Chapter 38
Nitrate Leaching

Tim G. Reichenau, Christian W. Klar, Victoria I.S. Lenz-Wiedemann, Peter Fiener, and Karl Schneider

Abstract Nitrate leaching has a significant influence on plant nitrogen supply and groundwater quality. Spatially detailed information on nitrate leaching is required to assess land-use management options and to develop effective groundwater resource protection measures. Comprehensive information for decision support can be derived based on spatiotemporally dynamic modelling.

Coupled simulations with the DANUBIA simulation system (plant growth, balances of carbon, nitrogen, water, energy) were performed for several test sites and for the Upper Danube catchment. Model validation results for soil mineral nitrogen show good correspondence between the model results and field measurements without a site-specific calibration.

For the spatially explicit analysis on the catchment scale, land-use and cultivation practice (timing, fertilisation) were set according to best-practice recommendations. Modelled nitrate concentrations in the leachate from the vadose zone were analysed for the period 1995–2000. A comparison of simulated and measured data proved the consistency of the model results.

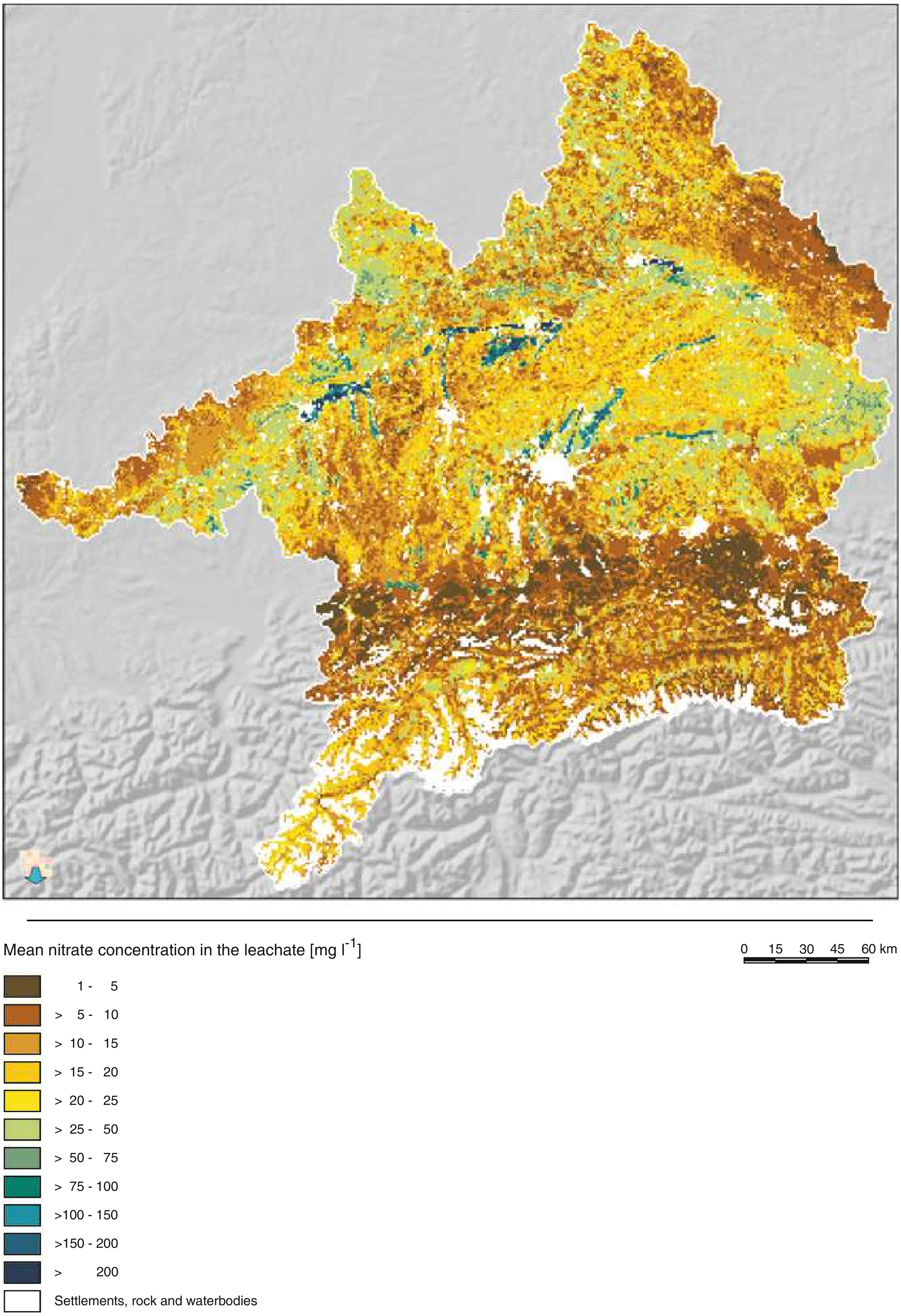
In general, nitrate concentrations above 50 mg l^{-1} were calculated mainly for regions characterised by intensive agriculture or peatland soils. The lowest nitrate concentrations occur in forested areas and regions with little arable land. Overall, the results reveal the potential for dynamic and comprehensive modelling of nitrogen leaching with DANUBIA.

Keywords Nitrate leaching • Plant growth • Nitrogen balance • DANUBIA • GLOWA-Danube • Ecosystem model

T.G. Reichenau (✉) • V.I.S. Lenz-Wiedemann • K. Schneider
Institute of Geography, University of Cologne, Cologne, Germany
e-mail: tim.reichenau@uni-koeln.de; victoria.lenz@uni-koeln.de; karl.schneider@uni-koeln.de

C.W. Klar
Forschungszentrum Jülich, Jülich, Germany
e-mail: c.klar@fz-juelich.de

P. Fiener
Institut für Geographie, Universität Augsburg, Augsburg, Germany
e-mail: peter.fiener@geo.uni-augsburg.de



Map 38.1 Nitrate leaching

38.1 Introduction

Nitrate leaching, defined as the process of nitrate percolation from the root zone, is one of the most important factors influencing groundwater quality. Moreover, nitrate leaching reduces N availability in soils and hence potentially affects plant growth. The majority of nitrate in groundwater originates from diffuse leaching from agricultural soils. However, in particular cases also point emission from farms and industry might be important.

Spatially detailed information on nitrate leaching is required to assess land-use management options and to develop effective groundwater resource protection measures. Comprehensive information for decision support can be derived based on spatiotemporally dynamic modelling. DANUBIA provides such a tool to analyse optimised, region-specific management options under climate change conditions.

38.2 Preparation of the Data

See Chaps. 8 and 21.

38.3 Description of the Model

In DANUBIA, the turnover and storage of soil nitrogen in arable land and grassland is modelled with a dynamic and process-oriented approach, while for forests, an empirical approach based on Feldwisch et al. (1999) and Block et al. (2000) is applied. Dynamic modelling is performed with the model-component SNT (Soil Nitrogen Transformation) which is closely linked to the process-oriented plant growth model-component Biological (see Chaps. 36 and 37). SNT is conceptually based on CERES Maize 2.0 (Jones and Kiniry 1986). This modelling concept on the one hand is suitable for regional applications because of its limited data demand; on the other hand, it considers the major processes potentially affected by land-use and climate change. The combination of regional applicability and process-oriented is major prerequisite for SNT to be used for Global Change Research in the Upper Danube catchment.

For arable land and grassland, SNT considers the following processes (see Fig. 38.1):

- Nitrogen mineralisation and immobilisation
- Nitrification
- Denitrification
- Hydrolysis of urea
- Nitrate redistribution within the soil profile

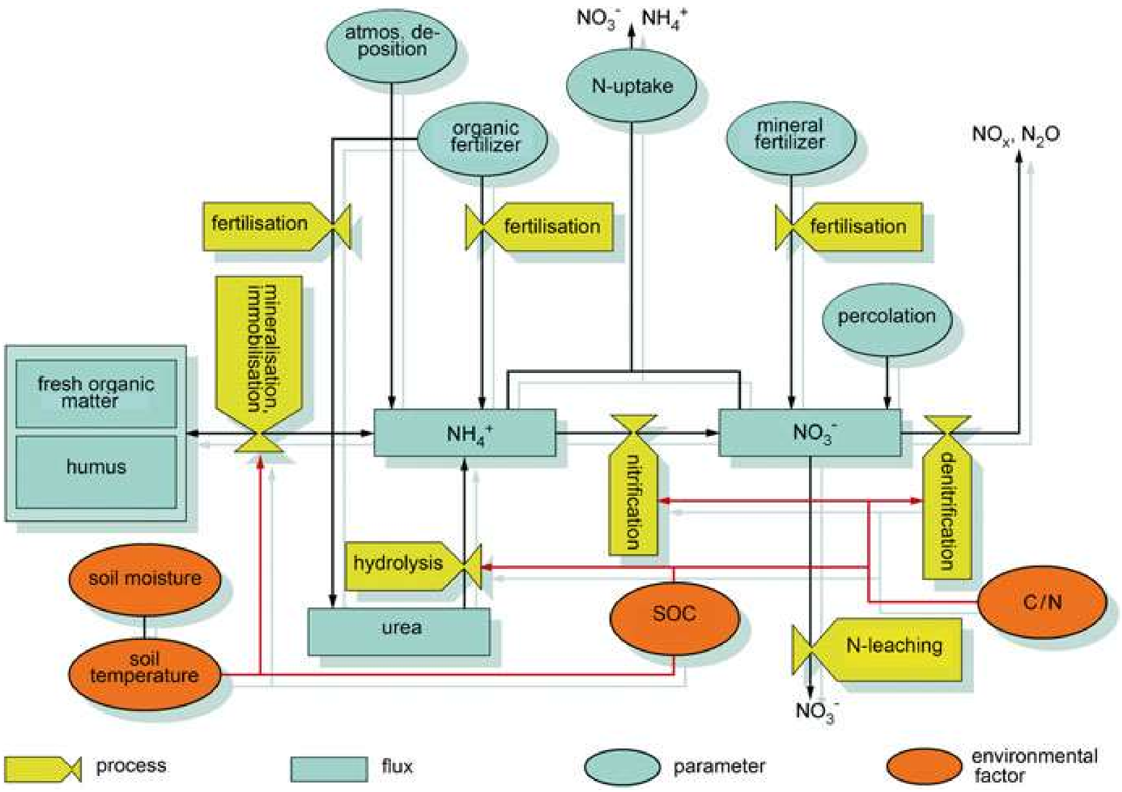


Fig. 38.1 Schematic diagram of SNT including modelled soil nitrogen storages, fluxes and turnover processes (Reprinted from Klar et al. (2008) with permission from Elsevier)

With the exception of the hydrolysis of urea, which is assumed to be limited to the top soil layer, all processes are calculated specifically for each soil layer. Vertical nitrate redistribution between soil layers is coupled to the modelled water fluxes. Considering the spatial resolution (1×1 km^2) of the modelling approach, lateral fluxes are neglected.

All N fluxes are calculated as a function of soil moisture and soil temperature as well as depending upon the physical and chemical characteristics (field capacity, saturated water content, wilting point, bulk density, soil organic carbon content and C:N ratio) of the soil. Nitrate redistribution within the soil profile is proportional to water percolation rates and nitrate concentrations within the individual soil layers. Nitrate leaving the lowest soil layer (max. 2 m) is equivalent to the amount of nitrate leaching from the vadose zone.

The nitrogen status and transformation within the soil is driven by nitrogen inputs (fertilisation, atmospheric deposition) and nitrogen losses (nitrate leaching, uptake by plants, denitrification). SNT accounts for the dynamics within the mineral (nitrate and ammonium) and organic (nitrogen in fresh organic matter and in the humus layer) nitrogen reserves (see Fig. 38.1).

The most important input parameters for SNT are (1) the nitrogen uptake by plants and (2) the N inputs from fertiliser application. Uptake of nitrogen is calculated in Biological as a function of root length density, soil water content, availability of mineral nitrogen (N_{min}) and current demand by plants. The modelling of N-demand is based on the concept of functional equilibrium between carbon and nitrogen in plants (Brouwer 1962). N-demand is modelled dynamically based on carbon assimilation (Lenz-Wiedemann et al. 2010). Due to the process-based simulation of plant growth, the model is able to appropriately address N-uptake under conditions of climate change. For modelling future land-use and land management scenarios, data on the quantity and composition of fertilisers are provided by the Farming component (see Chap. 39).

All processes are modelled on a daily basis, with the exception of nitrate redistribution, which is calculated hourly. Nitrate leaching is given as mass per unit area (kg ha^{-1}) or as nitrate concentration in the percolating water (N_c) from the lowest soil layer (mg l^{-1}). Nitrate leaching for a proxel is calculated as the area weighted mean of the total leaching from the land-use classes on the proxel. Modelled nitrogen availability within and nitrate leaching from soils are transferred to the DANUBIA components Biological and Groundwater.

38.4 Presentation of the Results

Modelled and measured annual dynamics of N_{min} content in three soil layers are exemplarily shown for two test fields (winter wheat and spring barley) in Fig. 38.2. In the top soil layer, the response of N_{min} content to fertiliser application is obvious for spring barley. Also, the dynamics without external N input (here: winter wheat) are correctly depicted. A comprehensive, field-related validation (Klar et al. 2008) showed good correspondence between the model results and the measurements without performing a site-specific calibration. This is an important prerequisite for the spatial transfer of the model to the scale of a drainage basin.

Map 38.1 shows the modelled mean nitrate concentration (mg l^{-1}) in water percolating from the lowest soil layer for 1995–2000. Data regarding soil management, especially fertiliser application, were estimated based on land-use data and information from literature (KTBL 2000/01) in combination with district-specific agricultural statistics (BStMLF 1996). Areas of settlements, rock and water bodies were not modelled and are masked in the map (white areas).

Overall, nitrate concentrations below the threshold of 50 mg l^{-1} (German Drinking Water Directive) can be found in almost the entire catchment (>95 % of area; see Fig. 38.3). Higher concentrations often correspond to regions that are characterised by intensive agriculture (e.g. Passau and Dungau districts); in addition, particularly high nitrogen concentrations are modelled for peatland soils (e.g. the Donaumoos and the Erdinger Moos). Here peak values of up to 440 mg l^{-1} were calculated. These very high concentrations are backed up by measurements in

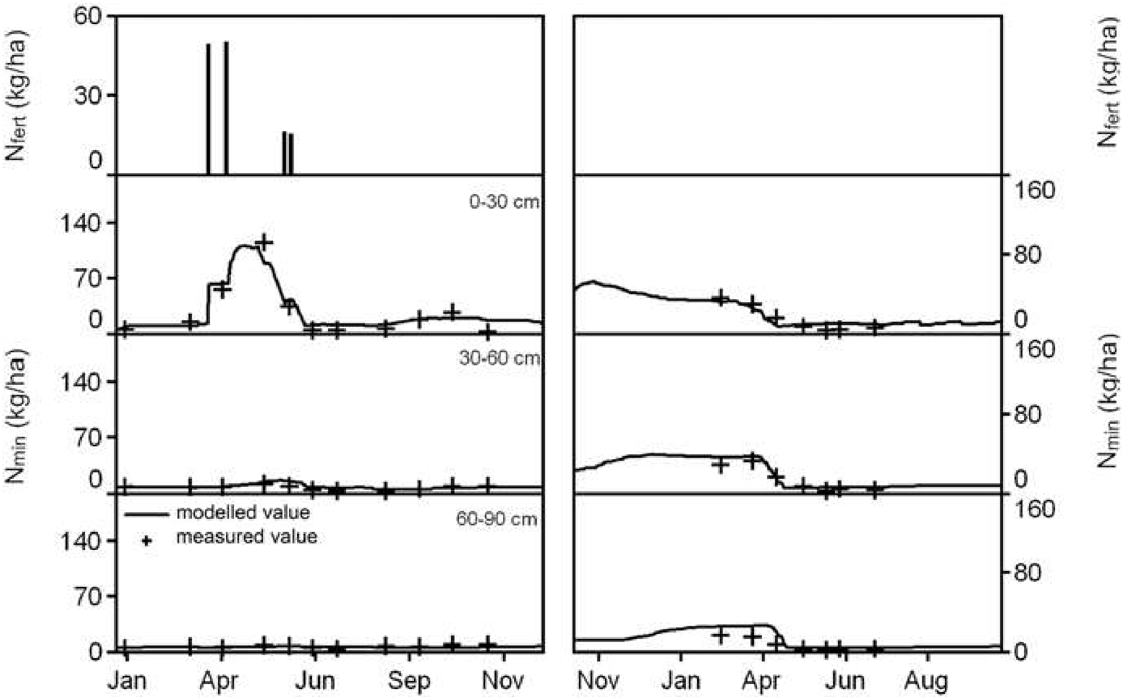


Fig. 38.2 Modelled and measured N_{min} dynamics in three soil layers under summer barley (*left*) and unfertilised winter wheat (*right*); applied fertiliser amounts given in topmost row (Reprinted from Klar et al. (2008) with permission from Elsevier)

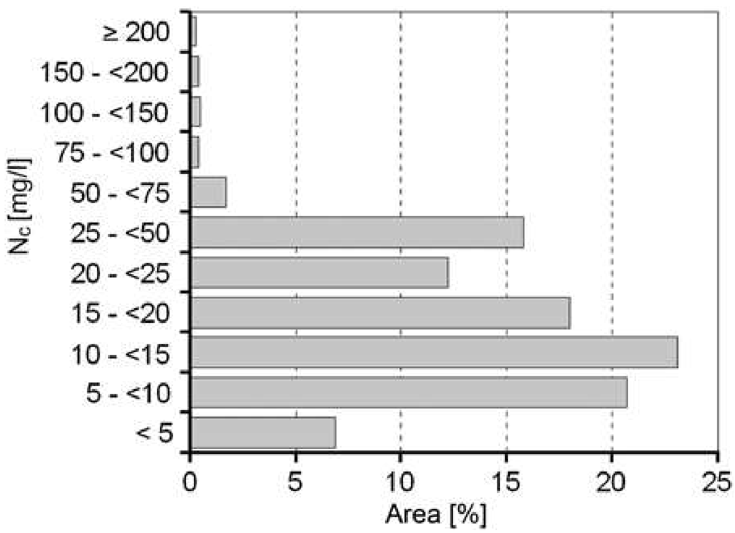


Fig. 38.3 Areal proportion of different nitrogen concentration classes in the Upper Danube catchment

the Donauried region where similar concentrations were observed (Briemle and Lehle 1991). In contrast, the lowest nitrate concentrations are modelled in forested areas and regions with little arable land, such as the Bavarian Forest and the Northern Alps.

Despite remaining conceptual uncertainties (e.g. processes of denitrification during percolation through the unsaturated zone between soil and groundwater), a

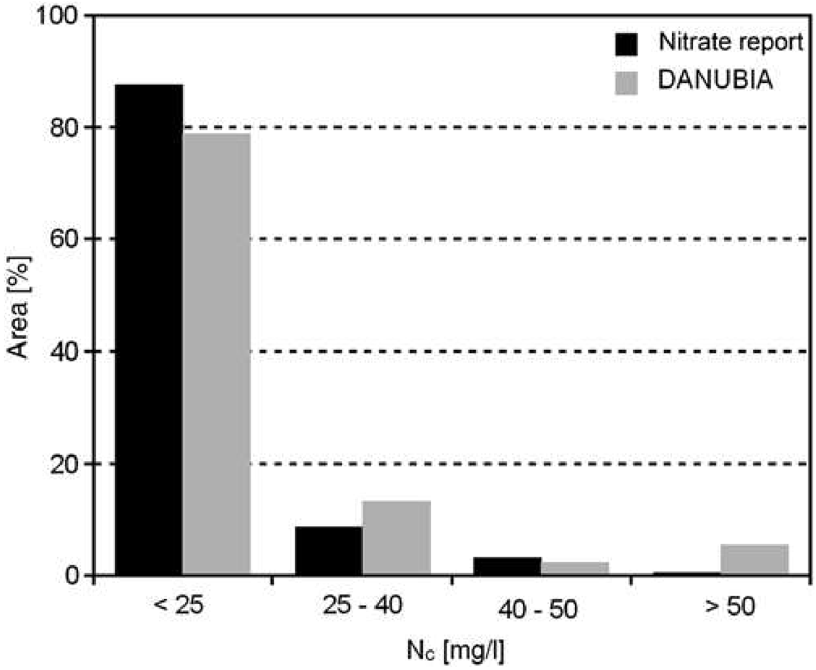


Fig. 38.4 Modelled areal proportion of different nitrogen loading classes compared to data taken from the nitrate report (LfU 2008) in the administrative region of Upper Bavaria for the year 2000

comparison of the modelled nitrate concentrations with measured data proves the consistency of the model results. This is illustrated in Fig. 38.4 which shows a comparison of modelled and measured N load classes for the administrative region of Upper Bavaria (approx. 17 500 km^2).

Overall, the results reveal the potential for dynamic and comprehensive modelling of nitrogen leaching within DANUBIA.

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