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Helsinki 2001
ISSN 0039-5471
Suo 52(1): 1–15

Discharge water quality from old ditch networks in Finnish peatland forests

Vanhoilta metsäojitusalueilta valuvan veden ominaisuudet

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Runoff water from 75 Finnish ditch networks was sampled for chemical analysis in 1990–1992. In total, 2815 samples were analyzed. Higher mean and median concentrations of total dissolved phosphorus were observed than reported earlier. Except for phosphorus, concentration of most elements increased with increasing site fertility. No clear relationship between phosphorus concentration and the site characteristics could be detected. The median concentration of suspended solids in runoff water from old ditch networks was as low as 2.4 mg l^{-1}.

Keywords: ditch networks, peatland forests, water quality

INTRODUCTION

Discharge waters from peatlands are generally more acid and have higher concentrations of dissolved organic matter and nitrogen and lower concentrations of sulphate and base cations than the stream waters from mineral soils (Saukkonen & Kortelainen 1995; Kortelainen & Saukkonen 1998). Low pH-values of peatland ditch discharge water are due to organic acids and thus associated with high concentrations of dissolved organic carbon (DOC) (Kortelainen 1993b, Kortelainen et al. 1997). The production of organic acids in peat adds excessive acidity and organic carbon in the runoff water. Inputs of drainage waters from ditched peatlands can increase the acid load and the loads of phosphorus and nitrogen to water courses (Ahtiainen 1990). However, according to Kenttämies (1987), concentrations of suspended solids, organic carbon, and total nitrogen in the discharge waters from old, already moss covered ditch networks do not differ much from those of drainage waters originating from pristine peatlands.

The aim of this study was, by using extensive sampling in different parts of Finland, to produce a representative description of the quality characteristics of runoff water originating from old ditch networks.

MATERIAL AND METHODS

Catchment characteristics

General description

In total, 75 small forested catchments containing old ditch networks were chosen for the study (Fig. 1). With a few exceptions, all areas were situated in

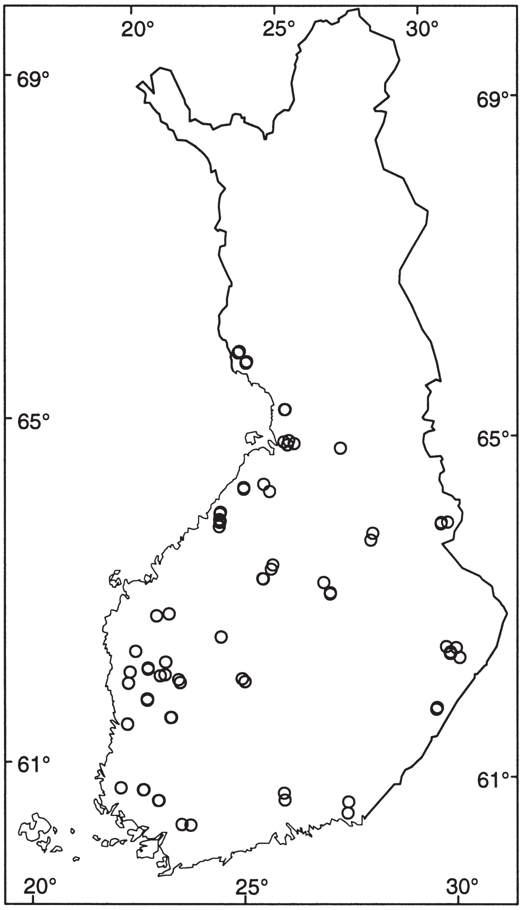

Fig. 1. The location of the 75 old ditch networks used in the study.

Kuva 1. Tutkimuksessa seurattujen 75 vanhan ojaston sijainti.

the southern half of Finland, where annual precipitation in 1961–90 varied between 600 and 750 mm and annual runoff between 250 and 400 mm (Hyvärinen et al. 1995).

When selecting the study sites, only catchments including forestry land (for definition see Finnish Statistical Yearbook of Forestry, p. 343) and forest roads were accepted. In all areas, the samples were taken from the main ditch of the forest ditch network. The size of the average catchment was 77 ha (13–222 ha) and comprised of 39 ha of drained peatland, 5 ha of pristine peatland and 33 ha of upland mineral soil. On average, 80% of the peatland area of a site was dominated by Scots pine and the remainder by Norway spruce. Open (treeless) peatlands accounted for less than 5% of the total peatland area on average. The average site quality class distribution of the catchments, including both peatlands and mineral soil sites, is given in Table 1 and further characteristics in Table 2. For determining the relationships between site type and water chemistry, the original, pre-drainage peatland site type (Laine & Vasander 1990) of each plot was estimated around the plot centerpoint. Finally, erosion of the ditches and other factors connected with ditch condition were noted.

Ditch characteristics

Ditch depth, ditch width and the condition of the ditch were surveyed on sample plots located systematically along the ditches. Depending on the

Table 1. Distribution of forest site quality classes (Huikari 1974) for the average catchment in the study.
Taulukko 1. Valuma-alueiden keskimääräinen ravinteisuusluokkajakautuma Huikarin (1974) luokitusmenetelmällä.

Site quality class *Keskim. ravinteisuusluokka*	Coverage of all sites, % of basin area *Peittävyys,* *% valuma-alueesta*	Coverage of peatland sites, % of peatland area *Peittävyys,* *% suopinta-alasta*
I Grove-like sites – *Lehtomaiset metsät*	-	-
II Herb-rich sites – *Ruohoiset metsät*	5	4
III Myrtillus sites- *Mustikkaiset metsät*	25	13
IV Vaccinium sites – *Puolukkaiset metsät*	35	33
V Calluna sites – *Kanervatason metsät*	30	45
I Cladina sites – *Jäkälätason metsät*	5	5

area of drained peatland, the number of sample plots varied between 22 and 204 per catchment. At each plot, the condition of the ditch was classified into one of the five classes of Keltikangas et al. (1986; class 1 = good ditch quality) for a 40 m ditch section. For the 75 study sites, the mean ditch quality class was 3.5. The width of the ditches averaged 132 cm (range 53–211 cm) and ditch depth 58 cm (34–86 cm).

The abundance of different plant species in the ditch was determined subjectively by using 10% coverage classes. The mean coverage of the most important plants were as follows: *Sphagnum* 48%, *Polytrichum* 14%, *Carex* 7%, *Eriophorum vaginatum* 6%, grasses 5%, and herbs 5% of the ditch surfaces. The most common sedges covering the ditch surfaces were *Carex rostrata, C. rynchospora, C. canescens, C. lasiocarpa* and mostly on the ditch slopes, *Carex globularis*. The most common grass species were *Calamagrostis purpurea, Deschampsia flexuosa, D. cespitosa, Molinia caerulea, Juncus sp, Festuga rubra, Agrostis canina* and sometimes also *Phragmites sp, Phalaris sp,* and *Poa sp*. Among the herb species, *Geranium sp, Gymnocarpium sp, Melampyrum sp, Linnaea borealis*, and *Equisetum sp* can be mentioned. The coverage percents of the dwarf shrubs and the bushes were well over three percent, respectively. Common dwarf shrubs were *Vaccinium vitis idaea*, *V. myrtillus*, *V. uliginosum*, *Ledum palustre*, *Andromeda polifolia*, *Empetrum nigrum*, *Betula nana,* and *Calluna vulgaris*. Small specimens of *Betula pubescens*, *Betula verrucosa*, *Alnus sp.*, *Salix sp.* and *Picea abies* were regarded as bushes. On the average 10% of the ditch surfaces were free of vegetation.

Tree stands

Stand characteristics were measured on sample plots located at intervals of $\sqrt{ab}$ metres, in which a = catchment area in m^2 and b = number of plots per area. A minimum number of 50 plots were measured per catchment.

The basal area of the stand was estimated with a relascope. In sapling stands, the stem number instead of basal area was estimated. Stand volume was estimated by species from measurements of breast height diameter and height of the median tree at each of the basal area sample plots.

The catchment means for breast height diameter, stand height, and stand volume were 11.5 cm, 9.5 m, and 72.3 m^3 ha^{-1} (from 9 to 190 m^3 ha^{-1}). The actual site values for stand volume are given in Table 2.

Sampling

Water samples were collected in 1990–1992. The number of water samples per catchment varied from 16 to 83 and averaged 37. In all, 2815–2850 samples were analyzed. The water samples were taken twice a week during the spring high flows, but otherwise weekly. Sampling continued until snowfall and freezing of the ditches in late autumn and no samples were taken in winter.

The samples were taken directly into 500 ml plastic bottles from a sampling point on the main ditch selected to enable sampling from flowing water without stirring the bottom sediment of the ditch. The samples were sent immediately to the Central Laboratory of the Finnish Forest Research Institute in Vantaa. Prior to analysis, the samples were stored at +5 °C.

Chemical analysis

Acidity and electric conductivity were determined using the standard methods of the Finnish Forest Research Institute (Jarva & Tervahauta 1993). The samples were then filtered (Fiber-glass, pore size 1.2 µm).The filtrate was analyzed for phosphorus, sodium, potassium, magnesium, calcium, sulfur, aluminum and iron concentrations using plasma emission spectrophotometry (ICP-AES, ARL 3580). Total dissolved nitrogen (N_{tot}), ammonium nitrogen (NH_4^--N) and nitrate nitrogen (NO_3^+-N) were determined spectrophotometrically with a Tecaton FIA-analyzer. The concentration of dissolved organic carbon (DOC) was determined with a Shimadzu carbon analyzer from 1992 onwards. DOC concentrations prior to 1992 were calculated from $KMnO_4$ consumption (SFS 3036 method) and the regression equation is presented in Fig. 2. This equation was derived from parallel measurements of both DOC and $KMnO_4$ concentrations from 714 samples. The filters were dried at 60°C and weighed to determine the amount of suspended solids.

Table 2. Some basin characteristics according to field observations in 1990-1994 and local forest authorities. (-): not estimated.
Taulukko 2. Tutkimuksessa seurattujen valuma-alueiden ominaisuuksia ja tunnuslukuja vuosina 1990-94 tehtyjen maastoinventointien ja metsänparannussuunnitelmien tietojen perusteella. (-): ei tiedossa.

Name of area *Alueen nimi*	Locality *Sijaintikunta*	Temp. sum *Lämpö-summa* d.d.	Basin area *Val.alueen pinta-ala* ha	Peatland area *Suopinta-ala* ha	Drained peatl. area *Ojitusala* ha	First drain. year *Uudisojitus-vuosi*	Stand volume *Puuston tilavuus* Basin *Va. alue* $m^3 ha^{-1}$	Peatlands *Suot*	Ditch cond class *Ojien kunto-luokka*	Fertiliz. years *Lann. vuodet*	Fertil. area *Lann. ala*
Sepänsuo	Pertteli	1275	62.4	19.6	17.8	1969	90.3	63.5	4.0	1975	14.3
Asunsuo	Kiikala	1261	104.4	27.4	27.4	1967	94.3	64.8	3.2	1972	6.0
Kaulanperä	Karinainen	1266	33.4	15.9	14.9	1956	190.0	-	4.2		0.0
Puistovuori	Karinainen	1276	21.9	9.4	9.4	1956	173.5	-	3.0		0.0
Isosuo	Laitila	1262	54.7	26.5	25.0	1967	83.8	49.8	4.1	1972	20.6
Sundgreninsuo	Laitila	1262	72.9	20.4	17.0	1968	136.2	95.3	2.9	1972	8.9
Vuohensuo	Yläne	1234	65.4	28.4	28.4	1965	43.4	22.7	4.8	1971, 76, 80	86.0
Kroopinsuo	Yläne	1234	174.6	60.2	59.4	1966	39.0	42.2	3.8	1971	51.2
Pitkäneva	Kankaanpää	1156	44.0	20.3	20.3	1964	75.3	84.2	4.0	1973	4.5
Varpuneva	Kankaanpää	1149	48.0	19.3	19.3	1978	57.2	46.3	3.0	1985	1.8
Hirsisuo	Noormarkku	1215	133.5	42.3	38.0	1965	93.2	114.1	3.7		0.0
Paloneva	Karvia	1087	31.3	30.2	30.2	1964	46.8	45.9		1970	23.0
Alkkia	Karvia	1087	79.0	65.7	48.3	1965	28.0	-	3.7	1977	11.0
Välisalonneva	Karvia	1085	53.8	47.2	47.1	1978	50.5	32.9	3.3		0.0
Porrasneva	Kihniö	1098	42.9	36.3	34.6	1969	51.9	51.9	3.4	1971	24.0
Peltomaa	Kihniö	1082	13.3	9.6	9.6	1973	47.5	-	3.7	1974	7.0
Kiekkoneva	Hämeenkyrö	1172	86.1	72.5	70.2	1956	88.4	91.4	2.9		0.0
Teerineva	Hämeenkyrö	1159	110.1	87.5	86.7	1961	52.9	47.6	3.7		0.0
Pottisuo	Orimattila	1275	75.2	35.7	35.7	1968	110.6	57.6	3.5	1969	25.0
Majasuo	Orimattila	1281	46.8	21.5	21.5	1973	66.9	80.8	2.7	1985	20.6
Liisansuo	Vehkalahti	1296	177.0	78.1	78.1	1969	115.9	91.0	3.8	1972	28.6
Homeperseensuo	Vehkalahti	1313	98.6	26.9	24.3	1965	93.9	82.2	3.9		0.0
Ruskeesuo	Pyhäselkä	1123	24.8	24.8	24.8	1964	96.5	96.5	5.0	1970, 85	34.3
Alaräme	Pyhäselkä	1104	59.8	30.6	28.5	1964	86.5	58.2	3.8	1970, 78, 85	34.5
Mäntylä	Pyhäselkä	1132	22.5	21.6	21.6	1967	72.4	70.1	2.9	1970, 83	25.0
Purnukorpi	Kiihtelysvaara	1085	100.2	48.8	46.9	1968	61.4	32.8	3.0	1970, 83	25.8
Laineensuo	Kiihtelysvaara	1092	54.6	40.5	32.0	1974	68.5	45.2	2.7		0.0
Mantilansuo	Punkaharju	1229	64.1	24.4	24.4	1965	87.8	58.5	3.6	1971, 72	26.3
Nenäsuo	Punkaharju	1226	42.1	23.5	22.2	1976	61.5	11.7	3.2	1978	6.0
Honkasuo	Pielavesi	1118	54.1	30.4	30.4	1963	134.7	129.3	3.5	1978	9.4
Tervasuo	Pielavesi	1106	117.9	81.8	68.5	1966	163.0	147.2	4.4		0.0
Suurisuo	Pielavesi	1097	101.5	76.1	73.3	1966	49.1	43.7	3.6		0.0
Soidinkorpi	Pihtipudas	1056	163.0	75.9	55.6	1960	71.1	38.5	3.5		0.0

Continued...

Table 2. Continues

Saarineva	Pihtipudas	1060	105.9	52.3	51.1	1974	68.8	34.2	3.2		0.0
Heinäsuo	Kinnula	1032	202.2	111.8	102.0	1938			3.3	1968	30.0
Käsälänkorpi	Kinnula	1028	104.8	23.8	22.5	1970	21.7	77.1	3.5		0.0
Haarasuo	Keuruu	1152	56.1	28.6	28.6	1965	145.8	93.3	2.7	1970	14.5
Käännetynsuo	Keuruu	1151	50.4	23.7	23.7	1970	140.3	69.6	3.0	1970	10.6
Kämppä	Ylistaro	1111	150.1	49.5	48.2	1962	112.0	61.8	4.2	1970	1.4
Viitikko	Ylistaro	1105	117.9	34.3	33.2	1978	78.7	81.8	3.3		0.0
Vähä-Oivari	Isojoki	1139	48.8	29.6	29.6	1969	24.0	25.0	4.4	1978	7.8
Toristonluoma	Isojoki	1145	32.7	21.7	20.8	1982	107.5		2.9		0.0
Hautakangas	Kauhajoki	1071	87.6	70.2	70.2	1974	33.2	28.6	3.5	1976	22.2
Juurakkoneva	Kauhajoki	1069	56.2	42.3	42.3	1965	29.9	27.7	2.0	1972, 78	28.3
Sydänkorven-rämäkkä	Kauhajoki	1058	89.1	77.8	69.3	1969	49.8	46.5	3.1	1971	44.6
Hosimäki	Kauhajoki	1067	52.0	29.9	29.9	1984	63.1	48.0	2.9		0.0
Takkikallio	Ähtäri	1059	89.7	44.4	43.9	1966	65.1	59.0	3.4	1974	4.0
Huikuri	Ähtäri	1050	31.5	22.6	22.6	1967	9.1	12.6	3.8		0.0
Tupasalo	Kannus	1051	26.2	15.4	15.4	1965	46.3	58.0	4.7	1973	5.3
Kiviniittu	Kannus	1048	85.5	49.6	45.7	1969	47.5	57.9	3.2	1969	20.8
Korpiala	Kannus	1057	66.4	30.1	30.1	1965	32.7	30.1	3.6	1974	13.7
Märsynräme	Kannus	1056	60.8	46.7	39.0	1969	50.8	45.1	3.0	1969	7.2
Valkiaräme	Toholampi	-	49.0	21.0	20.0	-	-	-	-	-	-
Raippamaanoja	Kalajoki	998	97.0	83.1	83.1	1956	57.7	54.8	3.9		0.0
Kannistonräme	Kalajoki	1024	31.0	28.4	28.4	1969	42.6	48.7	3.0	1979	26.0
Jänissuo	Sotkamo	958	97.0	44.9	41.3	1968	75.9	49.4	2.9	1969	7.6
Mustakorvensuo	Sotkamo	978	70.1	66.2	66.1	1968	83.7	81.7	3.7	1969	26.5
Rapasensuo	Kuhmo	928	63.4	45.3	28.0	1968	62.5	39.1	3.5	1983	19.4
Komulansuo	Kuhmo	960	119.9	81.5	45.1	1970	51.7	37.0	3.7	1980	9.5
Lutja	Kuhmo	960	79.0	37.8	36.1	1978	105.3	63.9	3.5	1978	18.8
Käärmekorpi	Yli-Ii	1014	51.9	51.4	45.3	1967	36.7	35.8	2.5		0.0
Heininsuosalmi	Yli-Ii	1011	115.7	94.1	85.0	1967	60.0	57.7	3.4		0.0
Hämäläisneva	Vihanti	1034	38.0	29.8	29.8	1961	44.3	37.9	3.0		0.0
Lievonkangas	Vihanti	1035	24.7	13.3	13.3	1972	137.0	92.8	2.7	1989	8.0
Pilpasuo	Oulu	1019	147.8	65.3	48.1	1965	61.0	51.0	3.8		0.0
Tuppisuo	Oulu	1002	222.0	130.0	90.5	1974	35.9	10.3	3.8	1975	33.0
Isosuonräme	Oulu	1027	122.6	77.6	64.0	1938	50.8	46.6	3.4		0.0
Korpikoskensuo	Oulu	1016	55.0	36.0	36.0	1964	36.5	41.2	3.3		0.0
Ruostekorpi	Utajärvi	969	48.6	46.2	46.2	1966	15.2	13.9	3.6	1987	28.0
Ollinneva	Pyhäjoki	991	52.5	49.4	49.4	1956	50.2	55.3	3.6		0.0
Pöytäpuunneva	Pyhäjoki	994	58.2	36.2	28.8	1962	55.3	40.8	3.8		0.0
Prakunmaa	Keminmaa	976	146.0	82.9	75.3	1965	72.1	97.7	3.7		0.0
Mykkä	Keminmaa	973	78.5	29.0	23.6	1971	98.3	87.9	2.9		0.0
Kontionjänkä	Tornio	973	30.0	30.0	23.2	1970	104.4	83.4	3.5		0.0
Pörhälä	Tornio	971	28.8	24.5	22.2	1978	68.9	76.6	3.1		0.0

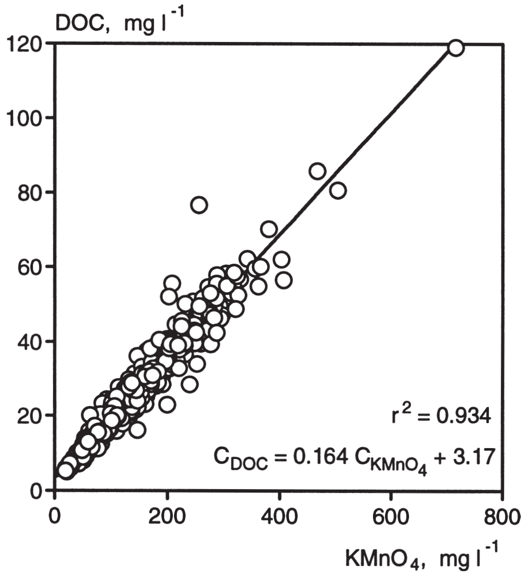

Fig. 2. Linear regression between DOC and $KMnO_4$-consumption. n = 714.

Kuva 2. Orgaanisen hiilen pitoisuuden ja kaliumpermanganaatin kulutuksen välinen lineaarinen korrelaatio. n = 714.

The water quality of the samples was characterised using descriptive statistics e.g. means, deviations, frequency distributions, Pearson correlation coefficient, regression analysis and mean tests. The statistical analysis was performed using the SYSTAT statistical package (SYSTAT 1996).

RESULTS

Ditch water quality

Nitrogen

Site mean total nitrogen concentration ranged from 0.22 to 2.02 mg l^{-1}. The average of all 2820 samples was 0.738 mg l^{-1} (Tables 3 and 4), which is almost double the value reported by Kortelainen et al. (1999) for stream water draining pristine forest land. In addition to the different fractions of N, total N concentrations were positively correlated with the concentrations of potassium, calcium, magnesium and iron (Table 5).

Table 3. Statistical parameters describing the runoff water quality of all samples from 75 forest ditch networks located throughout Finland. n = number of samples, $\bar{x}$ = arithmetic mean, S_d = standard deviation, $s_{\bar{x}}$ = standard error of mean, x_{min} = minimum value, x_{max} = maximum value, Q_1 = lower quartile, M_d = median, Q_3 = upper quartile. All concentrations in mg l^{-1}. SS = suspended solids, EC =electric conductivity, µS cm^{-1}.

Taulukko 3. Eri puolilla Suomea sijaitsevien 75 vanhan ojitusalueen valumavesien ravinnepitoisuudet, kiintoainepitoisuudet (SS), pH ja johtokyky (EC, µS cm^{-1}). n = havaintojen lukumäärä, $\bar{x}$ = keskiarvo, S_d = keskihajonta, $s_{\bar{x}}$ = keskiarvon keskivirhe, x_{min} = havaintojen minimiarvo, x_{max} = havaintojen maksimiarvo, Q_1 = alakvartiili, M_d = mediaani, Q_3 = yläkvartiili. Kaikki pitoisuudet on ilmoitettu mg l^{-1}.

	n	$\bar{x}$	S_d	$s_{\bar{x}}$	x_{min}	x_{max}	Q_1	M_d	Q_3
N_{tot}	2820	0.738	0.386	0.0073	0.090	4.78	0.485	0.670	0.920
NH_4^+-N	2820	0.042	0.115	0.0022	<0.007	1.76	<0.007	<0.007	0.033
NO_3^--N	2821	0.058	0.199	0.0038	<0.002	3.92	<0.002	0.016	0.045
DOC	2820	29.79	13.1	0.236	3.1	92.1	16.7	23.7	32.8
SS	2818	4.90	7.85	0.148	<0.20	148	0.80	2.40	6.0
EC	2820	43.2	24.3	0.457	10.3	232	28.0	37.2	50.1
pH	2821	5.61	1.01	0.019	3.29	8.58	4.81	5.54	6.35
Na	2815	2.25	1.69	0.032	0.137	48.8	1.32	1.79	2.74
K	2815	0.536	0.640	0.0121	<0.01	9.91	0.200	0.402	0.667
Ca	2815	3.65	3.93	0.074	0.455	43.5	1.75	2.52	3.90
Mg	2815	1.62	1.84	0.035	0.187	26.3	0.68	1.07	1.83
Al	2815	0.433	0.296	0.0056	<0.001	2.50	0.207	0.396	0.608
Fe	2815	1.59	1.42	0.0268	0.048	18.6	0.640	1.19	2.07
S	2815	1.89	1.94	0.0366	0.263	68.9	0.89	1.45	2.43
P	2815	0.056	0.0512	0.0001	<0.001	0.596	0.031	0.045	0.066
B	2815	0.0104	0.0093	0.0002	<0.001	0.116	0.0048	0.0091	0.0140

Site mean NH_4-N concentrations varied from 0 to 0.385 mg l^{-1} and the mean concentration of all samples was 0.042 mg l^{-1}. In most runoff water samples the NH_4-N concentration was close to zero, as indicated by the median value (Tables 3 and 4). The highest mean monthly N_{tot} and NH_4-N concentrations occurred in July – August (Fig. 3).

Site mean NO_3-N concentrations varied from 0 to 1.207 mg l^{-1}. Most samples had very low nitrate concentrations, the median concentration of all samples being 0.016 mg l^{-1} (Tables 3 and 4). There was no seasonal trend in the variation of nitrate nitrogen.

Phosphorus

The mean concentration of total dissolved phosphorus calculated from all samples (n=2815) was 0.056 mg l^{-1} and the median 0.045 mg l^{-1}. These values are higher than P_{tot}-values reported earlier for runoff water from peatlands (Heikurainen et al.1978, Kenttämies 1987, Saukkonen & Kortelainen 1995, Kortelainen & Saukkonen 1998). Site mean total phosphorus concentrations varied from 0.026 to 0.458 mg l^{-1} and the median concentration from 0.024 to 0.486 mg l^{-1}. Phosphorus concentrations were highest during the low flow period of July–August and were only weakly correlated with most of the other water quality parameters. There was a statistically significant correlation with organic nitrogen and DOC, though (Table 5).

DOC and pH

The site mean of DOC concentration varied from 6.88 to 47.09 mg l^{-1} and averaged 26.1 mg l^{-1}. The mean DOC concentration calculated from all samples (n=2820) was 29.8 mg l^{-1}. In agreement with what has been reported earlier by Kauppi (1979), DOC concentrations were the lowest during the high water flow period in spring and increased gradually towards autumn. The concentration of dissolved organic carbon correlated positively with total N and organic N concentra-

Table 4. Mean runoff water quality of 75 basins as calculated on the basis of all samples and basin means and medians. Concentrations; mg l^{-1}, SS = suspended solids (mg l^{-1}), EC = electric conductivity ($\mu S\ cm^{-1}$).

Taulukko 4. Valumaveden keskimääräiset kemialliset ominaisuudet 75 vanhassa ojastossa kaikkien näytteiden keskiluvuilla ja ojastokohtaisilla keskiluvuilla ilmaistuina Pitoisuudet mg l^{-1}, SS = kiintoainepitoisuus, EC = sähkönjohtavuus ($\mu S\ cm^{-1}$).

Water quality parameter *Vedenlaatu-muuttuja*	Arithmetic mean of all samples *Kaikkien näytteiden keskiarvo* (n=2815)	Average of basin means *Aluekeskiarvojen keskiarvo* (n = 75)	Median of all samples *Kaikkien näytteiden mediaani* (n = 2815)	Median of basin means *Aluekeskiarvojen mediaani* (n= 75)
N_{tot}	0.738	0.760	0.670	0.732
NH_4-N	0.042	0.039	0.000	0.018
NO_3-N	0.058	0.064	0.016	0.036
DOC	29.8	26.1	23.7	25.2
SS	4.90	4.72	2.40	2.84
EC	43.2	41.7	37.2	38.1
pH	5.61	5.61	5.54	5.56
Na	2.25	2.29	1.79	2.16
K	0.536	0.575	0.402	0.497
Ca	3.65	3.81	2.52	3.71
Mg	1.62	1.68	1.07	1.63
Al	0.433	0.448	0.396	0.432
Fe	1.59	1.60	1.19	1.38
S	1.89	2.04	1.45	1.88
P	0.056	0.061	0.045	0.055

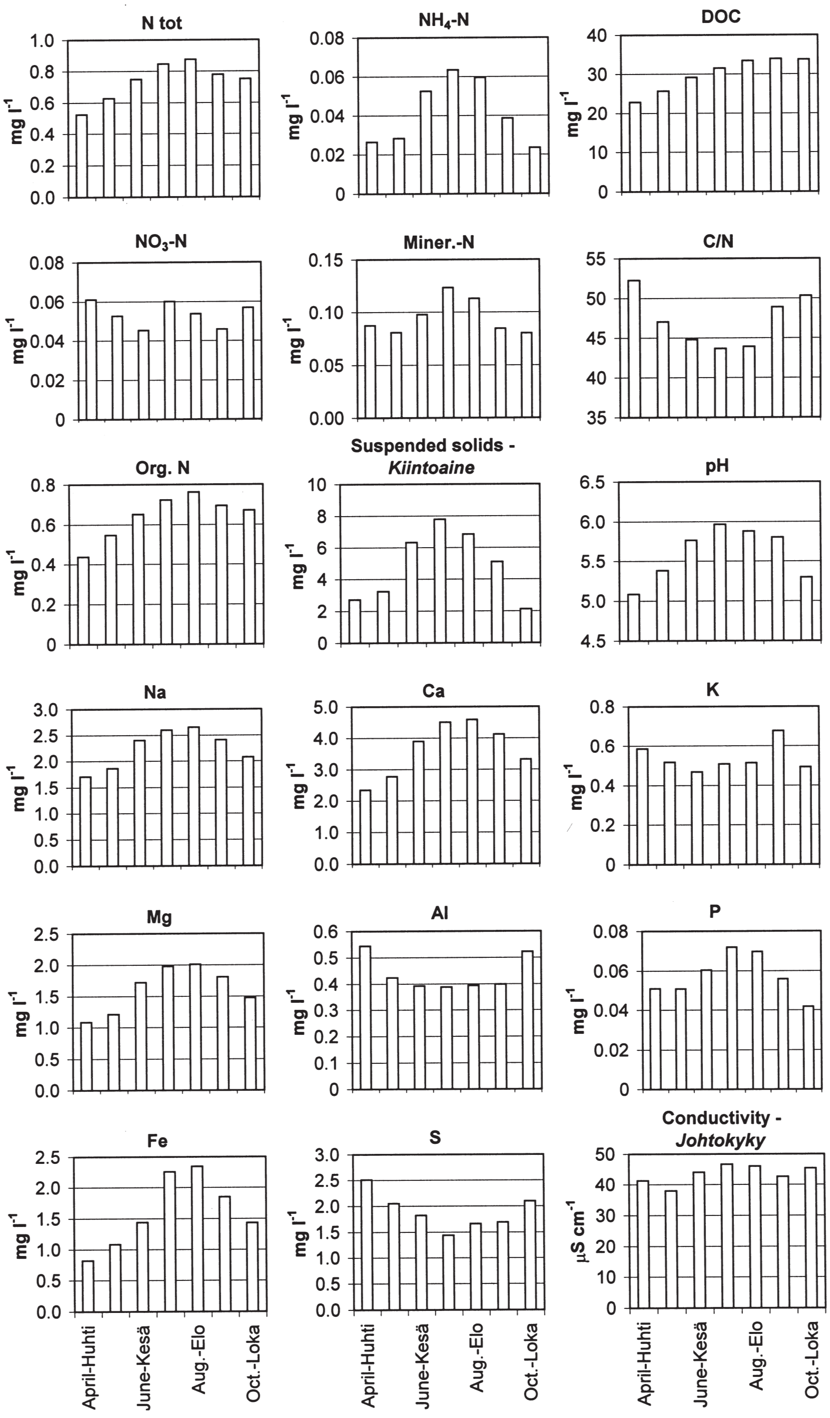

Fig. 3. Mean monthly pH, electric conductivity (EC), element concentrations, concentration of suspended solid material and C/N-ratio in runoff water from old ditch networks.

Kuva 3. Vanhoilta ojitusalueilta valuvan veden ravinnepitoisuuksien, kiintoainepitoisuuden ja liuenneen orgaanisen hiilen (DOC) pitoisuuden sekä pH:n, johtokyvyn (EC) ja hiili-typpisuhteen huhti-lokakuun keskiarvot.

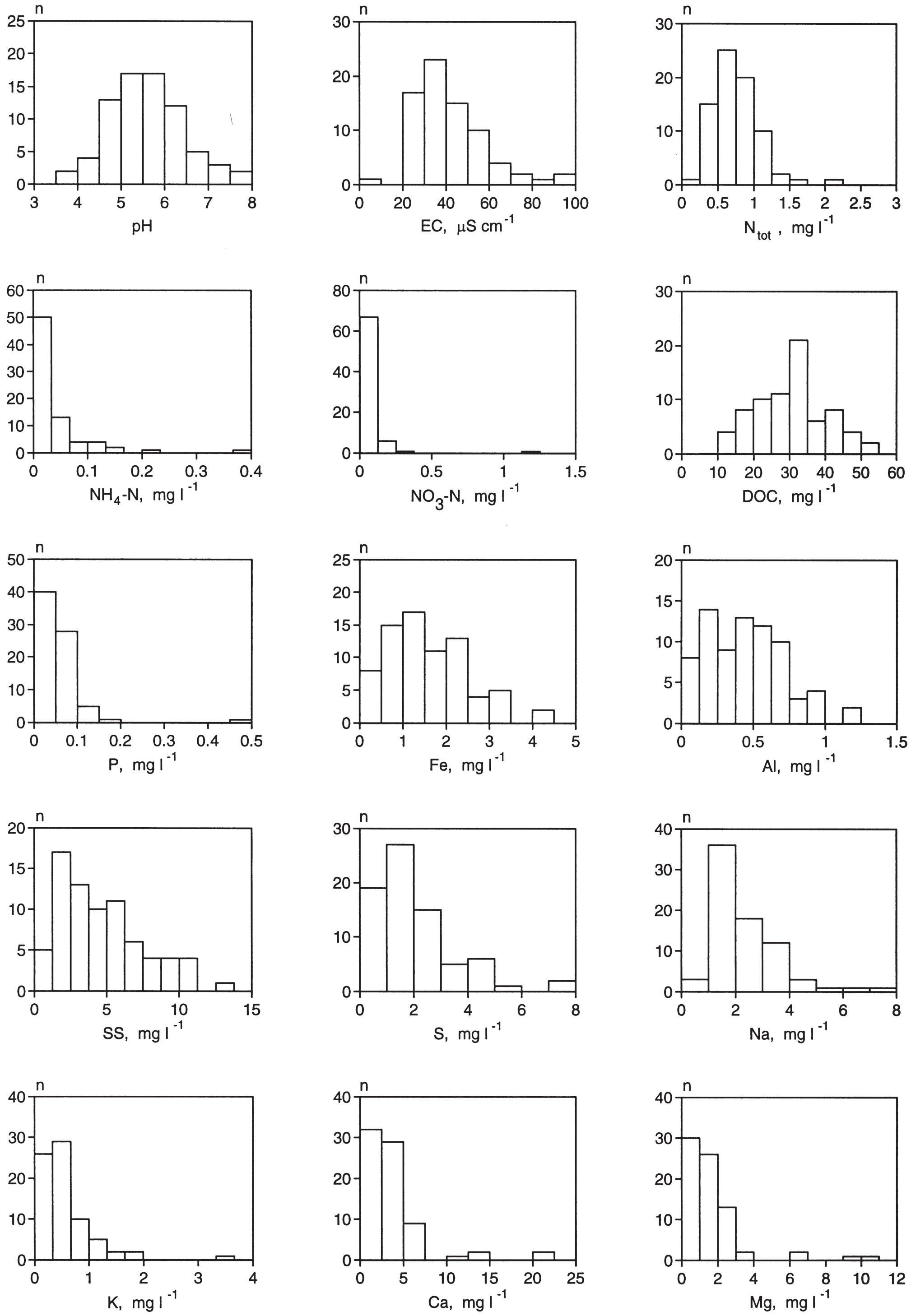

Fig. 4. Distribution of the 75 basin mean values of some water quality parameters.

Kuva 4. Tutkimuksessa seurattujen 75 vanhan ojaston vedenlaatutunnusten keskiarvojen jakaumat.

tions (Table 5).

The average pH-value of all samples was 5.61, and the site mean value varied from 3.89 to 7.63. Using H^+-concentration instead of sample pH, a mean pH value as low as 4.80 was arrived at. The site mean pH values were normally distributed. The average pH value was at its lowest in April (5.08) and at its highest in July (5.95) (Fig. 3).

Suspended solids

The site mean concentration of suspended solids varied from 0.91 to 13.1 mg l^{-1} and averaged 4.72 mg l^{-1} (Table 4). The median concentration of suspended solids calculated from all samples (n = 2815) was 2.40 mg l^{-1}, while the mean value is 4.90 mg l^{-1}, the difference indicated a skewed distribution (Fig. 4). The highest monthly mean concentrations of suspended solids occurred in July (7.77 mg l^{-1}) and the smallest in October (2.13 mg l^{-1}) and April (2.68 mg l^{-1}) (Fig. 3).

Base cations

Site mean concentration of sodium varied from 0.73 to 7.00 mg l^{-1}, with a mean value of 2.29 mg l^{-1}. The corresponding values for potassium were 0.12 to 3.47 mg l^{-1} and 0.58 mg l^{-1}. The site median K concentration was 0.50 mg l^{-1}. The concentration of potassium correlated positively and significantly with the concentration of nitrate nitrogen ($r = 0.75$; $p<0.001$) and the other cations.

The site mean concentration of calcium averaged 3.81 mg l^{-1} and ranged from 0.81 to 22.2 mg l^{-1}. There was a strong positive correlation between the site mean concentrations of calcium and magnesium ($r = 0.95$; $p<0.001$).

The site mean concentration of magnesium varied from 0.32 to 10.48 mg l^{-1} with a value of 1.68 mg l^{-1} and a median at 1.63 mg l^{-1}. With the exception of potassium concentrations, which did not show any seasonal trend, the concentrations of base cations were at their highest during midsummer.

Aluminum, iron and sulphur

The site mean concentration of aluminum varied from 0.04 to 1.19 mg l^{-1}, and for iron between 0.14 and 4.49 mg l^{-1}. The site mean concentrations of aluminum and iron were 0.45 mg l^{-1} and 1.60 mg l^{-1}, respectively. The mean concentration of aluminum was at its highest in April and October and that of iron in July–August.

Table 5. Pearson correlation coefficients between site mean values of some water quality parameters in runoff water from old ditch networks. SS = suspended solids, EC = electric conductivity. Statistically significant correlations ($p<0.05$; $n = 75$) marked with boldface.

Taulukko 5. Eräiden ravinteiden, kiintoaineen, pH:n, hiili-typpisuhteen, ja johtokyvyn väliset korrelaatiokertoimet vanhoilla ojitusalueilla. SS = kiintoaine, EC = sähkönjohtavuus. Tilastollisesti merkitsevät korrelaatiot ($p<0.05$; $n = 75$) merkitty lihavoidulla tekstillä.

	Ntot	NH_4-N	NO_3-N	Org N	Min N	DOC	C/N	SS	EC	pH	P	K	Na	Ca	Mg	Al	Fe	S
Ntot	1.000																	
NH_4-N	**0.267**	1.000																
NO_3-N	**0.625**	0.031	1.000															
Org N	**0.859**	0.086	0.181	1.000														
Min N	**0.673**	**0.386**	**0.934**	0.198	1.000													
DOC	**0.602**	0.039	–0.049	**0.819**	–0.031	1.000												
C/N	–0.189	–0.083	**–0.312**	–0.030	**–0.318**	**0.520**	1.000											
SS	**0.273**	0.335	0.163	0.175	**0.270**	–0.112	**–0.405**	1.000										
EC	**0.519**	0.040	**0.298**	**0.488**	**0.289**	0.337	–0.150	0.163	1.000									
pH	0.134	0.144	**0.260**	–0.024	**0.291**	**–0.436**	**–0.663**	**0.540**	0.077	1.000								
P	**0.326**	–0.012	0.001	**0.434**	–0.004	**0.404**	0.023	–0.032	**0.425**	–0.193	1.000							
K	**0.594**	0.019	**0.748**	**0.304**	**0.697**	–0.036	**–0.455**	**0.344**	**0.314**	**0.411**	0.100	1.000						
Na	**0.304**	0.092	0.167	**0.274**	0.186	–0.068	**–0.515**	**0.437**	**0.258**	0.610	–0.046	**0.523**	1.000					
Ca	**0.468**	0.068	**0.313**	**0.403**	**0.313**	0.047	**–0.433**	**0.281**	0.346	**0.653**	0.130	**0.446**	**0.470**	1.000				
Mg	**0.468**	0.018	**0.313**	**0.416**	**0.296**	0.055	**–0.438**	**0.320**	**0.345**	**0.667**	0.070	**0.479**	**0.563**	**0.952**	1.000			
Al	–0.068	**–0.276**	–0.107	0.046	–0.197	0.103	0.091	–0.224	–0.027	**–0.478**	0.053	–0.021	–0.108	**–0.358**	**–0.253**	1.000		
Fe	**0.526**	**0.380**	0.073	**0.556**	0.203	**0.368**	–0.158	**0.599**	0.155	**0.229**	0.065	**0.287**	0.473	0.220	**0.241**	–0.120	1.000	
S	**0.365**	–0.073	0.171	**0.392**	0.132	0.117	**–0.342**	0.115	**0.489**	0.117	**0.276**	0.424	**0.393**	**0.380**	**0.419**	0.216	–0.003	1.000

Aluminum concentrations were negatively correlated with pH-value ($r = 0.48$; $p<0.01$) and iron positively correlated with total nitrogen ($r = 0.52$; $p < 0.001$), organic nitrogen ($r = 0.55$; $p<0.001$) and suspended solids ($r = 0.60$; $p < 0.001$).

The mean concentration (n=2815) of S was 1.89 mg l^{-1}. The site mean concentrations (n = 75) varied between 0.50 and 7.52 mg l^{-1} and correlated positively with the concentrations of base cations ($r = 0.38–0.42$, $p < 0.001$). The highest concentrations of S were observed in spring and autumn (Fig. 3).

Relationships between basin characteristics and runoff water quality

The proportion of rich peatland site types was positively correlated with site mean total N concentration ($r = 0.28$, $p= 0.020$). Conversely, the proportion of poor peatland site types correlated negatively with N_{tot} concentration ($r = –0.45$, $p< 0.001$). No clear relationship between P concentrations and site characteristics could be detected.

Site mean pH values were positively correlated with the occurrence of herb-rich peatland site types ($r = 0.48$, $p < 0.001$) and spruce swamps ($r = 0.39$, $p < 0.001$) within the catchment. Calcium concentrations were also positively correlated with the occurrence of spruce swamps ($r = 0.42$, $p<0.001$), and the concentrations of magnesium positively correlated with the occurrence of herb-rich peatland site types ($r = 0.85$, $p< 0.001$) and spruce swamps ($r = 0.54$, $p<0.001$) within the catchment.

DISCUSSION

In order to determine discharge water quality from drained peatland areas typical for Finland we have sampled a large number of sites (75) for a relatively short period of time (1–3 years). Because of the large number of sites compared to long-term but site specific studies we were able to determine the dependence of runoff water quality on site characteristics.

The median concentrations of total N averaged 0.723 mg l^{-1} and were higher than the values reported by Kortelainen & Saukkonen (1995) and Kortelainen et al. (1997) based on 13 peatland dominated catchments. Median concentrations of mineral nitrogen (NH_4^+-N and NO_3^--N) were lower in our material. Mean concentrations of total N and NO_3^--N reported by Rekolainen (1989) fitted well within the ranges observed in our study. Mean total N concentrations in drainage water from old ditching areas (0.427–518 mg l^{-1}) observed by Kenttämies (1980, 1981) were only a little lower than the values we found, and did not differ much from total N concentrations in runoff from natural peatlands. Our total N concentration values were also similar to those reported for untreated Swedish catchments with high proportion of natural peatlands reported by Bergquist et al. (1984) and Lundin (1992), but higher (as also NO_3^--N concentrations) than reported for a study in eastern Finland, both before and after ditching (Ahtiainen 1990, Ahtiainen et al. 1995).

The concentration of phosphorus in runoff water from pristine peatlands in Finland rarely exceeds 0.02 mg l^{-1} (Kenttämies 1980). It appears that forest management increases runoff P concentrations. Median total phosphorus concentrations in this study were higher than reported by Saukkonen and Kortelainen (1995) for small, forested and peatland-dominated and forested catchments in Finland (0.028 mg l^{-1}, range 0.014–0.033 mg l^{-1}). Runoff P concentrations from six pristine catchments varied from 0.012 to 0.033 mg l^{-1} in a study reported by Ahtiainen & Huttunen (1995, 1999). After various forestry measures including ditching and clear cutting carried out in three of the catchments, the mean P concentration varied between 0.020 and 0.142 mg l^{-1} during the first three years. Rekolainen (1989) reported P concentrations in runoff water from small forest dominated catchments in Finland of 0.018 to 0.063 mg l^{-1}.

Ruskeesuo site had the highest mean phosphorus concentration (0.458 mg l^{-1}), which was almost tenfold the mean value of all site mean values. The surface peat layer at Ruskeesuo is poorly humified Sphagnum peat, which normally contains very little iron and aluminium for phosphorus retention (Nieminen & Ahti 1993, Nieminen 2000). The catchment area was fertilized with NPK in 1970, and later, in 1985, one third of it with PK. The high phosphorus concentrations we observed are therefore probably due to the fertilizations.

Fertilization of drained peatlands is known to increase the risk of phosphorus leaching to water courses (Ahti & Paarlahti 1988, Nieminen & Ahti 1993, Saura & al. 1995, Nieminen 2000). Many studies have also indicated that leaching of phosphorus after fertilization of peatlands is a long-term process (Malcolm & Cuttle 1978, Kenttämies 1981, Ahti 1983). In contrast to most other nutrients, runoff P were associated with the occurrence of poor peatland site types within the catchment. These site types are characterized by having oligotrophic *Sphagnum* peat that contain little aluminium and iron. The retention of P in peat is known to be strongly controlled by the amount of Al and Fe (Nieminen 2000). The relatively high mean and median P concentrations observed in this study is thus considered to be also partly due to the lack of retention of P applied in fertilizer. More than half of our study sites had been fertilized at least once during the two decades preceding sampling.

The concentration of dissolved organic material in the discharge water tends to increase with the proportion of peatland in the catchment (Lundin 1988, Saukkonen and Kortelainen 1995). Dissolved organic matter concentrations in runoff do not essentially differ between old ditching areas and pristine peatlands (Heikurainen et al. 1978, Kenttämies 1981, Sallantaus 1994). Laaksonen & Malin (1980, 1984) showed that DOC concentrations did not increase in the Finnish water courses during the decades of extensive peatland forestry ditching activity. In some sites, the concentrations of dissolved organic matter in stream waters have even decreased as a result of ditching operations (Hynninen 1988).

DOC concentrations in our material (site median 25.2 mg l^{-1}) was at the same level as the values of organic carbon measured by Kenttämies and Laine (1984) for drained peatlands, but somewhat higher than the concentrations of total organic carbon reported by Saukkonen and Kortelainen (1995, basin median 20.0 mg l^{-1}). However, Saukkonen and Kortelainen (1995) sampled runoff from forest streams and not from the main ditch on peatland as in our study.

Both the site mean and median concentration of suspended solids (Table 4) were similar to values reported in other studies. According to Kenttämies (1987) the concentration of suspended solids in runoff from peatlands drained 20–40 years ago was 5.08–9.24 mg l^{-1} and 3.32 to 7.78 mg l^{-1} for pristine peatlands. Saukkonen and Kortelainen (1995) reported an average median concentration value of 3.5 mg l^{-1} for catchments with a proportion of peatland cover > 35%. However, our concentrations of suspended solids were higher than those reported for natural brooks in eastern Finland (Ahtiainen 1988, 1990, Ahtiainen & Huttunen 1995).

Discharge waters from peatland catchments are more acid than those from catchments dominated by mineral soils (Rekolainen 1989, Saukkonen & Kortelainen 1995, Kortelainen & Saukkonen 1998). In our data, the site mean pH varied from 3.9 to 7.6. Our median pH value is similar to pH values reported by Heikurainen et al. (1978) and Saukkonen & Kortelainen (1995). We also found a clear seasonal pattern in pH, with highest values in July–August and lowest values in April and October. A similar seasonal pattern has been observed in the pH in natural brooks by Ahtiainen (1990).

As also found in other studies (e.g. Saukkonen & Kortelainen 1995, Kortelainen 1997), pH was positively correlated to the concentration of base cations and negatively correlated to DOC concentrations. The strong positive correlation between the concentration of base cations and the pH-value, and a negative correlation between the concentration of dissolved organic carbon and pH, were also reported by Saukkonen & Kortelainen (1995) and Kortelainen et al. (1997).

The median concentration of iron (1.9 mg l^{-1}) reported by Saukkonen and Kortelainen (1995) from 13 small catchments with a high proportion of peatlands was higher than the site median value (1.38 mg l^{-1}) in our study. Lower iron concentrations (0.7–1.0 mg l^{-1}) have been reported for Finnish catchments comprising of pristine forest land (Kortelainen et al. 1999). The concentrations of aluminum measured in pristine brook waters by Ahtiainen (1990) and in a sedge-rich peatland area in central Sweden (Lundin 1992) were lower than the site mean value in our study.

The concentrations of S observed in this study were considerably higher than the values calculated from the median SO_4 concentrations of Saukkonen & Kortelainen (1995).

With the exception of phosphorus, more nutrients seemed to leach into the ditch waters from catchments dominated by eutrophic peatland site types than from catchments dominated by oligotrophic types. The discharge waters from catchments dominated by rich sites were also less acid.

ACKNOWLEDGEMENTS

We wish to thank the staff of the Central Laboratory of the Forest Research Institute for an excellent job in performing the chemical analysis of our study and the staff of the local Forestry Centres in different parts of Finland for providing us with the major part of the information dealing with the ditch networks and for carrying out the water sampling. We also wish to thank Mr. Kauko Taimi for performing much of the field work in the planning stages of the study and Ms Inkeri Suopanki for help in processing the data. The English was revised by Dr. Michael Starr, who also contributed to the contents of the manuscript by valuable criticism.

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TIIVISTELMÄ

Vanhoilta ojitusalueilta valuvan veden ominaisuudet

Tässä työssä tarkastellaan vanhoilta ojitusalueilta valuvan veden laatua. Kirjoitus perustuu 1990-luvun alkupuolella Metsätalouden vesistöhaitat ja niiden torjunta -projektin (METVE) yhteydessä Metsätalouden kehittämiskeskus Tapion, Metsäntutkimuslaitoksen ja metsäkeskusten yhteistyönä keräämään kunnostusojituksen vaikutuksia käsittelevän tutkimuksen kalibrointivaiheen aineistoon (Ahti ym. 1995). Tutkimusaineisto käsittää 75 eri puolilla Suomea sijaitsevaa ojitusaluetta (Kuva 1, Taulukko 2). Kohteet valittiin metsäkeskusten kunnostusojitussuunnitelmakannasta siten, että muut kuin metsätaloustoimenpiteet vaikuttaisivat mahdollisimman vähän alueelta virtaavan veden laatuun.

Kaikilta alueilta otettiin vesinäytteitä metsäojitusalueen laskuojasta. Näytteenottojakson pituus vaihteli vuodesta noin kahteen ja puoleen vuoteen. Kaikkiaan analysoitiin n. 2800 vesinäytettä. Vesinäytteet otettiin yleensä viikottain. Näytteenotto pyrittiin aloittamaan keväällä mahdollisimman varhain. Kevättulvien aikana näytteitä otettiin kaksi kertaa viikossa, tulvakauden jälkeen kerran viikossa. Viikoittainen näytteenotto kesti lumentuloon ja ojien jäätymiseen saakka. Näytteet otettiin virtaavasta vedestä uoman keskikohdalta puolen litran muovipulloon.

Vesinäytteiden analyysit tehtiin Metsäntutkimuslaitoksessa yleisesti käytettävillä standardimenetelmillä (Jarva & Tervahauta 1993). Näyte suodatettiin (1,2 µm) ja suodattimeen jäänyt kiintoaine punnittiin kuivatuksen jälkeen (60 °C). Kemialliset analyysit tehtiin suodatetuista näytteistä. Kokonaisfosfori, natrium, kalium, magnesium, kalsium, rikki, alumiini ja rauta määritettiin ARL 3580 ICP plasmaemissiospektrofotometrillä (ICP). Kokonais- (N_{tot}), ammonium- (NH_4-N) ja nitraattityppi (NO_3-N) määritettiin spektrofotometrisesti Tecaton FIA-analysaattorilla. Veteen liuenneen orgaanisen aineksen määrä määritettiin aluksi kaliumpermanganaatin ($KmnO_4$) kulutuksena ja vuodesta 1992 lähtien orgaanisen hiilen määränä (DOC). Lisäksi näytteistä määritettiin pH ja sähkönjohtavuus.

Tutkimusalueiden ojien kunto kartoitettiin maastossa systemaattisella otannalla. Kartoituksessa mitattiin ojien syvyys ja leveys sekä arvioitiin niiden kunto Keltikankaan ym. (1986) käyttämää menetelmää soveltaen.

Valumaveden keskimääräiset ominaisuudet on esitetty taulukoissa 3 ja 4 sekä kuvissa 3 ja 4. Keskimääräiset kokonaistypen pitoisuudet olivat samaa suuruusluokkaa kuin muissa tutkimuksissa vanhoilta ojitusalueilta raportoidut kokonaistypen arvot. Sen sijaan kokonaisfosforipitoisuus oli korkeampi kuin aikaisemmissa tutkimuksissa on raportoitu. Liuenneen orgaanisen hiilen (DOC) ja kiintoaineen pitoisuudet sekä pH eivät oleellisesti poikenneet aikaisemmissa tutkimuksissa todetuista arvoista. Alueilta, joissa rehevät suotyypit ovat vallitsevia, huuhtoutui fosforia lukuun ottamatta enemmän ravinteita kuin karujen suotyyppien vallitsemilta alueilta. Kasvillisuudeltaan rehevien alueiden valumavesien pH oli myös korkeampi kuin karujen alueiden.

Received 11.05.2000, Accepted 31.1.2001