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Nitrogen and Phosphorus Fluxes from Finnish Agricultural Areas to the Baltic Sea

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Nutrient losses from small drainage basins were compared to the nutrient fluxes in small coastal rivers in order to study the representativeness of the Finnish monitoring network of small basins, especially as regards agricultural loading to the Baltic Sea. Additionally flux estimates from the period 1986-1990 were compared to those of the period 1981-1985 in order detect possible trends. The results suggest that in coastal regions with high proportions of agricultural land and with low lake percentage, the nutrient losses from agricultural areas mostly enter coastal waters with negligible retention in river channels. The net effect of the various processes in the rivers is small because most of the nutrient losses occur in spring, fall or early winter in connection with high water flows and current velocities, short residence times of water and low intensities of biogeochemical processes. Nitrogen losses from agriculture has probably increased during the 1980s due to increased winter flows and increased use of nitrogen fertilizers. The results indicate that nitrogen loading of the southern and south-western coastal waters of Finland has increased as well.

Introduction

One of the most harmful effects of human activities on surface waters is eutrophication caused mainly by nitrogen and phosphorus loading. In many industrialized as well as in developing countries the contribution of non-point sources to nitrogen and phosphorus losses is of the same order of magnitude or higher than that of point sources from industry and municipalities. Agriculture comprises the largest proportion of non-point nutrient sources also in countries, where agricultural land use is relatively small, such as Sweden, Norway and Finland (see *e.g.* Kronvang and Svendsen 1991).

In Finland the agricultural contribution of nutrient loading to water courses has been estimated to be higher than the nutrient load from industrial and municipal sources together (Kauppi 1984; Rekolainen 1989). The phosphorus load, particularly from municipalities, has been significantly reduced during the last two decades by intensive construction of wastewater treatment plants based on the simultaneous chemical precipitation. Therefore, the emphasis in eutrophication control has shifted from reducing point-source pollution towards non-point sources, especially from agriculture.

The monitoring of nutrient fluxes in representative drainage basins or in rivers loaded mainly by non-point sources is a method to estimate nutrient losses from these sources and to detect long-term trends. However, to achieve reliable estimates and to detect trends the monitoring program has to be designed to minimize the bias from the "true" loss and the imprecision of the loss estimates (see *e.g.* Walling and Webb 1982; Rekolainen *et. al.* 1991). This requires a careful design of sampling frequency, sampling strategy, analyzing procedures and calculation methods.

In Finland the long-term monitoring of nutrient losses in small agricultural and forested drainage basins was started in 1962. The high fluctuation of annual loss estimates are mainly caused by natural climatic variation and also by a relatively high uncertainty in loss estimates caused by infrequent sampling. Thus, detection of trends in losses can only be based on mean losses for periods covering several years. Earlier reports of nutrient losses from small drainage basins cover the years 1965-1977 (Kauppi 1984) and the years 1981-1985 (Rekolainen 1989).

The monitoring of river transport was started in 1970 (Wartiovaara 1975, 1978).

Although the fluctuation of fluxes in rivers is smaller than in small drainage basins, the relatively low sampling frequencies have allowed only the use of long time series or mean values of several years in flux and trend assessments (Pitkänen 1986; Pitkänen *et. al.* 1986).

The objective of this study was to give estimates of nutrient fluxes for the period 1986-1990 and compare these estimates to those from the period 1981-1985. Different calculation methods have been earlier reported to produce variable loss estimates (Walling and Webb 1982; Rekolainen *et. al.* 1991). To allow comparison of the results from this study to the results from the previous period the same calculation method was used. However, the results were compared to those obtained by various other calculation methods.

Due to the limited resources available for establishing and maintaining a dense network of representative drainage basins for assessing nutrient losses, the results from small basins were compared to monitoring results from rivers with a high proportion of agricultural land, low percentage of lakes, and relatively low point-source pollution. This comparison also allows to assess the net-effects of different biogeochemical processes on nutrient fluxes in the river channels.

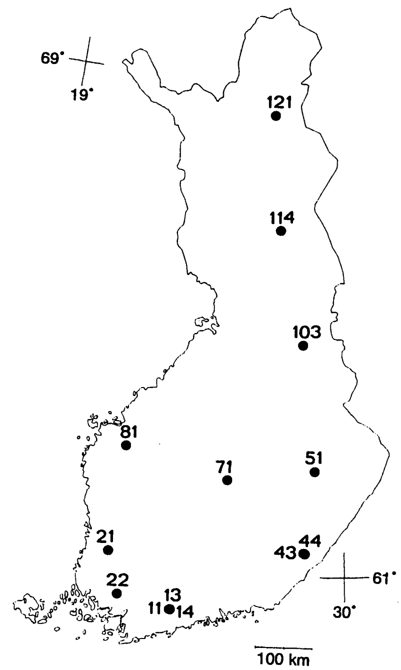

Fig. 1. Location of the 13 research drainage basins. The numbers refer to those in Table 1.

Material and Methods

Drainage Basins and Rivers

Generally, the estimation of nutrient losses is based on monitoring results from small drainage basins. In Finland a network of small research basins was established in 1957 for hydrological research and in 1962 the water quality monitoring was started in some of these basins. A description of the basins is given by Mustonen (1963, 1965) and Seuna (1983). In the period 1986-1990 the water quality monitoring program was carried out in 13 of these basins (see Fig. 1.). Area, proportion of agricultural land and soil types of the basins are given in Table 1.

On the basis of land use, these basins are divided into three classes:

- Forested basins (field percentage $< 4\%$)
- Mixed basins (field percentage 4-39%)
- Agricultural basins (field percentage $> 39\%$)

Table 1 – Area, proportion of cultivated land and distribution of soil types in the 13 research basins.

Basins	Area	Cultivated land	Graded soils					Peat soils	Moraines
			gravel	sand	fine sand	silt	clay		
	km^2	%	%	%	%	%	%	%	%
Forested basins:									
13 Yli-Knuutila	0.07	0	-	-	-	-	-	-	100
14 Teeressuonoja	0.69	0	-	5	-	5	2	13	75
44 Huhtisuonoja	5.03	0	1	-	1	-	-	45	53
51 Kesselinpuro	21.7	4	-	1	2	-	-	50	47
103 Myllypuro	9.86	2	-	-	-	-	-	27	73
114 Vähä-Askanjoki	16.4	0	-	-	-	-	-	17	83
121 Laanioja		0							
Mixed basins:									
43 Latosuonoja	5.34	19	-	5	7	1	-	26	61
71 Ruunapuro	5.39	22	-	11	27	10	-	11	41
Agricultural basins:									
11 Hovi	0.12	100	-	-	2	43	55	-	-
21 Löytäneenoja	5.64	68	-	-	32	16	26	2	24
22 Savijoki	15.4	39	-	-	1	1	34	7	57
Acid sulfate basin:									
81 Haapajyrä	6.09	58	-	-	16	17	33	23	11

Table 2 - Drainage areas, percentage of field area and lakes in the river basins, mean flows and the percentage of the winter flows (January-March), and the number of samples for chemical analysis for the periods 1981-1985 and 1986-1990 in rivers included in this study.

River	Area	Fields	Lakes	Mean flow		Winter flow		Number of samples	
				1981-1985	1986-1990	1981-85	1986-90	1981-1985	1986-1990
	km^2	%	%	$m^3 s^{-1}$	$m^3 s^{-1}$	%	%		
18 Porvoonjoki	1273	28.5	1.3	14.7	13.2	11	26	59	50
21 Vantaa	1686	23.4	2.3	19.3	16.6	16	34	56	50
25 Uskelanjoki	566	43.7	0.6	4.9	5.1	14	33	39	33
27 Paimionjoki	1088	43.0	1.5	7.8	7.6	17	36	81	73
28 Aurajoki	874	36.7	0.3	8.2	7.5	13	35	26	57

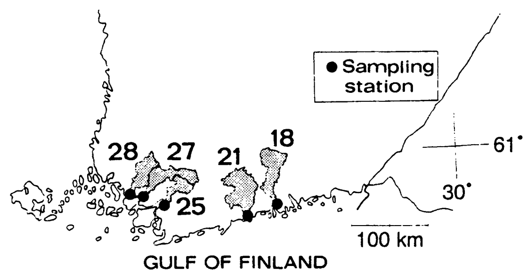

Fig. 2. Location of the studied river catchments. The numbers refer to those in Table 2.

At present the monitoring program for rivers discharging to the Baltic Sea consists of water flow and water quality measurement in 30 rivers which cover about 90% of the Finnish catchment area discharging directly (*i.e.* not via foreign territory) to the Baltic Sea. This program is described in detail by Wartiovaara (1975, 1978) and Pitkänen (1986, 1987). Based on the following criteria, five rivers have been selected for estimating the agricultural nutrient loading:

- field percentage $\geq$ 30%
- lake percentage $<$ 3%
- area $<$ 2,000 km^2
- mean pH $>$ 6

The drainage area, the proportion of cultivated land and the lake percentage of these rivers are given in Table 2 and the location of their catchments is shown in Fig. 2. The sum of the industrial and municipal nutrient loads into these rivers are presented in Table 4.

Flow Measurements, Sampling and Chemical Analyses

The flow in small drainage basins was measured continuously by a V-notch overfall weir and a water stage recorder. For the calculation of nutrient losses mean daily flow values were used, except for Löytäneenoja in 1986 and 1987, for Savijoki in 1987 and 1988, and for Hovi in 1989 and 1990. In these cases a automatic flow-weighted sampling produced frequent concentration data so that hourly flow values were used for calculation the nutrient losses.

The manual sampling in the basins was concentrated on high flow periods, and the sampling strategy was:

- six weekly samples in spring (mostly during the snowmelt period)
- six biweekly samples in fall (rainy season)

During the period of this study (1986-1990) an automatic flow-weighted sampling system was partly in operation in three of the basins: Hovi (1989-1990), Löytäneenoja (1986-1987) and Savijoki (1987-1988) producing a higher number of samles compared to the manually sampled basins. According to the evaluations of different sampling methods and strategies (Rekolainen *et. al.* 1991), the results from these years are less biased compared to the manually sampled basins and years. This has to be taken into account when comparing results to the results from previous periods, when only manual sampling was carried out.

In the selected rivers the water flow has been calculated from daily water level recordings, using calibrated flow-rating curves, in the Hydrological Office of the Finnish Water and Environment Research Institute.

In most of the rivers selected monthly sampling was performed during the period 1981-1985 (Table 2), whereas during 1986-1990 about 12 annual samples were taken flow-proportionally. This means that 6-7 samples were taken during the spring flood in April – early May and 3 samples during the autumn months from October to December. The remaining 2-3 samples were taken during the periods of low flow in winter and summer.

In this paper results for fluxes of total nitrogen and total phosphorus are presented. For determining total nitrogen, samples were oxidized with potassium peroxodisulphate and reduced to NO_2 with Hg-Cd or Cu-Cd columns and determined colorimetrically. For total phosphorus samples were digested by $K_2S_2O_8$ to reactive form and then analyzed spectrophotometrically based on the ammonium molybdate method by Murphy and Riley (1962) with ascorbic acid as a reducing agent.

Calculation of Nutrient Losses

Small Drainage Basins – In order to retain comparability to the loss estimates from the previous period (1981-1985) reported by Rekolainen (1989), the same method was employed for calculating total nitrogen and phosphorus losses in our paper. In this method the calculation of the annual losses is performed by a combination of two interpolation methods. This is done because of the intensive sampling in two short high-flow periods described above. For calculating the annual losses, a year was divided into four periods: spring and autumm (sampling periods), and winter and summer (no sampling or only a few samples).

The losses L_1 in spring/autumn (high-flow seasons) were calculated according to

$$L_1 = \sum_{i=1}^{n} c(t_i)\, q[T_i] \tag{1}$$

where $c(t_i)$ is the instantaneous concentration of individual sample taken at day t_i, $q[T_i]$ is the flow during period T_i (from the middle of a sampling interval to the middle of the next interval), and n is the number of samples in spring or autumn.

The losses in winter + summer L_2 were calculated as

$$L_2 = \bar{c}\, q[T] \tag{2}$$

where

$$\bar{c} = \frac{1}{n} \sum_{i=1}^{n} c(t_i) \tag{3}$$

and $q[T]$ is the total flow during winter + summer and n is the number of all samples of the year.

The losses for the two periods were summed to get the annual loss. This calculation method is called Method 1 in the following. This method has also been used by Pietiläinen and Rekolainen (1991) for estimating the losses of different phosphorus fractions from agricultural areas.

Method 1 was compared to three other frequently applied calculation methods in order to find out how much loss estimates calculated with these methods differ from Method 1. The methods used for this comparison are described below (see Rekolainen *et. al.* 1991):

Method 2: In this method the annual loss is calculated according to Eq. (1), applied for the whole year.

Method 3: In this case the annual loss is computed by Eq. (2), using the data for the entire year.

Method 4: In this method the sampled concentration values are weighted with the flow at the sampling times t_i,

$$L = q_a \frac{\bar{l}}{\bar{q}} \quad (4)$$

where $\bar{l}$ and $\bar{q}$ are the mean sampled loss and flow, respectively

$$\bar{l} = \frac{1}{n} \sum_{i=1}^{n} c(t_i) q(t_i) \quad (5)$$

and

$$\bar{q} = \frac{1}{n} \sum_{i=1}^{n} q(t_i) \quad (6)$$

and q_a is the total annual flow.

In the comparison of the methods only the annual losses based on infrequent manual sampling are used, *i.e.* the years with frequent automatic sampling are omitted, since the reference method (Method 1) is specifically designed for the manual sampling strategy described above.

Rivers

The annual river loads were calculated by multiplying the monthly concentration by the monthly flow and summing up the monthly loads

$$L = \sum_{m=1}^{12} c_m q_m \quad (7)$$

where c_m is the observed instantaneous concentration in month m (mean in case of several samples per month or seasonal average in case of missing monthly observations) and q_m is the monthly flow calculated form the daily flow values.

The different river sampling strategies affect the results of the load calculations. Higher estimates for the latter period are probable, because the flow-proportional sampling more reliably catches high concentration peaks than the previously applied monthly sampling which occasionally missed *e.g.* the early spring concentration peaks. However, the use of a 5-year averaging period and monthly mean values in the calculations largely smoothes the effect of concentration peaks. Thus the results of the two periods are relatively comparable. On the other hand, this method probably underestimates of the true fluxes (Walling and Webb 1985).

The point-source nutrient loads into the rivers used in this study (Table 4) are collected in accordance with the obligatory monitoring programs run by the municipalities and industrial plants, and are stored in the data bases maintained by the National Board of Waters and the Environment in Helsinki.

Results

In this paper the total nutrient losses from small drainage basins as well as the total nutrient fluxes for the selected rivers are reported for the period 1986-1990. These results are compared to the results for the period 1981-1985, for which the previous loss estimates were reported in Rekolainen (1989). Since nutrient fluxes are highly correlated with water flow, also the mean annual flows are reported.

Mean Water Flow

Calculated from the mean daily flow values, the mean annual flow in the small basins varied from 5.72 to 17.17 in the period 1986-1990 and from 5.22 to 12.87 $l\ s^{-1}\ km^{-2}$ in the period 1981-1985 in the small drainage basins (Table 3). In general, the mean flow for the period 1986-1990 was lower for the period 1981-1985. The difference in flows between these two periods was most pronounced in the forested basins located in eastern and northern Finland. In two of the agricultural basins (Löytäneenoja and Savijoki) the flows were about equal in these two periods, whereas in the Hovi basin the flow in the latter period was about 20% lower than in the former period.

The mean annual river flows varied from 7.0 to 10.5 $l\ s^{-1}\ km^{-2}$ in 1986-1990, the level being close to that of small basins (Table 2). In the rivers Vantaa, Porvoonjoki and Aurajoki the mean annual flows were 14%, 10% and 9% lower during the later period, resp., while the rivers Uskelanjoki and Paimionjoki showed very similar mean annual flows in both periods.

Losses of Phosphorus and Nitrogen

Small Basins

To retain the comparability of the loss results from the period 1986-1990 to the previous reported period 1981-1985 (Rekolainen 1989), the losses presented here are calculated using Eqs. (1) and (2). Note, that the losses for Hovi 1988-1990, Löytäneenoja 1986-1987 and Savijoki 1987-1988 are derived from more frequent

Table 3 – Loads of total phosphorus and total nitrogen, mean flow and the percentage of the winter flow (January-March) in 1981-1985 and in 1986-1990 in the research basins. For including a year in the loss estimate the minimum number of samples had to be 8 per year, *n*, is the number of years included in the estimate for 1986-1990.

	Tot-P($kgkm^{-2}a^{-1}$)			Tot-N($kgkm^{-2}a^{-1}$)			Flow $ls^{-1}km^{-2}$		Winter flow(%)	
	1981-85	1986-90	*n*	1981-85	1986-90	*n*	1981-85	1986-1990	1981-85	1986-90
Forested basins:										
Yli-Knuutila	8.9	8.5	5	300	280	5	5.72	5.22	14	31
Teeressuonoja	5.9	5.1	5	310	280	5	10.2	9.31	18	30
Huhtisuonoja	12	14	5	200	130	4	9.48	6.61	8.7	18
Kesselinpuro	16	11	5	270	180	5	10.6	8.00	5.3	8.8
Myllypuro	14	10	5	220	160	5	13.4	10.6	3.9	1.0
Vähä-Askanjoki	-	11	4	-	120	3	17.2	11.9	6.4	4.5
Laanioja	-	1.7	4	-	43	4	16.1	11.9	6.5	10
Mixed basins:										
Latosuonoja	14	10	4	590	330	4	10.40	7.42	11	22
Ruunapuro	53	28	5	490	360	5	9.66	8.99	9.6	13
Agricultural basins:										
Hovi	160	95	4	1400	2200	4	10.72	8.09	13	40
Löytäneenoja	75	65	5	1000	1400	5	10.14	10.53	9.0	36
Savijoki	66	76	5	890	1000	5	12.65	12.49	16	33
Acid sulfate basin:										
Haapajyrä	25	22	5	1400	1500	5	8.01	7.28	5.4	23

data (collected by an automatic sampler) than for the other basins. The annual loss estimates for these six cases are calculated by Method 2 using hourly flow values instead of daily values.

In forested basins the total phosphorus loss varied in 1986-1990 from 1.7 (Laanioja) to 14 kg km^{-2} a^{-1} (Yli-Knuutila), and for mixed basins from 10 to 28 kg km^{-2} a^{-1} (Table 3). In agricultural basins the total phosphorus loss varied from 65 (Löytäneenoja) to 95 kg km^{-2} a^{-1} (Hovi), while in the acid sulfate basin it was much lower (22 kg km^{-2} a^{-1}).

The total phosphorus losses in 1986-1990 were lower than in 1981-1985 in all the basins, except for Huhtisuonoja and Savijoki. In the Ruunapuro and Hovi basins the decrease of the total phosphorus loss was considerable.

The total nitrogen loss in 1986-1990 varied in forested basins from 43 (Laanioja) to 280 kg km^{-2} a^{-1} (Yli-Knuutila and Teeressuonoja). In the mixed basins the total nitrogen loss varied from 330 to 360 kg km^{-2} a^{-1}, while in agricultural basins the losses ranged from 1,000 (Savijoki) to 2,200 kg km^{-2} a^{-1} (Hovi). In the acid sulfate basin the total nitrogen loss was 1,500 kg km^{-2} a^{-1}.

For the forested and mixed basins the total nitrogen loss was lower in the period 1986-1990 than in the period 1981-1985. In the agricultural basins and in the acid sulfate basin the total nitrogen loss was higher during 1986-1990. Especially in Hovi and Löytäneenoja the increase was significant.

The loss estimates calculated using Method 1 (Eqs. (1) and (2)) were compared to the estimates calculated by Methods 2-4. Note, that for Hovi, Löytäneenoja and Savijoki the loss results from the frequent, automatically sampled data were not used, but calculated using the concentrations from a similar manual sampling strategy as used in the other basins.

All the calculation methods gave relatively similar results (Fig. 3). Method 2 and Method 3 gave slightly lower loss estimates, whereas Method 4 gave higher estimates compared to the reference method (Method 1). The estimates obtained by Method 3 were slightly closer to the estimates obtained by the reference method than those of the two other methods.

Rivers

We assumed that the loads from point sources into the rivers remain quantitatively unchanged in the course of the rivers, *i.e.* they are subtracted from the total fluxes measured at the river mouths in order to obtain non-points loads. The contribution of the municipal nutrient inputs of the total nitrogen and phosphorus fluxes were 27 and 21%, resp., for Porvoonjoki, and 22 and 12%, resp., for Vantaa (Table 4). In the other three rivers the contributions were less than 10%. The industrial contributions were negligible in all rivers studied.

The total fluxes of non-point phosphorus varied from 36 kg km^{-2} a^{-1} in Vantaa to 72 kg km^{-2} a^{-1} in Uskelanjoki during 1986-1990 (Table 5). The positive correlation between phosphorus transport and the field percentage in the river basin was very

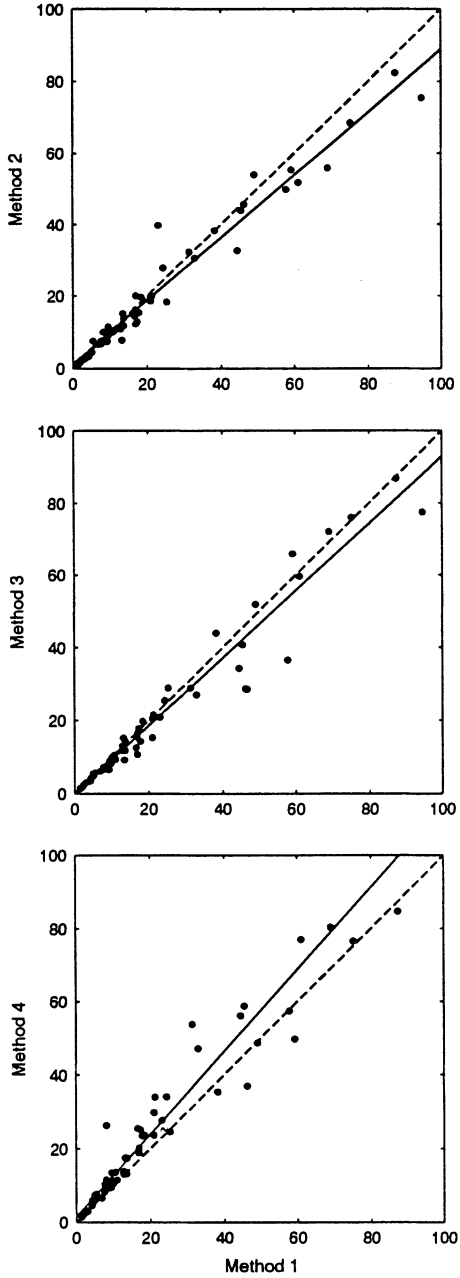

Fig. 3. Comparison of four different loss calculation methods (Methods 1-4, see text). The loss estimates calculated by Methods 2-4 are shown on the y-axes and Method 1 (the reference method) on the x-axes. The dotted lines represents the y=x line and the solid line the linear regressions between the methods.

Table 4 – Total river fluxes, sum of point source loads from municipalities and industrial plants, and non-point source loads for total phosphorus and total nitrogen in the periods 1981-1985 and 1986-1990.

		Tot-P(t a^{-1})		Tot-N(t a^{-1})	
		1981-85	1986-90	1981-85	1986-90
Total river load	Porvoonjoki	66	63	1500	1500
	Vantaa	96	68	1500	1400
	Uskelanjoki	36	42	360	440
	Paimionjoki	67	78	600	810
	Aurajoki	64	56	620	640
Point source loads	Porvoonjoki	15	13	430	410
	Vantaa	12	8.3	300	310
	Uskelanjoki	2.4	1.2	66	30
	Paimionjoki	2.3	1.7	32	38
	Aurajoki	0.7	0.8	8	11
Non-point source loads	Porvoonjoki	51	50	1100	1100
	Vantaa	84	60	1200	1100
	Uskelanjoki	34	41	290	410
	Paimionjoki	65	76	570	770
	Aurajoki	63	55	610	630

clear despite the relatively small variation in field percentages (see Table 2). The corresponding total nitrogen fluxes varied from 650 kg km^{-2} a^{-1} in Vantaa to 860 kg km^{-2} a^{-1} in Porvoonjoki. No clear correlation between nitrogen transport and field percentage could be observed in these cases.

Variations between the two studied periods are relatively small (< 20%) and can largely be explained by flow variations and the uncertainty due to the relatively low sampling frequencies (Table 5). The higher variations (> 20%) observed were the decrease in the P flux in Vantaa (due to the very high spring flows in 1981 and 1984) and the increase in the N flux in Uskelanjoki and Paimionjoki.

Table 5 – The total non-point source (kg km^{-2} a^{-1} for the total river basin area) and the agricultural phosphorus and nitrogen flux (kg km^{-2} a^{-1} for agricultural land) for the periods 1981-85 and 1986-90.

	Total non-point flux				Agricultural flux			
	Tot-P		Tot-N		Tot-P		Tot-N	
	1981-85	1986-90	1981-85	1986-90	1981-85	1986-90	1981-85	1986-90
Porvoonjoki	40	39	860	860	110	100	2200	2200
Vantaa	50	36	700	650	170	110	2000	1700
Uskelanjoki	60	72	510	720	110	140	600	1100
Paimionjoki	60	70	520	710	120	140	640	1100
Aurajoki	72	63	710	720	170	140	1200	1300

Discussion and Conclusion

Comparison of the Loss Calculation Methods

During the monitoring period reported in this paper (1986-1990), the manual sampling strategy concentrating the sampling in high flow seasons was still mostly used. According to the comparison of four different loss calculation methods, it seems that they all give similar results. Method 3, on which the mean annual flow is multiplied by the mean annual concentration, produced loss estimates which were closest to the refence method (Method 1). However, the best calculation method cannot be identified by such a comparison, since the "true" loss is not known.

In an earlier study in which different calculation methods were compared using more frequently sampled data (Rekolainen *et. al.* 1991), Method 3 was concluded to overestimate the "true" loss. In that study Method 4 was found to produce more accurate estimates, but the precision of these estimates was reported to be poorer compared to the estimates obtained by Method 2. Since the reference method in this study (Method 1) is not applicable for concentration data sampled flow-weighted by an automatic device, it is recommended to use Method 2, if loss estimates based on frequently sampled data are to be compared with estimates from more sparse concentration data.

As regards the river flux estimates, it is clear that with the present sampling frequencies of about 12 annual samples and the used calculation method (Eq. (7)) the "true" fluxes are mostly underestimated (Walling and Webb 1985). Results from weekly sampled data for the river Paimionjoki indicate that the estimates reported in this paper can be up to 20% lower than the "true" fluxes (Ekholm 1992).

Differences in Fluxes between the Two Observation Periods

The loss of total phosphorus from most of the studied small drainage basins was generally lower during the period 1986-1990 compared to the period 1981-1990 (Table 4). This is especially true for many of the forested basins. In two agricultural basins, Hovi and Löytäneenoja, the total phosphorus loss was lower in 1986-1990 compared to 1981-1985 period. In the agricultural basins the concentration data was collected by a frequent automatic sampling, which is supposed to produce higher, but more accurate, loss estimates. In Löytäneenoja the mean flow between these periods does not differ, and also in Hovi the lower flow in 1986-1990 cannot explain the change in the total phosphorus loss alone. Based on these facts, it can be assessed that the actual loss of phosphorus from these basins was lower in the period 1986-1990 than in 1981-1985.

The loss of total nitrogen was lower in the period 1986-1990 than in the period 1981-1985 except for the agricultural basins and the acid sulfate basin. In forested basins the reason for this is probably the lower flow during the period 1986-1990. The higher loss in the latter period in the three southern agricultural basins is most probably the higher proportion of flow during winters in the period 1986-1990

(Table 3). During the non-growing season the soluble nitrate concentration in soil is usually higher, and the more water leaves the root-zone during this period the higher is the overall nitrogen loss.

The winter-time flow for the agricultural and acid sulfate basins was clearly higher in the period 1986-1990 than in 1981-1985 (Table 4). In these basins the percentages of the winter flow was extremely high in 1989 and 1990, about 70-80% of the total annual flow. This effect seems to be most pronounced in southernmost agricultural basins. Another reason for the increase of the nitrogen loss from the agricultural basins can be the increase of the use of N-fertilizers. During 1986-1990 there was an increase in the N-fertilizer sale of 13% in Finland compared to the period 1981-1985.

In the rivers the differences in the estimates of the two periods can be largely explained by changes in the river flows and by the uncertainty due to the relatively low sampling frequencies (Table 5). However, the increase of about 40% in the nitrogen transport of Paimionjoki, cannot be explained only by these factors, especially because this river shows the highest sampling frequencies of the rivers studied, and practically no differences in the annual water flows were observed between the two periods (Table 2). The river basin has the highest field percentage (43%) of the monitored Finnish rivers. It is probable that the strongly increased winter water flows (Table 2) as well as the increased use of nitrogen fertilizers largely explain the increase. It is possible that the nitrogen flux in all rivers located in the agricultural area in southern and south-western coast has increased during the 1980s for these reasons. Similar trends were found earlier in the 1970s and early 1980s (Pitkänen 1986, 1987).

The Effects of Agriculture on Nutrient Losses

The effects of agriculture on nutrient losses are due to field cultivation. When estimating the loss from fields, the assumptions were made that the loss from forests and the natural loss from presently cultivated land is 10 kg km^{-2} a^{-1} of phosphorus and 250 kg km^{-2} a^{-1} of nitrogen (Rekolainen 1989). These assumptions are based on the monitoring results from forested basins during 1981-1985. The natural transport and the loss from forests was then subtracted from the total loss values for each basin. For the agricultural basins the specific loss from cultivated land was estimated from 80 to 170 kg km^{-2} a^{-1} of phosphorus and from 1,800 to 2,000 kg km^{-2} a^{-1} of nitrogen. In the acid sulfate basin the estimated specific phosphorus loss was lower (20 kg km^{-2} a^{-1}), but the nitrogen loss higher (2,200 kg km^{-2} a^{-1}).

Due to the very low number of agricultural basins monitored, it is uncertain, if the loss estimates based on them can be generalized to assess the overall agricultural load in Finland. After subtracting the background loss as well as the industrial and municipal point loads from the total river fluxes, the estimates of the agricultural phosphorus loads varied in these rivers from 100 to 140 kg km^{-2} a^{-1} and the nitrogen loads from 1,100 to 2,200 kg km^{-2} a^{-1} in the period 1986-1990 (Table 5). Taking into account uncertainties (see Materials and Methods), as well as the fact that the applied calculation method probably produces underestimates of the true fluxes, these results are similar to those obtained from small drainage basins. In addition the retention effect of lakes in the catchments has to be taken into account. According to Pitkänen (1986), even lake percentages lower than 3% (see Table 2) reduce the river flux to some extent.

Uncertainties in the agricultural load estimates derived from river monitoring are due to the fact that numerous processes in rivers (such as sedimentation, channel erosion, denitrification, biological processes) are not taken into account. However, it seems that the role of these processes remains relatively small in coastal rivers with low lake percentages (Pitkänen 1987). The reason for this is that high proportions of the annual river fluxes occur during the period of high flow in spring, late fall or early winter. This means that current velocities are high, residence times of water are short and biogeochemical activities are low in the river channels.

Thus most of the agricultural load from the coastal river basins reaches the Finnish coastal waters of the Baltic Sea, causing eutrophication there. Taking into account the locations of the cultivated areas and lakes in Finland, the coastal waters probably receive about two thirds of the total agricultural load into the Finnish water courses (Pitkänen 1987).

Since the loss estimates from small drainage basins and the load estimates from the rivers reported here give similar results, it can be concluded that the assessments for agricultural nutrient losses are representative for the large agricultural areas in southern and south-western Finland. However, due to the different climatic conditions in central and eastern Finland, the present estimates might not be accurate for these regions.

Based on the results for the period 1981-1985 and reported earlier by Rekolainen (1989), the total annual loss from agriculture in Finland was estimated to be 2,000-4,000 t for phosphorus and 20,000-40,000 t for nitrogen. The results for the period 1986-1990 show that the overall agricultural nutrient losses fall into the same ranges. However, mild, rainy winters in 1986-1990 have caused an increase in nitrogen losses in southern and south-western Finland. Also the higher nitrogen fertilization rates during the latter period have possibly increased the nitrogen losses. The monitoring results indicate a slight decrease in the agricultural phosphorus losses. However, at present it is unclear, whether this change is significant.

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