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HYDROLOGICAL REGIONS IN SCANDINAVIA AND FINLAND

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The rivers of Scandinavia and Finland are studied with regard to regime, regional distribution, and long-term variations in discharge. The regime studies are based on monthly mean coefficients, i. e. the relation between the monthly means and the average annual discharge for a 30-year period. Within the two main areas of nival highland and lowland regime and Atlantic snow and rain regime (Fig. 1), different regime types have been studied (Figs. 2 and 3, tables 2-4). The regional distribution has been estimated with correlation coefficients and relations between means for one year expressed as a percentage of the mean discharge of 1931-60. Some of the correlation coefficients are shown in Table 5. The variations of 30- and 10-year mean discharge in percentage of the mean discharge 1911-60 have been studied by the method of moving averages from the year 1901 (Figs. 4-9). As to the 30-year records there are four regions with different trends, the North Calotte with two parts, the Arctic Sea part and the inland, the Scandinavian high mountain district, Vestland in Norway, and the eastern lowland (Fig. 10). The relations between discharge, precipitation, and temperature are discussed. Based on the results of the studies, mainly those of regional distribution together with other elements such as the situation of drainage areas and runoff values, hydrological regions have been delineated, Fig. 11.

HYDROLOGICAL REGIONS IN SCANDINAVIA AND FINLAND

The main hydrological boundary in Scandinavia and Finland runs between two regions, the north where the rivers have nival mountain and lowland regimes and the south with rivers with Atlantic rain and snow regime according to the terminology of M. M. Pardé. The former rivers have high water in spring, relatively good water supply in the summer, and low water in winter; the latter rivers low-water in summer and high-water from autumn to spring with, as a

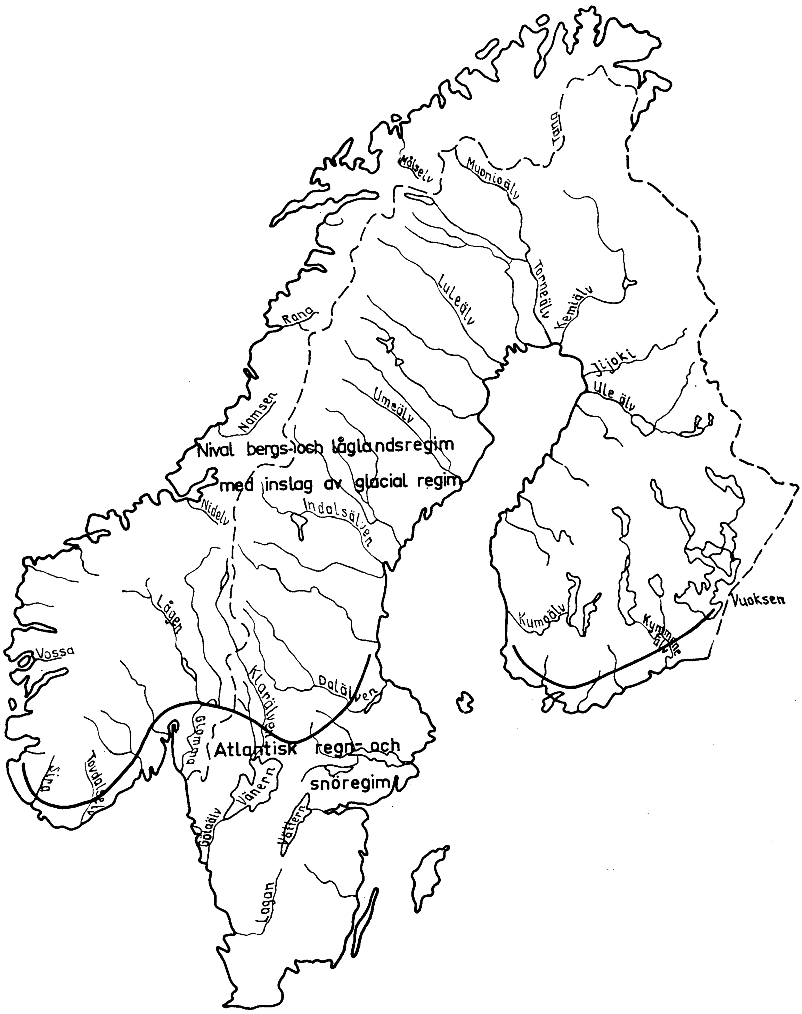

Fig. 1.

Lines dividing river systems with nival mountain and lowland regimes with some tributaries with glacial regime (Nival bergs- och låglandsregime med inslag av glacial regime), from systems with Atlantic rain and snow regime (Atlantisk regn- och snöregime).

rule, two maxima, one at the time of the autumn rains and the other when the snow melts in spring. The rivers of Norway and Finland, with the exception of small rivers in the south of both countries, and the rivers in the northern part of Sweden, from the river Torne-älv to and including the rivers Klar-älven and Dal-älven, belong to the nival regime and the rest to the Atlantic regime.

Between these groups there are rivers with both northern and southern characteristics, with variation in preponderence of the two patterns from year to year. In Norway and Sweden there are some rivers with glacial regime which are characterized by small winter flow, late spring flood, and large and fluctuating summer flow.

The earlier classifications of the rivers in the Nordic countries have been founded on their geographical situation and, to some extent, on the general hydrological conditions. The hydrological characterizations and their classification within the internorthern boundaries as given in this paper are founded on observations such as: (1) regime or seasonal variations, (2) regional distribution of discharge in percentage of mean discharge, (3) long-time variations.

Rivers with gauges used in these investigations appear on the map Fig. 10.

THE REGIME

It is not convenient to analyse the seasonal variations from run-off data given in m^3 per sec or litres per sec and km^2 because of the large differences in size of different rivers. Instead the analysis had been based on monthly mean coefficients of typical rivers, i. e. relation between mean for month and mean for year, a method earlier used by M. Maurice Pardé. The calculations have been based on the mean values for the period 1921-50 in Norway and Sweden, except for some rivers in the latter country, where other long-time series but not 1921-50 have been available. In Finland, the calculations are based on the mean for the period 1931-60. One example: at the gauge Polmak, situated in the river Tana, the run-off is for year 11.3 l/sec km^2 and for January 3.6 l/sec km^2 according to *Hydrologiske undersökelser i Norge* and the monthly mean coefficient for Jan. $= \frac{3.6}{11.3} = 0.32$. The monthly mean coefficients for some typical rivers are shown in Tables 2-4 and some of them are compared in Figs. 2 and 3. Only the general qualities of the regime can be arrived at through the long-time means. Thus the small floods common in some rivers in the north in autumn and winter will only be observed in the means when they occur regularly at about the same time each year.

The Norwegian rivers have, with some exceptions, a regime which can be characterized as nival mountain regime, often with touches of glacial regime. From the river Tana in the Finnmark to the rivers in the southern parts of the country, Vestland and Östland, there is generally high water in June, good water supply in summer, and low-water in winter. The lowland character of Tana is suggested by the high figures for May. In Tröndelag and Möre the mountain ranges are low and the warm, moist winds have a free passage into the interior. The rivers Namsen and Nid-elv, therefore, as a rule, have autumn floods as do the Swedish rivers on the other side of the watershed. Many of the big rivers in Östland have in their lower parts high water in May. The river Glomma has only slightly lower discharge in May than in June. The rivers Sira and Tovdals-elv, representative of the rivers in southern Norway, have a maximum in May, a secondary maximum in the autumn, and rather good water supply in winter and summer. In these rivers, but still more in smaller rivers in southern Norway and in the district near the Swedish frontier, the variations of discharge are about the same as in the rivers in northwestern Svealand and southern Finland. Small coast rivers in southern Norway have high water in winter and low water in summer, like the rivers in southern Sweden.

The large rivers in northern Sweden drain partly a high mountainland, partly a lower forest plateau with run-off respectively 15 to 40 l/sec km^2 and 10 to 15 l/sec km^2. As the snow melts successively from the lowland to the highland, the regime in spring will be influenced by the different proportions of water coming from the two parts. There is also a connection between regime and characteristic features of the drainage basins such as latitudinal position, height, and lake area in the basin. The last mentioned is as its highest (11.8 per cent) in the river Skellefte-älv. The differences in regime for the spring months can be studied in Table 1 where the monthly mean coefficients for the melting period in all the big rivers in northern Sweden have been brought together.

The northern rivers, from the river Torne-älv to the river Ljungan, have their maximums in June, except for Lule-älv and Skellefte-älv, where the maximum takes place in July, owing to the high mountains in the upper part of the Lule-älv basin and to the big lake-area of the Skellefte-älv basin. In the rivers Torne-älv, Kalix-älv, and in the Ljungan, all with large parts of their basins in the vast, low forest land, the earlier melting is indicated by almost the same values in May as in June.

The southernmost rivers, Ljusnan, Dal-älven, and Klar-älven, have maxima in May. All these rivers drain basins with small, rather low mountain lands and vast sections of low forestlands, but the melting time is naturally influenced by their height above sea-level and latitudinal position in the south of Norrland or the northern part of Svealand. As can be seen from the Table, the flow

Table 1.
Monthly mean coefficients for the snow-melt period in the large rivers in northern Sweden

Rivers	March	April	May	June	July
Kemiälv (Finnish)	0.26	0.38	3.28	2.22	1.01
Torneälv (frontier river with Finland)	0.20	0.28	2.55	2.75	1.60
Kalixälv	0.19	0.28	2.34	2.45	
Luleälv	0.18	0.21	0.85	2.14	2.72
Piteälv	0.23	0.33	1.72	2.48	
Skellefteälv	0.30	0.32	1.04	1.74	2.41
Umeälv	0.26	0.35	1.30	2.96	
Ångermanälven	0.26	0.38	1.80	2.82	
Indalsälven	0.28	0.34	1.74	2.73	
Ljungan	0.39	0.52	1.98	2.25	
Ljusnan	0.29	0.73	2.90	1.95	1.14
Dalälven	0.41	0.67	2.06	1.92	1.18
Klarälven	0.30	0.99	2.62	1.69	1.12

increases very little from March to April in the northern rivers down to and including the river Indals-älven, but in the south, increases from low figures in March to 0.52 in the river Ljungan and 0.99 in the river Klar-älven.

The big rivers in northern Sweden have good water supply, during the summer and low water in winter. The small rivers, which drain only the forest plateau, have their maximums in May, a small secondary maximum in autumn in some of the rivers, and low water in winter as well as often in the summer.

In the transition district in north Svealand the border between the nival and Atlantic regimes crosses the northern tributaries of the lakes Vänern and Mälaren. This line is more strongly marked in the east, where it curves off to the north, owing to the Swedish northern highland extension further south in the west. The rivers of the transition district have high water in May, rising water in autumn, and rather good water supply in winter and summer. In the rivers of southern Sweden with Atlantic regime, there are small differences between the western rivers which flow into the Kattegatt and those emptying into the Baltic. The latter have, as a rule, a smaller decrease of the discharge in winter and a more marked low water in summer than the former. This probably depends on the higher mean run-off in the western rivers which amounts to 11 to 20 l/sec km^2 but only to 6 to 11 l/sec km^2 in the eastern rivers.

Almost all the rivers of Finland have nival low-land regime. As the seasonal variations in many of the large rivers depend on large lake areas in their basins, it is more convenient to study the variations of discharge in small rivers, draining basins with small lake percentage. However, one large river, Kemi-

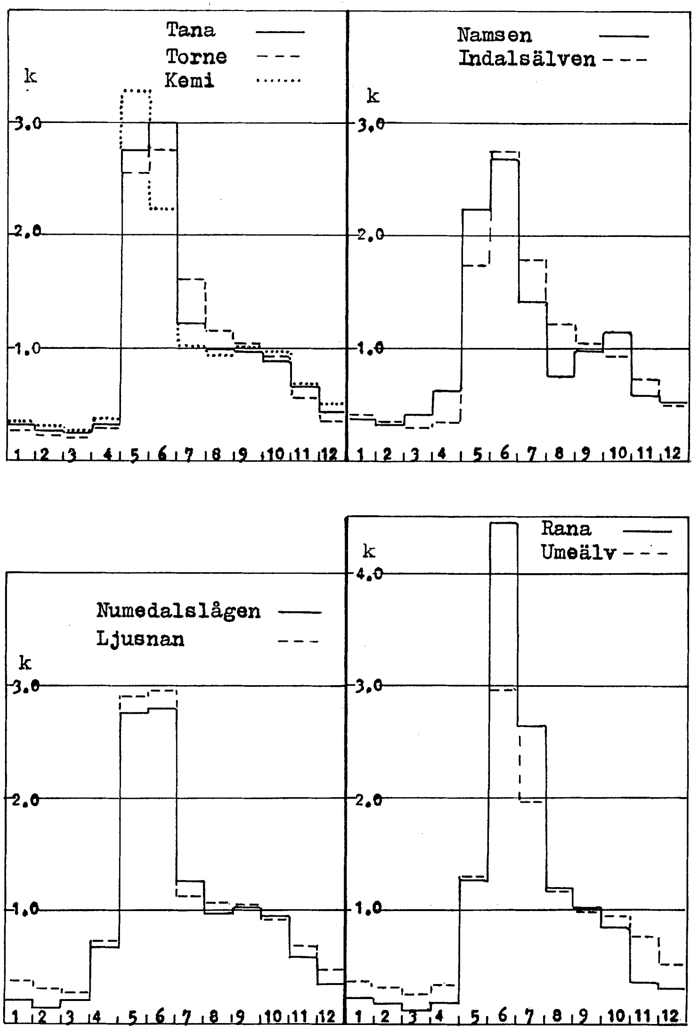

Fig. 2.

Coefficients of monthly mean run-off (k) $= \frac{\text{MQ month}}{\text{MQ year}}$

Rivers in Norway, Sweden, and Finland. (Names and position of rivers in Fig. 10).

älv in the north, drains a basin with a small lake area, only 2.3 per cent. The regime is about the same as in the Finnish-Swedish frontier river Torne-älv and the Finnish-Norwegian frontier river Tana (Fig. 2).

In the small coast rivers, the high water in spring is very pronounced as also the low water in winter. The discharge falls very quickly once the spring flood in May or April has passed, but rises again in autumn before the falling again in winter. This is about the same regime as in the Swedish coastal rivers on the other side of the Gulf of Bothnia. How the regime differs in coastal rivers from those which drain the interior forest plateaus in Finland and Sweden can

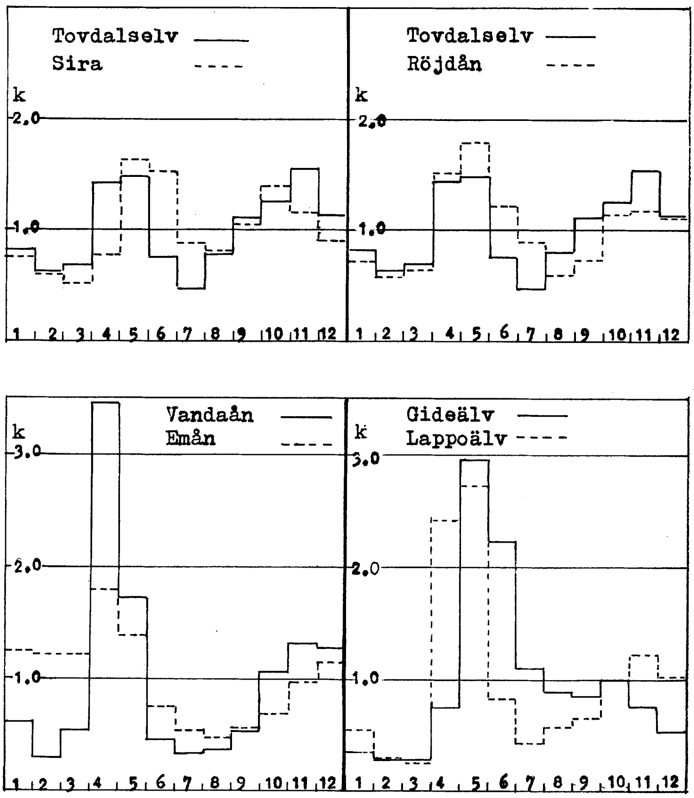

Fig. 3.

Coefficients of monthly mean run-off (k) $= \frac{\text{MQ month}}{\text{MQ year}}$

Rivers in Norway, Sweden, and Finland. (Names and position of rivers in Fig. 10).

be seen from the diagrams in Fig. 3 for the rivers Gide-älv in Sweden and Lappo-älv in Finland where the former may represent the interior, the latter the coast district. The earlier spring flood and the bigger autumn flood in the coastal river are the most characteristic differences.

The rivers that discharge the big lakes have late floods with monthly mean maximums in June in the rivers Ule-älv and Kymmene-älv, in May in the river Kumo-älv, and in January the following year in the river Vuoksen. There are small differences between highest and lowest mean monthly discharge; the smallest is in the river Vuoksen, between 1.06 and 0.93 per cent. The lake area is 19.9 per cent of the basin area.

The small rivers that discharge into the Archipelago Sea and the Gulf of Finland have a typical transitional character with summer low water like the south Swedish rivers but also winter low water and high, short spring floods like the northern coast and forest rivers in Finland and Sweden. The annual variation is about the same as in the transition areas in Norway and Sweden but the spring flood and summer low water are more marked in Finland because of the more continental climate and the lower height of the basins. The diagrams of Fig. 3 for the rivers Vanda-ån and Em-ån may illustrate the difference between the transition regims of a river in south Finland and the Atlantic regime of a river in south Sweden. The difference between the regime of the coast rivers in southern and northern Finland is shown by comparing the values in Table 4 for the river Vanda-ån and the two northern rivers Siika-joki and Kyro-älv. These two rivers have very low minimums in winter and higher in summer, whereas the minimum for river Vanda-ån is about the same in both winter and summer.

THE REGIONAL DISTRIBUTION OF THE YEARLY MEAN DISCHARGES IN PER CENT OF MEAN DISCHARGE FOR THE PERIOD 1931-60

When grouping together the rivers of the northern countries, the connection between the yearly mean discharges of rivers in different districts has scarcely been taken into consideration. The distribution of run-off in this respect is of climatic signification. Owing to the good correlation between precipitation and run-off in the Nordic climate, the run-off gives good knowledge about the general distribution of precipitation. The problem is also of importance in coordinating the power works in the northern countries. The investigation is confined to the yearly mean run-off and to the period 1931-60. All means are given in percentage of the means for that period. The results are based partly on relation diagrams and partly on correlation coefficients. At first the material is

Table 2.

Monthly mean coefficients $= \dfrac{\text{MQ for month}}{\text{MQ for year}}$

Norwegian rivers. Period 1921-50

River and gauge	Tana, Polmak	Rana, Nevernes	Namsen, Fiskumfors	Nidelv, Svean	Suldalslågen, S.-oset	Sira, Lundevatn	Tovdalselv, Flaksvatn	Glomma, Laugnes
Mq $1/s.km^2$	11.3	46.7	47.0	34.8	74.5	62.2	36.8	17.4
Jan.	0.32	0.24	0.36	*0.20*	0.31	0.75	0.81	0.28
Febr.	0.27	0.19	0.31	0.22	*0.23*	0.59	*0.62*	0.21
March	*0.25*	*0.13*	0.40	0.26	0.24	*0.51*	0.68	0.25
April	0.28	0.19	0.62	1.11	0.42	0.78	1.42	0.72
May	2.75	1.27	2.23	2.72	1.54	*1.63*	*1.48*	2.23
June	*3.00*	*4.45*	*2.66*	*2.78*	*2.50*	1.52	0.75	*2.25*
July	1.22	2.64	1.41	1.26	2.01	0.87	*0.47*	1.66
Aug.	0.99	1.19	0.74	0.86	1.28	*0.82*	0.79	1.30
Sept.	0.96	1.03	0.97	0.95	1.27	1.04	1.10	1.08
Oct.	0.86	0.86	1.14	1.12	1.18	1.39	1.25	0.92
Nov.	0.65	0.37	0.59	0.48	0.63	1.15	1.53	0.65
Dec.	0.42	0.32	0.51	0.34	0.40	0.90	1.12	0.40

Table 3.

Monthly mean coefficients $\equiv \dfrac{\text{MQ for month}}{\text{MQ for year}}$

Swedish rivers. Period 1921-50 (usually)

River and gauge	Kalixälv, Morjärv	Umeälv, Stornorrfors	Rapaälven, Litnok	Ljusnan, Ljusdal	Gideälv, Björnafallet	Röjdån, Kilen	Nissan, Johansfors	Emån, Järnforsen
Mq l/s.km²	10.2	16.9	21.0	12.8	10.7	13.8	15.5	8.0
% lake area	4.0	6.5	0.3	2.7	5.0	6.0	5.3	8.3
Jan.	0.26	0.38	0.10	0.38	0.35	0.70	1.29	1.25
Febr.	0.22	0.32	0.06	0.32	0.29	*0.57*	1.16	1.21
March	*0.20*	*0.26*	0.04	*0.29*	*0.29*	0.62	1.12	1.22
April	0.28	0.35	*0.04*	0.73	0.75	1.51	*1.37*	*1.72*
May	2.55	1.30	0.72	*2.90*	*2.95*	*1.78*	1.00	1.39
June	*2.75*	*2.96*	2.76	1.95	2.22	1.20	0.56	0.75
July	1.60	1.97	*3.62*	1.14	1.10	0.87	*0.50*	0.55
Aug.	1.15	1.23	2.34	1.08	0.88	*0.57*	0.66	*0.48*
Sept.	1.03	0.99	1.20	1.07	*0.85*	0.72	0.77	0.58
Oct.	0.92	0.95	0.56	0.92	1.00	1.12	0.98	0.67
Nov.	0.55	0.76	0.30	0.69	0.75	1.16	1.32	0.98
Dec.	0.35	0.51	0.19	0.49	0.54	1.11	1.29	1.15

Table 4.

$$\text{Monthly mean coefficients} = \frac{MQ \text{ for month}}{MQ \text{ for year}}$$

Finnish rivers. Period 1931-60

River and gauge	Kemiälv, Marraskoski	Uleälv, Vaala	Siikajoki, Länkelä	Kyroälv, Lansorsund	Kumoälv, Harjavalta	Vandaån, Åggelby	Kymmeneälv, Perno	Vuoksen, Imatra
Mq l/s.km²	10.2	10.8	8.0	8.9	7.8	9.0	7.7	9.8
% lake area	2.3	12.7	1.5	0.9	11.8	2.5	19.3	19.9
Jan.	0.38	0.90	0.32	0.43	0.90	0.61	0.96	*1.06*
Febr.	0.31	0.84	0.14	*0.20*	0.85	*0.30*	0.92	1.04
March	*0.26*	0.74	*0.12*	0.23	*0.87*	0.52	*0.87*	1.03
April	0.38	*0.67*	2.28	*2.50*	1.48	*3.45*	0.94	1.00
May	*3.28*	1.01	*4.00*	2.32	*1.57*	1.72	1.19	0.97
June	2.22	*1.49*	0.83	0.77	1.18	0.46	*1.28*	0.95
July	1.01	1.39	0.52	*0.49*	0.87	*0.34*	1.20	*0.93*
Aug.	0.94	1.09	*0.45*	0.58	0.80	0.38	1.05	0.97
Sept.	1.00	0.98	0.56	0.72	*0.76*	0.52	0.92	0.99
Oct.	0.97	0.93	0.83	1.05	0.85	1.07	0.86	1.00
Nov.	0.67	1.03	0.94	1.30	1.02	1.32	0.88	1.02
Dec.	0.50	0.98	0.80	1.07	1.06	1.27	0.95	1.03

dealt with for the different countries and later for Scandinavia as a whole. The diagrams have not been included in the article.

Norway

The discharge in the river Måls-elv in Troms shows less correlation with the river Rana in the Nordland than with the river Tana in Finnmark. A good correlation, c = 0.88, occurs between the rivers Rana and Namsen, the latter being the northernmost river in Tröndelag, but the correlation coefficient between the river Rana and the river Nid-elv in central Tröndelag is only 0.54. Good correspondence occurs between the river Nid-elv and the rivers Namsen and Aura, respectively north and south of the river Nid-elv. Between the river Aura and the adjacent river Jölstra, in Vestland, there is no good correspondence. Between all the rivers in Vestland, including the river Sira, which is one of the westernmost rivers in southern Norway, there are very good correlations. The eastern river Tovdals-elv in southern Norway has unsatisfactory correlations with the river Sira, as well as with the adjacent river Tokke in Östland. Between all the rivers in Östland there are good or rather good correlations but they are unsatisfactory between the rivers in Östland and in the neighbouring districts.

The correlation coefficients calculated for the Norwegian rivers are presented in the following Table.

Correlation-coefficients, Norwegian rivers

Rivers in the same district		Rivers in different districts	
Namsen/Rana	0.88	Nidelv/Rana	0.54
Nidelv/Namsen	0.75	Nidelv/Otta	0.43
Sira/Vossa	0.82	Vossa/Snarumselv	0.42
Lågen/Snarumselv	0.84	Nidelv/Vossa	0.53
Snarumselv/Glomma	0.88		

The above results can be summarized in the following way: From Troms there occurs a gradual change to the high mountainrange Dovre with good correlations between adjacent rivers but not so good when the rivers are very distant from each other. Thus there are good reasons for dividing the districts into two hydrological regions, Troms – Nordland and Tröndelag – Möre. In the south of Norway there is a marked difference from a hydrological point of view between Östland and Vestland. The river Sira belongs to Vestland, the river Tovdals-elv offers a particular case but it is convenient to include that river in the region of Östland. The results have in the main confirmed the traditional hydrological division of the Norwegian rivers after the counties in the north and the main districts in the south (Fig. 12).

Sweden

Between the river Lule-älv and the frontier river with Finland, the Torne-älv, there is not such a good correlation (c = 0.61) as between the Lule-älv and the more southern rivers Vindel-älv (c = 0.82) and Ume-älv (c = 0.78). Good correlations occur between the rivers Ångerman-älven and Indals-älven (c = 0.78) but not particularly good between the rivers Ångerman-älven and Lule-älv (c = 0.52) and between the rivers Indals-älven and Ljusnan (c = 0.59). The diagrams and coefficients for the rivers in southern Norrland and the influx-water of the lake Vänern show that there are good relations between the mean discharge in the rivers within a fairly vast region. The rivers in southern Sweden have an unsatisfactory relation, not only with the rivers in the above-mentioned region but also with each other. However, they have other hydrological qualities in common.

Correlation-coefficients, Swedish rivers

Rivers in the same district		Rivers in different districts	
Luleälv/Vindelälv	0.82	Luleälv/Torneälv	0.61
Luleälv/Umeälv	0.78	Ångermanälven/Luleälv	0.52
Indalsälven/Ångermanälven	0.78	Ljusnan/Indalsälven	0.59
Dalälven/Ljusnas	0.87	Vänern lake, influx/Lagan	0.57
Vänern/Dalälven	0.89		

The above results and the general hydrological conditions show that the Swedish rivers can be brought together in the following groups.

The rivers Torne-älv and Kalix-älv.

The northern mountain rivers including the rivers from Lule-älv southwards to Ume-älv.

The central mountain rivers Ångermanälven and Indals-älven.

The southern mountain rivers and the forest rivers in northern and north-western Svealand.

The south-western / the south-eastern groups on each side of the principal watershed in southern Sweden.

Finland

On account of the large lake area of the basins, corrections of the observations have been made for the yearly storage change in the lakes Vanaja-vesi and Näsi-järvi of the basin of the river Kumo-älv, in Päijänne and Keitel in the basin of the river Kymmene-älv, and in the Saima Lakes and Pielis-järvi in the basin of the river Vuoksen.

There are good relations between the mean discharge in the two northern rivers Kemi-älv and Iijoki and between them and the frontier river of Finland and Sweden, the Torne-älv, a rather unsatisfactory one between the rivers Kemi-älv and Ule-älv, but a very good one between the big southern rivers Kumo-älv, Kymmene-älv, and Vuoksen, which drain the large interior lake plateau in the central and southern part of Finland. The calculated coefficients are.

Kemi-älv/Torne-älv	0.89
Kemi-älv/Ule-älv	0.61
Kumo-älv/Ule-älv	0.60
Kumo-älv/Kymmene-älv	0.92

From the results we may conclude that the Finnish rivers from our point of view can be divided into a northern group with the rivers Kemi-älv and Iijoki, and a southern group composed of the three other large rivers Kumo-älv, Kymmene-älv, and Vuoksen. Between these groups the river Ule-älv occupies an intermediate position.

A summary for all the three countries

From the previous discussion it appears that the rivers can be divided into groups where the discharge in percentage of the mean discharge is of about the same dimension, whereas there are often great differences between the ri-

Table 5.
Correlation coefficients

Rivers in the same district		Rivers in different districts	
Kemiälv/Torneälv	0.89	Rana/Torneälv	0.38
Kemiälv/Tana	0.72	Kemiälv/Luleälv	0.46
Rana/Luleälv	0.72	Uleälv/Indalsälven	0.47
Uleälv/Luleälv	0.76	Kumoälv/Indalsälven	0.44
Uleälv/Umeälv	0.58	Snarumselv/Lagan	0.36
Nidelv/Indalsälven	0.85	Kumoälv/Vänern, influx	0.53
Glomma/Dalälven	0.82	Kymmeneälv/Dalälven	0.49
Glomma/Vänern, influx	0.88	Kymmeneälv/Lagan	0.41
Snarumselv/Vänern, influx	0.71		

vers in adjacent groups. Good and poor water supply do not occur too often in the entire territory under consideration. By investigating the water supply for each separate country, we have arrived at good knowledge about the northern-southern changes. Some differences have also been indicated between the western and eastern parts as those between the rivers in Östland and Vestland in Norway and between the south-west and south-east of Sweden. But it is possible to arrive at a more precise knowledge about the western-eastern changes by comparing the discharge in all the countries.

Table 5 gives the calculated correlation coefficients between mean discharges in rivers in the different countries.

It is evident that there are good relations between the yearly mean discharge in rivers within rather large districts overlapping the frontiers of the northern countries. Thus there is good correlation between the rivers Tana, Torne-älv, Kemi-älv, and Ii-joki; between the rivers Rana, Lule-älv, and Ule-älv; between the rivers Nid-elv and Indals-älven; and between the Norwegian Östland rivers and the rivers in southern Norrland and northern Svealand. The only very moderate correlation between the rivers in northern Svealand and southern Finland is somewhat unexpected.

The results of the above investigations concerning the relations of mean discharge have been used in drawing the lines in the map Fig. 11.

THE LONG-TIME VARIATIONS

The discharge relations dealt with in the former section must, of course, also appear in the long-time variations. But these variations give another aspect of the problem of similarities, and besides, they have a climatic value of their own, as they can often give better information on the variations in precipitation than the precipitation observations, the discharge observations being more homogenous and having the advantage of integrating large areas.

Investigations of long-time variations of Swedish rivers have previously been made by many writers, among them Axel Wallén (1923); Lindqvist, mainly on lake Vänern; Bergsten (1941); Eriksson-Nybrant (1942), a long series in southern and central Sweden; and the present writer (1967), a series with observations for the years 1901-65. Tollan (1960) has investigated the 5- to 15-year means in 15 Norwegian rivers up to the year 1960.

The present investigation deals chiefly with 30-year discharge means, but 10-year means have also been calculated. Discharge data used in this investigation were taken from 9 Norwegian, 10 Swedish, and 5 Finnish reports. I have been able to avail myself of the Norwegian material used by Tollan and put at my disposition by the Hydro-Power and Electricity Board of Norway. The Swedish data belong to the series earlier published, except the data for the river Motala-ström at the outlet of the lake Vättern.

The longest observation series in the Finnish rivers have been published by Sirén (1958) in communication No. XVI of the Hydrological Bureau in Finland. The observations used in the investigation derive from that paper and have been completed up to 1964 by data given in the Finnish hydrological yearbooks.

When investigating long-time variations, the observations used must be as homogeneous as possible. Discharge values are mainly calculated in two ways: from water-level observations and rating curve or from measurements in hydropower stations. At the Swedish discharge stations, the calculation was often made by the first method during the earlier years, and by the second during the later. When two methods have been used, the series are, of course, not homogeneous. But when the observations for the whole series are based on the same continually checked rating curve, the values must be considered homogeneous, since the curves, as a rule, are very stable. I have been obliged to use some not quite homogeneous series of good quality besides the homogeneous ones, but both series give approximately the same results. The results arrived at can therefore scarcely be questioned. The investigation covers a period from 1901 to the most recent time for which data are available. The method used for calculating the 30- and 10-year means is the well-known method of moving

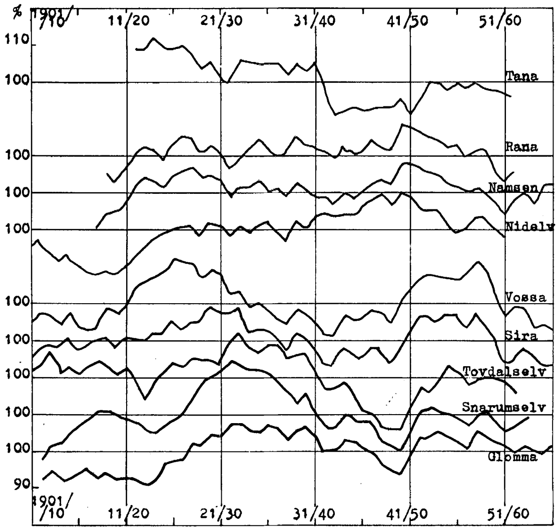

Fig. 4.
Variations of 10-year mean discharge in percentage of mean discharge 1911-60 with one year's overlap. Swedish rivers. (Names and position of rivers in Fig. 10.)

averages. For reference values have been used the yearly means for the fifty-year period 1911-60; in the following called MQ.

The diagrams in Figs. 4-9 are based on values given in percentage of these means. As may be seen from the diagrams, they have rather the same trend in adjacent rivers. It is therefore convenient to discuss the development of rivers in certain regions mainly distinguished before. The 30-year means are our main object.

1. The rivers of the North-Calotte, a name given to the northernmost part of Norway, Sweden, and Finland.

Discharge falling in the river Tana-älv, varying in the rivers Torne-älv, and Kemi-älv.

2. The mountain rivers in northern Scandinavia (the rivers of Troms, Nordland, Tröndelag, and Möre in Norway, the rivers from Lule-älv south to Indals-älven in Sweden): The 30-year-value increase from mean in the beginning of the century to a maximum for the period 1920-49 or 1921-50, at Ragunda on the river Indals-älven the value being a little higher for the period 1917-46. From the maximum values fall to the mean or – at the last value in 1926-65 – a little below the mean.

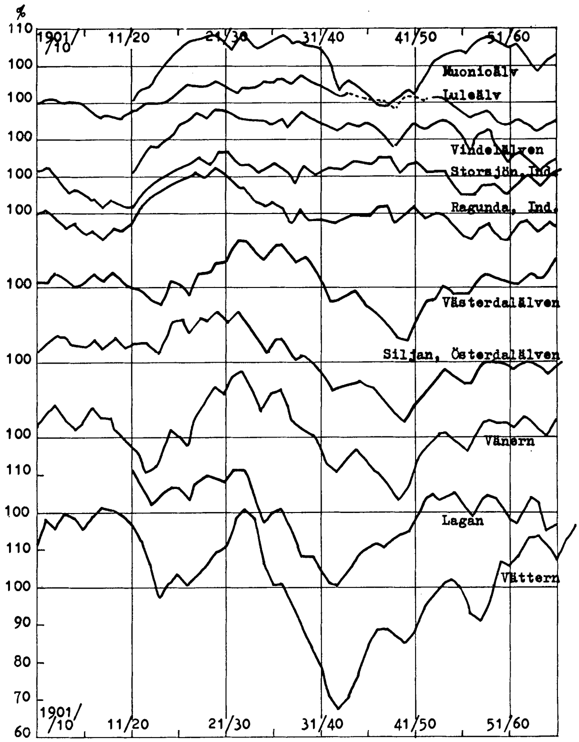

Fig. 5.

Variations of 10-year mean discharge in percentage of mean discharge 1911-60 with one year s overlap, Norwegian rivers. (Names and position of rivers in Fig. 10.)

3. The rivers of Vestland in Norway: The discharge in the rivers Vossa, Årdals-elv, and Sira do not rise continuously to a maximum as the other mountain rivers, but vary by 2 og 3 per cent around the normal value until 1929-58. Since then there is a small decrease to about 98 per cent of the normal value. The rivers Aura and Jölstra in the transition district between Tröndelagen and Vestland seem to have about the same character as in the Tröndelag district.
4. The rivers of Østland in Norway: The central rivers Glomma and Lågen show a marked rise from 96 per cent of MQ at the beginning of the century to 104 per cent in the 1924-53 period. Later the series began to descend. In the border districts the rivers have fairly high divergencies from this pattern. Thus the river Tokke, a mountain river near Vestland, shows a pattern reminiscent of the rivers in that district. The greatest divergencies are shown by the river

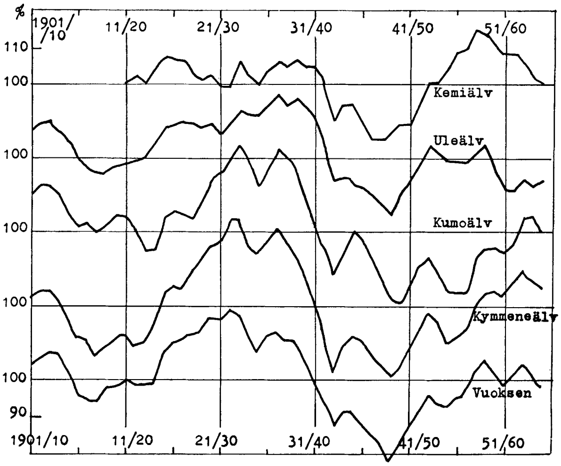

Fig. 6.

Variations of 10-year mean discharge in percentage of mean discharge 1911-60 with one year's overlap. Finnish rivers. (Names and position of rivers in Fig. 10.)

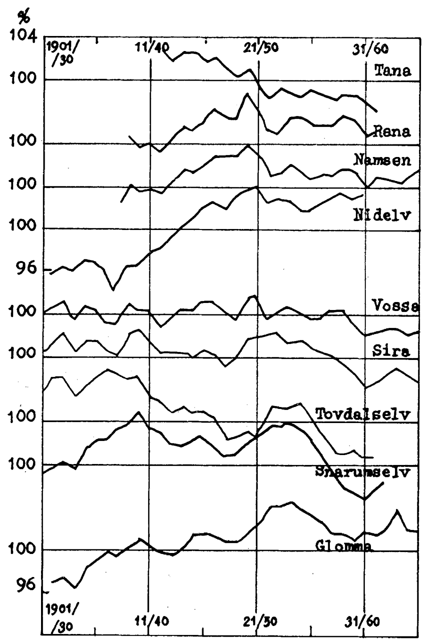

Fig. 7.

Norwegian rivers. 30-year means with one year's overlap as percentage of mean discharge 1911-60.

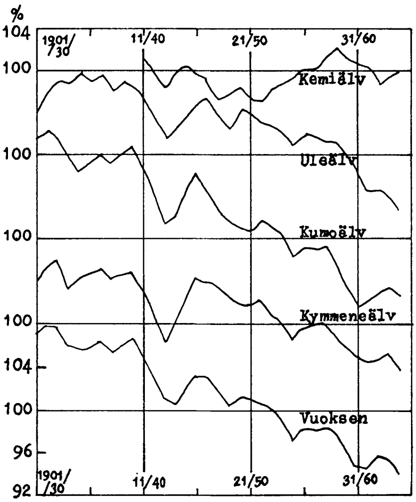

Fig. 8.
Finnish rivers. 30-year means with one year's overlap as percentage of mean discharge 1911-60.

Tovdals-elv. However, a development similar to that river can be found in the Swedish rivers in the north of Svealand. The river Snarums-elv has some features differing from the other rivers in the district but similar to those of the river Tovdals-elv.

5. The rivers of southern Norrland and northern Svealand (Dal-älven, Klar-älven, and the influx to the lake Vänern): Good water-supply in the beginning of the century, falling trend from the series 1909-38 to 1931-60, and later an increase. A marked secondary maximum is found in the series 1924-53.

6. The forest rivers in the north of Sweden: Only short-term observations are available, previously published (1967), but quite a good idea of the development can be formed, partly by comparing the diagrams for the upper and lower parts of the mountain rivers and partly from the diagrams of the Finnish rivers. Thus it is probable that the discharge in the rivers has a decreasing trend in the forest land of Norrland and the north of Svealand.

7. The rivers in southern Sweden: Observations for the whole period are available only for the river Motala-ström at the outlet of the lakes Vättern and for Roxen situated in dry, south-eastern Sweden. Only the series for the outlet of lake Vättern is included among the diagrams but the Roxen series and a series for the adjacent river Em-ån – closed in the year 1960 – have variations

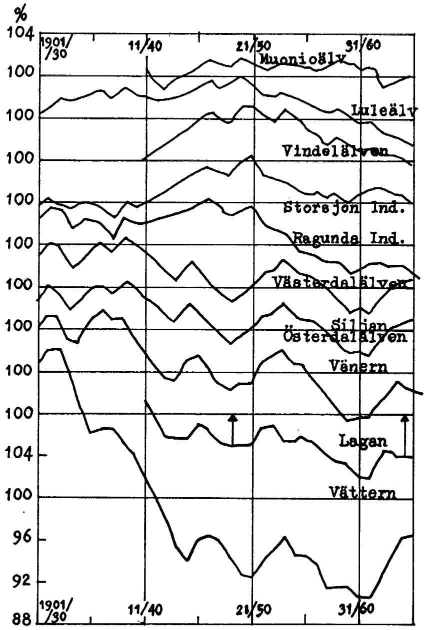

Fig. 9.
Swedish rivers. 30-year means with one year's overlap as percentage of mean discharge 1911-60.

quite similar to the series of Vättern. The water supply was very good to begin with and then rapidly fell to the series 1935-64. Afterwards, an increase began. The amplitude is very large, between 114 per cent of MQ at maximum and 90 per cent of MQ at minimum. Some 30-year series for southern Sweden beginning in the year 1911 and published 1967 have the same trend but a smaller amplitude.

8. The rivers of Finland, except the rivers Kemi-älv and Ii-joki, had, like the forest rivers in the north of Sweden, good water supply in the beginning and then a markedly decreasing trend to the last series 1935-64 in the diagrams. The amplitude is large for these rivers, too, between maximum 108 per cent of MQ and about 94 per cent of MQ at minimum.

Regions with about the same variation in the 30-year series

The brief summary given above of the variations in the 30-year series shows that the development trend is common to rivers in large districts. There is good reason to divide the northern countries into four regions in which the rivers in each region have similar development but differ from region to region. The four regions are the following:

Region A. The North Calotte (Nordkalotten). The region has been divided into two, the Arctic Sea part, where the discharge has a falling trend, and the inland part, with changing discharge about MQ.

Region B. The Scandinavian high-mountain region, except Vestland in Norway. The discharge increased from the beginning of the century to a maximum in the series 1920-49 in the northern rivers, although this took place slightly later in the south. In the southern rivers Glomma and Snarums-elv the maximum occurred in the series 1924-53. From the maximum there was a fall to MQ or slightly below.

Region C. Vestland, Norway: Varying discharge with no particular trend to about 1921-50 and after that a slight fall.

Region D. The eastern lowland region, covering the largest part of the forest plateau in northern Sweden, southern Sweden (Svealand and Götaland), coast districts of southern Norway, and Finland except the North-Calotte. The series had large values to begin with, mainly, as can be seen from the 10-year series, because of good water supply in the 1920's. There then followed a falling trend, which is most strongly marked in the south-east of Sweden and in Finland. In these two districts the precipitation is low and in the southern parts the evaporation high. Therefore the run-off is strongly effected by changes in the meteorological conditions.

The limits of the regions are marked on the map Fig. 10. Around the limits there are transition districts, where the trends are not clear. The observations are limited, as only a long, accurate series of investigations can be of use. Therefore it is not possible to draw a detailed map. Another difficulty is that some rivers flow through more than one of the regions. This applies in particular to the large mountain rivers in northern Sweden, which receive many tributaries when flowing through the forest plateau. Thus the border-lines may more express the inflow conditions than the discharge at the hydrological stations.

TEMPERATURE AND PRECIPITATION IN RELATION TO THE 30-YEAR SERIES OF DISCHARGE DATA

It has been established through several investigations that the mean temperature in the Nordic countries has risen since the middle of the 19th century. This

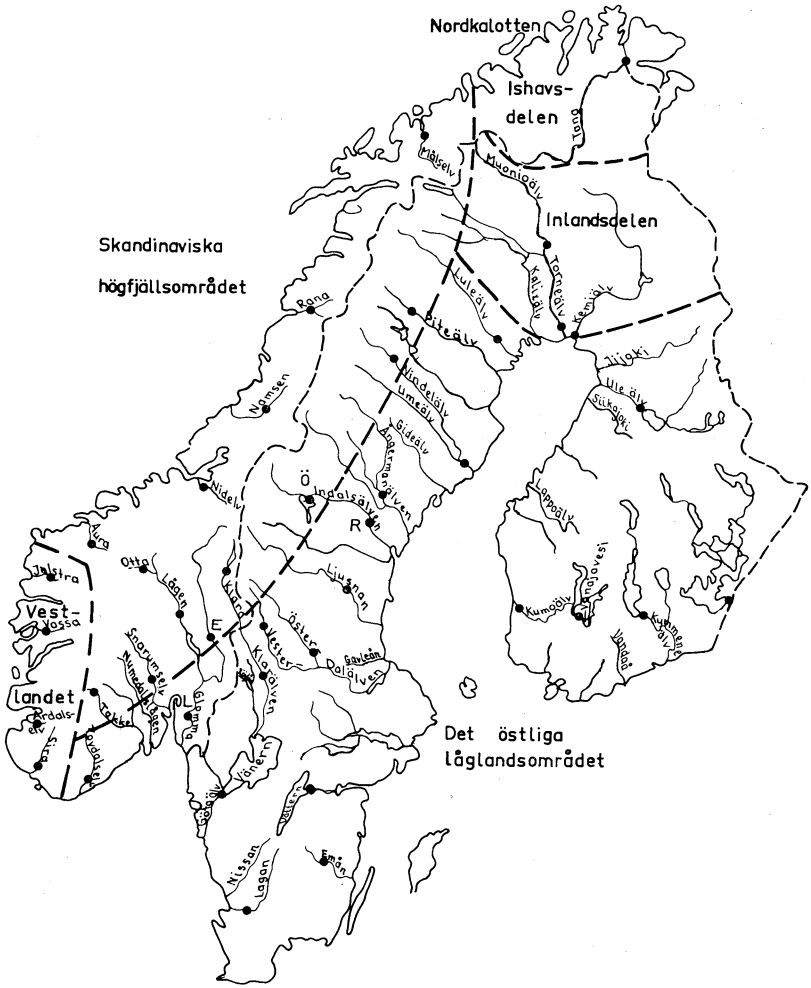

Fig. 10.

Regions in which the 30-year discharge series fluctuate in mainly the same way. A: The North Calotte (Nordkalotten): Arctic Sea part (Ishavsdelen) and the inland part (Inlandsdelen). B: The Scandinavian high mountain region (Skandinaviska högfjællsområdet). C: South-west Normay (Vestland). D: Eastern lowland region (Det östliga låglandsområdet).

Norwegian "elv"; Swedish "älv"; and Finnish "joki": "river".

Norwegian "vatn"; Swedish "sjö"; and Finnish "järvi"; or "vesi": "lake".

"å", "ån": small rivers in Norway, Sweden, and Finland. In Southern Sweden it is a common name for a river.

increase is most notable in the winter, whereas the summer temperature has even decreased during certain periods. Hesselberg & Birkeland (1943) report for Oslo an increase in winter temperature of 1.9° between the two 30-year periods of 1836-65 and 1909-38, and Ångström (1942) found an average increase of 2° in the three winter months of December, January, and February by comparing the 30-year periods 1781-1810 and 1901-30.

In the 20th century there appeared a marked rise in summer temperature (Liljequist 1949), in Norrland from the beginning of the century, and in southern Sweden somewhat later. Recent research (Rodhe 1968) on variations in mean temperature for 10-year periods has revealed considerable differences for different months. It is evident from the diagrams in Rodhe (1968) that the mean summer temperature in 1931-60 was higher than that of 1901-30 in southern Sweden, as well as in Norrland. These observations give unequivocal evidence of long-term variations in temperature.

Observations on precipitation, which have been made since the middle of the 19th century, do not give as reliable information on long-term changes in precipitation, partly owing to the irregularity in the distribution of precipitation, partly to lack of homogenity in the observations. A discussion on the source of errors is made in several works, perhaps most extensively by Ångström (1941). Research on the variations in precipitation has hinted at an increase for the whole period from 1861 on. Ångström (1942) compared the series of 1861-1900 and 1901-30 at 25 stations and found a mean increase between the two series of about 2.5 per cent in the south of Sweden and roughly 5 per cent in the north. Bergsten (1954) compared the series of 1901-30 and 1921-50 from stations in southern Sweden. Of the increase (8 per cent) only 2 per cent was left after elimination of gaps in homogenity caused by the fact that at a certain time the gauges had been screened. He thus proved that the screen had augmented the measure of precipitation by about 6 per cent. A later investigation by C. C. Wallén (1958) for the period of 1901-50 at 127 stations spread over the whole of Sweden indicates, according to the author, the existence of a rising trend at most stations.

In the discussion of changes in precipitation, an often quoted work is the investigation by Hesselberg & Birkeland (1941) of local variations in Norway. For the 20th century the results derive mainly from a comparison between the mean of two ten-year periods, 1896-1905 and 1929-38, at 25 Norwegian precipitation stations. The differences between the mean of the two series vary between – 15 per cent and + 20 per cent of the mean precipitation for the period 1901-30. From another analysis, based on observations at seven stations in Vestland and south Östland has been inferred that the mean precipitation has increased by 5 to 15 per cent between the periods of 1861-90 and 1909-38, except at one of the Vestland stations, where there was a decrease of 3 per cent. It is obvious that this material from Norway is quite insufficient to show the variations in the precipitation trend in 20th century Norway. The maritimization of the climate and above all the rise in winter temperature has been connected to an increase in atmospheric circulation which has carried a larger amount of humidity and heat from southern to northern latitudes. The increase in precipitation revealed by the investigations thus seems to be explained.

Research on long-term variations in precipitation thus indicates or, at any rate, hints at the probability of a rising trend. The results are constituted of very disparate, individual values at the stations. On the other hand, the development of run-off is very uniform, presenting mainly two different patterns, one in the rivers of the Scandinavian high mountain region, the other in the southern and eastern parts of the Nordic countries. The results coincide so well and the observation material is so comprehensive that the validity of the trend arrived at cannot be questioned, although the rise or fall of the trend may in certain cases have been exaggerated through lack of homogeneity in some of the series observed. There is a certain conformity between the northern development trend for the years 1901-50 and the precipitation increase obtained by Wallén for the same period in certain parts of northern Sweden. But in the south and the eastern parts the discharge is decreasing, whereas precipitation shows an insignificant rise. In two separate papers Blomqvist (1966) and Melin (1966) have emphasized the importance of an increase in evaporation, caused by the rising temperature, for the variations in discharge.

Table 6.
Precipitation (*P*) in mm, evapotranspiration (*E*) in mm, yearly means

River	District	P	E	$\frac{E}{P}100$
Kemi-älv	North-Calotte	506	150	30
Rana	Nordland, Norway	1670	200	12
Suldalslågen	Vestland, Norway	2550	200	8.5
Glomma	Östland, Norway	800	250	30
Ume-älv	Norrland, Sweden	783	225	29
Indals-älven	Norrland, Sweden	808	250	30
Dal-älven	Svealand, Sweden	657	250	38
Viskan	South-west Sweden	817	350	43
Outlet of lake Vättern	South-east Sweden	550	350	64
Kymmene-älv	Southern Finland	580	350	60

Table 7.
Mean temperature in degrees C, April-October

Gällivare	6.1	6.1	±0
Stensele	6.9	7.3	+0.4
Östersund	7.9	8.6	0.7
Falun	10.3	10.5	0.2
Karlstad	11.1	11.3	0.2
Stockholm	10.9	11.9	1.0
Linköping	11.2	12.2	1.0

The values of precipitation P and evapotranspiration E for some river basins are presented in Table 6.

The values in the Table show that evaporation in northern and above all western Scandinavia is small, but in southern Scandinavia and Finland is large in relation to the amount of run-off.

It may be of interest to give an estimate of evaporation as a consequence of the increase in temperature. It has been found that evaporation in a basin can be approximated as a single function of temperature. Thus Sirén has given the equation for evaporation in Finnish rivers $E = 57T - 235$, where T is the mean temperature of the months April to October. The variations of 1° C would thus appear to cause a change in evaporation by 57 mm. The mean temperature during April-October has increased from 1901-30 to 1931-60, for instance, by 1° C at Stockholm and Linköping and at some stations in Norrland by about 0.5° C. Values are given for some meteorological stations in Table 7.

It is evident that the decrease in run-off in the rivers of south-eastern Sweden where evaporation is about 350 mm and the run-off 200 mm depends to some extent on an increase in evaporation. This also applies to other rivers in the south of Sweden and southern Finland.

From the material presented here the following summary conclusions appear to be justified. In the northern parts of the Nordic countries, and in their very rainy western parts, the long-term variations in discharge indicate a corresponding variation in precipitation. In southern Sweden, particularly in the south-east, and in southern Finland the long-term discharge trend seems to be considerably influenced by changes in temperature.

The decreasing trend in the 30-year series for southern Scandinavia, central Sweden, and the main part of Finland is due to the frequent appearance of dry years towards the end of the 1930's and the beginning of the 1940's. In these regions the 10-year series offer pronounced minima between 1931-40 and 1941-50. The lowest value registered in the rivers of southern Sweden appeared in 1932-43, 67 per cent of the normal discharge for the outlet of lake Vättern and the river Em-ån and 80 per cent for the river Lagan. In southern Norway, central Sweden, and in Finland the lowest 10-year mean appeared at a later date, in 1940-49, and amounted to 80 per cent at the lowest of the normal average discharge. As the low-water years disappear from the 30-year series and are replaced by more average values, the 30-year discharge will probably increase. As a matter of fact, this rise has already begun in rivers with the earliest minima in ten-year mean values, which is apparent in the lake Vättern series, estimated as of 1967.

In northern Norrland from the river Lule-älv to the river Indals-älven, the development has been different. A long-lasting low-water period, corresponding to that of the rivers in southern and central Sweden, exists only in the North Calotte rivers Tana, Kemi-älv, Torne-älv, and Kalix-älv. The falling 30-year series is due to the numerous low-water years in the 1950's and the 1960's, which will be of influence for the 30-year means for some time to come. It is thus hardly probable that the 30-year series for the mountain rivers in Norrland should show a substantial rise during the next years. As for the northern rivers in Norway it is more difficult to give an opinion because of lack of observations during later years but there will probably be about the same development as in the north Swedish rivers.

A SURVEY OF THE HYDROLOGICAL REGIONS

Within the two principal regions where the rivers can be characterized as nival mountain and lowland regime and Atlantic rain-and-snow regime, respectively, it has been possible to distinguish qualities as regards the rivers' hydrology, mainly owing to the geographical position and height above sea-level. As for the 30-year series, four regions have been sorted out, all of them with a different trend. It has been shown that there is a close relation between the yearly mean discharges, not only in adjacent rivers, but also within fairly vast regions.

A division into hydrological regions must always be the result of a compromise between various principles, if the division is not to be too detailed but offers such a general hydrological view of the rivers that considers important similarities and differences. In a survey one must, moreover, insist on the principle that the whole river is assigned to one region, although the run-of originating in the various parts of the basin may present considerable differences. The big mountain rivers, for instance, may have a glacial regime in some of their tributaries and a lowland regime in the tributaries discharging a forest

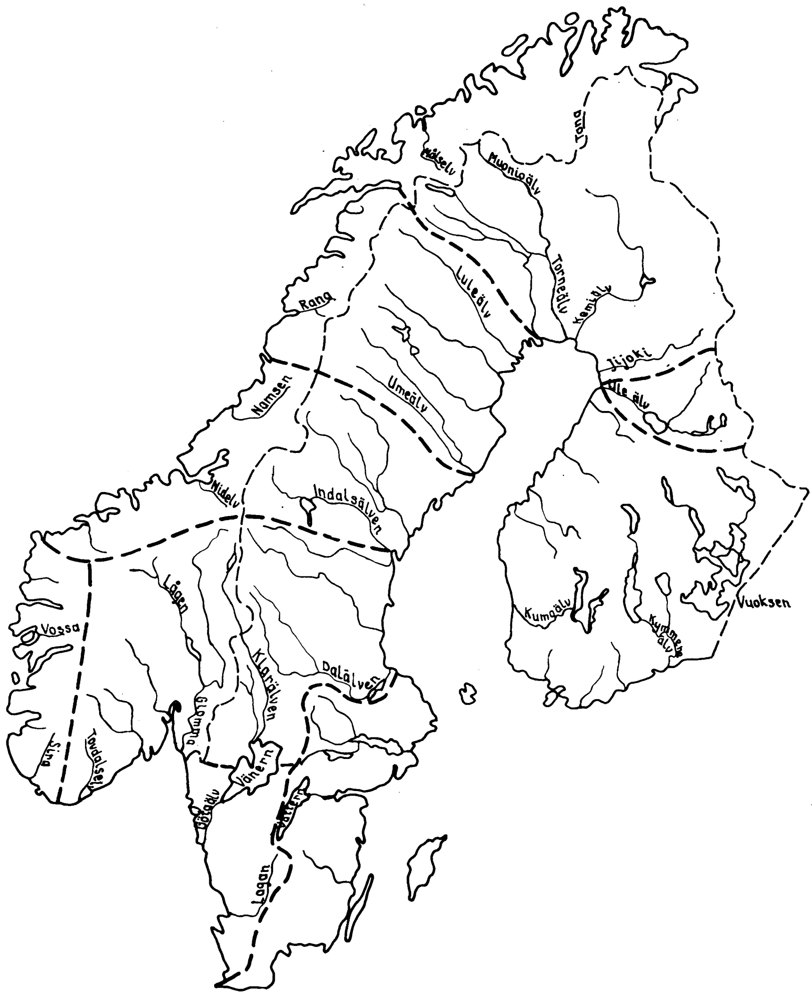

Fig. 11.
Hydrological regions in Scandinavia and Finland.

plateau in the lower part of the basins. When assigning these rivers to certain regions, it is the dominating factor that has to be considered, i. e., as far as the big rivers in northern Sweden are concerned, the ratio between the flow from mountain and lowland.

When dividing the various regions the size of run-off and the geographical position have been taken into account, besides the qualities just considered. What has particularly been kept in sight are the results obtained before as to the relation between the yearly means of run-off. In transition districts doubt has sometimes arisen as to which region a river should belong. The river Måls-elv in Troms may be quoted as an example. Its run-off and long-time variation are more closely related to the Rana river in Nordland than to the river Tana in Finnmark. The catchment area, however, is so closely connected with the upper area of the riverTorne-älv that the river Måls-elv has here been allotted to the North Calotte region. The 30-year series for the river Måls-elv makes it clear that the river Torne-älv, too, where it passes through the mountain region, enjoys that development of the 30-year series which in general is characteristic for the rivers of the Scandinavian mountain range.

The river groups

In consequence of the principles mentioned above it has been possible to divide the rivers in Scandinavia and Finland in the following groups.

1. The North Calotte, mountain and forest rivers.
   Norway: Rivers in Finnmark and Troms.
   Sweden: The rivers Torne-älv and Kalix-älv.
   Finland: The rivers Torne-älv, Kemi-älv, and Ii-joki.

High water in May for the Finnish rivers, in June for the others, but high values for May show an early melting of ice and snow. 30-year mean figures without clear tendencies in the Swedish and Finnish rivers, somewhat falling in the Finno-Norwegian river Tana. Average run-off 10-13 l/sec km^2. In the river Måls-elv the average run-off is 28 l/sec km^2.

2. Mountain rivers, northern group.
   Norway: Rivers in the Nordland.
   Sweden: The river Lule-älv as far south as and including the river Ume-älv.
   Finland: The river Ule-älv.

High water in June in the river Lule-älv in July because of a very high and extensive mountain area with a high percentage of lakes. 30-year mean in Norwegian and Swedish rivers rising to 1920-49; after that period, a falling trend. As for the river Ule-älv good water-supply until 1910-39; after that, a falling trend. Average run-off: Norway, 30-60; Sweden, 14-20; Finland, 11 l/sec km^2.

3. Mountain rivers, central group.
   Norway: The rivers of Tröndelag and Möre.
   Sweden: The rivers Ångerman-älven and Indals-älven.

High water in June; in the Norwegian rivers a small, secondary maximum in October, which has a counterpart in the Swedish rivers only in the high mountain tributaries. 30-year mean: Trend irregular in its initial stage, then rising till about 1921-50, later falling. Mean run-off: Norway, 35-38; Sweden, 15-18 l/sec km^2.

4. The rivers of Vestland in Norway, including the Sira river in the south.

High water in June (in May for the Sira river); a secondary maximum in September-October. 30-year mean: Tendency unvaried till 1921-50, after that falling. Average run-off: 50 to 80 l/sec km^2.

5 a. The rivers of Östland in Norway.

High water in June, for the rivers Tovdals-elv and lower Glomma in May; for the Otta river in July; a secondary maximum in November for the Tovdals-elv. 30-year mean: Tendency rising till 1924-53, after that falling. The rivers Tovdals-elv and Tokke had good water supply till 1910-39, after that falling. Average run-off: 15 to 40 /sec km^2.

5 b. The rivers of southern Norrland and Svealand in Sweden.

High water in May; for the river Ljungan in June. The southern rivers have a secondary maximum in November. 30-year mean: Good water supply till 1909-38, after that falling tendency. Average run-off: 11 to 16 l/sec km^2.

6 a. Forest and coastal rivers in northern Sweden.

The catchment area has not been marked out on the map, Fig. 11, because the area has not be accurately surveyed.

6 b. Inland rivers and coastal rivers in Finland.

6 a and 6 b: High water in May, secondary maximum in October-November. 30-year mean: Good water supply till about 1911-40, after that falling tendency. Average run-off: The rivers in Sweden 10 to 12, in Finland 7.5 to 9 l/sec km^2.

7 a. South Sweden, western rivers.

7 b. South Sweden, eastern rivers.

High water in April (maximum), and December-January; low-water in July-August. 30-year mean: Trend falling till 1931-60, later probably rising. Average run-off: western, 11 to 23 l/sec km^2; eastern, 5 to 11 l/sec km^2.

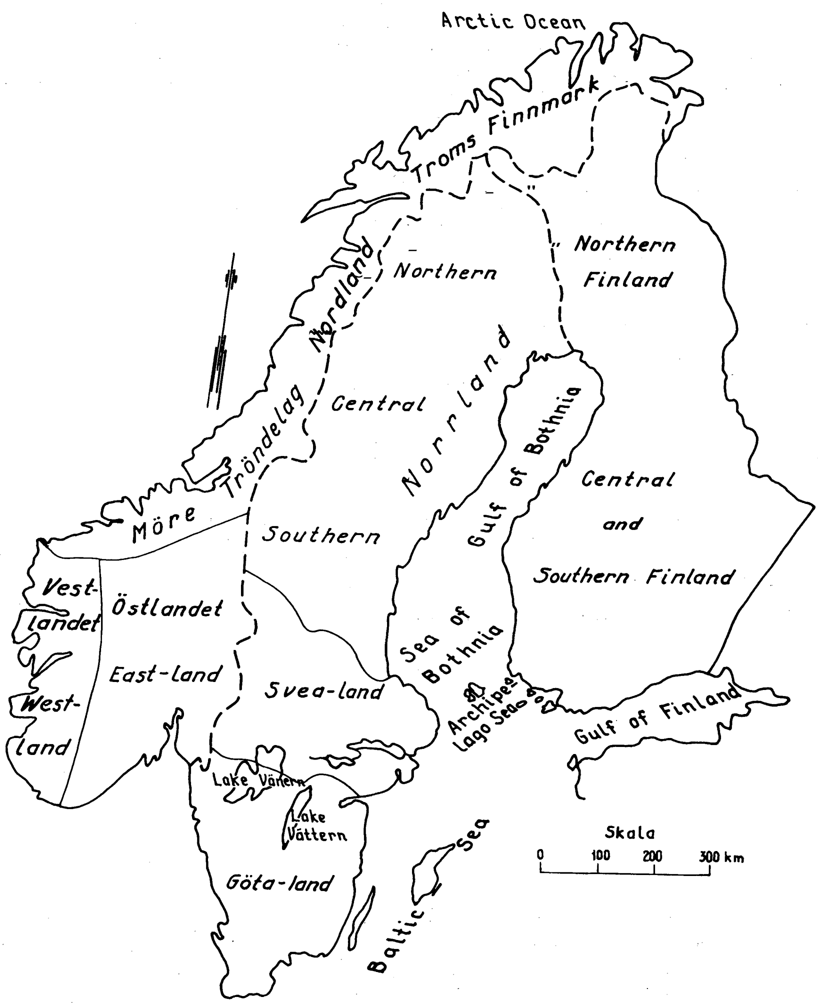

Fig. 12.
Names of geographical areas.

The region bordering both sides of the line drawn between nival and Atlantic regime, with the rivers offering traits of both types of regime, is wider in Sweden than in Norway and Finland, which is mainly due to the topographical character of the country in the transition district. In Sweden the country rises slowly and gradually towards the north, but in Norway it very rapidly reaches high levels. In Finland the line runs along the ridge of Salpausselkä. It divides the low coastal plain from the higher interior plateau and contributes to emphasizing the contrast between the southern and the northern types of regime, a contrast which is also more pronounced in Finland than in the Scandinavian countries, owing to the more continental climate of the country.

To the transition region on both sides of the line belong
the following rivers:

Norway: The coastal rivers of southern Norway and rivers in the south-east of Östland, bordering on Sweden.
Sweden: The northern tributaries of lake Vänern, the north-west tributaries of lake Mälaren.
Finland: Small rivers in southern Finland.

These rivers have their maximum in April-May, a secondary maximum in November, low water in February and July-August. The 30-year means have had a falling trend in the whole period. The run-off in Norway is 15 to 30 l/sec km^2; in Sweden, 8.5 to 14 l/sec km^2; and in Finland, 8.5 to 9 l/sec km^2.

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