore in a predominantly individualistic culture people place the individual before the community. Individual happiness, fulfillment, and welfare set the pace. People are expected to decide matters largely on their own and to take care primarily of themselves and their immediate family. In a particularistic culture, the quality of life for all members of society is seen as directly dependent on
opportunities for individual freedom and development. In the collectivistic culture the community is judged by the extent to which it serves the interest of individual members;

3. Neutralist/Affectivist Cultures: Neutralists believe the nature of their relationships with others should be objective and detached, that emotions confuse the issues. Affectivists; however, believe that all relationships with others are human affairs and that people should express their feelings openly. In a neutral culture people are taught that it is incorrect to show one's feelings overtly. This doesn't mean they do not have feelings, it just means that the degree to which feeling may become manifest is limited. They accept and are aware of feelings, but are in control of them. Neutral cultures may think the louder signals of an affective culture too excited, and over-emotional. In neutral cultures, showing too much emotion may erode your power to interest people;

4. Specific/diffuse cultures: Specifists believe relationships with others should be explicit, delineated and regulated as in a contract. Diffuse oriented people emphasise the real and personal contact of the whole person in a relationship. Closely related to the neutralist reason and the affectivist emotion, this cultural dimension depicts the engagement of others in specific or diffuse areas of life and personality levels;

5. Achievement/ascription cultures: Achievement aligned people believe that one's worth is dependent upon their capabilities, recent accomplishments and past record. Conversely, ascriptionists attribute status through social position, gender, age and association with important others. Ascribed status refers to what a person is and how others relate to his or her position in the community, in society or in an organization. In an ascriptive society, individuals derive their status from birth, age, gender or wealth. A person with ascribed status does not have to achieve to retain his status: it is accorded to him on the basis of his being;

6. Time orientation in cultures; sequential vs. synchronic cultures: Time can be structured in two ways. In one approach time moves forward, second by second, minute by minute, hour by hour in a straight line. This is called sequentialism. In another approach time moves round in cycles of minutes, hours, days, or years; synchronism. Problems that arise through the passage of time relate to whether the society places more importance on what has been achieved in the past versus what is planned for the future or what was accomplished yesterday as opposed to today. People structuring time sequentially tend to do one thing at a time. They view time as a narrow line of distinct, consecutive segments. Sequential people view time as tangible and divisible. They strongly prefer planning and keeping to plans once they have been made. Time commitments are taken seriously. Staying on schedule is a must. People structuring time synchronically usually do several things at a time. To them, time is a wide ribbon, allowing many things to take place simultaneously. Time is flexible and intangible. Time commitments are desirable rather than absolute. Plans are easily changed. Synchronic people especially value the satisfactory completion of interactions with others. Promptness depends on the type of relationship;

7. Internalist/Externalist cultures: Externalist cultures view nature as a force more powerful than the individual, a force to be feared or emulated. Internalist societies see the major force in life, the origins of vice and virtue as residing within the individual. Internalistic people have a mechanistic view of nature. They see nature as a complex machine and machines can be controlled if you have the right expertise. Internalistic people do not believe in luck or predestination. Externalistic people have a more organic view of nature. Mankind is one of nature’s forces, so should operate in harmony with the environment. Man should subjugate to nature and go along with its forces. Externalistic people do not believe that they can shape their own destiny.

The USA and Germany are regarded universalistic, while Russia, Indonesia and Malaysia for instance are on the particularistic end of the scale (Trompenaars 1993 paraphrased in Smotherman and Kooros 2001). The USA, The Netherlands and the United Kingdom are Individualistic while Egypt, France and Pakistan are collectivistic countries. When neutralist and affectivist are considered a split amongst western countries is apparent: United Kingdom and The Netherlands are classified as neutralist countries, while France and the USA are considered affectivist. The Netherlands, United Kingdom, Germany and the USA are specificist countries, while Egypt is regarded as a diffuse culture. Achievement versus Ascription cultures resulted in the USA, United Kingdom and Germany on one end of the scale and Egypt, and France on the other. Finally, Internalist vs. Externalist resulted in the USA, and Germany as internalist type of culture characterisation, versus Egypt being more externalistically oriented.

When using Trompenaars cultural dimensions much of the Egyptian government can be characterised as a family culture. The
family culture is personal, with close face-to-face relationships. The experience in DRI showed that employees appreciated these family-oriented relationships, although it was acknowledged that it also causes a weakness, as much time is spent on personal affairs (Shaalan, 2001). At the same time, a family structure is very hierarchical. It is a power-oriented corporate culture in which the leader is regarded as a caring father who knows better than his subordinates (see high PDI score in Table 3). In such a culture, it is obvious that delegation is very difficult. Moreover, family cultures have difficulty with project group organisations, where authority is divided/delegated (Trompenaars, 1993).

4.3 Maslow’s Hierarchy of Needs.
The essence of Maslow’s theory, known as the Hierarchy of Needs, is that he sought to explain why people are driven by particular needs at particular times (Maslow 1954). Why does one person spend considerable time on personal safety and another on pursuing the recognition by others? According Maslow, human needs are arranged in a hierarchy (Figure 2) from the most pressing to least pressing. People will satisfy their most pressing needs first and when they are satisfied they will address their next most pressing need, and on it goes until the needs of self-actualisation are reached.

Depending on local circumstances one may progress or regress in fulfilment of needs. For instance, after the war in Iraq, the people of Iraq are mostly concerned with the first two levels, but so are the coalition forces. A starving man will not take any interest in the happenings of the art world or be concerned about the ecology. Maslow’s Hierarchy of Needs has been applied to help explain people’s reactions in marketing, HRM, education, social services, counselling, and asylum issues. It also applies to Development Aid.

An interesting aspect of Development Aid is that people from a group that can be classified as having reached to the top of the pyramid in their home country, are addressing the needs of those at the base of the pyramid in the country of the project and have to place themselves in their shoes. This is a mismatch that can cause management problems when the objectives of projects actually aim at jumping several levels up the Hierarchy of Needs without satisfying the levels in between. One can move down in the hierarchy, and skip a level, but one cannot move up and skip levels without managerial consequences. It was observed that persons of level 4 and 5 of Maslow's classification would psychologically accept the needs of persons from a group at level 1 – 3 in the hierarchy, but had difficulty with incorporating those needs in the projects; they rather concentrated on “their”, higher, level of needs, leaving it to others to accommodate satisfaction of the lower levels of need.
Considering Maslow’s Hierarchy of Needs in the IS&OD fields of interest it can be observed that typical project objectives address the needs of levels 3 to 5, while the target groups are somewhere between levels 2 and 4. In case of the DRP projects one of the objectives was client-oriented research (level 5) but, comfortable and clean office space, with appropriate basic tools to get the job done, were a constant concern for both the local and expatriate consultants. Local staff was concerned about adequate salaries. Whereas the Projects seemed to jump into level 4 of the Hierarchy of Needs, and talked a lot about reaching level 5, they were brought down constantly by the lack of adequate fulfilment of other pressing needs lower on the hierarchy. When some of the basic needs seem to have been fulfilled as noted previously, it resulted in a marked difference in attitude of the staff at DRI.

These observations are valid for essentially all projects in Egypt, as well as applicable for similar situations elsewhere in the world. Hence aid that is targeted to the upper levels of satisfaction in the Hierarchy of Needs is inadequately considering the actual needs of the target group. Often these concerns are largely ignored. Typical aid does not want to concern itself with improving the office facilities and certainly not with increasing salaries, but does expect outputs as if those particular needs are fully satisfied. These concerns are waved-off as concerns of the people (country) themselves and not of those who wish to improve. Yet there is ample evidence of projects that when these lower needs are addressed appropriately the final result is more satisfactory. Case in point is also the earlier mentioned change in attitude at DRI when pressing needs such as appropriate and safe shelter, i.e. good office accommodation and equipment, were satisfied the attitude of staff changed for the better. It is expected that this will ultimately result in sustainable achievement of the objectives that were formulated in during the DRP projects, provide that some of the work done during these projects are revisited.

### Analysis

Assessment of Technical Assistance projects with institutional strengthening and organisational development components were reviewed with application of theories of culture and need from the social sciences. The environment of a typical setting in Egypt was described but it may be noted that many of the observations are relevant elsewhere. The links between these theories and Development Aid practices were made where apparent. Some additional relevant observations are described in this section with the main purpose to contribute to trans disciplinary awareness between engineering, managerial and social sciences. The objective of the sections below is also to show that although some of the theories presented are from the early 50’s and 70’s they are still hot topics of dispute and research.

Recent reviews of Hofstede’s original work show hardly any shift in the cultural dimensions, even though the wealth of nations has changed dramatically since the original work. His work is not without criticism (McSweeny 2002, Baskerville 2003), nor is Trompenaar’s (Hofstede 1996), but as Sondergaard (2002) observes the core of the debate is a methodological one with (little) practical implications for executives when considering what to do with the issue of cultural differences with, for instance, cross-border mergers. In Development Aid cultural differences have equal relevance for implementation of institutional changes. Both Hofstede’s and Trompenaar’s modelling of cultural aspects have their pros and cons, but they do provide valuable insights to the typical project manager and other executives. Moreover, they are very similar. Smotherman and Kooros (2001) investigated the databases that underlie Hofstede’s and Trompenaar’s studies and found that the country indices for most cultural dimensions strongly correlate (Table 3). The lack of correlation between masculinity dimension and the neutrality dimension is due to lack of sufficient data; in qualitative terms masculinity and neutrality have similar traits. They observed that Trompenaar’s work has yet to acquire the depth and breadth of social science research usage currently enjoyed by Hofstede’s work.

#### Table 4 Pearson Correlation of Hofstede and Trompenaars (Smotherman and Kooros 2001).

<table>
<thead>
<tr>
<th></th>
<th>Power Distance</th>
<th>Uncertainty Avoidance</th>
<th>Individualism / Collectivist</th>
<th>Masculinity / Femininity</th>
<th>Long/Short term orientation or Confucian Dynamism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universalistic / particularistic</td>
<td>-0.636</td>
<td>0.721</td>
<td></td>
<td></td>
<td>-0.528</td>
</tr>
</tbody>
</table>
From our review it would seem that Hofstede’s work is more appealing to non-social scientists; Trompenaar’s definitions of the dimensions are more esoteric rather than practical. The descriptions are perhaps more subtle and less distinct. Both require substantial data collection, however, for practical usage by Development Aid projects Hofstede’s characterisation of more than 90 countries and 5 regions is quite adequate (see for example the selection of countries in Table 3).

The description of the public sector is not unique to Egypt. In many other developing countries, the average public servant can be characterised as being poorly trained, paid, and managed (Schacter, 2000). The performance of the public sector can be improved by giving higher salaries, provide more training, and improve management. However, it is not that simple. Due to the strong centralisation, there is not much room for delegation. In the Ministry of Water Resources and Irrigation, decisions are routinely sent to higher levels of the system, and many seemingly small decisions go to the head of a Department or Authority or even higher (Merrey, 1995). One reason is that the law on delegation of procurement and financial authority is very restrictive. Another is that in the job descriptions, although tasks are well defined, the authority to make decisions is not clearly specified. But even when it is, officials are reluctant to make decisions, preferring to let their superiors decide. According to top government officials, they cannot delegate power because the middle level is not trusted and not seen as competent enough. Hence, the middle management has little responsibility, initiative or authority (Mayfield, 1996). As a result, an employee is dependent on the decision of his superior. This attitude was also prevalent at DRI where for procurement of even the smallest stationary items permission had to be asked of the Secretary General or the Deputy Director.

At a workshop organised by the Royal Netherlands Embassy in May 1996, it became clear that similar projects, of Dutch Aid and other donors, also experienced difficulties with the government system. According to the participants of the workshop, a main constraint was the low salaries, which had a negative impact on performance. Another constraint was the recruitment and personnel policies in use. Promotion was (and is) based on seniority. Staff evaluation is done internally and confidentially, and hence not transparent and clear for the subordinates. This also hampers performance, as performance is not a basis for promotion or for staff evaluation.

Concerning the core issues of salaries, training and improved management it becomes apparent that salaries, being part of the employment contract, are not the most important motivational factor. For instance, at Alterra, a privatised research institute in the Netherlands, salaries are 30% lower than in the private sector, but Alterra does not have any problems attracting personnel, mainly due to the idea of working for a ‘good cause’ (van der Zande, 2001). Clearly the lower pressing needs of Maslow’s Hierarchy of Needs are satisfied even at 30% lower salary such that it is attractive to work for an organisation that focuses on catering to questions that address self-actualisation and esteem needs of the Dutch community and government.

In Egypt, research has proven that prestige is by far the most important motivational factor (Level 4 in Maslow’s Hierarchy of Needs, Figure 2). Salaries came second, but only marginally higher than location and security (Palmer, 1988). This shows that within a country or group people can be at different levels of the Hierarchy of Needs. The question is whether Egypt in 2003 is still where it was in Palmers 1988 study. The answer is yes and no; living conditions seemed to have improved in different manners since the Open Door Policy of the 1970’s, but population increase abated many of the advances.

Training was used as a motivational instrument in Development Aid projects. This applied especially to the training abroad because of the relatively generous living allowances (per diems) that were provided, and the general status/value attached to travelling abroad. However, the effectiveness of training was diminished when participants were not motivated in their job upon return, partially because of their low salaries. Trained people left the organisation when better opportunities became available elsewhere. Training appears not to have much effect on better public sector performance. This can be illustrated by an example from another country as well (Schacter 2000):
“A study of Gambians who returned to their home institution after earning degrees from abroad showed that almost none were placed in positions where they could apply their new skills. Despite their new credentials, they were assigned similar duties to those they had before going on training. Similarly, in virtually all African countries, after series of management-related training courses have been provided to countless public servants at all levels, yet little evidence of tangible change has resulted. What is missing is conscious attention to integrating newly gained knowledge, practices and skills into everyday use in the trainees’ organisations.”

Grindle and Hildebrand (1995) state that for an effective public sector, a strong organisational culture, good management practices and effective communication are of major importance. To be able to reform the organisational culture, however, the receiving organisations should meet some prerequisites. In an evaluation of Dutch assistance on institutional strengthening, it appeared that success was more noticeable where organisations had a higher level of autonomy. When organisations, like most of the core government agencies, were hierarchical in character and operated through strict standards and procedures, actions to enhance one aspect of their capabilities (whether human resources development, marketing, or organisational improvements such as new monitoring systems or more policy oriented approaches such as encouraging participatory approaches) had an extremely limited impact on their overall character and capacities. This was particularly true where the drive for change was external and met internal resistance and, where key aspects of change (such as budgetary procedures or staffing policies) were beyond control of the particular organisation (NEDA, 2000).

According to a study of high-ranking bureaucrats in economic government agencies, many agree with this conclusion (Shnief and Handoussa, 2002). There was a firm belief that a greater degree of autonomy would improve performance of the agencies and that a more decentralised structure would be more appropriate. With respect to manpower, the sample concluded that the low productivity of workers was widely attributed to a lack of a merit-based system of promotion, to low wages and salaries, inadequate performance evaluation, inefficient recruitment process, and the inadequate system of incentives. It would appear that both NEDA (2000) and Shnief and Handoussa (2002) observations focus on the symptoms and suggest tools to remedy the shortfalls, but do not go deeply enough into the causes. Cause analysis requires an approach that is more sensitised to Maslow’s and Hofstede’s theories if nothing but to properly assess the proposed measures on their cultural ‘inheritance’.

However, the question is whether this really fits in the Egyptian culture. We think that consideration of the organisational and national cultures that affect management as well as that of the recipients of the project aid should dictate the type of management processes that are proposed for implementation. Also the speed of implementation requires more attention, as the willingness to take risks is low in Egyptian culture. The complexity of change management should be introduced gradually rather than the big bang approach as is sometimes advocated in business circles. Government cultures are only suited for the gradual approach, certainly when these proposed changes are at local levels rather than across the board.

The position on Maslow’s Hierarchy of Needs at which donors and recipients of aid were is different and so priorities of certain pressing needs were different. Whereas, all measures for change management, including financial aspects, should be controlled through one organisation, typical Development Aid projects do not allow this. Funding has local and foreign components that are controlled by the respective financing organisations. This leads to unintentional separation of addressing the lower pressing needs, such as better salaries and office accommodation, from the higher level needs. The latter concern reaching the intended higher level needs such as transparency and good governance, which are the objective of the aid and/or projects. These higher-level needs tend to be dealt with before the lower-level needs are met. The result is lower achievement of capacity building compared to objectives at the beginning of Development Aid projects.

6 Conclusions
The intent of capacity building in its broadest sense was reflected upon using typical technical assistance projects that were enhanced with processes improving aspects. The change in emphasis towards Institutional Strengthening and Organisational Development (IS&OD) has been incorporated to typical Development Aid projects over the last decade. Its success is mixed and the
The main focus of IS&OD was on improving salaries (by giving incentives), offering and executing training and creation of enabling environment and tools. From the analysis it can be concluded that the main factor for change in management is the improvement of the organisational culture. Though a start was made with reforming the organisational culture, it should be realised that this is a long-term process and that change has to come and be supported from within. Moreover, adequate funds for all components of the change process need to be committed. The Netherlands Ministry of Foreign Affairs recognises these problems. They state that the lack of sustainability in development projects is often due to the over-estimation of the capacity of the receiving organisation and the under-estimation of the complexity of the institutional environment (NEDA, 1999). It should be remarked upon that by not willing to give support to overcome the most pressing and basic needs of people and organisations (the first two levels in Maslow's Hierarchy of Needs), which were identified formally and informally by the consultants of the various projects, and are highlighted in this paper, means that IS&OD efforts are setup for failure. It would appear that more emphasis should be given to not only organisational culture, but also more so to the cross-national culture difference of staff working on the projects. HRM is much more than training, career planning, strategy formulation and structure setting. The processes for institutional change should be enhanced with contemporary Human Resources Management principles (Boxall and Purcell 2003).

During the execution of the DRP projects a number of the issues raised herein were recognised. At that time these were not articulated, nor were they backed up by findings of the literature. This paper has corrected that. The sense by all project staff of limited achievements at the conclusion of the project was correct. Yet it is clear that all parties involved (donors, recipients and external consultants) together still could not overcome the constraints imposed by the government, national and cultural settings even though top level administrators and consultants expressed concepts reflecting contemporary business style management (Abu Zeid 1998, El Azzazi 2001).

7 Recommendations

Before proposing an IS&OD project it is very important to analyse the internal and external environment. In a workshop organised by the Royal Netherlands Embassy in 1996, the institutional environment of Egypt was analysed (albeit not using Hofstede's and Maslow's theories), but unfortunately no follow-up took place. In our view, this analysis of the institutional environment is but one of the important aspects of successful IS&OD projects. There is an increasing important task for Embassies to stimulate the application of contemporary business management principles with the execution of projects. After all, these projects are major investments and some down to earth, transparent and innovative application of existing investment and appraisal tools can go a long way to achieve good governance.

Identification of managers who are willing, and dare, to change the organisational culture should be stimulated. Through technical assistance, the champions (the people who have the power) and the so-called change agents, who are willing to start the transformation process should be identified and supported (NEDA, 1999, Abu Zeid 1998). In such a situation, the process of change might be accelerated, provided proposals are also considered in light of cultural typologies, Hierarchy of Needs and the constraints of the internal and external environment as described in this paper.

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ABSTRACT

Capacity building is not something new, it has been a leading issue in development for many years. But despite all the commotion, capacity building remains a concept of enormous generality and vagueness. The calls for capacity building in irrigated agriculture suffer from these same vague generalities. The result is confusion over what capacity, and a lack of it, actually means and confusion over what course of action is needed to provide it.

This paper attempts to define more clearly what capacity building means for irrigated agriculture by reviewing the conceptual thinking of social scientists over the past decade and case studies that provide good examples of capacity development in irrigation and drainage.

Although a simple definition is unlikely, one principle that is important to understanding what capacity building means is very clear both from the literature and from the practical examples, the methods used to build capacity are essential to its success. It is the reason why many people now use the term capacity development rather than capacity building as it transfers the emphasis from the end result to the process of achieving it. This is the connection between the more 'concrete' aspects of capacity building such as individual training, establishing irrigation organisations and changing the legal system etc and the less tangible aspects that suggest it can only be done in response to internal initiatives with local ownership and leadership over a flexible time frame. The way in which donor aid and technical cooperation contribute to this process thus become critical issues.

A simple definition may not be achievable but it is possible to make a clear statement about the territory of capacity development. For this a framework is proposed that bridges the gap between the conceptual thinking of social science and the activities of a well-functioning water sector. This may also be a useful tool for pointing areas that need attention, for facilitating discussions between partners in development so there is clarity of purpose on areas of constraint and what needs to be done and for locating points of entry for donor support. The case studies help to refine the meaning of capacity development from a practical perspective and demonstrate how donors and technical cooperation can contribute positively. Elements are drawn from these experiences to support the development of a broader national strategy.

Recommendations are made for the production of guidelines on capacity development that are specific to irrigated agriculture. A consultation process is suggested to obtain more information on a range of recent capacity development initiatives, formulate the contents of guidelines to reflect the issues raised by the proposed framework and examine ways of managing this new knowledge to improve its accessibility, particularly to developing countries.

Keywords: Capacity Building, Irrigation, Drainage, Training, Institutions, Policy

1 INTRODUCTION

There is a general consensus among policy makers in the developing world and aid agencies that a lack of capacity is constraining the development and improvement of irrigated agriculture as a means of reducing poverty, increasing food security and improving livelihoods among both rural and urban populations.

Capacity building is not something new, it has been a leading issue in development for many years and comes from the widely acknowledged short-comings in development assistance over the past 50 years. Morgan (1998) points out that many developing countries say they need more capacity and aid agencies are keen to supply it or at least help to create it. But despite all the commotion, capacity building, or capacity development as it is increasingly called, remains a concept of enormous generality and vagueness. It is also wrapped up in a host of concepts such as participation, empowerment, technical assistance and organisational development. Moore (1995) suggests that: Capacity building includes everything that was covered by the different definitions of institution building and more besides…Aid agencies would be wise to have no truck with the new jargon of 'capacity building' and to insist on using language and terms that have identifiable and precise meanings. Others (Browne 2002) talk about the weary mantra of capacity building that is not leading anywhere. The calls for capacity building in irrigated agriculture suffer from these same vague generalities. The result is confusion over what capacity, and a lack of it, actually means and confusion over what course of action is needed to provide it.

The case for improving and increasing irrigated agriculture within the framework of Integrated Water Resources Management (IWRM) to reduce poverty and improve people's livelihoods in developing countries is a strong one. Most poor people live in rural communities and rely principally on agriculture and the environment for their livelihood. They tend to be concentrated in food deficient areas on small plots of land where rainfall is unreliable and highly variable. There is either too much or too little and there are frequent long, dry spells. In Tanzania, for example, droughts have caused more than 30 percent of all natural disasters while floods have caused around 40 percent, often in the same place and the same season (NRSP 2003). Irrigation can and does play a crucial role. It can raise productivity by as much as 400 percent over traditional rainfed methods and brings a range of economic and social benefits to households and protects them from droughts by securing production. It provides work opportunities for the land-poor and for women to engage in such enterprises as vegetable production. All of this not only attacks rural poverty but also reduces urban poverty by bringing down urban food prices (IPTRID 1999).
But most poor farmers in developing countries find it difficult to take advantage of these potential benefits. They seem unable, for a variety of reasons, to take up the technologies available and to realise the benefits of improving water management. Most senior government officials recognise the problems and talk about a lack of capacity constraining development. But they tend to oversimplify this and see solutions in terms of more infrastructure and training for farmers and local professionals.

Unfortunately donors have tended to reinforce this approach. They shaped technical cooperation by concentrating on new works and providing technical assistance to fill the skills gap and to pass on know-how rather than on national priorities. Typically a donor would invest in the construction of an irrigation scheme and train public sector professionals, technicians and farmers linked to the investment. Although individuals, and the investment, gained from this it was isolated from the broader institutional context in which they functioned. Disappointingly such approaches failed to yield the expected benefits.

Over the past decade there have been two important shifts in the development process that have had a profound influence on irrigated agriculture. The first is the growing recognition that development must be ‘locally owned’ and technical cooperation should not seek to do things for developing countries but with them. The second is an understanding that successful irrigation farming requires much more than investment in construction and training. Farmers are being encouraged to take on more responsibility for water management and they are increasingly being exposed to market forces of the private sector. To cope with these and other pressures they are beginning to demand better support services, advice, access to new technologies, finance, equitable and fair water management regulations and legal redress when things go wrong. These are seen collectively as a lack of ‘capacity’ and the need is to build or develop it so that the water sector can function properly and poor farmers can take on more responsibility for their own development.

This paper takes up Moore’s challenge and attempts to define more clearly what capacity building means for irrigated agriculture using language and terms that have more identifiable and precise meanings. This is achieved by looking at capacity building from two contrasting points of view. The first is based on the extensive conceptual thinking about this issue over the past decade among social scientists. From this a framework is proposed, for visualizing the components of capacity building, that bridges the gap between social science and the activities of a well-functioning irrigated water sector. Such a framework could prove useful for identifying where deficiencies lie so that useful contributions can be made. The second approach is from a practical point of view. There are an increasing number of examples of good capacity building in irrigation and drainage. Many involve support from aid donors who are beginning to reflect the shifts in development in the way they provide technical cooperation. Several of these are reviewed with the aim of clarifying what capacity building means in practical terms as well as testing the usefulness of the framework for identifying the issues.

Countries where there is significant reliance on irrigated agriculture are likely to seek a strategy for capacity development. For this reason some suggestions are made about the elements of a good strategy based on the framework and the practical experience of the case studies.

Recommendations are made for the production of guidelines on capacity development that are specific to irrigated agriculture. A consultation process is suggested to obtain more information on a range of recent capacity development initiatives, formulate the contents of guidelines to reflect the issues raised by the proposed framework and examine ways of managing this new knowledge to improve its accessibility, particularly to developing countries.

2 WHAT IS CAPACITY BUILDING?

The established model for capacity building developed with the advent of the aid era following World War II. The Marshall Plan was introduced to support the rebuilding of Europe and although it was very successful it generated an overly simplistic and optimistic view of what worked; transfer capital and know-how to other countries and swift economic development would follow (Fukuda-Parr, 2000). Subsequent experience showed that this view underestimated the importance of local knowledge and institutions in the process of economic development and was compounded by aid driven by politics rather than results. Aid was then criticized for undermining local capacity rather than building it, ignoring local wishes and favouring high profile activities.

Over the past decade there has been a shift in emphasis towards seeing development as ‘locally owned’ so that cooperation does not seek to do things for developing countries but with them. In support of this Fukuda-Parr (2000) points out that most countries evolved organically building their own capacities and so the assumption that developing countries should simply start from someone else’s blueprint flies in the face of history. She suggests that countries should build on the wealth of local knowledge and expand these to achieve whatever goals and aspirations the country sets itself. She uses Morgan’s description of capacity simply as ‘the ability to perform functions, solve problems and set and achieve objectives’ and raises the issue of national capacity being more than the sum of the capacity of individuals which points to the importance of people working in organisations and networking. This has become known as social capital and in its crudest terms it means ‘the more people trust each other, the better off their society’ (Economist 2003). Economists now recognise this as an addition to natural resources, the rule of law and the market that they believe guide the hand of selfish human actions to serve the common good.

2.1 Can it be defined?

Browne (2002) aptly suggests that capacity building is both easy and hard to define. The easy part is the generic definition about skills and capabilities – the ability to perform functions, solve problems and set and achieve objectives - and is a significant step from earlier definitions that looked only at human resource development. But the difficult part is answering the questions about which skills and whose capability and this raises many more issues about the complex nature of development.

Alaerts et al. (1999a) looks at several definitions applied to the water sector. But he avoids recommending one, as all have limitations and focus attention on different aspects of capacity building. Those that do try to be all-inclusive tend to become rather turgid and incomprehensible. So is there an acceptable definition or is there another way of describing it?
Towards sustainable irrigation and drainage through capacity building

Alaerts (in Alaerts 1999b) provides part of the answer to this by setting out the reasons why investments in the water sector have not proved effective in the past, namely, a lack of long term planning for water resources, inconsistent economic policies, poor support for users, a lack of ownership and willingness of users to pay and weak management within organisations responsible irrigated agriculture. He also points to the neglect of the key rules of the Dublin Water Conference (ICWE 1992) namely, that water should be managed as an economic good, planning and management should take place at the lowest appropriate level (subsidiarity) and that water should be managed in an integrated way. What he is in fact doing is defining the characteristics of a well-functioning water sector albeit in a negative sense and by implication he is also starting to define the elements of capacity that must be built to make good these deficiencies. This begins to put some substance on the more generic definitions that have emerged so far and broadens the issue beyond the training of individuals.

Although it seems unlikely that a simple and satisfactory definition will eventually emerge, one principle that is important to understanding what capacity development means is very clear from the literature, the methods used to build capacity are essential to its success. It is as much a process as an end product. Unlike the building of an irrigation and drainage system, which is not dependent on its construction methods for the usefulness of its canals and drains, the methods used to build capacity are vital to the outcome. This is the essential connection between the more ‘concrete’ actions of capacity building such as individual training, establishing irrigation organisations and changing the legal system etc and the less tangible aspects that suggest it can only be done in response to internal initiatives with local ownership and leadership over a flexible time frame that is not dictated by externally initiated one-time events. Eade (1997) emphasises this by saying that capacity building is an approach to development, not something separate from it and not a discrete or pre-packaged technical intervention intended to bring about a pre-defined outcome. It is the reason why many people now use the term capacity development rather than capacity building. It transfers the emphasis from the end product to the process of achieving it.

3 A framework for irrigated agriculture

Capacity building or development in irrigated agriculture may not be easily defined but a much clearer picture is needed if problems are to be identified and actions taken to solve them.

One approach is to examine the extensive conceptual thinking about capacity building in development that has been taking place over the past decade (Fukuda-Parr 2000, Browne 2002). From this thinking a generic framework has emerged that has become widely accepted in development. It is also gaining acceptance in the water sector and so it could be a useful visualization tool for irrigated agriculture.

3.1 A generic framework

Bolger (2000) describes this generic framework in terms of different levels of capacity, namely individuals, organisations and societies but emphasizes the links between them. For example, the performance of a water user association is shaped as much by society (laws, regulations) as it is by individuals (skills, leadership, relationships). Four levels of capacity emerge from this approach – individual, organizational, network/sectoral and the enabling environment (Figure 1). Each represents a level that can be examined and analysed and as well as a possible entry point for support from a donor or technical cooperation. So do these four levels provide a useful framework for describing the capacity development issues and constraints in irrigated agriculture?

The individual level is the most ‘concrete’ and familiar part of capacity development and involves the education and training of the various stakeholders such as farmers, local professionals, engineers and a whole range of disciplines that interact to develop irrigated agriculture. It may be short-term, on-the-job training for farmers who need water management skills or to understand the workings of a water user association or more substantial long-term training for professionals who undertake research, design irrigation works or provide advisory services.

Figure 1 A conceptual framework for capacity development (Bolger 2000) Individuals
The education and training of individuals is an important part of developing irrigated agriculture and it is the most familiar part of capacity development. Unfortunately it is usually the only level at which capacity development is interpreted, often in complete isolation from the other levels. This should not cause too much surprise because training lends itself to specific and identifiable ‘concrete’ actions that are more difficult to make at the higher levels. Some trainers would argue that everything eventually boils down to a training need even if it is an organisational deficiency. Training not only helps to improve practical skills and knowledge it can also be used to changes attitudes in the workplace.

3.1.1 Education

An educated population is an essential foundation for all aspects of development but it is not usually directly related to specific issues such as irrigation and so individuals are left to decide for themselves how they will use their education. Only in the more specialised courses in colleges and universities where individuals have chosen a career in agriculture or engineering do they begin to acquire knowledge about irrigated agriculture. Persuading people to enter this area of study is where incentives such as salary, career development and security become important.

Timing is a crucial issue as it takes many years to educate a professional agriculturalist or an engineer. So both the individuals and the organisations that employ them need to plan well ahead if the demands for such skills are to be met.

Equally the kind of education that professionals receive must equip them properly for their role. But too many colleges and universities are poorly resourced. Teachers are poorly paid and have little or no equipment to work with and continue to use out-dated curriculum that is no longer relevant to the world their students will inhabit. Without institutional changes within the education system the next generation of professionals and technicians will continue to perpetuate and even strengthen existing outmoded power structures and practices. This points to the need to re-educate the educators and provide the resources to produce the professionals and technicians for tomorrow.

Overseas education and training is seen as one way of overcoming some of these inadequacies. Over the past 40 years or so governments have sent many of their top professionals for postgraduate training overseas, usually on a scholarship provided by the host country or a donor agency. This exposed young professionals to new ideas and new ways of working and has helped many countries well. But it is now in rapid decline because of a lack of scholarship funding and the relatively high cost of a course in, say, Europe or USA (US$30,000 for full support for one year) as opposed to the home or a third country (US$2,000-5,000). Unfortunately, in many instances, this trend towards educating at home or in a third country is not matched by the resources needed to do the job well. The impact in the developed world is also profound as many international training centres have closed or are in decline with a loss of expertise that will be very difficult replace.

The rapid changes now taking place in society and technology in the developed world will also impact in developing countries. In the developed world people now expect to pursue a number of career paths in their working lives and this has changed education from a ‘one-time event’ to one of ‘life-long learning’. This will eventually influence working patterns and education in developing countries.

3.1.2 Training

Short-term training is usually geared to the acquisition of more immediate skills for well-defined tasks such as managing canals, designing pumping stations or organising water user associations. It may be on-the-job training or special courses on particular issues for a wide range of people from farmers to professionals. They may be conducted on site, at a college or overseas. Typically, short-term training forms part of an investment in irrigation and drainage to provide the skills specifically for operating and maintaining a scheme. Although such training can be very effective for the project it is often criticized for being narrowly focused and not giving adequate attention to organisational issues and the broader context in which irrigated agriculture functions.

Increasingly short-term training is also seen as a means of changing attitudes as both farmers and engineers take on new roles in the process of irrigation management transfer and there is a shift in the objective of training from mere knowledge transfer towards increasing problem solving capacities. Competencies are a complex interaction of knowledge, skills and attitudes and some programmes are now using participative training methods to engender a continuing process of participation in subsequent water management practices. This is particularly important when individuals form groups or organisations such as water user associations to undertake joint water management functions.

Short-term training in irrigation and drainage is not without its critics. There are many instances of training courses that are not effective in matching demand with supply in a timely manner. Typical issues raised include inappropriate skills and knowledge being provided, poor training methods, curriculum too theoretical and lacking practical application and poor course timing so that skills learnt are not used or needed. It is not uncommon for attendance at a training course to be seen as a reward for good service or it is this or that person’s turn to go rather than an opportunity to acquire new and useful skills.

Biswas (1996) provides a number of examples of irrelevant, inappropriate and expensive training that was either too general or not related to the job and suggests that this should be a major cause for concern.

3.1.3 Investing in people

There are few who would doubt the value of educating and training individuals but the paradox is that few are willing to invest in people as enthusiastically as they invest in concrete. In spite of the rhetoric the development of individuals is not receiving the type of support it needs and deserves (Biswas 1996). The mobility and fragility of labour are perhaps the main reasons for this. Irrigation schemes do not move around but people can and do. They also get sick and some die.

There are commonly held views of professionals who received large sums of money to train overseas in irrigation development only to return home and go into building work or banking. Unfortunately this is all too often the level of perception and debate when the training of professionals is being discussed. It is seen as a waste and a reason for not continuing to train others rather than as a contribution to the nation. Critics seem to give little thought to the very systems of education and training from which they themselves have personally gained great benefit in career development, personal choice and mobility of employment.
3.2 Organisational Level

At the organisational level are groups of people such as water user organisations, research groups, government extension agencies and private companies who share common objectives such as improved livelihoods at a farming level or improved water management or increased agricultural productivity at a national level. Institutions are the rules and agreements, formal and informal, and shared values that bind the organisations. So the capacity of an organisation is embedded in the ability of its individuals to work together within the established rules and values. A wide range of organisations are integral to the success of irrigated agriculture. At farm level there are water user groups who share and manage common water interests both technically, financially and legally. Other organisations, typically government run, are mandated to provide support services for farmers while others undertake research and education roles. The private sector is also increasingly making an impact, for instance through smallholders using low-cost affordable technologies.

3.2.1 Support services

Irrigation at farm level is not well served in terms of supporting organisations. Traditionally governments continue to be the only substantial organisations that can provide farmers with knowledge and skills through agricultural extension services. But these have tended to concentrate on crops, fertilizer and pesticides rather than on water, even in irrigated areas. Where governments have focused on water it has tended to be on the engineering and management of the main distribution systems and not on what happens at farm level. In cases where on-farm water management services are provided there is often a lack of resources to do the job properly. They tend to be under-funded and staffed by inexperienced people who do not have the logistical support to reach the farmers. Where there have been successes they have usually been underpinned by external aid and so there are question marks hanging over them about their sustainability once the support comes to an end. This criticism can also be applied to some developed countries as well. Since the privatisation of extension services in the UK in the 1970s there is a dearth of information on farm water management practices and much of what is available is oriented towards irrigated agricultural production and not the more environmentally sensitive water management issues that are more relevant today.

Farmers need organisations to support them but, like the investment in people, there is a preference for more concrete infrastructure. Very little has been documented and published about the role and function of irrigation advisory services and more specifically about how well they perform. There are few guidelines for others to follow (FAO 2003). This situation has not been helped in recent years by the trend of transferring irrigation management responsibilities from government to farmers and the increasing amount of irrigation advice being organised outside the traditional government agencies by NGOs that do not normally have the resources to publicise their experiences. This lack of information can mean that it is difficult to determine what services are available in a country and how well they are working and this adds to the difficulty of planning a strategy for capacity development.

3.2.2 Need for organisational linkages

Government ministries involved in irrigation such as agriculture, environment, and water resources are often criticized for a lack of cooperation in what is essentially an interdisciplinary activity. Although they usually have common objectives, they tend to work independently. A typical division of responsibility is between the planning, design and operation of irrigation systems, usually the responsibility of a Ministry of Irrigation or Water Resources, and irrigated agriculture, usually the responsibility of a Ministry of Agriculture. The former is staffed by engineers who have little knowledge of crops and farming and the latter by agriculturalists who have little knowledge of engineering and hydraulics. The sad fact is that most of those involved do not see the need for such knowledge nor for closer linkages with each other. As one senior irrigation consulting engineer put it: my engineers do not know the difference between wheat and rice – but the really sad thing is they do not want to know. This emphasises not just serious flaws in organisational attitude but in the education system that continues to produce young engineers who still think that a career in irrigation is only about building dams and pumping stations.

3.2.3 Organisational performance

There are many instances of poor organisational performance in the irrigation sector and some emanate from a mismatch between what the organisation was set up to do and what it actually does. The reasons for this are varied and complex. A government research institute may be carrying out research that interests its staff and encourages their career development through publication but critics may point to drainage practices being promoted that do not fit well with local physical and socio-economic conditions and do not address the priorities of local people. Typically, there may be poor links between researchers and farmers. Extension services are weakened by a lack of well-trained local professionals and resources to do the job properly. The local professionals have little to offer farmers beyond formalised messages about water management and do not have the skills to cope with today’s farmers seeking a livelihood from a range of natural resources. There are other similar examples.

Incentives play a crucial role in ensuring that individuals and organisations point in the right direction. Salary is important but individuals are motivated by other issues such as career prospects, security of tenure and the value of working in a worthwhile job. But there is little point in trying to improve the performance of a research institute by training its staff on the layout of field plot experiments when those same people have to do a second job in the evening to secure their livelihood.

3.2.4 Private sector

Although government and farmer organisations dominate irrigation in some countries the private sector, usually NGOs, is making an impact. An example is the introduction of affordable irrigation technologies for smallholders in Asia and Africa that are manufactured locally and bought by farmers on a commercial basis. This requires organisational structures, known as supply chains, which enable companies to manufacture equipment and sell to farmers through retail outlets or agents. Farmers expect spare parts to be available as well as technical support and credit arrangements in much the same way as any other small-scale enterprise would. The principal prerequisites for this are a strong market for the agricultural produce and profitability for all those in the chain. At present markets in Asia tend to be distorted by subsidies as government encourages the development of these new institutional structures. In Africa they are in their infancy but are more reliant on market forces.
NGOs are well suited to support the creation of these new structures as they are much better at connecting with people than government departments. They are also more adaptable to what is essentially a process in which timing cannot be allowed to dictate the outcome.

3.2.5 Elements of effective organisations
Kaplan (1999) provides a useful hierarchy of the elements of an effective organisation which is applicable to irrigation organisations, namely, farmer groups and the organisations that support farmers both private and public:

- A clear picture of the role of the organisation
- An organisational ‘attitude’ that enables it to act in a way that it can have an impact
- A clear strategy
- A defined organisational structure and procedures that reflect the strategy
- Relevant individual skills, abilities and competencies
- Sufficient and appropriate material resources.

He emphasizes that those elements of capacity at the bottom of the list are more quantifiable as they belong to the realm of material things. Those near the top belong to the intangible, invisible realm and are only observable through the effects they have. It is here that by and large the effectiveness of an organisation is determined.

Biswas (1996) suggests that good organisational performance starts at the top. First and foremost it is the essential to have a good cadre of capable senior managers in place. The institutions and policies, he argues, will then take care of themselves. This links back to the need for a good education system that can produce the professionals. Browne (2003) makes a similar point when he refers to the Indian Administrative Service as a highly respected organisation working relatively independent of political pressures. It has few problems recruiting capable professionals in spite of the modest pay levels.

3.3 Sector/network level
The sector/network level is often included as part of the enabling environment but this additional level is needed to make the point that irrigation is part of the larger picture of integrated water resource management. It reflects the increasing awareness of the need for policies that integrate and cover the whole of the water sector and not just irrigation, water supplies or the environment in isolation.

It also emphasizes the important function of networking for communications and keeping people up to date. The creation, for example, of a network for capacity developers in irrigated agriculture would not only enable people to share information and expertise but it could also become a place for synthesizing experience and lessons learned, identifying research areas and encouraging the exchange of views. Several countries have already developed their own web-based networks and FAO has set up a website specifically for participative training in water agricultural management and includes an email listing to keep members in touch with the latest information (FAO 2003). CAPNET (www.cap-net.org) is perhaps one of the largest international networks covering integrated water resources management and has a specialist section dealing with capacity building.

The ability of people in developing countries to access information and communications technologies can reduce the need for expatriate expertise. ‘Scan globally and re-invent locally’ (Browne 2002).

3.4 Enabling environment
The enabling environment represents the broad national and international context within which irrigated agriculture can develop and this has considerable influence over what happens at the lower levels. It is concerned with policy at the highest levels in government and the ability of people at the lower levels to influence it. It is also about the socio-economic conditions that enable or discourage irrigation development and the legal framework that provides farmers with security of tenure for land and water and the power to seek legal redress when contracts are broken.

This is the most influential and yet the most difficult level to change. Some issues are well beyond the control of most countries. A typical example is the low international price of basic food crops that mean many farmers are unwilling to grow irrigated crops beyond their immediate family requirements because the costs of production are greater than the returns. This is made worse by agricultural policies that favour developed countries and the dumping of surplus food on hungry countries.

But there are also local issues to consider. Tanzania provides a positive example of recent changes in government policy that now favours rainwater harvesting as a means of supporting small groups of farmers whereas in the past runoff was considered to be a hazard and needed disposing of quickly and safely. This was a process of change that started at the grass roots and was developed and encouraged by a dedicated research group with external funding over a period of 12 years (see case studies).

In India poor, seasonal irrigation farmers using tanks to store water are now beginning to change national government plans in favour of providing them with advisory services to introduce aquaculture into the farming systems. They are doing this using a variety of influencing methods based on sound research undertaken by an external agency (NRSP 2003).

But not all is encouraging. In Bulgaria large tracts of irrigated land went out of production during the transition to a market economy in the 1990s because the...
market for irrigated maize collapsed and the costs of pumping water to elevated farms was high and uneconomic. International lending agencies were encouraging farmers to take on the responsibilities for water management that traditionally belonged to the state and to invest in new irrigation infrastructure. But slow procedures in the transfer of land tenure to farmers meant that there was no enthusiasm at that time to take on these extra financial and management responsibilities.

Across the European Community there are serious concerns that new water legislation will render irrigation farming too expensive to produce crops that can be imported cheaper from elsewhere resulting in many farmers going out of business with consequent impacts on the rural economy. Few people appear to be listening to the farmers in the water debate at a time when the water demand for domestic use, industry and the environment are high on the agenda. The low priority given to agriculture is reflected in current research. Only one out of a reported forty research projects on water funded by the European Union is about agriculture.

These examples serve to show the complexity of the issues at this level and because of this initiatives that set out specifically to make changes here are quite rare (Alaerts in Alaerts 1999b). They take a great deal of time, in excess of 10 years and more, they are less predictable than contributions at the lower levels and the expertise available to support them is not readily available either in-country or internationally. However some initiatives do succeed in making significant changes and as two of the above experiences show, it may be the result of initiatives taken at the lower levels that then come through to change policy. Interestingly this is often the result of chance rather than design.

3.5 Extending the framework

From the preceding sections there is strong evidence that the generic framework does provide a useful aid for categorizing irrigated agriculture in capacity development terms and a basis for discussing issues and identifying constraints. But there needs to be more than just a generic structure. A ‘bridge’ is needed between the social science approach and the activities of a well-functioning water sector to aid communications between the disciplines. However, there are many issues to consider and adding them all can lead to the ‘all-inclusive trap’, cause confusion and paralysis whereas adding too little leads to the ‘over-simplistic trap’ where actions do not address important issues and so become ineffective.

A compromise is proposed here by introducing a second dimension based on the more familiar activities of planning, design, construction, operation and maintenance (Table 2). But also included is research, meaning the capacity to undertake formal research in a specialist institute or university, and education, meaning the capacity to undertake formal education in colleges, universities etc. This is not to say that these activities can be treated in isolation from all other aspects of improving water management but rather to highlight those that are central to building the platform on which irrigated agriculture stands.

Table 2 A framework for irrigated agriculture

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<th>Capacity levels</th>
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<td>IV Enabling env</td>
<td>Planning                                      Design                                      Construct          O&amp;M             Research</td>
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The addition of this dimension is meant to further clarify thinking about what capacity means and where capacity constraints lie. Clarity about constraints can then lead to identifying what needs to be done for which actions can be taken to achieve the desired impacts (see enlargement at the right of the framework). However, the simplicity of the framework should not mask the complexity of the tasks involved. Each activity requires various individuals, organisations, networks and an enabling environment in which to flourish. But there are also issues of subsidiarity (decision-making at the lowest possible administrative level) and participation to consider. The emphasis given to each level and activity may also be very different depending on local issues such as the way irrigation is practiced (e.g. privately run smallholder irrigation, publicly owned large irrigation and drainage networks and commercial farming) and the need to solve local problems (e.g. salinity and water-logging, inadequate education facilities, irrigation management transfer).

4 Capacity development in practice

An alternative way of looking at capacity development is from a practical point of view. There are an increasing number of examples of good capacity building. Many involve support from aid donors who are beginning to reflect the shifts in development in the way they provide technical cooperation. Several of these are reviewed with the aim of further clarifying what capacity development means as well as providing examples of how it can be achieved in practice. The case studies are also used to test the usefulness of the proposed framework for categorizing the issues raised.

Only the main points of each case study as they relate to capacity development are described; more details can be found by following up the references provided.

4.1 Developing farmer and institutional capacity – Zambia (FAO 2003)

This first case from Zambia is about improving knowledge and skills and changing the attitudes of local professionals and farmers.

In Zambia there is more than 100,000ha of private smallholder irrigation. The Zambian government advisory and support services are poorly developed and so smallholders rely on their own resources rather than on government support. But the government wanted to improve their productivity and to help more farmers to
take up irrigation to solve the country’s growing food security problem. It saw strengthening its advisory and support services to farmers as central to meeting this objective. An externally funded project with technical assistance was launched to introduce low-cost irrigation technologies as an entry point for training both local professionals and farmers.

This was an unusual move at a time when many governments were running down services and transferring responsibility for irrigation to farmers’ organisations. But Zambia does not have strong private organisations that can take on a support role and so it was decided to strengthen the existing government organisation rather than to build something new.

Government staff had little contact with farmers and where more familiar with top-down approaches to training and providing advice. So participative approaches and facilitation methods formed an important part of their training in addition to the more technical subjects. Training was done in a very structured way and implemented through a pyramid process of training trainers who then trained technicians who in turn trained the farmers. The methods used were based on the experience of using similar methods, but for differing circumstances, in Nepal, Cambodia, Bangladesh and Indonesia. They have led to the production by FAO of Guidelines on Participatory Training and Extension in Farm Water Management (PT&E-FWM) and a farmers’ training manual (FAO 2003).

In four years more than 10,000 ‘private’ farmers have been trained by the government service. A significant number of women joined the programme and indeed later in later training campaigns women outnumbered men in some districts.

The impact of the programme was measured by establishing what farmers had learnt and by measuring the uptake of technologies. But both methods produced inconclusive results, consumed a great deal of resources in data collection and proved far more complex to analyze than first envisaged. For example, the lack of a baseline survey of farmers’ knowledge made it difficult to determine what they had learnt from the training or what was the true level of technology uptake. This did not mean the attempt was without worth but it did highlight the complexity evaluation.

This case demonstrates how the provision of resources, technical assistance and training can strengthen a moribund government department, which in turn can have a significant impact on the private farming community. It also demonstrates that irrigation technology can provide a useful entry point to engage with farmers. Where private institutions are weak, the government still has a major responsibility for capacity development. The question of cost recovery from those who benefit has yet to be resolved and so the process may not continue once the external support has stopped.

4.2 Creating irrigation markets – Africa (World Bank 2003)

In separate initiatives, NGOs in Niger, Kenya and Zambia and Zimbabwe imported treadle pumps from Bangladesh to help smallholders to improve their livelihoods by providing access to water. But central to their successful introduction was not just the supply and modification of the pumps to meet local conditions but the development of local private capacity to manufacture, distribute, retail and maintain pumps at relatively low cost that would sustain their continued up-take in the medium and long term.

These are examples of a new approach to development known as the market creation approach. This is not so much concerned with creating markets for agricultural products, although this is clearly essential, but creating markets for new affordable irrigation products. In this case treadle pumps that encourage smallholders to take up irrigated agriculture. This produces a flow of benefits downstream as the purchasing power of smallholders increased but also benefits upstream from creating the chain that would supply and support the new products.

Capacity development in this context is about setting up the new supply chains and training individuals and groups to play their part in it. But the key element is an enabling environment, in this case a market for cash crops that could be grown by smallholders that stimulates the whole chain.

Kay and Brabben (2000) reviewed several case studies on the success of this market driven approach to capacity development that emphasizes the private sector requirements of publicity and marketing to spread information about technologies, reliable agricultural inputs and the identification of crops and markets where smallholders have a comparative advantage for the sale of their produce.

Most experiences of capacity development involve government in one way or another but this is an example of the role that the private sector can play in irrigation.
External funding and technical assistance were provided but the goal was to make the whole self-funding and profitable in the same way as any other private business. Capacity development involved training and transfer of a very wide range of skills but key to the success was a vibrant market for high value agricultural produce. This case spans all the levels in the framework and although it was principally about using treadle pumps there were also elements of planning, design and construction as well.

### 4.3 Measuring impact – Morocco (Kay 2001)

Large numbers of small, private farmers practice irrigation in group schemes in Morocco and in the past they have relied heavily on government for funding and advice. The government service wished to transfer various water management responsibilities to them and so organised the setting up of WUAs. The rural population, experiencing population pressures and water shortages, also appeared ready to take on responsibility for the management of small and medium scale irrigation schemes. Innovative ideas were used in a pilot project to integrate both government irrigation technicians and elected farmers in the day to day running of WUAs. Local, private consultants were used to implement a programme of farmer and irrigation technician training with external funding and assistance from an external consultancy.

A useful and practical method of evaluating the impact of the project was developed which could have much wider application. It was based on interviews conducted with farmers every 4-5 months to assess a range of parameters covering technical, social, managerial and administrative issues. Subjectively they decided whether a particular activity was still causing problems (negative); was not causing undue concern (neutral) or there had been noticeable improvement (positive). A statistical analysis of several surveys indicated a steady improvement in most areas. Although open to criticism the method proved to be informative, easy to organise and to analyze the results with practical outcomes.

Its success so far has encouraged a similar larger project to be undertaken and the setting up of a unit in the Ministry of Agriculture to continue the process. This is an interesting reversal of approach to the more traditional one of starting with the Ministry and then moving onto the farmers.

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This case study, unlike most others, was only about capacity development and not construction. It was externally funded with external assistance but implemented by local private consultants who worked directly with farmers once they were trained in participative methods, thus demonstrating the usefulness of the private sector in what is traditionally seen as the preserve of government. Its success was primarily due to the prevailing enabling environment.

### 4.4 Developing a research institute – Pakistan (Ritzema & Wolters 2002)

Pakistan has a successful agricultural economy, about 80 percent of which is irrigated. But irrigation has brought problems and 6mha are seriously affected by salt and some 2mha are reported abandoned because of severe waterlogging. Poor drainage is reported to cause a 25 percent reduction main crop production.

Visionaries within Pakistan recognised the need for research to solve these problems and so were instrumental in establishing a new research institute for this purpose with UN funding. But research institutes often have a reputation for working in their own world where personal and institutional reputations developed through publications have greater importance than solving the real problems of development. There are many varied and complex reasons for this not least of which are a lack of clear policy on the role of research, a lack of resources and poorly trained and motivated staff.

Capacity development began in 1988 with Dutch technical cooperation that provided a strong focus on the technologies of drainage design and installation. At the same time the salary structure was reviewed along with staff recruitment to bring in high quality well motivated people. Technical cooperation improved research skills, management and report writing among local staff. But almost by accident rather than by design the expatriate staff were also good capacity builders as well as technical specialists. They were experienced professionals that had learnt from many similar situations how to communicate with people and get them to take ownership of problems and solutions. They encouraged staff to think beyond the immediate technical issues and to put them into the context of drainage development and the real problems facing farmers. This was not in their job description nor was it the reason they were selected for the job. But it contributed greatly to the success of the institute which now has a growing international reputation for its research work.

Current research work is looking at the problems of participative drainage, which represents a further step in building the capacity of staff to work directly with farmers and to appreciate the complex social and cultural influences on their drainage research. Interestingly, because of the expertise that staff now have in this area the Institute has abandoned attempts to work with local NGOs because they had difficulty in adapting from their traditional village focus to the catchment thinking needed for participative drainage.
This is an example of how the capacity of a research institute can be developed to provide useful and economically viable research that is sensitive to the cultural and social needs of rural communities provided it is properly resourced and staff have incentives to work well. It is also an example of individuals within a country that have the capacity and strategic vision to see what is needed and take action to provide it. Personal connections with aid donors and international organisations such as the International Commission on Irrigation and Drainage (ICID), which fosters relationships across the irrigation world, also played a crucial part in setting the right environment for action.

4.5 Improving education and networking – India (Boonstra 2003)

India too has large tracts of irrigated agriculture that has led to areas of waterlogging and salinity. The difference between India and Pakistan was the variety of solutions needed to solve the problems in different parts of the country.

A network was set up, using Dutch funding and expertise with the Central Soil Salinity Research Institute as the centre working with four state agricultural universities in different parts of India chosen to investigate local drainage problems. Not only was drainage relatively new India but so was the idea of researching practical farming problems rather than working only in laboratory conditions. Resources were made available and researchers were supported by drainage specialists and trained to solve farmers’ drainage problems by working directly with them in a participative way. Universities were chosen specifically so that the knowledge gained would feed directly into the education system and so encourage long-term changes both in knowledge and the way future professionals would address drainage issues in the future.

The immediate result was that farmers who participated and took up the drainage solutions saw substantial increases in crop yield even in the first year after installation. The universities were inundated with requests from farmers for similar systems but as they were not geared to extension, steps were taken to bring in the local government extension departments. At the institutional level staff acquired new skills and status in their working relationships with farmers. But, although there was collaboration across the network in terms of training provision, the anticipated networking on drainage issues did not work so well as each university concentrated on its own problems and solutions. The links they created naturally with others, often within their own State, were much stronger. The links between universities and research institutes worked, be it not as successful as initially foreseen.

The case is a good example of using research as a means of building research capacity to solve real problems for farmers and working through the university sector as well as research institutes so that the results feed through into the training of future cadres of irrigation and drainage engineers. As with the Pakistan case the role of the technical specialists as capacity builders was an essential element in the programme.

4.6 Creating an enabling environment – Egypt & Tanzania

4.6.1 Egypt (APP 2003, Ritzema & Wolters 2002)

Egypt has relied for centuries on irrigated agriculture for its survival and development and as a result it has developed strong formal government based organisations to manage existing schemes and to plan new ones. But since the construction of Aswan Dam drainage has become a major issue as water tables have risen and land has become saline.

The Dutch government, with its own problems of dealing with drainage, has a long history of supporting Egypt. In 1976 a panel comprising Dutch and Egyptian drainage specialists and managers was set up to examine ways of dealing with the drainage of large tracts of the Nile Valley, to develop and transfer drainage technology from The Netherlands to Egypt and to administer Dutch donor funding for a series of drainage projects. Over the past 27 years this panel has grown in importance from a convenient administrative arrangement for a wide range of drainage projects, both in the field and in drainage research, and has become the basis of a partnership with Egyptian steering, that has now widened its scope by mutual agreement to include the wider issues of water management. An important aspect is, that it is addressing issues at the highest levels in Egypt on policy formulation in the sector and most recently institutional reform and capacity development. One of its key roles is to bridge the gap between applied research and policymaking and identify and set research priorities.

This partnership is regarded as a success by both countries and has led to significant technology developments and policy changes in Egypt. Several factors have influenced this, not least of which is the panel membership which has evolved over the years and now comprises some of the most senior government officials from both countries including representatives from all the ministries that are stakeholders in the water sector. The panel is currently chaired by the Minister of Irrigation and Water Resources. This ensures ownership of panel decisions at the highest levels in government. Other elements cited include the commitment of members, the inclusion of several women members who lead ministerial departments and the respect, natural empathy and personal relationships that have also grown over the years between panel members that has led to trust. This enables frank discussions to take place at an intimate and informal level as well as officially which is the essence of a good partnership.

It could also be argued that the ‘partnership’ works because of the funding provided by the Dutch government. There seems no doubt that this is important because without it the panel and its secretariat could not function. But the Egyptian ownership and driving force in the panel are probably more important factors and proponents point out that the financial support is modest in comparison with other aid donors and they have yet to develop the kind of influential panel
arrangements that have existed for over 27 years.

This is a good example of a mechanism that can help to establish an equal and influential partnership working at the highest levels in government in a situation that is always a difficult one, namely, where one partner is giving and one is receiving. It has also influenced the capacity of panel members as evidenced by their ability to change over time with the changing demands in irrigated agriculture. The Dutch would also argue that it has had a significant impact on the way in which they now administer their aid programmes to the benefit of other countries.

4.6.2 Tanzania (NRSP 2003)

Smallholders living in the tropical drylands of Tanzania, have to cope with the realities of inadequate and unreliable rainfall. Whilst policy makers recognise this and few doubt the critical importance of rainfall, they did not recognise the importance of runoff for water supply. Indeed, until recently, the overriding perception was that runoff was a hazard rather than a resource and led to soil erosion. Over many years this perception has driven government policy and programmes to the detriment of irrigation farming.

Sustained, externally donor-funded research and communications work over 12 years by a university team into the benefits of harvesting rainwater for improving productivity and smallholder livelihoods has transformed thinking at the highest levels of government. Work began initially as a research project into the technologies of rainwater harvesting but gradually the importance of communicating ideas and involving all the various stakeholders was realised if significant changes were to be made in the way in which farmers worked.

Rainwater harvesting is now seen as a resource and has this been incorporated in the development plans of certain district councils and NGOs, especially following the statement by the Tanzania Prime Minister that: 

*...the Government will strengthen and promote the use of rainwater harvesting technology, in both urban and rural areas* (Hansard Records, July 2nd, 2001).

This is an interesting example of how sustained efforts from the grass roots level can change government policy. The young age profile of the team that carried out the work is also an important lesson. They are usually less influenced by inflexible organisations, can be more up to date and flexible in their thinking, take risks and are ambitious to build their careers and make a worthwhile contribution. This is an important element to build into any strategy – the future is with the young.

4.7 Manpower planning

A common theme throughout all the case studies is the practical issue of manpower, the numbers of people and the skills needed for all the tasks of water management. Manpower planning is a methodology that was developed in the 1970s and 1980s to determine future training needs in the labour market. It enabled planners to determine the numbers of people and the skills needed to bridge the gap between labour supply and demand in an industry or sector. Clearly this is not an exact science because of the problems of forecasting the future and, therefore, what labor demands are likely to be.

FAO has studied methods for predicting manpower needs for agriculture such as livestock, fisheries and forestry (FAO 1970, 1979 and 1981). In 1970 FAO prepared a manpower study, as part of its Indicative World Plan for Agricultural Development, on a country by country basis but a lack of country data on which to base projections meant that the predictions where or limited value. In 1979 FAO published a practical reference work for those working at a national level in agricultural education but again limited data was a problem and the output had to rely on empirical formulae and staff norms predicted from ratios relating manpower to land areas or numbers of farming families.

Around this same time several attempts were made to apply manpower planning to irrigation and drainage. Nigeria provides an interesting and detailed example (Carter et al 1986). Other examples include Tanzania and Zimbabwe (FAO 1985), Mexico (Haissman, 1971) Sagardoy (in FAO 1982) and a worldwide view of staffing norms (80s and Storsbergen, 1978). All the studies recognised the importance of predicting the numbers required (quantity), ensuring they were well trained (quality) and that people worked within a sound institutional environment (organisations). But there is a tendency in many countries to remedy deficiencies in one aspect by substituting improvement in another. For example, overstaffing is common with under-qualified people working within poorly managed organisations. The importance of quality cannot be underestimated and the success of a scheme may well depend on it. Substituting more untrained people to try and make up for a lack of quality is unlikely to work. The importance of a sound methodology is as much to prevent overstaffing as to ensure adequate numerical levels.
One problem in the irrigation sector is the lack of norms for staffing levels. How many people does it take to run 1000ha of irrigation? It will be very different if it is 1-1000ha farm or 1000–1ha farms. Few countries have the experience or the data on manning levels and so irrigation specialists are often used to arrive at suitable norms and job descriptions for planning purposes.

Without doubt, any developments in irrigation and drainage will need sufficient, properly trained manpower. This in turn means education and training facilities with sufficient capacity to support the planned development and to allow not only for the long lead-time needed to develop professional and technical skills but also for the ‘wastage’ into other parts of the economy. This inevitably means predicting the numbers of people needed and the skills required both to build capacity in the education and training sector as well as for the more hands-on development of irrigation. Although manpower planning may be out of favour at the moment it does have the advantage that it focuses attention on these very issues, namely numbers, skills and education and training provision. It is unfortunate that the current literature on capacity building ignores these basic issues. In the current surge of interest in the more complex institutional aspects of capacity building there is a danger of neglecting the basics of numbers and skills and there appears to be a tacit assumption that the basic skills of irrigation and drainage are being well provided when this is clearly not the case. A visit to any university department, college and school in many developing countries would quickly provide a picture of under-funding, poor curriculum development in water issues, a lack of properly trained teachers on poor salaries and inadequate facilities to support practical and classroom training. There is a strong argument for capacity building to begin here as this is were the next generation of professionals and technicians will receive their basic education.

4.8 Refining the meaning

Many other similar cases could be cited but these few provide good, practical examples of capacity development and help to further refine its meaning for irrigated agriculture. They are all cases where infrastructure was not the central development objective as was traditionally the case in the past. The focus was on capacity development and not just in human resources terms. They all involved the training of individuals both in a formal and an informal sense. But all attempted to do this in the context of the organisations and institutions in which the individuals work and all tried to set this in the wider context of improving irrigated agriculture and the livelihoods of farmers.

The case studies were also good examples of the way in which the more sensitive approaches to external funding and technical cooperation, using the principles of participation and subsidiarity, contribute positively to capacity development.

An interesting aspect of the technical cooperation in Pakistan and India and to some extent in Egypt was that it started out as specialist technical help of a more traditional kind. But the external commitment in each case extended over a considerable time period and as the relationships progressed the importance of capacity development was recognised and this became one of the priority issues. The success of this had much do with the compatibility between the expatriate professionals and the local professionals and the institutional context in which they worked. Although expatriates were selected only for their technical abilities, they happened also to be capable and experienced enough to appreciate the difference between acquiring knowledge and just transferring it. They were able to go beyond their technical remit and to see their work in a wider development context and were able to train local staff to see their technical work in a similar way by using the principles of participation and subsidiarity. This was more by ‘accident’ than by design and it begs the question about how expatriate professionals are selected for capacity development work. Their technical expertise is essential but their ability to build capacity requires a wider range of communication skills and these should be recognised when selecting people for such jobs.

Although initiatives at the highest level are rare, some do succeed in making significant changes and can be the result of initiatives taken at the lower levels that then come through to change policy. Interestingly this is often the result of chance rather than design.

With regards to the usefulness of the framework, it was possible to clearly locate each case study on the matrix and to identify the contribution that each was making to the whole. From this it is proposed that the framework can be a useful tool for pin-pointing areas within irrigated agriculture that need attention. It could also provide a useful focus for discussion between partners in development so there is clarity of what is meant by capacity building, areas of constraint can be identified, and what needs to be done formulated.

5 Towards a capacity development strategy

The conceptual thinking and the practical experiences of the case studies both add clarity to the meaning of capacity development but they also help to define some of the elements for a strategy for developing capacity. This is not meant to be a comprehensive recipe but a list of issues that have arisen in this study.

5.1 Policy environment

Without doubt the importance of a favourable policy environment and political will for development is crucial to successful irrigation development and to developing
capacity and cannot be over-estimated.

Policies are largely determined by the quality and commitment of the leadership and senior management.

Within the policy, capacity development must be guided by clear strategies that address development needs and are nationally owned.

A period of review and experimentation with new approaches is essential before including them in any new policy.

5.2 Identifying and assessing capacity needs

Identification and assessment of capacity needs is one of the most difficult tasks. It is a question of who does it and how. It implies strategic planning capacity in a country and this too may require developing.

Expertise available from other countries is also limited because it needs people with interdisciplinary skills, with experience of working at high levels in government or the private sector and who are able to facilitate and not dictate discussion and decision-making.

Full participation of all the stakeholders in the public and private sectors, namely, farmers, engineers, agriculturists, researchers, educators, politicians and civil servants is essential and although it is a time consuming it is considered essential to the eventual ownership of any actions taken.

The lack of expertise and the extensive nature of consultation are unlikely to lead to a rapid conclusive or state-of-the-art solution. But it is essential that there is a locally owned consensus and that it is acted upon.

Capacity development is a complex process but complexity must not paralyze it. A framework such as the one proposed in this paper can provide a useful basis for discussions among stakeholders and for pin-pointing constraints and priorities.

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The challenge is to find ways through the complexity and make useful contributions. Like irrigation engineering, it is important to appreciate the complex nature of irrigated agriculture but at some point the engineer must be able to interpret this terms of constructing a good irrigation scheme.

5.3 The role of donors and technical cooperation

Although it is accepted that capacity development must come from within, there is also an acceptance that the process can be supported and accelerated by outside help.

Partnership is the essence of collaboration between donor and recipient and not the traditional north-south dialogue. This is always difficult to deal with when one is seen to be giving and one is receiving. Establishing true partnerships is a challenge facing both but the cases in Pakistan and Egypt show examples of good and effective collaboration.

Identifying capacity constraints and helping both governments and the private sector to take action can be is one of the most effective ways in which external agencies can help. An outsider view can often help those inside to focus their attention on the big issues.

The stimulation that external technical cooperation encourages can help to speed up processes and broaden thinking.

Long-term collaboration influences the process positively, among others as trust and effective work relationships develop over time.

Some donors may prefer not to become involved in lengthy processes and prefer a project approach. The implications of this in terms of budgets, timing and outputs can be at odds with the process of capacity development. But there may be specific actions at the lower levels of organisations and individuals lend themselves more to the project approach – capacity development projects.

Donors need entry points into capacity development. Typically the organisation is the level at which donors wish to contribute technical assistance, budgetary or infrastructure support.

People selected to help develop capacity need much more than technical knowledge and skills. They should be capable of working in a participatory manner in the
wider context of development and be able to convey such ideas to those who are being trained. This should be reflected in the selection process.

5.4 Organisations
It is at the organisational level that most countries suffer weaknesses. Most of the organisations supporting irrigated agriculture are government run but there is a growing input from the private sector. It is not a question of either one or the other but of the balance between them. The appropriate strengthening of both must be a priority in any strategy.

A good cadre of capable senior managers that can lead the processes of change is needed if organisations are to develop a good reputation and encourage the best people to join. Salaries are important but it is not the only criteria.

There are many advantages in working with existing organisations rather than inventing new ones. This may not always be attractive but new organisations can be a large drain on already limited management and administrative resources.

5.5 Individuals
Individuals are the heart of any organisation and their education and training must reflect the needs of irrigated agriculture and the roles they will play.

The 'people part of partnerships': Partnerships develop between people. While working together, more and better results will be possible over time, as mutual trust develops.

Manpower planning offers a tool for predicting the demand from manpower and a logical process for providing it through education and training. It focuses attention on the numbers of individuals needed, their skills and the education and training infrastructure needed to provide them.

Any strategy must address the young people who are less influenced by rigid organisations, are more flexible in their thinking, take risks and are ambitious to build their careers and make a worthwhile contribution.

5.6 Education and research
The capacity to educate future generations in the ways of irrigated agriculture and to undertake research to solve problems are fundamental to the sustainability of irrigated agriculture. It is essential that both are given a high priority in strategy development.

Education is essential to develop the future cadres of professionals who will become the managers and leaders of organisations and capacity builders. To achieve this the development of capacity within colleges and universities and to some extent in schools will need to be considered.

Research to solve the problems of irrigation and drainage and to encourage the take up of new ideas may require developing.

Research can be most successful, when linked to investment projects, where it can show its value directly.

5.7 Sustainability
Ensuring sustainability is still one of main challenges facing capacity development, particularly when it is supported by an external agency.

Sustainability is also a concept that requires careful thought. Should a training facility be sustained beyond its usefulness or should it be closed. Capacity development is not a fixed issue and any strategy must be flexible enough to meet changes in capacity needs.

6 Conclusions
This paper has attempted to define more clearly what capacity development means for irrigated agriculture, using language and terms that have more identifiable and precise meanings, by reviewing the conceptual thinking of social scientists over the past decade and case studies that provide good examples of capacity development in irrigation and drainage. It is unlikely that a simple and satisfactory definition will eventually emerge. But one principle that is important to understanding what capacity development means is very clear both from the literature and from the practical examples, the methods used to build capacity are essential to its success. It is as much a process as an end product. This is the essential connection between the more 'concrete' aspects of capacity building such as individual training, establishing irrigation organisations and changing the legal system etc and the less tangible aspects that suggest it can only be done in response to internal initiatives with local ownership and leadership over a flexible time frame. It is the reason why many people now use the term capacity development rather than capacity building. It transfers the emphasis from the end result to the process of achieving it.

All the case studies demonstrate this principle. They each involved the training of individuals and adopted the approaches of participation and subsidiarity. They attempted to do this in the context of the organisations and institutions in which the individuals work and in the wider context of improving irrigated agriculture and the livelihoods of farmers. Each involved external funding and sensitive approaches to technical cooperation that contributed positively to capacity development.

A simple definition may not be achievable but the review has shown that it is possible to make a clear statement about the territory of capacity development. For this a framework is proposed that bridges the conceptual approach to capacity development used by social science and the practical activities of a well-functioning water sector. This may also be a useful tool for pin-pointing areas that need attention and be helpful for discussions between partners in development so there is clarity of purpose on areas of constraint and what needs to be done. The case studies, that described some of the many and varied aspects of capacity development.
development, helped to reinforce the usefulness of this framework.

Countries where there is significant reliance on irrigated agriculture are likely to seek a strategy for capacity development. For this reason some suggestions are made about the elements of a good strategy based on the framework and the practical experience of the case studies.

## 7 Recommendations

This paper has demonstrated that it is possible to define the territory of capacity development in irrigated agriculture both in conceptual and practical terms. But much more is needed if people are to develop capacity in a structured way by building on the experience of others rather than trying to re-invent the wheel.

There is a great deal of knowledge and experience available from which others can benefit but it is not easily accessible. The following recommendations therefore address this issue of knowledge management.

The small number of case studies reviewed here demonstrate that there is a great deal of useful information available but it needs to be managed so that it is more accessible, particularly to developing countries, so that people can rapidly benefit from the experience of others. More case studies are needed that must go beyond the traditional descriptions of the irrigation set-up in a country and reflect all four levels of the proposed framework and the range of activities of a well-functioning water sector. To achieve this, guidelines for capacity development that are specific to irrigated agriculture are needed based on the conceptual framework and the experience of others. These would set out practical approaches to analyzing capacity development needs, strategy development, advice on implementation, the role of donors and technical cooperation, and methods of evaluating impact. Suggesting that people write and publish is one way of getting the information needed for this but for various reasons it is unlikely to yield useful results, at least in the short term. The authors of this paper used personal interviews with capacity developers to obtain the 'real stories' about capacity development. So one approach that is recommended here is to use a similar mechanism, but on a larger scale, to bring capacity builders together in a structured consultation process to formulate the guidelines.

The objective of a consultation would be to obtain information on a wide range of recent capacity development initiatives, formulate the contents of guidelines to reflect all four levels of the proposed framework and the range of activities of a well-functioning water sector, and examine ways of managing this new knowledge to improve its accessibility. Options for communication could include the WCA-infonet knowledge management system[^5] set up recently by IPTRID/FAO and the new FAO website devoted to participative training in water management[^6].

## 8 Acknowledgements

The authors wish to thank the FAO (AGLW) Rome and Alterra-ILRI, Wageningen for the financial and professional support in preparing this paper and for the many comments and suggestions made by staff members of both organisations. Comments made on the proposed framework by various members of research and training institutes based in Montpellier during a visit by Melvyn Kay were also appreciated.

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TOWARDS SUSTAINABLE IRRIGATION AND DRAINAGE THROUGH CAPACITY BUILDING


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[2] Irrigation consultant, RTCS Ltd. Email: kay@rtcs.co.uk
[3] Alterra-ILRI, Wageningen, E-mail: catharien.terwisscha@wur.nl
[4] The term irrigated agriculture is used to define all the ways of controlling and managing water for agriculture in an environmentally responsible manner. It is about water control technologies and practices for the irrigation of crops, water harvesting, drainage to dispose of surplus and saline water and flood mitigation to protect people and land against water damage.
[5] www.wcainfonet.org is recent addition to IPTRID/FAO networking activities and comprises a state-of-the-art Internet-based knowledge management system on water use in agriculture. If provides direct access to a wide range of information in many different countries. It is not just another website with connections to other sites – it contains only documents that have been approved by specialist editors. It has a section on capacity building and training and the author of this review is currently the editor of this section.
CAPACITY BUILDING IN FARMER’S WATER MANAGEMENT: THE FAO EXPERIENCE

Alice van Keulen[2], Martin Smith² and Daniel Renault²

1 Rationale

Among increasingly scarce resources, water is becoming a constraining factor in agricultural production and in sustaining life in urban and rural areas. Food security is inextricably linked to water security and can only be achieved through a concerted action to raise water productivity, maximizing crop production in both rainfed and irrigated agriculture. The gains from more effective water management are considerable. A range of techniques and technologies are available that will ensure a more effective use of water for agricultural production, both in rainfall and in irrigated agriculture. Investments are required, but more importantly: advise, technical guidance and financial support to the users to make sure that the initial constraints linked to the introduction and management of new water management techniques and technologies are adequately addressed.

Putting farmers in charge of water development and management has proved effective to achieve efficient and sustainable water management systems and to increase water productivity. This is evident in the transfer of management of irrigation systems to the immediate beneficiaries and through the formation of water users association, where users assume direct responsibilities in operation and maintenance of the irrigation system.

1.1 Definition

Farmers’ Water Management is the process in which individual farmers and farmers institutions set objectives for the management of their water resources; establish appropriate conditions, and identify, mobilize and use resources, so as to attain these objectives.

This definition of Farmers’ Water Management (FWM) applies to all types of water-control systems, including irrigation, drainage and flood control systems and associated activities that resort under the responsibility of farmers, either as individuals or cooperating in a specially established water users interest group.

1.2 Objective of capacity building in FWM

The objective of enhancing the capacity of farmers in water management is to intensify in a sustainable manner agricultural production through improved water control by farmers, with the goal to improve food security and farm income and raise livelihoods in particular for the small-holder.

1.3 The means: Participatory Training and Extension

One of the means that has been used and developed by FAO-AGLW in this program is the Participatory Training and Extension (PT&E) which is a training and extension approach that is based on a participatory analysis of the constraints and opportunities and based on the outcome of this analysis the introduction of new and appropriate technologies. Group based extension and training activities that enhance farmers’ capacities and skills, as well as capacity building of the staff involved in the extension activities go hand in hand.

Participatory Training and Extension is a tool to reach the goal of improved Farmers’ Water Management involving and supporting farmers. In order to support farmers and increase their capacity in FWM they need training and support for the introduction of technologies.

The main objective of PT&E is to empower farmers in order to develop, modify and diffuse appropriate and sustainable new technologies.

The programme for Participatory Training and Extension in Farmers’ Water Management (PT&E-FWM)[3] was developed within the framework of the FAO- Special Programme for Food Security. It has been implemented and tested in several countries (Zambia, Nepal, Cambodia and Bangladesh). Learning from the successes and mistakes of the first pilot projects, the programme has evolved over a number of years in a more improved and definite format.

The PT&E-FWM programme incorporates the concept of the Farmer Field School (FFS) introduced under the Integrated Pest
Management (IPM) programme. The FFS approach has enjoyed remarkable success as it showed that farmers can become experts at analyzing specific problems related to their farming activities and make informed decisions about necessary interventions. The PT&E-FWM programme is also partly based on staff training methodologies developed under the Farmers’ Water Management Training programme in Indonesia.

2 WATER SCARCITY AND NEED FOR SUSTAINABLE WATER USE

Water and food security are strongly connected. Many of the nearly 800 million chronically undernourished people live in water-scarce regions or in regions where water infrastructure has not been developed. In these areas limited access to water often plays a major constraint to improving food production.

Global population will continue to expand. The increase in population and changes in food preferences will result in a strong demand for additional food production. It is expected that much of the increase in crop production will come from irrigated lands, as irrigated agriculture is much more productive than rain-fed agriculture - irrigated agriculture contributes nearly 40 percent of world’s food production on 17 percent of cultivated land. But agriculture already counts for 70 percent of the freshwater withdrawals in the world - for developing countries this figure is even as high as 85 percent - and is seen as the main factor behind increasing global water crisis.

The key to increase world's food production without deepening the global water scarcity is improving the efficiency in the use of irrigation water. At irrigation scheme and farm level, irrigation efficiency can be sometimes as low as 30 percent. The gains from introducing effective water management and improved irrigation and water-control techniques and technology can be tremendous both in terms of water saving as well as in increase in productivity and stabilisation of erratic food production.

3 Farmers’ Focus

Although irrigation is crucial in increasing world's food production, many governments have found it increasing difficult to finance the cost of irrigation operation and management. This has led to rapid deterioration of infrastructure, poor management and subsequent wastage of water and advancing waterlogging and salinity. Poor system performance and the governments' inability to do something about it have spurted the efforts to increase farmers' participation in irrigation. One of the most noted effects of farmers' participation in irrigation is the reduction in government staff and expenditure requirements. However this does not motivate farmers to participate. Their participation must result in direct benefits.

By working with farmers and other stakeholders to identify and resolve agricultural production constraints in irrigated agriculture - whether they are of a technical, institutional or policy nature – and to demonstrate ways of increasing production opens the way for improved productivity and broader food access. Working with farmers to understand and, where possible, solve the problems that prevent them from producing more food is crucial. When farmers are involved in and responsible for development and improvements in water management, global experience has shown a number of tremendous benefits. In the first place building or introducing improvements in irrigation systems that are wanted, supported and owned by the users themselves provides the best assurance for sustainability. Further involvement of farmers in system management might lead to more equitable organisational arrangements and water distribution. Finally there might be secondary effects from farmers training and organisation. It can increase local capacity to co-ordinate input supplies, credit, marketing etc. and increase their negotiation power and ability to deal with governmental and non-governmental organisations involved in rural development.

Farmers' participation in irrigation does not eliminate the role and responsibility of the government and governmental organisations and agencies in irrigation. Water users groups will need to be mobilised, organised and trained while technical support in design, operation and maintenance of the systems is needed as well. These are all tasks that need to be implemented by governmental organisations. Further it is neither always feasible nor desirable that entire, mainly large-scale, irrigation systems come under farmers' responsibility and management.

Constructions are possible that farmers' are responsible for secondary and tertiary units while the responsibility of the main infrastructure remains with the governmental agency. Further farmers' participation in irrigation is only possible if a strong but flexible and transparent legal framework exists.
4 Farmers’ Water Management (FWM)

Giving special attention to farmers and their water management has proven highly instrumental in improving system performance and increasing water productivity. Water Management is not limited to the process of controlling the supply of water to and from the crop in the right quantity and time. Water management needs to be considered in a holistic manner as a range of human, agronomic economic and legal aspects that determine the process of water management. Good management involves setting well-defined criteria and standards that are determined by the specific objectives of the user. Similarly water management is determined by the objectives set by the water manager, who may opt for maximal production, minimize water for optimal production, and may set standards for equity in water distribution and maintaining good quality.

At individual or farm level, FWM comprises of setting the objectives and establishing the conditions and organizing the resources to meet the farm level objectives. Farm level FWM objectives are related to the specific farm objectives as set by the individual water manager and may relate to e.g. risk avoidance, maximizing agricultural production, attaining self-sufficiency etc.; are constrained and influenced by the available farm resources; and may be restricted by the FWM at group level. Farm level water management relates to the water control techniques (irrigation methods, field drainage and crop water management techniques) managed by the individual farmer on his/her own field and farm.

At group level FWM is organized by farmers, who jointly manage a hydraulic unit and share water from the same water source. This source may include a joint groundwater resource, river or dam, but also may include a tertiary unit or part of a larger irrigation system, where the main system is managed by an irrigation agency.

The need for joint management comes forth out a communal consensus to optimize available water resources and ensure the sustainable use of the system and resources. Individual objectives in water management may lead to conflicts in particular under conditions of scarce water supply.

Good maintenance of the system is often a first condition for sustainable water supply. FWM at group level comprises setting objectives to satisfy the individual FWM objectives, but also safeguarding the interests of all users on equal basis. FWM at group level is influenced and constrained by the physical, social, economic and legal environment as is illustrated in above figure. The water users group will establish the conditions and organize the resources to meet the joint objectives, controlling processes, maintaining and rehabilitating the system to enhance its capacities and perform monitoring as to ensure that the objectives are continuously met.

In contrast to the governmental managed systems, in ‘farmers’ managed systems’, the users and immediate beneficiaries set the objectives and establish the management structure and procedures. There is ample evidence that shows that communal management of water will lead to considerable better performance and sustainability of the water. Management of water by a group of farmers may lead to conflicting interests of individuals and there is a strong need to formalize obligations and rights of each individual user. A more formal arrangement with well defined rules and regulations and an organizational structure may be required for such water users groups.

Formation of Water Users Associations (WUA) with an accepted legal structure is therefore actively promoted in many countries, in particular where the devolution of irrigation management has become an official policy.

5 Participatory Training and Extension (PT&E)

In many countries, the ‘transfer of technologies’ model has been the prevalent practice for developing and spreading technological innovations. It is based on the assumption that transfer of technology and knowledge from scientists to farmers will trigger development. In this model it has been the researcher’s task to identify, analyze and solve farmers’ technical problems and the extension workers’ task to transfer the results as messages to the farmers. The results have been disappointing. The adoption rates of technologies remain low in most cases and the performance of researchers’ technologies is often disappointing under farmers’ management. Three main reasons were identified for these disappointing results:

- Specific constraints of farmers have not been taken into account;
- Social, cultural, organization and power issues at community level are neglected, and
It was obvious that more effective approaches needed to be developed. Since the 1970s, efforts have been made to improve the impact of research and extension. All have striven for the greater involvement of farmers in the process. The first effort was through the use of on-farm trials. The technologies were still developed by the researchers and adoption rates still did not increase. In an attempt to explain farmers’ continued non-adoption of technologies, the farming systems’ perspective was developed. This identified farm-level constraints to adoption. Input supply was improved and often fertilizer was given out free to give farmers a taste of the benefits. Still there was little adoption of the technology packages as the approach failed to address the diversity of farmers’ socio-economic and institutional environments.

In the late 1980s, it was realized that most technologies developed by researchers alone were inappropriate for smallholder farmers. Farmer participatory research became the approach to adapt technologies to farmers’ conditions and by the 1990s, to develop technologies together with farmers. Farmers were now seen as partners in research and extension, and the key players in the innovation process. The understanding that the main key to agricultural development is to enhance the farmers’ management and problem solving capacity and the farmers’ capacities to develop, modify and diffuse new technologies and techniques themselves from farmer to farmer led to the development of Participatory Extension.

PT&E is a tool to reach the goal of improved FWM involving and supporting farmers. In order to support farmers and increase their capacity in FWM they need training and support for introduction of technologies. In turn, staff involved in the programme need to be prepared for their task and thus their capacity needs to be build simultaneously.

Thus, group based extension and training activities that enhance farmers’ capacities and skills, as well as capacity building of the staff involved in the extension activities go hand in hand.

The main objective of PT&E is to empower farmers in order to develop, modify and diffuse appropriate and sustainable new technologies.

PT&E is participatory in terms of:

- participatory identification of needs and introduction of technical solutions, resulting in training and activity plans;
- use of participatory training methods;
- participatory methods for M&E of the programme and revision of plans and activities.

### Table 1 Comparison of “Transfer of Technology” and “Participatory Extension” Approaches

<table>
<thead>
<tr>
<th></th>
<th>Transfer of Technology</th>
<th>Participatory Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main objective</td>
<td>Transfer of technology</td>
<td>Empowerment of farmers</td>
</tr>
<tr>
<td>Analysis of needs &amp;</td>
<td>Outsiders</td>
<td>Farmers facilitated by outsiders</td>
</tr>
<tr>
<td>Priorities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extension messages</td>
<td>‘commandments’ messages</td>
<td>Principles</td>
</tr>
<tr>
<td>content</td>
<td>package of practices</td>
<td>Methods</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Basket of choices</td>
</tr>
</tbody>
</table>
The 'extension menu' | Fixed | According to choices
---|---|---
Farmers behaviour | Listen to messages | Use methods
Act on commandments | Apply principles
Adopt, adapt or reject package | Choose from basket & experiment
Outsiders' desired outcome | Widespread adoption of package | Wider choices for farmers
Farmers' enhanced adaptability
Main mode | Extension agent to farmer | Farmer to farmer
Roles of extension agent | Teacher | Facilitator
Trainer | Searcher for and provider of choice

6 Key issues in Capacity building on FWM
The majority of participants of a Participatory Extension and Training Programme in Farmers’ Water Management are adults, both women and men farmers. We consider therefore as essential in order to facilitate this capacity building activity to have a good understanding on:

- how adults learn
- how the role of the facilitator in this process should be
- how the different participatory learning techniques can be applied

6.1 Adult Learners
Adults have a wide experience and have already much knowledge and skills. Learning something new (experiencing) is not just achieved in an instant. Referring back and making use of the knowledge and skill is the basis of the adult learning process. It may sometimes be necessary to review the existing knowledge/skill (analyzing) as well as test the new ideas. The new learning will have to be internalized (processing) by making it relevant to one’s self. It may have to be shared with other people as part of the process. Only after this can the learning be applied when confronted with a similar situation (generalizing).

6.2 Role of the facilitator
The role of the facilitator and his relationship to farmers contrasts significantly from that of the instructor or trainer. The instructor imparts knowledge to farmers who adopt a passive role of merely receiving information. On the contrary, a facilitator creates conditions for farmers to learn, by arranging opportunities for the farmers to observe and interpret differences in conditions and crop performances, to carry out simple tests and exercises, and through discussions. The facilitator encourages farmers to adopt an active role in the learning process. In the PT&E in FWM the facilitator has direct contact with the farmers to assist them in taking decisions for the introduction of new technologies. Next, the facilitator also has the role of technical resource person explaining new technologies. Normally the field extension agent is the principal Farmer Field School facilitator, whereas the specialist in Farmers’ Water Management (district engineer, irrigation agronomist) assists in providing technical guidance. Only in exceptional cases does the Technicians and FWM specialist perform the role of facilitator.

Box 1: The facilitator

- The attitude of a facilitator is:
- To accept that there is no monopoly of wisdom or knowledge on the part of the facilitator;
To listen to farmers and respect their knowledge, experiences and perceptions;
To give farmers the confidence to share their knowledge and experiences;
The role of a facilitator is:
To be responsive to farmers' needs and flexible in organizing the training and extension activities;
To create suitable conditions and activities from which farmers can learn;
To increase farmers' knowledge, skills, problem-solving ability and capacity for innovation so that the facilitator becomes redundant.

6.3 Participatory learning techniques
A variety of participatory learning techniques are used in PT&E in FWM. These techniques include: plenary introduction, brainstorming, small group discussions, plenary discussion/presentation, practical (field) activities, field walk/field observations, role plays, field trials and field tours.

7 Elements of a methodology for Capacity Building in FWM

Setting up target groups
The farmers are the main target group of the PT&E-FWM programme. In order to reach the farmers effectively, a team of support staff needs to be trained on how to work with the Participatory Training and Extension Approach. So the support staff form the second target group of the training programme.

7.1 Farmers
The selection of collaborating farmers needs to be given due attention in order to have a lasting impact on the training and demonstration programme. In the selection of farmers, care is taken to have an appropriate representation of the different irrigation blocks, the different social groups, women farmers, land tenure and literacy. The first selection of the farmers is made by the facilitator of the Farmers' Training and may be influenced by the project mandate. Farmers are explained about the set-up and purpose of the extension programme and volunteers are asked to join the programme. In case there is an existing Water Users Association, the selection will often be made among the members of this Association.

7.2 Support Staff
The composition of the group of support staff may differ for each country where the programme is implemented. In each country the composition of Ministries, Departments and Institutes and their set-up, mandate and organizational structure might be different. In general the support staff consists of Support Units within the Extension Service and the Technical Support Service, like irrigation agents and crop husbandry agents. When staff of the private sector (for supplies, credit and marketing) and NGOs (for community development) provide support to the programme, they should be included in the training programme.

7.3 Developing a consistent set of training elements
For successful and sustainable introduction, use and improvement of water control techniques and technologies farmers should be encouraged to analyze their problems, search for solutions, monitor and evaluate the selected and implemented techniques and technologies, and adjust them according to their constraints and opportunities. Farmers Training (FT) aims to ensure continued farmers' participation and a sustainable implementation of this process.

Box 2: Objective of the Farmers Training (FT)

Objective of the Farmers Training (FT)
To put farmers in charge of the analysis and definition of the constraints, development opportunities and technologies through a participatory appraisal of priorities and their potential. Consequently, farmers' capacity is enhanced through the development of their skills in:
• the design, implementation, operation and maintenance of water control; establishing community capacity for joint management;
• the intensification of irrigated crop production through improved agricultural practices; and
• raising income through farm diversification.

FT forms the central element of the PT&E programme and is split up in two phases i.e. the Farmers Seasonal Planning (FSP) and Farmers Seasonal Training (FST). The FSP focuses on problem identification, selection of techniques and technologies to be tested and preparation of a seasonal work plan. During the FST the seasonal plan will be implemented and the selected techniques and technologies will be introduced, used and evaluated. The training sessions will be according to farmers’ needs and requirements and follow closely the various agricultural seasons.

To ensure sustained support to the implementation of the FT, a support structure needs to be created. Through an intensive and well-structured Staff Training (ST) programme an appropriate support structure is established. The programme that focuses on the support staff within the PT&E is the In-Service Training Programme (IST-P).

**Box 3: Objective of the Staff Training (ST)**

**Objective of the Staff Training (ST)**
The specific objective of the staff training is to develop the institutional capacity to provide support to the implementation of the farmers’ water management programme. More specifically the training aims:

• to introduce the concepts of participatory extension approach in farmers’ training;
• to enhance the technical knowledge and skills of staff of technical and extension agencies in the various irrigation technologies;
• to enhance the skills of staff of technical and extension agencies to facilitate Farmers’ Training;
• to develop an appropriate programme and work plan with the concerned staff at different levels;
• to monitor progress and constraints and adjust the programme to new requirements.

In most PT&E-FWM programmes the extension staff, who are already in close contact with the farmers, will be responsible for the implementation of the FT. For the implementation of the FT, the extension staff needs to have sufficient technical knowledge and master the required facilitation skills, to be able to assist the farmers in their analysis of the problems in water management and the implementation of solutions. Technical staff from district, provincial or national level can provide this training. In order to be able to support the extension staff, the technical staff also needs guidance. The ST entails training for both extension and technical staff and is therefore divided in Technical Staff Training (TST) and Extension Staff Training (EST).

The TST focuses on training of provincial and district irrigation and agricultural officers who will be responsible for the implementation of the extension staff. The EST focuses on training extension staff who will be responsible for the implementation of the FT.

### 7.4 Farmers Seasonal Planning

The first and most important phase of the FT is the establishment of an overall FWM plan. A representative group of farmers and members of the Water Users Association will select, through a participatory process of problem identification, the FWM techniques and technologies that they would like to introduce and improve during a predetermined number of seasons. The number of seasons normally equals the time span of the project or programme. A list of the selected FWM techniques and technologies forms the FWM plan, which sets the overall targets for the FT. The FWM plan is made during the first Farmers Seasonal Planning (FSP). Based on the FWM plan the farmers will also prepare a farmers seasonal plan for the coming season. This plan spells out in detail what activities will be carried out during the coming cropping season and is in line with the FWM plan.
The farmers' seasonal plan might include:

- a cropping plan for the crops that have been selected to be studied during the agricultural season;
- a crop water management plan, including experiments for field irrigation techniques and irrigation scheduling; and
- the structural improvements to be carried out on the irrigation, drainage or flood system.

The farmers' seasonal plan will further include an assessment of the inputs and support required to strengthening the WUA. In general, five sessions, scheduled over a five-week period, prior to the agricultural season, will be sufficient to formulate and agree on the FWM plan and the first farmers' seasonal plan.

During the succeeding FSPs the farmers will evaluate the implementation of the farmers seasonal plan. Based on the evaluation, farmers will update the FWM plan and prepare a new farmers seasonal plan for the next season. The succeeding FSPs can be shorter than the first FSP. In general, two sessions, scheduled over a two weeks period, prior to the next agricultural season, will be sufficient to update the FWM plan and to agree on the farmers' seasonal plan for the next season.

The main characteristics of the FWM plan and the farmers' seasonal plan are presented in Table 2.

### Table 2  Comparison between FWM Plan and Farmers' Seasonal Plan

<table>
<thead>
<tr>
<th></th>
<th>FWM Plan</th>
<th>Farmers’ Seasonal Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contents</strong></td>
<td>List of selected FWM techniques and technologies to be introduced during the project.</td>
<td>Activities for a season, including FWM, crop management, curriculum of FST, etc.</td>
</tr>
<tr>
<td><strong>Objective</strong></td>
<td>To guide FWM improvements in the irrigation scheme</td>
<td>To guide activities for a season in the PT&amp;E – FWM</td>
</tr>
<tr>
<td><strong>Time span</strong></td>
<td>Project period, 2-3 years</td>
<td>One season</td>
</tr>
<tr>
<td><strong>Developed during</strong></td>
<td>First FSP</td>
<td>Each FSP</td>
</tr>
<tr>
<td><strong>Adjusted during</strong></td>
<td>Subsequent FSPs</td>
<td>FST</td>
</tr>
</tbody>
</table>

#### 7.5  Farmers Seasonal Training

In the second phase of the FT, training and related development activities are implemented over one cropping season as determined in the FSP. The techniques and technologies to be introduced or improved as determined in the FSP form the topics of the Farmers Seasonal Training (FST).

Through the participatory training and extension approach, these techniques and technologies are introduced, following a step-wise procedure.

The topics of each meeting are related to the development stage of the crop, and associated farm management and water control practices, at that particular time. During the training sessions the farmers normally conduct a number of on-farm trials (studies) as well as demonstrations of alternative technologies which have been selected during the FSP. The activities are highly practical, involving careful observations of factors affecting farm performance and joint examination of possible solutions. During the training farmers will identify the underlying causes of their management problems and test possible solutions that fit their particular physical and socio-economic situation. Through utilizing the skills developed in local analysis farmers are enabled to adjust input recommendations or technical packages to suit local conditions.
Existing groups and communal management systems of water and land resources will be strengthened in order to ensure sustainable irrigation system management. Where appropriate new Water Users’ Associations (WUA) will be formed to manage and operate the irrigation system.

7.6 Staff Training
PT&E is based on participatory learning and associated facilitation techniques. The specific facilitation and learning techniques that are used for the FST and FSP are also used for the Staff Training (ST). In this way the support staff learns how to use these facilitation and learning techniques. In general, support staff have received technical education and have less experience in participatory training and extension. Therefore, at the start of the ST a lot of attention will be paid to training the support staff in participatory training and extension approaches and facilitation skills. As the support staff becomes familiar with these approaches and skills the focus of the ST will slowly shift more towards the technical content of the subjects.

Extension staff works at district or community level and are the ones responsible for the Farmers’ Training. It can be seen that by organizing one TST many farmers groups can be trained in the field.

In addition to the TST and the EST, a Staff Field Training (SFT) is organized. The SFT is organized during the agricultural season in the field to monitor and evaluate the progress of the field activities and to address any problems encountered. Both technical and extension staff participate in this field training.

7.7 Technical Staff Training
Normally, a team of national consultants carries out the technical staff training with help of selected resource persons at central level. For each training session the specific objectives need to be set. The TST includes organizational issues, facilitation skills and technical training. The technical staff in their turn is responsible for the implementation of the training of the agricultural extension staff. Therefore, adequate attention needs to be given to provide guidelines for the training of the extension staff.

Each of the training sessions needs to be based on a detailed time schedule and an appropriate balance between lectures, group activities, practical exercises and field demonstrations needs to be worked out. The topics of the training sessions are related to the expected field activities during the agricultural seasons.

In general two TST sessions are organized for each agricultural season. The first TST, which is held before the Farmers Seasonal Planning, will focus on the FSP and the technical issues related to expected field activities. The second TST will be held shortly after the FSP in which the FWM and seasonal plans are evaluated and a planning is made for the seasonal activities. The curriculum of the TST is based on the evaluation reports of previous Farmers Training, Extension Staff Training and Technical Staff Training sessions and on the mandate of the programme. The length of the TST is about 4 to 5 days and is scheduled just before the beginning of each EST.

7.8 Extension Staff Training
The agricultural extension staff will be involved directly with the implementation and day-to-day follow-up of the PT&E programme at field level. The Extension Staff (EST) is aimed at transfer of knowledge in FWM techniques and technologies and agricultural practices for irrigated crops through participatory training and appraisal techniques. The training will be organized and implemented at district level and facilitated by the technical staff of national, provincial or district level.

Similarly to the TST, the specific objectives need to be defined for each training session and includes organizational issues and a mixture of facilitation skills and technical training. The topics of the training sessions are related to the expected field activities during the agricultural seasons.

Also two EST sessions are organized during each season. The first EST focuses on the implementation of the FSP and relevant technical topics. During the second EST, just after the FSP a detailed seasonal planning will be worked out and training on technical issues and/or facilitation techniques can be added.

The curriculum of the EST is based on the evaluation reports of previous FT and EST sessions and on the mandate of the programme.
The length of the EST is also about 4 to 5 days and the sessions are scheduled just before a FT session.

7.9 Staff Field Training
The SFT normally coincides with a monitoring mission of the National Team. Both technical and extension staff participate in the SFT. The SFT is a mixture of monitoring and evaluation, field visits and training conducted at field level. The main purpose of the SFT is to monitor and evaluate the progress of the field activities and address technical and/or organizational constraints encountered during the implementation of the PT&E programme. The SFT can also be used to update the technical knowledge of staff on certain topics relevant to the agricultural season.

7.10 The training cycle
The Farmers Training has a cyclic character. During the first FSP the farmers prepare the FWM plan and based on this the farmers prepare a Farmers Seasonal Plan for the first agricultural season of the project. The Seasonal Plan is implemented during the first season and facilitated by the Farmers Seasonal Training. Just before the following seasons, the farmers evaluate the implementation of the first Seasonal Plan, update the FWM plan and prepare a new Seasonal Plan for the next agricultural season during the succeeding FSP. This process will continue as long as the project/programme lasts.

To guide this process the support staff is trained to facilitate the Farmers Training (FSP & FST) during the Staff Training (TST & EST). The output of the Farmers’ Training forms the input for the successive Staff Training to enable the support staff to provide tailored support to the farmers.

This process repeats itself each season. The cyclic nature of the ST and how it is integrated with the FT is depicted in Figure 1.

8 Conclusion: importance of a multi-actors approach in Capacity Building
In general a single agency is not capable to deliver all the required support functions. An appraisal of the agencies and institutions, both governmental and non-governmental, active in the project area needs to be undertaken to assess the type of support that they can deliver. In most countries the following agencies could be engaged in the programme to fulfill the four basic support functions.

• Extension Departments or Units maintain direct contacts with the farmers for transfer of knowledge. Therefore it is sensible that the extension agents are directly involved as facilitators of the Farmers Seasonal Planning and Farmers Seasonal Training. As such, the Extension Department or Unit plays a key role in the PT&E programme.

• The Irrigation Agency usually has the responsibility for technical designs, construction, operation and maintenance of the irrigation infrastructure. The major function other Irrigation Agency in PT&E will be to provide continuous technical advice and guidance to the extension staff and provide technical training.

• The Agricultural Agency will also be responsible for providing various technical advice and guidance services in relation to agricultural inputs such as agricultural research and agricultural extension.

• NGOs are often involved in community development at village level. As they have experience in working with the farmers, their support to the programme is to develop and strengthen Water Users Associations. Also when additional extension staff or extension skills are required, NGOs may be included in the training and extension activities.

• Supply of agricultural inputs such as seed, fertilizer and mechanical equipment is increasingly provided through the private sector.

• Banks or NGOs that implement credit programmes may be involved for the supply of credit systems to enable farmers to acquire the agricultural inputs.
Figure 1 Seasonal cycle of PT&E-FWM

The various agencies will have, in general, a decentralized structure at central, provincial, district, sub-district and village level, where staff will be allocated specific tasks. Support services to the programme will be along established lines of command and procedures.

An analysis of the institutional structure needs to be made to evaluate the present tasks and responsibilities of the staff at each level. Existing organograms can be used in support of this analysis. The combination of organograms of the different ministries, departments and other organisations involved can give a clear overview for the assignment of support tasks and responsibilities.

8.1 Defining the roles and tasks for staff at provincial, district, communal and/or village level

This step includes the definition of the roles and tasks for the various staff of each of the agencies to be assigned to the implementation of the PT&E-FWM. The task description for each person involved is specific for that person from that agency, on that level. For instance the Village Extension Worker has direct contact with the farmers and conducts the farmers training, so among others, the following specific tasks might be included

- to advise on the problems the farmers have with the existing irrigation techniques
- to plan and conduct the Farmers' seasonal Planning and Farmers' training;
  - to prepare the necessary training and extension materials; and
  - to advise on the procurement of the necessary agricultural inputs (seeds, fertilizers).

The Technical Staff, such as the Provincial and District Irrigation Engineers and Agricultural...
Officer is less involved in the training of farmers, but more responsible for assisting and advising the Village Extension Workers. Tasks of, for example, the District Irrigation Engineer might include:

- to provide technical guidance in the implementation of the various irrigation improvement works proposed by the farmers in their Farmers’ Seasonal Plan;
  - where appropriate to prepare terms of reference for surveys and designs to be made for the irrigation improvement works and advise on tendering procedures for construction works that are beyond farmers capacity;
  - to advise on the quantities and procurement of the various construction materials for construction works to be carried out by farmers; and
  - to advise and assist in the preparation of the necessary training and extension materials on Irrigation.

For a successful development of the PT&E, the support staff needs to be motivated during the whole cycle of development and implementation. Clear arrangements should be made in advance for incentives like field allowances, travel and training facilities.

### 8.2 Establishment of a Co-ordination Unit

Adequate attention needs to be given to co-ordination of the activities in the implementation of the PT&E to ensure timely inputs and contributions from all participating parties.

Once the Districts have been selected, the establishment of a Steering and Co-ordination Unit is recommended to ensure the essential co-operation between the different agencies and to provide overall guidance to the National Team. The Steering and Co-ordination Unit consists of Provincial and District representatives of the involved departments and agencies. The Steering and Co-ordination Unit should advise on the proposed activities and monitor progress, results and constraints encountered. On the basis of these discussions the Coordination Unit should provide advice on the implementation of the Programme.

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[3] Details of the implementation methodology and various training materials are available upon request on a CDROM FAO-AGLW CD 14 or can be accessed on our dedicated web page [http://www.fao.org/ag/agl/aglw/farmerwatertraining/default.htm](http://www.fao.org/ag/agl/aglw/farmerwatertraining/default.htm)