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The determination of the drainage factor as a criterion for the soils of the Indus Plains[1]

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Summary

In the Indus Plain in West Pakistan drainage factors had to be established as design criteria for comparing the cost of horizontal drainage with that of tubewell drainage, in particular for the saline groundwater areas. Drainage factors were calculated from recharge estimates and leaching requirements and the results compared. Several types of drainage factors were distinguished.
The following conclusions were drawn:
a. The recharge estimate results in higher drainage factors than the leaching requirement.
b. For tubewell drainage which will normally maintain the water table at a lower level than even possible with horizontal drainage the drainage factor derived from the recharge estimate should serve as a criterion for establishing the capacity to be installed.
c. For the calculation of the required spacing of horizontal drainage a drainage factor slightly higher than that derived from the leaching requirement should be preferred to take drainage of seepage from line sources into account.
d. If wide spacings are calculated with a relatively small drainage factor, the reaction of the water table halfway between the drains to intermittent recharge may be too slow and a smaller spacing may be required.
e. Although as accurate data as possible should be collected, the accuracy required for the drainage factor is limited and attempts should be made to collect additional data on the hydraulic conductivity of the soil.

Introduction

The Indus Plains constitute the heartland of the Province of West Pakistan and contain one of the world's oldest and largest irrigation areas. At present more than 30 million acres are under command of numerous river headworks and several thousands of miles of irrigation canals.
The soils of the Plains are mainly medium-textured silty loams, well-suited to irri-

[1] This article is based on data mostly collected in the course of the 'Indus Basin Survey' undertaken under the auspices of the International Bank for Reconstruction and Development on behalf of the West Pakistan Government; however, this does not mean that the opinions stated therein necessarily coincide with those of the aforesaid authorities (3).

gated agriculture. The whole of the Punjab, the northern part of the Plains, and the greater part of the Sind located downstream is underlain up to a depth of 1000 feet or more, by a highly pervious aquifer of unconsolidated and stratified layers of alluvium saturated with water.

In the second part of the nineteenth century the water table in the main part of the Plains was at a depth of 60 to 80 feet or more below surface. Only along the rivers rather small strips had a depth to groundwater of less than 10 feet. Through the inception of controlled irrigation and the construction of large-size new canals, the groundwater table in the Plains has risen, though at a different rate in the various parts. It is estimated from the latest available data that at present about 7.3 million acres or 40 per cent of the total commandable area in the Punjab and nearly 5 million acres or about 55 per cent of the cultivated area in Sind have a depth to groundwater of less than 10 feet.

The chemical quality of the groundwater varies considerably. The largest concentration of dissolved salts occurs in the central and lower parts of the Doabs, the areas enclosed by the rivers. Towards the sea, in the lower parts of Sind and in the Delta, the groundwater is extremely saline. In the saline zones the overlaying shallow groundwater is usually of a better quality.

The control of the depth to groundwater in the areas underlain by groundwater containing less than about 3000 ppm total salts will be effected by tubewell pumping, which is possible because of the extremely favourable aquifer conditions. For areas underlain by saline deep groundwater, tubewell pumping with disposal of the saline effluent is possible as well as drainage by means of open and closed conveyors. In the latter case, the effluent will contain considerably less salt and may be partly re-used.

The total area underlain by saline groundwater at a depth of less than 10 ft is not in immediate need of groundwater table control. In Sind the major part of this area is cropped with rice while of the remainder only a part has a water table at a depth which is sufficiently shallow to adversely affect cropping and to allow control by means of horizontal drainage. In the absence of accurate data it is assumed that at present for about 2 million acres in the whole Indus Plains horizontal drainage may be considered.

It is not the intention to discuss all factors influencing the choice between tubewell pumping and horizontal drainage for groundwater control. Only one aspect will be dealt with, i.e. the quantity of water to be removed to obtain water-table control and to prevent the accumulation of salts in the root zone of the soils.

The recharge of the aquifer inducing a rise of the groundwater table is derived from:

a) line sources such as canals and rivers;
b) percolation losses from irrigated fields;
c) rainfall throughput (percolation to groundwater).

The natural discharge from the aquifer consists of:

a) the difference between basin inflow and outflow;
b) return flow to the rivers during low river stages;
c) evaporation.

The influence of the first two items is extremely small and may be disregarded for the water-balance. Evaporation has, however, a most significant influence on water loss from the aquifer dependent on the depth to groundwater. The difference between recharge and natural discharge volumes has to be removed for water-table control.

The drainage factor is derived from the difference between recharge and natural dis-

charge of the ground-water or from the leaching requirement. At least four different drainage factors, each serving as a criterion are distinguished. These are:
1) the drainage factor to determine tile diameters;
2) the drainage factor to determine main drain dimensions;
3) the drainage factor to determine pumping requirements;
4) the drainage factor to determine drain spacings.
The latter is the most important for this discussion. It is an experimental quantity, not necessarily equal to the average discharge of a drainage system. Using a certain calculation method, this factor combined with selected de-watering requirements should result in satisfactory drain-spacings.

Drainage factor [1] derived from recharge estimates

Method of analysis
For the analysis of the water requirements for irrigation, the use of water by crops, the field losses and the canal losses under future conditions were estimated for each canal command per month. The calculations were carried out with the aid of a computer for various stages of development depending on the availability of surface water, groundwater development, canal enlargement and agricultural limits to attainable cropping intensities.
As the present discussion only pertains to areas underlain by saline groundwater where no groundwater development is possible, only the case of maximum agricultural development with enlargement of existing canals will be treated as this is the ultimate condition for which a drainage system will have to be designed. The calculated accretion to the groundwater should therefore be considered to represent maximum values within the limitations set by the accuracy of the many assumptions made for the calculations.
First, a cropping pattern for full agricultural development in each area is projected and then the crop water requirement on the field for this pattern is calculated for each month. This requirement is then carried to the head of the water course by including a farm efficiency loss and watercourse losses and finally to the canal head by including canal losses. The recharge is calculated by subtracting from the water quantities lost for irrigation a percentage used for evaporation from canal banks, bunds, roads and fallow fields.

Water requirements in the field
In Table 1 the projected cropping patterns for ultimate development are shown for a few selected areas.
The consumptive use of water of these cropping patterns is estimated based on the lake evaporation which is calculated by means of the procedure adopted by the US Weather Bureau, and on selected crop factors for each crop. In Table 2 the calculated water requirements for the cropping patterns mentioned are given as an illustration.
To satisfy net requirements by normal field irrigation methods more water should be supplied. Part of the excess water percolates to the sub-soil and is added to the groundwater and part of it is wasted. Measurement of the field efficiency is difficult

[1] Also termed drainable surplus, sub-surface run-off or design discharge.

Table 1 Cropping patterns, in percentages

Crops	*Shorkot Kamalia*	*Lower Jhelum*	*Ravi-Syphon Dip. Link*	*Lower Bari Doab*
rice		5	15	5
cotton	40	34	18	38
maize	5	4	5	4
kharif fodder [1]	15	21	21	20
pulses	5	3	4	3
wheat	33	27	28	26
rabi fodder [2]	13	17	18	17
oilseeds	4	2	2	2
gram	2	1	3	2
maize	3	4	4	3
green manure	10	10	10	10
sugar cane	10	8	12	10
fruit	6	10	6	6
vegetables	4	4	4	4
total	150	150	150	150

[1] kharif = summer
[2] rabi = winter

Table 2 Water requirement in feet depth

	Shorkot Kamalia	*Lower Jhelum*	*Ravi-Syphon Dip. Link*	*Lower Bari Doab*
Lake evaporation	5.92	5.67	4.96	5.63
Effective precipitation	0.55	0.51	1.00	0.33
Net yearly water requirement	2.00	2.43	2.47	2.96
Water requirement at w/c head	3.18	3.86	3.93	4.70

and very few reliable data are available on its magnitude. It varies throughout the year with the abundancy of the water supply, with the soil conditions and irrigation practices and with the individual farmers. It is estimated that under future conditions an efficiency of 70 per cent on an average is reasonable.

In the Indus Plains, farmers receive water through modules in the canal system. Each module supplies a continuous flow of water of 1 to 2 cusecs and serves an area of roughly 300 to 500 acres. This area and its internal system of water distribution is called a watercourse. Undoubtedly the distribution of water within the watercourse involves some losses, both conveyance and waste, which have been estimated at 10 per cent of the delivery at the watercourse head. Therefore the consumptive use values of Table 2 should be multiplied by $1/(0.7 \times 0.9) = 1.59$ to obtain the irrigation requirement at a watercourse head, which is also shown in Table 2.

Canal losses

To carry the water requirements from watercourse head to river offtake, the losses from the canal network should be estimated. The canal network consists of large main and branch canals which feed distributaries. Determining seepage losses is practice in largely an empirical question, although in recent years more research has been done in this respect and some mathematical solutions have been presented. The losses are assumed to be proportional to the average canal head withdrawals. As no linear relation with discharge exists, this would result in too high losses for full running canals or too low losses for canals running at less than their capacity. Therefore, a limiting loss as a percentage of the canal capacity was introduced. The losses for the Punjab canals were estimated at 30 % of the annual discharge. In view of the limiting influence of the canal capacities the average loss factor in the Punjab turned out at 28 per cent and in Sind at 23 per cent of the canal head diversions. As the total canal losses for the Plains will amount to about 20 million acrefeet per year it is clear that this method is too inaccurate for a detailed analysis. Therefore, a more accurate estimating of these canal losses is highly desirable.

Also losses from other line sources, such as rivers and link canals, were included in the calculations. Rainfall throughput to the groundwater was estimated according to the method used by Maasland (6).

Annual recharge

Part of the canal losses, watercourse losses and field losses described in the foregoing paragraphs percolates towards the groundwater reservoir as recharge. It is assumed that 80 per cent of the canal losses, 50 per cent of the watercourse losses and two thirds of the field losses go to recharge. The remainder will get lost by non-beneficial evaporation.

In Table 3 the average annual recharge values computed for all saline groundwater areas in the Plains are given. In the Doabs of the Punjab the annual recharge fluctuates around 1.5 cusecs per square mile for an average maximum cropping intensity of 150 per cent. The recharge in Sind is slightly higher and tends to approach 2 cusecs per square mile with the exception of the Rohri command in which the saline groundwater areas have a low recharge.

Table 3 Average annual recharge in perennial zones with deep saline groundwater

Area	*CCA MAc*	*Average Crop. Int.*	*MAF*	*Recharge Cusec/sq.mi.*	*mm/day*
Rechna doab	0.490	150	0.856	1.52	1.4
Bari doab	0.448	150	0.791	1.55	1.4
Thal doab	0.347	150	0.550	1.38	1.3
Chaj doab	0.291	150	0.416	1.26	1.2
Sutley Valley	1.748	150	3.016	1.52	1.4
Indus R. Bank	0.250	150	0.496	1.74	1.6
Ghotki	0.153	150	0.348	2.00	1.9
North-West	0.220	150	0.453	1.81	1.7
Khairpur W.	0.124	150	0.266	1.88	1.7
Khairpur E.	0.330	150	0.684	1.82	1.7
Rohri N.	0.476	150	0.595	1.10	1.0
Rohri S.	0.834	150	1.140	1.20	1.1
East Nara	1.602	150	3.530	1.93	1.8
Gaja	0.090	180	0.143	2.10	2.0
Tando Bago		150	0.199	1.94	1.8

CCA = culturable commanded area
MAc = million acres
MAF = million acre feet

About 60 per cent of the total annual recharge occurs during the summer cropping period and only 40 per cent during the winter season. The highest recharge is found during August and September and it is about 50 per cent higher than the monthly average. The lowest recharge is nearly 50 per cent lower than the average and occurs in November and December. Roughly half the total recharge is accounted for by the recharge from watercourse losses and farm losses.

Drainable surplus

The annual drainable surplus is defined as the amount to be removed annually by the drains. Tubewell drainage will maintain a water-table at a depth of 10 feet or more to reduce peak pumping-requirements. In that case the drainable surplus is only slightly lower than the recharge. For a horizontal drainage system, however, the non-beneficial evaporation from fallow land should be subtracted as the water-table is maintained at a considerably shallower depth.

The quantitative approach to the evaporation from below ground-level is a controversial issue. The Lower Indus Project (4) has given some interesting data on the evaporation of fallow land. With a water-table depth of 6 feet this will amount to about 10 per cent of the potential evaporation. The potential evaporation increases from about 65 inches to 85 inches per year from the Punjab to Sind. Thus the evaporation from a groundwater table at 6 feet can be estimated at 6.5 to 8.5 inches per year. Assuming that with an ultimate cropping intensity of 150 per cent about 30 per cent of the gross area will be fallow throughout the year in the case of horizontal drains the recharge can be reduced by about 0.15 cusecs per square mile in the Punjab and 0.20 in Sind or by 10 per cent on an average.

Consequently, the drainable surplus is estimated at 1.3 cusecs per square mile (1.2 mm/day) for the Punjab and 1.8 cusecs per square mile (1.7 mm/day) for Sind.

Drainage factor derived from leaching requirement

Equations to derive the leaching requirement

To maintain the productivity of a soil under irrigation, the salt input into the surface soil should equal the salt output to avoid soil salinity. Irrigation water, containing only 500 ppm total dissolved solids will already result in a salt content of the upper foot of soil high enough to affect the yield of sensitive crops in about 3 years if all salts of the irrigation water remain in the soil. Salt build-up is even faster when evaporation from a slightly saline groundwater table takes place. Groundwater containing only 1000 ppm salts at a constant depth of 2 feet below surface may bring enough salt to the surface to restrict cropping of sensitive crops within one to two years' time.

The salt balance can be achieved by controlling the water-table depth and by supplying extra water over and above the net crop water requirements to leach the remaining salts of the irrigation water downwards below the root zone. The extra depth of irrigation water required to maintain the salt content of the soil moisture at an acceptable low level, expressed as a percentage of the irrigation depth, is called the leaching requirement.

If the period is such that the difference in moisture content in the soil can be disregarded, the moisture balance of the profile is:

$D_{iw} + R_e = CU + D_{dw} + R_t$

in which: D_{iw} = depth of irrigation water; R_e = effective rainfall; Cu = consumptive use of the crop(s); D_{dw} = depth of irrigation water draining through the soil layer in question; R_t = rain throughout percolating to the groundwater.

In order to keep the salt content of the root zone at a certain level the amounts of salt added should be leached down. Ignoring the salt supplied by rain water, the salt balance for a certain depth of soil and over a given period of time is:

$D_{iw} \,.\, S_{iw} = D_{dw} + R_t \,.\, S_{dw}$

The equilibrium in the salt balance of the soil will be reached first in the surface layers and will gradually extend downwards and finally be established throughout the profile. As moisture is extracted by the plant roots over a certain zone in the profile, the equilibrium salt content will increase with depth.

Based on these equations the leaching requirement was calculated according to Boumans (2).

Defining the leaching requirement as the fraction of the irrigation water which should be drained to maintain EC_e at a pre-determined level, then

$$LR = \frac{EC_{iw}}{1.5\ f\ EC_e} \quad \text{for } R_t = O$$

in which f is a factor smaller than or equal to unity and termed leaching efficiency. This term takes into account the effect of rapid water movement through cracks and large pores and is estimated at 0.7 for the average soils of the Indus Plains. For any other value of R_t, LR depends on the actual depth of the irrigation water required.

Calculation of leaching requirements

The latest data on permissible salt concentration of the saturation extract, EC_e, in relation to plant growth and crop yields are given in Table 4 (1). The table shows EC_e values which cause a 10–15 per cent yield decrease for various crops and also the EC_e values related to a 50 per cent yield decrease. The critical EC_e values corresponding with an 85 to 90 per cent of the maximum yield is used for estimating the leaching requirements for each crop.

By means of the above-mentioned equation the leaching requirements for the most important crops are calculated. From the results as shown in Table 5 it appears that the leaching requirement varies considerably for the various crops. However, the leach-

Table 4 Salt tolerance of crop plants; electrical conductivity of saturation extract

Crops	*Yield decrease of*		*Crops*	*Yield decrease of*	
	10–15 %	*50 %*		*10–15 %*	*50 %*
Barley	12	18	Rice	5	8
Cotton	10	16	Maize	5	7
Oilseed	8	14	Vegetables	2–3	4–6
Wheat	7	14	Alfalfa	4	8
Pulses	6	10	Clovers	3	5
Sugar cane	4	9	Dates	8	—

Table 5 Calculated leaching requirements in % for some crops in West Pakistan

Salinity iw		Crops					
ppm	*mmhos/cm*	*barley*	*wheat*	*pulses*	*cotton*	*maize*	*yearly average*
500	0.78	6	11	12	7	12	12
1000	1.54	12	21	24	15	29	24
1500	2.30	18	31	36	22	44	36

ing requirement should be considered over a year's period and not for a single crop for the following reasons:
a) for single crop periods the differences in soil-moisture content before and after cannot be ignored, and
b) the quality of the surface water varies throughout the year. Therefore, in the last column the annual LR is calculated based on an average permissible EC_e of 6 millimhos per cm.
The data in Table 5 do not take any rain throughout into account. For practical purposes the following rule may be used. The annual LR may be lowered by 3 per cent for every inch rain throughput in case of irrigation water of 500 ppm and 2 per cent for every 1 inch of rain throughput in the case of water of 2000 ppm salts. The saline groundwater areas are as a rule not located in the high rainfall areas. Therefore, by making a conservative allowance for rainfall throughput and rounding off the values, an annual leaching requirement of 10 per cent may be taken for irrigation water containing 500 ppm salts and an LR of 20 per cent for water containing 1000 ppm salts.

The drainage factor derived from the leaching requirement
To convert the percentage of leaching required into quantified values the net irrigation requirements as determined by the consumptive use of the crops, the cropping pattern and intensity and the effective rainfall should be known. In the Tables 1 and 2 the cropping pattern and the crop water requirement for a few selected areas in the saline groundwater zone are shown.
By multiplying the net crop water requirements with the percentages found in the foregoing paragraph the annually required total leaching depth is found. It follows that the annual leaching depth varies from 0.20 ft to 0.30 ft for normal surface irrigation water which in most cases will contain slightly less than 500 ppm salts on the field and from 0.40 to 0.60 ft for water containing 1000 ppm salts. Rounding of these values results in the following conclusion: the drainage factor required for full-intensity cropping and good-quality irrigation water amounts to about 0.25 mm per day as an annual average to prevent salt accumulation in the root-zone of the soil. For water containing 1000 ppm salts this requirement increases to about 0.5 mm per day.

Comparison of results and discussion

Comparison of results
The recharge calculation and the estimate of the leaching requirement result in a widely differing drainage factor. Though the approximate nature of both recharge

calculation and the determination of the leaching requirement is fully appreciated, this difference can be well explained. The drainable surplus derived from the recharge includes seepage losses from line sources and losses from the field irrigation system. The estimate of the drainage factor via the leaching requirement ignores the groundwater recharge through the line sources which account for about half the total recharge. Moreover, a maximum field efficiency is assumed whereby no more water percolates downward than required for maintaining a salt balance.

For a groundwater table at such a depth that cannot be controlled by horizontal drainage, the first approach including the recharge from the line sources and losses by an irrigation field inefficiency seems the most correct one. However, in the case of horizontal drainage with, unavoidably, a rather shallow depth to water, a great part of the non-saline seepage flow can be used by the crops. Also the percolation losses on the fields exceeding the leaching requirement will be used by the crops. In fact, horizontal drainage will induce a higher irrigation water use efficiency as compared to tubewell drainage. Therefore, the latter method in which a drainage factor is calculated via the leaching requirement is better suited to the case of horizontal drainage with a shallow water table, although it will result in an underestimate of the total drainable surplus.

If the water table is maintained at a deep level, beyond the reach of the crop roots, the efficiency or irrigation water use is lower than with a water table at the bottom of the root-zone just within the reach of the roots. This is mainly caused by the necessity of removing the seepage losses from the line sources in the first case. Further, the higher efficiency of water use which can thus be attributed to horizontal drainage — in case of high cropping intensities — is mainly determined by the farmers' irrigation practices and by the physical properties of the soil profile.

Some remarks on the accuracy of drainage factors

Establishing a drainage factor for calculating the required drain-spacing is only needed if a steady state equation is used. The steady-flow equations should be considered as an analogue and no great meaning should be attached to the values of the individual criteria. The unknown of the greatest influence in this calculation is the hydraulic conductivity, which may vary from a few cm per day to several tens of metres per day. Moreover, the calculated spacings are normally rounded off to standard spacings with intervals of about 25%. As the drain-spacing is inversely proportional to the square root of the drainage factor, a fluctuation in the latter of about 50% will have no influence at all on the final spacing. The required accuracy for this type of drainage factor is therefore limited.

If calculations using steady flow conditions result in rather wide drain spacings, especially in areas having a rainfall which cannot be ignored, the effect of intermittent recharge should be taken into account. A check with a transient flow equation for cases with large reservoir coefficients (5) can be made and sometimes the drainage factor must be rather arbitrarily increased. In other cases with low intensity cropping and deep water tables at the beginning of the irrigation season, a lower drainage factor may be selected.

The drainage factor for determining tile diameters is normally multiplied with an arbitrarily selected safety factor to take account of reduction in the hydraulic flow section through silt deposits in the tile lines and through dislocation of tiles during laying. The greatest variations in the flow in the main drains will be caused by irrigation practices. Even with experienced irrigators a drain discharge containing 30%

or more surface water has been observed. To establish the required capacity of a pumping-station a stand-by is normally designed over the expected peak flow.
It appears that, though for different reasons, the drainage factors need not be known with great accuracy to be justly used in design work. It is felt that if a drainage factor can be estimated with an accuracy of plus or minus 25 per cent, additional efforts should rather be spent on collecting more information on the hydraulic conductivity of the soil than on the drainage factor. This will be especially the case for a developing agriculture when the drainage system is designed for a projected future cropping system.
The above-mentioned accuracy is somewhat less than that normally attached to irrigation requirements. This is correct since the drainage factors are derived from irrigation and evaporation estimates.

Selected drainage factors
As the criteria were only to be used for cost calculations, the estimates were limited to the drainage factors for spacing and for pumping requirements for the discharge of the effluent.
On page 30 the drainable surplus was calculated at 1.3 cusecs per square mile for the Punjab and 1.8 for Sind. These values are based on no consumptive use of conveyance losses of line sources, which account for about half the recharge. Assuming that with a shallow water table half these losses are used by the crops, the drainage factors for the Punjab and Sind reduce to 1.0 and 1.5 cusecs per square mile and still largely cover the required leaching through the root zone which is about 0.5 cusec per square mile for water containing up to 1000 ppm salts. With these factors, drain-spacings of one thousand feet or more can be calculated in the Indus Plains. A calculation showed that with these wide spacings a heavy rainshower may cause waterlogging halfway between the drains for a long period and that especially deep rooted crops may suffer from this. Therefore, the drainage factor should be adapted to a high discharge during the rainfall period.
The rainfall throughput, varying from about 1 inch per year in Sind and Lower Punjab to a maximum of about 5 inches per annum in the upper parts of the Punjab, is included on an annual basis. The actual throughput will occur only during the three months of maximum rainfall, July, August and September. Estimating the average throughput in the Punjab at 3 inches, the average drainable surplus during these months should be increased by about 1 inch per month or 0.9 cusec per square mile. Therefore the drainage factor for the calculation of the drain-spacing has been taken at 2 cusecs per square mile. This factor is valid for all regions, as the rainfall throughput in Sind is lower. Check calculations showed that with drain-spacings based on this factor, the groundwater table could be drawn down from the surface — after intensive rainstorms — to a depth of 2 feet in about 4 days which period is considered satisfactory even for deep-rooted crops.
It may be assumed that the zone affected by the losses of the line sources is limited to a strip on either side of the canal, the width of which depends on the canal-dimensions and hydrologic properties of the soil layers. In this case a single drain on either side of the canal may be adequate to relieve the pressure in the proximity of the canal and to eliminate waterlogging in the canal zone. The above discussion shows, however, that the consequent wide spacings, resulting from a small discharge factor, should be reduced because of the slow reaction of the water table depth halfway between the drains.

For the average pumping-requirements the above calculated average flows of 1.0 and 1.5 cusecs per square mile in the Punjab and in Sind should be taken. The pumping capacities to be installed have to be based on expected peak flows which are about 50 % higher than the average flows in August and September. Allowing for some spare capacity the installed capacities should be about 2 and 2.5 cusecs per square mile. These capacities do not leave much room for the removal of surface run-off after rain storms. If inlets for this type of drainage are planned, it must be considered whether the capacity should be increased depending on the expected surface run-off flows.

References

(1) Bernstein, L., 1964. Salt tolerance of plants. Agr. Inf. Bul. 283. USDA.
(2) Boumans, J. H., 1963. Reclamation of salt affected Soils (Editor: P. J. Dieleman). Publ. no. 11. International Institute for Land reclamation and improvement, Wageningen.
(3) Sir A. Gibb and Partners, ILACO and Hunting Technical Services Ltd., 1966. Programme for the development of Irrigation and Agriculture in West Pakistan. Report to the International Bank for Reconstruction and Development. (Not for publication).
(4) Hunting Technical Services Ltd. and Sir M. MacDonald and Partners, 1965. Lower Indus Project. Report to WAPDA (Water and Power Development Authority) of Pakistan. (Not for publication).
(5) Krayenhoff van der Leur, D. A., 1958, 1962. A study of non-steady groundwater flow with special reference to a reservoir coefficient. Part I: *De Ingenieur,* 70 (19): B 87—B 94; Part II: *De Ingenieur,* 74 (46): B 285—B 292.
(6) Maasland, M., Priest, C. E. and Malik, M. S., 1963. Development of Groundwater in the Indus Plain. Symposium on waterlogging and salinity in West Pakistan. West Pakistan Engineering Congress, Lahore.