VESIENTUTKIMUSLAITOKSEN JULKAISUJA
PUBLICATIONS OF THE WATER RESEARCH INSTITUTE 59

VESIHALLITUS—NATIONAL BOARD OF WATERS, FINLAND
Helsinki 1985

ISBN 951-46-8749-3
ISSN 0355-0982

Helsinki 1985. Valtion painatuskeskus

RIVER DISCHARGE IN FINLAND

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HYVÄRINEN, V. 1984. River discharge in Finland. Publications of the Water Research Institute, National Board of Waters, Finland, No. 59.

A review on the discharge regime in Finland is given. The construction of discharge rating curves for natural channels and the estimation of winter discharge are described. The fluctuations in discharge conditions caused by nature and by man are considered. Annual high flow and low flow are discussed in more detail.

Index words: River discharge, rating curve, ice reduction, land uplift, maximum discharge, minimum discharge.

1. INTRODUCTION

The main properties of the discharges of Finnish rivers are rather well known. The series of discharge measurements are long and reasonably accurate, even in an international context. The discharge measurement network meets the WMO recommendations and may be considered satisfactory, even if the developing society on the one hand and human influences on the other demand continued improvement and expansion. The study of discharges is made easier by the fact that the topographic relief is rather even in Finland and the discharge regime thus does not show abrupt areal changes.

The purpose of this treatise is to complement earlier statistical reviews of discharges of rivers in Finland (Hyvärinen and Gürer 1976, Hyvärinen 1977). These earlier publications contain a wide cellection of mean and extreme discharges, duration and fractile curves, mean discharges for months with low discharge and return periods for discharge maxima, based on the series of discharge observations collected by the Hydrological Office. The general properties and trends of the discharge regime, however, have not been discussed.

A complete description of the discharge regime in Finland would require not only an extensive review of all the studies already performed but also a large number of additional investigations, which in many cases would be extremely laborious or otherwise difficult to perform. Therefore, this paper is somewhat rhapsodical in composition. The following topics are discussed: Special features of the determination of discharges in Finland, changes in the discharge regime due to natural and human causes and relationships connected with maxima and minima of the discharge.

2. DETERMINATION OF THE DISCHARGE

2.1 General

The first discharge measurements in Finland were made in the eighteen-sixties with a Woltmann vane. Before the end of the nineteenth century 193 discharge measurements had been made and by 1914 close to 1000 (Sirén 1974).

The discharge measurements and the discharge determinations based on rating curves determined with such measurements may be regarded to have met approximately the present ISO standards 748, 1100/1, and 1100/2 from the beginning of the present century. The measurements were performed and the results evaluated along the lines developed by Harlacher in the eighteen-seventies and eighties and presented as a systematical method by N.N. Zukovskij shortly after 1900. This is the well-known method of velocity profiles, nowadays in general use all over Europe. The development of the method has been described in detail by Kopupaila (1940).

In Finland, the discharge measurements and construction of rating curves have from 1910 onwards mainly been the responsibility of the Hydrographic Office, founded in 1908. From 1980 onwards, the Hydrological Office, this being its present name since 1959, has recorded discharges at the 350 stations of the national network. The discharge file contains about 11 000 station-years of observations, or 4 million day discharges. Additionally, about half a million days of runoff data from small hydrological basins are also on file.

A dominating part of the discharge data have been computed from observed water stages using appropriate rating curves. However, a growing percentage of the discharge data consists of values obtained from hydroelectric power stations using output, head and efficiency data; in 1982 discharges from 120 power stations were filed. About 60 measuring weirs for the determination of the discharge from small hydrological basins were operative at the beginning of the nineteen-eighties.

An abstract of the discharge data is published in the hydrological yearbooks and in the monthly hydrological reports. Statistical digests, such as time and fractile curves, tables of return times for low and high flows, duration curves, etc., have also been published, as mentioned in the introduction.

Abstracts of the measuring weir data from small basins have been published separately (Mustonen 1971, Seuna 1982 and 1983). The discharge data in the files of the Hydrological Office have been used in an appreciable number of scientific studies.

2.2 Rating curves

The rating curves constructed at the Hydrological Office for naturally flowing channels are based on simultaneous flow measurements and water stage readings. Until about 1965 they were plotted on arithmetical millimeter paper. In the nineteen-sixties a change was made to log-log paper, because it could be confirmed that the connection between the discharge Q and the water stage W is rather well approximated by the function

$$Q(W) = a(W-c)^b \qquad (1)$$

where the constants a and b depend on the geometry of the channel and the constant c representes the threshold water stage, i.e. the effective or hydrodynamical sill height on the water gauge. In Finland, the value of the constant b varies around the value 2.0 (Table 1, see also Hyvärinen and Forsius 1982).

For some rating curves in use in Finland $b \leqslant 1.5$, which means that the discharge is not exclusively a hydromechanical function of the water stage above the sill. In practice, these rating curves have rendered reasonably good discharge values as long as the water stage changes slowly and natural events are not tampered with. However, when the water stage changes rapidly because of short-term regulation these rating curves become unreliable.

A major part of the old rating curves plotted before 1960 on millimeter paper in the Hydrological Office (310 curves) were replotted on log-log paper to obtain an estimate of to what extent the extrapolated part in the HQ area might have been deceptive in the arithmetical representation. Most of the empirical curves proved to agree rather well with a check with equation (1) or with the new curve on log-log paper. However, some of the old curves gave HQ values too small in 10 % of the cases, in the extrapolated area even up to 25 %. In a few cases, the reverse was found to be true. The error introduced by the old method is almost insignificant, however, because water stages and discharges seldom move at the extreme ends of the rating curves.

2.3 Ice reduction

Ice in its different forms poses a special problem in the determination of discharge in northern countries such as Finland. About one out of three rating curves becomes useless every winter because the hydraulic properties of the control part of the channel are changed by damming.

Formerly, the winter discharge was determined by applying an ice reduction to the water stage readings to compensate for the influence of the ice. From the ninteen-sixties onwards, the ice reduction has been determined in the Hydrological Office graphically on semilogarithmic paper (Hyvärinen 1973 and 1980). The use of this paper was adopted after it had been observed that the winter discharge in central and northern Finland often — but not always — decreases exponentially:

$$Q(t) = Q_o\, e^{-kt} \qquad (2)$$

where Q_o is the discharge before the formation of ice, t the time from freezing and k a constant which varies from one location to another and from winter to winter (see Figures 1 and 2).

The present routine of evaluating winter discharge is based on equation (2) together with two field measurements, one in the first part of the winter and one at the end of the winter. The constant k varies in an unpredictable manner (Hyvärinen 1980), usually between 0.007 and 0.01 d^{-1}. The resulting graph of the discharge obtained by the process described is shown in Figure 3. All the information obtained which may be of assistance when the ice reduction is calculated is taken into account: the discharge in sections of the same watercourse where no ice reduction is necessary, information from compar-

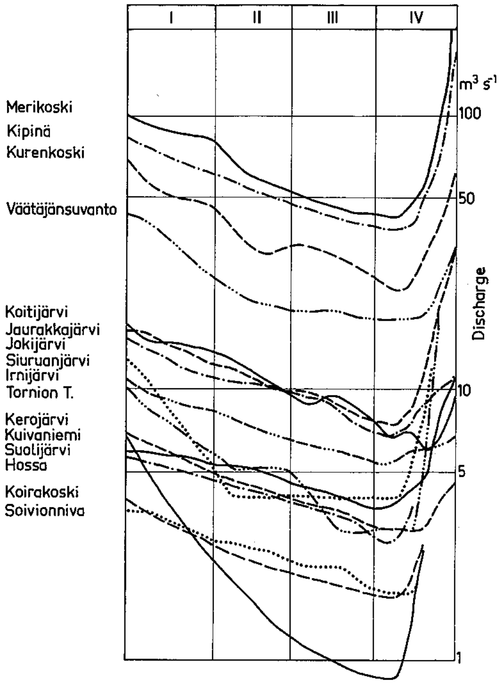


Fig. 1. Winter discharge at some measuring sites in northern Finland in 1964.

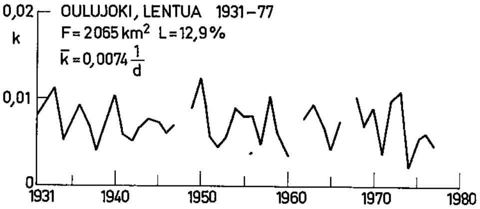


Fig. 2. An example of coefficient k of Equation (2).

Table 1. The mean values of the exponent b in the equation Q = a $(w-c)^b$ together with the standard deviation s and the variance C for northern Finland, the coastal areas and the lake district as obtained with the adjustment methods PNS, VAK and LOG, the number of cases being n. PNS = method of least squares, VAK = minimization of the relative deviations, LOG = logaritmic weighting.

Adjustment method		Northern Finland n = 11	Coastal areas n = 8	Lake district n = 10	Whole country n = 29
PNS	$\bar{b}$	2.068	1.919	1.713	1.904
	s	0.436	0.343	0.592	
	C	0.173	0.103	0.315	
VAK	$\bar{b}$	2.079	2.267	1.955	2.088
	s	0.416	0.329	0.846	
	C	0.157	0.089	0.640	
LOG	$\bar{b}$	2.052	1.934	1.752	1.915
	s	0.402	0.309	0.588	
	C	0.147	0.083	0.311	

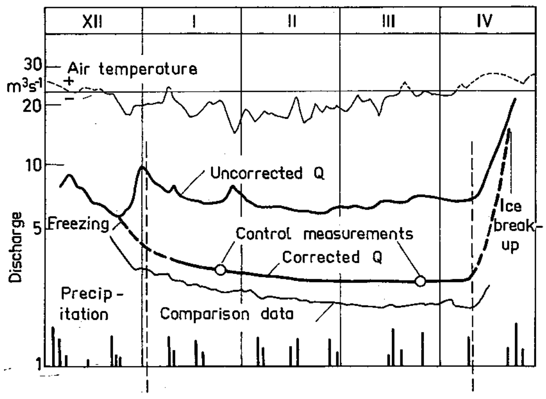


Fig. 3. Graphical ice reduction schematically. Semilogarithmic paper.

able watercourses, temperature data, times of ice formation and break-up, etc.

The method of determining the ice reduction described above is a modification of the methods in general use in northern and central Europe. These methods have been reviewed by Kovalev (1938) and presented in detail by Kolupaila (1939). In Finland, Saarinen (1960) has studied ice reduction for the River Eurajoki.

The discharges arrived at by application of ice reduction are of necessity less accurate than those arrived at for the period of open water. The winter discharges may in a few cases even after a laborious reduction be incorrect by as much as 20 %.

3. THE DISCHARGE REGIME

3.1 General

The term discharge regime is here meant to cover not only the runoff regime but also the influence of the hydraulic factors on the real discharge. Thus even the influence of human interference is covered.

The interrelation of the various entities connected with the hydrology of watercourses in Finland is shown in Fig. 4. The prime motors of the changes in discharge are climate and weather. The soil, geomorphology, vegetation and other natural factors modify the runoff. Additionally, in modern times the resulting discharge to a large degree depends on intentional and unintentional human interference. In the following, several aspects of the discharge regime in Finland will be considered.

A large number of publications cover the mean discharges and variations in discharge in the many river systems of Finland, as mentioned in section 2.1. Here we will pass these by and concentrate on some principal aspects. By way of a summary the character of the discharge regime in the period 1931 to 1960, expressed as MHQ/MNQ, is shown in Fig. 5.

3.2 Land uplift

The dominating geological phenomenon influencing discharges in Finland is the land uplift. The spatial configuration of the watercourses is continuously changing as the bedrock foundation of the country slowly tilts even more towards the southeast in southern and middle Finland and towards the northeast in northern Finland. The rate of land uplift is greatest along the coast of the Bay of Bothnia, about 9 mm a^{-1} and smallest in the southeast, about 2.6 mm a^{-1} (Kääriäinen 1963).

The consequences of this land uplift, with regard to the discharge regime, are:

1) The continental area of Finland is increasing along the Bothnian coast and the coast of the Gulf of Finland and the discharge areas of the rivers are also increasing. According to Renqvist (1929, ref. Hustich 1964), the land area of Finland increases because of land uplift, sedimentation and plant growth by almost 1 000 km^2 per century. With a runoff Mq = 1 s^{-1} km^{-2}, the discharge into the sea increases by 0.7 m^3 s^{-1} every year. According to Kukkamäki (1956) the increase is 710 km^2/100 a; consequently the discharge increases by about 0.5 m^3 s^{-1} annually.
2) The Suomenselkä divide is shifting gradually over towards the northwest. Thereby the drainage areas of the lake district increase at the expense of those of the Ostrobothnian rivers. A dramatic shift of the divide occurred when the water of the lake district of central Finland broke through the Salapusselkä esker forming the southeastern barrier, giving rise first to the river Kymijoki in about 6 000 BC and then to the Vuoksi river in about 5 000 BC. Before this the discharge from the lake district followed the present Kalajoki river to the Bay of Bothnia.

3) Because most of the lakes in the lake district have their outlets at the southeast or south of the country, the tilting of the bedrock causes the lakes to empty at a very slow rate. On average, the loss of water is less than 0.2 $m^3 s^{-1}$ as can be seen in Table 2.

On the major lakes, Oulujärvi is becoming larger because the outlet sill rises more rapidly than the main basin. The Kyrönsalmi narrows will eventually divide tha large Lake Saimaa into two lakes. At present, however, the narrows are so deep that the water level difference between the two parts of the lake has not begun to increase as yet. Furthermore, the shipping channels in the Saimaa system were dredged in the nineteen-sixties, which reduced the small differences in water level between the various parts of lake Saimaa (Hyvärinen and Forsius 1982).

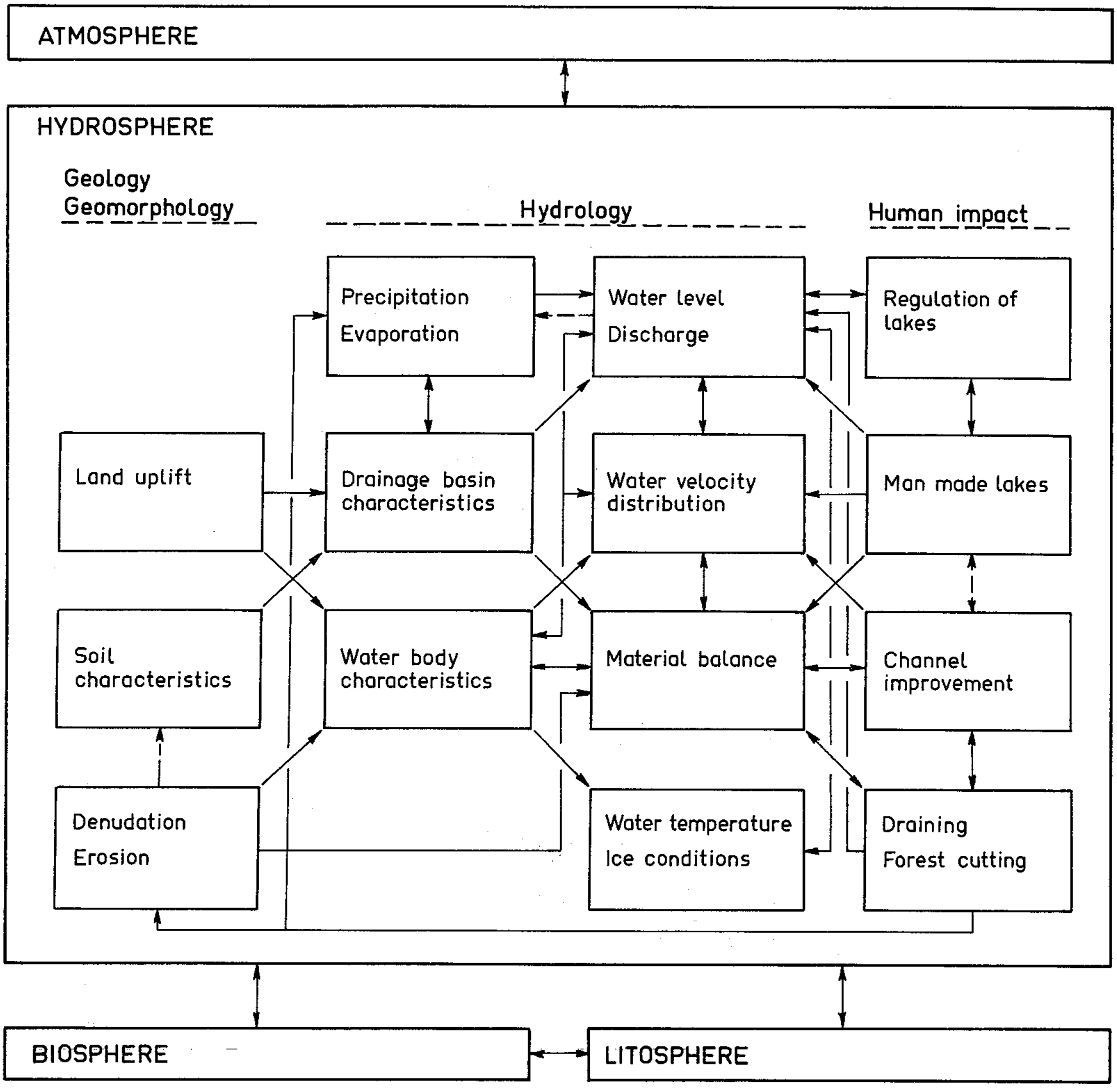


Fig. 4. Interrelations of various entities connected with the hydrology of watercourses in Finland.

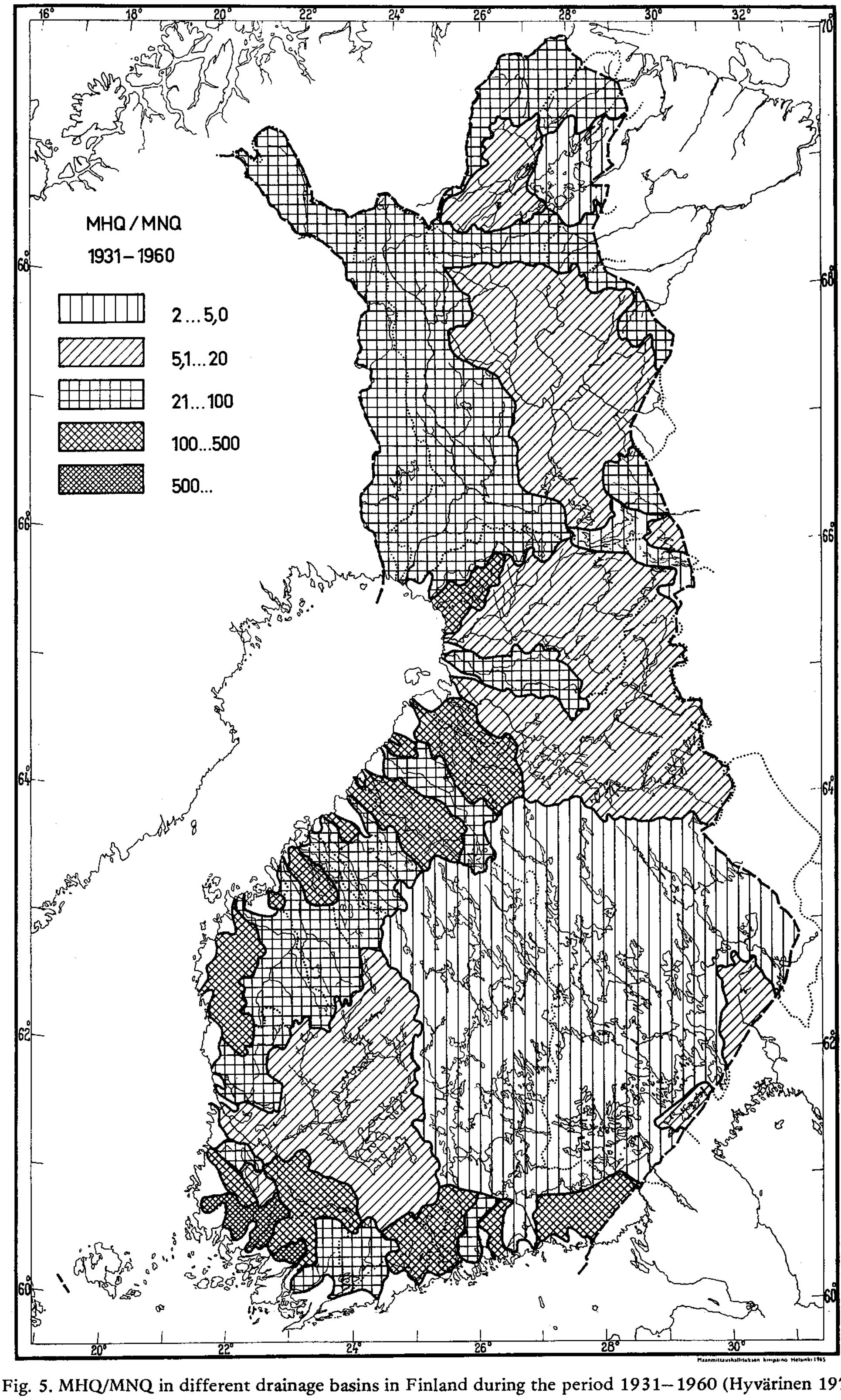


Fig. 5. MHQ/MNQ in different drainage basins in Finland during the period 1931–1960 (Hyvärinen 1974).

Table 2. The tilting of some major lakes due to uneven land uplift and the discharge caused by the tilting.

Lake	Area	Tilt mm a^{-1}		Change in volume 10^{-3} km^3 a^{-1}	Increment in discharge m^3 s^{-1}
		Sirén	Kääriäinen		
Pielinen	850	2.0	1.2	−0.8 . . .−0.5	0.016 . . .0.027
Kallavesi	710	1.0	1.0	−0.36	0.011
Suur-Saimaa	4 380	(1.5	2.0)	(−3.3 . . .−4.4)	(0.1 . . .0.14)
Keitele	485	1.5	0.4	−0.36. . .−0.10	0.01 . . .0.003
Päijänne	1 090	1.4	1.4	−0.76	0.026
Näsijärvi	280	(0.5)	1.0	(−0.07. . .−0.14	(0.002). . .0.004
Oulujärvi	890		−0.8	+0.36	−0.01
Inari	1 050	(2.0)		(−1.1)	(0.02)
Total					ca. 0.19

3.3 Lowering of lake levels and flood protection

Since the eighteenth century, lakes have been drained completely or their levels have been lowered to supply Finland with more arable land. This trend has continued to the middle of the present century. The most intensive activity in this direction took place in the middle of the nineteenth century, but a period of intense drainage occurred as late as after the second world war, when the refugees from ceded Carelia were resettled all over Finland and there was a desperate need for new agricultural land.

Lake drainage, upstream flood protection and forestry drainage caused a significant increase in the risk of flooding in the middle and lower reaches of rivers. This was compensated for the construction of artificial lakes from 1960 onwards. In northern Finland and in Lapland the artificial lakes are primarily or exclusively used for power storage.

There is no nationwide inventory of lake drainage activities in Finland. Because of this, only some examples can be cited in the following. The total decrease of lake surface from 1700 to 1960 may be taken to have been about two per cent. How drainage activities influence a watercourse depends largely on the nature of the watershed, primarily its area and lake percentage. The changes have been most drastic in the smaller rivers with only a few lakes in the coastal areas of the Gulf of Finland and the Gulf of Bothnia. In some of these the lake percentage was reduced to less than half, even almost to zero.

When a new outlet wad dug for lake Höytiäinen and the current ran out of hand in August 1859, the lake level fell by at least seven meters in one rush; when the sill was lowered further the next year the lake level was estabilised 9.6 meters below the original. The lake area decreased from 440 km^2 to 285 km^2 and the volume by about $3.5 \cdot 10^{10}$ m^3. The peak discharge through the Höytiäinen channel has been assessed at about 5 000 m^3 s^{-1} (Saukko 1960). In Kyrönsalmi between the upper and lower Saimaa the discharge increased to about 1 500 m^3 s^{-1}; the level of Pyhäselkä rose by about 2 m in August and that of lower Saimaa by about 0.6 m in August-September.

In the Kalajoki river basin (F = 4 310 km^2) the lake area decreased by 88 km^2 between 1700 and 1960, the lake percentage decreasing from 3.9 to 1.8. Most of the lake draining took place between 1850 and 1870. Since 1960 the construction of artificial lakes has increased the total lake area by 22 km^2 and the lake percentage by 0.5. According to the nomograms of Kaitera (1949) the mean annual high discharge has increased by about twenty per cent in the lower section and about 100 % just below the largest drained lake, Kalajanjärvi, which has an area of 40 km^2 (Hyvärinen 1983).

Elsewhere in Ostrobothnia the consequences of lake drainage will have been of the same order. Thus in the Vaasa water district (A = 16 000 km^2) the lake area has decreased by almost 90 km^2 since 1800 according to the files.

Haapanen and Waaramäki (1977) have compared old and new maps in their study of the living conditions of waterfowl and concluded that in the river basins of Ihodenjoki and Sirppujoki the lake area decreased from 31 km^2 to 15.5 km^2 from the end of the nineteenth century to

1972. This, too, has increased the discharge maxima by some tens of per cent.

When the mean discharge maxima are increased by ten per cent, the frequency of a predetermined discharge maximum is doubled (Hyvärinen 1977) in a typical Finnish river (c.f. Fig. 12 and 13).

Flood control, by dredging of rapids, building of embankments, or other means, changes the discharge in the same manner as lake drainage. In both cases the change may be evaluated from the spatial dimensions of the lake or the flooded area, the rating curve and the inflow (and evaporation) by the usual storage routing calculations. The change is illustrated in Fig. 6, showing how much the storage routing calculation predicts an increase in the discharge maximum for a given reduction in the flooded area. Here, the spring inflow I(t) into the flooded area has been taken to have the volume

$$V = \int I(t)\,dt = 100\ \text{mm} \qquad (3)$$

and the peak run-off $Hq = 100\ \text{l}\ \text{s}^{-1}\ \text{km}^{-2}$. The inflow time curve I(t) chosen was a typical one for the Ostrobothnian Kaidesluoma watershed ($F = 79\ \text{km}^2$), where the slope of the flat basin is 0.3 %. The curve shown is valid under the stated conditions only, but this example should represent rather well the conditions prevailing in those parts of Finland where flooding is a common phenomenon.

Lake drainage and flood protection cause the annual evaporation sum to decrease, as evaporation from a free water surface is greater than that from soil. This still more aggravated the increase of discharge caused by the change in hydraulic factors.

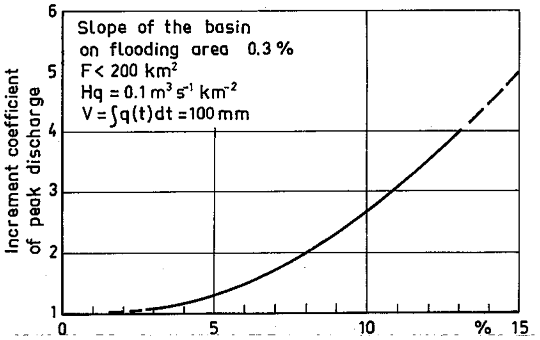


Fig. 6. The increment coefficient of peak discharge as a function of drained flooding area.

3.4 Regulation

The regulation of watercourses in northern Finland aims at supplying hydroelectric power, primarily in winter. By means of regulation it is possible to store the spring meltwater for use in the following autumn and winter. Thus in spring and summer the discharges decrease, to increase in winter as compared to the natural flow. Farther to the south, regulation often aims at flood protection. The requirements of flood protection and power production are often conflicting.

In Finland, natural as well as artificial lakes are used as storage basins for regulating discharges. How the regulated lake area has grown may be seen in Fig. 7.

In 1980, 156 lakes with area exceeding 1 km^2 were regulated, as well as 30 artificial lakes. Their total area was 10 700 km^2, of which 935 km^2 were artificial lakes. Most of the lakes serve multipurpose regulation: 128 power production, 71 flood protection, 37 navigation and 6 recreation (Vesihallitus 1983).

The way in which regulation influences the discharge varies from case to case and is predictable. Two typical examples are shown here. Fig. 8 shows the curve of mean daily discharges at the outlet of the river Oulujoki before and after regulation by season and Fig. 9 the hourly discharges in

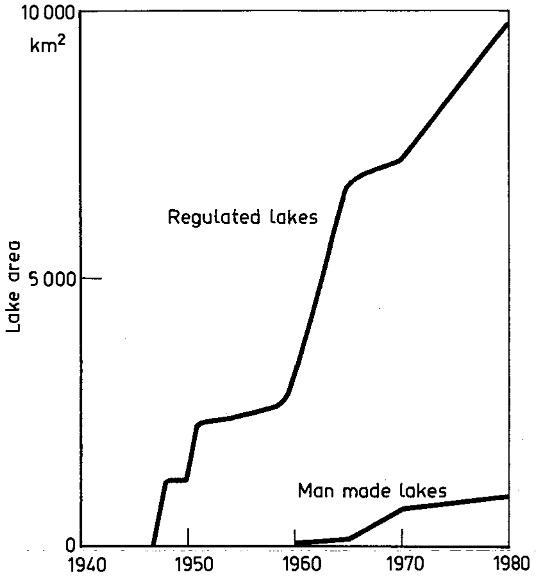


Fig. 7. The total area of regulated lakes in Finland in 1940–1980.

winter in a harnessed rapids of the Iijoki river regulated for peak demand. At the Hydrological Office a model has been developed (Forsius 1983) for calculating how the channel modifies the downstream discharges in a river regulated for peak demand.

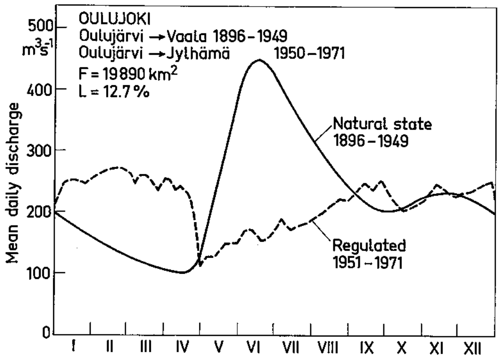


Fig. 8. Mean daily discharge in the Oulujoki river before regulation during the period 1896–1948 and during regulation 1951–1971.

3.5 Forestry techniques

Forests cover about 200 000 km^2 or 63 % of the area of Finland. Almost all of woodland is subject to commercial forestry. The three stand influences precipitation, evaporation and runoff and therefore large-scale forestry measures are expected to influence the hydrological balance. This influence has been the subject of many studies in Finland. In the following the main outlines will be reviewed.

Logging has all over the globe been observed to enhance the extremes of discharge. In Finland, forest growth and logging have largely been in balance, and thus the net effect has been relatively small. The logging over large areas in northern Finland after 1950 must have raised the discharges somewhat even in large rivers, but no thorough analysis has been made.

Forestry draining has increased mean and maximum discharges, as has been shown in many studies (Mustonen and Seuna 1971, Seuna 1980, Vehviläinen 1979, Hyvärinen and Vehviläinen

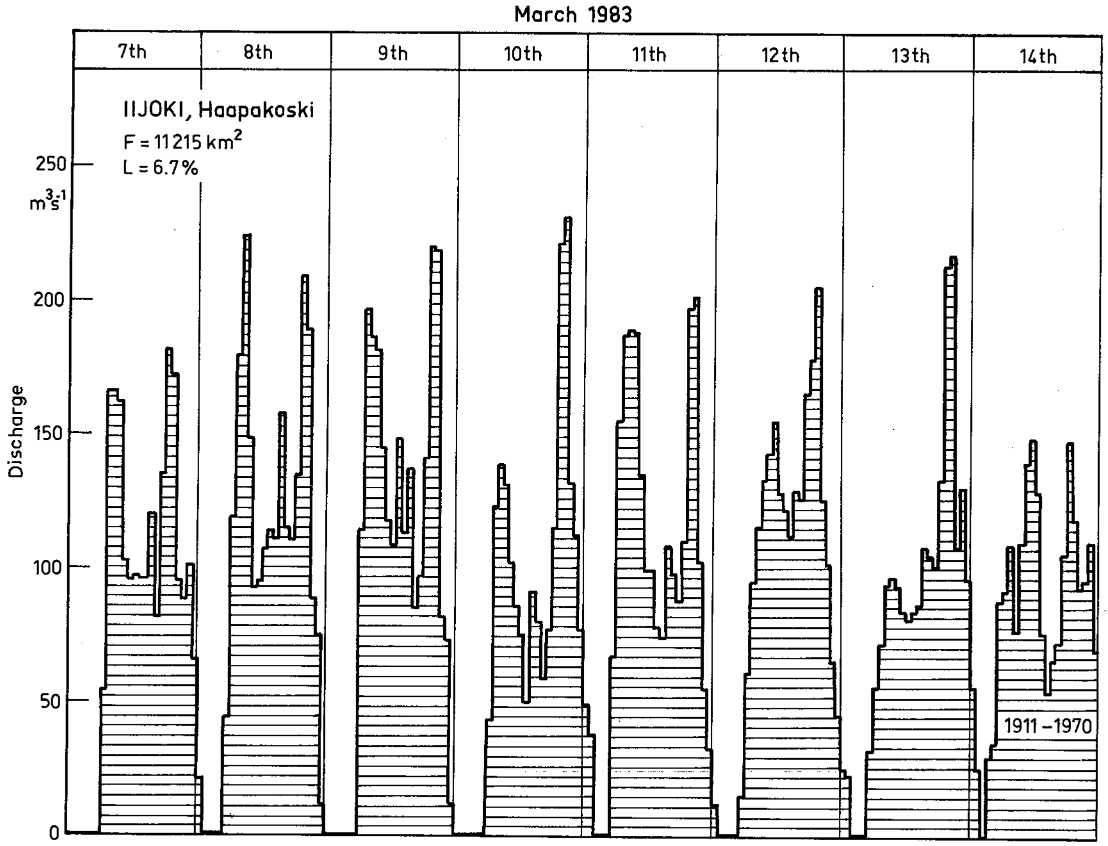


Fig. 9. Discharge through the Haapakoski power plant in Iijoki from 7th to 14th March 1983.

1978 and 1980). However, in some cases the discharge has leveled out (Heikurainen 1980). Measurements in small experimental basins show that the seasonal low discharges in summer and winter have increased. However, in large areas the annual discharge curves show that the major change is a decrease of the summer low discharge after ditch draining. These conflicting findings must be a consequence of the large number of variables involved, the ditching techniques used and the complexity of the run-off process. It is impossible to obtain a conclusive picture of the influence of woodland ditchdraining at present, but it seems that the summer discharge maxima have increased throughout Finland and the spring discharge maxima in most parts of central and northern Finland. Rather certain, as might logically be expected, is that the influence of the change decreases with time: after ten to twenty years the effect has reduced markedly, conceivably because the enhanced growth of the tree stand on the drained area increases evaporation and alters the snow situation (Seuna 1980 and 1983).

Drainage reduces the free water surface after the snow melt, especially on the fens. This leads to reduced evaporation, as does a drier soil surface. This in turn also influences the hydrological cycle outside the watercourse concerned. Global atmospheric models lead to the conclusion that the global distribution of precipitation depends to a much greater extent on continental surface phenomena, such as evaporation, than had previously been postulated (Mintz 1981). Sokolov (1978) found indications in this direction when studying the water balance in Europe. Drainage of large areas with a consequent decrease of evaporation must thus lead to a decrease of precipitation, most markedly in early summer. The decrease of precipitation may be expected to be equal to the decrease in evaporation, but it is difficult to assess the size of the geographic areas over which the difference is spread out. In Finland, the decrease in evaporation due to drainage is thought to be of the order of 1.0 km^2 per annum.

The channels of rivers and streams have been modified to suit **log rafting and floating** in most parts of Finland since the nineteenth century and particularly in the first part of the twentieth century. At the same time the hydraulic properties of the channels have changed. These changes have been of three kinds:

1) Dredging to make the channels suitable for rafting and floating has speeded the flow.
2) Booms and moorings, as well as timber in floating storage or in transit, dam up the discharge. This counteracts the aforementioned effect 1).
3) To make the discharge as steady as possible and sufficiently large during the floating season, the floating companies have stored spring melt-water in the headwaters and drawn it off gradually during the summer.

On the whole, rafting and floating activies have tended to reduce the spring maxima in the middle and lower sections of the rivers and to raise the summer discharge. This may be seen qualitatively in the discharge statistics of many rivers, but no quantitative analysis has been made. The change seems to be masked by other interference. Since the river transportation of timber was largely replaced by road transport after the middle of the twentieth century, the variations in discharge in spring and early summer have again increased in comparison to the first part of the century.

3.6 Other human interference

Irrigation

In Finland around 1980, there was sprinkler gear for irrigating about 60 000 hectares of tilled land. Most of this gear was stationed in the coastal area of southwestern Finland, where an early summer drought often limits the crop.

During a typical dry summer about 400 km^2 of land are irrigated, primarily only in June. Sprinkler doses are given on average 1.5 times per dry summer and amount to about 30 mm each. This corresponds to somewhat less than $2 \cdot 10^6$ m^3 of water needed, or spread over the whole of June, 0.7 m^3 s^{-1}. Mostly, however, the need for irrigation arises at the same time on all farms and the total amount of irrigation water is used within a few days: this raises the peak consumption to many times the stated 0.7 m^3 s^{-1}. As irrigation is dominantly applied in the southwest of Finland, where the watercourses carry only little water in summer, irrigation may use an appreciable part of the total discharge.

Routing water from one watercourse to another

From 1960 onwards and especially since 1970 water has been transferred from one watercourse

Table 3. Water transfer from one river basin to another in Finland.

From	To	Discharge $m^3 s^{-1}$	Years of operation
Kymijoki, Vesijärvi	Porvoonjoki; water protection	0.1 . . . 1.1	1979–
Kymijoki, Päijänne	(Vantaa) Helsinki region water consumption	0.1 . . . 2.3	1979–
Karjaanjoki, Hiidenvesi	Vantaa; Helsinki region water consumption	0 . . . 1.9	1969–1977
Paimionjoki	Aurajoki; Turku water consumption	0 . . . 0.5	1966–
(Eurajoki) – Lapinjoki	(Lapinjoki)–Rauma; water consumption	0.6 . . . 1.4	1962–

to another for water supply and water protection. The most notable projects are shown in Table 3.

4. DISCHARGE MAXIMA

4.1 General

The annual maximum discharge and the maximum discharge for a certain part of the year are among the most important parameters connected with the utilization of watercourses. Depending on the mode of utilization, the parameter of interest studied in Finland has been mean annual maximum discharge MHQ, the largest discharge ever measured HQ or the discharge which on average during a period of time T_r reaches or exceeds a threshold value $HQ1/T_r$ only once. The concepts highest conceivable discharge, maximum maximorum, or probable maximum flood have hardly found application in Finland.

The first printed scientific study of floods in Finland may be that by Kekonius and Gadd (1786). They ascribed heavy floods in the eighteenth century to the clearing of woodlands with the spread of habitation. The record floods of 1898–1899 led to an intensive study in this field and effective hydrological observations on a regular basis. The report of the Committee on Floods (Tulvakomitea 1939) throughly reviews all flood investigations up to that year. Between 1930 and 1970 equations were set up and nomograms drawn for the determination of MHQ and $HQ1/T_r$ etc., with the physiographic factors of the river basin and precipitation as well as snow observations as input data (Kaitera 1949, Niinivaara 1961, Mustonen 1968). After 1970, long observation series being available and computers having come into general use, statistical digests of the discharges were made (Hyvärinen and Gürer 1976, Hyvärinen 1977, Seuna 1982), statistical-mathematical distributions were analysed to determine how well they fit the recurrence probabilities of extremely high discharges (Kuusisto and Leppäjärvi 1978, Leppäjärvi 1979) and models were constructed for describing how floods develop (Kuusisto 1978, Karvonen 1980, Vehviläinen 1982, Seuna 1983 etc.)

When using MHQ, $HQ1/T_r$, nomograms, sets of curves for determining return times, or the distribution of HQ, it is presupposed that these quantities are objectively meaningful, i.e. that the discharge regime is stable over a long period of time and thus that the parameters which determine the discharge do not change. These parameters are thought, in a way, to be constants of nature. The stability concept is based on general geophysical considerations: the regular succession of seasons, the rather constant intensity of solar radiation, the slow rate of geological change, etc. The weather is taken to be the cause of random variations in the water balance and to determine the values of the parameters of distributions describing the variations.

On the other hand, the influence of changes in the environment on the discharges has been sought for and also found. No general agreement has been reached on which mathematical distribution should be applied when studying meteorological and hydrological concepts; one set of observations requires one distribution, a second set requires another. With pure statistical mathematics it can be shown that statistical variations allow large differences between two separate periods of observation although the regime remains unchanged and the distribution chosen is the same (Raudkivi 1979, Bell 1969 etc.), c.f. Fig. 12.

Here one example, illustrative of conditions in Finland, is given of how a change in the regime, human interference and meteorological factors may become entangled and of how difficult it is to determine "objective" criteria for dimensioning: The Uljua artificial basin was built in the late nineteen-sixties in the river Siikajoki watershed. The storage basin is supplied by the river Lamujoki ($F = 1\ 300\ \mathrm{km}^2$, $L = 0.9$ %), and in the planning stage the annual high discharge with a return period of twenty years was computed, using nomograms and comparison watercourses, as $HQ1/20 = 215\ \mathrm{m}^3\ \mathrm{s}^{-1}$. When the basin was ready the measured annual high discharges, when plotted into Gumbel paper, showed $HQ1/20 = 390\ \mathrm{m}^3\ \mathrm{s}^{-1}$. This difference is obviously much too large to be explained by random variations only. One reason for the discrepancy is the drainage of woodlands at this time, which was carried out in almost 40 % of the discharge area, channel dredgings, etc. As the weather conditions also underwent a change resulting in an increased spring discharge, it is almost impossible to discriminate exactly the different causes from one another in this case (Hyvärinen 1982b).

4.2 Distribution in time of discharge maxima

Moving five-year averages of the annual maxima of the discharges for three observation stations are shown in Fig. 10, together with moving five-year weighted means. The latter have the weights 0.1, 0.2, 0.4, 0.2 and 0.1 and deviate from the arithmetical averages by only 5 %, with the extremes falling on the correct year in most cases.

The standard deviation of the annual maximum discharge is some 25 to 40 %, with a mean value of about 30 %; a few examples are shown in Table 4.

Table 4. Mean annual discharge MHQ and its standard deviation σ_{HQ} at some stations in Finland.

Station	MHQ	σ_{HQ}	
	$\mathrm{m}^3\ \mathrm{s}^{-1}$	$\mathrm{m}^3\ \mathrm{s}^{-1}$	%
Kallavesi, Konnus + Karvio	326	94	29
Kymijoki, Petäjävesi	43	18	42
Vantaa, Oulunkylä	134	40	29
Kyrönjoki, Skatila	310	104	34
Tornionjoki, Karunki	2 188	502	23
Juutuanjoki, Saukkoniva	297	109	38

4.3 Return periods of the maxima

The ratios HQ/MHQ for return periods of 5, 10, 20, 50 and 100 a area shown for 52 observation stations in Table 5. The HQ have been chosen from a return period diagram to represent the various regions of Finland (Hyvärinen 1977). The length of the observation series was 44 ± 21 a.

According to Kaitera (1949) $Hq1/10 = 1.5$ MHq and $Hq1/50 = 2$ MHq for large discharge areas. According to Niinivaara (1961), this ratio depends on the lake percentage L in such a manner that it is at its largest for values of L between 12 and 15 % and at its smallest for very small and very large lake percentages. Mustonen (1968) has calculated the values $Hq1/10 = 1.67$ MHq and $Hq1/20 = 1.90$ MHq for small lakeless basins. The findings of Kaitera, Niinivaara and Mustonen are compared to those taken from Table 5 in Table 6.

In order to check the conclusions of Niinivaara, the data in Table 5 were used to determine the coefficients A, B and C in the equation

$$HQ/MHQ = A + BL + CL^2 \tag{4}$$

with regression analysis for the return times T_r of 5, 10, 20, 50 and 100 a. The results are shown in Table 7 and Fig. 11; they support Niinivaara's conclusions, but note the large deviations. The fact that the ratios HQ/MHQ have smaller values in the present material is easily explained by the use of different input data.

Mean values of the ratios HQ/MHQ in Table 5 may also be used as shown in Fig. 12. Here the return times as estimated on Gumbel paper are presented together with the theoretical 68 % confidence limits for obaservation series covering 25 and 100 years, represented by the horizontal bars (Bell 1969).

The empirical return time curve of HQ/MHQ ratios in Fig. 12, based on chosen HQ values, is compared to analytically calculated curves in Fig. 13. The empirical curve is based on the 52 observation stations listed in Table 5, whereas

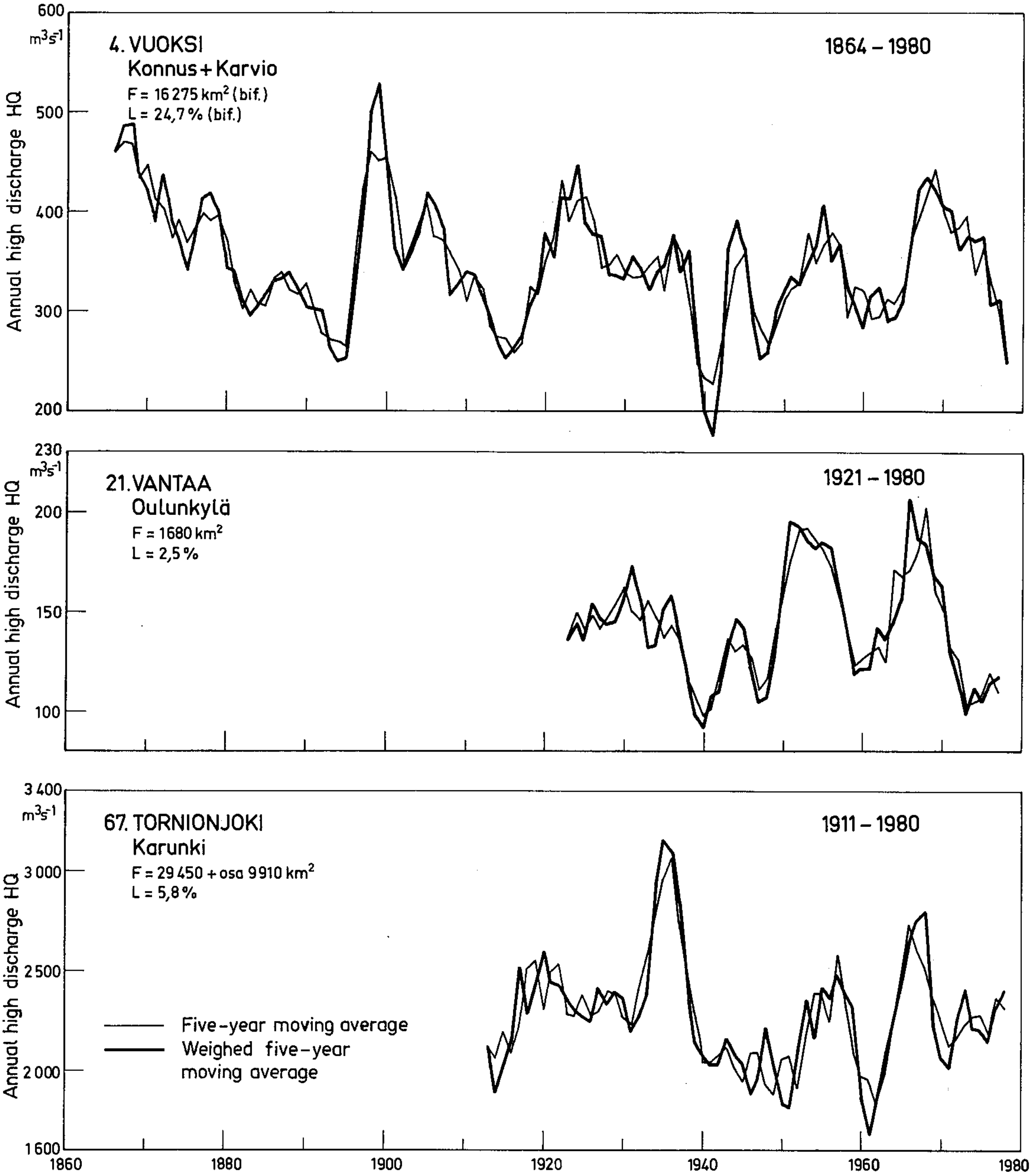


Fig. 10. Five year weighed average of annual high discharge in some Finnish rivers. The weights are: 0.1, 0.2, 0.4, 0.2, and 0.1.

Table 5. HQ/MHQ for different recurrence periods T_r (Hyvärinen 1977).

Station	F	L	Period	MHQ	HQ/MHQ				
					T_r (a)				
	km^2	%		m^3 s^{-1}	5	10	20	50	100
04 07700 Hiiskoski	2 125	12.4	1911–1954	54	1.16	1.31	1.41	1.54	1.63
04 08500 Höpöttäjänvirta	8 115	10.9	1937–1973	225	1.24	1.44	1.64	1.89	2.04
04 02410 Lylykoski	4 290	8.4	1936–1973	118	1.20	1.37	1.53	1.74	1.91
04 03700 Jakokoski	21 225	12.6	1911–1970	380	1.18	1.33	1.46	1.64	1.78
04 01100 Roukkajankoski	880	4.4	1963–1973	88	1.14	1.25	1.36	1.50	
04 04810 Puntarikoski	1 425	22.1	1941–1957	30	1.25	1.43	1.60	1.87	
04 06400 Viannonkoski	5 570	7.6	1881–1946	270	1.22	1.41	1.56	1.78	1.93
04 08087 Konnus+Karvio	16 270	15.3	1931–1973	360	1.18	1.32	1.46	1.65	
04 08610 Palokki	2 110	21.8	1911–1960	43	1.26	1.46	1.67	1.93	2.14
04 11750 Imatra	61 270	19.9	1847–1973	730	1.11	1.20	1.30	1.40	1.50
14 02210 Kapeekoski	9 515	15.3	1911–1973	192	1.20	1.34	1.50	1.68	1.82
14 04110 Simunankoski	6 880	20.7	1910–1973	100	1.20	1.35	1.52	1.74	1.90
14 06566 Kalkkinen	26 480	19.5	1911–1969	350	1.16	1.27	1.38	1.51	1.64
16 00110 Pyhäjärvi, l.	455	6.1	1954–1973	30	1.40	1.73	2.00	2.40	
19 00300 Ridanfors	780	2.5	1932–1965	73	1.23	1.41	1.60	1.80	1.99
21 01700 Oulunkylä	1 680	2.5	1937–1970	155	1.26	1.48	1.68	1.94	
35 04700 Kituskoski	565	9.2	1911–1972	21	1.22	1.39	1.56	1.80	1.95
35 05200 Kurenkoski	160	7.5	1931–1973	7.8	1.15	1.28	1.37	1.51	1.74
35 07900 Poltinkoski	490	10.6	1933–1973	19.5	1.22	1.38	1.56	1.79	
35 09400 Maurialankoski	2 650	3.5	1931–1973	218	1.33	1.56	1.81	2.15	2.38
35 10450 Harjavalta	26 025	11.8	1931–1960	590	1.17	1.31	1.44	1.61	
42 00600 Hanhikoski	3 815	1.1	1951–1973	280	1.25	1.46	1.68	1.93	
42 01000 Skatila	4 805	1.0	1911–1973	315	1.19	1.33	1.49	1.67	1.83
44 00600 Keppo	3 955	2.8	1931–1973	195	1.23	1.42	1.59	1.85	
51 00200 Lestijärvi, l.	380	20.2	1921–1973	6.4	1.19	1.34	1.50	1.67	
53 00800 Hihnalankoski	3 025	1.8	1911–1971	268	1.21	1.37	1.53	1.74	
54 00400 Pyhänkoski	3 400	5.7	(1912–1971)	225	1.22	1.40	1.60	1.83	
57 00700 Länkelä	4 395	1.5	1936–1973	470	1.15	1.28	1.39	1.55	
59 00900 Ristijärvi, l.	8 685	7.5	1911–1962	440	1.31	1.57	1.82	2.11	2.36
59 01300 Änättijärvi, l.	420	12.2	1911–1973	24	1.29	1.52	1.73	2.00	
59 01900 Lammasjärvi, l.	3 840	11.1	1937–1972	140	1.25	1.46	1.70	2.00	
59 02600 Nuasjärvi, l.	7 535	11.7	1896–1946	234	1.28	1.58	1.79	2.14	
59 03500 Vaala	19 890	12.7	1896–1949	500	1.22	1.40	1.58	1.80	
60 00400 Haukipudas	3 845	3.4	1911–1972	380	1.26	1.50	1.68	1.95	
61 00640 Jaurakkajärvi, l.	2 480	6.0	1960–1973	250	1.20	1.40	1.56	1.78	
61 01600 Leuvankoski	2 390	1.9	1959–1973	375	1.31	1.57	2.08		
61 01900 Merikoski	14 315	5.8	1911–1970	850	1.19	1.35	1.59	1.67	1.82
63 00210 Kuivaniemi	1 330	2.7	1911–1973	200	1.16	1.30	1.41	1.59	1.70
64 00410 Simo	3 125	6.3	(1911–1973)	440	1.18	1.32	1.44	1.61	
65 01700 Kummaniva	8 715	0.7	1921–1973	860	1.16	1.29	1.41	1.57	1.70
65 02000 Kemijärvi, l.	27 285	2.4	1921–1959	1 650	1.10	1.16	1.24	1.32	
65 03000 Ounasjärvi, l.	335	8.0	1949–1973	28	1.29	1.54	1.71	1.96	
65 03700 Marraskoski	12 335	2.3	1919–1970	1 020	1.15	1.25	1.37	1.52	1.62
65 04450 Taivalkoski	50 820	2.9	1911–1973	3 100	1.15	1.28	1.40	1.55	
67 00800 Muonio	9 515	3.7	1938–1973	950	1.19	1.33	1.48		
67 02000 Portimojärvi, l.	3 160	8.5	1954–1973	160	1.31	1.56	1.81	2.12	
67 02201 Kukkolankoski	1)		1911–1973	2 200	1.16	1.32	1.45	1.64	1.75
68 01100 Patoniva	1 470	2.3	1962–1973	200	1.30	1.53	1.75		
71 00700 Kettukoski	2 270	5.8	1948–1973	120	1.33	1.58	1.83	2.16	
71 00800 Saukkoniva	5 250	4.1	1921–1972	305	1.26	1.44	1.64	1.88	2.06
71 01600 Inari, l.	14 550	12.2	1921–1941	280	1.16	1.30	1.43		
73 00100 Kiutaköngäs	1 955	4,7	1966–1973	320	1.28	1.48	1.72		
Σ mean 52			44 a		1.22	1.40	1.57	1.78	1.87
σ			± 21 a		0.063	0.115	0.172	0.226	0.227

1) F = 29 450 (+ 9 910 partly) $\approx$ 35 000 km^2

Table 6. The relation HQ/MHQ for different T_r.

T_r	HQ/MHQ					
	Kaitera (1949)	Niinivaara (1961) L (%)			Mustonen (1968)	Table 4
a		2.5	12	22.5		
5						1.22
10	1.5	1.45	1.56	1.52	1.67	1.40
20		1.62	1.73	1.67	1.90	1.55
50	2.0	1.75	1.92	1.80		1.75
100		1.87	2.05	1.88		1.99

Table 7. Parametres A, B and C with their standard deviations determined for Equation (4) from the data in Table 4.

T_r a	n	A	σ	B	σ	C	σ
5	43	1.2189	0.0233	0.0040	0.0056	−0.00019	0.00025
10	43	1.3853	0.0421	0.0106	0.0100	−0.00050	0.00045
20	43	1.5815	0.0647	0.0091	0.0154	−0.00048	0.00069
50	38	1.7036	0.0884	0.0314	0.0205	−0.00129	0.00090
100	18	1.8580	0.1347	0.0109	0.0314	−0.00027	0.00139

the analytical curves, calculated by Leppäjärvi (1983), are based on the data from 32 stations, most of which are also to be found in Table 5. Leppäjärvi's curves calculated for Gumbel, log-normal and gamma distributions have been entered on Gumbel paper in the Fig. 13.

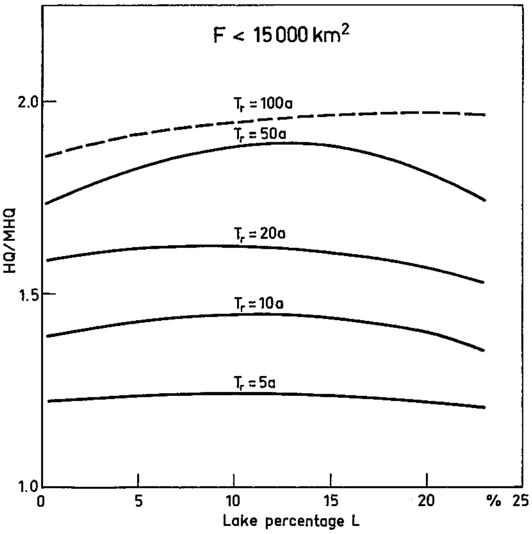


Fig. 11. HQ/MHQ as a function of return period Tr and of lake percentage L, according to Equation (4). F≤ 15 000 km^2.

As can be seen in Fig. 13, the Gumbel distribution gives a curve deviating from the other curves, which are all close together. All the probability distributions pass the Kolmogorov-Smirnov test (Leppäjärvi 1979). The method used above leading to the empirical curve appears to be acceptable and the kind of distribution paper used in the evaluation does not have much influence on the results.

4.4 Volume of the spring flood

When the large lake chains are excluded, about half of the annual runoff in Finland is discharged in springtime. Thus the runoff during the period of high discharge greatly influences the annual water balance. The season of spring flood begins in southern Finland usually in the first half of April, in central Finland at the end of April or the beginning of May and in Lapland at the end of May. In most watercourses the maximum is passed before the end of June. The summer minimum is reached some time between the beginning of June and the end of August, in the central lakes of the lake chains often not before the late summer or the autumn (e.g. Hyvärinen 1977).

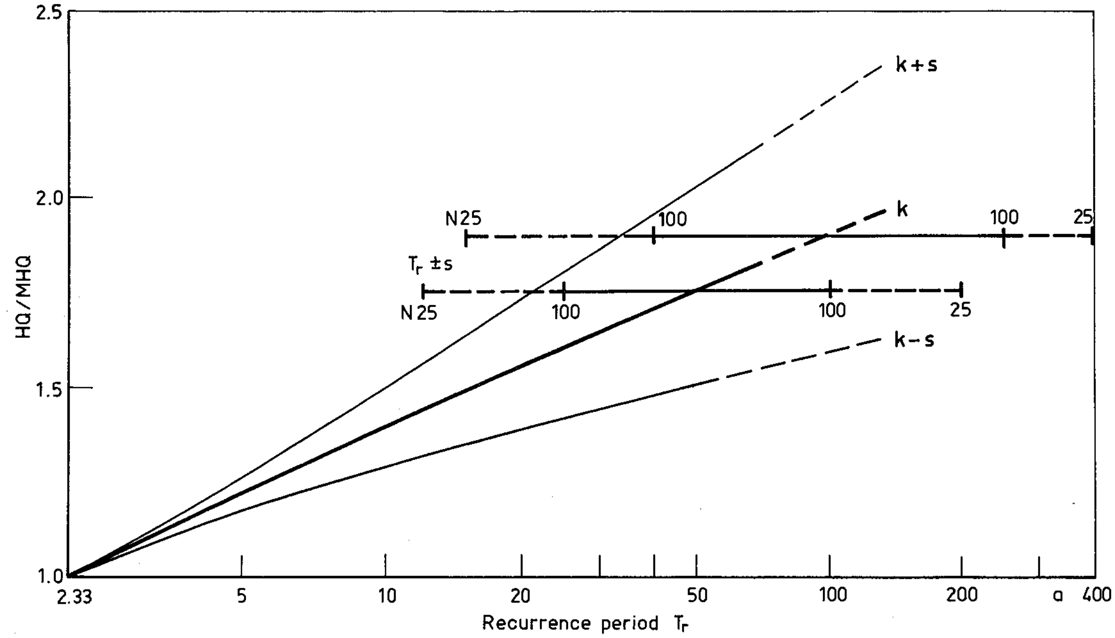


Fig. 12. k = HQ/MHQ and its standard deviation as a function of return period Tr. The horizontal bars show the 68 % confidence limits for observation series covering 25 and 100 a.

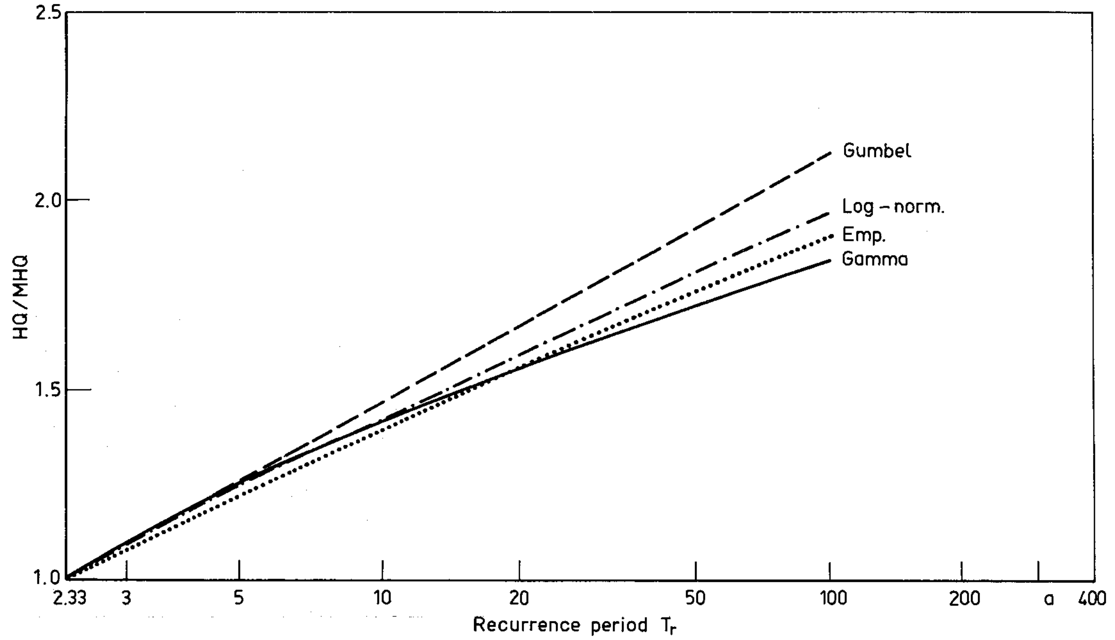
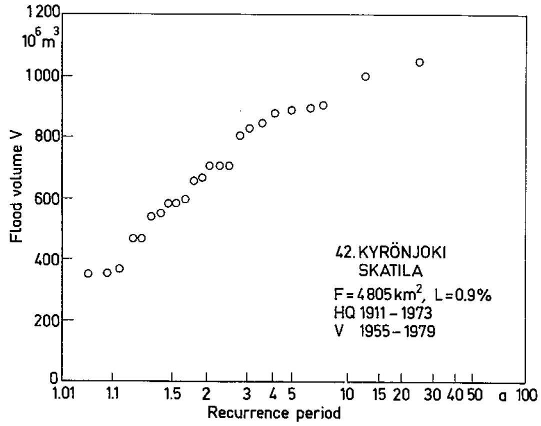


Fig. 13. HQ/MHQ as a function of return period Tr determined by using the Gumbel, log-normal and gamma distributions as well as empirical curve fitting (Emp).



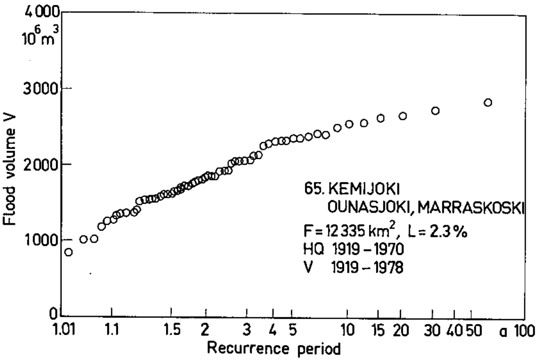


Fig. 14. Return period Tr of the volume V of spring high flow in river Kyrönjoki and river Ounasjoki.

The return times of the spring flood volumes in the river Kyrönjoki at the Skatila station and in the river Ounasjoki tributary of the river Kemijoki at the Marraskoski rapids are shown graphically in Fig. 14. The former represents the Ostrobothnian coastland, the latter northern Finland and Lapland. The flood volume V is defined as

$$V = \int_{t_1}^{t_2} Q(t)\,dt \qquad (5)$$

with $t_1 = t\ (NQ_w)$, the time when the winter minimum ends and the water begins to rise, and t_2 = June 30. The moment t_1 is usually easy to locate, but the end of the flood season is often rather vague, the melt-water runoff tapering into that from summer rains, for which reason the fixed date June 30 was chosen for t_2.

The point sequences in Fig. 14 are rather similar to the corresponding return time point sequences for the flood maxima (Hyvärinen 1977). Comparing the values for V and HQ it can be seen that in the mean $V = 2.2 \cdot 10^6 \cdot HQ$ at Skatila and $V = 2.0 \cdot 10^6 \cdot HQ$ at Marraskoski. In southern and southwestern Finland the ratio V/HQ varies between $0.9 \cdot 10^6$ and $2.6 \cdot 10^6$ s; in the headwaters of the lake district it varies between $2 \cdot 10^6$ and $5 \cdot 10^6$ s, typically between $2.5 \cdot 10^6$ and $4 \cdot 10^6$ s. In the large lake chains the concept "spring discharge forming factor" V/HQ loses its meaning. Again, applying regression analysis one obtains for Marraskoski.

$$V = 0.75 \cdot 10^6 \cdot HQ + 1.16 \cdot 10^9 (m^3) \qquad (6)$$

$(R^2 = 0.22 \qquad R = 0.47)$

and for Skatila

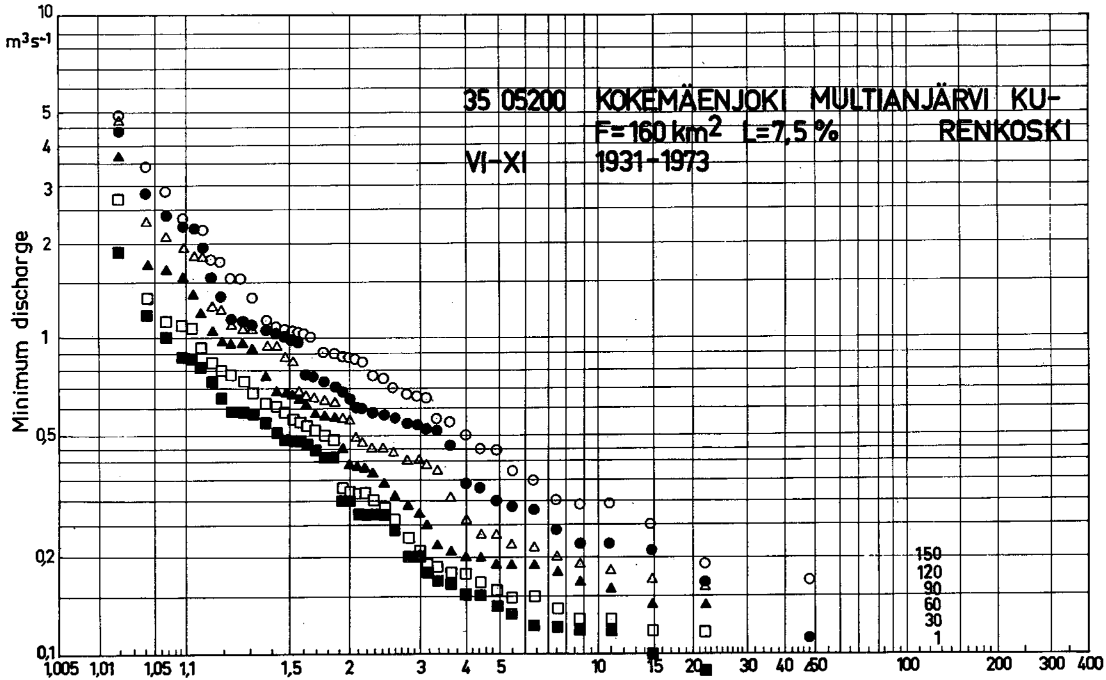
$$V = 1.40 \cdot 10^6 \cdot HQ + 2.54 \cdot 10^8 (m^3) \qquad (7)$$

$(R^2 = 0.32 \qquad R = 0.573)$

5. DISCHARGE MINIMA

The discharge minima vary to a large degree not only in time but also with the parameters of the drainage basin. Of primary importance are weather, the size of the drainage basin and the lake percentage, but other factors are also important. The discharge minima of small areas have been analyzed extensively by Mustonen (1971) and most recently by Seuna (1982). Studies on the discharge minima in large areas are to be found in the works of Kajosaari (1968) and Hyvärinen (1977). Fig. 15 has been taken from the latter work.

In Finland, the discharge minima usually occur in the winter. When assessing discharges it is often necessary to resort to comparison between similar discharge areas. This is also the case when attempting to determine winter discharges and ice reductions. However, even neighbouring watercourses usually correlate rather poorly. A correlation analysis of annual mean discharges (Hyvärinen and Vehviläinen 1980) shows the correlation factor to be zero when two watercourses are 1 000 km apart. A similar analysis of winter and summer discharges gave a still worse correlation (Fig. 16). It can be seen that the correlation factor becomes negative for summer as well as winter discharges when the distance between the watercourses becomes of the order of 700 km. The correlation is somewhat better



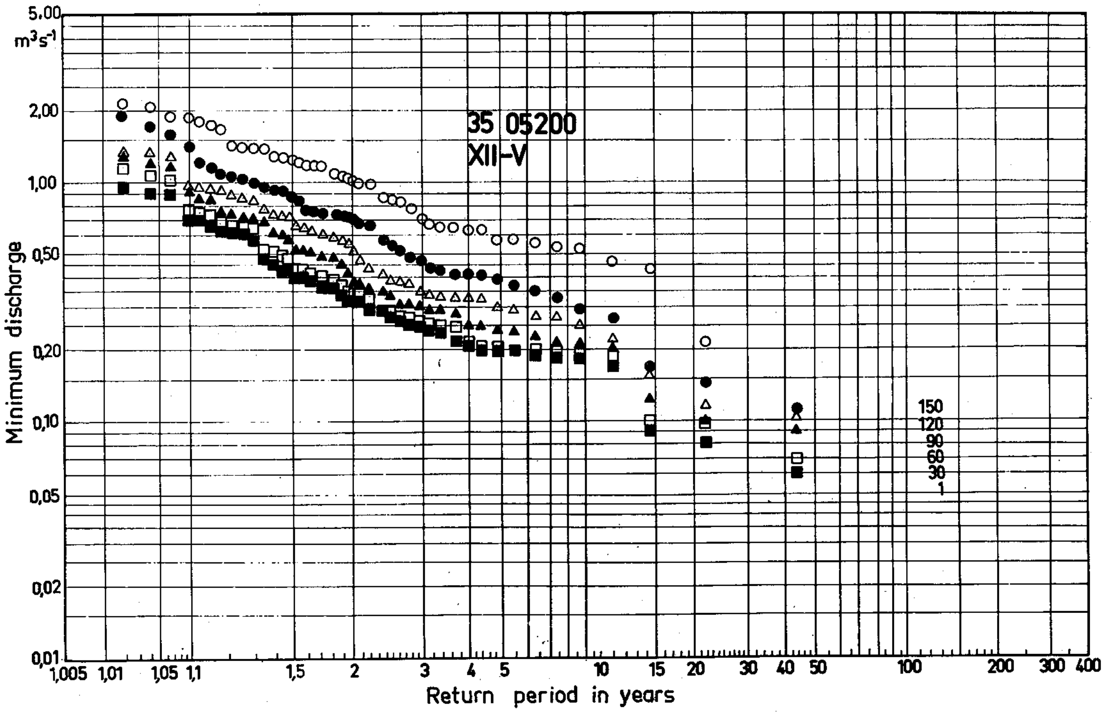


Fig. 15. Return period for the summer (VI–XI) and winter (XII–V) minimum discharges of 1 to 150 day long droughts at Kurenkoski.

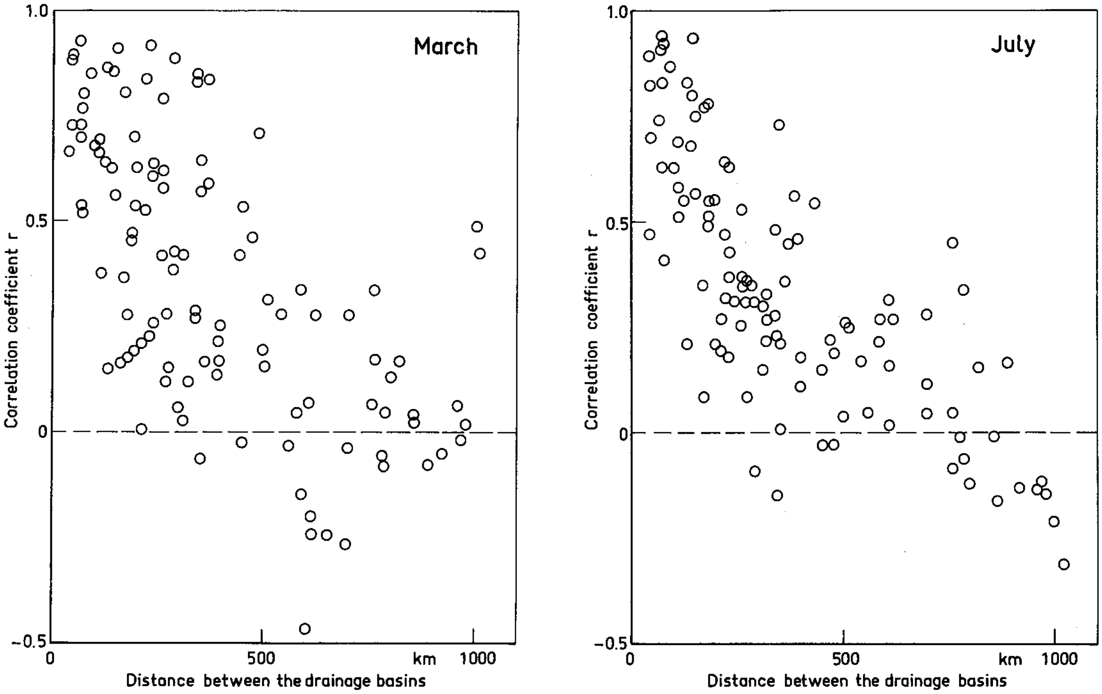


Fig. 16. Relation between the correlation coefficients of the March and July discharges and the distances between the drainage basins. Data for the correlations are from Finnish drainage basins.

when watercourses with similar discharge areas and lake percentages are compared, but is still not good.

Thus the historical data on discharge are not sufficient in water management; new observations and analyses are continuously needed.

6. FINAL REMARKS

As was pointed out in the introduction, this study is by no means a complete description of discharge conditions in Finland. New investigations on low flow conditions, for example, need more attention. There is much work to be done on a better estimation of winter discharge, especially in the regulated watercourses, etc.

Future may confront the hydrologists as well as those who use the water with new problems. It is not at all sure, that the precipitation and evaporation regimes will remain unchanged. The atmosphere is changing due to human activities, and so are also the evaporation conditions on the continents. The distribution of precipitation may be very sensitive to these trends. On the other hand, the hydraulic conditions of the soil and the watercourses, do not remain unchanged either.

ACKNOWLEDGEMENTS

This study is based on several investigations, mainly performed at the Hydrological Office during the 1960's, 1970's and the beginning of the 1980's. I owe my sincere gratitude to a number of persons who have contributed to this undertaking.

Helsinki, September 1984

Veli Hyvärinen

LOPPUTIIVISTELMÄ

Käsillä oleva kirjoitus on julkaistu likimain samanlaisena suomeksi Vesihallituksen monistesarjassa, nro 1984:278 (Hyvärinen 1984). Siksi tässä lopputiivistelmässä esitetään vain muutamia näkökohtia.

Virtaamien määrittäminen. Valtaosa Suomen virtaamatiedoista lasketaan yhä luonnonuomille määritettyjen purkautumiskäyrien avulla. Yhtälö $Q(W) = a(W-c)^b$ soveltuu yleensä melko hyvin kuvaamaan purkautumiskäyrää tai sen osaa; yhtälössä a ja b ovat määräävästä uoman osasta riippuvia parametrejä, c ns. efektiivinen tai dynaaminen kynnyskorkeus, W vedenkorkeus ja Q virtaama. Purkautumiskäyrän analyyttistä muotoa kannattaa kuitenkin käyttää harvoin. Hyötyä siitä on tutkittaessa onko purkautumiskäyräpaikka hydrodynaamisesti kelvollinen, eli onko $b \geqslant 1,5$. Yhtälöstä ja kokemuksesta on voitu päätellä, että on erittäin suositeltavaa käyttää apuna log-log-paperia purkautumiskäyrien piirtämissä aritmeettisen paperin rinnalla. Tämä menettely otettiin käyttöön hydrologian toimistossa 1960-luvun puolivälissä.

Virtaaman graafinen jääredukointi kehitettiin hydrologian toimistossa niin ikään 1960-luvulla nykyiseen muotoonsa, jossa talvivirtaamat arvioidaan puolilogaritmisella vuosipaperilla tehtyjen suoranaisten virtaamanmittausten tuella. Menetelmä sopii hyvin Keski- ja Pohjois-Suomen säännöstelemättömille joille. Säännöstely sekä Etelä-Suomen talvien epästabiilisuus tuottavat ongelmia, joita ei ole ratkaistu täysin tyydyttävästi.

Virtaamaolot. Kullakin vesistöllä on alueen ilmaston ja fysiografian määräämät tyypilliset valuntaolonsa. Sekä luonnonolot että ihmisen vaikutus voivat aiheuttaa muutoksia kaikkiin valuntaparametreihin tai osaan niistä. Virtaamaolotkäsite on tarkoitettu peittämään mm. virtaaman säännöstelyn. 1980-luvun alusta Suomen järvistä oli säännöstelyn piirissä n. 10 000 km^2. Maankohoaminen lisää Suomen vesistöjen valuma-aluetta 700–1 000 $km^2/100$ a, mikä lisää mantereelta Suomen alueelta purkautuvaa virtaamaa 0,5–0,7 $m^3 s^{-1}$ vuodessa. Järvialueen kallistuminen tyhjentää järviä n. 0,2 $m^3 s^{-1}$. Järvenlaskut, tulva-alueiden poistot, ojitus jne. ovat äärevöittäneet virtaamanvaihteluita, ts. mm. lisänneet tulvaisuutta. Tekojärvien rakentaminen on osittain kompensoinut tätä. Uitto lienee tasannut kevätkesän virtaamanvaihteluita. Kastelu kuluttaa kuivina kesinä merkittävän osan Lounais-Suomen vähäjärvisten vesistöjen virtaamasta. Veden johtaminen vesistöstä toiseen oli 1980-luvun alussa yhteensä n. 4 $m^3 s^{-1}$.

Ylivirtaamaa HQ luonnehtivat mm. suureet MHQ = keskimääräinen vuotuinen ylivirtaama ja HQ^1/T_r = HQ jonka suuruinen tai jota suurempi vuotuinen ylivirtaama esiintyy keskimäärin kerran ajanjaksolla, jonka pituus on T_r vuotta. MHQ on määritettävissä suhteellisen suurella varmuudella, jos havaintoja on käytettävissä muutamienkin kymmenien vuosien jaksolta. Sen sijaan HQ^1/T_r:n määrittämisessä esiintyy suurta epävarmuutta tilastollisista syistä ja siitä syystä, että HQ on melko herkkä valuntaolojen muutoksille. Alivirtaamaan nähden pätee periaatteessa sama epävarmuus.

Hydrologian toimistoon kerätyn havaintoaineiston avulla on laskettu suureelle HQ/MHQ uusia arvoja eri T_r:n arvoille. Tulokset eivät merkittävästi poikkea aikaisemmista Kaiteran, Niinivaaran ja Mustosen esittämistä arvoista.

Virtaamaolojen tulevaisuus. Ei ole olemassa varmuutta siitä, että sadanta- ja haihduntaolot säilyisivät muuttumattomina. Ihmisen toiminta on muuttamassa ilmakehää mutta myös mannerten haihduntaoloja. Sateisuuden jakautuminen saattaa herkästikin muuttua näistä syistä. Toisaalta maaperän ja vesistöjen hydrauliset olotkin ovat jatkuvasti muuttumassa mm. ihmisen vaikutuksesta. Aikaisemmin kerätty virtaamahavaintoaineisto ei välttämättä sovellu sellaisenaan esim. mitoitusperusteeksi. Koko ajan tarvitaan uusia havaintoja ja analyyseja.

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