Agricultural non-point load of nitrogen to surface waters. A regional estimation in GIS.
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Abstract

In the Netherlands the input of nitrogen to surface waters and groundwater from non-point-sources is a major environmental problem. About 60-90% of the total discharge of nitrogen on surface waters is caused by leaching from agricultural areas. The objective of much research is to quantify the contribution of leaching of nitrogen and to develop decision-support-systems for national and regional authorities, to study the effect of reducing the excessive use of fertiliser.

In this study a method for estimating the load of nitrogen from agricultural areas using existing geographical data-input is presented. The result is a relative simple model to study the spatial variation in the average annual leaching of nitrogen to surface waters. A Geographical Information System is used to handle spatial and non-spatial data from different sources.

The method is applied to the catchment of a low-land stream in the eastern part of the Netherlands, the ‘Groenlose Slinge’ catchment. Estimated annual loads of nitrogen are compared with measured data.

Introduction

The excessive use of fertiliser (mineral and farm manure) results in leaching of nitrate to surface waters. As a result many Dutch waters get highly eutrophicated which leads to instability of the aquatic ecosystems
(Ministry of Transport, Public Works and Watermanagement\(^9\)). The reduction of N-load to surface waters from point-source pollution is controlled by 'end-of-pipe' measures (e.g. sewage treatment plants). Non-point diffuse sources are much more difficult to monitor and control. Calculation of N-leaching from agriculture is mostly done by budget studies at different scales. The difference between the input and output of nitrogen in surface waters is addressed to leaching from agricultural landuse.

In this paper the procedure of estimating the potential N-leaching using a Geographical Information System (GIS) combined with a simple static model on field scale is presented. The aim of the study is to develop a relatively simple estimation method based on general existing geographical data. Results can be used for evaluation of measures for reducing the diffuse load of nitrogen on catchment scale. The method is applied to the catchment of the Groenlose Slinge. In this area of about 19,000 ha 89% of the ground is used for agriculture.

Geographical Information Systems (GIS) are computer-based data handling and display systems designed to handle large volumes of spatial and non-spatial information from different sources and scales. Recently GIS-packages are developed for Personal Computers and thus available for all kinds of land-related environmental issues. National and regional governments are developing GIS-databases which can be used en processed in an interactive way (Tim and Jolly\(^13\)). Studies in Germany show the possibilities of geographical analysis on general data (Wendland\(^14\); Reiche\(^12\)).

### Procedure of estimating leaching of nitrogen

Transport and transformations of nitrogen components in agricultural soils are complex. On plot and fieldscale processes can be described in deterministic models. In the Netherlands the model ANIMO is often used. For budget studies and policy analysis on surface water management calculation on catchment and regional scale are necessary.

N-losses to the environment are controlled by different factors at different scales. Table 1 presents major controlling factors at different scales.

Numerous studies have attempted to quantify rates of N-leaching and denitrification in relation to variables on different scales (e.g. De Klein\(^7\)). From these studies it is clear that available nitrate and moisture content are main controlling factors on field-scale. At different scales other factors can be identified (Groffman\(^5\); Seitzinger and Kroeze\(^11\)). To calculate losses on fieldscale controlling factors can be derived from secondary
data. Available nitrate (N-input) can be related to landuse and soilwater and organic carbon to soiltype.

Table 1. Controlling factors of N-leaching and denitrification at different scales.

<table>
<thead>
<tr>
<th>scale of study</th>
<th>controlling factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>plot, field</td>
<td>Soil water, available nitrate, organic carbon</td>
</tr>
<tr>
<td>landscape</td>
<td>soil type, plant community type</td>
</tr>
<tr>
<td>catchment, region</td>
<td>landuse, geomorphology</td>
</tr>
<tr>
<td>large river watersheds and estuaries</td>
<td>grade of urbanisation, population density, energy use</td>
</tr>
<tr>
<td>global</td>
<td>climate, biome type</td>
</tr>
</tbody>
</table>

For regional studies calculations on fieldscale have to be aggregated. In principle there are different concepts to aggregate results of local processes to whole catchments. The procedure used in this study is shown in figure 1.

Figure 1. Concept of aggregating fieldscale calculations to a catchment
In the catchment spatial categories are defined based on the discriminating factors of N-leaching on fieldscale. For every soiltype/landuse category annual discharge of nitrate to surface waters is calculated. The contribution of each category and its spatial distribution in the catchment is analysed and calculated using G.I.S.

Calculation of nitrate leaching on fieldscale

Annual average nitrate leaching from agricultural soils can be calculated as follows:

\[ LE = NM + NF + AD - PU - DE - VO - AC \]

where

- \( LE \) = leaching of N to groundwater (kgN/ha/year)
- \( NM \) = N-input of Mineral fertiliser (kgN/ha/year)
- \( NF \) = N-input of Farm manure (kgN/ha/year)
- \( AD \) = Atmospheric Deposition (kgN/ha/year)
- \( PU \) = Plant Uptake of Nitrogen (kgN/ha/year)
- \( DE \) = denitrification of nitrate (kgN/ha/year)
- \( VO \) = volatilisation of ammonia (kgN/ha/year)
- \( AC \) = accumulation of organic-N in the soil (kgN/ha/year)

The N-input surplus is transported in the soil and partially transformed in gaseous and organic N-compounds. The remaining nitrate leaches to groundwater and surface water. In this study it is assumed that the accumulation and release of organic N from soil are in equilibrium so the net-accumulation is zero. Measures to prevent the volatilisation of ammonia have proved to be very effective, especially the injection of manure in the soil. Therefore these losses of N to the atmosphere are very small and also neglected in this study.

The major loss of gaseous N to the atmosphere is caused by denitrification, i.e. reduction of nitrate to \( \text{N}_2\text{O} \) and \( \text{N}_2 \) under anoxic conditions. Denitrification capacity is controlled by the input of nitrate and soil properties.

With the static model NLOAD base leaching of nitrate to groundwater is calculated from fertiliser input and atmospheric deposition. NLOAD is tested with results of N-budget studies at several research fields (van Drecht). Specially on grasslands on sandy soils good results are obtained.

Part of the leaching nitrate is lost to the atmosphere by denitrification. This process is strongly related the groundwater level (Bouwmans). The fraction that is lost by denitrification is determined by
the coefficient of the groundwater table. The remaining fraction will leach to groundwater and surface water. Research in lowland stream catchments indicate that there is a relation between catchment runoff and total load of N to surface waters (v.d. Eertwegh). So in this study a second estimation was made accounting for the runoff in the estimated year related to the average runoff. Figure 2 shows the calculation flowchart.

![Flowchart of calculating nitrate leaching on fieldscale.](image)

**The ‘Groenlose Slinge’ catchment**

A similar estimation procedure was applied to the Province of Flevoland (Blind and De Klein). For this area no good loads and discharges were available so the results could not be validated properly. Therefore a new area was selected for which timeseries of flow and water quality were available. The Groenlose Slinge is a lowland stream in a merely agricultural area and its catchment is well defined. For more than 15 years flow and water quality are measured at several locations.

For different hydrological years loads of nitrogen to the surface waters in this catchment are estimated and compared to the measured data. Figure 3 shows the location of the research area. For this study the GIS MapInfo was used. MapInfo is a GIS-package for desktop mapping and interactive data handling (Mapinfo Corporation). It can be run under MS-Windows.
The geographical information used in this study came from different sources. The atmospheric deposition of nitrogen is assumed to be constant in space with a slight decrease in the last ten years.

A digital map of Landuse is available in a grid-based GIS on a scale of 25 x 25 m gridcells. Landuse is classified in about 40 classes. This highly detailed information is reduced by
- aggregating gridcells to 100 x 100 m
- reducing the number of landuse classes to 5

The soiltype map is digitised from the soilmap of the Netherlands (1:50,000). In this study, soiltype is reclassified to only two classes: Sand and Clay.

N-fertiliser input were determined for all landuse classes according present agricultural practice in this region (CBS-LEI; van Eck⁴).

![Figure 3. Location of the study area (within The Netherlands)](image)

Results

Estimates were made for the years 1989 and 1995 (dry years) and 1993 and 1994 (wet years). Figure 4 shows the spatial variation of nitrate
leaching in the catchment in 1993 and 1995. This figures are based on the second estimation, i.e. with the runoff coefficient correction.

Figure 4. Estimates of nitrate leaching in the Groenlose Slinge catchment
Average loads of nitrogen are estimated at 40 to 60 kgN/ha/year. In 1989 the load varied from 0 to 298 and in the other years from 10 to 200 kgN/ha/yr. Differences in the years can be related to hydrological situation (runoff) and fertiliser input.

The actual runoff is a major controlling factor in the nitrate leaching. The runoff correction was calculated from measured loads of nitrogen at three locations in the stream in a period of 10 years. The figure shows the relation between measured discharge and measured loads. Calculation of N-loads are made from flow measurements (daily) and water quality monitoring data (monthly). Therefore interpolation of quality data had to be made, which generates estimation errors (Huis in 't Veld). In figure 5 measured and estimated loads are shown. Separate calculations are made for the whole area and the eastern subcatchment. Both estimations (without and with runoff correction) are presented.

Figure 5. Measured and estimated loads of nitrogen to surface waters.
Generally the estimated loads are close to the measured loads especially in the second estimation where actual runoff is taken into account. 7 of 8 estimates with runoff correction are higher than the measured data (average difference is 9 %).

Discussion

The presented estimation method for agricultural non-point load of nitrogen to surface waters can be useful for policy analysis on regional scale. In the Groenlose Slinge catchment N-loads in the range of 40 - 60 kgN/ha/yr are estimated which differ less than 10% from measured loads. In most cases there is a over-estimation.

The method can be applied to other catchments when spatial data on landuse, soiltype, groundwatertable and runoff are available. Calculation results can be used for studying the effect of measures to reduce fertilizer application on surface water quality.

In most budget studies an uncertainty of about 10% might not be accurate enough. On the other hand calculation of actual N-loads from measured flows and (monthly) water quality data are probably not more accurate. Further research on nitrogen transformations and validation of the method in other catchments can lead to improvements.

References

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108 GIS Technologies and their Environmental Applications

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Section 2

Applications