SOILS2SEA DELIVERABLE NO. 2.1

BONUS
SCIENCE FOR A BETTER FUTURE OF THE BALTIC SEA REGION

Review of existing Scenario Studies of Nutrient Reductions

SOILS2SEA

Reducing nutrient loadings from agricultural soils to the Baltic Sea via groundwater and streams

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Review report on exisiting scenario studies of nutrient reductions

August 2015

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Reducing nutrient loadings from agricultural soils to the Baltic Sea via groundwater and streams

This report is a publicly accessible deliverable of the Soils2Sea project. The present work has been carried out within the project ‘Reducing nutrient loadings from agricultural soils to the Baltic Sea via groundwater and streams (Soils2Sea)’, which has received funding from BONUS, the joint Baltic Sea research and development programme (Art 185), funded jointly from the European Union’s Seventh Programme for research, technological development and demonstration and from The Danish Council for Strategic Research, The Swedish Environmental Protection Agency (Naturvådsverket), The Polish National Centre for Research and Development, The German Ministry for Education and Research (Bundesministerium für Bildung und Forschung), and The Russian Foundation for Basic Researches (RFBR).

Hashemi F and Olesen JE., Review report on existing scenario studies of nutrient reductions. Soils2Sea Deliverable 2.1. Aarhus University, Denmark, August 2015, www.Soils2Sea.eu

Contents

1. Summary

Nutrient loadings of nitrogen (N) and phosphorus (P) to aquatic environments is 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 also have considerable influence on nutrient transport, transformation and retention processes that all eventually affect loadings of the 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 implementation of such options or measures and quantifying their impacts through modelling. Setting up such scenarios often involves extensive discussions with stakeholders to ensure that measures are meaningful in the actual landscape and to structure valid model estimations for decision makers. 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 the period 1995 to 2014 having applied models to analyse scenarios of agricultural impacts on nutrients loadings at catchment scale.

The reviewed papers covered a wide range of climatic conditions from cool and wet to warm and dry. About 75% of the studies considered streams and lakes as being the aquatic environment of concern for protection, whereas groundwater and coastal environment were more rarely considered. Of these studies 38% considered only N, 28% considered only P, and 34 % considered both N and P. The most widely applied measures in the scenarios included changes in land use and agricultural land management, which were applied in 77 and 87 % of the papers, respectively. Fewer studies also applied changes in management of non-agricultural land (17%) or changes in management of water flows in the catchment (11%). Land use scenarios were particularly concerned with changes in agricultural land, such as converting between arable and other land uses (e.g., forest, grassland, urban) or more specifically by converting arable to set-a-side or for reconstructing wetlands. The management practices were to a large extent concerned with changes in fertilization rate (77% of studies) or with other forms of nutrient management (13%), livestock management (18%) or grazing management (30%). Changes in cultivation practices of the agricultural land have also been widely studied with use of catch crops (48% of studies), reduced tillage (43%) or conservation tillage (30%) as the most widely applied measures. Only 18% of the studies considered structural changes in the landscape such as buffer strips, and only 4% of the studies considered spatially targeting measures in the landscape, and such studies are more recent. Spatially differentiated options studied in the papers have been divided to land use modification and application of different land management options based on catchments characteristics, cropping conditions and climatic conditions. These measures did not include differentiation due to differences in reduction of N in groundwater. Conversion of arable to forest and annual crops to perennial grassland have been use mostly as spatially differentiated land use measures in most erodible areas. Shifting from conventional to organic farming and including the catch crops into crop rotation are some example of spatially land management measures in reviewed papers.

Almost a third of the publications also consider climate change as part of the scenarios, thus often combining changes in land use and management with climate change.

The assessment of the scenarios was in all cases based on models, which we categorized into process-based simulation models, empirical models and export coefficient models. Most studies used process-based models (75% of studies) and the majority of these used SWAT or INCA. The export coefficient models were used in 19% of studies, mainly for scenarios that focused on P flows, and empirical models were used for a few studies with both N and P. The use of process-based models allowed a larger number of measures in the scenarios to be evaluated than the empirical and export coefficient models.

A questionnaire survey on the design and subsequent use of the scenario studies was performed by asking the authors of the papers with a response rate of 55%. Of these respondents, 52% had used stakeholders to define the scenarios and there had in most cases been a wide participation of stakeholders, in particularly involving farmers, water managers and local authorities. In about 60% of the cases results of the scenario work was presented to stakeholders, and 60% of the cases this was done through workshops and 54% also reported personal interactions with stakeholders and policy-makers. In 22% of the cases respondents reported that the scenarios have affected land use and management, but a larger number of respondents considered that there had been more general effects of the studies on watershed management, policy and incentives.

The results of the review of scenario studies on nutrient loadings show a large focus on measures targeting land use and land management for reducing the source load of N and P in the landscape. Fewer of the studies have considered how to manage the flows of the nutrients or considering how changes in the landscape may be used to influence both flows and transformation processes. Most of the studies have been using 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 defining 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.

2. 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, drinking water usage and food production. Much of the degradation of water quality is related to excessive loadings of nutrients. The main reason for augmented loading and transportation of nutrients such as nitrogen (N) and phosphorus (P) to many water resources is the agricultural food production (Edwards et al., 1990; Han and Allan, 2012; Kronvang et al., 1993; Rabalais et al., 2010; Srinivas et al., 2011; Yang et al., 2010). This is a consequence of globally increasing demand for food and fibre (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 prerequisite for combatting water pollution is mainly to study how the sources of the pollution 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 structure and management (Johnes and Heathwaite, 1997; Lenhart et al., 2003; Li et al., 2009; Wang et al., 2010), intensive and poorly managed farming practices (Giri et al., 2014; Liu et al., 2013) and these may be influenced by climate change (Castillo et al., 2014; Jeppen, 2011; Rankinen et al., 2013; Wu et al., 2012). In many cases, agricultural nutrient excesses (non-point source) and sewage effluents generated from human waste and detergents (point source) 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). In particular, complex interaction between land use, land management and regional climate change modifies hydrology and water quality (Arheimer et al., 2012; Castillo et al., 2014; Nearing et al., 2005; Praskievicz and Chang, 2009). Coastal areas and their water bodies can be particularly vulnerable to climatic change, 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 becomes key issues to resolve for dealing with 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 future export of N and P 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, 2006) (Busch et al., 2004) taking scenarios as options for possible futures (Hesse et al., 2008) and 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 find appropriate measures for gaining a better ecological status (Arheimer et al., 2007; Ferrant et al., 2013; Hojberg et al., 2007; Jorgensen et al., 2007; Krysanova et al., 1989; Rivers et al., 2013).

Alternative future planning and assessment can simplify discussion and collaboration among stakeholders and policy makers, allowing economic, social and ecological evaluation of alternative priorities for agricultural regions (Andersson et al., 2008; Santelmann et al., 2004). A literature review of potential future 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 about European land use. A study comparing driving forces on agricultural land use in Western Europe concentrated on different quantitative land use scenarios and their results depending on global trade, increase in agricultural productivity and biofuel production (Busch, 2006), but there is no review study that addresses agricultural land use and management scenarios for studying N and P flows at catchment scale and how these may be influenced through management and policy - which is the entry point of this study.

In the above context, the aim of this paper is:

To analyse how scenarios have been designed and who has been involved in the design process.

To assess which components have been applied in scenarios for mitigating nutrient loads (framing conditions, drivers, land use and management measures including whether they have been spatially targeted).

To analyse which models have been used for assessing nutrient flows and loadings, how scenarios by applying the models have been used for analyzing mitigation measures for reducing nutrient pollution of water and to study on the main challenges of their applicability considering the requirements of the environmental policies.

To assess how and to what extent such scenario analyses have been used in stakeholder communication and policy making.

The study is based on published scientific literature and does not intend to provide a considerable list of studies but rather to give an impression based on a literature search of the most commonly used scenarios and models in relation to local, regional and international policy implementation to reduce non-point source pollution (N and P) and offering examples of their applications.

3. Material and methods

3.1 Scenario study selection

To review relevant scenario studies, a selection of published studies was made through ISI Web of Science for 1995-2014, with the following key words: Agriculture or Agricultural, Scenario, Nutrient or Nitrogen or Phosphorus, Catchment or Watershed and Model. The setup of search criteria yielded a total of 298 reports based on published scientific papers with detailed information about published items and citations in each year as presented in Fig. 1. A further selection of relevant studies was done by looking at titles, key words, and abstracts to identify the articles which appeared relevant for this review. This examination yielded a master bibliography of 130 articles. They were chosen because they covered all the desired key words and assessed agricultural land use/ management scenarios for N and/or P, covering watershed scale through modelling approach across the world.

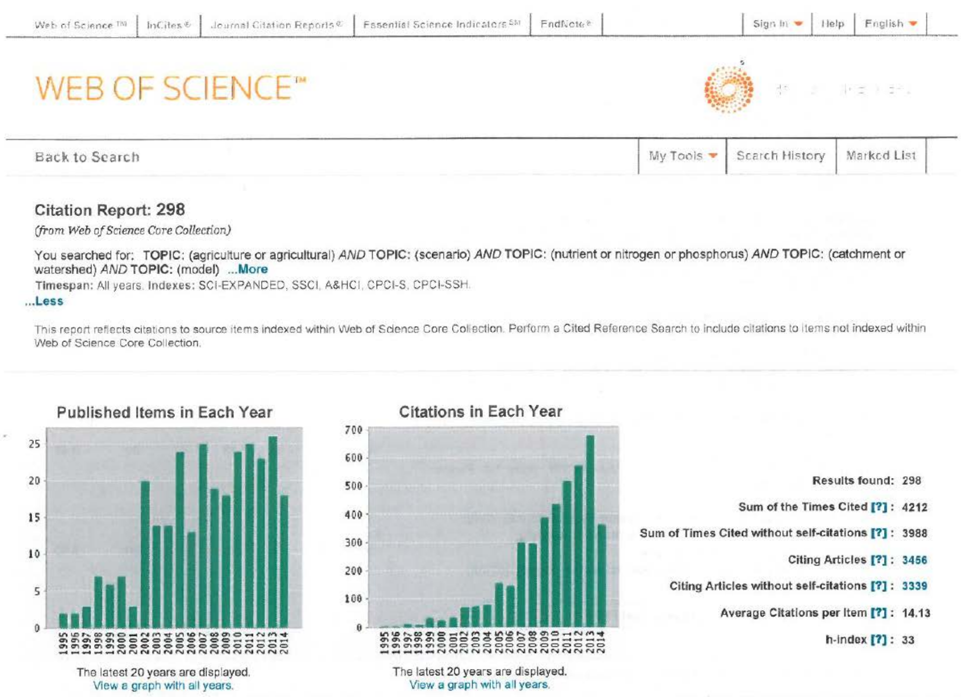

Figure 1: Representation of the references selected for the review

Table 1 provided as overview of the 130 studies that were selected and employed in different climate zones. These studies comprise six kinds of scenarios covering land use, land management, non-agricultural land management, water management, climate change and economic drivers and effects. The scenario studies vary in the nutrient loadings considered (P and/or N), and the spatial, temporal and economic aspects and different kinds of aquatic resources (ground water, stream/lake and coastal environment) that are taken into consideration.

In this analysis study sites with an average temperature higher than 10°C are considered as warm, less than 10°C considered cool, an annual precipitation of more than 700 mm are considered wet and less than 700 mm considered as dry climatic conditions. Table 1 shows that scenario studies have been performed over a broad range of climatic conditions. It also shows that most studies have included land use and management with a considerable focus on nutrient fluxes. There has in general been a greater focus on streams and lakes compared with groundwater and coastal environments.

Table 1: Number of studies in the review that consider various measures, aspects and affected water bodies under different climatic conditions

Selected review papers			Number of papers			
			Climate			
			Cool-Wet	Cool-Dry	Warm-Wet	Warm-Dry
Considered Measures	Land use		33	27	30	10
	Land management		36	29	33	16
	Non-agricultural land management		9	4	5	4
	Water management		8	-	7	-
	Economic incentives		2	2	6	1
Considered aspects	Spatial		4	3	3	1
	Temporal		3	2	-	-
	Biophysical	N	23	11	9	6
		P	12	8	12	5
		N and P	11	11	16	6
	Economy (cost-efficiency)		6	4	8	-
Considered water bodies	Groundwater		8	4	3	4
	Stream/lake		33	26	29	11
	Coastal environments		5	-	5	2

3.2 Focus areas for review of selected papers

To review the published scenario analyses the scheme presented in Fig. 2 is followed. Assumed components of study are as follow;

The scenarios are considered to have three major components (framing conditions (A), drivers (B) and measures (C)), and the scenario analyses also include the models used to assess the scenarios (D), the evaluation of results (E) and the communication and application of results (F):

(A) The framing conditions for the scenario analyses often define the objectives of the study but also provide that baseline against which to assess the scenario results,

(B) The main drivers affecting change, which may be global or local and which also include climate change, and

(C) The major measures considered to mitigate nutrients loadings , which may be indirect (e.g., economic incentives) or direct (e.g., changes in land use, agricultural and non-agricultural land management and water management).

(D) The scenarios are analyzed using models, which may have strengths or weaknesses in analyzing particular mitigation options

(E) The outcomes of model-based assessments of the scenarios are a range of biophysical and economic results that can be used to evaluate the scenarios against their objectives

(F) The final step is the communication of the scenario analyses and the application of lessons learned in policy and water management as well as for directing future research.

Given that different methods of scenario design and the feedback of results to policy and research are rarely completely addressed and explained in the reviewed papers, an online survey questionnaire was designed in Survey Monkey and sent to all the related authors. The result of the questionnaire responses is summarized in the last part of this report.

Scenarios

(A) Framing conditions
Research objectives according : Geographical conditions, , infrastructure soil types and climate

(B)Drivers
Global
National

(C) Measures
Land use
Land management
Non-agricultural land management
Water management
Economic Incentives

(D) Model
Empirical Models
Process - Based Models
Export- Coefficient Models

(E) Result
Biophysical Results
Economic Results

(F) Policy & Research
Recommendation
Communication
Impacts

Figure 2: Components of the scenario review approach

4. Scenarios

There is a general consensus that scenarios provide a useful instrument to support decision-making in the context of uncertainties that are beyond our control (EEA, 2007). (Van den Berg and Veeneklaas, 1995) defined a scenario as a delineation of the current situation of a feasible or desirable (often future) state as well as a series of events that could lead from the current interests to the mentioned state. Although scenarios rarely reveal themselves completely, if we look for steering the landscape evolution in a specific direction they help us in order to gain vision into future or alternative perspectives (Volkery et al., 2008). The principle of scenario analysis is to explore alternative developments with the aim of evaluating strategies to respond to such developments (Alcamo, 2008). Using two techniques, scenarios can be generated (Harms, 1995). Forecasting scenarios sketch current attitudes or expectations to the future, Hindcasting scenarios project possible alternatives which are contrasted with the present status (Volkery et al., 2008). Jones and Emmelin (1995) describe four possible scenario types: i) trend extrapolation that expands the landscape development present trends into the future; ii) effects of concrete policy measures that try to explain the effects of policy on the landscape; iii)normative future which presents landscape including favorable elements and iv) surprising future that represents the role of unanticipated landscape change. There is a large number of existing scenarios used to assess the fate of N and P in the environment. This review is restricted to scenarios applied at catchment scale and with the reported application (in the scientific literature) on the assessment of the effectiveness of N and P mitigation options. These rural environmental scenarios come in many variants, often tailored to the specific circumstances of the related research area such as soil types, geography, climate, available infrastructure in order to achieve agreed targets for different ecosystem services, which we here consider as framing conditions. The construction of the scenarios will be affected by the key elements acting as driving forces, divided into global and national drivers such as environmental and economic conditions, technology and policy. Finally, in order to estimate the water pollution through agricultural and non-agricultural options, different measures like land use, land management, water management, non-agricultural practices and economic incentives are usually proposed as part of scenario analysis.

4.1 Framing Conditions

Based on the information shown in Table 2, reviewed papers in this research followed different objectives including water quality improvement, increased agricultural production and biodiversity protection. There are a number of existing studies that have assessed different scenarios related to non-point (diffuse) and point source contributors of nutrient loading and their implications for the water quality. Our main focus in this study is on diffuse sources; however, in some studies scenarios related to both point and diffuse pollution sources have been targeted (Arheimer et al., 2012; Kronvang et al., 1999; Matias and Johnes, 2012d; Nielsen et al., 2013; Nikolaidis et al., 2009; Prochnow et al., 2008; Qu and Kroeze, 2012; Strokal et al., 2014; Thieu et al., 2010; White et al., 2010; Whitehead et al., 2011; Wulff et al., 2007). Land use and land management are key elements for diffuse sources scenario development. Most of the scenario studies have assessed the impacts of land management practices on the physical and chemical pollution of aquatic environment (Bosch et al., 2013; Hirt et al., 2012; Legge et al., 2013; Thorburn and Wilkinson, 2013). Some studies targeted land management practices to reduce diffuse pollution in order to achieve pollutant load reduction targets, spatiotemporal variability in critical source areas and specific constraints such as available funds (Akhavan et al., 2010; Diebel et al., 2008; Gaddis et al., 2014; Giri et al., 2014; Legge et al., 2013; Rankinen et al., 2006). A number of studies have been done to assess the possible reduction in nutrient pollution at catchment scale when alternative management practices in pollution controlling are used (Bosch et al., 2013; Hirt et al., 2012; Jha et al., 2007; Laurent and Ruelland, 2011). Several studies have aimed at comparison between the potential of different alternatives to achieve multiple goals ranging from environmental, economic and social metrics to modeled effects on native biodiversity and water quality (Bossa et al., 2012; Kunkel et al., 2008; Parish et al., 2012; Rankinen et al., 2006; Santelmann et al., 2004). While yet other studies simulate the effectiveness of each land management option to identify the most effective one (Giri et al., 2014; Huang et al., 2009; Liu et al., 2013; Rode et al., 2009; Tzyy-woei et al., 2013; Zhang and Zhang, 2011), other studies tried to evaluate selected environmental policies and measures to determine the scale of changes which might be necessary to reduce nutrient export (Glavan et al., 2012; Hirt et al., 2012; Huang et al., 2009; Sattar et al., 2014).

A variety of studies have been done on the impact of land use changes on hydrology and water quality, through quantifying nutrients discharge into the watersheds (Bhaduri et al., 2000; Chiang et al., 2010; Elias et al., 2013; Kunkel et al., 2008; LaBeau et al., 2014; Lee et al., 2010; Legge et al., 2013; Nikolaidis et al., 1998; Ouyang et al., 2008; Pikounis et al., 2003; Sahu and Gu, 2009; Sliva and Williams, 2001; Somura et al., 2012; Tong et al., 2009; Weller et al., 2003; Woli et al., 2004). Some land use scenarios aimed to evaluate the environmental effects of land-use changes, with a focus on understanding how the spatial distribution throughout a watershed influences their effectiveness (Kunkel et al., 2008; Tian et al., 2010; Yang et al., 2011). The objective of other studies was to speculate how a range of land use patterns, resulting from various policy driven choices would affect the risks associated with nutrient leaching (Moreau et al., 2013; Rankinen et al., 2013; Santelmann et al., 2004). There have also been several studies to assess the combined impact of land-use change and soil property variation on nutrient pollution (Farkas et al., 2013; Jha et al., 2010c; Ouyang et al., 2013). Although interactions between land use change and climate change are complex and currently not well understood (Lepers et al., 2005), a few scenario studies have analyzed the combined effects of climate and land use changes on stream flow and water quality (Arheimer et al., 2005; Castillo et al., 2014; Chang, 2004; Choi, 2008; Park et al., 2010; Qi et al., 2009; Rankinen et al., 2013; Tu, 2009; Woznicki and Nejadhashemi, 2014). Furthermore, only a small number of scenario studies integrate the effects of land-use change and climate change on biodiversity (Bomhard et al., 2005; Brook, 2008; de Chazal and Rounsevell, 2009; Hannah et al., 2002).

Predictions of the combined effects of land-use changes and land management changes on the total nutrient concentration over the whole catchment are important for such scenario studies, and this has been considered in many studies (Chaplot et al., 2004; Chiang et al., 2010; De Girolamo and Lo Porto, 2012g; Demissie et al., 2012; Farkas et al., 2013; Hirt et al., 2012; Huang et al., 2009; Matias and Johnes, 2012d; Müller-Wohlfeil et al., 2002; Volk et al., 2009; Wulff et al., 2014; Wulff et al., 2007; Yang et al., 2011; Zammit et al., 2005). A number of studies aimed to find possible land use and land management alternatives that would comply with current watershed management objectives (De Girolamo and Lo Porto, 2012g; Volk et al., 2009), whereas other studies attempted to investigate how changes in land use and land management practices may impact water quality improvement and how providing other ecosystem goods (e.g., biofuel feedstock) may impact biodiversity conservation (Demissie et al., 2012; Gelfand et al., 2013; Jain et al., 2010; Le et al., 2011; Love and Nejadhashemi, 2011; Ng et al., 2010; Parish et al., 2012; Robertson et al., 2011; Schmer et al., 2008; Thomas et al., 2009; Wu and Liu, 2012; YipingWu et al., 2013)

Table 2: Objectives of reviewed papers and options considered in the scenario analyses

Objectives	Number of studied with each considered changes to reach the aim of studies					
	Land management	Land use	Land use and land management	Land use and climate+	Land use and soil type	Point and diffuse sources
Water quality improvement	35	20	26	5	2	14
Agricultural production	14	7	21	3	4	-
Biodiversity protection	12	4	6	2	-	8

4.2 Scenario drivers

All agricultural land use scenarios refer to key constituents acting as driving forces, but only a number of reviewed studies have described the drivers affecting their scenario design. The information related to address the key drivers of land use scenarios for this study review is gathered in Table 3. The potential drivers are subdivided into large scale (global) and nationally (local) focused pathways. The large scale is summed up as demographic changes, policy, economic development, technological development and societal awareness while the local scale it also includes biophysical conditions, demand for biomass products and services and technological changes. On the one hand climate and technological changes (input type and intensity, innovation, management improvement, crop and livestock productivity) have fundamental impacts in driving supply for agricultural output, while on the other hand demographic changes (population growth), economic development (income growth or growth of GDP per capita), different enacted policies and societal awareness (organic food productions, meat intake and environmental policies) play a substantial role in driving demand for agricultural production and thus in changes of agricultural land use (Busch, 2006; Rounsevell et al., 2005). Altogether a large number of the studies of land use and land management scenarios related to N and P are driven by large scale driving forces such as demographic changes or economic growth, while local spatial patterns tend to be determined also by biophysical conditions of the local sites such as soil type, climate, and topography (Bormann et al., 2007; Ouyang et al., 2013; Romanowicz et al., 2005), which effectively are also part of the framing conditions.

Concerning population data such as population growth, population density and immigration most of the studies employed demographic changes as the main scenario driver for land use change (Bossa et al., 2012; Ducharne et al., 2007; Sattar et al., 2014; Whitehead et al., 2013). Fast economic development - resulting in a large demand for agricultural products and foods - especially for meat and milk - have been considered in a variety of studies through GDP growth per capita and agricultural production costs and prices for agricultural goods and services (Bossa et al., 2012; Sattar et al., 2014; YipingWu et al., 2013). Several studies have considered the effect of two types of driving forces: climate change and enhance production of renewable energy, in particular bioenergy (Bryan et al., 2010; Huang et al., 2009; Parish et al., 2012; Rankinen et al., 2013; Schilling et al., 2008; Wilson et al., 2011). The impact of climate change on agricultural water pollution has usually been studied by applying scenarios of changes in CO2 concentration, temperature, precipitation, and associated evapotranspiration.

Regarding the reviewed papers, the variability of agricultural scenarios and hydrological factors is affected by two types of other drivers as well: human activities and technological changes; the impacts of both of these drivers are mainly considered to be implemented through different agricultural land use and land management practices in order to increase crop yields resulting from high rate of innovation and biotechnological development rather than increased fertilizer inputs (Chiang et al., 2010; Mander et al., 2000; Rode et al., 2009; Tong et al., 2009; Zhang et al., 2013a). Moreover, some of the scenario studies assumed technological development as determining higher resource use efficiencies thus enhancing crop yields, and others considered higher crop yields to be induced by changes in agricultural intensity through increasing synthetic fertilizer input rates (Ducharne et al., 2007; Schilling et al., 2008).

Indeed higher agricultural intensity through production technologies and human activities (agricultural trade and development) affects the land use and management through changes in geographical distribution of crops and geographically differentiated land management measures such as changing land use type, grazing management and expansion of green fodder production. Such changes have divergent effects of polices at global, national and regional scales. Incentives and restrictions imposed by agricultural policies with environmental protection targets shape many agricultural scenarios via environmental regulations and market intervention (subsidies, quotas) and these driving forces also change other drivers like demand for energy crops and agricultural production (Chikondi et al., 2010; Kunkel et al., 2008; Rivers et al., 2011; Schilling et al., 2008; Shi et al., 2012; Thieu et al., 2010; Thorburn and Wilkinson, 2013). Finally societal awareness provides a major driver affecting both markets for products (e.g. effected by changes in diets and health concerns) and by consideration for a healthier and more natural ecosystems (Matias and Johnes, 2012a; Rankinen et al., 2013).

Table 3: Driving forces for land use and land management scenario design

Driving Forces		
Large Scale (Global)	Demographic changes	Population growth
	Policies	Environmental and rural
		Market intervention (subsi-
	Economic development	Economic growth (GDP)
		Rural income
	Environmental Effects	Climate change
		Renewable energies
	Technological development	Technology growth
		Agricultural intensity
	Societal awareness	Environmentalism and life quality (consumer prefer-
Local scale (National)	Biophysical conditions	Climate
		Soil type and topography
	Demand for biomass products and services	Urbanisation
		Recreation
		Food and fiber
		Bioenergy production
	Technological changes	Related to land use
		Related to land management

4.3 Measures

The reviewed land use and management scenarios suggest that future N and P loading to aquatic environments depends largely on environmental management actions taken at catchment scale (Strokal et al., 2014). The management options within reach of local management and national policies are called measures (Vermaat et al., 2012). Potential impacts assessment of a wide range of measures on water quality forms the concept of scenario analysis (Bouraoui et al., 2005; Tong and Chen, 2002; Yang et al., 2011). Here we divide scenarios into three major classes: production, water quality and biodiversity scenarios. Production scenarios considering agricultural regulation concentrate on profitable land cultivation, water quality scenarios aim at specified standards for water quality, and biodiversity scenarios aim to increase variety of agricultural products and crops according to the environmental requirements (Santelmann et al., 2004). Five dimensions are used to classify the broad span of measures that are used in each class of scenarios: Land use, agricultural land management, non-agricultural land management, water management and economic incentives. Table 4 presents the number of combined and single use measures in different scenario papers and highlights the number of papers that considered climate change scenarios. The reviewed studies considering combined land use, management and climate change scenario are explained after the measure descriptions. The number of papers considering various measures is shown in Tables 4 and 5.

Table 4: Number and type of measures considered in the scenario analyses

Scenarios	Measures	Number of the combined/single measures in reviewed papers: Land use	Land management	Non-agricultural land management	Water management	Economic incentives	Number of paper including climate change
Water quality	Land use	20	26	7	3	1	5
	Land management	26	35	12	7	7	11
	Non-agricultural land management	7	12	-	1	2	-
	Water management	3	7	1	-	3	1
	Economic incentives	1	7	2	3	-	-
Production	Land use	7	21	-	2	1	3
	Land management	21	14	-	3	4	2
	Non-agricultural land management	-	-	-	-	-	-
	Water management	2	3	-	-	-	5
	Economic incentives	1	4	-	-	-	-
Biodiversity	Land use	4	6	2	-	-	2
	Land Management	6	12	6	-	-	-
	Non-agricultural land management	2	6	-	-	-	-
	Water management	-	-	-	-	-	-
	Economic incentives	-	-	-		-	-

Table 5: Measures analysed in the various studies

Measures		Classification		Number of papers
Land use		**Conversion of the different land use classes**		**47**
		Changes within each land use class		**44**
		Spatially differentiated land use changes		**9**
Land management practices	**Managerial practices**	**Input managerial practices**	**Fertilization rate**	**100**
			Nutrient management	**17**
			Livestock management	**23**
			Grazing management	**39**
			Irrigation management	**4**
		Cultivation practices	**Catch crops**	**63**
			No-till	**56**
			Conservation tillage	**39**
			Contour strip cropping	**11**
			Terrace	**15**
	Structural practices	**Filter strips**		**23**
	Spatially differentiated land management options			**5**
Non-agricultural management				**30**
Water management				**19**
Economic incentives				**18**

4.3.1 Land use

Formerly, land use change effects on water resources were largely neglected, but currently an evaluation of historical efforts to understand the current situation and predict the consequences of future land use change on water resources is considered critical (Schilling et al., 2008). During the past decades changes in land-use patterns caused by demographic, economic, political and/or cultural drivers have attracted growing concerns on the sustainability of water resources and ecosystems (Chaplot et al., 2004; Jacobson, 2011; Schilling et al., 2008; Sohl et al., 2012; YipingWu et al., 2013). A variety of studies have been done on the impact of land use changes on hydrology and water quality (Choi, 2008; Demissie et al., 2012; Schilling et al., 2008; Sliva and Williams, 2001; Woli et al., 2004; Zhao et al., 2010). Assessments of land use changes in reducing losses of nutrients from agricultural watersheds have been done through adoption of qualitative methods, historical inversion, contrast designs, and extreme land use scenario design (Li et al., 2009; Zhang et al., 2013a). These methods attempt to comprise the factors influencing spatial variation or those under policy direction. However, this is difficult and a number of studies have directly examined spatially differentiated measures, where certain measures are targeted in particular parts of the landscape. Therefore studies with different land use measures are explained here under three main categories: conversion of the different land use classes, changes within each land use class, and spatially differentiated land use changes (Table 5).

4.3.1.1 Conversion of the different land use classes

We have categorized land use into 9 classes (Table 6). Transformation of land use between land use classes are here called replacement scenarios. Under water quality scenarios one of the typical replacement scenarios is the conversion to the original (natural) land use, where all or part of the anthropogenic operations including the arable and urban land is changed into grassland, forests or wetlands (Kuhnle et al., 2008; Müller-Wohlfeil et al., 2002; Ouyang et al., 2008; Prochnow et al., 2008; Rode et al., 2009; Šileika et al., 2013; Voinov et al., 2007; Volk et al., 2009; White et al., 2010; Wulff et al., 2007; Zammit et al., 2005). Conversely under production scenarios, in extreme case scenarios some studies examined intensive land use scenarios which are defined to explain impacts of intensively cultivated arable land (Chikondi et al., 2010; Hesse et al., 2008; Mander et al., 2000; Molina-Navarro et al., 2014; Prochnow et al., 2008; Rankinen et al., 2006; Voinov et al., 2007; Weller et al., 2003), historical land use (LaBeau et al., 2014; Santelmann et al., 2004; Voinov et al., 2007; Zhang et al., 2013h) and increased urbanization (Bockstael and Irwin, 2003; Elias et al., 2013; LaBeau et al., 2014; Prochnow et al., 2008; Tu, 2009; Voinov et al., 2007; Weller et al., 2003; Zammit et al., 2005). Regarding water quality scenarios, taking arable out of production through complete or partly set-a-side (Jha et al., 2007; Kronvang et al., 1999; Molina-Navarro et al., 2014) and wetland construction (Glavan et al., 2012; Mander et al., 2000; Ouyang et al., 2013; Schilling et al., 2008; Shi et al., 2012; White et al., 2010; Whitehead et al., 2013) have been included in many studies. The most frequent being conversion from arable to pasture land or set-a-side and construction of wetlands.

Table 6: Land use classes considered in the classification of scenarios

Land use classes	Definition
Urban	Residential land use, infrastructures, commercial uses and services
Arable	Regions with permanent crops under a rotation for long period
Grassland	Areas with less than 10% tree and shrub
Forest	The lands dominated by trees and shrubs
Set aside	Left agricultural land
Barren	Lands with less vegetation than grassland.
Other vegetated land	Dry and bare land
Wetlands	Regions which have the water table above or near the land surface for most parts of the years
Permanent ice and snow	Continual cover of either snow or ice

4.3.1.2 Changes within each land use class

Changes within each land use class is mainly relevant for arable land and means changing land cover (crops) with the aim of reducing nutrient loading (Demissie et al., 2012; Hesse et al., 2008; Thieu et al., 2010; Tian et al., 2010). This may include changes in crop rotations or schemes of annual crops (Chaplot et al., 2004; Giri et al., 2014; Rivers et al., 2013), decreases in cereal production (Matias and Johnes, 2012d), conversion of pasture to annual crops (Laurent and Ruelland, 2011; Santelmann et al., 2004), changes from maize to perennial legumes (Glavan et al., 2012), conversion from paddy rice to sugarcane (Yang et al., 2011) and other land use changes such as increase of areas under maize and winter rapeseed (Huang et al., 2009) and increasing land area under corn and wheat (Demissie et al., 2012). In many studies on land cover changes the expansion of bioenergy crop production has been considered (De Girolamo and Lo Porto, 2012a; Melillo et al., 2009; Prochnow et al., 2008; Schilling et al., 2008; Strokal et al., 2014; YipingWu et al., 2013; Zhang et al., 2010; Zhao et al., 2010). A number of studies have also considered changes within forest land (Rankinen et al., 2006; Zhang et al., 2013a).

4.3.1.3 Spatially differentiated land use changes

Awareness of spatial vulnerability and recognition of 'hot spots' in the watersheds to mitigate nutrient loss imply that caution should be taken before applying a one-size-fits-all approach to water quality management (Dunn et al., 2004; Giri et al., 2014; Jiang et al., 2007; LaBeau et al., 2014; Nielsen et al., 2013; Wulff et al., 2014). Using land use change as a measure to reduce N and P load can have a unique effect on each watershed area, and there will often be a need modify the plan and area selection for implementation of measures (Nielsen et al., 2013). In fact, both the amount and the location of a specific land use and land cover conversion as well as land management changes are important factors affecting the resulting environmental outcomes (YipingWu et al., 2013). Factors that affect the differential effectiveness of measures in the landscape include physical landscape characteristics such topography/slope, soils, water flow regimes and redox conditions in various parts of the landscape as well as uneven distribution of pollution sources in the space (Arheimer and Liden, 2000; Blomback et al., 2003; Glavan et al., 2012; Page et al., 2005; Rode et al., 2009; Thorup-Kristensen et al., 2003). Therefore spatially targeting changes in land use and land cover could be valuable to increase the efficiency of mitigation measures.

Our review shows that compared with numerous studies that have considered overall changes in land use only a few studies considered spatially differentiated land use changes. Some studies have considered land use conversions to improve nutrient retention in areas with different soil types (Glavan et al., 2012; Laurent and Ruelland, 2011; Nielsen et al., 2013; Ouyang et al., 2013; Rode et al., 2009; Vermaat et al., 2012). Wetland restoration has been used as a spatially differentiated method (Glavan et al., 2012; Jiang et al., 2007; Nielsen et al., 2013). In other studies considering different slopes and therefore existence of highly erodible areas, land use measures were targeted to erodible areas with conversion of arable to forest (Molina-Navarro et al., 2014; Tian et al., 2010; Yang et al., 2011) and annual crops to perennial grassland (Jha et al., 2010c; Zhang et al., 2013a).

None of the spatially differentiated land use measures studied in the papers include differentiation due to differences in reduction of N in groundwater.

4.3.2 Land management practices

Agricultural land management practices are prominent methods in scenario studies to reduce loss of nutrients and sediments from diffuse sources within a watershed (Bosch et al., 2013; Giri et al., 2014; Liu et al., 2013). We use the term “land management practices” for the set of farmer decisions (Dedieu et al., 2008; Moreau et al., 2013) made with the intention to limit the loss of N and P into groundwater, streams, lakes and marine aquatic environments (Laurent and Ruelland, 2011). Often, but not always, these are driven by public policies. Different studies have tracked the impacts of land management practices implemented at the watershed scale (Arabi et al., 2008; Arabi et al., 2006; Behera and Panda, 2006; Bracmort et al., 2006; Chiang et al., 2010; Mander et al., 2000; Rodriguez et al., 2011; Tuppad et al., 2010; Woznicki and Nejadhashemi, 2014)

As shown in Table 5, there are many types of land management practices. They can be divided into three categories: managerial practices, structural practices and spatially differentiated options.

4.3.2.1 Managerial practices

According to the reviewed papers, for the reduction of nutrient loading via managerial practices two different kind of measures are possible (1) those related to managing inputs, which focus on reduction of nutrient inputs to agricultural land and thus reducing surplus nutrients that may leach to surface and groundwater systems, and (2) those nutrient management measures that reduce the loss of nutrient from agricultural land by enhancing nutrient retention or promotion of transformation to non-reactive forms (in particular N_2). The managerial practices affecting inputs can functionally be separated into five parts: fertilization rate, nutrient management, livestock management, grazing management and irrigation management. Fertilization rate management includes seek to minimize concentrations of nutrients at the watershed outlets by reducing overuse of fertilizers (Chaplot et al., 2004; De Girolamo and Lo Porto, 2012a; Durand, 1999; Jha et al., 2007; Müller-Wohlfeil et al., 2002; Nielsen et al., 2013; Nikolaidis et al., 1998; Parish et al., 2012; Qu and Kroeze, 2012; Vermaat et al., 2012; Zammit et al., 2005). Nutrient management contains those measures to maintain the soil nutrients and reduce the loss into the water resources (Chiang et al., 2010; Ferrant et al., 2013; Laurent and Ruelland, 2011; Richardson et al., 2008; Tzyy-woei et al., 2013). Livestock management aims to minimize or limit the losses and emissions from associated with livestock systems, in particular confined animal systems that often have high nutrient surpluses (Nielsen et al., 2013; Rankinen et al., 2006; Sattar et al., 2014; Vermaat et al., 2012; Volk et al., 2009). Livestock grazing management considers options to minimize impacts of grazing on water quality, often by managing grazing intensity (Giri et al., 2014; Tzyy-woei et al., 2013; Woznicki and Nejadhashemi, 2014), and irrigation management (Woznicki and Nejadhashemi, 2014; Yevenes and Mannaerts, 2011) aims to improve the water use efficiency for farmers, but this may also affect nutrient flows and losses. Changes in cultivation practices include catch crops (often also called cover crops) (Durand, 1999; Ferrant et al., 2013; Laurent and Ruelland, 2011; Matias and Johnes, 2012d;

Thieu et al., 2010), use of no-till to maintain better surface structure (Bossa et al., 2012; Demissie et al., 2012; Laurent and Ruelland, 2011; Rankinen et al., 2013; Santelmann et al., 2004; Woznicki and Nejadhashemi, 2014), and conservation tillage to avoid soil erosion (Giri et al., 2014; Liu et al., 2013; Tian et al., 2010; Volk et al., 2009; Woznicki and Nejadhashemi, 2014), contour strip cropping (Liu et al., 2013; Woznicki and Nejadhashemi, 2014) and terracing that also reduce erosion (Giri et al., 2014; Tzyy-woei et al., 2013; Woznicki and Nejadhashemi, 2014). The most frequent land management measures applied in scenario studies are reduced fertilization, catch crops, no-till and conservation tillage.

4.3.2.2 Structural practices

Structural changes in the agricultural landscape are mostly associated with regulating the flows of water and nutrients in the landscape. A frequently applied option to control water flows to enhance agricultural production is through drainage (tile drain or ditches) and through reducing the extent of wetlands and river banks. Such measures also reduce the retention of nutrients in the landscape, and mitigation options therefore often deal with restoring landscape features that retain water and nutrients. These options include filter strips, buffer zones, recreating meanders, on and off-stream Constructed wetlands.

A number of studies have applied filter strip and riparian buffers to the critical areas along waterways as a useful structural practice to achieve nutrient retention (Ferrant et al., 2013; Hesse et al., 2008; Laurent and Ruelland, 2011; Lee et al., 2010; Nielsen et al., 2013; Shi et al., 2012; Tian et al., 2010; Vache et al., 2002; Vermaat et al., 2012; Whitehead et al., 2011; Zhang and Zhang, 2011). Buffer or filter strips with the aim of removing water pollutant are described as riparian barriers which can be planted or native (usually grassland) that are placed between pollutant source areas and receiving waters (Blanco-Canqui et al., 2004). Filter strips are considered attractive land management options because of their low establishment costs (Glavan et al., 2012; Locke et al., 2008).

4.3.2.3 Spatially differentiated land management options

Within each catchment a combination of land use, soil type, vicinity to the irrigation sources, climate, cropping conditions and slope affect critical source areas which normally generate excessive loading of pollutants (Gaddis et al., 2014; Giri et al., 2014). The necessity of spatially differentiated measures regarding the different nutrient retention and critical source areas has been recognized in a number of studies. The uniform implementation of land management changes all over the watershed is often infeasible, costly and time consuming; therefore, appropriate application of limited sources through the right selection criteria with respect to landscape features would be necessary. A number of studies have examined different managerial options according to soil type (Rode et al., 2009), with some studies specifically considering management changes for sandy soils such as shifting from conventional to organic farming (Hansen et al., 2001; Kersebaum et al., 2006). Other studies have considered the feasibility of including cover crops into the crop rotation depending on specific soil types, cropping conditions and climatic conditions (Blomback et al., 2003; Legge et al., 2013; Thorup-Kristensen et al., 2003). Rivers et al. (2013) pointed out the importance of the location of P-management strategies along the P-transport pathway, and the effectiveness of such actions on critical watershed components has also been shown.

None of the spatially differentiated land management measures studied in the papers include differentiation due to differences in reduction of N in groundwater.

4.3.3 Non-agricultural land management

Not only agricultural lands can be important in controlling water and nutrient flows in the landscape. Also management of other types of land may serve to protect the quality of vulnerable water bodies. This is particularly the case for point sources, often linked to settlements, but may also serve to capture loadings from agricultural sources.

In a number of papers improving nutrient retention spotted through point source controls, such installation of filter systems like constructed wetlands and improved sewage treatment (Kronvang et al., 1999; Nikolaidis et al., 2009; Prochnow et al., 2008; Qu and Kroeze, 2012; Šileika et al., 2013; Strokal et al., 2014; Thieu et al., 2010; White et al., 2010; Whitehead et al., 2011; Wulff et al., 2007). Reduced P inputs to watersheds from detergents for municipal use is also considered in some of the studies (Nikolaidis et al., 2009; Qu and Kroeze, 2012; Vermaat et al., 2012).

4.3.4 Water management

Water management concerns the management of water flows and nutrient retention and transformations in the water bodies. There are water management measures that decrease nutrient pollution via establishment of eco remediation methods like vegetated drainage ditches (Glavan et al., 2012; Rivers et al., 2013; Shi et al., 2012; Tian et al., 2010), retention ponds (Glavan et al., 2012; Shi et al., 2012; Zhang and Zhang, 2011), river system rehabilitation (Hesse et al., 2008; Kronvang et al., 1999), storm water treatment (Gaddis et al., 2014), stream bank stabilization (Tzyy-woei et al., 2013), and bank erosion control (Whitehead et al., 2011).

4.3.5 Economics incentives

Economic or regulatory incentives are often needed to ensure implementation of the scenarios, and several scenario studies have included economic incentives as main drivers for determining the mix of measures implemented in the scenarios. The economic drivers include price and productivity of agricultural products such as crops and dairy products. Average crops yields and dairy productions may be used for the competitive allocation of agricultural land for various agricultural productions in such a way that nutrient loadings are reduced (Parish et al., 2012; Rankinen et al., 2006). Government financial and investment support also affect nutrient loading as economic measures through encouraging farmers to set-a-side land for lowering nutrient loads (Rankinen et al., 2006).

4.4 Temporal aspects

In addition to spatial aspects of nutrient management there are also considerable temporal issues, in particular with agricultural land management, where improper timing of nutrient applications to crops or improper timing of grazing may lead to excessive nutrient loading. Such aspects relate often to sub-optimal agricultural management that often occur in practice, but are difficult to capture properly in scenario analyses.

4.5 Climate change scenarios

Climate change has significant effects on the hydrological cycle; runoff from watersheds, river discharge, irrigation water use, future availability of water resources and also modifying the turnover and transport characteristics of water pollutants (Arheimer et al., 2012; Beyene et al., 2010; Bukovsky and Karoly, 2011; Liu and Cui, 2011). Therefore, climate change is an important factor affecting water quantity/quality, agricultural production and biodiversity. Many studies have tested scenarios related to the impact of climate change on hydrology (Ferrant et al., 2013; Nikolaidis et al., 1998; Nikolaidis et al., 2009; Ouyang et al., 2008; Rankinen et al., 2006). These studies found that the variability of streamflow is dependent on climate change. There are also a number of studies on the impact of climate change on water quality (Molina-Navarro et al., 2014; Ouyang et al., 2013; Vermaat et al., 2012; Wu et al., 2012). Considering the importance of climate change, some of the studies simulated hydrological impacts from both climate change and land use change scenarios and they found precipitation to be a dominant driver of surface water flows and nutrient loadings (Bhaduri et al., 2000; Castillo et al., 2014; Jha et al., 2010a). Others studies have considered temperature changes with unchanged precipitation (Hesse et al., 2008). Many studies have illustrated the effects of climate or land-use changes on watershed processes (Elias et al., 2013; Rivers et al., 2011; Volk et al., 2009; Zhang and Zhang, 2011). The combined effects of climate and land-use changes on water resources have also been examined using climate change scenarios corresponding to the emission scenarios and specific projection periods, most often using results of global and regional climate models driven by IPCC SRES scenarios (Bossa et al., 2012; Molina-Navarro et al., 2014; Rankinen et al., 2013; Tu, 2009; Tzyy-woei et al., 2013; Wu et al., 2012; YipingWu et al., 2013). For example Tu (2009) analyzed the combined impact of climate and land use changes, the simulated stream flows and N loads by comparison of ‘‘current rate” and ‘‘double rate” land use change scenarios, under the A1B climate change scenario for a future periods with the corresponding their current conditions in the baseline period. YipingWu et al. (2013) examined nutrient loading combining A1B climate change scenario with different land cover (absence or presence of bioenergy crops) and land use (increase of pasture and decrease of rangeland percentages). Tzyy-woei et al. (2013) designed future climate for a period combined with future land use under global food security scenario such increased arable land from current situation.

5. Models

Numerous models have been applied to predict the effects of mitigation measures on water quality often addressing the concerns of river basin management plans (De Girolamo and Lo Porto, 2012a; Matias and Johnes, 2012d; Rankinen et al., 2006; Tong et al., 2009). Models are thus tools applied for identifying pressures, evaluation of current status of water bodies (De Girolamo and Lo Porto, 2012a) , effects of policy implementation, identifying suitable management of watersheds, and estimation of efficiency of measures(Arnold and Fohrer, 2005; Cugier et al., 2005; De Girolamo and Lo Porto, 2012a; Tong et al., 2009; Vigiak et al., 2011) . The results of model assessments are used to support decision on which mitigation measures to implement (Salmon-Monviola et al., 2011; Wilkinson and Eidinow, 2008). Quantifying the impacts of different measures helps to evaluate the outcomes of different policies and also help in prioritizing among conflicting targets. Here we aimed to analyze which models have been applied in scenario systems and how applicable they are for assessment of measures for N and P loading reduction and to address issues related to nutrient loss, transport and transformation process that all affect final nutrient loadings.

5.1 Models used for assessing N and P reduction targets

This review is restricted to catchment scale models and associated economic assessment being used in the 130 selected scientific papers on nutrient mitigation measures at catchment scale. Some studies have applied conceptual models to identify the nutrient sources and transport pathways of most importance before developing quantitative models to quantify these (Rivers et al., 2013). However, quantitative assessments of the scenarios require the use of mathematical models, which may be categorized as process-based, empirical or export coefficient models (Table 7).

Process-based models use a dynamic and spatially differentiated description of the watershed to describe the hydrology and the associated nutrient flows and transformation processes (Elias et al., 2013; LaBeau et al., 2014). Export coefficient models evaluate nutrient delivery from a variety of sources based on the efficiencies of the various sources of nutrients, utilization and transport (Johnes, 1996; McGuckin et al., 1999; Young et al., 1996), and empirical models are based on statistical analyses of relationships between watershed characteristics and the nutrient loadings to the aquatic environment (Rivers et al., 2013). Since the efficiency of non-point pollution control varies over space within a catchment some studies have also considered the economic efficiency of targeting measures spatially to minimize the extent of areas affected by restrictive land use and land management practices (Hirt et al., 2012; Kuhr et al., 2013; Kunkel et al., 2008). Coupling of the models with the economic assessments provides an integrated assessment of environmental effects with production and cost concerns (Hirt et al., 2012). Most of the studies have used process-based models (75% of studies). The use of process-based models allowed a larger number of measures in the scenarios to be evaluated than the empirical and export coefficient models.

The number of papers considering most used models for different aspects is shown in Table 8. The majority of process- based models were SWAT or INCA. The export coefficient models were used in 19% of studies, mainly for scenarios that focused on P flows, and empirical models were used for a few studies with both N and P.

Table 7: Number and type of models considered in the scenario analyses

Measures		**Classification**		**Number of used models**		
				Process based	**Export - coeffi-**	**Empiri-**
Land use		**Conversion of the different land use classes**		**39** **33**	**5** **5**	**3**
		Changes within each land use class				**6**
		Spatially differentiated land use changes		**9**	**-**	**-**
Land management practices	**Managerial practices**	**Input managerial practices**	**Fertilization rate**	**83**	**10**	**7**
			Nutrient management	**7**	**6**	**4**
			Livestock management	**15**	**8**	**-**
			Grazing management	**39**	**-**	**-**
			Irrigation management	**4**	**-**	**-**
		Cultivation practices	**Catch crops**	**60**	**3**	**-**
			No-till	**56**	**-**	**-**
			Conservation tillage	**39**	**-**	**-**
			Contour strip cropping	**11**	**-**	**-**
			Terrace	**15**	**-**	**-**
	Structural practices	**Filter strips**		**17**	**6**	**-**
	Spatially differentiated land management options			**5**	**-**	**-**
Non-agricultural management				**16**	**14**	**-**
Water management				**12**	**7**	**-**

5.1.1 Process based models

5.1.1.1 SWAT

The Soil and Water Assessment Tool, SWAT was developed at the USDA-ARS (Arnold et al., 1998). It is a time continuous and semi-distributed water quality model, intended for estimation of agricultural nutrients flows, pesticides and sediments in the soil, ground water and surface water in relation to land use and land management practices. SWAT allows calculation of input, output and flows and it applied the concept the hydrologic response unit (HRU), where a given combination of soil type, land use type and a sub catchment is assumed to behave in specific way. SWAT is the most employed model for simulating the different land management and land use options and evaluating the effects of them on water quality and reduction of nitrogen and phosphorous loading in to the water resources (Alexander et al., 2001; Gassman et al., 2007). Here more studies have reported the use of SWAT for studying N than for P (Table 8). The flexible framework of SWAT is considered a key strength allowing simulation of a wide variety of measures (Liu et al., 2013), such as conversion between different land use classes (Laurent and Ruelland, 2011; Pikounis et al., 2003), changes within each land use class (Lorz et al., 2007; Weber et al., 2001; White et al., 2010) spatially differentiated land use changes (Jha et al., 2010a; Zhang et al., 2013a), changes in fertilizations rate (Lee et al., 2010; Ullrich and Volk, 2009), structural land management practices (Filter strips) (Lee et al., 2010; Zhang and Zhang, 2011), use of catch crops (Bosch et al., 2013; Rode et al., 2009), no-till (Ferrant et al., 2013), conservation tillage (Giri et al., 2014; Liu et al., 2013), terraces (Giri et al., 2014), grazing management (Bossa et al., 2012; Woznicki and Nejadhashemi, 2014) and livestock management (Glavan et al., 2012; Santelmann et al., 2004).

5.1.1.2 INCA

The Integrated Nutrients in CAtchment (INCA) model is a semi-distributed model integrating hydrology and nutrient processes (Wade et al., 2002) allows simulation of the water cycle, both nitrogen and phosphorous transformation and concentrations in soil, surface and ground water. INCA has been used widely all over the Europe as well as in Brazil, Australia and Nepal (Whitehead et al., 2011). The INCA model has been used to test some measures for N and P, for instance the impact assessment of land use conversions (Flynn et al., 2002; Rankinen et al., 2006), changes within a land use class (Farkas et al., 2013), some land management practices such as changes in fertilization rates (Farkas et al., 2013; Whitehead et al., 2013), buffer strips (Flynn et al., 2002; Whitehead et al., 2011), no tillage (Farkas et al., 2013), cover crops (Durand, 1999), and livestock management (Rankinen et al., 2006), and the implementation of water management measures (Rankinen et al., 2006; Whitehead et al., 2013). Compared with other process-based models, INCA has been more applied to study P than N flows (Table 8).

5.1.2 Export coefficient models (ECM)

The export coefficient model (ECM) proposed by (Johnes, 1996) has been used in several studies for assessing non-point source pollution (Ierodiaconou et al., 2005). The estimation of nutrient loads in any point of rivers is related to all aggregated sources containing different actions related to land use and land management (Bouraoui and Grizzetti, 2014). The limited input requirements such land use and other information has made this approach attractive as compared with more complex approaches (Johnes et al., 2007; Johnes, 1996). Generally, it applies only to the flat terrain regions with uniform rainfall, and it does not well address major changes in land use, land management and other factors (Soranno et al., 1996; Worrall and Burt, 1999). ECM has been applied to assess various measures such as different land use distributions (Johnes, 1996; Worrall and Burt, 1999) fertilization application rates (Qu and Kroeze, 2012; Vermaat et al., 2012), filter strips (Shi et al., 2012; Vermaat et al., 2012), catch crops (Matias and Johnes, 2012d), non-agricultural practices (Nikolaidis et al., 2009; Vermaat et al., 2012) and water management options (Gaddis et al., 2014; Rivers et al., 2013; Shi et al., 2012). This modelling approach is mostly applied for P load into the water bodies (Table 8).

5.1.3 Empirical models

Empirical models in this study refer to models based on statistical analyses of the relation between determining factors in the catchment and the monitored water quality. The main idea behind this kind of modelling is to put aside the actual process of pollutant migration in the surface area and calculate the output of the pollutants regarding to quality of the receiving waters (Shen et al., 2012). Empirical models need large quantities of measured data and are suitable for catchments with enough basic information, therefore they only have limited utilization in some catchments or areas outside of those for which they were developed (Shen et al., 2012). However, they may still provide satisfactory results for long-term trends of nutrient loads from agricultural catchments (Andersen, 1994; Joelsson and Hoffmann, 1998). These models have been applied in some catchments to predict point and diffuse source pollution load through evaluating different measures. For instance Weller et al. (2003) developed linear statistical model and recognized that it may effectively represent how land use changes altered water discharge and nutrient concentrations under the weather regime that was observed. Mander et al. (2000) described the variations of total-N and total-P runoff in both the whole catchment and its agricultural sub catchments with utilization of a simple empirical model incorporating fertilization intensity, soil parameters, land-use pattern and water discharge.

Table 8: Number and type of models considered for different assessment aspects

Considered assessment aspects	Number of used models					Number of paper including Economic assessment
	Process based			Empirical	ECM	
	SWAT	INCA	Other models			
N	28	6	8	3	4	11
P	17	7	-	-	13	4
N&P	29	-	3	4	8	3

5.2 Economic assessment

Literature reviews on hydro-economic modelling in context of the EU Water Framework Directive (Harou et al., 2009; Heinz et al., 2007) have demonstrated increased integration of economic assessment in hydrologic and nutrient emission models. Some of the studies applied interdisciplinary methods connecting economic and ecologic perspectives for watershed management (Kragt et al., 2011; Riegels et al., 2011; Shmelev and Powell, 2006) and others assessed water quality (Balana et al., 2011; Brouwer et al., 2008; Vinten et al., 2012; Volk et al., 2008).

A number of reviewed papers in this study considered economic assessment and modelling. Santelmann et al. (2004) applied the EPIC model (Williams et al., 1988) to calculate crop yields and using data on crop prices, this was subsequently used to estimate effects on land value. Kuhr et al. (2013) for assessment of N pollution of surface and groundwater in Germany coupled a hydrogeological model with an agro-economic model, which was a regionally differentiated agricultural sector model (Kreins et al., 2007) as a regionally differentiating agricultural sector model developed for Germany in the 1990s. This allows effects of alternative policies to be assessed. Such approaches may also be used to assess economically efficient measures of managing nutrient inputs Hirt et al. (2012).

6. Evaluation of scenario studies

Implementation of substantial changes in land use and land management practices have multiple effects by affecting agricultural production, water quality and native biodiversity. These changes may be acceptable to farmers and preferred to current trends as long as agricultural enterprises remain profitable (Santelmann et al., 2004). The result of the scenario studies through modelling provide information for the different stakeholders, e.g., farmers in the farm level management, environmental agencies, researchers and policy makers could benefit from their special knowledge of the basin and the available data. Here we aim to divide the evaluations between biophysical and economic aspects.

6.1 Biophysical results

6.1.1 Land use

Conversion of the different land use classes under different scenarios has significantly affected the diffuse source of pollution loads. Based on the reviewed papers, the increase in arable usually resulted in increased nutrient loadings. Laurent and Ruelland (2011) with the conversion of 32% of catchment area covered by temporary pastures to cereals and rapeseed reported increased nitrate flow by 18%. LaBeau et al. (2014) reported an increase of P loads associated with arable land expansion. Previous studies have shown that when the land-use changes from forest to agriculture or from wetland to agriculture, there is usually a corresponding increase in the in-stream concentrations of total N and P (Karvonen et al., 1999; Tufford et al., 1998), and land use change from arable to forest is expected to result in P and N export reductions. In this regard Zammit et al. (2005) have reported reductions of N by 50% and P by 85% from conversion to forest land. Müller-Wohlfeil et al. (2002) found a high reduction in nutrient loadings based on afforestation of 10% of the arable land, and Liu et al. (2013) also reported reduced diffuse pollution loads in the Xiangxi River watershed with more forest cover. In contrast the deforestation of catchments may lead to an increase in N and P flows. An increase of orchards with the decrease of forest area led to an increase in the potential pollution loads of N by 5% and P by 4% (Zhang et al., 2013a). Chikondi et al. (2010) planned a hypothetical 10% deforestation of catchments which led to an increase in N and P loads by 16 and 3%, respectively. Farkas et al. (2013) considered an afforestation scenario of 50% of the arable land and the result of their study led to substantial reduction in P losses. Changing from arable to grassland would reduce amounts of nutrients loads; Farkas et al. (2013) thus showed 28% reduction of P loss by converting half of the arable land to grassland. Similar results have been seen in other studies (Šileika et al., 2013; White et al., 2010).

Urbanization has also often been reported to increase the amount of N and P loads. According to Bossa et al. (2012), P and N loads are expected to increase about 4% and 12%, respectively, during the 10 years following urbanization. Elias et al. (2013) also showed increase of P and N loads caused by urban and suburban growth. Tong et al. (2009) studied the nutrients loads reduction from low-density residential land use with for example a

12% total impervious area and 10% total continuous impervious area compared with arable land and found a reduction in diffuse pollution source via low-density residential land use. Zhang et al. (2013h) also designed urbanization scenarios and the result showed 11% increase of surface run off in the related catchment area.

Combined climate and land use change scenarios have shown interactive effects on nutrients loss, compared running the scenarios individually (Molina-Navarro et al., 2014). In one study this was related to the seasonal distributions of the stream flow and N load rather than to changes in the average annual stream flow and N load (Tu, 2009). Weller et al. (2003) observed noticeable differences between wet and dry years in the responses to land use change, thus illustrating the importance of considering different weather conditions in predicting the effects of watershed changes on nutrient loads. Molina-Navarro et al. (2014) studied the effect of both arable land expansion and set-aside on N export under future climate change with possible reduced run off compared with the current climatic condition. They found that both changes increase the concentration of N in the runoff.

As mentioned above, changes within each land use class are mainly relevant for arable and mean changing land cover (crops) with the aim of reducing nutrient loads. Studies have documented strong effects of changes within each land use class, particularly arable, on N discharges (Jordan et al., 1997a, b; Liu et al., 2000; Rankinen et al., 2006). These effects depend on crop type and the timing of events. Chaplot et al. (2004) replaced corn-soybean rotation by winter wheat and found an increase if nitrate-N loads in early fall, immediately after harvest. Yang et al. (2011) with increased sugarcane in arable lands depict increased loads of N and P. In general N is more sensitive than P to changes of crop type (Hesse et al., 2008).

Targeted application of different land use measures based on the spatially varying vulnerability within catchments has been demonstrated to increase the efficiency of control measures for mitigating nutrient losses. For example Jha et al. (2010c)converted row crops to grass in highly erodible land, upper basin, and floodplain areas as spatially differentiated land use changes and reported more reduction of nitrate loads than previous status by 47%, 16%, and 8%, respectively. Yang et al. (2011), Tian et al. (2010) and Zhang et al. (2013a) considered the slope within the landscape for targeting measures for effective reduction of N, P and sediments loads.

6.1.2 Land management practices

In most of the studies which developed scenarios related to less fertilizer application, considerable decrease of N and P concentrations in targeted water bodies have been reported, often without significant effects on crop yields (Durand, 1999; Jha et al., 2007; Zammit et al., 2005). But there are some reports on increase of nutrient loads despite reducing fertilization rate, for instance Molina-Navarro et al. (2014) with the reduction of fertilizing rate in the year of rotating peas gave increased nitrate-N, probably due to enhanced biological N fixation.

The loading of N is found to be more sensitive than P to changes in fertilization regimes (Hesse et al., 2008). Although Zammit et al. (2005) found that reduction in P fertilizer application produced a linear response with respect to P export, several studies have not found such responses. Farkas et al. (2013) analyzed scenarios based on reduction in fertilizer amounts which did not lead to high reduction in P losses. Whitehead et al. (2011) defined scenarios assumed fertilizer reductions to the lower level of the recommended application rates but this did not lower P concentration and P loads; however, with some differential effects in different seasons. Therefore nutrient fertilizer reduction schemes can be considered as possible control strategies, in particular by adjusting the fertilizer rate better in time and space to the crop requirements.

There are some studies which considered scenarios assumed increased fertilizers application rates, those scenarios predicted to have minor impacts on crop yields resulted in sizeable increases in nutrient loadings; for example Jha et al. (2007) did not estimate any changes in maize yields but presented sizeable increases in nitrate-N loadings.

The necessity of increasing nutrient use efficiency in livestock production has been considered in several studies and may be achieved through appropriate feeding, manure collection, storage and application practices (Predotova et al., 2010; Rufino et al., 2007). Based on the result of a scenario study on livestock, grazing and manure management, feeding dairy cattle regarding to their requirements will enhance milk and meat production and if it is coupled with regular manure collection and measures to reduce losses from manure storages, significant amounts of nutrients are recycled to arable and may resulted substantial reductions in environmental pollution (Diogo et al., 2013).

Application of filter strips mostly showed reduction of nutrients loads. Laurent and Ruelland (2011) reported reduction in nitrate flow of 8% with filters strips, Glavan et al. (2012) also reported reduced average annual loads at the main catchment outlet for N by 21.2% and for P by 47.7%. Buffer zones have also many advantages as structural practices. They reduce the direct runoff flow velocity and filter the direct runoff (Rabeni and Smale, 1995). Tzyy-woei et al. (2013) reported only limited improvement of pollution reduction depending on the width of the buffer zone (when width of field border reaches over 10 meters) and physical characteristics of the site. In another study installation of buffer zones without agricultural use around surface water bodies resulted in nutrient concentration reduction due to decreased nutrient loads caused by a smaller fertilized area in the catchment (Hesse et al., 2008).

Some of the studied land management practices were targeted at specific locations rather than at random or uniformly across the landscape showing a greater reduction in nutrient loadings with modified land management practices placed in high source locations (Bosch et al., 2013). Rode et al. (2009) by selecting different land management options in a catchment study showed the possibility of the highest N leaching reduction by considering different soil types The result of spatially differentiated land management assessments could provide information for watershed managers to develop more appropriate incentives that would reduce costs for achieving the load reduction targets (Gaddis et al., 2014).

Including catch crops in the rotations have mostly shown reduced nutrient loadings, often by reduction N flows by up to 20% (Ferrant et al., 2013). Laurent and Ruelland (2011) and Durand (1999) found a reduction in nitrate-N flow of 11% with use of catch crops. When combining catch crops and reduced fertilization rates, Durand (1999) obtained a reduction in both concentration and N fluxes at the outlet of a catchment of 30% over 9 years of simulations.

The soil tillage intensity is considered important for controlling soil erosion, run-off and nutrient losses from arable land (Richardson and King, 1995). The use of no-tillage systems is increasingly being applied under diverse climate and soil conditions (Derpsch et al., 2010). Laurent and Ruelland (2011) estimated a reduction of nitrate-N flow of 12% with no-tillage practices and Jha et al. (2010c) also estimated reductions in nutrient loads of 0-11% for no-tillage. An important aspect of this method is the combination of no tillage with soil surface cover, in particular outside the main growing season (Lundekvam, 2007). Conservation tillage is the combination of no-tillage with crop residue management and use of catch crops. According to (Liu et al., 2013) and (Farkas et al., 2013) conservation tillage and contour strip cropping also can both reduce N and P loadings, but conservation tillage has a greater effect in controlling the losses of nutrients than contour farming(Liu et al., 2013).

6.1.3 Water management

A numbers of the studies have used retention ponds as a water management option and their results indicated reduction in sediment, P and N fluxes to the water bodies (Chikondi et al., 2010; Zhang and Zhang, 2011). Zhang and Zhang (2011) also evaluate the effectiveness of vegetated ditches and buffer zones on nutrient loss reductions and assessed the dependency of their physical dimension and vegetation cover.

6.1.4 Non-agricultural management

Usually scenarios that have included management of non-agricultural land aimed to decrease the P loads, in particular by considering the P loads from residential areas which have been reduced by measures that strip P from the waste water streams (Matias and Johnes, 2012a). A scenario modelling by (Vermaat et al., 2012) suggests that use of sewage treatment, possibly in combination with other measures would be sufficiently effective to reach current targets.

6.1.5 Combined measures

In most cases several measures are needed to achieve the target reductions in N and P loads (Hesse et al., 2008; Müller-Wohlfeil et al., 2002). This does not mean that each individual measure is not effective in its own; rather, combining measures may offer a more effective and less costly approach, in particular when it is adapted to local conditions (Tzyy-woei et al., 2013). For example Kronvang et al. (1999) utilized a combination of improved sewage treatment with 20% set-aside of arable and river system rehabilitation at the catchment scale to achieve a considerable reduction of both N (53%) and P (46%) export.

Shi et al. (2012) also recognized a great difference between the results before and after the implementation of land management practices. Qu and Kroeze (2012) with the objective of reducing nutrient loads to the coastal waters of China concluded the need for a mix of land management measures, sewage and energy use measures simultaneously addressing differences among and within catchments in hydrological conditions and sources of N and P.

6.2 Economic evaluations

To assist and ensure implementation of the scenario results, some of the studies included economic incentives aimed to identify appropriate and applicable measures in the catchments. For example Yang et al. (2011) found considerable economic benefits with a scenario that involved increased sugarcane cultivation, but this was not found applicable because of high estimation of N and P loads. Lee et al. (2010) considered four different land use management practices and found buffer zones to be unattractive due to their higher costs. Volk et al. (2009) found reducing the intensity of land use as unrealistic from an economic point of view, even though they had environmental benefits. This included reduction of arable land from 77% to 46%, increase of pasture land from 4% to 15%, afforestation from 10% to 21% and increase of protected wetlands from 0% to 9%. Vermaat et al. (2012) analyzed the feasibility and cost-efficient increase in the degree of sewage treatment and concluded that reduction of N loadings of up to 47% would be feasible. (Gaddis et al., 2014) also in order to maximize cost-effectiveness of the measures pointed the necessity of developing optimization algorithms to account for sources, neighbor effects and land use specific implementation costs.

7. Methods for scenario design

Several of the reviewed papers did not clearly describe the scenario design methods, and there is in general also a lack of information on the application of the scenario studies for use in watershed management or policy formulations. For this reason, an online questionnaire survey with 9 questions on the design and subsequent use of the scenario studies was performed through Survey Monkey by asking the corresponding authors of the 130 reviewed papers. In this regard, the methods of scenario design through a number of reviewed scientific publications and the result of the questionnaire are presented.

7.1 Scenario design methods applied in reviewed papers

The related studies on the design of land use and land management scenarios mainly adopt historical inversion, qualitative methods, the contrast and extreme land use scenarios design (Chen et al., 2009; Li et al., 2009; Yaomin et al., 2009). For instance Molina-Navarro et al. (2014) designed six scenarios based on the recent historical data of a catchment and collected the information via interviews with the local farmers and other possible management interventions of modeling interest. Ferrant et al. (2013) devised two agricultural scenarios based on historical agricultural data on the land use management practices which have been implemented in 1992, both scenarios corresponded to other possible mitigation measure in addition to the existing ones. Some of the studies designed their scenarios in collaboration with stakeholders (De Girolamo and Lo Porto, 2012a; Gaddis et al., 2014; Laurent and Ruelland, 2011; Vermaat et al., 2012) and according to current agricultural practices (Laurent and Ruelland, 2011; Zhang and Zhang, 2011). Some others used previous literatures on scenario design (Matias and Johnes, 2012d; Qu and Kroeze, 2012; Rabotyagov et al., 2010) and specific results of model-based sensitivity analyses (Matias and Johnes, 2012a). Mander et al. (2000) developed the scenarios on land use changes during the last 10 years with possible changes in hydrological regime, and possible economic development in their country. Wu et al. (2012) planned the scenarios according to the environmental databases. Glavan et al. (2012) considered interviews with the Environment Agency and local farmers to design the scenarios. There are also a number of studies which used the available policies and regulations in the context of scenario studies, for example Chikondi et al. (2010) selected the scenarios on the basis of available possibilities in the framework of the environmental policies and deforestation rate. Thieu et al. (2010) designed the scenarios by considering available options currently included in the regulation framework. Volk et al. (2009) also designed land use and management scenarios on the basis of policy instruments such as the support of agro-environmental measures by the EU Common Agricultural Policy and regional landscape development programs. Rode et al. (2009) defined the scenarios in close collaboration with agricultural agencies to ensure the design of realistic and site specific agricultural management practices which was looking for a high degree of acceptance by the farmers. Some of the studies included developments in the energy market to design agricultural practice changes in the scenarios (Huang et al., 2009). Tong et al. (2009) employed existing land-use development plans to formulate a future land-use impact assessment for the watershed and it provided a ‘snap- shot‘of the probable land-use development scenarios in the catchment.

7.2 Questionnaire survey on scenario development and use

The designed questionnaire survey included 5 main aspects:

1. The methods to define the scenarios.
2. The involvement of different stakeholders in scenario designation.
3. The presentation of the result of scenario studies to the stakeholders.
4. The effect of communication to the future land use and land management.
5. The effect of scenario studies on policy and future researches.

There were 71 respondents (55%). Not all of them replied to the questions on involvement of different stakeholders (but 52% did), on presentation of the results to the stakeholders (but 61% did), on the effect of the communication on land use and management (but the majority of 94% did), on the changing the scenario design after their studies (but 51% did), and the effect of the scenario studies on policy (but a majority of 82% did). Reports on these aspects in the published articles were not included in the statistics.

7.2.1 The survey questions

During your scenario design, was there any stakeholder involvement or participation?

Answer options	Response Percent	Response Count
Yes	52	37
No	48	34
Answered question		71
Skipped question		0

Of those who did respond, just around half of the respondents designed their scenarios based on stakeholder involvement.

Which groups of stakeholders were involved?

Answer Options	Response Percent	Response Count
Farmers	54	22
Representatives of the forestry division	15	6
Nature conservationists	32	13
Water resource managers	63	26
Fishers	5	2
Local authorities	73	30
Policy makers	42	17
Other NGOs	22	9
Other (please specify)		2
Answered question		37
Skipped question		34

As more than one tick box could be ticked, the involvement of local authorities (over two-thirds of the respondents replying local authorities, 73%), water resource managers (63%), farmers (54%) and policy makers (42%) seem to be most mentioned options amongst respondents. Only two of the studies specified other scenario design participated members as planners and a resource center.

Were the results of the scenarios presented to stakeholders?

Answer Options	Response Percent	Response Count
Yes	61	43
No	39	28
Answered question		71
Skipped question		0

Most of the respondents (61%) presented the results of their scenario studies to the stakeholders.

How were the results presented to stakeholders?

Answer Options	Response Percent	Response Count
One way communicated report	25	13
Through a workshop or seminar with stakeholders discussion	58	30
Scientific article	87	45
Published article in targeted stakeholder magazine	12	6
Presentation in a scientific conference	67	35
Personal discussion with key stakeholders and policy- makers	54	28
Other (please specify)		0
Answered question		43
Skipped question		28

As more than one box could be ticked, about 60% of the cases related to scenario work presentation to the stakeholders were done through workshops and 54% also reported personal interactions with stakeholders and policy-makers.

The last set of questions was related to the effects of the scenario studies on future policy's measures and research.

Have your study and related communications affect the land use and management?

Answer Options	Response Percent	Response Count
Yes	22	15
No	78	52
Answered question		67
Skipped question		4

In about 22% of the cases respondents reported that the scenarios have affected land use and management.

Among the reported cases on the effects of their scenarios on land use and management, we have received some explanation mentioned the results being used for changing the timing of the applied fertilizers, setting up the priorities for water quality improvement, targeting the conservation practices and planning the floodplain restoration. The others believe that the scenario communications has to some degree affected the land use and management, because they believe the actual implementation of catchment land management practices is a complex issue that moves well beyond the evidence-based science into the murky world of policy and politics. The modelling that they completed has not resulted in widespread adoption of improved catchment management practices but it has developed a much broader and more informed network of advocates for practice change.

Would you consider your study affects?

Answer Options	Response Percent	Response Count
Farm management	29	17
Watershed management	84	49
Policy	55	32
Incentives	22	13
Other (please specify)		3
Answered question		58
Skipped question		13

A larger number of respondents considered that there had been more general effects of the studies on watershed management, policy and incentives.

After your study, have you designed scenarios differently?

Answer Options	Response Percent	Response Count
With more stakeholders involvement in scenario design	17	6
Addressing other managerial options	56	20
Addressing other policy or governance structures	17	6
Addressing other drivers	11	4
Other (please specify)		3
Answered question		36
Skipped question		35

About half of the respondents considered that the experience in scenario design have led to differences in the way scenario are being designed, mostly by addressing other managerial options (55%), and with more stakeholders involvement in scenario design (17%) and addressing other policy or governance structures. About 11% addressing other drivers (not specified).

8. Discussion

The sources and flow pathways of nutrients (N and P) in agricultural catchments are very diverse, and scenarios to target nutrient load reductions therefore need to be adapted to local geographic and climatic conditions as well as to the human modifications of land use , land and water management. Despite this large variation in local conditions, the most widely used measures in the scenarios included changes in land use and agricultural land management. Major changes in land use as associated with conversion between arable and other land uses which is related to contrasting global needs for increased global production of food, feed and biofuels with the needs to protect water quality, conserve biodiversity and protect carbon stocks to reduce greenhouse gas emissions. The first objective is most readily met by expanding or intensifying arable land use, whereas the second set of objectives are best met by reducing the arable land and maintain these in forest cover or with other permanently covered vegetation (e.g., grassland). Therefore conversion between land use classes are one of the primary ingredients of scenarios studies related to non-point source nutrient pollution in agricultural landscapes.

There has also been a considerable focus on agricultural land management, in particular addressing fertilization practices, nutrient management and crop and soil management, such as use of catch crops and changes in tillage and crop residue management. All of these practices influence the source loadings of nutrients from the agricultural (arable) land. In contrast there is often less focus in the scenarios on the transport pathways in the landscape and how measures to increase retention may be adopted to protect the aquatic environments. Such measures include buffer strips and retention ponds, which have been applied in the scenarios, but there may in many landscapes be additional transport pathways through groundwater and drainage systems that should be considered in order to mitigate nutrient loadings. The objective would in many cases be to achieve effective nutrient reductions without affecting agricultural production and with as low costs as possible. To achieve this there is often a need to better understand which parts of the landscape and which agricultural systems contribute most to the nutrient loadings, and there is also a need to understand how these individual sources can best be managed, either through reducing the source loading or through enhancing the retention of the nutrients after they are lost from the agricultural systems. These aspects are currently not well covered in the published scenario studies.

A large set of scenario studies have been conducted that describe a broad range of conditions and also of changes in land use and management at catchment scale. Several of the scenario studies reviewed have involved stakeholders following a bottom-up approach (involvement of the local authorities and farmers) on local level to define the scenarios analyses. Some of them followed a top-down approach taking into account actors at larger scales (policy makers). To better account for important decision levels, top-down and bottom-up approaches should be included in a complimentary way that would allow learning between these scales. Therefore in order to build scenarios, both modeling and narrative storylines could be used to described the baseline and the challenges that provide the background for the scenario analyses. Thus the scenario building process should consider both the available spatial differentiated information and the use of participatory approaches.

Considering different spatial information could help to make consistent and cost-effective land use land management measures. Participatory scenario approaches also would be helpful to address conflicting interests and the complicated interactions between many different aspects at the catchments scale, which are important in the scenario building process.

Scenario evaluation in all different studies was carried out with a limited set of models because of the ability of those few models to estimate future effects of land use/land management options changes at catchment scales. This reduces the ability to assess the uncertainties in estimated effects of the scenarios evaluations, in particular because there is rarely more than one model used for evaluating the effects of different scenarios. There is thus a need to apply different models or even different parameterizations of the same model to assess the uncertainties involved in addressing nutrient load mitigations. This need would likely be greater if more sophisticated scenarios were developed, such as those involving spatially or temporally targeted measures.

All scenario studies have limitations as well as technical and conceptual uncertainties. It is important that such potential limitations and uncertainties are addresses in the scenario study design process and preferably also discussed with stakeholders. This may have contributed to addressing and reducing uncertainties as well and making watershed managers and policy makers aware of such issues, which in the end may contribute to more informed decisions. Such uncertainties may arise from many sources. It could be the way that current agricultural systems are conceptualized in the scenarios and models, the way mitigation measures are implemented that may not align with realistic options, the setup of models to and how they are calibrated for the current situation, and how climate change is assumed to influence hydrological and nutrient flow processes. With all of these issues there are also multiple interactions that may contribute to uncertainties, and it is very difficult (impossible) to address all such issues. Applying a conceptual model of the system in an initial dialogue between researchers and stakeholders may help to better identify and target key issues that of importance for determining uncertainties that are critical to decision making.

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The present work has been carried out within the project 'Reducing nutrient loadings from agricultural soils to the Baltic Sea via groundwater and streams (BONUS SOILS2SEA)', which has received funding from BONUS, the joint Baltic Sea research and development programme (Art 185), funded jointly by the EU and national funding agencies: Innovation Fund Denmark, The Swedish Environmental Protection Agency (Naturvårdsverket), The Polish National Centre for Research and Development, The German Ministry for Education and Research (Bundesministerium für Bildung und Forschung), and The Russian Foundation for Basic Research (RFBR).