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PUBLICATION

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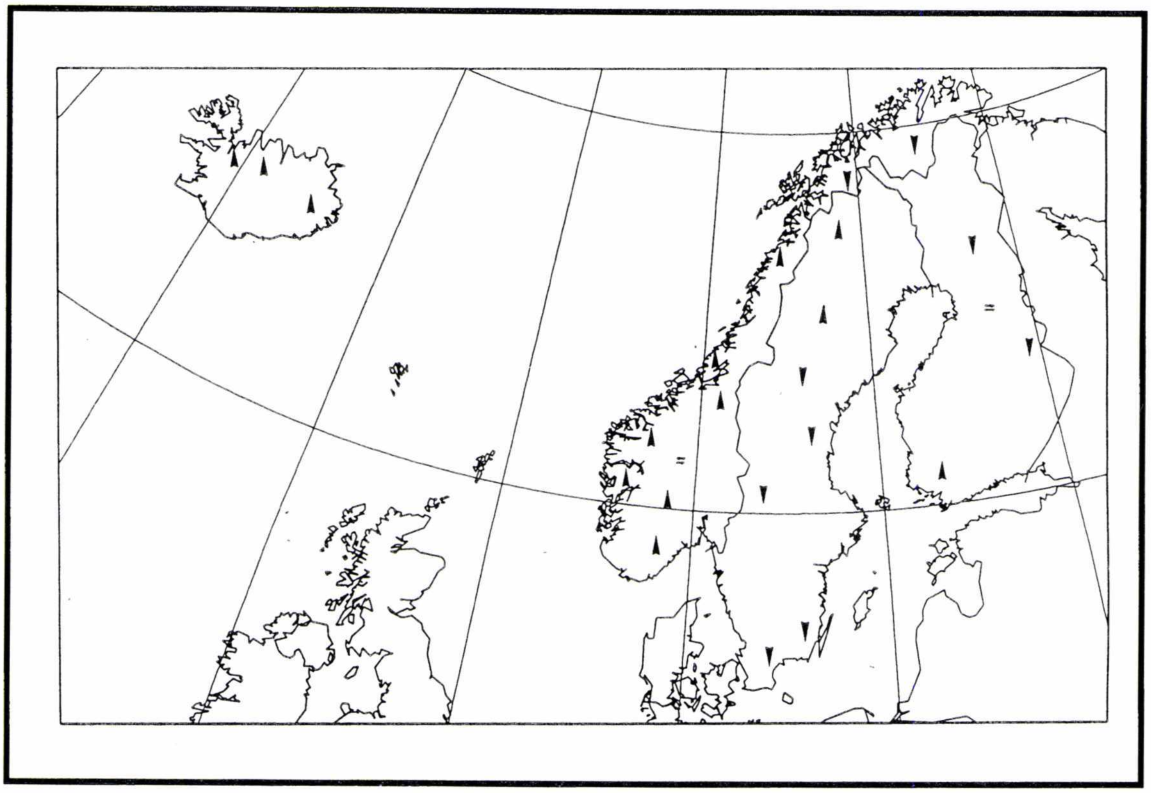
# CLIMATE CHANGE AND ENERGY PRODUCTION - STATISTICAL FLOOD FREQUENCY ANALYSIS



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ABSTRACT

This flood frequency analysis was done as a part of the Nordic project "Climate change and energy production." The goal has been to find the regional trends in changes in flood frequencies in the Nordic countries, resulting from different climate change scenarios.
Different climate change scenarios have been used; change of temperature, without precipitation change, and change in both temperature and precipitation.

The result of the analyses is that the springfloods are decreasing while the floods in the autumn are increasing.The annual flood is decreasing in those parts of the Nordic countries where the springflood is dominating, while the annual flood will increase in those part of the Nordic countrie where the autumn flood is dominating.

SAMMENDRAG

Denne publikasjonen beskriver det arbeid som er gjort for å studere endringer av flomstørrelser ved en eventuell fremtidig klimaendring. Arbeidet er en del av det nordiske prosjektet "Climate change and energy production". Det er foretatt flomfrekvensanalyse på 24 nordiske serier. Analysen har sammenliknet beregnede middelflommer, Q100 og Q1000 verdier under dagens forhold mot de forhold en kan få 30 og 100 år frem i tid. Endringene som er simulert er endringer i bare temperatur, og endringer i både temperatur og nedbør.

Resultatene viser grovt sett at vårflommene avtar mens høstflommene øker. Årsflommene reduseres der vårflommene er årets største flom, mens årsflommen øker i de områder der høstflommene dominerer. Bildet er imidlertid sammensatt og det er variasjoner både innad i Norden og mellom de ulike scenariene.



SUBJECT TERMS

Climate change
Flood frequency


RESPONSIBLE

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Director, Hydrology Department

## PREFACE

This report presents the flood frequency analysis that has been carried out as part of the Nordic project "Climate Change and Energy Production". The project, running from 1991 to 1995, is supported by the Nordic Council of Ministers. The main objects of the project is to develop scenarios and forecasts for runoff and hydropower production potential for a time horizon of up to 100 years, given the state-of-art information on climatic change and using the best available analysis tools.

The flood frequency analyses presented here, are based on runoff series for different climate scenarios produced as a collaborative effort, both in model development and runoff simulations, by the Nordic project group.

Oslo, October 1995

Kjell Repp
seksjonssjef

**CONTENTS**

# 1 INTRODUCTION

This flood frequency analysis is part of the Nordic project "Climate change and Energy production." The objective has been to study climate change induced regional and seasonal trends in the flood regimes in the Nordic countries.

Flood characteristics are not only influenced by precipitation - soil moisture content, which is strongly affected by evapotranspiration, is another factor, and in high latitude and mountain areas the snow regime is of great importance. All these components are influenced by climate change. The influence of changes in the snow regime is through two effects:

- snow melt floods are a combined effect of winter precipitation accumulation and meteorological conditions during the snow melt period

- reduction of the length of the period with snow fall and snow covered ground increases the length of the rain flood season - and flood statistics is a combination of precipitation statistics and the probability of the precipitation falling as rain and on the catchment in a critical state (high soil moisture content)

The first effect tends to reduce the spring flood, the second effect to increase the autumn/winter rain and combined rain/melt floods. In the Nordic hydrological regimes, the flood characteristics can thus change quite dramatically even without changes in precipitation statistics. These changes are fairly well simulated by temperature index methods (Bergström *et al.*, 1992).

# 2 CATCHMENTS

The catchment selected should have input data (temperature and precipitation) covering the period 1961-90, but it has not been possible to obtain this for all catchments. Twentyfour catchment where included in the analysis (table 1 and figure 1).

*Table 1. Catchment used in the analysis.*

| Country | Number of catchments | Number of years |
|---|---|---|
| Finland | 4 | 30 |
| Iceland | 3 | 15-25 |
| Norway | 10 | 30 |
| Sweden | 7 | 20 |

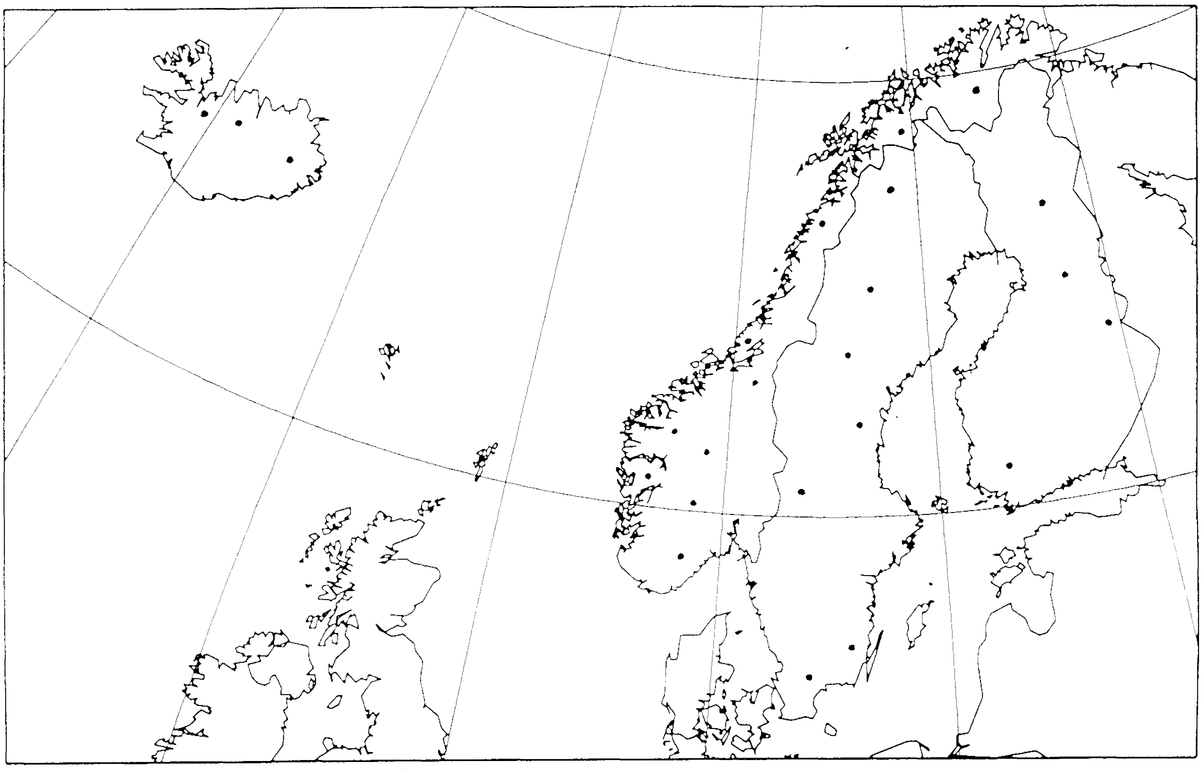

*Figure 1. Location of the catchments used in the analysis.*

## 3 DATA SERIES

A set of climate change runoff series has been produced for the project "Climate change an energy production" (Sælthun *et al.*, 1994a; 1994b). The principal tool for establishing these series has been the HBV model - a rainfall-runoff model in widespread use both within and outside Scandinavia (Bergström, 1992). For the project, a modified version has been used (Sælthun, 1995). The simulations have been based on climate change scenarios established by a Nordic expert group (Jóhannesson *et al.*, 1995). These scenarios indicate temperature increases of 0.4 deg C per decade (more in the continental areas, less in the Atlantic region), and precipitation increases of 1.5 percent per decade (somewhat more on the west coast of Norway). Seasonal changes is also indicated.

Based on these "best guess" predictions, actual daily value temperature and precipitation series have been manipulated into scenario sceries by increasing the temperature and the precipitation by the changes indicated by the scenario group. Such series has been established for time horizons +30 and +100.

Simulated values were used for all the analysis. This is the case both for the control period and for the different climate change scenarios.

On this background different climate change scenarios have been used:

1) Change of temperature, same precipitation as present. (T)
2) Change in both temperature and precipitation. (T & P)

This gives five different simulated series:

1) Control data, present situation
2) Change of temperature, no change in precipitation, + 30 years
3) Change of both temperature and precipitation, + 30 years
4) Change of temperature, no change in precipitation, + 100 years
5) Change of both temperature and precipitation, + 100 years

More details on the scenarios and the data series simulations are found in Sælthun *et al.* (1994a; 1994b).

When analysing these results, it is important to keep in mind that a fairly subjective choice of strategy for adjusting the precipitation amount has been made. The number of precipitation days has been kept unchanged, and all precipitation amounts have been adjusted with the same factor. The precipitation extremes have thus been changed with the same ratio as the average precipitation. Seen isolated, this is probably a high estimate of change of precipitation intensity, as it is quite natural to expect also the number of precipitation events and precipitation days to increase - this would point to a smaller increase in extremes than in average values. Investigations of the historical variations of precipitation statistics for western Norway show that even though most stations display a strong increase in precipitation in the last decades, the number of precipitation days has increased nearly proportionally, and the extreme precipitation statistics do not display any increase (Førland, 1993). The precipitation increase in this area is mainly caused by a higher number of autumn and winter frontal passages. Other regions display different relationships between annual precipitation and extreme precipitation.

For most of the simulations, the same model version has been used (Sælthun, 1995). However, for the Finnish catchments, the Finnish flood forecasting version of the HBV model has been applied (Vehviläinen, 1994). This model has a slightly different algorithm for calculating potential evapotranspiration, which tends to give less increases in actual evapotranspiration with temperature than the model used for the other catchments. The result of this is that the Finnish simulations give higher runoff under climatic change conditions. This could be regarded as an illustration of some of the model uncertainty in this study. For one of the catchments, Loimijoki in south Finland, results from both models are presented.

*Table 2. Frequency factor, K(T), for different sample sizes.*

| Sample size | Return period 100 years | Return period 1000 years |
|---|---|---|
| 15 | 4.005 | 6.265 |
| 19 | 3.870 | 6.058 |
| 25 | 3.729 | 5.842 |
| 28 | 3.683 | 5.773 |
| 29 | 3.668 | 5.750 |
| 30 | 3.653 | 5.727 |
| ∞ | 3.137 | 4.936 |

## 4 FLOOD FREQUENCY ANALYSIS METHODOLOGY

The analysis of the flood frequency was done for different seasons; spring and autumn, and on annual series. Seasons are separated in the following way:

Spring: February 1. - July 31.
Autumn: August 1. - January 31.

The annual series were generated from the highest value of the two; spring or autumn.

In the analysis the Gumbel distribution (Extreme value distribution, Type 1, EVI) is used, estimated by the moment method, to calculate floods with a return period of 100 and 1000 years (Q100 & Q1000). The following equation has been used:

$$Q_T = Q_m + K(T) \bullet S$$

where $Q_T$ is a flood with the selected return period, $Q_m$ is the mean flood, S is the standard deviation of the floods and K(T) is a frequency factor (tab. 2) taken from Haan (1977). Values not available in Haan (1977) were calculated with linear interpolation.

An analysis of the seasonal distribution of floods has been carried out. For the control data and for each climate change scenario the years when the spring flood is highest, and years when the autumn flood is highest were analysed separately.

An important aspect is that climate change invalidates to some extent the conditions for use of flood frequency analysis on historical data. The basic assumption in these approaches is that the past, the observed data set, is representative of the future.

# 5 RESULTS

## 5.1 Summarized results

The results of the analysis are presented in details in appendix 1. Table 3 summarizes the main results.

*Table 3. Changes in floods. Numbers show for how many catchments the floods increase (+), decrease (-) or are unchanged (=).*

+30 Year T changed

| | Qm | Q100 | Q1000 |
|---|---|---|---|
| Spring | 1+ 23- | 2+ 21- 1= | 4+ 20- |
| Autumn | 13+ 5- 6= | 12+ 11- 1= | 13+ 11- |
| Annual | 5+ 19- | 7+ 17- | 8+ 16- |

+30 Year T & P changed

| | Qm | Q100 | Q1000 |
|---|---|---|---|
| Spring | 2+ 21 - 1= | 6+ 16- 2= | 7+ 16- 1= |
| Autumn | 19+ 5= | 17+ 2- 5= | 16+ 3- 5= |
| Annual | 6+ 15- 3= | 8+ 15- 1= | 9+ 14- 1= |

+100 Year T changed

| | Qm | Q100 | Q1000 |
|---|---|---|---|
| Spring | 24 - | 2+ 22- | 2 + 22- |
| Autumn | 14+ 9- 1= | 16+ 7- 1= | 15+ 8- 1= |
| A nnual | 3+ 21- | 5+ 19- | 5+ 18- 1= |

+100 Year T & P changed

| | Qm | Q100 | Q1000 |
|---|---|---|---|
| Spring | 2+ 19 - 3= | 4+ 20- | 6+ 18- |
| Autumn | 22+ 2= | 22+ 2= | 21+ 3= |
| Annual | 6+ 15- 3= | 7+ 15- 2= | 9+ 15- |

## 5.2 Discussion of the individual scenarios

### 5.2.1 <u>+30 years: Change of temperature, no change in precipitation</u>

For this scenario the result will be reduced spring floods for Qm, Q100 and Q1000. An exception should be mentioned; Jökulsá i Fljótsdal. This catchment has a much higher glacier coverage than the other catchments, and thus an unusual reaction on an increase in temperature. A few other catchments get higher flood values for Q100 and Q1000. This is probably a spurious result, caused by increased flood variance.

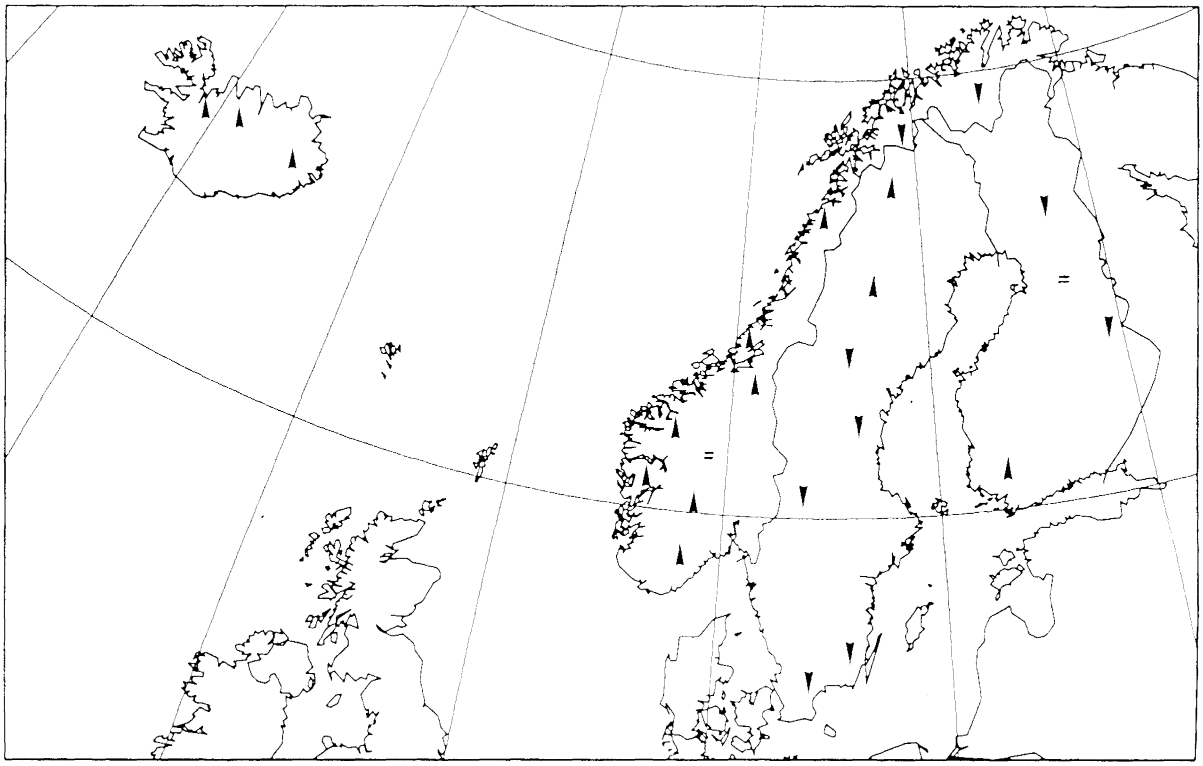

*Figure 2. Autumn floods, +30 years, change in temperature, no change in precipitation.*

The autumn floods will increase in about half the catchments and will decrease in the other half (figure 2). Increases are found in the coastal part of Norway and on Iceland. The reduction in autumn floods is found in the more continental part of Norway, in Sweden and in Finland.

There will be a general decrease in the annual floods, but in some catchments there will be an increase in the annual flood values. Those catchments are located on the western coast of Norway, and the highly glaciated catchment on Iceland; Jökulsá i Fljótsdal.

### 5.2.2 +30 years: Change of temperature and precipitation

This scenario also will result in a decrease in spring floods for Qm, Q100 and Q1000. Also for this scenario Jökulsá i Fljótsdal is an exception, as well as Øyungen in Norway. As mentioned earlier Jökulsá is highly glaciated. For Øyungen the snow melt floods are reduced, but the winter floods, occuring in the same season, are increased.

The autumn flood will increase or be at the same level for all catchments in respect to Qm. For Q100 and Q1000 there is decrease in autumn floods for a few catchments (2 and 3 catchments).

The annual floods are reduced in the more continental catchments that are dominated by snow melt floods, while there is an increase in floods in the coastal part of Norway where the catchments are dominated by rain floods and in Jökulsá on Iceland (figure 3).

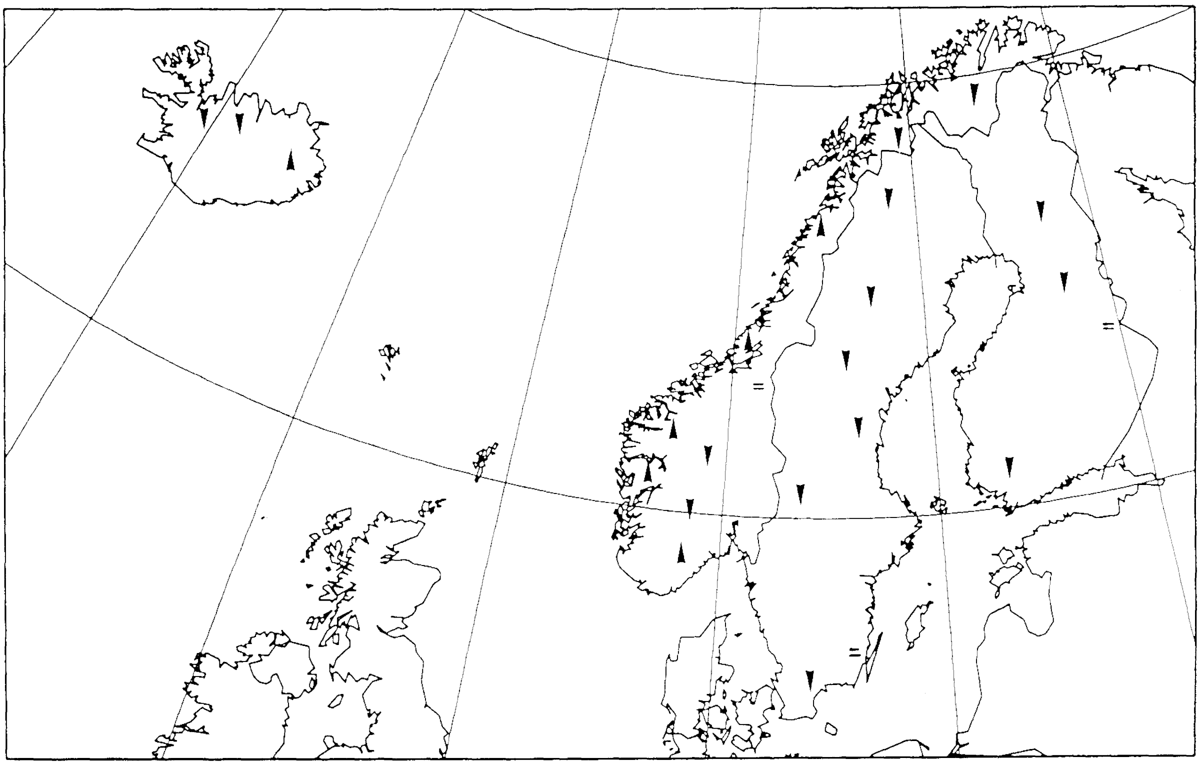

*Figure 3. Annual floods, +30 years, change in temperature and precipitation.*

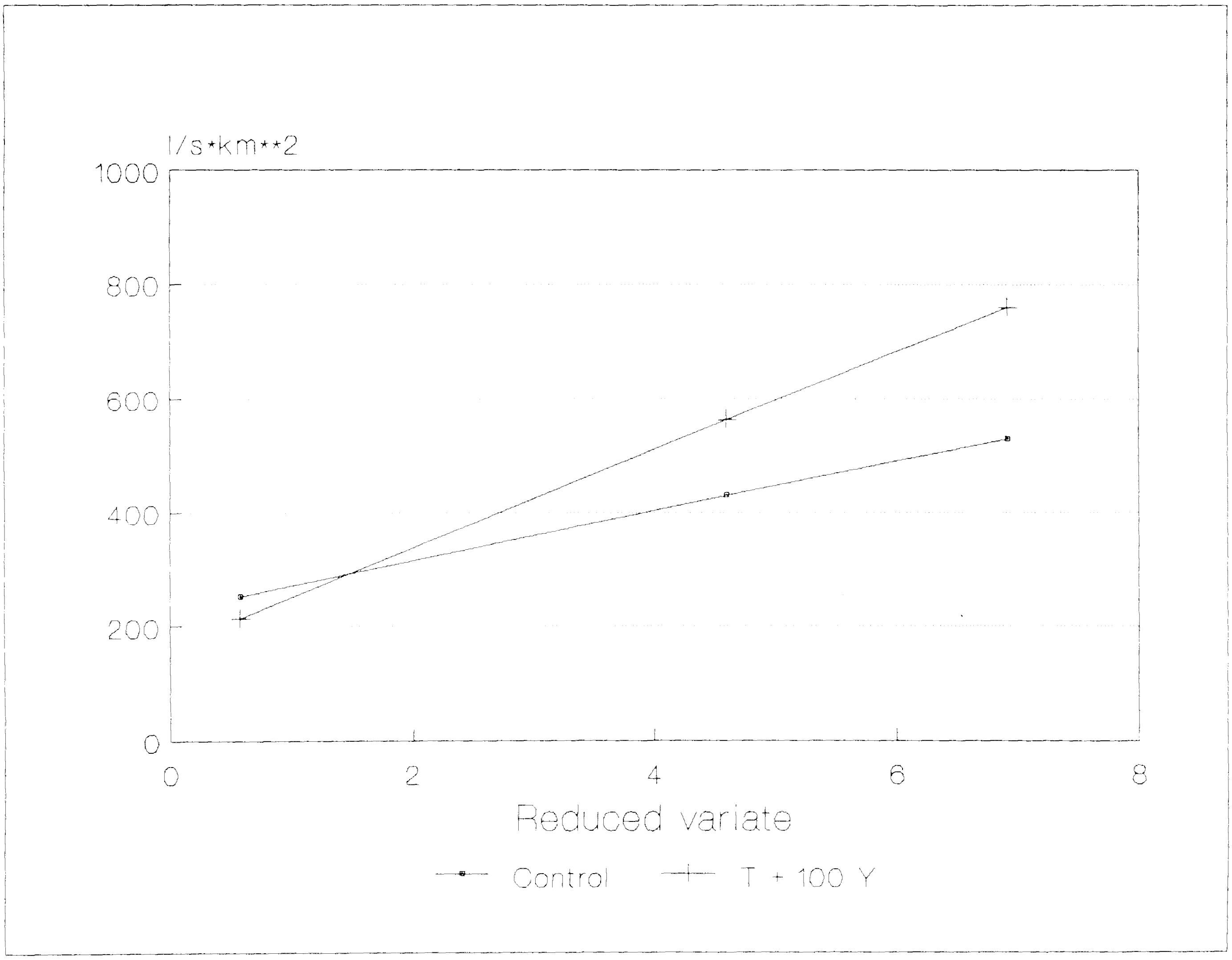


*Figure 4. Calclulated Qm, Q100 and Q1000 for Bulken, Norway.*

### 5.2.3 +100 years: Change of temperature, no change in precipitation

For this scenario it is a decrease in spring floods for all catchments. Two catchments have an increase in the calculated values for Q100 and Q1000. That is Bulken and Skarsvatn i Norway. This is probably a result of the increase in standard deviation values (figure 4).

The autumn floods will increase in about 2/3 of the catchments, decrease in the other 1/3 of the catchments (figure 5). The increases are found on Iceland, Norway and in parts of Sweden. The decreases are found on the east coast of Sweden and in Finland.

The annual floods are decreasing in most catchments. The exceptions are three catchments on the western coast of Norway.

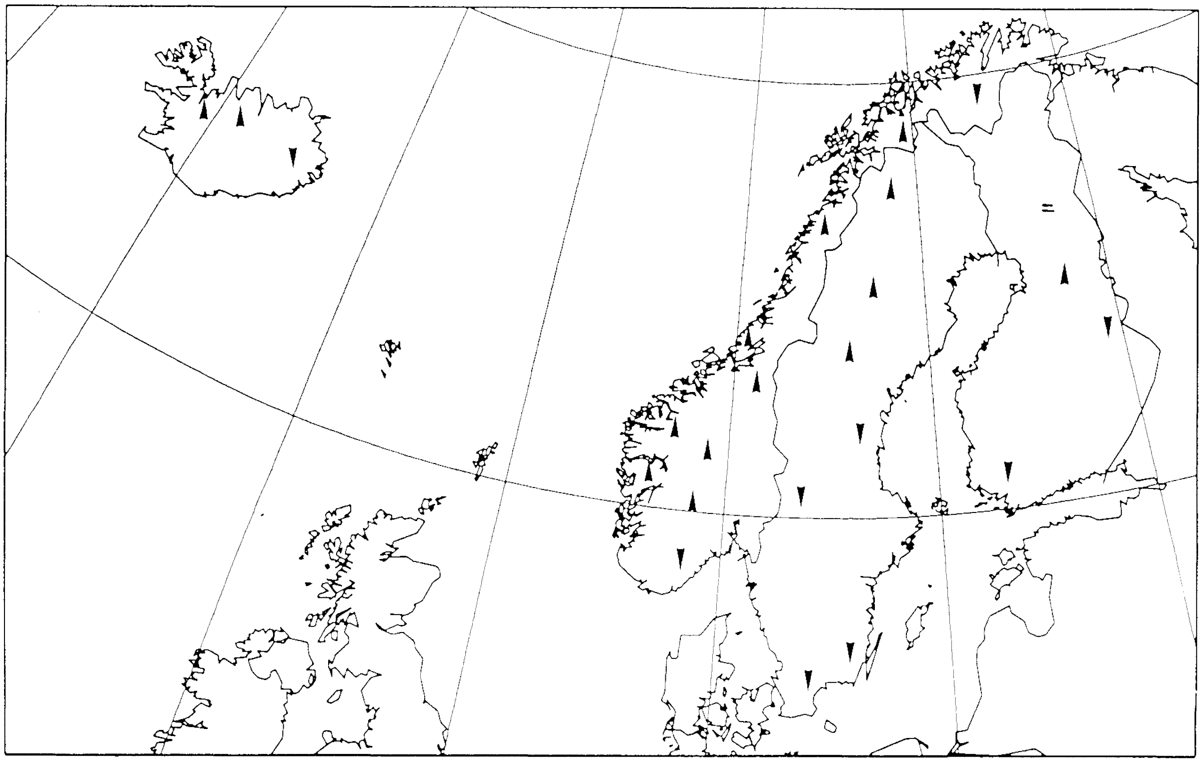

*Figure 5. Autumn floods, +100 years, change of temperature, no change in precipitation.*

5.2.4 +100 years; Change of temperature and precipitation

For this scenario there is a decrease in spring floods for all catchments except two coastal catchments in Norway.

The autumn flood will increase in all catchments for this scenario.

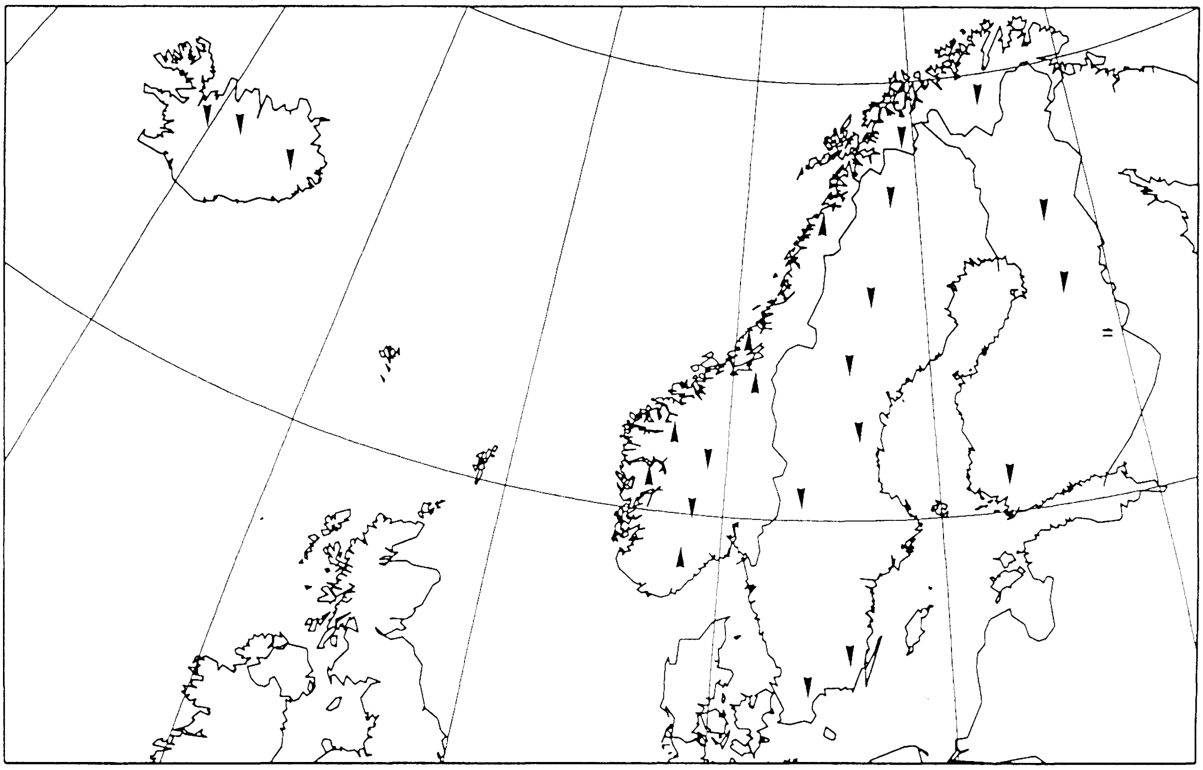

*Figure 6. Annual floods, +100 years, change in temperature and precipitation.*

The annual floods will increase in the catchments on the western coast of Norway. For the rest of the Nordic countries there is a decrease in the annual flood (figure 6).

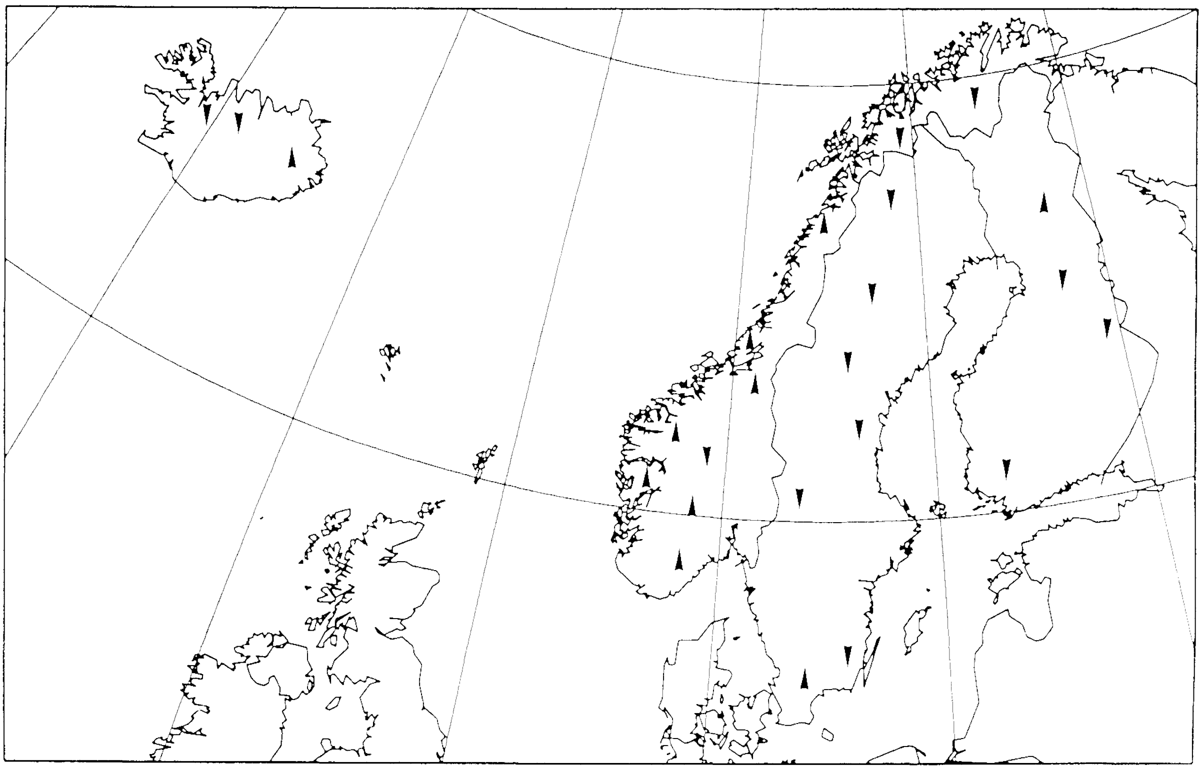

*Figure 7. Changes in Q1000, +30 years, change in temperature and precipitation.*

### 5.3 Change in Q1000

In connection with dam safety it is of special interest to take a closer look on the Q1000, the flood with a return period of 1000 year. The change in Q1000, independent of season, is therefore analysed in more detail. The scenario used is change in both temperature and precipitation, calculated for +30 years and +100 years.

The 30 year scenario into the future shows an increase in Q1000 values for 10 catchment and a decrease for 13 catchments (figure 7). The increases are on the western coast of Norway and Sweden and in the glaciated catchment on Iceland (Jökulsá in Fljótsdal).

For the 100 year scenario into the future the same pattern is seen (figure 8). In this scenario 14 catchments show increase in Q1000 values while 9 display decrease. The increases will take place on the western coast of Norway and in some of the more continental catchments in Norway. In addition most of the catchments in Sweden will have an increase in Q1000 values.

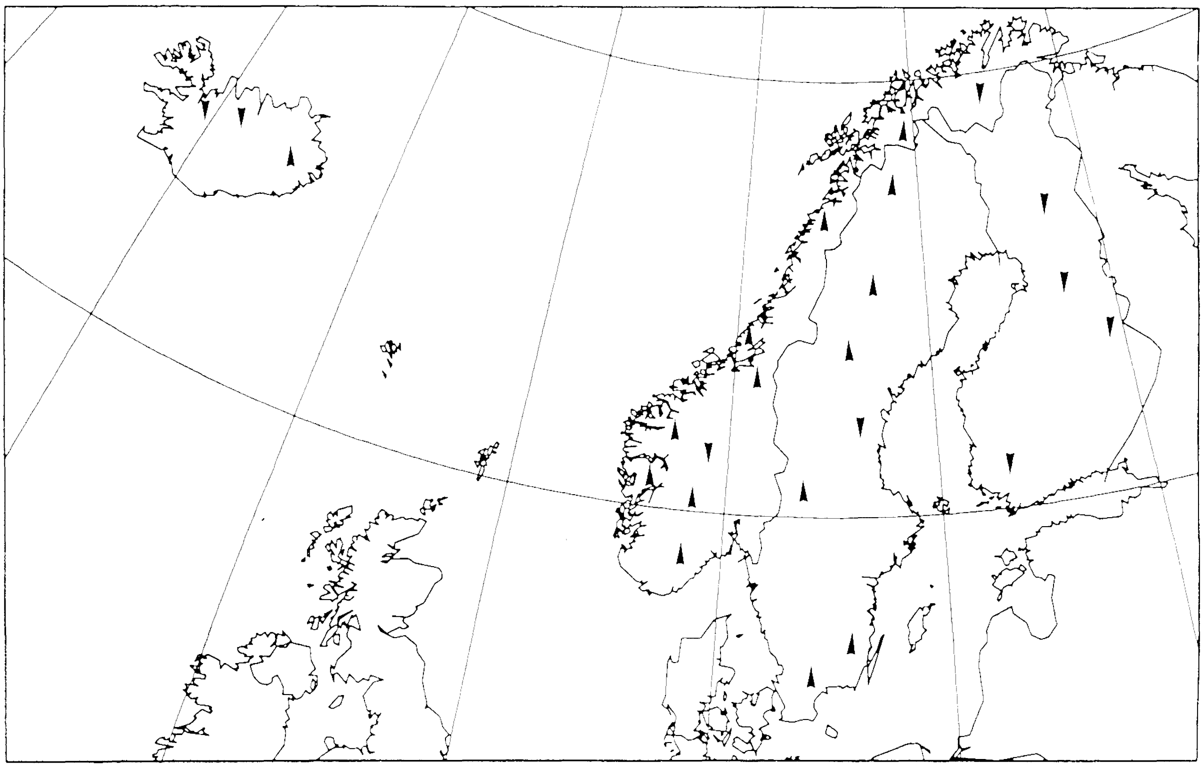

*Figure 8. Change in Q1000, +100 years, change in temperature and precipitation.*

## 5.4 Seasonal distribution

Table 4 shows the changes in season distribution of floods. The table shows that the main shift of flood distribution is from spring floods to autumn floods. This is a result of changes toward a shorter snow season and an increase in precipitation in the autumn.

*Table 4. Changes in seasonal distribution of floods. +A : a shift for more autumn floods, +S : a shift for more spring floods, = : no changes in seasonal distribution.*

| | +30 years | +30 years | +100 years | +100 years |
|---|---|---|---|---|
| | T | T & P | T | T & P |
| + A | 13 | 16 | 22 | 21 |
| + S | 1 | 0 | 1 | 0 |
| = | 10 | 8 | 1 | 3 |

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## Appendix 1. Result of the flood frequency analysis

Each table presents the result from a single catchment. The table has been separated in four. The first three parts presents the result from the analysis of mean flood, floods with a return period of 100 years and floods with a return period of 1000 years. Situation for each season and annual series for each of the five scenarios is calculated.

The last part of the table presents the seasonal distribution of the floods.

Catchment : Kuumaniva, Finland

Q mean $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 97 | 76 | 81 | 48 | 61 |
| Autumn | 32 | 31 | 34 | 32 | 44 |
| Annual | 97 | 76 | 81 | 53 | 68 |

Q 100 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 168 | 168 | 174 | 120 | 146 |
| Autumn | 79 | 73 | 79 | 81 | 112 |
| Annual | 168 | 166 | 172 | 113 | 140 |

Q 1000 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 208 | 220 | 228 | 161 | 194 |
| Autumn | 106 | 97 | 104 | 109 | 150 |
| Annual | 208 | 217 | 223 | 147 | 181 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 28 / 0 | 26 / 2 | 26 / 2 | 22 / 6 | 22 / 6 |

Catchment : Ruunaa, Finland

Q mean (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 22 | 19 | 22 | 16 | 21 |
| Autumn | 16 | 15 | 16 | 14 | 18 |
| Annual | 22 | 20 | 22 | 17 | 22 |

Q 100 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 44 | 39 | 44 | 32 | 42 |
| Autumn | 38 | 33 | 36 | 30 | 38 |
| Annual | 44 | 39 | 44 | 32 | 42 |

Q 1000 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 57 | 50 | 56 | 40 | 54 |
| Autumn | 50 | 43 | 47 | 39 | 50 |
| Annual | 57 | 51 | 56 | 40 | 53 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 23 / 5 | 22 / 6 | 22 / 6 | 18 / 10 | 20 / 8 |

Catchment : Kultsjön, Sweden

Q mean $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 234 | 190 | 200 | 102 | 128 |
| Autumn | 82 | 85 | 91 | 133 | 168 |
| Annual | 234 | 191 | 200 | 142 | 178 |

Q 100 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 450 | 382 | 397 | 264 | 317 |
| Autumn | 260 | 237 | 256 | 340 | 409 |
| Annual | 449 | 383 | 397 | 342 | 412 |

Q 1000 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 572 | 491 | 509 | 355 | 424 |
| Autumn | 361 | 324 | 350 | 457 | 545 |
| Annual | 571 | 491 | 509 | 455 | 544 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 18 / 1 | 18 / 1 | 18 / 1 | 5 / 14 | 5 /14 |

Catchment : Ströms Vattudal, Sweden

Q mean (l/s*km²)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 93 | 65 | 71 | 38 | 51 |
| Autumn | 33 | 32 | 35 | 41 | 55 |
| Annual | 94 | 66 | 72 | 49 | 67 |

Q 100 (l/s*km²)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 199 | 137 | 146 | 95 | 127 |
| Autumn | 99 | 93 | 101 | 123 | 162 |
| Annual | 199 | 139 | 148 | 121 | 156 |

Q 1000 (l/s*km²)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 259 | 178 | 189 | 128 | 170 |
| Autumn | 137 | 127 | 138 | 169 | 223 |
| Annual | 259 | 181 | 191 | 161 | 206 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year | | 100 year | |
|---|---|---|---|---|
| | T | T & P | T | T & P |
| 18 / 1 | 18 / 1 | 18 / 1 | 7 / 12 | 7 /12 |

Catchment : Torpshammar, Sweden

Q mean (l/s*km$^2$)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 36 | 24 | 26 | 12 | 17 |
| Autumn | 13 | 11 | 12 | 10 | 13 |
| Annual | 36 | 24 | 26 | 13 | 18 |

Q 100 (l/s*km$^2$)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 87 | 55 | 61 | 28 | 38 |
| Autumn | 33 | 30 | 32 | 25 | 33 |
| Annual | 87 | 55 | 61 | 28 | 38 |

Q 1000 (l/s*km$^2$)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 115 | 73 | 80 | 37 | 50 |
| Autumn | 44 | 40 | 44 | 34 | 45 |
| Annual | 115 | 73 | 80 | 36 | 50 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year | | 100 year | |
|---|---|---|---|---|
| | T | T & P | T | T & P |
| 19 / 0 | 18 / 1 | 18 / 1 | 12 / 7 | 13 / 6 |

Catchment : Suorva, Sweden

Q mean (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 185 | 167 | 175 | 117 | 140 |
| Autumn | 85 | 87 | 94 | 107 | 130 |
| Annual | 186 | 170 | 178 | 138 | 165 |

Q 100 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 338 | 294 | 306 | 272 | 315 |
| Autumn | 215 | 218 | 230 | 273 | 329 |
| Annual | 336 | 288 | 300 | 286 | 334 |

Q 1000 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 425 | 367 | 381 | 360 | 413 |
| Autumn | 288 | 291 | 308 | 368 | 442 |
| Annual | 422 | 355 | 369 | 368 | 429 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 18 / 1 | 18 / 1 | 18 / 1 | 13 / 6 | 11 / 8 |

Catchment : Blankaström, Sweden

Q mean (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 22 | 17 | 19 | 11 | 17 |
| Autumn | 12 | 10 | 12 | 8 | 12 |
| Annual | 22 | 19 | 21 | 12 | 19 |

Q 100 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 52 | 43 | 47 | 29 | 40 |
| Autumn | 31 | 29 | 32 | 25 | 38 |
| Annual | 52 | 40 | 44 | 28 | 39 |

Q 1000 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 70 | 57 | 63 | 39 | 53 |
| Autumn | 42 | 39 | 43 | 35 | 53 |
| Annual | 68 | 52 | 58 | 36 | 50 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 16 / 3 | 14 / 5 | 14 / 5 | 14 / 5 | 15 / 4 |

Catchment : Torsebro, Sweden

Q mean (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 34 | 25 | 28 | 17 | 25 |
| Autumn | 24 | 22 | 26 | 15 | 26 |
| Annual | 38 | 30 | 34 | 21 | 32 |

Q 100 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 86 | 54 | 60 | 44 | 59 |
| Autumn | 80 | 76 | 88 | 54 | 90 |
| Annual | 90 | 71 | 81 | 53 | 85 |

Q 1000 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 115 | 71 | 78 | 58 | 78 |
| Autumn | 112 | 107 | 123 | 76 | 126 |
| Annual | 119 | 93 | 108 | 72 | 115 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 14 / 5 | 13 / 6 | 12 / 7 | 13 / 6 | 12 / 7 |

Catchment : Höljes, Sweden

Q mean ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 76 | 51 | 56 | 27 | 38 |
| Autumn | 29 | 27 | 29 | 24 | 33 |
| Annual | 76 | 52 | 57 | 31 | 43 |

Q 100 ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 155 | 118 | 127 | 67 | 91 |
| Autumn | 103 | 104 | 112 | 87 | 114 |
| Annual | 155 | 124 | 132 | 88 | 116 |

Q 1000 ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 200 | 156 | 167 | 90 | 121 |
| Autumn | 146 | 148 | 158 | 122 | 161 |
| Annual | 200 | 164 | 175 | 120 | 157 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 19 / 0 | 17 / 2 | 18 / 1 | 13 / 6 | 14 / 5 |

Catchment : Blanda, Iceland

Q mean (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 100 | 90 | 94 | 73 | 81 |
| Autumn | 54 | 61 | 62 | 70 | 76 |
| Annual | 100 | 92 | 97 | 82 | 91 |

Q 100 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 265 | 228 | 241 | 134 | 157 |
| Autumn | 95 | 113 | 116 | 172 | 205 |
| Annual | 263 | 224 | 236 | 180 | 218 |

Q 1000 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 358 | 306 | 324 | 169 | 199 |
| Autumn | 119 | 142 | 147 | 230 | 278 |
| Annual | 354 | 298 | 315 | 235 | 290 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 13 / 2 | 14 / 1 | 13 / 2 | 10 / 5 | 12 / 3 |

Catchment : Austari Jökulsá, Iceland

Q mean ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 157 | 142 | 148 | 104 | 118 |
| Autumn | 72 | 78 | 80 | 81 | 92 |
| Annual | 157 | 142 | 148 | 108 | 126 |

Q 100 ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 347 | 321 | 336 | 230 | 278 |
| Autumn | 125 | 132 | 140 | 159 | 203 |
| Annual | 347 | 319 | 335 | 229 | 277 |

Q 1000 ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 455 | 422 | 443 | 302 | 367 |
| Autumn | 155 | 163 | 173 | 203 | 266 |
| Annual | 455 | 419 | 441 | 297 | 362 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 19 / 0 | 17 / 2 | 17 / 2 | 16 / 3 | 14 / 5 |

Catchment : Jökulsá i Fljótsdal, Iceland

Q mean (l/s*km²)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 209 | 217 | 220 | 145 | 165 |
| Autumn | 169 | 189 | 192 | 151 | 177 |
| Annual | 212 | 222 | 226 | 168 | 199 |

Q 100 (l/s*km²)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 318 | 333 | 331 | 268 | 358 |
| Autumn | 290 | 304 | 314 | 309 | 405 |
| Annual | 320 | 332 | 335 | 308 | 412 |

Q 1000 (l/s*km²)

| | Control | 30 year | | 100 year | |
|---|---|---|---|---|---|
| | | T | T & P | T | T & P |
| Spring | 379 | 399 | 394 | 338 | 467 |
| Autumn | 359 | 369 | 383 | 399 | 534 |
| Annual | 381 | 394 | 397 | 387 | 532 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year | | 100 year | |
|---|---|---|---|---|
| | T | T & P | T | T & P |
| 19 / 6 | 19 / 6 | 18 / 7 | 12 / 13 | 13 /12 |

Catchment : Alta, Norway

Q mean $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 96 | 73 | 79 | 24 | 34 |
| Autumn | 18 | 17 | 18 | 16 | 23 |
| Annual | 96 | 73 | 79 | 27 | 38 |

Q 100 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 175 | 135 | 146 | 69 | 86 |
| Autumn | 63 | 59 | 63 | 50 | 70 |
| Annual | 175 | 135 | 146 | 69 | 84 |

Q 1000 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 220 | 171 | 184 | 95 | 115 |
| Autumn | 89 | 82 | 89 | 70 | 96 |
| Annual | 220 | 171 | 184 | 93 | 110 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 29 / 0 | 29 / 0 | 29 / 0 | 21 / 8 | 22 / 7 |

Catchment : Øyungen, Norway

Q mean (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 331 | 319 | 357 | 283 | 404 |
| Autumn | 360 | 386 | 431 | 369 | 558 |
| Annual | 413 | 443 | 500 | 401 | 602 |

Q 100 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 794 | 955 | 1100 | 761 | 1111 |
| Autumn | 974 | 1023 | 1191 | 976 | 1619 |
| Annual | 1052 | 1168 | 1364 | 1033 | 1675 |

Q 1000 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 1056 | 1316 | 1521 | 1033 | 1513 |
| Autumn | 1322 | 1385 | 1622 | 1321 | 2222 |
| Annual | 1415 | 1580 | 1855 | 1392 | 2285 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 16 /13 | 10 /19 | 11 / 18 | 9 / 20 | 7 /22 |

Catchment : Bulken, Norway

Q mean $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 252 | 208 | 222 | 214 | 266 |
| Autumn | 268 | 282 | 301 | 324 | 400 |
| Annual | 296 | 299 | 318 | 349 | 431 |

Q 100 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 430 | 388 | 409 | 563 | 688 |
| Autumn | 522 | 562 | 595 | 613 | 754 |
| Annual | 492 | 504 | 536 | 564 | 695 |

Q 1000 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 530 | 491 | 516 | 761 | 927 |
| Autumn | 665 | 722 | 761 | 777 | 954 |
| Annual | 603 | 620 | 660 | 686 | 845 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 11 / 18 | 9/20 | 9/20 | 6/23 | 6/23 |

Catchment : Møsvatn, Norway

Q mean (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 246 | 216 | 225 | 116 | 140 |
| Autumn | 102 | 106 | 112 | 136 | 162 |
| Annual | 246 | 219 | 228 | 150 | 179 |

Q 100 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 413 | 399 | 411 | 247 | 294 |
| Autumn | 278 | 287 | 304 | 283 | 337 |
| Annual | 411 | 399 | 410 | 270 | 324 |

Q 1000 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 508 | 503 | 516 | 322 | 382 |
| Autumn | 378 | 390 | 412 | 366 | 437 |
| Annual | 505 | 501 | 513 | 339 | 406 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 28/1 | 28/1 | 27/2 | 11/18 | 11/18 |

Catchment : Øye, Norway

Q mean (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 273 | 249 | 263 | 198 | 238 |
| Autumn | 264 | 289 | 310 | 353 | 441 |
| Annual | 318 | 322 | 341 | 365 | 452 |

Q 100 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 529 | 503 | 528 | 423 | 504 |
| Autumn | 638 | 684 | 725 | 864 | 1054 |
| Annual | 626 | 651 | 696 | 833 | 1029 |

Q 1000 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 675 | 647 | 678 | 550 | 656 |
| Autumn | 851 | 908 | 961 | 1154 | 1402 |
| Annual | 800 | 838 | 897 | 1099 | 1356 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 16/13 | 10/19 | 10/19 | 4/25 | 4/25 |

Catchment : Skarsvatn, Norway

Q mean ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 289 | 238 | 247 | 248 | 293 |
| Autumn | 199 | 252 | 268 | 308 | 375 |
| Annual | 318 | 312 | 326 | 363 | 434 |

Q 100 ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 654 | 645 | 663 | 682 | 786 |
| Autumn | 627 | 756 | 795 | 1024 | 1235 |
| Annual | 711 | 817 | 854 | 1037 | 1242 |

Q 1000 ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 861 | 876 | 900 | 929 | 1066 |
| Autumn | 869 | 1042 | 1094 | 1430 | 1723 |
| Annual | 935 | 1103 | 1154 | 1421 | 1702 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 22/7 | 14/15 | 12/17 | 13/16 | 11/18 |

Catchment : Lundberg, Norway

Q mean $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 347 | 318 | 331 | 227 | 259 |
| Autumn | 150 | 146 | 160 | 186 | 224 |
| Annual | 347 | 318 | 331 | 247 | 286 |

Q 100 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 581 | 546 | 565 | 472 | 540 |
| Autumn | 380 | 368 | 399 | 448 | 533 |
| Annual | 581 | 546 | 565 | 493 | 573 |

Q 1000 $(l/s*km^2)$

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 713 | 675 | 698 | 612 | 699 |
| Autumn | 511 | 494 | 596 | 596 | 708 |
| Annual | 713 | 675 | 698 | 632 | 736 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 29/0 | 29/0 | 29/0 | 20/9 | 20/9 |

Catchment : Lalm, Norway

Q mean (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 142 | 129 | 134 | 80 | 134 |
| Autumn | 60 | 60 | 64 | 82 | 64 |
| Annual | 142 | 129 | 135 | 101 | 135 |

Q 100 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 268 | 251 | 259 | 181 | 259 |
| Autumn | 141 | 133 | 142 | 241 | 142 |
| Annual | 267 | 250 | 257 | 238 | 257 |

Q 1000 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 339 | 320 | 329 | 238 | 329 |
| Autumn | 187 | 175 | 187 | 330 | 187 |
| Annual | 339 | 318 | 327 | 316 | 327 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 28/1 | 28/1 | 12/17 | 12/17 | 28/1 |

Catchment : Høggås bru, Norway

Q mean (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 256 | 205 | 220 | 187 | 227 |
| Autumn | 208 | 215 | 237 | 241 | 298 |
| Annual | 266 | 248 | 267 | 253 | 311 |

Q 100 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 461 | 441 | 467 | 433 | 545 |
| Autumn | 463 | 456 | 494 | 542 | 653 |
| Annual | 463 | 470 | 501 | 544 | 657 |

Q 1000 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 578 | 574 | 607 | 572 | 725 |
| Autumn | 609 | 591 | 639 | 714 | 854 |
| Annual | 575 | 595 | 634 | 709 | 854 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 21/8 | 9/20 | 9/20 | 8/21 | 8/21 |

Catchment : Flaksvatn

Q mean (1/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 156 | 144 | 154 | 131 | 165 |
| Autumn | 246 | 248 | 265 | 234 | 290 |
| Annual | 258 | 260 | 276 | 249 | 307 |

Q 100 (1/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 349 | 318 | 336 | 330 | 395 |
| Autumn | 389 | 697 | 733 | 691 | 817 |
| Annual | 658 | 663 | 699 | 654 | 780 |

Q 1000 (1/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 459 | 416 | 439 | 443 | 525 |
| Autumn | 940 | 952 | 999 | 950 | 1116 |
| Annual | 885 | 891 | 938 | 883 | 1049 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 6/23 | 6/23 | 6/23 | 7/22 | 6/23 |

Catchment : Kiantajärvi, Finland

Q mean ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 90 | 59 | 64 | 32 | 43 |
| Autumn | 26 | 26 | 28 | 32 | 41 |
| Annual | 90 | 59 | 64 | 41 | 54 |

Q 100 ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 192 | 124 | 134 | 84 | 111 |
| Autumn | 50 | 53 | 57 | 84 | 105 |
| Annual | 192 | 124 | 134 | 92 | 119 |

Q 1000 ($l/s*km^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 250 | 161 | 174 | 113 | 150 |
| Autumn | 64 | 69 | 73 | 113 | 142 |
| Annual | 250 | 161 | 174 | 121 | 156 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 29/0 | 29/0 | 29/0 | 17/12 | 17/12 |

Catchment : Loimijoki, Finland (***)

Q mean (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 94 | 65 | 71 | 32 | 48 |
| Autumn | 44 | 48 | 55 | 33 | 56 |
| Annual | 95 | 73 | 80 | 43 | 66 |

Q 100 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 226 | 187 | 199 | 114 | 152 |
| Autumn | 136 | 144 | 157 | 119 | 166 |
| Annual | 226 | 181 | 194 | 133 | 174 |

Q 1000 (l/s*km²)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 302 | 256 | 272 | 162 | 212 |
| Autumn | 189 | 199 | 216 | 168 | 229 |
| Annual | 300 | 243 | 258 | 184 | 235 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 25/3 | 20/8 | 19/9 | 12/16 | 10/18 |

Catchment : Loimijoki, Finland (***)

Q mean (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 112 | 77 | 83 | 42 | 57 |
| Autumn | 54 | 65 | 70 | 57 | 79 |
| Annual | 113 | 91 | 97 | 65 | 86 |

Q 100 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 253 | 216 | 227 | 142 | 166 |
| Autumn | 162 | 186 | 197 | 164 | 199 |
| Annual | 252 | 212 | 223 | 172 | 203 |

Q 1000 (l/s*km$^2$)

| | Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|---|
| Spring | 333 | 295 | 309 | 199 | 227 |
| Autumn | 223 | 255 | 269 | 224 | 266 |
| Annual | 331 | 281 | 295 | 232 | 270 |

Seasonal distribution (Spring / Autumn)

| Control | 30 year T | 30 year T & P | 100 year T | 100 year T & P |
|---|---|---|---|---|
| 25/3 | 17/11 | 16/12 | 7/21 | 6/22 |

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