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Review

Review of scenario analyses to reduce agricultural nitrogen and phosphorus loading to the aquatic environment

Fatemeh Hashemi *, Jørgen E. Olesen, Tommy Dalgaard, Christen D. Børgesen

Department of Agroecology, Aarhus University, Blichers Allé 20, 8830 Tjele, Denmark

HIGHLIGHTS

- The most widely applied measures in scenarios are changes in land use and agricultural land management.
- None of the reviewed papers considered spatial differentiated measures due to variation in groundwater reduction of nitrogen.
- Scenario evaluation was carried out with a limited set of models.
- All scenario studies have limitations as well as technical and conceptual uncertainties.
- Scenario building should better consider spatial information and the use of participatory approaches.

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ABSTRACT

Nutrient loadings of nitrogen (N) and phosphorus (P) to aquatic environments are of increasing concern globally for managing ecosystems, drinking water supply and food production. There are often multiple sources of these nutrients in the landscape, and the different hydrological flow patterns within stream or river catchments have considerable influence on nutrient transport, transformation and retention processes that all eventually affect loadings to vulnerable aquatic environments. Therefore, in order to address options to reduce nutrient loadings, quantitative assessment of their effects in real catchments need to be undertaken. This involves setting up scenarios of the possible nutrient load reduction measures and quantifying their impacts via modelling. Over the recent two decades there has been a great increase in the use of scenario-based analyses of strategies to combat excessive nutrient loadings. Here we review 130 published papers extracted from Web of Science for 1995 to 2014 that have applied models to analyse scenarios of agricultural impacts on nutrients loadings at catchment scale. The review shows that scenario studies have been performed over a broad range of climatic conditions, with a large focus on measures targeting land cover/use and land management for reducing the source load of N and P in the landscape. Some of the studies considered how to manage the flows of nutrients, or how changes in the landscape may be used to influence both flows and transformation processes. Few studies have considered spatially targeting measures in the landscape, and such studies are more recent. Spatially differentiated options include land cover/use modification and application of different land management options based on catchments characteristics, cropping conditions and climatic conditions. Most of the studies used existing catchment models such as SWAT and INCA, and the choice of the models may also have influenced the setup of the scenarios. The use of stakeholders for designing scenarios and for communication of results does not seem to be a widespread practice, and it would be recommendable for future scenario studies to have a more in-depth involvement of stakeholders for the elaboration and interpretation of scenarios, in particular to enhance their relevance for farm and catchment management and to foster better policies and incentives.

Contents

1. Introduction . . . 609
2. Materials and methods . . . 610

* Corresponding author.
E-mail address: fatemeh.hashemi@agro.au.dk (F. Hashemi).

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2.1. Selection of scenario studies. . . . 610
2.2. Focus areas for review 610
3. Scenarios 610
3.1. Framing conditions. . . . 611
3.2. Scenario drivers 612
3.3. Measures 612
3.3.1. Land cover and land use 613
3.3.2. Land management practices 615
3.3.3. Non-agricultural land management 616
3.3.4. Water management 616
3.3.5. Economic incentives 616
3.4. Temporal aspects 616
3.5. Climate change 616
4. Models 617
4.1. Models used for assessing N and P reduction targets. . . . 617
4.1.1. Process based models 617
4.1.2. Empirical models 618
4.1.3. Economic assessment 618
5. Evaluation of scenario studies 618
5.1. Biophysical results 618
5.1.1. Land use 618
5.1.2. Land management practices 619
5.1.3. Water management 620
5.1.4. Non-agricultural management 620
5.1.5. Combined measures 620
5.2. Economic evaluations 620
6. Methods for scenario design 620
6.1. Scenario design methods applied in reviewed papers 620
6.2. Questionnaire survey on scenario development and use 620
7. Discussion and conclusions 621
Acknowledgements 622
Appendix A. Supplementary data 622
References 622

1. Introduction

In recent decades water quality degradation has been a main concern for societies, since this has direct impacts on biodiversity, ecosystems, human well-being, and drinking water usage and food production. Much of the degradation of water quality is related to excessive loadings of nutrients. The main reason for increased load and transport of nutrients such as nitrogen (N) and phosphorus (P) to water resources is the agricultural food production (Edwards et al., 1990; Han and Allan, 2012; Rabalais et al., 2010; Srinivas et al., 2011; Yang et al., 2010). This is a consequence of global increasing demand for food and fiber (Olesen and Bindi, 2002) affected by the correlation between increased per capita meat consumption, economic growth (Gerbens-Leenes et al., 2010) and population growth (Qu and Kroeze, 2012; Sattar et al., 2014).

As the results of increased nutrient loads to aquatic environments are observed globally (Barile, 2004; Bouwman et al., 2009; Seitzinger et al., 2005; Seitzinger et al., 2010), the main prerequisite for combatting water pollution is to study how the pollution sources can be traced and reduced (Müller-Wohlfeil et al., 2002). Excessive nutrient loadings into water bodies can come from different sources (Giri et al., 2014) such as improper land use and management (Johnes and Heathwaite, 1997; Lenhart et al., 2003; Li et al., 2009; Wang et al., 2010), intensive and poor farming practices (Giri et al., 2014; Liu et al., 2013) and these may also be influenced by climate change (Castillo et al., 2014; Jeppen, 2011; Rankinen et al., 2013; Wu et al., 2012). In many cases, excess agricultural nutrients and sewage effluents generated from human waste and detergents are the main sources of nitrogen (N) and phosphorous (P) pollution (Bayram et al., 2013; Kronvang et al., 1996; Lam et al., 2010; Schilling et al., 2005; Strokal and Kroeze, 2013). Complex interactions between land use, land management and regional climate change modify hydrology and water quality (Arheimer et al., 2012; Castillo et al., 2014; Nearing et al., 2005; Praskievicz and Chang, 2009). In particular, coastal areas and their water bodies are vulnerable to climatic change, land cover/land use transformations and nutrient loadings (Klein and Nicholls, 1999; McGranahan et al., 2007). Given the importance of agricultural systems for nutrient loadings, agricultural land use and management often become key issues to resolve for improving water quality.

Since both societal and environmental conditions are constantly changing, it cannot be expected that the former conditions stay unchanged, and future water management decisions should be more adaptive (Hesse et al., 2008). Although environmental management is important for N and P loadings by streams and rivers, predicting this under future land use and management change is difficult (Strokal et al., 2014). Therefore, predictive tools have been developed to allow better understanding of the complex interactions between land use change, human activities, climate change and nutrient loads (Busch et al., 2004). Scenario studies provide insights on possible futures (Hesse et al., 2008) or possible past pathways, providing quantitative information on impacts at the catchment scale (Arheimer and Brandt, 1998; Arheimer et al., 2012; Chaplot et al., 2004; Ouyang et al., 2013; Schoumans et al., 2009). Model based scenario analyses can be useful in order to identify appropriate measures for improving ecological status of aquatic systems while maintaining provision of other ecosystems goods and services (Arheimer et al., 2007; Ferrant et al., 2013; Hojberg et al., 2007; Jorgensen et al., 2007; Krysanova et al., 1989; Rivers et al., 2013).

A literature review of potential future for European land use scenarios showed the existence of many different scenarios (Busch et al., 2004); comprehensives studies, such as the "Scenario Europe 2010" project (Bertrand et al., 2001) or the "VISIONS" project (Rotmans et al., 2001), focused on qualitative information on European land use. A study compared driving forces on agricultural land use in Western Europe, concentrated on different quantitative land use scenarios and their results linked to global trade, increase in agricultural productivity