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Research article

Using a map-based assessment tool for the development of cost-effective WFD river basin action programmes in a changing climate

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ABSTRACT

For the 2nd and 3rd river basin management cycles (2015–2027) of the Water Framework Directive (WFD), EU Member States are required to fully integrate climate change into the process of river basin management planning (RBMP). Complying with the main WFD objective of achieving ‘good ecological status’ in all water bodies in Denmark requires Programmes of Measures (PoMs) to reduce nitrogen (N) pollution from point and diffuse sources. Denmark is among the world's most intensively farmed countries and in spite of thirty years of significant policy actions to reduce diffuse nutrient emissions, there is still a need for further reductions. In addition, the impacts of climate change are projected to lead to a situation where nutrient loads will have to be reduced still further in comparison to current climate conditions. There is an urgent need to address this challenge in WFD action programmes in order to develop robust and cost-effective adaptation strategies for the next WFD RBMP cycles. The aim of this paper is to demonstrate and discuss how a map-based PoMs assessment tool can support the development of adaptive and cost-effective strategies to reduce N losses in the Isefjord and Roskilde Fjord River Basin in the north east of Denmark. The tool facilitates assessments of the application of agri-environmental measures that are targeted towards low retention agricultural areas, where limited or no surface and subsurface N reduction takes place. Effects of climate change on nitrate leaching were evaluated using the dynamic agro-ecosystem model ‘Daisy’. Results show that nitrate leaching rates increase by approx. 25% under current management practices. This impact outweighs the expected total N reduction effect of Baseline 2015 and the first RBMP in the case study river basin. The particular PoMs investigated in our study show that WFD N reduction targets can be achieved by targeted land use changes on approx. 4% of the agricultural area under current climate conditions and approx. 9% of the agricultural area, when projected climate change impacts on nitrate leaching rates are included in the assessment. The study highlights the potential of the PoMs assessment tool to assist in evaluation of alternative WFD RBMP scenarios to achieve spatially targeted and cost-effective reductions of N loads at catchment scale in the context of a changing climate.

1. Introduction

Across EU Member States discussions are on-going as to how to integrate climate change into the process of river basin management planning (RBMP) for the 2nd and 3rd management cycles (2015–2027) of the Water Framework Directive (WFD) (European Commission, 2000). A key challenge in this context is the adaptation to climate change impacts through the design and implementation of Programmes of Measures (PoMs) at river basin scale (European Commission, 2009; Kronvang et al., 2005; Quevauviller, 2011; Wilby et al., 2006). In Denmark, eutrophication of surface waters is recognized as being one of the most important problems to overcome in order to meet the ‘good ecological status’ (GES) objective of the WFD (Conley et al., 2002; Kronvang et al., 2005; Windolf et al., 2012). Denmark is characterized as having one of the most intensive and export-oriented agricultural sectors in the world. With farming accounting for more than 60% of the total land

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use and a 7500 km long coastline with shallow estuaries and coastal waters, this has led to severe environmental problems (Dalgaard et al., 2014). Since the late 1980s, several national action plans have been implemented in Denmark to reduce nitrogen (N) and phosphorous (P) loading to the aquatic environment. Nevertheless, further reductions of N loads to Danish estuaries are required during the implementation of the WFD to meet the objective of GES (Dalgaard et al., 2014; Refsgaard et al., 2014; Windolf et al., 2012). The first generation of Danish WFD RBMPs (2009–2015) has been considerably delayed, but in 2014 RBMPs for the 23 Danish river basins were adopted with catchment specific load targets for each estuary. Included in these plans are possibilities of implementing targeted mitigation options such as wetland restorations, catch crops etc. without identifying specific locations. A major part of the estimated N load reductions necessary to meet the GES objective in the Danish estuaries has been postponed to the next WFD planning cycles (Danish Ministry of the Environment, 2010a; Danish Ministry of the Environment, 2014). Several Danish studies stress that future N reductions should be achieved through spatially targeted and river basin tailored action programmes (Commission on Nature and Agriculture, 2013; Dalgaard et al., 2014; Kronvang et al., 2008; Refsgaard et al., 2014; Windolf et al., 2012), where agricultural management practises in robust areas can be optimised. The most vulnerable agricultural areas (drained low lying soils), on the other hand, can be converted to less intensive agriculture or taken out of production.

The future impacts of climate change in southern Scandinavia are, especially due to rising temperatures and changes in precipitation patterns, projected to lead to conditions where nutrient loads will have to be further reduced compared to current climate conditions (Andersen, 2012; Jeppesen et al., 2011; Meier et al., 2012; Oeygarden et al., 2014). Nutrient concentrations and loads in the aquatic environment are likely to increase in a future climate due to increasing winter precipitation resulting in higher fluxes of N and P to surface waters. Combined with increasing water temperatures, this is expected to result in a deterioration of the ecological status of the aquatic system (Andersen et al., 2006; Jeppesen et al., 2011; Søndergaard et al., 2006). Understanding the potential effect of climate change on N leaching is essential in this context (Jabloun et al., 2015; Jensen and Veihe, 2009). In Denmark, N leaching from agriculture accounted for approx. 70% of the total N loadings to coastal waters in the period 2007–11 (Dalgaard et al., 2014). Both nutrient loads, temperature and wind conditions affect the risk of anoxia causing extensive fish death and ecosystem damage.

Historically, water management systems have been operated under the assumption of stationarity (Ferrier et al., 2010). More integrated and dynamic concepts, such as integrated catchment management, have been developed in the last decades (Harris, 2010; Lerner et al., 2011), and climate change further increases the need for flexible and adaptable management systems. Even though the WFD does not explicitly mention the risk posed by climate change to the achievement of the environmental objectives, several studies highlight that there is a strong case for integrating climate change impacts within the step-wise and cyclical approach of the WFD planning process (European Commission, 2009; Quevauviller et al., 2012; Wilby et al., 2006). To do this there is a need to incorporate future perspectives, including the development of scenarios with long-term projections as part of the development of strategies and forward plans (Carter and White, 2012). The lack of knowledge on long-term development of ecosystems and a complete account of future stress factors and impacts poses a challenge in this context. However, so far, consideration of climate change has not been addressed in the Danish WFD RBMPs (Danish Ministry of the Environment, 2014).

In the Danish implementation of the WFD, a catalogue of recommended measures has been developed using statistical empirical data to estimate effects and cost-effectiveness. To support spatially targeted and cost-effective action programmes, a map-based PoMs assessment tool has been developed that facilitates spatial representation of potential measures for catchment-scale evaluations through the river network and sub-basin structure of a catchment (Kaas et al., 2008; Kaspersen et al., 2013). The objectives of the present paper are: (i) to investigate the potential effect of projected far-future climate change on N leaching rates for the Isefjord and Roskilde Fjord River Basin in Denmark using the dynamic agro-ecosystem model Daisy; and (ii) to examine how the map-based PoM's assessment tool can support the development of adaptive N management strategies at the river basin level, focusing on the potential implementation of agri-environmental measures targeted towards vulnerable lowland agricultural areas as recommended by the Danish Commission on Nature and Agriculture (2013). The results are considered in the context of estimated N load reductions required to fulfil the GES objective for Isefjord and Roskilde Fjord, including effects of climate change on N leaching.

2. Methods

2.1. Case study river basin and WFD implementation

The study area is one of the 23 Danish WFD river basins and covers the Isefjord and Roskilde Fjord River Basin of approx. 2000 km^2 in northeastern Denmark (Fig. 1). The river basin contains 20 municipalities and encompasses a broad spectrum of water bodies such as streams, lakes, fjords and groundwater as well as major pollution sources, e.g. intensive agricultural production and a range of point sources such as wastewater treatment plants and stormwater outfalls.

Land use in Isefjord and Roskilde Fjord River Basin is dominated by agriculture, covering more than 60% of the catchment area (approx.123.000 ha). The major part of the agricultural land is characterized by cereal production systems (61%) (Gyldenkærne, 2014), which is typical for the eastern part of Denmark. There has been a change in the land use pattern on Zealand since the 1980s from a dominance of spring barley to winter wheat. The cultivation of root crops has decreased significantly, whereas the area covered by maize has increased (Jensen and Veihe, 2009). Livestock production is less widespread in the study area compared to western parts of Denmark, but detailed analyses at the farm-level show a high density of pig and cattle production in some parts of this river basin (Kaspersen et al., 2013).

Agriculture contributes 77% of the current total land-based N-loading to Isefjord and Roskilde Fjord, whereas background loading contributes 12% and point sources such as sewage treatment works discharges account for the remaining N loads (Danish Ministry of the Environment, 2014). Current annual land-based N loads (2005–2009) to Isefjord and Roskilde Fjord are 853 t N and 905 t N, respectively (Danish Ministry of the Environment, 2014). N leaching from agriculture is clearly the single most important contributor of N loading in the river basin. The spatial distribution of nitrate leaching through agricultural soils is determined by, for example, soil type, soil depth and management practices.

The dominant cultivated soil types found in the study area are sandy clay soils, clayey sandy soils and clayey soils, making up 51%, 21% and 20% of the area, respectively. The soil types, Map Color Codes (MCCs), according to the Danish Soil Classification (Madsen et al., 1992), are shown in Fig. 2.

The definitions of the soil types and their distribution in the study area are shown in Table 1. Forest and urban areas are not classified on the soil map so there is a high degree of