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Reprint of "Mapping of nitrogen risk areas"☆

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ABSTRACT

Loading of nitrogen (N) from diffuse sources to Danish marine waters was reduced by 41% in the period 1990–2012 by a suite of general measures. However, further reductions in N loading are required if the ambitious quality goals of the EU Water Framework Directive are to be achieved. Measures will be more effective if they are implemented in N loss hot spots or risk areas. Additionally, the highly variable N reduction in groundwater and surface waters needs to be taken into account as this strongly influences the resulting effect of mitigation measures. The objectives of this study were to develop and apply an N risk tool to the entire agricultural land area in Denmark. The purpose of the tool is to identify high risk areas, i.e. areas which contribute disproportionately much to diffuse N losses to the marine recipient, and to suggest cost-effective measures to reduce losses from risk areas. In the N risk mapping part of the tool, we combined a modelled root zone N leaching with a catchment-specific N reduction factor which in combination determines the N load to the marine recipient. N leaching was calculated using detailed information of agricultural management from national databases as well as datasets of percolation and soil parameters as input parameters to an empirical N leaching model. The developed N risk tool showed that the Danish agricultural area is distributed almost evenly between N retention classes (N retention being divided into classes of <40%; 40–60%; 60–80% and >80% N retention). Hot spots for marine N loading are, however, mainly located in catchments with N retention less than 80%. Hot spots for N leaching from the root zone are mainly located in the western part of Jutland, while hot spots for marine N loading are found in all regions and especially in small catchments close to the coast. In a case study for the catchment of the Danish Odense Fjord estuary, we demonstrated how the tool facilitates cost-effective implementation of measures and how measures can be combined to reach a given reduction target for an estuary.

1. Introduction

Large anthropogenic nutrient inputs to aquatic ecosystems have long been recognised as the primary cause of eutrophication in European waters (EEA, 2007). Eutrophication reduces the water quality and alters the ecological structure and function of aquatic ecosystems (Dodds and Welch, 2000). To remedy this, the European Union implemented the Water Framework Directive (2000/60/EC) in 2000 with the aim to maintain or restore groundwater and all surface waters to a state close to a pristine or near-pristine state. Denmark is traditionally a farming country; thus, about 63% of the entire country is used for intensive farming. Agricultural activities are the main pollutant source of Danish groundwater, surface waters and seawaters. The total load of nitrogen (N) from point and diffuse sources to surface and coastal waters has decreased by almost 50% since 1990 (95% confidence interval = 39%, 58%) (Windolf et al., 2012, 2013). Point sources are now increasingly controlled via the establishment of N removal at wastewater treatment plants (WWTPs). Danish agriculture has in a range of national action plans been requested to implement a number of measures to decrease diffuse N losses (Fig. 1). The action plans include requirements regarding manure storage capacity, rules for timing and application of manure and limits for the maximum amount of N

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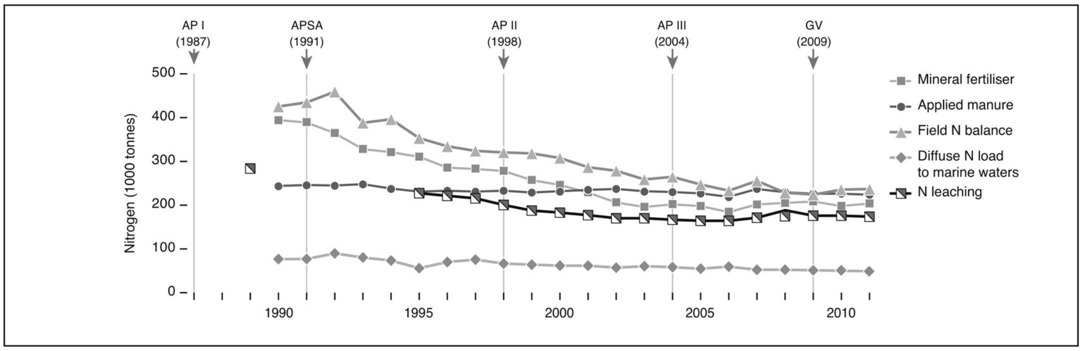

Fig. 1. National N leaching from the root zone, field N balance, consumption of mineral N fertilisers and applied N in manure for the Danish agricultural area and N loading of marine waters from diffuse sources (Grant et al., 2009; Windolf et al., 2012). Action Plan for the Aquatic Environment I–III (API-III), Action Plan for a Sustainable Agriculture (APSA) and Action Plan for Green Growth (GV).

which may be applied to different crops (Kronvang et al., 2008). Common for these measures is that they are general, i.e. they have been applied uniformly everywhere irrespective of, for instance, geology and the natural nitrate reducing capacity in the subsoil and irrespective of the vulnerability of the receiving water body to eutrophication. The action plans have led to a 41% decrease in N loading from diffuse sources to marine waters (95% confidence interval = 36%, 50%) for the period 1990–2012 (Windolf et al., 2012, 2013). Today, the loading from diffuse sources accounts for more than 90% of the total land-based N loading of the aquatic environment (Kronvang et al., 2009).

However, further N loading reductions are required if the ambitious quality goals of the Water Framework Directive are to be achieved (Økonomi- og Erhversministeriet, 2009). These reductions must come through diminished loading from diffuse sources as further reductions of point source loading would be very costly (Miljøministeriet, 2010). Given the complexity of the rural landscape, this is a difficult task because diffuse pollution varies considerably due to the complex interactions between soil, climate, topography, hydrology, land use and management (Heathwaite et al., 2005). Mitigation measures will be more effective if implemented in N loss hot spots or risk areas. Additionally, the highly variable N attenuation (retention) in aquifers and surface water should be taken into account as this strongly influences the overall effect of mitigation measures on the resulting N loading of freshwater and marine ecosystems.

An overview of the previous work on agricultural N risk assessment is given in Buczko and Kuchenbuch (2010). Modelling of N loading to aquatic systems and calculation of effects of mitigation measures by dynamic models have been undertaken for a few individual Danish catchments (Styczen and Storm, 1993a,b). More simple models have ranked the level of N leaching as a function of soil, climate, management and off-site impacts as shallow vs. confined aquifers, tile drained areas, lakes and buffer strips (Shaffer and Delgado, 2002; Williams and Kissel, 1991; Pierce et al., 1991). Common for these studies is that the N loss is addressed as the leaching out of the root zone, thus ignoring the very variable N attenuation in groundwater and surface waters. Bechmann et al. (2009) describe an integrated assessment tool for both N and phosphorus (P) and found that critical source areas differ for N and P, implying that use of different mitigation methods will often be necessary in order to reduce losses of both P and N in a catchment. In Margette et al. (2007) N leaching via soil and groundwater and N loss by overland flow was set up for agricultural systems with grassland in Ireland. Management input in this model is based on a coarse level of agricultural management data. Identification of N risk areas by direct measurement will be too expensive to implement on larger scales. Physically based dynamic models have huge demands for input data and calibration data and are often difficult and time consuming to operate. Thus for large-scale work, there is a need for a more simplified, transparent approach which includes N retention in groundwater and surface waters.

The objective of this study was to develop a transparent and simple-to-use tool for mitigation of diffuse N loading to marine areas, and subsequently to apply this tool to the entire Danish agricultural area. The purpose of the tool is two-fold: (i) to identify risk catchments and areas, i.e. areas which contribute disproportionately much to diffuse N losses to the marine recipient, and (ii) to suggest cost-effective measures to reduce losses from risk areas. In the tool we have combined a detailed calculation of root zone N leaching at field block scale (average field block size = 8 ha) with estimates of nitrate reduction in groundwater and surface waters at catchment scale. For each field block (in total more than 330,000 field blocks in Denmark), we have assessed the potential of seven different measures to mitigate the N loss and calculated the effects and costs of the measures. As a demonstration of the tool, we showed for the 1000 km^2 Danish River Odense catchment draining into an estuary how the tool can be used to fulfil a set N reduction target by suggesting cost-effective measures to be applied to identify risk areas within the catchment.

2. Methods

In this study a tool to map risk of N loss and to plan mitigation methods was developed. In the N risk mapping part of the tool, we combined a calculated root zone N leaching with a catchment-specific N reduction factor that in combination determine the N load to the marine recipient. This was done for all the field blocks in Denmark. A field block is a collection of fields (from one to ten fields) defined by the natural borders in the landscape. The field block level is the smallest areal unit with nationally available agricultural management information. In the N mitigation planning part of the tool we included seven mitigation measures. For each of these measures we calculated the areal potential, the effect on root zone N leaching, and the resulting reduction of the N load to the marine recipient and the cost of implementing the measure. A potential user of the tool will decide which measure(s) to apply to the selected field blocks, for instance the most effective measure or the most cost-effective measure, and will automatically get access to the pre-calculated areal potentials, effects and costs. In the demonstration exercise on the River Odense catchment, the cumulated effect and costs of selected measures are calculated.

N loading of marine areas from agricultural areas can be divided into three steps: (i) N leaching from the root zone of agricultural fields, (ii) transport from the root zone to the catchment outlet through groundwater and surface waters; during this transport part of the nitrate may be reduced to atmospheric N, and (iii) transport through surface waters from the catchment outlet to the sea;