Pentti Kaitera
Estimation of the maximum and minimum discharge in Finland
Aqua Fennica, 1971, s. 28–45

Eripainos
AQUA FENNICA 1971

ESTIMATION OF THE MAXIMUM AND MINIMUM DISCHARGE IN FINLAND

Pentti Kaitera

Hydrological phenomena depend on so many different factors that it is not possible to use uniform methods to estimate such factors as maximum and minimum flow in different kinds of climatological and geological regions. Finland is, however, both climatologically and geologically so homogenous a region, that it is possible to apply the same rules in estimating the factors mentioned before, in the whole country.

In this paper I shall be chiefly concerned with estimating the maximum and minimum unit discharge. This is expressed in Finland as litre per second and km^2. In particular I shall be describing how the maximum discharge caused by melting snow differs from that of rainfall. The estimations of the average maximum or the maximum of the return periods of different duration are most important in small catchment areas in planning drainage and flood control works. In large catchment areas in Finland we can generally use hydroligical observations of 30—120 years collected by the Hydrological Office. Finnish engineers and hydrologists have long traditions in river management and flow regulation for the generation of hydroelectric power. For these purposes forecasts have been made concerning the maximum flow situation in the lakes and rivers caused by melting snow.

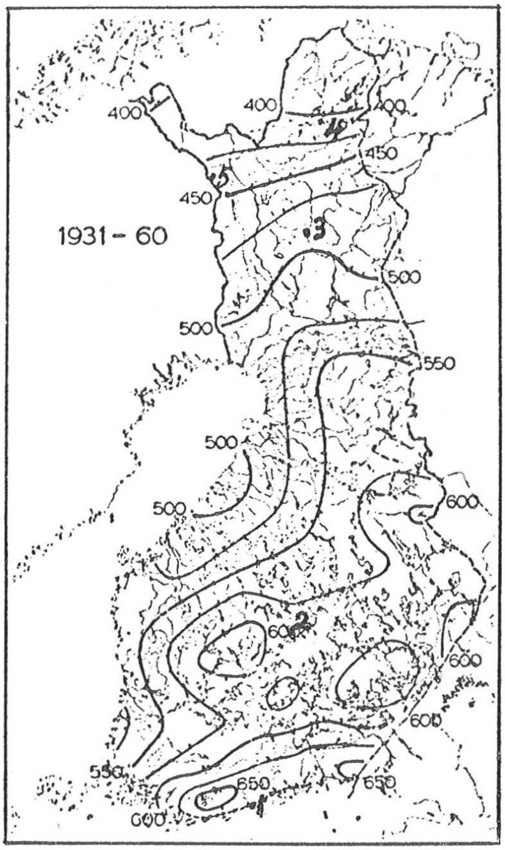


Fig. 1. Average annual precipitation (mm) in Finland in years 1931—1960 (12).

Kaitera, Pentti
D.Sc. (Eng.),
Professor of Hydrology and Water Resources Development,
Helsinki University of Technology

Precipitation and annual hydrological cycle

The annual precipitation in southern Finland is 500—650 mm and in north Finland 400—550 mm (Fig. 1). Precipitation in different years usually varies less than 30 % on each side of the average values. These variations are rougly similar over the whole country, as you can see from Fig. 2. The annual cycle is also very similar over the whole country. The minimum monthly precipitation is in March and the maximum in July —

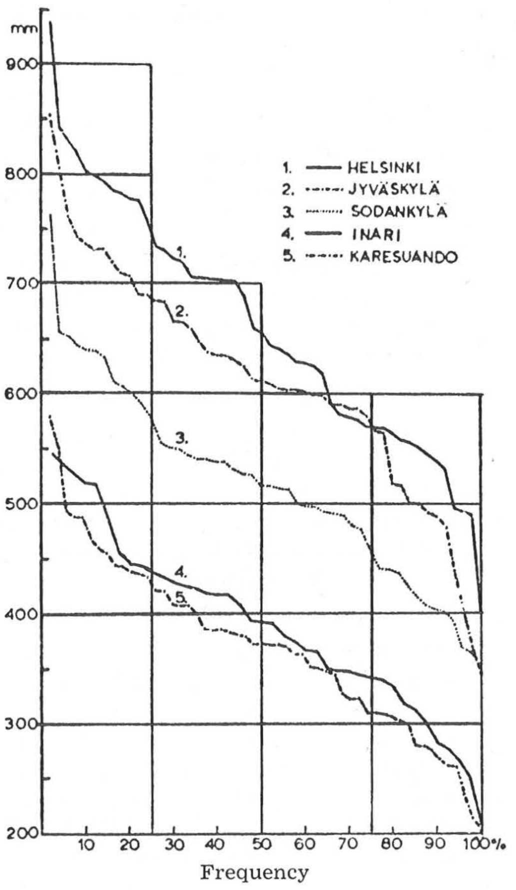


Fig. 2. The frequency of the annual precipitation 1915—1964 (12). The location of the observation stations can bee seen in Fig. 1.

August (Fig. 3). This annual precipitation cycle has, however, only a small influence on the runoff cycle (Fig. 4), because winter precipitation is accumulated in the snow cover, which melts during one month in spring. Much of the summer precipitation also infiltrates the empty spore volume of the soil formed by evaporation. In southern Finland 30—40 % of the annual precipitation and 40—60 % in northern Finland falls as snow. Thus particularly in the north the annual maximum mainly depends on melting snow.

In Fig. 5 the maximum precipitation caused by rainfall is compared with that caused by melting snow. The figure shows the average maximum rainfall during 1—30 days in the years 1934—1948 in different regions. The average maximum decrease in the water content of snow during 1—30 days is also shown in this figure. It can be seen that the values of the average daily rainfall are higher than those of melting snow. But when the period is longer, the values for melting snow in central and north Finland are greater than the average rainfall maximum. In south-west Finland the values for average maximum snow melting and average maximum rainfall are nearly equal in periods longer than one day.

In southern Finland, however, the runoff maximum caused by melting snow is also usually greater than that caused by rainfall, because the spore volume of the soil is filled with water during the springtime. In southern Finland nearly one third of the annual maximums are due to precipitation in autumn, when evaporation is slight. In north Finland this happens about once in twenty years. Snow observations over 15 years pointed out that the relative values of snow melting

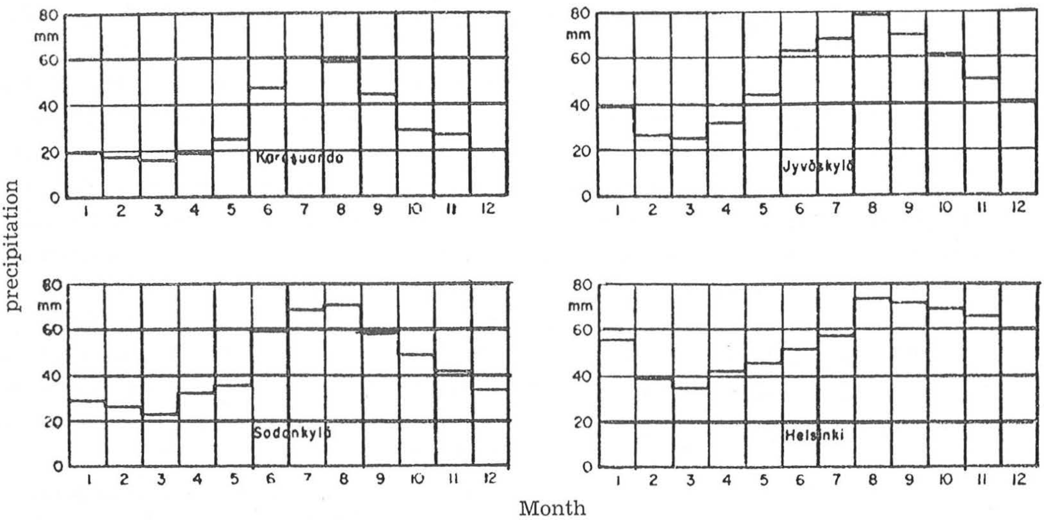


Fig. 3. Average monthly precipitation (mm) at the four observation stations named in Fig. 2 (12).

in spring at different long periods are almost the same in the whole country when compared with the spring maximum of the water content of snow (Fig. 6). This makes it possible to use the spring maximum of water content of snow as a parameter also to indicate the differences in melting water of short duration in different regions.

Daily rainfall can in exceptional cases rise to 200 mm, but even 50 mm daily rainfall is so uncommon that its return period is about 20 years. This can be seen from Fig. 7, which also shows the

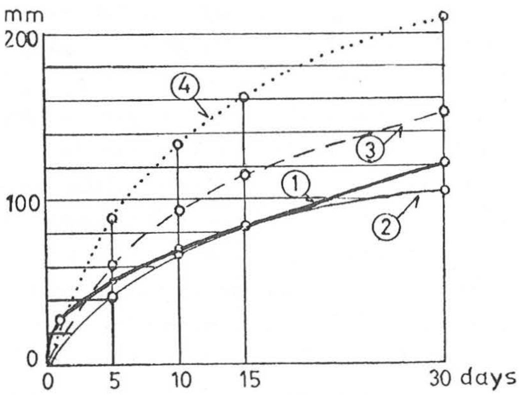


Fig. 5. Average maximum rainfall (1) during 1—30 days 1934—1948 in the whole country and the quantitaties of water released from snow during the melting season in different regions. (2 = South-West Finland, (3) = Central Finland, (4) = North Finland(3).

Fig. 4. The annual cycle of discharge in relation to the average annual discharge in certain catchment areas 1911—1940 according to Renqvist (11).

Catchment area Name	Size km²	Lakes %	Location
1. Vantaanjoki	1680	2,5	South-Finland
2. Karjaanjoki	1995	12,5	» »
3. Lestijoki	380	20,2	West-Finland
4. Kalajoki	2990	1,9	North-Finland
5. Koitajoki	4290	8,4	East-Finland
6. Nilsiän reitti	2455	10,8	Central-Finl.
7. Kokemäenjoki	26025	11,8	West-Finland
8. Kymijoki	36535	19,3	Central-Finl.
9. Vuoksi	61275	19,9	East-Finland
10. Oulujoki	19890	12,7	North-Finland
11. Kemijoki	27285	2,4	» »

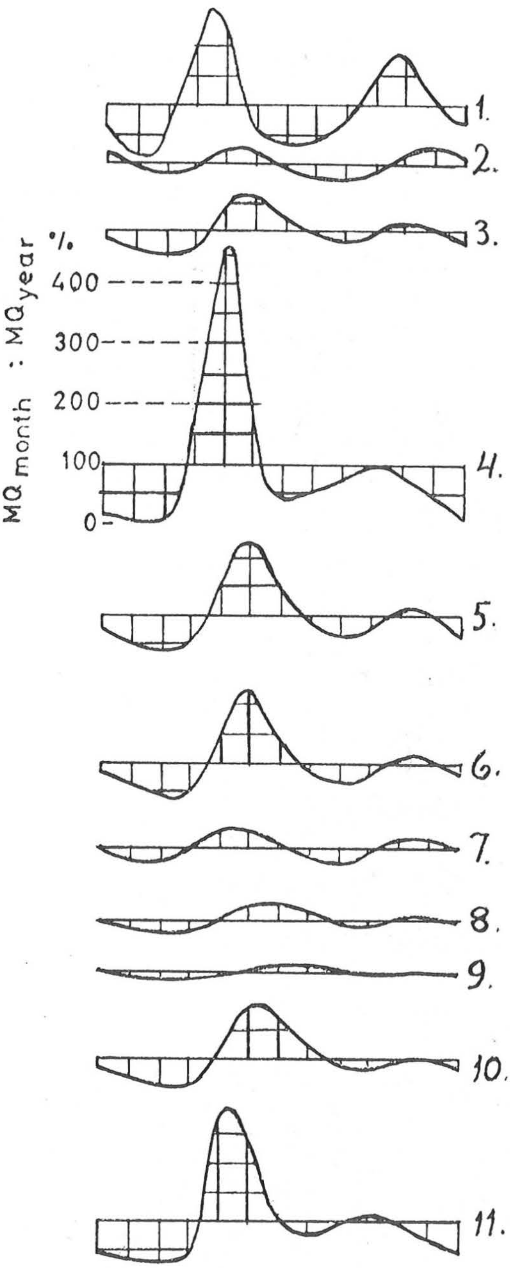


Fig. 4

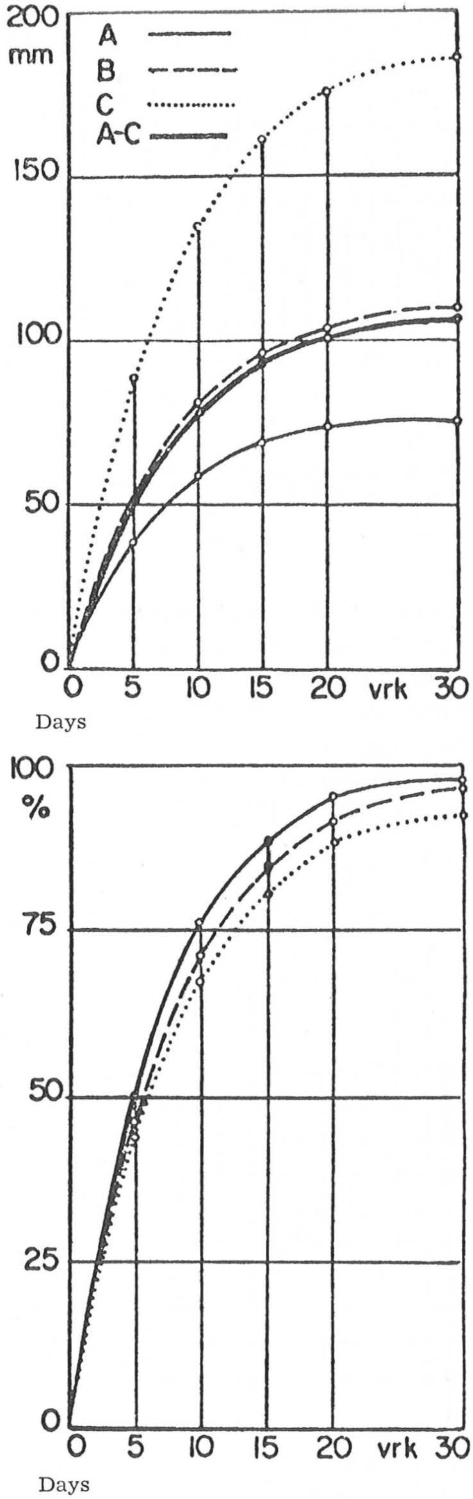


Fig. 6

→

Fig. 6. Maximum decrease in water content of snow (upper chart in mm, lower chart % of the annual maximum water content) in different regions (A = South-Finland, B = Central Finland, C = North-Finland) during 1—30 days. Average maximum values for the period 1934—1948 (3).

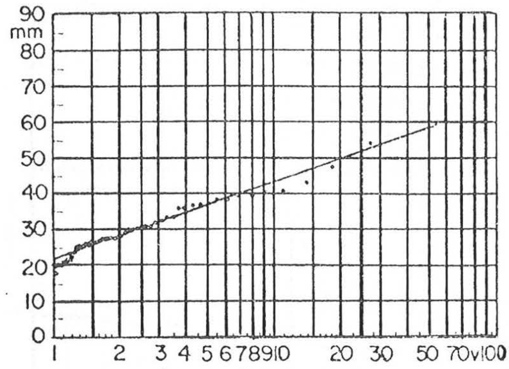


Fig. 7. Correlation between the annual maximum rainfall during one day and the length of the return period in Helsinki 1909—1962 (5).

situation in the whole country. The intensity of the short convective rainfalls is also about the same in the whole country, as can be seen from Fig. 8. Thus short downpours like these can cause maximum runoff only in cities and densely populated places.

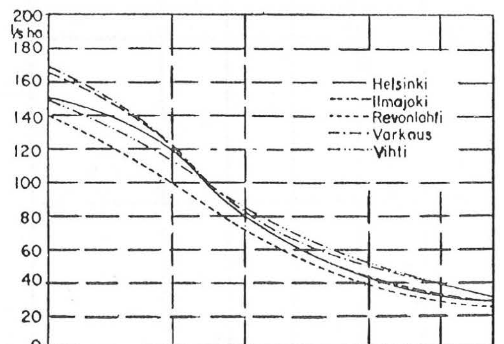


Fig. 8. Average intensity of heavy rainfall occurring once in a year in different part of the country (1, 15).

Maximum discharge

The maximum unit discharge in natural catchment areas in Finland depends mainly on three factors; the amount of water discharging in connection with spring snow melting, the percentage of lakes and the size of the catchment area. Renqvist did this kind of research in the 1930's using the average spring maximum of runoff of 46 catchment areas and daily spring maximum of melting snow. He placed the data observed in suitable groups according to the size of the catch-

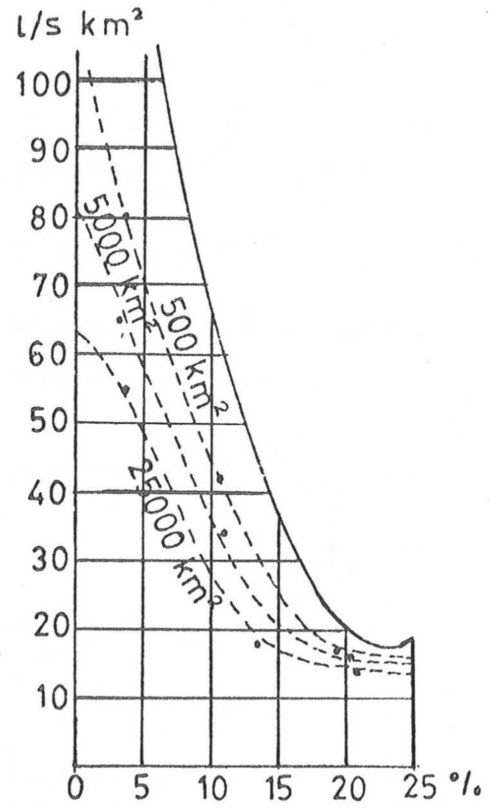


Fig. 9. Correlation between MHq (l/s.km²) and percentage of lakes in catchment areas of 500, 5000 and 25000 km². The Juselius curve represents the maximum discharge (Hq) correlating with the percentage of lakes (10).

ment area and lake percentage and calculated the group averages. The results are shown in Fig. 9. Note that the percentage of lakes has a stronger effect on the discharge maximum than the size of the catchment area. Also marked in the Figure is a curve presented by Juselius as long ago as 1905. This curve is based on observations made during the exceptionally great flow in 1899. Measurements were made in seven watercourses.

In view of these results I have developed a method for estimating the average unit discharge maximum, based on observations in 184 catchment areas. The duration of the observations in these basins varied from 10—40 years (3).

Observation results were also grouped in this research according to the percentage of lakes and the size of the catchment area. The group averages of unit discharge were altered with the aid of Renqvist's research to correspond to the equal annual maximum water content of snow (130 mm) in five lake groups with a lake percentage of 1.5, 5, 9.5, 14 and 22 %. The results can be seen in Fig. 10. The points in each of these five lake groups are connected by dotted lines and the average trend of these five groups is indicated by straight lines paralled to each other. According to these lines, the maximum unit discharge diminishes in inverse proportion to the term $\sqrt[8]{A + 1}$ (A = catchment area km²) as the area increases.

In 1880 Bürkli—Ziegler gave the following formula for estimating maximum unit discharge:

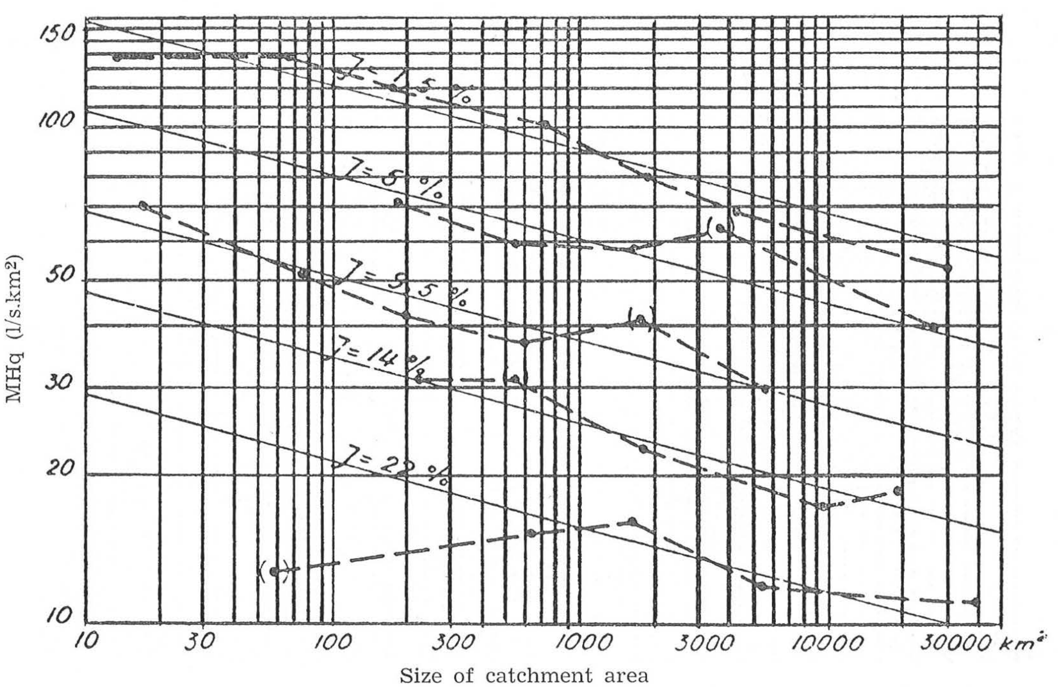


Fig. 10. Correlation between the MHq caused by melting snow and the size of the catchment area when the percentage of the lakes is 1.5, 5, 9.5, 14 and 22 % and the maximum water content of snow is 130 mm (3).

$$H_q = \frac{\psi\, Hu}{\sqrt[4]{A}}$$

H_q = maximum unit discharge

Hu = intensity and amount of precipitation

ψ = gradient factor

This formula has been a model for many later formulas. Some of the researchers have assumed that the maximum unit discharge diminishes in inverse proportion to the 4—6 root of the catchment area. It seems that the rate of diminishing is slower when the maximum discharge is caused by melting snow than by rainfall, because during the rainfall the intensity of precipitation per square kilometer also decreases as the catchment area increases. On the other hand, as the snow melts and water is freed to flow into the rivers, this happens in Finland usually at the same intensity in small and large areas except the northest part of Finland. In small areas without lakes in particular the influence of the size of the catchment area on the maximum unit discharge caused by melting snow is very slight, because in such areas the unit discharge reaches the intensity of melting snow and depends mainly on this.

These results have been allowed for by constructing a nomogram (Fig. 11) to estimate the average maximum unit discharge. This has been done by means of the three most important factors; the percentage of lakes, the size of the catchment area and the maximum water content of snow according to the map in

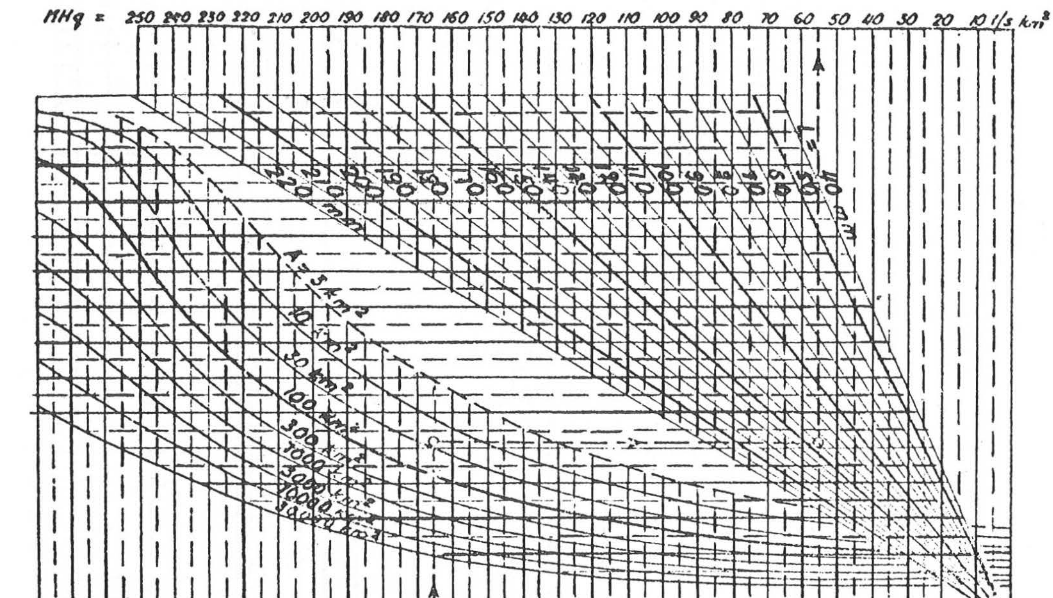


Fig. 11. Nomogram for estimating MHq (l/s.km²) according to the percentage of lakes (P), the size of the catchment area (A) and the average annual maximum water content of the snow cover L (3).

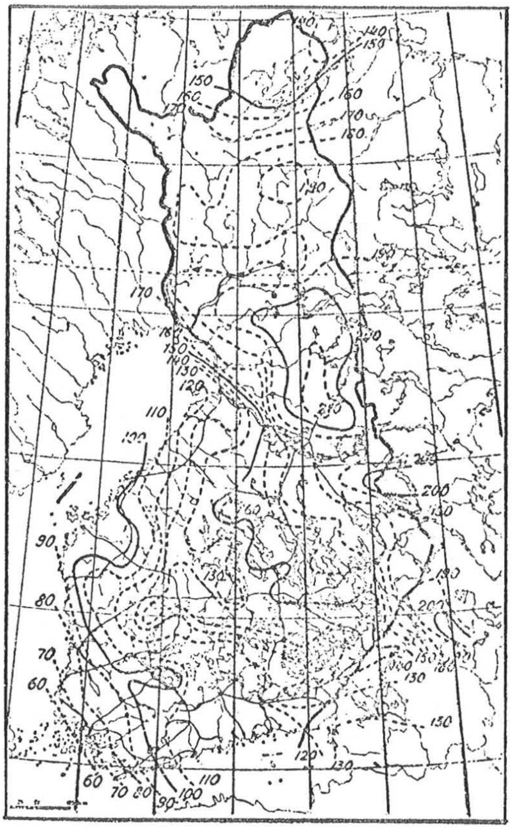


Fig. 12. Average annual max. water content of snow according to the observations of snow depth 1892—1941 and of snow density 1934—1948 (3).

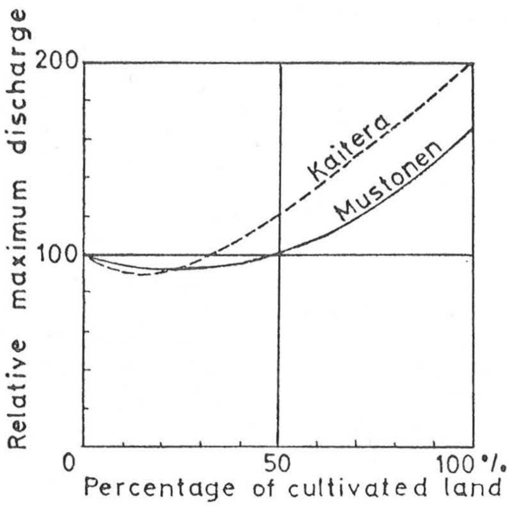


Fig. 13. Influence of cultivated land on the MHq in small lakeless catchment areas (3, 6).

Fig. 12. The location of lakes is also of great importance. This can be allowed for in the nomogram following certain rules.

In small areas without lakes the amount of forests and cultivated fields influences the maximum discharge as shown in Fig. 13. This is due to the fact that during the spring snow melts and water discharges from the cultivated area some days before the forest area.

When these factors are allowed for in estimating the average maximum unit discharge the standard error between the estimated and observed values is ± 15 %.

This accuracy in estimating the maximum discharge with the aid of the catchment area is satisfactory for many technical purposes. Infiltration into the soil is also a factor influencing the maximum unit discharge, but in Finland we have only a few large soil formations where infiltration is of great consequence. The ground of basins is like a mosaic and consideration of the influence of this factor is very difficult. Frost also influences infiltration during the spring. The maximum discharge in different years varies and long duration cycle also appears. This can be seen from table 1, which gives the decennial average relative values for some catchment areas. According to this table the standard deviation from the normal maximum discharge observed in 10 years is about 10 %.

The terrain gradient seems not to be of any great importance to the maximum discharge caused by melting snow. Finland has only low hills, and the highest points are not often 100 m higher than

Table 1. Relative decennial MHq-values (MHq 1911—1960 = 100) of certain catchment areas

Catchment area			Relative decennial MHq-values								MHq
Observation place	Size km²	Lakes %	1881 1890	1891 1900	1901 1910	1911 1920	1921 1930	1931 1940	1941 1950	1951 1960	1911—1960 l/s.km²
Kalajoki, Tynkä	2990	2,5	—	—	—	103	108	94	83	101	83,6
Vanajavesi, Kuokkala	8680	14,4	94	115	112	102	113	101	81	106	14,1
Kokemäenjoki, Nokia	16975	14,4	—	119	98	99	115	97	85	102	14,9
Kymijoki, Kalkkinen	26475	19,5	97	115	106	95	115	102	84	104	12,5
Vuoksi, Imatra	61280	19,9	92	105	104	92	115	100	84	110	11,6
Oulujoki, Vaala	19860	12,7	—	—	119	105	110	105	101	80	21,9
Iijoki, Merikoski	14315	5,5	—	—	—	87	96	104	87	127	57,6
Kemijoki, Taivalkoski	50820	2,9	—	—	—	91	98	93	106	111	61,2

the valleys. In terrain like this the snow melts at different times on the northern and southern slopes, which has a retarding influence on the melting snow. In addition, melted water starts to flow in hilly terrain at the beginning of the melting season into the watercourses, but on flat ground without drains it is held back by snow banks until the end of the melting season, then discharging rapidly.

Shorter convective rainfalls are the cause of maximum discharge in the systems in small populated areas with asphalt covering over the earth, but not generally in natural terrain. Cyclonical rainfalls lasting a couple of days often induce maximum runoff in summer, especially in southern Finland. This kind of rainfall can also occur in very large areas, so that exceptional cyclonical rainfall can also cause a very high discharge even in large catchment areas.

Niinivaara has investigated the influence of the size of the catchment area and lakes on the relative discharge maximum of different long return periods. The results can be seen from Fig. 14, which shows that the influence of the percentage of lakes is greatest between 10—15 %.

The use of statistical methods in hydrological research provides new potential for more detailed investigation now that it is possible to use computers. About 10 years ago Mustonen organized a hydroligical network of 34 small lakeless basins (the size of these areas varies from

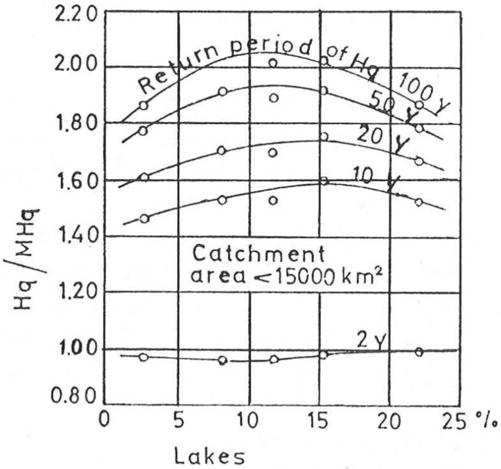


Fig. 14. Influence of the size and of the lakes of catchment area on the relative maximum discharge (Hq/MHq) of different return periods (9).

0.7 to 122 km²). For measuring runoff there are measuring dams at all the observation basins. Mustonen constructed a nomogram for estimating the maximum discharge unit caused by melting snow (Fig. 15). The correlation coefficient is R = 0.65 and this nomogram explains 42 % of the variables of the maximum discharge in individual years.

Mustonen's investigations confirm some results previously published concerning the influence of melting snow on the maximum unit discharge:

— in small lakeless areas (< 100 km²) an increase in the size of the catchment area has no significant effect on the maximum unit discharge

— the percentage of cultivated land has an effect which is approximately the same as that mentioned before

— the effect of the land gradient is not very significant and the maximum runoff can even decrease as the land gradient increases.

According to these investigations, when the return period is 10 years, the maximum discharge caused by melting snow is about 67 % greater than the average maximum, and when the return period is 20 years, the relative value is about 90 % greater than the average maximum. The maximum unit discharge caused by rainfall is about the same as the average maximum caused by melting snow. You

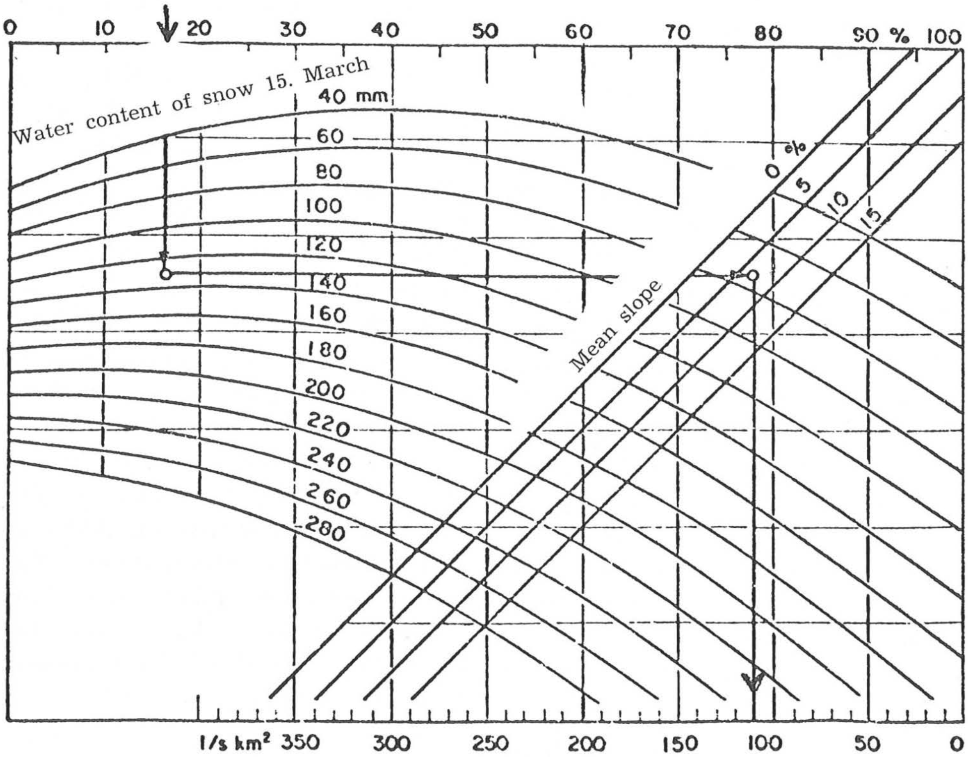


Fig. 15. Nomogram for estimating Hq (l/s km²) caused by snow melting in small lakeless catchment areas (7).

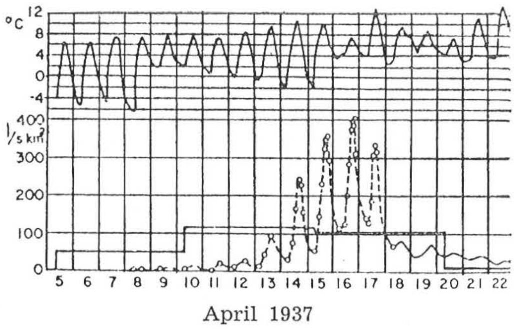


Fig. 16. Daily variations in discharge during the spring maximum in the southern Finland in a lakeless catchment area of 5 km² and of 75 % of cultivated land (2).

can see (Fig. 14) that in small lakeless areas the relative values are greater than in large areas, when the return period is $<$ 20 years.

I may mention that all these maximum discharge investigations have been stated as the average daily maximum. In spring it can happen, especially in southern Finland, that the air temperature varies so much between day and night that in the cultivated small lakeless areas this phenomen can cause very clear daily variations in runoff, as can be seen from Fig. 16.

Mustonen (7) has analysed the data observed in these 34 lakeless catchment areas using normal linear multivariate regression analyses. The significant independent meteorologic and basin variables were selected by the orthogonial regression method — the significance limit was at 0.05 level. The most suitable model as well as other usable models, total correlation coefficients and other statistical factors were analyzed. The spring maximum discharge has the following equation.

$$Y_5 = 51 + 0.41\, x_{14} - 0.60\, x_{15} + 0.031\, x_{14} \cdot x_{21} + 1.2\, x_{22} - 2.6\, x_2 - 0.35\, x_3 + 0.012\, x_3$$

(R = 0.713)

Y_5 = spring maximum unit discharge (l/s · km²)

x_2 = mean land slope (%)

x_3 = percentage of cultivated land (%)

x_{14} = water equivalent of snow, March 15. (mm)

x_{15} = frost depth Marsch 31. (mm)

x_{21} = mean temperature on the day of maximum discharge and the day preceeding it (C°)

x_{22} = precipitation on these two days (mm)

The correlation between independent variables greatly complicates and diminishes the chances of interpreting this kind of analysis. Each variable represents a large group of meteorological and basin characteristic variables. The spring maximum discharge in lakeless basins is very unstable and thus it was difficult to explain the model for a year, but generally it shows the influence of basin characteristics. The water equivalent of snow is a prime variable. Frost depth, for instance, decrease the spring maximum discharge, but in particularly this variable correlate with many other variables.

Mustonen has also made investigations in very small lakeless areas into the runoff resulting from heavy rainfall using the unit hydrograph method. When the amount of rain is more than 30 mm per day, this method can give a good correlation, especially in small catchment areas where infiltration is slow. Fig. 17 shows runoff caused by rainfall of about 50 mm per day in September 1962 in a cultivated area of 12 ha with clay soil.

The runoff resulting from a period of rain can also be investigated in small lakeless areas by statistical methods, using

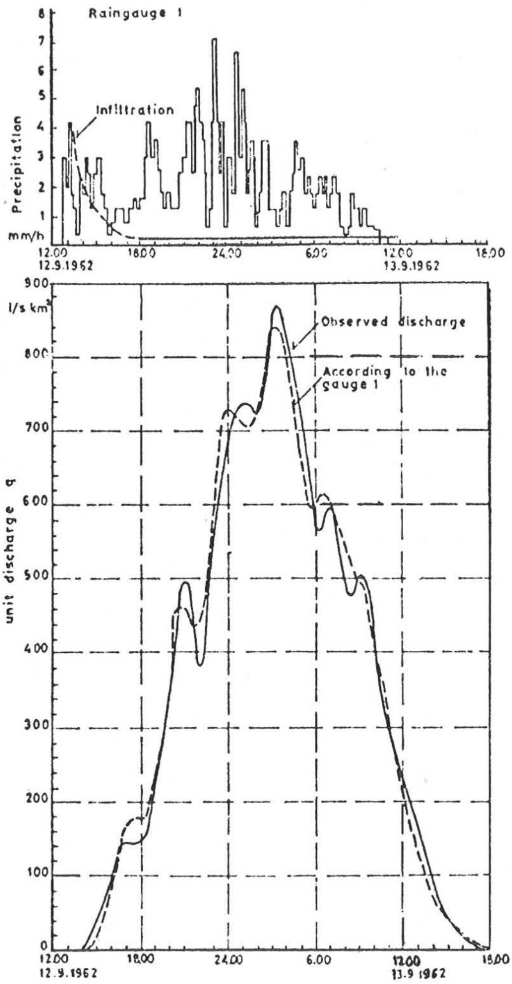


Fig. 17. Runoff caused by rainfall of about 50 mm in September 1962 in a cultivated catchment area of 12 ha with clay soil. The dotted curve was calculated using the unit hydrograph method (5).

the rainfall measured as the main characteristic. In these methods it is very difficult to measure the moisture deficiency in the soil. The most accurate method of determining moisture deficiency in the soil is by recording the daily rainfall and evapotranspiration. Mustonen has tried to investigate how accurately the runoff resulting from a period of rain can be determined with the use of rainfall readings alone. He applied the method of graphical correlation described by Linsley, Kohler, and Paulus. Fig. 18 shows the nomogram concerning the same 12 ha of cultivated area in southern Finland, as in Fig. 17. The average discharge resulting from all rain periods in July over ten years, was 0.05 mm. Using Fig. 18 the standard error was computed as 0.47 mm, which is 1000 % of the average discharge. However, we can estimate the total runoff resulting from the July rainfall periods so accurately that the standard error of 0.47 mm is only 5 % of the average rainfall (10 mm).

Minimum discharge

The annual unit discharge is roughly similar over the whole country, as can be seen from Fig. 19. The reason is that in southern Finland heavier annual precipitation (Fig. 1) compensates for heavier annual evaporation compared with the corresponding values in northern Finland (Fig. 20). Fig. 4 shows that the annual discharge variations are also rather small when the percentage of lakes is great. As can be seen from Fig. 4, in Finland there are two minimum discharge periods in the year. Due to the long winter period late winter generally becomes more critical than late summer, especially in northern Finland, where the winter period, with no melting snow, lasts longer than the dry summer period, which often follows rich melting water. When it is a question of using the water as a liquid, in southern Finland even a summer dry-period can cause a water shortage.

So far we have concentrated on hydrological dry-periods in Finland, mainly

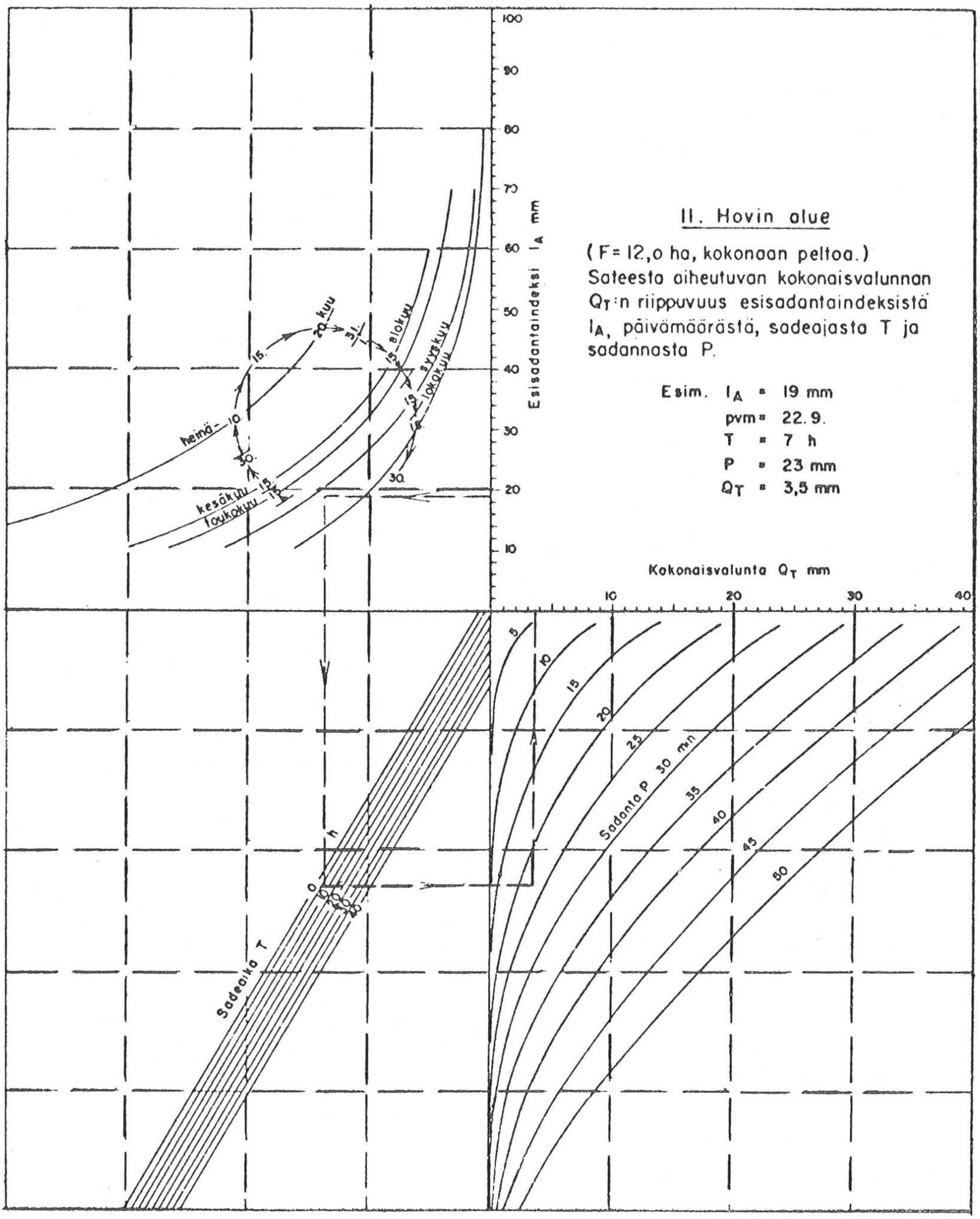


Fig. 18. Nomogram for estimating the discharge by using rainfall readings only in the same catchment area as in Fig. 17 (5).

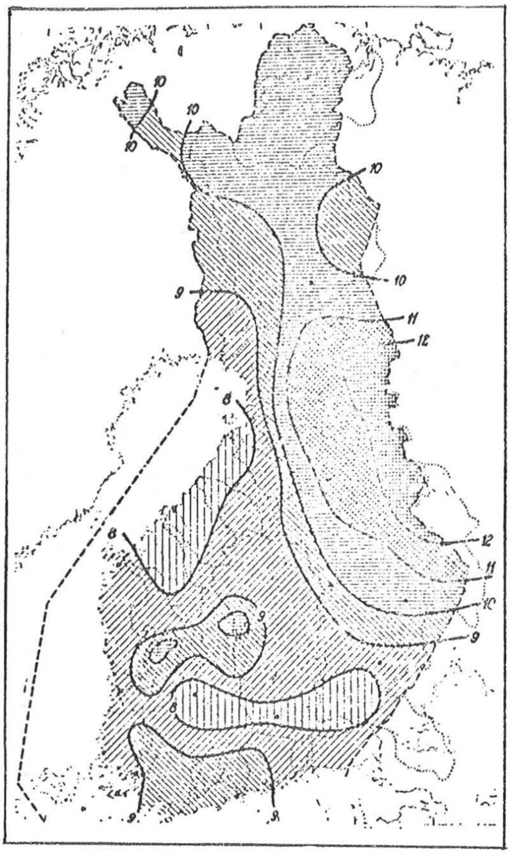


Fig. 19. Average annual unit (l/s.km²) discharge in Finland (13).

with a view to hydraulic power. Water power has been the most important source of energy. In winter the question of sufficient energy has every now and then become a burning problem. In order to provide sufficient energy for consumption, Finland has introduced runoff regulation in the lakes of basins. This began in the 1930's to a noticeable degree. During the last 10 years, more and more attention has been paid to minimum discharge and hydrological dry-periods. This change in attitude is due to the fact that water consumption has greatly increased in industry and populated areas. For instance, during 1956—1965 water consumption for these purposes almost doubled. In Finland it is estimated that this kind of water consumption is nearly 100 m^3/s. Even taking into consideration the amount of water flowing into the sea along the rivers, about 3000 m^3/s, water consumption is still inly 3 % of this amount. Investigations have been made to cut down on the water used in industry, and during the last few years water consumption has begun to decrease though the capacity of industry has increased.

But pollution caused by waste water has also turned our thought towards minimum discharge, which partly determines the degree of dilution. Settlement and industry are concentrated in areas in south-west Finland, where catchment areas are small and poor in lakes. In this kind of watercourse minimum discharges are also small and periods of sufficient flow very short. The main problem is,

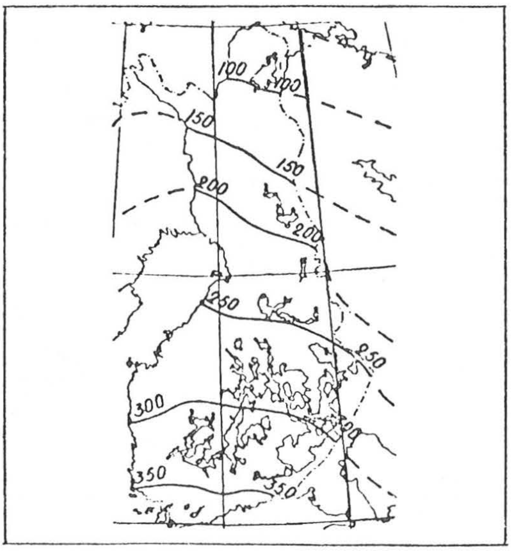


Fig. 20. Average annual evaporation in Finland (8).

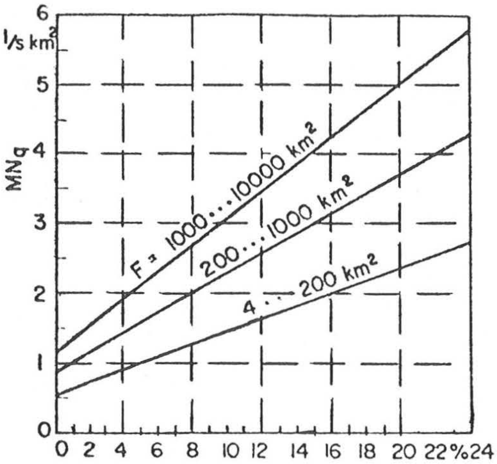


Fig. 21. Nomogram for estimating the average minimum discharge (MNq) according to the size of the catchment area (14).

however, that the Finnish lakes are very sensitive to water pollution.

Partly owing to the fact that in Finland we have had enough water, and rather easily available, estimation methods of minimum discharge have been very formal. In cases, where no hydrological observations have been available, estimations have been made on the basis of the catchment area, so that the influence of the area on the minimum discharge is shown as a function of the size of the catchment area and of the percentage of lakes (Fig. 21).

Kajosaari has pointed out the problem of increasing the minimum discharge by regulating the runoff in the watercourses. Velner and Kask have made similar investigations in the USSR, in Esthonia, using the conception of specific deficit of runoff. By this they mean the storage volume which is needed per unit of the catchment area so that the runoff during the period does not become lower than the mean runoff during this period. The method for calculation of the specific de-

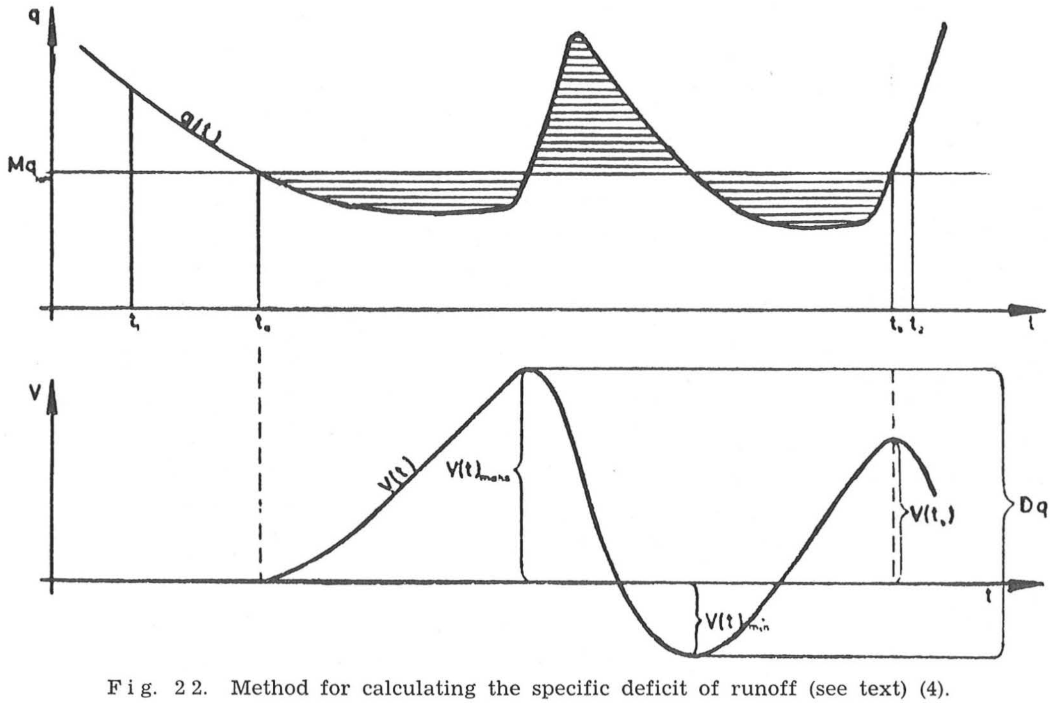


Fig. 22. Method for calculating the specific deficit of runoff (see text) (4).

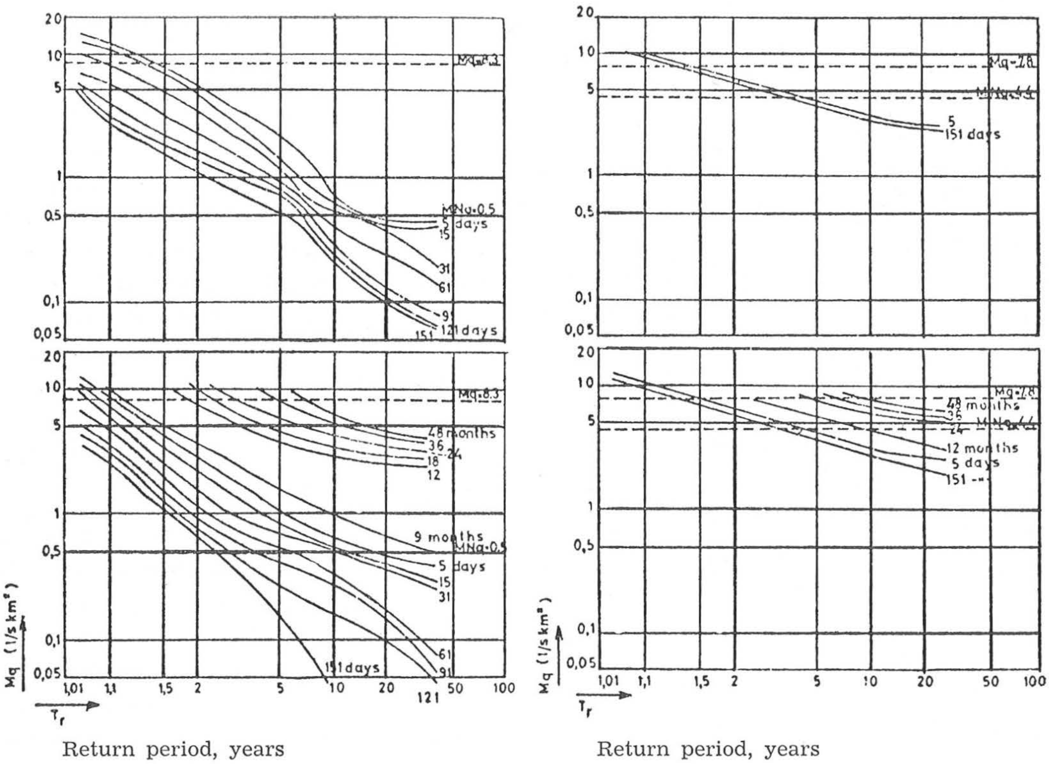
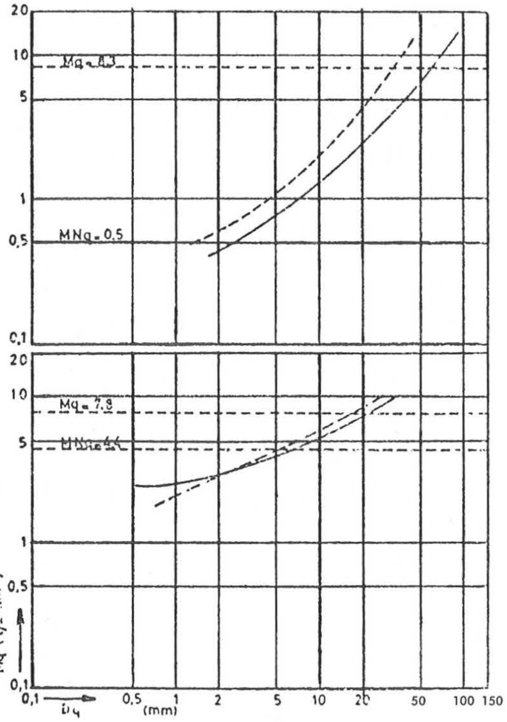


Fig. 23. Correlation between return period T_r and dry-period's t mean runoff Mq_{Nt} (l/s.km²). Winter dry periods in upper, summer dry periods and prolonged droughts in lower chart. Left = Maurialankoski, right = Jääsjärvi catchment area. (4).

ficit of runoff can be seen from Fig. 22. The upper curve shows the variation of runoff in a dry period, the duration of which is t. The period begins at a moment t_1 and ends at a moment t_2. At a moment t_a the runoff first goes below the mean runoff of the period and the last time at a moment t_b.

To support the steady runoff at a time $t_a - t_b$, a storage volume is needed, when Q is less than the mean runoff. The variations in the storage used is shown in the lower curve, the difference in maximum and minimum is indicated by the amount of specific deficit. Kajosaari has calculated by computer the mean runoff of dry periods for different return periods. Fig. 23 shows these values in a basin in southern Finland, the catchment area of which is 2650 km² and percentage of lakes 3.5 % (Maurilankoski). Fig. 23 also shows the corresponding values in a watercourse, the catchment area of which is 1425 km² and the percentage of lakes 26.4 % (Jääsjärvi). You can see that the lakes make the curves indicating dry periods of different long duration come nearer each other. Kajosaari has also shown that the data observed correspond to the basins as a correlation of mean runoff and specific deficit of runoff. Fig. 24 shows this comparison in the areas mentioned, which offers means of estimating the regulation basins needed.



Specific deficit of runoff

Fig. 24. Specific deficit of runoff D_q (mm) as a function of mean runoff Mq_{N151} (l/s.km²) of 151 days dry period. Maurialankoski upper and Jääsjärvi lower chart (4). Summer: broken line, winter: solid line.

Tiivistelmä

Artikkelissa esitellään aluksi sadantaa ja vuotuista hydrologista jaksoa koskevia tietoja (kuvat 1—8). Toisessa luvussa selostetaan maksimivaluntaa koskevien tutkimusten tuloksia (kuvat 9—18) ja kolmannessa luvussa minimivaluntaa (kuvat 19—24). Tutkimusluonteinen osa kohdistuu lähinnä lumen sulamisesta ja vesisateista aiheutuvan maksimivaluman erilaisuuksien vertailuun, jolloin tarkastellaan vuorokauden keskivalumaa ylivaluman ajankohtana. Näistä erilaisuuksista mainittakoon seuraavat:

— Valuma-alueen suuruuden kasvaessa lumen sulamisen aiheuttama maksimivaluma pienenee hitaammin kuin vesisateista aiheutuva maksimivaluma, kun on kysymys suurista alueista (valuma-alue > 200 km²). Tämä johtuu siitä, että lumen sulaminen tapahtuu likimäärin samanaikaisesti laajoillakin alueilla (paitsi Lapissa), kun taas keskimääräinen sadanta etenkin lyhytaikaisissa sadejaksoissa pienenee pinta-alayksikköä kohdan alueen kasvaessa.

— Pienillä järvettömillä alueilla (< 100 km²) valuma-alueen suurenemisella ei ole merkittävää vaikutusta lumen sulamisesta aiheutuvaan maksimivalumaan, kun taas vesisateitten kyseessäollen maksimivaluma pienenee voimakkaasti alueen kasvaessa. Tämä johtuu siitä, että lumen sulamisen yhteydessä maksimivaluma tällaisilla alueilla saavuttaa likimäärin sulamisvesien tulointensiteetin, jolloin aluevaikutus heikkenee. Näin ei ole asian laita vesisateiden kyseessäollen.

— Peltoalan vaikutus maksimivalumaan on kuvan 13 mukainen, kun on kysymys lumen sulamisen aiheuttamasta valumasta järvettömillä alueilla. Käyrän muoto johtuu ennen muuta siitä, että lumi sulaa pelloilta aikaisemmin kuin metsäalueilta ja ehtii huomattavassa määrin virrata pois ennenkuin metsäalueen maksimi esiintyy.

— Valuma-alueen mäkisyydellä ei ole kovin suurta vaikutusta maksimivalumaan lumen sulamisen yhteydessä, voipa mäkisyys pienentääkin sitä pienillä järvettömillä alueilla. Sensijaan vesisateiden yhteydessä mäkisyys lisää maksimivalumaa. Tämä ero johtuu siitä, että mäkimaastossa lumi sulaa eri aikoina eri ilmansuuntiin viettävillä rinteillä ja valuu niitä myöten vesiuomiin jo varhain sulamiskaudella. Tasaisessa maastossa sulaminen tapahtuu enemmän samanaikaisesti ja sulamisvedet kerääntyvät lumivallien taakse purkautuakseen samanaikaisesti vasta sulamiskauden loppupuolella. Vesisateiden yhteydessä rinteet jouduttavat veden virtausta ja siirtävät sitä lähemmäksi sademaksimin ajankohtaa.

Mustosen tutkimukset kolmen viimeksimainitun ryhmän osalta vahvistavat Kaiteran aikaisempia tuloksia.

References

1. *Angervo, J. M.*, 1962. Lyhyt sääoppi ja sääennustajan opas, Helsinki.
2. *Kaitera, P.*, 1938. Maankuivatuksen vaikutuksesta alapuolisen vesistön purkautumissuhteisiin, MIY:n vuosik., Helsinki.
3. *Kaitera, P.*, 1949. On the melting of snow and its influence on the discharge maximum in streams and rivers in Finland, TKK:n tutk. n:o 1, Helsinki.
4. *Kajosaari, E.*, 1968. Kuivakausista Suomen vesistöissä erityisesti vedenhankintaa ja vesiensuojelua silmälläpitäen, Hydr. toim. tied. XXVIII, Helsinki. (Droughts in Finnish watercources with reference to water supply and pollution control).
5. *Mustonen, S.*, 1963. Kesäsateiden aiheuttamasta valunnasta, Maat.hall. ins.os., Helsinki. (On the runoff due to sommertime rainfall).
6. *Mustonen, S.*, 1965. Meteorologisten ja aluetekijöiden vaikutuksesta valuntaan, Maa- ja vesitekn. tutk., Helsinki. (Effects of meteorologic and basin charasteristic on runoff).
7. *Mustonen, S.*, 1968. Ylivalumasta pienillä alueilla, Rakennustekniikka, Helsinki.
8. *Niinivaara, K.*, 1953. Haihtumisesta pienehköillä vesistöalueilla Suomessa, TKK, Helsinki.
9. *Niinivaara, K.*, 1961. Ylivalumien todennäköisestä vaihtelusta Suomessa päävesistöjen alueilla, Tekn. Aikak. 1., Helsinki.
10. *Renqvist, H.*, 1933. Sadealueen suuruuden vaikutuksesta tulvamäärään, Tekn. Aikak. 1., Helsinki.
11. *Renqvist, H.*, 1936. Sisävedet, Suomen maantieteen käsikirja, Helsinki.
12. *Simojoki, H.*, 1966. Suomen vesitaloudesta, Hydr. toim. tied. XXIV, Helsinki.
13. *Siren, A.*, 1955. Suomen vesistöalueet ja keskimääräiset valuma-arvot, Hydr. toim. tied. XV, Helsinki.
14. *Wäre, M.*, 1954. Om vattendrag och deras förorening, Tekn. För. i Finland förh. 7., Helsinki.
15. *Wäre, M.*, 1961. Sateiden rankkuus toukolokakuussa lähinnä Vihdissä vuosina 1939—58 suoritettujen havaintojen perusteella, Maa- ja vesitekn. tutk. n:o 19. 2, Helsinki.

Vammala 1971, Vammalan Kirjapaino Oy