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EFFECT OF DRAINAGE BASIN CHARACTERISTICS ON THE DIFFUSE LOAD OF PHOSPHORUS AND NITROGEN

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The diffuse load of phosphorus and nitrogen was studied in 23 small drainage basins between 1965 and 1974. Total phosphorus and total nitrogen concentrations were analyzed monthly and runoff measured continuously. Mean concentrations and loads for each basin are presented. The mean concentrations of phosphorus varied from 8.3 to 98 $\mu g\ l^{-1}$ and of nitrogen from 190 to 2 400 $\mu g\ l^{-1}$. The dependence of concentrations on runoff was in most basins rather slight, but the highest concentrations were usually observed during the spring floods. The mean loads of phosphorus varied from 4.0 to 44 $kg\ km^{-2}a^{-1}$ and of nitrogen from 79 to 740 $kg\ km^{-2}a^{-1}$. The dependence of concentrations and loads on basin characteristics was studied by linear regression analysis. The percentage of cultivated land was found to be the most descriptive variable of the characteristics of the basin; it also reflects the loading caused by sparse population and by domestic animal population because of the strong intercorrelations between these variables.

Index words: Diffuse load, nitrogen, non-point source loading, phosphorus, representative basins.

1. INTRODUCTION

Human activity has in many ways influenced nutrient cycles between air, soil and water. In the case of watercources this influence has in general been disadvantageous: eutrophication is one of the most important questions in water protection. Effects of sewage and industrial effluents have been investigated intensively. However, the amount and effects of the so-called diffuse load are more difficult to determine. The movements of nutrients in soil are examined by lysimetric tests, but the application of the results obtained to complete drainage basins presents some problems. Another method is to measure the discharge volume and nutrient concentrations of runoff water and thus calculate the nutrient load. This method has been used in the calculations of amounts of substances discharged by rivers (Viro 1953, Ahl and Odén 1971, 1972, Wartiovaara 1975, Ahl and Wartiovaara 1976).

In the early 1960's a programme was initiated by the Soil and Hydrotechnical Research Bureau of the Board of Agriculture to follow changes in water quality in 34 small drainage basins. From 1962 this work was continued by the Water Pollution Control Office (since 1970 the Water Research Office). Studies on the loading were made possible by the continuous measurement of discharge in these basins. Water quality was investigated once a month. The drainage basins were surveyed during the years 1958 to 1962 to measure basin characteristics (Mustonen 1965a). On this basis a report concerning the effects of meteorological and basin characteristics on runoff was drawn up (Mustonen 1965b). Results of investigations on loads have been published earlier for the case of nutrients (Särkkä 1972), alkali metals (Kohonen 1974) and organic matter (Kauppi 1975). The findings have been summarized by Kohonen (1976). Mustonen (1971) and Mustonen and Seuna (1971) have published hydrologic investigations of the basins.

In addition to research based on information obtained from these drainage basins and river observations the diffuse load of nutrients has been examined in Finland for instance by Kajosaari (1965), Kangas (1968), Tossavainen (1971) and Kaijalainen (1972). In the field of agricultural chemistry particular attention has been paid to the leaching of phosphorus (Hartikainen 1976). In Sweden, Brink has carried out much research on leaching (Brink 1965, 1970, 1974, Brink and Gustafson 1970, Brink et al. 1975) from the point of view of agricultural science, while Ahl is more concerned with its significance for watercourses (Ahl 1968, 1977, Ahl and Odén 1971, 1972).

The dependence of nutrient loads on the characteristics of the drainage basin has been investigated to a much lesser extent than the load itself. The data obtainable from the small drainage basins provides a good basis for this investigation. Särkkä (1972) has presented the correlations of phosphorus and nitrogen concentrations and loads with the characteristics of the drainage basin during the years 1962—1968. Ranta-Pere (1974) has developed a formula for estimation of the extent of the diffuse load. The use of this formula is made difficult because a great amount of work is required to determine the various components of the potential loading.

In planning the treatment of newer data from the small drainage basins (1965—1974), an important consideration was to arrive at a practical, i.e. sufficiently simple, method of estimating the diffuse load. This required a more precise selection of basins included in the investigation. Only "normal" non-point loading basins were included. Such were those areas in which loading was derived from agriculture and sparse population, and in which the soil type was very similar to that typical for Finland. The first consideration excluded areas with a considerable load of waste water and also those in which large-scale forest fertilization schemes had been implemented. It has been shown that forest fertilization considerably increases nutrient concentrations in watercourses if a large part of the drainage basin has been treated (Särkkä 1970). The consideration of soil type led to the exclusion of certain drainage basins near the Ostrobothnian coast, which Särkkä (1972) grouped separately on account of unusually high concentrations of alum in the soil. Clay minerals often have clear adsorption maxima of phosphorus at pH 4—5 (Edzwald et al. 1971), which is a typical value in the Ostrobothnian soils.

The aim of this investigation was to study the effect of drainage basin characteristics on the diffuse load and concentrations of phosphorus and nitrogen.

2. OBSERVATION BASINS

The hydrologic observation network consisted of 34 drainage basins, of which 23 were included in this study as representing typical diffuse loading areas. These 23 basins were: Teeressuonoja, Kylmänoja, Löytäneenoja, Paunulanpuro, Katajaluoma, Ravijoki, Latosuonoja, Korpijoki, Kesselinpuro, Kuokkalanoja, Mustapuro, Kaidesluoma, Heinäjoki, Ruunapuro, Pahkaoja, Tuuraoja, Huopakinoja, Vääräjoki, Myllypuro, Korintteenoja, Vähä-Askanjoki, Kuusivaaranpuro and Myllyoja. The basins were distributed fairly uniformly throughout the country (Fig. 1).

Investigations of drainage basin characteristics and loading factors have been reported in detail by Mustonen (1965a) and Särkkä (1972). The

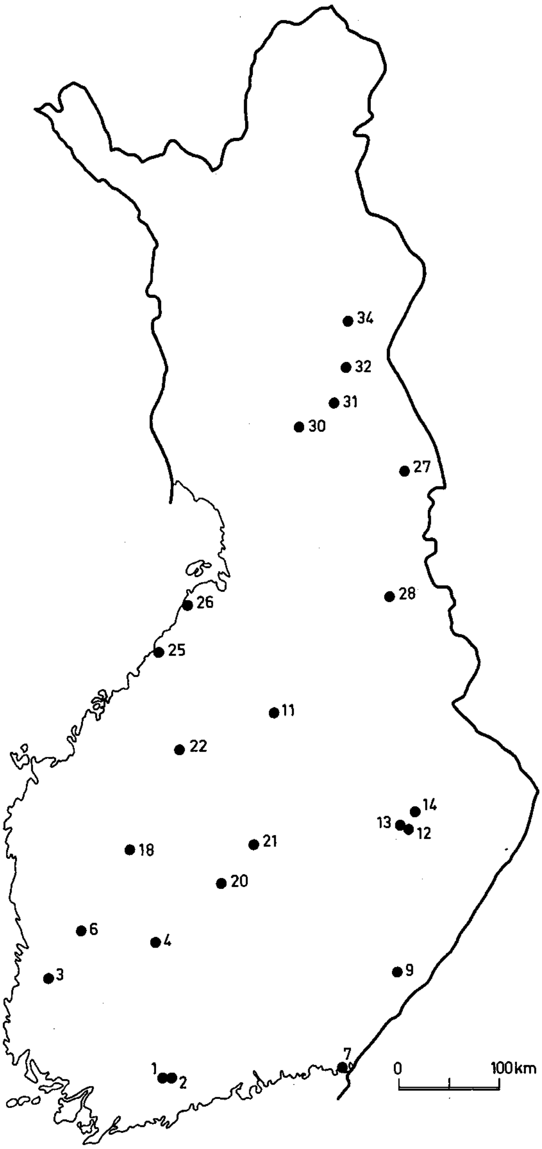

Fig. 1. The location of the observation basins.

Nr	Basin	Community
1	Teeressuonoja	Vihti
2	Kylmänoja	Vihti
3	Löytäneenoja	Kokemäki
4	Paunulanpuro	Orivesi
6	Katajaluoma	Ikaalinen
7	Ravijoki	Virolahti
9	Latosuonoja	Ruokolahti
11	Korpijoki	Kiuruvesi
12	Kesselinpuro	Outokumpu
13	Kuokkalanoja	Outokumpu
14	Mustapuro	Outokumpu
18	Kaidesluoma	Alavus
20	Heinäjoki	Korpilahti
21	Ruunapuro	Laukaa
22	Pahkaoja	Lestijärvi
25	Tuuraoja	Kalajoki
26	Huopakinoja	Pattijoki
27	Vääräjoki	Kuusamo
28	Myllypuro	Hyrynsalmi
30	Korintteenoja	Rovaniemen mlk.
31	Vähä-Askanjoki	Kemijärvi
32	Kuusivaaranpuro	Salla
34	Myllyoja	Savukoski

percentage of cultivated land had changed in some basins since 1958. The factors taken into this study were the percentage of soils composed of fine particles, clay and silt (%), the percentage of cultivated land (%), sewages (persons per km^2), and other habitation and livestock (person equivalents per km^2). All the factors varied considerably between the different basins (Table 1). The correlations between the factors were:

	Fine particles (%)	Cultivated land (%)	Sewages (p km^{-2})
Cultivated land (%)	0.79***		
Sewages (p km^{-2})	0.78***	0.87***	
Other habitation+ livestock (peq km^{-2})	0.68***	0.84***	0.93***

*** = statistically highly significant (99.9 % prob.)
** = statistically significant (99.0 % prob.)
* = statistically almost significant (95.0 % prob.)

3. MATERIAL AND METHODS

Hydrologic observations in the drainage basins were carried out by the Hydrological Office of the Water Research Institute. A measuring weir with a recording gauge was built in each drainage basin for making runoff observations. Runoff values have been published for the years 1962–1975 (Mustonen 1965a, Mustonen and Seuna 1969, Hydrological Yearbook 1969–1970, 1971, 1972–1973, 1974–1975).

Since 1962 water samples were taken from the overflow of each measuring weir once a month.

Table 1. Factors defining the characteristics of the basins (p km^{-2} = persons km^{-2}, peq km^{-2} = person equivalents km^{-2}).

Basin	Size (km^2)	Fine soils (%)	Cultivated land (%)	Sewages (p km^{-2})	Other habitation + livestock (peq km^{-2})
Teeressuonoja	0.7	9	0	0	27
Kylmänoja	4.0	31	27	11.5	164
Löytäneenoja	5.6	43	67	16.3	453
Paunulanpuro	2.0[1]	16[1]	1.7[1]	0.6[1]	24[1]
Katajaluoma	11.2	0	3	0	0
Ravijoki	56.9	13	17	3.7	157
Latosuonoja	5.3	2	14	0.4	2
Korpijoki	122	3	8	1.7	94
Kesselinpuro	21.7	0	3	0.6	38
Kuokkalanoja	2.8	0	11	7.3	280
Mustapuro	11.2	20	11	2.7	120
Kaidesluoma	45.5	4	13	5.5	160
Heinäjoki	9.4	0	8	4.8	171
Ruunapuro	5.4	10	17	7.8	182
Pahkaoja	23.3	0	2	0	25
Tuuraoja	23.5	0	16	0.3	18
Huopakinoja	19.7	1	17	2.7	95
Vääräjoki	19.3	0	0	0	2
Myllypuro	9.9	0	2	1.1	11
Korintteenoja	6.1	2	2	1.7	24
Vähä-Askanjoki	16.4	0	0	0	0
Kuusivaaranpuro	27.6	1	2	0	0
Myllyoja	28.5	0	0	0	0

[1] The Paunulanpuro drainage basin decreased in size in 1968 because of ditching; the reported values are means weighted for time.

The samples were analyzed at the district laboratories of the National Board of Waters, and alkali metals in the laboratory of the Water Research Office. Normal water analyses were carried out using standard methods (Erkomaa et al. 1977). The data obtained were stored in the water quality register of the National Board of Waters. The values for the years 1962–1964 were excluded from this examination because of the uncertainty of the results. The data finally chosen were from 23 drainage basins over a 10-year period and were composed of observations made at intervals of one month. In this work examination was made only of total phosphorus and total nitrogen concentrations and loads.

The mean monthly load was calculated according to the equation (1)

$$\bar{L}_m = K_p \frac{1}{n} \sum_{i=1}^{n} C_i \cdot q_i \qquad (1)$$

L_m = mean monthly load, kg km^{-2} $month^{-1}$
K_p = coefficient for alteration of dimensions
C_i = concentration in the i:th observation, $\mu g\ l^{-1}$
q_i = mean runoff of the month corresponding to the i:th observation, $l\ s^{-1}\ km^{-2}$

The annual load (kg $km^{-2}a^{-1}$) was calculated by appropriate summation of the values of the above equation.

Seasonal and overall means of nitrogen and phosphorus concentrations and loads were calculated for each basin. Division into three seasons – winter; spring; summer and autumn – was made on the basis of runoff and water temperature values for each basin separately (Appendix 1). The dependence of nitrogen and phosphorus concentrations on runoff was investigated by calculating the correlations for each drainage basin. Trends in nitrogen and phosphorus concentrations and loads were also calculated for each basin.

The dependence of the mean concentrations and annual loads of phosphorus and nitrogen on the drainage basin characteristics was studied by linear regression analysis.

4. RESULTS

4.1 Concentrations of phosphorus and nitrogen

Phosphorus and nitrogen concentrations varied considerably between the drainage basins. Mean values of total phosphorus concentration varied between 8.3 and 98 µg l^{-1}, and seasonal variations between the basins were even greater (Table 2). In the case of total nitrogen concentration mean values varied between 190 and 2 400 µg l^{-1}. The lowest seasonal mean was the Winter mean for the basin of Myllyoja, 160 µg l^{-1}, while the highest was the summer mean in Löytäneenoja, 2 700 µg l^{-1} (Table 3). The inorganic nitrogen fraction (NH_4–N, NO_3–N) was between 17 and 79 % over the whole period depending on the basin concerned. Some statistically significant trends could be observed in the concentrations of total phosphorus and total nitrogen during the observation period (Table 4). On a regional basis it appeared that increases in nutrient concentrations were mainly confined to Central and Southern Finland. The only significant trends observed in the Northern basins were decreases in concentrations.

The dependence of phosphorus and nitrogen concentrations on runoff was rather slight. In many basins the highest concentrations were observed during the spring floods, but in some basins the concentrations were actually smallest at this period. The correlation between total phosphorus concentration and runoff was positive

Table 2. Seasonal and overall means of total phosphorus concentrations ($\bar{x}$) and their standard deviations (s).

Basin	Total phosphorus (µg l^{-1})							
	Winter		Spring		Summer+ Autumn		Mean	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Teeressuonoja	17	8.5	22	16	17	21	18	17
Kylmänoja	77	56	110	98	85	68	86	70
Löytäneenoja	84	73	130	130	97	99	98	96
Paunulanpuro	28	12	38	38	29	11	30	16
Katajaluoma	44	22	35	15	46	21	43	21
Ravijoki	67	52	62	37	83	41	75	45
Latosuonoja	30	31	120	180	74	110	67	110
Korpijoki	59	31	120	100	80	100	78	81
Kesselinpuro	45	84	44	49	30	19	39	59
Kuokkalanoja	28	38	67	100	28	17	33	48
Mustapuro	29	26	43	32	24	15	28	23
Kaidesluoma	36	35	53	34	43	21	43	31
Heinäjoki	19	11	21	12	24	13	21	12
Ruunapuro	63	40	88	64	56	33	64	44
Pahkaoja	36	61	32	47	34	37	35	50
Tuuraoja	89	74	69	53	73	42	79	59
Huopakinoja	81	47	120	73	84	38	86	47
Vääräjoki	19	30	14	14	14	16	17	24
Myllypuro	20	24	27	22	22	18	22	21
Korintteenoja	11	23	24	36	10	11	12	22
Vähä-Askanjoki	6.3	4.8	8.5	6.2	12	8.2	8.3	6.6
Kuusivaaranpuro	18	38	24	23	15	9.2	18	30
Myllyoja	9.0	17	15	12	10	8.3	10	14

Table 3. Seasonal and overall means of total nitrogen concentrations ($\bar{x}$) and their standard deviations (s).

Basin	Total nitrogen (µg l^{-1})							
	Winter		Spring		Summer+ Autumn		Mean	
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Teeressuonoja	750	430	700	170	630	270	680	320
Kylmänoja	1 300	1 100	2 600	2 100	1 200	1 200	1 400	1 400
Löytäneenoja	2 700	1 200	2 700	1 200	2 000	1 200	2 400	1 300
Paunulanpuro	560	180	680	290	650	190	620	210
Katajaluoma	1 100	230	920	210	1 100	320	1 100	280
Ravijoki	1 200	470	1 500	650	1 200	500	1 200	520
Latosuonoja	640	270	1 500	670	860	590	890	590
Korpijoki	800	250	1 300	860	830	270	890	440
Kesselinpuro	780	850	820	320	770	450	780	640
Kuokkalanoja	860	490	1 600	870	1 000	660	1 000	660
Mustapuro	760	700	1 400	810	700	430	810	640
Kaidesluoma	1 000	300	990	390	860	220	940	300
Heinäjoki	640	220	670	200	630	160	640	190
Ruunapuro	1 200	620	1 300	820	1 000	360	1 100	580
Pahkaoja	770	430	650	320	730	460	740	430
Tuuraoja	1 000	440	850	270	900	660	940	540
Huopakinoja	970	620	1 400	880	820	240	940	550
Vääräjoki	420	280	410	200	410	200	420	240
Myllypuro	330	240	370	160	350	140	340	190
Korintteenoja	180	150	330	110	280	170	230	160
Vähä-Askanjoki	160	91	320	100	300	130	230	130
Kuusivaaranpuro	250	120	410	160	390	190	320	160
Myllyoja	160	120	210	120	250	100	190	120

Table 4. Statistically significant (≧95 % prob.) trends in concentrations of total phosphorus and total nitrogen over the period 1965–1974.

Basin	Total phosphorus		Total nitrogen	
	Positive	Negative	Positive	Negative
Teeressuonoja		**		
Kylmänoja	***		*	
Löytäneenoja			***	
Katajaluoma		***		
Ravijoki		*		
Latosuonoja	*			
Korpijoki			***	
Kaidesluoma			***	
Heinäjoki				***
Ruunapuro	*		*	
Tuuraoja				***
Vääräjoki		*		
Korintteenoja				**

*** = statistically highly significant (99.9 % prob.)
** = statistically significant (99.0 % prob.)
* = statistically almost significant (95.0 % prob.)

and statistically significant at the 5 % risk level in 11 basins, and negative with the same significance in 2 basins. The corresponding results for nitrogen concentration and runoff were 13 positive and 2 negative correlations at the same risk level (Table 5).

4.11 Effect of drainage basin characteristics on the concentrations of phosphorus and nitrogen

Phosphorus and nitrogen concentrations in runoff were found to depend considerably on the basin characteristics, (Table 6). The dependence of phosphorus concentration on the percentage of cultivated land (FP) is quite clear (Fig. 2). Phosphorus concentrations increase logarithmically with increasing percentage of cultivated land. The correlation with the logarithmic expression

Table 5. Correlations of total phosphorus and total nitrogen concentrations with runoff over the period 1965–1974.

Basin	Number of observations	Correlation coefficient (r)	
		Tot. P	Tot. N
Teeressuonoja	120	0.23**	0.16
Kylmänoja	119	0.22*	0.29***
Löytäneenoja	90	−0.04	0.16
Paunulanpuro	115	0.09	0.04
Katajaluoma	115	−0.21*	−0.19*
Ravijoki	119	−0.12	0.21*
Latosuonoja	115	0.26**	0.56***
Korpijoki	117	0.43***	0.28**
Kesselinpuro	119	0.03	0.13
Kuokkalanoja	117	0.29**	0.50***
Mustapuro	119	0.40***	0.53***
Kaidesluoma	128	0.39***	0.21*
Heinäjoki	120	0.09	0.22*
Ruunapuro	119	0.52***	0.48***
Pahkaoja	104	−0.18	−0.25**
Tuuraoja	109	−0.23*	−0.12
Huopakinoja	114	0.40***	0.62***
Vääräjoki	119	−0.06	−0.13
Myllypuro	109	0.03	−0.02
Korintteenoja	83	0.39***	0.24*
Vähä-Askanjoki	83	0.28**	0.42***
Kuusivaaranpuro	85	0.09	0.20
Myllyoja	83	0.13	0.39***

*** = statistically highly significant (99.9 % prob.)
** = statistically significant (99.0 % prob.)
* = statistically almost significant (95.0 % prob.)

of FP, $\log_{10}$ (FP+1), is 0.84***. The regression function is (2)

$$Y_{P\text{-conc.}} = 46.4 \log_{10}(FP+1)+7.2 \quad (n=23) \quad (2)$$

$Y_{P\text{-conc.}}$ = phosphorus concentration, µg l^{-1}

This function explains the variance in phosphorus concentration rather well, r^2=0.71. As the variables are not normally distributed, the weight of the most extreme value (FP=67) in determining the shape of the curve is very high. When this value is excluded, the correlation between phosphorus concentration and the logarithmic expression of FP is slightly weaker (r=0.81) than that between phosphorus concentration and FP itself (r=0.84).

In general the cultivated land is situated close to watercourses, but with increasing percentage of cultivated land in some areas fields necessarily become more distant. As phosphorus readily adsorbs to soil particles, it is probable that proportionately less phosphorus reaches the watercourse from the more distant fields. For calculation purposes the fields should therefore be weighted for their distance from the nearest watercourse. The need for such weighting is illustrated by the Heinäjoki basin, where the mean phosphorus concentration in water was

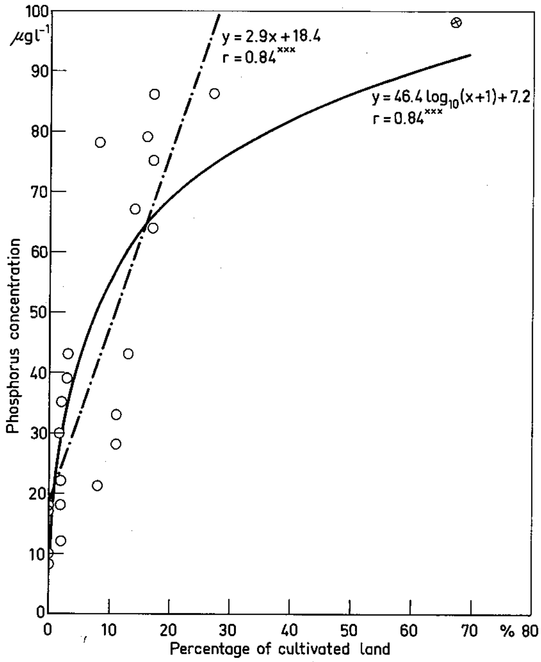

Fig. 2. Dependence of the total phosphorus concentration on the percentage of cultivated land in the basin. — Value ⊗ included. —·—·— Value ⊗ excluded.

Table 6. Correlation of mean phosphorus and nitrogen concentrations with some drainage basin characteristics (df = 21).

Basin characteristic	Correlation with	
	tot. P	tot. N
Fine soil particles (%)	0.50*	0.74***
Cultivated land (%)	0.75***	0.91***
Sewages (p km^{-2})	0.56**	0.81***
Other habitation + livestock (peq km^{-2})	0.51*	0.80***

*** = statistically highly significant (99.9 % prob.)
** = statistically significant (99.0 % prob.)
* = statistically almost significant (95.0 % prob.)

only 21 µg l^{-1} and the phosphorus load 6.5 kg $km^{-2}a^{-1}$, although the area of cultivated land amounted to 8 % of the total area. The fields in question were near the outskirts of the basin, and there were no running water connections between the fields and the watercourse. As it was not possible in this study to carry out the required weighting of the areas of cultivated land the less precise logarithmic dependence of phosphorus concentration on percentage of cultivated land had to suffice. Regardless of whether the value FP=67 was included in the calculation of the regression function, the result obtained was to all practical intents the same.

Because of the strong correlation between the independent variables, the introduction of the other variables to the equation did not markedly improve the model. Thus equation (2) can be regarded as correct. The phosphorus concentrations predicted by this model correspond quite closely with the observed values (Fig. 3).

The dependence of nitrogen concentration on the most relevant variable, percentage of cultivated land, is clearly linear (Fig. 4a). Nitrogen does not adsorb on to soil particles like phosphorus, but is transported freely through the soil. Distance of the fields in question from the watercourse therefore has very little significance. The regression function obtained using all 23 observation basins is (3)

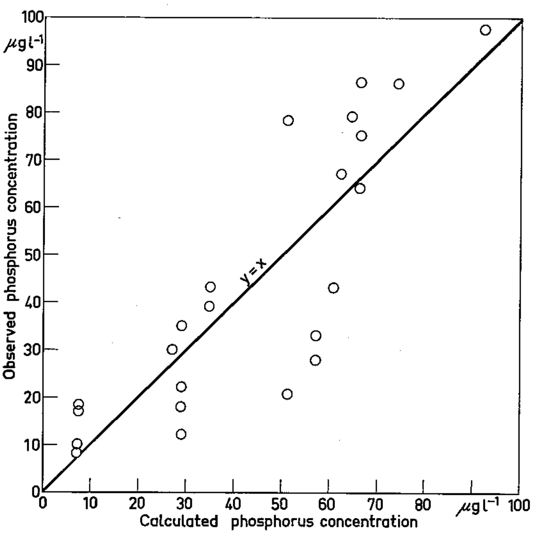

Fig. 3. Correlation between observed and calculated phosphorus concentration.

$$Y_{N\text{-conc.}} = 30\,FP + 500 \qquad (n=23) \qquad (3)$$

$Y_{N\text{-conc.}}$ = nitrogen concentration, µg l^{-1}

This equation explains 82 % of the observed variance in nitrogen concentration. When the value FP=67 is excluded the regression function becomes (4):

$$Y_{N\text{-conc.}} = 36\,FP + 460 \qquad (n=22) \qquad (4)$$

and it explains 66 % of the variance.

The nitrogen concentrations observed in water from basins in a natural state varied from 190 to 680 µg l^{-1}. Concentrations were lower in the northern basins. This may partly be explained by the fact that movement of nitrogen is largely dependent on biological activity, which itself is partly dependent on ambient temperatures. The soil is frozen for longer periods in Northern than in Southern Finland, and of course the average temperature is lower, too. This is reflected in the observed nitrogen concentrations. The dependence of nitrogen concentration on the percentage of cultivated land was calculated for the basins situated in Central and Southern Finland. A total of 17 basins remain and the correlation is 0.95*** (Fig. 4b). The equation of the regression line is (5)

$$Y_{N\text{-conc.}} = 25\,FP + 650 \qquad (n=17) \qquad (5)$$

This equation explains 89 % of the observed variance in nitrogen concentration. Exclusion of the most extreme observation (FP=67) does not markedly alter the result (6):

$$Y_{N\text{-conc.}} = 22\,FP + 690 \qquad (n=16) \qquad (6)$$

Equation (5) can be considered as applying only to Southern and Central Finland. As the observations from northern regions were all from non-cultivated basins, a corresponding method of estimating nitrogen concentrations cannot be presented here.

Introduction of the other independent variables did not significantly improve the degree of explanation. In fact, the percentage of cultivated land also describes the other variables quite accurately as the correlations between the independent variables are very strong.

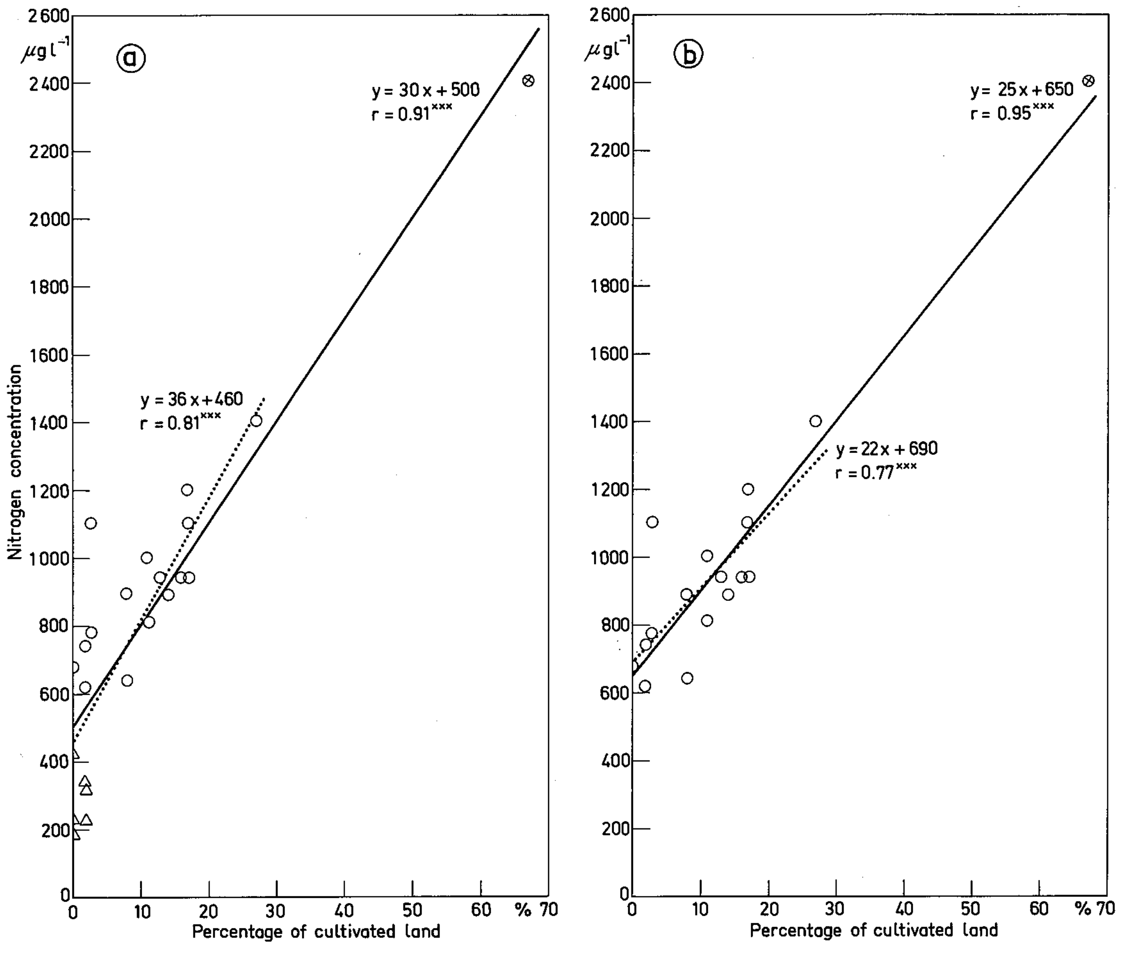

Fig. 4. Dependence of the total nitrogen concentration on the percentage of cultivated land in the basin. a) Including the values for the basins in Northern Finland (△). b) Without the values for the basins in Northern Finland. — Value ⊗ included. ···· Value ⊗ excluded.

4.2 Diffuse load of phosphorus and nitrogen

The high seasonal variation observed in concentrations was accentuated in the loads, as runoff varied to a much larger extent than did concentrations. Thus in some cases half of the total annual load came during one month in the spring. More often, however, the maximum load observed during one spring month was a third or a quarter of the annual load. The load of phosphorus deposited in the Korpijoki basin was exceptionally high (on average 44 kg $km^{-2}a^{-1}$). The mean loads of phosphorus and nitrogen varied from 4.1 to 44 kg $km^{-2}a^{-1}$ and from 79 to 740 kg $km^{-2}a^{-1}$, respectively (Tables 7 and 8).

No statistically significant trends were observed in the phosphorus load during the period of this study in any of the basins. Increase in the nitrogen load was observed in three of the basins: Kaidesluoma, Rűunapuro and Pahkaoja. These trends were significant only at the 95 % level of probability. The ten-year period involved is, from the point of view of hydrology, so short that normal variation in runoff values is sufficient to cover any possible trend taking place over this time.

Table 7. Seasonal and overall means of monthly phosphorus loads ($\bar{x}$), and their standard deviations (s), and annual loads.

Basin	Phosphorus load								
	Monthly (kg km^{-2} month $^{-1}$)								Annual (kg km^{-2}a^{-1})
	Winter		Spring		Summer +Autumn		Mean		
	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$
Teeressuonoja	0.26	0.21	1.3	1.3	0.27	0.32	0.43	0.68	5.2
Kylmänoja	1.4	2.7	5.5	3.6	1.4	1.9	2.1	2.9	25
Löytäneenoja	1.7	5.2	10	14	0.91	2.0	2.8	7.3	34
Paunulanpuro	0.20	0.25	2.7	4.1	0.32	0.43	0.72	2.0	8.7
Katajaluoma	0.38	0.51	3.1	2.4	0.61	0.63	0.92	1.5	11
Ravijoki	1.1	1.3	6.0	4.8	2.1	2.6	2.4	3.2	29
Latosuonoja	0.37	0.59	7.7	12	1.6	3.6	2.2	6.0	26
Korpijoki	0.62	1.0	15	19	2.3	6.8	3.6	10	44
Kesselinpuro	0.39	0.72	3.6	5.2	0.52	0.60	0.89	2.3	11
Kuokkalanoja	0.52	1.1	6.2	9.7	0.45	0.53	1.3	4.0	15
Mustapuro	0.70	1.5	3.9	3.1	0.61	0.77	1.1	1.9	13
Kaidesluoma	0.41	0.47	4.7	4.7	0.51	0.70	1.5	3.0	18
Heinäjoki	0.27	0.34	1.8	1.3	0.36	0.39	0.55	0.82	6.5
Ruunapuro	0.79	0.80	5.5	4.4	0.70	0.69	1.5	2.6	19
Pahkaoja	0.30	0.43	1.7	1.0	0.36	0.36	0.53	0.72	6.4
Tuuraoja	0.69	1.0	4.8	4.1	0.72	0.95	1.2	2.1	14
Huopakinoja	1.6	3.2	12	12	0.80	0.92	2.3	5.2	27
Vääräjoki	0.18	0.25	1.5	1.7	0.41	0.39	0.46	0.84	5.6
Myllypuro	0.32	0.62	2.7	3.1	0.55	0.52	0.81	1.6	9.7
Korintteenoja	0.11	0.32	2.6	3.5	0.25	0.55	0.47	1.5	5.6
Vähä-Askanjoki	0.094	0.15	1.0	0.80	0.43	0.41	0.34	0.51	4.0
Kuusivaaranpuro	0.15	0.25	2.4	2.4	0.30	0.37	0.46	1.1	5.6
Myllyoja	0.11	0.23	1.4	1.0	0.31	0.27	0.35	0.62	4.2

4.21 Effect of drainage basin characteristics on the diffuse load of phosphorus and nitrogen

Phosphorus load, like phosphorus concentration, correlates most strongly with the percentage of cultivated land (FP), r=0.65*** (Table 9).

The dependence of phosphorus load of FP is also logarithmic (Fig. 5). The correlation with the logarithmic expression of FP, $\log_{10}$ (FP+1) is 0.75***. The exceptionally high phosphorus load already noted for the Korpijoki basin is presumably accounted for by the fact that forest fertilization had been carried out in this basin. The fertilized areas were in fact quite small, but were situated close to the measuring station and their effect was therefore considerable. The phosphorus concentrations observed in the spring floods after the fertilization were extremely high, as much as 550 µg l^{-1}. This corresponds to a monthly load of 40–60 kg phosphorus per square kilometre. Accordingly, values for the Korpijoki basin were not included in the calculations for the dependence of phosphorus load on the basin characteristics. The correlation with the logarithmic expression of the percentage of cultivated land, $\log_{10}$ (FP+1), is then r= 0.88*** and the regression function is (7)

$$Y_{P\text{-load}} = 15.1 \log_{10}(FP+1)+1.9 \quad (n=22) \qquad (7)$$

$Y_{P\text{-load}}$ = annual phosphorus load, kg km^{-2}a^{-1}

Equation (7) explains 77 % of the variance in annual phosphorus load. Although the equation of the logarithmic curve was largely determined by the most extreme point, this curve was considered to be correct for the same reason as in the case of phosphorus concentration. For purposes of comparison the regression line obtained using 21 points has been drawn in Figure 5. The

Table 8. Seasonal and overall means of monthly nitrogen loads ($\bar{x}$), and their standard deviations (s), and annual loads.

Basin	Nitrogen load								
	Monthly (kg km^{-2} month $^{-1}$)								Annual (kg km^{-2}a^{-1})
	Winter		Spring		Summer+Autumn		Mean		
Teeressuonoja	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$
Teeressuonoja	13	13	36	18	11	11	15	15	180
Kylmänoja	26	53	170	250	24	38	47	120	560
Löytäneenoja	44	83	180	150	35	49	62	98	740
Paunulanpuro	5.0	6.9	43	25	8.0	10	13	19	160
Katajaluoma	10	14	77	41	20	22	26	33	310
Ravijoki	22	27	140	93	31	43	45	64	540
Latosuonoja	8.3	12	95	56	17	26	26	42	310
Korpijoki	11	18	130	110	15	20	31	63	370
Kesselinpuro	10	15	62	40	15	19	19	27	230
Kuokkalanoja	23	42	140	100	20	27	38	64	460
Mustapuro	23	48	120	72	19	21	34	54	410
Kaidesluoma	13	15	80	47	12	15	29	39	350
Heinäjoki	9.3	9.3	50	25	11	9.9	17	20	200
Ruunapuro	18	21	73	44	14	15	25	33	300
Pahkaoja	9.0	9.8	51	30	9.8	7.6	16	20	190
Tuuraoja	11	17	60	28	12	16	18	24	210
Huopakinoja	22	48	140	160	8.8	9.8	26	66	320
Vääräjoki	5.0	5.7	46	37	15	14	15	22	180
Myllypuro	4.0	5.6	32	32	10	9.4	11	18	130
Korintteenoja	2.0	4.5	30	14	7.6	10	7.4	12	89
Vähä-Askanjoki	2.5	3.3	35	16	13	15	11	15	130
Kuusivaaranpuro	2.8	4.1	35	16	8.0	7.0	8.5	13	100
Myllyoja	2.5	4.2	20	13	7.9	5.6	6.6	8.9	79

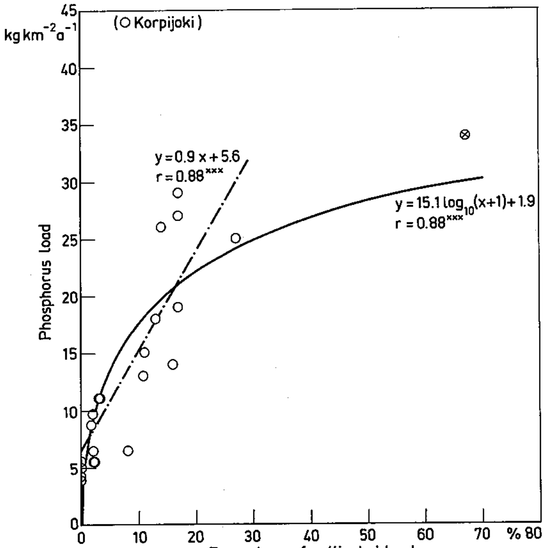

Fig. 5. Dependence of the diffuse phosphorus load on the percentage of cultivated land in the basin. — Value ⊗ included. –·–·– Value ⊗ excluded.

Table 9. Correlation of annual phosphorus and nitrogen loads with some drainage basin characteristics (df = 21).

Basin characteristic	Correlation with	
	P-load	N-load
Fine soil particles (%)	0.44*	0.74***
Cultivated land (%)	0.65***	0.83***
Sewages (p km^{-2})	0.52*	0.81***
Other habitation+ livestock (peq km^{-2})	0.54**	0.83***

*** = statistically highly significant (99.9 % prob.)
** = statistically significant (99.0 % prob.)
* = statistically almost significant (95.0 % prob.)

high loads obtained for the Korpijoki basin confirm the theory that areas near to the measuring station have more influence on the phosphorus load than similar areas further away.

Inclusion of the other variables did not significantly improve the model. Equation (7) can therefore be considered to be correct. Observed

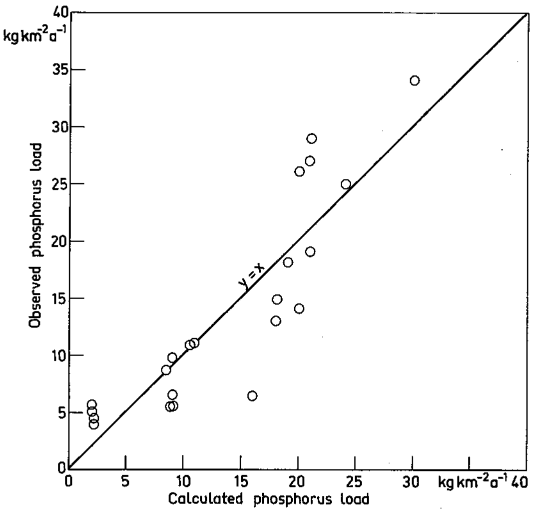

Fig. 6. Correlation between observed and calculated phosphorus loads.

and calculated phosphorus loads correspond quite well (Fig. 6).

The nitrogen load (kg $km^{-2}a^{-1}$) correlates almost equally strongly with cultivated land (r=0.83★★★), sewages (r=0.81★★★) and livestock (r=0.83★★★). As the percentage of cultivated land is the easiest of these variables to determine in practice, it was taken into the model as the first variable. The dependence of nitrogen load (kg $km^{-2}a^{-1}$) on FP was found to be almost linear (Fig. 7). The regression function obtained using all the 23 points is (8)

$$Y_{N\text{-load}} = 9.8\ FP+180 \qquad (n=23) \qquad (8)$$

$Y_{N\text{-load}}$ = annual nitrogen load, kg $km^{-2}a^{-1}$

The equation explains 70 % of the variance in annual nitrogen load. The influence of the extreme point for Löytäneenoja on the slope of the regression line is quite considerable. Without this point the correlation coefficient is r=0.79★★★ and the equation is (9)

$$Y_{N\text{-load}} = 14.6\ FP+150 \qquad (n=22) \qquad (9)$$

The correlations with and without the value for Löytäneenoja differ considerably from each other (Fig. 7a). If the percentage of cultivated land varies from 0 to 27 percent, equation (9) should be considered to be more reliable. Nitrogen loads in the non-cultivated areas of Southern and Northern Finland differed from each other as in the case of concentrations. In the southern non-cultivated areas nitrogen load was almost 200 kg $km^{-2}a^{-1}$, whereas in northern areas the corresponding load was about 100 kg $km^{-2}a^{-1}$. The equation of the regression for Central and Southern Finland (Fig. 7b) is (r=0.82★★★, df=15)

$$Y_{N\text{-load}} = 8.4\ FP+230 \qquad (n=17) \qquad (10)$$

Without the value for Löytäneenoja this becomes (11):

$$Y_{N\text{-load}} = 11.7\ FP+200 \qquad (n=16) \qquad (11)$$

The correlation is statistically significant (r= 0.70★★★, df=14). Finding of the best possible equation to describe the actual values would entail further observations in those areas in which the percentage of cultivated land is 20–60 %. It was not considered worthwhile to include the other variables in the equations, since they did not significantly improve the models.

5. DISCUSSION

The observation network of 34 drainage basins was initially intended for the collection of hydrological information. This resulted in certain difficulties in research and calculations concerned with loading. One was the fact that the distribution of basin characteristics was not normal, as the statistical treatment strictly speaking would require. In future investigations it would be important to include basins corresponding in land use and habitation to areas insufficiently weighted in the present study. However, regardless of these failings, the observation network and the information gained therefrom must be regarded as being of considerable value. On the basis of ten years' regular observation the loading results can be considered reliable. In many research projects on the same subject carried out in Sweden the observation period has been 2–3 years or even less (cf. Brink and Gustafson 1970), whereupon

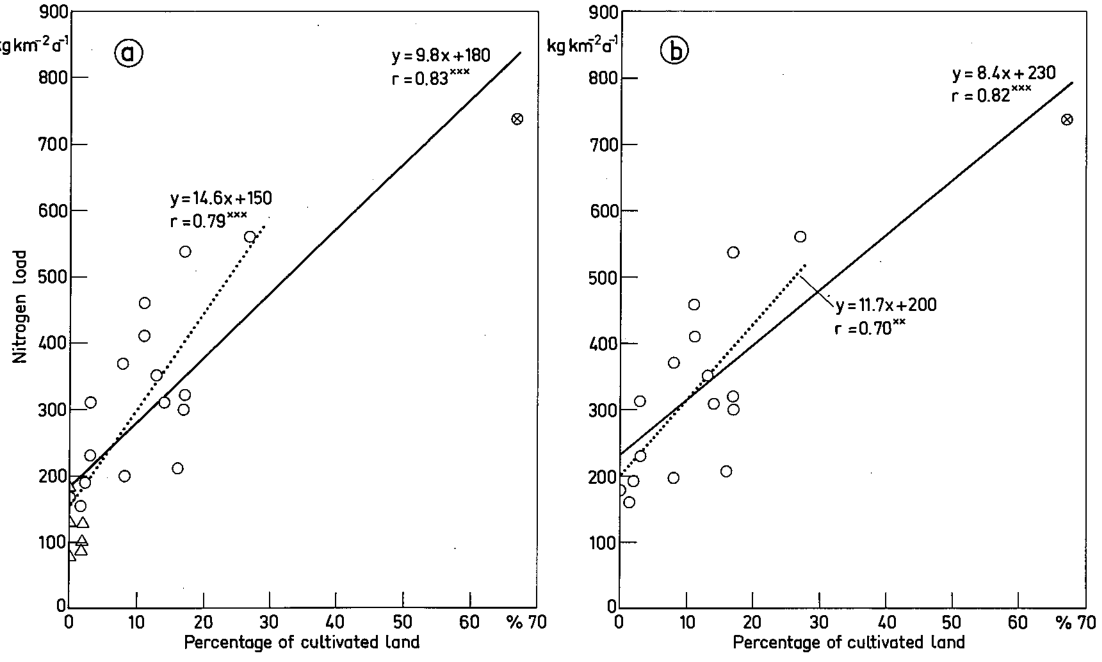

Fig. 7. Dependence of the diffuse nitrogen load on the percentage of cultivated land in the basin. a) Including the values for the basins in Northern Finland (△). b) Without the values for the basins in Northern Finland. — Value ⊗ included. ···· Value ⊗ excluded.

reliability of the results is highly dependent on how well the years in question represented normal years. The effect of exceptional years on diffuse load is considerable. An example of this is the loading of Lake Tuusulanjärvi during the years 1974—1976 (Ojanen and Kenttämies 1977). Discharges, phosphorus and nitrogen loads for these years were:

	1974	1975	1976
P-load, kg $km^{-2}a^{-1}$	73	26	18
N-load, kg $km^{-2}a^{-1}$	1 280	310	340
Discharge, $10^6 m^3 a^{-1}$	44	15	10

The average loads are difficult to determine on the basis of these results. However, the observation series obtained from the small drainage basins are sufficiently long and numerous to calculate diffuse loads.

5.1 Concentrations of phosphorus and nitrogen

The concentrations of total phosphorus and total nitrogen were clearly higher in the small drainage basins than at the running-water and deep-water stations (Laaksonen 1970, Analyysituloksia syvännehavaintopaikoilta v. 1970, 1972). Laaksonen (1970) has stated that the significance of lakes as sedimentation reservoirs should be emphasized.

The dependence of nutrient concentrations on runoff in the small drainage basins was rather weak. In most basins the highest concentrations were measured in Spring, but in some cases the reverse was true. According to Wartiovaara (1975) the dependence of concentration on discharge has the following form (12):

$$C = \frac{a'}{Q} + b' + c'Q \qquad (12)$$

C = concentration
Q = discharge
a', b', c' = coefficients typical of each quality parameter, observation station and time series

In most of the small drainage basins the factor c', which may be regarded as a coefficient describing the non-linear dependence of influx of material on discharge, was of greater magnitude than factor a'. One interesting result was that forest fertilization resulted in particularly high concentrations during spring, whereas field fertilization caused generally high nutrient concentrations without marked seasonal variation.

Only a few trends were found in phosphorus and nitrogen concentrations during the observation period. Nutrient concentrations increased in those basins with considerable levels of agricultural activity and human population. Although the effect of fertilization on nutrient load was not specifically studied in this study, it could be concluded on the basis of these trends that fertilization did to some extent increase nutrient loading. The negative trends observed may be due to better methods of analyzing phosphorus and nitrogen as well as to more precise interpretation of the results.

The percentage of cultivated land in a drainage basin has often been used as an indicator of land use in the basin (cf. Kajosaari 1965, Gächter and Furrer 1972, Ahl 1977, Larsen 1977). This factor is, however, usually associated with many other effects of agricultural activity and sparse population. Laaksonen (1970) has pointed out that it would be more realistic to refer to agriculture than to cultivated land. This has in practice two different effects. On the one hand it restricts the use of the statistical models obtained to areas in which agriculture and habitation are in equilibrium, i.e. to sparsely populated areas. On the other hand, if it is possible on the basis of percentage of cultivated land to estimate the diffuse load, much work could be avoided by abolishing the need for detailed determination of the levels of human and animal populations. The percentage of cultivated land can be reliably obtained from suitable maps. Furthermore, Ahl (1977) has shown that the dependence of nutrient concentrations on the percentage of cultivated land is stronger than that on human or animal population density. Similarly, the phosphorus and nitrogen concentrations observed in the small drainage basins were correlated most strongly with cultivated land.

Laaksonen (1970) found the percentage of cultivated land to be the best predictor of nitrogen concentration of running-water stations. In the case of phosphorus concentration the best predictor was the percentage of clay- and silt-type soils.

Gächter and Furrer (1972) observed a strong positive correlation between nutrient concentrations and the percentage of cultivated land in the region of the Lower Alps in Switzerland (Fig. 8). Prochazkova (1977) found a highly significant negative exponential correlation between nitrate concentration in water and the percentage of forest land in the drainage basin. This is in agreement with the results of the present study. The functions describing these relationships are of course considerably different from one another. For example the rate of decay of organic matter is very different in different climatic and terrain-type conditions. This variation can also be observed between different areas of Finland.

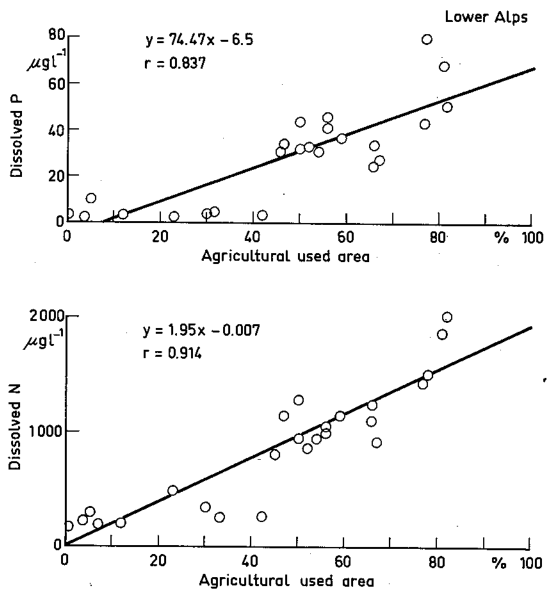

Fig. 8. Dependence of the concentrations of dissolved phosphorus and nitrogen compounds on the percentage of agricultural used area in the Lower Alps according to Gächter and Furrer (1972).

5.2 Diffuse load of phosphorus and nitrogen

The values of diffuse loading calculated from the observations of the small drainage basins represent the total diffuse loading from the soil, because none of the areas included lakes functioning as sedimentation basins. Viro (1953) and Wartiovaara (1975) have estimated the amounts of substances discharged by rivers. The amounts obtained on the basis of river observations are, despite loading caused by waste waters, of the same order as those obtained from the small drainage basins. This reflects the role of lakes as sinks for nutrients.

Kajosaari (1965) has studied the dependence of phosphorus load on the percentage of cultivated land in the drainage basin. He observed that more phosphorus reached the watercourse from cultivated than from forest land. The difference was particularly noticable during the spring floods. The loads calculated by Kajosaari were quite high. This may be due to inaccuracy of analysis methods; in the early 1960's the analysis of low concentrations often yielded too high results.

In Sweden many projects on leaching have been carried out, often however based on rather short-term observation periods. The results obtained for non-cultivated areas (forest) agree well with those obtained in Finland: Brink (1965) has recorded annual loads of phosphorus and nitrogen, from forested basins in Uppland, of 6.4 and 220 kg per km^2 respectively. However, the values obtained for cultivated land differ markedly from those obtained in Finland. According to Brink and Gustafson (1970), the diffuse loads of phosphorus and nitrogen from cultivated land in Uppland are 8.9 and 350 kg km^{-2}a^{-1} respectively, which is only slightly more than the corresponding values for forested land. In Finland cultivation has been shown to increase the diffuse load considerably more. The low values presented by Brink and Gustafson (1970) presumably result from exceptionally low runoff during the investigation period (on average only 61 mm/a).

Brink (1974) has also collected information concerning the leaching of nutrients in European countries, according to which the average leaching values in Denmark are 100 kg km^{-2}a^{-1} phosphorus and 1 500 kg km^{-2}a^{-1} nitrogen. In addition, Edens and Soldberg (1977) have studied the discharge of nutrients in Denmark from a 90 km^2 watershed. The percentage of cultivated land was 74 % and the discharge obtained was 35 kg km^{-2} a^{-1} phosphorus and 1 300 kg km^{-2}a^{-1} nitrogen. Population density was 9.4 persons km^{-2}. The values are in good agreement with those obtained from the small drainage basins in Finland.

Gächter and Furrer (1972) observed a clear dependence of phosphorus and nitrogen load on the percentage of cultivated land in the region of Lower Alps (Fig. 9).

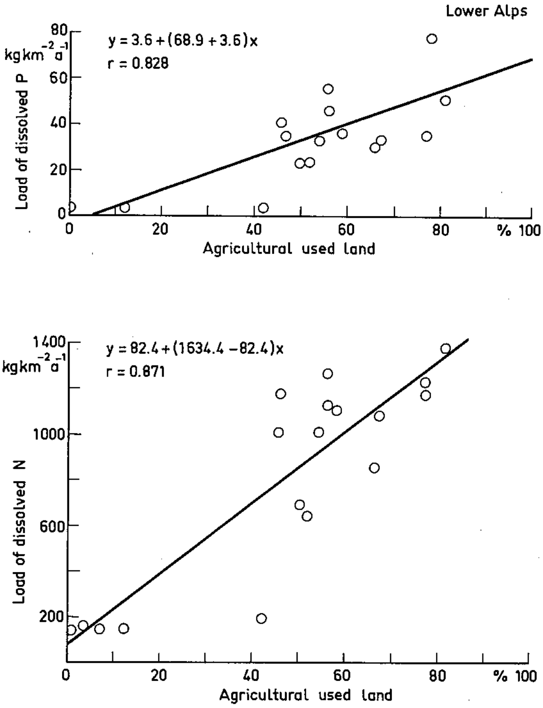

Fig. 9. Dependence of annual loadings of dissolved phosphorus and nitrogen compounds on the percentage of agricultural used area in the Lower Alps according to Gächter and Furrer (1972).

The area of Vänern studied by Ahl (1977) can be regarded as most closely corresponding to Finnish conditions. This is reflected in the fact that the diffuse load in forested basins was, according to Ahl (1977), 6–9 kg km^{-2}a^{-1} phosphorus and 80–120 kg km^{-2}a^{-1} nitrogen. In areas under cultivation the values were 93 and 2 250 kg km^{-2}a^{-1}, respectively. These values are higher than those obtained in Finland, and may result from the use of higher amounts of fertilizers than those normally used in Finland. This possibility is supported by the results of

Jonsson (1975), according to which recovery of fertilizer nitrogen decreases with increasing levels of nitrogen fertilization. Ahl (1977) also observed that the diffuse load of nutrients depends strongly on fertilization and on the percentage of cultivated land (Figs. 10 and 11). On the other hand the correlation with population density was not so clear-cut.

In the light of rather similar results obtained from different parts of the world it would appear to be justified to use the percentage of cultivated land as a means of estimating non-point source loading. However, it should always be borne in mind that the percentage of cultivated land reflects the combined effect of agriculture and scattered population.

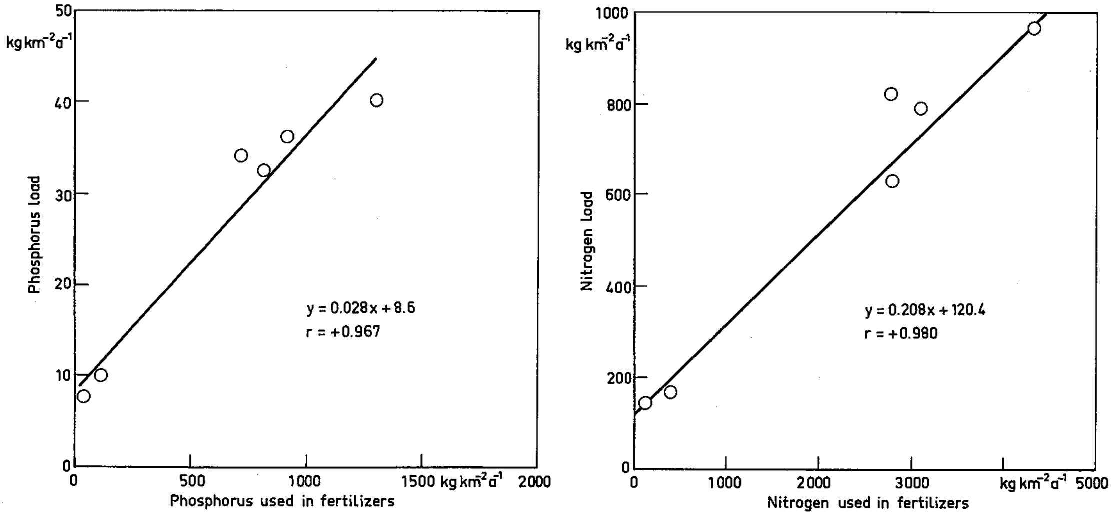

Fig. 10. Dependence of phosphorus and nitrogen loads on fertilization in the drainage basin according to Ahl (1977).

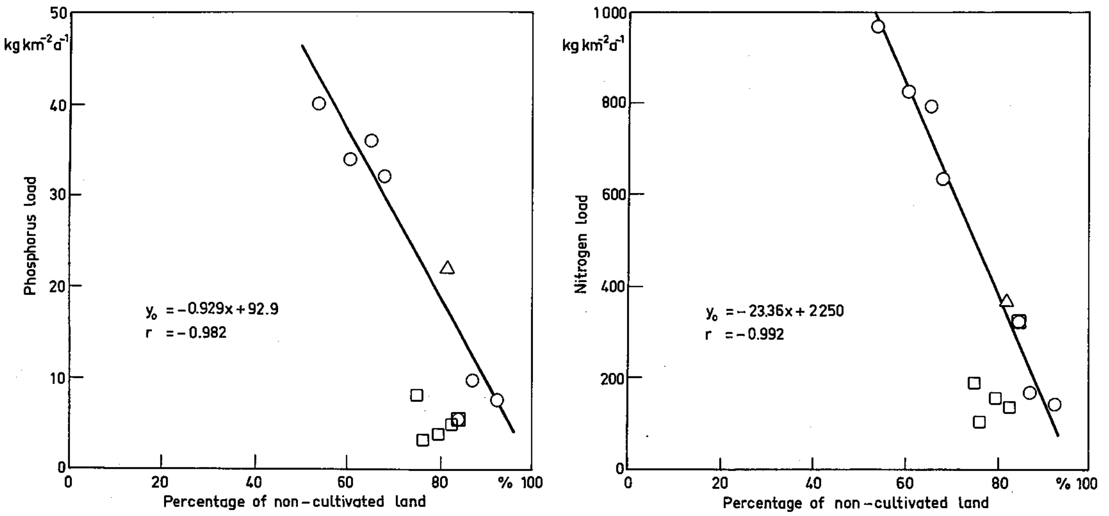

Fig. 11. Dependence of phosphorus and nitrogen loads on the percentage of non-cultivated land in the drainage basin according to Ahl (1977).

○ Lake percentage $<$ 10

□ Lake percentage $>$ 10

△ Includes industrial effluents

Nutrients dissolved in rainwater also comprise an important part of non-point source loading. Observations of rainwater quality were started at 42 stations in 1971 by the Water Research Institute. One of the aims of the study is to determine the magnitude of the effect of nutrients arriving with rainwater on non-point source loading in the small drainage basins (Haapala 1972). Many of the rainwater observation stations are in fact situated in the small drainage basins. The average values for phosphorus and nitrogen reaching the soil in rainwater were in 1973 8.4 and 430 kg $km^{-2}a^{-1}$, respectively, for the whole country (Haapala 1974). Haapala (1977) has presented averages for some of the observation stations for the years 1971–1976. In Southern Finland the amount of nutrients arriving dissolved in rainwater were: 14.4–15.6 kg $km^{-2}a^{-1}$ phosphorus and 528–828 kg km^{-2} a^{-1}nitrogen. The rest of the diffuse loading seems to be more dependent on the basin characteristics according to the present study: in Southern Finland the leaching values obtained varied between 5.2 and 34.0 kg $km^{-2}a^{-1}$ phosphorus and 160 and 740 kg $km^{-2}a^{-1}$ nitrogen. Amounts of phosphorus and nitrogen arriving with rainwater in Northern Finland were 6.0–7.2 and 144–312 kg $km^{-2}a^{-1}$, respectively. For both nutrients these values were higher than the corresponding average values for leaching, which were 4.0–5.6 and 79–130 kg $km^{-2}a^{-1}$, respectively. In non-cultivated areas throughout the country the amounts of phosphorus and nitrogen arriving in rainwater generally exceed the amounts of these nutrients leaching from the soil. Soil and vegetation both fix part of the nutrients, and some of the nitrogen is released to the atmosphere by denitrification.

6. SUMMARY

In the early 1960's the Soil and Hydrotechnical Research Bureau of the Board of Agriculture initiated a research programme to follow the physical-chemical characteristics of water in 34 small drainage basins. From 1962 this work was continued by the Water Pollution Control Office (since 1970 the Water Research Office). The aim of the study was primarily to determine the diffuse load of nutrients and factors affecting this load. When the interpretation of the collected data was started in 1975 the aim was more precisely defined as an attempt to determine the effect of agriculture and sparse population on the diffuse load of phosphorus and nitrogen.

Of the 34 drainage basins, 23 were considered as representing typical diffuse loading areas and were included in the study. The observation period was 1965–1974. Total phosphorus and total nitrogen concentrations were analyzed monthly and runoff measured continuously. Other information concerning the basins was also collected, including percentage of soils composed of fine particles (clay and silt), percentage of cultivated land, density of population with sewerage and density of animal population. Mean values of phosphorus and nitrogen concentrations and diffuse loads were calculated for each drainage basin. The dependence of these mean values on the basin characteristics mentioned above was studied by linear regression analysis.

Concentrations and diffuse loads varied considerably for both nutrients between the different basins. The range of the mean values of phosphorus concentrations was 8.3–98 µg l^{-1}, and the corresponding range for nitrogen concentrations 190–2 400 µg l^{-1}. The dependence of concentrations on runoff was in most basins rather slight, but the highest concentrations were usually observed during the spring floods.

Marked changes in phosphorus and nitrogen concentrations were observed only in a few basins during the 10-year period. Similarly, very few trends were observed in the diffuse loads: no statistically significant trends were found for the case of phosphorus load.

The seasonal variation in loads was considerably greater than that observed for concentrations, because runoff values varied considerably. In non-cultivated areas the annual phosphorus load was for the whole country 4.0–5.6 kg $km^{-2}a^{-1}$. Nitrogen load depended more on the location of the basin: the means of annual nitrogen loads of non-cultivated basins varied from 79 to 180 kg $km^{-2}a^{-1}$. The leaching of nitrogen was clearly more extensive in Southern than in Northern Finland.

The effect of agriculture and sparse population on concentrations and diffuse loads was obvious for both nutrients. All the dependent variables correlated most strongly with the percentage of cultivated land (FP) in the drainage basin. The fact that other independent variables were not of significance in regression analysis is a result of the strong intercorrelations between the variables. The percentage of cultivated land also reflects the loading caused by sparse population and by domestic animal population. It is in fact a measure of non-point source loading.

The dependence of total phosphorus concentration ($Y_{P\text{-conc.}}$, $\mu g\ l^{-1}$) on the percentage of cultivated land (FP, %) is described by the equation (2):

$$Y_{P\text{-conc.}} = 46.4 \log_{10} (FP+1)+7.2 \qquad (2)$$

The equation explains 71 % of the variance in phosphorus concentration. The corresponding equation for total nitrogen concentration ($Y_{N\text{-conc.}}$, $\mu g\ l^{-1}$) is (3):

$$Y_{N\text{-conc.}} = 30\ FP+500 \qquad (3)$$

This equation explains 82 % of the observed variance. A regression function was also calculated for nitrogen concentration on the basis of observations in 17 basins in Central and Southern Finland (5):

$$Y_{N\text{-conc.}} = 25\ FP+650 \qquad (5)$$

The degree of explanation is 89 %.

The phosphorus load ($Y_{P\text{-load}}$, $kg\ km^{-2}a^{-1}$) can be estimated from the percentage of cultivated land by the equation (7):

$$Y_{P\text{-load}} = 15.1 \log_{10} (FP+1)+1.9 \qquad (7)$$

This equation explains 77 % of the variance in diffuse phosphorus load.

The diffuse load of nitrogen ($Y_{N\text{-load}}$, kg $km^{-2}a^{-1}$) also depends on the location of the basin. For the whole research material the equation is (8):

$$Y_{N\text{-load}} = 9.8\ FP+180 \qquad (8)$$

Accounting for 70 % of the variance. For the 17 basins located in Central and Southern Finland this equation becomes (10):

$$Y_{N\text{-load}} = 8.4\ FP+230 \qquad (10)$$

This equation explains 67 % of the variance in nitrogen load.

In estimating concentrations and loads of phosphorus and nitrogen on the basis of the above equations, the limitations imposed by the research material itself should not be forgotten. The equations may not be applicable to areas containing lakes functioning as sedimentation basins, or to areas subject to loading other than normal non-point source loading. The loading caused by more densely populated urban areas must be estimated separately.

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Helsinki, September 1978

Lea Kauppi

LOPPUTIIVISTELMÄ

Vuonna 1961 aloitettiin maataloushallituksen maa- ja vesiteknillisen tutkimustoimiston toimesta veden fysikaalis-kemiallisten ominaisuuksien seuranta tutkimustoimiston kolmellakymmenellä neljällä ns. pienellä valuma-alueella. Tätä työtä jatkoi myöhemmin vesiensuojelutoimisto ja vuodesta 1970 lähtien vesihallitus. Tutkimuksen tarkoituksena oli lähinnä selvittää ravinteiden huuhtoutumista ja siihen vaikuttavia tekijöitä. Aineiston käsittelyn alkaessa vuonna 1975 tarkoitusta täsmennettiin niin, että pyrittiin selvittämään nimenomaan maatalouden ja haja-asutuksen vaikutuksia fosforin ja typen huuhtoutumiin.

Alueista otettiin tähän tutkimukseen mukaan ne, jotka edustivat normaaleja hajakuormitusalueita. Aineisto käsittää kahdellakymmenellä kolmella valuma-alueella vuosina 1965–1974 kerran kuukaudessa tehdyt veden kokonaisfosfori- ja kokonaistyppipitoisuuksia koskevat havainnot, alueiden päivittäiset valuma-arvot sekä aluetta koskevat tiedot. Viimeksi mainittuihin sisältyvät hienojen maalajien osuus, pellon osuus, viemäröidyn asutuksen tiheys sekä eläintiheys.

Fosfori- ja typpipitoisuuksista ja huuhtoutumista laskettiin havaintoaluekohtaiset keskiarvot, joiden vaihtelua verrattiin alueen ominaisuuksia koskeviin tietoihin korrelaatioanalyysin avulla. Tällöin siis yksi aluekeskiarvo muodosti yhden havainnon.

Sekä pitoisuudet että huuhtoutumat vaihtelivat molemmilla pääravinteilla suuresti alueesta riippuen. Fosforipitoisuuksien aluekeskiarvojen vaihteluväli oli 8.3–98 µg l^{-1} ja typellä vastaavasti 190–2 400 µg l^{-1}. Pitoisuuksien riippuvuus valumasta oli useimmilla alueilla vähäinen, yleensä kuitenkin niin, että suurimmat pitoisuudet havaittiin kevättulvien aikaan. Vain muutamalla alueella oli havaittavissa pitoisuuksien pienenemistä suurien valumien aikaan.

Fosfori- ja typpipitoisuudet ovat keskimäärin pysyneet samalla tasolla koko havaintojakson ajan. Trendejä on havaittavissa hyvin vähän. Sama on tilanne huuhtoutumien kohdalla. Fosforihuuhtoutumalla ei ole havaittu yhtään tilastollisesti merkitsevää trendiä.

Huuhtoutumien kausivaihtelu on huomattavasti suurempaa kuin pitoisuuksien, koska vesimäärät vaihtelevat moninkertaisesti verrattuna pitoisuuksiin. Lisäksi useimmilla alueilla pitoisuus- ja valumahuiput osuvat samaan ajankohtaan. Luonnontilaisten alueiden vuosihuuhtoutumat ovat fosforin osalta noin 4.0–5.6 kg $km^{-2}a^{-1}$ koko maassa. Typpihuuhtoutuma on enemmän riippuvainen alueen sijainnista, sillä luontainen typpihuuhtoutuma vaihtelee saatujen tulosten mukaan 79–180 kg $km^{-2}a^{-1}$. Etelä-Suomen typpihuuhtoutumat ovat selvästi suurempia kuin Pohjois-Suomen. Muilta osin huuhtoutumat riippuvat alueen maankäyttöoloista ja yleensä hajakuormituksen suuruudesta.

Maatalouden ja haja-asutuksen vaikutus pitoisuuksiin ja huuhtoutumiin on sekä fosforilla että typellä selvä. Kaikki selitettävinä olevat muuttujat korreloivat voimakkaimmin peltoprosenttiin (PP). Typellä toinen merkittävä tekijä on alueen sijainti. Se, että peltoprosentin lisäksi muut selittäjät eivät regressioanalyysissä ole tulleet merkitseviksi, johtuu selittäjien voimakkaista keskinäisistä korrelaatioista. Pellon osuus kuvaa itse asiassa myös haja-asutuksen ja kotieläinten aiheuttamaa kuormitusta. Se on eräänlainen hajakuormituksen mitta.

Kokonaisfosforipitoisuuden ($Y_{P\text{-pit.}}$, µg l^{-1}) riippuvuutta pellon osuudesta valuma-alueella (PP,%) kuvaa yhtälö (2)

$$Y_{P\text{-pit.}} = 46.4 \log (PP+1)+7.2 \qquad (2)$$

Yhtälö selittää 71 % kokonaisfosforin pitoisuuden varianssista. Kokonaistyppipitoisuudella ($Y_{N\text{-pit.}}$, µg l^{-1}) vastaava yhtälö (3) on muotoa

$$Y_{N\text{-pit.}} = 30\ PP+500 \qquad (3)$$

Selitysaste on 82 %.

Typpipitoisuudelle on laskettu myös regressioyhtälö Etelä- ja Keski-Suomen alueiden (17 aluetta) havaintoihin perustuen (5):

$$Y_{N\text{-pit.}} = 25\ PP+650 \qquad (5)$$

Yhtälö selittää 89 % typpipitoisuuden varianssista.

Fosforihuuhtoutuma ($Y_{P\text{-huuht.}}$, kg km^{-2} a^{-1}) voidaan varsin hyvin arvioida valuma-alueen peltoprosentin avulla seuraavasti (7)

$$Y_{P\text{-huuht.}} = 15.1 \log(PP+1)+1.9 \qquad (7)$$

Yhtälö selittää 77 % fosforihuuhtoutuman varianssista.

Kuten jo aikaisemmin todettiin, typpihuuhtoutuma (Y_N-huuht., kg $km^{-2}a^{-1}$) riippuu myös alueen sijainnista. Koko aineistosta laskettu yhtälö (8) on seuraava

$$Y_N\text{-huuht.} = 9.8\ PP + 180 \quad (8)$$

Selitysaste on 70 %.

Etelä- ja Keski-Suomen alueiden perusteella lasketun yhtälön (10) selitysaste on 67 %:

$$Y_N\text{-huuht.} = 8.4\ PP + 230 \quad (10)$$

Arvioitaessa pitoisuuksia ja huuhtoutumia edellä esitettyjen yhtälöiden perusteella on muistettava ne rajoitukset, jotka johtuvat lähtöaineistosta. Alueella ei saa olla merkittävässä määrin sedimentaatioaltaina toimivia järviä. Toiseksi alueen on oltava normaalia hajakuormitusaluetta, ts. varsinaisten taajamien kuormitus on arvioitava erikseen.

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App. 1. Division of research material into three seasons — winter, spring and summer + autumn - in the different basins.

Basin	Starting date		
	Winter	Spring	Summer+ Autumn
1 Teeressuonoja	1.12.	1.4.	11.5.
2 Kylmänoja	1.12.	1.4.	11.5.
3 Löytäneenoja	1.12.	1.4.	11.5.
4 Paunulanpuro	1.12.	1.4.	20.5.
6 Katajaluoma	1.12.	1.4.	20.5.
7 Ravijoki	1.12.	1.4.	20.5.
9 Latosuonoja	1.12.	1.4.	20.5.
11 Korpijoki	1.11.	10.4.	20.5.
12 Kesselinpuro	15.11.	15.4.	1.6.
13 Kuokkalanoja	15.11.	15.4.	1.6.
14 Mustapuro	15.11.	15.4.	1.6.
18 Kaidesluoma	1.11.	1.4.	1.6.
20 Heinäjoki	1.11.	1.4.	1.6.
21 Ruunapuro	1.11.	1.4.	1.6.
22 Pahkaoja	1.11.	10.4.	25.5.
25 Tuuraoja	1.11.	10.4.	20.5.
26 Huopakinoja	20.10.	10.4.	25.5.
27 Vääräjoki	1.11.	1.5.	15.6.
28 Myllypuro	25.10.	10.4.	1.6.
30 Korintteenoja	15.10.	1.5.	15.6.
31 Vähä-Askanjoki	15.10.	1.5.	25.6.
32 Kuusivaaranpuro	1.10.	1.5.	15.6.
34 Myllyoja	25.9.	1.5.	25.6.