Netherlands Journal of Agricultural Science 49 (2001) 163-177

Nitrate in the upper groundwater of 'De Marke' and other farms

L.J.M. BOUMANS*, B. FRATERS AND G. VAN DRECHT

RIVM, National Institute of Public Health and the Environment, P.O. Box 1, NL- 3720 BA Bilthoven, The Netherlands
* Corresponding author (e-mail: ljm.boumans@rivm.nl)

Received: 5 June 2001; acccepted: 3 November 2001

Abstract

Groundwater-nitrate concentrations are compared between the experimental farm 'De Marke' – which was designed to minimize nutrient surpluses – and farms being representative for the sandy region of the Netherlands. Samples were collected during the period 1991–1999 at 'De Marke' and during 1992–1995 at 94 representative farms. Between 1991 and autumn 1992 groundwater nitrate at 'De Marke' decreased from 193 mg l^{-1} to 115 mg l^{-1}. No decrease was found at the representative farms. The decrease at 'De Marke' was attributed to new farm management. After autumn 1992, groundwater nitrate at 'De Marke' fluctuated between 30 and 115 mg l^{-1}. A comparable pattern in time was found at other farms. This variation is attributed mostly to variation in groundwater table and precipitation. After autumn 1992, farm management did not result in a further reduction in groundwater nitrate. Only 9 of the 94 representative farms had an average nitrate concentration lower than that at 'De Marke' during 1992–1998. If differences in groundwater table and precipitation are taking into account, it is estimated that only three of the representative farms would have had a lower average nitrate concentration than 'De Marke'.

Keywords: groundwater table, groundwater recharge, nitrogen surplus, sandy soil, monitoring, EU nitrate standard.

Introduction

Background

Following regulations of the European Communities (EC) it is compulsory for member states to establish an action programme to reduce nitrate losses by leaching and surface runoff and to monitor the effectiveness of this programme (Anon., 1991). To monitor the effectiveness of the action programmes, EC members are allowed to use existing monitoring programmes. For instance, Denmark uses a monitoring programme that was initiated in 1988 (Rasmussen, 1996).

N surpluses in the Netherlands are large compared with other European countries (De Walle & Sevenster, 1998). Since 1985, the Dutch government has implemented several laws and regulations to prevent expansion of animal husbandry and to stop the increase in nutrient losses from agriculture (Henkens & Van Keulen, 2001). Since 1990, the use of manure in the Netherlands has been restricted on the basis of phosphate load. In 1998, a 'MINeral Accounting System' (MINAS) was introduced to regulate and reduce nitrogen (N) and phosphate losses (Anon., 2000).

In 1989, the Ministry of Agriculture, Nature Management and Fisheries and the Ministry of Housing, Physical Planning and the Environment initiated a 'National Monitoring Programme for Effectiveness of the Minerals policy' (LMM). LMM is carried out by, and under responsibility of The National Institute of Public Health and the Environment (RIVM) and the Agricultural Economics Research Institute (LEI-WUR). LMM monitors nutrient (nitrogen) surpluses and groundwater quality (nitrate) on representative farms to evaluate the effectiveness of Dutch legislation. Ninety-four farms representative for the sandy areas have been selected from the LEI Farm Accountancy Data Network (LEI-FARN) (Fraters *et al.*, 1998; 2000). To predict effects of legislation, LMM has also monitored farms with lower nutrient surpluses. Experimental farm 'De Marke' is the most intensively studied 'low surplus' farm.

Nitrogen leaching and nitrate concentration

In the Netherlands, highly intensive animal farming is found most frequently in the sandy regions. So in the sandy regions, current and historical nutrient load is on average higher than in other areas (Anon., 1993). Moreover, sandy soils are more susceptible to nitrate leaching than clay and peat soils (Spalding & Exner, 1993; Van Drecht, 1993).

N is mainly leached as nitrate, but ammonia and organic N are also susceptible to leaching. In a sample from the upper metre of groundwater in the sandy areas, on average 82% of the N occurred as nitrate, 5% as ammonia, and 13% as organic N (Fraters, 1998). However, it is not clear to what extent ammonia and organic N are generated during sampling (see Appendix).

Nitrate concentrations in the upper groundwater in the sandy regions are mainly regulated by the following three factors:

1. *Groundwater table.* In the Netherlands, the groundwater table is mostly within 5 m below the surface. As the groundwater table approaches the root zone, anaerobic conditions are more likely to occur, causing a decrease in nitrate by denitrification (Anon., 1985; Boumans *et al.*, 1989). Studies from other countries about this groundwater-table effect are scarce. Bauld *et al.* (1992), quoted by Loftis (1996), found surprisingly low nitrate concentrations in an irrigated area in south-eastern Australia, which can be explained by the very shallow groundwater levels, i.e., a median value of about 1 m.
2. *Precipitation and evapotranspiration.* The hydraulic conductivity of sandy subsurface soil layers is about 2 km per year (Meinardi *et al.*, 1978). Sandy surface layers contain more loam and clay, resulting in a lower conductivity. In the sandy parts of the Netherlands the average hydraulic gradient is about 1 m km^{-1}. The horizontal distance covered by the upper metre of groundwater will be less than a few metres per year, so the origin of groundwater will largely be local.

Variations in precipitation and evapotranspiration result in variations in groundwater recharge. In the Netherlands, replenishment of the upper metre of ground water requires an average groundwater recharge of 300 mm per year and a soil with 33% porosity. A double groundwater recharge resulted in a decrease in nitrate concentration in the upper metre of groundwater by a factor of 2 (Fraters *et al.*, 1998). No other literature confirming this process was found.

3. *Farm management (crop and soil management, N surplus).* Nitrate leaching is influenced, amongst other things, by crop type and tillage operations. This probably is a result of denitrification (Kolenbrander, 1981; Patni *et al.*, 1998). Other environmental and management factors being equal, a higher N surplus will result in higher nitrate concentrations. Differences in nitrate concentration among farms that result from differences in farm management can only be related to differences in N leaching if effects of groundwater table depth and groundwater recharge are included.

Findings from the past for 'De Marke'

'De Marke' and the 94 representative farms were compared for the first time in 1995 (Boumans & Fraters, 1995). Average nitrate concentration for the farming system 'De Marke' decreased from 193 mg l^{-1} in 1991 to 115 mg l^{-1} in 1992. This decrease was ascribed to the modified farm management. From 1992 to 1994 the nitrate concentration further decreased to 50 mg l^{-1}. Over the same period, nitrate concentrations on the representative farms decreased by a factor of 2. This decrease was attributed to more groundwater recharge. In 1992, after 3 years of new farm management, apparently a new balance between farm management and nitrate concentration in the upper groundwater had been established.

Others also investigated nitrate dynamics. According to Hack-Ten Broeke & De Groot (1995) variations in the hydrological situation have a stronger influence on nitrate concentration at 'De Marke' than variations in management. Conijn (2000) found no clear differences in nitrate concentration for the three types of land use on 'De Marke' during the period 1993–1998. After 1993, variation in weather conditions rather than in farm management seem to have affected nitrate concentration.

Objectives

In this study, groundwater nitrate concentrations at 'De Marke' are investigated with the following objectives:

1. Determine the lowest attainable and economically viable nitrate concentration in the upper groundwater.
2. Determine the length of the period necessary to establish a new balance between farm management (lower N surplus) and this lowest nitrate concentration.
3. Show effects of lower N surpluses by comparing N leaching at 'De Marke' with that of the 94 representative farms.

'De Marke' has its own objective, i.e., to demonstrate for the most vulnerable part of the country that it is possible to attain a nitrate concentration in the upper groundwater that does not exceed the EU nitrate standard of 50 mg l^{-1} (Aarts *et al.*, 1992).

Material and methods

Monitoring groundwater nitrate

The monitoring of the representative farms within the LMM programme has been described by Fraters *et al.* (1998, 2000). The following is a brief summary.

In the period 1992–1995 the number of representative farms in the sandy region in the period was 94. These farms are representative for 62% of the agricultural area of the sandy region. Thirty farms were sampled during all 4 years, 55 farms were sampled during 3 years (1992, 1993 and 1995) and 9 were sampled during 2 years (1992 and 1993). The number of farms that were sampled varied from year to year because of experimental reasons and because of farms leaving LEI-FARN.

Of these representative farms only the data from the period 1992-1995 were used. Although a new group of representative farms has been monitored each year since 1997, the data for the period 1997–1999 need first to be adjusted for differences in composition of the group of farms among years (Fraters *et al.*, 2000). Data from 'De Marke' were available for the period 1991–1999. Furthermore, 5 farms from the project Management Sustainable Dairy Farming (MSD) (Beldman, 1997), which are characterized by low N surpluses, were monitored during the period 1993–1998. At the 5 MSD farms, groundwater samples were taken following the procedures for the representative farms. The results from 'De Marke' are also compared with the mean of these MSD farms.

Sampling procedures

In 1992, 1993 and 1994, forty-eight individual groundwater samples were taken per farm. The number of samples per field was proportional to its area, with samples distributed evenly within the field. In 1995, after monitoring had been optimized, the number of samples per farm was reduced to 16. With this lower number the sample locations within each field were selected at random. Samples were taken each year at about the same location, if possible.

De 'Marke' was sampled during the period 1991–1999. Three samples were taken per hectare. A minimum of 3 and a maximum of 13 samples were taken per field. Sampling locations were distributed proportionally over the fields on the basis of their areas, and distributed evenly within each field. Each year about 180 samples were taken at about the same locations.

The upper groundwater was sampled. For each sample a new temporary well was used (see Appendix). To this end a hole was made with an auger up to 0.80 m below the groundwater table. A 0.50 m collar was inserted into the hole to prevent rootzone material from contaminating the groundwater. The hole was then furnished with a rigid, 0.50 m long, perforated PVC tube with a diameter of 1 inch (2.54 cm).

This tube was placed at about 0.25 m under the groundwater table, and connected with a flexible 4-mm polyethylene tube to the surface. The groundwater was lifted to the surface by suction. Before the actual sample was taken, first one litre of groundwater was extracted from the well. The sample was filtered (filter pore diameter was 0.45 μm), acidified to pH 2 (with 3 N H_2SO_4, pro analysis) and stored at 4 °C until chemical analysis.

Groundwater samples of 'De Marke' were not filtered or acidified. Because of the large number of samples this would have taken too much time. Moreover, our primary interest was nitrate, not phosphate. For possible effects of this modification see the Appendix.

Data for groundwater tables

For groundwater tables, two types of data were collected:

1. *Gt-classes.* De Vries & Denneboom (1992) described annual average fluctuations of the groundwater table by means of Gt-classes on a 1:50 000 soil map. The farms were assigned to the appropriate Gt-class by making an overlay of the Gt map and the digitized farm surface on the topographical map. The different Gt-classes were grouped as *neutral* (Gt V, Gt V* and Gt VI), *dry* (Gt VII, Gt VII* and Gt VIII) and *wet* (remaining classes: Gt I, Gt II, Gt II*, Gt III,Gt III* and Gt IV). For each farm the grouped Gt-classes were expressed as the surface percentages *neutral, dry* and *wet*. The three percentages combined are called 'Gt'.
2. *Actual groundwater table depth.* The depth of the actual groundwater table was measured in each temporary well during sampling.

Data for groundwater recharge

The Royal Netherlands Meteorological Institute (KNMI) provided data on total precipitation and total Makking evaporation (Makking, 1957) over 10-day periods, for 9 districts in the sandy region of the Netherlands. These data were translated into a parameter that characterizes groundwater recharge. The meteorological data and the computer code ONZAT (Van Drecht, 1983) were used to model the concentration – in the upper metre of the groundwater – of a hypothetical tracer that was applied every 10 days on the soil surface at a rate of 10 mg m^{-2}. This concentration is called 'the index-concentration'. Variations in the index-concentration are indicative for variations in groundwater recharge. The index-concentration was calculated for only one soil type (surface soil number 1 and subsurface soil number 1 of Table 3 in Wösten *et al.*, 1987), one vegetation type (grass), 10 drainage levels (0.50, 1.00, 1.50, etc. up to 5.00 m depth) and 9 districts. For each of the 9 districts this resulted in 10 different sequences of calculated index-concentrations, related calculated groundwater table levels and related dates.

Each groundwater sample is related to an index-concentration on the basis of district, sampling date and groundwater table depth at the time of sampling.

Exploring farm management effects on nitrate concentration

Regression analysis was used to relate farm mean nitrate concentration to farm mean index concentration, Gt and farm mean groundwater table depth, and resulting regression models were only used if the coefficients were statistically significant ($P < 0.05$). The expected nitrate concentration for a standard index-concentration, Gt and groundwater table depth were calculated with the model. This concentration is the so-called *standard nitrate concentration.* A standardized nitrate concentration was calculated as the sum of the standard nitrate concentration and the residual of the measured nitrate concentration derived from the model.

The following nitrate concentrations are compared:
1. Farm mean of 'De Marke' and the 5 MSD-farms (Figure 1).
2. Farm mean of 'De Marke' and the 94 representative farms (Figure 3).
3. Standardized farm mean for index-concentration and Gt of 'De Marke' and the 94 representative farms (Figure 4).
4. Standardized farm mean for index-concentration and groundwater table depth of 'De Marke' and the 94 representative farms (Figure 5).
5. Standardized mean for index-concentration and groundwater table depth of 'De Marke' (Figure 6).

Results

'De Marke' and other low nitrogen-surplus farms

The average nitrate concentration at 'De Marke' decreased from 193 mg l^{-1} in 1991 to 30 mg l^{-1} in 1996 (Figure 1). The decrease at 'De Marke' between 1991 and 1992 was identified as an effect of adapted farm management: no clear difference between these years was observed for the representative farms. The decrease between 1992 and 1993 was identified as an effect of higher precipitation: the representative farms showed a similar decrease (Boumans & Fraters, 1995). In 1993, the average nitrate concentration of the other 5 low-N surplus farms (MSD farms) had possibly not yet reached a new equilibrium. During the period 1994–1998, average concentrations at both 'De Marke' and the 5 MSD farms show a comparable pattern with time. This suggests that meteorological effects dominated the annual variation in nitrate concentration, and that there was no additional effect of farm management. This is confirmed by Figure 2, showing the relation between measured average nitrate concentration and index-concentration for the period 1992–1999. The year 1991 deviates from this.

The average nitrate concentration at 'De Marke' for the period 1992–1998 was 63 mg l^{-1}, which is above the EU nitrate standard for drinking water of 50 mg l^{-1}. In 1999, 'De Marke' acquired agricultural land from other farms. In that year, mean nitrate concentration for the farm was 80 mg l^{-1}, and for the newly obtained land 230 mg l^{-1}. Without the 'new' land, the mean concentration in 1999 for 'De Marke' was 66 mg l^{-1}.

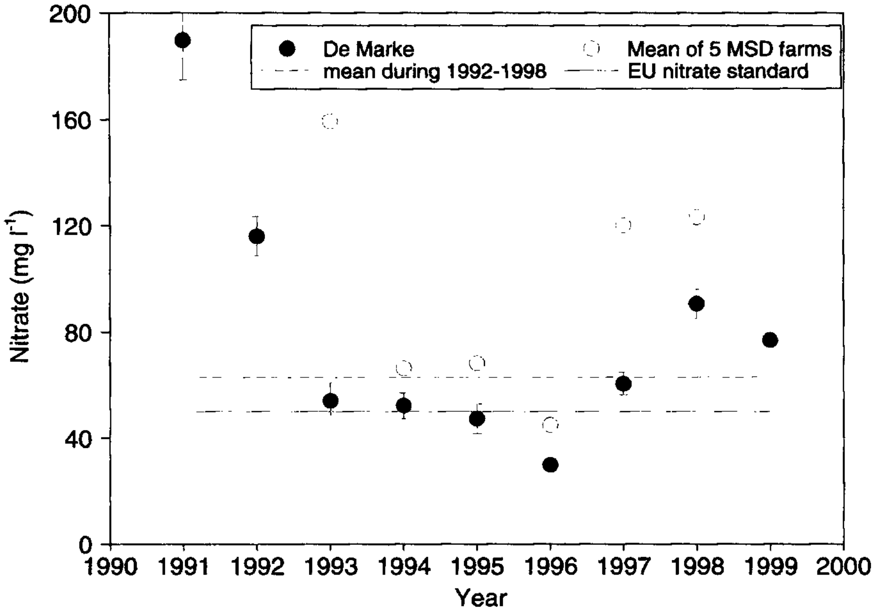

Figure 1. Annual measured farm mean nitrate concentrations of the upper metre of groundwater at 'De Marke' during 1991–1999, and at 5 MSD farms during 1993–1998.

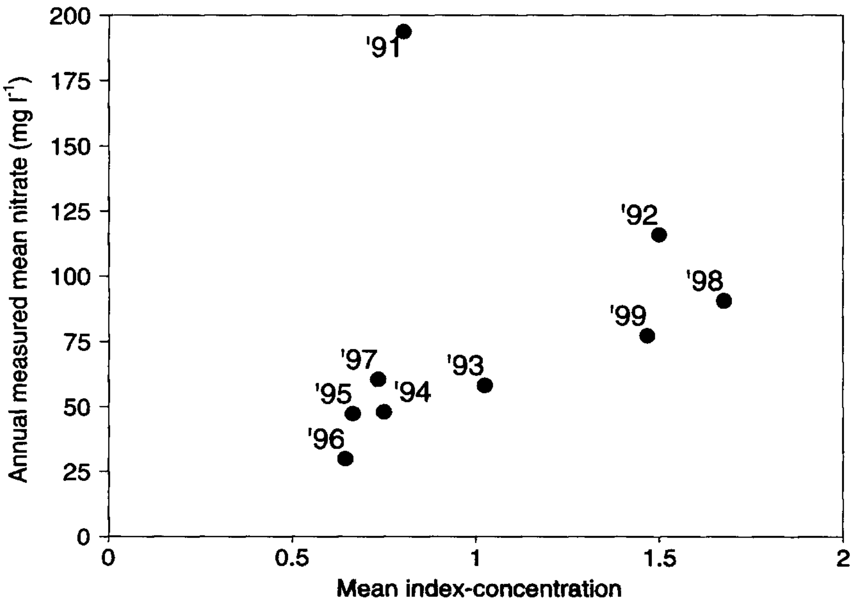

Figure 2. Annual measured farm mean nitrate concentrations and groundwater recharge (expressed as index-concentrations; see text for explanation) of the upper metre of groundwater at 'De Marke' during the period 1992–1998.

'De Marke' and representative farms

When the farm mean nitrate concentrations for the 94 representative farms and 'De Marke' are placed in increasing order (Figure 3), only 9 farms show concentrations that are lower than the concentration at 'De Marke'. Assuming the representative farms to be truly 'representative', it is estimated that 81% of the farms in the sandy regions of the Netherlands showed significantly higher nitrate concentrations than 'De Marke' ($P < 0.025$).

Discussion

Influence of index-concentration and groundwater regime (Gt)

According to Hilhorst & Oenema (2001) the groundwater regime at 'De Marke' is classified as dry, which implies a relatively high risk of nitrate leaching. According to the 1: 50 000 soil map and compared with the representative farms, the area of wet soils at 'De Marke' is small, i.e., 3% versus 39% for the representative farms. On the other hand, the area of dry soils at 'De Marke' is comparatively small too, i.e., 7% against 13% for the representative farms. The mean index-concentration for 'De Marke' is 0.98. For the representative farms this mean is 1.17, varying between 0.3 and 2.5. The mean nitrate concentrations of the representative farms have been standardized for index-concentration and Gt at 'De Marke' (Figure 4).

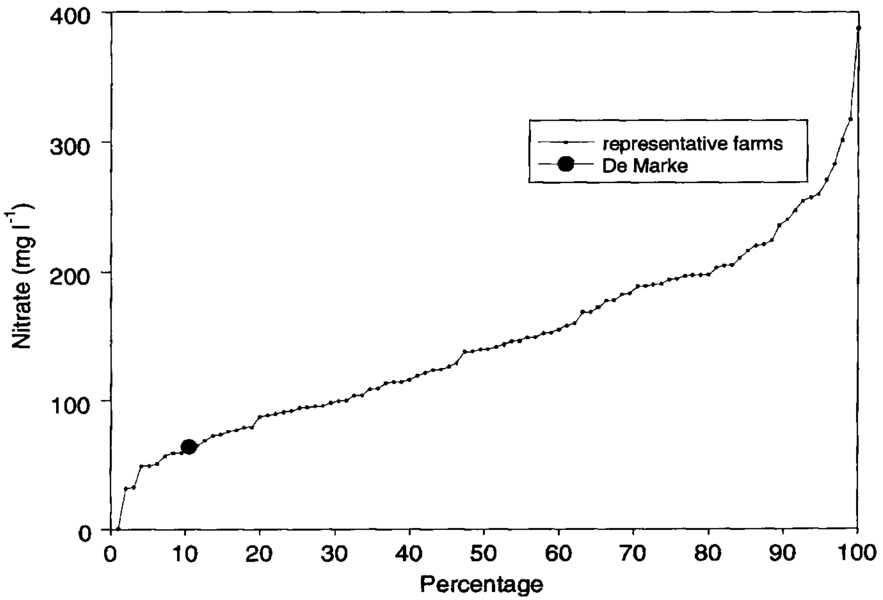

Figure 3. Annual measured farm mean nitrate concentrations of the upper metre of groundwater at 'De Marke' during the period 1992–1998, and at 94 representative farms during the period 1992–1995.

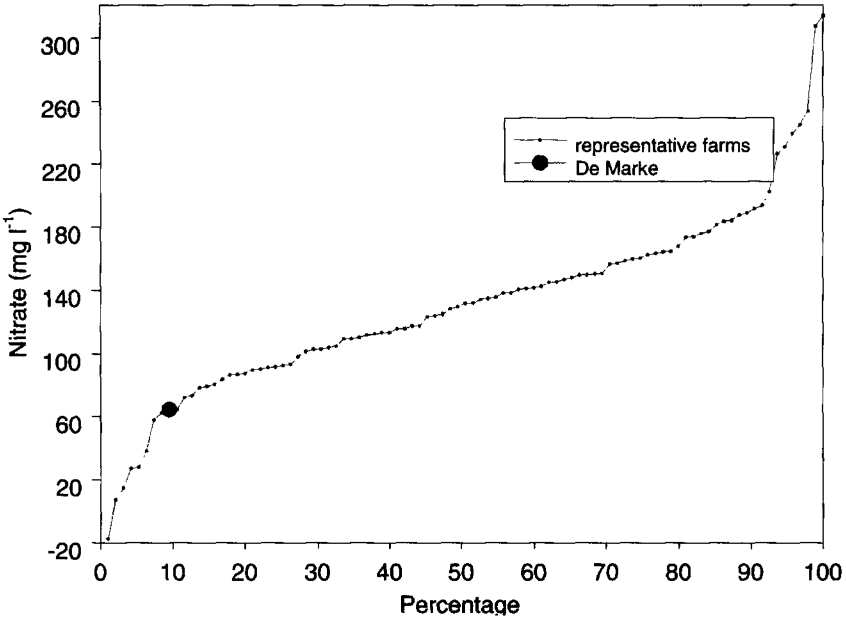

Figure 4. Farm mean nitrate concentrations of the upper metre of groundwater at 94 representative farms, standardized for the mean groundwater recharge and the groundwater dynamics at 'De Marke', and the mean nitrate concentration at 'De Marke' (period 1992–1998).

There is little difference between Figures 3 and 4. In other words, the meteorological conditions (mean index-concentration) and the groundwater regime (Gt) had the same influence on the nitrate concentration at 'De Marke' as at the representative farms. Hack-Ten Broeke (2001) also concluded that – compared with other sandy soils – the 'De Marke' soils are not extremely susceptible to nitrate leaching.

Influence of index-concentration and actual groundwater table

The groundwater-regime maps (Gt) used, were not up to date (Van Het Loo, 1997). They were also less accurate than groundwater-table measurements at the sample locations. So measured groundwater-table depths at the time of sampling could give a better indication of susceptibility of 'De Marke' soils to nitrate leaching than the Gt maps. The mean groundwater-table depth at 'De Marke' was 2.15 m, whereas at the representative farms it was 1.30 m, varying between 0.30 and 3.50 m. There is one complication, however. 'De Marke' was sampled in the period September-October, whereas the representative farms were sampled in the period March-June. Groundwater tables usually are lower in autumn than in spring, making the comparison questionable. On the other hand, most representative farms were sampled twice in 1992 and 1993, when groundwater tables were low, and once in 1995, when groundwater tables were high. 'De Marke' was sampled during a longer period with high groundwater tables (1994–1999).

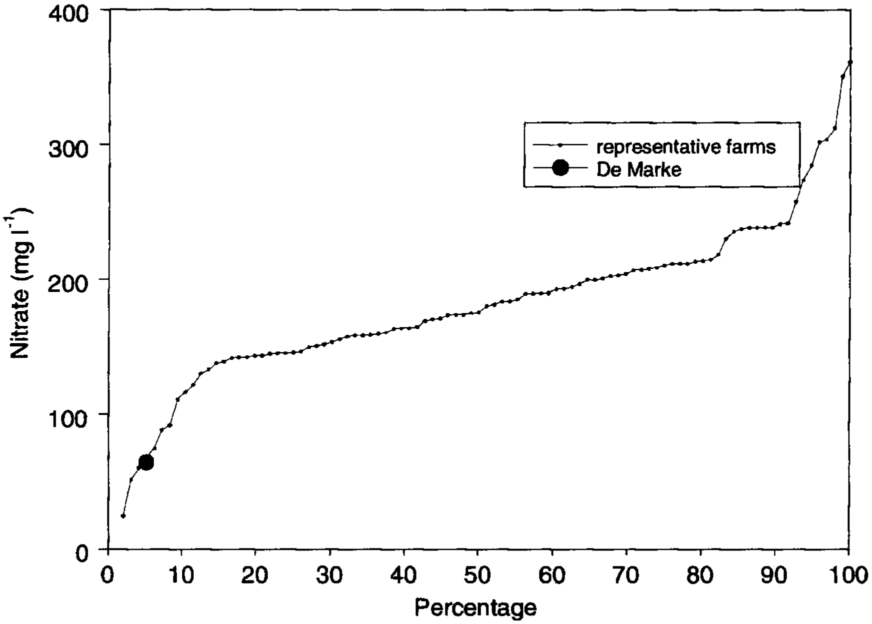

Figure 5. Farm mean nitrate concentrations of the upper metre of groundwater at 94 representative farms, standardized for the mean groundwater recharge index and the mean groundwater table depth at 'De Marke', and the mean nitrate concentration at 'De Marke' (period 1992–1998).

The nitrate concentrations at the representative farms, standardized for the mean index-concentration and groundwater table of 'De Marke' during the period 1992–1998, are depicted in Figure 5. 'De Marke' now ranks fourth in the row with the 94 representative farms and has a significantly lower mean nitrate concentration. Ninety-five percent of the representative farms have a higher standardized nitrate concentration. Of the farms in the sandy regions 90% have higher nitrate concentration ($P< 0.025$).

Figure 1 shows the dynamics of the annual measured mean nitrate concentrations for 'De Marke'. Apart from a comparison with representative farms, we wanted to investigate whether a possible trend in nitrate concentration could have been masked by meteorological and hydrological influences. Boumans & Fraters (1995) concluded that the decrease in nitrate concentration between 1992 and 1993 could be attributed to increased precipitation (Figure 2). A similar decrease was found at the representative farms. Apparently, a new balance between farm management and nitrate concentration had been established. Standardized nitrate concentrations for each year at 'De Marke' in the period 1992–1998 were calculated for the mean index-concentration and groundwater table of this farm (Figure 6).

The mean nitrate concentration in the upper metre of groundwater in the period 1992–1998 was 63 mg l^{-1}. During the period 1992–1998 the average and standardized concentrations were fluctuating around this mean value and did not show a clear trend. The variation in mean nitrate concentrations was thus primarily the result of variations in meteorological and hydrological conditions.

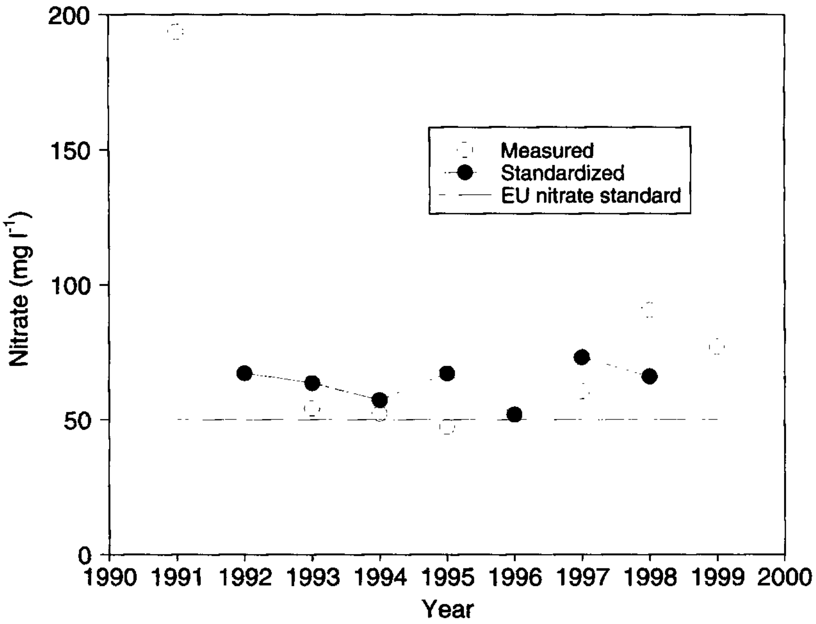

Figure 6. Average nitrate concentrations in the upper metre of groundwater at 'De Marke' during the period 1992–1998, measured and standardized for the mean groundwater recharge and the mean groundwater table depth at 'De Marke'.

Conclusions

Mean nitrate concentration in the upper metre of groundwater at 'De Marke' in the period 1992–1998 was 63 mg l^{-1}. Of the farms in the sandy regions of the Netherlands 81% had a higher concentration ($P< 0.025$). 'De Marke' was more susceptible to nitrate leaching than the representative farms because of its hydrological conditions. If the farm management of 'De Marke' would be practised on farms with an average susceptibility to nitrate leaching, the nitrate concentration in the upper metre would be lower (cf. Hack-Ten Broeke, 2001).

The mean nitrate concentration at 'De Marke' fluctuated between 30 and 115 mg l^{-1}. The fluctuations can be attributed mainly to fluctuations in precipitation and groundwater-table depth. During the period 1992–1998 no significant decrease or increase in nitrate concentration was detected. Three years after the introduction of new farm management, the nitrate concentrations in the upper metre of groundwater had reached a new equilibrium.

Precipitation in the period 1992–1998 was higher than in the period 1975–1998. If precipitation would decrease to the mean value for the past 25 years, the nitrate concentration would increase, and exceed the EU nitrate standard for drinking water of 50 mg l^{-1}.

References

Aarts, H.F.M., E.E. Biewinga, & H. Van Keulen, 1992. Dairy farming systems based on efficient nutrient management. *Netherlands Journal of Agricultural Science* 40: 285–299.

Alva, A.K., S. Paramasivam, & W.D. Graham, 1998. Impact of nitrogen management practices on nutritional status and yield of Valencia orange trees and groundwater nitrate. *Journal of Environmental Quality* 27: 904–910.

Anderson, D.L., E.A. Hanlon, O.P. Miller, V.R. Hoge & O.A. Diaz, 1992. Soil sampling and nutrient variability in dairy animal holding areas. *Soil Science* 153: 314–321.

Anonymous, 1985. Problems with nitrate in groundwater for the drinking water industry in the Netherlands. Werkgroep Nitraatuitspoeling Waterwingebieden, Rapport No 12, ICW, Wageningen, 49 pp. (In Dutch)

Anonymous, 1991. Directive of the Council of December 12, 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC). European Communities, Brussels, 8 pp.

Anonymous, 1993. Integral report nitrogen. Milieurapportage I. Rapport No 482533001, National Institute of Public Health and the Environment (RIVM), Bilthoven, 101 pp. (In Dutch)

Anonymous, 2000. Manure and the environment. Ministry of Agriculture, Nature Management and Fisheries, The Hague, 20 pp.

Bauld, J., W.R. Evans, & M.W. Sandstrom, 1992. Groundwater quality under irrigated agriculture: Murray Basin, southeastern Australia. In: Fei Jin (Ed.), Groundwater and Environment. Proceedings of international workshop on groundwater and environment, Beijing, China. Seismological Press, Beijing. pp. 447–457.

Beldman, A.C.G., 1997. Management on sustainable dairy farms. MDM Publicatie No 6, PR, Lelystad, 119 pp. (In Dutch)

Boumans, L.J.M.& D. Fraters, 1995. Quality of shallow groundwater of the experimental farm 'De Marke'. In: H.F.M. Aarts (Ed.), Weide- en voederbouw op De Marke. De Marke Rapport No 12, De Marke, Hengelo, pp. 45–62. (In Dutch)

Boumans, L.J.M., C.R. Meinardi & G.J.W. Krajenbrink, 1989. Nitrate and groundwater quality of grassland in the sandy areas of the Netherlands. Rapport No 728472013, National Institute of Public Health and the Environment (RIVM), Bilthoven, 44 pp. (In Dutch)

Conijn, J.G., 2000. Groundwater nitrate related to climate and management. In: H. Van Keulen (Ed.), Duurzame melkveehouderij en stikstofmanagement. Rapport No 21, PRI, Wageningen, pp. 35–59. (In Dutch)

De Vries, F. & J. Denneboom, 1992. Digital soil map of the Netherlands. SC-DLO, Technisch Document No 1, Wageningen, 47 pp. (In Dutch)

De Walle, F.B., & J. Sevenster, 1998. Agriculture and the Environment. Kluwer Academic Publishers, Dordrecht, 211 pp.

Fraters, B., 1998. The quality of the upper groundwater at farms in the sandy region of The Netherlands in 1999. Briefrapport No 714852001, National Institute of Public Health and the Environment (RIVM), Bilthoven, 111 pp. (In Dutch, with English summary)

Fraters, B., L.J.M. Boumans, H.F.M. Reijnders, T.C. Van Leeuwen & D.W. De Hoop, 2000. Monitoring the effectiveness of the Dutch Mineral Policy on nitrate in groundwater. In: Proceedings of the International Conference on agricultural effects on ground and surface waters. 1–4 October 2000, Wageningen, pp.1–9.

Fraters, B., L.J.M. Boumans, G. Van Drecht, T. De Haan & D.W. De Hoop, 1998. Nitrogen monitoring in groundwater in the sandy regions of the Netherlands. *Environmental Pollution* 102: 479–485.

Hack-Ten Broeke, M.J.D., 2001. Nitrate leaching to groundwater at experimental farm 'De Marke' and other Dutch sandy soils. *Netherlands Journal of Agricultural Science* 49. (This issue)

Hack-Ten Broeke, M.J.D. & W.J.M. De Groot, 1995. Nitrate leaching towards groundwater. In: H.F.M. Aarts (Ed.), Weide- en voederbouw op De Marke Rapport No 12, De Marke, Hengelo, pp. 33–44. (In Dutch)

Henkens, P. & H. Van Keulen, 2001. Mineral policy in the Netherlands and nitrate policy within the European community. *Netherlands Journal of Agricultural Science* 49. (This issue)

Hilhorst, G.J., J. Oenema & H. Van Keulen, 2001. Nitrogen management on experimental dairy farm 'De Marke': farming system, objectives and results. *Netherlands Journal of Agricultural Science* 49. (This issue)

Jones, L.J., & L.M. Roberts, 1999. The relative merits of monitoring and domestic wells for ground water quality investigations. *Ground Water Monitoring and Remediation* 19: 138–144.

Kolenbrander G.J., 1981. Leaching of nitrogen in agriculture. In: J.C. Brogan (Ed.), Nitrogen Losses and Surface Run-off from Landspreading of Manures. Martinus Nijhoff Publications, The Hague, pp.199–216.

Loftis J.C., 1996. Trends in groundwater quality. *Hydrological processes* 10: 335–355.

Makking G.F., 1957. Testing the Penman formula by means of lysimeters. *Journal of the Institution of Water Engineers* 11: 277–288.

Meinardi, C.R., C. Van Den Akker, C.J. Dekker, G.J. Heij & J.W. Kieft, 1978. Geohydraulic data for Zuidelijk Flevoland and Gelderse Vallei. Rapport No 78–4, RID, Leidschendam, 50 pp. (In Dutch)

Patni, N.K., L. Masse, & P.Y. Jui, 1998. Groundwater quality under conventional and no tillage: I. Nitrate, electrical conductivity, and pH. *Journal of Environmental Quality* 27: 869–877.

Ramsey, M.H., 1992. Sampling and analytical quality control (SAX) for improved error estimation in the measurement of Pb in the environment using robust analysis of variance. *Applied Geochemistry*, Suppl. Issue No. 2: 149–153.

Rasmussen, P., 1996. Monitoring shallow groundwater quality in agricultural watersheds in Denmark. *Environmental Geology* 27: 309–319.

Spalding, R.F. & M.E. Exner, 1993. Occurrence of nitrate in groundwater- A review. *Journal of Environmental Quality* 22: 392–402.

Van Drecht, G., 1983. Simulation of vertical non-stationary transport of water and a solute. Mededeling No 83–11, RID, Leidschendam. (In Dutch)

Van Drecht, G., 1993. Modelling of regional scale nitrate leaching from agricultural soils, The Netherlands. *Applied Geochemistry*, Suppl. 2: 175–178.

Van Het Loo, H., 1997. Sample for soil properties and groundwater regimes from the soil map of the Netherlands 1:50 000 Map units with GT II. Rapport No 483.2, DLO-Staring Centrum, Wageningen, 48 pp. (In Dutch)

Wösten, J.H.M., M.H. Bannink & J. Beuving, 1987. Water holding capacity and hydraulic conductivity of soils and sub-soils in the Netherlands. Rapport No 18, ICW, Wageningen, 75 pp. (In Dutch)

Appendix

Monitoring groundwater nitrate

Local spatial variability often is the main cause of variation among groundwater samples (Ramsey, 1992; Anderson *et al.*, 1992) and can mask effects of differences in farm management on nitrate concentration (Patni *et al.*, 1998). Assuming that quick sampling does not introduce systematic errors, many quick samples will give a better estimate of the average than a few laborious ones. However, systematic errors are not important if the objective is to quantify differences.

The upper groundwater was sampled, as it best reflects recent farm management (Jones & Roberts, 1999). Moreover, sampling upper groundwater is less laborious than sampling soil moisture.

A new temporary well was made by hand for each sample. Many investigators have used permanent wells (Jones & Roberts, 1999; Alva *et al.*, 1998; Patni *et al.*, 1998; Rasmussen, 1996). In the Netherlands, it is easier to make temporary wells. In the subsurface soil, stones and rocks are absent and the groundwater table in the sandy region is on average within 1.5 m from the surface (Fraters, 1998).

Temporary wells have a number of advantages:

1. No effect of age of the well on the sample. For instance, the surrounding soil is not disturbed by frequent visits.
2. Their installation, removal and use take less time.
3. Because of fluctuating groundwater tables, sampling of the upper metre of the groundwater is more accurate.
4. No disturbance by, or interference with agricultural activities.

However, the installation of temporary wells disturbs the soil and can influence groundwater quality. To mitigate possible influences and to rinse the well and the sampling equipment, one litre of groundwater was extracted before the actual sample was taken. But rinsing of the well before sampling can have the disadvantage of extracting groundwater from deeper layers that contain fewer nitrates. This was verified by extracting groundwater samples from 48 representative farms in the conventional way, followed by second samples taken from the same wells after an extra extraction of 10 litres of groundwater. In the 48 conventional samples the average ammonia and nitrate concentrations were 0.7 and 84 mg l^{-1}, respectively. The average difference in ammonia and nitrate concentration between first and second samples was –17% and +4%, respectively. The difference in nitrate concentration was statistically not significant. The difference in ammonia concentration was significant, confirming the hypothesis that the installation of temporary wells does influence the results.

The groundwater samples collected at 'De Marke' were not filtered nor acidified. To establish possible effects of this modification, samples taken from 18 representative farms (3 samples per farm) were treated in three different ways:

1. Conventional sample; no treatment.

2. Sample filtered and acidified immediately, and
3. Sample filtered and acidified after storage for one week in the laboratory.

In the conventional samples the average nitrate concentration was 138 mg l^{-1}, as against 136 mg l^{-1} in the other two types of sample. It was concluded that the modified treatment of the groundwater samples had no effect.