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THE EFFECTS OF CLIMATIC FLUCTUATIONS AND MAN ON DISCHARGE IN FINNISH RIVER BASINS

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Trends and fluctuations in mean annual discharge, summer and winter low flow and high discharge due to climatic fluctuations have been investigated. Attempts have also been made to establish eventual trends due to human activities. In Finland the water regime is particularly influenced by river and lake regulation. Due to the vast drainage of forest and peatlands, the spring and summer high flow has increased in central and northern Finland. It has not yet been possible to establish the effects of drainage on low flow.

Index words: Climatic fluctuations, human impact, discharge.

1. INTRODUCTION

In 1978 the Hydrological Office inititated a research project aimed at producing a comprehensive report on the development of the state of river discharge in Finland. Discharge fluctuations, caused by both the climate and by man, were investigated. The work is continuing and only part of the results will be given here.

Climate causes the basic fluctuations in the river regime in Finland, and human influences are superimposed upon it. Regulation of natural lakes, construction of manmade lakes, channel improvements for flood control and drainage for agriculture and forestry are the main human measures affecting the river regime. Timber cutting and floating have their effects; urbanization is of only minor importance.

2. LONG TERM FLUCTUATIONS

Figure 1 shows 10-year moving averages of annual discharge for some Finnish rivers. Five-year moving averages for summer (July) and winter (March) flows are shown in Fig. 2.

Lake regulation or other human measures do not particularly affect long-term mean flow. Therefore Fig. 1 mainly reflects the long-term climatic fluctuations, i.e. the difference between precipitation and evaporation. Lowering of lake levels in the nineteenth and early twentieth century, agricultural and forest draining, forest cutting, etc. may have affected them slightly by decreasing evaporation. Better growth on arable land and in the forests may, on the other hand, have increased evaporation in recent years.

The moving average curves of annual discharge

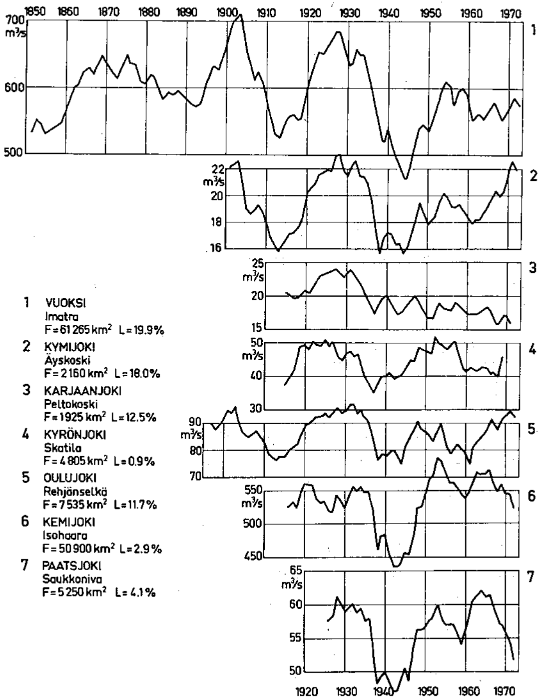

Fig. 1. Ten-year moving averages of annual discharge for some rivers in Finland.

in Fig. 1 are sometimes very similar, sometimes totally dissimilar. To find out the correlations between the annual discharge series of neighbouring and distant drainage basins, correlation coefficients r were calculated and plotted against the distance between the basins in Fig. 3. The points show the conditions in Finland; some values from neighbouring countries have also been added.

The correlation coefficients r in Fig. 3 have been calculated for the period 1911—1970 and for the decades 1911—1920, . . . , 1961—1970. The correlation coefficients for individual decades may differ considerably. The correlation coefficient between the annual discharges of the rivers Kalajoki and Kyrönjoki, for example, varies from 0.11 to 0.9, and that of the Vuoksi and Vänern-Göta (Sweden) from —0.3 to 0.8.

A practical rule can be obtained from Fig. 3: under Finnish conditions the discharge data for a basin can be estimated reliably by comparison of data from the neighbouring drainage basin only if the distance between the basins does not exceed, say, 100 km.

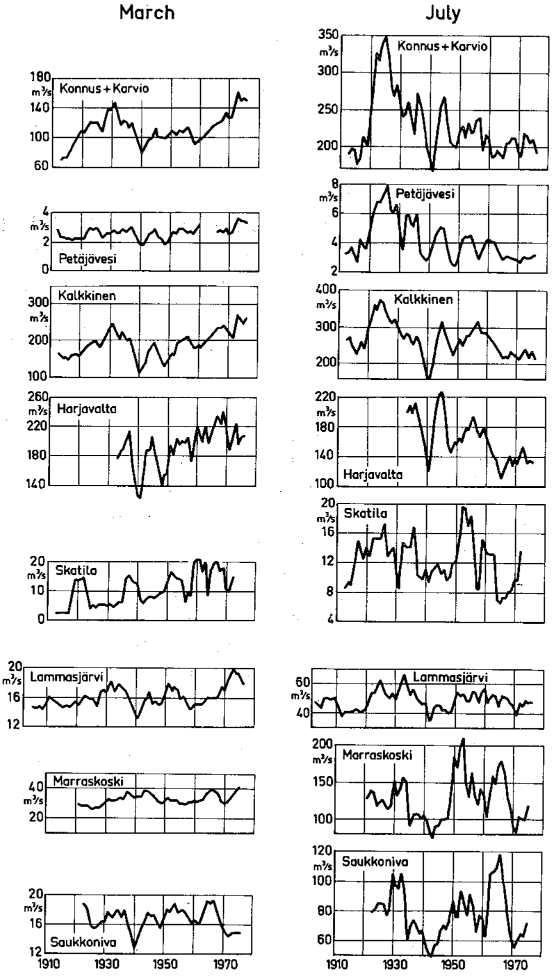

Fig. 2. Five-year moving averages of March and July discharges for some rivers in Finland.
Explanations in Table 1.

3. LAKE REGULATION

More than half of Finland's bigger lakes are regulated. Their levels are partly controlled to maintain reasonably low levels during summer for agricultural purposes but mainly to increase water power. This means basically that the water from the snowmelt in spring is stored in the lakes to be used next autumn and winter.

Figure 2 shows a decreasing trend in the July discharge and an increasing trend in the March discharge in many Finnish rivers. Table 1 lists the causes of these trends. In many cases the reason for these trends is regulation of the lakes but, simulta-

Table 1. Evident and possible contributors to the trends and fluctuations of March and July discharges for the drainage basins of Fig. 2. C = climate variations, L = lake regulation, AL = man made lakes, D = forest draining, T = timber floating, TC = timber cutting, FG = forest growth, AG = growth on arable land (irrigation etc.), Cl = channel improvement

Drainage basin					Contributors	
Station	Lat. N	Long. E	F (km^2)	L(%)	March	July
Imatra	61°13'	28°47'	61 265	19.9	C, L	C, L
Konnus + Karvio	62°33'	27°45'	16 270	15.3	C, L, D?	C, L, D?, T?
Petäjävesi	62°15'	25°10'	665	5.4	C, D?	C, T, D?, FG? L?
Kalkkinen	61°17'	25°35'	26 480	19.5	C, L	C, L, D?, T?
Harjavalta	61°30'	21°34'	26 025	11.8	C, L	C, L, D?, T?, AG?
Skatila	63°06'	21°52'	4 805	0.9	C, AL, D?	C, AL, D?, Cl?, AG?, FG?
Lammasjärvi	64°08'	29°31'	3 480	11.1	C, D	C, D?, T?, TC?
Marraskoski	66°48'	25°26'	12 335	2.3	C, TC	C, TC
Saukkoniva	68°52'	26°48'	5 250	4.1	C	C

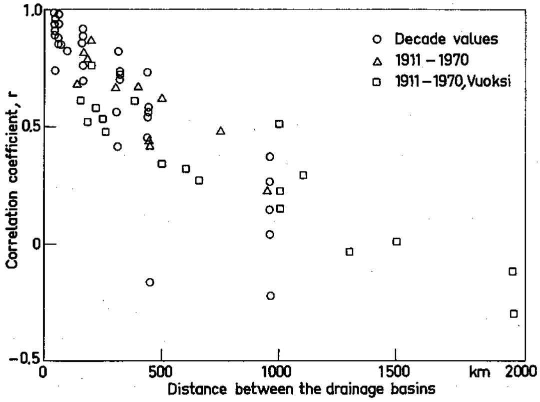

Fig. 3. Relation between the correlation coefficients of annual discharge and the distances (km) between the drainage basins. Most of the basins are from Finland, with some reference basins from Sweden, Norway and the Soviet Union.

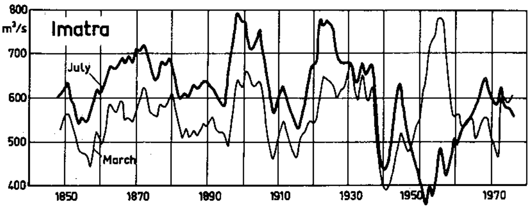

Fig. 4. Five-year moving averages of March and July discharges for Saimaa—Imatra.
Explanations in Table 1.

neously during this century, the summers have become drier and the winters wetter in southern Finland. Similar trends have been observed in the total inflow to the Baltic Sea, as reported by Hupfer et al. (1979).

The effect of the regulation of Lake Saimaa since the late 1940s is seen clearly in Fig. 4. Figure 5(a) shows an example of the effects of a rather severe lake regulation (Oulujärvi) and Fig. 5(b) the effects of a slight regulation (Lake Päijänne) on the discharge — duration curve downstream.

4. DRAINAGE OF FOREST AND PEATLANDS

Effective forest drainage in Finland began at the end of the 1950s. Since about 1965, 2000 to 3000 km^2 have been drained annually, and by the end of the 1970s, drainage activities were decreasing.

Marshlands cover about 100 000 km^2 or about one third of the area of Finland. Today 60 000 km^2 marshland has been drained. The drainage has been carried out mainly in Ostrobothnia, in the northern parts of central Finland and in northern Finland. In Lapland forest drainage in of less importance.

Spring high flows have increased in several drainage basins since draining. One reason for this is the increased precipitation during spring (Table 2). Another reason may also be the drainage. To sep-

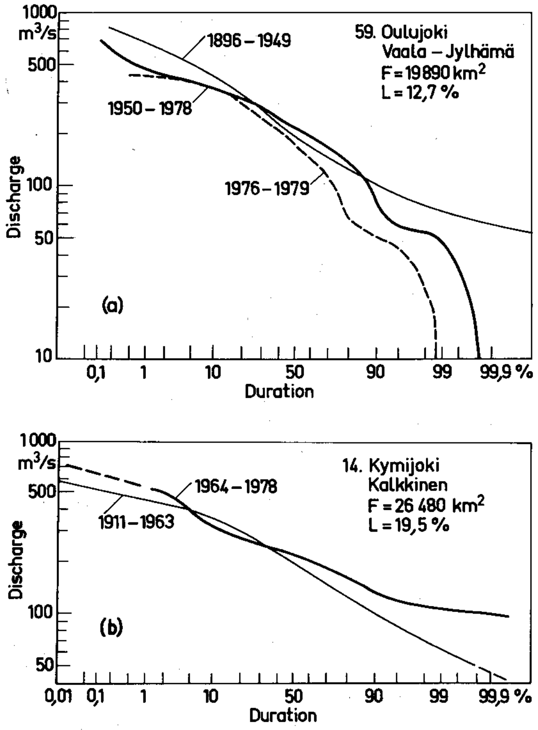

Fig. 5. (a) Discharge duration curves for Oulujärvi outlet during the periods 1896—1949, 1950—1978 and 1976—1979. (b) Discharge duration curves for Päijänne—Kalkkinen during the periods 1911—1963 and 1964—1978.

arate these two effects, multiple regression models to explain the spring high flow were calculated for 12 drainage basins. The first phase of the work has been reported earlier by Hyvärinen and Vehviläinen (1978) and the final results by Vehviläinen (1979).

The twelve drainage basins investigated (Fig 6) were chosen from the network of the Hydrological Office so that forest drainage would be the main significant human impact on the areas. The drainage basin areas were 160—3500 km², mostly about 500 km². Their characteristics are describad in Tables 3 and 4.

The regression models for spring maximum discharges were calibrated using observations from the period 1936 to about 1965 before the intensive drainage. A comparison was made between the observed maximum discharges and those calculated by the models for the period since drainage, mainly from 1965 onwards.

The best models to explain the spring high flow, obtained by stepwise regression analysis, were of the form

$$HQ = aW + bP + cP_A + d$$

or

$$HQ = aW + bP + cMQ_A + d$$

where HQ is the maximum spring discharge; W, the water equivalent of the snow cover before the melting season; P, precipitation during the melting

Table 2. The changes of the spring maximum discharge HQ, the water equivalent of snow cover W, the precipitation of melting season P, the autumn precipitation P_A, and autumn mean discharge MQ_A from the calibration period (1936—1960) to the draining period (1960—1977); observed values.

	Δ HQ %	Δ W %	Δ P %	Δ P_A %	Δ MQ_A %
Southern areas					
Aurejärvi	+5	—3	+17	+1	—1
Petäjävesi	+2	—1	+43	+8	—3
Salosjärvi	—2	0	+36	+5	—3
Vähämultianjärvi	—6	—7	+26	+4	—19
Kitusjärvi	—6	—4	+19	+4	—16
mean	—1	—3	+28	+4	—8
Northern areas					
Pääjärvi	+8	—10	+12	+6	—4
Alaluostanjärvi	+18	+17	+46	+13	+4
Koivujärvi	+18	0	+24	+8	+30
Murtosalmi	+36	—10	+18	+16	+7
Änättijärvi	+20	—3	+27	—1	—12
Lentua	+24	0	+28	+2	+8
Lammasjärvi	+24	—6	+17	+4	+8
mean	+21	—2	+25	+7	+6

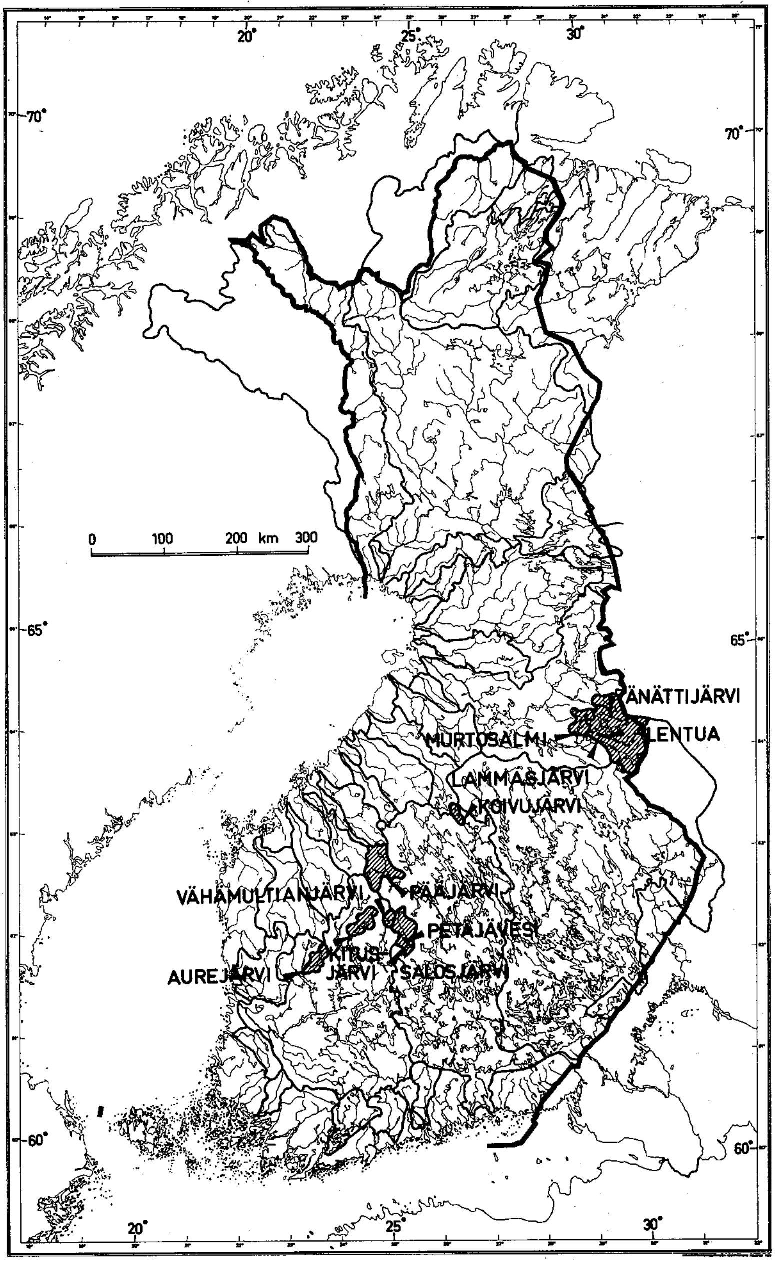

Fig. 6. The drainage basins used in investigating the effects of forest draining.

season; P_A, autumn precipitation during the previous year; MQ_A, autumn mean discharge during the previous year; and a, b, c, ć, and d are coefficients. The models are seen in Table 5.

The squared multiple correlation coefficient R^2 was 0.8 on average varying from 0.71 to 0.91. For northern areas, from 63°N northward, the models fitted better ($R^2 = 0.820$) than for southern areas ($R^2 = 0.781$).

In five southern drainage basins the observed maximum spring discharges were an average of nine per cent smaller than the calculated ones (Table 6). In the northern basins the observed HQ was an average of five per cent greater than the calculated

Table 3. Characteristics of the basins.

Basin	F km^2	L %	Hq l/s · km^2	Land use % of the area		
				Marsches1)	Forest1)	Cultivated2)
Aurejärvi	490	10.6	36	40	80	5
Petäjävesi	665	5.4	62	40	80—90	6
Salosjärvi	895	6.2	53	30	90	5
Vähämultia	160	7.5	54	30	80	4
Kitusjärvi	565	9.2	36	40	80—90	4
Pääjärvi	1230	7.8	39	50	75	6
Koivujärvi	195	14.1	34	50	70—80	6
Murtosalmi	562	10.0	48	50	80	1
Änättijärvi	420	12.2	56	50	70—80	1
Lentua	2065	12.9	32	50	70—80	1
Lammasjärvi	3480	11.1	36	50	70—80	1

1) Uusi yleiskartta 1977

2) Suomen kartasto 1960

Table 4. Forest drainage and forest cutting on the study areas.

Basin	Drained marshes (%)			standing timber (m^3/ha) 1964—1970	The change of standing timber % from 1951—1953 to 1964—1970
	during calibration period	after calibration period	total		
Aurejärvi			10—15	80	—7
Petäjävesi	6	28	34	100	—15
Salosjärvi	6	24	30	100	—15
Vähämultianjärvi	3	12	15	100	—15
Kitusjärvi			10—20	80	—10
Pääjärvi	≥24 1)		≥24	70	—15
Koivujärvi	7	18	25	80	~0
Murtosalmi	≥2 1)	20	22	80	—15
Änättijärvi			~15	100	—15
Lentua	0—5 1)	≥11 1)	≥11—15	70	—15
Lammasjärvi			~15	70	—15
mean	4 %	19 %	21 %	80 m^3/ha	—10 %

1) The data of the drainage of forest companies is missing.

Table 5. The regression models for the spring high flow. Precipitation values P are corrected.

Aurejärvi	$HQ = 0.100\ W + 0.0910\ P + 0.0360\ P\ (9...12) — 7.64$	$R^2 = 0.734$
Petäjävesi	$\ln HQ = 0.537 \cdot 10^{-2}\ W + 0.650 \cdot 10^{-2}\ P + 0.186 \cdot 10^{-2}\ P\ (9...11) + 2.25$	$R^2 = 0.777$
	$HQ = 0.188\ W + 0.229\ P + 0.0849\ P\ (9...11) — 12.8$	$R^2 = 0.734$
Salosjärvi	$HQ = 0.223\ W + 0.238\ P + 0.0772\ P\ (6...12) — 19.0$	$R^2 = 0.854$
Vähämultianjärvi	$HQ = 0.0309\ W + 0.0201\ P + 0.0244\ P\ (6...12) — 4.00$	$R^2 = 0.735$
Kitusjärvi	$\ln HQ = 0,654 \cdot 10^{-2}\ W + 0.698 \cdot 10^{-2}\ P + 0.204\ MQ_3 + 1.24$	$R^2 = 0.804$
	$HQ = 0.0967\ W + 0.0999\ P + 0.0516\ P\ (6...12) — 14.4$	$R^2 = 0.773$
Pääjärvi	$HQ = 0.414\ W + 0.358\ P + 0.405\ MQ\ (9...12) — 34.0$	$R^2 = 0.787$
Koivujärvi	$\ln HQ = 0.0816\ W + 0.0147\ P + 0.457 \cdot 10^{-4}\ P^2 — 0.0642$	$R^2 = 0.905$
	$HQ = 0.0415\ W + 0.0333\ P + 0.259\ NQ — 31.0$	$R^2 = 0.864$
Murtosalmi	$HQ = 0.160\ W + 0.325\ P + 9.93 \ln MQ\ (9...11) — 73.2$	$R^2 = 0.828$
Änättijärvi	$HQ = 0.115\ W + 0.372\ P — 17.1 \ln P + 49.6$	$R^2 = 0.730$
	$HQ = 0.101\ W + 0.151\ P + 0.178\ MQ\ (9...11) — 6.75$	$R^2 = 0.694$
Lentua	$HQ = 0.324\ W + 0.479\ P + 24.1 \ln MQ\ (9...12) — 127$	$R^2 = 0.846$
Lammasjärvi	$HQ = 0.471\ W + 0.899\ P + 0.170\ P\ (6...12) — 77.4$	$R^2 = 0.811$

HQ; in two cases the difference was over + 10 per cent. The differences are not statistically significant because of the short period of comparison. The results may also reflect the different distribution of climatic factors in northern and southern areas in a way that the regression analysis technique does not reveal. It is, however, quite clear that spring high discharges have decreased in southern areas and increased in northern areas. Latitude 63°N is the approximate limit, in Ostrobothnia, say 62°30'N. This also means that forest drainage has principally increased the spring floods; most of the drained areas are situated to the north of latitude 63°N.

4.1 Differences between southern and northern areas

In northern areas marshes are mostly aapa-fens. They are usually open, thinly forested at the borders and quite large. The surface of an aapa-fen is below the level of the surroundings. This causes surface and subsurface water to flow from adjacent areas into the aapa-fens, and in spring, water from snowmelting forms flood lakes.

Southern areas have mainly raised bogs. Their central parts stand higher than the adjacent areas. There is only a little surface runoff to the borders of the bog. No flood lakes develop on raised bogs.

Spruce swamps, which are quite wooded and fertile forest land, are rather common in southern areas. Forest grows well on them after drainage operations. The growing forest lowers the groundwater table and the dense stock of standing timber lengthens the melting season. Runoff coefficient during melting season is for open areas 0.75. . .0.85 and for forest 0.25. . .0.50 (Subbotin 1965).

Forest cutting, including clearcutting, has been quite intensive in northern areas during the 1960s and 1970s. This may also increase the maximum spring discharges. In southern areas there has been nearly as much forest cutting as in the north but little clearcutting (Table 4).

Regulation of shedwaters may have lowered the maximum discharges of Petäjävesi and Salosjärvi in the calculation period.

The reasons for the different changes in spring high discharges in southern and northern drainage basins may be the following:

Flood increase in northern drainage basins:

(1) aapa-fens lose their water regulation capacity as flood lakes can no longer develop there after drainage,

(2) clearcutting,

(3) forest has not yet grown on the drained marshes (and on the clearcut areas).

Flood decrease or no change in southern drainage basins:

(1) drainage does not affect the water regulation capacity of the raised bogs and spruce swamps as strongly as it does aapa-fens,

(2) clearcutting is limited,

(3) forest grows well on the drained, originally forested marshlands.

(4) lake regulation (Petäjävesi and Salosjärvi)

Table 6. The percentual difference $\Delta = 100\ (HQ_{obs} - HQ_{calc})/HQ_{obs}$ between the observed and calculated spring maximum discharges since the beginning of effective draining (during about the period 1965—1977)

Station	Lat. N	Long. E	F(km^2)	L(%)	Δ(%)
Southern drainage basins					
Aurejärvi	61°56'	23°05'	490	10.6	0
Petäjävesi	62°15'	23°10'	665	5.4	(—10)
Salosjärvi	62°04'	25°10'	895	6.2	(—17)
Vähämultianjärvi	62°25'	24°48'	160	7.5	—12
Kitusjärvi	62°17'	24°04'	565	9.2	—5
Northern drainage basins					
Pääjärvi	62°51'	24°48'	1230	7.8	+8
Koivujärvi	63°27'	26°14'	195	14.1	+10
Murtosalmi	64°12'	29°02'	560	10.0	+1
Änättijärvi	64°24'	29°51'	420	12.2	+4
Lentua	64°12'	29°42'	2065	12.9	+4
Lammasjärvi	64°08'	29°31'	3480	11.1	+12

5. DISCUSSION

Until now, only the spring high flow analyses for estimating the possible changes in river regime due to forest draining have been prepared by the regression analysis technique. More accurate results than described above may be achieved after prolonged observation periods. The numerous factors affecting runoff are always changing, however, and the investigations into the ordinary discharge data series possibly never give very accurate results. More exact comparison methods with specially planned observation networks are needed, similar to those used by Mustonen and Seuna (1971) and by others. Such observations are carried out in eastern Finland.

The summer floods differ considerably from snowmelt floods. Snowmelt runoff is limited by melting capacity. With heavy rains there are no such limits, and discharge is determined by evaporation, interception, infiltration, storage and drainage patterns. Thus, wetland draining may well increase the summer high flows more than the spring high flows, as reported by Mustonen and Seuna (1971).

The investigations by Mustonen and Seuna (1971) indicate a considerable decrease in evaporation after draining peatlands, exceeding 100 mm/year in southeastern Finland. If the figure 100 mm/year were applied to all the drained forests and peatlands in Finland, it would mean 5 km^3 less evaporation annually. This is obviously too high a figure, but in any case the decrement in evaporation must lead to a decrement in convective rains. The proportion of the rains that originate from evaporation within the boundaries of Finland is unknown. Based on the distribution of convective and frontier rains in Finland during summer, when nearly all the evaporation occurs, it can be very approximately estimated that the decrease in evaporation causes a decrease of at least 1 km^3 in summer rains in Finland. This effect may be mainly valid in the early summer.

6. NEED FOR FURTHER INVESTIGATIONS

It has not yet been possible to establish the effects of forest drainage on summer and winter low flow. Channel processes due to increased erosion and sedimentation by drainage and by channel improvement are very poorly known in Finland.

The dark airborne particles from highways, industry and densely populated areas accumulating on the snow surface change the radiation balance of the snow and consequently the snowmelting process and runoff; these effects are poorly known. The long term fluctuations in water regime due to climate variations can only be investigated in cooperation with the meteorologists; only little work has been done in this field so far.

ACKNOWLEDGEMENTS

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Helsinki, December 1980
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LOPPUTIIVISTELMÄ

Pitkissä virtaamahavaintosarjoissa esiintyvä vaihtelu on Suomessa peräisin ensisijaisesti ilmastollisten olojen, lähinnä sateen, vaihteluista. Ihmisen toiminta tuntuu virtaamahavaintosarjoissa vain vähäisinä trendeinä tai vuodensisäisinä rytminmuutoksina.

Virtaamaoloihin ovat aikojen kuluessa vaikuttaneet järvenlaskut, peltojen ja metsien ojitukset, hakkuut, metsän- ja peltojen kasvun muuttumiset sekä paikallisesti uitto, uomanperkaukset, kastelu jne. Urbanisoitumisella on vähäinen vaikutus. Nykyoloissa vaikuttavat eniten säännöstely ja metsäojitus.

Vuosivirtaaman pitkäaikaisiin liukuviin keskiarvoihin säännöstely ei sanottavasti vaikuta (kuva 1), kesä- ja talvialivirtaaman liukuviin keskiarvoihin vaikutus on sen sijaan tuntuva (kuvat 2 ja 4).

Vertaamalla keskenään vierekkäisten ja kaukana toisistaan sijaitsevien valuma-alueiden vuosivirtaamia voidaan havaita, että pitkäaikaisvaihteluiden riippuvuus toisistaan vähenee melko nopeasti alueiden välimatkan lisääntyessä (kuva 3).

Tässä työssä on analysoitu hydrologian toimiston pitkäaikaisia virtaamahavaintosarjoja, jotta voitaisiin päätellä metsäojitusten vaikutus kevätylivirtaamiin laajoilla alueilla. Menettelyllä saadaan analyyseille suuri ajallinen ja alueellinen edustavuus, mikä on ollut ongelmana muissa analyyseissa.

Intensiivinen metsäojitus on alkanut 1960-luvun jälkipuoliskolla. Vertaamalla keskenään todellisia kevätylivirtaaman arvoja HQ v. 1965 lähtien ennen tätä vuotta havaittujen arvojen perusteella määritettyjen regressiomallien antamiin tuloksiin voitiin mahdollisia muutoksia estimoida. Parhaiten selittäviksi malleiksi ilmenivät askeltavalla regressioanalyysilla kaavat $HQ = aW + bP + cP_A + d$ ja $HQ = aW + bP + c'MQ_A + d$. Näissä W = lumen vesiarvon maksimi, P = sulamiskauden sadanta, P_A = syksyn sadanta, MQ_A = syksyn virtaama ja a,b,c,c' ja d kertoimia. Eteläisillä alueilla R^2 on keskimäärin 0,78 ja pohjoisilla alueilla 0,82 (taulukko 5).

Eteläisillä alueilla, n. 63. leveyspiiristä etelään päin, kevätylivirtaama HQ näytti pienentyneen ojitusten jälkeen tai pysyneen muuttumattomana, pohjoisilla alueilla suurentuneen. Kun analyysiin liittyy eteläisillä alueilla enemmän epävarmuustekijöitä, mm. ojitusten aloittaminen ennen 1965, voidaan analyysin lopputulos sanoa karkeasti yleistäen: metsäojitus on lisännyt kevätylivirtaamia siellä missä ojia on avattu aapasuoalueilla, ts. Keski- ja Pohjois-Suomessa. Lisäyksen suuruudesta ei voida esittää tarkkoja lukuja; lisäys riippuu ilmeisesti hyvin monista tekijöistä. Lisäyksen hyvin karkea keskiarvo lienee n. 0,5 % valuma-alueen yhtä ojitusprosenttia kohti.

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