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

WATER BALANCE IN FINLAND DURING THE PERIOD 1961–1975 AS COMPARED TO 1931–1960

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SOLANTIE, R. & EKHOLM, M. 1984. Water balance in Finland during the period 1961–1975 as compared to 1931–1960. Publications of the Water Research Institute, National Board of Waters, Finland, No. 59.

Runoff, precipitation and evaporation were determined as annual means for the period 1961–1975, both basin-wise and by isoline analysis on maps. Precipitation was corrected for measuring errors. Evaporation was calculated in two ways, firstly as the residue from the water balance equation and secondly by an equation rendering evaporation from land areas as a function of three parameters representing air temperature, the amount of growing stock and the effect of open bogs. Further, the changes of these main components of the water balance between the periods 1931–1960 and 1961–1975 were investigated.

Index words: Water balance, corrected precipitation, evaporation estimation, runoff.

1. INTRODUCTION

Hydrological and climatological statistics are in the first place calculated for ”normal periods”, successive periods of 30 years, according to WMO practice. At present (1984) the period 1961–1990 is in progress. However, some information concerning the components of water balance since the end of the last 30-year period is already needed in the nineteen-eighties. To obtain this information, it is practical to use the halves of the normal periods. Results for 10-year periods are somewhat inaccurate mainly due to storing problems, and 20-year periods cannot be added to form normal periods. The period 1961–1975 was chosen also because the main components of the water balance are climatological parameters or depend on these, and the most recent climatological statistics are available for the period 1961–1975 (Heino 1976).

In this study the annual means of the main components of the water balance were calculated, both basin-wise and as map analyses.

2. BASINS USED IN THE STUDY

Areal values were calculated for precipitation (P), runoff (R) and evaporation (E). Evaporation was calculated both from the water balance equation (E_B) and from the evaporation equation developed by Solantie, Equation 2, section 6.1. For obtaining E_B, the change in water storage per year (M) was also needed. Only basins with observations available for the whole period 1961–1975 were used. For some of the basins, the changes in the components from the period 1931–1960 to the period 1961–1975 could be obtained.

The areal runoff and corrected precipitation were calculated for the basins on the basis of data from discharge observation sites (National Board of Waters 1980). All the basins were included for which E_B could be obtained accurately enough as the difference between P and R+M. In addition, the basins Peerajärvi, Kilpisjärvi and Utsjoki were included. For these basins P was obtained as the sum of R and E_k because orographic effects and exposed terrains make observed precipitation inaccurate. The basins are listed in Appendix 1 and shown in Fig. 1 (1a, 1b). Those basins for which the standard error of E_B, denoted by S (E_B) and obtained as $\sqrt{S^2\ (P)+S^2\ (R)}$, was greater than 25 mm, were rejected. However, the aforementioned three basins in northern Lapland were retained. Furthermore, in regions with particular features in the water balance, values of S(E_B) up to 30 mm were accepted if more accurate results were not available. The regions are as follows:

1. Regions including basins bounded by flow observation sites both downstream and upstream called in this paper "intermediate" basins. In these basins values of R are obtained as residues, being therefore somewhat less accurate.
2. Regions of areal precipitation maxima, mostly including small basins around river headwaters or on the coasts.
3. Northern Lapland, where precipitation stations are far apart.

Because runoff is determined more accurately than precipitation, S(R) was neglected. S(P) = 25 mm corresponds to a certain minimum of the area of the basin, denoted by F_{min}. Further, F_{min} depends on the density of precipitation stations (ρ). Because ρ was in 1982 approximately the same as in the period 1961–1975, it was calculated by latitudinal zones from the station list for 1982 of the Finnish Meteorological Institute by multiplying the latitudinal numbers of the stations by 0.8 which is the proportion of accepted stations (see Section 4.1). Minimum areas are shown in Table 1.

Table 1. Density of precipitation stations (ρ = number of station per 1 000 km^2) and the minimum area of the basins (F_{min}) by latitudinal zones.

Zone	Latitude (ϕ) degrees	ρ	F_{min} km^2
1	≤ 61.5	2.71	700
2	$61.5 < \phi \leq 62.5$	1.88	1 000
3	$62.5 < \phi \leq 64.5$	1.55	1 200
4	$64.5 < \phi \leq 67.5$	1.10	1 800
5	> 67.5	0.53	3 300

For obtaining E_B, 17 "too small" basins were accepted (2 at the southern coast, 3 at the precipitation maxima on the Suomenselkä divide, 9 in the watershed regions of the provinces Kainuu and Koillismaa and 3 in northern Lapland). In the intermediate basins, (29 % of all, denoted by index v) P_V becomes less accurate with smaller values of the parameter v_F:

$$S(P_V) = \frac{S(P)}{v_F} \cdot \sqrt{1+(1-v_F)^2} \qquad (1)$$

where

$S(P_V)$ = standard error of P in "intermediate" basins

$S(P)$ = standard error P in other basins

v_F = proportion of the "intermediate" basin (bounded by discharge observation sites both downstream and upstream) of the total basin area upstream of the downstream site

The 30 mm upper limit of S(E_B) determines a lower limit for v_F, decreasing with decreasing S(P) or with increasing ρ and F.

Most intermediate basins occur in the lake district of Finland, represented by zone ϕ_2. Corresponding to the value of ρ for zone ϕ_2, one obtains 1/4 as the lower limit of v_F for large basins (about 8 000 km^2) and 1/3 as that for small basins (about 1 200 km^2).

By dividing basins into parts down to these accuracy limits of area or of v_F, 72 separate basins were obtained, for which the water balance components could be determined with mutual independence. However, in some cases a very small basin is within a very large one. The principle of mutual independence of basins was in such cases only slightly injured, because the sizes of the two basins were of different orders. The mean area of these 72 basins was 3 592 km^2, and the total area 248 770 km^2 or 74 % of the area of Finland.

In addition to these 72 basins, the water balance components were obtained for 16 combinations of these basins. Regarding further the 3 before mentioned cases in Lapland, the water

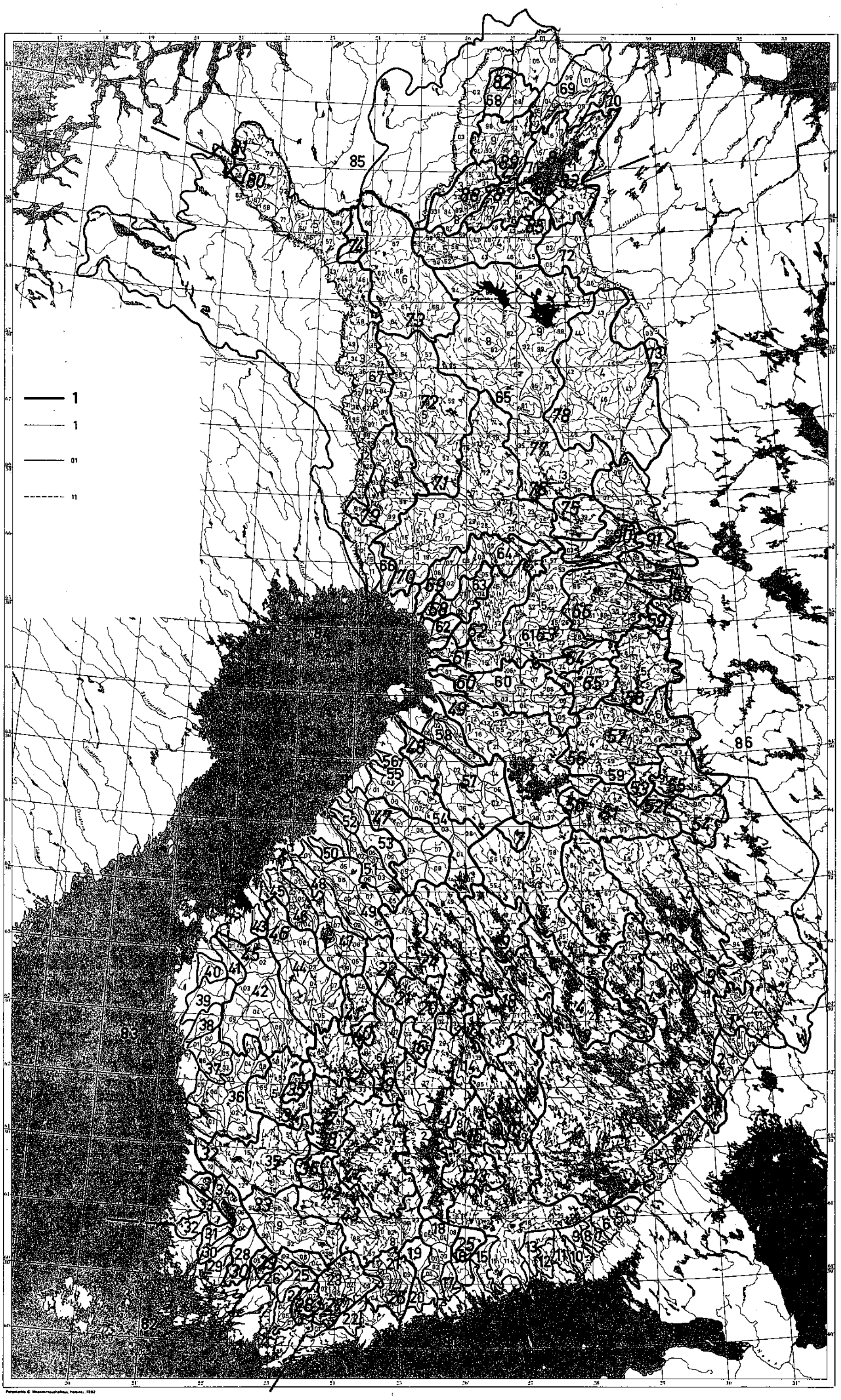

Fig. 1a. Basins for which the water balance was determined for the period 1961—1975.

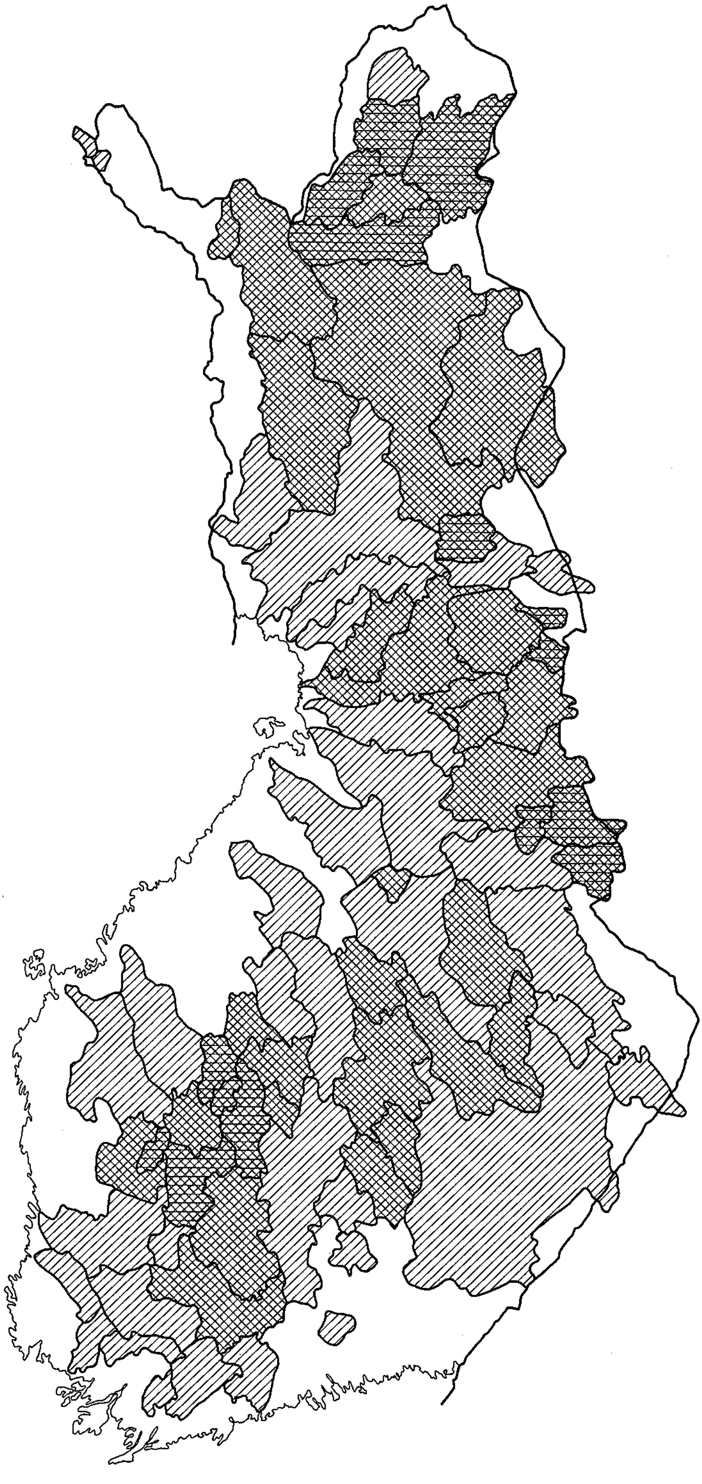

Fig. 1b. Large basins for which the water balance was determined for the period 1961–1975 in addition to the balance of their sub-basins.
/// = determined only separately
XXX = determined separately and as part of a larger basin
⋇⋇⋇ = determined separately and as part of two larger basins

balance components are given for 91 basins in total. Of the mutually independent basins, the changes in water balance components from period 1931—1960 to period 1961—1975 could be obtained for 39 basins.

3. RUNOFF

3.1 Basic data

The basic data for the mean annual runoff (R) during the period 1961—1975 comprises measurements made by the Hydrological Office of the National Board of Waters, Finland at flow gauging and hydroelectric power stations. Large basins were divided into sub-basins by using discharge series at sites inside them, which were above the size limit below which precipitation is too inaccurate (Section 2). If only a few years of observations were lacking these were interpolated by using reference values from neighbouring stations.

3.2 Location and correction of erraneous values

Some observation series, for which R disagreed with corresponding values for neighbouring stations and other water balance components, were subjected to a closer examination.

The error and the correct value could be calculated by using values of R observed at neighbouring stations and estimates of R from the water balance equation for the remainder of the basins. However, because neighbouring stations were available, the estimated values were not used in this study. Only in one case (Kilpisjärvi basin) was the value of R really needed. The values of P around Kilpisjärvi basin were inaccurate and only one neighbouring discharge series was available. Therefore, the discharge curve was examined closer. It was found to be partly erraneous and corrected for obtaining the required value of R.

The corrections made were as follows:

1. Discharges at Kilpisjärvi (Q—819), located in the upper part of the Tornionjoki basin, were reduced by 13 % after an examination of the discharge curve in the nineteen-seventies. Consequently, the corrected value of R (490 mm) was used instead of the original (565 mm) for the Kilpisjärvi basin (denoted by 81 in Fig. 1 and Appendix 2). The result is somewhat uncertain because the time when the discharge curve changed is unknown. However, the corrected value is rather close to the corresponding value for the neighbouring Peerajärvi basin (449 mm), located at about the same altitude.
2. The corrected value of R for the Iijoki basin upstream of Raasakka hydroelectric power station (419 mm) is 16 mm greater than the original value (403 mm), obviously because of problems caused by change of observation site during the period. Consequently, the discharge series here was replaced by two others in combination, namely those for the Kipinä flow gauging station and the Leuvankoski flow gauging station at the Siuruanjoki tributary (the Iijoki basin is denoted by 61 in Fig. 1 and Appendix 2).
3. The corrected value of R for the basin upstream of Kaukonen (Q—846) on the river Ounasjoki is 331 mm or 7 % smaller than the corresponding original value of 356 mm. The discharge series was replaced by that at Köngäs (Q—840, the basin upstream denoted in Fig. 1 and Appendix 2 by 73).
4. The corrected value of R for the upper part of the Kymijoki basin above the Vaajakoski hydroelectric power station (300 mm) is about 8 % greater than the corresponding original value of 278 mm. This discharge series was replaced by two others in combination, one for Simunankoski (Q—31, the basin upstream denoted by 17 in Fig. 1 and Appendix 2) and the other for Kapeekoski (Q—825, the other upstream basin, denoted by 23).
5. The corrected value of R for the Kymijoki basin above the Kuusankoski hydroelectric power station (279 mm) is 7 % larger than the corresponding original value of 261 mm. This discharge series was replaced by two other series in combination, the one for Kalkkinen (Q—55, the next basin upstream, denoted in Fig. 1 and Appendix 2 by 14) and that for Ripatinkoski (Q—63b, the tributary upstream basin denoted by 10).

3.3 Laying out of the runoff maps

The mean annual runoff (R) during period 1961—1975 is also shown cartographically (Fig. 2). For the details of the isolines, maps of P (Fig. 3) and E

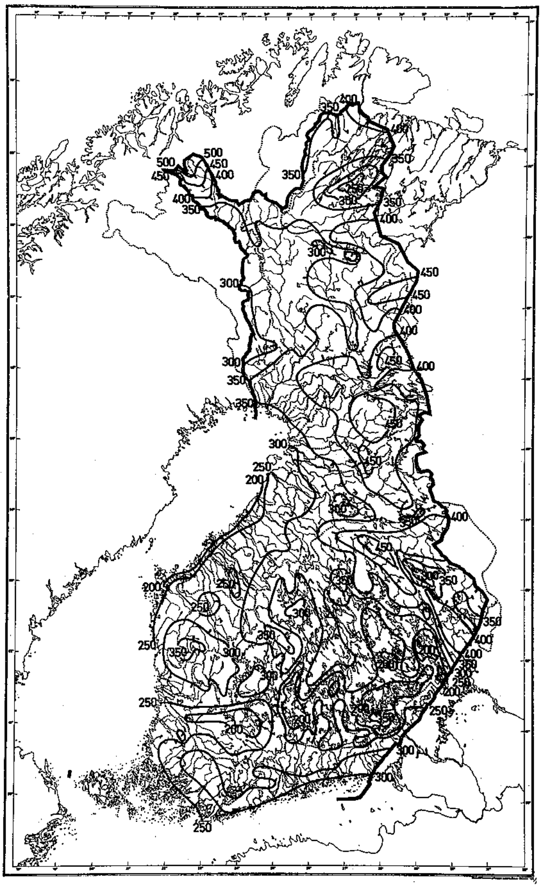

Fig. 2. Mean annual runoff during the period 1961–1975 (mm).

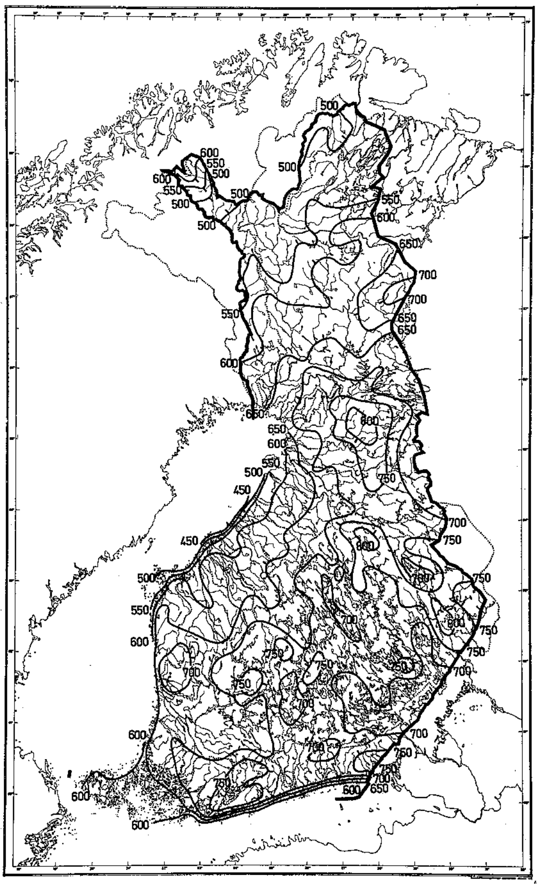

Fig. 3. Mean annual precipitation (corrected) during the period 1961–1975 (mm).

(Fig. 4) were used. The change in R from period 1931–1960 to period 1961–1975 is shown in Fig. 10.

3.4 Temporal variation in the annual runoff

The temporal variation in the annual amounts of runoff (R_O), precipitation (P_O) and evaporation (E_O) was studied in a sample of eight basins (the basic material: Hydrografinen toimisto 1935, 1936, 1938, 1944, 1948, Tie- ja vesirakennushallitus 1954, 1957, 1962, 1963, 1965, 1968, 1970, National Board of Waters 1972, 1975, 1976, 1977). These basins are not included in the list of basins for which the water balance was determined (Appendix 2). However, in Appendix 2, basins or their combinations practically the same as those used here may be found. There are two reasons for such a choice of the basins. Firstly, basins as large as possible are needed for avoiding the disturbances caused by changes in the station sets, particularly in northern Finland. Secondly, accurate values of snow storage are needed for calculating annual values of evaporation (Section 6.7). The standard deviation of the annual amounts of runoff, denoted by S (R_O), was calculated both for period 1931–1960 and period 1961–1975.

The change of S (R_O) between the periods, denoted by d S (R_O), was also obtained. Further, the smoothing of the variation of R_O due to water storage was studied in the light of the differences S (R_O) – S (P_O). Because of the shortness of the periods, these differences were calculated for the period 1931–1960+1961–1975.

These results and some information concerning the basins are presented in Table 2.

The values of S (R_O) were in all basins some-

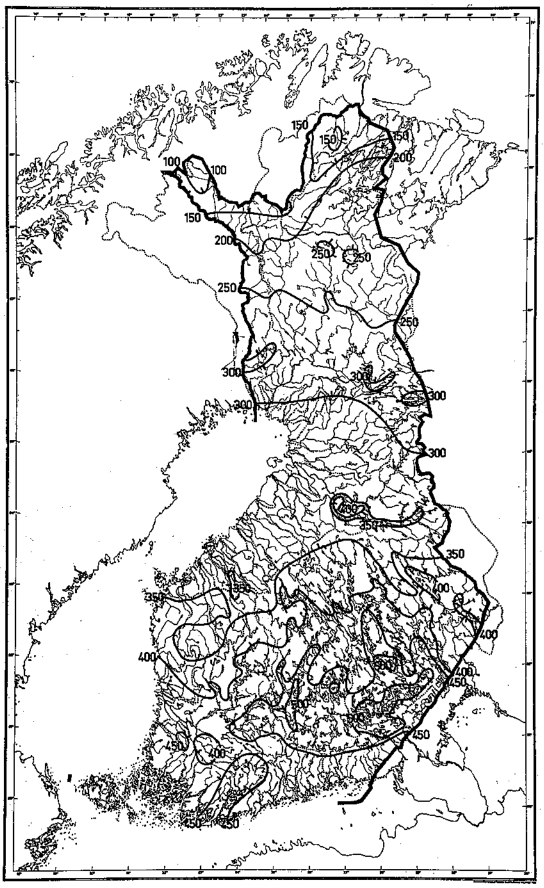

Fig. 4. Mean annual evapotranspiration from land- and water areas during the period 1961–1975 (mm).

what smaller in period 1961–1975 than in period 1931–1960, these changes being however not statistically significant at the 5 % level. According to the statistics for the period 1961–1975, S(R_0) is markedly smaller than S (P_0) in the basins where L is about 20 %, as is usual in the Lake district. Thus, storage in large lakes for periods longer than one year markedly smoothes the variation in runoff. This effect is somewhat weaker in the basin Kokemäenjoki, Harjavalta, belonging only partly to the Lake district. The storage of water in aapa bogs is reflected in the rather small values of S (R_0) in comparison to S (P_0) in the two last basins. Elsewhere in Finland, excluding the regions of aapa bog complexes and the Lake district, S (R_0) is greater than S (P_0).

4. PRECIPITATION

4.1 Correction of measuring errors in precipitation for obtaining mean annual precipitation during the period 1961–1975 basin-wise and as isolines on a map

The basin values (Appendix 2) and a map of corrected values were obtained by correcting the map and basin values of mean annual precipitation (National Board of Waters 1980) for errors in

Table 2. The standard deviation of annual values of R_0 (denoted by S (R_0) in periods 1931–1960 and 1961–1975, its change between the periods (denoted by d S (R_0), and its deviation from S (P_0). Additional information concerning the basins is also given.

Basin	Corresp. basin in Appendix 1 and Fig. 1a.	S (R_0) mm 1931–1960	S (R_0) mm 1961–1975	dS (R_0) mm	S (R_0)–S (P_0) mm (1931–1960)+(1961–1975)
Vuoksi, Imatra	2–9	70	54	–16	–23
Kymijoki, Kalkkinen	14–24	81	50	–31	–20
Vantaajoki, Oulunkylä	26	132	114	–18	+ 8
Kokemäenjoki, Harjavalta	32–39	83	73	–10	–13
Kyrönjoki, Lansorsund	45	110	101	– 9	+21
Kalajoki, Hihnalankoski[1]	47	95	69	–26	+ 7
Iijoki, Merikoski	61	91	60	–31	–12
Kemijoki, Isohaara	70–78	85	62	–23	– 9
Average		93	73	–21	– 5

[1] During the period 1931–1970 Kalajoki, Hihnalankoski (F = 3 025 km^2, L = 1.8 %).
During the period 1971–1975 Kalajoki, Niskakoski (F = 3 005 km^2, L = 1.8 %).

measurement. For the preparation of this map of observed precipitation, both basin and station specific values had been used. Each basin value had been obtained as an average of the 180 monthly values of period 1961–1975. Consequently, it had also been possible to use short observation periods. In each month, values from about 120 stations had been rejected and about 500 accepted for calculating basin values. Because basins with calculated values cover most of Finland, long period averages from single stations (278) had mostly been used only for a more close analysis within large basins.

The correction of annual precipitation due to the measuring error (about 100 mm) consists of the adhesion correction and wind-plus-evaporation correction. The long period average of the annual adhesion correction (T) is about 26 mm (Solantie 1976) and that of the wind-plus-evaporation (B) about 74 mm. Because the relative wind-plus-evaporation correction (per cent of observed precipitation) varies depending on the forms of precipitation being at its greatest during dry snowfalls, the long period average of its mean value depends on the region as well as on the proportions of different forms of precipitation. In addition, it depends on the exposure of the observation site (α) being proportional to the exposure number of the site (Korhonen 1941). Values of α are calculated as weighted means of its components in different compass directions (α_i), the weights being the frequencies of winds during precipitation. Values of α_i vary between 0 (a totally shielded sector) and 1 (a totally exposed sector). The mean of $\alpha, \overline{\alpha}$, is 0.35 and its standard deviation S (α) about 0.18. Consequently, $S(B) \cong$ 38 mm. The number of stations in a typical large basin (8 000 km^2) is about 15 and in a typical small one (1 200 km^2) about 3 (because stations outside the basin but close to its boundaries are also included).

Now it is possible to correct the basin values of P so that the exposure at all stations is approximated by $\overline{\alpha}$. For such a correction ($\overline{B}$) the standard error $S(\overline{B})$ due to the approximation amounts for large basins to about 10 mm and for small basins to about 20–25 mm. These values are the upper limits of errors, however, because the most exposed stations have been discarded. The parameters from the accepted stations are denoted by the index C. In the qualified material $\overline{B}_c$, $\overline{b}_c$ and $S_c(\overline{B})$ are smaller than $\overline{B}$, $\overline{b}$ and $S(\overline{B})$ in the total material. Since $S_c(\overline{B}) < S(\overline{B})$, values of $\overline{B}_c$ were regarded as sufficiently accurate, i.e. wind-plus-evaporation correction was determined at all stations as a function of $\overline{\alpha}$.

A map analysis of the relative total correction of mean annual amounts of precipitation based on the total material was made for period 1931–1960. These relative corrections (denoted by $\overline{k}$) can also be applied to the corresponding material of period 1961–1975 if the proportions of different forms as well as the monthly amounts of precipitation are equal during both periods. However, the application of $\overline{k}$ to the accepted material of period 1961–1975 leads to an overcorrection (biased correction). The level of bias was determined using annual amounts of precipitation in period 1961–1975 from a sample of 9 basins. These basins were denoted by 2, 26, 27, 40, 45, 48, 61 and 71 in Appendix 2 and Fig. 1a.

First, the annual basin values taken from the total data were estimated from isoline analyses of maps of annual precipitation (The Finnish Meteorological Institute 1963–1979). By multiplying these by $1+\overline{k}$ and averaging over the years, corrected and unbiased amounts of mean annual precipitation were obtained basin-wise. By subtracting from these the corresponding uncorrected values of the "accepted" material, unbiased total corrections for the latter were obtained, the mean correction being 85.2 mm. The corresponding mean of biased correction was 105.6 mm. By substracting the mean adhesion correction (T= 26 mm) from both corrections, the corresponding average wind-plus-evaporation corrections became 59.2 and 79.6 mm, their ratio (0.74) being the reducing factor for biased values of $\overline{b}$. The standard error of their difference (5 mm) divided by the latter correction approximates to the standard error of the reducing factor (0.06.). This error, corresponding to an inaccuracy of 3 to 4 mm in annual precipitation, is negligible. To ensure accuracy, the effects of climate on changes in b between the two periods were studied around the Iijoki basin, where this effect was obviously greatest. Observations at Taivalkoski were used. In winter (November 1 to April 30), observed precipitation at this station was as much as 53 mm greater in period 1961–1975 than in period 1931–1960. In addition, only in northern Finland was the snow fall period (October 1 to May 31) colder in period 1961–1975 than 1931–1960, this difference in the mean temperature being 0.54 $^{\circ}$C at Taivalkoski. For both reasons, the percentage of annual precipitation falling as solid (denoted by p) was greater in period 1961–1975 than in period 1931–1960. The monthly mean temperature is denoted by t ($^{\circ}$C). To obtain monthly differences in p between the periods, monthly values of $\partial p/\partial t$ were estimated by using both changes from month to month and geographical differences between the stations at Taivalkoski and Kajaani. Only in October and April was the derivative significant (5 to 6), while in midwinter it was negligible. As the mean precipitation values during period 1961–1975 at Taivalkoski were corrected monthly by taking into account also the changes of p between the periods, we obtain the mean annual precipitation as being 797 mm. By using the standard correction for period 1961–1975, we obtain the result 793 mm. Thus, the "climatological correction" is 4 mm or smaller, generally about 2 mm. To observe this correction, biased values of $\bar{b}$ were multiplied by 0.76 instead of 0.74. Thus, corrections in mm based on the values of $\bar{k}$ in the map of Fig. 6 were obtained by multiplying the observed amounts of precipitation by $0.76 \cdot \bar{b}$ and by adding $0.24 \cdot T = 6.2$ mm to the result.

The mean ± standard deviation of correction was 90±9 mm. The following estimates for the standard errors can be given (n = number of stations in the basin)

- typical large basins ($F = 8\,000$ km^2, $n = 12$) 10 mm
- typical medium size basins ($F = 3\,600$ km^2, $n = 5$) 14 mm
- typical small basins ($F = 1\,200$ km^2, $n = 1{,}5$) 27 mm

Because the map analysis and basin values were corrected by the same method, no disagreement between them was observed (Fig. 3, Appendix 2). The map analysis of P was controlled in northern Lapland by the sums of runoff and evaporation (Equation 2. Section 6.1) for the basins 80, 81 and 82 (Fig. 1a, Appendix 2). The agreement was good.

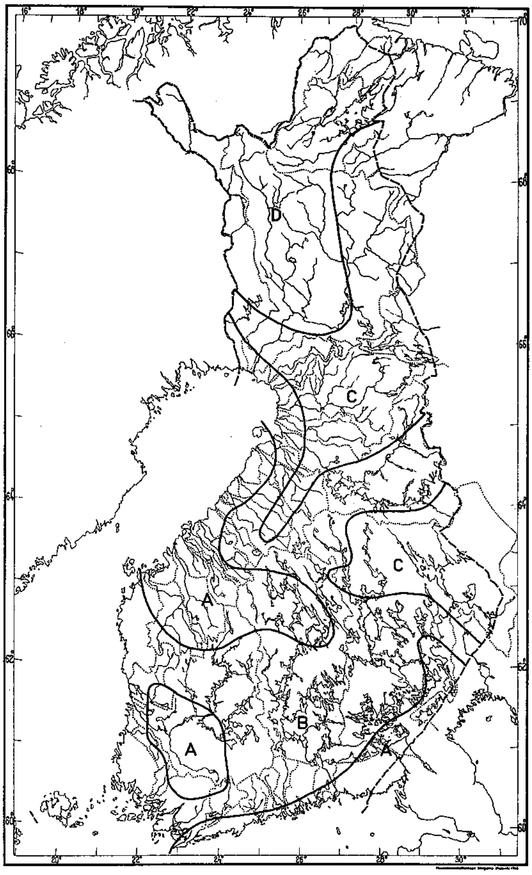

Fig. 5. Division into regions characterizing the classes of seasonal changes of precipitation from the period 1931–1960 to the period 1961–1975 as follows:

A = decrease in early summer, increase in autumn
B = decrease in early summer, increase in autumn and winter
C = increase in autumn and winter
D = no marked changes in any season

4.2 Precipitation during the periods 1931–1960 and 1961–1975

The map analysis of the change of annual precipitation from period 1931–1960 to period 1961–1975 (Fig. 11) was made by using station-wise values. The sample of stations comprised the synoptical and climatological stations of permanent location and in addition some permanent precipitation stations. Regarding changes of precipitation in different seasons and per year, it was possible to identify regions with four different kinds of change (Table 3 and Fig. 5).

In those basins in which the main components of water balance were calculated for both periods, precipitation increased on average 28±25 mm (mean ± standard deviation). Class C occurs in two separate regions of central and northern Finland (Fig. 5). In these regions P increased by about 50 mm. Of this increase 2/3 occurred in winter and 1/3 during the infiltration period of subsurface water storage, whereas during the depletion period of subsurface water storage the change was negligible. In class D, prevailing in Lapland northwest of region C, marked changes did not occur in any season.

Classes A and B prevail between and south of the regions of type C. In both classes, P decreased in the depletion period of subsurface water storage by about 20 mm. In the infiltration period of subsurface water storage precipitation increased in both classes, but markedly (by about 25–30 mm) only in class B. In winter precipitation increased by about 20 mm in class B but did not change in class A. Consequently, the annual change was marked (about 30 mm) in class B but not in class A.

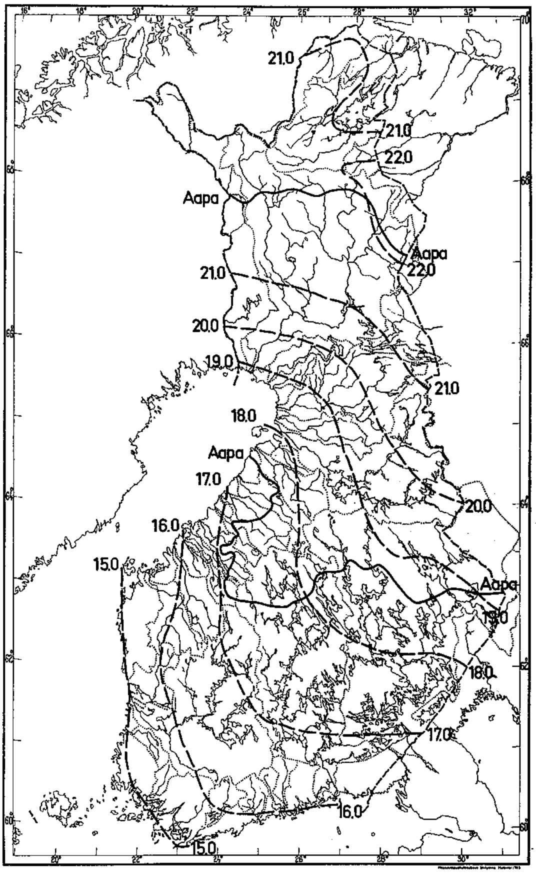

Fig. 6. Total correction of precipitation (% of observed) for stations with an exposure of 35 %, which is the mean among a non selected sample of stations (broken lines) and northern and southern boundaries of the region formed by the northern and middle zones of aapa bogs. Solid lines with "AAPA" at their ends.

4.3 Temporal variation in the mean annual, January and July values of precipitation

The temporal variation in the annual amounts of precipitation (P_O) was examined for the same basins as for runoff (Section 3.4) by using uncorrected values (Hydrografinen toimisto 1935, 1936, 1938, 1944, 1948, Tie- ja vesirakennushallitus 1954, 1957, 1962, 1963, 1965, 1968, 1970, National Board of Waters 1972, 1975, 1976, 1977). The standard deviation of the annual amounts of precipitation in periods 1931–1960 and 1961–1975, denoted by S (P_O), and their differences, denoted by d S (P_O), are shown in Table 4.

During period 1961–1975, S (P_O) was about equal to or slightly smaller than in period 1931–1960 in the basins Vuoksi, Imatra (Lake district, eastern part); Vantaa, Oulunkylä (Transition zone); Kyrönjoki, Lansorsund (Eastern Bothnian region) and Kalajoki, Hihnalankoski (Eastern Bothnian region). In the other basins (Kymijoki,

Table 3. Changes of mean annual and seasonal amounts of precipitation from the period 1931–1960 to the period 1961–1975 (dP), classified according to the seasonal course as A, B, C and D. For each class, results are given as mean ± standard deviation of the station values.

Class (region in Fig. 5)	Number of stations	Year	V–VII	VIII–XI[1)	XII–IV[2)
A	10	−8 ±16	−22 ± 6	12±10	2 ± 7
B	9	31 ± 9	−18 ± 7	28± 6	22 ± 8
C	7	51 ±18	−5 ±16	22±14	34 ±13
D	2	2 ± 5	−8 ± 6	8± 2	2 ± 9

1) = Kuusamo (C), Taivalkoski (C), Sodankylä (D) VIII–X
2) = Kuusamo (C), Taivalkoski (C), Sodankylä (D) XI–IV

Table 4. Standard deviation of P_0 denoted by S (P_0) in the years of periods 1931–1960 and 1961–1975 and their difference denoted by d S (P_0).

Basin	S (P_0) mm		d S (P_0) mm
	1931–1960	1961–1975	
Vuoksi, Imatra	85	87	+ 2
Kymijoki, Kalkkinen	101	72	−29
Vantaanjoki, Oulunkylä	120	117	− 3
Kokemäenjoki, Harjavalta	99	79	−20
Kyrönjoki, Lansorsund	88	81	− 7
Kalajoki, Hihnalankoski	80	72	− 8
Iijoki, Merikoski	92	69	−23
Kemijoki, Isohaara	94	65	−29
Average	97	80	−15

Table 5. Standard deviation of P_0 denoted by S (P_0) in January and in July during the periods 1931–1960 and 1961–1975.

Basin	S (P_0) in January		S (P_0) in July	
	1931–1960	1961–1975	1931–1960	1961–1975
Vuoksi, Imatra	13.7	13.3	28	33
Kymijoki, Kalkkinen	13.2	12.9	35	35
Vantaanjoki, Oulunkylä	20.2	16.6	29	31
Kokemäenjoki, Harjavalta	14.6	14.8	33	31
Kyrönjoki, Lansorsund	14.0	15.9	39	34
Kalajoki, Hihnalankoski	10.3	15.1	30	32
Iijoki, Merikoski	10.6	18.2	30	35
Kemijoki, Isohaara	9.5	11.4	28	24
Average	13.3	14.8	32	32

Kalkkinen and Kokemäenjoki, Harjavalta in the western part of the Lake district and Iijoki, Merikoski and Kemijoki, Isohaara in the Northern Bothnian region) S (P_0) decreased from period 1931–1960 to period 1961–1975 by 15 to 29 mm. However, these changes were not statistically significant at the 5 % level.

Additionally, the values of S (P_0) were calculated for both periods in January and in July (Table 5). In January the change in S (P_0) between the periods was marked only in the basins Kalajoki, Hihnalankoski and Iijoki, Merikoski, both located between the latitudes 63.5 ° and 66 °N. In the latter basin, the change was statistically significant at the 5 % level. In the areas around these basins, mean precipitation during winter increased markedly. Consequently, this increase was caused by the occurrence of winters of abundant precipitation during period 1961–1975 but not during period 1931–1960; on the other hand, the frequency of dry January months remained unchanged. Farther north (basin Kemijoki, Isohaara) S (P_0) remained small. S (P_0) was greatest in the basin Vantaanjoki, Oulunkylä; great variation of P_0 in autumn and winter are typical only for the southern coast, due to orographical factors. In the four other basins of southern and central Finland, all values were between 12.9 and 15.9 mm during both periods.

During period 1931–1960, therefore, it would appear that intensive cyclone centres occurred in January up to 63° of latitude and during period 1961–1975 to about three latitude degrees further north.

In July no marked differences in S (P_0) were found between either the periods or the regions.

5. CHANGES IN WATER STORAGE

The mean annual change of water storage between the beginning and the end of period 1961–1975 was estimated by considering the water levels in the lakes and the snow cover. For the changes in water storage in the lakes (M_L), the average change in lake water level in the basin was approximated by that in a dominating lake or by averaging over several large lakes (detailed in Appendix 1). For the change of snow storage (M_S), the values of water equivalent in large basins on January 1 1961 (Tie- ja vesirakennushallitus 1963) and on January 1 1976 (National Board of Waters 1980) were used (details in Appendix 1). The role of the change in water storage was mostly insignificant: the mean ± standard deviation of the basin values of $-M_S-M_L$ ($n = 72$, Appendix 2), was -1 ± 5 mm.

6. EVAPORATION

6.1 Influence of temperature on evaporation during the period 1961–1975

According to the evaporation equation of Solantie (1975) the annual evaporation (mm) can be given as:

$$E_k = -42 + 0.315\ G + 1.14\,(1-L) \cdot K_d + L \cdot E_L \tag{2}$$

where

G = the sum of effective temperature or the sum of daily mean temperature excess above +5 °C

L = the proportion of lakes in the basin area

K_d = amount of growing stock on land area ($m^3\ ha^{-1}$)

E_L = the term for lake evaporation ($mm\ a^{-1}$)

The change in G from period 1931–1960 to period 1961–1975 was calculated by taking the sum of the differences between daily mean temperatures (temperature statistics: Kolkki 1966, Heino 1976). As a result, the values of this change and of the corresponding changes in E_k became negligible, the former being in all basins within the limits ± 30 °C d and the latter within limits ± 10 mm. These climatological changes, being so small, can hardly be separated from the effects caused by the changes in the observation sites. Consequently, the effect of temperature on evaporation could be neglected.

6.2 Influence of the amount of growing stock on evaporation

Evaporation increases with the amount of growing stock as indicated by Equation 2 in section 6.1. The contribution of this effect to the change of evaporation from period 1931–1960 to period 1961–1975 (d E_k, mm) could be obtained as the corresponding change in the term $1.14 \cdot (1-L) \cdot K_d$ of the equation. Consequently, the mean amount of growing stock on land area (K_d, $m^3\ ha^{-1}$) was needed on an average during both periods (Fig. 7.). By denoting these values of K_d by K_a and K_b respectively, one obtains

$$K_a = C_2 K_2 + C_3 K_3 \tag{3}$$

$$K_b = C_5 K_5 + C_6 K_6 \tag{4}$$

where K_2, K_3, K_5 and K_6 are values of K_d according to the 2nd, 3rd, 5th and 6th national forest inventories (Ilvessalo 1957a, Kuusela 1967, Kuusela and Salovaara 1968, 1969, 1971, 1974, Kuusela and Salminen 1976, 1978) and C_2, C_3, C_5 and C_6 their weights. The basin values of K were approximated by the corresponding values by forestry board districts or by their weighted means (details in Appendix 1). The values of K_3 were also given for combinations of basins and the values of K_1 and K_2 only as values for combinations of basins (Ilvessalo

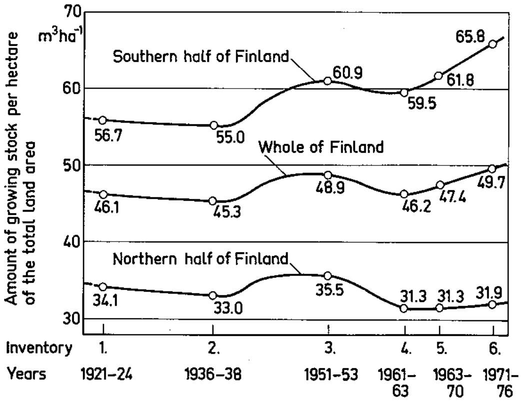

Fig. 7. Course of the amount of growing stock in Finland from 1923 to 1975 ($m^3\ ha^{-1}$). Regarding changes, one $m^3\ ha^{-1}$ corresponds to an evaporation of about 1.14 mm).

1957b). When denoting the values of K for forestry board districts by K'' and those for combinations of basins by K', (Appendix 1), values of K'_2 may be converted into values of K_2'' by the equation

$$K_2'' = K_2' \cdot (K_3''/K_3') \qquad (5)$$

In order to obtain the weights in equations (3) and (4) from a graph showing K as a function of time, the values of K_1, K_2, K_3, K_4, K_5 and K_6 were calculated for Finland as a whole and for its southern and northern halves (the latter comprises the four northernmost forestry board districts). These values of K_3, K_4, K_5 and K_6 were obtained as means of the values of K_3'', K_4'', K_5'' and K_6''. In order to obtain corresponding values of K_1, and K_2,, corresponding values of K_1, K_2 and K_3 were first calculated as means of the values of K_1', K_2' and K_3'. The final values of K_1 and K_2 were then obtained by multiplying K_1' and K_2' by the values of K_3''/K_3', which were 1.013 for the southern half and 0.986 for the northern half of Finland.

Assuming that $K_1 ... K_6$ represent values of K in the middle of the period of the first...sixth inventory, a curve of K as a function of time could be obtained for Finland as a whole and for its halves. By graphical integration, the corresponding averages for the periods 1931–1960 and 1961–1975 could be obtained. In equations (3) and (4) the coefficients became equal in both halves of Finland, being:

$$C_2 = 0.50, C_3 = 0.50, C_5 = 0.75 \text{ and } C_6 = 0.25.$$

By applying equations (3) and (4) to individual basins, the change in the basin values of K_d from period 1931–1960 to period 1961–1975 could be obtained, as well as the basin values of dE_k (Appendix 2). In those 39 basins in which the water balance could be obtained for both periods, the mean ± standard deviation of dE_k was $+ 3 \pm 6$ mm.

6.3 Influence of dry summers and of winters with abundant snow cover on evaporation during the period 1961–1975

Equation (2) in Section 6.1, approximating potential evaporation, does not take into account the effect of soil water deficit on evaporation. In Finland, this effect is obtained only in the hemiboreal and southern boreal vegetational zones (Fig. 9) or hydrologically in the Baltic regime, the transition regime and the regime of the Lake district, where the climate of the growing season is the driest. The effect is noticeable in dry summers, particularly when preceeded by winters of small snow storage. Such winters usually occur only in regions where the mean annual maximum of the water equivalent of the snow cover is less than 100 mm (Solantie 1981). Particularly in the regions where the change in precipitation between periods 1931–1960 and 1961–1975 was of class A (Fig. 5), such areas of thin snow cover reached farther inland from the coast and farther northward along the coast in period 1961–1975 than in period 1931–1960, in Ostrobothnia reaching even into the region of the Eastern Bothnian regime (Figs. 8 and 9). Of the 67 basins for which the value of $E_b - E_k$ could be obtained, more than half of all five basins, denoted by 31, 32, 33, 43 and 44 in Fig. 1 and in the Appendix 1, is situated in those parts of the hemiboreal and southern boreal zones in which the mean maximum snow storage is less than 100 mm. The major part of basins 45 and 46 is located just north of the common northern boundary of the southern boreal vegetational zone and the transition regime. However, in period 1961–1975, during which summers in these basins were especially dry, the climate there was temporarily similar to that characteristic of the southern vegetational zone. Further, because in the major parts of basins 45 and 46 the mean maximum snow storage was less than 100 mm, they were also classified as "dry" basins, thus making a total of seven.

Actual evaporation can be approximated by E_B and potential evaporation by E_k. Evaporation is greatest in forests, increasing with the amount of growing stock (Equation 2 in Section 6.1). Therefore, the deviation in actual evaporation from the potential value was obtained for each basin by regression analysis, using the mean amounts of growing stock in the forests denoted by x as the independent variable. The dependent variable was also given for forest areas, not for total areas. Consequently, parameter $y = (E_B - E_k):((1-L) \cdot m_d)$ was used instead of $E_B - E_k$. Here, $(1-L) \cdot m_d$, indicating the proportion of forest of the total area (denoted by m), is given as a product of the proportion of land of the total area and the proportion of forests of the land area (m_d). Negative values of y indicate

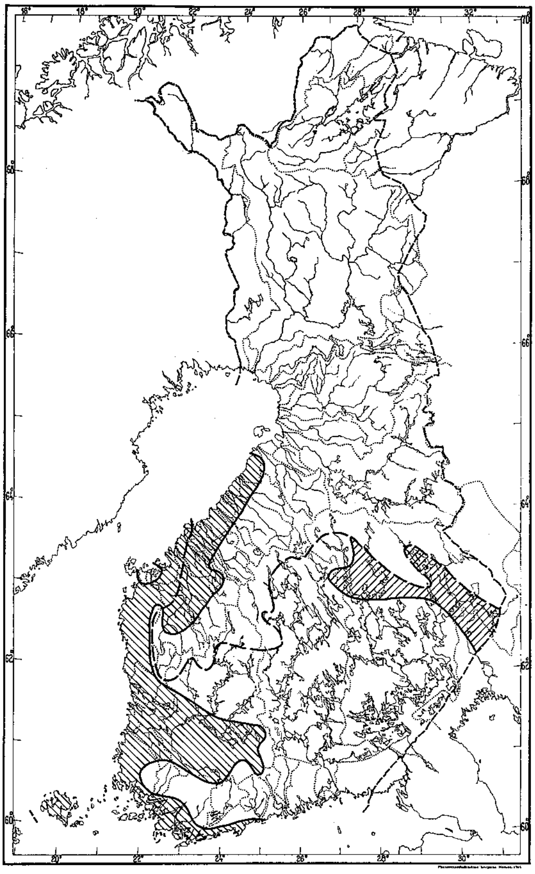

Fig. 8. Northern boundary of the southern boreal vegetational zone (broken line) south of which early summers are generally drier than north of it (see also Fig. 9).

/// = region in which summers, particularly in the period 1961–1975, were more humid than generally

\\\ = region in which scant snow storage was connected with dry summers in the period 1961–1975; north of the broken line summers, particularly in the period 1961–1975, were less humid than generally.

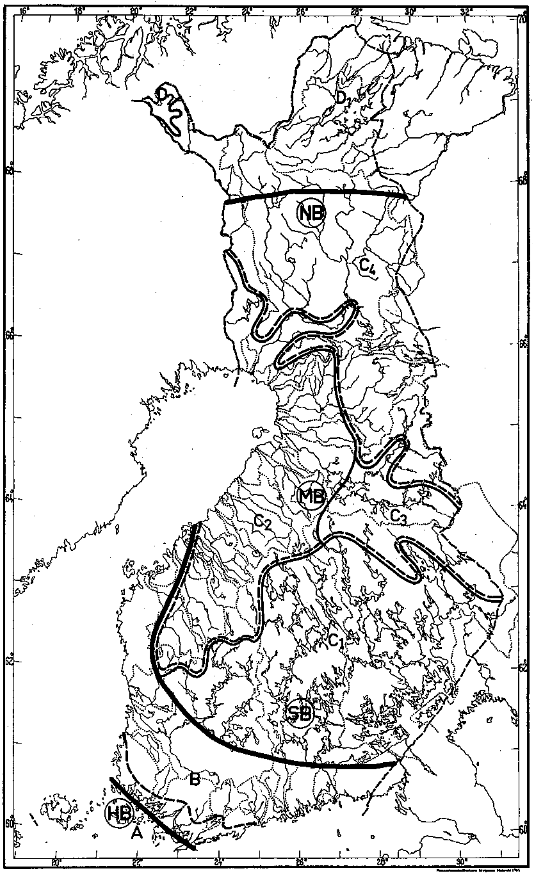

Fig. 9. Hydrological zones and regions together with the vegetational zones.

Hydrological zones and their division into hydrological regions (thin continuous lines):

A = Baltic zone
B = transition zone
C = inland zone
C_1 = Lake district
C_2 = Eastern Bothnian region
C_3 = Maanselkä region
C_4 = Northern Bothnian region
D = fjeld zone
D_1 = Lapland region
D_2 = Kilpisjärvi region

Vegetation zones (broken lines):

HB = hemiboreal zone
SB = southern boreal zone
MB = middle boreal zone
NB = northern boreal zone

that actual evaporation is smaller than the potential value. The values of x and m_d were estimated by map analyses based on results of the 5th inventory (Atlas of Finland 1976). These values are shown basin-wise in Table 6.

As a result, a regression equation was obtained:

$$y = 184 - 2.14\,x \qquad (6)$$

Coefficient of correlation = 0.714 (significant at a 5 % level).
Standard error of estimate of y on x = 29 mm.
Percentage of explained variance = 51 %.

The pair ($y = 0$, $x = 86$) indicates that as the mean volume of growing stock in the forest exceeds around 86 m^3 ha^{-1} the actual evaporation from the forests becomes smaller than the potential value. By multiplying this value by the mean value of m, it was found that this limit corresponds to 50 m^3 ha^{-1} of the total area. In the three of these 7 basin, having the greatest value of x (basins 33, 43 and 44 in Table 6, all belonging to the main basin Kokemäenjoki), the theoretical deviation of the actual evaporation from the potential during period 1961–1975 was in forests –51 mm and in the whole basin area –30 to –34 mm. The values of $E_B - E_k$, being –19 to –41 mm, agree well with the latter figures. For the 5 basins in which $x > 86$ m^3 ha^{-1}, the mean deviation of $E_B - E_k$ from 0 was significant at the 10 % level. Consequently, even during periods of unusually dry summers in the hydrologically driest basins, the influence of drought on evaporation is hardly noticeable because of the rather humid climate of Finland. In addition, the soil in forests of the densest stand is mostly moraine including clay or even pure clay and therefore has a good field capacity.

After winters rich in snow, aapa bog complexes do not always rid themselves of snow melt waters in summer. Particularly in the aapa bog complex zones of Eastern Bothnia and Southern Lapland (Ruuhijärvi and Hosiaisluoma 1981, Fig. 6), in which aapa bogs are the widest and wettest (Ruuhijärvi 1960), wide water surfaces occur. Because on aapa bog complexes the bottom layers of loose Carex peat are somewhat isolated from melt- and rainwater by a rather dense peat layer having a poor vertical water conductivity, the depth and width of the water layer on a bog varies mainly according to the inflow of melt waters from the surroundings of the bog. In the aapa bog complex zones of Eastern Bothnia and southern Lapland the water surfaces were in period 1961–1975 obviously either wider than (in regions of class C, Fig. 5) or approximately as wide as (regions of class B and D, Fig. 5) those prevailing in period 1931–1960. The influence of these water levels on evaporation in period 1961–1975 was studied by regression analysis, in which basin values of $E_B - E_k$ in period 1961–1975 were obtained as functions of the proportions of open bogs (denoted by p_n) in the basin areas. All the basins in these two zones of aapa bog complexes in which p_n is at least 5 % were included. In this way, only the basins near the southern boundary of the aapa bog complex zone of Eastern Bothnia, belonging to the southern boreal vegetational zone, were neglected. In addition, the basins 50 and 56, where p_n is rather small, were included without dividing them into parts. The values of p_n were obtained by multiplying the proportion of land of the total basin area by the proportion of peatlands of the land area and by the proportion of open bogs of the peatland area. The two latter factors were estimated from a map analysis by Ilvessalo (1960) based on results from the 3rd forest inventory. In these 23 basins rich in open bogs

$$\overline{E_B - E_k} \pm S(E_B - E_k) = 25.9 \pm 21.7 \text{ mm and}$$

$$\overline{p_n} \pm S(p_n) = 15.2 \pm 7.5\ \%$$

Table 6. Values of y indicating deviation of actual evaporation from the potential evaporation in forests of the 7 "dry" basins, where this deviation is expected to be negative during the period 1961–1975, and corresponding values of x indicating the mean volume of growing stock in the forests (m^3 ha^{-1}). Values of y were obtained by dividing the difference between the estimates of actual and potential evaporation ($E_B - E_k$) by the proportion of forest of the total area (m). The proportion of forest of the land area (m_d) is also given.

Basin (numbers refer to Fig. 1a and Appendix 2)	m_d %	m %	$y=(E_B-E_k):m$ (mm)	x (m^3 ha^{-1})
31	60	52	+25	90
44	70	64	–30	110
43	73	66	–47	110
33	60	58	–70	110
32	65	60	+33	80
45	53	52	–61	90
46	53	51	+6	80
Mean	62.0	57.6	–20.6	95.7
Standard deviation	7.8	6.1	4.2	14.0

As a result from the regression analysis we obtain

$$E_B - E_k\,(\mathrm{mm}) = 1 + 1.62\ p_n \qquad (7)$$

Coefficient of correlation = 0.561 (significant at a 1 % level). Standard error of estimate of $E_B - E_k$ on p_n = 17.7 mm. Percentage of explained variance = 31 %.

The basins included in this regression analysis are set apart in Appendix 2 by having values entered for p_n, for the increase of evaporation due to this effect ($E_{kn} - E_k$, where $E_{kn} = E_k + 1 + 1.62\ p_n$) and for the error of estimate ($E_B - E_{kn}$). In these basins, on average, $E_{kn} - E_k$ was equal to $E_B - E_k$ = 26 mm. By setting p_n = 100 in equation (7), one finds that in period 1961–1975 a partial water cover on aapa bogs increased the annual evaporation there by about 163 mm.

According to equation (2) in Section 6.1, annual evaporation on treeless areas ($k_d = 0$) is in these zones of aapa bog complexes about 250 mm. About 3/4 of this evaporation (about 190 mm) occurs during the period between the date of final thaw of snow cover over open bogs (about May 10) and the end of September. One may approximate evaporation from the water surfaces of such bogs by the mean evaporation from Class A pans of the National Board of Waters, Finland between the 64° and 68.5°N lines of latitude. Thus approximated, mean evaporation during the period June 1 to September 30 in the years 1961–1975 amounted to 357 mm (National Board of Waters 1980). Parts of the Class A pan observations were already commenced in May. Using these, the mean evaporation for the period May 10 to 31 can be estimated as being about 40 mm. The total evaporation from pans during the period May 10 to September 30 was about 390 to 400 mm. Consequently, on such bogs, the annual evaporation from water-covered surfaces is about 210 mm greater than from bog surfaces not watercovered. This value is not much greater than the estimate of the corresponding addition to the evaporation on open bogs during period 1961–1975 caused by the water partially covering them (163 mm as given above). Considering that the increase in evaporation spread over the total area of the region in question (the two zones of aapa bog complexes) is 26 mm, and that the evaporation in the basins of this region was in period 1931–1960 on average 19 mm less than in period 1961–1975 (values of dE_B in Appendix 2), the increase due to water cover for the total area of the region was in period 1931–1960 only about 7 mm.

Consequently, in summer, water obviously covered on average 3/4 of these bogs in period 1961–1975 but only 1/4 in period 1931–1960. In agreement with this, the water equivalent of the snow cover on the mean date of the winter maximum, April 1, denoted by V, was during period 1931–1960 on average 22.7 mm smaller in this region than in period 1961–1975. Consequently, we can obtain the change of $E_B - E_k$ with V as being

$$\partial\,(E_B - E_k)/\partial\,V \approx 0.837 \cdot p_n/\bar{p}_n = 0.055\ p_n,$$

where regional means of basin values are denoted by bars.

It is now possible to obtain a common solution of an equation giving $E_B - E_k$ as a linear function of V. Equation (7) represents a single solution of this function, being valid when V is equal to the mean in this period, denoted by V_b.

Consequently,

$$E_B - E_k - (1 + 1.62\ p_n) = 0.055 \cdot (V - V_b) \cdot p_n,$$

from which

$$E_B - E_k = 1 + 0.055\ p_n\,(V + 30 - V_b) \qquad (8)$$

Now solve the equation for V in the cases

a) p_n = 100 %, $E_B - E_k$ = 1 mm (no water on peat)
b) p_n = 100 %, $E_B - E_k$ = 210 mm (peat totally water-covered).

In case a), $V = V_b - 30$ mm. For even smaller values of V, $E_B - E_k$ = 0. In case b), $V = V_b + 8$ mm. On the other hand, for even greater values of V, $E_B - E_k$ = 210 mm.

In this equation, V_b is intentionally made to vary basinwise. In order to use this equation, the values of V_b can be read off the map analysis for the mean annual maximum of the water equivalent of snow cover during the period 1961–1975 (Solantie 1981). The arguments for this are as follows: The development and preservation of aapa bog formation are caused firstly by water supply from surrounding lands (Ruuhijärvi 1960) and secondly by conditions being so humid in early summer that water remains on the peat throughout the season. Further, the minimum width of the water surfaces in summer should vary annually from 0 to 100 %, shallow water layers being typical. Similar melt water inflows on bogs per unit area of bogs can occur in regions of different mean values of V. The lower limit of the relative area of the mineral lands surroundings the bog increases as the mean value of V decreases. Therefore, aapa bogs become ever more common going northward. The southern boundary of aapa bog complexes is however mainly determined by the difference between mean evaporation and precipitation in June (Solantie 1974). Firstly, in the southern boreal vegetational zone, evaporation in the forests with greater amounts of growing stock than in more northerly zones is from the snow melt onwards intensive enough to decrease rapidly the runoff into the bogs (Solantie 1974). Secondly, the difference between precipitation and evaporation on the bogs is in June perhaps a more important reason for the occurrence of aapa bogs. In eastern Finland, where June is somewhat more humid, aapa bogs therefore also occur in the northernmost part of the southern boreal vegetational zone, but farther west they are absent in the southern and western parts of the middle boreal vegetational zone, where the vicinity of the sea reduces precipitation in June (Solantie 1974).

Because weather conditions during summer are also important for the width of water surfaces on bogs, equation (8) is applicable over periods of several years. Further, storage of water for several years may occur in aapa bog complexes.

6.4 Changes in mean annual evaporation between the periods 1931–1960 and 1961–1975

For the basins of the aapa bog zones of Eastern Bothnia and southern Lapland, in which the main components of the water balance could be calculated both for period 1931–1960 and period 1961–1975 (n=11), the following changes from 1931–1960 to 1961–1975 were obtained as values of mean ± standard deviation (mm):

dR	dE_B	dP
+27 ± 24	+19 ± 20	+47 ± 27

The corresponding values for basins outside these regions (n=28) were

dR	dE_B	dP
+23 ± 25	−4 ± 26	+20 ± 19

and those for all the basins (n=39)

dR	dE_B	dP
+24 ± 25	+2 ± 27	+28 ± 25

In the region of aapa bog complexes annual precipitation increased about 30 mm more than elsewhere. Taking into consideration the fact that the mean value of dE_k, indicating the influence of changes of wood stand on evaporation, is in this region −2 mm, dE_B is practically totally caused by the variation in bog evaporation. Consequently, aapa bog complexes somewhat reduce the long-term variation in runoff.

In areas outside the aapa bog regions the effect of changes of wood stand was also insignificant (mean ± standard deviation of dE_k was + 3 ± 6 mm in the basins for which dE_B was obtained). All other effects are also generally negligible, because the mean of $dE_B - dE_k$ did not deviate from 0 even at the 90 % level of significance (mean ± standard deviation −8 ± 26 mm). If the effect of dry summers is further eliminated using equation (6), the mean change is even more insignificant (mean ± standard deviation being −6 ± 26 mm).

For all basins in Finland for which dE_B could be obtained, the mean ± standard deviation of this parameter was + 2 ± 27 mm. Thus evaporation did not change noticeably from period 1931–1960 to period 1961–1975. Consequently, the increase of precipitation is only reflected in an approximately equal increase in runoff.

In the light of the theories presented in this study, annual evaporation varies less than annual precipitation. As the standard deviation of the sum of effective temperatures (G) is in long period series about 130 °C, the corresponding standard deviation of E_k (Equation 2, Section 6) is for 30 year means 7 mm and for the difference between two such means 10 mm. The standard deviation of annual corrected precipitation is about 100 mm. For example, in the sample of 9 basins in Section 4.1 the standard deviation of the mean of annual precipitation was 97 ± 4 mm (average standard deviation ± standard deviation among basins). Consequently, the standard deviation of the 30 years' mean of precipitation is about 18 mm and that of the difference between two such means about 25 mm.

Runoff in Finland is thus approximately the difference between two mutually independent variables. The standard deviation of its 30 years' mean is about 21 mm and the difference between two such means about 30 mm.

The estimates of the magnitude of the variation of R and E_B presented in this section agree well with the results for a sample of basins in Sections 3.4 and 6.7.

6.5 Confidence level of evaporation

By comparing evaporation obtained by the water balance equation method (E_B) with that obtained with the evaporation equation of Solantie (E_k, Equation (2)), the mean ± standard deviation of their difference is in the aapa bog region (23 basins, basins 50 and 56 undivided, Fig. 1a and Appendix 2) 26 ± 22 mm, in other regions (44 basins) −6 ± 20 mm and in the whole of Finland +5 ± 25 mm; this both in the case that basins 50 and 56 are divided into parts (n=72) or treated as wholes (n=67). If the effect of water surfaces of bogs on evaporation is further taken into account (Equation 7), the error of estimate (mean ± standard deviation) is in the aapa bog region (n=23) 0 ± 18 mm and in the whole of Finland (n=67) −4 ± 19 mm. By further taking into account the effect of dry summers (Equation 6), the corresponding values are outside the aapa bog region (n=44) −3 ± 18 mm and in the whole of Finland (n= 67) −2 ± 18 mm. Consequently, the evaporation equation by Solantie (Equation 2), particularly when applied with correction for the effects of water on bogs and for dry summers, renders a mean evaporation in the period 1961–1975 without any systematical errors.

6.6 Laying out of the map of mean annual evaporation during the period 1961–1975

The draft evaporation map was fitted in detail on the basis of the values of E_{kn}, values of E_k (Equation 2) being corrected by the effect of water on bogs according to Equation 7. However, a basin-wise check was carried out to ascertain that the analysis was in agreement with the values of E_B, and isolines were shifted a little where necessary.

6.7 Temporal variation in the annual amount of evaporation

Considering that the standard deviation of the sum of effective temperatures is about 130 ^oC d, the standard deviation (S) of the annual amount of evaporation (E_o) according to Solantie's evaporation equation (6.2) is about 40 mm. The value of S (E_o) was also calculated using annual values of E_B for the period 1961–1975 for a sample of basins (Table 7). To obtain E_o for this purpose, uncorrected basin-wise values of P_o were used. In order to avoid the problematics of water storage in lakes, only basins of a small relative lake area were included out of those for which S (R_o) had been calculated. Consequently, the three basins of the Lake district (Section 3.4) were discarded.

The annual change in water storage (M_o) was approximated by that in snow cover on the basis of the values of the water equivalent of the snow cover on January 1 (Hydrografinen toimisto 1935, 1936, 1938, 1944, 1948, Tie- ja vesirakennushallitus, 1954, 1957, 1962, 1963, 1965, 1968, 1970, National Board of Waters 1972, 1975, 1976, 1977). To obtain the variation of M_o, S (M_o) was also calculated. Because snow stores were less well known during period 1931–1960, values of E_o could not be determined for this period.

The values of S (E_o) agree well with the rough estimate based on Eq. (2). The generally small dependence of evaporation on precipitation in the humid climate of Finland (Solantie 1975) is reflected in these results. However, the dryness of summers in southern Finland and the abundance of water surfaces on bogs in the middle zone of aapa bogs, both of which accentuated particularly in the period 1961–1975, show up as correlations somewhat higher than 0. The effect of dryness shows well only inside the dry region (Vantaanjoki, Oulunkylä) but not at its northern boundary (Kyrönjoki, Lansorsund). This is also seen in the variance of the other water balance components. If it is assumed that R is the sum of the independent variables P_o, $-E_o$ and $-M_o$ so that $S(E_o) = \sqrt{-S^2(P_o) - S^2(M_o) + S^2(R_o)}$, the result for the basin Vantaajoki, Oulunkylä would be imaginary, whereas the corresponding result for the Kyrönjoki, Lansorsund (56 mm) is of the magnitude of the observed value (37 mm). By approximating values of S (M_o) during period 1931–1960 by those for period 1961–1975, we also obtain the values of S (E_o) according to such an assumption for the period 1931–1960. The result, 10 mm for the basin Vantaajoki, Oulunkylä, agrees well with the fact that during period 1931–1960 summers were more humid than during period 1961–1975. The result for the basin Kyrönjoki, Lansorsund (49 mm) is also realistic.

Of the three northern basins, Kalajoki, Hihnalankoski is located around the southern boundary of the aapa bog region but Iijoki, Merikoski and Kemijoki, Isohaara are well within it. In the two latter basins, S (P_o) $>$ S (R_o) in both periods 1931–1960 and 1961–1975; consequently, Corr. (P_o, E_o) is in this area significantly positive also in period 1931–1960. In the basin Kalajoki, Hihnalankoski S (P_o) $>$ S (R_o) and Corr (P_o, E_o) $>$ 0 in the period 1961–1975 as in the other two basins, because abundant waters covered the

Table 7. The values of the standard deviation of the annual amount of evaporation (E_0), denoted by S (E_0), the correlation coefficient between the annual amount of precipitation (P_0) and (E_0), denoted by Corr. (P_0, E_0), the percentage of the variance of E_0 depending on P_0, denoted by F (P_0) and the standard deviation of the annual change in water storage, (denoted by S (M_0).

Basin	Hydrological zone/ region	S (E_0) (mm)	Corr.(P_0, E_0)	F (P_0)	S (M_0) (mm)
Vantaanjoki, Oulunkylä	Transition zone	37	0.64	41	45
Kyrönjoki, Lansorsund	Eastern Bothnian region	37	0.01	0	35
Kalajoki, Hihnalankoski	Eastern Bothnian region	30	0.27	7	27
Iijoki, Merikoski	Northern Bothnian region	48	0.38	18	42
Kemijoki, Isohaara	Northern Bothnian region	44	0.45	20	46
Average		37	0.35	16	39

bogs, but only to a lesser degree. In period 1931–1960, during which the bogs were less covered by water, the value of S (E_0) for the basin Kalajoki, Hihnalankoski, obtained by assuming that R is a sum of three independent variables, is 43 mm. This appears to be a realistic magnitude. Consequently, both the regional and temporal differences in Corr (P_0, E_0) agree well with the effect of aapa bog complexes on evaporation.

As a conclusion, in two regions of Finland in the southern and in the northern parts of the country, Corr (P_0, E_0) is slightly positive, the degree of dependence being sensitive to climatological changes. The southern region comprises the Baltic zone, the transition zone and obviously also the southern part of the Lake district, whereas the northern region comprises the southern and middle zone of aapa bogs. Between these regions, there is a zone in which evaporation is in practice totally independent of precipitation. In cool and wet summers, short warm periods and low temperatures reduce evaporation to about the same extent as interception on branches increases it, taking into consideration the rather small amount of growing stock in this area. Even in warm and dry summers peat, occurring commonly in this region, retains moisture sufficiently to maintain a potential evaporation.

7. SUMMARY

In this study, annual means of runoff (R), precipitation (P) and evaporation (E) were obtained for the years 1961–1975 both basin-wise and as isoline analyses on maps. Precipitation was corrected for measuring errors but not station-wise. Evaporation was calculated by two methods. Firstly, it was obtained as a residue from the water balance equation taking into account the changes of water storage in lakes and snow cover. Secondly, evaporation was calculated by the evaporation equation of Solantie (E_k), approximating E as a function of the sum of effective temperature and the volume of growing stock. This equation was improved by adding terms taking into account the corrections for bogs being partially flooded and on the other hand for heavily wooded land where drought may reduce evaporation.

After correcting the values of E_k by these two corrections, all systematical errors were practically eliminated. For all basins in Finland, the mean ± standard deviation of the values of $E_B - E_k$ was without the additional corrections 5 ± 25 mm and with them −2 ± 18 mm. Consequently, the overall results improved somewhat with the correction. The standard error of E_B and E_k should be smaller than the standard deviation of $E_B - E_k$.

The water balance in Finland in the period 1961–1975 was obtained as mutually independent components for 72 separate basins, covering altogether 74 % of the area of the country. Some small basins between discharge measurement sites up- and downstream were first rejected on the basis of insufficient accuracy of P and E. The change in values of the components from the period 1931–1960 to the period 1961–1975 could be obtained for 39 basins. The mean ± standard deviation of this change was for P +28 ± 25 mm, for R +24 ± 25 mm and for E +2 ± 27 mm. Precipitation and runoff increased about equally (Fig. 10 and 11), but evaporation did not

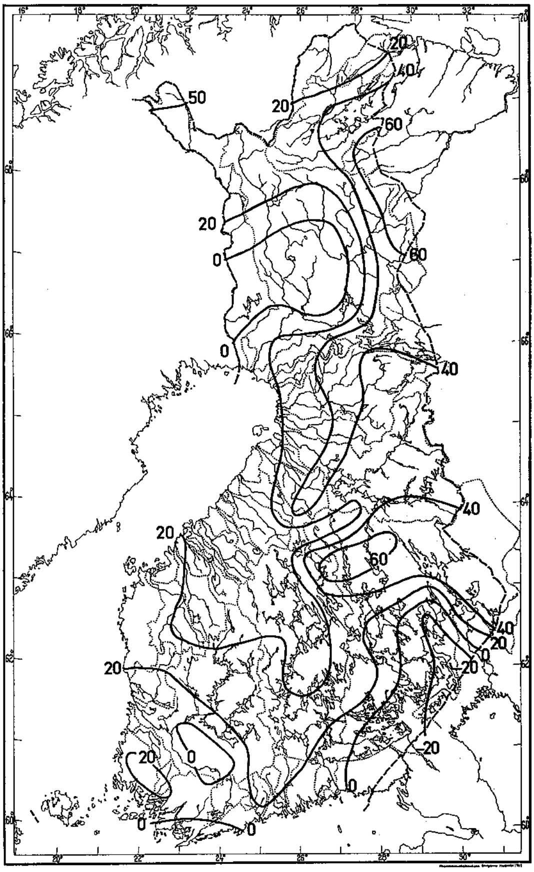

Fig. 10. Change of runoff (mm a^{-1}) from the period 1931–1960 to the period 1961–1975.

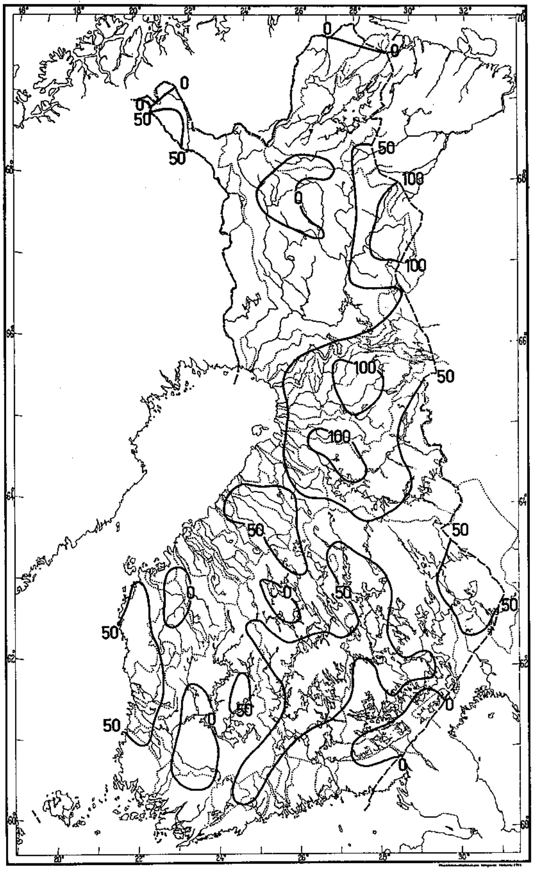

Fig. 11. Change of corrected precipitation (mm a^{-1}) from the period 1931–1960 to the period 1961–1975.

change much. In agreement with the change in E_B, E_k remained unchanged because the amount of growing stock and the mean annual sum of effective temperatures were also unchanged.

ACKNOWLEDGEMENTS

The contribution concerning runoff was made by Matti Ekholm, that concerning precipitation and evaporation by Reijo Solantie and the remainder of the work was carried out in co-operation.

The authors thank Mr. Svante Nordström and Michael Bailey for linquistic revision, Mr. Veli Hyvärinen and Ms. Raija Leppäjärvi for useful remarks and prof. Seppo Mustonen for background advice of the work.

Helsinki, October 1984

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LOPPUTIIVISTELMÄ

Tässä tutkimuksessa laskettiin vesitaseen pääkomponentit sadanta (P), haihdunta (E) ja valunta (R) keskimäärin kauden 1961–1975 vuotta kohti sekä valuma-alueittain (liite 2) että kartta-analyyseinä (kuvat 2–4). Tuloksia verrattiin myös kauden 1931–1960 vastaaviin arvoihin. Sadanta korjattiin tarttumisvirheen sekä tuuli- ja haihtumisvirheen osalta. Jo tämän kauden keskimääräisen korjaamattoman vuosisadannan karttoja laadittaessa ja aluearvoja laskettaessa (Vesihallitus 1980) oli hylätty sijainniltaan avoimimmat asemat (20 % kaikista). Sovellettaessa tähän aineistoon kaikkien asemien aineistolle laskettuja korjauskertoimia (Solantie 1976), tulevat arvot ylikorjatuiksi. Ylikorjauksen selvittämiseksi laskettiin 9 valuma-alueen otokselle korjattu vuosisadanta keskimäärin kautena 1961—1975 myös valikoimattomasta aineistosta (perusaineistona vuosisadannan kartta-analyysit sarjassa "Sade- ja lumihavainnot 1961—1975"). Näiden korjattujen aluearvojen ja vastaavien hyväksytyn aineiston korjaamattomien aluearvojen erotuksena saatiin todelliset korjaukset. Otosalueilla keskimäärin oli oikea korjaus 74 % ylikorjauksesta; ottaen huomioon, että korjauskertoimet oli laskettu kaudelle 1931—1960, kerrottiin ylikorjaukset muuttuneet ilmasto-olot huomioiden 0.74:n sijasta 0.76:lla. Sadantoja korjattaessa katsottiin sadeasemaverkko niin tiheäksi, että korjaukseen vaikuttavaa aseman avoimmuutta ei tarvinnut huomioida asemakohtaisesti.

Valunta laskettiin 72 erilliselle valuma-alueelle, jotka käsittivät yhdessä 74 % Suomen pinta-alasta. Alueiden sisälle ja välille saatiin yksityiskohdat sadanta- ja haihduntakartan avulla. Valunnat laskettiin vain alueille, joilla myös sadanta saatiin erittäin tarkoin (paitsi Enontekiöllä ja Utsjoella, missä sadanta laskettiin eräille alueille valunnan ja arvioidun haihdunnan summana). Vesitase jätettiin laskematta pienimmille ns. välialueille eli alueille, joita myös virtaamamittauspaikat yläjuoksulla rajaavat. Toisaalta eräitä sadanta- ja haihdunta-arvojen kanssa ristiriitaisia valunta-arvoja tutkittaessa ne havaittiin epätarkoiksi ja tarkennuksen jälkeen vesitaseeseen hyvin sopiviksi.

Myös vesivarastojen muutokset kauden vuotta kohti arvioitiin lumi- ja järvivarastojen muutoksina. Ne osoittautuivat merkittäviksi vain harvoissa tapauksissa.

Haihdunta laskettiin sekä jäännösterminä vesitaseyhtälöstä (E_B) että siitä riippumattomana parametrina E_k ns. Solantien (1975) haihduntayhtälöstä:

$$E_k = -42 + 0.315 \cdot G + 1{,}14 \cdot (1-L) \cdot K_d + L \cdot E_L, \qquad (1)$$

missä

G = tehoisan lämpötilan summa (kasvukauden vuorokausikeskilämpötilojen + 5 °C:n ylittävien osien summa)

L = järvien osuus pinta-alasta (%)

K_d = puuston määrä ($m^3\ ha^{-1}$) maa-alueella ja

E_L = järvihaihdunta ($mm\ a^{-1}$)

Tälle yhtälölle laskettiin kaksi korjaustermiä selittämällä E_B-E_k:n arvoja regressioanalyysillä. Lisähaihdunta selitettiin Pohjanmaan ja Perä-Pohjolan aapasuovyöhykkeissä (Ruuhijärvi ja Hosiaisluoma 1981; kuva 6) haihduntana turpeen päälle runsaslumisten talvien jälkeisinä kesinä jäävästä vedestä, riippumattomana muuttujana nevojen prosenttiosuus pinta-alasta (p_n):

$$E_B - E_k = 1 + 1{,}62\, p_n \text{ (mm)} \qquad (2)$$

Valuma-alueita oli 23 kpl ja E_B-E_k:n keskiarvo niillä 26 mm. Korrelaatiokerroin (0.561) on merkitsevä 1 %:n riskitasolla.

Koska kausi 1961—1975 oli näillä alueilla erityisen runsasluminen, oli aapasoilla vesipintaa ilmeisesti huomattavasti enemmän kuin esim. vähälumisena kautena 1931—1960. Merkittäessä lumipeitteen vesiarvoa 1.4. eli maksimin keskimääräisenä ajankohtana V:llä ja erityisesti sen keskiarvoa kautena 1961—1975 V_b:llä, saadaan kausien 1931—1960 ja 1961—1975 V:n ja E_B-E_k:n arvojen kautta kulkeva suora, jonka yhtälö

$$E_{kn} = E_k + 1 + 0{,}055\, p_n(V - V_b + 30) \text{ (mm)} \qquad (3)$$

antaa yleisen ratkaisun E_{kn} nevahaihdunnan osalta korjatulle E_k:lle tarkasteltavan kauden tai vuoden V:n arvon ja kahden valuma-aluekohtaisen vakion (V_b ja p_n) funktiona. V_b:n on syytä olla valuma-aluekohtainen siksi, että aapasoita syntyy niihin kohtiin, missä suolle sen valuma-alueelta keväällä tuleva vesimäärä on suon pinta-alayksikköä kohti tiettyä kynnysarvoa suurempi. Vähälumisilla alueilla vähimmäisvesimäärän edellyttämä suon ja sen valuma-alueen pinta-alojen suhteen yläraja on pienempi kuin runsaslumisilla seuduilla, mikä heijastuu lähinnä p_n:n pienenemisenä kohti vähälumisia seutuja.

Yhtälön (3) mukaan nevalla ei ole päällysvettä, kun $V = V_b - 30$ mm tai pienempi, ja neva on veden peittämä, kun $V = V_b + 8$ mm.

Toinen korjaus E_k:n arvoihin tarvitaan kuivilla alueilla. Kuiva kesäilmasto vastaa Suomessa hemiboreaalista ja eteläboreaalista kasvillisuusvyöhykettä eli hydrologisesti Itämeren vyöhykettä, siirtymävyöhykettä ja Järvi-Suomen aluetta (kuva 9); erityisen kuivakesäisenä kautena 1961—1975 kuivan kesäilmaston alue ulottui Pohjanmaalla vähän pohjoisemmaksikin (kuva 8). Hyvin vähälumisia talvia, joiden jälkeen kevätkosteuskin on vähäistä, sattuu alueella, jossa lumipeitteen vesiarvon keskimääräinen vuosimaksimi on alle 100 mm (Solantie 1981). Niillä 7 valuma-alueella, joissa kautena 1961–1975 kesän kuivuus ja talven vähälumisuus yhdistyivät, saatiin kuivuuden vaikutusta kuvaamaan regressioyhtälö

$$(E_B - E_k) : m = 184 - 2.14 \cdot K_m \qquad (4)$$

missä

m = metsän osuus valuma-alueen pinta-alasta ja

K_m = puumäärä metsässä (m^3 ha^{-1})

Korrelaatiokerroin = 0.714 (merkitsevä 5 %:n riskitasolla). Yhtälön (4) mukaan kuivuus pienentää haihduntaa, kun K_m on vähintään 86 m^3 ha^{-1}. Suurinta K_m:n arvoa 110 m^3 ha^{-1} vastaten $(E_B - E_k):m = -51$ mm ja $E_B - E_k \sim -32$ mm. Kun E_k:n arvoihin tehtiin yhtälöiden (2) ja (4) mukaiset korjaukset, muuttui $E_B - E_k$:n keskiarvo ± keskihajonta koko Suomen aineistossa 5 ± 25:stä –2 ± 18:aan mm:iin. Sekä E_B:n että E_k:n keskivirhe on tietysti pienempi kuin $E_B - E_k$:n keskihajonta.

Kaikenkaikkiaan vesitase selvitettiin 72 erilliselle alueelle, jotka käsittävät 74 % Suomen pinta-alasta. Lisäksi vesitaseen pääkomponenttien muutos kaudesta 1931–1960 kauteen 1961–1975 voitiin selvittää 39 valuma-alueella. Muutos (keskiarvo ± keskihajonta) oli sadannalle 28 ± 25 mm, valunnalle +24 ± 25 mm ja haihdunnalle (E_B) + 2 ± 27 mm. Sadanta ja valunta kasvoivat suunnilleen saman verran (kuvat 10 ja 11), ja haihdunta pysyi suunnilleen ennallaan; vain aapasuoalueilla tuntui sadannan lisäys (47 ± 27 mm) myös haihdunnan lisäyksenä (19 ± 20 mm). Sopusoinnussa E_B:n muuttumattomuuden kanssa ei E_k koko Suomessa keskimäärin muuttunut lainkaan (puuston määrä ja tehoisan lämpötilan summa jokseenkin muuttumattomat).

LIST OF SYMBOLS

1. Correction of precipitation

T = mean adhesion correction or error (mm a^{-1})

B = wind-plus-evaporation correction or error (mm a^{-1})

b = relative wind-plus-evaporation correction (ratio of B to observed precipitation)

k = relative total correction (ratio of B+T to observed precipitation)

p = proportion of solid precipitation of the total

t = monthly mean temperature (°C)

S = For S, see symbols of group 4 below

C = index, indicating that stations most exposed are neglected (''accepted material''). It is used only for avoiding confusion with total material

α = exposure of the observation site

α_i = the component of α in a certain compass direction

2. Water balance components

P = mean annual precipitation (mm a^{-1})

R = mean annual runoff (mm a^{-1})

E_B = mean annual evaporation from the water balance equation (mm a^{-1})

E_k = mean annual evaporation from the Solantie evaporation equation (mm a^{-1})

M_S = mean annual change of water storage in the lakes from the period 1931–1960 to the period 1961–1975 (mm a^{-1})

M_L = mean annual change of water storage in the snow cover from the period 1931–1960 to the period 1961–1975 (mm a^{-1})

M = mean annual total change of water storage from the period 1931–1960 to the period 1961–1975 (mm a^{-1})

d = (in front of symbols) = the change in the parameter from period 1931–1960 to period 1961–1975

3. Symbols connected with the determination of evaporation

G = sum of effective temperatures being the sum of daily mean temperature excesses above 5 °C during the growing season

K_m = mean amount of growing stock in the forests (m^3 ha^{-1})

K_d = mean amount of growing stock on the land areas (m^3 ha^{-1}), for which the following symbols were also used in particular cases:

K_a = mean of k_d during the period 1931–1960
K_b = mean of k_d during the period 1961–1975
K" = values of k_d for forestry board districts
K' = values of k_d for combinations of basins
Indexes 1,2...6 for k_d and its particular symbols are used for the ordinals of the national forest inventories
m = proportion of forest of the total area
m_d = proportion of forest of the land area
p_n = proportion of open bogs of the total area
V = water equivalent of the snow cover on April 1
V_b = value of V in the period 1961–1975
E_L = annual evaporation from lakes

4. General symbols

S = standard deviation or standard error of any parameter, following S in parentheses
L = proportion of lakes of the total area
A, B, C, D = classes of change of precipitation (dP)
F = area
v = index indicating an "intermediate" basin, that is a basin bounded by flow observation sites both downstream and upstream
v_F = proportion of the area of an intermediate basin of the total basin area upstream of the downstream discharge site
ρ = density of observations (number/unit area)
ϕ = latitude
n = number of cases
y = a symbol of dependent variables in regression analysis
x = a symbol of independent variables in regression analysis

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APPENDIX 1. Description of the river basins (more detailed explanation in the end of the table) *)

No (Fig. 1a) 1.	Number and name of river basin (and of discharge station) 2.	F (km²) 3.	L (%) 4.	National forest inventory		Lake, for which change of storage was calculated 7.	River basin, for which change in snow storage was calculated 8.
				Forestry board district 5.	Main river basin 6.		
1.	1 Jänisjoki, Ruskeakoski	1 570	7.0	Pohjois-Karjala	Saimaa, northern	Höytiäinen	Vuoksi
2.	4 Saimaa, southern	22 355	30.0	1/2 Etelä-Savo 1/2 Itä-Savo	Saimaa, southern	Pyhäselkä; Puruvesi Saimaa; Haukivesi (mean)	Vuoksi
3.	Saimaa, northwestern	16 270	15.3	Pohjois-Savo	Saimaa, northern	Kallavesi	Vuoksi
4.	Kallavesi, surroundings	10 025	16.0	Pohjois-Savo	Saimaa, northern	Kallavesi	Vuoksi
5.	Juojärvi, Palokki	2 110	21.8	Pohjois-Savo	Saimaa, northern	Juojärvi	Vuoksi
6.	Nilsiä watercourse, Juankoski	4 135	10.4	Pohjois-Savo	Saimaa, northern		Vuoksi
7.	Salahminjoki, Salahmi	510	4.9	Pohjois-Savo	Saimaa, northern		Vuoksi
8.	Höytiäinen, Puntarikoski	1 425	22.1	Pohjois-Karjala	Saimaa, northern	Höytiäinen	Vuoksi
9.	Pielinen, surroundings	10 520	14.7	Pohjois-Karjala	Saimaa, northern	Pielinen	Vuoksi
10.	14 Mäntyharju watercourse, Ripatinkoski	3 530	23.3	Etelä-Savo	Päijänne, southern	Puulavesi	Kymijoki
11.	Mäntyharju watercourse, middle part	2 045	27.7	Etelä-Savo	Päijänne, southern	Puulavesi	Kymijoki
12.	Mäntyharju watercourse, Läsäkoski	1 485	17.2	Etelä-Savo	Päijänne, southern	Puulavesi	Kymijoki
13.	Rieveli, Sulkavankoski	870	16.0	1/2 Itä-Häme 1/2 Etelä-Savo	Päijänne, southern	Jääsjärvi	Kymijoki
14.	Päijänne, surroundings	8 660	22.1	1/2 Keski-Savo			
15.	Sysmä watercourse, Tainionvirta	1 425	26.4	1/2 Itä-Häme 1/2 Etelä-Savo	Päijänne, southern	Jääsjärvi	Kymijoki
16.	Jämsä watercourse, Petäjävesi	655	5.4	Keski-Suomi	Päijänne, northern	Keurusselkä	Kymijoki
17.	Rautalampi watercourse, Simunankoski	6 880	20.7	Keski-Suomi	Päijänne, northern	Pielavesi; Nilakka; Iisvesi (mean)	Kymijoki
18.	Rautalampi watercourse, lower part	4 720	21.9	Keski-Suomi	Päijänne, northern	Iisvesi	Kymijoki
19.	Rautalampi watercourse, Äyskoski	2 160	18.0	Keski-Suomi	Päijänne, northern	Pielavesi; Nilakka (mean)	Kymijoki
20.	Rautalampi watercourse, Hietamankoski	3 025	9.9	Keski-Suomi	Päijänne, northern	Keitele; Kivijärvi (mean)	Kymijoki
21.	Saarijärvi watercourse, lower part	1 230	13.0	Keski-Suomi	Päijänne, northern	Keitele; Kivijärvi (mean)	Kymijoki
22.	Saarijärvi watercourse, Kouheroisenkoski	1 775	7.7	Keski-Suomi	Päijänne, northern	Keitele; Kivijärvi (mean)	Kymijoki
23.	Keitele, surroundings	4 215	20.2	Keski-Suomi	Päijänne, northern	Keitele	Kymijoki
24.	Viitasaari watercourse, Huopanankoski	2 275	13.7	Keski-Suomi	Päijänne, northern	Kivijärvi	Kymijoki
25.	16 Koskenkylänjoki, Pyhäjärvi	455	6.1	1/3 Helsinki 2/3 Uusimaa-Häme	Southern coast		Vantaanjoki
26.	21 Vantaanjoki, Oulunkylä	1 680	2.5	1/3 Helsinki 2/3 Uusimaa-Häme	Southern coast		Vantaanjoki
27.	23 Karjaanjoki, Peltokoski	1 925	12.5	1/3 Helsinki 2/3 Uusimaa-Häme	Southern coast	Lohjanjärvi	Vantaanjoki
28.	24 Kiskonjoki, Koski	600	9.8	Lounais-Suomi	Southern coast	Lohjanjärvi	Vantaanjoki
29.	27 Paimionjoki, Juvankoski	790	2.2	Lounais-Suomi	Southwestern coast		Vantaanjoki
30.	28 Aurajoki, Halinen	730	0.0	Lounais-Suomi	Southwestern coast		Vantaanjoki
31.	34 Eurajoki, Suutelankoski	1 330	13.3	1/2 Lounais-Suomi 1/2 Kokemäenjoki,western	1/2 Southwest. coast 1/2 Kokemäenjoki, western	Pyhäjärvi	Kokemäenjoki
32.	35 Kokemäenjoki, lower part and Ikaalinen watercourse	6 360	7.7	1/2 Satakunta 1/2 Pirkka-Häme	Kokemäenjoki, western		Kokemäenjoki

1.		2.	3.	4.	5.	6.	7.	8.
33.		Loimijoki, Maurialankoski	2 650	3.5	1/2 Uusimaa-Häme 1/2 Satakunta	Kokemäenjoki, western		Kokemäenjoki
34.		Ikaalinen watercourse, Kyröskoski	2 705	10.1	1/2 Pirkka-Häme 1/2 Satakunta;	Kokemäenjoki, western	Kyrösjärvi	Kokemäenjoki
35.		Aurejoki, Poltinkoski	490	10.6	Pirkanmaa	Kokemäenjoki, western	Kyrösjärvi	Kokemäenjoki
36.		Näsijärvi watercourse and Pyhäjärvi, surroundings	8 305	14.8	Pirkanmaa	Kokemäenjoki, western	Näsijärvi	Kokemäenjoki
37.		Näsijärvi, surroundings	3 945	17.8	Pirkanmaa	Kokemäenjoki, western	Näsijärvi	Kokemäenjoki
38.		Näsijärvi watercourse, Tammerkoski	7 520	14.7	Pirkanmaa	Kokemäenjoki, western	Näsijärvi	Kokemäenjoki
39.		Keuruu watercourse, Vilppulankoski	1 980	11.8	1/3 Keski-Suomi 1/3 Pirkka-Häme 1/3 Pohjanmaa, southern	1/3 Kokemäenjoki, western 1/3 Päijänne, northern 1/3 Pohjanmaa, southern	Keurusselkä	Kokemäenjoki
40.		Pihlajavesi watercourse, Pihlajakoski	375	10.5	1/3 Keski-Suomi 1/3 Pirkka-Häme 1/3 Pohjanmaa, southern	1/3 Kokemäenjoki, western 1/3 Päijänne, northern 1/3 Pohjanmaa, southern	Keurusselkä	Kokemäenjoki
41.		Ähtäri watercourse, Kahilanjärvi	1 220	10.5	1/3 Keski-Suomi 1/3 Pirkka-Häme 1/3 Pohjanmaa, southern	1/3 Kokemäenjoki, western 1/3 Päijänne, northern 1/3 Pohjanmaa, southern		
42.		Vanajavesi watercourse, Lempäälä	8 710	14.4	Uusimaa-Häme	Kokemäenjoki, eastern	Roine; Vanajavesi (mean)	Kokemäenjoki
43.		Vanajavesi, surroundings and Hiidenjoki	4 280	9.8	Uusimaa-Häme	Kokemäenjoki, eastern	Vanajavesi	Kokemäenjoki
44.		Längelmävesi and Hauho watercourses, Valkeakoski	4 430	18.8	Pirkanmaa	Kokemäenjoki, eastern	Roine	Kokemäenjoki
45.	42	Kyrönjoki, Skatila	4 805	0.9	Etelä-Pohjanmaa	Pohjanmaa, southern		Kyrönjoki
46.	44	Lapuanjoki, Keppo	3 955	2.9	Etelä-Pohjanmaa	Pohjanmaa, southern		Kyrönjoki
47.	53	Kalajoki, Niskakoski	3 025	1.8	Keski-Pohjanmaa	Pohjanmaa, northern		Kalajoki
48.	57	Siikajoki, Länkelä	4 395	1.7	Pohjois-Pohjanmaa	Pohjanmaa, northern	Uljua 1)	Oulujoki, Kalajoki
49.	59	Oulujoki, lower part and Oulujärvi, surroundings	6 680	16.1	Kainuu	Oulujoki	Oulujärvi	Oulujoki
50.		Sotkamo watercourse, Koivukoski	7 535	11.7	Kainuu	Oulujoki	Ontojärvi, Lentua (mean)	Oulujoki
51.		Sotkamo watercourse, western part	3 495	12.6	Kainuu	Oulujoki	Ontojärvi	Oulujoki
52.		Sotkamo watercourse, eastern part	4 040	10.9	Kainuu	Oulujoki	Lentua	Oulujoki
53.		Sotkamo watercourse, Konapinkoski	560	10.0	Kainuu	Oulujoki	Lentua	Oulujoki
54.		Sotkamo watercourse, southeastern part	1 415	8.5	Kainuu	Oulujoki	Lentua	Oulujoki
55.		Sotkamo watercourse, Lentua	2 065	12.9	Kainuu	Oulujoki	Lentua	Oulujoki
56.		Hyrynsalmi watercourse, Leppikoski	8 685	7.5	Kainuu	Oulujoki	Kiantajärvi	Oulujoki
57.		Hyrynsalmi watercourse, lower part	5 230	6.0	Kainuu	Oulujoki	Kaintajärvi	Oulujoki
58.		Hyrynsalmi watercourse, Ämmäkoski	3 455	9.7	Kainuu	Oulujoki	Kiantajärvi	Oulujoki
59.		Hyrynsalmi watercourse, Hossa	890	4.3	Kainuu	Oulujoki	Kiantajärvi	Oulujoki
60.	60	Kiiminkijoki, Haukipudas	3 845	1.4	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
61.	61	Iijoki	13 710	5.9	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
62.		Siuruanjoki, Leuvankoski	2 395	1.9	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
63.		Iijoki, lower part and Livojoki	4 915	4.5	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
64.		Korvuanjoki and Puhosjoki	1 185	7.1	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
65.		Korpijoki, Suolijärvi	1 295	5.0	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki

1.	2.	3.	4.	5.	6.	7.	8.
66.	Iijoki, Väätäjänsuvanto	3 920	9.9	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
67.	Iijoki, Soivionniva	330	13.1	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
68.	Kuivajoki, Luujokihaara	1 965	2.8	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
69.	63 Simojoki, Simo	3 125	6.3	Pohjois-Pohjanmaa	Simo-Ii-Kiiminkijoki		Iijoki
70.	65 Kemijoki, lower part	9 975	3.6	Lappi	Kemijoki	Kemijärvi	Kemijoki
71.	Ounasjoki, Marraskoski	12 335	2.6	Lappi	Kemijoki		Kemijoki
72.	Ounasjoki, lower part	7 820	1.7	Lappi	Kemijoki		Kemijoki
73.	Ounasjoki, upper part	4 180	3.0	Lappi	Kemijoki		Kemijoki
74.	Ounasjoki, Ounasjärvi	335	8.0	Lappi	Kemijoki		Kemijoki
75.	Jumiskonjoki, Jumisko	1 305	13.7	Koillis-Lappi	Kemijoki		Kemijoki
76.	Kemijärvi, Seitakorva	27 285	2.9	1/3 Koillis-Lappi 2/3 Lappi	Kemijoki	Lokka; Porttipahta (mean)[2]	Kemijoki
77.	Kemijärvi surroundings, Kitinen and Luiro	18 570	3.9	Lappi	Kemijoki	Lokka; Porttipahta (mean)[2]	Kemijoki
78.	Kemihaara, Kummaniva	8 715	0.7	Koillis-Lappi	Kemijoki		Kemijoki
79.	67 Tengeliönjoki, Portimojärvi	3 160	8.5	Lappi	Tornio-Muoniojoki	Raanujärvi; Vietonen; Miekojärvi (mean)	Ounasjoki
80.	Tornionjoki, Peerajärvi	102	6.0				
81.	Tornionjoki, Kilpisjärvi	290	13.9				
82.	68 Utsjoki, Patoniva	1 471	2.3				
83.	71 Inarijärvi, Jäniskoski	14 575	12.2	Lappi	Jäämeri	Inarijärvi	Paatsjoki
84.	Inarijärvi, surroundings	6 025	25.8	Lappi	Jäämeri	Inarijärvi	Paatsjoki
85.	Ivalojoki	3 300	0.3	Lappi	Jäämeri		Paatsjoki
86.	Inarijärvi, surroundings and Ivalonjoki	8 325	16.8	Lappi	Jäämeri	Inarijärvi	Paatsjoki
87.	Juutuanjoki, Saukkoniva	5 250	4.1	Lappi	Jäämeri		Paatsjoki
88.	Lemmenjoki and Vaskojoki	2 980	2.8	Lappi	Jäämeri		Paatsjoki
89.	Kettujoki, Kettukoski	2 270	5.8	Lappi	Jäämeri		Paatsjoki
90.	73 Kitkajoki, Käylä	1 740	21.7	Koillis-Suomi	Simo-Ii-Kiiminkijoki	Kemijärvi; Kuusamojärvi (mean)	Iijoki
91.	Kuusinkijoki, Myllykoski	830	13.3	Koillis-Suomi	Simo-Ii-Kiiminkijoki	Kuusamojärvi	Iijoki

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*) The river basins, for which the water balance has been calculated as annual means for the period 1961–1975. Their number on the map, Fig. 1a in the 1st column; in the 2nd column the number and name of river basin, in the 3rd the basin areas and in the 4th the lake percentages. In the 5th and 6th column, the regions of forestry statistics, for which amounts of growing stock are known. In the 7th column the lakes, for which changes of storage was estimated. In the 8th column river basins, for which values of snow storage are available; by these values, all basin values were approximated.

1) During the period 1961–1975 the area of the artificial lake Uljua was weighted by 0.33 according to the date of its filling.

2) During the period 1961–1975 the areas of the artificial lakes Porttipahta and Lokka are weighted by 0.25 according to the date of their filling.

APPENDIX 2. Water balance during the period 1961–1975 basin-wise.

No. (Fig. 1a) 1.	Number and name of river basin (and of discharge station) 2.	$k^{a)}$ 3.	$P^{b)}$ 4.	R 5.	$-M_S$ 6.	$-M_L$ 7.	$-M_S-M_L$ 8.	$E_B(E_k)$ 9.	$dP^{c)}$ 10.	dR 11.	dE_B 12.	dE_k 13.	$E_B-E_k{}^{d)}$ 14.	P_n 15.	$E_{kn}-E_k$ 16.	E_B-E_{kn} 17.
1.	1 Jänisjoki, Ruskeakoski	14.9	772	422	0	− 2	− 2	348	-	-	-	+ 2	−27	-	-	-
2.	4 Saimaa, southern	14.2	693	204	0	−13	−13	476	+22	−12	+14	+ 8	+ 9	-	-	-
3.	Saimaa, northwestern	14.8	720	338	0	− 3	− 3	379	+18	+28	−15	+ 5	−14	-	-	-
4.	Kallavesi, surroundings	14.7	710	328	0	− 3	− 3	379	+18	+25	−14	+ 5	−16	-	-	-
5.	Juojärvi, Palokki	14.9	724	314	0	− 2	− 2	408	+17	+27	−12	+ 4	−10	-	-	-
6.	Nilsiä watercourse, Juankoski	15.0	743	389	0	− 4	− 4	350	+19	+49	−34	+ 5	−24	-	-	-
7.	Salahminjoki, Salahmi	15.0	696	316	0	—	0	380	-	-	-	-	+19	9	+16	+ 3
8.	Höytiäinen, Puntarikoski	14.9	747	328	0	− 5	− 5	414	+17	−28	−40	−40	+ 1	-	-	-
9.	Pielinen, surroundings	15.6	747	354	0	− 4	− 4	389	+47	+48	− 5	+ 2	+ 4	-	-	-
10.	14 Mäntyharju watercourse, Ripatinkoski	14.3	719	277	+ 1	+ 1	+ 2	444	-	-	-	+11	−15	-	-	-
11.	Mäntyharju watercourse, middle part	14.2	731	253	+ 1	+ 2	+ 3	481	-	-	-	+10	+12	-	-	-
12.	Mäntyharju watercourse, Läsäkoski	14.3	702	310	+ 1	+ 2	+ 2	394	+55 +32 2)	+81	−26	+12	−49	-	-	-
13.	Rieveli, Sulkavankoski	13.9	703	250	+ 1	+ 1	+ 2	455	-	-	-	+12	+ 1	-	-	-
14.	Päijänne, surroundings	14.4	708	238	+ 1	− 1	0	470	+47	+12	+33	+ 3	+33	-	-	-
15.	Sysmä watercourse, Tainionvirta	14.1	704	275	+ 1	+ 2	+ 3	432	+61	+29	+34	+10	−27	-	-	-
16.	Jämsä watercourse, Petäjävesi	14.2	739	346	+ 1	0	+ 1	394	-	-	-	− 5	−16	-	-	-
17.	Rautalampi watercourse, Simunankoski	14.7	701	307	+ 1	+ 1	0	394	+16	+54	+40	− 4	−13	-	-	-
18.	Rautalampi watercourse, lower part	14.7	707	307	+ 1	− 1	0	400	+15	+62	−49	− 4	−16	-	-	-
19.	Rautalampi watercourse, Äyskoski	14.7	587	307	+ 1	− 1	-	380	+17	+35	−18	− 4	− 7	-	-	-
20.	Saarijärvi watercourse, Hietamankoski	14.7	670	292	+ 1	+ 1	+ 2	380	+16	+ 6	+12	− 5	+ 6	-	-	-
21.	Saarijärvi watercourse, lower part	14.6	690	282	+ 1	+ 2	+ 2	410	-	-	-	− 5	+18	-	-	-
22.	Saarijärvi watercourse, Kouheroisenkoski	14.7	655	299	+ 1	+ 1	+ 2	358	-	-	-	− 5	− 2	-	-	-
23.	Keitele, surroundings	14.9	686	302	+ 1	+ 2	+ 3	387	+31	+54	−20	− 4	− 6	-	-	-
24.	Viitasaari watercourse, Huopanankoski	14.7	639	277	+ 1	+ 1	+ 2	364	− 1	+ 2	− 2	− 5	− 7	-	-	-
25.	16 Koskenkylänjoki, Pyhäjärvi	13.7	704	291	+ 2	-	+ 2	415	-	-	-	+12	−32	-	-	-
26.	21 Vantaanjoki, Oulunkylä	13.6	736	312	+ 2	-	+ 2	426	+13	+28	−13	+14	−17	-	-	-
27.	23 Karjaanjoki, Peltokoski	13.4	753	285	+ 2	+ 6	+ 8	476	+18	− 5	+30	+12	+20	-	-	-
28.	24 Kiskonjoki, Koski	12.8	748	300 3)	+ 2	+ 5	+ 7	455	-	-	-	+ 7	+ 3	-	-	-
29.	27 Paimionjoki, Juvankoski	13.2	685	288	+ 2	-	+ 2	398	−32	-	-	+ 9	−15	-	-	-
30.	28 Aurajoki, Halinen	12.8	697	307	+ 2	-	+ 2	392	− 4	+21	−23	+ 9	−25	-	-	-
31.	34 Eurajoki, Suutelankoski	12.9	674	225	+ 1	+ 2	+ 3	452	+34	-	-	+ 5	+13	-	-	-
32.	35 Kokemäenjoki, lower part and Ikaalinen watercourse	13.2	671	245	+ 1	+ 2	+ 3	429	+ 8	+ 1	+10	+ 4	+20	-	-	-
33.	Loimijoki, Maurialankoski	13.1	649	274	+ 1	-	+ 1	376	−23	+11	−33	+ 4	−41	-	-	-
34.	Ikaalinen watercourse, Kyröskoski	13.5	697	303	+ 1	+ 3	+ 4	398	− 2 −32 2)	+35	−29	+ 4	− 2	-	-	-
35.	Aurejoki, Poltinkoski	13.5	714	303	+ 1	+ 3	+ 4	415	-	-	-	+ 7	+23	-	-	-
36.	Näsijärvi watercourse and Pyhäjärvi, surroundings	13.9	696	276	+ 1	+ 3	+ 4	424	+15	+ 5	+13	+ 6	+ 6	-	-	-
37.	Näsijärvi, surroundings	13.7	691	262	+ 1	+ 4	+ 5	434	-	-	-	+ 6	+ 4			

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
38.	Näsijärvi watercourse, Tammerkoski	13.9	698	287	+ 1	+ 3	+ 4	415	-	-	-	+ 6	+ 3			
39.	Keuruu watercourse, Vilppulankoski	14.5	718	316	+ 1	0	+ 1	403	-	-	-	+ 2	− 1	-	-	-
40.	Pihlajavesi watercourse, Pihlajakoski	14.3	720	320	+ 1	0	+ 1	401	+44	+ 8	+37	+ 2	+28	-	-	-
41.	Ähtäri watercourse, Kahilanjärvi	14.2	682	310	+ 1	0	+ 1	373	-	-	-	+ 2	+ 6	-	-	-
42.	Vanajavesi watercourse, Lempäälä	13.8	669	254	+ 1	+ 3	+ 4	419	+20	+24	− 2	+ 6	−25	-	-	-
43.	Vanajavesi, surroundings and Hiidenjoki	13.8	662	252	+ 1	+ 3	+ 4	414	-	-	-	+ 6	−31	-	-	-
44.	Längelmävesi and Hauho watercourse, Valkeakoski	13.8	676	256	+ 1	+ 3	+ 4	424	-	-	-	+ 5	−19	-	-	-
45.	42 Kyrönjoki, Skatila	13.2	628	302	+ 1	-	+ 1	327	− 3	+21	−23	+ 6	−32	-	-	-
46.	44 Lapuanjoki, Keppo	13.8	619	255	+ 1	-	− 1	365	+12	+15	− 2	+ 6	+ 3	-	-	-
47.	53 Kalajoki, Niskakoski	14.3	622	284	− 1	-	− 1	337	+50	+22	+27	+ 1	+23	10	+18	+ 5
48.	57 Siikajoki, Länkelä	14.7	638	294	− 2	-	− 2	342	+39	+30	+ 7	0	+38	22	+36	+ 2
49.	59 Oulujoki, lower part and Oulujärvi, surroundings	14.9	684	311	− 3	− 7	−10	363	-	-	-	− 3	+34	11	+19	+15
50.	Sotkamo watercourse, Koivukoski	16.3	721	385	− 3	− 8	−11	325	+43	+32	− 4	− 3	− 2	7	+13	−15
51.	Sotkamo watercourse, western part	16.2	741	367	− 3	−16	−19	355	-	-	-	− 3	+12	-	-	-
52.	Sotkamo watercourse, eastern part	16.3	704	401	− 3	− 1	− 4	299	-	-	-	− 3	−22	-	-	-
53.	Sotkamo watercourse, Konapinkoski	16.2	722	411	− 3	− 1	− 4	307	-	-	-	− 3	−22	-	-	-
54.	Sotkamo watercourse, southeastern part	16.3	735	380	− 3	− 1	− 4	351	-	-	-	− 3	+23	-	-	-
55.	Sotkamo watercourse, Lentua	16.3	678	412	− 3	− 1	− 4	262	-	-	-	− 3	−51	-	-	-
56.	Hyrynsalmi watercourse, Leppikoski	16.2	718	389	− 3	− 1	− 4	325	+42	+26	+11	− 3	+14	10	+18	− 4
57.	Hyrynsalmi watercourse, lower part	16.0	725	392	− 3	− 1	− 4	329	-	-	-	− 3	+14	-	-	-
58.	Hyrynsalmi watercourse, Ämmäkoski	16.5	707	384	− 3	− 1	− 4	319	-	-	-	− 3	+13	-	-	-
59.	Hyrynsalmi watercourse, Hossa	16.5	712	422[3)]	− 3	− 1	− 4	286	-	-	-	− 3	− 5	-	-	-
60.	60 Kiiminkijoki, Haukipudas	14.7	707	361	− 1	-	− 1	345	+97	-	-	0	+43	24	+40	+ 3
61.	61 Iijoki	15.7	747	422[5)]	− 1	-	− 1	324	+96	+47	+48	0	+32	20	+33	− 1
62.	Siuruanjoki, Leuvankoski	15.7	737	422	− 1	-	− 1	314	-	-	-	0	+32	29	+48	−16
63.	Iijoki, lower part and Livojoki	15.1	746	381	− 1	-	− 1	364	-	-	-	0	+79	28	+46	+33
64.	Korvuanjoki and Puhasjoki	15.7	782	438	− 1	-	− 1	343	-	-	-	0	+29	15	+26	+ 3
65.	Korpijoki, Suolijärvi	15.7	767	451	− 1	-	− 1	315	-	-	-	0	− 6	8	+14	−20
66.	Iijoki, Väätäjänsuvanto	16.6	737	459	− 1	-	− 1	277	-	-	-	0	−15	11	+19	−34
67.	Iijoki, Soivionniva	16.9	715[4)]	430	− 1	-	− 1	284	-	-	-	0	− 2	12	+21	−23
68.	63 Kuivajoki, Luujokihaara	15.6	727	400[3)]	− 1	-	− 1	326	-	-	-	0	+33	28	+46	−13
69.	64 Simojoki, Simo	15.7	709	391[3)]	− 1	-	− 1	321	+56 +79[2)]	42	13	0	+36	29	+48	−12
70.	65 Kemijoki, lower part	16.4	645	303	0	− 3	− 3	339	-	-	-	− 2	+58	13	+23	+35
71.	Ounasjoki, Marraskoski	18.0	577	338	0	-	0	239	+32	+16	+16	− 2	+18	8	+14	+ 4
72.	Ounasjoki, lower part	18.0	601	331	0	-	0	270	-	-	-	− 2	+30	12	+21	+ 9
73.	Ounasjoki, upper part	18.0	535	350	0	-	0	185	-	-	-	− 2	+ 2	-	-	-
74.	Ounasjoki, Ounasjärvi	18.0	511	358	0	-	0	153	-	-	-	− 2	−25	-	-	-
75.	Jumiskonjoki, Jumisko	17.1	656	339	0	− 3	− 3	311	-	-	-	− 2	+34	14	+24	+10

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.
76.	Kemijärvi, Seitakorva	17.8	623	360[3]	0	− 5	− 5	258	+29	+26	− 2	− 4	+23	-	-	-
77.	Kemijärvi, surroundings, Kitinen and Luiro	17.6	606	332	0	− 7	− 7	267	+11	+ 6	− 2	− 2	+25	17	+28	− 3
									+36[2]							
78.	Kemihaara, Kummaniva	18.3	660	420	0	-	0	240	+70[2]	71	− 1	− 8	+20	6	+11	+ 9
79.	67 Tengeliönjoki, Portimojärvi	16.8	625	310	0	− 3	− 3	312	+ 4	−25	+47	− 1	+27	12	+21	+ 6
								25	+25[2]							
80.	Tornionjoki, Peerajärvi	-	555[1]	449	0	-	0	(106)	+78	+78	-	0	-	-	-	-
81.	Tornionjoki, Kilpisjärvi	-	614[1]	490	-	-	0	(124)	−23	−23	-	0	-	-	-	-
82.	68 Utsjoki, Patoniva	17.2	499	366[1]	+ 1	-	+ 1	(134)	+23	−14	-	0	-	-	-	-
		-	544[1]	411[3]	+ 1	-	+ 1		+68	+31	-	0	-	-	-	-
83.	71 Inarijärvi, Jäniskoski	16.9	526	325	+ 1	−12	−11	190	-	-	-	− 3	−10	-	-	-
84.	Inarijärvi, surroundings	16.4	519	293	+ 1	−24	−23	203	-	-	-	− 3	−31	-	-	-
85.	Ivalojoki	18.0	542	344	+ 1	-	+ 1	199	-	-	-	− 3	+17	-	-	-
86.	Inarijärvi, surroundings and Ivalojoki	16.8	527	311	+ 1	−16	−15	201	+14	+51	54	− 3	−15	-	-	-
87.	Juutuanjoki, Saukkoniva	17.2	525	349	+ 1	-	+ 1	177	+28	+18	+11	− 3	± 0	-	-	-
88.	Lemmenjoki and Vaskojoki	17.4	527	350	+ 1	-	+ 1	178	+20	− 9	+30	− 3	± 0	-	-	-
89.	Kettujoki, Kettukoski	16.8	522	348	+ 1	-	+ 1	175	+39	+54	−14	− 3	+ 2	-	-	-
90.	73 Kitkajoki, Käylä	17.4	675	399	− 1	− 9	−10	266	-	-	-	− 7	+48	11	+19	+29
91.	Kuusinkijoki, Myllykoski	17.5	673	346	− 1	− 2	− 3	324	+79	+34	+42	− 8	− 2	11	+19	−21

a) Correction of mean annual precipitation on 1961–1975 (k, % of observed precipitation)

b) Mean annual components of water balance in 1961–1975 (mm a^{-1}): P = precipitation, corrected for measuring errors, R = runoff, M_S = change of water storage in the snow cover, M_L = change of water storage in lakes, E_B = evaporation from the water balance equation. When needed, the components were substituted by the values of E_k in parenthesis; E_k = evaporation from Solantie's evaporation equation (Equation 2 in Section 6)

c) Changes in P, R, E_B and E_k from the period 1931–1960 (denoted by d P, d R, d E_B and d E_k, mm a^{-1})

d) Differences between mean annual amounts of evaporation in 1961–1975, obtained in different ways. In addition to $E_B - E_k$, the differences $E_{kn} - E_k$ and $E_B - E_{kn}$ are given for basins of the aapa bog region (Fig. 6). Here, E_{kn} is obtained by adding 1.62 p_n to E_k for observing the additional evaporation from water on peat; p_n = percentage of open bogs of basin area.

[1] from the water balance equation

[2] P in 1931–1960 from the water balance equation

[3] corrected values:

river basin	reference basin	corrected years
Utsjoki, Patoniva	Kettujoki	1961
Kemijärvi	Ounasjoki, Marraskoski	1961, 1962
Simojoki, Simo	Siuruanjoki, Leuvankoski	1961–1964
Kuivajoki, Luujokihaara	Siuruanjoki, Leuvankoski	1961–1964
Yläjoki, Hossa	Kiantajärvi	1961, 1962
Kiskonjoki, Koski	Karjaanjoki, Peltokoski	1961, 1962

[4] estimated by map analysis

[5] Components are given for the river basin above Leuvankoski (in the Siuruanjoki tributary; F = 2 395 km^2, L = 1.9 %) and that above Pahkakoski (F = 11 315 km^2, L = 6.7 %). Runoff for Pahkakoski was, however, approximated by that for Kipinä (F = 11 005 km^2, L = 6.7 %).