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INFLUENCE OF SUB-DRAINAGE ON WATER QUANTITY AND QUALITY IN A CULTIVATED AREA IN FINLAND

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In this study the effects of sub-drainage on the quantity and quality of runoff are described. A control basin method was used. A small cultivated area, 12 ha, was changed from open ditches to sub-drains in 1971, as a result of which surface runoff decreased for the most part. Notable surface runoff was observed only during the spring flood, and especially when soil frost was deep. The average annual surface runoff was 23 per cent of the total runoff. Due to sub-drainage the following changes in average total runoff could be calculated: mean annual runoff +0.91 l s^{-1} km^{-2} or 15.1 per cent for the calendar year, +1.06 l s^{-1} km^{-2} or 18.2 per cent for the hydrological year; spring runoff + 15 mm or 12 per cent; spring maximum runoff —9 l s^{-1} km^{-2} or 4 per cent; summer maximum runoff —27 l s^{-1} km^{-2} or 36 per cent; 30 days winter minimum runoff + 0.11 l s^{-1} km^{-2} or 160 per cent and 30 days summer minimum runoff + 0.04 l s^{-1} km^{-2}. Some evidence of the compacting of the soil was noticed during the post-treatment period. This probably corresponds with the sites dug for sub-drains. Total nitrogen and nitrate nitrogen concentrations increased after sub-drainage: before sub-drainage annual means of total nitrogen concentrations varied from 1.4 to 3.6 mg l^{-1} and of nitrate nitrogen from 0.68 to 1.7 mg l^{-1}, whereas after sub-drainage the variation was from 4.9 to 20 mg l^{-1} and from 2.0 to 17 mg l^{-1}, respectively. Increase in annual loads varied from 150 to 2300 kg km^{-2} $year^{-1}$ or from 52 to 410 per cent for total nitrogen. For nitrate nitrogen the relative increase was even greater: from 170 to 2400 kg km^{-2} $year^{-1}$ or from 106 to 840 per cent. For phosphorus no clear effect of sub-drainage was observed.

Index words: hydrological effects, water quality changes, sub-drainage

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1. INTRODUCTION

This study discusses the influence of sub-drainage on the quantity and quality of runoff. In this connection the term sub-drainage is used as an opposite to open ditches. By sub-drainage an underground network in a cultivated area is meant, consisting in general of tile or plastic pipes at a depth of about 1 m. Both sub-drainage and open-ditching are in common use in Finland. At present 800 000 ha or 32 per cent of farmland are sub-drained and the annual changeover from open-ditched to sub-drained farmland is 35 000 ha. Until 2000 the total area sub-drained is planned to be 1.8 mill.ha, i.e. 70 % of the total cultivated area.

2. METHOD

The effects of sub-drainage were studied using the control basin method. In this method the research basins are kept in their natural state during a calibration period, after which the experimental basin is treated in the manner to be investigated (= sub-drained) and the other basin is kept in its natural state as a control basin for the entire study period. Regression equations are computed for the desired quantities between the treatment and control basins for the calibration period. These equations are used after the treatment for the computation of what the runoff or quality parameter of the treated basin would have been if the treatment had not been carried out. The difference between the observed and computed value indicates the change caused by sub-drainage, if no other treatments were given.

In this investigation trends in the runoff changes during the treatment period were also studied, in most cases after purifying the raw trends. Purification was performed by subtracting the influence of runoff magnitude from the changes using regression analysis. In some cases, where the change did not correlate with runoff magnitude, unpurified trends were calculated.

Runoff quantities studied were mean annual, snowmelt period, spring and summer maximum, winter and summer minimum runoffs. Quality parameters considered in this investigation were total nitrogen, nitrate nitrogen and total phosphorus. Quality analyses were carried out using standard methods (Erkomaa et al. 1977).

The monthly nutrient loads were calculated by multiplying concentrations by the mean runoff of the month. Monthly loads were then summed to obtain the annual load.

The control basin method could not be used for concentrations because of weak correlations between the concentrations in the basins. The differences in concentrations between the basins were therefore tested for the calibration and treatment periods separately. Increases in differences represented the effect of sub-drainage.

3. BASINS AND TREATMENTS

This study was started in 1953 when measuring weirs were built and various hydrological observations were begun in two adjacent basins in southern Finland (60° N, 24° E). Water quality observations were started in 1966, since when water samples have been taken at monthly intervals from the overflow of the measuring weirs and analysed. The experimental basin, Hovi, was entirely open-ditched cultivated land, while the control basin, Ali-Knuutila, was composed of 48 per cent open-ditched cultivated land and 42 per cent forest (Fig. 1, Tables 1 and 2), (Mustonen 1963).

The growing stock of the Ali-Knuutila basin was 114 m^3 ha^{-1} in the forest area corresponding the regional mean of the country. The soil at the Hovi basin is for a notable part heavy clay and heavy clay dominates in the cultivated part of the Ali-Knuutila basin as well. In the forest area of the Ali-Knuutila basin sand moraine prevails.

There is a climatic station about 2 km from the research plots. Measurements of snow cover and soil frost were performed on the research basins.

As indicated in Tables 1 and 2 there are differences between the experimental (Hovi) and control (Ali-Knuutila) basins. The cultivated areas of the basins were originally of much the same nature, but the forest area of the control basin causes certain differences. These do not, however, create serious disadvantages, as can be confirmed by the fairly close correlations found between the quantities of the experimental and control basin during the calibration period.

In 1971 the Hovi basin was sub-drained (Fig. 2). Drainage density was 443 m ha^{-1} and drainage was performed using 55 mm plastic tubes as minor drains and 100 mm steel and plastic tubes as main drains. By building low embankments the watershed was kept unchanged. This was repeated every autumn in connection with the ploughing. After sub-drainage surface runoff and runoff from the sub-drains could be measured separately by weirs.

The calibration period was in general 1953—1970 for water quantity parameters and the treatment period mostly 1972—1979. For water quality the calibration period was 1966—1970 and the treatment period 1972—1978.

Climatic conditions varied considerably in both periods (Table 3). The treatment period was on average slightly warmer and drier than the calibration period but these differences were not statistically significant.

4. INFLUENCE OF SUB-DRAINAGE ON RUNOFF

4.1 Distribution of runoff

The variations of different runoff quantities before

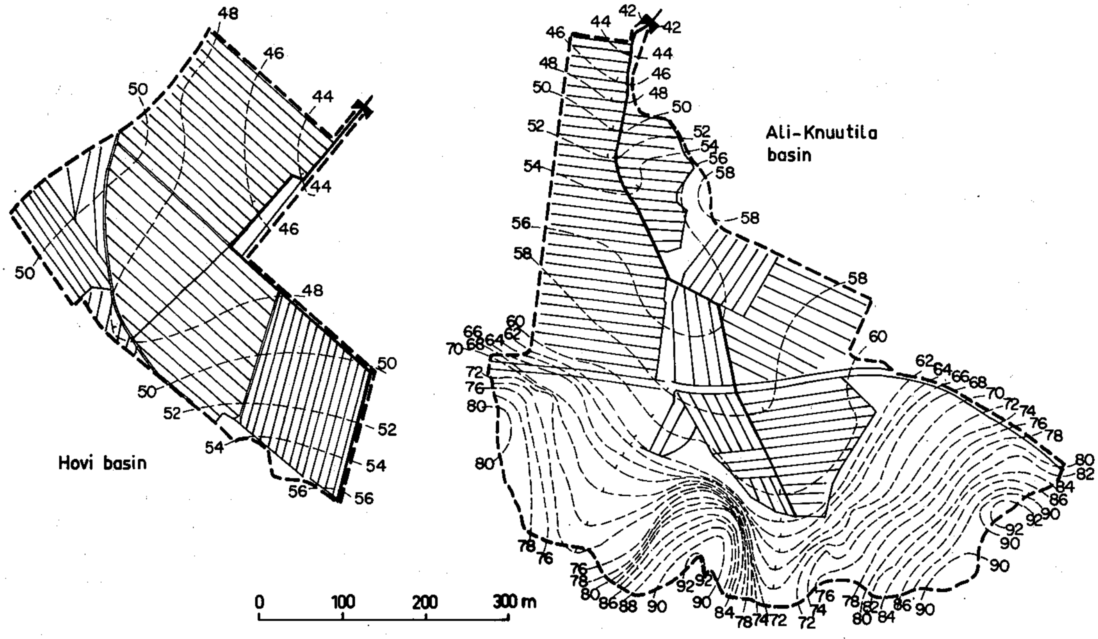

Fig. 1. Hovi and Ali-Knuutila research basins. Hovi = the treatment basin, Ali-Knuutila = the control basin.

Table 1. Physiographic characteristics of the research basins (Mustonen 1963).

Basin	Area (ha)	Cultivated land (%)	Forest (%)	Building, site, pasture, road (%)	Mean slope (%)	Drainage density (m ha^{-1})
Hovi	12.0	100	0	0	2.8	920
Ali Knuutila	24.6	48	42	10	10.0*	454†

* Cultivated land 3.9 per cent, forest 16.0 per cent.
† Cultivated land 950 m ha^{-1} of open ditch, forest unditched.

Table 2. Distribution of soil types in the research basins (%).

Basin	Graded soils				Moraines			
	Clay	Silt	Sand	Gravel	Clay	Silt	Sand	Gravel
Hovi	55	43	2	0	0	0	0	0
Ali-Knuutila	23	24	5	1	2	8	27	10

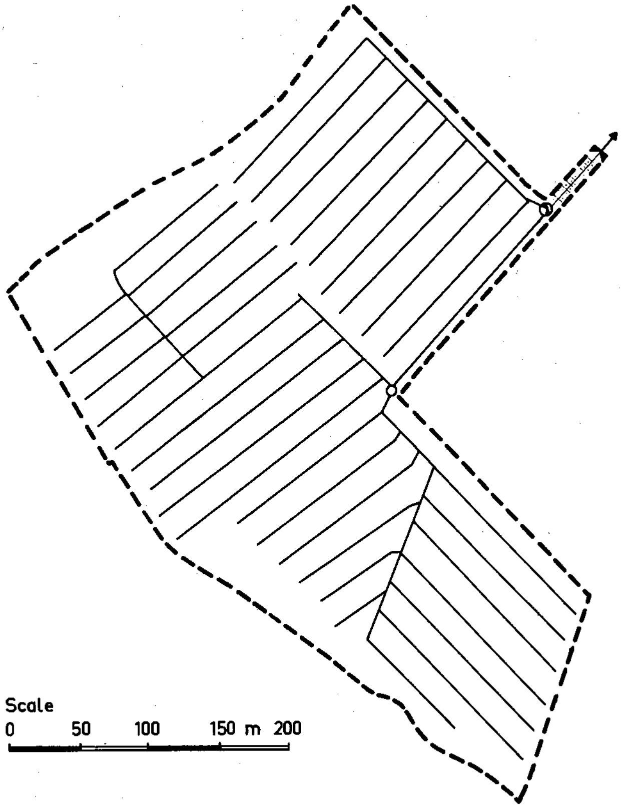

Fig. 2. Sub-drainage network of the Hovi basin.

Table 3. Precipitation (mm) and air temperature (°C) at the research basins.

	1953—1970		1972—1979	
	Range	Mean	Range	Mean
Mean annual air temperature	+ 2.2 to + 5.5	+ 3.7	+ 2.5 to + 5.8	+ 4.1
Annual precipitation	448 to 836	626	467 to 701	573
Mean February temperature	— 0.9 to — 15.2	— 9.1	— 0.3 to — 13.2	— 7.0
Mean July temperature	13.7 to 17.4	15.9	14.3 to 19.3	16.2

and after the sub-drainage are given in Tables 4—7. After drainage surface runoff decreased considerably, of course. Of the total annual runoff 77 per cent came from sub-drains and only 23 per cent from surface runoff, on average, in 1972—78. During the snowmelt period (1 March -31 May) 59 per cent of the total runoff came from sub-drains, on average. Runoff from sub-drains averaged 56 per cent of the total spring maximum runoff and 98 per cent of the summer maximum runoff (Figs. 3—5), although the soil is very clayey. During the instantaneous maximum the runoff from sub-drains averaged 38 % in spring and 97 % in summer of the total instantaneous maximum.

The instantaneous spring maximum runoff (total) of the treatment basin was 110 % higher than the average daily maximum in the calibration period. For the post-treatment period this figure was 120 %. For summer the percentages were 225 % and 130 %, respectively.

Table 4. Mean annual runoff Mq and Mq_h (1.1.—31.12 and 1.11.—31.10 resp.) and spring runoff q_w (1.3.—31.5.). H = Hovi, sum of surface and sub-surface runoff from the treatment basin; A = Ali-Knuutila, the control basin; H_{sub} = runoff from sub-drains of the treatment basin.

Year	Mq ($l\ s^{-1}\ km^{-2}$)			Mq_h ($l\ s^{-1}\ km^{-2}$)			q_w (mm)		
	H	A	H_{sub}	H	A	H_{sub}	H	A	H_{sub}
1953	7.27	6.98					141	132	
1954	9.78	8.79		6.77	6.01		104	89	
1955	6.42	7.44		9.31	9.38		162	152	
1956	10.51	8.60		9.86	9.37		238	191	
1957	11.07	11.88		10.47	10.48		147	166	
1958	3.64	4.59		5.69	6.45		107	117	
1959	6.44	5.84		6.52	6.07		198	174	
1960	5.88	7.60		3.72	4.93		106	126	
1961	4.30	6.05		5.04	7.55		61	92	
1962	12.97	13.47		12.29	12.06		182	177	
1963	6.24	6.12		7.35	7.57		101	88	
1964	6.47	5.06		5.20	4.16		127	82	
1965	3.27	4.14		4.88	5.46		64	75	
1966	8.53	9.78		7.39	8.86		206	243	
1967	10.09	10.69		11.13	11.20		199	199	
1968	8.46	9.11		7.93	8.97		177	183	
1969	7.11	7.29		6.10	6.37		139	141	
1970	9.26	10.45		9.58	9.73		204	201	
1971	5.68	4.91		7.46	7.82		115	103	
1972	6.87	7.24	5.61	4.94	5.21	3.40	133	127	100
1973	3.90	3.56	3.79	5.50	5.22	5.23	85	65	81
1974	12.67	12.00	12.05	7.08	6.96	6.59	151	137	136
1975	3.81	4.20	3.77	9.94	9.43	9.81	59	68	58
1976	6.19	3.32	1.90	5.13	3.06	0.86	158	83	24
1977	9.43	8.26	8.34	7.79	6.53	6.88	178	151	155
1978	5.80	5.35	2.19	7.80	6.97	3.98	138	117	29
1979							153	156	42
M 1953—1971	7.65$^{1)}$	7.99$^{1)}$		7.60$^{1)}$	7.92$^{1)}$		146	144	
M 1972—1979	6.95$^{2)}$	6.28$^{2)}$	5.38$^{2)}$	6.88$^{2)}$	6.20$^{2)}$	5.25$^{2)}$	132	113	78

1) 1953—1970
2) 1972—1978

During springs with deep soil frost (1972, 1976, 1978 and 1979) the percentage of surface runoff was greater than the average, as would be expected. The structure of soil frost obviously had an effect on the distribution of runoff. In the years 1973 and 1975, when the upper layer of soil frost had already melted until the spring maximum runoff the percentage of surface runoff was extremely small, although the total depth of the soil frost was still considerable (Figs. 4 and 6). The relationship between runoff from sub-drains RS ($l\ s^{-1}\ km^{-2}$) and frost depth FD (cm) was $RS = -2.01\ FD + 170$, $R = -0.857$. This means that with no soil frost, spring maximum runoff from sub-drains in this area would be about 170 $l\ s^{-1}\ km^{-2}$ which in fact is near to the normal design value for sub-drains used in Finland. In summertime, practically no surface runoff has been measured after the sub-drainage (Fig. 7). Even during the heaviest rains almost all runoff has discharged through the sub-drains. It seems evident that the permeability of soil decreased to some extent during the post-treatment period especially at the sites of the sub-drains. This was reflected in the increase in the percentage of surface runoff during the last years, especially in the case of spring runoff. This trend, although a little mixed with the effect of frost depth variation, may be expected to continue in the future.

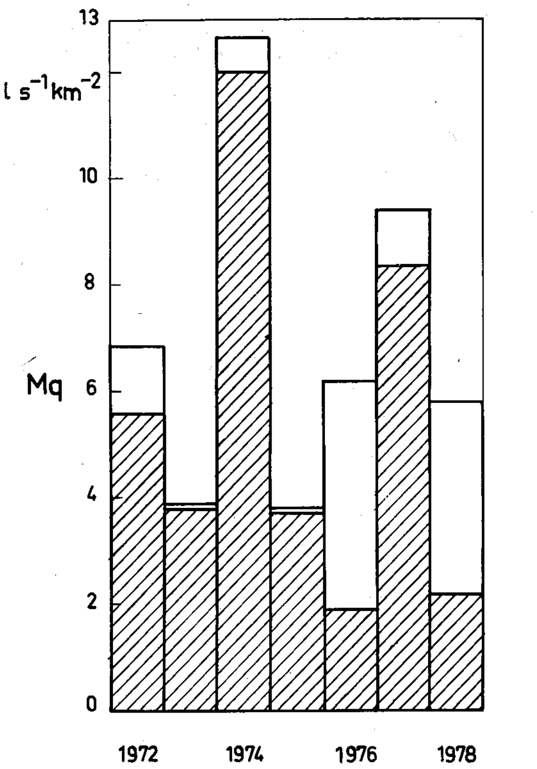

Fig. 3. Mean annual runoff (Mq) from sub-drains (hatched) and surface (unhatched) in the Hovi basin after sub-drainage.

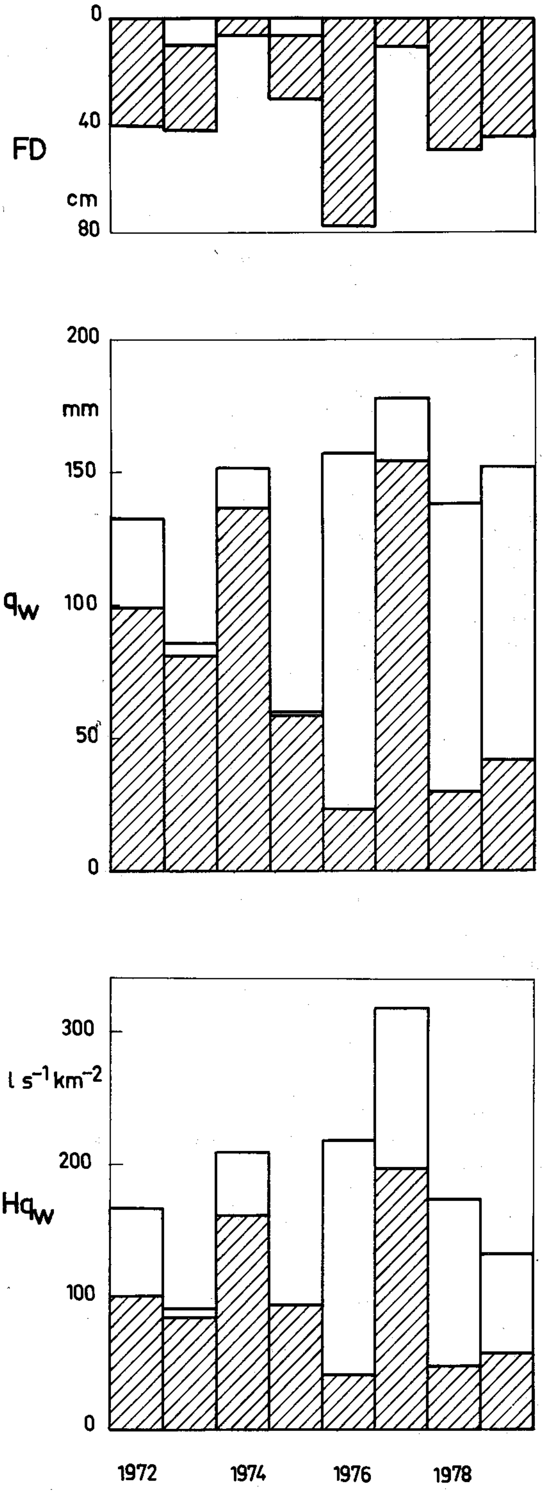

Fig. 4. Spring runoff (q_w) and spring maximum runoff (Hq_w) from sub-drains (hatched) and surface (unhatched) in the Hovi basin after sub-drainage. FD indicates the depth of soil frost during the spring maximum runoff.

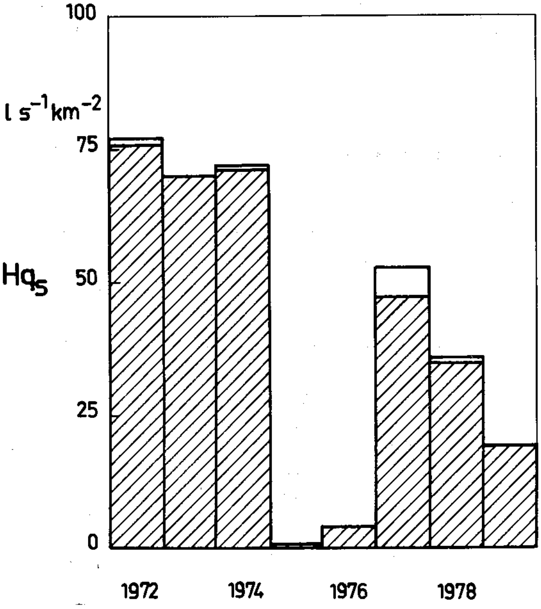

Fig. 5. Summer maximum runoff (Hq_s) from sub-drains (hatched) and surface (unhatched) in the Hovi basin after sub-drainage.

Table 5. Spring (Hq_w) and summer (Hq_s) maximum runoff (daily values). H = Hovi, sum of surface and sub-surface runoff from the treatment basin; A = Ali-Knuutila, the control basin; H_{sub}runoff from sub-drains of the treatment basin.

Year	Hq_w (l s^{-1} km^{-2})				Hq_s (l s^{-1} km^{-2})		
	H	A	H_{sub}		H	A	H_{sub}
1953	309	245			113.9	136.9	
1954	124	92			96.6	60.0	
1955	366	230			3.1	12.4	
1956	329	210			113.5	66.6	
1957	222	138			195.0	151.9	
1958	151	131			0.7	9.4	
1959	186	137			0.5	4.3	
1960	372	292			24.4	34.5	
1961	139	130			58.6	64.2	
1962	259	137			355.4	246.7	
1963	261	100			257.2	172.5	
1964	165	94			5.8	13.4	
1965	106	118			13.4	21.9	
1966	463	452			11.4	21.0	
1967	237	134			150.7	142.8	
1968	253	171			289.9	240.2	
1969	282	139			60.8	56.2	
1970	234	208			131.2	115.0	
1971	145	93			1.3	3.4	
1972	166	142	100		77.3	176.1	75.7
1973	90	81	85		70.4	86.7	70.2
1974	209	145	161		71.4	60.7	72.0
1975	94	55	94		0.6	1.6	0.5
1976	219	112	42		3.7	3.5	3.9
1977	317	124	197		53.0	48.8	47.4
1978	173	65	49		36.1	29.7	35.3
1979	133	143	58		19.2	20.1	19.4
M 1953—1971	242	171		M 1953—1970	104.6	87.2	
M 1972—1979	175	108	98	M 1972—1979	41.4	53.4	40.6

Table 6. Instantaneous spring ($Hq_{w\ inst}$) and summer ($Hq_{s\ inst}$) maximum runoff. H = Hovi, sum of surface and sub-surface runoff from the treatment basin; A = Ali-Knuutila, the control basin; H_{sub} = runoff from sub-drains of the treatment basin.

Year	$Hq_{w\ inst}$ (ls^{-1} km^{-2})			$Hq_{s\ inst}$ (ls^{-1} km^{-2})		
	H	A	H_{sub}	H	A	H_{sub}
1953	514	412		422	355	
1954	228	181		182	239	
1955	739	654		2.7	22	
1956	739	424		241	104	
1957	819	470		643	391	
1958	254	162		1.1	38	
1959	306	300		0.7	9.0	
1960	505	406		55	100	
1961	267	391		79	92	
1962	467	300		897	602	
1963	819	228		575	425	

Table 6. (cont.)

1964	340	327			9.4	17	
1965	193	181			53	86	
1966	1209	980			35	118	
1967	376	221			539	512	
1968	414	197			1872	915	
1969	751	316			267	219	
1970	505	327			254	391	
1971	254	118			2.2	4.4	
1972	554	480	152		193	1050	182
1973	138	162	125		172	523	167
1974	389	344	234		143	246	138
1975	147	124	143		0.8	9.3	0.5
1976	670	260	49		9.8	16	11
1977	564	237	247		82	94	75
1978	274	140	102		73	68	75
1979	356	155	113		99	70	102
M 1953—1971	510	347		M 1953—1970	340	257	
M 1972—1979	387	238	146	1972—1979	96	259	94

Table 7. Thirty days winter ($Nq_{w\ 30d}$) and summer ($Nq_{s\ 30d}$) minimum runoff. H = Hovi, sum of surface and subsurface runoff from the treatment basin; A = Ali-Knuutila, control basin; H_{sub} = runoff from sub-drains of the treatment basin.

Year	$Nq_{w\ 30d}$ ($l\ s^{-1}\ km^{-2}$)				$Nq_{s\ 30d}$ ($l\ s^{-1}\ km^{-2}$)		
	H	A	H_{sub}		H	A	H_{sub}
1953					0.01	0.01	
1954	0.00	0.09			0.01	0.01	
1955	0.25	1.33			0.00	0.00	
1956	0.01	0.09			0.01	0.10	
1957	0.02	0.00			0.00	0.07	
1958	0.00	0.47			0.05	0.01	
1959	0.20	0.45			0.00	0.00	
1960	0.00	0.00			0.05	0.22	
1961	0.31	3.35			0.00	0.05	
1962	0.21	0.42			0.18	0.90	
1963	0.00	0.09			0.00	0.00	
1964	0.00	0.00			0.00	0.00	
1965	0.01	0.10			0.02	0.00	
1966	0.01	0.03			0.01	0.00	
1967	0.16	0.35			0.00	0.00	
1968	0.02	0.00			0.02	0.03	
1969	0.02	0.18			0.00	0.00	
1970	0.12	0.05			0.04	0.03	
1971	0.17	0.53			0.08	0.00	
1972	0.18	0.00	0.04		0.02	0.00	0.00
1973	0.20	0.01	0.07		0.04	0.00	0.01
1974	0.39	0.71	0.21		0.16	0.01	0.03
1975	0.43	1.36	0.34		0.00	0.00	0.00
1976	0.04	0.00	0.02		0.04	0.00	0.05
1977	0.07	0.06	0.09		0.04	0.04	0.03
1978	0.12	0.10	0.10		0.09	0.05	0.09
1979	0.02	0.00	0.03		0.08	0.09	0.04
M 1954—1971	0.08	0.42		M 1953—1970	0.02	0.08	
M 1972—1979	0.18	0.28	0.11	M 1972—1979	0.06	0.02	0.03

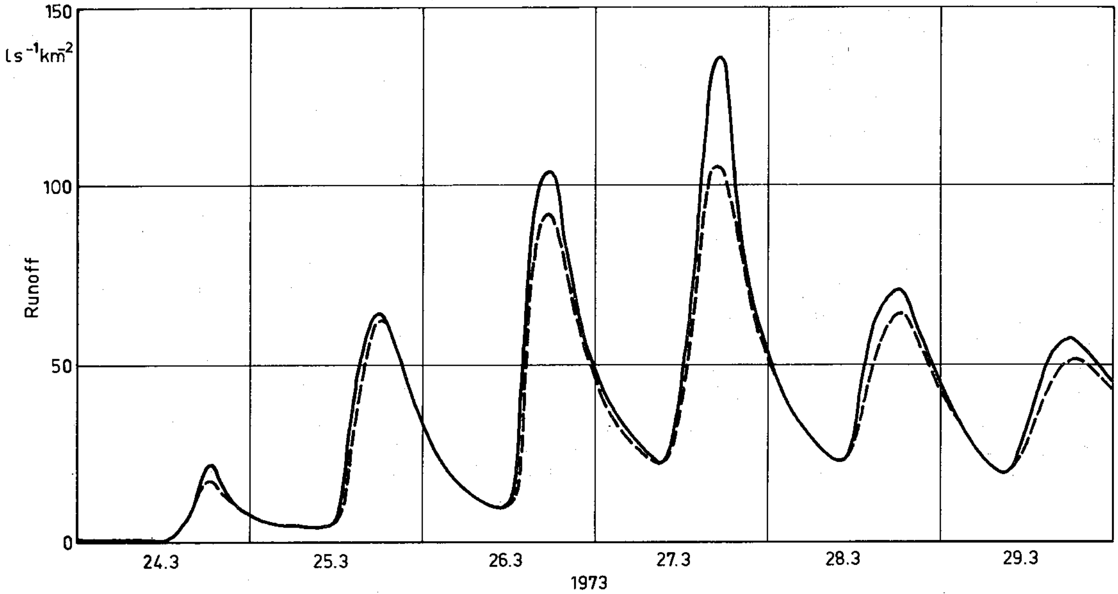

Fig. 6. Distribution of runoff during snowmelt at the Hovi basin in 1973. Solid line indicates total runoff, dotted line sub-surface runoff.

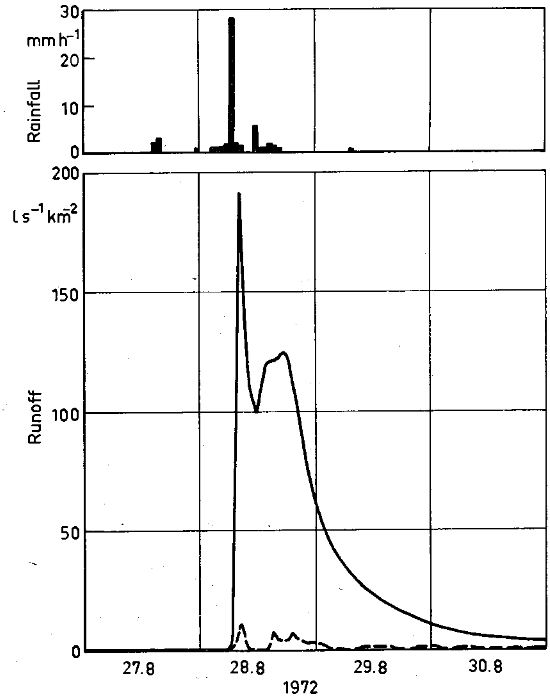

Fig. 7. Distribution of runoff from a heavy rain at the Hovi basin in August 1972, the next year after sub-drainage. Solid line indicates total runoff, dotted line surface runoff.

4.2 Increase or decrease in runoff

Runoff changes caused by sub-drainage were computed for mean annual (Mq), snowmelt (q_w), spring maximum (Hq_w), summer maximum (Hq_s), 30 days winter minimum (Nq_w) and 30 days summer minimum (Nq_s) runoff. In this connection values of total runoff, i.e. the sum of runoff from sub-drains and surface runoff are used. Regression equations for the calibration (1953—1970) and treatment (1972—1979) periods were as follows (treatment basin = y; control basin = x):

Mq (1 Jan.—31 Dec.)	1953—1970	$y = 0.95x + 0.08$	$R = 0.921$
	1972—1978	$y = 0.95x + 1.02$	$R = 0.937$
Mq_h (1 Nov.— 31 Oct.)	1954—1970	$y = 1.00x - 0.31$	$R = 0.934$
	1972—1978	$y = 0.84x + 1.66$	$R = 0.918$
q_w (1 Mar.—31 May)	1953—1971	$y = 0.93x + 12.2$	$R = 0.902$
	1972—1979	$y = 0.84x + 36.5$	$R = 0.775$
Hq_w	1953—1971	$y = 0.93x + 83.7$	$R = 0.855$
	1972—1979	$y = 0.90x + 77.3$	$R = 0.445$
Hq_s	1953—1970	$y = 1.35x - 13.2$	$R = 0.975$
	1972—1979	$y = 0.45x + 17.4$	$R = 0.832$
Nq_w	1954—1971	$y = 0.10x + 0.04$	$R = 0.754$
	1972—1979	$y = 0.27x + 0.10$	$R = 0.877$
Nq_s	1953—1970	$y = 0.19x + 0.01$	$R = 0.936$
	1972—1979	$y = 0.48x + 0.05$	$R = 0.318$

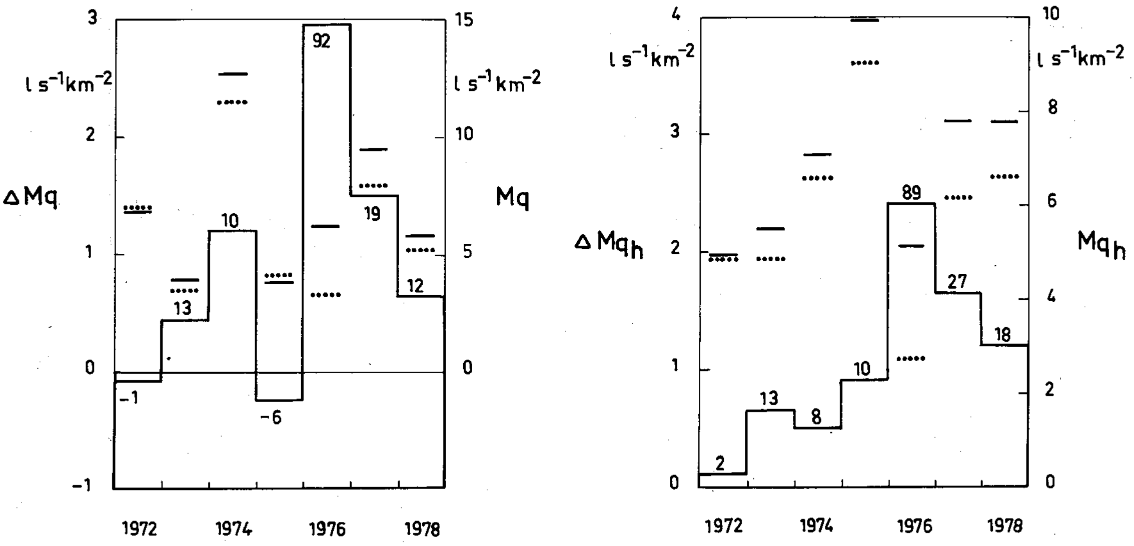

Fig. 8. The change in mean annual runoff (ΔMq = calendar year, ΔMq$_h$ = hydrological year) caused by sub-drainage in the Hovi basin. The figures at the top of the columns indicate the percentage of the change. The observed (solid line) and calculated (dotted line) mean annual runoffs (Mq and Mq$_h$) are shown on the right-hand scale.

Using equations from the calibration period 'undrained' values for the treatment basin after treatment were calculated. The difference between observed and calculated runoff indicates the change caused by sub-drainage (Figs.8—11).

Mean annual runoff (total) increased on average 0.91 ls^{-1} km^{-2} or 15.1 per cent for the calendar year and 1.06 l s^{-1} km^{-2} or 18.2 per cent for the hydrological year (1 November—31 October) (Fig. 8). The increase was statistically significant at five per cent risk. Annual runoff for the hydrological year was increased in all years. There was a slightly rising trend in this increase, however, the unpurified trend was not statistically significant. The increase in annual runoff can be explained in two ways. Firstly, evapotranspiration and especially evaporation probably decreased after sub-drainage. Secondly, the infiltrated water was mostly drained through the sub-drains and did not percolate to the passive groundwater layer.

Spring runoff (1.3—31.5) increased on average 14.6 mm or 12.4 per cent as compared with the calculated 'undrained' value (Fig. 9). This increase was not statistically significant. No trend could be found. Although the increase was especially high in 1976, when soil frost was deepest during the post-treatment period, in the other springs with deep frost the increase was not remarkable.

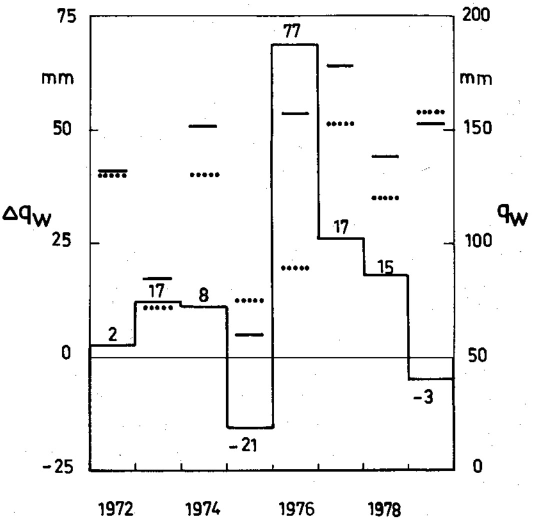

Fig. 9. The change in spring runoff (Δq$_w$ 1 March —31 May) caused by sub-drainage in the Hovi basin. The figures at the top of the columns indicate the percentage of the change. The observed (solid line) and calculated (dotted line) spring runoffs (q$_w$) are shown on the right-hand scale.

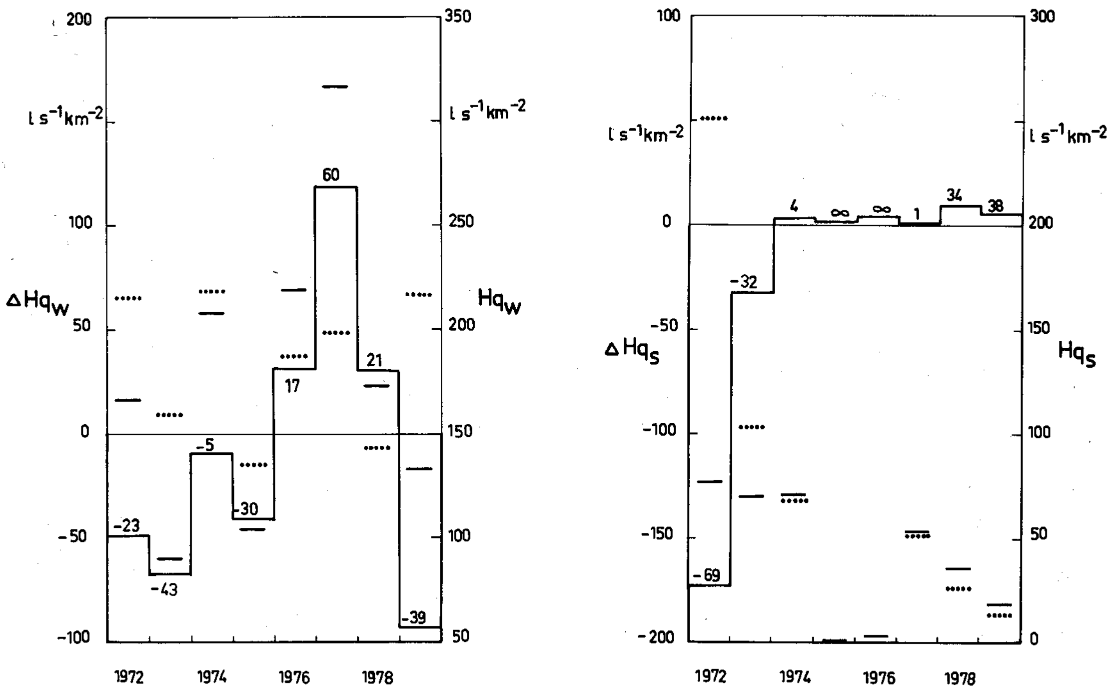

Fig. 10. The change in spring (ΔHq_w) and summer (ΔHq_s) maximum runoff caused by sub-drainage in the Hovi basin. The figures at the top of the columns indicate the percentage of the change. The observed (solid line) and calculated (dotted line) spring and summer maximum runoffs (Hq_w and Hq_s) are shown on the right-hand scale.

Spring maximum runoff (daily maximum caused by snowmelt) decreased to some extent due to sub-drainage (Fig. 10). The average decrease was 9 l s^{-1} km^{-2} or 4.3 per cent. This decrease was not statistically significant. The trend appeared to be rising except for 1979; however, the purified trend was not statistically significant. During the winter of 1979 an ice layer had formed on the depression in front of the embankment (= water divide). Due to the ice some surface runoff flowed out from the basin. However, the amount has not been significant according to the survey performed.

The instantaneous spring maximum runoff decreased 8 l s^{-1} km^{-2} or 2 % on average due to sub-drainage. The decrease was not statistically significant. No trend on the post-treatment period was observed.

Summer maximum runoff (daily maximum between 1 June and 31 October) decreased 27 l s^{-1} km^{-2} or 36 per cent on average due to sub-drainage (Fig. 10). This decrease was not quite statistically significant, although it was very clear in the first years after sub-drainage. Some years after sub-drainage no remarkable influence could be found on the summer maximum runoff. During the treatment period there was a rising trend in runoff change, which was evidently due to the packing of soil in sites of sub-drains. The unpurified trend was statistically significant at 95 per cent probability level. The purified trend could not be used because of the low correlation in the purification method mentioned above.

The instantaneous summer maximum runoff decreased 271 l s^{-1} km^{-2} or 74 % on average due to sub-drainage. The decrease was statistically significant at 1 % risk. On the post-treatment period a rising trend appeared at the statistical significance of 5 % risk.

Winter minimum runoff (30 days minimum during 1 January -spring food) was increased in all years after sub-drainage (Fig. 11). The average increase of 30 days winter minimum runoff was 0.11 l s^{-1} km^{-2} or 157 per cent as compared with 'undrained' runoff. The increase was statistically significant at one per cent risk. Before sub-drainage there was no runoff in some winters. After the treatment runoff has not ceased in any winter although it has still been small. During the post-treatment period there was a decreasing trend in runoff. The purified trend was statistically significant at five per cent risk.

Summer minimum runoff (30 days minimum

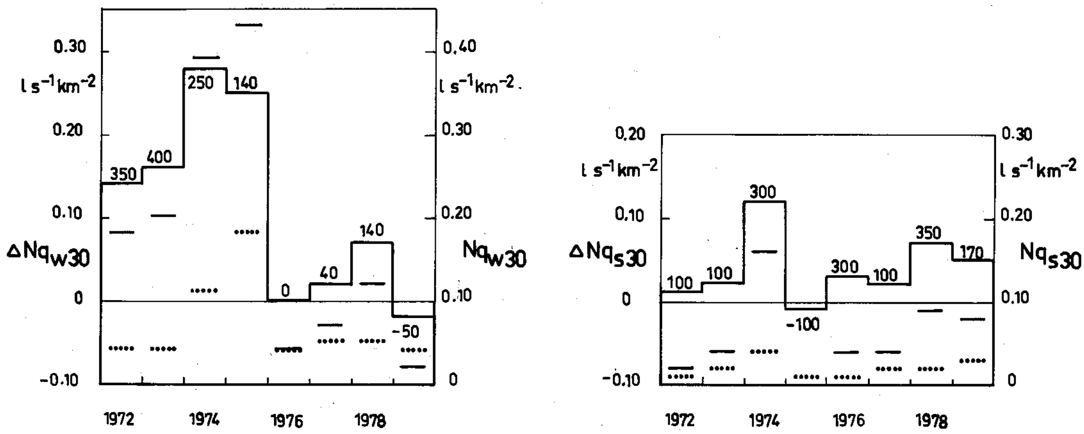

Fig. 11. The change in 30 days winter (ΔNq_{w30}) and summer (ΔNq_{s30}) minimum runoff caused by sub-drainage in the Hovi basin. The figures at the top of columns indicate the percentage of the change. The observed (solid line) and calculated (dotted line) winter and summer minimum runoffs (Nq_{w30} and Nq_{s30}) are shown on the right-hand scale.

during 1 June—31 October) increased in all years but one (Fig. 11). The average increase was 0.04 l s^{-1} km^{-2} or 200 per cent of the calculated value. This increase was highly significant at 0.1 per cent risk. No trend during the post-treatment period was noticed.

In general, the flow peaks were considerably lower in the post-treatment period than in the calibration period. This was the case also on the control basin (Table 5).

5. INFLUENCE OF SUB-DRAINAGE ON WATER QUALITY

Concentrations of total nitrogen and nitrate nitrogen increased considerably after the sub-drainage (Fig. 12). Almost all the total nitrogen was in the form of nitrate. Especially high concentrations of nitrate were found in autumn after the crop had been harvested. The strongest immediate effect of subdrainage lasted for about three years, but as late as in autumn 1976 nitrate concentrations exceeding 60 mg l^{-1} were encountered. Apparently, meteorological factors favoured the leaching of nitrate in autumn 1976.

The differences in total nitrogen and nitrate nitrogen concentrations between the Hovi and Ali-Knuutila basins increased after sub-drainage (Table 8). Annual means were tested with the t-test for the periods 1966—1970 and 1971—1978: the t-values for total nitrogen for these periods were respectively 0.845 and 3.55, and those for nitrate nitrogen 0.715 and 3.43. Before the sub-drainage annual means of total nitrogen and nitrate did not differ significantly between the two basins, but after the sub-drainage concentrations in the Hovi basin were statistically significantly (99 per cent confidence level) higher than in the Ali-Knuutila basin.

Total phosphorus concentrations were not influenced by sub-drainage.

Annual loads did not differ systematically between the basins during the calibration period (Table 9).

Monthly nutrient loads (kg km^{-2} month^{-1}) correlated quite well between the two basins during the calibration period:

Total N load: $y = 0.56x + 32.02$ $R = 0.669^{xxx}$
NO_3-N load: $y = 0.30x + 21.56$ $R = 0.649^{xxx}$
Total P load: $y = 0.34x + 1.39$ $R = 0.793^{xxx}$

Thus the control basin method appeared to be a valid research method. After the sub-drainage, observed nitrate and total nitrogen loads were significantly greater than calculated loads (Table 10). Increase in annual loads varied from 52 to 390 per cent in the case of total nitrogen (Fig. 13). For nitrate nitrogen the increases were even greater: from 113 to 839 per cent (Fig. 14). Observed phosphorus loads were in some years greater and in other years smaller than calculated loads (Fig. 15).

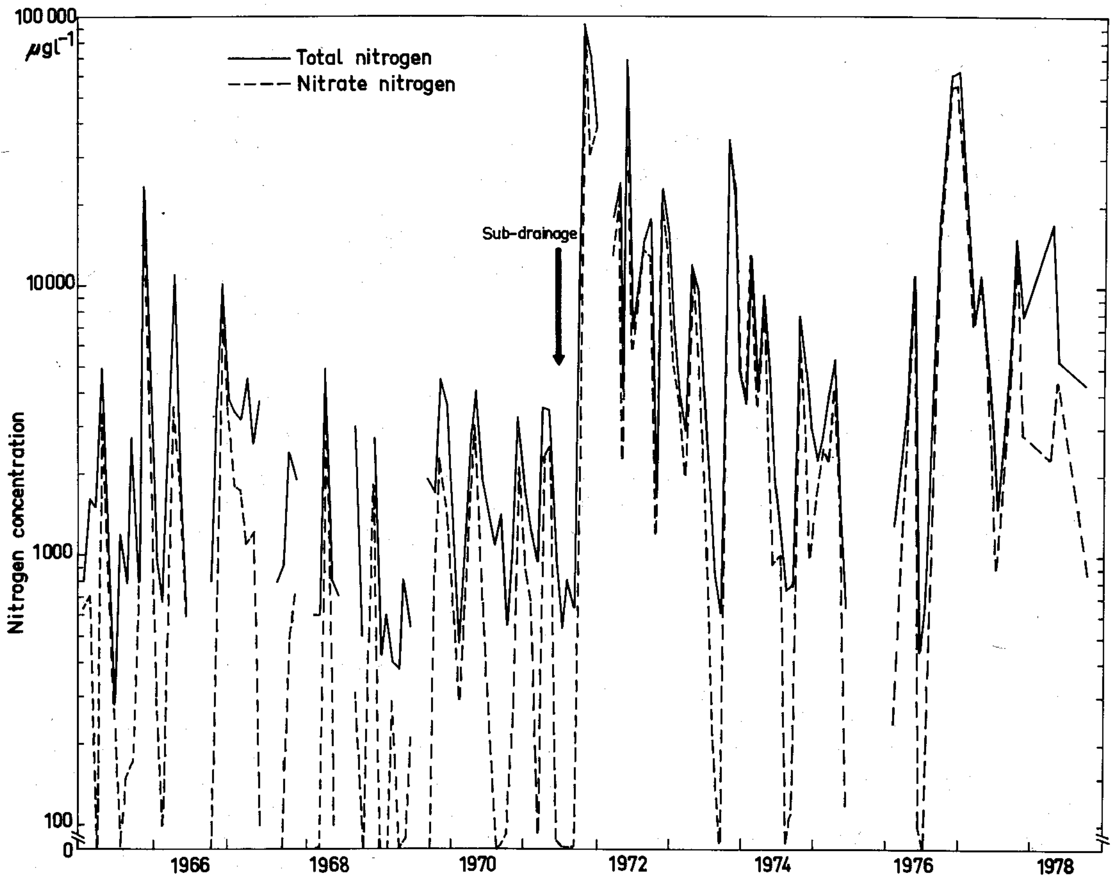

Fig. 12. Concentrations of total nitrogen and nitrate nitrogen in the sub-drainage basin in 1966—1978. Note the log scale.

Table 8. Annual means (1966—1978) of total nitrogen, nitrate nitrogen and total phosphorus concentrations in the sub-drainage basin (Hovi) and the control basin (Ali-Knuutila).

Year	Total N (mg l^{-1})		NO$_3$-N (mg l^{-1})		Total P (mg l^{-1})	
	Hovi	Ali-Knuutila	Hovi	Ali-Knuutila	Hovi	Ali-Knuutila
1966	3.58	1.99	1.71	0.72	0.17	0.21
1967	2.60	1.78	1.19	0.98	0.17	0.11
1968	1.64	2.03	0.83	0.78	0.18	0.26
1969	1.43	1.22	0.58	0.52	0.10	0.10
1970	1.92	2.49	1.02	1.49	0.16	0.20
1971	17.58	1.08	13.08	0.48	0.12	0.14
1972	14.42	3.46	17.18	2.40	0.31	0.21
1973	5.10	2.43	8.79	1.44	0.10	0.34
1974	4.94	1.74	3.69	1.06	0.12	0.20
1975	2.77	1.13	2.03	0.57	0.10	0.12
1976	19.48	9.71	17.28	6.43	0.09	0.17
1977	7.04	4.63	6.05	3.54	0.17	0.27
1978	8.87	2.77	2.52	1.38	0.66	0.37

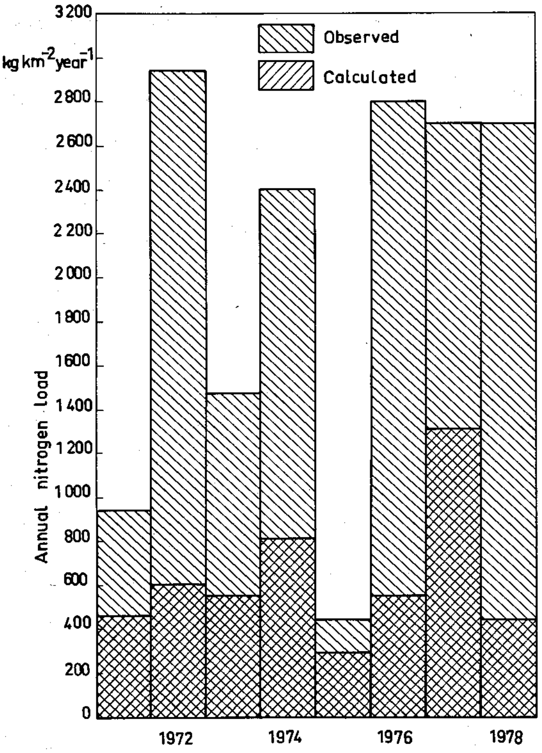

Fig. 13. Increase in annual nitrogen loads after sub-drainage.

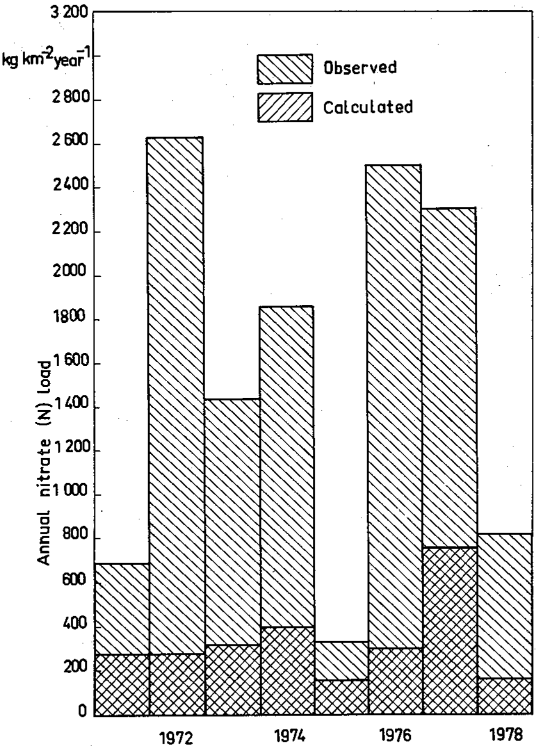

Fig. 14. Increase in annual nitrate loads after sub-drainage.

Annual phosphorus loads obtained from the observations are strongly dependent on the timing of observations. Most of the phosphorus loading comes during one to two months in the spring. Observations should be made very frequently at this time in order to determine the true load, because concentrations vary considerably from day to day depending on runoff, frost etc. (cf. Kohonen 1982). Because of this lack of observations, it is not possible to discuss the influence of sub-drainage on phosphorus loads. However, it can be stated that phosphorus loads have not decreased in this basin because of sub-drainage, as might have been expected.

The differences between observed and calculated annual loads in 1971—1978 were also tested with the t-test. In the case of total nitrogen and nitrate nitrogen the differences were statistically significant at the 99 per cent confidence level, and in the case of phosphorus at the 90 per cent confidence level: the t-values for total nitrogen, nitrate nitrogen and total phosphorus were respectively 4.84, 4.15 and 2.13. Nitrate is totally mobile in the soil. It follows the movement of soil water and is not bound to soil colloids (Lind 1978). It can therefore easily be understood why such high

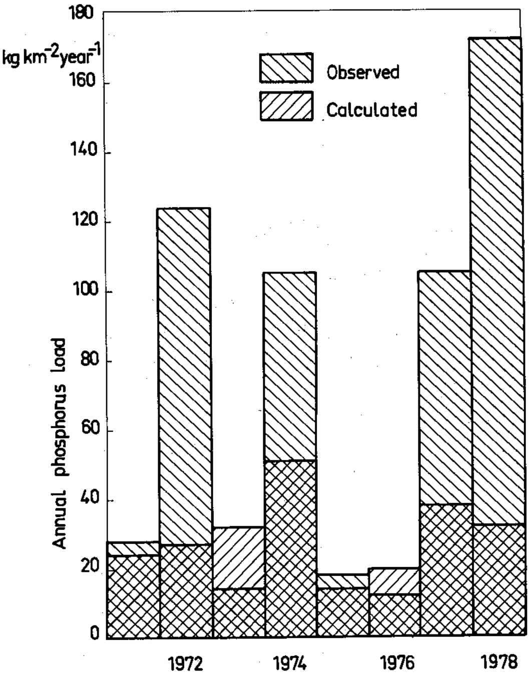

Fig. 15. Increase/decrease in annual phosphorus loads after sub-drainage.

Table 9. Annual loads of total nitrogen, nitrate nitrogen and total phosphorus in the sub-drainage basin (Hovi) and the control basin (Ali-Knuutila) during the calibration period 1966—1970.

Year	Total N (kg km^{-2} year^{-1})		NO_3-N (kg km^{-2} year^{-1})		Total P (kg km^{-2} year^{-1})	
	Hovi	Ali-Knuutila	Hovi	Ali-Knuutila	Hovi	Ali-Knuutila
1966	1800	850	840	380	27	94
1967	810	800	180	520	59	53
1968	950	750	550	320	58	88
1969	400	710	180	160	30	21
1970	680	1800	400	1300	38	92

Table 10. Observed (O) and calculated (C) values of annual loads of total nitrogen, nitrate nitrogen and total phosphorus in the Hovi basin in 1971—1978.

Year	Total N (kg km^{-2} year^{-1})			NO_3-N (kg km^{-2} year^{-1})			Total P (kg km^{-2} year^{-1})		
	O	C	O—C	O	C	O—C	O	C	O—C
1971	940	460	480	690	280	410	28	24	4
1972	2940	600	2340	2630	280	2350	124	27	97
1973	1470	550	920	1440	320	1120	14	32	—18
1974	2400	810	1590	1860	400	1460	105	51	54
1975	440	290	150	330	160	170	18	14	4
1976	2800	550	2250	2500	300	2200	12	20	—8
1977	2700	1310	1390	2300	760	1540	105	38	67
1978	2000	420	1580	600	160	440	172	32	140

nitrate concentrations were found in the drainage water.

ACKNOWLEDGEMENTS

In this report the description of the basins and the treatments as well as the hydrological studies have been performed by Seuna and the studies concerning water quality were carried out by Kauppi.

Helsinki, December 1980
Pertti Seuna, Lea Kauppi

LOPPUTIIVISTELMÄ

Tutkimuksessa on selvitetty salaojituksen vaikutuksia alueelta purkautuvan veden määrään ja laatuun vertailualuemenetelmää käyttäen. Vuodesta 1953 avo-ojitettuna ollut 12 ha peltoalue, Hovi, salaojitettiin kesällä 1971. Sen 24 ha suuruinen rinnakkaisalue, Ali-Knuutila, joka käsittää puolet peltoa ja puolet metsää, on pidetty mahdollisimman muuttumattomana koko tutkimusjakson 1953—1979 ajan (kuvat 1 ja 2, taulukot 1 ja 2). Valuma-alueiden pellot muistuttavat toisiaan sekä maaperän että kaltevuuden suhteen, mutta Ali-Knuutilan metsä aiheuttaa alueiden kesken tiettyä erilaisuutta. Korkeahkot korrelaatiokertoimet alueiden valumasuureiden välillä kalibrointikaudella osoittavat kuitenkin, että vertailualuemenetelmän käyttö on tässä yhteydessä oikeutettua.

Salaojituksessa käytettiin imuojina 55 mm muoviputkea ja kokoojaojina 100 mm teräs- ja muoviputkia niin, että kokonaisojatiheydeksi tuli 443 m/ha. Salaojista tuleva valunta mitataan mittapadolla ja vedenkorkeuspiirturilla.

Salaojituksen vaikutuksesta Hovin alueen pintavalunta lakkasi suureksi osaksi. Keskimäärin pintavalunta oli 23 % vuosivalunnasta. Pintavalunnan osuus oli suuri vain sulamisaikoina ja erityisesti, mikäli routa oli rakenteeltaan tiivistä ja sitä oli runsaasti (kuvat 3—5). Keskimäärin kevätylivaluman vuorokausiarvosta 44 % ja hetkellisestä huipusta 62 % oli pintavaluntaa. Kesäylivaluman vuorokausiarvosta oli keskimäärin vain 2 % ja hetkellisestä huipusta 3 % pintavaluntaa (taulukot 5 ja 6). Suurimmat hetkelliset huiput Hovin alueella ylittivät ennen salaojitusta selvästi 1000 l/s km^2 sekä keväällä että kesällä. Keskimäärin olivat keväthuiput selvästi suurempia kuin kesähuiput, mutta kesäylivaluman jakauma oli paljon äärevämpi. Siten sattumistodennäköisyydeltään harvinaiset kesähuiput nousivat keväthuippuja suuremmiksi (taulukko 6).

Salaojitus lisäsi vuosivaluntaa keskimäärin 0,91 l/s km^2 eli 15,1 % (kuva 8). Lisäys oli tilastollisesti merkitsevä 5 % riskillä. Vuosivalunnan lisäyksellä oli lievästi nouseva trendi, joka ei kuitenkaan ollut tilastollisesti merkitsevä.

Kevätvalunta (1.3.—31.5.) lisääntyi keskimäärin 14,6 mm eli 12,4 % verrattuna vertailualueen perusteella laskettuun "salaojittamattomaan" arvoon (kuva 4). Lisäys ei kuitenkaan ollut tilastollisesti merkitsevä eikä siinä ollut todettavissa trendiä.

Kevätylivaluma (lumen sulamisen aiheuttama suurin vuorokausivaluma) väheni keskimäärin 9 l/s km^2 eli 4,3 %. Muutos ei ollut tilastollisesti merkitsevä (kuva 4). Myöskään tilastollisesti merkitsevää muutoksen trendiä ei esiintynyt, vaikka lievästi nouseva (palautuva) trendi näyttääkin todennäköiseltä.

Hetkellinen kevätylivaluma väheni keskimäärin 8 l/s km^2 eli 2 %. Muutos ei ollut tilastollisesti merkitsevä, eikä myöskään merkitsevää trendiä esiintynyt.

Kesäylivaluma (1.6.—31.10.) väheni keskimäärin 27 l/s km^2 eli 36 % (kuva 5). Muutos oli erityisesti ensimmäisinä vuosina hyvin selvä, mutta ei koko kaudelle laskettuna saavuttanut aivan tilastollisen merkitsevyyden tasoa.

Hetkellinen kesäylivaluma väheni keskimäärin 271 l/s km^2 eli 74 %. Muutos oli tilastollisesti merkitsevä 1 % riskillä. Ajan mittaan valuma palautui kohti lähtötasoa ja trendi oli merkitsevä 5 % riskillä.

Talvialivaluma (1.1.—kevättulva) lisääntyi kaikkina ojituksen jälkeisinä vuosina (kuva 11). Keskimääräinen lisäys 0,11 l/s km^2 eli 157 % oli tilastollisesti merkitsevä 1 % riskillä. Muutoksella oli laskeva trendi, joka oli tilastollisesti merkitsevä 5 % riskillä.

Kesäalivaluma (1.6.—31.10.) lisääntyi keskimäärin 0,04 l/s km^2 eli 200 % (kuva 12). Lisäys oli tilastollisesti merkitsevä 0,1 % riskillä. Trendiä ei esiintynyt.

Hovin alueen kokonaistypen ja nitraattitypen pitoisuudet kohosivat selvästi salaojituksen vaikutuksesta: salaojitusta edeltäneen havaintojakson aikana kokonaistypen vuosikeskiarvot vaihtelivat välillä 1,4—3,6 mg l^{-1} ja salaojituksen jälkeen 4,9—20 mg l^{-1}. Nitraattityppipitoisuus vaihteli vastaavasti kalibrointijaksolla välillä 0,68—1,7 mg l^{-1} ja salaojituksen jälkeisellä kaudella 2,0—17 mg l^{-1}.

Nitraatin suhteellinen osuus kokonaistypestä lisääntyi salaojituksen jälkeen. Tämä on luonnollinen seuraus pintavalunnan osuuden pienenemisestä. Kokonaistyppi- ja nitraattityppikuormissa salaojituksen vaikutus tuli vielä selvemmin esille kuin pitoisuuksissa. Kokonaistypen vuosikuorma kasvoi 150—2300 kg km^{-2} eli 52—410 prosenttia verrattuna vertailualueen tulosten perusteella saatuihin "laskettuihin" arvoihin. Nitraattitypellä vastaava lisäys oli 170—2400 kg km^{-2}a^{-1} eli prosentteina 106—840. Kokonaisfosforin pitoisuuksissa ja kuormissa ei havaittu selvää muutosta salaojituksen johdosta.

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