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Adaptation to Climate Change by Agri-Environmental Policy in Finland

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Abstract: An agri-environmental subsidy program that states water protection as one of its main objectives has been in place in Finland since 1995. The programme is the main tool within Water Framework Directive (WFD) to control nutrient load from agricultural areas in Finland. In this work we created story-lines for agricultural production influenced by climate change on a small agricultural catchment in southern Finland. We used dynamic, catchment scale model to simulate the influence of increased precipitation and temperature on runoff and nutrient leaching with and without different water protection methods, including the changes in production and field use. This study showed that it is possible to decrease inorganic N load by correct combination of crop and water protection methods. The most effective method is nutrient cycling (organic farming) though that happens on the cost of yield. If the target is to reduce suspended sediment load, more effective and/or targeted measures are needed.

Keywords: water protection; nutrient leaching; climate change; agricultural production

1 INTRODUCTION

The ecological state of the Baltic Sea and the inland waters has raised interest to reduce nutrient losses from anthropogenic sources. At an international level, the Ministers of Environment of the Baltic Sea States decided that anthropogenic loading to the Baltic Sea should be reduced by 50% from 1987 levels by the year 1995. More recently, the Helsinki Commission (HELCOM) negotiated the Baltic Sea Action Plan that aims at cutting phosphorus (P) and nitrogen (N) inputs to the Baltic Sea by 42% and 18%, respectively, from the average loads of 1997–2003 by the year 2016. Finally, the main goals of the EU Water Framework Directive is to achieve good ecological and chemical status for all inland and coastal surface waters by the year 2015 (WFD, 2000), and the Marine Strategy Framework Directive aims at achieving or maintaining a good environmental status of European marine waters by 2020 (MSFD 2008).

On a national level the Finnish Council of State issued a Decision-in-Principle on the water protection targets to 2005 (Ministry of the Environment 1998). These failing to be met, new targets to be achieved by the year 2015 were set down in 2006. The key objective is that nutrient loads entering water bodies from agriculture should be reduced by a third compared to their levels over the period 2001–2005. Further, Prime Minister Matti Vanhanen set a national target for nutrient re-cycling in Finland (Baltic Sea Action Summit 2010) recognising the problem that energy and nutrients are resources not to be wasted.

In Finland, water protection policy concentrates on agriculture, as it comprises the largest source of nutrients into water bodies. An agri-environmental subsidy program that states water protection as one of its main objectives has been in place in Finland since 1995. The programme is the main tool within Water Framework Directive (WFD) to control nutrient load from agricultural areas in Finland. The annual agri-environmental support totals some 300 M€ and forms a significant part of Finland's environmental policy expenses.

At the same time risks for surface and groundwater quality are seen in Finland's National Strategy for Adaptation to Climate Change. Expected increase in temperature and precipitation (Ruosteenoja et al. 2011) will lead to milder winters and increase in non-point source loading from catchments dominated by agriculture due to enhancing runoff, floods and decay of organic matter. At the same time conditions during growing season will alter leading to changes in crop production, which should be taken into account when evaluating the effects of climate change on nutrient loading.

In this work we evaluated the options to achieve the goals of nutrient reduction in change of climate and other agricultural policies. Target years were 2040-2069 when climate change is already visible, but we can influence to land use by political decision made now. We created storylines for agricultural production influenced by climate change on a small agricultural catchment in southern Finland. We used a dynamic, catchment scale model to simulate the influence of increased precipitation and temperature on runoff and nitrogen and suspended sediments transport with and without different water protection methods, including the changes in production and field use. Our aim was to answer the question whether the concern of increase in nutrient loading due to climate change is justified, or is it possible to compensate that with either water protection measures defined in agri-environmental policy and other political targets or climate change induced changes in agricultural production.

2 MATERIALS AND METHODS

2.1 Catchment Description

Lepsämänjoki catchment (214 km^2, 30-95 m.s.l) is a sub-basin of the Vantaanjoki river basin (Fig. 1) in southern Finland. The river Lepsämänjoki is divided into two branches. The main river is meandering slowly in the middle of the fields while the tributary collects waters from forested upland area. The river is also prone to floods, especially during snow melting. The mean discharge in the river Lepsämänjoki was 2.2 m^3 s^{-1} in 2000's. The average annual precipitation in the area was 650 mm, and annual average temperature was 4 °C. Main soil types in the are clay and rocky soils. As clay soils are erosion sensitive, total phosphorus transport correlates well with suspended sediment transport. Fields cover 25% of the area the rest being mainly forest. Crop production is the main production line in the catchment. Main crops are spring cereals, but at the upper reaches of the catchment (study site) there is also some cabbage cultivation (about 3% of the area).

Changes in discharge and nutrient transport were modelled by Watershed Simulation and Forecasting System (WSFS; Bergström 1976, Vehviläinen 1994) and the Integrated Nutrients in Catchments (INCA; Whitehead et al. 1998, Wade et al. 2002) models. The INCA model was calibrated against observed discharge at the outlet of the river. Inorganic nitrogen and suspended sediment time series (12-22 measurements in year) were available also in the middle of the catchment.

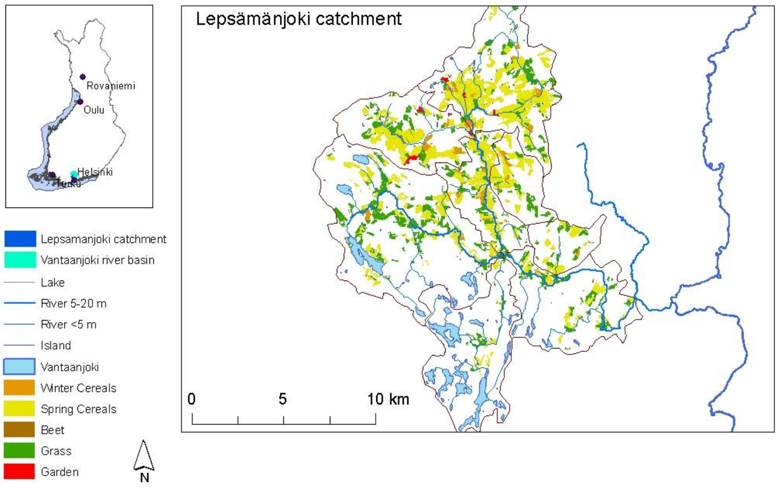

Figure 1. Location of the Lepsämänjoki catchment

2.2 Models

The WSFS is a conceptual hydrological model, used in Finland for operational flood forecasting and for research purposes. The system is based on watershed model, which has a HVB-model structure and simulates the hydrological cycle using standard meteorological data.

Model inputs are precipitation and temperature and optionally potential evaporation. In climate change simulations the potential evaporation is calculated by an empirical equation from temperature, precipitation and time of year, which is used to indicate the amount available of shortwave radiation (Vehviläinen and Huttunen 1997). Actual evapotranspiration is calculated from potential evaporation using simulated soil moisture. The simulated components of hydrological cycle are snow accumulation and melt, soil moisture, evaporation, ground water, runoff and discharges and water levels of main rivers and lakes.

The dynamic INCA models integrate hydrology and nutrient processes. The models are semi-distributed in that the land surface is not described in detail, but in hydrologically representative units (HRU) in sub-basins (Ekholm 1993). In this application HRUs equal to land-use classes. Hydrologically effective rainfall (HER) is used to drive nutrients through the catchment system. HER is defined as that part of total incident precipitation that reaches stream channels as runoff and it is given as a daily input time series, which can be calculated by a hydrological model (in this case WSFS). Hydrology within the sub-catchments is modelled using a three-box approach, with reservoirs of water in a reactive soil zone and in the deeper groundwater zone and surface runoff.

In the INCA-N model sources of N include atmospheric deposition, fertilisers, leaching from the terrestrial environment and direct discharges. Terrestrial N fluxes are calculated in up to six user-defined land use classes. The mass balance equations for NO_3-N and NH_4-N in the soil and groundwater zones are solved simultaneously with the flow equations. The key N processes that are solved in the soil water zone are nitrification, denitrification, mineralization, immobilisation, N fixation and plant uptake of inorganic N. No biochemical reactions are assumed to occur in the groundwater zone. In the river the key N processes are nitrification and denitrification.

In the INCA-SED model the main river channel is divided into series of reaches and the land area that drains into each of these reaches is defined as a sub-catchment. The basic modelling unit of soil erosion processes is then a land use class in the sub-catchment. In addition, the model incorporates environmental data of hydrometeorology, land use, erodibility and catchment and channel morphology. For each sub-catchment available sediment is generated on the catchment slopes by raindrop impact. Given sufficient direct runoff this material is transported from the land to the in-stream phase of the model. Direct runoff can also further erode sediment from the soil surface. In the river suspended sediment concentration increases with stream power. With decreasing stream power the sediment in suspension will settle and be deposited on the stream bed.

The calibration period was 2003-2009 which provided the best continuous observation time series. Nash-Sutcliffe efficiency (Nash and Sutcliffe 1970) was 0.699 for discharge at the outlet of the catchment. For nitrate R^2 was 0.404 at the outlet and 0.392 in the middle of the catchment, respectively. For suspended sediments the values of R^2 were 0.552 and 0.199. The baseline scenario and validation was run using the data of years 1971-2000. For nitrate R^2 value was 0.495 in the middle of the catchment and 0.184 for suspended sediments, respectively. Data from the outlet of catchment was not available.

2.3 Future Changes in Climate, Land Use and Water Protection Measures

Climate change scenarios were calculated as averages of 19 climate models and emission scenarios B1, A1B and A2 (IPCC SRES 2000). By interpolation from the surrounding network of meteorological stations, climate scenarios were projected to the study area in Lepsämänjoki.

Agri-environmental programme together with Nitrate Directive defined the current situation in agricultural water protection (BAU, Business As Usual). Although agri-environmental programme is voluntary over 90% of farmers have joined to it. The programme is consisted of basic, additional and special measures. Obligatory basic measures contain maximum allowed fertilization levels for different crops. Farm ers should also choose some of the additional measures, which contain e.g. reduced fertilization and winter-time vegetation cover. Special measures are clearly targeted measures like wetlands or buffer zones. The water protection measures in this work were based on recommendations of the river basin management plans of the WFD. The selected measures were *Green cover* in which stubble remains over winter in all spring cereal fields and *Reduced fertilization* in which nitrogen balance decreases to 20 kg N ha^{-1}.

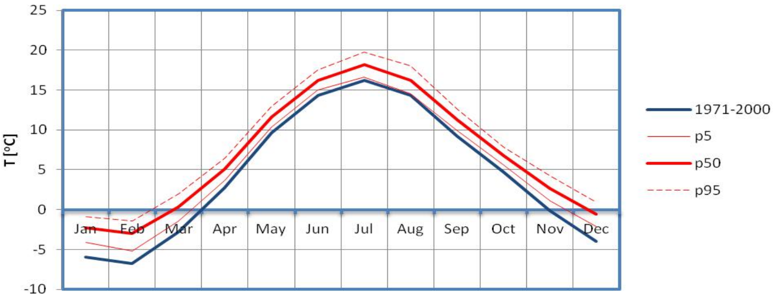

Figure 2. Baseline temperature and temperature in 2040-2069 in the Lepsämänjoki catchment

Storylines for future crop production were done by expert judgement based on two potential drivers causing changes to cropping systems: climate change and agricultural policy (Peltonen-Sainio et al. 2010). The storylines were generated for a study area including 720 ha of arable land at the upper reaches of the catchment. The study did not include any considerations of current or future farm structure, in terms of farm size or land tenure. Grasslands and leys were not included in any of the production scenarios 1-3. It was assumed that the present regional structure of agriculture is maintained.

Storyline 1 was based on idea that protein crop production is heavily promoted in order to increase the presently alarmingly low protein self-sufficiency and thereby, to decrease the dependency on imported soybean. This is targeted according to national strategy for improving protein self-sufficiency. *Storyline 2* was based on idea that future policies heavily promote cultivation of winter crops that provide sufficient soil cover over winter time to protect against leaching and erosion especially in forthcoming decades. This is in line with current environmental policy emphasis on protecting the surface waters from eutrophication in Finland (Prime Minister's Office 2011) and the current agri-environmental programme (MAVI 2011). *Storyline 3* postulates a business as usual situation. No substantial policy incentives are used to promote changes crop production. This may result in domination of cereal monocultures (likewise today), and in ignoring the opportunities and adaptation needs in the changing climate. *Storyline 4* is a nutrient recycling scenario in which we included organic farming which integrates animal and crop production (Grandstedt et al. 2008).

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3 RESULTS AND DISCUSSIONS

3.1 Changes in Discharge

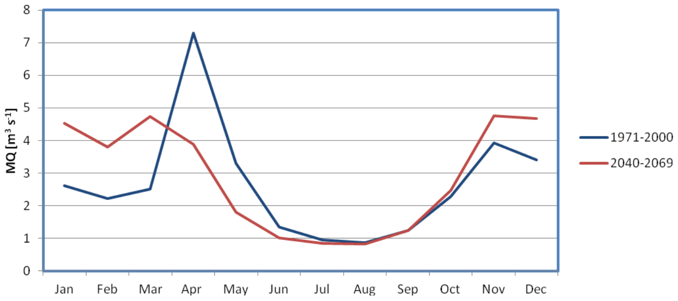

Figure 3. Simulated change in discharge

In 2040-2069 the annual average temperature is predicted to increase by 2.5 degrees from the average of the years 1971-2000. Mid-winters the temperature will still drop below 0 ˚C (Fig. 2), and some frost and snow cover remains. Mean annual discharge will increase by 8% in Lepsämänjoki catchment, compared to discharge during baseline period. There will be change towards higher discharges in winter, so that current peak due snow-melting in April will disappear (Fig. 3). On the other hand, no change is seen in discharges during summer and early autumn. Snow cover will not totally disappear but will be lower and start to melt earlier. Veijalainen et al. (2010) assessed climate change impacts on flooding on a national scale in Finland. They also found a significant shift in the seasonality of runoff and floods, with increasing floods during autumn and winter, and diminishing floods in spring, especially in southern Finland and central Finland,

3.2 Nutrient Leaching According to Future Land Use and Water Protection

In *Storyline 1* oilseed rape, turnip rape, faba bean and field pea will gain area, at expense of spring sown cereals. Spring wheat, barley, oat and winter wheat will remain in the selection. Small and impractically located and managed patches of fields are turned to conservation fallows for enhancement of biological diversity. In *Storyline 2* following the projections of Peltonen-Sainio et al. (2010) winter cereals will gain area (Fig. 4). In *Storyline 3* cereals are favoured by the farmers, and only negligible areas are devoted to spring oilseed rape. In mid-century, to gain from high genetic yield potential of winter types compared to spring cereals, winter wheat, rye and triticale (Peltonen-Sainio et al. 2010) are grown at 50 % of total hectares in the study area. In *Storyline 4* 5 years crop rotation of grass, spring cereals and N fixing crops were introduced with manure as a fertilizer.

According to the *Storylines 1-3* the area of winter cereals will increase though the highest increase is in *Storyline 2*. This will keep soil covered and thus help decreasing erosion and suspended sediment transport. In *Storyline 2* ("winter cover") suspended sediment load did not change in 2040-2069, compared to load during baseline conditions. The same applied to *Storyline 1* ("protein crops"), probably due to higher area of green fallows. In *Storyline 3* ("monoculture") the increase in suspended sediment load was 12%. When combining these land uses with water protection measures (*Green cover*: stubble on spring cereal fields), highest decrease by 5% from current state was achieved in *Storyline 1*.

In 2040-2069 changes in inorganic N loading were relatively small in all the alternative uses of the farmland. Surprisingly, the *Storyline 3* ("monoculture") seems to provide the lowest inorganic nitrogen loading so that the increase is only 3% by the 2040-2069. In general, the fertilization level of spring cereals are lower than that of winter cereals, and we did not assume any changes in crop-specific fertilization amounts. The highest reduction (by 17%) in inorganic N loading was achieved when combining this land use with water protection measures (combination of *Green cover* and *Reduced Fertilization*).

Water protection scenario *Green cover* did not seem to compensate for increase in inorganic N leaching. The higher plant uptake of winter cereals was met by higher fertilization level than that of spring cereals, so that average field N balance remained in 42 kg ha^{-1}. The highest leaching risk was connected to the "protein crops". Even though field N balance decreased to 33 kg ha^{-1}, the leaching outside the growing season increases. Thus, it looks like leaching losses from cultivation based on mineral fertilizers only are smaller as the fertilization rates can be adjusted to crop uptake. On the other hand, nitrate concentrations did not increase close to 50 mg l^{-1}, the boundary value of Nitrate Directive.

Storyline 4 ("nutrient cycling") is the only one which alone is able to decrease nutrient loading to meet the targets (Fig. 5). Further, in this storyline phosphorus loading can be assumed to decrease in process of time, as manure is the only phosphorus input. However, in organic farming yields are typically lower than in conventional farming. Typical 5 years crop rotation includes two years of grass cultivation which reduces erosion and suspended sediment load.

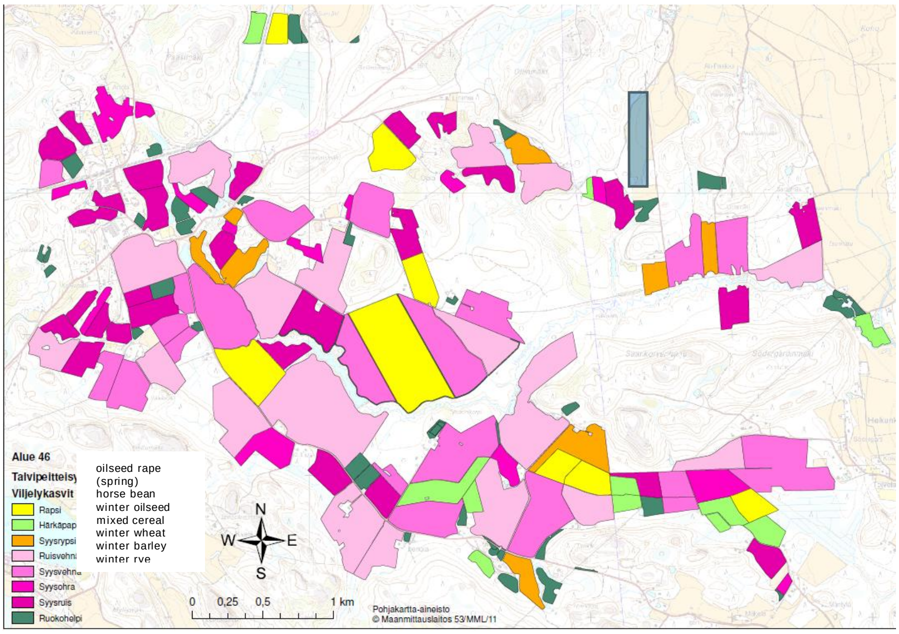

Figure 4. Storyline 2: "*Winter cover*"

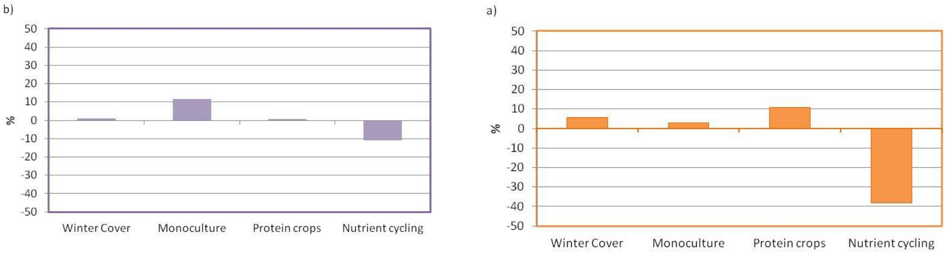

Figure 5. Changes in inorganic nitrogen (a) and suspended sediments (b) loading in different land use scenarios in changing climate

4 CONCLUSIONS

By 2040-2069 maximum increase in nutrient and suspended sediment loading due to climate change is moderate. Inorganic N loading may increase by 10% in storyline *Protein cro,s* and suspended sediment loading in storyline *Monoculture*. On the other hand, this study showed that it is also possible to decrease both inorganic N and suspended sediment loading by correct combination of crop and water protection methods. The most effective method to reduce inorganic N loading is *Nutrient cycling* (organic farming) though that happens on the cost of yield. If the target is to reduce suspended sediment loading, considerably, more effective and/or targeted measures are needed.

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