How much can be gained by optimizing nutrient abetment spatially – Cost – efficiency comparison of non – point arable loads from different Finnish watersheds

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How much can be gained by optimizing nutrient abatement spatially -Cost-efficiency comparison of non-point arable loads from different Finnish watersheds

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Abstract

Targeting has become the buzz word in the national agri-environmental policy reform in Finland. It is generally accepted that more environmental benefits could be reaped by implementing environmental protection measures where they have the biggest positive impact. However, considering one of the main environmental problems in Finland resulting from agriculture, eutrophication, the identification of first-best policy or even the biggest contributors among the diffuse nutrient sources remains as a considerable challenge. The model developed in this study aims to demonstrate how the agricultural nutrient load potential can be calculated in a way which supports the identifying of cost-efficient abatement policies. We use metamodeling of dynamic nutrient load model (ICECREAM) to establish load parameters for non linear economic optimization to derive abatement cost functions for nutrient loads of 2 Finnish catchments. We calculate the difference in costs of the spatially optimal allocation of reduction measures and compare with the costs based on average non-targeted measures.

Keywords: nutrient abatement, nitrogen, phosphorus, non-linear optimization, GIS

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1. Introduction

According to the Finnish ecological classification of surface waters, 52 % rivers, 12 % lakes and 63 % of coastal waters are in less than good condition (SYKE, 2008). Similarly, the usability index shows that the water quality in Finland could be improved (SYKE, 2005; Vuoristo, 1998). Bad water quality leads to less people benefiting from the recreational water activities and less benefits for those who enjoy the activities in Finland (Vesterinen et al., 2010). The Water Framework Directive (WFD) of the European Union aims to achievement of good ecological and chemical status of the water environment across the Europe (EC, 2000). In Finland, the targets set by WFD pose a considerable challenge due to large quantity of water bodies not meeting the objectives, but also because considerable share of the environmental burden is stemming from non point source nutrient loads, which are difficult to control. Previous estimates regard agriculture as the main source of nutrients in the surface waters at the Baltic catchment (HELCOM, 2005). Given that the current measures to improve the water quality have had poor results in some catchments facing nutrient flows from arable lands in Finland (Ekholm and Mitikka, 2006), it seems that the directive objectives will not be reached for 2015 assessment, or at least, that new policy measures are needed.

According to WFD, less demanding environmental objectives can be set, if it can be shown that reaching the good quality would have been excessively costly (EC, 2000). This clause raises the question on how to calculate the costs in general for the purposes of water protection. In the case of agricultural non point source pollution, the question does not have an easy answer since the diffuse loads and the effects of control measures are difficult to quantify. The seasonal and inter annual variations mask the effect of control measures on loads, while the costs of the measures themselves fluctuate due variable prices and yields of agricultural products. Monitoring the loads is so costly that gathering extensive information, which could allocate the required reductions in loads across the country, is currently considered to be infeasible. Thus, monitoring has been frequently combined with environmental modeling to estimate loads and impacts of reduction measures on wider scale (some Finnish examples include (Tattari et al., 2001; Granlund et al., 2004; Puustinen et al., 2010)). What these efforts lack is the cost component, but the idea of combining economic aspects to nutrient load models has been around for at least some decades and many of the challenges have been illustrated for example by Vatn et al. (1999). The ecological models such as CREAMS (Knisel, 1980) and it's Finnish modification ICECREAM (Rekolainen and Posch, 1993) have been developed for evaluating the effects of different farming practises on nutrient loads at the field scale. Hence, the input data is on a fine scale, and to apply the models for a watershed level economic analysis requires up-scaling both temporally and spatially. Earlier work on rescaling has demonstrated how to connect field scale models such as ADAPT to control variables which are meaningful at the policy level by metamodeling (Wu and Babcock, 1999; Johansson, 2004). The idea of metamodeling is to create a statistical response that approximates the results of a more complex simulation model (Wu and Babcock, 1999). In this paper we construct a metamodel of ICECREAM, which allows us to evaluate and compare cost-efficient nitrogen and phosphorus reductions for two geophysically variable watersheds in Finland. We up-scale the output of the process model to an annual scale for combinations of agricultural management practises and geophysical factors. We attempt to retain the geographic heteregeneity of the most important factors determining the nutrient loads in order to extend the scope of the current watershed level policy models such as Helin et al. (2006). Heterogeneous description of farm land allows us to analyse the benefits of having a targeted policies for example the estimation of load impact and costs of retiring steep slopes from production at the watershed level.

2. Material and methods

2.1. Economic Model

The farming activities are described by a representative farm for each watershed. We assume that the farmers are risk neutral profit-maximizers who have perfect information on the (fixed) properties of their fields including the soil type l and slope s. Fields can be cultivated with various k tillage practices and crops j. The farming capital is given and the variable costs c_k specific to tillage technology are calculated from the price of contracting. In addition to the allocation of land $X_{j,k,s,l}$, the farmers can choose how much nitrogen $N_{j,k,s,l}$ and phosphorus $P_{j,k,s,l}$ to use. Given a fixed phosphorus stock $\bar{P}_{j,k,s,l}$ in soil and the annual fertilisation per hectare, land produces yield $y_{j,k}(N_{j,k,s,l}, P_{j,k,s,l}, \bar{P}_{j,k,s,l})$

Let us assume that the more direct abatement measures at fields are more efficient than changes in the animal diet, animal numbers or manure management (Helin, 2007). The effect on animal operations is captured only in the modeled silage demand, which determines a lower bound for the share of grass land for the region. For the profit maximization problem of the representative farms at each watershed (1)-(2)

$$\max_{X_{j,k,s,l},N_{j,k,s,l},P_{j,k,s,l}} \pi\left(X_{j,k,s,l},N_{j,k,s,l},P_{j,k,s,l}\right) \tag{1}$$

$$= \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{s=1}^{S}\sum_{l=1}^{L}\left\{p_j y_{j,k}\ \left(N_{j,k,s,l},P_{j,k,s,l},\bar{P}_{j,k,s,l}\right) - c_k - p_P P_{j,k,s,l} - p_N N_{j,k,s,l} + u\right\} X_{j,k,s,l} \tag{2}$$

$$s.t. \quad \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{s=1}^{S}\sum_{l=1}^{L} r_{i,j,k,s,l} X_{j,k,s,l} \leq \bar{R_i}, \quad \forall i \tag{3}$$

$$\sum_{j=1}^{J}\sum_{k=1}^{K} X_{j,k,s,l} = \omega_{s,l}, \quad \forall s,l \tag{4}$$

$$X_{j,k,s,l} \geq 0, N_{j,k,s,l} \geq 0, P_{j,k,s,l} \geq 0 \tag{5}$$

where u is the subsidy per hectare of arable land. Including the crop hectare based subsidy in farmer's profit maximizing problem reflects Single Farm Payment (SFP) of the European Union on the reference year 2009. Various biological, technical and political limitations in crop farming can be represented with a constraint function (3), where $\bar{R_i}$ is the resource maximum/minimum for the given criteria. The farmer's inability to change the basic land characteristics is described by the equation 4 where $\omega_{s,l}$ is the fixed land distribution. It is assumed that there is no feasible way for the farmer to remove land or remove nutrients from the land beoynd crop uptake (e.g. non-negativity constraints in 5).

2.2. Nutrient Load Model

The agricultural load is based on a field plot level process model ICECREAM. ICECREAM is a dynamic, field-scale model calculating soil transport and nutrient leaching at one day time resolution (Tattari et al., 2001; Yli-Halla et al., 2005; **?**). ICECREAM is based on CREAMS and GLEAMS leaching models (Knisel, 1980; **?**), but it is modified so that it is suitable for Finnish conditions (Rekolainen and Posch, 1993). It can be used for simulations of the effects of cultivation practices and buffer zones on material transport as well as for transport with different combinations of soil texture - plant - meteorology.

Since the description of some processes (surface runoff) and knowledge about some processes governing nutrient losses are inadequate, ICECREAM can be considered as a mixture of physically based descriptions and empirical equations. The surface runoff, for example, is based on a factor called 'curve number', which is based on field experiments in the USA. In addition, the model does not take into account subsurface drainage pipes and a simplified effect of macropores was included in the model in 2009.

ICECREAM model has been used for long and it has been developed in single research projects. However, the field-scale experimental data has been lacking in Finland and therefore extensive testing of the model has been difficult. Nevertheless, the results obtained by ICECREAM are utilized in the VEPS load assessment system (Tattari and Linjama, 2004). Here, 10-year runs with different soil/plant/weather/cultivation -combinations were performed at field-scale, the results of which were then upscaled to represent the agricultural loading at 3rd order catchment scale.

Since ICECREAM is a comprehensive simulation model the required input is quite extensive. ICECREAM requires daily datasets of meteorological information on precipitation, temperature, radiation/cloudiness, relative moisture and wind speed. In addition to this, the model needs amply data on e.g. soil characteristics, vegetation and cultivation practices.

ICECREAM incorporates 282 output variables including components of water balance, erosion and the fractions of N and P. In the model soil is divided in at max. 7 horizontal layers, which partly explains the large number of output variables because the results are calculated for every layer separately.

ICECREAM simulations for this study cover load, runoff and erosion estimates for combinations of 7 crop types (including green lay), 7 fertilisation levels, 3 tillage types, 4 soils types and for 4 slope classes. These model runs, however do not comprehensively cover all possible variation in the available data. Hence, to improve the spatial coverage of the analysis, we have interpolated from the simulation results as described below.

2.3. Meta Model

Capturing the effect of choice variables on the annual nutrient loads can lead to rapid growth of the model and lead to what is commonly known as the curse of dimensationaliy in optimization modeling. By reducing the amount of calculations required for any solution, the complex weather dependent processes can be simplified and solved for the global optimum. Metamodel is a simplified statistical construct of a more complex model. For constructing the metamodel we've used emprically established connections between the amount of phosphorus ending up in rivers and the amount of surface runoff water and erosion (Uusitalo and Ekholm, 2003; Uusitalo, 2004). These results have been modified as in Helin (2007) to account for the effect of annual fertilisation on the phosphorus load, which has been divided to dissolved reactive form ($P^{DR}_{j,k,s,l}$) and form bound to eroded soil particles ($P^{P}_{j,k,s,l}$). These components of the total phosphorus load are shown correspondingly in equations 6 and 7.

$$P^{DR}_{j,k,s,l} = \left[\theta_{j,k,s,l}\left(2\left[\bar{P}_{j,k,s,l} + 0.01P_{j,k,s,l}\right] - 1.5\right)\right] * 10^{-4} \tag{6}$$

$$P^{P}_{j,k,s,l} = \Delta_{j,k,s,l}\left[250\ln\left[\bar{P}_{j,k,s,l} + 0.01P_{j,k,s,l}\right] - 150\right] * 10^{-6} \tag{7}$$

The $P^{DR}_{j,k,s,l}$ and $P^{P}_{j,k,s,l}$ sum to P^{TP} once the particle P has been converted back from the bioavailable form with the total eroded phosphorus by cofficient η. The total phosphorus load of the watershed is thus given by equation 8.

$$\bar{P}^{TP} = \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{s=1}^{S}\sum_{l=1}^{L}\left[P^{DR}_{j,k,s,l}\left(P_{j,k,s,l},\bar{P}_{j,k,s,l}\right) + \eta P^{P}_{j,k,s,l}\left(P_{j,k,s,l},\bar{P}_{j,k,s,l}\right)\right] X_{j,k,s,l} \tag{8}$$

The ICECREAM model is used to estimate the erosion $\Delta_{j,k,s,l}$ and runoff $\theta_{j,k,s,l}$ for the combinations of crop, tillage, slope and soil types for each watershed. To limit the number of needed ICECREAM model runs, the erosion and runoff are given as function of slope, which is estimated from the ICECREAM results of four slope percent values. Therefore, it is not necessary to run the ICECREAM simulations for all slope classes of the watershed data. The functional form given in equations 9 and 10 was chosen to fit the ICECREAM results based on plot diagrams.

$$\theta_{j,k,l,s} = \beta^{R}_{j,k,l} + \alpha^{R}_{j,k,l} + \varepsilon_{j,k,l} \tag{9}$$

$$\Delta_{j,k,l,s} = \beta^{E}_{j,k,l}\exp\left(\alpha^{E}_{j,k,l}S_{j,k,l}\right) + \varepsilon_{j,k,l} \tag{10}$$

The nitrogen load $\bar{N}^{L}_{j,k,l,s}$ is parametrised for all the model dimensions as a function of fertilization in equation 11. As for phosphorus, the scope of the slope is extended by metamodeling. For nitrogen we do not divide the load in subcomponents, and hence we have used a direct regression between the ICECREAM

Table 1: Different parametrizations of the model

v	Kalajoki	Aurajoki
1	heterogen	heterogen
2	homogen	homogen

load and the slope as shown in the equation 12. Functional forms were chosen based on plots of the ICECREAM results.

$$\bar{N}^L = \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{s=1}^{S}\sum_{l=1}^{L}\left[\phi_{j,k,s,l}\exp\left[\gamma_{j,k,s,l}N_{j,k,s,l}\right]\right]X_{j,k,s,l}. \tag{11}$$

$$\bar{N}^S_{j,k,l,s} = \beta^N_{j,k,l}S_{j,k,l} + \alpha^N_{j,k,l} + \varepsilon_{j,k,l} \tag{12}$$

$$\bar{N}^L_{j,k,l,s} = \left[\phi_{j,k,s,l}\exp\left[\gamma_{j,k,s,l}N^S_{j,k,s,l}\right]\right] + \varepsilon_{j,k,l} \tag{13}$$

The metamodel for nitrogen load is estimated from ICECREAM results for eight fertilization levels. This range covers the allowed nitrogen fertilization amounts in the Finnish environmental subsidy scheme (table **3**).

The baseline levels of the respective nutrient loads are given by solving the profit-maximizing problem specified above. By introducing the equations 6 to 11 as constraints on the farmer's profit-maximizing problem and reducing the load from the baseline by $\tau\bar{P}^{TP}$ or $\tau\bar{N}^L$ for $0 < \tau < 1$, constrained profit solutions are given for both of the nutrients. Thus, the abatement costs C^{TP} and C^N are given by the difference between the baseline profits π and the constrained profits π^N or π^{TP} in equations 14 and 15.

$$C^{N^v} = \pi - \pi^N\left(\tau\bar{N}^{L^v}\right) \tag{14}$$

$$C^{TP^v} = \pi - \pi^{TP}\left(\tau\bar{P}^{TP^v}\right) \tag{15}$$

where v refers to different parametrizations of the load functions (table 1). We compare the costs between the different watershed and between the average $\theta_{j,k}$, $\Delta_{j,k}$ and $\gamma_{j,k}$ and heterogeneous $\theta_{j,k,s,l}$, $\Delta_{j,k,s,l}$ and $\gamma_{j,k,s,l}$ parameters.

The simulation results from equations 14 and 15 are then used to fit abatement cost functions for v model specfications. All the OLS analyses were computed in GAMS as minimization problems of the sums of the error terms ($\varepsilon_{j,k,l}$). The sets j,k,l,s for the available Finnish data are defined below.

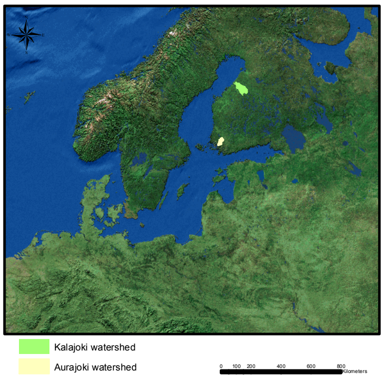

Figure 1: The study regions of Aurajoki and Kalajoki

Table 2: Different tillage types

k	tillage	Kalajoki %	Aurajoki %
1	normal plough	86	90
2	cultivator	9	2
3	direct sowing	5	8

1) The baseline tillage types following (Pyykknen and Groenroos, 2004)

2.4. *Farm systems data*

The climatic conditions in Finland generally lead to farming systems which rely on natural rainfall on artificially drained soil. The research areas are illustrated in the Figure 1.The growing season is short and generally only single grain yield can be obtained annually. In the past the dominant method of tillage has been conventional ploughing of soil, while cultivation and conservation tillage practices have been rather marginal, but are gaining popularity (Pyykknen and Groenroos, 2004). As the change in tillage has implications for nutrient loads, all three types are considered in the model and presented in Table 2. However, the data was not sufficient to describe the existing distribution of tillage methods between the crop, soil and slope classes. Hence, for all parcels it is assume that the status quo distribution of tillage is constant over the slope and soil classes in the calibration of the nutrient load. The input and output prices are calculated from the statistics of year 2009 (TIKE, 2004).

Table 3: Common crops, their share of total arable land in 2003 and nitrogen fertilization levels N $kg\ ha^{-1}\ a^{-1}$ for different soils recommended by the Finnish environmental subsidy system

j	Crop type	Kalajoki	Aurajoki	Limits[1)]		
				clayey	sandy	organic
		%	%	$kg\ ha^{-1}$	$kg\ ha^{-1}$	$kg\ ha^{-1}$
1	winter wheat	<1	2.4	120	110	70
2	spring wheat	3.3	26.3	120	110	70
3	spring rye	<1	<1	120	100	40
4	winter rye	<1	1.2	120	100	40
5	barley	31	10.3	110	100	60
6	barley(malt)	<1	19	90	80	60
7	oats	11.5	8.1	110	90	60
8	mixed grain	1.7	<1	120	110	70
9	peas	<1	1.3	50	50	40
10	potato	<1	<1	60	60	60
11	potato(industrial)	<1	<1	80	80	80
12	sugarbeet	<1	1.3	120	120	120
13	spring rapeseed	<1	9.4	120	110	50
14	winter rapeseed	<1	<1	120	110	50
15	silage, grass and hay	31.9	7.8	180	180	180
16	green fallow	10	11	-	-	-

1) The fertilization upper limits of 2003 environmental subsidy system (MAF, 2003)

2.5. Land use and crop type data

The arable land use data was obtained from the database of Information Service of the Ministry of Agriculture and Foresty in Finland for the year 2003. ICECREAM model results for the metamodel of both of the study regions and both nitrogen and total phosphorus were obtained for barley, winterwheat, potato, sugarbeet, grass and green fallow. These crops cover approximately 75 % of the agricultural land on Kalajoki watershed and 52 % of the Aurajoki watershed. The share of most common crops from the total agricultural land is presented in the table 3.

While majority of the existing agricultural crop cover could be represented with these parameters, the model coverage was improved by modeling a broader set of crops based on the parameters from other crops. Spring cereal and pea parameters are based on spring barley, while other winter cereals are based on

Table 4: Distribution of field slopes

s	Slope class[1] (%) slope	Kalajoki %	Aurajoki %
1	0-0.5	56.6	54.9
2	0.5-1	21.1	18.5
3	1-2	15.3	16.3
4	2-3	4.1	5.1
5	3-6	2.5	4.4
6	>6	0.4	0.7

1 Based on 25x25 DEM of Finland (Maanmittauslaitos, 2007)

winter wheat. The grass load parameters were used for all of the types of silage and hay. The difference between the crops with same load parameters in terms of nutrient abatement follows from different prices and optimal fertilization levels.

The crop yields are modeled as additive non-linear functions of nitrogen and phosphorus fertilization. The nitrogen yield response follows (Lehtonen, 2001) and the phosphorus yield (Saarela, 1995). The effect of tillage method on yields is modeled as in (Helin et al., 2006). Rapeseed pest control is modeled by restricting its annual field area to 1/3 of the total arable area. Contractual sugarbeet and potato arrangements between farms and the food industry are included in the model by setting an upper limit of 4% of total arable area for these crops.

2.6. Field slope data

Slope tool of ArcGIS spatial analyst was used in calculating the map of slopes based on the Digital Elevation Model (DEM) of the study region. For each given cell of the DEM grid, the altitude of neighboring cells are compared and the slope is calculated based on the maximum altitude difference between the cell and its neighbors. The resulting elevation grid was converted to five slope classes shown in the table 4.

The mean slope of the arable land of the Kalajoki watershed is 0.7% and 2.9% for the Aurajoki watershed. The slope of 0-3% covers majority of the arable land area of the watersheds. The steeper, more erosion prone slopes are important to include as targetting them would be expected to lead to bigger load reductions than on flat land. The steepest areas were modeled as part of the 3-6% class for Kalajoki and as its own >6% class for Aurajoki. The OLS regression was used to calculate the parameter values for the mean slope of each class. The steepest

Table 5: Distribution of average P content of soil

$\bar{P}$	Soil P $mg\ l^{-1}$	Kalajoki (%) share	Aurajoki (%) share
1	8	-	13.4
1	9	24.8	-
2	10	-	3.3
2	11	27	-
3	12	28.5	34.4
4	13	6.8	41.7
5	16	-	5.7
5	18	12.9	
6	25	-	1.1

1) Based on rounded municipal avarages from soil samples analysed by (ViljavuuspalveluOy, 2007)

slope class of Aurajoki was calculated with 7% value instead of the mean so that it would not be skewed by few very steep values in the data.

2.7. Soil data

Soil bodies have been classified according to the World Soil Reference Base from the Finnish soil classification types and maps (Lilja et al., 2006). ICE-CREAM load parameters were available for four soil types, which follow the Finnish soil classification. Some extrapolation and generalization was required for a better spatial coverage of soil not included in the ICECREAM model runs. For arenosol and podsol soils the parameters follow the Finnish soil class of coarse sand (0.06-0.2 mm). Regosol load parameters are based on the class of fine sand (0.02-0.06 mm) and cambisol-gleysol parameters on the Finnish class of silty clay, in which the silt particles constitute approximately 40% and clay 60%. The histosol load parameters are given by sandy clay, which simplifies the load parameter estimation considerably. The unmatched soil of arable land follows the gleye soil parameters. The soil of land use classes is summarized in the table 6. The phosphorus stock parameter $\bar{P}_{j,k,s,l}$ presented in table 5 is from the municipal level average data (ViljavuuspalveluOy, 2007).

Table 6: Soil classes and parametrization

l	FAO class[1]	Load parameter	Particle size[2] (mm)	Aura %	Kala %
1	Eutric Regosol	HHt	0.02-0.06	0.4	20.3
1	Anthrosol	HHt	0.02-0.06	*	*
2	Eutric Cambisol 1	HsS	$<$0.002	*	*
2	Eutric Cambisol 2	HsS	$<$0.002	*	23.9
2	Vertic Cambisol	HsS	$<$0.002	86.4	*
2	Umbric Gleysol 1	HsS	$<$0.002	0.2	*
1	Umbric Gleysol 2	HHt	0.02-0.06	*	0.1
3	Dystric Gleysol	Hts	$<$0.002	0.6	0.7
4	Haplic Podzol 1	KHt	0.06-0.2	*	15.8
4	Haplic Podzol 2	KHt	0.06-0.2	1.1	11.4
4	Gleyic Podzol 1	KHt	0.06-0.2	*	0.2
4	Gleyic Podzol 2	KHt	0.06-0.2	*	0.3
4	Dystric Leptosol	KHt	0.06-0.2	8.4	0.2
4	Lithic Leptosol 1	KHt	0.06-0.2	1	*
4	Lithic Leptosol 2	KHt	0.06-0.2	*	*
3	Fibric/Terric Histosol 1	Hts	$<$0.002	0.7	11.8
3	Fibric/Terric Histosol 2	Hts	$<$0.002	0.3	15
3	Fibric/Terric Histosol 3	Hts	$<$0.002	*	0.2

1) The FAO class allocation is based on (Lilja et al., 2006)

2) Dominant particle size of the load parameter class

3. Results

3.1. Nutrient loads

The baseline average nitrogen loads of the model were 3.71 kg ha^{-1} for Aurajoki watershed and 5.89 kg ha^{-1} for Kalajoki watershed and correspondingly 0.74 kg ha^{-1} and 0.24 kg ha^{-1} for phosphorus. Compared to other Finnish nutrient load estimation models (i.e. VEMALA), the Kalajoki nitrogen load given fixed fertilization is above the average loads, while the phosphorus load is under the VEMALA average as shown in figure 2 . For Aurajoki watershed the modeled baseline phosphorus load is close to the VEMALA results, while nitrogen load is significantly lower. The nitrogen loads from the modeled economic optima are lower since the low prices of crops and high fertilization prices of 2009 lead to reduced fertilization levels compared to the past interview results and sale statistics, which are used as input for models such as VEMALA. Running the model with nitrogen fertilization levels corresponding with the levels in VEMALA gives 8 % lower load estimate at Aurajoki and 24 % higher at Kalajoki. The immediate significance of the annual fertilization of phosphorus for the load is smaller than for nitrogen. The low phosphorus load at Kalajoki watershed is partly explained by the flat characteristics of the region's fields. However, the main difference between the watersheds is the soil composition, which at claye fields of Aurajoki leads to higher erosion. Furthermore, the ICECRERAM model has not been calibrated specifically at Kalajoki and there is more uncertainty on the performance of the underlying bio physical model than at Aurajoki watershed. The low erosion at Kalajoki results underestimate the total phosphorus load. While we focus on the relative differences between the model specifications in this study, the reliability of the abatement cost estimation of Kalajoki suffers from these issues. The estimated load parameter matrices can be inqueried from the corresponding author.

3.2. Abatement costs

Given, the uniform reduction target of 30 % set in the Finnish government plans for 2015 (Valtioneuvosto, 2006), we've calculated the costs when policies can be targeted within the watersheds and when the watersheds are treated as homogenous units with no variation in soil type or slope induced nutrient loads. When we allow for spatial targeting, the nitrogen abatement costs for meeting the 30 % reduction are 1.51 ha^{-1} for Aurajoki watershed and 8.34 ha^{-1} for Kalajoki watershed. Correspondingly for phosphorus 36.2 ha^{-1} and 1231.37 ha^{-1}.

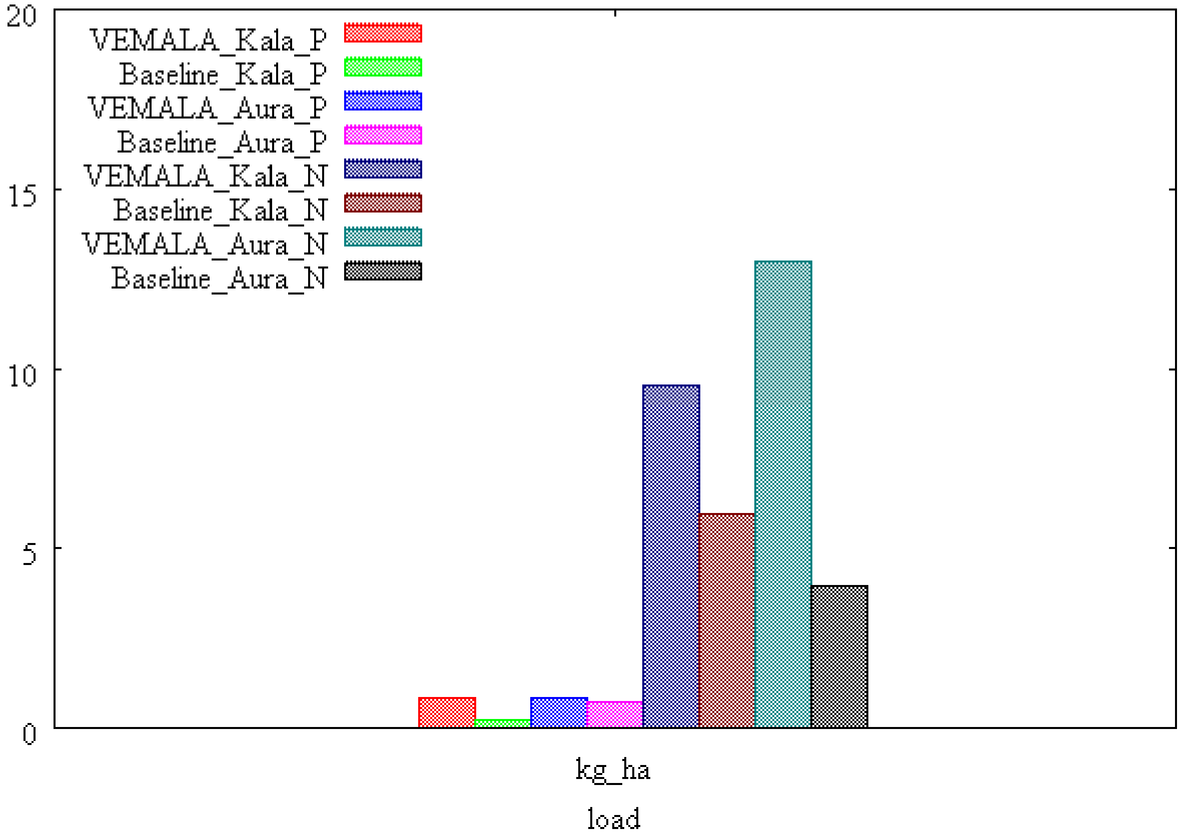

Figure 2: Nutrient loads. For comparison of the modeled loads, we have used other Finnish modeling tool, VEMALA, which estimates the total nutrient load of all watershed sources. The share of agriculture of these loads is given by using the shares presented in watershed protection plans of WFD

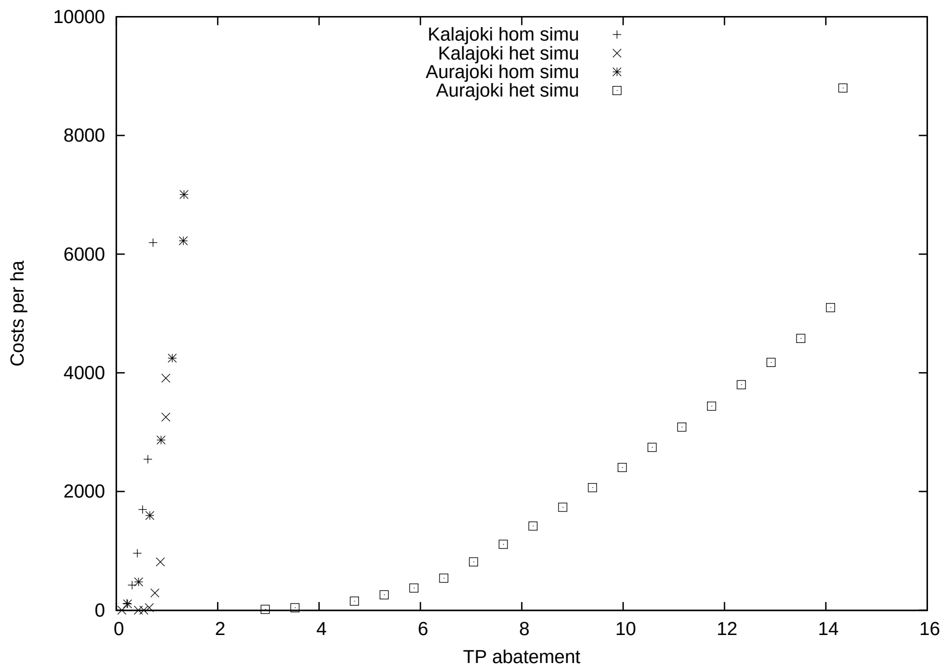

Figure 3: Phosphorus abatement costs

As Figure 3 shows benefits from targeting the measures for most erosion prone regions were larger at Aurajoki than at Kalajoki. The national abatement targets of 30 % is used for reference point of comparing what can be saved by targeting. For Aurajoki watershed, not beeing able to account for spatial heterogeneity leads to 80 % higher phosphorus abatement costs than the heteregenous first best solution of the model. At Kalajoki the corresponding cost difference was 41 %.

For nitrogen, the gains from targeting are not so clear. At Kalajoki the homogenous cost were 26 % higher and at Aurajoki the modelling results suggest higher abatement costs for the heterogenous than the homogenous model specification. As shown on figure 4, the nitrogen abatement costs at Aurajoki are higher than at Kalajoki. This results from the higher yield response at Aurajoki watershed.

4. Discussion

At Kalajoki watershed, the flatness, less erosion prone soil and greater share of grassland diminish the effectiviness of erosion control measures and hence lead to

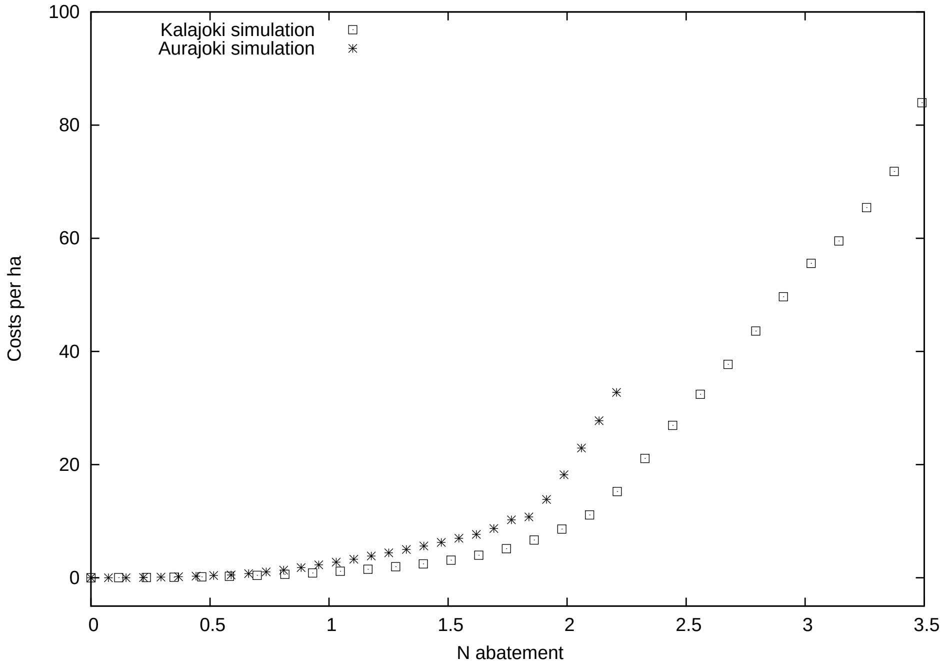

Figure 4: Nitrogen abatement costs

higher phosphorus abatement costs than at Aurajoki watershed where particulate bound phosphorus can be decreasesed more effectively. Compared to the baseline at both watersheds, reallocating the grass land for erosion prone regions is the most efficient way, since no costs are incurred for the change of location in the model. In practise, for example manure transport and productivity differences between parcels can incur reallocation costs. As the grass demand is less at Aurajoki than at Kalajoki watershed, where there is more cattle, the reallocation of existing grass land at Aurajoki watershed provides less abatement potential. The effects of increasing the share of grass land of total arable area would have repercussions on the animal production and would require more complicated models with animal husbandry.

The baseline solutions for both watersheds contain very little phosphorus fertilization (around 1 kg ha^{-1}) compared to the limits set in the environmental subsidy programme or used on the Finnish farms on average. The static model does not cover the yield benefits that are gained by the effect of annual fertilization on the phosphorus stock and hence cannot be regarded as the global optimum for longer time span abatement policies. However, it is worth noting that on both of the watersheds there are animal husbandry farms, which are likely to have elevated soil P content compared to the municipal averages used in this study. Hence, to meet the reduction targets, the animal production farms could supply the excess phosphorus for the rest of the region and reduce the need of chemical phosphorus fertilisation. The economic incentives to do so are hindered by the compound good nature of manure; the farm exporting excess phosphorus would be also exporting valuable nitrogen and potassium from its fields.

According to the results, the effect of modeled phosphorus abatement methods relies on reducing the particle phosphorus, while relatively minor reductions can be achieved with dissolved reactive phosphorus. As the abatement target increases larger proportion of the remaining total load consists of dissolved reactive phosphorus. According to our results there is some tendency for the runoff and thus also the DRP load to increase as conservation tillage is adopted to decrease the particle bound phosphorus. Therefore, the efficiency of soil conservation practices, irrespective of soil and slope classes, decreases. Given the modeled measures, the significance of this effect will rule out reaching the 30 % target, if the overall reduction objective would be set based on the algae available phosphorus instead of the total phosphorus. Ultimately, to avoid the negative environmental impacts of eutrophication at phosphorus limited water bodies, the abatement measures would need to reduce the algae available share of the total phosphorus load.

According to the model, spatial distribution is not as important factor for nitrogen abatement as it is for the phosphorus. The differences of the abatement costs of nitrogen between the watersheds are less siginificant than for phosphorus. It seems that the differences in the weather between the watersheds are not affecting the nitrogen abatement cost results on average greatly despite that the interannual variation in the loads in the ICECREAM model are large for both nutrients. Given the validity of the underlying biophysical process modelling, this result indicates that the watershed specific weather data might not be crucial for assessing the cost-effectiveness of the abatement measures. Moreover, counting for different distributions of land characteristics should be done with due dilligence for watershed heterogenity.

The differences in the abatement costs between the watersheds mean that uniform abatement targets for reaching the national environmental commitments will not be cost-efficient. In addition to the national abatement targets, Finland is part of international agreements on reducing the nutrient loads to the Baltic Sea (HELCOM) and under the WFD of EU, which sets the targets based on ecological indicators specific for each watershed. In terms of cost-efficiency in reaching the HELCOM targets of Baltic Sea protection for Finland, more efforts should be guided towards the Aurajoki watershed, but reaching the ecologically good status required in WFD would demand abatement action also at Kalajoki.

5. Conclusions

Applying the nutrient loading models for economic analysis in Finland results in large uncertainties in the effects and costs of common abatement measures such as reducing the fertilization and conservation tillage. The models abstracting from heterogeneity of spatial features are especially vulnerable since the abatement cost estimates are sensitive to the average characterization of soils and surface elevation. Small changes in the estimation methods of these parameters can then lead to large changes in the expected costs, and will hinder assessment of any control policies relying on this information. Alas, including spatial heterogeneity in economic analysis is not without problems. The underlying process model for estimating the required parameters has uncertainties(i.e. Paasonen-Kiveks et al. (2006)) , which cannot be avoided even with the decreasing the dependency on single erosion or runoff estimate. The uncertainty of these factors will manifest to the abatement cost estimation. Furthermore, accounting the heterogeneity in the economic optimization will require paying attention to the balance between the best description of the environmental data and the curse of dimensionality. Failing to do so leads to omitting the possible gains from targeting the policies or to intractable pattern of locally optimal solutions and feasibility issues with the non-linear constraints.

Targeting abatement efforts has been attempted recently by specific project funding at athe Aurajoki watershed, but the use of economics in targeting has been neglible so far. The modeling approach presented in this study will hopefully provide a tool for further efforts for more efficient protection abatement policies.

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