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The effects of peatland forest ditch maintenance on suspended solids in runoff

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In 1990–1994, the effect of peatland forest ditch maintenance on the concentration of suspended solids in runoff water was studied in Finland in 37 catchments by using a short pre-treatment period and comparing with 31 control areas. On the average, the concentrations of suspended solids were 4–5 mg l^{-1} in the control areas and in the treatment areas before ditch network maintenance. During a period of 1–3 years after maintenance, the concentration of suspended solids in the water leaving ditch network and entering sedimentation ponds averaged 45.8 mg l^{-1}. The magnitude of the increase depended on the area subjected to ditch maintenance as well as the prevailing soil type at the bottom of the ditches. Measured as 1–3 year averages, only half of the sedimentation ponds reduced the concentration of suspended solids. During the first year after ditch network maintenance, the suspended solids concentration in the water entering the sedimentation ponds averaged 71.3 mg l^{-1} and the water leaving the ponds 58.1 mg l^{-1}. In the second year, the corresponding values were 26.8 mg l^{-1} and 21.1 mg l^{-1} and in the third year, 12.8 mg l^{-1} and 12.4 mg l^{-1}, respectively.

Introduction

During the 20th century, forest drainage in Finland has transformed more than five million hectares of wetland areas into productive forest. Drainage activity reached a maximum in 1970 when 295 000 hectares were drained. Since then, the emphasis has turned from the ditching of new areas to the maintenance of existing ditch networks. Ditch cleaning and digging of supplementary ditches are the new forms of ditching activity in Finland. In 1990–94, 74 000 hectares of drained peatlands on the average were treated in such way (Statistical Yearbook of Forestry 1996).

The effects of draining pristine peatlands on runoff water quality have been studied in a number of experiments (Heikurainen *et al.* 1978, Kenttämies 1980, 1981, Seuna 1982, Hynninen and Sepponen 1983, Sallantaus and Pätilä 1983, Kenttämies and Laine 1984, Ahtiainen 1988, 1990, Ahtiainen *et al.* 1988, Ahtiainen and Huttunen 1995, Sallantaus 1986, 1988, 1995). According to many reports, an increased load of suspended solid material (also "suspended material" by Johansson (1983) and "suspended matter" by Ihme *et al.* (1991b)) is probably the most detrimental effect of initial forest drainage affecting watercourses. High loads are usually associated with the actual ditching work (Heikurainen *et al.* 1978), and even afterwards, high loads can occur during snow melt and other periods of high flow. High concentrations of suspended solids during flood flow periods have been attributed to erosion of the main ditches (Hynninen and Sepponen 1983), and to the direct erosion of bare soil surfaces during heavy rains (Heikurainen *et al.* 1978). Long-term increases in the concentrations of suspended solids have been reported by Heikurainen *et al.* (1978) and Kenttämies and Laine (1984).

In forest ditch networks, the discharge from individual drainage ditches (also called field ditches in peat mining areas; Ihme *et al.* 1991c), usually dug 30–50 meters apart, is often small and therefore erosion and the transport of solid material are low. In contrast, large amounts of water are collected by main ditches and they are therefore frequently subject to considerable erosion. The peat layer often being thinner than the depth of the main ditch, erosion of assorted mineral subsoils was a problem when draining pristine peatlands for forestry.

Only a few reports dealing with the effects of maintaining forest ditch networks on runoff water quality are available (Joensuu 1992, 1997, Ahti *et al.* 1995, Manninen 1995). It has been assumed that the changes in the quality of runoff waters in connection with initial ditching are analogous to those occuring when maintaining old ditch networks, but the magnitude of change would be smaller in the case of the latter.

The main principle of reducing the load of suspended solids to watercourses is to decrease the velocity of the water flow, and thereby increase sedimentation or filtration. In connection with ditch network maintenance, the construction of sedimentation ponds (or sedimentation basins; Ihme *et al.* 1991b) of varying size and form, bottom weirs, and various technical solutions of overland flow can be used to reduce the load of suspended solids.

Although sedimentation ponds are quite commonly used nowadays in peatland forestry, their effectiveness in reducing the concentration of suspended solids from discharge waters is not well known. More intensive and thorough studies have been carried out in peat mining areas (Aho and Kantola 1985, Selin and Koskinen 1985, Marja-Aho and Koskinen 1989, Ihme *et al.* 1991a, 1991b, 1991c, 1992, Ihme 1994). Because of the less intensive nature of peatland forestry, the sophisticated techniques used in peat mining areas can seldom be applied directly in connection with ditch network maintenance.

The main purpose of this study was to find out, how much the concentration of suspended solids in drainage water increases with ditch network maintenance. A secondary aim was to determine, how effective sedimentation ponds constructed in practical forestry are in retaining suspended solids. The effect of ditch maintenance on the load of suspended solids as well as the retention capacity of the ponds were related to catchment characteristics.

Material and methods

In order to obtain a large variation in catchment characteristics and to be able to generalize the results, 37 catchments were monitored (Fig. 1). Assuming minor changes in runoff, the main emphasis in the monitoring was concentrated to the quality of runoff water. The concentrations of suspended solids are dealt with in this paper. Control catchments were used in estimating the change in the concentration after treatments.

The pre-treatment monitoring of six pairs (treatment and control) of drained catchments started in 1990, and the remaining catchments in 1991. Some control areas were used for several treatment areas. The data of 37 treatment areas and 31 control areas from 1990 to 1994 are included in this study. Catchment size of the treatment areas varied from 26 to 217 hectares, with a mean of 83 ha (Table 1). The area subject to ditch network maintenance usually comprised most of the drained peatland area within each catchment and averaged 35 hectares.

Ditch network maintenance was performed in the first six catchments in 1991. The remaining areas were treated in 1992 and 1993, i.e. after a calibration period of one or two years. The digging operations were started by construction of the sedimentation pond in the outlet ditch of the catchment, and then continued by ditch cleaning or by supplying complementary ditches.

During the calibration period, water samples were taken from the outlet ditches of each catchment once a week during the snow-free period, usually from late April until the end of October. After construction of the sedimentation pond, samples were taken from the inlet and outlet ditch of the pond. During the digging operation and spring flood, samples were taken twice a week. The samples were taken into 0.5 l polyethene bottles directly from the ditches by sinking the bottle below the water level. Samples were not taken during dry periods with no apparent water flow. The samples were filtered through 1.0 µm glass fiber filters. The filters were dried at 60 °C and weighed for suspended solids.

After ditch network maintenance, discharge was monitored using simple 90° V-notch (Thompson) weirs. Before maintenance, the order of magnitude of discharge was estimated by measuring the height of the water level in the ditch at sampling. In 1993, most basins had been fitted with a weir. The ditch water level data was used for omitting the water samples taken during zero-discharge periods.

To estimate sediment accumulation (= original volume of the pond substracted by current volume of the pond) the volume of the ponds was determined at least twice a year and additionally before and after emptying the ponds. The settling volume was estimated from values of water depth measured at intervals of 0.5 metres along transverses two metres apart over the pond. The variation in the water level of the ponds was taken into consideration by levelling. The settling volumes given in Table 1 were observed immediately after pond construction, and comprised ca. 55% of the total volumes of the ponds.

During 1994, peat depth, peat type and the degree of decomposition (von Post's scale; e.g. Paavilainen and Päivänen (1995)) as well as the texture of mineral subsoil were determined from the ditch profiles at 50 m intervals along the main ditch and mostly at 100 m intervals along the drainage ditches. The aim was to make about 50 observation points per catchment.

Simple linear regression was calculated for the pre-treatment period using simultaneous values from each control and treatment area. With the regression equations, the future "untreated" values of suspended solids concentration were predicted for each treatment area. In addition to using average concentrations, the difference between predicted and measured values was used to indicate the change caused by ditch network maintenance.

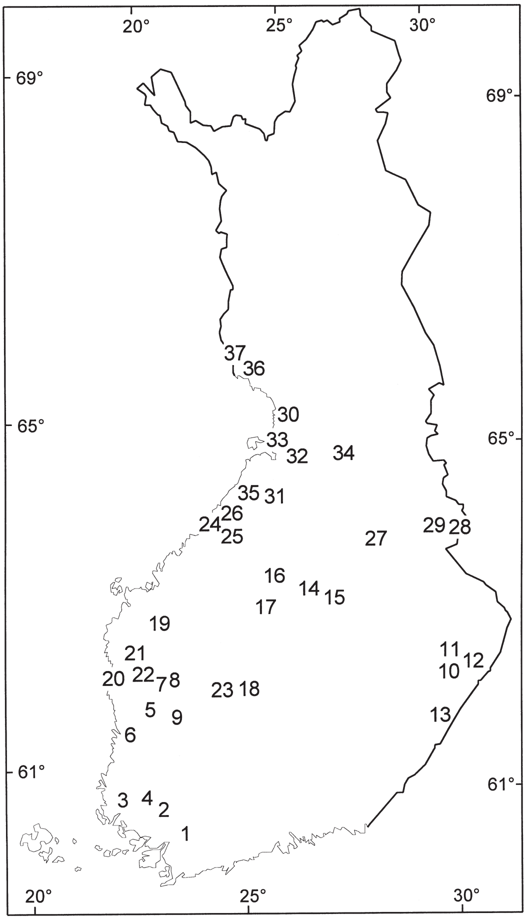

Fig. 1. Location of the study areas in Finland. The numbers indicate the areas listed in Table 1.

Monthly specific loads of suspended solids during the first year after ditch network maintenance were roughly approximated by Eq. 1:

$$\mathrm{LO}_{\mathrm{sp}} = \frac{kn\left(q_{\mathrm{t}}\mathrm{Css}_{\mathrm{t}} - q_{\mathrm{c}}\mathrm{Css}_{\mathrm{c}}\right)A_{\mathrm{maint}}}{A_{\mathrm{catch}}} \qquad (1)$$

where: $\mathrm{LO}_{\mathrm{sp}}$ = specific load (kg month^{-1} per treated hectare), $k = 0.0864$; converts mg ha^{-1} s^{-1} to kg ha^{-1} day^{-1}, n = number of days per month, q_t = average monthly runoff from the treatment areas (l s^{-1} ha^{-1}), q_c = average monthly runoff from the control areas (l s^{-1} ha^{-1}), Css_t = average monthly concentration of suspended solids in the water entering the ponds during the first year after maintenance (mg l^{-1}), Css_c = average monthly concentration of suspended solids in the control areas during the first year after maintenance (mg l^{-1}) A_{maint} = ditch maintenance area (ha), A_{catch} = catchment area (ha).

Results

Concentration of suspended material in runoff water after ditch network maintenance

The concentration of suspended solid material in runoff water increased by one order of magnitude after ditch network maintenance (Table 2, Fig. 2a). Even if the change was statistically significant judged by the standard error of mean (Table 2) and the 95% confidence interval of the mean

Table 1. General characteristics of the treatment areas.

No. of catchment	Location of catchment: name of rural district and coordinates		Catchment area (ha)	Ditch maintenance area (ha)	Reference catchment area (ha)	Pond settling volume (m^3)
1	Pertteli	60°26´N, 23°24´E	63	18	104	84
2	Pöytyä	60°42´N, 22°49´E	34	14	23	40
3	Laitila	60°49´N, 21°53´E	51	28	73	82
4	Yläne	60°49´N, 22°26´E	60	28	171	276
5	Kankaanpää	61°52´N, 22°22´E	41	19	45	105
6	Noormarkku	61°34´N, 21°55´E	136	17	27	116
7	Karvia	62°10´N, 22°39´E	30	30	51	210
8	Karvia	62°11´N, 22°46´E	81	46	51	242
9	Hämeenkyrö	61°41´N, 23°00´E	86	25	109	266
10	Pyhäselkä	62°28´N, 30°04´E	27	27	23	98
11	Pyhäselkä	62°29´N, 30°04´E	57	24	23	70
12	Kiihtelysvaara	62°25´N, 30°18´E	102	21	56	63
13	Punkaharju	61°59´N, 29°40´E	65	25	43	110
14	Pielavesi	63°20´N, 26°48´E	46	31	101	118
15	Pielavesi	63°12´N, 26°58´E	117	43	101	450
16	Pihtipudas	63°29´N, 25°24´E	161	57	106	318
17	Kinnula	63°22´N, 25°12´E	217	23	102	251
18	Keuruu	62°09´N, 24°48´E	57	16	52	98
19	Ylistaro	62°52´N, 22°27´E	149	39	120	424
20	Isojoki	62°11´N, 21°53´E	51	16	41	193
21	Kauhajoki	62°26´N, 21°59´E	148	53	57	435
22	Kauhajoki	62°15´N, 22°20´E	90	70	44	496
23	Ähtäri	62°40´N, 24°09´E	90	43	31	93
24	Kannus	64°03´N, 23°58´E	26	15	83	48
25	Kannus	64°02´N, 23°59´E	66	31	61	90
26	Kalajoki	64°07´N, 23°58´E	98	85	32	158
27	Sotkamo	63°55´N, 28°07´E	101	31	70	387
28	Kuhmo	64°01´N, 30°09´E	65	23	79	193
29	Kuhmo	64°01´N, 29°59´E	119	42	79	171
30	Yli-Ii	65°21´N, 25°40´E	52	42	116	333
31	Vihanti	64°25´N, 25°18´E	37	29	25	128
32	Oulu	64°57´N, 25°46´E	152	40	225	102
33	Oulu	64°59´N, 25°40´E	119	63	225	118
34	Utajärvi	64°55´N, 27°15´E	51	47	30	51
35	Pyhäjoki	64°26´N, 24°35´E	53	50	58	127
36	Keminmaa	65°55´N, 24°55´E	145	59	78	323
37	Tornio	66°00´N, 24°17´E	30	22	26	160

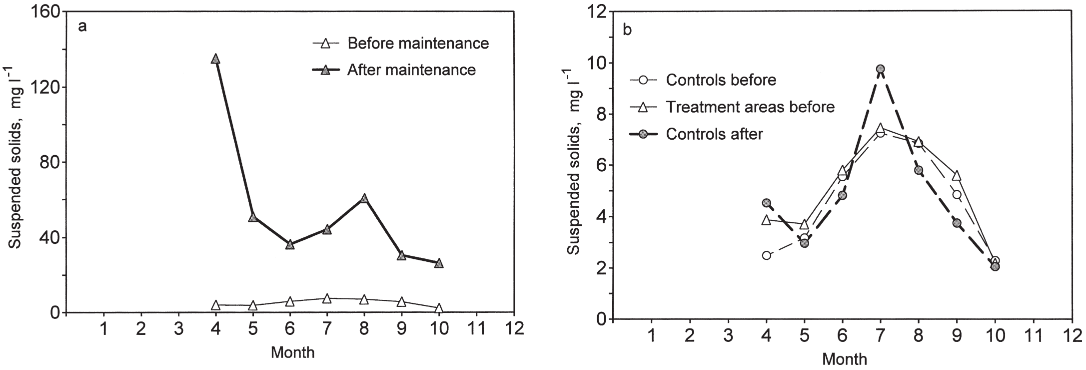

Fig. 2. — a: Mean monthly concentrations of suspended solids in the discharge water before and after ditch network maintenance in 37 catchment areas. — b: Mean monthly concentrations of suspended solids for the control and treatment areas during the pre-treatment period, and for the control areas, also after the treatments. The data of 31 control areas and 37 treatment areas are included.

(Fig. 2a), a large variation in time is revealed by the standard deviation (SD; Table 2). Since the monthly concentrations of the control areas did not differ much from the concentrations of the treatment areas during the pre-treatment period (Table 2), they are presented separately on a larger scale (Fig. 2b). The highest average concentrations of the treatment areas were observed during the first snow melt period following the digging operations (Fig. 3). The variation of the mean concentrations of suspended solids between individual catchments was large (Fig. 4). Obviously, the large standard deviations of Table 2 are due to a large variation both in time and between sites. The median (Md), being much smaller than the mean, as well as the first (Q_1) and the third quartiles (Q_3) show that the values of suspended solids concentration are not normally distributed but strongly

Table 2. Average concentrations of suspended solids ($\bar{x}$, mg l^{-1}) in all runoff samples from 31 control areas and 37 treatment areas in 1990–1994. Number of samples (n), standard deviation (S.D.), standard error of mean ($s_{\bar{x}}$), maximum ($x_{\max}$) values, median (Md), pseudostandard error of median (S.E.) proposed by J. W. Tukey (Dixon *et al.* 1990), first quartile (Q_1), third quartile (Q_3), and the 90% percentile (P_{90}) are included. Because of different years of treatment, the values of the second and the third year after ditch network maintenance include data from a smaller number of catchments than the values from the first year after maintenance.

Period	n	$\bar{x}$	S.D.	$s_{\bar{x}}$	$x_{\max}$	Md	S.E.	Q_1	Q_3	P_{90}
Control areas, pre-tr. period	1123	4.63	6.48	0.193	80.0	2.40	0.173	0.80	6.10	11.1
Control areas, after maint.	1626	4.46	6.40	0.159	55.0	2.10	0.058	0.80	5.33	11.5
Treatm. areas, pre-tr. period	1321	5.04	7.53	0.207	99.2	2.60	0.173	0.80	6.40	12.8
Treatment areas, after maint.										
— first year, entering pond	1189	71.29	251.2	7.29	4914	12.3	0.635	5.50	39.8	139
— first year, leaving pond	1185	58.13	178.6	5.19	3643	11.5	0.433	5.65	37.5	114
— second year, entering pond	848	26.75	77.5	2.66	1248	8.20	0.375	4.20	19.1	49.1
— second year, leaving pond	846	21.09	56.4	1.94	675	8.10	0.375	4.20	16.0	38.3
— third year, entering pond	394	12.84	24.1	1.22	281	7.70	0.548	3.60	13.0	21.9
— third year, leaving pond	394	12.41	23.1	1.16	271	8.10	0.433	3.80	13.1	22.7
— all samples, entering pond	2463	45.82	182.3	3.67	4914	9.60	0.260	4.70	24.0	75.0
— all samples, leaving pond	2457	37.42	130.2	2.63	3643	9.40	0.346	4.80	22.9	66.5

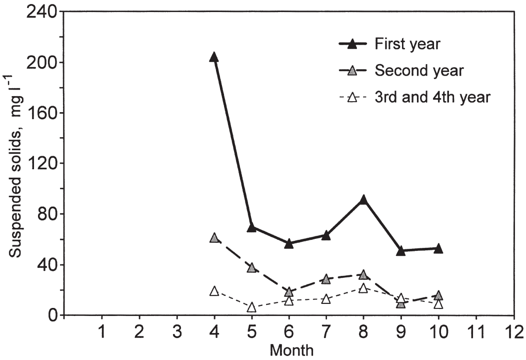

Fig. 3. Mean monthly concentration of suspended solids in different years after ditch network maintenance (37 catchments included). The data from the third and fourth year are merged.

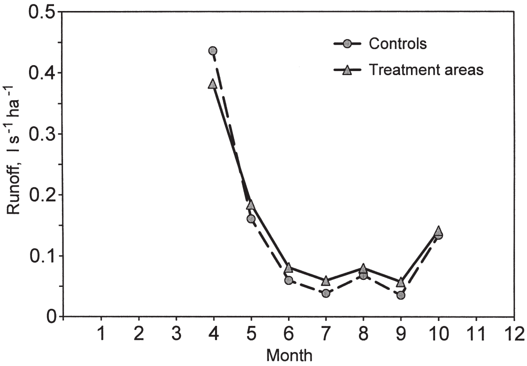

Fig. 5. Mean monthly runoff during the treatment period. The data of 26 control areas and 33 treatment areas are included.

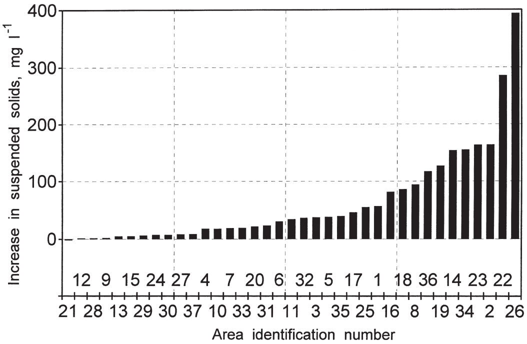

Fig. 4. The increase in the concentration of suspended solids after ditch network maintenance in 37 catchments. Area identification number refers to Fig. 1 and Table 1.

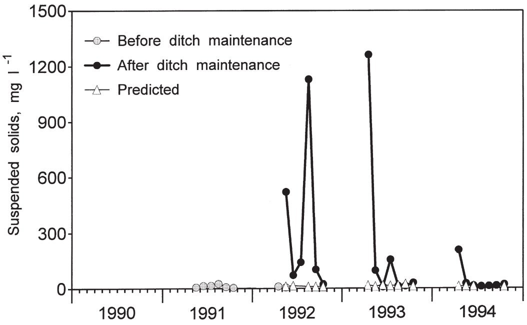

Fig. 6. The effect of ditch maintenance on the suspended solid concentration in the Kalajoki catchment 26 with sand as the predominant subsoil.

dominated by low concentrations.

In the control areas, the highest concentrations of suspended solids were observed in July and August (Fig. 2b). In general, the effect of ditch network maintenance clearly decreased after the first year, but was still conspicuous during the second year. Considering that the digging operations were performed in June in almost half of the areas, the mean concentration of suspended solids has remained unexpectedly low during that month (Fig. 3).

The monthly average runoff pattern of the treatment areas did not differ much from the control areas after treatment (Fig. 5). The mean runoff from the end of April to the end of October for 33 of the treatment areas during the whole post-treatment period corresponded to 193 mm of precipitation.

Examples on three main types of effects of ditch network maintenance are displayed in Figs. 6–8. In areas with coarse-textured subsoils, increased concentrations of suspended solids were detected during the digging operation or immediately after it, and during high flow periods in general (Fig. 6). In catchments with fine-textured (clay and silt) subsoils, the concentrations of suspended solid materials were almost constantly higher after ditch maintenance (Fig. 7). In areas dominated by poorly decomposed deep peat or with compact till as subsoil, the increase in the concentration of suspended solids was usually small (Fig. 8).

There was a statistically significant, positive correlation between the concentration of suspended solids in the runoff water entering the ponds and the total length of maintained ditches.

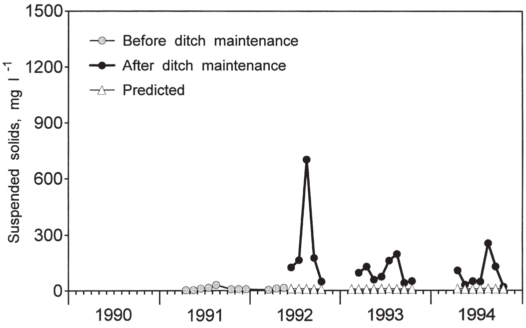

Fig. 7. The effect of ditch maintenance on the suspended solids load in the Pöytyä catchment 2 with clay as the predominant subsoil.

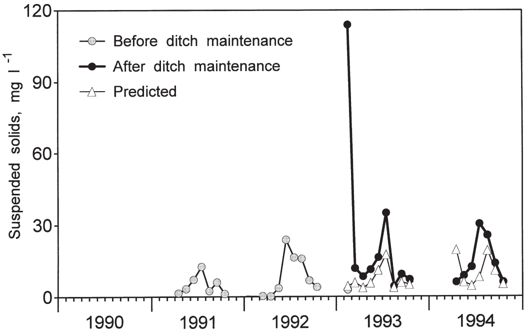

Fig. 8. The effect of ditch maintenance on the suspended solids load in the Yläne catchment 4 with undecomposed peat as the predominant soil type.

Also, the concentration of suspended solids was connected to the subsoil chararcteristics. Combining length of ditches maintained and subsoil texture into four independent variables, the following regression equation can be derived:

$$\mathrm{Css} = 26.1L_{\mathrm{ft}} + 8.73L_{\mathrm{mt}} + 4.98L_{\mathrm{ct}} + 2.97L_{\mathrm{p}} - 14.4 \qquad (2)$$
$$(R^2 = 0.49, F = 7.678)$$

where: Css = mean concentration of suspended solids after ditch network maintenance (mg l^{-1}), L_{ft} = total length of the ditches dug into fine-textured subsoil within each catchment, km ($p < 0.001$), L_{mt} = total length of the ditches dug into medium-textured subsoil, km ($p < 0.001$), L_{ct} = total length of the ditches dug into coarse-textured subsoil, km ($p = 0.042$), L_{p} = total length of the ditches dug into deep peat, km ($p = 0.212$).

Catchment size, average discharge and slope of main ditch were less significant than L_{p}.

The effect of ditch network maintenance on load of suspended solids

The concentration of suspended solids was considerably higher during the first year after ditch network maintenance than during the following years (Fig. 3). Using average monthly values of runoff and the first year concentrations of suspended solids, rough approximations of suspended matter loads and specific loads were obtained (Table 3).

Table 3. Approximated monthly loads (LO) of suspended solids during the first year after ditch network maintenance (t = treatment, c = control). Specific load ($\mathrm{LO_{sp}}$) refers to the increase in load per treated hectare. Css = average monthly concentration of suspended solids during the first year after treatment.

	Treatment areas				Control areas		
Month	q_{t} ($\mathrm{l\ s^{-1}ha^{-1}}$)	$\mathrm{Css_t}$ ($\mathrm{mg\ l^{-1}}$)	$\mathrm{LO_t}$ ($\mathrm{kg\ ha^{-1}}$)	$\mathrm{LO_{sp}}$ ($\mathrm{kg\ ha^{-1}}$)	q_{c} ($\mathrm{l\ s^{-1}ha^{-1}}$)	$\mathrm{Css_c}$ ($\mathrm{mg\ l^{-1}}$)	$\mathrm{LO_c}$ ($\mathrm{kg\ ha^{-1}}$)
April	0.382	204.6	67.5*	156.5	0.436	4.02	1.51
May	0.184	69.8	34.4	78.1	0.161	3.39	1.46
June	0.081	57.0	12.0	26.3	0.059	5.90	0.90
July	0.059	63.4	10.0	21.4	0.038	9.63	0.98
August	0.079	91.4	19.3	43.7	0.068	4.75	0.87
September	0.057	51.3	7.6	17.4	0.035	2.88	0.26
October	0.141	53.2	20.1	45.9	0.134	2.11	0.76
Total			170.9	389.3			6.74

* 10 last days of April included

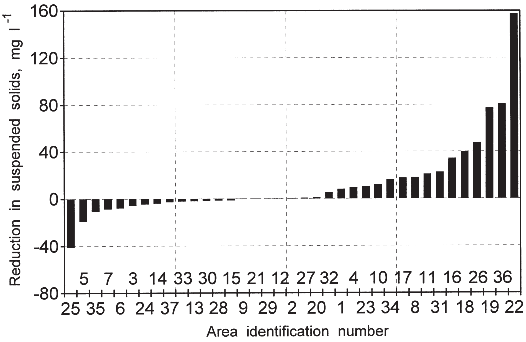

Fig. 9. The distribution of the reduction in the concentration of suspended solids by the sedimentation ponds (37 areas included). Area identification number refers to Fig. 1 and Table 1.

The effects of sedimentation ponds

Reduction in the concentration of suspended solids

During the first year after maintenance the concentrations of suspended solids were reduced by the sedimentation pond in 20 areas and increased in 17 areas (Fig. 9). Averaged over the 37 catchment means of the treated areas, the concentration decreased from 68.7 mg l^{-1} to 56.1 mg l^{-1} (18.3%). For the 17 ponds showing an increase, the concentration increased from 30.0 to 36.6 mg l^{-1} on the average. In the 20 areas, where the concentration was reduced by the pond, the average concentration decreased from 101.5 to 72.6 mg l^{-1} (28.4%).

For 18 catchments out of the 37, the mean concentration of suspended solids in the water entering the pond exceeded 40 mg l^{-1} during the first year after maintenance. Within these 18 catchments, with an average input concentration of 123.2 mg l^{-1}, the pond reduced the concentration of suspended solids by 24 mg l^{-1} on the average. However, the variation within this group of catchments was large: from an increase in suspended solids concentration by 41.2 mg l^{-1} to a reduction of 157 mg l^{-1}.

The efficiency of some ponds was poor during the first year due to the collapse of the pond walls. During the second year, the pond walls stabilized and the sedimentation efficiency increased again (Fig. 10). In most catchments with medium- and coarse-textured subsoils, the sedimentation ponds functioned satisfactorily (Fig. 11).

In catchments with fine-textured subsoils, especially clays, the effect of the ponds was negligible. In the Pöytyä study area (area 2) practically no retention of suspended solids was observed during the whole monitoring period (Fig. 12).

Sediment accumulation

The annual average accumulation of solid material correlated positively with the area of ditch network maintenance, length of ditches dug, pond volume, and concentration of suspended solid material in runoff water entering the pond. Also, the proportion of medium-textured and coarse subsoils within the area correlated positively with the annual accumulation of sediment. Although catchment area, slope of main ditch, and degree of peat decomposition were positively correlated with the annual accumulation of sediment, the coefficients were not significant. The area of ditch network maintenance and pond volume explained more than 60% of the variation in annual accumulation of solid material in the ponds (Eq. 3). When using the concentration of suspended solids in the water entering the pond (C_{in}) and the maximum runoff of the catchment ($q_{\max}$) as independent variables instead of the area of ditch maintenance, more than 80% of the variation could be explained (Eq. 4). The term with the highest F-value in Eq. 4 was C_{in}.

$$V_{\text{acc}} = -71.3 + 0.258V_{\text{pond}} + 1.999A_{\text{maint}} \quad (n = 37, R^2 = 0.633, F = 29.3^{***}) \tag{3}$$

$$V_{\text{acc}} = -66.1 + 0.266V_{\text{pond}} + 0.849C_{\text{in}} + 0.204q_{\max} \quad (n = 26, R^2 = 0.803, F = 29.8^{***}) \tag{4}$$

where: V_{acc} = annual sediment accumulation, average for several years (m^3 yr^{-1}), V_{pond} = original volume of pond (m^3), A_{maint} = area of ditch maintenance (ha), C_{in} = concentration of suspended solids entering the pond (mg l^{-1}), $q_{\max}$ = maximum runoff (l s^{-1} ha^{-1}).

In about 25% of the ponds, only a few cubic

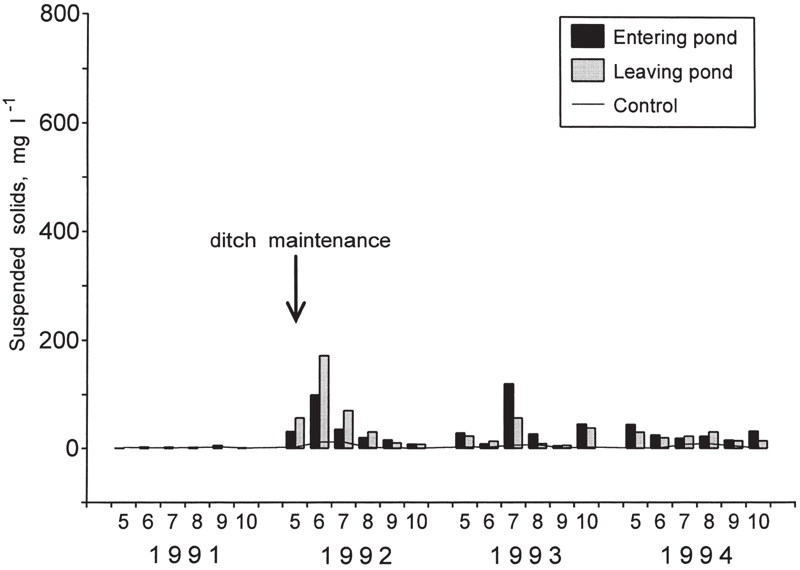

Fig. 10. The effect of the sedimentation pond on the concentration of suspended solids in one of the Karvia catchments (Nr. 8).

meters of sediment were accumulated per year. In contrast, about 20% of the ponds were half filled with sediments after one year and, depending on the year, some ponds were completely filled and required emptying. The pond inlet and outlet difference in suspended solid concentration correlated positively ($r = 0.7$) with the amount of sediment that had accumulated in the ponds annually. Because runoff was measured only during the snow-free period, it was not possible to estimate annual accumulation of sediment on the basis of the difference between inlet and outlet samples. Probably, part of the coarse-textured material that was transported along the bottom of the ditches was not fully represented in the samples.

Discussion

Since ditch network maintenance does not influence runoff, especially the runoff peaks much (Ahti *et al.* 1995, Manninen 1995), the changes observed in the suspended solids load were mainly due to changes in concentration.

Because of the large number of catchments in our study, we regard the average concentrations presented in Table 2 as representative for ditch network maintenance in Finland. Even if high concentrations occurred during the actual digging operation, which usually lasted several weeks, these periods of high concentration were probably so short that they were not to be seen in the averaged data as clearly as the high concentrations during the first spring maximum flow after ditch network maintenance.

The increase in the concentration of suspended solids after ditch network maintenance found in this study resembled the values reported by Ahtiainen *et al. (1990)* for initial ditching. The concentrations of suspended solids prior to ditch network maintenance were close to those reported for pristine peatlands by both Ahtiainen *et al.* (1990) and Seuna (1982). The discharge of suspended solids from a catchment of 5 600 hectares in northern Finland, of which 17% was drained for forestry, increased by 62–105 kg ha^{-1} yr^{-1}, which corresponds to a specific load of 365–618 kg ha^{-1} yr^{-1} (Seuna 1982). In a separate experiment in the same area, the discharge of suspended solids was as much as 2 300 kg ha^{-1} during the first spring flood after ditching.

Hynninen and Sepponen (1983) studied the effects of initial ditching in brooks and tributories of river Kiiminkijoki in northern Ostrobothnia. High concentrations and loads of suspended solids were detected in part of the brooks, but in most cases, the changes were short-lived. In the case of Syväoja brook, with a catchment of 11.6 km^2 out of which 41% was drained in 1973, high concentrations of suspended solids were still observed

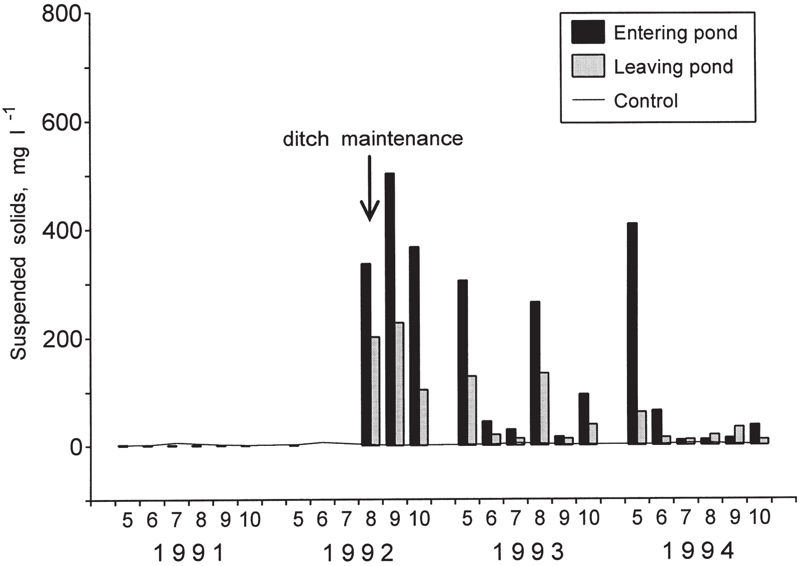

Fig. 11. The effect of the sedimentation pond on the concentration of suspended solids in one of the Kauhajoki catchments (Nr. 22), typical of medium- and coarse texture subsoils.

during the rainy summer of 1974: the mean concentration was as high as 395 mg l^{-1}. Even higher concentrations between 378 and 647 mg l^{-1} were observed during the first spring flow after ditching in 1973 (Hynninen and Sepponen 1983).

As a whole, the changes in the concentration of suspended solids in runoff water after ditch network maintenance appear to be of the same order of magnitude and duration as after ditching of pristine peatlands. The average concentrations of suspended solids from peat mining areas appear to be of the same order of magnitude as in runoff waters from peatland forests during the first year after ditch network maintenance (Selin and Koskinen 1985, Ihme *et al.* 1991a, 1991b, 1991c, Ihme 1994). However, in peatland forests the high concentrations of suspended solids are likely to decline in a few years, as in peat mining areas, high concentrations will probably occur as long as the mining activity continues. It is probable, also, that a greater part of the suspended material is of mineral origin in the runoff water coming from peatland forests than from peat mining areas.

Even if the arithmethic means of suspended solids concentrations instead of averages weighted by discharge (e.g. Ahtiainen *et al.* 1990) were used in this study, both the concentrations and the approximated loads of suspended solids for the control areas appear to be of the same order of magnitude as prior to ditching in the catchments of Ahtiainen *et al.* (1990). Consequently, we consider the rough load estimates in Table 3 to be of the right order of magnitude. The effect of using mean concentrations weighted by discharge for each observation remains to be demonstrated by a detailed analysis of individual catchments.

The efficiency of sedimentation ponds in reducing the concentration of suspended solids in sites used for peat mining (Selin and Koskinen 1985, Ihme *et al.* 1991b) have varied both between sites and in time. Ihme *et al.* (1991b) reported a variation range from an annual increase of 216% to an annual reduction of 73% by different sedimentation ponds in different years in Kurunneva peat mining area, Central Finland.

In Ireland, the effectiveness of sedimentation ponds to retain suspended solid materials originating from peat mining areas has been monitored for a considerable period of time (Hannon and Coffey 1984, Wynne 1992). According to the results of these studies, correctly sized sedimentation ponds are capable of retaining over 90% of the solid material entering the pond. As in this study, the retaining capacity of the ponds appears to increase with increasing concentration of suspended solids. At low concentrations, especially in areas with undecomposed peat, the concentration of suspended solid material in the water leaving the pond was greater than that of the water entering it.

In this study, ca. 60% of the annual accumula-

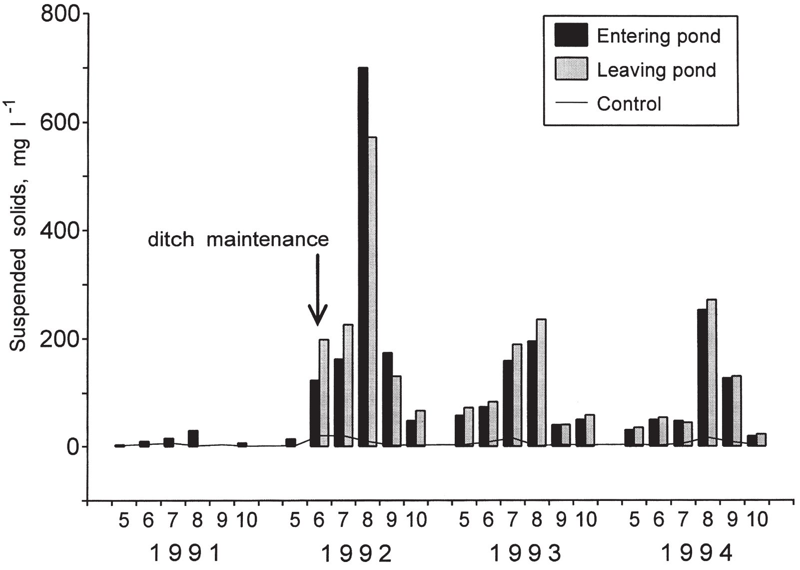

Fig. 12. The effect of the sedimentation pond on the concentration of suspended solids in the Pöytyä catchment 2 with predominant subsoil of clay.

tion of suspended solids could be explained by pond volume and area of ditch network maintenance. The significant positive correlation found between average annual accumulation of sediments and pond size indicates that our ponds were too small on the average.

Since the maximum discharge is largely determined by basin area and erosion is determined by the discharge, it was expected that the suspended solids concentration after ditch network maintenance would be closely related to total catchment area. However, ditch network maintenance area was more closely related to both the concentration of suspended solids in the runoff water and to sediment accumulation than the total area of the catchment. This might be connected to some other catchment characteristics influencing maximum discharge than catchment area. It might also imply the existence of errors in determining the catchment area or measuring runoff.

Because the peat layer subsides after ditching, and due to enhanced decomposition, the future risks of erosion may even be greater in connection with ditch network maintenance than with the initial operation. This further emphasizes the importance of water protection.

We have shown how much the load of suspended solids caused by ditch network maintenance can be reduced by using sedimentation ponds sized and constructed according to the guidelines for water protection applied in Finland in 1992. In areas with fine-textured subsoils, methods of water protection other than sedimentation ponds should be used.

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