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Mesoscalic estimation of nitrogen discharge via drainage systems

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Abstract

A complex approach has been developed for estimating mesoscalic nitrogen discharges via drainage systems using spatial information about land use, drainage areas, nitrogen balances and soil and site characteristics. Determining the total drainage area involves certain difficulties for larger areas, as on the one hand, the available databases are incomplete, and on the other hand the localisation and digitalisation of large subsurface drainage areas is a very time-consuming process. Knowledge of the history and causes of drainage systems in landscapes is required. To solve this problem a method has been developed to calculate the drainage areas for large catchments. In order to obtain a complete data set of subsurface drainage areas, representative areas were selected to enable the proportion of subsurface drainage area to be determined for various soil and site characteristics. These proportions were extrapolated to the entire area and the approach tested in the Mulde River Catchment Area in Germany.

The rate of drained arable land is about 25.2% of the total area, which can be broken down into grassland (19.0%) and arable land (27.4%). The results differ for sandy soils with up to 8% drained areas and 57.8% for stagnant soils. This shows that the proportion of drained land is highly dependent on the nature of the soil in the catchment area, which has profound implications for approaches to nitrogen modelling.

Average nitrogen discharge for the whole catchment area via drainage water was 33 kg ha^{-1} yr^{-1} in the 1980s and 10 kg ha^{-1} yr^{-1} in the 1990s. The nitrogen discharge varies from one soil type to another: in regions with sandy substrate (11,900 ha) discharge was 34 kg ha^{-1} yr^{-1} in the 1980s (14 kg ha^{-1} yr^{-1} in the 1990s), while in areas with loess lessivé soils (89,200 ha) it was about 26 kg ha^{-1} yr^{-1} in the 1980s (9 kg ha^{-1} yr^{-1} in the 1990s). The reduction can be explained by the complete change in farming strategy since the demise of the former German Democratic Republic (GDR).

The approach shown is well suited to future model approaches on a regional scale. By creating and integrating new data sets derived from modern GIS operations the approach reduces the uncertainty of water and nitrogen modelling. This gives us a better understanding of nitrogen discharges into surface and groundwater and temporal discharge dynamics. The discharge data are highly valuable to predict environmental protection measurements for streams, lakes, coastal waters and groundwaters.

Keywords: Subsurface drainage; Tile drainage; Nitrogen discharge; Regional modelling; Mulde River catchment

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Introduction

The high nitrogen input into rivers and the North Sea shows that action must be taken to reduce diffuse pollution by nitrogen. Action plans based on policy decisions introduced to reduce N loadings nowadays result in significant changes of loading of streams, lakes and coastal waters (e.g. Kronvang et al., 2005, for Denmark; Oenema, van Liere, & Schoumans, 2005 for the Netherlands).

Drainage systems beneath the groundwater systems are the main pathways for diffuse nitrogen input into rivers. Drainage data are valuable to produce better model results in order to predict nutrient discharges. They are essential e.g. for models like DRAINMOD-N (Helwig, Madramootoo, & Dodds, 2002) or for the DRIPS – Decision Support System for the estimation of the input quantity of pesticides (Röpke, Bach, & Frede, 2004). The shorten nutrient outflow via drainage systems and the reduced denitrification capacity in drained soils contribute to the high proportion of nitrogen in drainage waters. There is a great need for information regarding the amount of nitrogen discharge from drainage systems at landscape level, because most of the leading tile drainage related models and measurement schemes refer only to small catchment areas as it is shown by Sogbedji, van Es, Klausner, Bouldin, and Cox (2001) for a test site of 15 ha maize, Gentry, David, Smith, and Kovacic (1998) for a watershed of 40 ha, or Bučienė, Švedas, and Antanaitis (2003) for a drained system of 7.4 ha. Only some studies refer to larger catchments and a longer time period, for instance Behrendt et al. (2001) estimated the nutrient and heavy metal emissions into the river system of the Odra with a macro-scale method for 45 subcatchments in Germany, Poland, and the Czech Republic. The result shows that up to 33.1% of the nitrogen input into the subcatchments resulted from tile drainage during the period of 1993 to 1997.

The results presented here arose in connection with the project 'Water and nutrient fluxes in the loess region of the Elbe catchment as basis for the implementation of sustainable land use' promoted by the Federal Ministry for Education and Research. Modelling was carried out over all diffuse and point pathways of the nitrogen household in the Mulde catchment area (Hirt, 2003; Becker & Lahmer, 2004; Hirt, 2004).

This paper outlines an approach to determine nitrogen discharge for large catchment areas. Three main aspects are discussed. Firstly, we will explain the causes and problems of drainage and different drainage techniques in landscape, the second part provides a brief method for calculating the usually unknown proportions of drained areas in arable lands by improving a method suggested by Behrendt et al. (1999), and, thirdly, we will calculate the nitrogen discharge via drainage systems as a missing link from nitrogen modelling. This approach will be adopted for the Middle Mulde River catchment (area: 2700 km^2) in Saxony/Germany.

Impact of drainage on the landscape water household

Drainage improves the efficiency of land use for agricultural purposes but at the same time it constitutes substantial interference in the water household of the landscape and the nutrient cycle (Scheffer, 1993).

Drainage can be carried out by means of drainage pipes or open ditches. Ditches are often used to drain grassland, as this method is economic in terms of both effort and cost. As ditches severely restrict cultivation of the field by machinery, ploughed fields are mostly drained by subsurface drainage systems (Dörter, 1989; Pollack, 1991).

Drainage systems mainly consist of clay or plastic pipes or channels can be pressed into the soil body without solid walls, which is referred to as pipe-less drainage or mole drainage. The life-time of mole drains, the advantage of which is the low cost, can be more than 10 years under favourable conditions (Dörter, 1989; SRU, 1985). Pipe drainage is used to drain soils waterlogged with groundwater. Stagnant soils are drained using pipes if the groundwater horizon is more than 0.5 m below the surface of the land (Dörter, 1989; Scheffer, 1993).

Drainage operations change the proportions of individual discharge pathways in the water household. The surface run-off is reduced because of the higher infiltration capacity. The drainage run-off leads to a reduction in the groundwater recharge. This tends to reduce the collection of drinking water but it also reduces the entry of soil water arising from agricultural use with any high nitrate content into the groundwater. Although the drinking water is protected from nitrate inputs, the nitrate still gets into brooks and rivers via drainage pipes and ditches.

The extent to which the groundwater recharge is reduced depends on the amount of drainage. The volume of seepage water that enters the groundwater cannot be precisely determined, as it varies depending on the distance from the drainage pipes and the type of soil (Ernstberger & Sokollek, 1984; Lammel, 1990). Bengtson, Carter, Morris, and Bartkiewicz (1988) came to the conclusion, when carrying out investigations in a drained river catchment area, that the surface run-off was reduced 34% by drainage, but that the total run-off increased by 35% because of the increase in drainage run-off (Bengtson et al., 1988).

Evaporation on the surface of the soil is reduced because of the reduction in groundwater content. On the