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Nitrogen load predictions under land management scenarios for a boreal river basin in northern Finland

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In Finland municipal and industrial waste water purification has effectively decreased nutrient emissions from point sources leading to improved water quality. No clear effects of decreasing non-point loading (atmospheric deposition, agriculture, forestry) are found, however, and nitrate concentrations are increasing in some rivers. The aim of this study was to determine the origin and timing of inorganic nitrogen loading to the Simojoki using the dynamic, semi-distributed INCA-N model. The simulation results showed that, at the river outlet, only about half of the inorganic nitrogen load originated from anthropogenic sources. The inorganic nitrogen load largely depended on runoff and half of the annual load was centred around the snowmelt period in April–May. There was a risk of increasing nitrogen load due to changes in agricultural land use. Water protection measures at all diffuse sources could decrease the anthropogenic part of the inorganic N load to the sea, but individual measures would only result in small reductions.

Introduction

Eutrophication of surface waters due to increased nutrient loading during the last decades is one of the main environmental concerns in Finland. According to Kauppila and Bäck (2001), the surface area of eutrophicated sea increased in northern parts of the Baltic Sea (Gulf of Finland, the Gulf of Bothnia) in the late 1980s, and the situation had not essentially changed during the 1990s. Räike *et al.* (2003) analyzed nutrient concentration trends in 23 rivers and 173 lakes in Finland. A long-term analysis (years 1975–2000) showed that municipal and industrial waste water purification has effectively decreased nutrient emissions from point sources leading to improved water quality, whereas no clear effects of decreasing non-point loading are found. On the contrary, nitrate concentrations were found to increase in some rivers located in the Gulf of Bothnia catchment area, where peatlands dominate the land cover and intensive agriculture is practiced.

Nowadays nutrient releases from non-point sources (agriculture, forestry and scattered settlement) exceed industrial and municipal loads, including peat harvesting and fish farming. Agriculture comprises the largest single source of nutrients to surface waters in Finland (Rekolainen *et al.* 1995, Vuorenmaa *et al.* 2002). The effects of forestry differ from those of agriculture in that, although being strong in some cases, they are often of limited duration.

In their natural state, peatlands act as sinks for inorganic nutrients, but when drained for forestry purposes they become sources. Both low flows and peak runoff tend to increase after drainage. The increase in runoff ceases within 15–20 years as the water carrying capacity of ditches decreases and transpiration of growing trees compensates for decreased evaporation (Seuna 1990, Laine *et al.* 1995, Kenttämies 1998). Peat harvesting causes elevated nutrient and suspended solids leaching to downstream waters (Heikkinen 1990, Klöve 2001).

Forest felling, especially clear cuts, increases annual runoff and sharpens peak runoffs in spring and summer due to decreased evaporation and interception. This increase is not long-lasting as new vegetation starts to recover soon after felling (Kenttämies 1998). Upon clear fellings, the stems are harvested and the logging residue are left at the site to decompose. Nitrification is also found to increase at felling (Tamm *et al.* 1974, Dahlgren and Driscoll 1994, Paavilainen and Smolander 1998). Inorganic nutrients released may leach to ground water and surface waters (Likens *et al.* 1970), and increased nitrate concentrations in ground water have been observed in several studies in Finland (Kubin 1998, Soveri *et al.* 2001, Rusanen 2002, Mannerkoski *et al.* 2005).

About 19% of Finnish households are not connected to municipal sewer networks, but have on-site wastewater systems. Such private wastewater treatment is usually inadequate, especially in old houses. Loading of both phosphorus (P) and nitrogen (N) per person has been shown to be clearly higher from private systems than from municipal sewer networks (Rontu and Santala 1995).

There are a number of recent international and national regulations that deal with the loading of nutrients to surface waters. The EU Water Framework Directive sets new challenges for integrated river basin management, with levels of ecological and chemical parameters for surface waters to be achieved by 2015. In 1998, the Finnish Council of State issued a Decision-of-Principle on water protection targets to be met by 2005 including a 40% reduction in anthropogenic N loads as compared with those at the beginning of the 1990s (Ministry of the Environment 1998). In 2004 another national regulation water quality came into force. On-site waste water treatment in one-family houses should be improved to fulfill current standards by 2014.

Since 1995, the Finnish agricultural policy has been based on the EU Common Agricultural Policy (CAP). CAP was reformed in the Agenda 2000 agreement, in which producer prices of cereal crop, milk and beef were reduced. In June 2003, CAP was further reformed and major parts of the CAP supports were decoupled from production. Finland has decided to move over to the reformed CAP in 2006. The most important policy measure controlling agricultural nutrient loading is the Finnish Agri-Environmental Programme (FAEP) (Valpasvuo-Jaatinen *et al.* 1997, Ministry of Agriculture and Forestry 2004). In 2002 it covered about 92% of farms and 93% of the arable area (Ministry of Agriculture and Forestry 2004). Support funds are paid to farmers to prepare a farm environmental management plan, establish filter strips on the sides of main ditches and water courses, and to conform to targeted levels of fertilizer and manure application. Special measures supported include establishment and management of 15-m-wide buffer zones, wetlands and sedimentation ponds. In forestry, buffer zones, wetlands and sedimentation ponds are recommended measures. Wetlands and sedimentation ponds are also connected to terms of environmental permits with peat harvesting.

The monitoring of diffuse pollution sources is not as accurate as the monitoring of point sources. Estimation of emissions from non-point sources based on river monitoring requires knowledge about retention and other losses in the river system, but these are generally unknown (Behrendt and Bachor 1998). Mathematical modeling of processes, sources and sinks at the catchment scale would be particularly helpful in this context (Arheimer and Brandt 2000, Arheimer and Lidén 2000, Lepistö *et al.* 2001, Jarvie *et al.* 2002).

In this study, we used the dynamic, semi-distributed INCA-N model (Whitehead *et al.* 1998, Wade *et al.* 2002) to investigate the timing and origin of inorganic N loading to the Simojoki during 1995–1999. This period covered the first program period of FAEP. Secondly, the effects of intensifying forestry and agriculture practices on inorganic N fluxes from the Simojoki basin

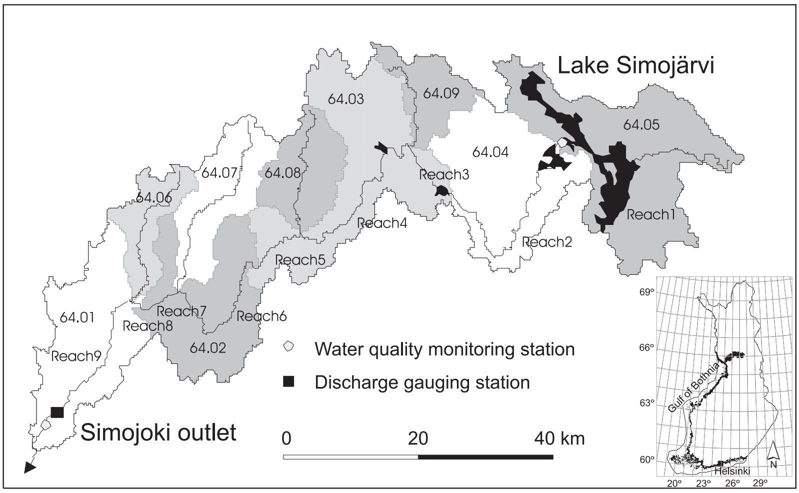

Fig. 1. Location of the Simojoki river basin in northern Finland.

to the sea in the target year 2010 were estimated. Changes in forestry were based on Finland's National Forest Programme (Ministry of Agriculture and Forestry 1999). The impacts of EU's agricultural policy on land use were assessed by the dynamic regional sector model DREMFIA (Lehtonen 2001, 2004). This model can be used to evaluate the effects of different agricultural policies simultaneously on land use, animal husbandry and agricultural income. Thirdly, the indicative effects of water protection measures on inorganic N fluxes were included by grounding effectiveness of these measures in other experimental research studies and expert judgements.

The land use change and water protection scenarios were run for the same period 1995–1999 than the basic model calibration. The relative importance of these scenarios was indicated by the percentage change in annual inorganic N fluxes as compared with the basic model calibration run above. Changes in atmospheric deposition of N were left out from this study, as the expected changes were earlier found to have no influence on N loads in the Simojoki basin (Rankinen *et al*. 2004b).

Material and methods

The Simojoki basin

The study area, the Simojoki basin, is located in southern Lapland, northern Finland. The main stream of the Simojoki represents a Fennoscandian natural river habitat type in the NATURA 2000 network (Blanplain 1998). The dominant human impacts in the area are forestry, agriculture, scattered settlement and atmospheric deposition. The only industrial activity is peat harvesting. The Simojoki discharges to the Gulf of Bothnia in the Baltic Sea (65°66´N, 25°09´E) and its basin (3160 km^2) can be divided into nine sub-basins (Fig. 1) (Ekholm 1993). Over the period 1961–1975, the mean annual precipitation in the area was 650–750 mm and mean annual runoff 350–450 mm. There are about 170–180 winter days and the mean annual temperature is 0.5–1.5 °C (Perkkiö *et al*. 1995). The duration of the snow cover is from the middle of November to early May. The river freezes at the end of October or beginning of November and the ice cover persists until the middle of May. The growing season (daily mean temperature > 5 °C) started on 10 May in the period 1961–1990 and lasted 140 days on average.

The river is unregulated, there are several rapids and Atlantic salmon spawn in the river. There are no major point-sources of pollution. Groundwater resources in the basin are very restricted. Much of the basin is covered by ground moraine, mainly sandy till. In the lower reaches there are also river deposits, and some areas of clay. Almost one third of the river basin is covered by peatlands which are mainly forested.

Forests cover most of the basin and an average of 0.5% of the total river basin area is felled annually. Drainage of peatlands for forestry was most extensive during the 1960s and 1970s, and by 1991 over 30% of the total river basin area had been drained. Peat harvesting in the area started in 1975 and in 1995 peat harvesting areas covered 0.4% of the basin area. Settlement covers only 0.1%. A municipal sewage treatment plant with direct outlet to the sea was built in 1972. Agriculture covers 2.7% of the basin area (Perkkiö *et al.* 1995) with grass cultivation for animal husbandry being the most common form of production.

There are two discharge gauging stations on the river, one at the outlet and one at the Hosionkoski. Daily discharge values were obtained from daily water level recordings with calibrated flow-rating curves. In 1965–2002, mean daily flow at the outlet was 40 $m^3 s^{-1}$. During the same period, the maximum discharge was 730 $m^3 s^{-1}$ and the minimum discharge 3 $m^3 s^{-1}$. The N concentration data for the Simojoki were obtained from the water quality database maintained by the Finnish Environment Institute (SYKE) and regional environment centres. During the study period, water quality samples were taken 12–17 times per year at the outlet gauging station. N_{tot} was analysed by digestion with alkaline $K_2S_2O_8$, and NO_3-N was measured by reduction of NO_3-N to NO_2-N in a Cu-Cd column followed by colorimetric determination of azo-colour. NH_4-N was determined colourimetrically with hypochlorite and phenol to produce indophenol.

The INCA-N model

The dynamic INCA-N (Integrated Nutrients in Catchments–Nitrogen) model integrates hydrology and N processes (Whitehead *et al.* 1998, Wade *et al.* 2002, Wade 2004). The model is semi-distributed because the land surface is not described in detail, but rather by land-use classes in sub-basins. Sources of N include atmospheric deposition, leaching from the terrestrial environment and direct discharges. Terrestrial N fluxes were calculated in up to six user-defined land use classes.

Hydrologically effective rainfall (HER) was used to drive N through the catchment system and N can enter the river system by lateral flow through the surface soil layers or by vertical movement and transport through the groundwater zone. HER was 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. Hydrology within the sub-catchments was modelled using a simple two-box approach, with reservoirs of water in a reactive soil zone and in the deeper groundwater zone.

The mass balance equations for NO_3-N and NH_4-N in the soil and groundwater zones were solved simultaneously with the flow equations. The key N processes that were solved in the soil water zone were nitrification, denitrification, mineralization, immobilisation, N fixation and plant uptake of inorganic N in six land use classes. It was assumed that no biochemical reactions occur in the groundwater zone. In the river the key N processes are nitrification and denitrification.

The river flow model was based on mass balance and uses a multi-reach description of the river system. Within each reach, flow variation was determined by a non-linear reservoir model. Point source inputs of N can be added as parameters when they are daily averages for the whole simulation period. Discharge which varies with time may be added as effluent time series which contain flow ($m^3 s^{-1}$) and NO_3-N and NH_4-N concentrations ($mg l^{-1}$).

The INCA-N model set-up in the Simojoki river basin

In this paper the original calibration described in Rankinen *et al.* (2004b) was updated for the current model version (INCA1v9) and improved to use more exact N leaching data from small research catchment studies. Input data for the years 1995–1999 were used as these years corresponded to the land use classification, forest drainage data and covered the first programme period of FAEP. Mean discharge in 1995 and 1996 were close to long term average discharge, whereas 1997 was dryer (32 $m^3 s^{-1}$) and 1998 clearly wetter (62 $m^3 s^{-1}$). Model parameters were adjusted to get simulated and observed discharge and inorganic N concentrations close to each other. Simulated annual inorganic N fluxes were compared with values reported in literature or small research catchment studies.

Hydrological input data (including HER) were calculated with the watershed model WSFS (Watershed Simulating and Forecasting System) (Vehviläinen 1994). WSFS simulates runoff using precipitation, potential evaporation and temperature as inputs. The principles of the WSFS are based on the HBV model (Bergström 1976). The system uses meteorological and hydrological databases and is used for flood forecasts and water resources management nationally.

Land-use classes were derived from satellite image-based land use and forest classification of Finland (Vuorela 1997) supplemented with satellite image-based maps of final cuttings on mineral and organic soils provided by the Finnish Forest Research Institute. Forest land was assumed to consist of managed forests where typical silviculture is practiced (drainage, thinning, regeneration or clear cut), and more than 10 years ago. Areas treated within the last 10 years were simulated separately. Forests on mineral soil covered 35% with new clear felling (1–10 years old) 4%, forests on organic soil 52% with new clear felling 1%, agriculture 2% and open surface water 6% of the river basin area. The areas of 'forest on organic soil' were assumed to have been drained during the 1960s or 1970s. Ground vegetation was assumed to start to recover on new felling areas.

Net loading of inorganic N from new forest ditching areas, peat harvesting areas and from scattered settlement were added as effluent time series. N processes in lakes ('open surface water') were calculated using the same equations as in terrestrial areas. Simulated river discharge and inorganic N concentrations were calibrated to measured values at the outlet of Simojärvi.

Farming in the basin was assumed to follow the same typical cultivation practices as described in the FAEP interview research (Palva *et al.* 2001, Pyykkönen *et al.* 2004). Maximum fertilization levels of mineral (154 kg N ha^{-1}) and organic fertilizers (165 kg N ha^{-1}) according to the FAEP basic measures and interview research were assumed.

Specific loads from land use classes

Annual inorganic N leaching from different INCA-N land-use classes was calibrated by comparing simulated N leaching to leaching estimates based on literature or small catchment studies. Small catchments are often used when studying hydrology and diffuse loading because of the close link between the loads measured at the outlets and the surrounding land. In selecting which leaching values to use for calibration only those based on similar land use and climatic conditions to those in the Simojoki river basin were used.

Such values for agricultural and forest land use classes were taken from the database on the small research catchments maintained by SYKE (Mustonen 1963, 1971, Seuna 1983), the VALU network for forested catchments in eastern Finland (Finér *et al.* 1997) and from the Nurmes catchment research project (Ahtiainen and Huttunen 1999). Kortelainen *et al.* (1997) estimated long-term leaching from 22 forested study catchments in Finland based on daily measured discharge and water quality (approximately 12 samples per a). These catchments included typical forest management practises (ditching, clear felling, scarification and low levels of N fertilization < 110 kg N km^2).

Inorganic N leaching from catchments in which the cover of peatland was > 34% were used to calibrate inorganic N leaching from the 'forest on organic soil' land-use class. Two of these study catchments, Kotioja and Ylijoki (both 66°14´N, 26°15´E), are actually located in the Simojoki river basin (sub basin 64.03). Peatlands cover over 50% of these catchments. Forest drainage carried out mainly in the 1960s accounts for respectively 26% and 30% of the area of these catchments (Seuna 1982, Kortelainen *et al.* 1997). Those catchments, in which peatland percentage was < 34%, were used to calibrate the 'forest on mineral soil' land-use class. Those two catchments located close to the Simojoki river basin, were Vähä-Askanjoki (66°55´N, 27°69´E) and Kuusivaaranpuro (66°76´N, 28°13´E). Specific inorganic N loading due to forest felling for new felling areas was estimated from the data of the Iso-Kauhea catchment (63°53´N, 28°37´E), where > 50%

of the area is peatland, and the Kangasvaara catchment (63°51´N, 28°58´E), where area of peatlands is < 10%.

Vuorenmaa *et al.* (2002) estimated agricultural losses of dissolved inorganic N from agricultural catchments in southern Finland in 1991–1995 based on measured discharge and water quality sampling. In the Hovi catchment (60°42´, 24°38´) 100% of the area was cultivated, and in the Löytäneenoja catchment (61°27´, 22°25´) 68% of the area was cultivated. As these catchments are located in southern Finland, results of a field scale study of inorganic N leaching from perennial grass ley fertilized by slurry and mineral fertilizer conducted by Turtola and Kemppainen (1998) in northern Finland are also included.

Effluent time series

Forest drainage

In 1988–1998, 14 700 ha in the Simojoki basin were drained, so that half was first time drainage and half ditch cleaning and supplementary drainage. Experimental data from two study catchments, Koivupuro (63°52´N, 28°30´E) and Suopuro (63°52´N, 28°30´E) were used to derive specific inorganic N loading due to forest drainage areas. The Koivupuro catchment (118 ha) is 57% peatland and in 1983 27% of the peatland area was ditched. Over the next ten years, the increase in annual specific loading of inorganic N from the treated area averaged 0.97 kg N ha^{-1}. Data from the Koivupuro catchment was used in the basic calibration.

This specific value was used to calculate a percentage increase in simulated daily leaching from the 'forest on organic soil' land-use class. Discharge from ditched areas was assumed to increase by 0.6% per percentage of ditching area (Seuna 1990) and the duration of increased loading was assumed to be 10 years. Inorganic N loading from ditched areas was further assumed to be only in the form of NH_4-N (Laine *et al.* 1995). Calculated annual mean concentrations of NH_4-N in runoff water from ditched areas varied between 0.18 and 0.58 mg l^{-1}. Joensuu *et al.* (2001) reported mean NH_4-N concentrations in runoff water from ditched areas 0.08–0.12 mg l^{-1} between the snow melt period in spring and freezing in late autumn for sites all over Finland. Hynninen and Sepponen (1983) reported concentrations between 0.02 and 0.42 mg l^{-1} in northern Finland.

Table 1. Loading from different on-site waste water systems including the percentage of N_{tot} accounted for by NH_4 and NO_3 (Vilpas *et al.* 2005).

Method	N_{tot} (g day^{-1} person^{-1})	NH_4-N (%)	NO_3-N (%)
Septic tank	14.5	92.6	7.4
Subsurface disposal system	5.3	27.2	72.8
Batch treatment plant	7.6	60.5	39.5

Peat harvesting

In 1995 there were 1365 ha of peat harvesting fields in the Simojoki basin. By 1999 this area increased to 1409 ha. Inorganic N loads from these areas were taken from annual reports to the water authorities (Vääränen 2000, Kaikkonen and Salo 2004). Net loading of NH_4-N during production season (weeks 22–37) in 1999 averaged 27.9 kg d^{-1}. Monitoring at the Lumiaapa peat harvesting area is continued all year round (Kaikkonen and Salo 2004) and seasonal loading percentages (weeks 45–16: 23%, weeks 17–20: 29%, weeks 21–39: 38.5% and weeks 40–44: 9.5%) from this site were adapted to other peat harvesting areas.

Scattered settlement

Catchment-scale N loading from areas of scattered settlement was based on the results from the RAVINNE-SAMPO project (Table 1), in which nutrient loading from one-family houses with different on-site waste water systems was studied (Vilpas *et al.* 2005). Numbers of persons and houses outside municipal sewerage systems were taken from official statistics for 2000 (Anon. 2000). Information about on-site waste water system types in the Simojoki basin was based on a questionaire (Nenonen 2004).

Accordingly, over 90% of the households had septic tanks and the most common methods for sewage treatment were subsurface disposal systems (about half of households). Estimates of inorganic N loading from the scattered settlement in the Simojoki river basin are presented in Table 2.

Land use change and water protection measures

Evaluating changes in agricultural land use

The impacts of the EU's agricultural policy (CAP) reforms on agricultural land use in the Simojoki basin were assessed using the DREMFIA model (Lehtonen 2001, 2004). All agricultural production and land use variables in the Simojoki region were included in DREMFIA and validated close to observed levels. The output of the DREMFIA model includes annual variation in the total area of agricultural land use as well as a break down into the area of main crops and levels of fertilizer use, which were used as input to the INCA model (Rankinen *et al*. 2004c).

The BASE scenario followed Agenda 2000, which was assumed to stay unchanged up to 2020. Accordingly, national financial support, investment support and environmental support were assumed to stay at the same level as in 2004. EU prices of dairy products as well as the producer price of milk (exogenous in the DREMFIA model) were assumed to fall by 15% while domestic prices (endogenous in the model) decreased by 12%. In the BASE scenario the total utilised area of agricultural land will increase by 25% by 2010 from the level in 1995. After 2010 it will slowly decrease back to the 1995 level by 2020. Grass cultivation will remain the main production form accounting for 98% of the field area.

The Mid Term Review (MTR) scenario followes the CAP reform agreed in 2003. In the MTR scenario the quota system for milk was assumed to stay, but the producer price in the EU was assumed to decrease by 22% by the year 2007, while the domestic milk prices remain slightly higher due to reduction of aggregate milk production by 5%–10%. In the MTR scenario, the total area of agricultural land will increase by 35% by the year 2010 and then level off. Hence, the total area of agricultural land use will increase relatively more and then stay at the higher level as compared with that given by the BASE scenario. Grass cultivation stays the main form of agricultural production at the Simojoki river basin (93% of the agricultural area). However, by the year 2020 milk production will have decreased by 40% and consequently the area of grass cultivation decreases (down to 52% of agricultural land) and the area of green fallow increases (up to 46%). This happens as a result of decreasing milk price and de-coupled payments decrease dairy investments while set-aside land is eligible for de-coupled payments. Also, some farms change to grain production (2% of the field area).

Changes in forest management areas

An increase of 20% in forest felling areas (CUT scenario) based on Finland's National Forest Programme (Ministry of Agriculture and Forestry 1999) was assumed. In the forest management plan of Lapland mainly thinnings are planned and the volume of stems harvested will stay at the present levels (Riissanen and Härkönen 2000). Forest drainage, mostly ditch cleaning and supplementary drainage of existing drained areas, is set to increase in the future. The area for such remedial forest drainage for the whole of Lapland during 2001–2005 was planned to be 10 700 ha. However, as no official targets

Table 2. Loading from scattered settlement in the Simojoki basin (Finnish Environment Institute).

Sub basin	Reach	Inorganic N load (kg a^{-1})
64.05	Reach 1	1296.5
64.04	Reach 2	341.7
64.09	Reach 3	100.5
64.08	Reach 4	132.3
64.03	Reach 5	1674.9
64.07	Reach 6	40.6
64.02	Reach 7	860.9
64.06	Reach 8	1.1
64.01	Reach 9	2226.5

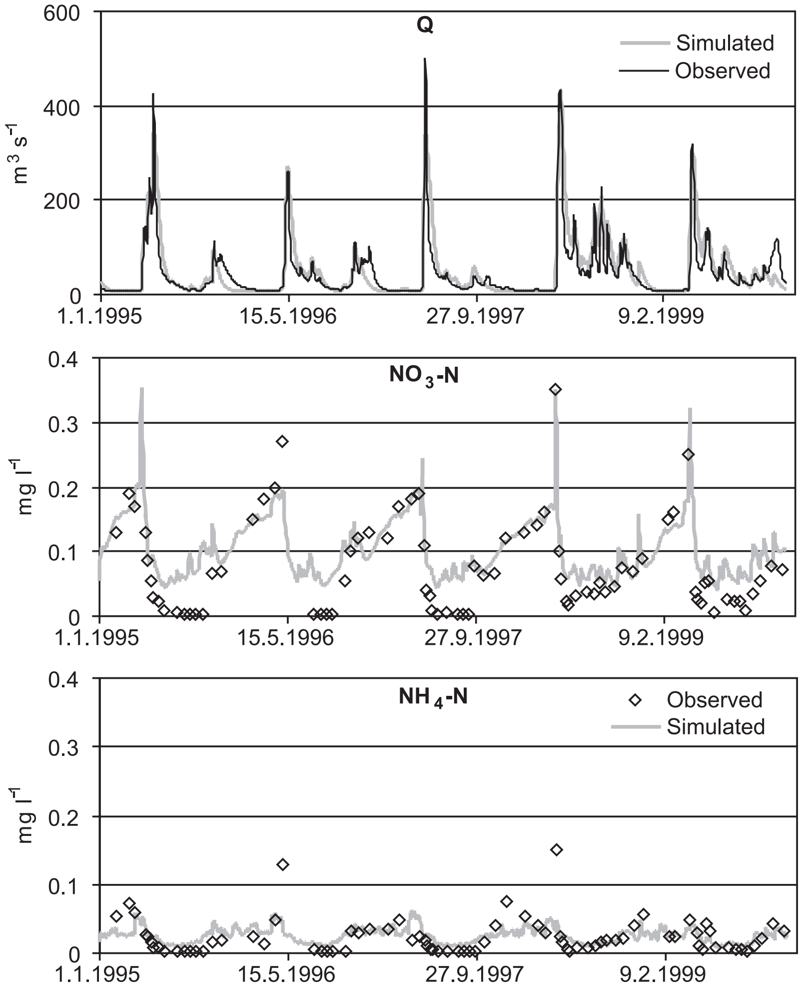

Fig. 2. Observed and simulated discharge and inorganic N concentrations with the INCA-N model at the outlet of the Simojoki.

for forest drainage in the Simojoki basin were available, the total area for forest drainage was assumed to stay at the present level.

Water protection measures for agriculture, forestry and scattered settlement

Crop production in the Simojoki basin is mainly perennial grass, so there is vegetation cover on the fields all year round. We have assumed that farmers will follow both fertilization levels and times to spread manure recommended in FAEP basic measures. In this case the most effective water protection measures are buffer zones and wetlands.

Studies have shown that 15-m-wide buffer zones established along rivers can decrease inorganic N surface leaching by 30%–50% (Puustinen 1999), and wetlands can decrease inorganic N leaching up to 30% (Koskiaho and Puustinen 2004). As most of the agricultural land in the Simojoki basin is located adjacent to the river, both buffer zones and wetlands were assumed to be established on 15% of the fields. This combination leads to about 10% decrease in simulated inorganic N loading from agricultural areas.

For the specific load of inorganic N a value from the Suopuro research catchment (Ahtiainen and Huttunen 1999) was used in the scenario runs. The Suopuro catchment is 113 ha, 70% of which is peatland. In 1983, 13% of the area was ditched and a 10-m-wide protective zone between the ditched area and the brook was left. Over the following ten years the increase in spe-

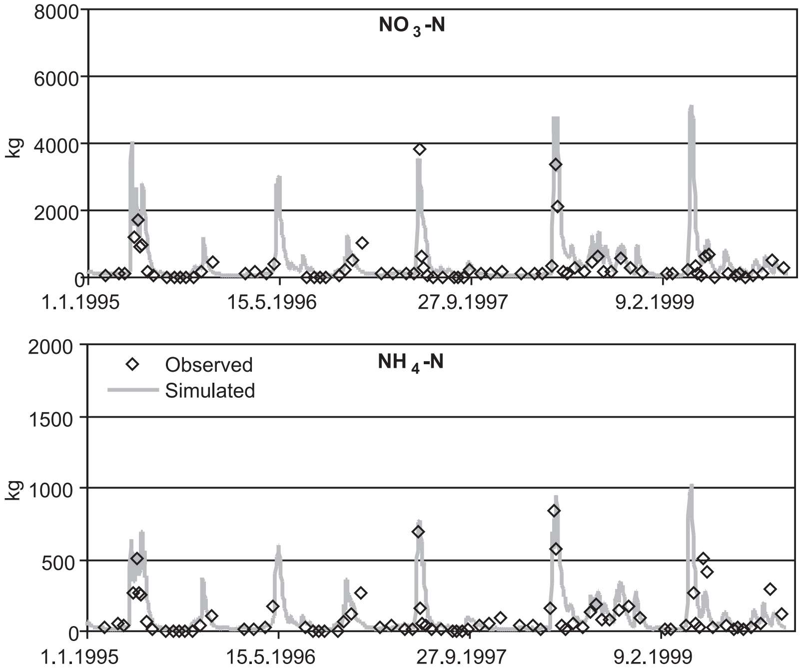

Fig. 3. Calculated based on observations and simulated inorganic N load with the INCA-N model at the outlet of the Simojoki.

cific loading from the ditched areas was 0.26 kg N ha^{-1} a^{-1}. No special water protection measures on new (1–10 years old) forest felling sites were assumed.

As the dwellings in the Simojoki basin are relatively old, subsurface disposal systems were assumed not to be as efficient as new ones. In the scenario, inhabitants in one-family houses were assumed to renew their sewage treatment system to reach the current recommended purification capacity, but not to change system type. The loading from renewed subsurface disposal systems was assumed to decrease by 30% based on the RAVINNE-SAMPO study (Vilpas *et al.* 2005).

Results

Simulated discharge and inorganic N concentrations

Observed inorganic N concentrations in the river water were generally low (≤ 0.5 mg l^{-1}). Simulated and observed discharge and inorganic N concentrations are presented in Fig. 2. The fit between simulated and observed discharge was good with Nash and Sutcliffe efficiency (Nash and Sutcliffe 1970) R^2 = 0.76. The model represented the seasonal dynamics in NO_3-N and NH_4-N concentrations with R^2 efficiencies 0.61 and 0.30, respectively. The fit between simulated and observed inorganic N concentrations during the dormant season was good, but during the growing season simulated concentrations remained relatively high while observed inorganic N concentrations fell to detection limit values.

Loads and source apportionment of inorganic N

Inorganic N load at the outlet of the Simojoki is presented in Fig. 3 and simulated inorganic N leaching from different land use classes are presented in Table 3 together with calculated leaching from small research catchment studies. Inorganic N load to the sea was 41% higher in the wet year 1998 and 29% lower in the dry year 1997 than the average load during 1995–1999. The ratio of inorganic N load to water flow was highest in the beginning of the snow melt period (Fig. 4). During the growing season (June–September) the proportion of water flow was higher than the inorganic N load. On average, 52%

Table 3. Inorganic N leaching from different land use classes simulated with the INCA model.

Land use class	Simulated		Observed		Catchment	Reference
	NO_3-N (kg ha^{-1} a^{-1})	NH_4-N (kg ha^{-1} a^{-1})	NO_3-N (kg ha^{-1} a^{-1})	NH_4-N (kg ha^{-1} a^{-1})		
Forest on mineral soil	0.12–0.14	0.17–0.19	0.14	0.11	Vähä-Askanjoki	Kortelainen *et al.* 1997
			0.12	0.09	Kuusivaaranpuro	
			0.27	0.11	Average of 9 catchments	
Forest felling on mineral soil	0.23–0.26	0.18–0.19	0.12*	0*	Kangasvaara	unpublished
Forest on organic soil	0.19–0.22	0.17–0.18	0.32	0.06	Kotioja	Kortelainen *et al.* 1997
			0.33	0.19	Ylijoki	
			0.19	0.29	Average of 13 catchments	
Forest felling on organic soil	0.49–0.51	0.38–0.40	0.21*	0.12*	Iso-Kauhea	unpublished
Agriculture	5.86–6.36	0.87–0.89	8.8**		Hovi	Vuorenmaa *et al.* 2002
			9.8**		Löytäneenoja	
			7			Turtola and Kemppainen 1998***

** TIN; *** field scale study

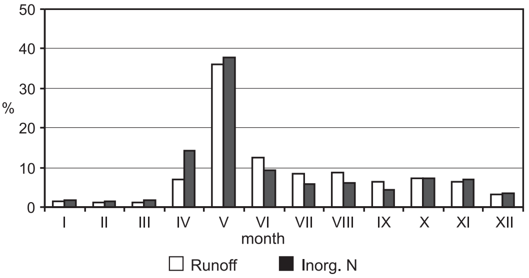

Fig. 4. Simulated monthly runoff and inorganic N load as percentages of annual runoff and inorganic N load with the INCA-N model.

of the total load of inorganic N was leached in April–May (Fig. 4).

The simulated inorganic N gross load in the Simojoki was partitioned according to source, as shown in Fig. 5. In the upper parts of the river, the inorganic N originated mainly from forests in the near-natural state. The contribution from anthropogenic sources increased in the lower reaches and at the outlet of the river they constituted more than half the inorganic N load, with agriculture, forestry and the scattered settlement accounting for almost equal amounts of the total load.

Effect of land-use change on the inorganic N load

The effect of land use changes on inorganic N load to the sea is presented in Fig. 6. Increased forest felling by 20% of area would not change inorganic N load to the sea. If the total area of agricultural fields would settle down to the extent according to BASE scenario in 2010, it would increase the inorganic N load by 4%, and according to the MTR scenario by 5%. In a combined scenario with forest felling and MTR agricultural land use, inorganic N load would increase by 6%.

The inorganic N load to the sea simulated with both scenarios was the highest in 2010, when the total area of both agricultural land and grass cultivation was the greatest. By the year 2020 land-use change according to the BASE scenario did not increase the total inorganic N load to the sea, and according to the MTR scenario the load was decreased by 3%.

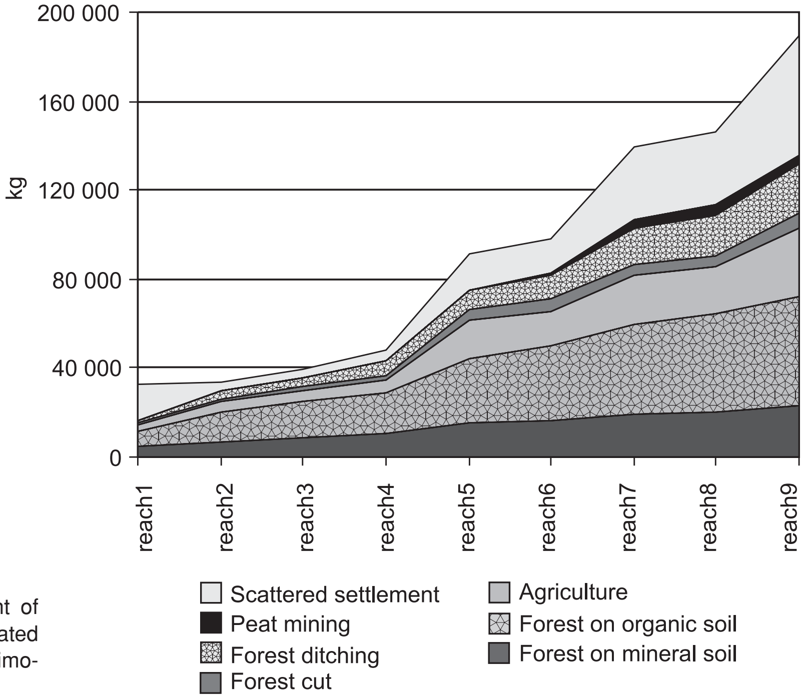

Fig. 5. Source apportionment of inorganic N gross load simulated by the INCA-N model in the Simojoki.

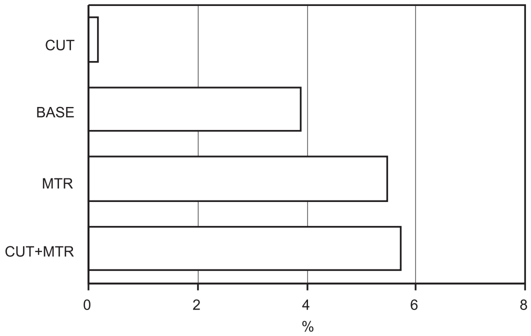

Fig. 6. Effect of various scenarios of land use change on inorganic N load to the sea in year 2010 simulated by the INCA-N model.

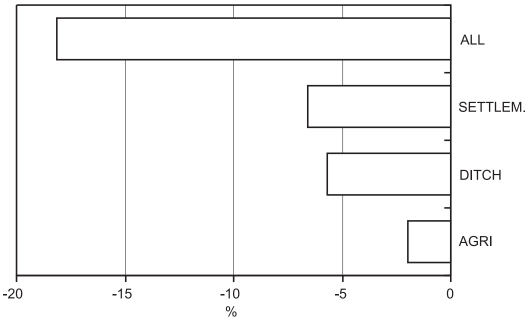

Fig. 7. Effect of water protection measures on inorganic N load to the sea in year 2010 simulated by the INCA-N model.

Effects of water protection measures on the inorganic N load

The effect of water protection measures on the inorganic N load to the sea is presented in Fig. 7. The use of buffer zones and wetlands would decrease the inorganic N load by 2% when established in the agricultural fields. Buffer zones in forest drainage areas would decrease the inorganic N load by 6%, and settlement renewed subsurface disposal systems would decrease the load by 7%. Combining all the different measures would lead to a reduction in the inorganic N load of about 18%.

Discussion

The INCA-N model was able to simulate the observed discharge in the Simojoki as well as annual dynamics of inorganic N concentrations in the river, except during the growing season. The overestimation of inorganic N concentrations during the growing season may be because uptake by aquatic plants is not taken into account in the INCA-N model (Jarvie *et al.* 2002). There may be also more retention in the terrestrial environment than is taken into account in the model. In small boreal catchments there is usually wetland at the outlet. Nutrients are effectively retained during the growing season, but during winter and snowmelt most of the runoff flows over frozen land. In agricultural areas nutrients are retained in ditches and ditch banks during the growing season. Deelstra *et al.* (2004) estimated that from agricultural areas N losses measured at the catchment scale are 28% lower than measured losses at the drainage field scale due to different retention processes. However, the overestimation of inorganic N concentration during growing season had little effect on annual inorganic N loads at the outlet of the river because of low flows.

Loading from the river basin was concentrated to peaks during high flow periods, especially the snowmelt period in spring. The higher loading was not only due to increased runoff but also to higher inorganic N concentrations. Overwinter N mineralization probably resulted in an accumulation of inorganic N in the soil which was then flushed out during snowmelt giving rise to the higher concentrations. Rankinen *et al.* (2004a) estimated net mineralization in the Simojoki basin during the season when soil is mainly frozen to account for about 40% of the annual N mineralization.

The more dense population around Simojärvi increased the river inorganic N load in reach 1, but this increase disappeared in retention processes in the lake. At the river basin outlet about half of the inorganic N load was from anthropogenic sources. Ecological studies of the Simojoki reflect the increase in anthropogenic loading moving downstream. A river bottom fauna survey (Liljaniemi 2003) and a diatom survey (Miettinen 2003) of the Simojoki both indicate that the upper parts of the river are in an almost natural state but that lower reaches are affected. However, inorganic N concentrations in the Simojoki are low and not even peak concentrations of NO_3-N exceed the levels of 2–3 mg l^{-1} which is considered to be fatal for biodiversity (Giles 2005).

The structure of the current version of the INCA-N model does not allow hydrological inputs to be changed in land-use classes but only in sub-catchment. The influence of land-use change on runoff should be added to the model as effluent time series. Runoff from large peat harvesting areas is conducted to one outlet where water quality and discharge are monitored. This justifies the treatment of peat harvesting areas as point sources in the Simojoki basin. When adding the loading from forest drainage areas as percentual increase to that from the land-use class 'forest on organic soil' it was assumed that the seasonal dynamics of loading was captured. Peat harvesting and forest drainage both increase the spring peak runoff (Seuna 1990) and NH_4-N concentration in runoff from forest drainage areas are higher during the dormant season than during the growing season (Hynninen and Sepponen 1983, Laine *et al.* 1995). A more realistic approach to INCA-N would be to include changes in both discharge and N concentrations in the land-use classes.

Increasing the area of agricultural land-use and changes in it both had a stronger influence on inorganic N leaching than expected. Agricultural activities in the Simojoki basin were clearly policy driven and prices of agricultural products and supports paid for farmers affected production and thus nutrient load. The simulated expansion of agricultural land is well in line with the already observed 11% increase in agricultural area in northern Finland in 1996–2003 (Information Centre of the Ministry of Agriculture and Forestry 2003). In this study, the increase in agricultural area was limited by the existing area of available agricultural land, including some marginal land currently not fully utilised. Increases in the area of agricultural land through converting forest to agricultural land were not considered in this study. It is uncertain if such new agricultural land would be eligible for agricultural support, without which it would be uneconomic to make such a land-use change.

The forest felling scenario had no marked effect on inorganic N leaching. The area annually harvested is small (~0.5% of catchment area), and scattered throughout the basin. Westling *et al.* (2001) considered that if the area harvested does not exceed 10% of the total catchment area, water chemistry is mainly defined by the natural variation from untreated areas. However, the local effect of felling can be much greater than observed at the outlet of a river basin (Ahtiainen and Huttunen 1999).

Even though water protection methods have been applied to peat harvesting and agricultural areas during the last decade, P and N concentrations in the Simojoki have not declined (Räike *et al*. 2003). The standard of sewage treatment in private dwellings has remained the same during the last decade (Perkkiö 1995, Nenonen 2004). Ditching of peatlands for forestry was most intensive in the 1960s and 1970s and now the emphasis is on ditch cleaning and supplementary drainage (Perkkiö 1995). In the 1990s the area of peat harvesting did not change much but water protection measures were improved (Perkkiö 1995, Vääränen 2000). The main changes in N loading can be assumed to be due to changes in agricultural practices and land-use due to EU agricultural policy. The FAEP was established in 1995 to ensure agricultural practices changed towards higher sustainability (Valpasvuo-Jaatinen *et al*. 1997). The effect of these changes on nutrient leaching is difficult to evaluate as little information of local agricultural practices before 1995 is available.

Our modelling results indicate that water protection measures carried out on agricultural and forestry areas and in scattered settlement would decrease the leaching of inorganic N more effectively than concentrating on one source only. However, the effects of different land-use changes and the effects of improved water protection methods may cancel each other out. Furthermore, between year variation in hydrological and meteorological conditions had a greater influence on simulated inorganic N leaching than the expected changes in land-use or use of water protection methods. According to expected climate change in Finland (Carter and Kankaanpää 2004), winter-time runoff is likely to increase leading to increased inorganic N leaching.

The main reason for implementing water protection methods in the Simojoki basin is to improve the state of the Gulf of Bothnia. Nitrogen from the clearly P-limited Bothnian Bay flows to the south to the N-limited Bothnian Sea where eutrophication was observed throughout the 1980s and 1990s (Pitkänen 2004).

Conclusions

The simulation results from this study showed that the inorganic N in the upper parts of the Simojoki mainly originated from forested areas, but that anthropogenic sources increased downstream. At the discharge outlet of the basin about half of the inorganic N load originated from anthropogenic sources, with agriculture, forestry and scattered settlement accounting for about one third each. Most of the variation in the annual inorganic N load was determined by annual runoff. Half of total annual load occurred during snow melt in April–May. Peat harvesting and forest drainage both tended to increase inorganic N leaching in spring. While the EU's agricultural policy has focused attention on controlling agricultural nutrient loading, it has also increased the risk of N loading through promoting changes in agricultural land-use and concentrating animal farming into larger units. Expected changes in forestry land were small and would not increase inorganic N loading to the Gulf of Bothnia, and water protection measures related to forest drainage areas could actually decrease it. Water protection measures properly established in agriculture, forestry and scattered settlement areas have the potential to better decrease the anthropogenic part of the inorganic N load to the Gulf of Bothnia than concentrating such measures to one land-use class only.

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