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Consequences of future nutrient load scenarios on multiple benefits of agricultural production

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Summary

Nutrient load rates to the Baltic Sea need to be reduced. Agricultural land is regarded as the most significant contributor to the loads, and measures to reduce losses of nitrogen (N) and phosphorus (P) loads have been proposed, both for the near and far future. Agricultural production was to a large extent considered in these scenarios, whereas effects on other ecosystem services were not evaluated. The question to be answered by this report is whether the measures adopted to reduce N and P losses improve or impair multiple benefits of agriculture. The question is answered for a specific catchment (Svärtaån) located in Sweden, but the method is thoroughly described to provide a potential method to also evaluate other catchments. This work was performed as a part of the Baltic Compass project (2013).

Method

The evaluations were applied on two types of scenarios for N and P losses. The first type "Future scenarios", centred on 2020 and 2050 respectively, project effects of changes in land use, yield and management due to changes in the "surrounding world" that are regarded as "unavoidable changes" from the Svärtaån catchment perspective, e.g. climate change, world market prices, etc. The second type, "Adaptation scenarios" were evaluated by applying changes to agriculture practices (best available practice "BAP" measures) so as to reduce the nutrient loads of the Future scenarios to levels set by today's environmental targets.

These scenarios were then evaluated for six multiple benefit (MB) categories: greenhouse gas (GHG) emissions, biosecurity, biodiversity, cost effectiveness, soil quality and water protection. The question on whether these ecosystem services (MB-categories) were improved or impaired in the future was then answered by first evaluating, as far as possible, a well defined and predictable MB-factor (MBf) for each category. Changes to these MB-factors (e.g. soil organic matter) were then the base for evaluations of changes to the wider concepts of the categories (e.g. soil quality). The MB-categories were evaluated in terms of an index (MBi) between zero and ten, defined within each MB-category as compared with the Current situation centred on 2005.

Whereas the boundaries of the scenarios were quite well defined, by means of their inputs on the environmental conditions and agricultural practice at the field level, and the outputs on N and P leaching from the field and in the outlet of the catchment, the boundaries of the MB-categories were vaguer. An exception was the GHG emission that basically was evaluated as a function of the scenario influence on soil mineral N content. The biosecurity category was defined as the consequences of pathogen leaching from the field to the surrounding water for animal and human health, and biodiversity as the improvement in biodiversity and landscape. Cost effectiveness was defined by a single value composite of the changes to income for landowners/farmers, land values, and transaction costs. Soil quality was evaluated in terms of changes to soil organic matter (SOM) and its effects on erosion, nutrient runoff and its capacity to sustain plant productivity. Water protection, finally, was evaluated as the relative difference in nutrient loading due to the changes of measures, land use and climate of the Adaptation scenarios.

The evaluations of the changes to the multiple benefits were based on expert judgements and fully transparent methods were used only in a few cases. To improve the transparency, however, the experts provided written descriptions of their evaluations.

Site

The scenarios were evaluated in the Svärtaån catchment, the outlet of which is located 100 km south of Stockholm (Sweden) just north of the city of Nyköping. The catchment area is rather small (372 km^2 or 37.2 kha) and mainly forest (ca.55 %). The fraction of agricultural land is around 25 %, of which about half is classified as nitrate vulnerable zones. Pasture and leys occupy 40 % of the agricultural land and in the arable fields (i.e. excluding pasture) cereals occupy 40 % with primarily winter crops. The input of fertilisers per hectare in the total catchment area is 18 kg N/ha/yr, while crop productivity in the terms of N yield is 17 kg N/ha/yr. The corresponding values for the arable area are 92 and 87 kg N/ha/yr, respectively. Silty clay loam is the dominating soil texture.

Scenario factors

The "Future scenarios" and "Adaptation scenarios" were determined by three research and stakeholder groups, the core being the modelling group applying the nutrient load simulation models. The input/output group estimated and provided input data of the models for the future conditions on crop choice, biomass yields, sowing and harvest dates and climate change. These data factors, together with the BAP measures to reduce the N and P leaching provided by the stakeholder group, constitute the input factors of the nutrient load scenarios. The MB evaluations were mainly based on changes in these scenario input factors compared with the "Current situation" (centred on 2005). The adapted measures to be evaluated were specific values for reduced fertilisation, spring cultivation instead of autumn cultivation, catch crop, buffer-zones, structural liming, constructed wetlands, sedimentation ponds and liming in tile drains. Also scenario output factors were used in the evaluations, although to a minor extent except for the GHG emission evaluations being based on the predicted changes in N mineralisation.

Effects on multiple benefits (MB)

In the near Future scenario, 2020, the climate change was small and not considered significant for MB evaluations, although crop yields increased resulting in increased N fertilisation to achieve N concentration of crop yields similar to the Current situation. This was expected to increase GHG emissions from fields and to have a strong negative effect on the GHG emission category. On all the other MB-categories the near Future scenario caused a slight positive change, mainly due to increased yields (biodiversity and water protection were not evaluated for the Future scenarios). The same results were achieved for the 2050 Future scenario, except that the effect on biosecurity was evaluated to be non-significant due to positive effects of changes in animal density being counteracted by negative effects of heavier rains during wintertime due to climate change.

The negative effects of the "unavoidable" changes on GHG emissions were reduced by the Adaptation scenario including reduced N fertilisation whereas increased spring cultivation and catch crops had no effects. In three cases the BAP measures had a negative effect; spring cultivation, catch crops and buffer-zones made agricultural production less cost efficient for the farmer. The most positive effect on biosecurity was caused by buffer-zones, and in 2050 by sedimentation ponds. For biodiversity the positive effects were generally lower than for the other MB-categories, but spring cultivation, buffer-zones and wetlands were evaluated to influence it slightly more positive than the other measures. The cost efficiency of agriculture was evaluated to be strongly positively influenced by adapted N fertilisation and liming. Liming also had a positive influence on soil quality. Spring cultivation was the measure most positively influencing water protection, and was also positive for soil quality, especially in 2050. In general the influences of the BAP measures were rated similarly for 2020 and 2050, with a few exceptions where the influences were more positive in 2050 (see Table 1).

Table 1. *Qualitative effects of 2020 scenario factors on the Multiple Benefit Categories. +/0/- = positive/no/negative effect; Quantitative evaluations are given in Table 4.7.*

Scenario factor	*GHG*	*Biosecur.*	*Biodiver.*	*Cost eff.*	*Soil qual.*	*Water prot.*
Future scenario	-	+		+	+	
Adapted N fertilisation	+	0	0	+	+	+
Adapted P fertilisation		0	0	+	0	+
Spring cultivation	0	+	+	-	+	+
Catch crop	0	+	+	-	+	+
Buffer-zones		+	+	-	+	+
Structural liming		+	0	+	+	+
Constructed wetlands		+	+	+	0	+
Sedimentation ponds		+	+	0	0	+
Liming in drains		0	0	+		0

Conclusions

The answer to the main question of whether the measures adopted to reduce N and P losses from agricultural fields improved or impaired multiple benefits of agriculture, seems to be that they improved. Most of the BAP measures had a positive influence on most of the MB-categories, the clearest exception being liming in tile drains which only improved the cost effectiveness. Except for water protection, the biosecurity MB-category was positively influenced by the most measures (6 out of 9) and with soil quality the next highest (5 out of 9). It is less clear how the absolute values evaluated for the MB index, can be compared among MB-categories. Among the BAP-measures, structural liming was the most positive measure (summing up the indices of all MB-categories), followed by buffer-zones and spring cultivation the next, although the cost effectiveness of these latter measures was evaluated to decrease. In the “unavoidable” future (Future scenarios) GHG emissions strongly increased. The only measure that mitigated that effect was reduced N fertilisation, providing more arguments for applying reduced fertilisation than only to reduce leaching.

The evaluations of the MB-category “water protection”, which in this report were based on expert judgement, suggested almost all the BAP measures to be positive, i.e. the same measures as the model assessments of the Adaptation scenarios evaluated the best to reduce the N and P leaching in the Svårtaån catchment. However, when it comes to the rating among the measures the methods were less coherent. This indicates both discrepancy and agreement between the two evaluation methods used (simulation models and expert judgement, respectively). Otherwise the uncertainties of the evaluations were not addressed in this study, implying that its results should be used with care and preferably compared with similar other studies when available.

Future work
The evaluations of this study were based on expert judgement, which might give good results, but cannot be regarded as fully scientific as this method is not transparent and testable against observations. The reason for using expert judgement was the lack of transparent predictive methodologies that have been tested scientifically, and the availability of input data to feed such models. Hence, there is a need to develop such predictive models. Such methodologies might allow for comparing the single measure effect with its marginal effect when applied together with other measures. It would also allow for assessing the uncertainties of the evaluations, which were not addressed in the current study.

Time scales of the predictions differed between MB-categories. The GHG emission assessments were basically calculated by a function that was regarded to reflect changes due to climate change predictions for 2050, which in turn were basically consequences of physical and thermodynamic laws response to increased greenhouse gas concentrations in the atmosphere. The cost efficiency evaluations were based on assumptions of prices, for which persistent general functional rules similar to those of the thermodynamics were lacking, and regarded basically impossible to predict for more than a few years. However, the long term perspective was to some extent considered by means of evaluating changes in land value, but in general these differences in time scales were combined in a vague way. Research is needed to integrate these time scales. For instance, how should we weight the evaluations of different multiple benefit categories against each other depending on their time horizons? Cost efficiency is probably a dominant category in the short term but provides quite uncertain results in the long term, compared with the predictions based on natural laws on mass and energy balances etc., e.g. GHG-emissions and soil quality.

1. Background

The nutrient losses from land to the Baltic Sea are too high and need to be reduced to improve its water quality (HELCOM, 2004; 2011). Agricultural production contributes with a substantial part of the nutrient loads and hence its practice needs to be controlled to achieve the environmental goals. The agricultural practice is mostly adapted to production goals in terms of providing agricultural products cost effectively. However, there are also other concerns of agriculture and it is a key issue to evaluate how modifications of practice to reduce the nutrient loads influence several beneficial factors of agriculture. The evaluation of whole cropping systems is quite complicated and includes processes on different scales and of different character. There are advanced methods trying to integrate different processes into common indices, e.g. for economic, social and environmental sustainability (cf. Sadok *et al*. 2009), and methods integrating management options to optimise single farm productivity (cf. Giller *et al*. 2011 for African agriculture). In our study, however, we do not evaluate the sustainability explicitly, and not specific farm types. Instead we evaluate changes to benefits of agriculture due to the manipulation of the system on a catchment scale. We evaluate each benefit category of agricultural production separately. To enable a comparison, although vague, between the different categories we assess an index with a common scale; zero being a strongly negative, and ten a strongly positive change to the category concerned.

This work evaluates the consequences of future nutrient load scenarios on agricultural production in a specific catchment. The evaluation is part of a larger scenario work within the Baltic Compass project (2013). In the framework the inputs of the nutrient load model have been categorized into two groups depending on disciplinary character and influence on the scenario work (Figure 1.1). (i) Exogenous inputs are climate etc. (environmental conditions) and land use, crop potential yield etc. (ecosystem services) that are not under the control of the stakeholders actions at the catchment scale. These inputs are primarily assumed to be independent of the scenario output and regarded “unavoidable” from the catchment perspective. (ii) Endogenous inputs are the best available practices (BAP) and can be modified by stakeholders. These inputs will be modified if the results are not satisfactory; hence these inputs interact with the scenario outputs.

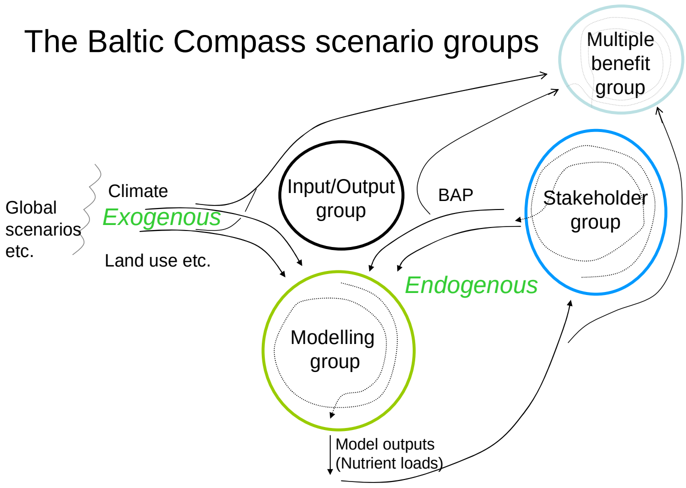

Figure 1.1. *Flow of information between groups in the scenario work of the Baltic Compass project (2013; Henrik Eckersten, Staffan Lund, Uppsala 2011-09-30)*

Four types of assessments constitute the whole scenario work starting from the "Current situation" simulating present observed conditions. Then scenarios are constructed by introducing changes to the model inputs of the "Current situation". First the exogenous inputs are modified to create an "unavoidable" "Future scenario". Then the endogenous inputs are changed on top of the "Future scenario" to create the "Adaptation scenarios". At last the influence of these scenarios on Multiple Benefits of agricultural production is evaluated. In summary the following assessments are made in the scenario work:

a) A **Current situation** for the monitored reference period (centred on 2005) for which the model assessments have been compared and adjusted to observations.
b) **Future scenario 2020** and **Future scenario 2050** using the proposed changes of the exogenous inputs (changes in land use and climate due to inevitable changes in the future due to changes in the surrounding world).
c) **Adaptation scenario 2020** and **Adaptation scenario 2050** using, in addition to the exogenous inputs of the Future scenario, changes in BAP measures as proposed by the Stakeholder group
d) **Multiple benefits evaluations** of the Adaptation scenarios.

The latter evaluation (d) is the topic of this report, whereas (a-c) are background information provided by Blombäck *et al*. (2013), who made the scenario work in the following steps: (i) The "Current situation" and (ii) "Future scenarios" as described above; (iii) Stakeholders suggest measures to be taken to fulfil environmental and production goals; (iv) The modellers interpret and apply these measures on top of the Future scenarios, resulting in the so called "Adaptation scenarios". Points iii and iv are made in loops.

Then the changes of inputs/outputs factor of the Adaptation scenarios, compared with the Current situation, are evaluated for their effects on Multiple Benefit factors and categories. The work presented in this report concerns this last task, i.e. to evaluate the consequences on MB-factors of the scenarios that already have been done.

The Current situation simulation, which was the base for all the following scenarios, was tested against observations over a long period (ca. 20 years as concern climate). Hence, in this report the year notations 2020 and 2050 represent average conditions during long periods centred on these years. The aim of this study is then to evaluate the effects of the changes added to the Current situation (changes that result in the Adaptation scenarios) on selected Multiple Benefit categories.

Author contribution

Dennis Collentine: Cost effectiveness; Henrik Eckersten: Editor, general parts and soil quality; Anna Norman Haldén: Biosecurity; Jakob Ryd Ottoson: Biosecurity; Eva Salomon: GHG emissions; Sofi Sundin: Editor and soil quality; Sirkka Tattari: Biodiversity and water protection; Judith Braun: Soil quality; Mikko Kuussaari: Biodiversity.

2. Introduction

Six multiple benefit (MB) categories, which were expected to be influenced by the scenarios and to be of common interest to society, were selected. As a basis for selecting MB-categories, the concept "Ecosystem services" was used. These services could be defined as the benefits people gain from ecosystems (MEA, 2005; Schröter *et al*., 2005) and be categorized as belonging to either of four sub-groups: provisioning services such as food and water; regulating services that affect climate, floods, disease, and water quality; cultural services that provide e.g. recreational benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling (MEA, 2005). In the agricultural ecosystem the provisioning service is the most obvious by means of providing food. However, this service is in turn dependent on supporting services, e.g. a managed meadow with high biodiversity can enhance primary production of fields and bring recreational services as well. Also other factors, such as monetary profitability are important factors to consider understanding, predicting and controlling agriculture. In our study six MB-categories were selected (emission of greenhouse gases (GHG), biosecurity, biodiversity, cost effectiveness, soil quality, and water protection) of which most are ecosystem services. The method of evaluation was largely based on expert judgement due to both practical and theoretical limitations. Of this reason the selection of categories was limited by the topics that the available expertise and evaluation methods covered (Baltic Compass project, 2013). The evaluations were expressed in terms of a dimensionless index ranging between very strong positive and negative impacts on the category concerned, and to a minor extent expressed in terms of observable physical units, e.g. soil N and soil organic matter as used in LCA analyses (e.g. Roer *et al*., 2012, for a number of cropping systems in Norway).

The boundaries of the evaluations were set by the scenario inputs, i.e. to the changes in environmental conditions and agricultural practice applied to the field. Then the outputs of the scenarios set the next boundaries in terms of the nutrient losses from the fields (leaching and crop harvest), and on the catchment level in terms of nutrient loads in the outlets. The boundaries of the MB evaluations of this study were then set differently for each MB-category (see the section on definition of multiple benefit categories below).

2.1. GHG emissions

In Sweden about 14 % of greenhouse gas (GHG) emissions are estimated to originate from agricultural production. However, concerning emissions of nitrous oxide (N_2O) and methane (CH_4) agricultural production is the main source. These gases have a much higher greenhouse effect than carbon dioxide (CO_2) per kg gas emitted. One kilo of CH_4 corresponds to 21 kg CO_2-equivalents and one kg of N_2O corresponds to 310 kg CO_2-equivalents (IPCC, 2007). Measures to mitigate GHG emissions from Swedish agriculture needs to include further improvement of efficiency concerning choice of feed and feed utilization, N fertilizers and N utilization in crop production, less amounts of input with goods and services, more high yielding crops, and increased productivity in dairy and beef production (SCB *et al*., 2012).

2.2. Biosecurity

Intensified animal production is likely to cause excess manure on the farm level and to be associated with higher disease prevalence. In case of also more intensive precipitation, there will be an increased probability of disease transmission from animal farms to the water environment, e.g. via land application of manure and animals on pasture, with consequent risks for animal and human health. Animal manure can contain disease causing microorganisms (pathogens) that can be transmitted between farms and to humans via irrigation, bathing and drinking water. Of potential zoonotic[1] pathogens in manure five are known to frequently cause illness worldwide; parasitic protozoans *Giardia* spp. and *Cryptosporidium* spp. and bacteria *Salmonella* spp., *Campylobacter* spp. and verotoxin producing *Escherichia coli* (VTEC/EHEC) (Dufour *et al*., 2012). All these agents have been associated with cattle faeces, whereas the main risk from poultry manure is campylobacter and salmonella. Pigs can be infected with salmonella but the main zoonotic risk is probably the emerging Hepatitis E virus (genotype 3) which can frequently be detected in piglets (Widén *et al*., 2011).

Yearly an estimated 10^{13} kg of manure is produced (worldwide), the main part emanating from cattle (57 %), followed by poultry (16 %), human (14 %), sheep (8 %) and pig (5 %) faeces (Dufour *et al*., 2012). Food- and waterborne diseases are costly for the society and can cause individual suffering. In 2005, manure contaminated irrigation water caused a lettuce-borne EHEC outbreak in Sweden leading to 117 cases, out of which 17 were severe, needing hospitalization (Söderström *et al*., 2008). Disease outbreaks can be costly for the producer and the society, but probably only reflect the tip of the iceberg in terms of total disease transmitted from food and water. A surveillance study in Uppsala showed that the majority of food borne disease was due to single rather than outbreak cases (Lindqvist *et al*., 2001).

[1] A zoonosis is a disease that can be transmitted from animals to humans.

2.3. Biodiversity

Agricultural intensification and loss of open semi-natural farmland habitats has caused large-scale losses of farmland biodiversity (Pitkänen and Tiainen, 2001; Krebs *et al*., 1999). Indicators of the state of farmland biodiversity such as the area of semi-natural grasslands and the number of threatened farmland species have shown that farmland biodiversity is declining (Luoto *et al*., 2003; Kleijn *et al*., 2011), Also the grassland specialist butterflies have declined (van Swaay *et al*., 2006; Kuussaari *et al*., 2007). Measurement of changes in biodiversity may be very demanding. For instance, the impacts of changing farming practices on biodiversity may be weak and thereby difficult to detect. In addition, species typically react to environmental change with a time delay (Kuussaari *et al*., 2009). Therefore, it may take several years before the positive impacts of beneficial changes in farming practices can be seen as increasing biodiversity. According to Kuussaari *et al*. (2004) some of the nationally useful biodiversity indicators may be too crude measures for detecting changes at smaller spatial scale. Therefore there is a need to monitor the effectiveness of current agri-environmental measures based on field studies and develop farmland biodiversity indicators also at a smaller scale. The key factors needed to take into account are (i) the amount of variation in plant, insect and bird biodiversity in ordinary farmland, (ii) the factors affecting species diversity at different spatial scales, and (iii) the relationship between landscape structure and biodiversity. The biodiversity effects are not seen immediately after the measurement has been implemented and therefore there is a time lag until the measurable effect can be seen.

2.4. Cost effectiveness

A comparison of the costs between alternative scenarios is determined by the change in the use of resources. In a cost-benefit analysis the change in resources would be associated with the change in benefits. However, in a cost effectiveness type of analysis as in this study, this change is only valued as the resource use for one alternative compared to another. For the type of measures to be evaluated this is the change in income for the farmer/landowner as a measure for the net resources used in moving between alternatives, the change in the value of farmer/landowner capital assets (land) and the transaction costs associated with the measure.

2.5. Soil quality

Soil quality is often evaluated in terms of how well the soil serves the crop growth. The soil organic matter (SOM) is regarded an important component for this (Bot and Benites, 2005). Most of the positive effects of SOM result from an improved soil structure derived from the microbial transformation of organic matter (Tate, 1987; Bohn *et al*., 2001), and as being an energy source for microbes in the nutrient mineralisation process. Improved soil structure, maintains tilts and reduce runoff and erosion. SOM originates mainly from plant residues and contains all of the essential plant nutrients (Bot and Benites, 2005); SOM supplies nearly all the nitrogen (N), 50 to 60 % of the phosphorus (P), about 80 % of the sulphur (S), and a large part of the boron (B) and molybdenum (Mo) adsorbed by plants in unfertilized soils (Baldock and Nelson, 2000). Soil organic carbon (SOC) is the main fraction of SOM. It accounts for on average 58 % of SOM (Andrén *et al*., 2008) and is widely accepted as a major factor indicating the overall health of soils. The evaluations of soil quality in this study are based on a literature study by Braun (2012).

2.6. Water protection

Monitoring of agricultural impacts on the chemical quality of surface and drainage waters can serve many purposes including determination of fate and transport of water, definition of nutrient vulnerable areas, evaluation of effectiveness of various agricultural measures, and validation and calibration of models to local conditions (Clausen, 1996; USDA, 2003). Assessment of diffuse pollution from agriculture can usually be carried out on three scales: plot, field and/or small catchment scale. The mitigation measures decreasing the runoff of solid matter and nutrients from field cultivation can be divided into measures taken on the field, at the edge of the field and outside the field. As for the measures taken on the fields, fertilization levels of phosphorus and nitrogen have generally decreased significantly. At the same time the total area plowed in autumn has decreased in some areas in the Nordic countries and been replaced by reduced tillage. Although shown to reduce, especially erosion and particulate phosphorus runoff but also the runoff of total nitrogen (Puustinen *et al*., 2005; Bechmann *et al*., 2009; Turtola and Paajanen, 1995; Eltun *et al*., 2002), not all measures have been applied in the Svärtaån catchment. The problems related to dissolved phosphorus runoff, especially from fields with soils rich in phosphorus, still call for separate solutions, e.g. reducing the overall P content of fields.

The reduction in nutrient load achieved by buffer-zones depends not only on the extent of the measure itself but also on the other, on-field measures implemented on the portion of the field remaining in cultivation. The efficiency of buffer-zones is better for erodible fields with high slope steepness. The efficiency of wetlands depends on how much field area is included in the upstream catchment area and what is the area of the wetland in relation to the catchment area. The total effect of wetlands and buffer-zones is typically less than that of the measures taken on the fields, since the latter can be applied to large number of fields.

The estimations of changes in agricultural nutrient loads in water bodies involve much uncertainty and not all of the changes can be measured with direct monitoring methods. Therefore, also models have been utilized to assess the efficiency. In reality the nutrient load from agriculture will start to decrease noticeably only after several different measures are implemented on a wide range. The smaller the proportion of cultivated fields in the catchment area, the harder it is to perceive significant changes in load levels on the catchment scale.

2.7. Objectives

The objective of this study is to evaluate the effects of adaptation measures, proposed to reduce nutrient losses from agricultural land, on multiple benefits of agriculture, in terms of a case study for the Svärtaån catchment. The effects of the measures are evaluated for differences in measures and nutrient and water losses between the “Adaptation scenarios” (under future conditions) and the “Current situation” (a well-defined period with available observations). The multiple benefit categories are selected to be of large importance to agricultural production, and feasible to evaluate in terms of available evaluation methods and information. Most categories are related to environmental impacts, but also cost efficiency is evaluated. Agricultural production is not evaluated in this study as it was considered in the selection of measures for the Adaptation scenarios.

3. Material and Methods

The input of the Multiple Benefit (MB) evaluations were (i) changes in climate and land use of the Future scenarios, (ii) adaptation (best available practice "BAP") measures proposed by the stakeholders for the Adaptation scenarios, and (iii) the outputs of the scenarios (e.g. changed nutrient load). From this information the changes in multiple benefits between the Adaptation scenario and the Current situation were evaluated. The evaluations were made separately for each input factor. The effects of changes in climate and land use were evaluated separately by comparing the Future scenario with the Current situation.

The effects of each scenario factor were expressed in terms of an index ranging from 0 to 10. The effects were presented separately for each scenario factor as there was no well defined method to integrate them to an overall effect on the MB-index concerned. The input information needed for the MB evaluations were taken from other publications (Blombäck *et al*., 2013), and in some cases, like climate and land use changes, described in detail in the Appendix 2 and 3. The best available practice (BAP) measures are described in the Result section.

3.1. Svärtaån site description

The MB evaluations were made for Adaptation scenarios of the Svärtaån catchment in Sweden, latitude ranging ca.58.8 - 59.0°N, and longitude ca.16.9 - 17.3°E (Figures 3.1a-b). Basic information about the catchment is given in Blombäck *et al.* (2013). Here the site is presented briefly.

Figure 3.1a. *Sub-catchment of Svärtaån (Photo Judith Braun, 29 August 2012)*

Figure 3.1b. *Two step ditches in a sub-catchment of Svärtaån (Photo Judith Braun, 29 August 2012)*

The total area of the Svärtaån catchment is 370 km^2 (37 kha), where 93 % (345 km^2) is land and 7 % (25 km^2) water surface. Of the land area about 25 % (ca.9000 ha = 90 km^2) is used for agriculture of which most (ca. 7500 ha) is used for crop production and the rest for pasture. About 55 % of the catchment is forested, and the rest is categorized as other open land (12 %) and urban area (less than 1 %). Cereals occupy ca.40 % (winter cereals are slightly more common than spring cereals) of the total agricultural area and cultivated leys ca. 25 %. Fallow covers about 15 % and the rest of the agricultural land is used for other crops (7 %) and extensive leys (14 %) (Brandt *et al*., 2008). The main soil type of the agricultural area is silty clay loam (80 %) and the rest mainly silty loam. Some areas with clay loam also exist. The majority of the soil (ca. 85 %) has a high soil P concentration (ca.1.4 g P (kg soil)$^{-1}$) in the top 30 cm and 95 % less in deeper layers (Table 3.3a; Brandt *et al*., 2008). Erosion sensitive agricultural land (0 – 50 m from watercourses) is divided into three slope classes: 1.4 %, 2.6 %, and 4.7 %, respectively. About one third of the area is in the highest slope class (Johnsson *et al*., 2008). The average fertilisation rate is 92 kg N/yr per hectare field (haF) of which 79 kg is applied as chemical fertiliser. The average N yield is 87 kg N/haF/yr.

3.2. Definitions of multiple benefit categories

The multiple benefits are divided into six categories (MB-categories): Greenhouse gas (GHG) emissions, Biosecurity, Biodiversity, Cost effectiveness, Soil quality and Water protection. A specific category is regarded to partly be abstract, not necessarily possible to relate to precise observations, and evaluated in terms of a dimensionless index (MB-index). By having a common scale for large positive and negative effects, this index is potentially comparable among categories. The MB evaluations, however, starts by evaluating a better defined and possibly observable factor, a so called Multiple Benefit factor (MB-factor) and are expressed in category specific terms. The effect on the MB-factor is thereafter translated into the effect on the MB-index (for definitions see Table 3.2).

3.2.1. GHG emission

The MB-factor of GHG emissions was defined as the difference in mineral N in field at risk to be lost as gaseous, which was calculated from the difference in net input to the soil mineral N pool (per hectare of arable land) between the Adaptation scenario and the Current situation. This means that an estimate of mineral N in soil of the Current situation is used as a base, and that the change to this value is assessed for each BAP measure separately. Changes in BAP measures proposed to reduce phosphorus losses are regarded less important for GHG emissions and not evaluated.

3.2.2. Biosecurity

The term biosecurity is widely used but varies between sectors and countries. The Food and Agricultural Organization of the United Nations (FAO) has a wide definition of biosecurity as: "…a strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) that analyse and manage risks in the sectors of food safety, animal life and health, and plant life and health, including associated environmental risk. Biosecurity covers the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of genetically modified organisms (GMOs) and their products, and the introduction and management of invasive alien species and genotypes. Biosecurity is a holistic concept of direct relevance to the sustainability of agriculture, food safety, and the protection of the environment, including biodiversity." (www.fao.org).

Farm biosecurity refers to all efforts undertaken to prevent introduction of pathogens to the farm, to prevent the spread of disease within the farm, and to prevent pathogens from leaving the farm (risk of disease transmission via the environment). The MB-factor of the biosecurity was defined as reduced pathogen leaching from the field to the surrounding water. This is important since the potential for further transmission of diseases from water is substantial with many different exposure routes for humans and animals. The biosecurity evaluations in this report put its main focus on effects inside catchments, *i.e.* mainly at the field level but also as regards constructed wetlands on the sub-catchment level.

3.2.3. Biodiversity

In the MB evaluations of biodiversity several different factors were considered: (i) how well the goals of the measure focus on enhancing biodiversity and how the briefing is done, (ii) in what way the effect of the measure settles in the agri-environment e.g., field, edge of the field, agricultural biotope, applicability in the farm, and (iii) how the measure affects species diversity. The evaluations were based on a Finnish study that besides of a literature review, also monitored birds, butterflies, vascular plants and bees in randomly selected 1 km^2 grid squares within agricultural areas (Kuussaari *et al*., 2005; Aakkula *et al*., 2012).

3.2.4. Cost effectiveness

The MB-factors for cost effectiveness were evaluated for each of the proposed measures with respect to three economic effects; (i) change to farmer/landowner income, (ii) change in land value and (iii) transaction costs. The change in farmer/landowner income is a proxy for the net value of resources used when the measure is implemented; this is a short run effect. The second effect considers the changes which may be caused by the capitalization of the measure in land values; this is a long run effect. Finally, transaction costs for information, administration, legal services, and monitoring/reporting associated with the implementation of each measure were considered.

3.2.5. Soil quality

Soil quality is a wide concept and defined by the Soil Science Society of America (SSSA) as: “the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation” (Karlen *et al*., 1997). In our case, the soil quality as a MB-category was based on the SSSA definition but defined stricter to the field conditions. The MB-factor was defined as the soil organic matter content (SOM). SOM is regarded an important factor for soil quality, as higher SOM levels improve soil structure in terms of aggregate size and stability, infiltration and aeration which lead to higher microbial and fauna activity, more nutrients available to plant growth and higher root biomass which improves porosity and, after harvesting the crop, is available for decomposition. Those factors improve the functioning of the soil to sustain plant and animal productivity. Lower SOM contents lead sooner or later to a compacted soil inducing erosion and nutrient runoff (N and P) and to an environment not suitable for plants to develop properly (Braun, 2012).

3.2.6. Water protection

The MB-factors for water protection were evaluated based on the analysis made as part of the Finnish Agri-environmental programme for the period 2000-2006, in which several experts evaluated water protection measures applied in field experiments made under Finnish conditions. Most of the data available for assessing their efficiencies in reducing nutrient losses from agriculture were available from late 1990´th up to present time. In the first evaluation phase, the effect of the measure was assessed in comparison to a reference situation, characterised by the dominating cultivation practice in the area. In the second phase, factors such as the extent of the measure as well as the quality of the measure were taken into account. The experts evaluated what extra benefits could be achieved if the measure would be applied widely and if it could be improved with new technology.

Table 3.2. *Definitions of the MB-factors (MBf) and the MB-index (MBi)*

Multiple Benefit category	***Definition of Multiple Benefit factor and index***
GHG emissions	*MB-factor:* The difference in mineral N content of a hectare of arable land between the Adaptation scenario and the Current situation. *MB-index:* Mineral N changes are graded in steps of 5 kg N/ha/yr.
Biosecurity	*MB-factor:* Reduced pathogen leaching from the field to the surrounding water *MB-index:* Consequences for animal and human health.
Biodiversity	*MB-factor:* Change in biodiversity (general assessment). *MB-index:* Improvement in biodiversity and landscape
Cost effectiveness	*MB-factors:* Changes in income for landowners/farmers, land values, and transaction costs. *MB-index:* Single value composite of the three MB-factors being an indicator of the expected economic impact both in the short and long run of the measures evaluated.
Soil quality	*MB-factor:* Changes in soil organic matter content (SOM). *MB-index:* The capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant productivity, and maintain or enhance water quality. Both MBf and MBi refer to an “average agricultural soil” of the catchment.
Water protection	*MB-factor:* The relative difference in nutrient loading between the Adaptation scenario and the Current situation. *MB-index:* Nutrient reduction, 5 class evaluation

3.3. Scenario factors

The Scenario factors evaluated were both inputs (climate, land use, BAP measures etc.) and outputs of the scenarios. The changes in the factors that were a base for MB evaluations are presented in Tables 3.3a-b (see also Appendix 2 and 3), or given in a form from which the changes can be derived. The scenario factors used were taken from Blombäck *et al*. (2013), however, the information might differ from what we used as their final scenarios were not available for our MB evaluations. It should be noted, though, that in a few cases these scenario factors have not strictly been used as a base for the evaluations, because the expert have found other bases for the evaluations more appropriate. For instance any effect of liming on crop yield have not been considered in these scenario factors, but by some experts assumed to increase yield (see further the Result section).

Table 3.3a. *Scenario input factors of Svärtaån. X is a scenario factor identifier used among different scenario works. All differences are given in relation to the Current situation unless specified. Data for Current situation are absolute values. (Data from Blombäck et al., 2013). The unit ha refers to hectare arable land (haF) or hectare agricultural land (haA).*

X	Scenario-Input-Factor	Current situation	2020	2050
	Inputs of Future scenario			
	Climate (monthly range)	-3°C January +17°C July	T: -0.1 to +0.5°C Prec: -10 to +10%	T: +0.3 to +2.1°C Prec: -5 to +25%
	Land use	[d]	More grass	More grass + maize 2%
	Yield	87 kgN/haF/yr	+11%	+22%
	Calendar	[d]	Ca.3 days	6 to14 days
	Fertilisation	92 kgN/haF/yr	+18 kg N/haF/yr	+23 kg N/haF/yr
4	Climate, land use, animal etc		see Appendices 2-4	see Appendices 2-4
	Inputs of Adaptation scenario (BAP measures)			
11a	Adapted N fertilisation	92 kgN/haF/yr	-10% from Future 2020[b]	-10% from Future 2050[c]
11b	Adapted P fertilisation	73% of area 10 kg P/ha/yr; The rest 34.5 kgP/ha/yr	ca.-10% in soil P content	ca.-20% in soil P content
12	Spring cultivation	0 haF	75% of potential, i.e. spring cultiv. on 46% of all fields	As in 2020
13	Catch crop	0 haF	50% of all spring cultivation (=23% of all fields)	As in 2020
14	Buffer-zones	170 haF, 6-20 m width[a]	Along all water bodies (6 m width). Adapted zones <60haF	As in 2020
15	Structural liming	0 haF	80% of all arable area (P reduction effect = 20%)	As in 2020 but (P reduction effect = 30%)
16	Constructed wetlands	0 haA	240 haA = 3% of agric. land.	As in 2020
17	Sedimentation ponds	0 haF	14 haF, 0.2% of arable land (20% effectiveness)	30 ha, 0.4% of arable land (40% effectiveness)
18	Liming in drains	0 haF	0 haF	50% of the arable land

[a]the model sets it to 10 m; [b] +9 % compared with Current situation; [c] +17 % compared with Current situation; [d]see Blombäck *et al*. (2013) and section on Svärtaån site description above

Inputs of Future scenario

Due to practical reasons the scenarios to be evaluated were based on only one future situation ("socioeconomic story line"), although a number of alternative "story lines" exist. It was assumed that the society is developed in accordance with a high technological development rate (see Blombäck *et al.*, 2013).

-*Climate:* In 2020 there is only a small change in climate in Svärtaån compared with the Current situation, and temperature increases on average by only ca 0.1˚C (Appendix 2). In 2050 the average temperature is projected to increase by 0.3˚C to ca. 2˚C depending on the month, compared with the Current situation. In summer, precipitation might decrease slightly during some months, whereas in winter, it is projected to increase by up to 25 %.

-*Land use:* For 2020 the proportion among crop types in the crop rotation was changed. Ley is the main crop that increased its area most, whereas fallow decreased its area and oats almost disappeared. For 2050 the same crop rotations as for the 2020 scenarios were used, except that fodder maize was introduced on 2 % of the area. The change in total arable land was assumed to remain unchanged by 2020. The increase in urban area was assumed to be marginal. In 2050 land use was basically assumed to be the same as for 2020, due to lack of reliable scenarios. Under the Current situation vegetation period starts on average on April 6 and ends November 7. In 2020 as a consequence of climate change the start occurs slightly earlier (4 days), whereas the end date does not change. In 2050 the vegetation period on average starts 11 days earlier (March 26) and ends 11 days later (November 18), than in the Current situation. Sowing dates changed accordingly, i.e. only slightly in 2020 but 1-2 weeks in 2050. Harvest dates were 3 days earlier in 2020 and 10 days earlier in 2050, compared with Current situation. N fertilisation levels were adjusted to the changed yields taking into account changes of soil N mineralisation. In the Future scenario 2020 N fertilisation increased by 18 kg N/ha/yr (20 %) and in 2050 by another 8 kg N/ha/yr (+28 % compared with the Current situation). Yields in the Future scenario mostly increased. For leys it increased with 10 % by 2020 and with 25 % by 2050. Some crops reduced their yields following current trends. On average N yields increased from 87 to 99 kg N/ha/yr in 2020, and to 110 kg N/ha/yr in 2050.

-*Animals:* It is assumed that the numbers of animal units (defined as in the Swedish legislation in 2012; Swedish Environmental Code, 2012) will decrease by 2020 following current linear trends in the area. In 2050 the number of animals is assumed to be the same as in 2020 (see Appendix 4 for details).

Inputs of Adaptation scenario (BAP measures)

-*Adapted N fertilization:* The N fertilization rates (92 kg N/ha/yr in the Current situation of which 13 kg is given as manure) increased in the Future scenarios by 18 and 26 kg N/ha/yr for 2020 and 2050, respectively. The Adapted N fertilisation measure then reduced these new levels by 10 kg N/ha/yr (ca. -10 %) assuming no changes in yields. It was the mineral part that was adjusted in all cases, i.e. manure fertilisation rate remained at 13 kg N/ha/yr.

-*Adapted P fertilization:* In the Current situation 100 % of field area received 10 kg P/ha/yr the day after sowing. A quarter (27 %) of the area got another 22 kg P/ha/yr from organic fertilisers (400 kg DW/ha/yr) added by 2.5 kg P/ha/yr mineral fertilisers, usually applied in spring. It is assumed that reduced P fertilization until 2020 would reduce the soil P content from the highest P class 3 (1.4 g P/kg soil in 0-30 cm level), which occupy 86 % of the area, to class 2.5 (1.25 g P/kg soil), i.e. a 11 % reduction. By 2050 the reduction was another 12 %, i.e. the soil P class 2.5 decreased to 2 (1.1 g P/kg soil). The reduced P content is assumed not to influence the crop yield.

-*Spring cultivation* does not take place in the Current situation. The areas that could be spring cultivated are mainly those with spring crops, spring sown leys and fallows. In the Adaptation scenarios spring cultivation is practiced on 46 % of all fields. The cultivation is made about one day before sowing (the same measure for 2020 and 2050).
-*Catch crops* are not used in the Current situation. In the Adaptation scenarios catch crops were sown on 50 % of the area where there were spring cultivated crops. This equals 23 % of all field area. The catch crops are undersown in the spring crop and incorporated in soil in autumn if the following crop is a winter crop, and in spring if it is a spring crop (the same measure for 2020 and 2050).
-*Buffer-zones* exists in the Current situation along some of the water bodies (lakes, streams and ditches). In total 170 ha of agricultural land have buffer-zones of 6-20 m width (ca. 1 700 000 m^2/10 m=170 km). In the Adaptation scenarios there were buffer-zones along all water bodies, though only of 6 m width. Buffer-zones were strips of non-harvested unfertilized grass assumed to reduce surface runoff and erosion of P. In addition "adapted buffer-zones" will be introduced on up to 60 ha, which differ from common buffer-zones in being constructed in any location where it is assumed to decrease P losses, e.g. in slopes where erosion is high, or on land where there is risk of flooding. The adapted buffer-zones reduced P losses from a larger area than common buffer-zones of corresponding width. A single adapted buffer-zone might be up to 1 – 2 ha depending on needs (the same measure for 2020 and 2050).
-*Structural liming* is not used in the Current situation. The measure has proved to improve soil structure by strengthening the clay aggregates (Ericsson *et al.*, 1975; Wiström, 2012; pers. comm.), to stabilise soil and improve percolation and thereby decrease phosphorus losses. Trials have shown that phosphorus losses (particulate and dissolved P) might decrease in both drainage water and surface runoff (Ulén *et al.*, 2008). The measure was assumed to be effective only on soils with more than 15 % clay content, i.e. on the silty clay loam soils. This restricted the application to 80 % of total arable area. The P load reduction effect per unit area was assumed to be 20 % in 2020 and 30 % in 2050. The product used was a mixture with 15 weight-% of slaked lime and 85 % $CaCO_3$. The addition of lime was also said to affect the soil pH. The initial effect was high but quickly declined. In the long term the effect is expected to be like that from application of limestone powder ($CaCO_3$; Berglund, 2012; pers. comm.). There was a pH effect during the first 1 – 2 years (pH might rise to ca. 7.8 – 8) but thereafter declined to more normal levels (Anderson, 2012; pers. comm.) The expected application rate was ca. 5 tonnes/ha/yr, but can be up to10 t/ha/yr depending on clay content (Berglund, 2012; pers. comm.).
-*Constructed wetlands* for reduction of nutrient losses were established on 240 ha on areas outside the arable land at optimal position by means of damming and embankment of farm land. In the Current situation there were no constructed wetlands in the catchment. The function of the wetland will last for at least 20 years, providing it is managed. Wetlands are areas covered with wetland vegetation that has either permanently high water level or are periodically waterlogged with otherwise water regime that varies over the year. The wetlands collect water that has already passed the field and have no effect on the field coefficients but on water in streams and in the outlet. The medium size was about 3.5 ha, but when possible up to 5 ha. The assumption was that a P reduction of about 11 % is achieved if the retention time was larger than 48

hours. In the upper part of the catchment all or most of the discharged water passed through wetlands, whereas furthest down only a very small proportion passed through (down to 0.5 % of the total discharge).
Sedimentation ponds for reduction of P losses were not available in the Current situation. In 2020 ponds were introduced in all sub-catchments downstream of Lake Likstammen (i.e. in 12 out of 16 sub-catchments). The sedimentation ponds received water only from arable land. In total 14 ha (0.2 % of arable land) received runoff from 50 % of the arable land and reduced the tot-P content of that water by 20 %. In 2050 two alternatives were applied a) the same as in 2020, and b) 30 ha (0.4 %) of arable land receiving runoff from 100 % of the arable land and reducing the tot-P content by 40 %. The pond consisted of one deep section (inlet), 1 – 1.5 m deep (1/4 of pond size) and one shallow section, 0.2 – 0.4 m deep, with vegetation. Sediments in the deeper part must be removed every few years, and was assumed to be put back on the arable land. The ponds were preferably located in open trenches, close to erosion sensitive areas with soil particle size < 0.02 mm.
-*Liming in drains* was not present in the Current situation, and not in 2020. By 2050 it was assumed to have been installed on 50 % of all arable land, as part of a reconstruction of the drainage system needed to maintain its water regulating capacity. Trenches were assumed to be of 0.5 m width and the spacing between drainage pipes 10 m. The same type of lime as for structural liming (mixture of 15 weight-% of slaked lime and 85 % $CaCO_3$) would be mixed into trench backfill (soil) in an amount of about 5 % of soil wet weight (equals about 20 kg/m of trench; Wiström, 2012; pers. comm.). A field experiment has shown that the pH of the drainage water increased directly after lime addition but quickly returned to normal (6.7 – 7); in three weeks pH was about 0.1 unit above normal and no effect could be seen after one month (Wiström, 2012; pers. comm.). The P content of the drained water was assumed to be reduced by 30 %, and the effect to rest for 25 – 30 years.

Scenario outputs

The scenario output factors concerns total phosphorus (P) and nitrogen (N) loads from fields and in the outlet of the catchment. The loads from fields (TN_F, TP_F) are expressed per unit field area (haF) contributing to the flow, and the loads in the outlet (TP_O, TN_O) per unit of catchment land area (haL). The loads in the outlet that originates from the field and expressed per unit field area are denoted TP_{FO} and TN_{FO}, respectively. In Table 3.3b the absolute values are given for the Current situation and the Future scenarios. For the Adaptation scenarios the relative differences refer to the Current situation. Wetlands and liming were the most efficient measures in 2020 and liming and especially sedimentation ponds in 2050, as concern reduction of P losses. For reduction of N losses wetlands were efficient in 2050, but otherwise adapted (reduced) N fertilization was the most efficient measure.

Table 3.3b. *Simulated P and N loads from Svärtaån catchment (all values are averages of the whole catchment, except for TPC_O sub-catchment ranges). All relative changes (%) refer to the Current situation (Curr.). X denotes BAP measures (see footnote *, Table 3.3a and text) Combinations of measures are: [a]X11+X12; [b]X11+X12+X13. For explanation of symbols, see list in Appendix 1. The values were taken from the study of Blombäck et al. (2013), however, the information might differ from their final scenarios.*

Variable	**Curr.**	**2020 Future**	**% X11**	**% X12**	**% X13**	**% X14**	**% X15**	**% X16**	**% X17**	**% [a]**	**% [b]**
TPC_F (mg/l)	0.43	0.46(+6%)	+2	-1						-10	
TP_F (kg/haF)	0.95	0.95(0%)	-8	-5			-17	0	0	-13	
TP_O (kg/haL)	0.24	0.24(0%)	-7	-5		-6	-15	-16	-8	-11	
TPC_O (mg/l)	0.11	0.12(0%)	-6	-5		-6	-14	-16	-7	-10	
TPC_S		0%to+1%	-8to 0	-6to -4		-8to -2	-15to -12	-16to -10	-8to -6	-13to -4	
TP_{FO} (kg/haF)	0.9	0.9(0%)									
$TP_{F/O}$	75%	75%									
TN_F (kg/haF)	10.9	13.2(+21%)	-4%	+18	+19			+25		-11	-23
TNC_F (mg/l)	5.8	6.9(+19%)	-7%	+11	+19						
TN_O (kg/haL)	3.0	3.5(+16%)	-3%	+12	+12			+4		-8	-16
TNC_O (mg/l)	1.4	1.7(+21%)									
TN_{FO} (kg/haF)		11.7(+21%)									
$TN_{F/O}$		67%									
S/T_W	3.7%	3.6%									
Veg. start (VS)	April 6	April 2									
Veg. end (VE)	Nov 7	Nov 7									
S/T_P	27%	26%	+26	+23						+23	
Variable	**Curr.**	**2050 Future**	**% X11**	**% X12**	**% X13**	**% X14**	**% X15**	**% X16**	**% X17**	**% [a]**	**% [b]**
TPC_F (mg/l)	0.43	0.52(+21%)	+2	+9						+3	
TP_F (kg/haF)	0.95	1.08(+14%)	-4	+5			-17	+12			
TP_O (kg/haL)	0.24	0.26(+8%)	-4	+4		+4	-16	-8	-24		
TPC_O (mg/l)	0.11	0.13(+16%)	+1	+10		+10	-11	-3	-19		
TPC_S		+14%to +17%	-2to +17	+8to 12		+7to 15	-13to-9	-3to +4	-22to -16		
TP_{FO} (kg/haF)	0.9	1.02(+13%)									
$TP_{F/O}$	75%	77%									
TN_F (kg/haF)	10.9	10.2 (-6%)	-20	-4	-2			-1		-23	-27
TNC_F (mg/l)	5.8	6.3(+10%)	-11	+7	+10						
TN_O (kg/haL)	3.0	2.9(-5%)	-17	-6	-5			-17		-19	-22
TNC_O (mg/l)	1.4	1.5(+7%)									
TN_{FO} (kg/haF)		8.8(-8%)									
$TN_{F/O}$		61%									
S/T_W	3.7%	2.4%									
Veg. start (VS)	April 6	March 26									
Veg. end (VE)	Nov 7	Nov 18									
S/T_P	27%	18%	+18	+17						+18	

* X11= adapted fertilisation, X12 = spring cultivation, X13 = catch crop, X14 = buffer-zones, X15 = structural liming, X16 = constructed wetland, X17 = sedimentation ponds

3.4. Evaluation methods

The effects of nutrient load scenarios on multiple benefits of agricultural BAP measures were evaluated in two steps. Firstly the effects of Scenario Factors on the MB-factor (MBf) were assessed in terms of physical units of the MBf concerned, as far as possible (see below). Secondly, the Multiple Benefit Index (MBi) was estimated for each MBf. The MBi is the MBf transformed into an index that represents the general effect on the MB-category (GHG-emissions, biosecurity etc.). For instance, the MB-factor (MBf) pathogen leaching represents the biosecurity MB-category and is expressed in units that are biosecurity specific. MBi is then a further interpretation of what that change in MBf would mean for the biosecurity as a category, and expressed in a dimensionless scale between 0 and +10, used for all the MB-categories. The value 0 represents a large negative change, +5 no change, and +10 a large positive change of the category concerned. The relation between the grading of MB-factor and the MB-index is specific for each category. The evaluations were for most categories based on expert judgements, but for the MBf evaluations also more transparent methods were used in some cases (Table 3.4). To improve the transparency, however, the experts provided written descriptions of their evaluations (see the section on Results).

Table 3.4. *Methods used to estimate the multiple benefit factors (MBf) and indices (MBi)*

Multiple Benefit Category	*Type and description of the Evaluation method*
GHG emissions	MBf: (i) Factors influencing GHG emissions are divided into sources of mineral N, (ii) changes of defined sources are calculated, (iii) other agricultural sources than arable land were excluded due to lack of information. MBi: expert judgment
Biosecurity	MBf and MBi: Literature review and expert judgement
Biodiversity	MBf and MBi: Expert judgement based on research results (in Finland)
Cost effectiveness	MBf: Rural Development Program payments and expert judgement MBi: Expert judgement
Soil quality	MBf and MBi: Literature review and expert judgement
Water protection	MBf and MBi: Expert judgement based on literature review and research results (in Finland)

The evaluation of the differences between the Adaptation scenario and the Current situation was made in a number of steps, depending on which scenario factor that was evaluated. Theoretically the steps would be the following:

(i) First the effects of “unavoidable changes” (i.e. Future scenario = changes in climate, land use etc.) were evaluated, i.e. the differences in the MB-factor (quantifiable and partly representing the MB-category) between the Future scenario and the Current situation were evaluated.

(ii) Second, on top of that, the effect of single BAP measures taken was evaluated; i.e. the difference between the MB-factor of Adaptation scenario and the MB-factor of the Future scenario was evaluated.

(iii) Thereafter the evaluation of the MB-factor was converted into the MB-index (representing the whole MB-category), and expressed in relation to the Current situation. An example of how this evaluation can be made is given in Appendix 5.

3.4.1. GHG emission

The assessments of the scenarios on N_2O emissions from soil werr based on the effect the scenario factors had on the addition of N to the amounts of soil mineral N ($N_{MineralSoilAdd}$) and N_2O losses directly related to N flows in the soil-plant system ($N_{MineralLoss}$). The reason of choosing the sum of these factors ($N_{MineralRisk}$) as the indicator for the N_2O emissions (and the MB-factor) was that the access of mineral N in soil (NH_4-N and NO_3-N) is regarded the most influencing factor on N_2O emissions from soil by IPCC (2006).

$$N_{MineralRisk} = N_{MineralSoilAdd} + N_{MineralLoss} \quad (1)$$

To calculate the effect of inputs of N per year on mineral N content in soil, the following variables were considered; kg chemical N fertilizers applied ($N_{FertChem}$), kg N from animal manures and other organic fertilizers as NH_4-N ($N_{FertNH4}$), and kg N mineralised from soil organic matter ($N_{Mineralisation}$) (IPCC, 2006).

$$N_{MineralSoilAdd} = N_{FertChem} + N_{FertNH4} + N_{Mineralisation} \quad (2)$$

Values (taken from the scenarios) for N chemical fertilizers ($N_{FertChem}$) and N mineralisation ($N_{Mineralisation}$) varied among the scenarios. Organic N inputs to the field in terms of harvest residues and fertilisers were considered in terms of the effects they have on N mineralisation, which were taken from the scenario assessments based on models including these processes. $N_{FertNH4}$ was constant for all scenarios. There was no data concerning applied N from faeces and urine droppings at grazed areas and therefore this factor was excluded from the assessments.

The loss of gaseous N from field (being a risk for N_2O emissions) was set proportional to fertilisation rate and the leaching rate. Two % of applied amounts of N with chemical N fertilizers were assumed to be lost (Hutchings *et al.*, 2001) and the contribution from animal manure was taken arbitrarily to be 30 % of applied NH_4-N. All nitrates leaching ($N_{LeachNO3}$) was assumed to be at risk for being lost as gaseous. N leaching data needed for these assessments were taken from the modeled scenario outputs of the Svärtaån nutrient load scenarios (IPPC, 2006).

$$N_{MineralLoss} = 0.02\ N_{FertChem} + 0.3\ N_{FertNH4} + N_{LeachNO3} \quad (3)$$

In the Svärtaån case the difference between the Adaptation scenario and the Current situation in N mineral content at risk to be a source for N_2O emissions ($N_{MineralRisk}$) was graded in steps of 5 kg N/ha/yr, assuming changes within -5 to +5 kg N/ha/yr change to be neglectable due to uncertainties involved in the assessments. A strong change (MBi graded as 0 or 10) was assumed to be 25 kgN/ha/yr, based on the assumption that soil mineral content (0-100 cm depth) in early spring on arable fields is in the range of 25 kg N/ha and a doubling of this content would severely increase the risk of N_2O emissions (Table 3.4.7).

3.4.2. Biosecurity

Effects on biosecurity were assessed by literature review and expert judgements, see further the result section. Reported effects of pathogen reduction for BAP measures were compiled. Experimental data on pathogen reduction over buffer-zones, constructed wetlands and in sedimentation ponds have been published. Amongst data, the publications describing conditions similar to those in Svärtaån, regarding climate, slopes, width of buffer-zones etc., were chosen in front of other data. The other scenario factors were assessed by expert judgement concerning how and in what way they could influence the risk of disease transmission from the field to surrounding waters. Pathogens can be transmitted from fields to surface water via various pathways, such as surface runoff, sub-surface transfer in highly permeable soils, and via artificial soil drainage (*e.g.* Oliver *et al*., 2005). Since surface runoff has been suggested as a significant cause of microbial surface water contamination (reviewed by Tyrell and Quinton, 2003), and since the risk of transport through the soil in the Svärtaån catchment is considered low (Wiström, 2012; pers. comm.), measures mitigating surface runoff were considered beneficial for biosecurity. Since none of the scenario factors would lead to an increased biosecurity risk, the MB-factor was either zero or positive, with positive divided into three levels: can be positive (+), will be positive + and will reduce the biosecurity risk significantly + + (Table 3.1.4). For the MB-index, the MB-factor was applied to the specific outcome of scenario factors on human and animal health in the whole Svärtaån catchment (Table 3.1.4).

3.4.3. Biodiversity

The MB-factors for biodiversity were evaluated for each of the proposed measures based on the analysis made on the Finnish Agri-environmental programme for 2000-2006 (Kuussaari *et al*., 2008). This evaluation was based both on the expert knowledge and on field research results. The use of the Finnish study to evaluate the efficiency of the measures in the Svärtaån catchment is partly justified by the climatic conditions being rather similar in both areas, and partly by the measures used in the Svärtaån area being similar to the measures assessed in the Finnish evaluation. In the analysis, weak positive/negative means that there is a small effect on biodiversity and strong positive/negative in turn means that the effect is larger keeping in mind that an intensively cultivated agricultural area can hardly ever be an area where biodiversity can blossom.

3.4.4. Cost effectiveness

Cost effectiveness is a relative concept; if the cost to achieve a particular target with one alternative is lower than for another alternative, then the lower cost alternative is more cost effective. The objective of the scenario work in this study is to evaluate the impact of alternative scenarios on nutrient loads in the catchment area.

For this study the cost impact of the scenarios is evaluated as a one percentage unit of load reduction of one nutrient at a time, either phosphorus or nitrogen, or a one kilogram reduction of one of these nutrients. The economic impacts of the scenarios are described individually for each of the measures and an evaluation is performed with respect to the volume and impact of each measure as described in Section 3.3. This is a simplification of reality in which several measures are applied at the same time and their nutrient load reducing effects and application costs influence each other (for an elaboration of these points see Section 5 below).

A comparison of the costs between alternative scenarios is determined by the change in the use of resources. There can be positive changes in farm income (for example lower costs for fertilization) or negative changes (higher costs for herbicides) these are described for each measure. In addition some of the effects may be incorporated into the value of the land (capitalization). If climate change improves agronomic conditions and this leads to a general increase in harvests in the area this would increase the value of land which in turn is subsumed in the alternative cost of using the land in production. Then effect of the increase in yields may not have an effect on income. Land capitalization is not realized in accounting terms until the land is sold but the cost of using the land in production is the opportunity cost of land which includes changes in value whether they are realized or not. The changes in income are based on payments already made to farmers as part of the Swedish Rural Development Program unless otherwise note while the changes in land values are based on expert judgment.

Descriptions of possible implicit and explicit transaction costs are included in the evaluation of the measures and scenarios described in this study (see McCann *et al*., 2005 for this typology of transaction costs). Explicit costs can include for example paying a consultant to evaluate an agri-environmental program while the time spent by a farmer talking to government officials or reading documents related to the policy are considered to be implicit costs. The hiring of new staff in the public sector to administrate a policy is an explicit cost while the reallocation of existing staff to work on a policy may be an implicit cost. The transaction costs associated with the measures in this study are based on expert judgment (see further discussion below in Section 5).

The measures and scenarios are evaluated in the following section with respect to three criteria; changes in income for landowners/farmers, changes in land values, and transaction costs. Each of these three categories is considered as a separate MB-factor for this study. The MB-index is a single value composite of the three MB-factors. The MB-factor is a range from "+ +" for the most favorable outcome of all the measures evaluated (lowest negative change in income, most positive change in land value, lowest transaction costs) to "- -" for the least favorable outcome (highest negative change in income, least positive change in land value, highest transaction costs). Each of these factors is evaluated for each measure relative to other measures. The MB-index has a starting value of 5 and each MB-factor plus/ minus is added/subtracted up to a maximum of 10 (highest positive MB) or down to a minimum of 0 (lowest negative MB).

3.4.5. Soil quality

The influences on soil quality were assessed by expert judgement based on research papers, reviews, and textbooks. All scenario factors were judged as concern how and in what way they could affect SOM and its influence on crop growth. The full list of studies (papers, reports) used for the evaluations can be found in the reference list and Braun (2012).

The scale for grading the effects of scenario factors on the MB-factor (MBf) was divided into five levels; two positive (weak +; strong + +), two negative (weak -; strong - -), or no change (0). The definition of a strong effect was based on results of the Ultuna (Uppsala, Sweden; Latitude 59.8°N) continuous soil organic matter field experiment which showed that in a period of 53 years the C concentration of topsoil (0-20 cm) decreased by a third (33 %) in bare fallow regularly manually weeded (Kätterer *et al*., 2011). According to those results, topsoil C was changing annually by an average of 0.75 %/yr. This accounted for a decrease of ca. 10 % of SOM in 15 years. A decrease of 0.7 % SOM/year was then regarded to have a strong negative effect on soil quality. The further grading from the MB-factor to the MB-index (the wider definition of the soil quality category) was basically proportional, except that the MBi scale had a finer scale allowing further differentiation due to that more factors may be considered for the MBi grading. This caused an overlap between the MBf and MBi scales. The estimation of MBi values were made by expert judgement (Table 3.4.7; see also section on Results).

3.4.6. Water protection

The influences on the water quality were assessed by expert judgement based on research papers, reviews, monitoring and modelling results from other studies. All scenario factors were judged as concern how and in what way they could affect water quality and its influence on nutrient leaching (phosphorus and nitrogen). The Svärtaån modelling results were used as further information to confirm the evaluation. The expert judgement of different measures was made based on work made in Finland (Grönroos *et al*., 2007).

The scale for grading of the effects of scenario factors on the MB-factor was divided into five levels; two positive (weak +; strong + +), two negative (weak -; strong - -), or no change (0). The definition of whether a certain measure was regarded to have a strong or weak effect was based on the Finnish analysis on the effect of agri-environmental support system in Finland. In that study the weak positive/negative means that some change (5-15 %) in nutrient loading can be expected. The strong positive/negative means that the change is higher, around 20-35 %. However, in practice, it is very difficult to assess correct values for the efficiency of a certain measure. Here in this study, the small change means that some positive/negative effects are possible and the strong positive/negative change in turn means that based on the knowledge e.g. on field experiments, the effect is substantial at the field scale but the change in the river water quality might still be difficult to show at the outlet of river Svärtaån.

3.4.7. Summary

Table 3.4.7. *Scales for evaluating MB-factor (MBf) and MB-index (MBi) of different Multiple Benefit (MB) categories*

Effect of Scenario factors on MBf	**MBf Grading**	**Effect of MBf on MBi**	**MBi grading (0-10)**
GHG emission Effect on $N_{RiskMineral}$			
0-5 kg N/ha/yr	0	Proportional	5
6-10 "	+; -	"	6, 4
11-15 "	++; --	"	7, 3
16-20 "	+++; ---	"	8, 2
21-25 "	++++; ----	"	9, 1
>25 "	+++++; -----	"	10, 0
Biosecurity Risk-reduction			
0	0	No effect on biosecurity	5
< 30%	(+)	Can have an effect	6
30%< x < 90%	+	Has an effect	7-8
> 90%	+ +	Reduce the risk significantly	9-10
Biodiversity Change in biodiversity			
Strong negative	--	Proportional and overlapping	0-3
Weak negative	-	"	2-5
No change	0	"	4-6
Weak positive	+	"	5-8
Strong positive	++	"	8-10
Cost effectiveness Change of income, land value, transaction costs			
	--	Proport. to the Σ of all three	0
	-	"	
	0	"	5
	+	"	
	++	"	10
Soil quality Effect on SOM			
≤ -10% SOM/15 years	--	Proportional and overlapping	0-3
Negative effect	-	"	2-5
No effect	0	"	4-6
Positive effect	+	"	5-8
≥ +10% SOM/15 years	++	"	8-10
Water protection Effect on nutrient reduction			
Strong negative	--	Proportional and overlapping	0-3
Weak negative	-	"	2-5
No change	0	"	4-6
Weak positive	+	"	5-8
Strong positive	++	"	8-10

4. Results

4.1. GHG emissions

The evaluation of changes in GHG emissions were based on a calculation of the effect on the total mineral N being at risk for N_2O emissions ($N_{RiskMineral}$; eq. 1). The inputs of these calculations were taken from input and output data of the scenarios. The results are given in Table 4.1. In the scenarios changes in fertilization rates were adjusted with mineral fertilizer, whereas the amount of applied manure was the same in all scenarios.

Table 4.1. *Changes in the GHG emission MB-factor (MBf = $N_{RiskMineral}$). The MB-factor of GHG emissions as calculated from the different terms of the N mineral risk factor. The mineralisation factor ($N_{Mineralisation}$) was weighted according to the soil types (80 % silty clay loam and 20 % silty loam). All values are in kg N/ha/yr. For explanation of symbols see equations 1-3.*

			2020					
X	***Scenario-Input-Factor***	***MBf***	***Change vs Current***	***N*** *RiskMineral*	***N*** *FertChem*	***N*** *FertNH4*	***N*** *Mineralisation*	***N*** *LeachNO3*
	Current situation		0	205	79	6	106	10.9
4	Future scenario	- - - - -	+30	235	97	6	116	13.2
	BAP-measures		***Change vs Future***					
11a	Adapted N fertilisation	+++	-17	218	87	6	112	10.2
12	Spring cultivation	0	-2	233	97	6	114	12.4
13	Catch crop	0	+3	238	97	6	119	12.5
	Combinations of BAP							
	X11a+X12	+++	-19	216	87	6	111	9.4
	X11a+X12+X13	-	+8	243	87	6	113	8.1

			2050					
X	***Scenario-Input-Factor***	***MBf***	***Change vs Current***	***N*** *RiskMineral*	***N*** *FertChem*	***N*** *FertNH4*	***N*** *Mineralisation*	***N*** *LeachNO3*
	Current situation	0	0	205	79	6	106	10.9
4	Future scenario	- - - - -	+49	254	105	6	130	10.2
	BAP-measures		***Change vs Future***					
11a	Adapted N fertilisation	+++	-17	237	95	6	125	8.3
12	Spring cultivation	0	+2	256	105	6	131	10.0
13	Catch crop	0	+4	258	105	6	133	10.1
	Combinations of BAP							
	X11a+X12	++	-15	239	95	6	127	8.0
	X11a+X12+X13	++	-9	243	95	6	131	7.5

Future scenario

The simulation of N mineralisation in the nutrient load model (used for the Adaptation scenarios) is dependent on variations in amount of degradable biomass, temperature and soil water content. *The changes in climate, land use and crop distribution, and the*

increased N fertilization adjusted to match the increased crop N demand caused an increase of N application by 10 kg N/ha in 2020 and 24 kg N/ha in 2050 compared to the Current situation. The increased mineralization was mainly due to the yield increase of the leys, resulting in increased amount of biologically degradable material in root biomass and stubble.
[Future scenario 2020 MBf = -----; MBi = 0 and 2050 MBf = -----: MBi = 0]

Adapted N fertilisation
The reduced N fertilisation lead to a reduction in mineralised N per hectare compared with the Future scenario, in both 2020 and 2050 (by 4 and 5 kg, respectively). However, still the mineralization rates were considerably higher than in the Current situation (6 and 19 kg N/ha/yr, respectively), since the yield levels were only slightly reduced and the amount of degradable biomass still was larger than in the Current situation.
[Adapted N fertilisation 2020 MBf = +++; MBi = 8 and 2050 MBf = +++: MBi = 8]

Spring cultivation
The shift from autumn to spring ploughing on about a quarter of the area reduced the mineralization due to reduced inputs of organic matter to soil in autumn. The decrease in the mineralization was larger in 2020 (4 kg N/ha/yr) than in 2050 (2 kg N/ha/yr), although still small compared with the increase due to the Future scenario, especially in 2050. However, the model response to this measure is regarded uncertain (Markensten, 2012 pers. comm.), and therefore the effect of this measure was regarded small when setting the MBi value (i.e. the MBi value of the Future scenario was not changed due to the modeled mineralisation change).
[Spring cultivation 2020 MBf = 0; MBi = 5 and 2050 MBf = 0: MBi = 5]

Catch crop
The introduction of more catch crops did not influence the mineralisation significantly. The evaluation of the catch crop Adaptation scenarios compared with the Current situation was thus the same as for the Future scenarios, as concern mineralisation.
[Catch crop 2020 MBf = 0; MBi = 5 and 2050 MBf = 0: MBi = 5]

When combining the measures of adapted N fertilization and spring cultivation, mineralisation was reduced as much as with the single measure adapted N fertilization and in 2050. In 2020 the mineralisation rates were close to those of the Current situation.
[Combinations of BAP 2020 MBf = +++; MBi = 8 and 2050 MBf = ++: MBi = 7]

In summary, the nutrient load scenario factors increased the risk of N_2O emissions considerably from arable land in the future. Among the single measures the adapted N fertilization was the one that significantly could mitigate the “unavoidable” increase of GHG-emissions (MB-indices being about 8 both in 2020 and 2050),

4.2. Biosecurity

Future scenario

Animal: The number of animals is assumed to decrease by 2020 and be the same in 2050. Considering the amount of faeces produced and which organism they can harbour, biosecurity risk from animals was graded from high to low: cattle > poultry > pigs > sheep > horses. From a zoonotic disease transmission point of view, cattle harbour are the ones most important for public health (Ottoson, 2012). Numbers of cattle and pigs are expected to decrease (see Appendix 4), which will lead to less zoonotic pathogens potentially transmitted from agriculture in the Svärtaån catchment.

Land use: In the Future scenario, increased fertilisation levels (+20 % 2020, +28 % 2050) compared to current is predicted; however manure use will not change and therefore land use will not affect biosecurity.

Climate: There will only be a small difference in climate in Svärtaån between 2020 and the Current situation, with mean temperature increases by only ca. 0.1°C. In 2050, the average temperature is expected to increase with approximately 0.3 to 2.1°C compared to the Current situation, which may result in a slightly more rapid inactivation of pathogens. The precipitation in 2050 is predicted to decrease in summer (-5 %) and increase (+25 %) in winter compared to the Current situation. Although a small surface runoff decrease (-9 %) is predicted in the Future scenario for 2050 (Blombäck *et al.*, 2013), the increased precipitation in winter is judged to result in an increased risk of pathogens being transported from the fields to surface waters. Considering that heavy rains have shown to increase disease incidence in specific catchments (Tornevi and Forsberg, 2012), climate change may lead to a slight increase in biosecurity risk.

Altogether this gives slightly positive MBi (6) for 2020 due to the scenario factor "animal", whereas by 2050 this is counteracted by climate (more heavy rains during wintertime). *[Future scenario (Animal, Climate) 2020 MBf = (+); MBi = 6 and 2050 MBf = 0: MBi = 5]*

Adapted N and P Fertilisation

Since the manure fertilisation rate will not change, no effect on biosecurity is expected. *[Adapted N and P fertilization 2020 and 2050: MBf = 0; MBi = 5]*

Spring cultivation

In the Adaptation scenario, spring cultivation is practiced on 46 % of all fields, compared to 0 % in the Current situation. The prediction is that this measure will reduce the surface runoff slightly (-3 % 2020, -1 % 2050), hence leading to reduced leaching of pathogens from those fields. The effect is expected especially during heavy rains and snow melting periods, which are the most important from a biosecurity perspective.
[Spring cultivation 2020 and 2050: MBf = (+); MBi = 6]

Catch crops

Catch crops are used mainly as a measure to reduce the leaching of N, but might to some extent also reduce the risk of erosion and surface runoff and, hence, also the risk of pathogen leaching from fields to waters. The use of catch crops on 23 % of all field area in Svärtaån by 2020 and 2050 can have a moderate positive effect on biosecurity.

[Catch crop 2020 and 2050; MBf = (+); MBi = 6]

Buffer-zones
Reduction of microorganisms over vegetated buffer-zones depends on width, vegetation, and slope (Dufour *et al*., 2012). In Svärtaån, most of the field area close to waters is classified as being within slope class 3 (5 % slope). Adaptation scenarios will lead to some strips being reduced in width compared to the Current situation but the total area covered will increase. Buffer-zones of ≤ 6 m width have in lab-scale and field studies shown to reduce pathogen run-off by up to 99 % (range 56 – 99 %, 1 – 6 m) (Larsen *et al*., 1994; Atwill *et al*., 2002; Goel *et al*., 2004). The net impact of using the smaller width but along all ditches, would reduce the total leaching of pathogens from fields to surface waters by 2020 and 2050.
[Buffer-zones 2020 and 2050: MBf = +; MBi = 8]

Structural liming
The improved soil structure after structural liming may increase percolation, and thus reduce the risk of surface runoff. Accordingly, the risk of pathogen surface transport to watercourses may be reduced. Pathogens, especially bacterial, can be inactivated efficiently in low (< 4) or high pH (>9) (Ottoson *et al*., 2008). However, liming in soils will give a rise in pH of approximately 8 (Anderson, 2012; pers. comm.), thus not enough to provide a reduction of potential pathogens and hence biosecurity risks will likely not be affected. The possible reduced risk of surface transport will, however, likely improve biosecurity to some extent.
[Structural liming 2020 and 2050: MBf = (+); MBi = 6]

Constructed wetlands
Constructed wetlands are extensively used to polish secondary treated wastewater to reduce nitrogen, phosphorus and pathogen levels in receiving waters and have a positive effect on reducing the transmission of faecal indicators. Up to 99.9 % reduction over a wetland has been reported (Dufour *et al*., 2012). However, the biosecurity effects will only be beneficial for water downstream the wetland. An uncertainty is the possible exposure of humans and livestock to the wetlands. Furthermore, wetlands serve as attractive bird habitats, with the potential for vector transmission of pathogens, and breeding grounds for mosquitoes.
[Constructed wetlands 2020 and 2050: MBf = +; MBi = 7]

Sedimentation ponds
Sedimentation ponds make the water move slower and due to sedimentation and UV inactivation the transport of pathogens from the captured runoff water will decrease. Vinten *et al*. (2008) have shown sedimentation ponds to reduce faecal microorganisms by more than 90 %. Since surface runoff from fields are the most important transport route for viable pathogens, sedimentation ponds trapping surface runoff will have a positive effect on biosecurity.
[Sedimentation ponds 2020 MBf = +; MBi = 7 and 2050 MBf = +: MBi = 8]

Liming in drains
By 2050, 50 % of drainage water will pass through trenches with 5 % lime. Although surface runoff from fields are the most important transport route for viable pathogens, transport through soils may be significant in areas with risk of fast transport, *e.g.* via by-pass flow. However, the risk of fast transport through the soils in Svärtaån is considered low (Wiström, 2012; pers. comm.). Moreover, liming in drains will not result in any long-term pH increase in the drainage water (0.1 units raise observed after three weeks; no effect after one month) and thereby no pathogen inactivation due to this. Hence, this scenario factor will likely not lead to any improvement of the biosecurity.
[Liming in drains 2050: MBf = 0; MBi = 5]

4.3. Biodiversity

Future scenario
It has been shown that the loss of biodiversity is one of the major impacts of agriculture (Tilman *et al*., 2001; Hildén *et al*., 2005).This impact is the result of a loss of specific habitats such as meadows, pastures and landscape features such as open ditches. Climate change may on one hand improve conditions for many southerly distributed species. For example, a significant number of butterfly species have expanded their distribution area towards northern Europe during the recent period of warm climate (Pöyry *et al*., 2009). It is also noteworthy that agricultural pests are likely to benefit from the climate change. However, according to Thomas *et al*. (2004) the more average temperatures rise, the more species will be threatened with extinction. So in this study no conclusion is made concerning the effect of the Future scenarios on biodiversity.

Adapted N and P Fertilisation
No significant biodiversity effect is expected within cultivated fields which have high levels of nutrients in the soil and which tend to be species poor habitats.
[Adapted N and P fertilization 2020 and 2050: MBf = 0; MBi = 5]

Spring cultivation
In the Adaptation scenario, spring cultivation is practiced on 46 % of all fields, compared to 0 % in the Current situation. With this measure the period when soil is covered by vegetation will increase considerably and therefore the conditions for e.g. farmland birds, soil animals and ground-living insects will be improved. Due to the fact that the soil is ploughed before seeding in the spring, the measure is not as good as the ones where there is a permanent vegetation cover such as green fallows, buffer-zones or field margins.
[Spring cultivation 2020 and 2050: MBf = 0 to +; MBi = 6-7]

Catch crops
Catch crops have a similar effect on biodiversity as spring cultivation. In the Svärtaån catchment the areal coverage (23 % of all field area) is, however, smaller for catch crops than spring cultivation and therefore their efficiency can be rated smaller. The best effect for biodiversity would be achieved in case no-tillage is applied.
[Catch crop 2020 and 2050; MBf = +; MBi = 6]

Buffer-zones

Reduction of microorganisms over vegetated buffer-zones depends on width, vegetation, and slope (Dufour *et al*., 2012). In Svärtaån, most of the field area close to waters is classified as being within slope class 3 (5 % slope). Adaptation scenarios will lead to reduced width of strips but an increase in total area. It is always positive for plant and insect species when the share of actively cultivated arable area decreases and open semi-natural area increases. If there are also some scattered trees and bushes in the buffer-zone area, the conditions are favourable for farmland birds (Tiainen, 2004). As with wetlands, there may be positive impacts also for the waterfowl, in the number of birds that use the wetland as feeding ground and population that lives in the waterfront area, because buffer-zones are mainly built close to the waterways. The efficiency is rated slightly positive.

[Buffer-zones 2020 and 2050: MBf = +; MBi = 6-7]

Structural liming

No effect on biodiversity. *[Structural liming 2020 and 2050: MBf = 0; MBi = 5]*

Constructed wetlands

Constructed wetlands are extensively used to reduce nitrogen, phosphorus levels in receiving waters. Wetlands increase the landscape-level habitat variety, and may add an important new habitat type into intensively cultivated landscapes in which natural wetlands have often been effectively dried up during the decades of agricultural expansion. The positive impact is seen in the waterfowl, in the number of birds that use the wetland as feeding ground and population that lives in the waterfront area. In addition, a high number of invertebrate species benefits from even small patches of constructed wetlands (Heliölä *et al*., 2010; Thiere *et al*., 2010). If the wetland is constructed on the area far from the waterways, the effect is likely to be larger than in landscapes with many other existing wetlands. The management of a wetland has a great impact on the diversity of nature.

[Constructed wetlands 2020 and 2050: MBf = +; MBi = 8-9]

Sedimentation ponds

Sedimentation ponds are smaller than wetlands and therefore their efficiency on biodiversity can be considered smaller than for wetland. Nevertheless, a high number of invertebrate species may benefit even from small patches of constructed sedimentation ponds (Heliölä *et al*., 2010; Thiere *et al*., 2010). The conclusion is that the effect is smaller than in wetlands with a larger size.

[Sedimentation ponds 2020 and 2050: MBf = 0 to +; MBi = 8]

Liming in drains

This scenario factor will not lead to any improvement of the biodiversity.

[Liming in drains 2050: MBf = 0; MBi = 5]

4.4. Cost effectiveness

Future scenario

Changes in agronomic conditions may have an effect on both costs and product prices. However, product prices are market driven and the choice by individual farmers or changes in output in a small catchment area will have no effect on these. Changes in the costs of production will also be the same for all landowners with similar agronomic conditions such as climate. Therefore changes in land use due to climate change would be expected to be reflected in the value of land. If climate changes lower costs and (or) lead to higher yields this could in the short run raise income but in the long run would increase the value of land in the area which in turn raises the opportunity cost of land in production and this process would continue as long as economic rents in the area remain higher than in other areas. The long run net effect on changes in income would be negligible. This would be true for 2050 as well as 2020. *[Land value change (+); income change (0); transaction costs (0); Sum of MBf = +1; MBi = 6]*

Adapted N Fertilization

In the Adaptation scenario N fertilization is reduced by about 10 % (10 kg N/ha/yr). This reduction does not reduce yields therefore it lowers cost (by 1.3 €/kg N or 13 €/ha/yr) and raises income. This positive income change continues as long as yields are constant at the lower fertilization rate. Higher income per hectare in the long run will also increase the value of land. Transaction costs are close to zero for this measure. *[Land value change (+); income change (++); transaction costs (++); Sum of MBf = +5; MBi = 10]*

Adapted P Fertilization

Lowering P fertilization with no change in yields will also lead to a long run increase in income and land values (as above for N). However, since rates are based on measured soil P content, monitoring and informational transaction costs are expected to be significant. *[Land value change (+); income change (++); transaction costs (-); Sum of MBf = +1; MBi = 7]*

Spring cultivation

The area under spring cultivation is expected to cover 46 % of all fields (3520 ha). This is expected to reduce field edge losses compared to the Future scenario by around 5 % for P (both 2020 and 2050) and 6 % for N in 2020 and 2 % for N in 2050. The change in income for the measure is assumed to be 500 SEK/ha. This is the compensation currently paid out for spring cultivation to farmers in the Rural Development Program. The cost per unit of reduction is around 10 000 SEK/kg P if the phosphorus load is the primary target and between 60 SEK/kg N in 2020 and 2500 SEK/kg N in 2050 per unit of reduction if nitrogen is the target. All of these changes in income for a reduction are quite high. There would be no effect expected on land values as the change in income is expected to be neutral and taking into account the net change in costs and benefits. Transaction costs would be positive (program administration, information and monitoring) but low. *[Land value change (0); income change (--); transaction costs (-); Sum of MBf = -3; MBi = 2]*

Catch crop

Catch crops in the Adaptation scenario are expected to be sown on 23 % of all fields (1750 ha). This is expected to reduce edge of the field nitrogen losses by 5 % in 2020 and 1 % in 2050. The change in income for the measure is assumed to be 1200 SEK/ha (an average cost based on payments for autumn and spring incorporation under the Rural Development Program). The cost per unit of reduction is between 2070 SEK/kg N in 2020 and 12000 SEK/kg N in 2050 which is a very high cost per unit of reduction. There would be no effect expected on land values if the measure is compensated for by direct payments of the type described above and these are equal to the change in income. Transaction costs would be positive (program administration, information and monitoring) but low. *[Land value change (0); income change (--); transaction costs (-); Sum of MBf = -3; MBi = 2]*

Buffer-zones along watercourses

While there are currently 170 ha of agricultural land in buffer-zones (6-20 m in width) the Adaptation scenario projects that there will be full coverage of buffer-zones with a width of 6 m in the catchment in 2020 and 2050. Estimates of potential area, reduction effects and land use costs were recently published in a database at the Department of Soil and Environment at SLU and publicly available at <http://fyrisskz.slu.se/daro/64000/>. From this database the potential length (watercourses bordered by agricultural blocks) in full coverage is approximately 1064 km which at a width of 6 meters gives 638 ha of buffer-zones. The reduction for this area is 705 kg P, an average of 1.10 kg P/ha. The alternative cost for this area is estimated at 2033 SEK/ha which gives an average abatement cost of 1848 SEK/ kg P. If this is fully compensated for by direct payments (as for catch crops) then there would be no change in land values. Since there is a standard requirement (6 m) and a long term commitment, the transaction costs would be expected to be low. *[Land value change (0); income change (0); transaction costs (-); Sum of MBf = -1; MBi = 4]*

Buffer-zones in agricultural fields (adapted buffer-zones)

This type of buffer-zones may be located anywhere there is deemed to be a risk for P-losses due to erosion or flooding. The Adaptation scenario expects there to be 60 ha of this type of buffer-zones in place for both 2020 and 2050. The effect of this type of zone is estimated to be greater than a similar area along a watercourse. The opportunity cost for land may be expected to increase due to the negative effect that this type of buffer-zones could have on operational costs for the field due to the placement of the zones. The higher cost and higher effect may result in a lower cost per reduced kilogram P/ha than for the other type of buffer-zones. There may be a negative effect on land values as this area could lower the profitability of the field. Transaction costs would be higher than for the standard buffer-zones along watercourses because of the need for on-site evaluation. *[Land value change (-); income change (+); transaction costs (-); Sum of MBf = -1; MBi = 4]*

Structural liming

The area that is applicable for this measure encompasses 80 % (6100 ha) of the agricultural fields in the Svärtaån River catchment. The measure is expected to reduce P losses at the edge of the field by 17 % (0.16 kg per ha) in 2020 and by 26 % (0.24 kg/ha) in 2050. At an average cost of 5000 SEK/ha (Brink, 2012; pers. comm.) for an application rate between 5-10 tonnes/ha (depending on the clay content of the soil) that is estimated to have an effect over a 20 year period, then the change in income per kg P reduced is about 1560 SEK in 2020 and 1050 SEK in 2050 The investment in structural liming will also improve the yields and/or reduce the need for other inputs. Both of these would improve profitability and lead to higher land values. Transaction costs are relatively low since the measure is applied once while the effects continue to flow for a number of years. *[Land value change (++); income change (+); transaction costs (+); Sum of MBf = +4; MBi = 9]*

Constructed wetlands
It is expected that there will be 240 ha of wetlands established in the catchment with a focus on nutrient retention. These are expected to reduce transport of total P from fields to the catchment outlet by 16 % in 2020 and 2050. The transport of N to the outlet would be reduced by 11 % in 2020 and 14 % in 2050. Assuming a cost of construction cost (including land) of 200 000 SEK/ha and an annual maintenance cost of 5 000 SEK (the maximum amounts currently paid out under the Rural Development Program). The annual cost for a wetland is approximately 15 000 SEK/ha/yr. For the 240 ha of wetlands the annualized cost is then around 3 600 000 SEK. This reduces to a cost of around 225 000 SEK/percentage unit of reduction of N and one unit of P. This measure reduces P and N losses at the outlet and for P reduction it is more expensive than the cost for structural liming. While there may be an increase in the amenity value of the wetland in general the land value is not expected to change. There will be positive transaction costs (in particular information costs) associated with wetland construction. *[Land value change (0), income change (++), transaction costs (-); Sum of MBf = +1; MBi = 6]*

Sedimentation ponds
Up until 2020 it is expected that sedimentation ponds would be constructed on a total of 14 ha of arable land. This area would increase to 30 ha by 2050. These ponds would reduce the P concentration in inflowing water by 20 % in 2020 and by 40 % in 2050. The estimated construction costs for a sedimentation pond (including land) are 300 000 SEK/ha (Rural Development Program payment level) which annualized over a 20 year period would be approximately 15 000 SEK/yr. This implies a cost of between 750 SEK and 375 SEK per percentage unit of reduction of P at the outlet of the pond which compares favourably to the P reduction income change for structural liming. There are limited amenity values associated with this type of wetland and there may be a decrease in land values due to the placement of the pond. Transaction costs would be similar to that for wetlands. *[Land value change (-); income change (++); transaction costs (-); Sum of MBf = 0; MBi = 5]*

Liming in drains
By 2050 50 % of the arable land in the catchment will have limed trenches over field drainage pipes (tile drains). The limed trenches are expected to reduce the P content of drainage water by 30 %. The material needed for liming the trenches is estimated at 20 t/ha (20 kg structural lime per meter of trench multiplied by 1000 meters of trench/ha i.e. assuming 10 meter trench spacing). The material needed for trench liming is estimated to

be a factor of four higher than for structural liming (estimated at 5-10 t/ha and 5000 SEK/ha). Then costs may be around 20 000 SEK/ha. With an effect time of 25 years these results in an annualized income change of around 800 SEK/yr or a cost of around 26 SEK per percentage unit of reduction of P, which is very low. There might be a positive expected change in land values due to the capital improvement and investment of the measure and as for structural liming transaction costs are very low as the measure is applied only once every 25 years. *[Land value change (+); income change (++); transaction costs (+); Sum of MBf = +4; MBi = 9]*

Table 4.4. *Scenario factors' influence on cost effectiveness factors. X is a scenario factor identifier.*

			2020, 2050		
X	***Scenario-Input-Factor***	***Land***	***Income***	***Transaction***	***MBi***
4	Future scenario	+1	0	0	6
	BAP:				
11a	Adapted N fertilisation	+1	+2	+2	10
11b	Adapted P fertilisation	+1	+2	-1	7
12	Spring cultivation	0	-2	-1	2
13	Catch crop	0	-2	-1	2
14	Buffer-zones, watercourses	0	0	-1	4
14b	Buffer-zones, in fields	-1	+1	-1	4
15	Structural liming	+2	+1	+1	9
16	Constructed wetlands	0	+2	-1	6
17	Sedimentation ponds	-1	+2	-1	5
18	Liming in drains	+1	+2	+1	9

4.5. Soil quality

Future scenario

In 2020 there is only a small change in *climate* in Svärtaån compared with 2005, and temperature increases on average by only ca. 0.1˚C (Appendix 2). This increase would hardly be significant and, if it would, it would decrease SOC by 1.4 %, assuming an increase of 1˚C to decrease SOC by 10 % (Kirschbaum, 1995). Further, because crop yield is increasing there is a counteracting effect tending to increase SOM. The increased yield resulted in increased N fertilisation by 18 kgN/ha (+20 %). Altogether the climate change in 2020 is considered to have a slight positive effect on SOM. In 2050 the average temperature might increase by 0.3˚C to 2.1˚C depending on the month, compared with the Current situation. Increasing temperature might lead to increasing microbial activity and thus decreasing SOM contents. Due to the increased temperature evaporation is increasing as well which leads to potentially reduced decomposition in summer, and also precipitation might decrease although only slightly (-5 %). In winter, on the other hand precipitation is predicted to increase (+25 %). Yields of the Future scenario 2050 are increasing for leys by 25 % which in absolute values might be ca. 1.25 tonnes/ha/yr. It was estimated that ca. 250 kg/ha/yr of organic matter might enter the SOM, based on rough assumptions about the fraction of root mass and other residues of the crop that are returned into the soil. This is a notable but not very high increase of SOM, although expected to be higher than the decrease due to enhanced decomposition. This judgement is supported by that the model predicted an increased need of fertilisation by 26 kg N/ha/yr (+28 % compared with the Current situation) as the modeled increased N supply

by mineralisation was lower than the increased plant demand. By 2020 sowing and harvest dates are changed by less than 3 days compared with the Current situation, which is evaluated to have no significant influence on SOM. Also the distributions of most crop types do not change significantly, except leys which increase its share from 28 % to 37 %, which though, is evaluated to have a minor increasing influence on SOM. The total agricultural land is decreasing slightly (-3 %) which probably enhance SOM for the catchment as a whole. In 2050 spring cereals are sown 14 days earlier and harvested 10 days earlier in comparison with the Current situation. This would influence SOM by means of increased yields, which was considered already above. Longer period between harvest and sowing in autumn might cause a reduction of net input of SOM. Soil moisture might be lower at harvest as it takes place earlier and therefore the risk of soil compaction might be lower. The introduction of maize in 2050 might reduce SOM due to higher erosion potential because maize plants do not cover the soil completely, as do for instance leys. However, the maize cultivation is only 2 % of total arable land, and the slopes are moderate and the negative effect is estimated negligible. In total, land use change is evaluated to have no effects on soil quality. *Animal* influence on SOM would be considered by means of changes in organic fertilization. However, the manure fertilization rate is not changed in the Future scenario. Altogether:
[Future scenario (climate change, Land use, animal) 2020 and 2050: MBf = +; MBi = 6]

Adapted N Fertilisation
Mineral N fertilization is reduced by about -10 % (from 110 to 100 kg N/ha/yr in 2020; no change of organic fertilisation rate) which would decrease the risk of leaching, but might also lead to reduced yield. However, the model results do not show any yield reduction. Therefore, a reduction of N fertilizer by 10 % is considered to have no effect on SOM but a small positive effect on soil quality due to reduced risk of leaching. Also in 2050 N fertilization is reduced by 10 % from its expected optimum.
[Adapted N-fertilization 2020 and 2050: MBf = 0; MBi = 5.5]

Adapted P Fertilisation
By 2020 soil P contents will be reduced by about 10 % on 86 % of all arable land, i.e. from 1.4 g/kg in the Current situation to 1.25 g/kg in 0-30 cm soil depth. Soil P in deeper layers is reduced similarly, but from a much lower level. Plant available and fixed P is assumed to decrease in equal proportions. By 2050 the P content of these soils is assumed to be reduced by another 10 %. Because yield is assumed to not be influenced by these reductions the adapted P fertilization is evaluated to not influence SOM.
[Adapted P-fertilization 2020 and 2050: MBf = 0; MBi = 5]

Spring cultivation
The area of spring cultivation will increase from zero in the Current situation to 46 % of all fields by 2020. Delaying soil cultivation until spring leads to lower decomposition rates during autumn and thus to higher amounts of SOM (Stenberg *et al*., 1999). However, the positive effect is evaluated to be moderate. By 2050 no change in area is assumed, but since the temperature increase during winter is higher than in 2020, the beneficial effect of reduced decomposition is evaluated to be higher.
[Spring cultivation 2020: MBf = +; MBi = 7; and 2050: MBf = +; MBi = 8]

Catch crop
From not being used at all in the Current situation, catch crops will be cultivated on about 23 % of the field area in 2020 and 2050. Catch crops has probably its highest leaching reducing effect on the soil types with most risk of leaching, in this case silty loam soils which is 20 % of the area. Based on model simulations (with SOIL/SOILN models) adapted to field experiments, Blombäck *et al.* (2003) showed that catch crops increased SOM content by less than 2 % per 6 years. This would then correspond to a moderate positive effect on SOM. In the Adaptation scenarios, N leaching is slightly decreased compared with the Future scenarios by this measure (more in 2050 than in 2020), which is also regarded positive for soil quality.
[Catch crops 2020 MBf = +; MBi = 6 and 2050 MBf = +: MBi = 6.5]

Buffer-zones
By 2020 there will be buffer-zones along all ditches, compared with only parts of the system in the Current situation. Vegetation of buffer-zones is not harvested in these areas and would therefore add to the SOM. This means that SOM of the agricultural area of the whole catchment increases. The vegetation of buffer-zones could also prevent wind erosion to reduce SOM of adjacent cultivated soils and thus affect SOM positively. Buffer-zones are expected to reduce particle P discharge in the surface runoff. The fraction of P lost by surface is reduced in the Future scenario 2050, which would make the inflow to the buffer-zones less than in 2020, and SOM would increase less, assuming that SOM is stimulated by the inflow of nutrient rich water.
[Buffer-zones 2020: MBf = +; MBi = 7.5 and 2050: MBf = +; MBi = 7]

Structural liming
The modeled effect of structural liming on most of the arable land (80 %) shows a considerable reduction of P losses and a lot more phosphorus stays in the soil, where it is plant available. Yield is expected to increase because of the liming (cf. Berglund, 1990), due to improved soil structure and nutrient availability. This would increase input to SOM. Liming will also increase pH which would also be positive for yield (Eriksson *et al.*, 2005) and SOM. However the significance of this effect is unclear since the agricultural soils have a relatively high pH already from the beginning, and that the initial effect is expected to decline quickly and approach that from limestone powder ($CaCO_3$; Berglund, 2012; pers. comm.). We here judge liming to have a positive effect on yield despite that this effect was not considered in the scenarios. Although, increased nutrient release would be a result of increased soil fauna activity, which would reduce SOM by degradation, the positive effects on soil quality are judged to be essentially larger. The scenarios assume the P load reduction effect to be 20 % in 2020, and by 2050 to increase to 30 % which would improve the soil quality further.
[Structural liming 2020: MBf = ++; MBi = 8 and 2050: MBf = ++; MBi = 9]

Constructed wetlands
The construction of wetlands on 240 ha would increase SOM on the area concerned although in Svärtaån the wetlands were placed on non-agricultural area. The removed

vegetation might be put on nearby agricultural land, however, in the scenarios the organic fertiliser input was not changed. Therefore, the effect is judged to be zero.
[Constructed wetlands 2020 and 2050: MBf = 0; MBi = 5]

Sedimentation ponds
The sedimentation ponds will capture eroded or disturbed soil that is washed off during rain storms, and protect the quality of nearby water (Palmer-Fegate *et al*., 2011). Conversion of agricultural land into sedimentation ponds will then capture P and SOM that otherwise would have been flushed into the streams. However, this area is very small (0.2-0.4 % of total arable land) and thus regarded non-significant for all agricultural soil of the catchment. Instead, the sediments (including SOM and P) that might be put back on the productive land area when maintaining the ponds, will affect the SOM of the agricultural land positively. This effect might be significant since the amount of P captured in the ponds is large especially in 2050. However, no such return of P to the fields is considered in the scenarios and SOM remain unchanged.
[Sedimentation pond 2020 and 2050: MBf = 0; MBi = 5]

Liming in drains
Drains will be limed in the 2050 Adaptation Scenario in order to bind and thereby reduce the P leaching in the drainage water. This is not affecting the SOM and soil quality of the cultivated area because the water is limed after it leaves the agricultural field.
[Liming in drains 2050: MBf = 0; MBi = 5]

4.6. Water protection

The Future scenarios are not evaluated for their effects on the MB-category "water protection".

Adapted N and P Fertilisation
The Adapted N fertilisation measure reduces the new fertilisation levels by 10 kg N/ha/yr (ca. -10 %) assuming no changes in yields. This would slightly decrease the risk of leaching. Sometimes this measure is connected to oversized yield expectations which results in over fertilization. Since the fertilization levels change only slightly, only a very small positive effect is expected.
[Adapted N and P fertilization 2020 and 2050: MBf = 0 to +; MBi = 5- 6]

Spring cultivation
In the Adaptation scenario, spring cultivation is practiced on 46 % of all fields, compared to 0 % in the Current situation. The prediction is that this measure will reduce the surface runoff slightly (-3 % 2020 and -1 % 2050) which might have a small positive effect and reduce nutrient leaching via surface routes. The actual efficiency of this measure is gained by reduced tillage in autumn and increased vegetation cover during the whole winter period. Since this measure can be applied to large arable land area, the total efficiency is higher than for example the efficiency of buffer-zones, It has been shown by field experiments that when soil is covered by vegetation, there is less erosion and particle bound phosphorus loading (Puustinen *et al*., 2005). However, the total efficiency is deteriorated by the fact that there might be increased leaching of dissolved phosphorus.

To conclude, the efficiency of this measure can be rated at the lowest level of the MB index "strong positive".
[Spring cultivation 2020 and 2050: MBf = + to ++; MBi = 8]

Catch crops
Well established catch crops are effective in reducing nitrate leaching, because they remove nitrate from the soil at the time the leaching takes place. Catch crops absorb nitrogen in autumn before a spring sown crop. The efficiency of catch crops is dependent on the date of sowing and a successful establishment – especially the cruciferous crops require care at the establishment (Baltic Deal project, 2013). Catch crops are used mainly as a measure to reduce the N leaching of the Adaptation scenarios, but might to some extent also reduce the risk of erosion and surface runoff. The use of catch crops on 23 % of all field area in the Svärtaån catchment, both by 2020 and 2050, can have a moderate positive effect on water protection, especially in reducing N loading.
[Catch crop 2020 and 2050; MBf = + to ++; MBi = 7-7.5]

Buffer-zones
Reduction of microorganisms over vegetated buffer-zones depends on width, vegetation, and slope (Dufour *et al*., 2012). In Svärtaån, most of the field area close to waters is classified as being within slope class 3 (5 % slope), which is quite high slope steepness. Adaptation scenarios will lead to some strips being reduced in width compared to the Current situation ,but the total area covered will increase. The risk of surface runoff is highest on steep sloped fields and in times of heavy rains and during the snow melt period. The risk is higher also when the crop is fairly undeveloped so that the soil is poorly covered by the crop. The efficiency of buffer-zones is on the same level or slightly smaller than that of catch crops.
[Buffer-zones 2020 and 2050: MBf = +; MBi = 6-7.5]

Structural liming
This measure has proved to improve soil structure by mainly strengthening the clay aggregates (Ericsson *et al*., 1975; Wistöm, 2012; pers. comm.). The measure is assumed to be effective only on soils with more than 15 % clay, i.e. this criterion is fulfilled on the silty clay loam soils of the Svärtaån catchment. The measure can be applied widely (80 % of arable fields), and therefore its efficiency is expected to be good. However, even if there is very little research studies on the long-term efficiency of structural liming on nutrient loading, the studies done so far have shown that the measure is effective. Therefore, combining these two factors (high efficiency and widely applied) the rating of this measure is the best of all measures applied in the Adaptation scenarios.
[Structural liming 2020 and 2050: MBf = ++; MBi = 8-8.5]

Constructed wetlands
This measure has a great potential for nutrient retention. In the Svärtaån catchment the suggested area of wetlands is 240 ha, which is 3 % of the total agricultural area. Wetlands capacity to retain nutrients is highly dependent on the characteristics of the wetland. They need to be large enough to allow purification processes to occur even under high flow peak events. However, the area of wetlands is only 240 ha and therefore the efficiency is

somewhat limited. In addition, the management of a wetland has a great impact on the retention capacity of the wetland. To conclude, the rating of this measure is smaller than for structural liming but about of the same order of magnitude as for the buffer-zones.
[Constructed wetlands 2020 and 2050: MBf = +; MBi = 6-7.5]

Sedimentation ponds
Sedimentation ponds are smaller than wetlands and therefore their efficiency on water protection can be considered smaller than for wetlands. Due to the smaller size of sedimentation ponds, their capacity to retain nutrients is minor. Commonly one average-sized flow event washes away all the nutrients retained in the pond. The conclusion is that the effect is only very small.
[Sedimentation ponds 2020 and 2050: MBf = 0 to +; MBi = 5-6]

4.7. Summary

To compare the effects of scenario factors among different MB-categories (e.g. GHG emissions and biosecurity), the MB indices (MBi) of BAP measures are listed for each category in Table 4.7. A value > 5 represents a positive effect due to the changes of the adaptation (BAP) measure concerned, and <5 represents a negative change, compared with the Current situation. The MBi value of the Future scenario shows the effect if no changes in the BAP measures would have been made. The MBi values of the BAP measures were evaluated assuming the measure to have been applied in the future situation. In most cases the “unavoidable changes” of the Future scenarios have a beneficial effect on the MB-categories, except for GHG emissions where the increased availability of mineral N at the field scale cause a strong negative effect. The pattern is similar for both 2020 and 2050, except that the positive effects of the “unavoidable changes” disappear for biosecurity in 2050.

The BAP measures applied in the future situation have in most cases a positive effect on the MB-category concerned. In several cases there is no effect. Only for cost efficiency there are negative effects (of applying spring cultivation, catch crops or buffer-zones). Adapted N fertilisation and liming are quite cost efficient, though. Liming is also quite positive for soil quality, mainly due to expected improved crop growth. The adapted N fertilisation is also the most positive measure for GHG-emissions. Most positive for biosecurity are buffer-zones and sedimentation ponds, and for biodiversity wetlands and sedimentation ponds. All measures are positive for water protection, but only structural liming has a quite positive effect, the next best being catch crop.

In case of the GHG-emission evaluations it might be appropriate to combine the MBi values of the separate BAP measures, since they are all based on calculations of the risk of changed soil mineral N. The strongly increased risk of GHG-emissions of climate change (MBi = 0) can hardly be compensated for by the proposed level of adapted N fertilisation reducing the risk (MBi = 8). For the other MB-categories this way of combining effects of different BAP measures are less clear, e.g. to what extent the negative effect of buffer-zones on cost efficiency can be compensated for by the positive effect of climate change.

Table 4.7. *Effects of Scenario factors on the Multiple Benefit index (MBi); Values equal to 0, 5 and 10 represent very negative, no and very large effect, respectively, in the future situation compared with how the situation is currently. Multiple Benefit categories are: GHG (GHG emissions), BioS (Biosecurity), BioD (Biodiversity), Cost (Cost efficiency), Soil (Soil quality), and Water (Water protection). X is a scenario factor identifier used among different scenario works.*

				2020			
X	***Scenario-Input-Factor***	***GHG***[1]	***BioS***	***BioD***	***Cost***	***Soil***	***Water***
4	Future scenario	0	6		6	6	
	BAP:						
11a	Adapted N fertilisation	8	5	5	10	5.5	5.5
11b	Adapted P fertilisation		5	5	7	5	5.5
12	Spring cultivation	5	6	6.5	2	7	8
13	Catch crop	5	6	6	2	6	7.3
14	Buffer-zones		8	6.5	4	7.5	6.8
14b	Buffer-zones in fields				4		
15	Structural liming		6	5	9	8	8.3
16	Constructed wetlands		7	8.5	6	5	6.8
17	Sedimentation ponds		7	8	5	5	5.5
18	Liming in drains		5	5	9		

				2050			
X	***Scenario-Input-Factor***	***GHG***[1]	***BioS***	***BioD***	***Cost***	***Soil***	***Water***
4	Future scenario	0	5		6	6	
	BAP:						
11a	Adapted N fertilisation	8	5	5	10	5.5	5.5
11b	Adapted P fertilisation		5	5	7	5	5.5
12	Spring cultivation	5	6	6.5	2	8	8
13	Catch crop	5	6	6	2	6.5	7.3
14	Buffer-zones		8	6.5	4	7	6.8
14b	Buffer-zones in fields				4		
15	Structural liming		6	5	9	9	8.3
16	Constructed wetlands		7	8.5	6	5	6.8
17	Sedimentation ponds		8	8	5	5	5.5
18	Liming in drains		5	5	9	5	

[1]Evaluations made only for measures assumed to affect N.

The BAP-measure effects might possibly be ranked by identifying which measures that have positive effects on most MB-categories. Quite many measures are positive for four MB's, i.e. spring cultivation, catch crop, buffer-zones, structural liming and wetlands, of which buffer-zones and wetlands have the highest overall record, disregarding the negative effect of buffer-zones on cost efficiency. Least number of positive effects is for liming in drains only improving cost efficiency, although quite much.

Hence, although the MBi's provide quantitative values there are no observations to which they can be compared. Therefore it is difficult to interpret the physical meaning of their values and they need to be used with care.

5. Discussions and conclusions

5.1. GHG emissions

Agriculture significantly contributes to total Swedish GHG emissions, especially as concerns N_2O emissions (70 %) and methane emissions (60 %). Agricultural land is the main source of N_2O emissions, contributing with 44 % of the total GHG emissions from agriculture (SCB et al., 2012). Soils with high organic matter content are important contributors to GHG emissions on a national level representing 10 % of all agricultural land in Sweden (Berglund, 2011). However, in the Svärtaån catchment nutrient load scenarios no such soil types were included. The other main sources are methane emissions from digestion of feed, contributing with 26 % and carbon dioxide emissions from soil, contributing with 12 % of the total GHG emissions from agriculture (SCB et al., 2012). In the Future scenarios 2020 and 2050 the animal density is decreasing, indicating that the Svärtaån catchment area will contribute with less methane emissions from digestion of feed as the number of animals and amounts of manure will decrease. But we might ask whether the increased fodder production in this area would cause increased emissions of methane and N_2O from manure storage (Chadwick et al., 1999), somewhere else to where the feed is exported.

Future scenario: The proportion of leys increase in the Future scenario 2020 and maintains its proportion in 2050. Including perennial crops and crops with deep root systems in the crop rotation by means of leys, has the potential to favor carbon storage in soil (Rees et al., 2005), mitigate N_2O emissions during winter (Gregorich et al., 2005) and reduce nitrate leaching (Watson et al., 2005). In the Future scenarios of Svärtaån yields increased due to more favored climate conditions and increasing amounts of applied chemical N fertilizers. Also, annual soil N mineralization increased considerably (10 kg N/ha in year 2020 and 24 kg N/ha in year 2050) leading to that the risk of N_2O emissions was assessed to increase significantly. It seemed that the higher proportion of temporary leys, which would reduce soil mineral N and potentially mitigate GHG emissions, did not compensate for climate change increasing the soil mineral N. The importance of fertilizer N and soil decomposition for GHG emissions has also been found in other studies, (e.g. Roer et al., 2012, making LCA analyses of spring crop systems).

Adaptation scenarios: The main part of N fertilizers applied was in the form of chemical fertilizers and it was this type of fertilizer that was reduced by 10 % in the scenarios. When assessing risk of N_2O emissions concerning adapted N fertilization both production of N fertilizers and N-use efficiency in crop production needs to be considered (Berglund et al., 2009). In the scenario analyses risk of N_2O emissions during the production steps of N fertilizers were not considered since the boundary of the system is at field level. In a larger system perspective, to which the results of these scenario analysis would be an input, it would be of interest to consider different strategies to (i) receive new N into agricultural system via chemical N fertilizers and biological N fixation, and (ii) re-use N already in the cycle (i.e. animal manure, crop residues, organic N in soil). These larger perspective strategies would then ask for field scale assessments that also include the risk for N_2O emissions of using chemical N fertilizers instead of, or in addition to, biological N fixation as source for N addition to the cropping systems.

Scientific studies comparing N_2O emissions from conventional versus reduced tillage are conflicting, and differences between the two tillage systems are likely to also change over time (Novak and Fiorelli, 2010). Therefore the assessments of the spring cultivation measure in this study are unsure.

In the Adaptation scenario analyses mineralization did not respond to catch crop significantly and consequently it did not influence the risk assessment of N_2O emissions. However, in case the catch crops would have contributed to a yield increase in the main crop, it would have improved the utilization of mineralized N in soil (Doltra and Olesen, 2012) and thus lowered the risk of N_2O emissions.

Summary: The nutrient load scenario factors increased the risk of N_2O emissions from arable land in 2020 and in 2050, compared with the Current situation. With help of the adapted N fertilisation measure an almost neutral influence was achieved. The situation was not improved when combining the measures of adapted N fertilisation and spring cultivation. However, the assessments were conducted at field level and other results would be expected in a larger system perspective including e.g. fertiliser production. The risk of changed methane and carbon dioxide emissions was not assessed. Therefore we have not been able to assess the total influence of agricultural production on GHG emissions in the Svärtaån catchment area.

5.2. Biosecurity

Biosecurity, as regards pathogen transmission to surface waters, mainly depends on animal density and manure handling practices. The predicted decrease in animal density 2020 and 2050 is the single largest factor reducing biosecurity risks in the Svärtaån catchment. Moreover, the decreased proportion of cattle and increased proportion of horses further reduces the biosecurity risks since cattle harbour many zoonotic pathogens such as EHEC, Campylobacter and Cryptosporidium, whereas zoonotic disease transmission from horses rarely has been described.

In general, measures that reduce surface runoff or increase the retention time (sedimentation) were considered to be beneficial for the biosecurity in the Svärtaån catchment. The assessment of pathogen reduction potential of catch crops, spring cultivation, and structural liming was entirely based on their potential to reduce surface runoff to watercourses. No published data on pathogen reducing effect of these measures were found, however, for buffer-zones, constructed wetlands and sedimentation ponds, scientific studies investigating the pathogen reduction potential are available. Generally, though, there are relatively few published data on pathogen reduction of the measures suggested for Svärtaån compared to for instance data on nutrient leakage and therefore further investigations of pathogen reduction potential of these measures are needed.

Constructed wetlands have proven to reduce microbial contamination of surface waters by 2-3 log (Dufour *et al.*, 2012), a reduction potential that would qualify for an MBi of 10. However, the potential disease transmission from the wetland to wildlife and humans was taken into account. Wetlands may serve as an endemic site for disease transmission between wildlife species, aquatic as well as terrestrial. The uncertainty of how important these interactions are for the ecology of zoonotic pathogens was the reason for a lower MBi than for example other measures with similar reduction potential, e.g. buffer-zones. There are, however, several ways to reduce the risk of disease transmission from constructed wetlands, such as use of gently sloping sides, marginal vegetation and by raising public awareness (Carty *et al*., 2008). Moreover, it is recommended that constructed wetlands should in general not be used for bathing, fishing or animal watering. If these safety measures are implemented, the positive effect of constructed wetlands on biosecurity will be rated higher than was reported in this study. Reported microbial attenuation rates of buffer-zones vary between studies and range from zero to complete removal, however most studies report significant reduction rates (40-99 %) (Dufour et al., 2012). In soils with high infiltration capacity, and thus rapid vertical flow, e.g. in well structured clay soils (Collins et al., 2004), the effectiveness of buffer-zones on microbial attenuation will likely be reduced as water may enter watercourses via subsurface flow. Moreover, the effectiveness of buffer-zones is reduced at high-flow conditions (Collins et al., 2004).

In conclusion, most of the measures suggested for the Svärtaån catchment to reduce nutrient leaching have been judged to be positive also for biosecurity, with buffer-zones, sedimentation ponds and constructed wetlands being rated as the most effective measures.

5.3. Biodiversity

In the performance analysis, the best measures for the biodiversity turned out to be constructed wetlands (see Table 4.7). However, to more substantially enhance biodiversity it is essential to develop wide-ranging and hence more effective measures that create larger patches of (permanently) open semi-natural habitat. The efficiency of the measures is difficult to estimate, and, in addition, species typically react to environmental change with a time delay. In the Svärtaån catchment the area covering buffer-zones was estimated to be only 170 ha in 2020 and 2050, which is less than 2 % of the total agricultural land area. It is evident that the effectiveness cannot be very high. The effectiveness of the buffer-zones might be better if such uncultivated zones would be established not only along water ways but also along field-forest edges and along road verges. The buffer-zones are more effective when established in a way that they form a congruent zone (as in the Adaptation scenario with buffer-zones along all watercourses) instead of individual buffer-zones located in separate places.

The area of wetlands in the scenarios (240 ha, 3 % of the total agricultural area) was slightly higher than the area of buffer-zones. Wetlands importantly increase the landscape level habitat variety. The positive impact is seen in the waterfowl, in the number of birds that use the wetland as feeding ground and population that lives in the waterfront area, and in a high number of invertebrate species, such as dragon flies, dependent on small and larger patches of inland water. If the wetland is constructed on the area far from the waterways, its effectiveness in promoting biodiversity is particularly high (Heliölä et al., 2010; Thiere et al., 2010). The management of a wetland has a great impact on the diversity of nature. In conclusion, the buffer-zones and wetlands suggested for the Svärtaån catchment have a positive effect on biodiversity, but mainly locally. More wide-ranging measures (creating larger patches of open semi-natural habitat) are needed to improve the efficiency on biodiversity.

5.4. Cost effectiveness

Cost effectiveness is a relative concept; if the cost to achieve a particular target with one alternative is lower than for another alternative, then the lower cost alternative is more cost effective. For this study the cost impact of the scenarios is evaluated as the load reduction of one nutrient, either phosphorus or nitrogen. Although many of the measures in the Adaptation scenarios that target phosphorus may also reduce nitrogen loads, it is assumed that this is a secondary effect to the primary objective, the reduction of phosphorus loads. If both objectives were to be evaluated at the same time this would require some type of weighting to describe the relative importance of each of these. Using cost per unit of reduction is not sufficient as this implies an implicit weighting and a decision about the relative importance of the two objectives. Therefore each of these effects has been evaluated and described separately. In this study the MB-factor is defined as the cost for reducing either a percentage unit of total phosphorus (TP) or nitrogen (TN), or alternatively a one kilogram unit reduction. However, this definition must also be qualified. There are many other secondary effects associated with each of the scenarios, i.e. the other multiple benefits are considered secondary as they are not the primary target of the scenarios.

The BAP measures and effects evaluated in the economic analysis do not reduce loads in single units. They are regarded as a block of measures which result in a total reduction measured as a percentage or in kilograms. There is a spread of cost per unit of reduction in each of the measures from low per unit costs to high per unit costs. Since the measures are taken as a block (for example liming in 80 % of the agricultural land in the catchment) the cost for the last unit included (marginal cost) may be quite high if the lowest cost measures are assumed to be included first. Using this last unit measure would be the appropriate choice for a cost effectiveness analysis but using the average cost for all the units included in the block would be the marginal cost for the decision to include the measure. Since the purpose of evaluating cost effectiveness in this study is to illuminate the multiple benefit aspect of the scenarios a mixed approach is used. The economic impacts of the scenarios are described individually for each of the measures and an evaluation is performed with respect to the relative economic impact of the measure as a block. For the type of measures to be evaluated this is the change in income for the farmer/landowner, as this is a measure for the net resources used in moving between alternatives and the transaction costs associated with the measure.

Transaction costs are all the costs associated with designing, implementing and maintaining an institutional structure capable of achieving the specified goal (McCann et al., 2005). Transaction costs can be categorized into four general forms: information costs, administration costs, legal costs, and monitoring/reporting costs (Collentine and Meachem, 2011). These costs occur over time through various stages of the environmental policy process. Initially there are costs associated with the design phase of a policy when details of the policy are being formulated and agreed upon by stakeholders (politicians, producers, consumers and administrative authorities). When a policy has reached the point in time that guidelines and regulations are approved and ready for implementation there will then be transaction costs over this adoption stage. Finally, when stakeholders have adjusted to the policy there may continue to be operational transaction costs during this stage which will continue as long as the policy is in place. The results reflect evaluation of transaction costs to both the landowner/farmer as well as authorities involved in the design, approval or monitoring of the measure.

5.5. Soil quality

The soil quality evaluations were based on estimated changes of SOM due to the changes in scenario factors. When SOM losses were of the same magnitude as the highest observed change rates in field experiments of different cropping systems, the effect of the scenario factors on soil quality was graded very negative, when considering SOM alone. Although the definition of soil quality also included the effect on crop performance (Table 3.2), the SOM evaluations were dominant in the evaluations and a positive effect reflects that more carbon will be stored in the soil due to the scenario factors. This would then reflect increased carbon storage and reduced GHG emissions, i.e. a positive effect on the GHG emission category as well in case CO_2 emissions would have been included in that category. However, the higher SOM content was partly a consequence of increased fertilisation and soil mineral N contents that strongly increased the risk of GHG emissions. Generally high SOM content of agricultural soils is regarded a risk factor for GHG emissions (cf. Roer et al., 2012), suggesting that increased soil quality makes GHG emissions more sensitive to agricultural practice.

5.6. Water protection

Based on changes of input factors (e.g. measures and climate change) of the Adaptation scenarios, the best measures enhancing water protection in the Svärtaån catchment were analyzed to be spring cultivation, catch crops, buffer-zones, structural liming and constructed wetlands, of which liming was rated most efficient (Table 4.7).

The main reason for rating catch crops relatively high was their applicability to a large area (23 % of the agricultural land). Catch crops absorb nitrogen in autumn and are very effective in reducing nitrate leaching because they remove nitrate from the soil during periods when leaching takes place. Buffer-zones function as a filter for erosion and phosphorus loading and are most efficient in steep sloped fields where the erosion risk is high. They decrease mainly the losses of particulate bound phosphorus, and they are not that efficient to reduce dissolved phosphorus load. In constructed wetlands water is exposed to many natural water purifying mechanisms. To improve the efficiency of wetlands the size of the wetland compared to the catchment area above it, need to be large enough to let the water stay a long time in the wetland, and waters coming into the wetland must have a high nutrient concentration. It is difficult to estimate the performance of the wetlands without knowing the above mentioned factors.

Some measures are more effective for nitrogen than for phosphorus leaching and therefore the overall covering term water protection might be appropriate for one of them but misleading for another. Catch crops reduce especially nitrate, and buffer-zones seem to be more effective for phosphorus. Wetlands seem to work for both nutrients. Structural liming is a good measure to reduce phosphorus loading. The buffer-zones can purify only the runoff waters that flow via surface runoff from the above field plot. Therefore their efficiency depends a lot on the size of the field plot and also on the crop type that is growing in the above field. The buffer-zones' long term effect (from the year 1991 to 2008) on reducing phosphorus leakage has been examined in a Finnish field study in clay soil (Uusi-Kämppä and Jauhiainen, 2010). When the adjacent field was conventionally tilled, the total solids and total phosphorus removal efficiencies were over 50 % for buffer-zones grown with grass and 27–36 % for vegetated buffer-zones. With other tillage methods the removal efficiency was smaller.

The fields in Svärtaån are typically drained and therefore large parts of water and nutrient flows occur via drains and are thus not influenced by buffer-zones, and the efficiency might be reduced. In a future climate with possibly more extreme weather conditions, the efficiencies of all these measures are deteriorated. To stabilise the soil structure may also improve percolation and thereby decrease phosphorus losses. Trials have shown that phosphorus losses (particulate and dissolved) in these areas can decrease both in drainage water and surface runoff (Ulén et al., 2008). To really improve water protection both wide-ranging and several different measures are needed. In the future, the reduction of nutrient loads might also be improved by making use of the new water purification techniques currently used in the waste water treatment plants.

The analysis of the Adaptation scenarios effects on water protection was here evaluated mainly based on the changes in the input factors of the scenarios. The scenario output factors concern water quality, thus expected to be partly similar to the MB evaluations of water protection. In line with this all the nine measures of the Adaptation scenarios assessed to be beneficial for reducing N and P losses from field (Table 3.3b), also were evaluated beneficial for water protection by our MB evaluations (Table 4.7), and structural liming was evaluated to be the most efficient measure. However, the Adaptation scenarios also propose reduced fertilisation and sedimentation ponds to be among the best measures. The discrepancies and similarities between these two evaluation methods to some extent reflect the uncertainty of the expert judgment methodology used in this study in relation to model assessments.

5.7. Concluding discussion

The expert judgment methodology used in this study (see Table 4.7) might provide good predictions of the effects of BAP-measures on MB-categories, and maybe even better predictions than would be provided by assessments with tested models, if available and applied. However we do not know since the uncertainty in the expert judgment predictions could not be evaluated as they were based on non-transparent subjective evaluations that might differ from time to time. In contrast to this the predictability of assessments made by transparent and tested models would have been possible to evaluate quantitatively. In case of the water protection MB-category we could compare the expert judgment evaluations (Table 4.7) with the modeled nutrient loss assessments of the Adaptation scenario outputs (Table 3.3b). Both methods proposed the same BAP measures to be effective but differed in evaluating their efficiencies, which to some extent reflects the uncertainty in our evaluation methodologies. It should be noted though, that in practice also the model assessments included a number of subjective evaluations due to that all information needed to model these complex agricultural systems, was not available for the catchment concerned.

The answer to the main question of whether the measures adopted to reduce N and P losses from agricultural fields improved or impaired multiple benefits of agriculture, seems to be that they improved. Most of the BAP measures had a positive influence on most of the MB-categories, the clearest exception being liming in tile drains which only improved the cost effectiveness (Table 1). Except for water protection, the biosecurity MB-category was positively influenced by the most measures (6 out of 9) and with soil quality the next highest (5 out of 9). It is less clear how the absolute values evaluated for the MB index, can be compared among MB-categories. However, if we accept the values and sum them up for all MB-categories, structural liming is the most positive measure, followed by buffer-zones and spring cultivation the next, although the cost effectiveness of these latter measures was evaluated to decrease. In the "unavoidable" future (i.e. Future scenarios without any changes in BAP measures) GHG emissions strongly increased. The only measure that mitigated that effect was reduced N fertilisation, providing more arguments for applying reduced fertilisation than only to reduce leaching.

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6. References

Aakkula J., Kuussaari M., Rankinen K., Ekholm P., Heliölä J., Hyvönen T., Kitti L., Salo, T., 2012. Follow-up study on the impacts of agri-enviromental measures in Finland. – Pages 111-128 in OECD: Evaluation of Agri-Environmental Policies: Selected Methodological Issues and Case Studies. – OECD Publishing.

Anderson, 2012. SMA mineral, personal communication (http://www.smamineral.se/)

Andrén, O., Kätterer, T., Karlsson, T., Eriksson, J., 2008. Soil C balances in Swedish agricultural soils 1990–2004,with preliminary projections.Nutrient Cycling inAgroecosystems, 81, 129–144.

Atwill E., Hou L., Karle B.M., Harter T., Tate K.W., and Dahlgren R.A., 2002. Transport of *Cryptosporidium parvum* oocytes through vegetated buffer strips and estimated filtration efficiency. Applied and Environmental Microbiology, 68(11):5517-5527.

Baldock, J.A. and Nelson, P.N., 2000. Soil Organic Matter. (Section B: Soil Chemistry,Chapter 2). In: Handbook of soil sciences. Malcolm E. Sumner (editor in chief). CRC Press LLC, Boca Raton, Florida.

Baltic Compass project, 2013. www.balticcompass.org

Baltic Deal project, 2013. web-page http://www.balticdeal.eu/measure/catch-crops

Bechmann, M., Stålnacke, P., Kværnø, S., Eggestad, H.O. and Øygarden, L. 2009. Integrated tool for risk assessment in agricultural management of soil erosion and losses of phosphorus and nitrogen. Science of the Total Environment 407:749-759.

Berglund, 2012. Kerstin Berglund, Dept. of Soil and Water, Swedish University of Agricultural Sciences, Uppsala. Personal communication.

Berglund, K., Carlgren, K., Nilsson, G. and von Polgár, J., 1990. Markförbättring och odlingsanpassningar på lågavkastande jordar, Report 162, Dept. of Soil Sciences, Div. of Agricultural Hydrotechnics, Uppsala 1990, ISSN 0348-1816, ISBN 91-576-4365-2
Berglund, M., Cederberg, C., Carlson, C., Henriksson, M. and Törner, L. 2009. Jordbrukets klimatpåverkan – underlag för att beräkna växthusgas utsläpp på gårdsnivå och nulägesanalyser av exempelgårdar. Delrapport o Jokerprojektet. Hushållningssällskapet Halland. ISBN:91-88668-63-0. 117 sidor.
Berglund, Ö. 2011. Greenhouse gas emissions from cultivated peat soils in Sweden. Doktorsavhandling, institutionen för mark och miljö, SLU. Acta Universitatis agriculturae Sueciae 2011:2
Blombäck K., Duus Børgesen C., Eckersten H., Gie³czewski, M., Piniewski, M., Sundin S., Tattari S., Väisänen S., Eds., 2013. Productive agriculture adapted to reduced nutrient losses in future climate - Model and stakeholder based scenarios of Baltic Sea catchments. (http://www.balticcompass.org/PDF/Reports/WP5-Productive-agriculture-adapted-to-reduced-nutrient-losses-in-future-climate.pdf) (2013-10-15)
Blombäck, K., Eckersten, H., Lewan, E., Aronsson, H., 2003. Simulations of soil carbon and nitrogen dynamics during seven years in a catch crop experiment. Agricultural Systems, 76, 95–114.
Bohn, H.L., McNeal, B.L., O´Connor, G.A., 2001. Soil Chemistry.3rd Edition. Chapter 6: Soil organic matter p. 155- 170. John Wiley &Sons, Inc., New York.
Bot, A., Benites, J., 2005.The importance of soil organic matter. Key to drought-resistant soil and sustained food production.FAO Soils Bulletin, 80. Food and Agriculture Organization of the United Nations, Rome.
Brandt M., Ejhed H. and Rapp L., 2008. Näringsbelastningen på Östersjön och Västerhavet 2006. Rapport 5815, 95pp, Naturvårdsverket, Bromma (Stockholm).
Braun, J., 2012. Consequences of Adaption scenarios for reduced nutrient leaching on multiple benefits of agricultural production. Case study for effects on Soil Quality in the Svärtaå catchment. Final report. As part of practical training as an Erasmus-student during 04.06.2012 - 31.08.2012 at the Department of Crop Production Ecology, Swedish University of Agricultural Sciences (SLU)
Brink, 2012. Karin Brink Länstyrelsen Södermanlands län, Nyköping. Personal communication
Carty A., Scholz M., Heal K., Gouriveau F., Mustafa A., 2008. The universal design, operation and maintenance guidelines for farm constructed wetlands (FCW) in temperate climates. Bioresour Technol. 2008 Oct;99(15):6780-92. doi: 10.1016/j.biortech.2008.01.045. Epub 2008 Mar 24.
Chadwick, D. R., Sneath, R. W., Phillips, V. R., Pain, B. F., 1999. A UK inventory of nitrous oxide emissions from farmed livestock, Atmos.Environ. 33, 3345-3354.
Clausen, J.C., 1996. National Handbook of Water Quality Monitoring. Part 1. United States Department of Agriculture. Natural Resources Conservation Service.
Collentine, D. and Meacham, M., 2011, Comparative analysis of transaction costs for three alternative programs to reduce the discharge of nutrients to the Baltic Sea from wastewater treatment plants, special report prepared for the Swedish Environmental Protection Agency, Final report NV-05645-11.
Collins R., Donnison A., Ross C., and McLeod M., 2004. Attenuation of effluent-derived faecal microbes in grass buffer strips. New Zealand Journal of Agricultural Research, 47:565-574.
Doltra, J. and Olesen, J. E. 2012. The role of catch crops in the ecological intensification of spring cereals in organic farming under Nordic climate. Europ. J. Agronomy. 44: 98 – 108.
Dufour A., Bartram J., Bos R., and Gannon V. ed., 2012. Animal Waste, Water Quality and Human Health. World Health Organisation, IWA Publishing, London, UK.
Eltun, R., Korsaeth, A., Nordheim, O., 2002. A comparison of environmental, soil fertility, yield, and economical effects in six cropping systems based on an 8-year experiment in Norway. Agriculture, Ecosystems and Environment 90, 155–168.
Ericsson, J., Berglund, G. and Persson, J., 1975. Kalktillstånd, kalk och kalkning, Lantbrukshögskolan, Rapporter från avdelningen frö växtnäringslära, nr 90 1975.
Eriksson, J., Nilsson, I., Simonsson, M., 2005. Wiklanders marklära, Studentlitteratur, Lind. ISBN: 978-91-44-02482-0
Fogelfors, H., Wivstad, M., Eckersten, H., Holstein, F., Johansson, S., and Verwijst, T., 2009. Strategic Analysis of Swedish Agriculture - Production systems and agricultural landscapes in a time of change. *Report 10,* Department of Crop Production Ecology, Swedish University of Agricultural Sciences, Uppsala, Sweden. 68 pp. http://pub.epsilon.slu.se/4626/

Giller K.E., P. Tittonell, M.C. Rufino, M.T. van Wijk, S. Zingore, P. Mapfumo, S. Adjei-Nsiah, M. Herrero, R. Chikowo, M. Corbeels, E.C. Rowe, F. Baijukya, A. Mwijage, J. Smith, E. Yeboah, W.J. van der Burg, O.M. Sanogo, M. Misikom, N. de Ridder, S. Karanja, C. Kaizzi, J. K'ungu, M. Mwale, D. Nwaga, C. Pacini, B. Vanlauwe, 2011. Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. Agricultural Systems 104 (2011) 191–203.

Goel P.K. Rudra R.P. Gharabaghi S. Das, and Gupta N., 2004. Pollutants removal by vegetative filter strips planted with different grasses, American Society of Agricultural Engineers, Annual Meeting, Paper number 042177, ASAE, St Joseph Michigan, USA.

Gregorich, E. G., Rochette, P., VandenBygaart, A. J., Angers, D. A. 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada, Soil Till. Res. 83, 53 – 72.

Grönroos, J., Hietala-Koivu, R., Kuussaari, M., Laitinen, P., Lankoski, J., Lemola, R., Miettinen, A., Perälä, P., Puustinen, M., Schulman, A., Salo, T., Siimes, K., and Turtola, E. 2007. Analyysi maatalouden ympäristötukijärjestelmästä 2000-2006 (Significance of the Finnish agri-environmental support scheme for biodiversity and landscape, Final report 2000-2006. Suomen ympäristö 19/2007, 168 s. (in Finnish).

Gustafson, 2012, pers. comm. Anders Gustafson, Ragnsells waste company.

HELCOM, 2004. Baltic Sea Environment Proceedings, No 93. The fourth Baltic Sea pollution load compilation (PLC-4). Helsinki Commission, 188 p.

HELCOM, 2011. Activities 2011. Overview.Baltic Sea Environment Proceedings No. 132. Helsinki Commission, 50 p. (http://www.helcom.fi/stc/files/Publications/Proceedings/BSEP132%20FINAL.pdf)

Heliölä J., Heikkilä S., Kuussaari, M., 2010. Erityistuella perustettujen kosteikkojen merkitys hyönteisille. – Pages 79-90 in J. Aakkula, T. Manninen and M. Nurro (eds.): Maatalouden ympäristötuen vaikuttavuuden seurantatutkimus (MYTVAS 3) – Väliraportti. Maa- ja metsätalousministeriön julkaisuja 1/2010.

Hildén, M., Lehtonen, H., Bärlund, I., Hakala, K., Kaukoranta, T. and Tattari, S., 2005. The practice and process of adaptation in Finnish agriculture. FINADAPT Working Paper 5, Finnish Environment Institute Mimeographs 335, Helsinki, 28 pp.

HS 2012. HS Konsult, Uppsala (Hushållningssällskapet; personal communication, 2012-06-18)

Hutchings, N. J., Sommer, S. G., Anderssen, J. M. and Asman, W. A. H. 2001. A detailed ammonia emission inventory for Denmark. Atmospheric Environment 35: 1951-1968.

IPCC, 2000. Intergovernmental Panel on Climate Change. IPCC special report – emission scenarios – summary for policymakers. ISBN: 92-9169-113-5

IPCC, 2006. Guidelines for National Greenhouse Gas Inventories – Volume 4 Agriculture, Forestry and Other land use. Chapter 11, N2O Emissions form managed soils, and CO2 emissions form lime and urea application.

IPCC, 2007. Climate Change 2007 – The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [S. Solomon, D. Quin, M. Manning, Z, Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and new York, NY, USA, 996 pp.

JBV, 2004. Swedish Board of Agriculture and Statistics Sweden: *JO 24 SM0501,* Hästar och anläggningar med häst 2004 (Horses and horse establishments in 2004) Resultat från en intermittent undersökning.

JBV, 2010. Swedish Board of Agriculture and Statistics Sweden: *JO 24 SM 1101,* Hästar och anläggningar med häst 2010 (Horses and horse establishments in 2010) Resultat från en intermittent undersökning.

JBV, 2011. Gödsel och miljö 2011. –lagring och spridning av gödsel –höst- och vinterbevuxen mark, Swedish Board of Agriculture

JBV, 2012 [http://www.jordbruksverket.se/amnesomraden/djur/hastar/godsel/ lagragodsel.106.4b00b7db11efe58e66b8000532.html] 2012-05-28

Johnsson, H., Larsson, M., Lindsjö, A., Mårtensson, K., Persson, K. and Torstensson, G., 2008. Läckage av näringsämnen från svensk åkermark. Beräkningar av normalläckageav kväve och fofor för 1995 och 2005. Naturvårdsverket Rapport 5823, 153 pp.

Karlen, D.L., Mausbach, M.J., Doran, J.W., Cline, R.G., Harris, R.F., Schuman, G.E., 1997. Soil quality: A concept, definition, and framework for evaluation. Soil Science SocietyOf America Journal, 61, 4-10.
Kirschbaum, M.U.F., 1995. The temperature dependence of soil organic matter decomposition and the effect of global warming on soil organic carbon storage. Soil Biology & Biochemistry 27: 753-760.
Kleijn, D., Rundlöf, M., Scheper, J., Smith, H.G., Tscharntke, T., 2011. Does conservation on farmland contribute to halt biodiversity decline? Trends Ecol. Evol., 26, 474-481.
Krebs, J. R., Wilson, J. D., Bradbury, R. B. and Siriwardena, G. M., 1999. The second silent spring? Nature 400: 611-612.
Kuussaari, M., Bommarco, R., Heikkinen, R.K., Helm, A., Krauss, J., Lindborg, R., Ockinger E., Pärtel M., Pino J., Rodà F., Stefanescu C., Teder T., Zobel M., Steffan-Dewenter I., 2009. Extinction debt: a challenge for biodiversity conservation. Trends Ecol. Evol., 24, 564–571.
Kuussaari M., Heliölä J., Luoto M., 2004.: Farmland biodiversity indicators and monitoring in Finland. - Pages 29-40 in Groom, G. (editor): Developments in strategic landscape monitoring for the Nordic countries. Nordic Council of Ministers. ANP 2004:705.
Kuussaari, M., Heliölä, J., Pöyry, J., Saarinen, J., 2007. Contrasting trends of butterfly species preferring semi-natural grasslands, field margins and forest edges in northern Europe. Journal of Insect Conservation, 11, 351–366.
Kuussaari, M, Heliölä, J, Pöyry, J, Saarinen, K, Huldén, L., 2005. Developing indicators for monitoring biodiversity in agricultural landscapes: differing status of butterflies associated with semi-natural grasslands, field margins and forest. In: Kühn, Elisabeth, Feldman, Reinart, Thomas, Jeremy A., Settele, Josef (eds.). Studies on the ecology and conservation of butterflies in Europe : Vol. 1: General concepts and case studies. [Proceedings of the Conference held in UFZ Leipzig, , 5-9th of December, 2005]. Sofia, Pensoft. P. 89-91. Pensoft Series Faunistica; 52. ISBN 954-642-247-9
Kuussaari M, Heliölä J, Tiainen J and Helenius J. (Eds), 2008. Importance of the agri-environmental scheme for the biodiversity and landscape. Monitoring under MYTVAS-project 2000–2006. The Finnish Environment 4/2008. Finnish Environment Institute, Helsinki (in Finnish with English summary).
Kätterer, T., Bolinder, M. A., Andrén, O., Kirchmann, H., Menichetti, L., 2011. Roots contribute more to refractory soil organic matter than aboveground crop residues, as revealed by a long-term field experiment. Agriculture Ecosystems and Environment. Volume: 141 Number: 1-2, pp 184–192. [http://dx.doi.org/10.1016/j.agee.2011.02.029]
Larsen R.E., Miner J.R., Buckhouse J.C., Moore J.A.. 1994. Water-quality benefits of having cattle manure deposited away from streams. Bioresource Technology, 48(2):113-118.
Lindqvist, R., Andersson, Y., Lindback, J., Wegscheider, M., Eriksson, Y., Tidestrom, L., Lagerqvist-Widh, A., Hedlund, K.O., Lofdahl, S., Svensson, L., Norinder, A., 2001. A one-year study of foodborne illnesses in the municipality of Uppsala, Sweden. Emerging Infectious Diseases 7, 588-592.
Luoto, M., Rekolainen, S., Aakkula, J., Pykälä, J., 2003. Loss of plant species richness and habitat connectivity in grasslands associated with agricultural change in Finland. Ambio 32, 447–52.
Markensten, 2012. Hampus Markensten, Dept. of Soil and Water, Swedish University of Agricultural Sciences, Uppsala. Personal communication
Malgeryd, J., 2006. Hästgödsel – en naturlig resurs. Så utnyttjar du hästgödsel så bra som möjligt utan att miljön påverkas negativt av hästhållningen. Jordbruksinformation 7 – 2006 [http://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/Pdf_jo/jo06_7.pdf] 2012-06-18
McCann, L., Colby B., Easter K., Kasterine A. and Kuperan K.V., 2005. Transaction cost measurement for evaluating environmental policies. Ecological Economics 52: 527 - 542.
MEA, 2005. Millennium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC. [http://www.maweb.org/en/index.aspx].
Novak, S. M. and Fiorelli, J. L. 2010. Greenhouse gases and ammonia emissions from organic mixed crop-dairy systems: a critical review of mitigation options. Agron. Sustain. Dev. 30: 215-236.
Oliver, D.M., Clegg, C.D., Haygarth, P.M., Heathwaite, A.L. 2005. Assessing the potential for pathogen transfer from grassland soils to surface waters. Advances in Agronomy 85:125-180.
Ottoson, J.R., 2012. Dricksvatten och mikrobiologiska risker från lantbrukens djur. Lantbrukarnas riksförbund, Stockholm.

Ottoson, J., Nordin, A., von Rosen, D., Vinneras, B., 2008. Salmonella reduction in manure by the addition of urea and ammonia. Bioresource Technology 99, 1610-1615.
Palmer-Fegate, E.J., Mortimer, R.J.,Krom, M.D., Jarvie, H.P., Williams, R.J., Spraggs, R.E., Stratford, C.J., 2011. Internal loading of phosphorus in a sedimentation pond of a treatment wetland: Effect of a phytoplankton crash. Science of The Total Environment,409, 2222–2232.
Pitkänen, M. and Tiainen, J. (eds.), 2001. Biodiversity of Agricultural Landscapes in Finland. BirdLife Finland Conservation Series (No. 3). Helsinki: Yliopistopaino.
Puustinen, M., Koskiaho, J., Peltonen, K., 2005. Influence of cultivation methods on suspended solids and phosphorus concentrations in surface runoff on clayey sloped fields in boreal climate. Agriculture Ecosystems and Environment 105, 565–579.
Pöyry J, Luoto M, Heikkinen RK, Kuussaari M, Saarinen K, 2009. Species traits explain recent range shifts of Finnish butterflies. Glob Change Biol 15:732–743.
Rees, R. M., Bingham, I. J., Baddeley, J. A., Watson, C. A., 2005. The role of plants and land management in sequestering soil carbon in temperate arable and grassland ecosystems, Geoderma 128, 130-154.
Roer, A.-G., Korsaeth, A., Henriksen, T.M., Michelsen, O. and Hammer Strømman, A. 2012. The influence of system boundaries on Life Cycle Assessment of grain production in Central Southeast Norway. Agricultural Systems 111: 75-84.
Rounsevell, M. D. A., Ewert, F., Reginster, I., Leemans, R. and Carter, T. R., 2005. Future scenarios of European agricultural land use II. Projecting changes in cropland and grassland. Agriculture Ecosystems & Environment 107 (2-3), 117-135.
Sadok, W., Angevin, F., Bergez, J.-E., Bockstaller, C., Colomb, B., Guichard, L., Reau, R., Messean, A, Dore, T., 2009. MASC, a qualitative multi-attribute decision model for ex ante assessment of the sustainability of cropping systems. Agron. Sustain. Dev. pp 447-461.
SCB, Jordbruksverket, Naturvårdsverket och LRF, 2012. Hållbarhet i Svenskt jordbruk. 119 sidor.
Schröter, D., Acosta-Michlik, L., Arnell, A.W., Araújo, M.B., Badeck, F., Bakker, M., Bondeau, A., Bugmann, H., Carter, T., de la Vega-Leinert, A.C., Erhard, M., Espiñeira, G.Z., Ewert, F., Fritsch, U., Friedlingstein, P., Glendining, M., Gracia, C.A., Hickler, T., House, J., Hulme, M., Kankaanpää, S., Klein, R.J.T., Krukenberg, B., Lavorel, S., Leemans, R., Lindner, M., Liski, J., Metzger, M.J., Meyer, J., Mitchell, T., Mohren, F., Morales, P., Moreno, J.M., Reginster, I., Reidsma, P., Rounsevell, M., Pla, E., Pluimers, J., Prentice, I.C., Pussinen, A., Sánchez, A., Sabaté, S., Sitch, S., Smith, B., Smith, J., Smith, P., Sykes, M.T., Thonicke, K., Thuiller, W., Tuck, G., van der Werf, G., Vayreda, J., Wattenbach, M., Wilson, D.W., Woodward, F.I., Zaehle, S., Zierl, B., Zudin, S. and Cramer W., 2005. ATEAM Final report 2004, Section 5 and 6 and Annex 1 to 6, Detailed report, related to overall project duration Reporting period:01.01.2001-30.06.2004., 139 pp.
SMHI, 2011. Swedish Meteorological and Hydrological Institute. http://www.smhi.se/klimatdata/klimatscenarier/scenariodata/1.6200
Söderström, A., Osterberg, P., Lindqvist, A., Jonsson, B., Lindberg, A., Blide Ulander, S., Welinder-Olsson, C., Lofdahl, S., Kaijser, B., De Jong, B., Kuhlmann-Berenzon, S., Boqvist, S., Eriksson, E., Szanto, E., Andersson, S., Allestam, G., Hedenstrom, I., Ledet Muller, L., Andersson, Y., 2008. A large Escherichia coli O157 outbreak in Sweden associated with locally produced lettuce. Foodborne Pathogens and Disease 5, 339-349.
Steineck, S., Svensson, L., Jakobsson, C., Karlsson, S. and Tersmeden, M., 2000. Hästar – gödselhantering, Teknik för lantbruket 82, JTI
Stenberg, M., Aronsson, H., Lindén, B., Rydberg, T., Gustafson, A., 1999. Soil mineral nitrogen and nitrate leaching losses in soil tillage systems combined with a catch crop. Soil and Tillage Research, 50, 115-125.
Swedish Environmental Code, 2012. Miljöbalken > Förordning (1998:899) om miljöfarlig verksamhet och hälsoskydd" (updated until SFS 2011:996), Appendix, section 1 [http://www.notisum.se/rnp/sls/lag/19980899.htm] (2012-11-06)
Tate, R.L.,1987. Soil organic matter.Biological and ecological effects. John Wiley & Sons, Inc., New York.
Thiere, G., Milenkovski, S., Lindgren, P.E., Sahlen G., Berglund, O., Weisner, S.E.B., 2010. Wetland creation in agricultural landscapes: Biodiversity benefits on local and regional scales. Biological Conservation 142:964—973.
Tilman D., Fargione J., Wolff B., D'Antonio C., Dobson A., Howarth R., Schindler D., Schlesinger W.H., Simberloff D., Swackhamer D., 2001. Forecasting agriculturally driven global environmental change. Science 292, 281–284

Tiainen, J. 2004. Maatalousympäristön historia. In J. Tiainen, M. Kuussaari, I. Laurila, T. Toivonen (eds.). Elämää pellossa – Suomen maatalousympäristön monimuotoisuus. Edita Helsinki, pp. 26-40. (in Finnish).
Thomas J.A., Telfer, M.G., Roy, D.B., Preston, C.D., Greenwood, J.J.D., Asher, J., Fox, R., Clarke, R.T., Lawton, J.H., 2004. Science 19, Vol. 303, No. 5665, pp. 1879-1881.
Tornevi, Forsberg, 2012. Samband mellan nederbörd uppströms ett dricksvattenverk och samtal till sjukvårdsupplysningen gällande mag-tarm symtom. Åttonde Nordiska Dricksvattenkonferensen, Stockholm18-20 juni 2012.
Turtola, E., Paajanen, A., 1995. Influence of improved subsurface drainage on phosphorus losses and nitrogen leaching from a heavy clay soil. Agricultural Water Management 28, 295–310.
Tyrrel S.F., Quinton J.N., 2003. Overland flow transport of pathogens from agricultural land receiving faecal wastes. J Appl Microbiol. 2003;94 Suppl:87S-93S.
Ulén, B., Aronsson, H., Bergström, L., 2008. Åtgärdskatalog, För minskade fosfor- och kväveförluster från jordbruk till vatten, Institutionen för Mark & Miljö, SLU.
USDA, 2003. National Water Quality Handbook. United States Department of Agriculture Natural Resource Conservation Service, 368 pp.
Uusi-Kämppä, J., Jauhiainen, L., 2010. Long-term monitoring of buffer zone efficiency under different cultivation techniques in boreal conditions. Agriculture, Ecosystems and Environment 137 1-2: 75-85.
Van Swaay, C., Warren, M., Loïs, G., 2006. Biotope use and trends of European butterflies. J. Insect Conserv., 10, 189-209.
Vinten, A. J .A., Sym G., Avdic K., Crawford C., Duncan, A., Merrilees D.W., 2008. Faecal indicator pollution from a dairy farm in Ayrshire, Scotland: Source apportionment, risk assessment and potential of mitigation measures. Water Research, 42 (4-5):997-1012.
Watson, C. A., Oborn, I., Eriksen, J., Edwards, A. C. 2005. Perspectives on nutrient management in mixed farming systems, Soil Use Mange. 21, 132-140.
Widén F., Sundqvist L., Matyi-Toth A. Metreveli G., Belák S. Hallgren G., and Norder H., 2011. Molecular epidemiology of hepatitis E virus in humans, pigs and wild boars in Sweden. Epidemiology and Infection, 139(3): 361-71.
Wiström, 2012. Dennis Wiström, Länsstyrelsen I Södermanland. Agricultural advisor in the Svärtaån catchment. Personal communication
Öborn, I., Magnusson, U., Bengtsson, J., Vrede, K., Fahlbeck, E., Jensen, E.S., Westin, C., Jansson, T., Hedenus, F., Lindholm, Schulz, H., Stenström, M., Jansson, B., Rydhmer, L., 2011. Five Scenarios for 2050 – Conditions for Agriculture and land use. Uppsala, Swedish University of Agricultural Sciences. ISBN: 978-91-576-9032-6. (www.slu.se/framtidenslantbruk)
Öborn, I., Bengtsson, J., Hedenus, F., Rydhmer, L., Stenström, Vrede, K., Westin, C., Magnusson, U., 2013. Scenario Development as a Basis for Formulating a Research Program on Future Agriculture: A Methodological Approach. Ambio, Vol. 42(7), 823-839

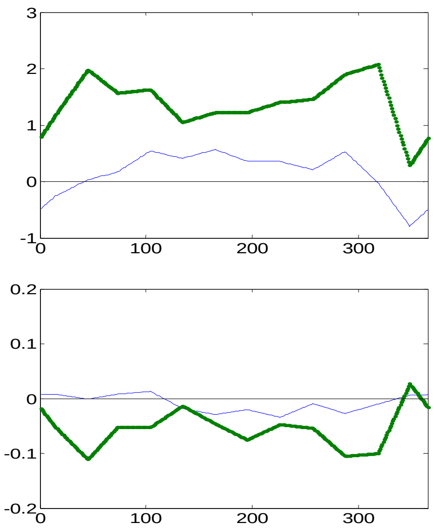
7. Appendices

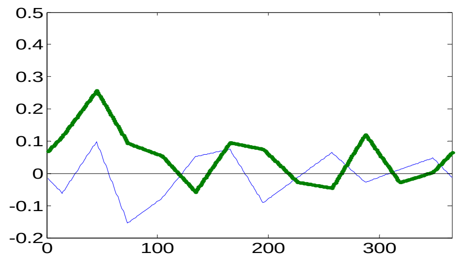
7.1. Appendix 1: List of symbols

TPC_F= Mean P concentration of total run off from field (mg/l)
TP_F= Total P leached from field (kg P/haF/yr)
S/T_P= Surface to Total P leaching ratio (%)
TP_O= Total annual P loads at the Outlet of the main river (kg P/haL/yr)
TP_{FO}= The same as TP_O but with wetland introduced as a BAP measure (kg P/haL/yr)
TPC_O= Mean P concentration in the Outlet of the main river (mg/l)
$TP_{F/O}$ = Fraction of total P loads at the Outlet of main river that originates from the field area (%)
TPC_S = Mean P concentration in the outlet of sub-catchments of the main river (mg/l)
TN_F= Total N leached from field (kg N/haF/yr)
TNC_F= Mean N concentration of total run off from field (mg/l)
TN_O = Total annual N loads at the Outlet of the main river (kg N/haL/yr)
TNC_O= Mean N concentration in the Outlet of the main river (mg/l)
TN_{FO}= Total annual N loads at the Outlet of the main river that originates from field area (kgN/haF/yr)
$TN_{F/O}$ = Fraction of total N loads at the Outlet of main river that originates from field area (%)
S/T_W= Surface to Total water runoff ratio (%);
VS = Vegetation period start (Month, day);
VE = Vegetation period end (Month, day)
haF = per ha Arable area (also named Field = Agricultural area – pasture area)
haA = per ha Agricultural area (=Arable + pasture area)
haL = per ha total land area

7.2. Appendix 2: Climate change

Climate change scenarios were used for two 30-year periods centred on 2020 and 2050, respectively. The climate change scenarios (Echam5-r3) based on IPCC A1b-emission scenario (IPCC, 2000) were used and taken from SMHI (2011).





Figures 7.2a-c. *Svärtaån climate change scenarios for 2020 (thin solid line) and 2050 (thick dotted line), respectively, as monthly differences (°C; temperature) or ratios (-; other variables) to the 30-year period centred on 1995. a (upper left) is temperature, b (upper right) is precipitation and c is global radiation, respectively. X-axis is day number from January 1.*

In 2020 air temperature changes were small ranging between -0.1 and +0.5°C, and for precipitation the change was ± 10 %, compared with the Current situation. The solar radiation (global radiation) generally decreased only a few percent. In 2050 the temperature increase ranged from +2°C in February and November as most to +0.3°C in December as least. Otherwise, in general the smallest temperature increases occurred during the summer months. The precipitation changes ranged between +25 % in February and -5 % in May. The solar radiation generally decreased under climate change, although at most about 10 %, and then during the dark period of the year (Figures 7.2a-c).

7.3. Appendix 3: Land use

Table 7.3a. *Svärtaån: Changes in sowing and harvest dates compared with 2005. (From Blombäck et al., 2013)*

	~2020	***~2050***
Crop type	***Change***	***Change***
Sowing date spring cereals (not maize)	-3 days	-14 days
Sowing date maize	0	ca.15 May
Harvest date winter cereals	-3 days	-10 days
Harvest date spring cereals (not maize)	-3 days	-10 days
Harvest date green maize	0	ca.20 October
Sowing date winter cereals	no change	[a]

[a]Increase the number of days between sowing date and the end of vegetation period by 5 days

Table 7.3b. *Svärtaån: Crop distribution (%) and change in land use. (From Blombäck et al., 2013)*

	2005	*2020*	*2050*
Crop type	***(%)***	***(%)***	***(%)***
Spring_barley	18	18	18
Winter_wheat	14	14	14
Ley	28	37	36
Fallow	19	17	17
Oats	10	1	1
Spring_wheat	5	5	5
Winter_rye	2	2	2
Spring_rape	4	5	5
Maize	0	0	2
Stubble_fallow	9	7	7
% change compared with 2005			
Total arable land	-	-3	-3
Urban area	-	4	4

7.4. Appendix 4: Animals

7.4.1. Animal trends

Table 7.4.1a. *Changes in number of animals during 15 years for the catchment of Svärtaån[4], the municipality of Nyköping[5], and Södermanland County[6], respectively. Values for 2020 are extrapolations of annual value trends, 2001-2010, by linear regression. The column to the right, 2015, is estimated by a 15-year extrapolation of the linear trend of three values; 1995, 2000 and 2005*

		Average 2001-2010	***2020***	***Average 1995-2005***	***2015***
Animal	***Region/location***	***k=1000 Nr***	***Change 15yr***	***k=1000 Nr***	***Change 15yr***
Dairy cows	Södermanland	12k	-47%	15k	-100%
	Nyköping	1.8k	-9%	2.4k	-100%
	Svärtaån			0.6k	-100%
Bovine animals (all cows)	Södermanland	51k	-21%	59k	-100%
	Nyköping	10k	-29%	11k	-53%
	Svärtaån			2.8k	-95%
Pigs [a]Porker	Södermanland	66k	-27%	40k[a]	+234%
	Nyköping	7k	-6%	3.8k[a]	-26%
	Svärtaån			2.1k[a]	+47%
Hens/Chickens [b]Hens	Södermanland	969k	+20%	234k[b]	+23%
	Nyköping			42k[b]	-100%
	Svärtaån			2.1k[b]	-100%
Sheep	Södermanland	219k	+69%		
	Nyköping	4k	+69%		
Horses[1]	Södermanland	4.1k	+56%	3.4k	+39%
	Nyköping	0.8k	+63%	0.7k	+24%
	Svärtaån			0.4k	+24%
Livestock Units[2]	Svärtaån			2.9k	-83%
Livestock Density[3]	Svärtaån			0.17	

[1]Numbers of horses at agricultural holdings. Approximately 1/3 of all horses in the area.
[2]Swedish Livestock Units: The reference unit used for the calculation of one animal unit is one adult bovine animal equivalent to horses 1, young bovine animals (heifers, steers > 1 yr) 2, Calves (> 1 yr) 4, Sows 3, Porkers (>3 month) 10, Piglets (<3 month) 20, Lamb and sheep 10, and Poultry (hens, chicken, broilers) 100 (see further [4]).
[3]The Livestock Density is calculated on the basis of required spreading area in relation to available fields and grazing areas; 30 % of the required spreading area may consist of grazing area outside arable fields (see further [4]).
[4]Statistics Sweden Statistical data for drainage areas 1995, 2000 and 2005; Na 11 SM 9701, MI 11 SM 0301, MI 11 SM 0701corrected version
[5]Swedish Board of Agriculture Database yrs 1999, 2003, 2005, 2007, 2010
[6]Swedish Board of Agriculture Database yrs 2001 - 2010

Table 7.4.1b. *2020 scenarios of changes in production and consumption of animals, % of red meat of whole meat consumption, and the consumption to demand ratio. All scenarios refer to Europe.*

	SCENAR 2020 II Ref. scenario / Lib. (EU15) Δ%(2020-2005)[1]	***SCENAR 2020 II Lib. scenario (EU27) Δ%(2020-2005)[1]***	***ATEAM 2020[3] A1F1, A2 (High tech)***	***ATEAM 2020[3] B2 (Extensive)***
Production				
Beef[2]	-10 / -40			
Poultry	+10 / 0			
Pork	+5 / 0			
Cheese	+20 / +20			
Consumption				
Beef[2]	-10 / +5			
Poultry	+10 / +5			
Pork	+5 / 0			
Cheese	+10 / +10			
Meat/capita		+10%		
%Red meat		from 21% to 18%		
Consumption/Demand ratio (year 2000 =1)				
Agric. fields products			1.25, 1.14	1.06
Grassland products			0.85, 0.91	0.91

[1]Approximated readings from graphs; Ref. and Lib. are the Reference and Liberalization scenario, respectively

[2] Modeled as an independent activity. There is positive cross-price elasticity between beef and milk production, but the price elasticity of beef dominates the supply response. The strong supply response in the Lib. scenario is due to the response of specialized beef production, not including the supply response of dairy cows. Price elasticity show how many % the demanded quantity of the product changes when the price increases by 1 %. Normally it is a negative value, i.e. the demand decreases when the price rises.

[3]Rounsevell *et al*., 2005 (see also Fogelfors *et al*., 2009)

Table 7.4.1c. *2050 scenarios of consumption of animals and plants and the consumption to demand ratio. All scenarios refer to Europe. BLM is the % of Beef/Lamb/Milk meat of all meat consumption*

	FA[1], SLU, 2050 Scenario1,2,3 (High tech)	***FA[1], SLU, 2050 Scenario 4 / 5 (Extensive)***	***ATEAM 2020[3] A1F1, A2 (High tech)***	***ATEAM 2020[3] B2 (Extensive)***
Animal% / Plant% based consumption	10 / 90 or 30 / 70 BLM=45-50%	20 / 80 BLM=30%		
Consumption/Demand ratio (year 2000 =1)				
Agric. fields products			1.51, 1.31	1.09
Grassland products			0.87, 0.67	0.67

[1] Current situation = 28 / 72 and BLM=48% (FAOSTAT; FA, SLU)

[2] Future Agriculture, SLU (Öborn *et al*., 2011 ; 2013)

[3]Rounsevell *et al*., 2005 (see also Fogelfors *et al*., 2009)

7.4.2. Livestock manure

Table 7.4.2a. Production of P from livestock (JBV, 2011)

Type of animal and production	**Specification**	**Standard value for extracted kg P/yr**
Bovine animals		
Cow for milk prod.	6 000 kg milk/yr	14.9
	8 000 kg milk/yr	15.9
	10 000 kg milk/yr	17.4
	12 000 kg milk/ yr	19.1
Heifers and steers 1 – 12 months (1)		3.1
Bull < 1 yr		5.0
Heifers, bulls and steers 1 yr and above		8.0
Suckler cow		12.0
Pigs		
Porker	3 batches/yr, per place	2.3
	3.5 rounds/yr, per place	2.7
Sow*	Trad. Prod., 2.2 litters/yr	10.3
	Sow pool, hub: placement in satellite 3 w. before litter, per sow	4.2
	Sow pool, hub: placement in satellite 7 w. before litter, per sow	3.1
	Sow pool, satellite: placement in satellite 3 w. before litter, per place with 3.26 litters/yr	9.1
	Sow pool, satellite: placement in satellite 7 w. before litter, per place with 3.26 litters/yr	10.7
Poultry		
Broilers	7 batches/yr, per place (phytase add. in feed)	0.057
Laying hens	Enriched cages, per place (phytase add.)	0.13
	On floor or grass, per place (phytase add.)	0.15
Young hens	0 – 16 v., 2.2 batches/yr (phytase add.)	0.059
Turkey, duck, geese, per place		0.24
***Equidae** (hoarse, donkey)*		
	Horse	8.9
	Pony (300 kg)	6.4
Sheep and goat		
	Sheep, female with 1.8 lambs	1.5
	Goat 800 kg milk	1.7
Other animals		
Rabbit	Female incl. 32 kits/yr	1.6
Mink	Female, male and 4.5 – 5 pups/yr	1.1
Ostrich for meat prod.		3.9

Table 7.4.2b. Production, storage and losses of N from livestock (JBV, 2011)

		(kg N per animal and yr)		
Type of animal	**Type of manure**	**Total N extraction**	**Losses stable/storage**	**Left after losses**
Bovine animals				
Cow for milk prod. 8 000 kg milk/yr	Liquid manure	117	12	105
	Solid manure	71	17	54
	urine	46	11	35
Cow for milk prod. 10 000 kg milk/yr	Liquid manure	139	14	125
	Solid manure	85	20	65
	urine	54	13	41
Heifers and steers 1 – 12 months	Liquid manure	22	1.5	21
Suckler cow, 12 months	Liquid manure	63	4.3	59
	Deep bedding system	69	30	39
Pigs[1]				
Porker, 28.5 – 110 kg, 3 batches/yr	Liquid manure	11	1.9	9.1
Sow, 2.2 litters/yr	Liquid manure	36	6.3	30
	Solid manure	21	6	15
	Urine	15	4	11
Sow in satellite, incl. piglets 3 w. up to 28.5 kg, 3,26 litters/ yr	Liquid manure	30	5	25
Poultry				
Broiler, 7 batches/yr	Deep bedding system	0.28	0.05	0.23
Laying hens, cage 60 w.	Semi-solid manure	0.52	0.09	0.43
Laying hens, floor 60 w.	Semi-solid manure	0.6	0.14	0.46
Chickens (”unghöns”) 0 – 16 v. 2.2 batches	Deep bedding system	0.22	0.08	0.14
Equidae *(hoarse, donkey)*				
Horse, 500 kg, race	Solid manure	61	26	35
Horse, 500 kg, recreation	Solid manure	48	20	28
Pony, 300 kg	Solid manure	33	14	19
Sheep and goats				
Sheep incl. 1,8 lambs	Deep bedding system	14	6.4	7.6

[1]In the sow pool production system of one unit (the hub) delivers pregnant sows to several other units. In the satellite units the sows litters and is thereafter transported back to the hub. At the hub the sows are again inseminated. At the satellites the piglets are bred until sold or ready for slaughter.

7.4.2. Horses

Between two assessments (JBV, 2004 and 2010) the increase of horses between 2004 and 2010 was estimated to be 10 – 20 % in all counties but Södermanland and Norrbotten (where it was not estimated due to that methodological improvements were made between 2004 and 2010 implying that the 2004 records needed to be increased by 20 000 – 45 000 animals). In the County of Södermanland in 2004 the share of horses that was registered at agricultural holdings was 35 % of the total amount. In 2010 the value was excluded as the standard error of estimate was high (> 35 %).

Storage capacity of horse manure in sensitive coastal areas should exceed 8 months in case Livestock units (bovine, horse, sheep, goat) exceed 10, and 6 months for Livestock units being between 2 and 10 (JBV, 2012).

A horse of > 500 kg produces ca. 8 – 10 tons of faeces and urine per year. A small horse produces about a quarter of this (Steineck *et al*., 2000). According to a survey in 2001, 52 % of the horse manure was recycled to arable land, 4 % to landfill, 4 % to other use than landfill on disposal plant, 10 % to soil improvement, 5 % to other uses, and for 25 % the disposal was unknown. The trend that can be seen is that the EU regulations make it more complicated for horse owners to get rid of the manure in a legal way, and waste companies have been taking a larger share of the waste. The share of horse manure that is recycled to arable land has probably decreased slightly during the last years (Gustafson, 2012, pers. comm.). If the feed is produced on the farm where the horses are kept, manure is usually spread on farmland. In stables close to urban areas with no spreading area available the manure is stored in containers. The manure is then taken care of in a waste facility (HS, 2012, pers. comm.).

A survey (spring 2005) in Östergötland County, just south of Södermanland County, revealed that 82 % of 387 horse owners declared that manure from their horses was spread on farmland. Since January 2005 it is forbidden to deposit organic waste in landfills. It is however still common that horse manure is delivered to waste facilities where it is incinerated or used in other ways, as remediation in soils polluted by waste oils or as add-mixer in filling compounds (Malgeryd, 2006).

7.4.3. Poultry

Storage capacity of poultry manure in sensitive coastal areas should exceed 10 months in case livestock units (other animals than bovine, horse, sheep and goat) exceed 10; and 6 months for Livestock units being between 2 and 10 (JBV, 2012).

7.5. Appendix 5: Evaluation example

As an example of the MB-factor evaluation method, we here chose N mineralisation as the MB-factor (MBf; which could for instance represent a MB-category like "soil nutrient supply capacity). First we need to define the scale of assessment [--, -, 0, +, ++] in terms of kg N. Let us assume that a change of more than 20 kg N/ha/yr is regarded large [-- or ++] and change < 5 kg N/ha/yr as no change [0]. Then in 2020 we have:

(i) Future scenario tells us that climate becomes warmer, yield increases and fertilisation increase, which imply that mineralisation increases. To get a quantitative value we use the nutrient model outputs of the Adaptation scenario which gives that mineralisation increases from 104 in the Current situation (C) to 114 kg N/ha/yr in the Future scenario 2020 (F) (i.e. +10kg N/ha/yr).

We rate this change as: Mineralisation(F-C) = +

(ii) The Adapted N fertilisation measure (in the Adaptation scenario) tells us that fertilisation will be reduced, which implies that mineralisation will decrease. The model outputs are used again: N mineralisation decreases from 114 in the Future scenario 2020 to 110 kg N/ha/yr in the Adaptation scenario 2020 (A) (i.e. - 4kg N/ha/yr).

We rate this change as: Mineralisation(A-F) = 0
(iii) Then we get the difference between the Adaptation scenario and the Current situation by summing this up (i.e. + and 0) to equal Mineralisation (MBf; A-C) = +
(iv) Since we in this case had a model that could estimate the MBf-value quantitatively it would have been better to use the model outputs of the difference between the Adaptation scenario and the Current situation, directly. Then we get N mineralisation = 110-104 = +6 kg N/ha/yr, which, in this case gave the same answer:
Mineralisation (MBf; A-C) = +

Doing the corresponding evaluation for 2050 we get:
(i) The Future scenario tells us that climate becomes even warmer than in 2020, and yield and fertilisation increase even more, which implies that mineralisation increases even more as well. The model outputs is used again: Mineralisation increases from 104 in the Current situation to 127 kg N/ha/yr in the Future scenario 2050 (i.e. +23kg N/ha/yr).
We rate this change as: Mineralisation (F-C)= ++
(ii) The Adapted N fertilisation measure tells us that fertilisation is reduced, which implies that mineralisation decreases. The model outputs again: N mineralisation decreases from 127 in the Future scenario 2050 to 122 kg N/ha/yr in the Adaptation scenario 2050 (i.e. - 5kgN/ha/yr).
We rate this change as: Mineralisation (A-F) = –
(iii) We sum this up (i.e. ++ and -) to equal Mineralisation (MBf; A-C) = +
(iv) The more proper calculation method is to use the model outputs of the difference between the Adaptation scenario and the Current situation, directly. Then we get N mineralisation = 122-104 = +18 kg N/ha/yr which gives:
Mineralisation (MBf; A-C) = +

Also in this case we got the same answer with both methods. However, this depends on how we defined the scale [--,-,0,+,++]. Other limits for + and ++ might result in that the two methods differ. If the model is believed to be reliable, the model approach would be the most proper. The assessments of effects on the MBf ultimately depend on the method used. The methods differ depending on the MBf to be assessed. In this example we used the nutrient load model to assess the changes in the N mineralisation. However, established transparent methods for quantitative assessments (models and experiments) are often not available, and in most cases expert judgements were used (Table 3.3).

The MB-index (MBi), that represents a whole MB-category, is thereafter evaluated based on the MB-factor (MBf). In this case, where the MB-factor is N mineralisation, the MB-catergory might be for instance “soil nutrient supply capacity”. This category concerns more nutrients than N and further judgements are needed. A scale for converting MBf into MBi is needed to be introduced. The conversion from MBf to MBi is regarded quite complex and expert judgement is the main methodology in the current study. The assessed changes in the MBi:s refer to the differences between the Adaptation scenario and the Current situation.