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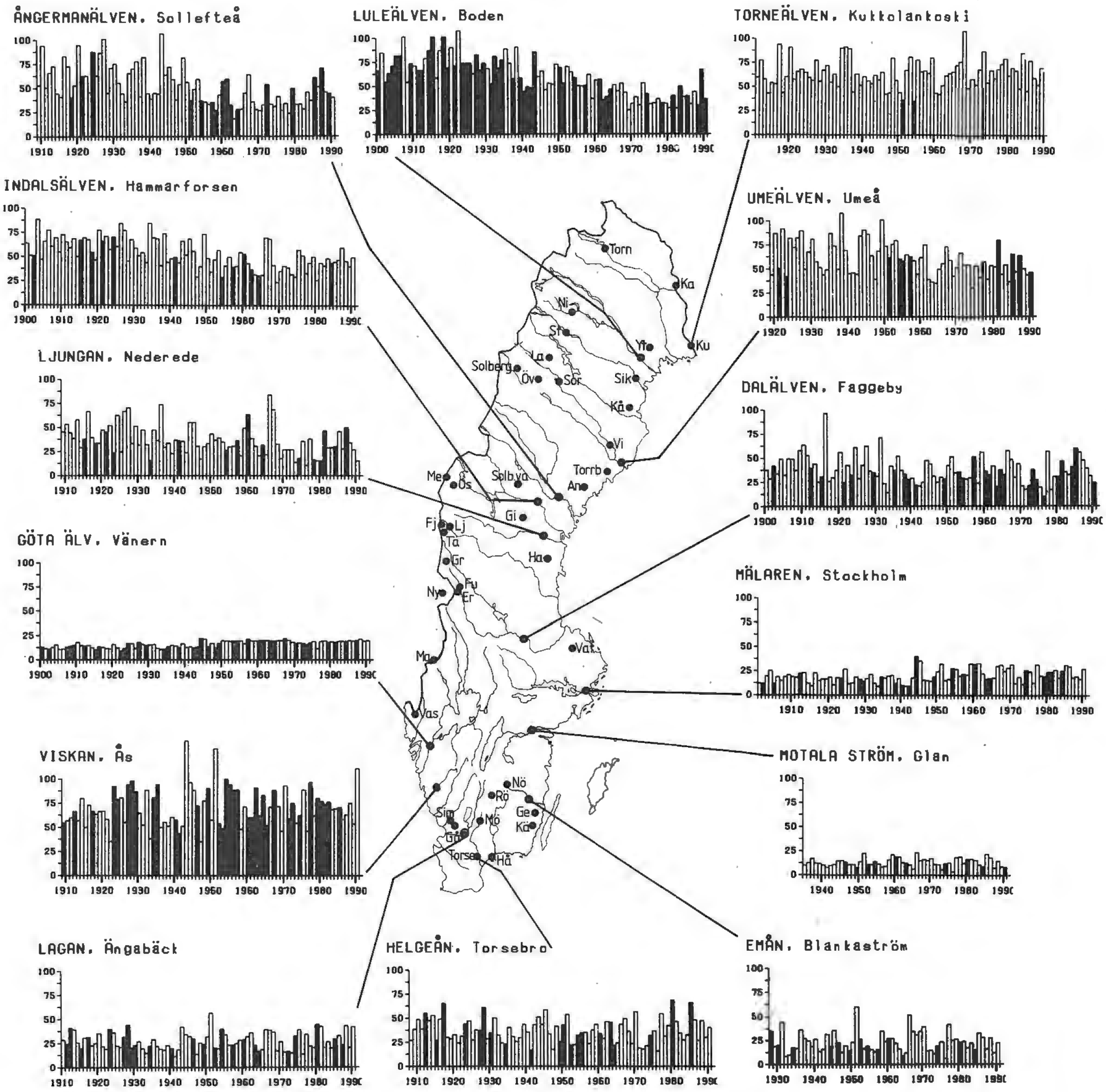

FLOODS IN SWEDEN — TRENDS AND OCCURRENCE

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Abstract

Sweden experienced a number of large floods in the 1980-ies. This raised the question of whether floods were becoming more frequent. A systematic study on floods was carried out, to provide a perspective to past and future floods. Frequency analysis was made using 16 methods. A split-sample test was used for evaluation of the predictive power of the methods. Numerical criteria were used for measuring the goodness of fit. The return periods of observed floods were estimated by use of plotting positions.

No convincing evidence of trends was found. The 1980-ies had larger floods than usual, whereas the 1970-ies had few high floods, especially in the autumn. This may have led to the impression of a trend. No evidence of autocorrelation or periodicity was found. For most of Sweden, the spring was found to be the season with highest extremes. The flood-moderating effect of regulation was illustrated, although floods were also found to occur in regulated systems. The results from the frequency analysis depended on the choice of criteria. In general, however, distributions with two parameters performed best. Neither a two component model treating spring and autumn separately, three parameter distributions, nor regional analyses gave any improvements. The spatial correlation within the data was considerable.

Key words

Floods, Sweden, Trends, Frequency analysis, Seasonal distribution, Regulation.

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PREFACE

After floods in Dalälven and Voxnan in September 1985, the Swedish government appointed an investigation on dam safety and flood protection. The investigation (SOU, 1987) suggested that research, with state funding, be initiated on flood protection and dam safety. This report describes the results from one of the projects carried out within this framework.

1. BACKGROUND AND INTRODUCTION

An apparently large number of high floods occurred in Sweden during the 1980-ies. The most notable one was the September flood in 1985 in the rivers Voxnan and Dalälven. This flood, in combination with a jammed gate, caused the failure of the Noppikoski dam in a tributary to Dalälven and also of some 30 smaller dams. Other large floods in the 1980-ies occurred for example: in Helgeån in December 1980 and December 1985, in Ångermanälven in August 1987, in the province of Dalsland in September 1988, in Luleälven in August 1989, and on the west coast during the winter of 1990.

The floods raised concern in the society. Usually, the spring flood is the largest flood during the year, but many of the floods in the 1980-ies were caused by rainfall in the autumn. It was discussed whether floods were really more frequent in the 1980-ies than in the preceding decade, and if this was then only because the latter period had unusually few extreme events. A problem in this context is the short human memory and lack of perspective. Possible links between large floods and changes in land use, e.g. forest clearfelling and drainage, were discussed. At present, there is also a discussion on possible climate change, due to increasing amounts of greenhouse gases in the atmosphere, and its implications for runoff.

Floods were also in focus within another context: dam safety analysis. Following floods in Indalsälven and Ångermanälven in the autumn of 1983, the Swedish hydropower industry and the SMHI took the initiative to forming "Flödeskommittén", a committee with the task of reviewing Swedish and international hydrological spillway design practice, and of suggesting new guidelines for that purpose. The committee concluded its work in 1990 (Flödeskommittén, 1990). Hydrological criteria for dam safety were also in focus in many other countries at the time. For example, the 16th International Congress on Large Dams (ICOLD, 1988) was largely devoted to this question.

Hydrological design of structures such as bridges, spillways for dams etc., has traditionally been one of the central tasks in hydrology. The future climatic variation and weather extremes cannot be predicted, and the problem has been treated by statistical methods, i.e., frequency analysis. The objective is usually to compute a design flood, with a return period which by far exceeds the length of observations. Extrapolation of some type is needed. Such an extrapolation is not of any mathematical difficulty, provided that the structure of the statistical distribution is known, together with its parameters. This is unfortunately never the case in practice.

1.1 Objectives

This study is primarily descriptive. The behaviour of observed floods in Sweden was studied with the following objectives:

- Describe the natural variation pattern of floods to give a perspective to past and future high flood events.

- Analyze possible trends, both linear and periodic, in floods, in different seasons and regions of the country.

- Study the probability of floods, and in particular test different methods of frequency analysis in extrapolation outside the range of observations.

- Illustrate the effect of regulation on floods.

2. DESCRIPTION OF FLOOD CHARACTERISTICS IN SWEDEN

Recorded discharge series from the database of the SMHI were compiled and presented graphically, simply to give an overview of the characteristics of floods in Sweden. No statistical analysis was made in this context.

2.1 General overview

All maximum floods (HHQ) from unregulated stations with at least 15 years of observations were taken from the compilation by SMHI (1975). Daily values were used. The data were divided into two categories, basins from river Dalälven and to the north, and those to the south of the same river. The total number of stations was 181, with an average record length of 38 years. Figures 2.1.1 - 2.1.2 illustrate that the magnitude of the highest specific runoff ever recorded (HHQ) is related to, for example, basin area and mean discharge. The basin area is thus important, even when it comes to specific runoff. A standardization of recorded floods by division with the mean of the highest floods for each year (MHQ) is called an index flood. The highest index flood at any station was about 3.3 and corresponds to a high flood on the 27 June, 1951, at the station Fångåmon in river Indalsälven. The main part of the stations had ratios between 1.5 and 2.0. The Figures 2.1.3 - 2.1.4 show that even the highest index flood is related to basin characteristics, e.g., lake percentage and mean discharge. There was only a weak correlation between the ratio HHQ/MHQ and the number of observation years at the station.

A general observation is that the flood variability is relatively low in Sweden, with few events which by far exceed the average high flood of the year (MHQ). The variability is higher in areas with low average runoff, i.e. for example in the south of the country. In an international perspective the Swedish climate is moderate, and flash floods due to very intense rainfall are rare.

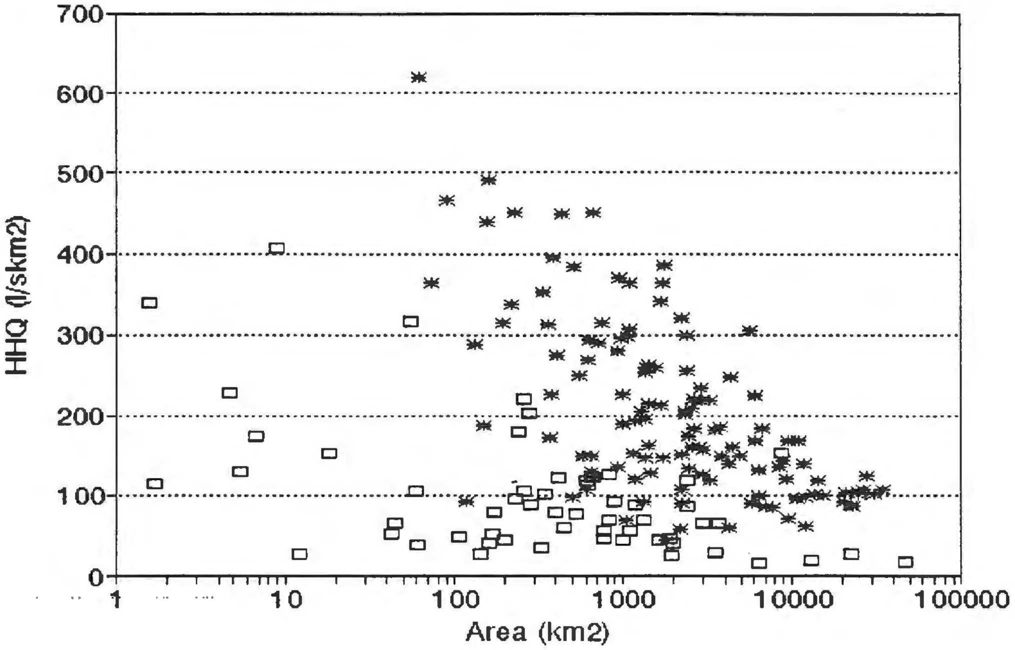


Figure 2.1.1. *The highest recorded specific runoff, HHQ, versus basin area, for 181 stations, located in river Dalälven and to the north (asterisk) and to the south of the same river (empty square).*

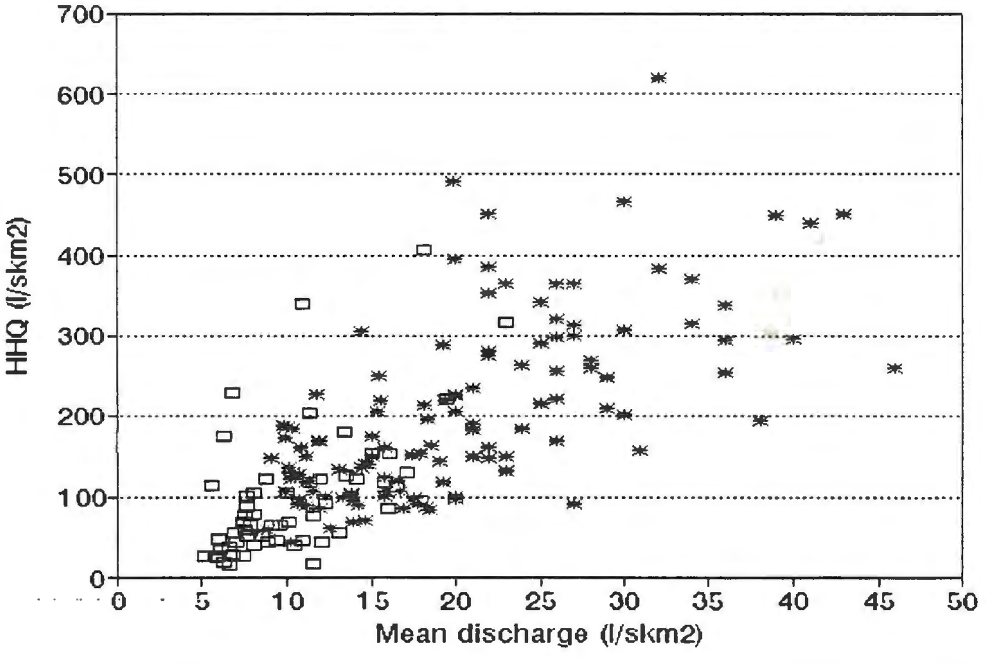


Figure 2.1.2. *The highest recorded specific runoff, HHQ, versus mean specific runoff, for 181 stations, located in river Dalälven and to the north (asterisk), and to the south of the same river (empty square).*

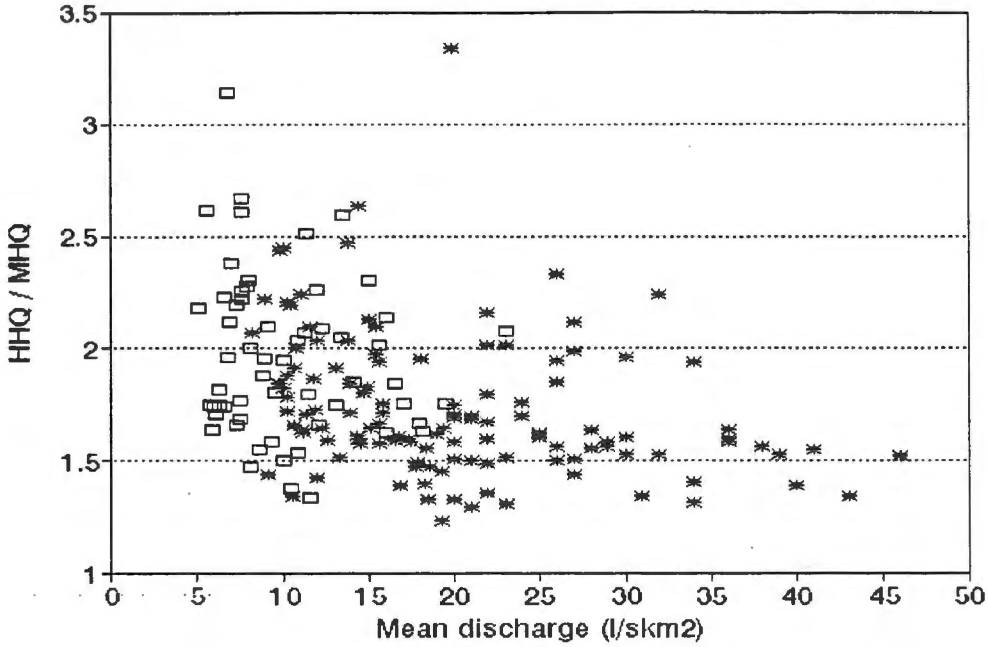


Figure 2.1.3. The highest recorded index flood (HHQ/MHQ) versus mean specific runoff, for 181 stations, located in river Dalälven and to the north (asterisk), and to the south of the same river (empty square).

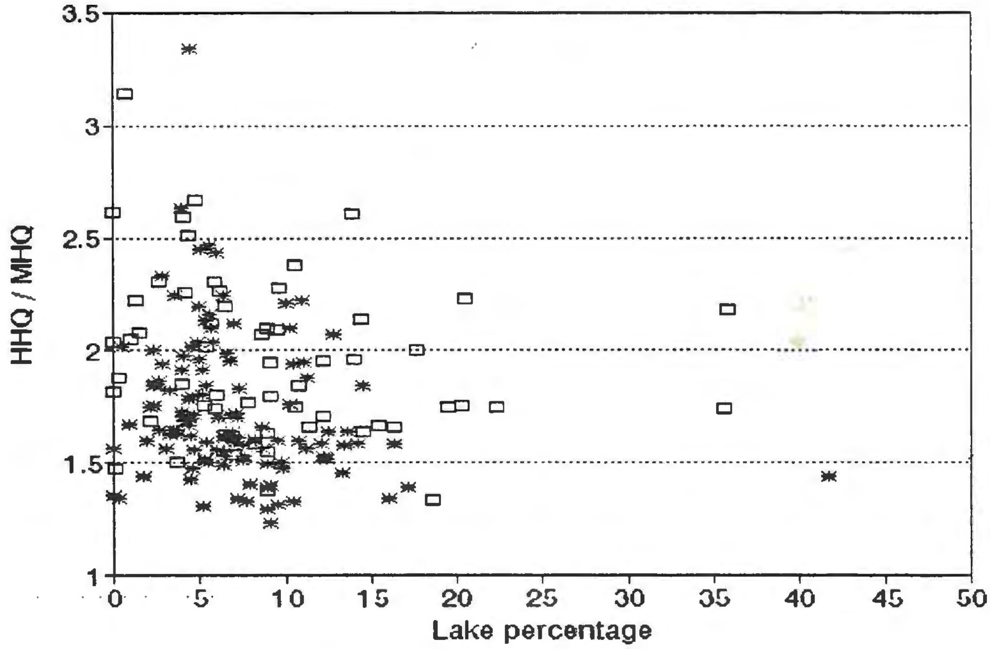


Figure 2.1.4. The highest recorded index flood versus lake percentage, for 181 stations, located in river Dalälven and to the north (asterisk), and to the south of the same river (empty square).

2.2 Long records

There are many stations with long records, still in operation, in Sweden. Some of the long series were described in more detail by Melin (1955). Three discharge records are of outstanding length: Göta Älv at the outlet of the largest lake in Sweden (Vänern), Motala Ström at the outlet of the second largest lake (Vättern) and the station Fäggeby which covers the main part of the basin of the river Dalälven. Daily values from these three series are shown in Figure 2.2.1. The floods in Göta Älv and Motala Ström appear larger in the last part of the period. This is, at least in the lake Vänern, primarily an effect of the regulation, which started around 1940 in the two basins. A high discharge is prescribed at high water levels. The increase in flood peaks is not reflected in any increase in annual runoff (cf. Jutman, 1991).

Relatively long records also exist for some of the stations where flood problems occurred in the 1980-ies. To give a perspective to these events some of the stations are shown in Figure 2.2.2. It is only in Voxnan, which is regulated and has a short record, that the 1980-ies stand out from the rest of the period. The figure gives an impression of floods sometimes occurring in a sequence, so that a high flood one year is often followed by another high flood the following year. An example of this is Voxnan the years 1985 and 1986.

Figures 2.2.3 to 2.2.5 show time series of annual, spring and autumn maximum floods for selected large river basins with relatively long records, irrespective of any recent flood problems. The figures contain both unregulated and regulated basins. No general tendency of increasing floods can be seen. To the contrary, a reduction of spring floods can be seen in the regulated rivers, e.g. Luleälven and Ångermanälven. The relatively large floods in these rivers in the 1980-ies were still modest in comparison with the flood magnitudes during unregulated conditions.

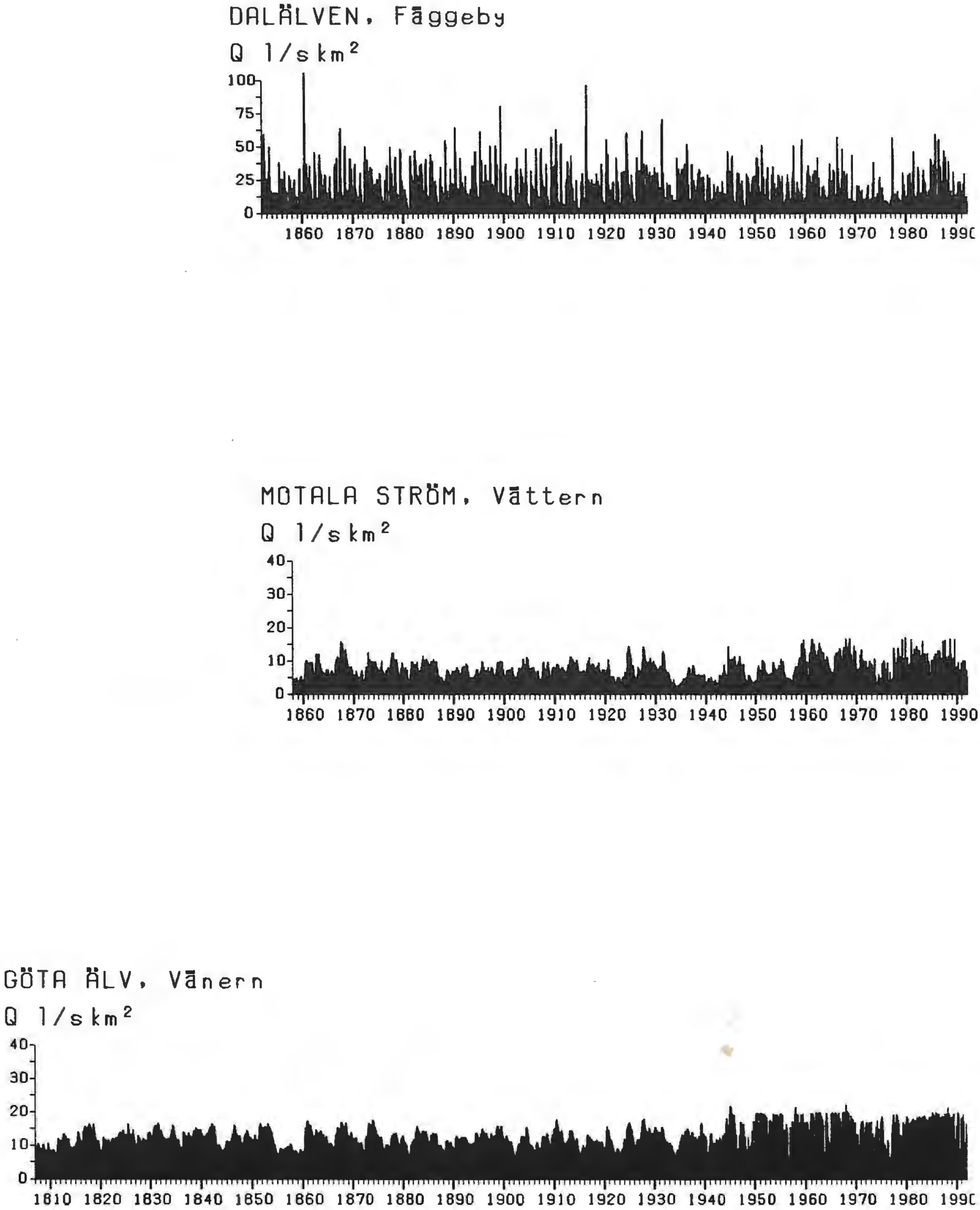


Figure 2.2.1. *Three discharge records of outstanding length in Sweden: Dalälven at Fäggeby (25 037 km², regulated from 1920) Motala ström at Vättern (6 359 km², regulated from 1940) and Göta Älv at Vänern (46 830 km², regulated from 1938). The figure shows daily values, but drawn with a much thicker line.*

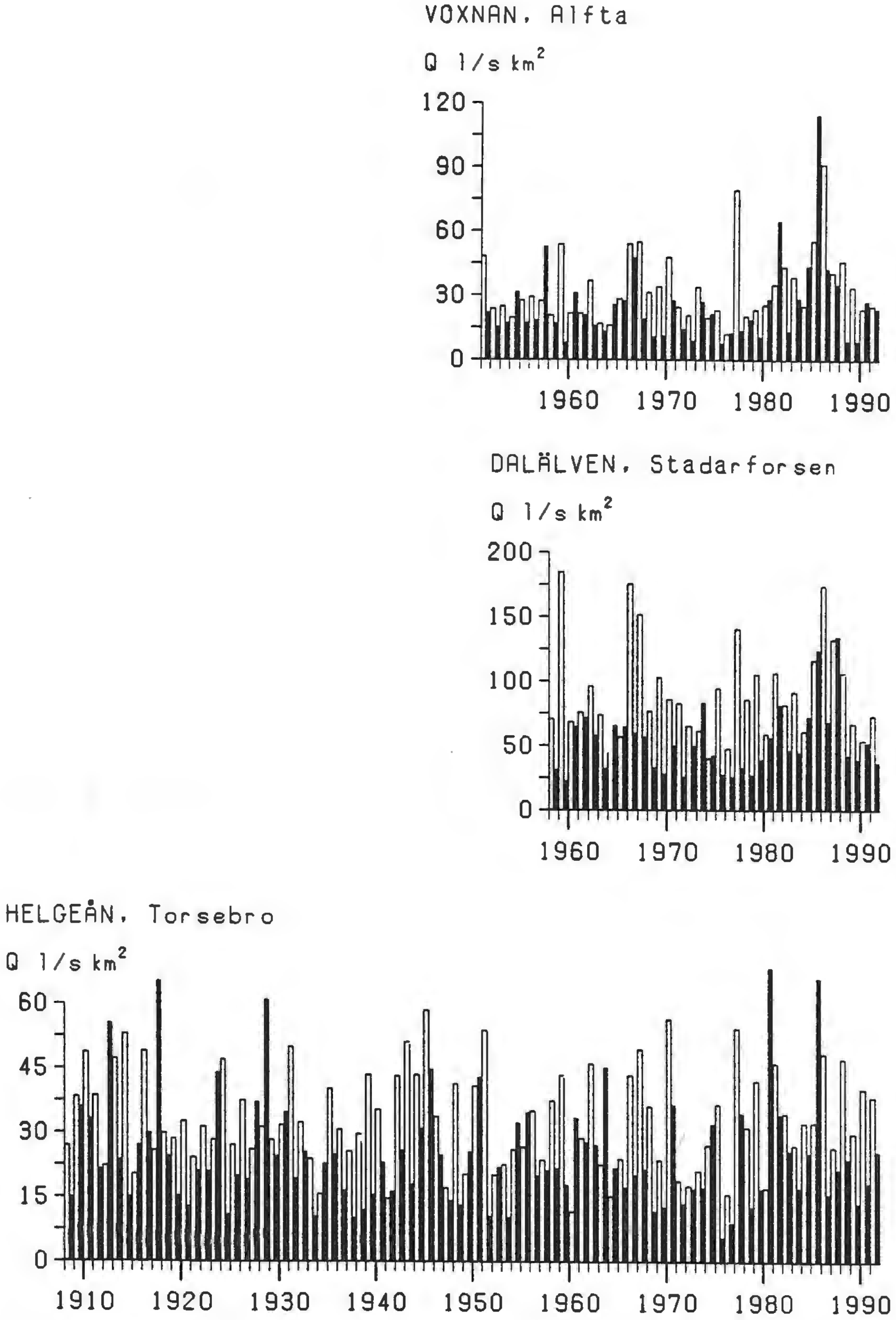


Figure 2.2.2. *Examples of maximum spring and autumn floods from relatively long records in rivers where high floods occurred in the 1980-ies. Alfta (3 140 km^2) Stadarforsen (4 506 km^2) and Torsebro (3 676 km^2). Voxnan is affected by regulation upstream of the station, whereas the other two rivers are almost unaffected. An unfilled bar shows the spring maximum (here 1 January to 30 June) and a filled bar shows the autumn maximum (here 1 July to 31 December).*

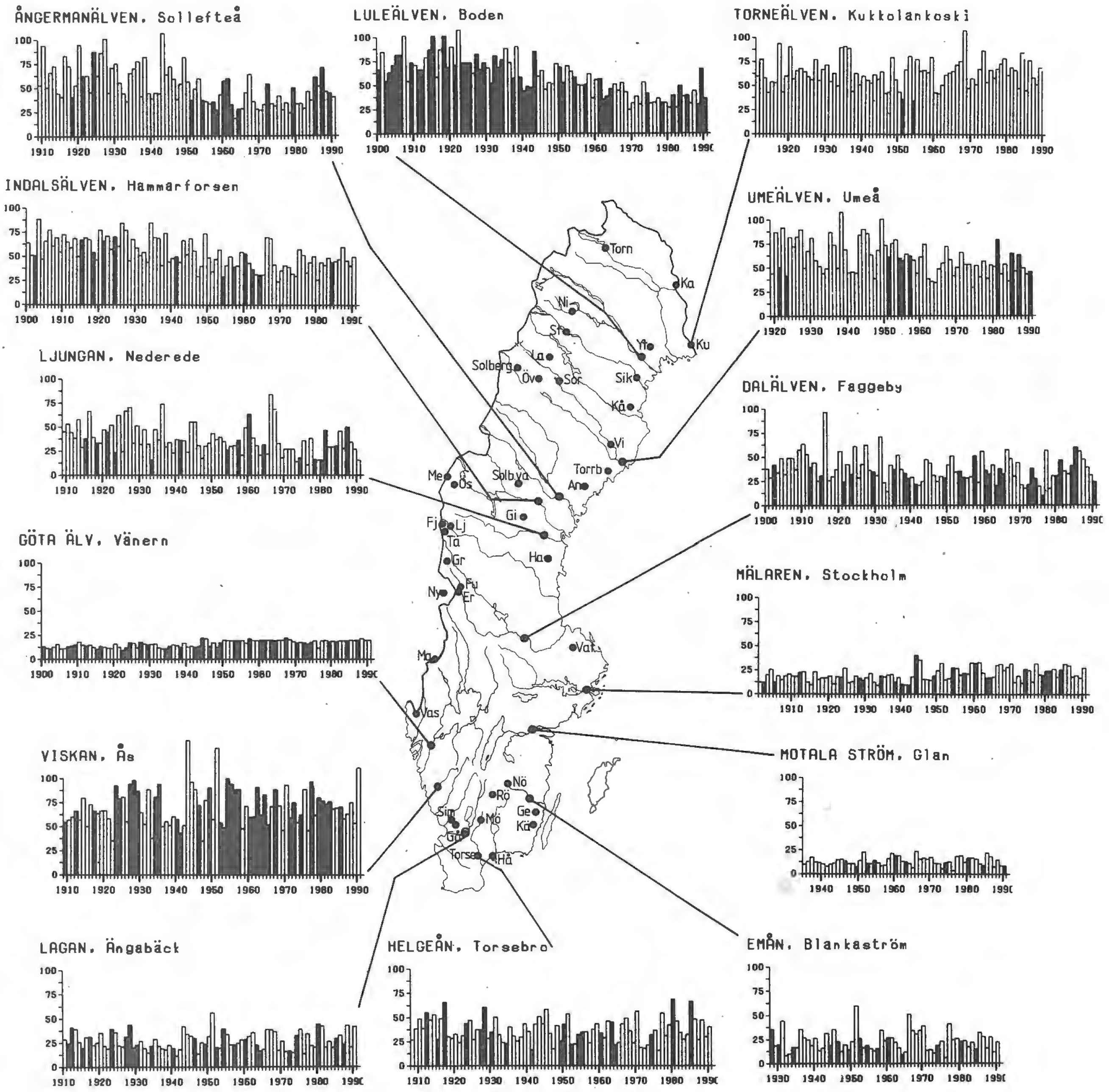


Figure 2.2.3. *The highest recorded runoff (l/s km^2) for each year for selected large river basins. An unfilled bar denotes that the flood occurred before 1 July, and a filled bar denotes that the flood occurred 1 July or later. Note that also regulated periods are included.*

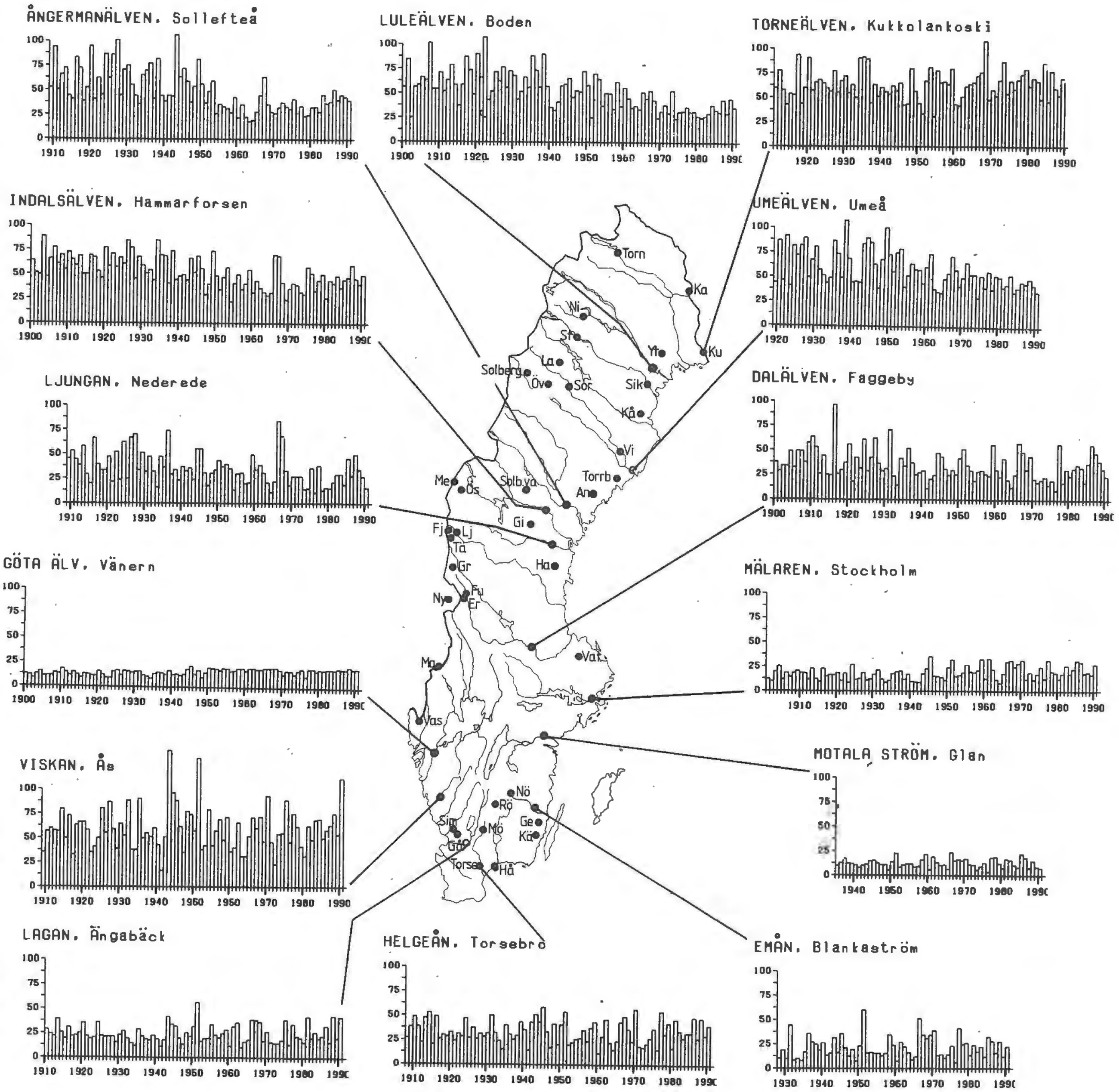


Figure 2.2.4. The highest recorded runoff (l/s km²) each spring (here before 1 July) for selected large river basins. Note that also regulated periods are included.

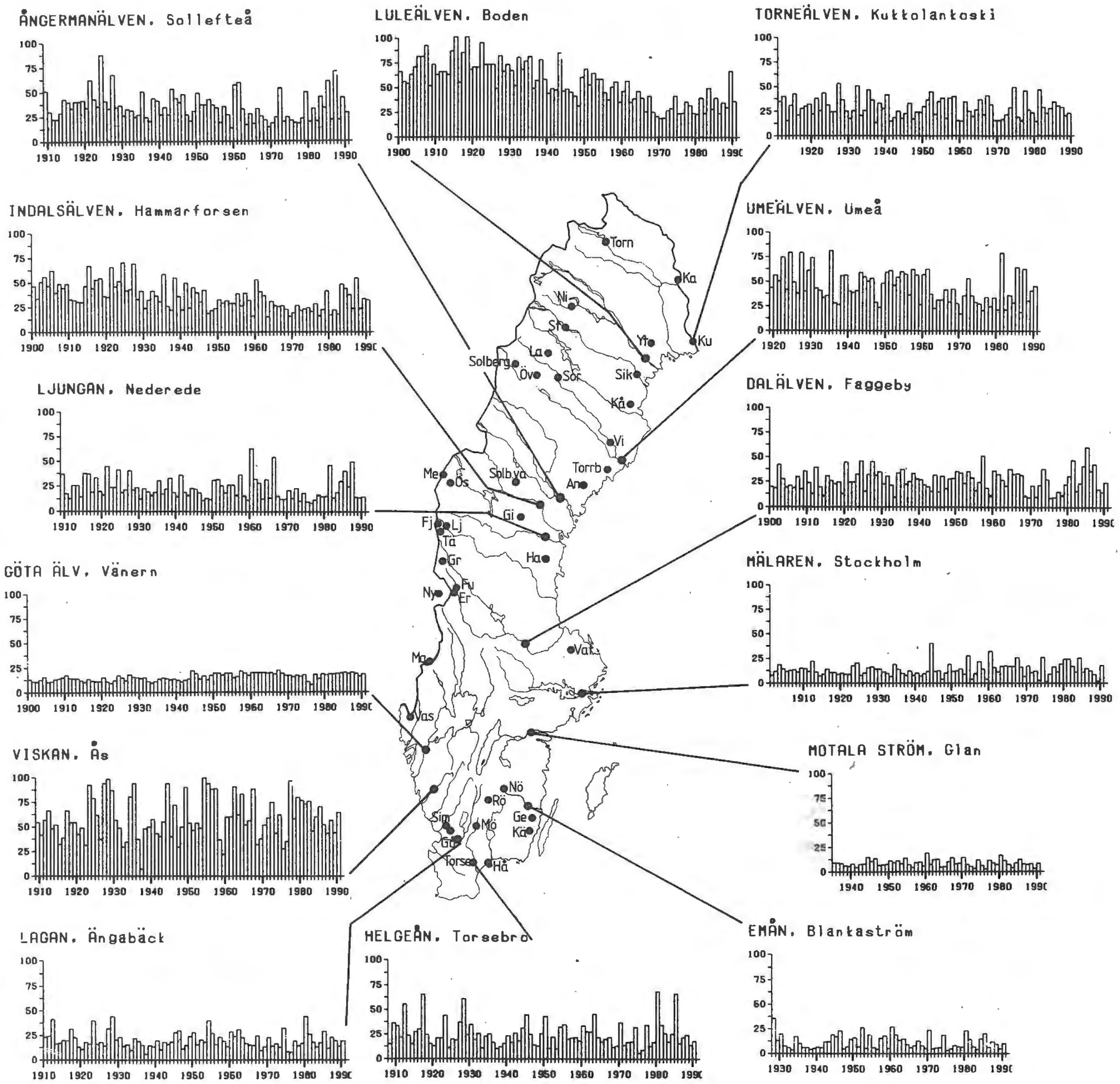


Figure 2.2.5. The highest recorded runoff (l/s km²) each autumn (here after 1 July) for selected large river basins. Note that also regulated periods are included.

2.3 Seasonal distribution of floods

The time of the year for floods in different parts of the country was illustrated by plotting the largest recorded discharge for each day of the year for a number of selected stations (Figures 2.3.1 and 2.3.2). The figures show that spring floods dominate most of the country, except in the far south, where winter floods also occur. They also show that there is a close relation between the time distribution of the average discharge and the extremes. It is therefore likely that the most extreme floods occur in the season with the highest average discharge, at least for unregulated basins. Most of Sweden has the most intense precipitation in summer, with the highest values in July and August (see e.g. Vedin and Eriksson, 1988). The intense precipitation is, however, not often reflected in extreme floods during this time of the year, because of the flood moderating influence of a soil moisture deficit built up by summer evapotranspiration (see e.g., Brandt et al., 1987). Convective rainfall may nevertheless be the cause of the highest floods in very small basins and urban areas.

Figure 2.3.3 shows an increase in runoff in the 1980-ies as compared to that of the 1970-ies. The increase is distributed over the whole year. A longer time perspective is given in Figure 2.3.4, where the periods 1931-60 and 1961-90 are compared. Thirty years is the standard length of a climatological normal period. An increase in spring floods can be noted in some basins, but the differences are in general small.

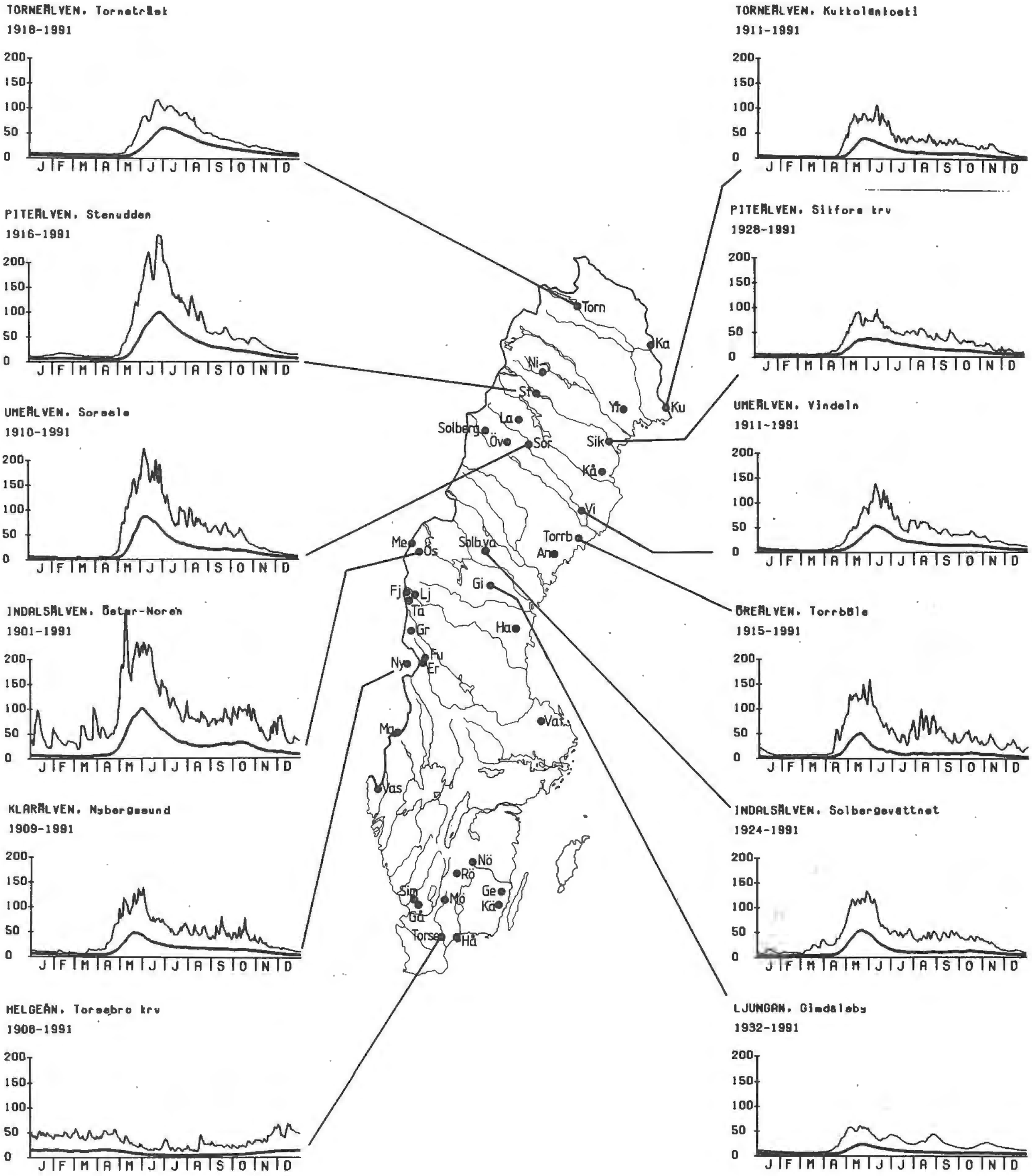


Figure 2.3.1. The highest (thin line) and average (thick line) recorded runoff in l/s km² for each day of the year for selected unregulated stations with a drainage basin larger than 2 000 km².

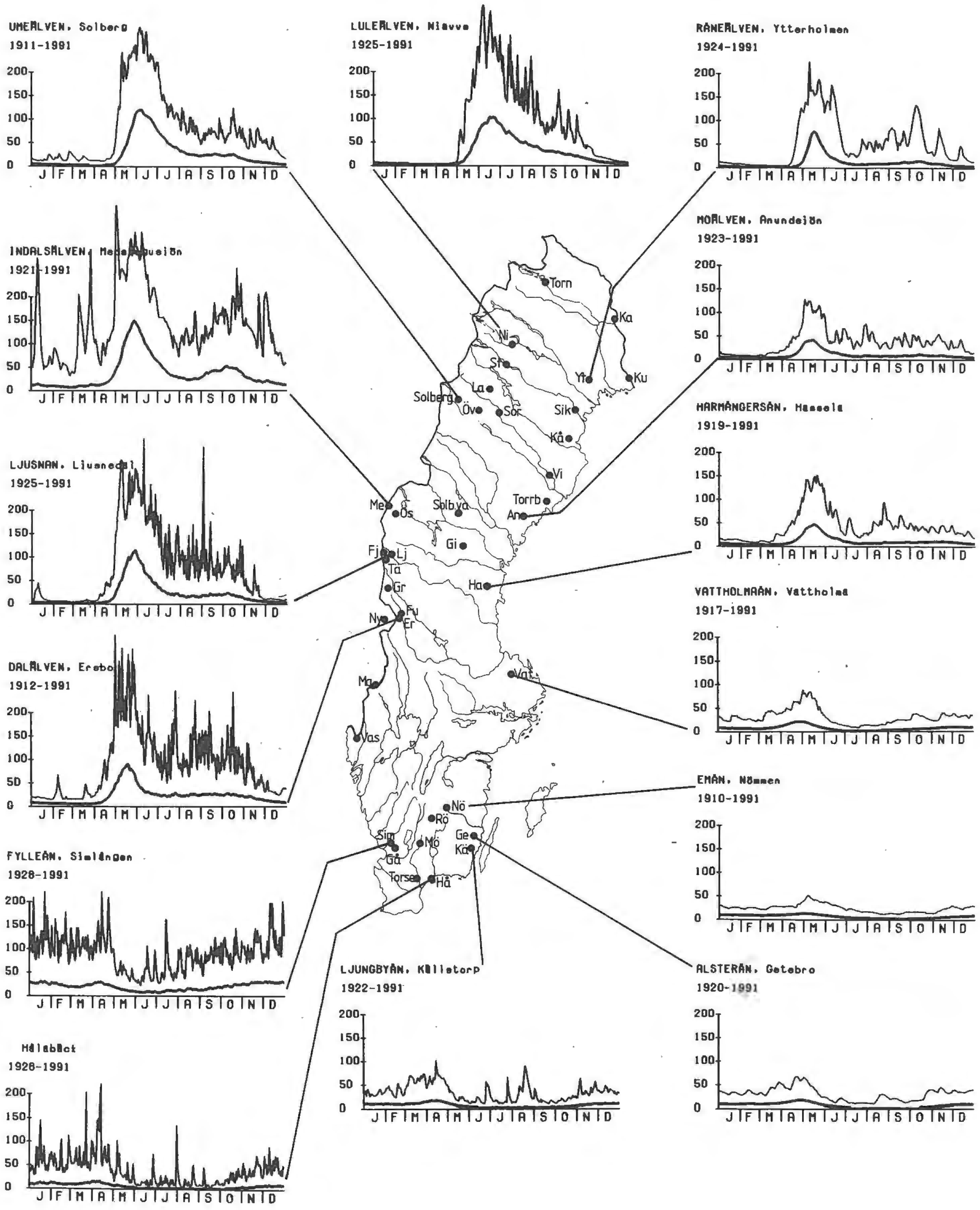


Figure 2.3.2. The highest (thin line) and average (thick line) recorded runoff in l/s km² for each day of the year for selected unregulated stations with a drainage basin smaller than 2 000 km².

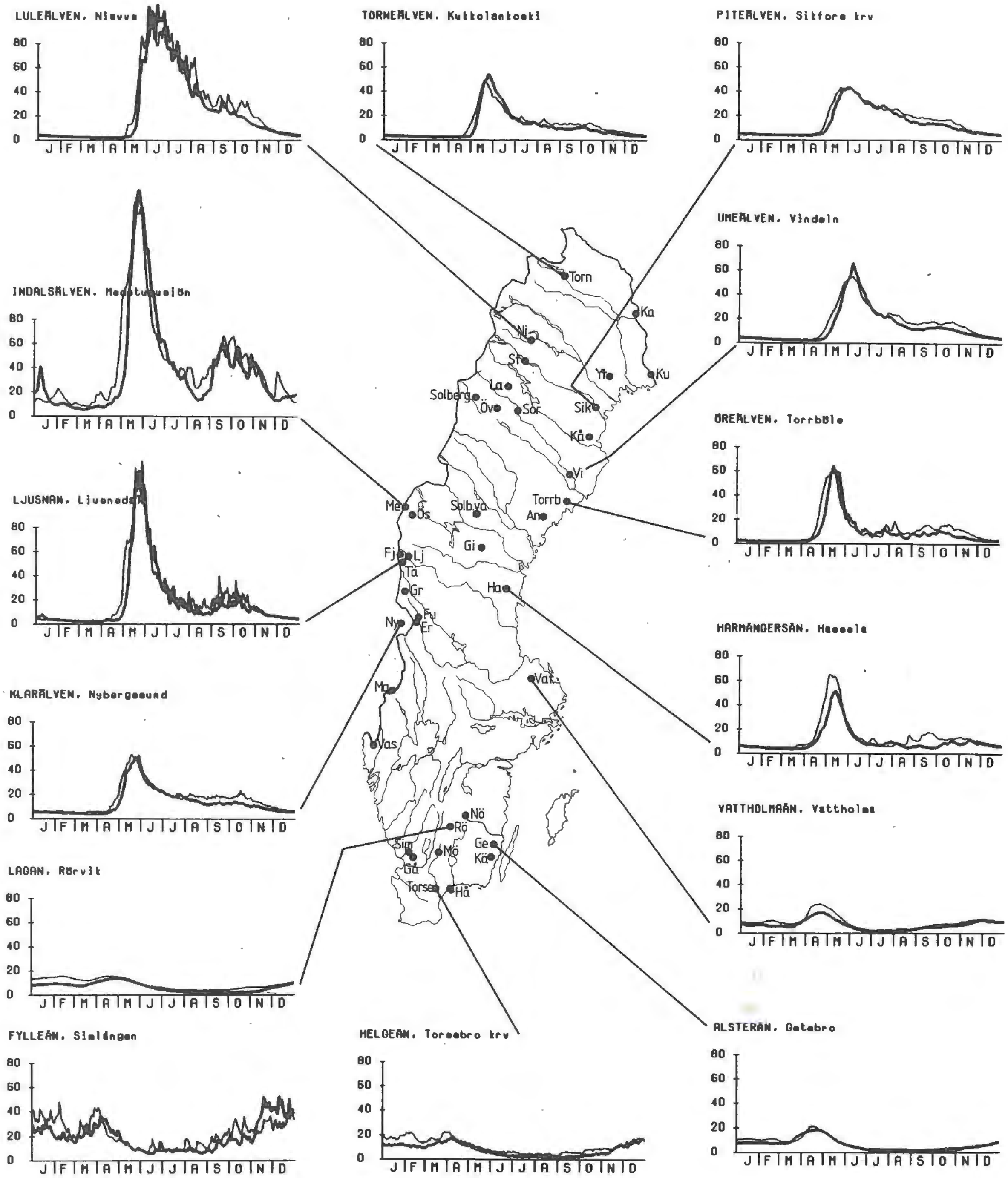


Figure 2.3.3. The average recorded runoff (l/s km^2) for each day of the year for selected unregulated stations, 1971 - 1980 (thick line) and 1981 - 1990 (thin line).

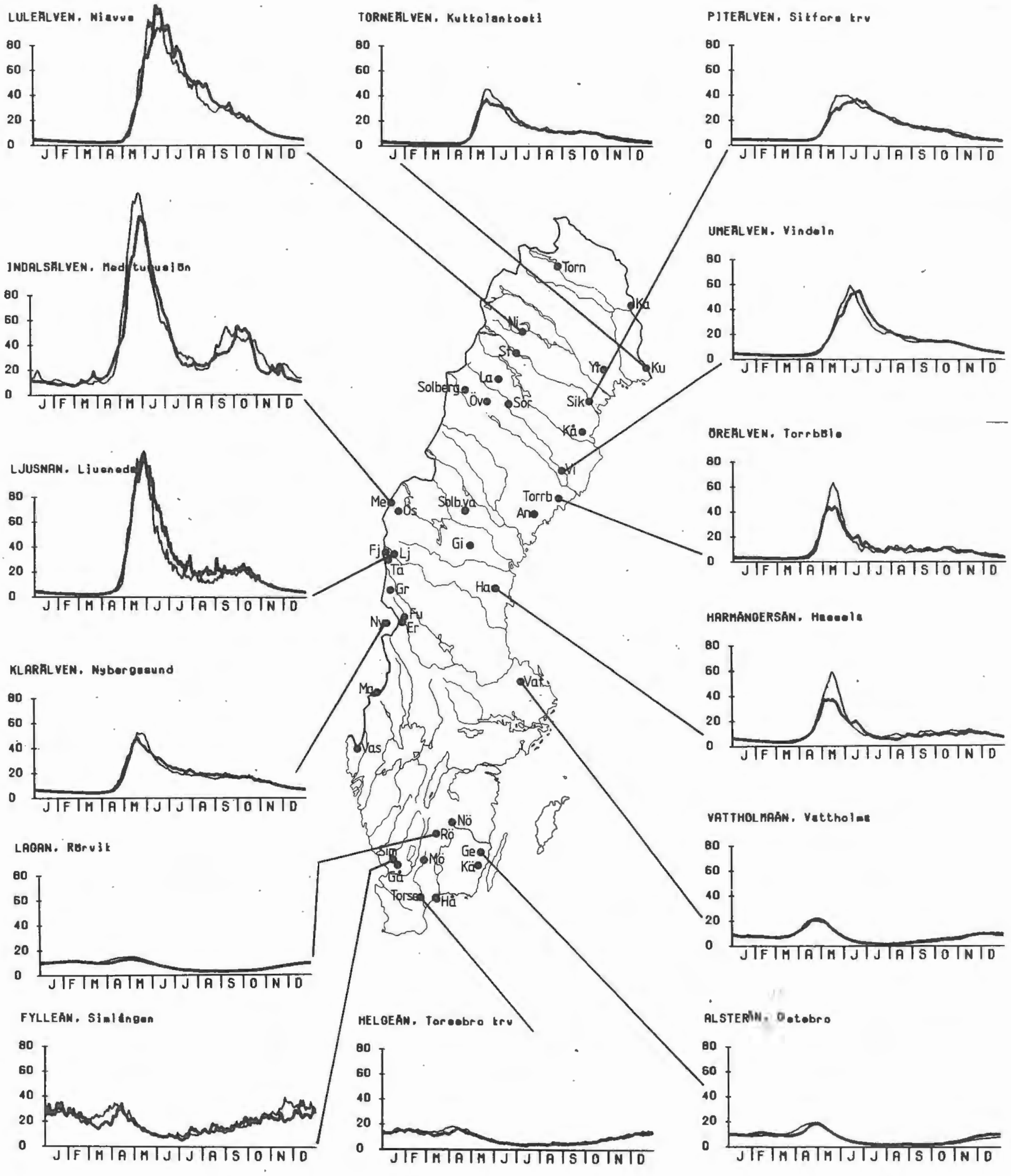


Figure 2.3.4. The average recorded runoff (l/s km²) for each day of the year for selected unregulated stations 1931 - 1960 (thick line) and 1961 - 1990 (thin line).

2.4 Effects of regulation

It was noted above that the flood peaks in Lake Vänern have been increased slightly by the regulation. This is, however, not the typical situation. Most of the rivers in the north of Sweden are regulated for hydropower generation. The reservoir system was mostly developed until about 1980. After that, there has been relatively little extension as far as increased regulation volumes is concerned. The reservoirs are emptied during the winter and refilled primarily by the snow melt, but also by rain floods. Many snowmelt-induced peaks thus occur while the reservoirs are still not full. A few examples of reconstructions of the natural flow, and the regulated flow as observed in some important rivers are given in Figures 2.4.1 - 2.4.3. The reduction of flood peaks is clear. All the annual maxima were lowered by the regulation, except for two years (1981 and 1985) in Umeälven. The flood moderating effect of regulation, particularly in the spring, can also further be seen in Figures 2.2.3 to 2.2.5, e.g., Luleälven and Umeälven.

Regulation is, however, only a redistribution of water in time, and at least the base flow is usually much higher than for natural conditions (see e.g. Figure 2.4.4). An example of a flood event where even the regulated discharge peak slightly exceeded the natural one is shown in Figure 2.4.5. This event, in August 1989 has been given considerable attention. It shows that certain flood peaks may even become larger in a regulated system, than in a natural system of flood moderating lakes if the flood occurs when all reservoirs are full. The consequences may then be considerable since floods are not expected to occur in regulated systems, and since the society has gradually adjusted to the new flood regime. Regulation does nevertheless reduce the magnitude of floods of moderate return periods.

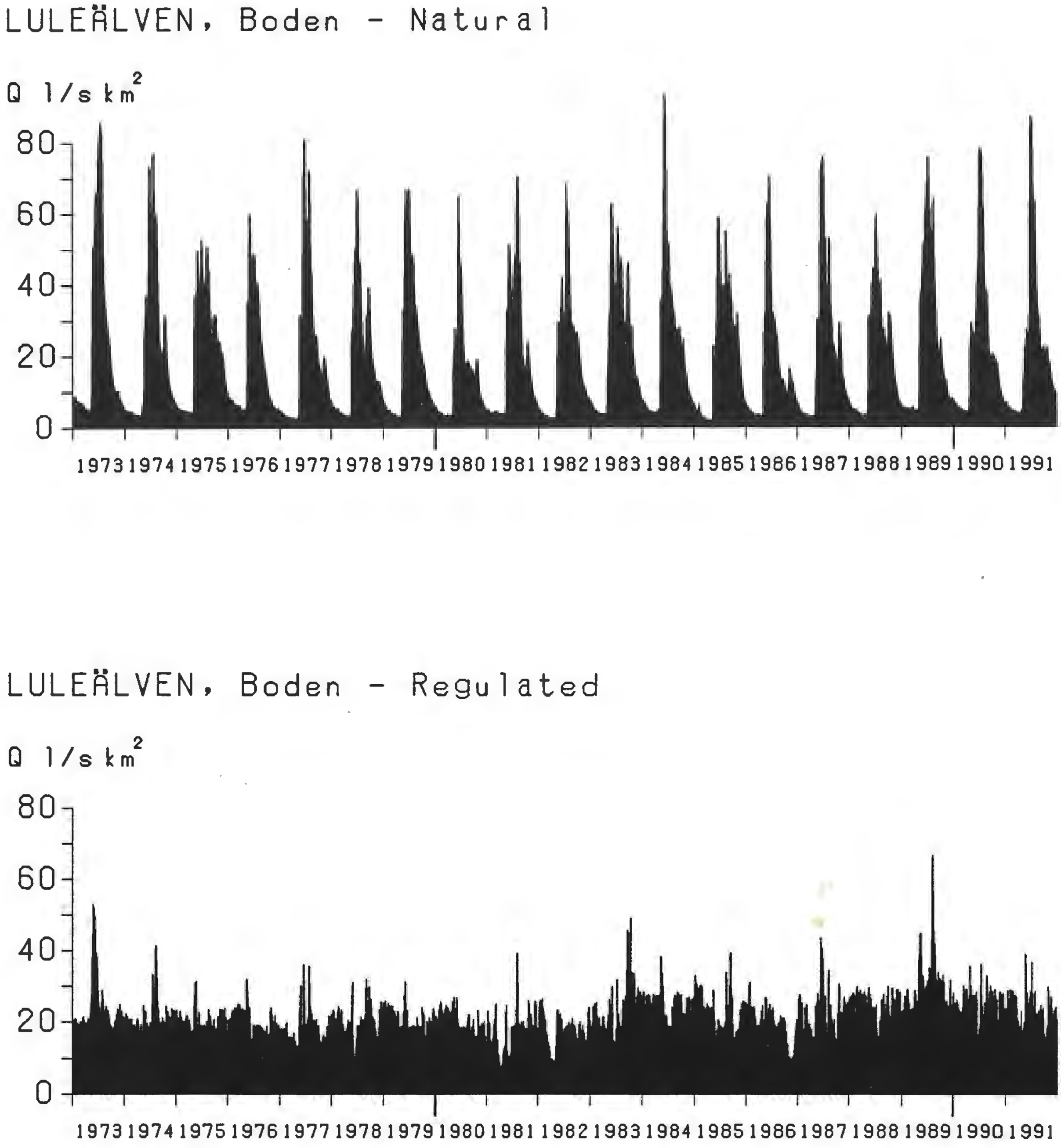


Figure 2.4.1. *Example of the influence of regulation on the flow in the River Luleälven at Boden (24 488 km^2) near the outlet into the Baltic sea. Above: Reconstructed natural. Below: Recorded regulated.*

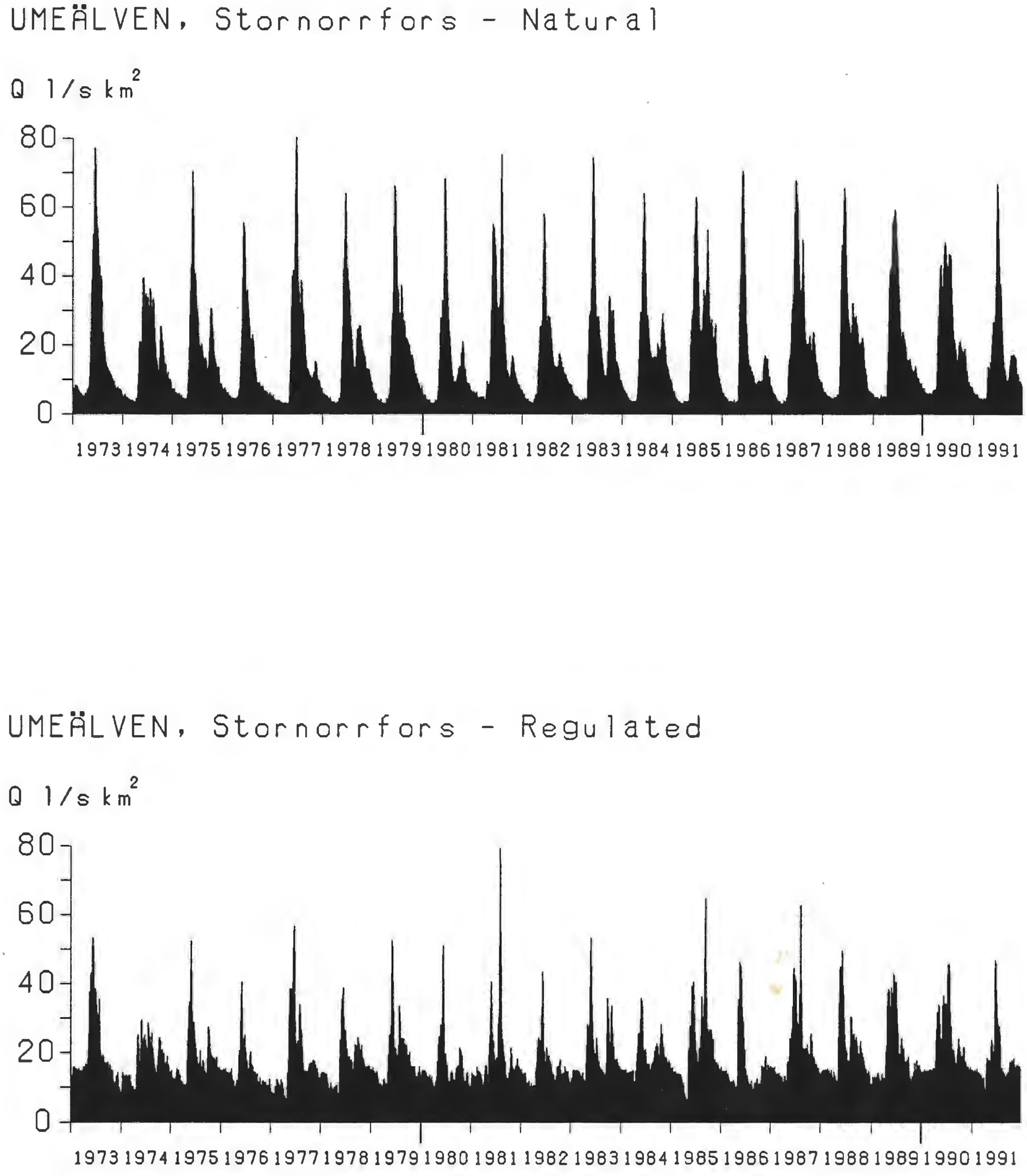


Figure 2.4.2. Example of the influence of regulation on the flow in the River Umeälven at Stornorrfors (26 449 km^2) near the outlet into the Baltic sea. Above: Reconstructed natural. Below: Recorded regulated.

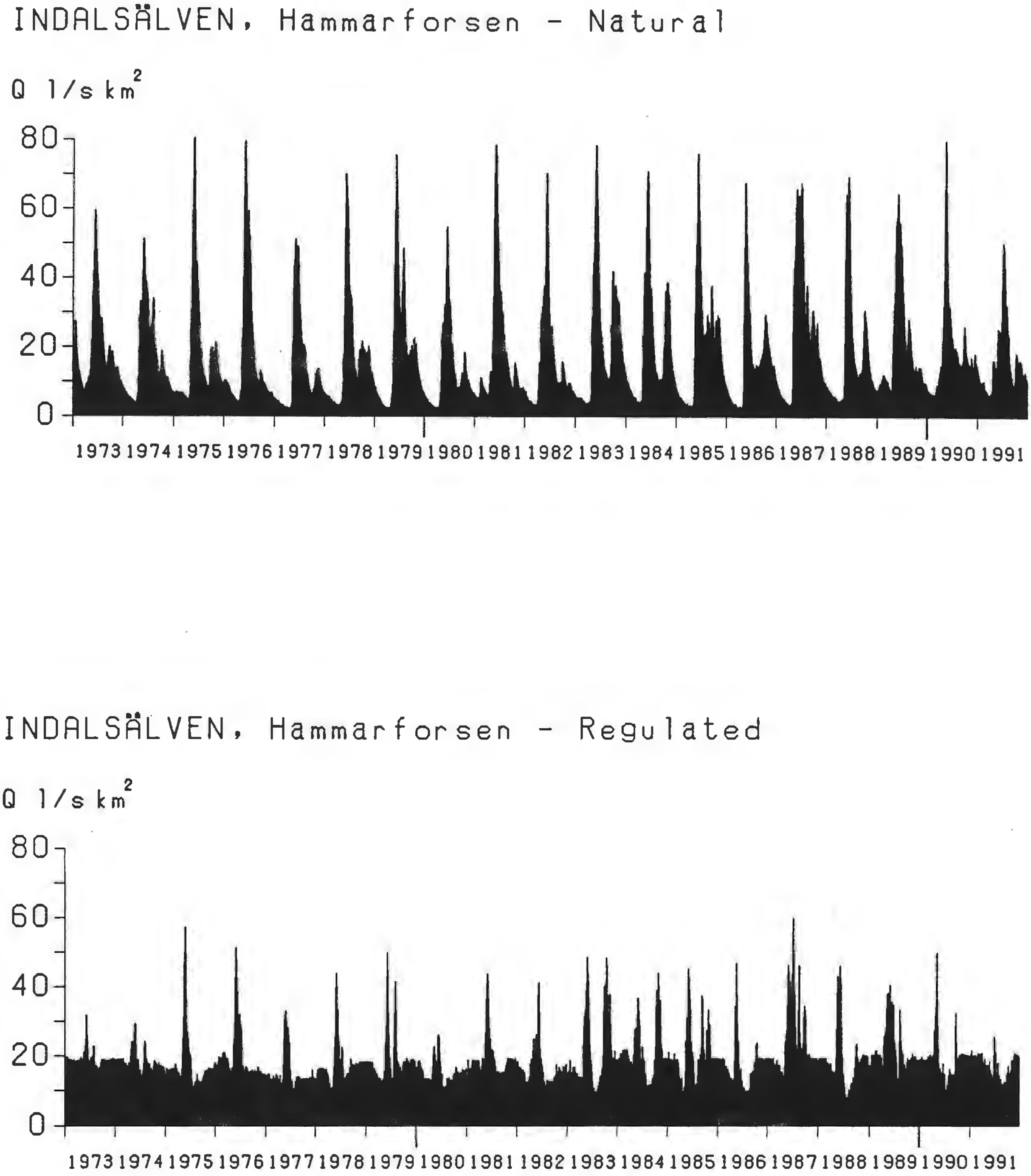


Figure 2.4.3. Example of the influence of regulation on the flow in the River Indalsälven at Hammarforsen (23 839 km²) near the outlet into the Baltic sea. Above: Reconstructed natural. Below: Recorded regulated.

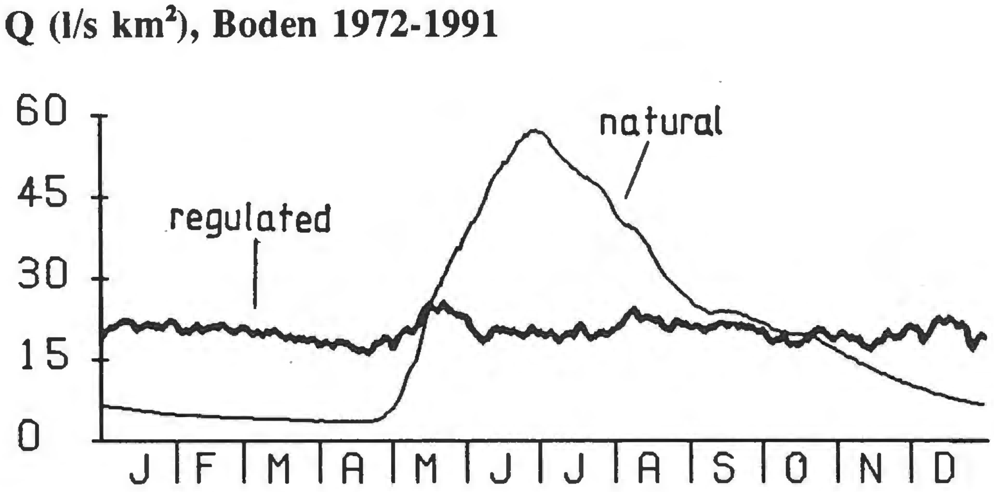


Figure 2.4.4. *Illustration of the redistribution of water in the River Luleälven. Daily mean values of the flow in l/s km² for the period 1972-1991 are presented. Thin curve: Reconstructed natural. Thick curve: Recorded regulated.*

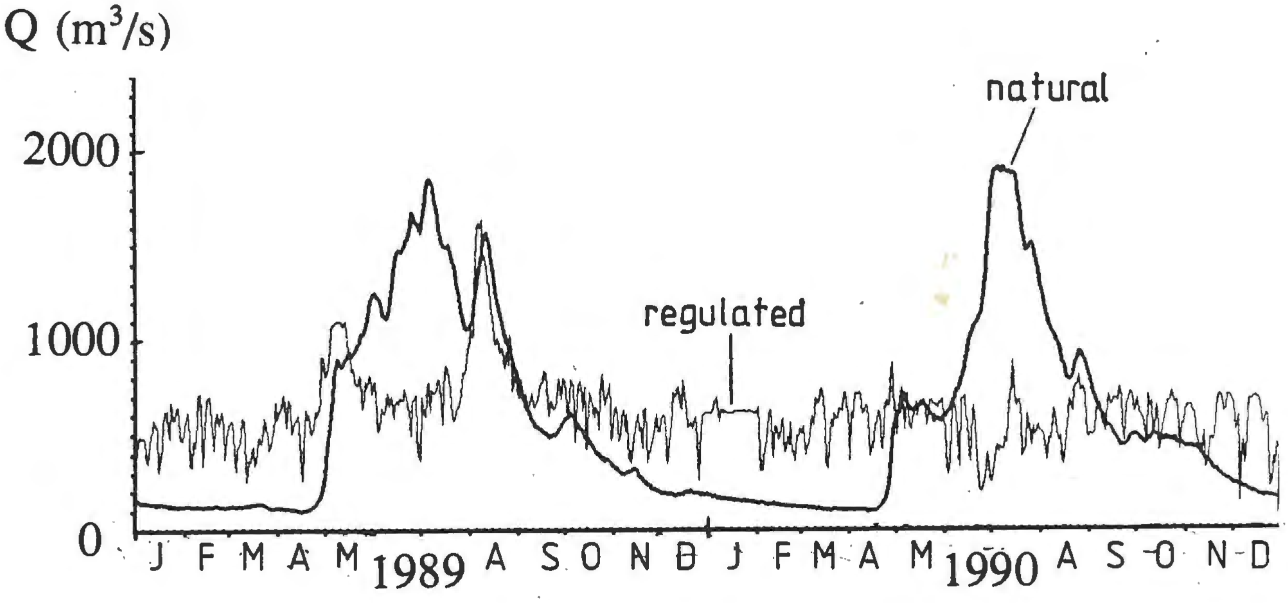


Figure 2.4.5. *Example of the influence of regulation on the flow in the River Luleälven at Boden (24 488 km²) near the outlet into the Baltic Sea. Thick curve: Reconstructed natural. Thin curve: Recorded regulated.*

3. DATA FOR STATISTICAL ANALYSIS

Stations with at least 60 years of continuous observations were chosen for the trend and frequency analyses. Two of the stations are Norwegian and one is Finnish, but located in basins partly in Sweden. Only stations which are still in operation and not affected by regulation were selected. The frequency analysis was further restricted to the years 1932 - 1991 in order to use a common time period. This excluded the earliest period where the observations may be of lower quality. The selected series should include a minimum of values calculated by interpolation or relations with other stations.

In the southern part of the country, all series were divided into hydrological years to avoid a false autocorrelation between years because of floods in December. The beginning of the hydrological year was for convenience set at a date when low flow usually prevails. 39 records from different parts of Sweden were selected, covering a total of 2885 station years (Table 3.1). The series were divided into spring - primarily snowmelt-induced floods - and non spring periods primarily floods due to rainfall - (referred to as autumn in the text). Winter floods sometimes occur in southern Sweden due to rainfall, and January and February were therefore considered as a non spring period. The largest flood during each year was extracted, together with the largest floods each spring and autumn. The geographical location of the stations is shown in Figure 3.1 and plots of the data are found in the appendix.

Daily flow records were used, i.e., not instantaneous maxima. Before 1970 almost all readings were made manually, about once a day. Automatic recording has gradually been introduced, and today practically all stations are equipped with automatic gauges, giving daily mean flow records. This change causes an inconsistency in the data, which has not been taken into account in this study. Another problem in any analysis of extreme floods is that these floods are almost always estimated by extrapolation of the rating curve. It was outside of the scope of this study to take this uncertainty into account, although methods for studying this effect have been suggested by for example Rosso (1985).

Table 3.1. Data series used in the statistical analysis.

Basin	River No.	Station No.	Area (km^2)	Lake %	Years	Spring	Start of hydrological year
Torneträsk	1	50 145	3 294	13.3	1918-1991	Jan-Jun	1 Jan
Kukkolankoski	1	16 722	34 063	4.7	1911-1991	Jan-Jun	1 Jan
Kallio	1	50 148	14 340	3.2	1911-1991	Jan-Jun	1 Jan
Ytterholmen	7	1 123	1 004	2.6	1924-1991	Jan-Jun	1 Jan
Niavve	9	591	1 700	4.5	1925-1991	Jan-Jun	1 Jan
Stenudden	13	37	2 440	11.1	1916-1991	Jan-Jun	1 Jan
Sikfors krv	13	1 788	10 797	6.8	1928-1991	Jan-Jun	1 Jan
Kåge	19	50 128	897	2.5	1924-1991	Jan-Jun	1 Jan
Solberg	28	436	1 067	5.5	1911-1991	Jan-Jun	1 Jan
Överstjuktan	28	50 130	407	9.6	1911-1991	Jan-Jun	1 Jan
Sorsele	28	50 131	6 110	4.1	1909-1991	Jan-Jun	1 Jan
Vindeln	28	50 023	11 898	5.2	1911-1991	Jan-Jun	1 Jan
Laisan	28	50 149	1 786	4.6	1910-1991	Jan-Jun	1 Jan
Torrböle	30	50 107	2 880	2.4	1915-1991	Jan-Jun	1 Jan
Anundsjön	36	50 027	1 449	4.0	1923-1991	Jan-Jun	1 Jan
Öster-Noren	40	50 058	2 389	7.0	1901-1991	Jan-Jun	1 Jan
Medstugusjön	40	50 059	219	10.8	1921-1991	Jan-Jun	1 Jan
Solbergsvattnet	40	50 068	2 463	5.2	1924-1991	Jan-Jun	1 Jan
Gimdalsby	42	97	2 178	12.8	1932-1991	Jan-Jun	1 Jan
Hassela	44	50 109	658	3.6	1919-1991	Jan-Jun	1 Jan
Ljusnedal	48	1 169	340	0.9	1925-1991	Jan-Jun	1 Jan
Fjällnäs	48	1 183	109	6.1	1928-1991	Jan-Jun	1 Jan
Tänndalen	48	1 223	233	5.6	1929-1991	Jan-Jun	1 Jan
Grötsjön	53	1 171	559	5.7	1928-1991	Jan-Jun	1 Jan
Ersbo	53	654	1 101	0.5	1912-1991	Jan-Jun	1 Jan
Fulunäs	53	655	882	2.6	1913-1991	Jan-Jun	1 Jan
Vattholma	61	50 110	284	4.8	1917-1991	Mar-May	1 Aug
Nömmen	74	50 090	169	13.9	1910-1991	Mar-May	1 Aug
Getebro	75	855	1 345	6.5	1920-1991	Mar-May	1 Aug
Källstorp	77	50 091	344	1.3	1922-1991	Mar-May	1 Aug
Hålabäck	86/87	736	5	0.7	1928-1991	Mar-May	1 Aug
Möckeln	88	1 069	1 015	12.2	1922-1991	Mar-May	1 Aug
Torsebro krv	88	2 191	3 676	6.0	1908-1991	Mar-May	1 Aug
Rörvik	98	200	162	17.6	1907-1991	Mar-May	1 Aug
Simlången	100	50 097	262	5.3	1928-1991	Mar-May	1 Aug
Gårdsilt	100	1 207	55	1.5	1928-1991	Mar-May	1 Aug
Magnor	108	10 016	361	4.3	1912-1991	Mar-May	1 Aug
Nybergssund	108	10 014	4 420	9.4	1908-1991	Jan-Jun	1 Jan
Vassbotten	112	751	621	10.8	1914-1991	Mar-May	1 Aug

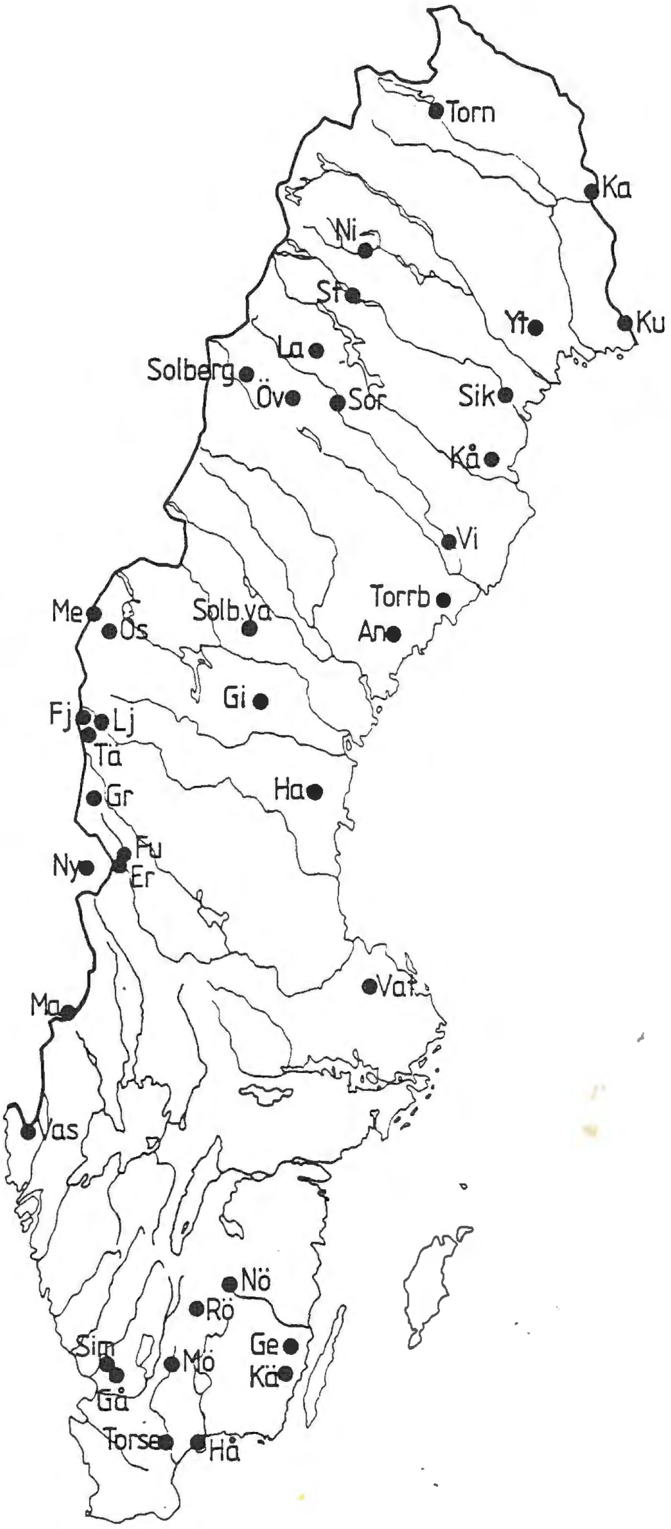


Figure 3.1. *Geographical location of the stations selected for statistical analysis.*

4. STATISTICAL METHODS

The statistical methods which were used are briefly described below. A more detailed description is given in the appendix. A confidence level of 95 % was used in all tests of significance. All calculations were made with time series of the highest flood peak each year, each spring or each autumn.

4.1 Trend analysis

The occurrence of floods in time and space was first illustrated by simple techniques. Time series of index floods were prepared, i.e. the floods were standardized by division with the mean high flood (MHQ). The average index-flood for a whole region was thereafter calculated and plotted. Another simple data check was to extract all occurrences of floods in the upper 25 % and 10 % respectively.

Trend analysis was thereafter performed for time series of annual and seasonal extremes at each station. In the British Flood Studies Report (NERC, 1975), a number of distribution free methods were used to test the randomness of series of annual maximum floods. In this study, two techniques for trend analysis were used: a distribution free test, and regression. The distribution free test is based on ranks and it is a modified form of Kendall's tau (Hirsch et al., 1982, and Hirsch and Slack, 1984). Another form of the same test is also described by Hansen (1971). An advantage of the distribution-free test is that no assumption is required about independent and normally distributed observations. The efficiency of the test is according to Conover (1980) comparable to that of Spearman's rank order test, which was used in the Flood Studies Report.

Trend analysis by regression, on the other hand, implies the assumption of a normal distribution (see e.g. Hansen, 1971). When the necessary requirements for regression are fulfilled, it is, however, a more powerful test. Linear regression for trend analysis was for example used by Gustard et al. (1989) for flood studies in the FREND project. The linear regression equation reads:

$$Q = a_1 + b_1 t \qquad (1)$$

where a_1 and b_1 are the regression parameters to be estimated.

A relative increase per time, i.e., a relative trend, was obtained by dividing b_1 by the mean value of Q for the period (i.e. MHQ). This was done in order to allow a comparison of the results between different basins. The significance of the trend can readily be tested (see e.g. Yevjevich, 1972 or Hansen, 1971). The test, however, depends on the assumption of normally distributed data.

The lognormal distribution is usually preferred to the normal distribution in analysis of hydrological extreme events (see, for example, Cunnane, 1989 or Gottschalk, 1983). Logarithmic regression was made as a complement to the linear one, in order to study the sensitivity to the assumption of normally distributed data. Such logarithmic transformations are quite common in hydrology and in time series analysis in general (see e.g. Bras and Rodríguez, 1985, and Box and Jenkins, 1976). The logarithmic regression equation then reads:

$$lnQ = a_2+b_2t \tag{2}$$

The slope parameter b_2 is in this case directly the relative increase per time, i.e., the relative trend, since:

$$dQ/Q = b_2dt \tag{3}$$

The relative trends by the two methods (linear and logarithmic) are essentially equal, although different results could be expected concerning the significance of the trends.

In addition to the above mentioned trend tests, the ordinary t-test (e.g. Hansen, 1971) was used to examine whether the 1980-ies had significantly higher floods than the total preceding period. Logarithmic flood data were then used to reduce non normality.

4.2 Time series analysis

The discharge in a river is correlated from one day to another, due to storage of water in the basin. Large river basins and basins with large lakes have a long memory, maybe many months. There could possibly even be a correlation between the flood peak from one year to another, due to the large volumes of water which are stored in the basin. Furthermore, in hydrographs it is sometimes seen that a large flood one year is followed by another large flood the following year. Examples of this can be seen in Figure 2.2.2. The assumption of independence between flood peaks is crucial in frequency analysis. Time series analysis was carried out in order to investigate if any autocorrelation could be found in time series of annual peaks.

A non parametric test was used in addition to estimating the autocorrelation function, as a search for possible dependence in time. The non parametric test is known as the runs-test (e.g. Hansen, 1971 or Wonnacott and Wonnacott, 1984), and is used for testing if the persistence differs significantly from that of a purely random sequence. In the runs-test, the original time series Q_t of n observations was converted into a new sequence where each observation above the median value was given a plus (+) and each observation below the median was given a minus (-). The number of runs, A, was counted. A run is here defined as a subsequence of identical observations (+) or (-). If, as in this case, the two signs have equal probability, then the mean and variance of A are known (see eg. Hansen, 1971 or Wonnacott and Wonnacott, 1984), and can be used for a test of independence. A persistence, pers, was estimated as:

$$pers = \frac{n-A}{n-1} \tag{4}$$

The regression trend estimated above was temporarily removed for the computation of the autocorrelation and periodogram. The autocorrelation and its significance was estimated as given by Box and Jenkins (1979).

Periodic fluctuations were searched for by classical periodogram analysis. The periodogram was computed by two methods: Fourier analysis of the original time series, and by Fourier transformation of the estimated autocorrelation function. A significance test (Hansen, 1971) was used for the first method. Hansen attributes the test to Fischer (1950). The two methods gave similar results and to avoid redundancy only results by the first method were included in this report.

Kite (1988) stated that the logarithms of hydrologic events have sometimes been found to be more correlated than the recorded events. The time series analysis was therefore carried out with both the recorded data and the logarithms.

4.3. Frequency analysis

4.3.1 Choice of distribution

The objective of a frequency analysis is to estimate the probability of future floods based on the magnitude of observed floods rather than on the physical processes which produced them. The normal assumptions in a frequency analysis are that the observations are a set of independent observations from one probability distribution with constant parameters in time. The probability P that a certain flood, Q_T, will be exceeded during any year, is given by the probability function $F(Q_T)$:

$$P = 1 - F(Q_T) \tag{5}$$

The inverted value of the probability has the dimension time, and is called the return period, T:

$$T = 1/P \tag{6}$$

In Sweden, it is clear that the assumption of one population of floods may be questioned, as most of the country is affected by both snowmelt floods and floods caused by rainfall. In a long time perspective, the condition of constant parameters can also be questioned since the climate is known to have changed historically.

Frequency analysis is met by considerable skepticism by many hydrologists (see e.g. Klemeš, 1986), and according to Cunnnane (1989) some also believe that it underestimates the risk of very large floods. The debate is not a new one. In Sweden, for example, an interesting discussion on how to estimate the probability of extreme floods followed a high flood in the river Umeälven in early june 1938 (Svenska Kraftverksföreningen, 1939). More recently, the Swedish Committee for design flood determination (Flödeskommittén, 1990 and Bergström et al., 1992) ruled out the use of frequency analysis for the design of high hazard dams. For low hazard dams, where a failure would not cause risk for human lives, the Committee allowed frequency analysis for computation of a design flood with a return period of at least 100 years, as one alternative. No guidance on how to compute this design flood was given. Frequency analysis was one of the approaches used for assessing the return periods of the proposed design floods (Flödeskommittén, 1990 and Bergström et al., 1989). The design floods were found to, on average, stay well above the flood with a return period of 10 000 years, but the results differed from one distribution function to another.

There are numerous methods for flood frequency analysis, and the literature on the subject abounds. The number of possible candidates increases continuously. A recent overview was given by Cunnane (1989). However, there is no general consensus on which methods to choose. This is frustrating, since it in practice is often necessary to resort to frequency analysis. The fitness of different distribution functions is often studied by e.g. the χ^2-test, the Kolmogorov-Smirnov test or moment ratio diagrams. They cover the whole probability range, and not only the upper extreme, and their value is therefore sometimes questioned by hydrologists (see e.g. Haan, 1977). Many comparisons have also been based on Monte Carlo simulations (e.g. Lettenmaier and Potter, 1985, and Hosking et al., 1985). These studies, however, suffer from the necessary assumption of a parent distribution. The problem of choosing a method is a classical but still relevant problem. For example Haktamir (1992) states that "the question of better fit among these countless models is always a fresh one".

Studies have been made in many countries on the fitness of different distributions for flood frequency analysis. Among the recommended distributions are: Log Pearson type III in the USA (Benson, 1968) and the General Extreme Value distribution (GEV) in the United Kingdom (NERC, 1975). The Gumbel (Extreme value type I) and the Log normal distributions with two parameters are, however, in extensive use, and the recommendations for choice of distribution function are often subjective (Cunnane, 1989). In Sweden there is no officially recommended method for flood frequency analysis. Gottschalk (1983) studied various distributions, using the χ^2 goodness of fit test. He found no decisive difference in the fit of the distributions, with the exception of the normal distribution, which, as expected, was not suitable for flood frequency analyses. Three parameter distributions were no better than those with two parameters.

An objection to the use of frequency analysis is that it is often based on short records, compared to the return periods of interest. A natural remedy would be to add information from surrounding areas, i.e., to substitute time for space. This is the rationale for a regional frequency analysis, and regional analyses are often said to be better than single-site analyses (see e.g. Cunnane, 1989). The substitution of time for space, however, usually means using the same years again, only from another site, since the observations are usually parallel in time. Two seemingly contradicting factors need to be reconciled, namely homogeneity and independence. Some different possibilities for establishing homogeneous regions are to identify geographical regions, statistically similar regions or physiographically similar groups (e.g. Cunnane, 1989). Just as with the choice of distribution function, there is no general consensus on how to establish homogeneous regions. According to Gottschalk (1985), Sweden is too heterogeneous to be treated as one homogeneous region. On the other hand, Gustard et al. (1989) found that Sweden was less heterogeneous than most other countries in Europe.

The most obvious difference between basins is usually accounted for by normalizing the flood data by division with the mean value (MHQ). This gives an index-flood, and the method has been in extensive use during the last thirty years. In the index-flood approach it is assumed that the first moment is best estimated by site-specific data alone, whereas higher moments should be estimated regionally. It is hence assumed that the sampling variability for short samples is larger than the real differences within a region. The division into statistically similar regions, is, nevertheless sometimes based on site specific sample statistics. It is thus to some extent subject to the same weakness as single-site methods.

The tested methods are described and references given in the appendix. Kite (1988) gives a very detailed description of many of the methods. The following D/E-combinations (distribution and estimation method) were tested in this study:

Table 4.3.1. Combinations of distribution and estimation methods in the test, and their abbreviations:

Single-site
1) Normal / Moments (SNOR-MOM)
2) Gumbel / Moments (SGUM-MOM)
3) Gumbel / Probability weighted moments (SGUM-PWM)
4) Gumbel / Maximum likelihood (SGUM-ML)
5) Log normal 2 / Moments (SLN2-MOM)
6) Two parameter Gamma / Moments (SGAM-MOM)
7) Exponential-peak over threshold / Moments (SEXP-MOM)
8) General Extreme Value / Probability weighted moments (SGEV-PWM)
9) Pearson type III / Moments (SPE3-MOM)
10) Log Pearson type III / Moments (SLP3-MOM)
11) Two components Gumbel / Moments (STWO-MOM)

Regional
12) Gumbel / Moments (RGUM-MOM)
13) General Extreme Value / Probability weighted moments (RGEV-PWM)
14) Log Pearson type III with regional skewness / Moments (RLP3-MOM)
15) Station year / Plotting position (RSTY-PPO)
16) Effective Station year / Plotting position (REFF-PPO)

Sample statistics; mean ($\overline{x}$), coefficient of variation (CV), and coefficient of skewness (CS) were computed. The skewness coefficient was computed both for the original flood data and for the logarithms. Ratios between the highest recorded discharge (HHQ) and the average (MHQ) were computed together with the ratio between the highest and the second highest observations (SHQ). A test, which according to Cunnane (1989), is due to Hosking et al. (1985a) was used to test if the parameter k in the General Extreme Value distribution differed significantly from zero. For k = 0 the GEV distribution reduces to a Gumbel distribution. A negative value of k indicates that the distribution has a lower limit, whereas an upper limit is indicated by a positive k (e.g. Chow et al., 1988). This test was only applied to the complete record, i.e. all years in Table 3.1. In the split-sample test for goodness of fit, the GEV distribution was treated as a full three parameter distribution.

The regional method based on effective station years is based on estimation of the spatial correlation. It thus gives this value ($\bar{R}$) and the effective number of stations (N_E, see the appendix) as byproducts.

4.3.2 Split sample test and goodness of fit

The emphasis in this study was put on testing the predictive rather than descriptive ability, since the goal of a frequency analysis is normally to predict the magnitude of floods with a return period larger than the length of observations. A split-sample technique was used, with calibration on one part of the data and verification on another. Harlin (1992) used a similar approach when simulating extreme floods by a conceptual rainfall runoff model. He studied the performance of different model formulations by calibrating on moderate sized floods and checking the agreement on the largest floods in the observations.

Frequency analysis was made for annual, spring and autumn maximum values. The complete data set of 60 years was divided into 3 continuous subsets, each with 20 observations. The parameters were estimated for each 20 year period and D/E-combination. The predicted discharge Q_{TP} at return period T was calculated and compared with the observations in the remaining data set. The comparison was made for the 3 largest floods in the remaining data set, and thus made with independent data most of which were beyond the range of calibration. The technique is illustrated in Figure 4.4.1. This procedure was thereafter repeated for the following 20 year periods. 20 years was chosen as this is sometimes as a rule of thumb said to be a minimum record length for any meaningful frequency analysis. Only the northernmost 27 stations in Figure 3.1 were used in the reference run of the frequency analysis, in order to reduce the heterogeneity in the regional methods.

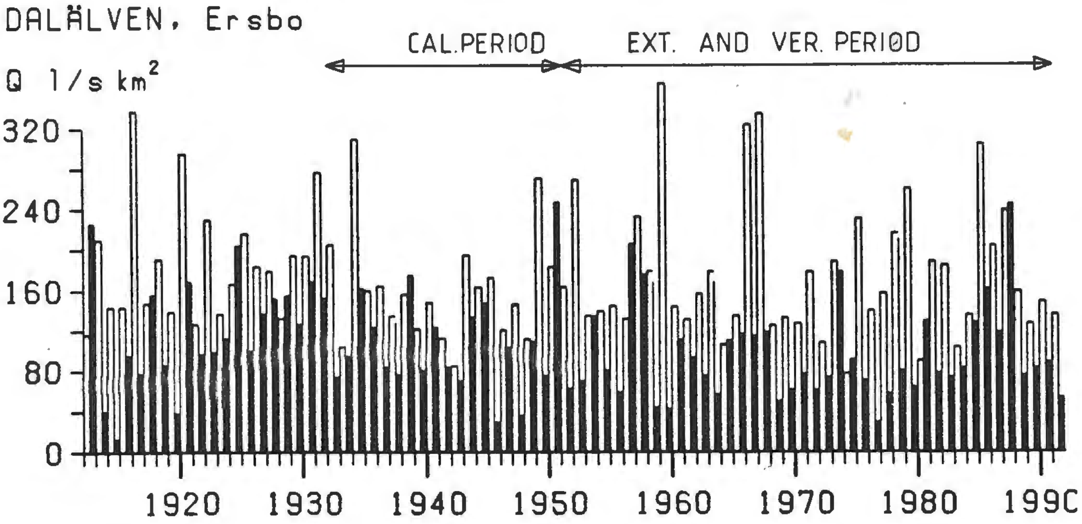


Figure 4.3.2.1 Illustration of the split-sample technique. The procedure was followed for all 3 periods of 20 years within the full 60 year period.

A difficulty arises when defining the goodness of fit, and NERC (1975) in fact showed that the choice of criterion can be decisive for which distribution that comes out as the best one. The question is therefore how to define what is meant by the best method. Statistically used measures of the performance of quantile estimates are the bias, standard error and root mean square error (see e.g. Cunnane, 1989). The definitions of these criteria, however, include the expected quantile $E[Q_{TP}]$, which is unknown. Goodness of fit has therefore sometimes been measured by numerical criteria based on probability plots (see Cunnane, 1989). This means assigning a return period, T, to each observed flood record, and measuring the deviation between Q_{TP}, the predicted flow magnitude, and Q_{TR}, the recorded flood magnitude, both at the return period T. In a similar fashion as in both the American (Benson, 1968) and British studies (NERC, 1975), the deviations

$$d_i = \frac{Q_{TP}-Q_{TR}}{Q_{TR}} \tag{7}$$

were used here. The reason for dividing by the observed flood was to enable a comparison between different basins. Based on N computed relative deviations d_1, d_2, ..., d_N, a relative bias, RDEV, was computed as

$$RDEV = \frac{1}{N}\sum_{i=1}^{N} d_i \tag{8}$$

As in NERC (1975), a relative absolute deviation, RADEV, was estimated as:

$$RADEV = \frac{1}{N}\sum_{i=1}^{N} |d_i| \tag{9}$$

The two criteria, RDEV and RADEV, were calculated individually for each subset of data and return period T. Each value was thus based on 3 subsamples and 3 return periods, i.e., N = 9. Arithmetic mean values for all basins were thereafter calculated for each D/E combination.

4.3.3 Plotting position

In the split-sample test each observed flood observation was assigned a return period, by use of a plotting position. A thorough discussion on plotting positions was given by Cunnane (1978). A general form which covers most plotting positions is:

$$T_i = \frac{n+1-2\alpha}{i-\alpha} \tag{10}$$

where i is the rank of the flood data in descending order, and n the number of years. The parameter α depends on the distribution. For example, $\alpha = 3/8$ for the normal distribution (Blom plotting position), $\alpha = 0.44$ for the Gumbel distribution (Gringorten plotting position). The Weibull plotting position corresponds to $\alpha = 0$, and the Hazen position to $\alpha = 0.5$. Reinius (1982) suggested the use of $\alpha = 0.37$. The median plotting position, which assumes the return period as the median of all possible return periods obtained from a population of equally sized samples, corresponds to $\alpha = 0.31$ (Cunnane, 1978). The Weibull formula is the most widely used (Cunnane, 1989). It was recommended by Gumbel (1958) and Yevjevich (1972) among others. It fulfills the 5 plotting position postulates suggested by Gumbel. Cunnane (1978), however, asserted that the Weibull plotting position is biassed, and he suggested the use of $\alpha = 2/5$ as a good distribution-free alternative.

Benson (1968) used the Weibull plotting position in the American comparison of observed floods and those predicted by frequency analysis, whereas the British Flood Studies team (NERC, 1975) used the general equation above, with different values of α for different distributions, although near the compromise value of 2/5. Both of these two studies found that the results depended on the choice of plotting position. The differences between plotting positions are small except for the lowest and highest observations in a sample. The largest floods are exactly the focus of this study. It is therefore important to choose a plotting position which does not introduce any bias in the flood estimates. Because of the importance of the plotting position and since the form of the real flood distribution is unknown, the matter was investigated further.

For each station the totally available observation period was split into subsamples of 10 years. The largest flood in each sample was extracted. This flood was given a return period, dependent on α:

$$T(\alpha) = \frac{10+1-2\alpha}{1-\alpha} \tag{11}$$

As an example this gives a return period of 11 years for $\alpha = 0$ and 20 years for $\alpha = 1/2$. The average, $E[Q_{T(\alpha)}]$, over all the subsamples was computed, giving an estimate of the $T(\alpha)$ year flood. A better estimate of the $T(\alpha)$ year flood should be obtained by using the full sample for a station, since the differences between plotting positions are smaller within a sample than at the ends. This new estimate of the flood $Q^*_{T(\alpha)}$ was computed, by attributing a return period according to the general equation above to each flood data in the full sample. Interpolation was used whenever necessary. Here, a relative bias was taken as:

$$\boldsymbol{bias}(\alpha) = \frac{E[Q_{T(\alpha)}] - Q^{*}_{T(\alpha)}}{Q^{*}_{T(\alpha)}} \tag{11}$$

This was computed for each station in Table 3.1, and the average of all these was taken. The bias was estimated for $\alpha = 0$, 0.3, 0.4 and 0.5. The test was repeated with subsamples of 20 years, to study the sensitivity to the choice of subsample length.

4.3.4 Sensitivity of the frequency analysis

The chosen way of evaluating different methods for frequency analysis relies on many assumptions, e.g. the choice of criteria for goodness of fit, and the choice of homogeneous regions. Some of the critical assumptions were identified and the sensitivity to these was studied by changing one factor at a time while keeping all other factors as in the reference situation. The following tests were made:

Test 1. The use of root mean square deviations (RMSE) instead of the reference criterion RADEV.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} d_i^2} \tag{12}$$

Test 2. Parameter estimation by using 10 years and subsequent extrapolation to 50 years, i.e., an extrapolation factor of 5 instead of 2.

Test 3. $\alpha = 0.5$, i.e., the Hazen plotting position formula.

Test 4. $\alpha = 0.3$, i.e. almost the median plotting position

Test 5. $\alpha = 0.0$, i.e. the Weibull formula.

Test 6. Division of Sweden into less heterogeneous geographical regions. In the test, the region D1 as proposed by Gottschalk (1985) for basins < 2000 km^2 was chosen. This region comprises most of southeastern Sweden. 7 basins in the study belong to this region, namely: Vattholma, Nömmen, Getebro, Källstorp, Hålabäck, Möckeln and Rörvik)

Test 7. As above, but for the region B2 (Ersbo, Fulunäs, Grötsjön, Ljusnedal, Fjällnäs and Tänndalen).

Test 8. As above, but for the region C (Ytterholmen, Kåge, Anundsjön and Hassela).

Test 9. As above, but for the region A (Torneträsk, Stenudden, Sorsele, Öster-Noren and Solbergsvattnet

Test 10. All the northernmost 27 basins were used, as in the reference run, with the exception that all basins where significant trends for the years 1931 - 1990 were found, were excluded, i.e., exclusion of Torneträsk, Torrböle, Medstugusjön, Solbergsvattnet and Hassela.

5. RESULTS FROM THE STATISTICAL ANALYSIS AND DISCUSSION

5.1 Trend analysis

The existence of possible trends was investigated both by studying time series plots and by statistical tests. Tables 5.1.1 - 3 show the time of occurrence of large floods at all stations in Table 3.1. Individual years stand out in the analysis, with large floods in many basins during the same year. The stations are thus not independent, and many of the features cover large parts of the country. Figures 5.1.1 - 2 are a further illustration of this. Examples of years with high spring floods in most of the country are 1966 and 1967.

The relative absence of high autumn floods in the 1970-ies is clear (Tables 5.1.1 - 3 and Figures 5.1.1 - 2). After this followed a period richer than normal in floods, both in spring and in autumn. This may have caused the impression of a change, but seen in a longer perspective, the 1980-ies do not seem extreme. The difference between the 1970-ies and 1980-ies was both in spring and autumn. A high frequency of floods in the 1980-ies over large parts of Western Europe was also noted by Gustard et al. (1989). Tables 5.1.1 to 5.1.3 indicate a slightly higher frequency of moderate floods from about the mid 1960-ies than before that, especially in spring floods.

The results from the statistical trend analysis are given in Tables 5.1.4 - 5.1.6. The distribution free trend test and the two regression methods all gave similar results for the possible significance. With a 95 % level for significance, the tests should indicate trends for some 5 % of the samples, if they were completely random. A somewhat higher number than this, was found. The trends were slightly more often positive than negative. However, the different subperiods differed considerably. The trend results thus depend on the choice of subperiod. Furthermore, the series are not independent, since the observations are parallel in time.

The subperiod which deviated the most from the expected was 1931 - 1990, with considerably more significant trends than expected in many parts of the country. However, the 1920-ies were slightly above normal in floods, especially in the autumn, whereas the beginning of the 1930-ies had a few years with low floods. As an example, for Torrböle (see the appendix), the statistical tests indicate a positive trend from 1931 to 1990, but in the late 1920-ies a few high floods occurred which changes the picture. For autumn conditions, positive trends were found for most basins for the subperiod 1971 - 1990, many of them significant. The trends are, however, in many cases reversed for longer periods. This agrees with the observation above that the 1970-ies had rather few high floods, whereas the 80-ies had rather many.

The results above suggest somewhat higher floods in the 1980-ies than in the preceding decade. However, in a longer perspective, no significant differences were found by t-tests between the floods during the 1980-ies and during the complete period available prior to 1980, neither for annual, spring nor autumn maxima. The magnitude of the observed floods in the 1980-ies therefore fits in with the natural variability, seen in a longer perspective.

Visual inspection of the graphs in the appendix, does not reveal any general significant trend in floods. This agrees qualitatively with the results by Jutman (1991), who found very weak, if any, trends in yearly mean runoff in Sweden. There are, nevertheless some stations, for which a tendency can be noted. Hålabäck is one example of this. Torneträsk is another, where the gauging station is located at the inlet of a long lake rather than at the outlet. It is known that the observations there are uncertain due to the land elevation, which is rather strong in this part of the country. Other stations which are known to behave differently than nearby stations in double mass plots are Hålabäck and Möckeln. Some seeming trends may thus be due to uncertainties in the observations.

As a summary, the results do not allow any conclusion about a change in flood frequency. Furthermore, the end period for all analyses, the 1980-ies, was not chosen arbitrarily. The reason for initiating this study was the seemingly large number of floods in the 1980-ies. One can therefore expect slightly more significant trends than in randomly chosen samples.

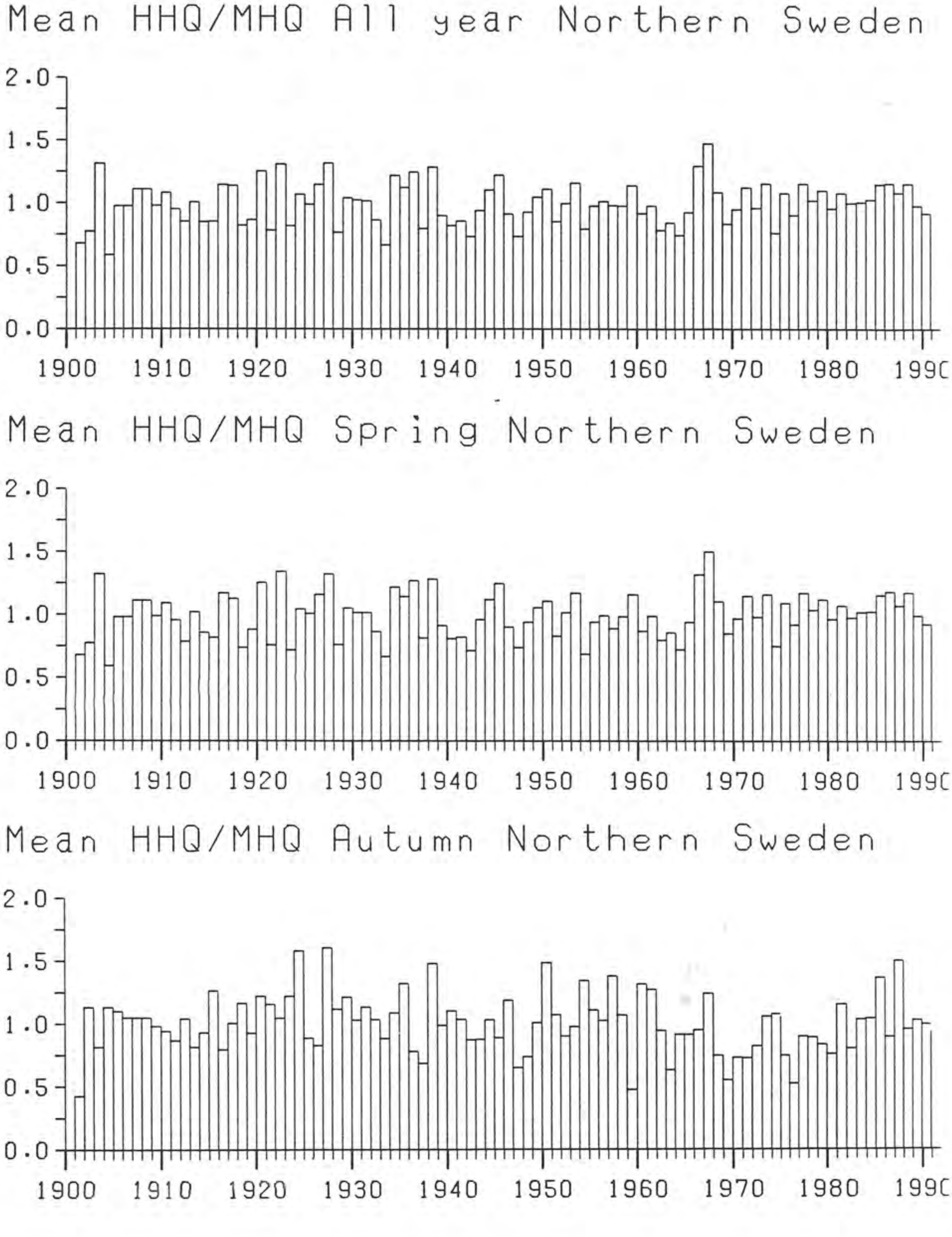


Figure 5.1.1. Average ratios HHQ/MHQ for calendar years, in the 27 northernmost stations in Figure 3.1. Note that only 1 station was operating until 1907.

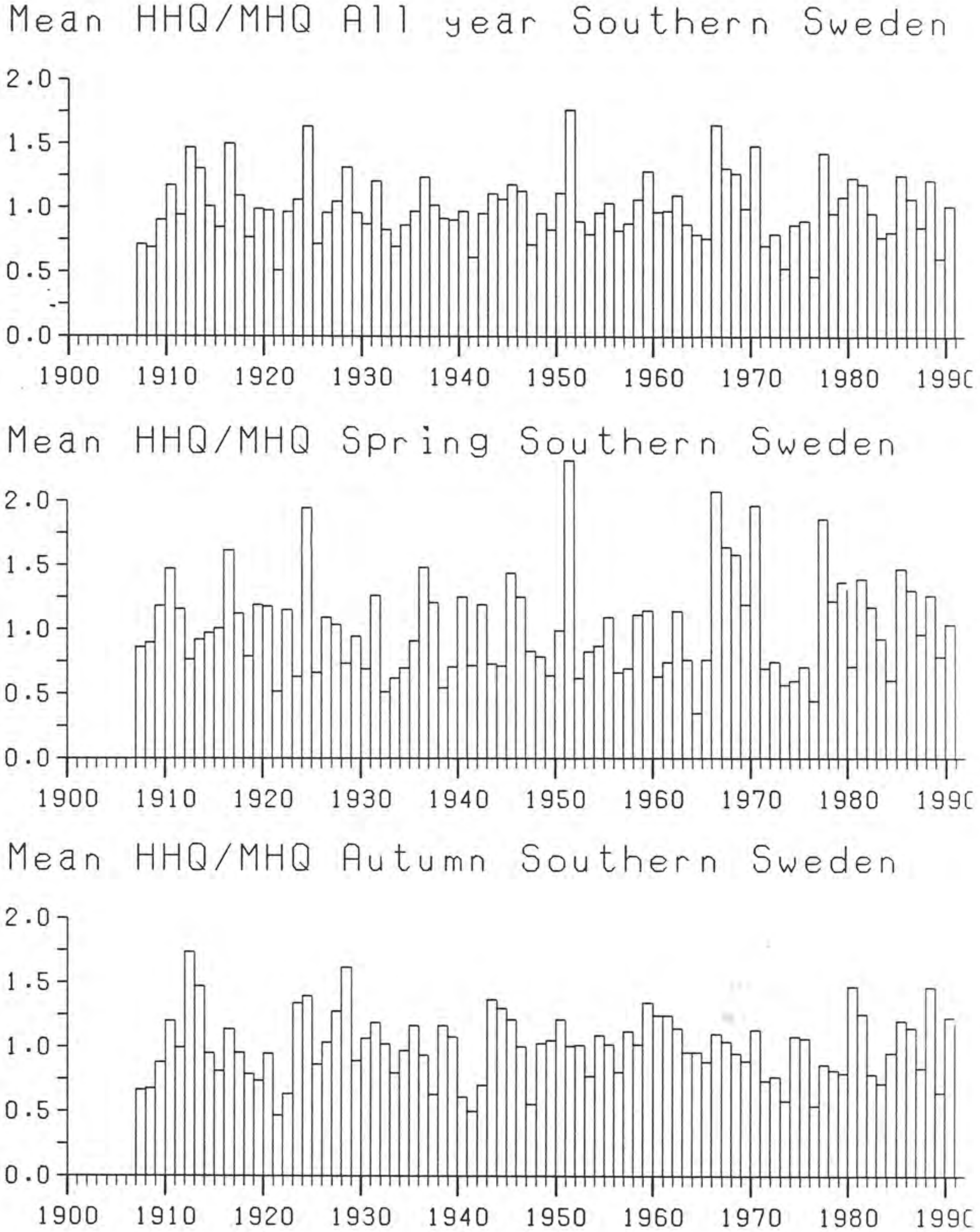


Figure 5.1.2. Average ratios HHQ/MHQ for calendar years, in the southernmost 12 stations in Figure 3.1. Note that only two stations were operating until 1912.

Table 5.1.1. *Time distribution of large annual floods, calendar years. The floods belong to the largest 25 % (o) and largest 10 % (O). "-" denotes that the station was not operating. The time period is from 1900 to 1991.*

```
Basin              00        10        20        30        40        50        60        70        80        90
===============================================================================================================

Torneträsk         ------------------O   oo   o    OoOo  o    O  o  o  oO    o      o       O          o
Kukkolankoski      ----------- o    O  O      o  o   OOO           o    o o   o      ooO    O    oo    O o
Kallio             ----------- o    O  O      O  o o OOO           o   oo O   o      ooO          o    o o
Ytterholmen        ------------------------ o o      OOO           o o    o    o      O   o O ooO o o
Niavve             -------------------------  o       OO Oo    oO   oO     o o o          O  o          o     o
Stenudden          ---------------- oo o O  o O Oo  o oo OO     o   oO  O    o             o
Sikfors krv        ---------------------------- oo   oOO O         oO  o  o          O    ooO         o   o
Kåge               ------------------------  oO      ooO        o       oo  O         o Ooo o o O          o
Solberg            -----------           o       o   oo  Oo   O     OO  O       O     Oo  Ooo  o   oo  o
Överstjuktan       -----------     o   o    ooo oO    O  O      O   Oo  o             O   O o  Oo  o
Sorsele            ----------      o     O o o   O    o  Oo    Oo   oo                Oo  O     o oO  o       o
Vindeln            -----------     o   o O   oo  o    Oo O     OO   O   o             Oo  O o   o  o  o
Laisan             ----------o           O o oo  O    O  Oo    oo          O    o     o   Oo    o  O  o       O
Torrböle           ---------------     o     OO        O o              O o o o      OO   o o o o        Oooo
Anundsjön          -----------------------   Oo   o    O        O       o     o O    oO  oo     o     o  O oo
Öster-Noren        -  O             o    o           O   O  o  O o  O   o         o  oOo    O  O o  O  oo  o o
Medstugusjön       --------------------- o               o oo  O    o   o            oO     O  o o  O  o   o O
Solbergsvattnet    ------------------------o OO      o o        o             o      OO       ooo o     oO O o
Gimdalsby          --------------------------------    o        O             oo     OOo      O O    oo oooO
Hassela            -------------------O  o    o   o    oo       oo            O      OO  o      O     o OOoo
Ljusnedal          -------------------------o        O   O  o  O       oo            OO     o    oo o o O
Fjällnäs           ---------------------------- O    O   O  Oo o   o    o    o       oo     O  o oo     O
Tänndalen          -----------------------------o    O   O  o  O             o       Oo     o  o oo oo  O
Grötsjön           ----------------------------   o  o o        o    oO       O      OO       o  oo o   Oo o
Ersbo              ------------oo  O   O o  o     O  O              oo o    o O      OO       o  oo     O o
Fulunäs            -------------   O   o   o     oO  o o             ooo      O      OO         o o     oOOo
Vattholma          -----------------  o  O O            O      oo     O o  o  o  O   Oo oO           o  o
Nömmen             ----------  OO  oo o    O  oO  o                   O              OooO     o O ooo      o
Getebro            --------------------    O   o  O    O o O        o Oo     o       ooo O      O o     o
Källstorp          ----------------------  o   oO      O   ooo  Ooo   O              o o o o    o       o
Hålabäck           ----------------------------   O    O   o O   O        o  oO     oO   o      o   o   o  o
Möckeln            ---------------------- o    O              o      oO         o    OOo      o o  OO   oo O o
Torsebro krv       --------  o Ooo oO      o   O  o           o O     o          o    o  O      O  Oo   Oo o
Rörvik             -------     OO         OO  oO              o      oO              Ooo o    o O ooo   o  o o
Simlången          ----------------------------    Oo o       oo      O   O   O    o     O         o         o
Gårdsilt           ----------------------------o   o  O         o    oO   O  oO  o o     O         Oo  o
Magnor             ------------    O              o  O  O             OO    o o oO o Oo o       o o      ooO
Nybergssund        ---------oo     O   O   o oo   Oo O o             o      o o   o  OO                 OO o
Vassbotten         --------------             O o  o  o  o    oO    o O     o    o    OO   o o  o    O   o   O
```

Table 5.1.2. *Time distribution of large spring floods, calendar years. The floods belong to the largest 25 % (o) and largest 10 % (O). "-" denotes that the station was not operating. The time period is from 1900 to 1991.*

```
Basin              00        10        20        30        40        50        60        70        80        90
===============================================================================================================

Torneträsk         ------------------    O    O o  oo O  o    O  o  o  OO    o      o  o    O          o    o
Kukkolankoski      ----------- o    O  O      o  o   OOO           o    o o   o      ooO    O    oo    O o
Kallio             ----------- o    O  O      O  o o OOO           o   oo O   o      ooO          o    o o
Ytterholmen        ------------------------ o o      OOO           o o    o    o      O   o O ooO o o
Niavve             -------------------------  o       OO Oo    oO o oO     o o o          Oo                  o
Stenudden          ---------------- o  o O  o O Oo  o oo OO     o   oO  O                  o           o
Sikfors krv        ---------------------------- oo   oOO O         oO  o  o          O    ooO         o   o
Kåge               ------------------------  oO      ooO        o       o   O         o Ooo o o O          o
Solberg            -----------           o       o   oo  Oo   O     OO  O       O     Oo  Ooo  o   oo  o
Överstjuktan       -----------     o   o    ooo oO    O  O      O   Oo  o             O   O o  Oo  o
Sorsele            ----------      o     O o o   O    o  Oo    Oo   oo                Oo  O     o oO  o       o
Vindeln            -----------     o   o O   oo  o    Oo O     OO   O   o             Oo  O o   o  o  o
Laisan             ----------o           O o o   O    O  Oo    oo          O    o     oo  Oo    o  O  o       O
Torrböle           ---------------     o     OO        O o         o    O o o o      OO   o o o o        O oo
Anundsjön          -----------------------   Oo   o    O        O       o     o O    oO  oo     o     o  O oo
Öster-Noren        -  O             o    o           O   O  o  O o  O   o         o  oOo    O  O o  O  oo  o o
Medstugusjön       --------------------- o               o oo  O    o   o            oO     O  o o  O  o   o O
Solbergsvattnet    ------------------------o OO      o o        o             o      OO       ooo o     oO O o
Gimdalsby          --------------------------------    o        O             o      OOo      O O    oo oooOo
Hassela            -------------------O  o    o   o    oo       oo            O      OO  o      O     o OOoo
Ljusnedal          -------------------------o        O   o  o  O       oo            OO     O    oo o o O
Fjällnäs           ---------------------------- O    O   O  Oo o   o    o    o       oo     O  o oo     O
Tänndalen          -----------------------------o    O   O  o  O             o       Oo     o  o oo oo  O
Grötsjön           ----------------------------   o  o o        o    oO       O      OO       o  oo o   Oo o
Ersbo              ------------ o  O   O o  o     Oo O              o  o    o O      OO       o  oo     Ooo
Fulunäs            -------------   O   o   o      O  o o              oo      O      OO         o o o   oOOo
Vattholma          -----------------  o  O O            O      oo     O o  o  o  O   Oo oO           o  o
Nömmen             ----------o     oo o    O      o     o             O          o   OOOOo      O o     o  o o
Getebro            --------------------    O o  o O    Oo  O          O      o       ooo O      Ooo o   o
Källstorp          ----------------------  o o  O o    O   ooo   oo   O      o       o o o      o       o
Hålabäck           ----------------------------        O   O O  oO    o  oO       o oOo  o      o   o   o
Möckeln            ----------------------  o                  o o     O   o      o   OOO o    o o o O    o O O
Torsebro krv       -------- oOo            O o    o        o o  Oo    O              OO  O      O o oo   o o o
Rörvik             -------   o      o  o   O                  O o    oO   o          OOooo      O o o o o  O O
Simlången          ----------------------------            o o  O     O          o   OoO O      ooo Oo  oo
Gårdsilt           ----------------------------              o  O     O       o  o   Ooo O      ooo Oo  oo
Magnor             ------------    O   o       o  o  O  O          o oOO      O  O   Oooo       o o      o o
Nybergssund        ---------oo     O   O   o oo   Oo O o             o        o   o  OO          o      OO o
Vassbotten         --------------      o   o  O o     o o             O       o  o   OOOoo      Oo      oo   O
```

Table 5.1.3. *Time distribution of large autumn floods, calendar years. The floods belong to the largest 25 % (ȯ) and largest 10 % (O). "-" denotes that the station was not operating. The time period is from 1900 to 1991.*

```
Basin              00        10        20        30        40        50        60        70        80        90
===============================================================================================================

Torneträsk         ------------------O   °O   °    O°OO  °    °  °  °  °O    °      °  °    O
Kukkolankoski      ----------- °  °     ° O   O°   O  O°   °          °O  ° °°      ° °      O  O   O
Kallio             ----------- °  O   O°  °°  O    O  °    °     °        ° °O  °   ° °      O  O   O
Ytterholmen        ------------------------°    O °   °°   O   ° O       °      O     O      °  °O    ° °
Niavve             -------------------------  °    °     °O   ° °    O   O  °                OO      °  O °   °
Stenudden          ----------------  O ° O°°° O  ° °  O  °°      °   O       O             °°                °°
Sikfors krv        ---------------------------- O °   °  °°O     °   O O O  °              °    °   °     °   O
Kåge               ------------------------°    O    O°    ° °          °O     O      O      °      °   °°O  °
Solberg            -----------   °O  O °  °O° O   °   °     O   °    O    ° °°             °°        °      O
Överstjuktan       -----------    °    °   O  O°°O°   O          O   OO  °O °  °°                   °   ° °
Sorsele            ----------    °°  O °   O  O  O    O      °   °   O°   ° °°                      O     ° ° °
Vindeln            -----------   °   ° ° ° O  O °O    O      °       °O  °° O°         °            O     O   °
Laisan             ----------    °O  O °  °O  O  °    O  °   °       O    ° OO       °      °       °°      °
Torrböle           ---------------    ° O °O  °   °     °O°   °         °O  °  O°     °           O     ° O
Anundsjön          ----------------------- O  O°°     °  O  °   O        °      O     O      °    °    °°    °
Öster-Noren        -             °O       O°° O   °°  °        O °O  O    O  ° ° °  ° °        O         ° °
Medstugusjön       ---------------------   °       °°           O OO°     °  O  O      O  °    °      ° °° O
Solbergsvattnet    ------------------------O  O °        °  O             ° °  ° °         ° °    O   O°O °   °
Gimdalsby          --------------------------------   °  °  °  °°      °    °  O°    °              O  OO O   °
Hassela            -------------------         °     °°     °            O OO  O   ° O   °   °      O °°°O   °
Ljusnedal          -------------------------  O °   °    O°°    °    °O  O O ° O      °     °              °
Fjällnäs           ---------------------------- °   °°°  O          °O°   °O   °°     °     O          °    O
Tänndalen          -----------------------------°   °°   O           O   °°O    O     °     °          °   °O
Grötsjön           ----------------------------° O      °°           O     O°  °            °      °    O O°O
Ersbo              ------------O    °  °   O °°° °°  °   O    °°     O  °  OO               O           ° O
Fulunäs            -------------    °  O   O °°° O°      °     °     O  °  °°               O          °O°O
Vattholma          -----------------       O  °    O O °       O         °  O° O°            °   ° °O  ° °   °
Nömmen             ----------  OO         °O  °O °O           °                °°°   °  O     O    °°      O °°
Getebro            --------------------   °    O °       O°   °°   OOO O      °O°        °               ° °
Källstorp          ---------------------- °° ° O  ° O°   O    °°O° °°O         °           O
Hålabäck           ----------------------------   O   °   °   °       °      OO     OO°° °                 O  °
Möckeln            ---------------------- O    O              °°     °   °    ° °             O    OO   °O O °
Torsebro krv       --------  ° O°O °O     °    O  O       °   O°°             °  °°                O°   O° °
Rörvik             -------     OO  °      OO  °O              °      °   °      °    °  °     °    OO   °° O °
Simlången          ----------------------------    O° O       °°          O   O  °°O °           ° O   °     °
Gårdsilt           ----------------------------°   O  O         °    °   °O  °O  ° O   °           O   °     °
Magnor             ------------°             ° °°        °    °°         °  O   O° O° O °°              ° OO °
Nybergssund        ---------   O  O  °     O  O  °       °°    °     O  °  °O  °            °          °O O °
Vassbotten         --------------             O °  °  °  O    °O °  °       °    °    O    ° °       O   °°  O
```

Table 5.1.4. *Results from the trend analysis for different periods, annual floods. * denotes 95 % significamce. The relative trends by regression, b_1 and b_2, are given in %/year, regardless whether significant or not.*

Basin	11-90	31-90	51-90	71-90	11-90	31-90	51-90	71-90	11-90	31-90	51-90	71-90
	Nonparametric test				Lin. regression				Log. regression			
					(%/y)	(%/y)	(%/y)	(%/y)	(%/y)	(%/y)	(%/y)	(%/y)
Torneträsk		-*	-	+		-0.5*	-0.5	-0.2		-0.4*	-0.4	-0.2
Kukkolankoski	+	+	+	-	0.0	0.1	0.1	-0.6	0.0	0.1	0.2	-0.7
Kallio	-	-	-	-	-0.2	-0.2	-0.2	-0.3	-0.2	-0.2	-0.1	-0.5
Ytterholmen		+	+	-		0.2	0.4	-1.1*		0.3	0.5	-1.1
Niavve		+	+	-		0.0	0.2	-1.0		0.1	0.2	-0.9
Stenudden		-	+	-		-0.4	0.0	-0.6		-0.3	0.1	-0.4
Sikfors krv		-	+	-		-0.2	0.0	-0.5		-0.1	0.1	-0.3
Kåge		+	+	+		0.3	-0.1	-0.9		0.5	0.1	-0.6
Solberg	+	+	+	-*	0.2	0.2	0.1	-1.6*	0.2	0.2	0.2	-1.6*
Överstjuktan	+	+	+	-*	0.1	0.2	0.4	-1.4	0.1	0.3	0.5	-1.2
Sorsele	+	+	+	-	0.1	0.1	0.3	-1.2	0.1	0.2	0.3	-1.0
Vindeln	+	+	+	-	0.1	0.0	0.1	-1.5	0.1	0.1	0.1	-1.3
Laisan	+	+	-	-	0.0	0.0	-0.1	-1.4	0.0	0.1	-0.1	-1.3
Torrböle		+*	+	+		0.6*	0.3	1.1		0.8*	0.4	1.2
Anundsjön		+	+	+		0.4	0.4	1.4		0.5	0.5	1.3
Öster-Noren	+*	+	+	+	0.4*	0.2	0.5	0.4	0.4*	0.3	0.5	0.5
Medstugusjön		+*	+*	+		0.4*	0.8*	0.6		0.4*	0.8*	0.5
Solbergsvattnet		+*	+*	+		0.6*	1.1*	1.6		0.6*	1.2*	1.6
Gimdalsby			+	+			0.8	2.2			0.8	2.4
Hassela		+*	+*	+		0.8*	1.3*	2.8		0.9*	1.4*	3.0
Ljusnedal		+	-	+		0.0	0.1	0.5		0.0	0.0	0.6
Fjällnäs		-	+	-		-0.1	0.3	-0.1		0.0	0.3	0.0
Tänndalen		+	+	+		0.1	0.6	0.7		0.1	0.7	0.9
Grötsjön		+	+	+		0.4	0.3	1.0		0.4	0.4	1.1
Ersbo		+	-	+		0.0	-0.2	0.7		0.0	-0.2	0.7
Fulunäs		+	+	+		0.1	0.1	2.5		0.1	0.1	2.7
Vattholma		+	-	+		0.0	-0.8	1.5		0.1	-0.6	1.9
Nömmen	+	+*	+	+	0.2	0.8*	0.7	0.8	0.2	0.9*	0.9	1.7
Getebro		-	-	-		0.0	-0.1	-0.1		0.0	-0.1	0.2
Källstorp		-*	-	-		-0.9*	-0.1	-2.0		-0.8*	-0.1	-1.7
Hålabäck		-	-	+		-0.8	-0.8	2.3		-0.8	-1.2	1.8
Möckeln		+*	+	+		0.8*	0.5	2.1		0.8*	0.5	2.7
Torsebro krv	-	+	+	+	0.0	0.2	0.8	2.2	0.0	0.2	0.7	2.7
Rörvik	+	+*	+	+	0.1	0.6*	0.6	1.4	0.1	0.6*	0.7	1.8
Simlången		-	-	+		-0.1	-0.1	0.4		0.0	0.0	0.3
Gårdsilt		-	-	+		0.0	-0.3	0.4		0.1	-0.2	0.3
Magnor		-	-	+		-0.1	-0.5	3.0*		0.0	-0.4	2.9*
Nybergssund	-	+	+	+	0.0	0.0	0.1	1.1	0.0	0.0	0.1	1.2
Vassbotten		+	+	+		0.2	0.5	0.9		0.2	0.5	1.3

Table 5.1.5. *Results from the trend analysis for different periods, spring floods. * denotes 95 % significance. The relative trends by regression, b_1 and b_2, are given in %/year, regardless whether significant or not.*

Basin	11-90	31-90	51-90	71-90	11-90	31-90	51-90	71-90	11-90	31-90	51-90	71-90
	Nonparametric test				Lin. regression (%/y)	(%/y)	(%/y)	(%/y)	Log. regression (%/y)	(%/y)	(%/y)	(%/y)
Torneträsk		–	–	–		-0.3	-0.3	-0.3		-0.3	-0.1	-0.5
Kukkolankoski	+	+	+	–	0.0	0.1	0.2	-0.6	0.0	0.1	0.3	-0.7
Kallio	–	–	–	–	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.1	-0.5
Ytterholmen		+	+	–		0.2	0.4	-1.1*		0.4	0.6	-1.1
Niavve		+	+	–		-0.1	0.3	-0.7		0.1	0.3	-0.5
Stenudden		–	+	–		-0.4	0.2	-0.7		-0.3	0.4	-0.6
Sikfors krv		+	+	–		-0.1	0.3	-0.5		0.0	0.4	-0.3
Kåge		+	+	–		0.3	0.1	-1.1		0.5	0.3	-0.8
Solberg	+	+	+	–*	0.2	0.2	0.1	-1.6*	0.2	0.2	0.2	-1.6*
Överstjuktan	+	+	+	–*	0.1	0.2	0.4	-1.4	0.1	0.3	0.5	-1.2
Sorsele	+	+	+	–	0.1	0.1	0.3	-1.2	0.1	0.2	0.3	-1.0
Vindeln	+	+	+	–	0.1	0.0	0.2	-1.5	0.1	0.1	0.2	-1.3
Laisan	+	+	+	–	0.0	0.0	0.0	-1.4	0.1	0.1	0.1	-1.3
Torrböle		+*	+	+		0.6*	0.4	0.8		0.7*	0.5	0.8
Ånundsjön		+*	+	+		0.4	0.4	1.4		0.5*	0.5	1.3
Öster-Noren	+*	+	+	+	0.4*	0.2	0.5	0.4	0.4*	0.3	0.5	0.5
Medstugusjön		+*	+*	+		0.5*	0.8*	0.6		0.5*	0.8*	0.5
Solbergsvattnet		+*	+*	+		0.6*	1.1*	1.6		0.6*	1.2*	1.6
Gimdalsby			+	+			1.0	2.1			1.1	2.3
Hassela		+*	+*	+		0.8*	1.5*	2.7		0.9*	1.7*	2.6
Ljusnedal		+	–	+		0.0	0.1	0.5		0.0	0.0	0.6
Fjällnäs		–	+	–		-0.1	0.3	-0.1		0.0	0.3	0.0
Tänndalen		+	+	+		0.1	0.6	0.7		0.1	0.7	0.9
Grötsjön		+	+	+		0.4	0.3	0.8		0.4	0.4	0.9
Ersbo		+	–	+		0.0	-0.1	0.8		0.0	-0.1	0.9
Fulunäs		+	+	+		0.2	0.4	2.5		0.2	0.4	2.5
Vattholma		+	–	+		0.1	-0.8	1.4		0.1	-0.7	1.7
Nömmen	+	+*	+	+	0.2	0.8	0.8	0.8	0.2	0.8*	1.1	1.5
Getebro		+	–	–		0.2	0.2	-0.4		0.2	0.2	-0.5
Källstorp		–	–	–		-0.6	0.1	0.3		-0.4	0.0	0.2
Hålabäck		–	–	+		-0.8	-0.4	0.0		-0.4	-0.7	0.1
Möckeln		+*	+	+		0.8*	0.9	1.7		0.9*	0.9	2.0
Torsebro krv	+	+	+	+	0.3	0.5	1.1	1.5	0.2	0.5	1.2*	1.9
Rörvik	+	+	+	+	0.2	0.5	0.8	1.2	0.2	0.6	1.0	1.2
Simlången		+	+	+		0.5	0.9	0.9		0.5	1.1	1.4
Gårdsilt		+*	+	+		0.7	1.0	1.0		0.8*	1.2	1.6
Magnor		+	–	+		0.0	-0.5	2.3		0.3	-0.1	2.7
Nybergssund	–	+	+	+	0.0	0.0	0.1	1.0	0.0	0.0	0.2	1.0
Vassbotten		+*	+	+		0.9*	0.9	3.5		0.9*	1.0	4.6*

Table 5.1.6. *Results from the trend analysis for different periods, autumn floods. * denotes 95 % significance. The relative trends by regression, b_1 and b_2, are given in %/year, regardless whether significant or not.*

Basin	11-90	31-90	51-90	71-90	11-90	31-90	51-90	71-90	11-90	31-90	51-90	71-90
	Nonparametric test				Lin. regression				Log. regression			
					(%/y)	(%/y)	(%/y)	(%/y)	(%/y)	(%/y)	(%/y)	(%/y)
Torneträsk		-*	-	-		-0.6*	-0.5	-0.7		-0.5*	-0.5	-0.7
Kukkolankoski	-	-	-	+	-0.2	-0.1	-0.4	0.2	-0.2	-0.1	-0.3	0.7
Kallio	-	-	-	+	-0.3	-0.2	-0.4	0.6	-0.3	-0.1	-0.4	1.8
Ytterholmen		-	-	+		-0.7	-0.5	1.5		-0.6	-0.5	3.1
Niavve		-	+	+		-0.2	0.5	0.7		-0.3	0.5	0.8
Stenudden		-	-	-		-0.3	-0.1	-0.4		-0.3	-0.1	-0.4
Sikfors krv		-*	-	-		-0.4*	-0.6	-0.5		-0.4*	-0.6	-0.5
Kåge		+	+	+*		0.1	0.2	5.7*		0.1	0.5	6.8*
Solberg	+	+	+	+	0.1	0.1	0.4	1.5	0.1	0.1	0.5	1.5
Överstjuktan	-*	-	-	+	-0.4	-0.4	-0.5	1.3	-0.4	-0.3	-0.2	1.0
Sorsele	-*	-	-	+	-0.4*	-0.2	-0.2	0.5	-0.4*	-0.3	-0.3	0.1
Vindeln	-	-	-	+	-0.3*	-0.3	-0.7	0.6	-0.3*	-0.4	-0.6	0.3
Laisan	-*	-	-	-	-0.5*	-0.4	-0.3	-0.1	-0.5*	-0.4	-0.4	-0.6
Torrböle		+	-	+		0.1	-0.2	2.6		0.1	0.0	2.5
Anundsjön		-	+	+*		-0.2	0.3	4.1		-0.3	0.3	6.3*
Öster-Noren	-	-	-	+	-0.1	-0.2	-0.4	1.0	-0.1	-0.2	-0.4	1.0
Medstugusjön		+	+	+		0.1	0.1	1.0		0.1	0.0	1.0
Solbergsvattnet		+	-	+		0.1	-0.1	1.1		-0.1	-0.3	2.0
Gimdalsby			-	-			0.0	1.6			-0.4	0.2
Hassela		+	+	+		0.6	0.4	4.6		0.4	0.2	4.4
Ljusnedal		-	-	+		-0.7	-1.0	2.0		-0.6	-0.8	2.7
Fjällnäs		-	-	+*		-0.5	-0.6	2.1		-0.5	-0.4	2.8
Tänndalen		-	+	+*		-0.2	0.1	3.0		-0.1	0.1	2.9
Grötsjön		-	+	+*		0.2	0.8	5.1*		0.0	0.7	5.7*
Ersbo		-	+	+		-0.2	0.4	2.5		-0.2	0.5	2.6
Fulunäs		-	+	+*		0.0	0.6	4.9*		-0.2	0.5	5.5*
Vattholma		+	+	+		0.2	1.0	2.3		0.4	1.3	3.2
Nömmen	+	+*	+	+	0.0	0.8*	0.7	2.3	0.1	0.8*	0.8	2.9
Getebro		-	-	+		-0.4	-0.3	3.4		-0.3	-0.2	3.5
Källstorp		-*	-	-		-1.2*	-0.3	-3.1		-1.0*	-0.2	-1.6
Hålabäck		-	-	+		-0.6	-1.4	4.2		-1.0	-1.9	3.3
Möckeln		+*	+	+		0.8*	0.6	2.6		0.8*	0.6	3.3
Torsebro krv	-	-	+	+	-0.3	0.1	0.6	3.4	-0.3	0.0	0.4	3.7
Rörvik	+	+*	+	+	0.0	0.6*	0.7	3.1*	0.1	0.6*	0.7	3.7*
Simlången		+	+	+		-0.1	-0.1	0.8		0.0	0.1	0.9
Gårdsilt		-	-	+		0.0	-0.3	0.8		0.0	-0.2	1.0
Magnor		+	-	+		0.4	-0.2	4.2		0.5	-0.5	3.2
Nybergssund	-	-	-	+	-0.1	-0.1	-0.2	2.4	-0.1	-0.2	-0.2	2.3
Vassbotten		+	+	+		0.1	0.7	1.6		0.1	0.8	2.0

5.2 Time series analysis

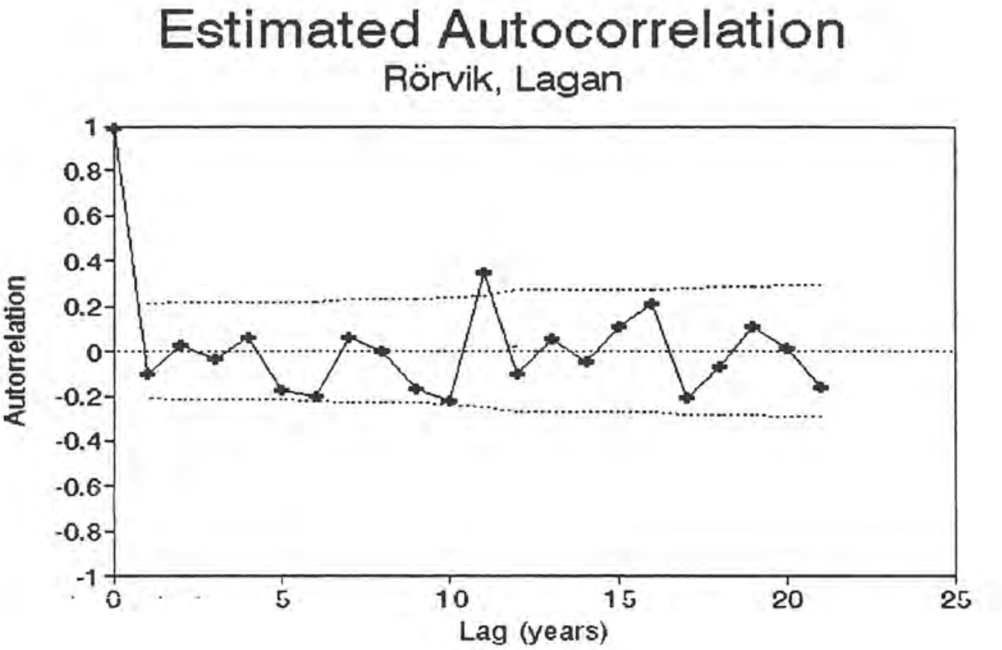
The trend analysis above provided no evidence of any change in flood frequency. Sometimes the sign of a supposedly significant trend was reversed, when another time period was chosen. A possible reason for this could be the existence of autocorrelation or periodical fluctuations.

The results from the time series analysis are given in Table 5.2.1. No persistence nor autocorrelation was found. The runs-test corresponded fairly well to the autocorrelation test. In Great Britain, NERC (1975) also came to the conclusion that series of annual maxima are uncorrelated in time, by using 3 different tests for serial dependence, and in New Zealand, McKerchar and Pearson (1989) did not find any conclusive evidence of non randomness in thirteen series of annual maxima.

No periodical behaviour could be found by the periodogram analysis. Figure 5.2.1 gives examples of estimations of autocorrelation and periodogram. A station for which a significant periodic component supposedly exists, was chosen for the figure. No convincing time dependence can be seen, neither in this example, nor in the other basins. Inspection of all the stations together did not reveal any systematic behaviour which was hidden by the analysis of one station at a time, nor did the time series analysis of the logarithmic flood data.

Table 5.2.1. Results from the time series analysis for annual maximum floods. "" denotes 95 % significance for the persistence (pers) from the runs-test, the one year autocorrelation r(1) or the periodic component attributing to the largest variance.*

Basin	Persistence (%)	Autocorrelation r(1)	Strongest period (years)
Torneträsk	51	-0.09	2.6
Kukkolankoski	48	-0.06	4.7
Kallio	39	-0.11	2.6
Ytterholmen	48	0.05	2.3
Niavve	48	-0.03	3.0
Stenudden	51	-0.14	2.4
Sikfors krv	59	0.10	16.0
Kåge	51	0.14	8.5
Solberg	54	-0.04	4.7
Överstjuktan	56	0.09	4.7
Sorsele	48	0.00	4.6
Vindeln	54	0.03	4.4
Laisan	51	-0.07	4.1
Torrböle	50	0.10	2.4
Anundsjön	44	-0.02	4.9
Öster-Noren	51	-0.18	2.9
Medstugusjön	46	-0.19	2.9
Solbergsvattnet	54	0.11	9.7
Gimdalsby	56	0.12	7.5
Hassela	60	0.13	10.3
Ljusnedal	50	-0.07	2.4
Fjällnäs	40	-0.24	2.9
Tänndalen	44	-0.04	3.0
Grötsjön	57	0.09	7.1
Ersbo	46	-0.06	3.6
Fulunäs	46	0.04	7.1
Vattholma	55	-0.14	2.6
Nömmen	43	0.00	2.7
Getebro	46	-0.11	2.2
Källstorp	47	-0.05	5.2
Hålabäck	42	-0.10	3.9
Möckeln	51	-0.18	2.2*
Torsebro krv	41	-0.20	2.7
Rörvik	48	-0.10	3.8*
Simlången	58	-0.14	3.9
Gårdsilt	50	-0.13	3.9
Magnor	43	0.09	2.9
Nybergssund	45	0.01	3.9
Vassbotten	49	-0.15	2.5



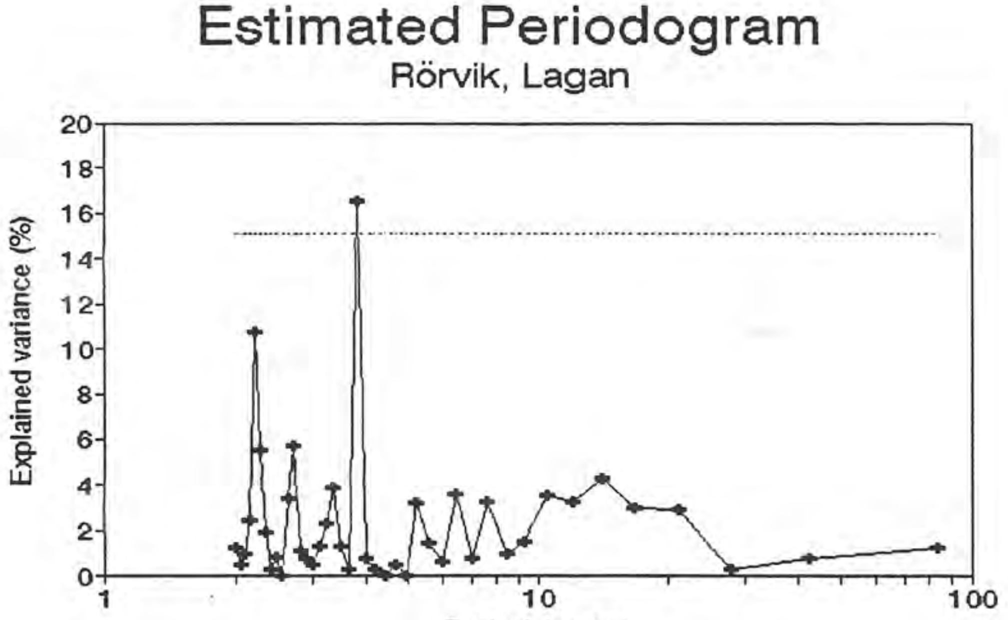


Figure 5.2.1. Estimated autocorrelation function and periodogram for annual maximum floods at Rörvik, Lagan as an example. The common 95 % level for significance is shown as a dotted line.

5.3 Frequency analysis

The analyses above showed no evidence of non stationarity or departure from independence. Frequency analysis can thus not be rejected only on the grounds of these results. The frequency analysis was made primarily in order to study the goodness of fit of different methods. It also gives some additional information which is summarized below.

Sample statistics for annual maximum floods are given as an example in Table 5.3.1. The skewness of the logarithms was in general negative, which is a common observation (e.g. Landwehr et al., 1978). The logarithmic data were, however, less skewed than the original data. This suggests that the lognormal distribution in general should be a better choice than the normal for high floods, something which is generally accepted, and which has here been used in the preceding analysis. The average coefficient of variation for autumn (0.45) was only slightly higher than that for spring (0.38). The mean value for spring (100 l/s km^2) was, on the other hand, almost twice as high as the average for autumn (58 l/s km^2). The skewness was almost the same for spring (0.83) as for autumn (0.86). In most of the country it is therefore likely that the spring not only produces the highest floods on average, but also the most extreme floods. This agrees with the qualitative analysis in the general overview.

The largest ratio between the highest flood ever recorded (HHQ) and the average of the annual maxima (MHQ) was 3.3. This corresponds well with the results from the general overview earlier. The ratio between the largest and second largest floods was 1.35 at the most. There are thus few extremes which considerably differ from all other floods in the studied basins.

The parameter k in the General Extreme Value distribution did only in few basins differ significantly from zero (Table 5.3.1). This agrees with the results from the FREND-project (Gustard et al., 1989), where a Swedish national value of $k = 0.001$ was estimated. In the cases of a significant difference from zero, k was positive. In these basins, the use of the Gumbel distribution (equivalent to $k = 0$) should lead to an overestimation rather than underestimation of the flood frequency. The k-value was, however, sensitive to the choice of plotting position in the computation of probability weighted moments.

Table 5.3.2 shows the results from studying the bias due to plotting positions. The compromise recommendation by Cunnane (1978) to use $\alpha = 2/5$, gave no bias in this sampling test, whereas other values of α gave biassed results. The same result was obtained when the experiment was repeated with subsamples of 20 instead of 10 years. The recommendation to use $\alpha = 2/5$ was therefore followed as the reference for computing the numerical criteria RDEV and RADEV.

A regional pattern of variation was noted in the preceding trend analysis, with large floods in many basins during the same year. The strong dependence between stations, noted earlier, manifested itself again in the spatial correlation $\bar{R}$ and the low number of effective independent stations N_E (Table 5.3.3). The estimated correlation corresponded well with that computed for Sweden (0.20) by Gustard et al. (1989). The low number of independent stations is partly due to the fact that some stations are situated in the same river basins, and that they sometimes even overlap each other. The autumn floods were almost as correlated as the spring floods.

Examples of the frequency analysis for selected basins and the Gumbel distribution estimated by three different methods are given in Figure 5.3.1. Only basins for which no trends were found in annual floods during 1931 - 1990 were selected for the figure.

The goodness of fit of the 16 methods for frequency analysis was judged by the numerical fitness criteria RDEV and RADEV. Tables 5.3.4 - 6 show the results from the reference run, in which the 27 northernmost stations in Figure 3.1 were treated as one region. The sensitivity analysis is summarized in Table 5.3.7. The results are not unequivocal, and they must be interpreted with caution. The sensitivity analysis showed that the results were sensitive to the choice of plotting position, and even more to the choice of numerical criteria. In fact, when another numerical criteria was used, a new method came out as the best one: the Normal distribution by moments. A similar experience was made by NERC (1975). They argued that there is no logical reason for choosing one criterion rather than the other. Benson (1968) also concluded that "there is no rigorous statistical criteria on which to base a choice of method". The results from the present study do therefore not allow any general conclusion on which distribution to choose. Some observations can nevertheless be made.

The normal distribution, as expected, had a negative bias, RDEV, (Table 5.3.4) and underestimated the floods. According to the test, most other methods were also biassed, although less so. The computed bias, however, depended on the choice of α, and is thus affected by the uncertainty in the plotting position. A bias was also found by Benson (1968) in most two parameter distributions.

The Gumbel distribution estimated by maximum likelihood gave the lowest absolute errors on average, RADEV, (Table 5.3.5), for annual, spring and autumn floods alike. All analyses are, however, not fully comparable, since different estimation methods were used, with the maximum likelihood as the statistically preferred one (Cunnane, 1989). When only the single-site two parameter distributions estimated by ordinary moments were studied in the reference run, the order of performance was: Gumbel, Gamma and Normal, Lognormal and Exponential.

The three parameter distributions generally performed worse than those with two parameters. This is not surprising, considering the short subsample length of 20 years. The result agrees with that of Gottschalk (1983), who found no better fit by three parameter distributions than with two parameter ones. However, in traditional tests of goodness of fit, three parameter distributions frequently come out as the best ones (e.g. Benson, 1968 and NERC, 1975). The advantage of the split-sample method used here, is that the agreement is checked by comparison with independent data. Three parameter distributions are likely to fit observed data better, because of its additional parameter. Cunnane (1989), however, stated that two parameter distributions are usually biassed, but nevertheless more attractive for single-site analysis, than distributions with 3 parameters. The reason is the high variability in flood estimates by three parameter functions. He suggested that three parameter distributions should be used only when complemented by a regional analysis. Three parameter distributions sometimes impose an upper bound to the floods, the existence of which is unknown. For example, the Log Pearson type III has an upper bound when the skewness of the logarithms is negative (e.g. Chow et al., 1988), as is the case in most Swedish basins.

The three parameter distributions, here the General Extreme Value, and Log Pearson type III, performed slightly better when the parameters were estimated by regional methods. The regional methods did, however, not outperform the single-site two parameter distributions. The regional methods performed somewhat better when Sweden was divided into more homogeneous regions, than when treating all of northern Sweden as a unit, and for the short sample length of 10 years. The Gumbel distribution with a regional coefficient of variation usually performed best of the regional methods.

No improvement was offered by considering spring and autumn floods separately in the two-component Gumbel model by moments, as compared to the Gumbel for annual floods only. A similar result was found by Lamberti and Pilati (1985), who pointed out that the additional information is mostly in the range of smaller floods, and therefore adds more noise than information. Another source of uncertainty may be the assumption of independence between autumn and spring peaks.

The autumn floods were in general more difficult to predict than spring floods (Table 5.3.5). Apart from that, the same general observations were made for the individual seasons as for annual maxima.

Table 5.3.1. *Estimated sample statistics and k in the GEV distribution for the whole observation periods, annual maximum values. CV, CS, CSlog are the coefficients of variation, of skewness and of skewness of the logarithms respectively. "*" denotes 95 % significance for* $k \neq 0$.

Basin	Mean (l/s km^2)	CV	CS	CSlog	HHQ/ MHQ	HHQ/ SHQ	GEV-k
Torneträsk	70	0.23	0.43	-0.24	1.69	1.12	0.11
Kukkolankoski	62	0.23	0.55	-0.06	1.72	1.15	0.11
Kallio	72	0.25	0.45	-0.15	1.65	1.04	0.10
Ytterholmen	122	0.25	0.21	-1.17	1.84	1.19	0.26*
Niavve	208	0.25	0.33	-0.16	1.64	1.04	0.16
Stenudden	127	0.27	1.04	0.24	2.00	1.15	0.01
Sikfors krv	55	0.25	0.72	-0.03	1.74	1.05	0.10
Kåge	90	0.40	0.92	-0.34	2.20	1.07	0.01
Solberg	200	0.23	0.15	-0.75	1.48	1.03	0.32*
Överstjuktan	174	0.27	0.00	-0.59	1.58	1.05	0.27*
Sorsele	133	0.24	0.35	-0.19	1.69	1.07	0.19*
Vindeln	76	0.27	0.62	0.03	1.81	1.10	0.11
Laisan	185	0.30	1.47	0.36	2.26	1.11	-0.05
Torrböle	81	0.32	0.44	-0.92	1.95	1.07	0.15
Anundsjön	67	0.34	0.76	-0.08	1.91	1.03	0.00
Öster-Noren	144	0.28	0.83	-0.21	2.07	1.27	0.09
Medstugusjön	219	0.28	0.30	-0.34	1.79	1.16	0.18*
Solbergsvattnet	73	0.30	0.70	0.03	1.84	1.13	0.01
Gimdalsby	29	0.44	0.68	-0.19	2.03	1.03	0.01
Hassela	71	0.48	0.62	-0.15	2.11	1.05	0.00
Ljusnedal	210	0.23	0.51	-0.28	1.68	1.05	0.12
Fjällnäs	254	0.29	0.98	0.10	2.05	1.24	0.03
Tänndalen	213	0.29	1.10	0.20	2.11	1.35	-0.01
Grötsjön	122	0.37	0.75	0.10	2.03	1.08	-0.02
Ersbo	180	0.35	1.06	0.37	2.02	1.08	-0.11
Fulunäs	125	0.31	0.65	-0.26	1.81	1.03	0.06
Vattholma	31	0.52	1.44	0.06	2.81	1.04	-0.12
Nömmen	18	0.45	1.26	-0.12	2.73	1.21	-0.04
Getebro	29	0.45	0.85	-0.23	2.29	1.03	-0.01
Källstorp	40	0.52	0.77	-0.11	2.53	1.13	-0.01
Hålabäck	67	0.61	1.62	-0.57	3.31	1.09	-0.08
Möckeln	21	0.41	0.50	-0.40	2.01	1.02	0.08
Torsebro krv	36	0.34	0.54	-0.19	1.89	1.04	0.08
Rörvik	19	0.36	0.74	-0.35	2.03	1.03	0.05
Simlången	127	0.30	0.66	-0.64	1.74	1.00	0.02
Gårdsilt	153	0.30	1.14	-0.25	2.06	1.18	-0.01
Magnor	100	0.43	1.32	-0.58	2.82	1.32	-0.04
Nybergssund	71	0.29	0.83	-0.03	1.95	1.09	0.08
Vassbotten	63	0.29	0.42	-0.33	1.81	1.04	0.16
Mean	106	0.33	0.73	-0.22	2.02	1.10	0.06

Table 5.3.2. Results from the sampling experiment of bias due to plotting position, with a subsample length of 10 years.

α	Average relative bias
0	0.08
0.3	0.02
0.4	0.00
0.5	-0.02

Table 5.3.3. Estimated average spatial correlation ($\bar{R}$) and the effective number of independent stations (N_E) for the three 20 year periods in the frequency analysis of annual maximum values. Above: The 27 northernmost stations in Figure 3.1. Below: The 12 southernmost stations in the same figure.

North	Annual		Spring		Autumn	
Period	$\bar{R}$	N_E	$\bar{R}$	N_E	$\bar{R}$	N_E
1932-51	0.32	2.9	0.32	2.9	0.26	3.5
1952-71	0.34	2.8	0.36	2.6	0.32	2.9
1972-91	0.13	6.1	0.14	5.9	0.20	4.3

South	Annual		Spring		Autumn	
Period	$\bar{R}$	N_E	$\bar{R}$	N_E	$\bar{R}$	N_E
1932-51	0.39	2.3	0.49	1.9	0.40	2.2
1952-71	0.44	2.0	0.64	1.5	0.25	3.2
1972-91	0.45	2.0	0.67	1.4	0.37	2.4

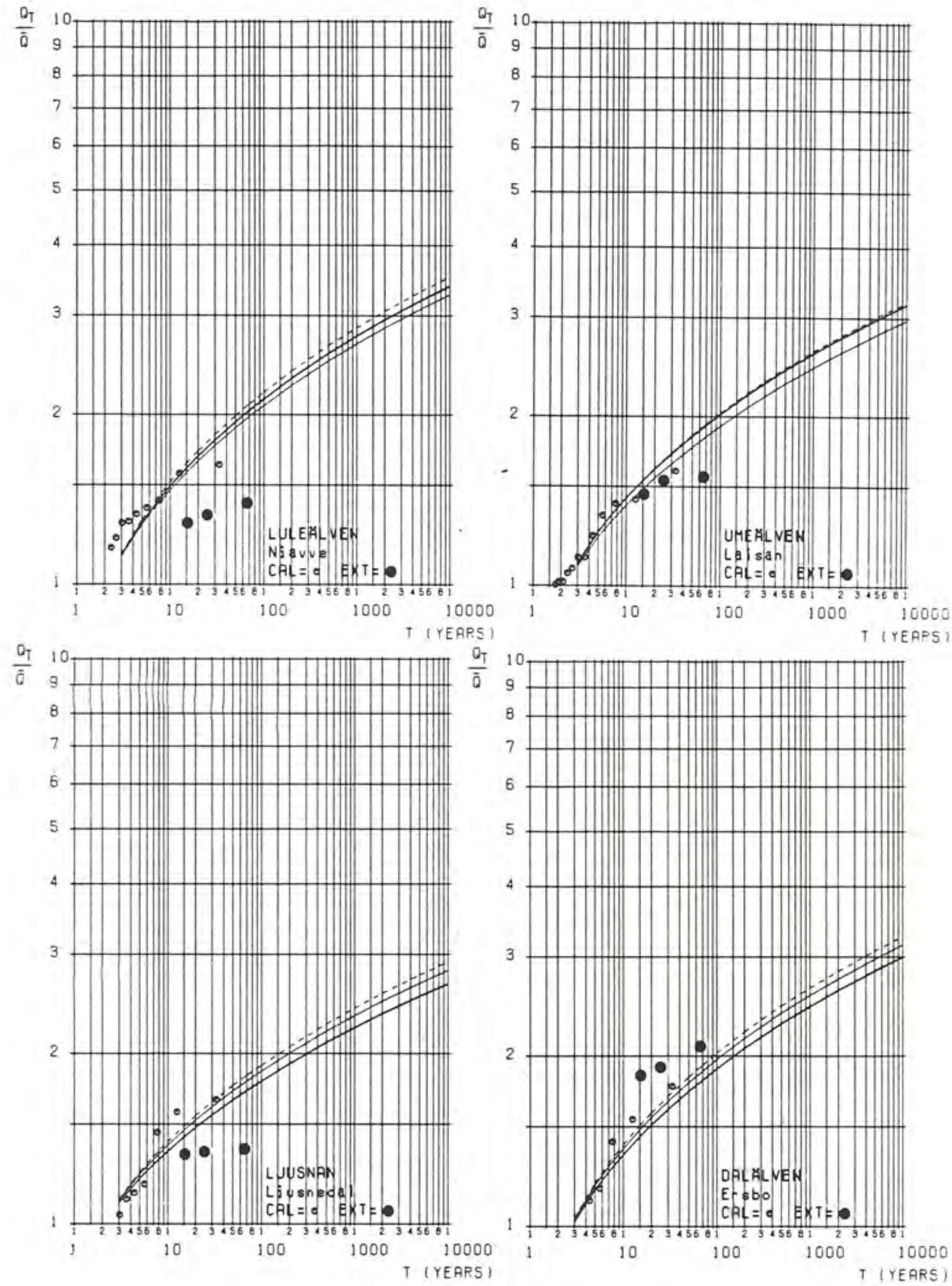


Figure 5.3.1. Example of frequency analysis by the Gumbel distribution and maximum likelihood (thick line), ordinary moments (thin line) and probability weighted moments (dashed line) for some selected stations, and annual maximum values. The reference plotting position was used, i.e. $\alpha = 0.4$. The parameters were estimated using the data from 1932 - 1951 (CAL), and the agreement checked by comparison with the 3 largest floods in the remaining period, 1952 - 1991 (EXT). All flood data in the figure were divided by $\bar{Q}$, the MHQ for the years 1932 - 1991.

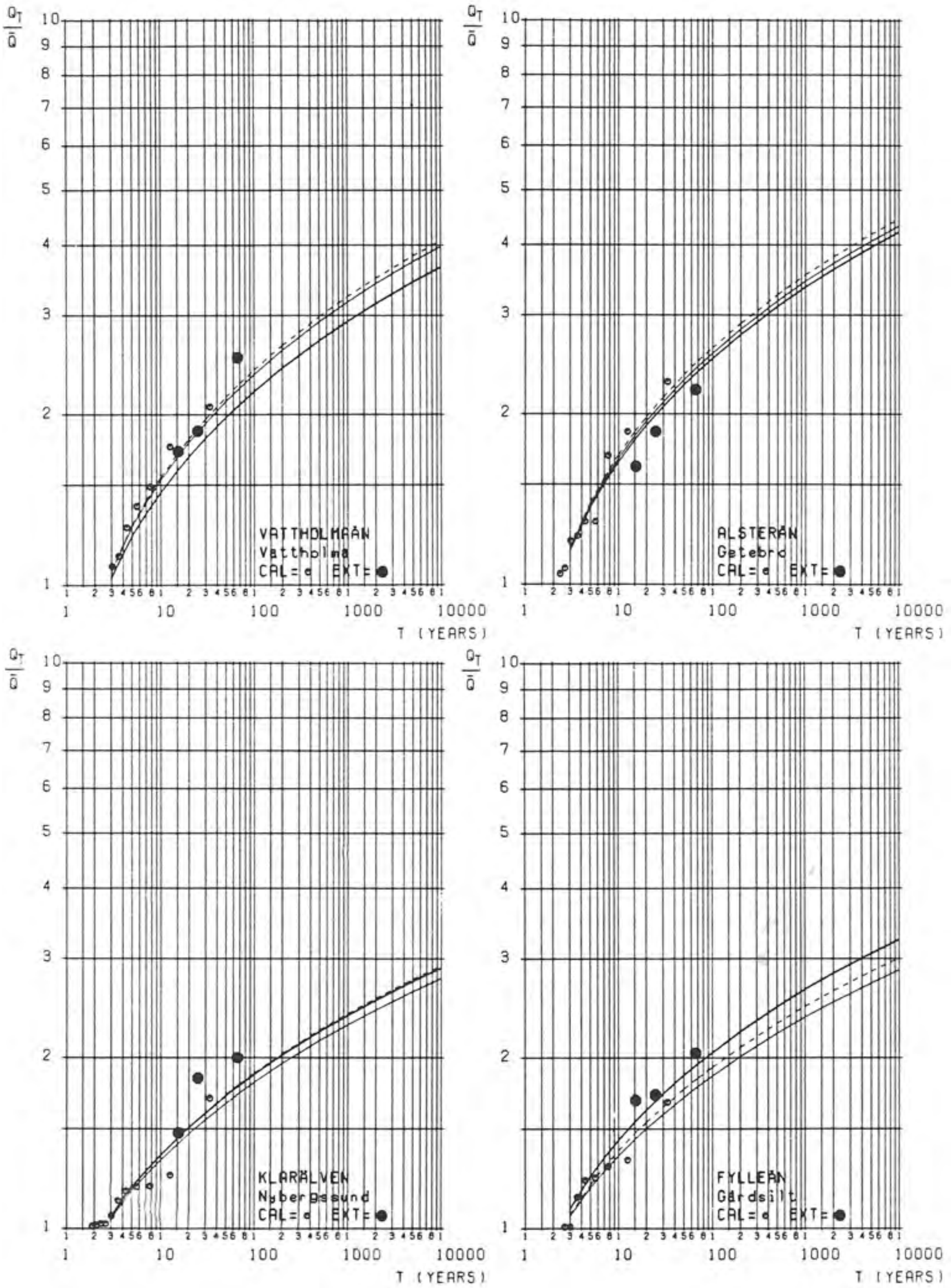


Figure 5.3.1. Continuation.

Table 5.3.4. *Mean relative deviation or bias, RDEV, (‰), in the reference frequency analysis of annual maximum values. Spring and autumn below.*

Basin	SNOR -MOM	SGUM -MOM	SGUM -PWM	SGUM -ML	SLN2 -MOM	SGAM -MOM	SEXP -MOM	SGEV -PWM	SPE3 -MOM	SLP3 -MOM	STWO -MOM	RGUM -MOM	RGEV -PWM	RLP3 -MOM	RSTY -PPO	REFF -PPO
Torneträsk	-34	23	61	53	15	-5	41	36	-4	3	86	100	121	4	2	39
Kukkolankoski	-29	29	68	51	19	1	11	38	3	15	33	99	119	9	7	46
Kallio	-15	46	92	84	54	18	66	53	2	27	48	89	109	42	24	65
Ytterholmen	-30	29	65	103	63	5	30	18	-13	-32	34	78	98	54	10	51
Niavve	-11	49	99	77	52	22	86	55	3	39	90	120	142	43	28	71
Stenudden	-48	6	48	24	-6	-21	20	26	-16	-2	64	92	114	-14	-13	25
Sikfors krv	-54	5	45	33	2	-21	19	23	-29	-8	25	59	80	-7	-15	27
Kåge	-113	-44	-27	-55	-24	-60	20	-5	-45	-43	-41	-142	-127	-38	-70	-23
Solberg	0	56	106	99	52	27	90	65	13	29	56	174	196	44	36	74
Överstjuktan	-14	49	94	94	65	22	63	52	4	24	49	87	107	54	26	69
Sorsele	-27	30	72	68	27	3	36	36	-6	9	31	106	127	18	11	50
Vindeln	-53	6	43	19	0	-19	3	28	-25	5	11	48	68	-8	-13	30
Laisan	-40	20	58	16	7	-8	27	60	0	23	31	69	88	-3	-4	35
Torrböle	-59	3	40	47	32	-22	-2	10	-27	-35	8	10	27	20	-21	21
Anundsjön	-67	3	23	0	9	-19	-10	18	-14	6	4	-57	-40	-5	-24	23
Öster-Noren	-54	8	43	50	26	-16	-8	13	-21	-20	8	25	44	16	-15	28
Medstugusjön	-17	43	85	120	66	15	63	34	-5	-12	45	85	104	51	16	54
Solbergsvattnet	-70	-8	25	-6	-16	-32	-12	19	-26	-5	-5	-15	2	-30	-34	6
Gimdalsby	-87	-8	16	-20	32	-21	-18	27	-27	22	-4	-165	-151	9	-44	4
Hassela	-71	13	38	-25	64	7	78	76	-3	80	23	-195	-181	39	-23	31
Ljusnedal	-41	14	52	29	-2	-14	25	37	-12	4	5	108	129	-11	-8	30
Fjällnäs	-52	10	44	27	7	-15	6	31	-12	3	10	27	48	-2	-12	31
Tänndalen	-45	18	45	3	-1	-6	53	62	10	27	18	14	34	-12	-4	40
Grötsjön	-52	21	42	-1	27	3	93	59	3	47	25	-80	-64	10	-7	42
Ersbo	-98	-28	-12	-83	-50	-46	53	41	-28	13	-25	-116	-100	-65	-55	-10
Fulunäs	-67	0	28	16	18	-24	24	6	-33	-11	24	-36	-19	0	-30	12
Nybergssund	-84	-22	0	-23	-31	-46	-41	-7	-36	-20	-17	-37	-20	-44	-46	-6
Mean	-49	14	48	30	19	-10	30	34	-13	7	24	20	39	6	-10	32
Mean Spring	-47	18	52	36	31	-5	33	36	-11	12	-	25	40	12	-8	38
Mean Autumn	-64	13	32	2	79	5	32	36	-6	38	-	34	67	36	-3	78

Table 5.3.5. ***Mean relative absolute deviation, RADEV, (‰), in the reference frequency analysis of annual maximum values. Spring and autumn below.***

Basin	SNOR -MOM	SGUM -MOM	SGUM -PWM	SGUM -ML	SLN2 -MOM	SGAM -MOM	SEXP -MOM	SGEV -PWM	SPE3 -MOM	SLP3 -MOM	STWO -MOM	RGUM -MOM	RGEV -PWM	RLP3 -MOM	RSTY -PPO	REFF -PPO
Torneträsk	88	100	115	91	92	95	126	114	105	107	125	152	165	96	109	135
Kukkolankoski	61	64	75	72	68	65	54	68	70	61	67	99	119	71	79	95
Kallio	92	109	126	102	112	101	116	130	101	120	109	125	137	114	115	147
Ytterholmen	115	114	109	120	132	123	128	141	137	131	109	86	107	139	125	135
Niavve	161	161	154	151	177	167	184	161	165	176	150	136	151	184	172	182
Stenudden	187	183	176	171	186	187	196	186	186	191	182	179	187	194	194	201
Sikfors krv	208	209	200	166	208	215	217	237	227	243	206	164	171	216	221	232
Kåge	134	92	96	125	117	93	103	89	82	85	93	157	146	120	105	103
Solberg	57	84	115	114	90	70	122	89	65	73	84	174	196	92	86	117
Överstjuktan	46	61	98	96	75	49	102	67	45	51	61	87	107	78	57	91
Sorsele	86	95	111	81	97	95	120	114	103	118	96	111	128	102	113	131
Vindeln	184	183	174	154	191	190	175	205	194	212	181	131	137	198	194	204
Laisan	51	54	71	79	65	45	44	65	34	49	58	86	97	72	51	76
Torrböle	99	83	83	70	71	88	83	97	101	112	90	97	91	75	96	88
Anundsjön	85	74	61	71	77	75	62	68	100	69	75	82	80	84	83	102
Öster-Noren	136	135	128	123	154	144	115	143	150	151	135	81	94	163	148	159
Medstugusjön	76	65	86	120	76	67	64	64	77	56	63	85	104	66	55	62
Solbergsvattnet	102	109	119	109	108	103	94	117	114	113	112	65	56	96	102	104
Gimdalsby	111	104	118	124	119	96	122	117	82	115	109	165	151	101	72	64
Hassela	98	117	123	109	140	113	136	146	109	148	121	195	181	122	97	103
Ljusnedal	125	117	100	81	104	123	139	139	147	142	104	132	141	113	131	136
Fjällnäs	193	194	180	158	190	200	182	206	215	217	194	159	166	198	205	217
Tänndalen	145	144	129	113	132	149	155	162	168	159	144	121	131	140	155	164
Grötsjön	86	66	63	61	54	69	113	121	94	94	64	92	82	52	87	107
Ersbo	170	161	143	126	147	168	197	175	172	181	156	145	134	152	174	173
Fulunäs	118	117	102	70	89	112	139	148	149	147	121	103	102	81	120	117
Nybergssund	158	150	128	102	125	156	148	188	180	172	154	127	123	131	162	162
Mean	117	116	118	110	118	117	127	132	125	129	117	124	129	120	123	134
Mean Spring	120	119	122	117	127	121	131	134	127	133	–	129	133	125	124	137
Mean Autumn	157	155	154	146	172	156	166	168	165	171	–	192	204	155	159	184

Table 5.3.6. ***Rank in the criteria RADEV in the frequency analysis of annual floods for each basin, annual floods. Ranks for the average RADEV below for annual, spring and autumn floods.***

Basin	SNOR -MOM	SGUM -MOM	SGUM -PWM	SGUM -ML	SLN2 -MOM	SGAM -MOM	SEXP -MOM	SGEV -PWM	SPE3 -MOM	SLP3 -MOM	STWO -MOM	RGUM -MOM	RGEV -PWM	RLP3 -MOM	RSTY -PPO	REFF -PPO
Torneträsk	1	6	11	2	3	4	13	10	7	8	12	15	16	5	9	14
Kukkolankoski	2	4	12	11	7	5	1	7	9	2	6	15	16	10	13	14
Kallio	1	5	13	4	7	2	10	14	2	11	5	12	15	8	9	16
Ytterholmen	6	5	3	7	12	8	10	16	14	11	3	1	2	15	9	13
Niavve	6	6	5	3	13	10	15	6	9	12	2	1	3	15	11	14
Stenudden	9	5	2	1	6	9	15	6	6	12	4	3	9	13	13	16
Sikfors krv	6	8	4	2	6	9	11	15	13	16	5	1	3	10	12	14
Kåge	14	4	7	13	11	5	8	3	1	2	5	16	15	12	10	8
Solberg	1	5	12	11	9	3	14	8	2	4	5	15	16	10	7	13
Överstjuktan	2	6	14	13	9	3	15	8	1	4	6	11	16	10	5	12
Sorsele	2	3	9	1	6	3	14	12	8	13	5	9	15	7	11	16
Vindeln	8	7	4	3	10	9	5	15	11	16	6	1	2	13	11	14
Laisan	5	7	11	14	9	3	2	9	1	4	8	15	16	12	5	13
Torrböle	14	4	4	1	2	7	4	12	15	16	9	12	10	3	11	7
Anundsjön	14	6	1	5	9	7	2	3	15	4	7	11	10	13	12	16
Öster-Noren	8	6	5	4	14	10	3	9	12	13	6	1	2	16	11	15
Medstugusjön	10	7	14	16	10	9	5	5	12	2	4	13	15	8	1	3
Solbergsvattnet	5	10	16	10	9	7	3	15	14	13	12	2	1	4	5	8
Gimdalsby	8	6	11	14	12	4	13	10	3	9	7	16	15	5	2	1
Hassela	2	7	10	4	12	6	11	13	4	14	8	16	15	9	1	3
Ljusnedal	8	6	2	1	3	7	12	12	16	15	3	10	14	5	9	11
Fjällnäs	7	8	4	1	6	11	5	13	14	15	8	2	3	10	12	15
Tånndalen	9	7	3	1	5	10	11	14	16	13	7	2	4	6	11	15
Grötsjön	9	6	4	3	2	7	15	16	12	12	5	11	8	1	10	14
Ersbo	10	8	3	1	5	9	16	14	11	15	7	4	2	6	13	12
Fulunäs	10	8	4	1	3	7	13	15	16	14	12	6	4	2	11	8
Nybergssund	11	8	5	1	3	10	7	16	15	14	9	4	2	6	12	12
Rank in RADEV annual floods	3	2	6	1	6	3	12	15	11	13	3	10	13	8	9	16
Rank in RADEV spring floods	3	2	5	1	8	4	11	14	8	12	-	10	12	7	6	15
Rank i RADEV autumn floods	6	3	2	1	12	5	9	10	8	11	-	14	15	3	7	13

Table 5.3.7. Sensitivity of the frequency analysis of annual floods. Rank in average RADEV or RMSE for each test.

Basin	SNOR -MOM	SGUM -MOM	SGUM -PWM	SGUM -ML	SLN2 -MOM	SGAM -MOM	SEXP -MOM	SGEV -PWM	SPE3 -MOM	SLP3 -MOM	STWO -MOM	RGUM -MOM	RGEV -PWM	RLP3 -MOM	RSTY -PPO	REFF -PPO
Ref.	3	2	6	1	6	3	12	15	11	13	3	10	13	8	9	16
Test 1 RMSE	1	4	10	3	6	2	13	15	6	11	9	12	16	6	4	14
2 10 years	2	2	7	2	10	6	15	13	9	11	2	1	13	11	8	16
3 alfa = 0.5	2	4	8	1	6	3	12	15	10	13	5	11	13	8	6	15
4 alfa = 0.3	7	3	2	1	4	6	11	15	11	13	4	9	13	7	9	16
5 alfa = 0.0	11	4	2	1	3	7	8	10	14	13	4	9	11	6	14	16
6 Region D1	9	2	2	4	15	4	6	9	8	11	7	1	11	14	13	16
7 Region B2	10	8	4	1	3	9	12	15	13	13	7	2	5	6	11	16
8 Region C	10	3	1	7	13	5	8	12	8	10	4	15	14	6	2	16
9 Region A	4	5	9	3	7	6	9	14	12	15	9	1	2	13	8	16
10 No trend	6	2	2	1	6	5	12	15	10	14	2	8	12	9	11	16

6. CONCLUSIONS

No convincing evidence of trends in extreme floods was found. The 1980-ies had an unusually large number of high floods, whereas the 1970-ies were drier than normal, especially when it comes to autumn floods. This may have led to the impression of a trend in floods. The 1980-ies were rich in both high spring floods and autumn floods. No clear differences between regions were found. The observed variation fits in with the typical fluctuations of natural systems. A slightly higher frequency of moderately sized floods from the mid 1960-ies than before that was, however, noted. The results from the statistical trend tests depended on the choice of subperiod.

There was a considerable spatial dependence in the observations. For example, the number of effective independent stations equivalent to a total of 27 stations in northern Sweden was as low as about 4. Examples of individual years which stand out in the analysis are 1951, 1966 and 1967 with high spring floods.

Time series analysis of annual, spring and autumn extremes, did not reveal any signs of persistence, autocorrelation or periodicity. Large floods thus occur randomly and can not be predicted on the basis of the floods during the immediately preceding years.

Regulation has decreased the magnitude of the common floods, although individual events and rivers can be found, where floods have been slightly increased by regulation. The consequences of a flood in a regulated system could nevertheless be considerable, even though the flood may be lower than those experienced during unregulated conditions. Floods are not expected in a regulated system, and the society may have adjusted to the new flood regime. The effect of regulation on floods is naturally greater in the spring than in the autumn.

A close relation was found between the seasonal distribution of the average runoff and the extremes. It is therefore likely that the most extreme floods should occur in the season with the highest average runoff, at least for unregulated conditions. Spring floods dominate most of the country, except in the far south, where winter floods also occur. In almost all of Sweden, it is therefore likely that the spring not only gives rise to the highest floods on average, but also to the most extreme ones. On the other hand, autumn floods may also have a potential for causing flood problems, as they are more difficult to predict and can occur at a time when the regulation reservoirs are full.

The annual runoff was higher in the 1980-ies than in the 1970-ies, but no convincing signs of a change in the seasonal distribution of runoff could be seen. No clear changes in the annual runoff were seen in a longer perspective, when the periods 1931-1960 and 1961-1990 were compared.

The conclusions from the frequency analysis must be drawn with great care, and only a few of all possible methods were tested. The results were found to be sensitive to the choice of method for evaluating the performance of the different methods. This shows that the answer to the question of best method for frequency analysis, depends on how the question is formulated. In fact, the sensitivity analysis revealed that the distribution which came out as the best one depended on the choice of numerical criterion. Since none of the tested criteria can logically be preferred to the other, no general conclusion about which distribution to choose can be made. Some observations can nevertheless be made.

The three parameter distributions generally performed worse than those with two parameters. This is not surprising, considering the short subsample length of 20 years. Three parameter distributions can be made to fit observed data better, because of its additional parameter. The advantage of the split-sample method used here, is that the agreement is checked by comparison with independent data, which can reveal overparameterization. The Gumbel distribution often came out as the best distribution.

The single-site two parameter methods generally performed better than the regional ones. When shorter sample lengths or smaller regions were used, the regional methods approached the single-site ones in performance. The Gumbel distribution with a regionally estimated coefficient of variance was then the best regional method. The use of both spring and autumn floods in a two-component Gumbel model, did not yield any improvement, as compared to the normal Gumbel for annual maxima only. Nor did an exponential peak over threshold model perform better than the annual maximum models.

The advantages of the method which was used for evaluating the predictive power of different methods for frequency analysis are that it is easy to understand, and that the agreement is tested with independent data. Traditional χ^2-tests or Kolmogorov-Smirnov tests could not be used since both annual maximum models and peak over threshold models were tested. Disadvantages of the evaluation method are that the method does not take into account the natural variability of the largest observations, and that the return periods of the observation have to be estimated by use of plotting positions. The largest floods in a record are furthermore very uncertain. This study only covered relatively modest extrapolation. The best method for short range extrapolation may not necessarily be the best one for longer range extrapolation, although the sensitivity to extrapolation length was not alarming.

7. ACKNOWLEDGEMENTS

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8. PUBLICATIONS FROM THE PROJECT

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Appendix - Frequency analysis

Given a time series x_i of n observations, the arithmetic mean ($\overline{x}$), variance (s^2), coefficient of variation (CV) and coefficient of skewness (CS) were estimated as described by for example Chow et al. (1988). No correction was made for small sample bias (cf. Wallis et al., 1974). Probability weighted moments, PWM, (Greenwood et al., 1979) were computed as:

$$PWM_j = \frac{1}{n} \sum_{i=1}^{n} (F_i)^j x_i \tag{14}$$

$$F_i = \frac{i-0.35}{n} \tag{15}$$

where i is the rank in ascending order, and F_i can be seen as a plotting position (see e.g. Cunnane, 1989). This plotting position was recommended by Cunnane and by Hosking et al. (1985b) among others. The results, especially from the General Extreme Value distribution were found to be sensitive to the choice of plotting position.

Frequency factors K_T can be formulated for many distributions, which gives that:

$$x_T = \overline{x} + K_T\, s \tag{16}$$

The used distributions and parameter estimation methods were:

1. <u>Normal distribution / Moments</u>

See e.g. Chow et al. (1988).

2. <u>Gumbel distribution / Moments</u>

See e.g. Chow et al. (1988).

3. <u>Gumbel distribution / Probability Weighted Moments</u>

See e.g. Cunnane (1989).

4. <u>Gumbel distribution / Maximum likelihood</u>

See e.g. Landwehr et al. (1979).

5. <u>Log Normal distribution / Moments</u>

See e.g. Chow et al. (1988).

6. Two parameter Gamma distribution / Moments

See e.g. Yevjevich (1972).

7. Exponential distribution-peak over threshold / Moments

See e.g. Cunnane (1989) or NERC (1975). The peak floods for the analysis were extracted from the annual, spring and autumn maximum series. Alternative thresholds were tried, but finally the threshold was set equal to $\overline{x}$, i.e. MHQ for the subsample period, to assure that at least some observations were found above the threshold even in very short samples in the sensitivity analysis.

8. General Extreme Value distribution / Probability Weighted Moments

See Hosking et al. (1985b) or Cunnane (1989). The test whether the parameter, k, differs from zero is according to Cunnane (1989) due to Hosking et al. (1985a).

9. Pearson distribution type III / Moments

See e.g. Chow et al. (1988).

10. Log Pearson type III / Moments

See e.g. Chow et al. (1988).

11. Two components Gumbel / Moments

The Gumbel distribution parameters were estimated by the method of moments for spring and autumn floods individually. The method below mainly follows that of Waylen and Woo (1982). An alternative two component model has been used in Italy by Rossi et al. (1984). If the cumulative probability for two seasons (here spring and autumn), assumed to be independent, are denoted $F_1(x)$ and $F_2(x)$ respectively, then the cumulative probability $F_A(x)$ for the annual maximum can be obtained in the following way (cf. Kite, 1988). The probability of exceedence is $1 - F_A(x)$, $1 - F_1(x)$ and $1 - F_2(x)$ respectively for the whole year, spring and autumn. The probability that neither the spring flood nor the autumn flood exceeds the given flood magnitude x is F_1F_2. This gives that:

$$F_A(x) = F_1(x)F_2(x) \tag{17}$$

and since $F_A(x) = 1 - 1/T$:

$$F_1(x)F_2(x) = 1 - 1/T \tag{18}$$

from which the flood magnitude x can be found by iteration.

12. Regional Gumbel distribution / Moments

Regional average values of the dimensionless coefficient of variation CV were computed. Cunnane (1989) attributes the method to Nash and Shaw (1966). The arithmetic mean ($\overline{x}$) and coefficient of variation (CV) were estimated for each station. The station specific mean was used, but the standard deviation was estimated from the regional CV and the station mean. The parameters u and α were thereafter computed by the method of moments.

13. Regional GEV distribution / Probability Weighted Moments

Regional averages of standardized PWMs (PWM_i/PWM_0) were calculated. An index-flood was computed by using these parameters and it was then multiplied by the mean flood ($\overline{x}$) for each station and sample. The method was used by Greis and Wood (1981) and by Hosking et al. (1985b), and is described in detail by Cunnane (1989). It was applied to Swedish data by Gustard et al. (1989).

14. Log Pearson type III with regional skewness / Moments

The same procedure as for the single-site LP3 distribution was followed, except that the coefficient of skewness, CS, was replaced by the average value of the same quantity for the whole region. This method is similar to that recommended by the U.S. Water Resources Council (see e.g. Chow et al., 1988), where the sample skewness is complemented by a regional map skewness.

15. Regional station year / Plotting position

This method is a station-year approach, i.e. a substitution of time by space. It is thus distribution-free. All observations were normalized by subtracting the mean and dividing by the standard deviation for the station. This means that the first two moments are estimated specifically for each site. The normalized data were thereafter pooled into one large data set. The skewness is thus estimated regionally, by establishing a common frequency factor K_T for the whole region. The normalized data were ranked and each observation was attributed a return period of $(Nk + 1)/i$, were i is the rank from largest to smallest, N the number of stations and k the number of years at each station. The dependence between stations was not taken into account here. Pairs of return period T and the estimated frequency factor K_T are thus obtained. Linear interpolation, and extrapolation when necessary, were used between individual estimates of K_T.

16. Regional effective station year / Plotting position

The method is an extension of the one above. An attempt is made to take the computed correlation between stations into account. As above, all observations were normalized, and pooled into one large data set. An average cross-correlation $\overline{R}$ between stations was computed as:

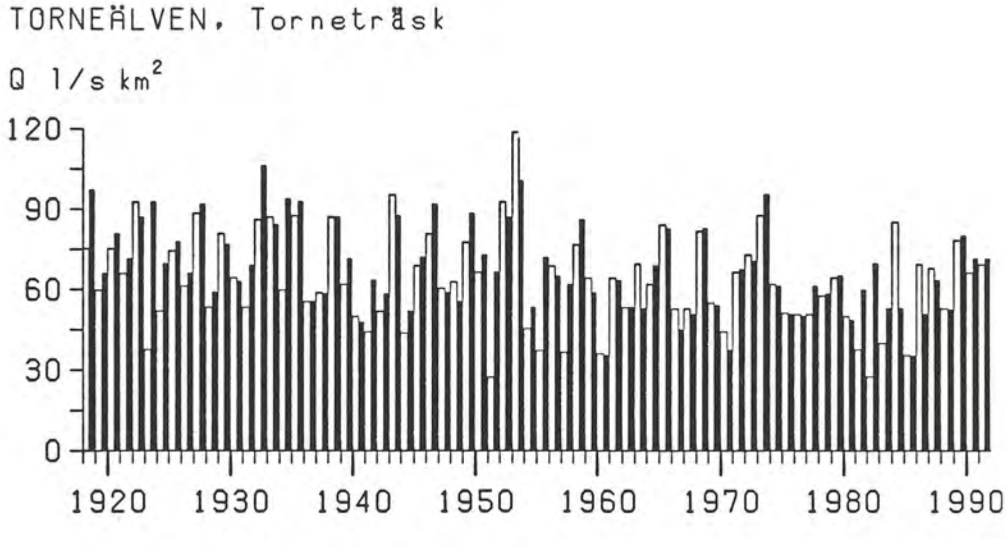
$$\bar{R} = \frac{1}{n^2-n} \sum_{i,j=1;i\neq j}^{n} R_{ij} \tag{19}$$

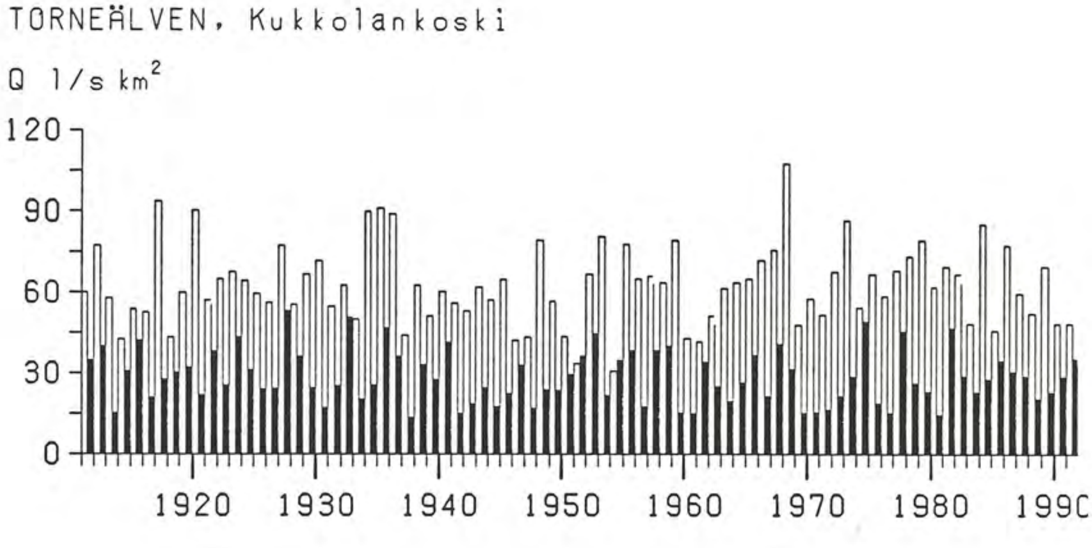
where R_{ij} is the correlation between stations i and j. An effective number of stations N_E was then estimated from the total number of stations as (see e.g. Kite, 1988 or Gottschalk, 1989):

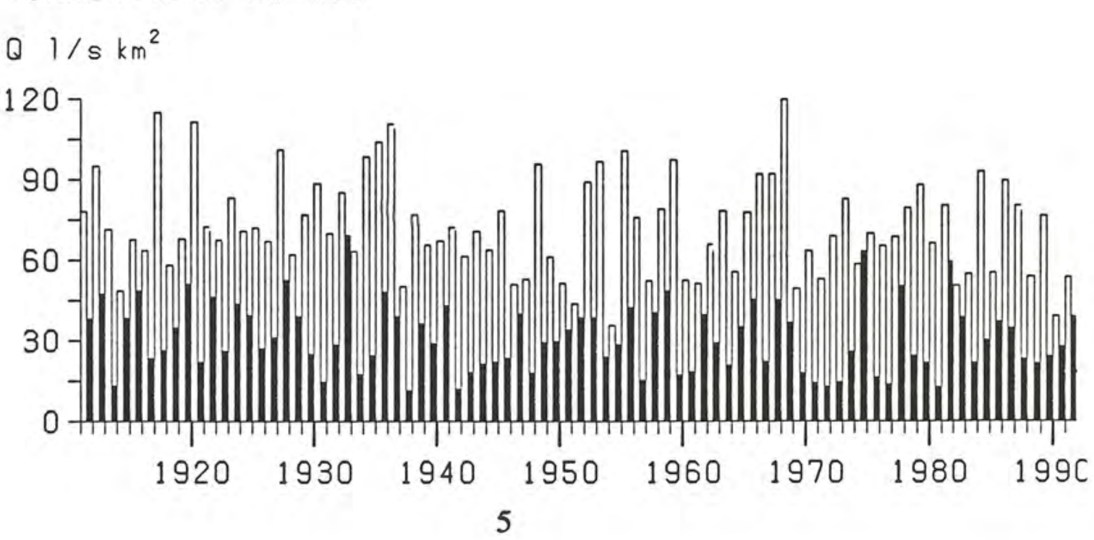
$$N_E = \frac{N}{1+\bar{R}(N-1)} \tag{20}$$

The largest of the data was given a return period T of $(N_Ek + 1)$, and the probability of exceedance F_1 was then equal to $N_Ek/(N_Ek + 1)$. Similarly, the smallest observation was attributed a probability of exceedance $F_{Nk} = 1/(N_Ek + 1)$. F was thereafter increased in steps of $df = (F_1 - F_{Nk})/(Nk - 1)$ for each data in the full data set, starting at the largest observation and arriving at the return period of $(N_Ek + 1)/(N_Ek)$ for the smallest one. As above, pairs of return period T and the estimated frequency factor K_T are obtained.

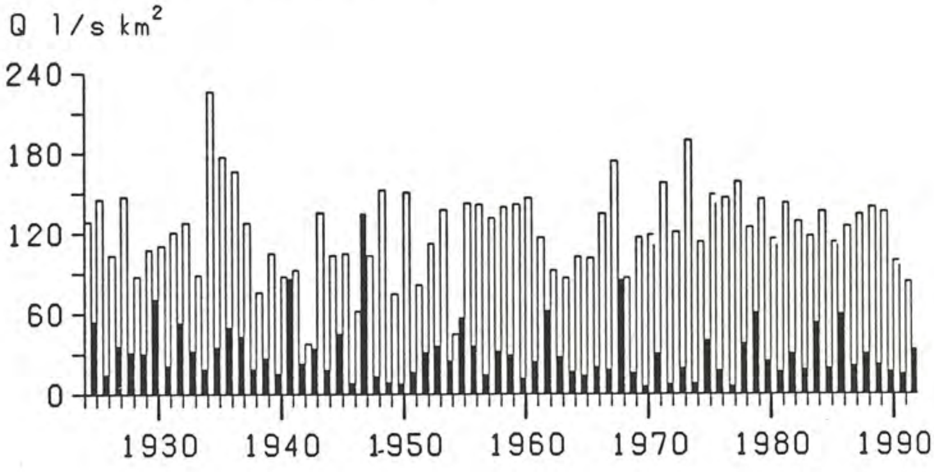
Appendix - Time series plots



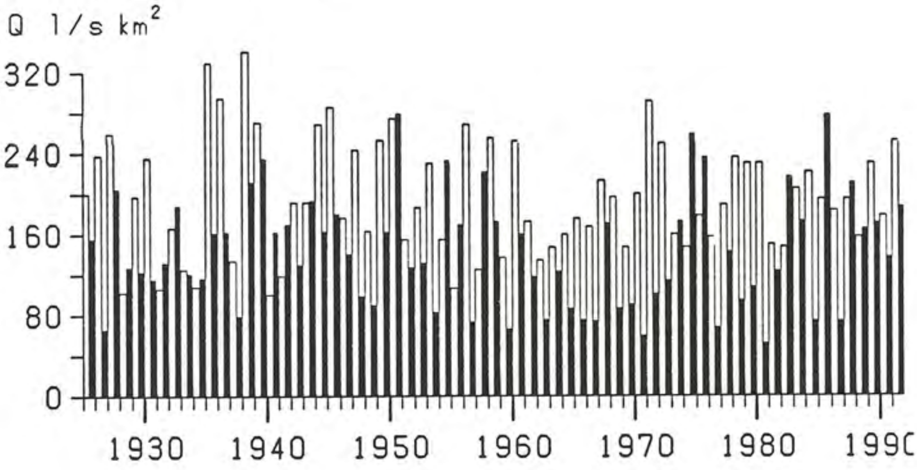




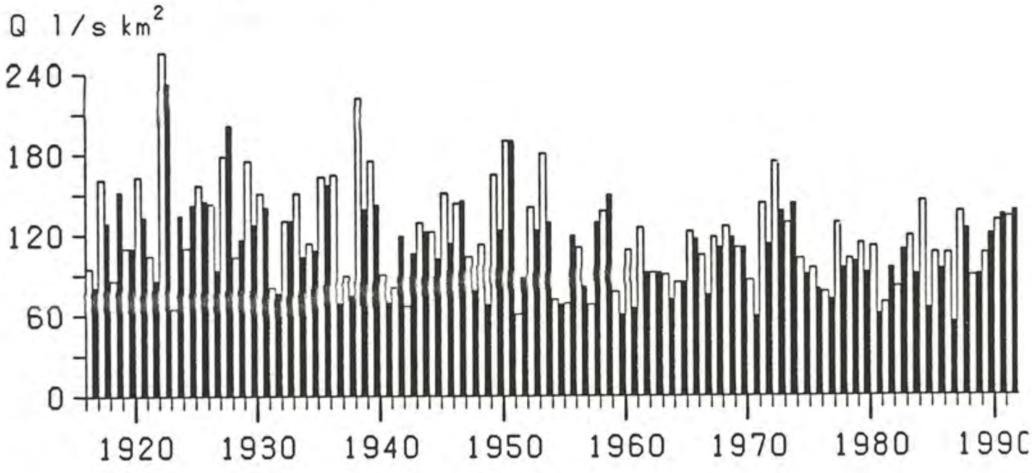
RÅNEÄLVEN, Ytterholmen

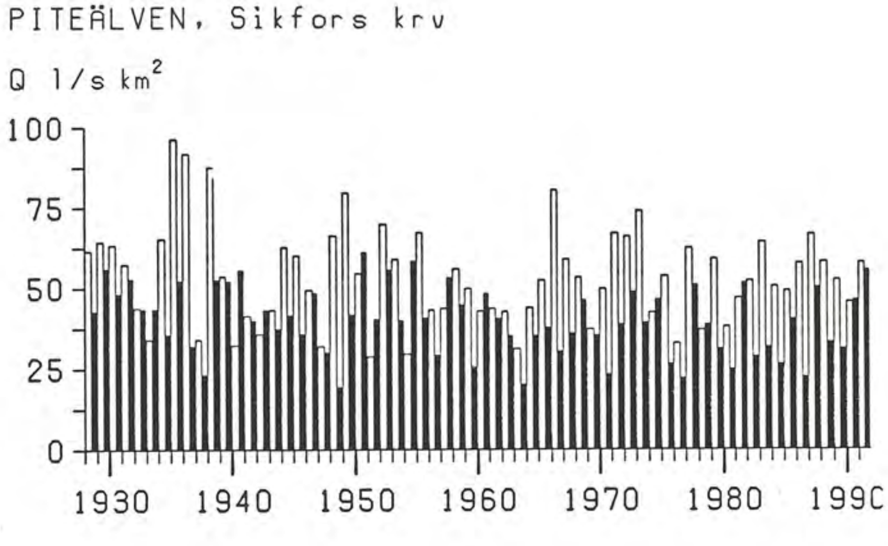


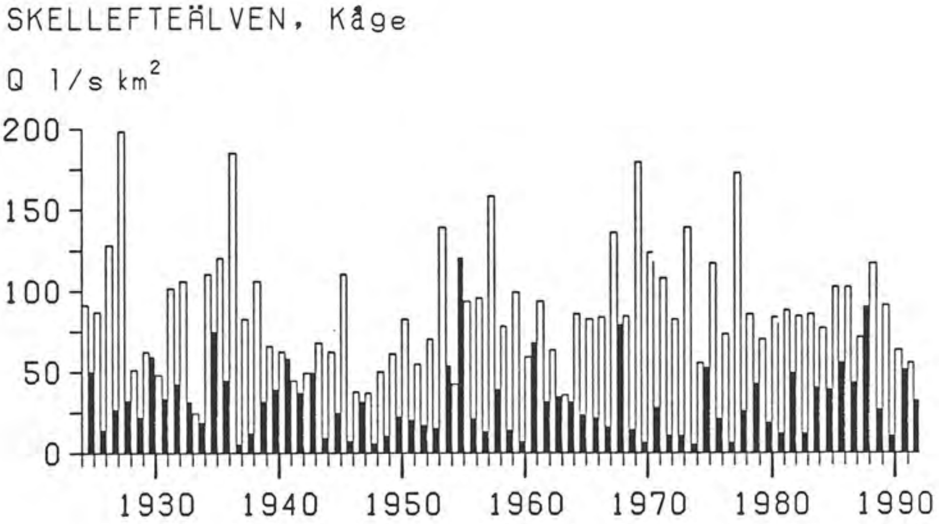
LULEÄLVEN, Niavve

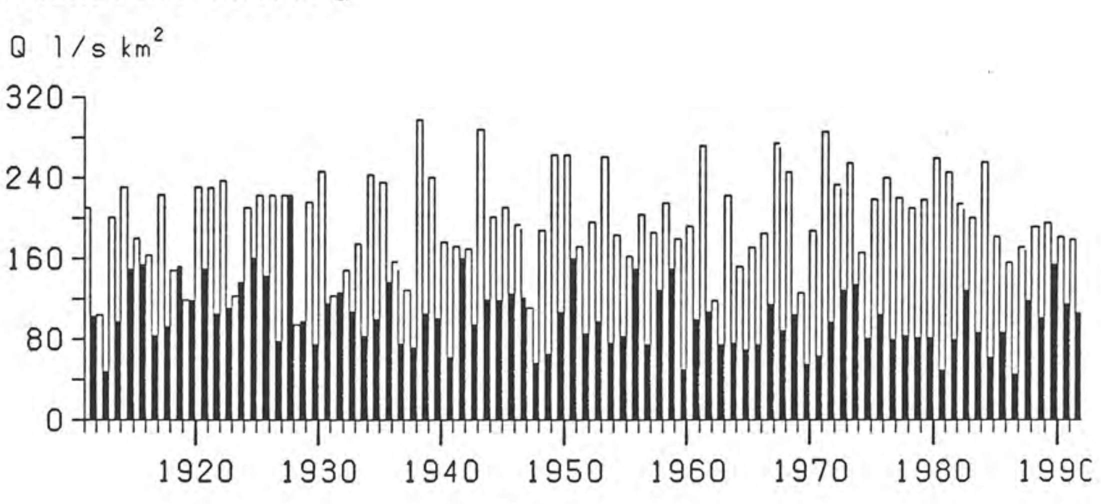


PITEÄLVEN, Stenudden

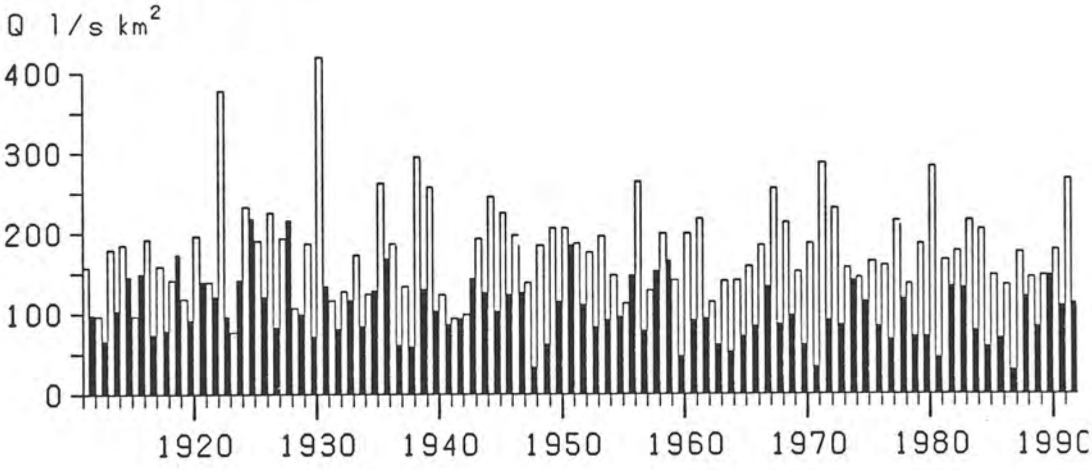



PITEÄLVEN, Sikfors krv
Q l/s km²
100
75
50
25
0
1930
1940
1950
1960
1970
1980
1990


SKELLEFTEÄLVEN, Kåge
Q l/s km²
200
150
100
50
0
1930
1940
1950
1960
1970
1980
1990


UMEÄLVEN, Solberg
Q l/s km²
320
240
160
80
0
1920
1930
1940
1950
1960
1970
1980
1990

UMEÄLVEN, Laisan



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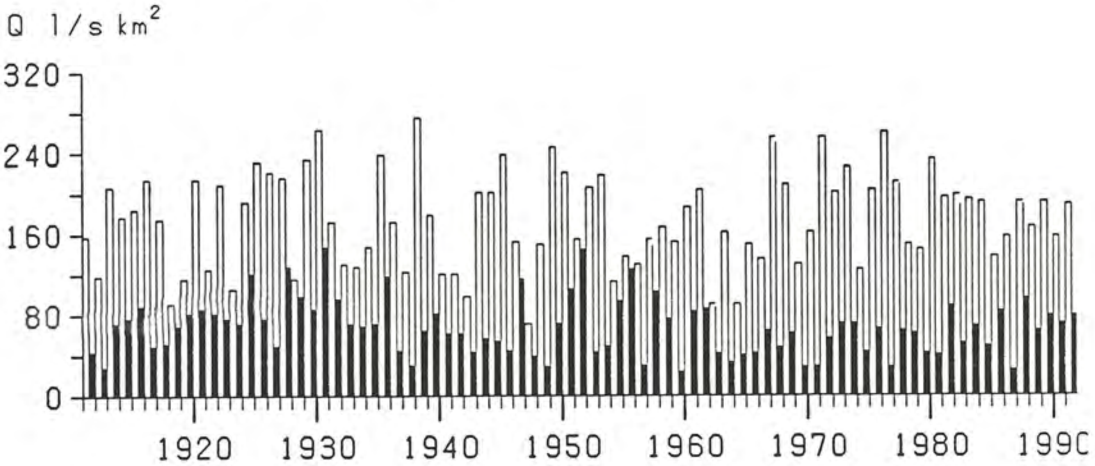

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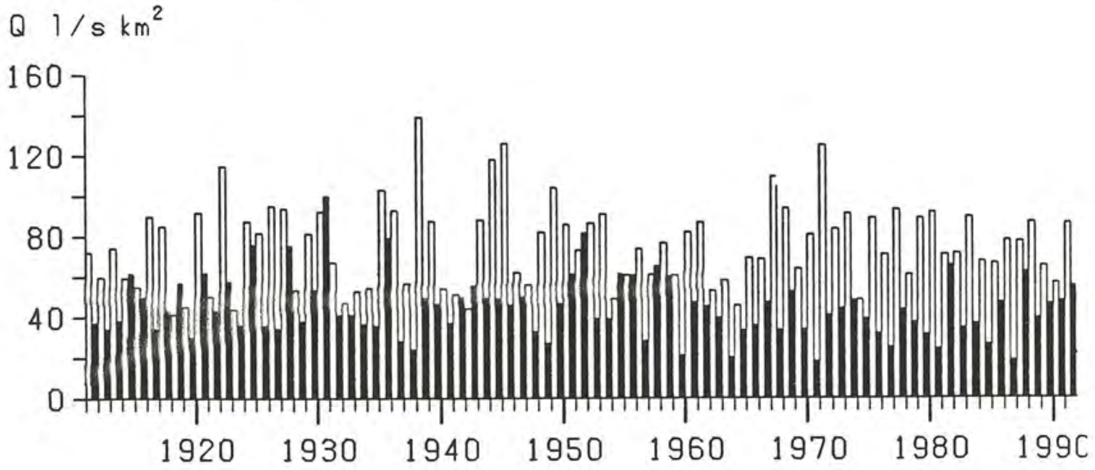
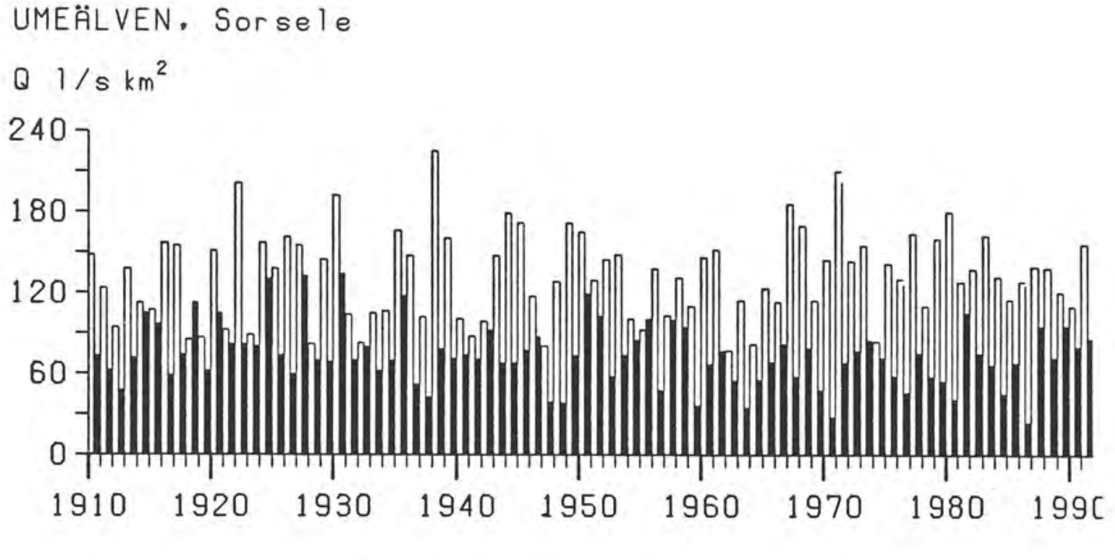
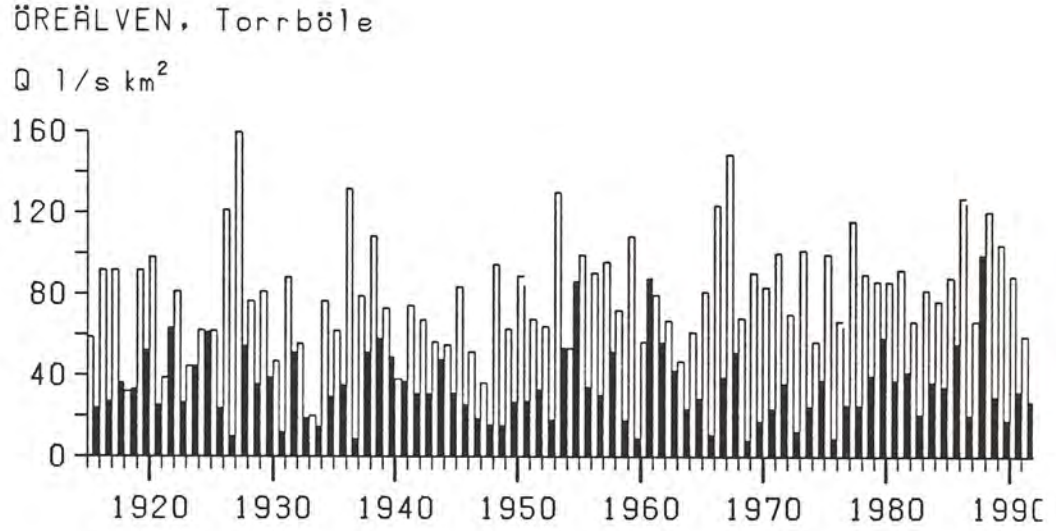
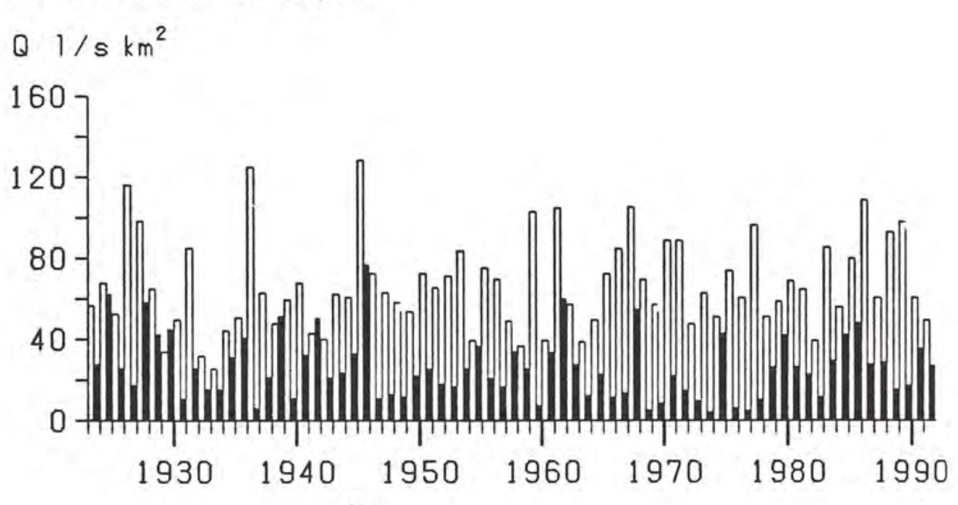
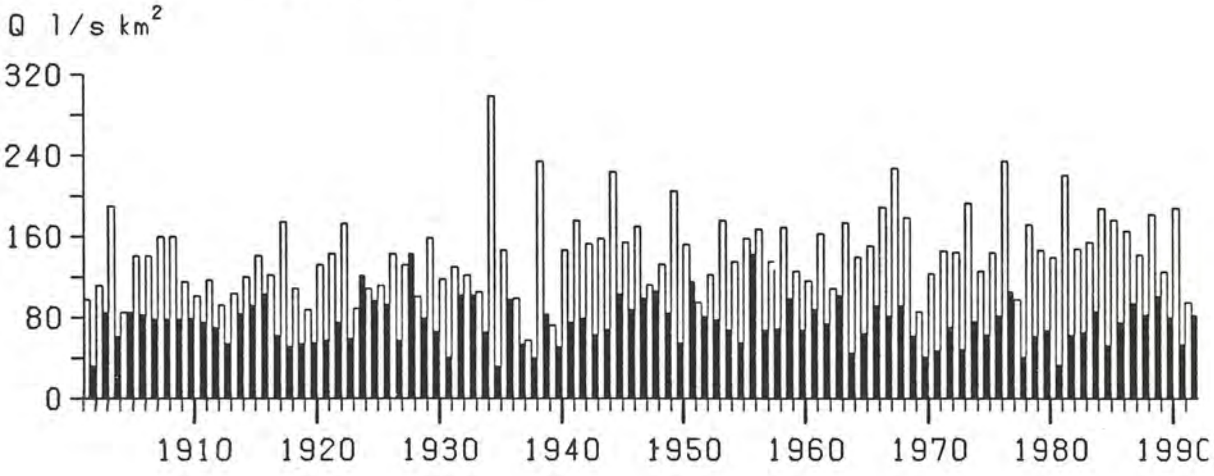
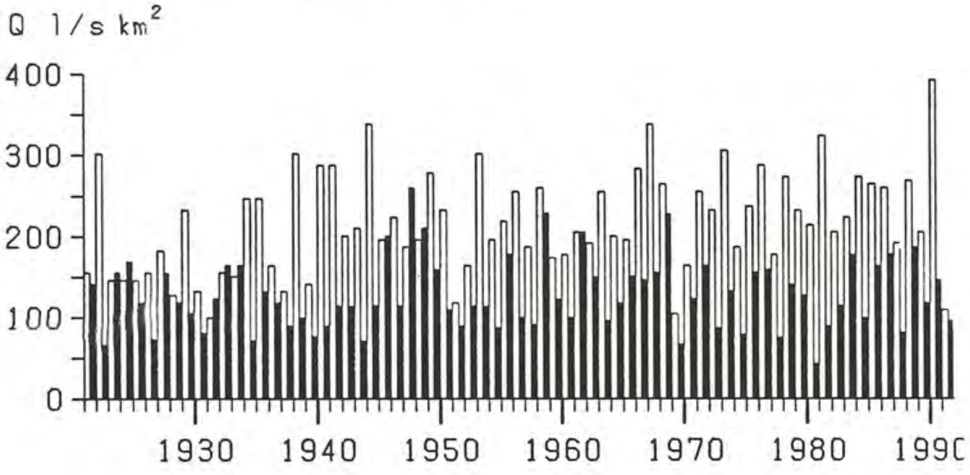


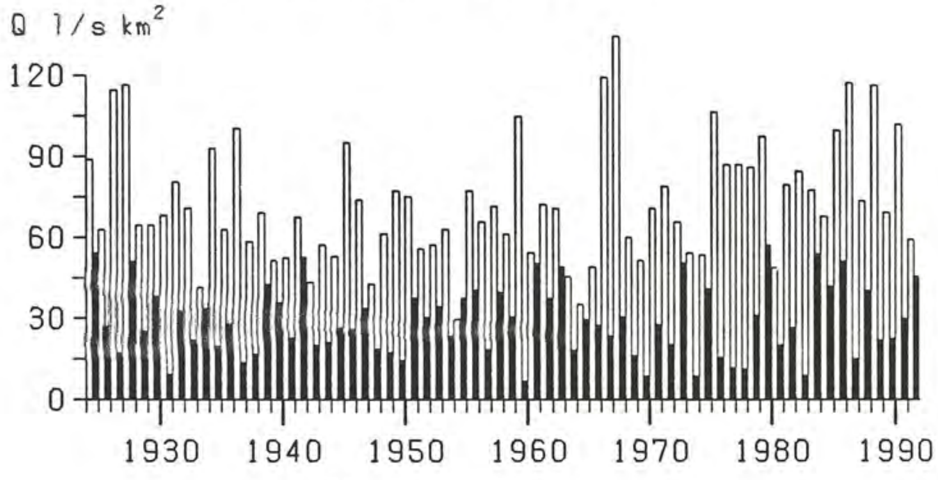

UMEÄLVEN, Sorsele
Q l/s km²
240
180
120
60
0
1910
1920
1930
1940
1950
1960
1970
1980
199

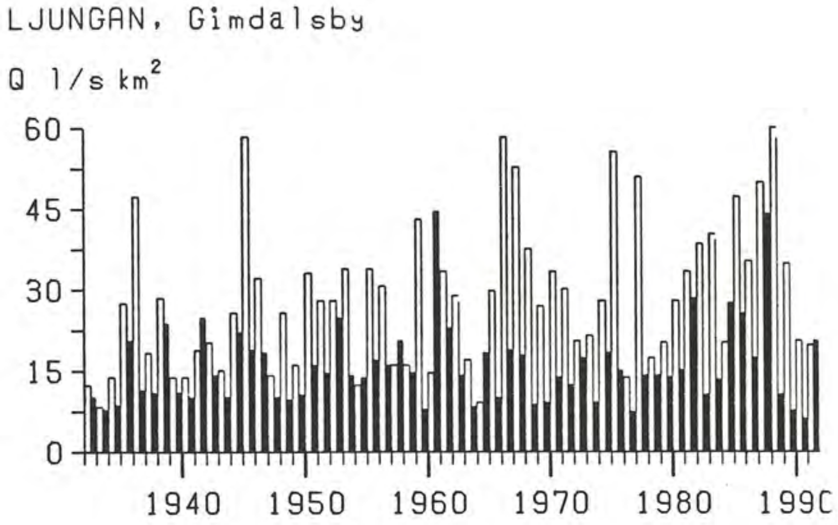

ÖREÄLVEN, Torrböle
Q l/s km²
160
120
80
40
0
1920
1930
1940
1950
1960
1970
1980
199

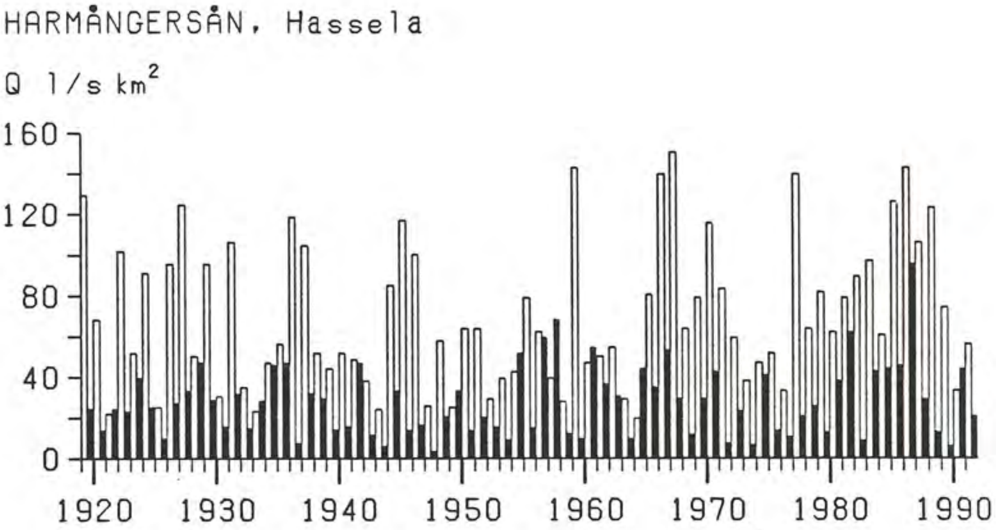

MOÄLVEN, Anundsjön
Q l/s km²
160
120
80
40
0
1930
1940
1950
1960
1970
1980
1990

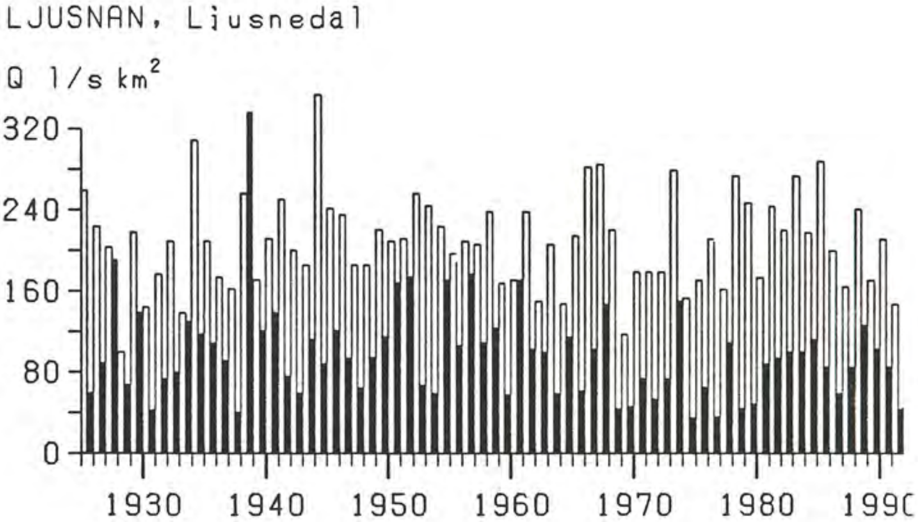

INDALSÄLVEN, Öster-Noren

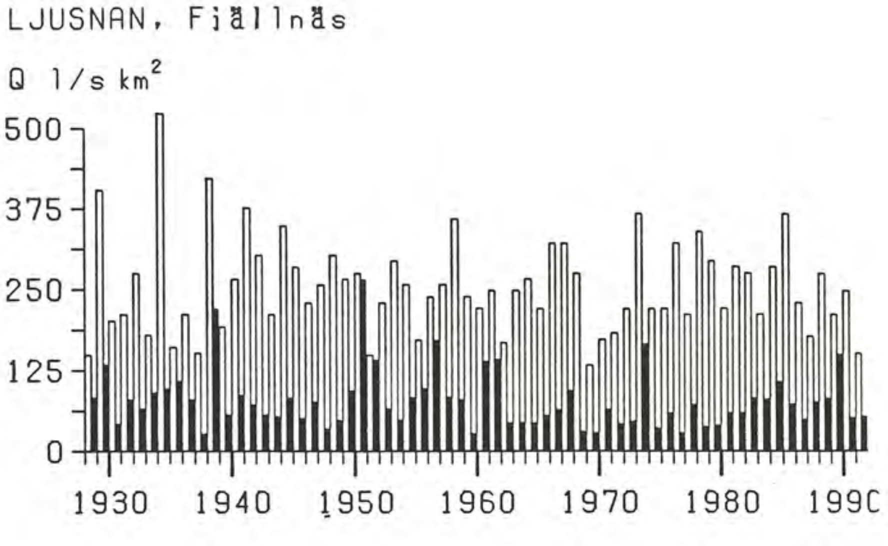

INDALSÄLVEN, Medstugusjön

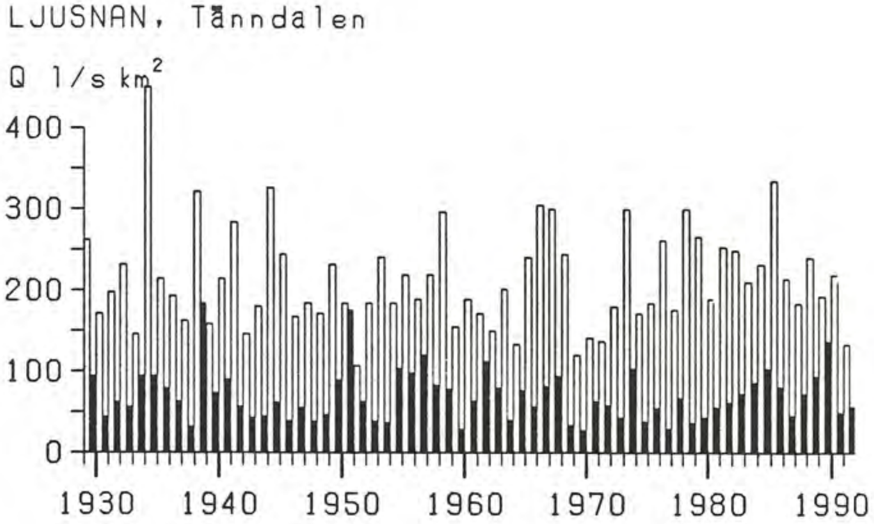

INDALSÄLVEN, Solbergsvattnet

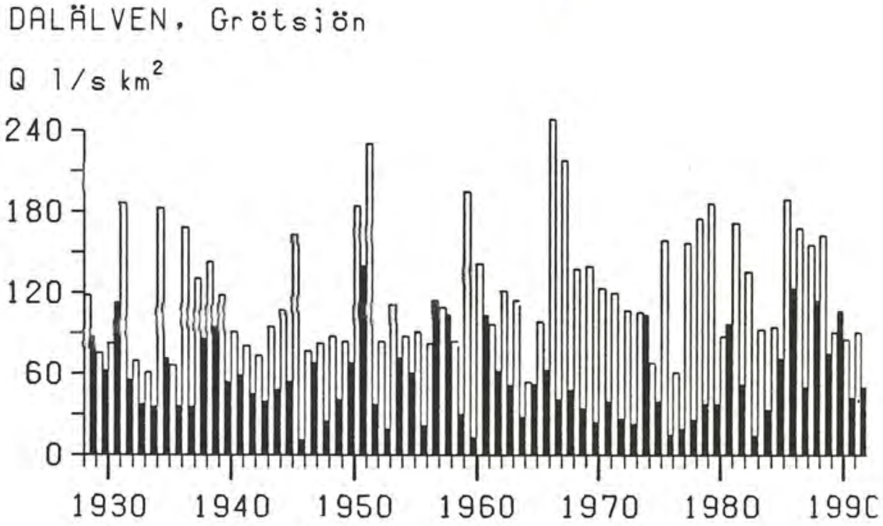

LJUNGAN, Gimdalsby
Q l/s km²
60
45
30
15
0
1940
1950
1960
1970
1980
199


HARMÅNGERSÅN, Hassela
Q l/s km²
160
120
80
40
0
1920
1930
1940
1950
1960
1970
1980
1990

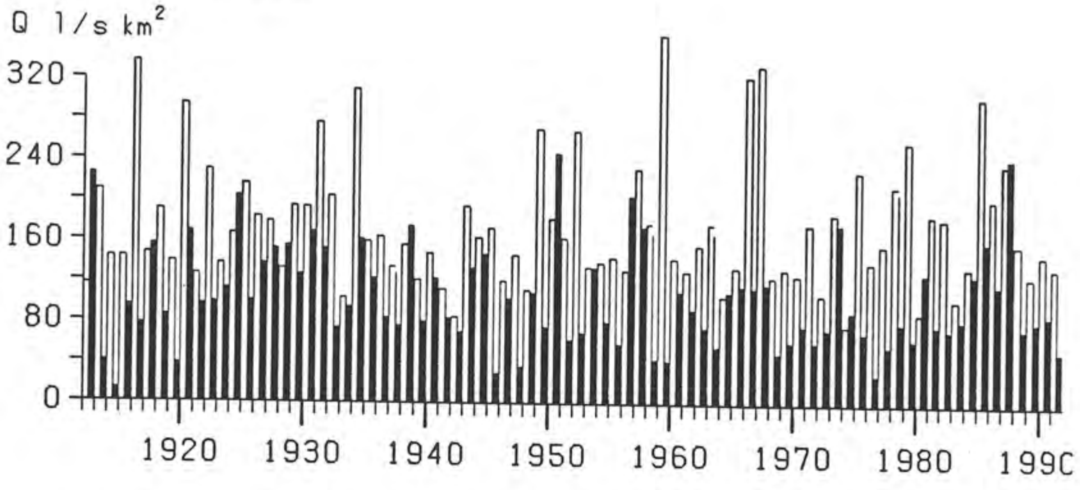

LJUSNAN, Ljusnedal
Q l/s km²
320
240
160
80
0
1930
1940
1950
1960
1970
1980
199


LJUSNAN, Fjällnäs
Q l/s km²
500
375
250
125
0
1930
1940
1950
1960
1970
1980
1990

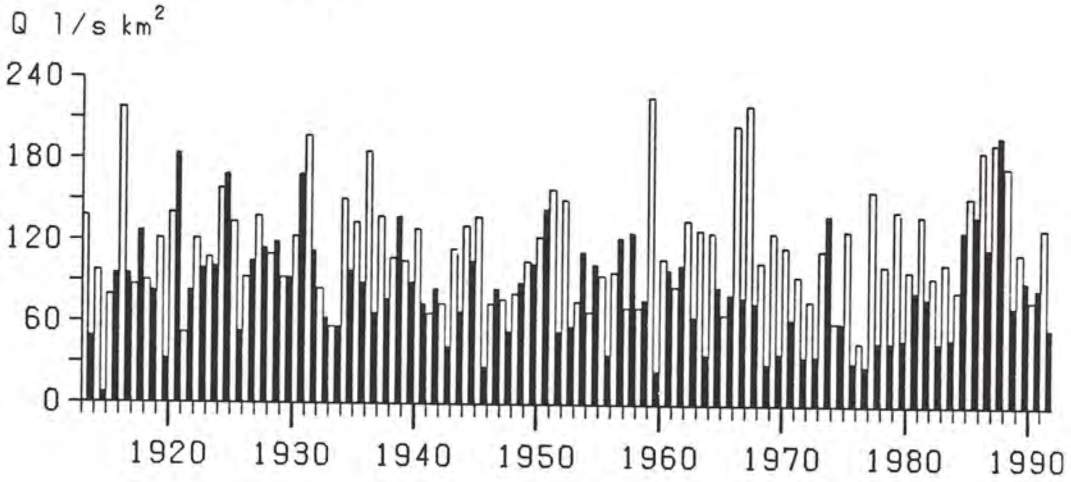

LJUSNAN, Tänndalen
Q l/s km²
400
300
200
100
0
1930
1940
1950
1960
1970
1980
1990


DALÄLVEN, Grötsjön
Q l/s km²
240
180
120
60
0
1930
1940
1950
1960
1970
1980
1990

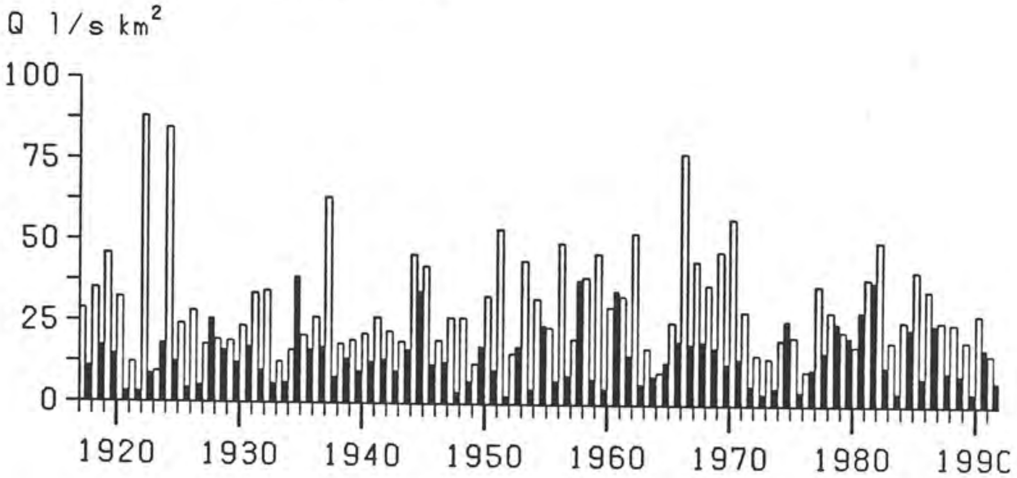
DALÄLVEN, Ersbo

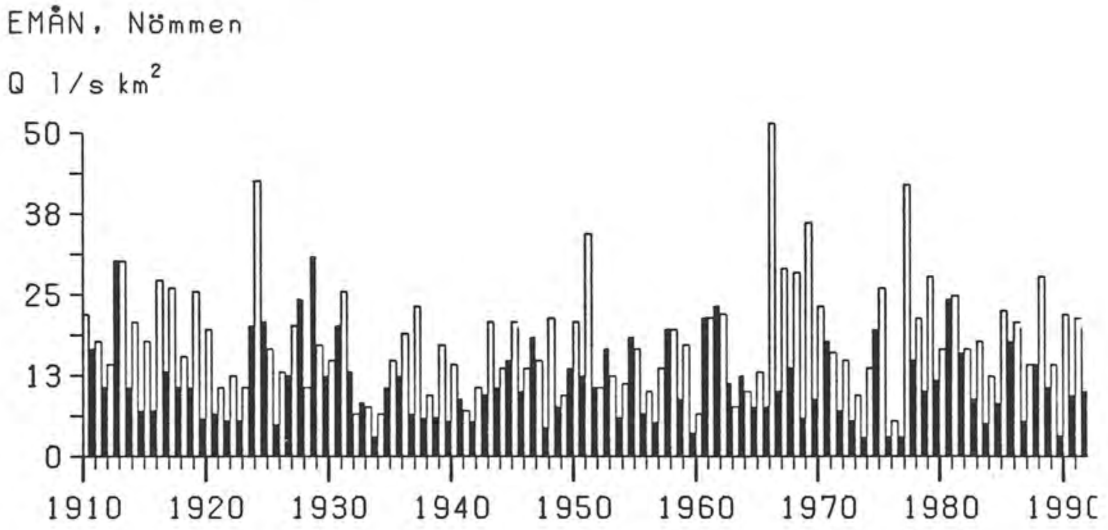


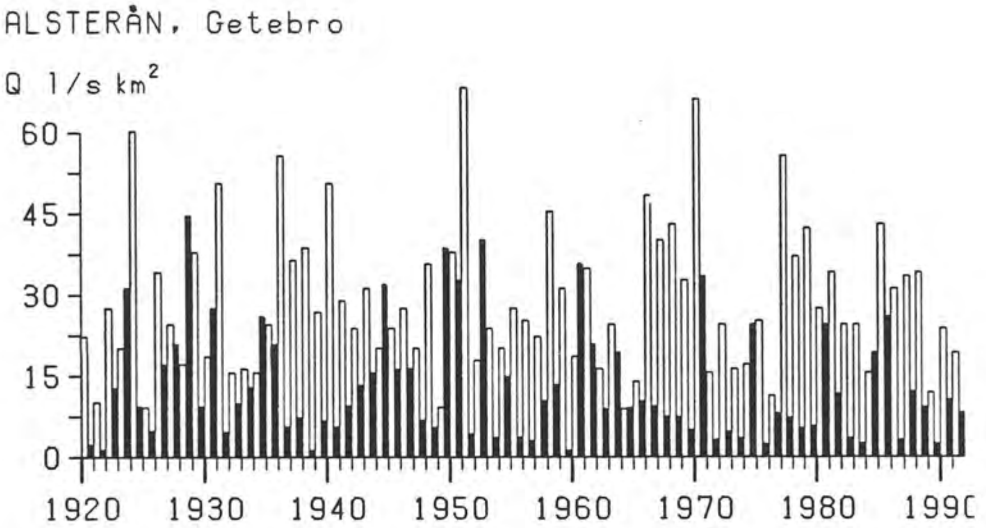
DALÄLVEN, Fulunäs

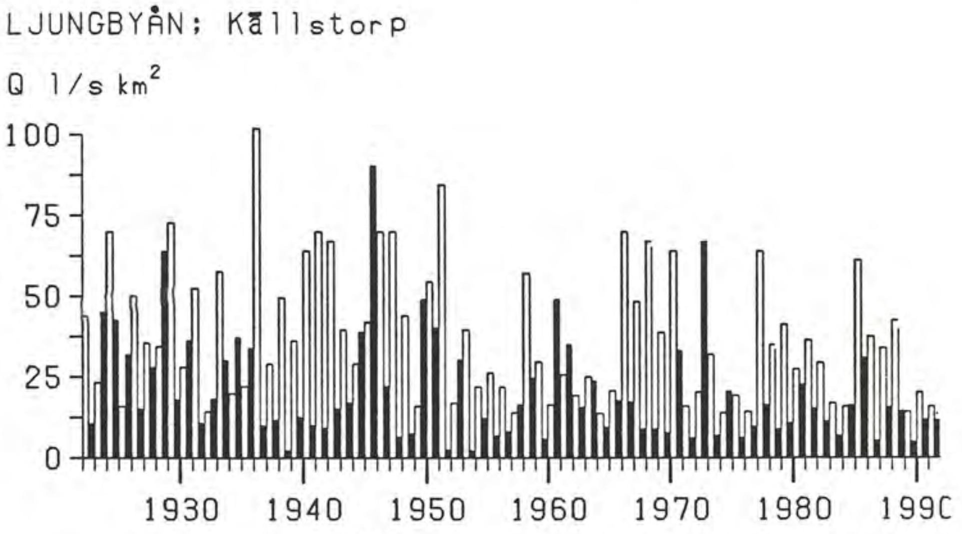


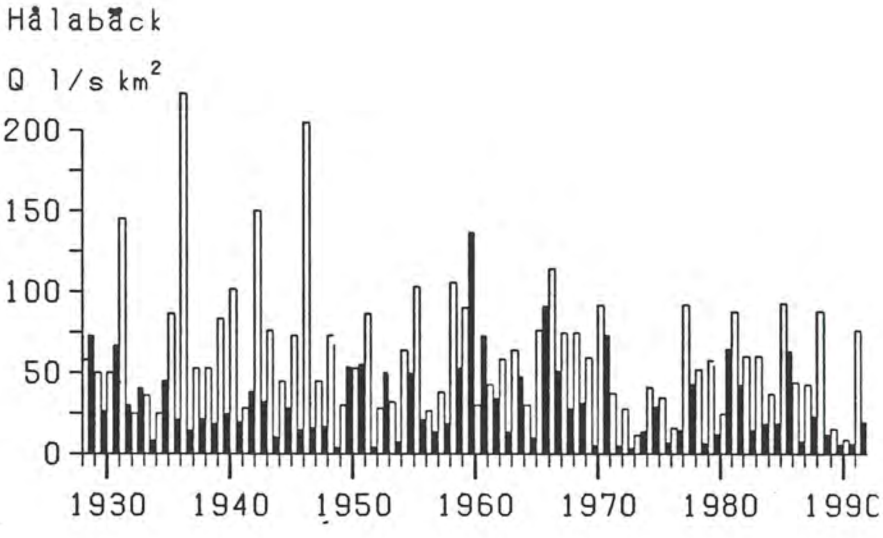
VATTHOLMAÅN, Vattholma

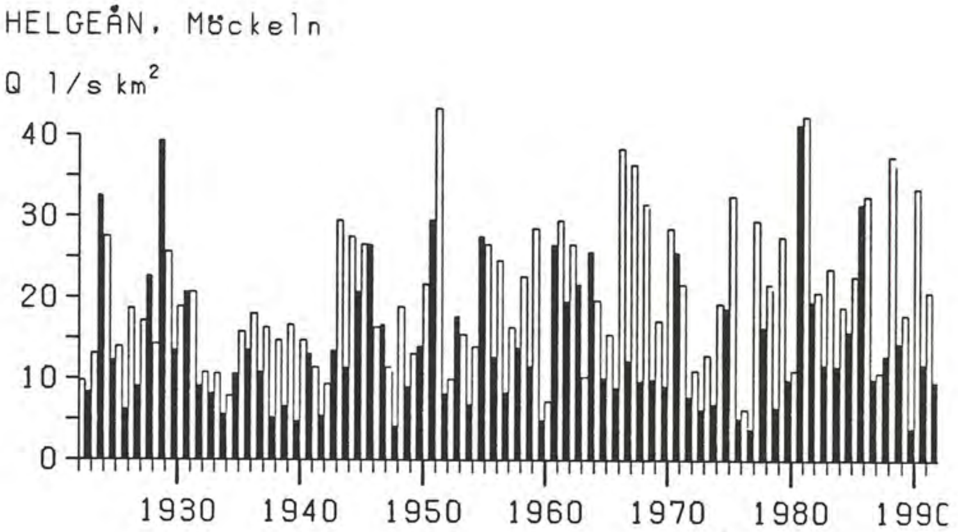


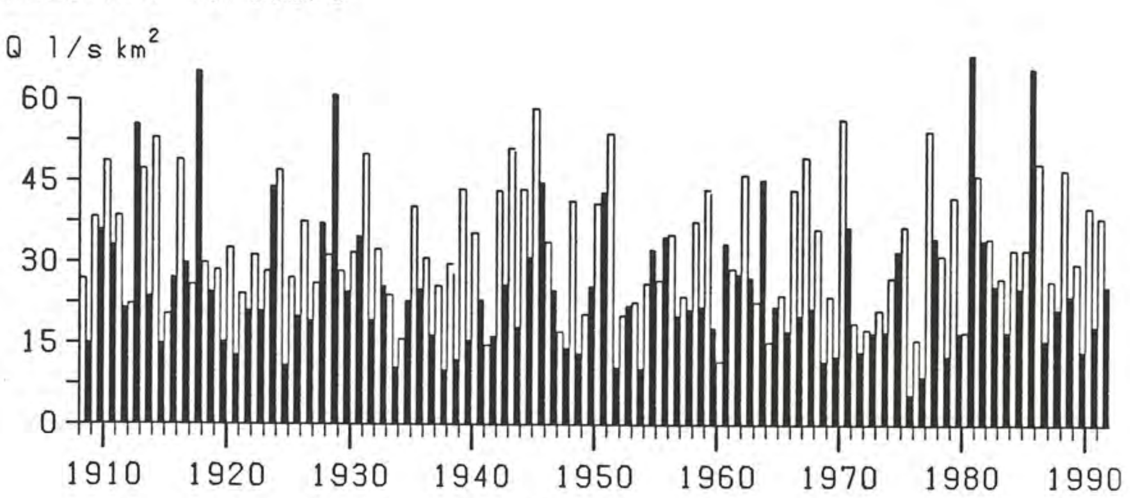

EMÅN, Nömmen
Q l/s km²
50
38
25
13
0
1910
1920
1930
1940
1950
1960
1970
1980
1990

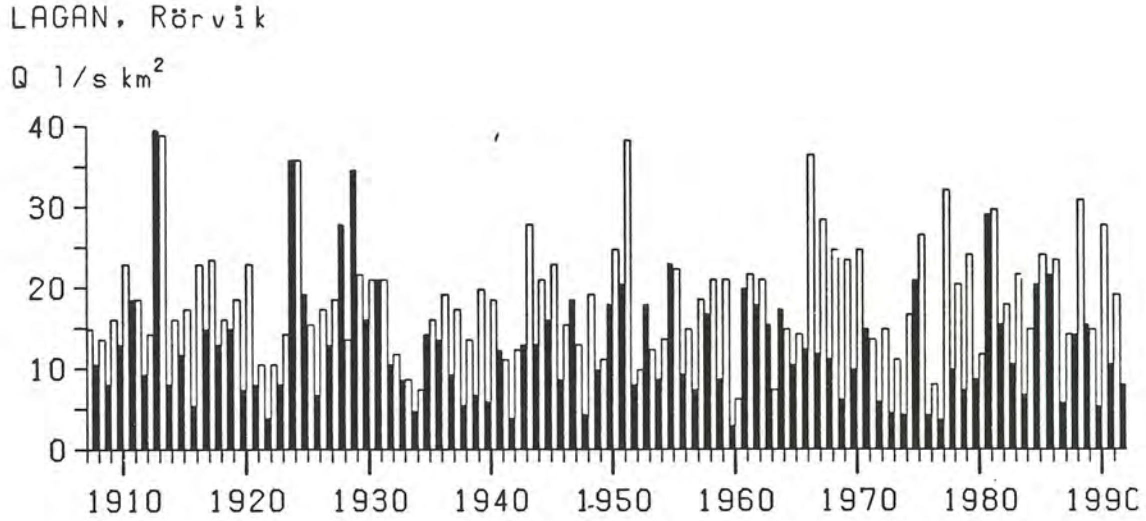

ALSTERÅN, Getebro
Q l/s km²
60
45
30
15
0
1920
1930
1940
1950
1960
1970
1980
1990

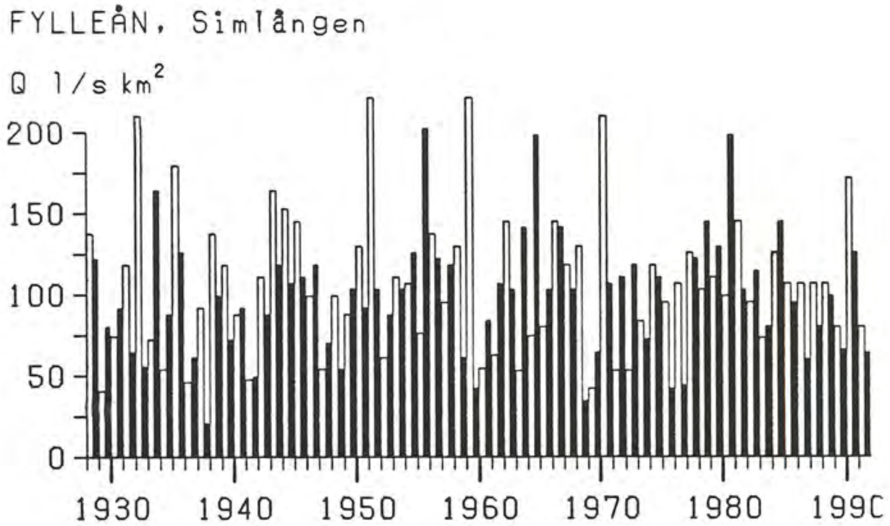

LJUNGBYÅN; Källstorp
Q l/s km²
100
75
50
25
0
1930
1940
1950
1960
1970
1980
1990

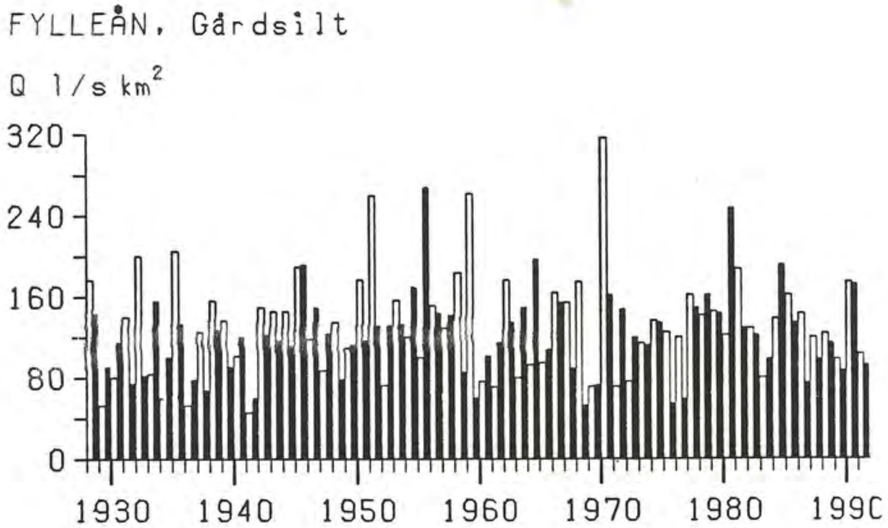

Hålabäck
Q l/s km²
200
150
100
50
0
1930
1940
1950
1960
1970
1980
1990


HELGEÅN, Möckeln
Q l/s km²
40
30
20
10
0
1930
1940
1950
1960
1970
1980
1990

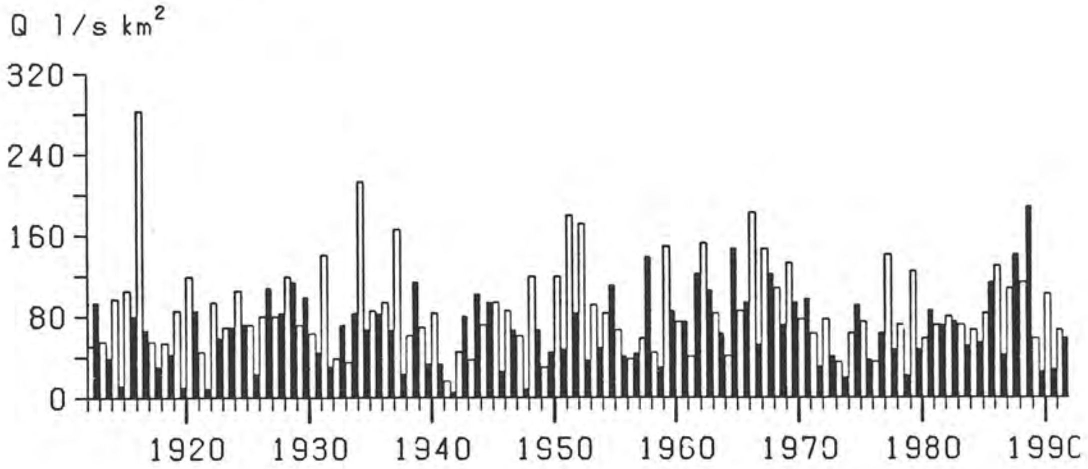

HELGEÅN, Torsebro
Q l/s km²
60
45
30
15
0
1910
1920
1930
1940
1950
1960
1970
1980
1990


LAGAN, Rörvik
Q l/s km²
40
30
20
10
0
1910
1920
1930
1940
1950
1960
1970
1980
1990

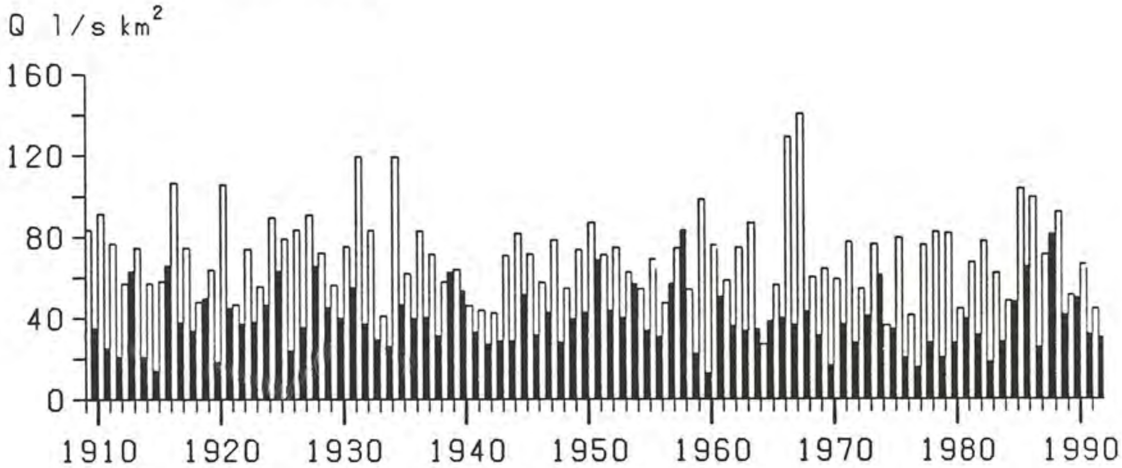

FYLLEÅN, Simlången
Q l/s km²
200
150
100
50
0
1930
1940
1950
1960
1970
1980
1990


FYLLEÅN, Gårdsilt
Q l/s km²
320
240
160
80
0
1930
1940
1950
1960
1970
1980
1990

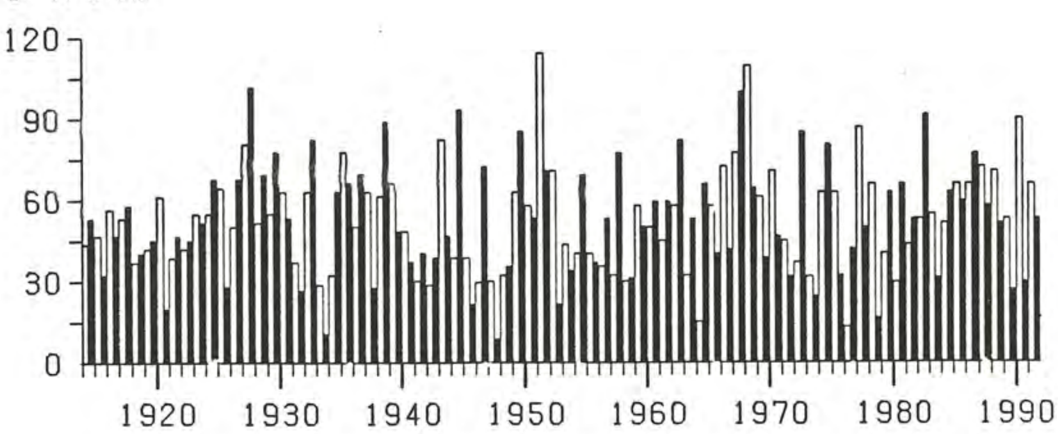
GÖTA ÄLV, Magnor



GÖTA ÄLV, Nybergsund



ENNINGDALSÄLVEN, Vassbotten



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