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CLIMATE CHANGE IMPACT ON NORWEGIAN WATER RESOURCES

NORWEGIAN WATER RESOURCES AND ENERGY ADMINISTRATION

Frontispiece: Waterfall in Låtefossen
Photograph: K.O. Hillestad

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ABSTRACT
This report describes physical and to some extent socio-economical consequences of climatic change on Norwegian river systems and water resources. The investigation is based on climate scenarios reported by a Norwegian expert team. The analysis is based on simulations of the effects on runoff, soil water and snow cover, and assessments of effects on glaciers, water temperature and ice cover. The consequences for erosion, floods and hydropower are analysed, and impacts on agriculture, recreation, water supply and water resources management are considered.

SUBJECT TERMS

Climate change
Runoff
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SIGNATURE

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PREFACE

This report is an adapted and condensed English version of the report "Klimaendringer og vannressurser" ("Climate change and water resources"), prepared for the Norwegian Interministerial Climate Change Policy Study and financed by the Ministry of Oil and Energy.

The work has been carried out at the Norwegian Water Resources and Energy Administration. The Power Pool of Norway has assisted in the hydropower simulations, and the short summary on water quality is based on a parallel investigation at the Norwegian Institute for Water Research.

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Nils Roar Sælthun, editor, chapters 1,2,7,9
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Oslo, October 1990

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CONTENTS

SUMMARY

This report describes physical and to some extent economical consequences of climatic change on Norwegian water courses and water resources. This study is a contribution to the Norwegian Interministerial Climate Change Policy Study. The work is based on scenarios reported by a Norwegian expert team (Eliassen & al., 1989; Eliassen & Grammeltvedt, 1990) based on an increase of the greenhouse gases corresponding to a doubling of the CO_2 content of the atmosphere, which is expected to occur around 2030. The scenarios are given for temperature and precipitation; the most likely scenario indicates a temperature increase of 1.5 to 3.5 deg., mostly in the winter and in the inland. The precipitation is expected to increase by 7 to 8 %.

The **runoff** has been simulated for seven Norwegian water courses over a 30 year period, both for the present climate and for two scenarios. The simulation describes the changes for basins in three elevation bands, a mountainous, an intermediate level and a lowland basin. The model applied for these simulation also predicts changes in the snow cover, soil moisture and ground water regime. These simulations are the basis for the subsequent evaluation of possible consequences.

The most likely scenario indicates a moderate increase in the annual runoff in mountainous districts and districts with high annual precipitation. The annual runoff will decrease in lowland basins and in forested basins in the inland because of increase in the evapotranspiration. The **seasonal pattern** will change significantly, in particular in basins within the intermediate elevation band. The spring flood will be strongly reduced in many basins. The winter runoff will increase manifold, while the summer runoff will decrease. Floods will occur more frequently in the autumn and the winter.

The duration of **snow cover** on the ground will be reduced by one to three months. The soil moisture deficit will increase, indicating an increase in the need for artificial irrigation in most areas except the western costal zone. Increased irrigation demand and reduced summer runoff can give water shortage in small water courses.

The scenarios indicate that the **glaciers** will decrease, in particular glaciers in inland areas. The net melting will be lower on glaciers near the west coast, the glaciers near the coast of Northern Norway will most likely remain without changes.

The **water temperature** will most likely increase with the air temperature in the summer. The rise in the water temperature from zero to close to the air temperature will occur one month earlier because of the earlier termination of the snowmelt. The duration of ice cover will decrease, and many of the larger lakes in Southern Norway are expected to remain without ice cover in most winters.

Erosion and sediment transport is expected to increase strongly during the winter unless the agricultural practices of keeping the fields with open soil is changed. Loss of soil could develop into a serious problem.

The predicted changes in the runoff regime are not expected to cause deteriorate of the **water quality** in large and deep lakes. Negative changes can, however, be expected in more shallow lakes with higher bioproduction. The most negative consequences are expected in shallow mesoeutrophic lakes surrounded by farmland. The nitrogen storage in Norwegian soils is large, and increased rate of decomposition of organic soil components may result in acidification of soil and water courses. Increased sediment yield and nitrogen release can also give eutrophication problems and algae bloom conditions in estuaries and fjords (Gulbrandsen & al, 1990).

Flood damage is expected to increase, in particular in small basins and urban areas. These damages are estimated to at least 100 mill. NOK per year under the present conditions; the most likely scenario indicates a doubling of this amount. The increased uncertainty in the flood estimates must be taken into account when new dams are constructed and older dams are revised.

The **hydropower energy production** is expected to increase with possibly 2-3 % given the most likely scenario. This is partly due to an increase in the inflow to the reservoirs, but also due to reductions in the overflow spill. The seasonal distribution of the runoff will be more similar to the consumption, and lead to increased firm power yield. The high scenario indicating 16-17 % increase in the precipitation, results in significantly higher increase in the inflow and the production. Under this scenario flood spill will increase unless the production system is adjusted.

The reduced snow cover will significantly influence the **winter recreations**, and commercial skiing facilities in lower altitudes will have their season reduced, and will experience winters without stable snow cover.

Water supply will probably mainly be affected through changed water quality. Surface water systems with low reservoir capacity and marginal yield may experience increased summer shortages.

1 INTRODUCTION

1.1 Climate change

"Everybody talks about the weather, but we are the first to do anything about it"

Discussions are running high whether the extreme weather situations of the eighties are results of man-made climatic change, or just another whim of mother Nature. Some facts are certainly worth pondering:

- since preindustrial time the atmospheric content of carbon dioxide (CO_2) has increased by 25 per cent, and is now at the highest level of the last 160 000 years

- as far back as the analyses goes (approx. 300 000 years there has been a clear correspondence between the level of atmospheric CO_2 content and global surface temperature

- it is a generally recognized fact that CO_2 together with other gases in the atmosphere absorbs long wave thermal radiation and reduces heat losses from the earths surface and the lower parts of the atmosphere

- the global mean temperature has increased by approximately 0.5 degree centigrade the last hundred years

- the six warmest years globally this century has been in the eighties

- concentration of CO_2 and other "greenhouse gases" in the atmosphere will increase strongly into the next century

(Source: between others; Houghton and Woodwell, 1989).

When climatologists are forecasting the climate changes to be expected in the years to come, they have two main sources of information. One is the numerical climate models, which to varying degrees of sophistication describe the interactions between greenhouse gases, atmosphere and ocean energy balance, and climate. The other source is knowledge about the earths climate in earlier periods with a warm climate; for instance the last interglacial, 120 000 yrs ago, and the postglacial warmest period, 6000 years ago.

The large general circulation models, GCMs, are the most powerful tools for predicting climate change. They simulate the global atmospheric and oceanic circulation with typical time steps of ten minutes for periods up to hundred years. They require very large computer resources, and there are only a handful around. They have been greatly improved since the first versions early in the seventies, but do still operate on a very coarse grid, 200 - 300 km mesh. As a consequence, they can not describe local climatic variations, and only to some extent regional variations.

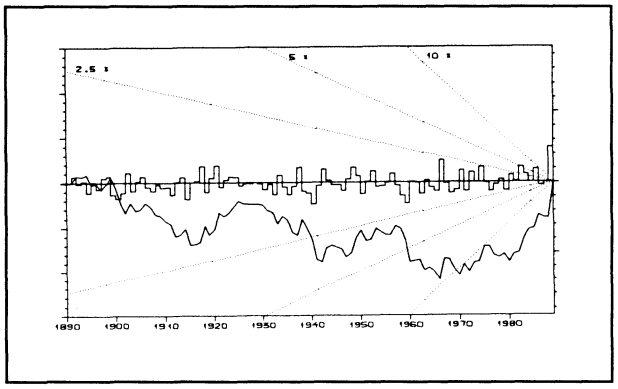
It is quite common to refer the simulations results to a increase of the greenhouse gases (carbon dioxide, CO_2; methane, CH_4; chlorated fluorocarbons, CFCs; nitrous oxide N_2O) equivalent to doubling of CO_2 from pre-industrial levels (270 ppm). With the present increase of emission levels, this stage is expected to be reached in about forty years. The different models yield somewhat differing results, but the general trends are coinciding. Typical results are:

- increase of mean global temperature of about 2 degrees (range 1.5 - 4.5 degree)
- largest temperature increase on high latitudes
- largest temperature increase during winter
- precipitation increase, especially on high latitudes

A temperature increase of 2 degrees might seem modest, but would raise the global temperature to the highest level of the last millon years. The models indicate that we in a decade or two will

experience the same global temperature conditions as our forefathers in the bronze age, the warmest period after the last ice age.

Globally, an temperature increase of about 0.5 degrees is observed the last hundred years. In Scandinavia few, if any meteorological or hydrological time series have been discovered to display significant influence of climatic change so far. The Norwegian Meteorological Institute has analyzed long temperature and precipitation series (Aune, 1989). The only clear tendency is a persistent increase of autumn precipitation. Analyses of runoff series do not show clear trends either, except a notable increase over the last 25 years in south-west Norway (fig 1.1, from Roald & Sælthun, 1990).



Figur 1.1 *River runoff, south west region, accumulated deviations from long term mean.*

1.2 Climate scenarios

Starting point for all impact appraisals in this study are climate scenarios for Norway presented in a report by a Norwegian expert panel to the Norwegian Interministerial Climate Change Policy Study (Eliassen & al, 1989, Blindheim & al, 1990). The scenarios are referenced to the effective doubling of atmospheric CO_2, a stage expected to be reached about year 2030. This preliminary report estimates mean temperature increase to 2 degrees for the months June to August, and 3-4 degrees for the months December through February. Expected precipitation changes are only given qualitatively:

"Precipitation is expected to increase all year round, and most in spring"

"More of the precipitation is expected as showers"

In an addendum (Eliassen & Grammeltvedt, 1990), the scenarios in table 1.1 are specified. For the present study, these scenarios have been distributed to monthly estimates.

In this report the "probable" temperature and precipitation scenarios have been combined to one scenario, denoted as SC1, and the "high" scenarios is referred to as scenario SC2.

Tabell 1.1 *Doubled CO_2 scenarios for Norway, from Eliassen & Grammeltvedt (1990). Numbers in brackets denote high, but not unrealistic changes.*

	coast	inland
Temperature changes, deg		
winter	+3.0 (+3.5)	+3.5 (+5.0)
summer	+1.5 (+2.5)	+2.0 (+3.0)
Precipitation changes, %		
spring	+15 (+15)	+10 (+15)
summer	+10 (+15)	+10 (+15)
autumn	+ 5 (+20)	+ 5 (+20)
winter	+ 5 (+15)	+ 5 (+15)

2 RUNOFF SIMULATIONS

2.1 Simulation model

The scenarios presented in chapter 1 are used to manipulate historic temperature and precipitation series into new series that are assumed to represent the future climate. This is done by increasing the temperature of each day in the thirty year long series by the differential values, and each precipitation value by the percentages given in table 1.1. The variability of the temperature is thus unaltered, and so is the number of precipitation days. The standard deviation of precipitation is increased in the same proportion as the mean, the coefficient of variation remaining unchanged.

With the assistance of an hydrological model we are then able to compute runoff series representing present and future hydrological regimes. This approach is quite common in hydrological climatic impact studies (for instance Lettenmaier & Gan, 1990), and was first applied in Norway by Lundquist (1988). The method requires that the hydrological system (catchment processes) do not change significantly, or that we are able to predict and represent such changes in model applied.

In this study a modified HBV model has been used. The HBV model is a relatively simple conceptual model originally developed by the Swedish Meteorological and Hydrological Institute (Bergström, 1976), and further developed and in widespread use all over Scandinavia. It could be argued that it is conceptually too simple for impact studies; on the other hand it has a well proven structure and performance, and operates on temperature and precipitation only.

A system sketch of the model is given in fig 2.1. The most important difference from the basic HBV model is that the evapotranspiration has been made temperature dependent; potential evapotranspiration is assumed proportional to temperature above freezing, by a seasonally varying coefficient. The HBV model normally operates with seasonal values for potential evapotranspiration. The uncertainty inherent in calculating evapotranspiration from temperature and precipitation alone has to be underlined; this important water balance term is certainly depends on many other factors; air humidity, wind, radiation, vegetation cover and land use. The direct impact of increased atmospheric CO_2 on plant transpiration is also poorly known (Kuchment & al, 1989). On the other hand, in most parts of Norway evapotranspiration is smaller than the runoff term, for large areas an order of magnitude smaller; the overall results are thus less sensitive to evapotranspiration modeling errors than in many other areas of the world.

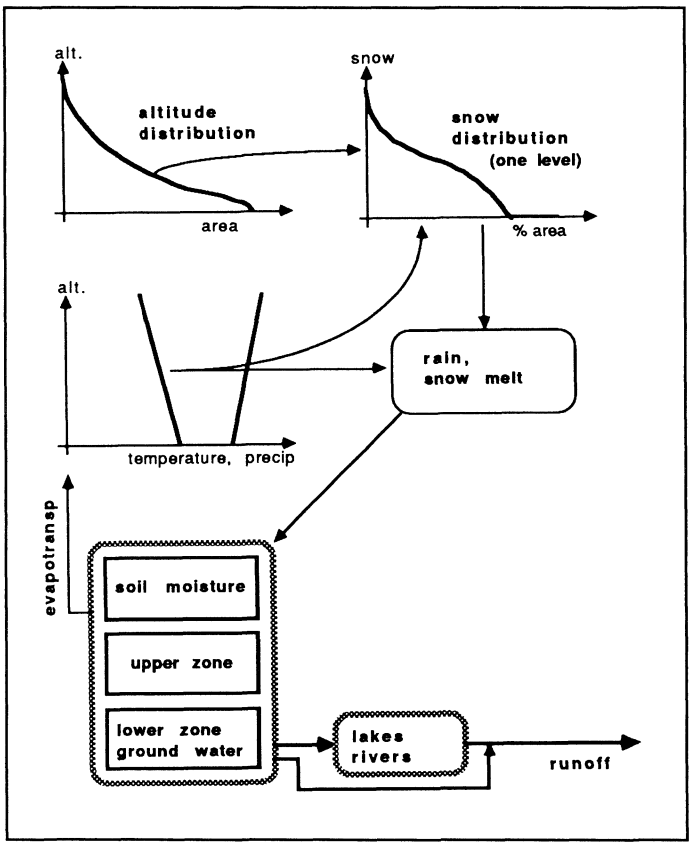


Fig. 2.1 Structure of the HBV model

In addition to the effect of increased temperature, the evapotranspiration is also augmented by the longer snow free season.

The relation between snow melt and temperature has been made dependent on season, to avoid errors caused by the earlier start of the melt season. The snow melt is related to temperature, precipitation, time of the year, latitude and snow ageing. The model does not simulate frozen ground or thaw effects.

All simulations are based on calibrations on actual basins, but in addition results are presented for three standard catchments for each set of climatological series: a highland catchment with rectangular altitude distribution from 1000 to 1500 m asl (presently above the forest line), an intermediate catchment with altitudes 500 to 1000 m asl, and a lowland catchment, altitudes 0 to 500 m asl.

The soil moisture storage in the highland catchments has been set to 100 mm in western Norway and the central mountains, 150 mm elsewhere. The temperature index of potential evapotranspiration has been set to 0.15 mm per degree and day for snow free areas. For the intermediate catchments the soil moisture storage has been set to 150 mm, and evapotranspiration index varying from 0.15 mm in winter to 0.3 in May. For the lowland catchments the soil moisture storage is 200 mm, with the same evapotranspiration indices as the intermediate catchments.

Snow distribution is assumed to be somewhat less skewed in the two lower levels than in the highland elevation band, and the melt intensity also lower, both effects mainly caused by the presence of forests. Lake percentage is set to 5 per cent for all standard catchments; this is close to the national average. Other model parameters are the same as for the catchment used for calibration.

Simulations have been carried out for seven basins; the Vosso river, western Norway; river Otta in the central mountains; the Flisa river in eastern Norway; the Forra river in mid-Norway; lake Øyungen in coastal mid-Norway, the Tovdal river in southern Norway, and the Alta river in northern Norway. Additional simulations has been made for the Leira river near Oslo. See map, fig 2.2. The simulations have been made for approximately thirty years; basic data period is 1957 to 1988. All simulations are made with time step one day.

2.2 Analyses

2.2.1 Discharge, floods

The model simulations produces thirty years of daily runoff values. The information contained in these series has been condensed in tables in chapter 2.3 and in the appendix. These tables present annual water balance, monthly mean runoff, flood and low flow statistics. For comparison, simulated runoff is used both for the present situation and the scenarios.

Gumbel (EV I) distribution is used for the extreme value analysis. The tables present mean flood and flood with 1000 year return interval, and low flow with 10 year return interval. In addition the standard deviations are listed, allowing calculations for any return interval with frequency factor formulas:

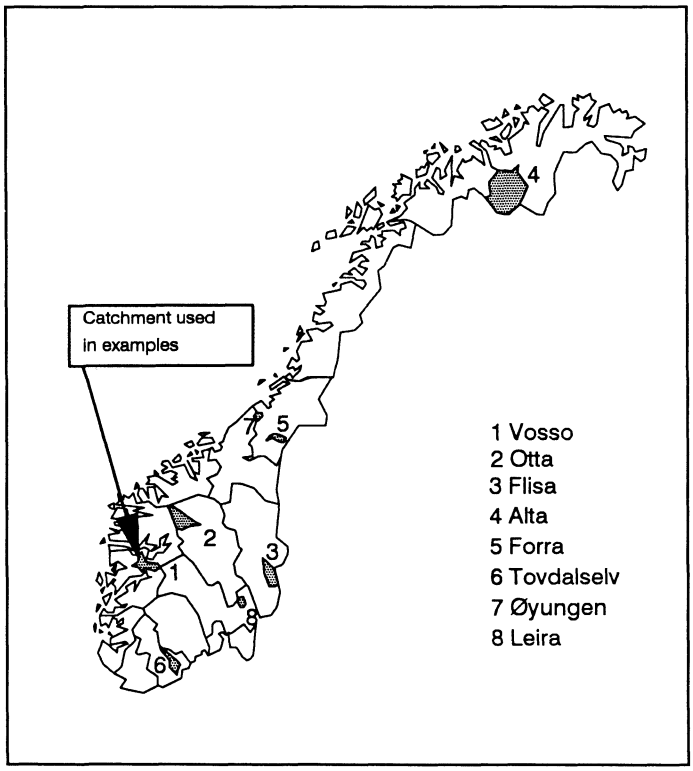


Fig 2.2 Catchments used for simulations with hydrological model

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

where Q_T is T-year flood, Q_m mean annual flood, S standard deviation and K(T) frequency factor for return period T years. Values for K(T) are found in several textbooks, instance Haan (1977). For statistics based on 30 years of observations, K(100) is 3.7 and K(1000) 5.7. In Norway the standard deviation for autumn floods is approximately 25 per cent. Using the frequency factors we find that for the 1000 year flood a change of the standard deviation by 10 per cent influences the 1000-year flood estimate more than a 10 per cent change of the mean flood. This illustrates the fact that the frequency of extreme floods is very sensitive to changes in precipitation variability, a climatic characteristic that we so far do not know how will change due to climatic change. Any estimate of changes of extremes must thus be regarded with caution.

As a rule of the thumb, a general increase of the flood values by 15 per cent will double the frequency floods above a given level.

2.2.2 Other hydrological variables

Snow cover. The model simulates several snow variables. Only one is presented in the tables; average number of days with more than 25 per cent snow cover. These values are estimated to be of an accuracy corresponding to the accuracy of the runoff predictions.

Soil moisture, ground water. The tables in the appendix presents estimates of the average soil moisture deficit in millimeters for the growing season, and average number of days with deficit higher than 50 mm. These are lumped catchment values, in the actual catchments the soil moisture deficit will show large local variations. The soil moisture submodel is relatively simple, and the calculations must only be regarded as indications. Seasonal values of shallow ground water (as catchment mean values in millimeters) are also given in appendix B. The ground water simulations by the HBV model has been shown to be good indices on actual ground water reservoir variations, but again the simulations should only be looked upon as indications.

2.3 Simulations

The main simulation results are given in the appendix. A brief description of the individual catchments and some important results are given below.

Table 2.1 *Simulation results for western Norway, river Vosso*

Catchment ident: 062.Z

Catchment area: 1102 km^2
Altitude range: 47 - 1580 masl
Median altitude: 850 masl

Water balance, mm/yr:

	present	SC1		SC2	
	mm/yr	mm/yr	%	mm/yr	%
precipitation	2045	2200	+8	2390	+17
evapotranspiration	170	265	+55	295	+75
runoff	1875	1935	+3	2095	+12

Table 2.2 *Simulation results for central mountains, river Otta*

Catchment ident: 002.DHZ

Catchment area: 3942 km^2
Altitude range: 360 - 2470 masl
Median altitude: 1300 masl

Water balance, mm/yr:

	present	SC1		SC2	
	mm/yr	mm/yr	%	mm/yr	%
precipitation	950	1100	+8	1105	+17
evapotranspiration	80	140	+75	170	+115
runoff	870	870	0	935	+7

Table 2.3 *Simulation results for eastern Norway, river Flisa*

Catchment ident: 002.GZ

Catchment area: 1625 km^2
Altitude range: 164 - 805 masl
Median altitude: 400 masl

Water balance, mm/yr:

	present	SC1		SC2	
	mm/yr	mm/yr	%	mm/yr	%
precipitation	675	725	+8	785	+17
evapotranspiration	250	325	+30	365	+45
runoff	425	400	-6	420	-1

Table 2.4 *Simulation results for northern Norway, river Alta*

Catchment ident: 212.Z

Catchment area: 5693 km^2
Altitude range: 274 - 975 masl
Median altitude: 440 masl

Water balance, mm/yr:

	present	SC1		SC2	
	mm/yr	mm/yr	%	mm/yr	%
precipitation	490	525	+8	570	+17
evapotranspiration	135	180	+35	205	+50
runoff	355	345	-3	365	+3

Table 2.5 *Simulation results for western coast, lake Øyungen*

Catchment ident: 138.Z

Catchment area: 238 km^2
Altitude range: 103 - 675 masl
Median altitude: 355 masl

Water balance, mm/yr:

	present	SC1		SC2	
	mm/yr	mm/yr	%	mm/yr	%
precipitation	1760	1900	+8	2055	+17
evapotranspiration	220	300	+35	325	+50
runoff	1540	1600	+4	1735	+12

Table 2.6 *Simulation results for mid-Norway, inland, river Forra*

Catchment ident: 124.AZ

Catchment area: 491 km^2
Altitude range: 93 - 1249 masl
Median altitude: 510 masl

Water balance, mm/yr:

	present	SC1		SC2	
	mm/yr	mm/yr	%	mm/yr	%
precipitation	1470	1580	+8	1715	+17
evapotranspiration	190	270	+50	310	+65
runoff	1280	1310	+2	1405	+10

Table 2.7 *Simulation results for southern Norway, Tovdalselv river*

Catchment ident: 020.Z

Catchment area: 491 km^2
Altitude range: 19 - 1101 masl
Median altitude: 355 masl

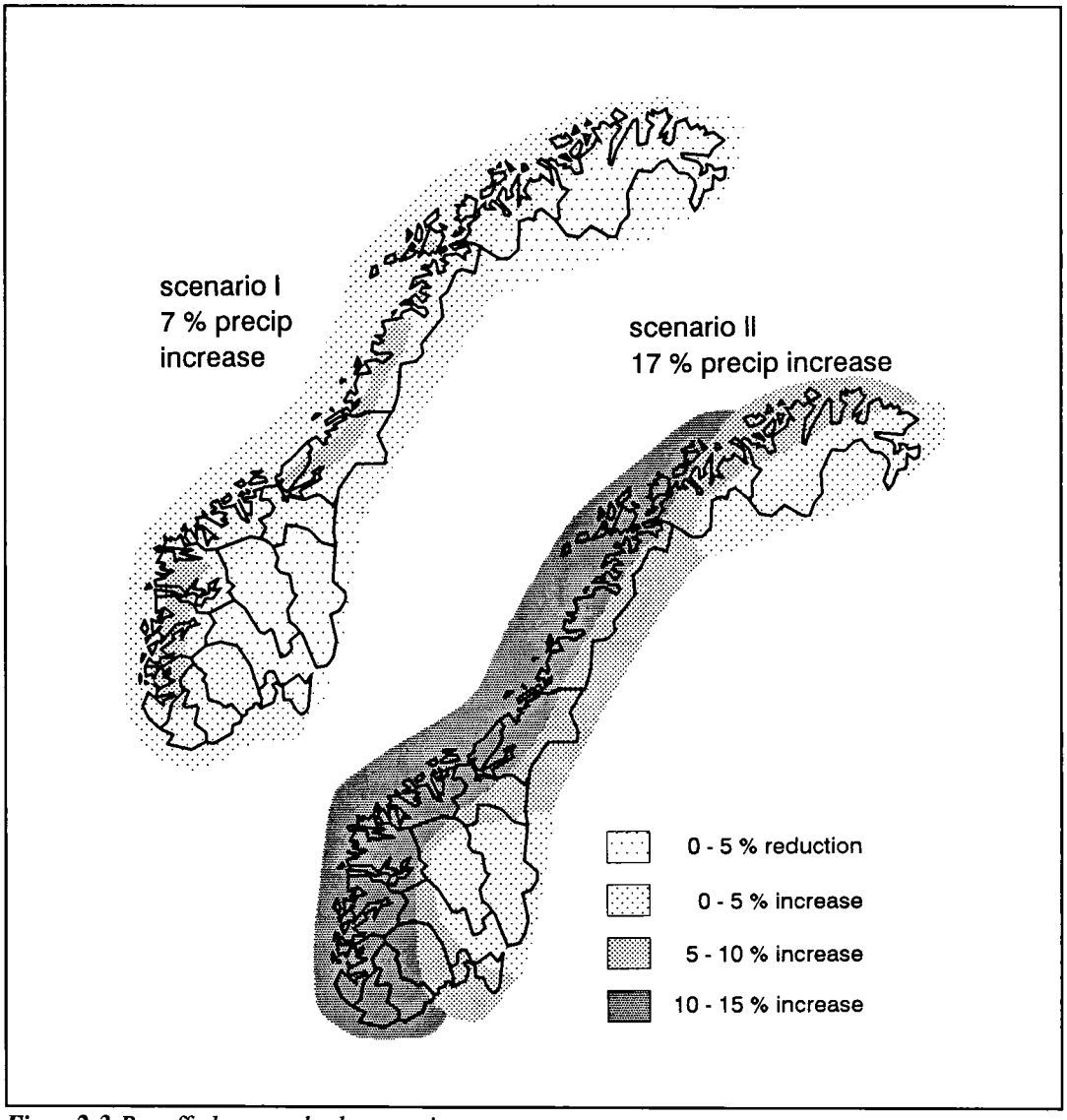
Water balance, mm/yr:

	present	SC1		SC2	
	mm/yr	mm/yr	%	mm/yr	%
precipitation	1350	1455	+8	1575	+17
evapotranspiration	300	385	+30	410	+35
runoff	1050	1070	+2	1165	+11

2.4 Discussions

2.4.1 Annual runoff

Changes of annual runoff are primarily controlled by changes in the precipitation and the evaporation. The increase in the precipitation is given by the scenarios, while the increase in the evaporation is given by the model assumptions. The model predicts an increase in evapotranspiration by 40 to 55 mm per year in mountainous areas, 45 to 55 mm in the intermediate elevation band and 50 to 110 mm in the lowland. The simulated evaporation is not influenced much by moderate increases in the precipitation. The predicted increase in evaporation can therefore be considered as equal to the increase in the precipitation required to maintain the annual runoff at the same level as before. Any increase in the precipitation in excess of this will equal the increase in the annual runoff. The most likely scenario assumes an increase in the annual precipitation of 7.5 %. The annual runoff can thus be expected to increase in mountainous basins with more than 750 mm precipitation today.
Expected runoff changes are shown in fig 2.3.



***Figur 2.3** Runoff changes, both scenarios*

2.4.2 *Seasonal distribution of runoff*

The model predicts a drastic change in the seasonal distribution of the runoff. The runoff will increase considerably in the winter, the spring flood will be reduced and occur earlier, while the runoff will decrease in the summer. The changes are mostly controlled by the temperature. The model describes these changes well, the results are therefore considered as fairly reliable. The large relative increase in the winter runoff in mountainous basins is caused by the very low winter runoff under the present conditions. The most drastic reduction in the spring flood occurs in the lower elevation bands of regions which presently have stable snow cover in the winter. The seasonal distribution is not expected to change much in the coastal region without stable snow cover. The summer runoff is expected to decrease significantly in inland basins with low rainfall and in inland mountain basins where the summer runoff today is maintained by melting snow through much of the summer. The autumn runoff is expected to change proportional to the rainfall until the snow season starts. Seasonal runoff changes for the three elevation bands in Vosso are shown in fig 2.4.

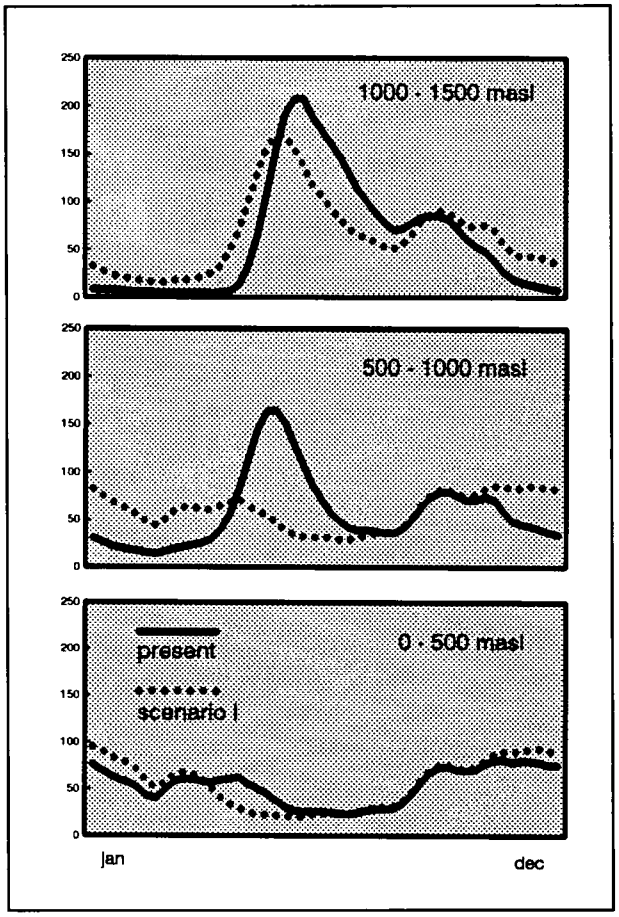


Fig 2.4 Runoff changes in the three elevation bands, river Vosso, western Norway.

The variability will increase strongly in the winter runoff in all regions and elevation bands except in the coastal region. Although the winter runoff will increase in most years, and there will be more frequent floods in the winter, some cold winters with snow and runoff conditions much as now is likely to occur even in a warmer climate.

2.4.3 *Floods*

The scenarios do not take into account a possible increase in the variability of the precipitation. The extreme precipitation is simply assumed to increase proportional to the total precipitation. The predicted changes in floods caused by rainstorms are therefore quite uncertain. The annual flood has a substantial contribution from snowmelt in most areas in Norway. The dependency between the snowmelt and the temperature makes it possible to predict the changes in the flood regime with more confidence than in regions with rainstorms as the major flood generating mechanism.

The simulations predict that the spring flood will be reduced in almost every region and elevation band. The autumn flood will increase, because of increase in the rainfall and a longer flood season. The changes in the flood condition will depend both on the location and the size of the basin in question. Basins prone to autumn floods under present conditions are likely to suffer an increased risk of floods. This is also the case for lowland basins which today has stable snow cover in most years. The risk of floods is expected to increase in smaller basins and decrease along the major rivers which today is mostly exposed to spring floods, because of the increased dominance of rainfall as the cause of floods and because the rainfall is expected to occur more as showers. The risk of damage floods may double in the most exposed areas. The floods are expected to increase proportional to the rainfall for basins on the coast.

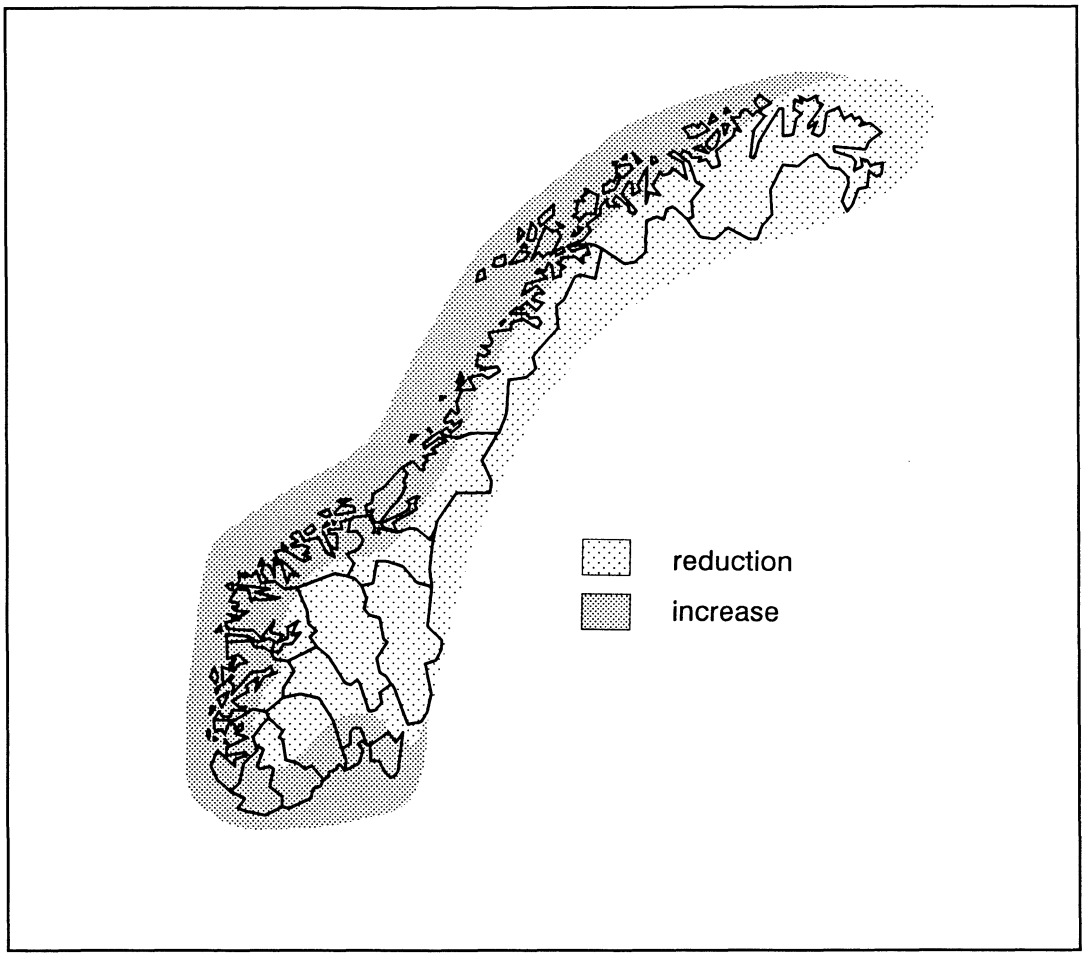


Fig 2.5 Estimated flood regime changes

The predicted changes in the annual flood may be summarized as follows:

- lowland basins on the coast: moderate increase (5 - 10 %)
- basins in the coastal region up to 1000 m asl: significant increase (15 - 20 %).
- basins with low precipitation in the inland: reduction in large basins, increase in small.
- mountain region: no change or moderate increase in the west, reduction in the drier areas in the east

Indications of the expected changes of flood risks are given in fig 2.5. As these changes are uncertain and strongly influenced by catchment area and altitude distribution, the map should only be regarded as an illustration of regional trends.

Autumn or winter floods tend to increase more with the return period than the spring flood. The probable maximum flood may therefore increase even if the 1000 year flood design flood is reduced because of the shift from spring floods to autumn or winter floods.

2.4.4 Snow cover

The season with the ground covered by snow is expected to decrease by one to three months, most in the lowland region. Large areas in the lowland and intermediate altitude levels which today has stable snow cover in most winters may in the future loose it.

2.4.5 Soil moisture

The model predicts an increase in the soil moisture deficit in all regions and elevation bands for the growing season. Typical changes of snow cover and soil moisture deficit are given in fig. 2.6

2.4.6 Ground water

The level of the groundwater will increase in the winter and be reduced in the summer. No changes are expected in the autumn. An increase is expected in the spring in the higher elevation bands and a reduction in the lower.

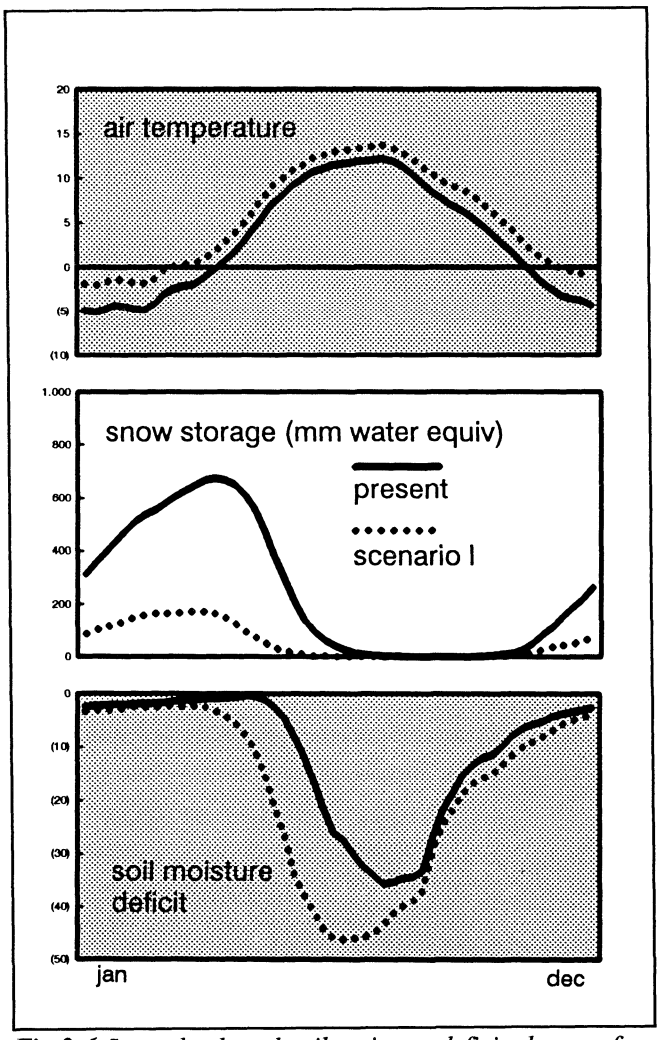


Fig 2.6 Snow depth and soil moisture deficit changes for river Vosso, western Norway.

3 GLACIERS

3.1 General

Norway has a glacier surface area of approximately 2700 km^2 , somewhat less than one per cent of the total land area (Østrem & al, 1973; 1988). Catchments with glaciers have a seasonal variation of runoff that is somewhat different from non-glacierized catchments in the same elevation zones; the runoff remains high during summer after the normal snow melt season due to glacier ice melt. The glaciers also act as longterm storage; water from years with high winter precipitation is stored to be released in years with warm and dry summers. This is of course a desirable effect on summer low flow.

Though the hydrological models like the HBV model will simulate the year by year and seasonal fluctuations of glacier mass balance and runoff, they are not able to describe the glacier dynamics and the longterm variations of glacier extent. Several models have been developed for description of the dynamic behavior of glaciers (for instance Budd & Jenssen, 1975; Bindschadler, 1978; Oerlemans, 1986; Reeh, 1988). A recent simulation for Gråbreen glacier in southern Norway describes the effect of climatic change, taking into account glacier dynamics and topography (Laumann & Tvede, 1989).

In the present study, the assessments are based on simplified mass balance calculations and qualitative evaluations.

3.2 Mass balance calculations

The glaciers chosen are Nigardsbreen (part of the Jostedalsbreen glacier in the fjord districts of western Norway), Hellstugubreen (a continental glaciers in the central Jotunheimen mountains), and Engabreen (part of the Svartisen glacier in northern Norway). The two glaciers in southern Norway have been monitored by mass balance observations since the early 1960s, Engabreen since 1970. Hellstugubreen has displayed negative mass balance, i.e net melt, the other two positive mass balance. The longterm changes are shown in table 3.1, together with average longterm runoff (for equilbrium conditions).

Table 3.1 *Mean annual net mass balance for the observation period, and average long term runoff.*

glacier	obs. period	net balance mm/yr	eq.runoff mm/yr
Nigardbreen	1963 - 1987	250	2840
Hellstugubreen	1963 - 1987	-345	760
Engabreen	1979 - 1987	695	4130

The mass balance calculations for the two climate scenarios are based on the observed mass balance profiles. These profiles have been adjusted by the temperature and precipitation changes depicted by the two scenarios (chapter 1). As a rule of the thumb, 1 degree increase of temperature corresponds roughly to 500 mm net melt during the melt season. Fig 3.1 shows the locations of the glaciers and the calculated mass balance changes. The given melt rates are changes from the observed net balance rather than a glacier in equilibrium.

The calculations indicate that for both scenarios Nigardsbreen and Hellstugubreen will release stored water in addition to the increased precipitation. The effect is most pronounced for the

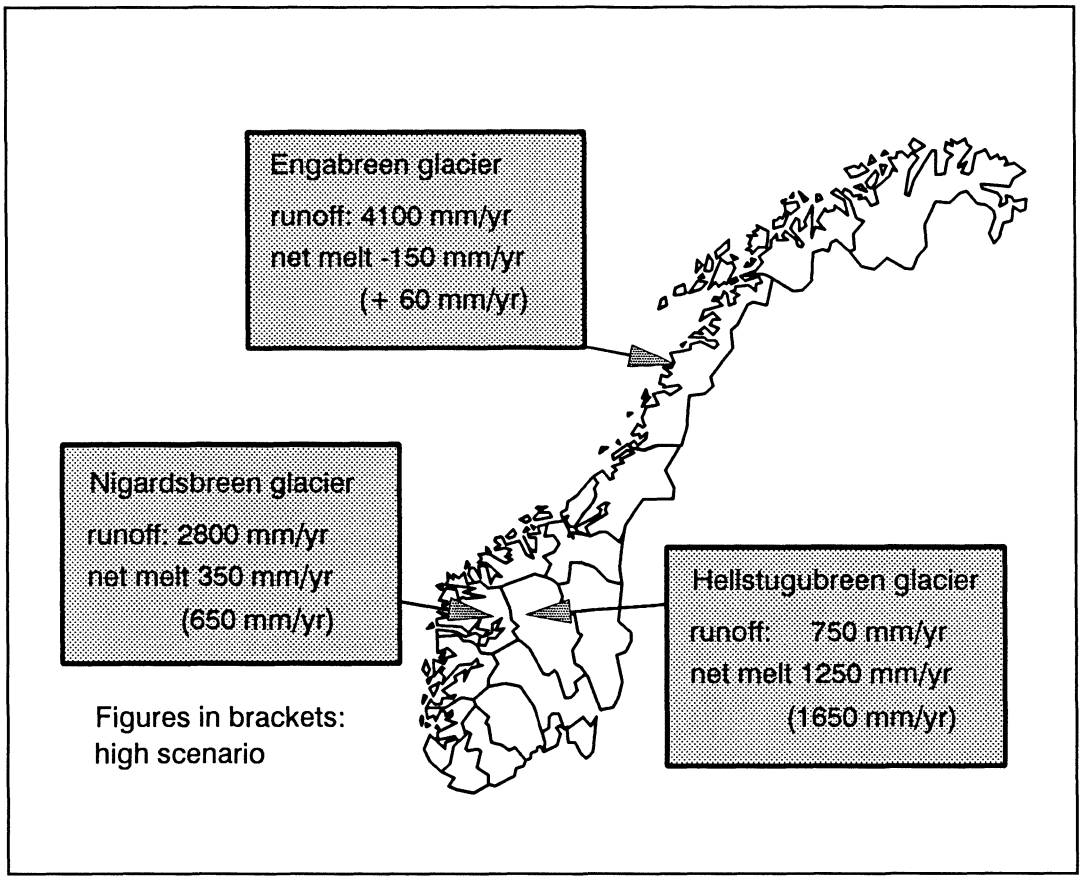


Fig. 3.1 *Runoff and net melt for the glaciers Nigardsbreen, Engabreen og Hellstugubreen.*

continental glacier Hellstugubreen, where net melt could amount to twice the equlibrium longterm runoff of this area. For Nigardsbreen the net melt is in the order of 10 to 30 per cent of the present runoff, while Engabreen seems to come close to equilibrium. These calculations do not include the effects of longer melt season, and is thus probably on the conservative side.

The changes to be expected in glacier mass balance and runoff depend not only on the temperature and precipitation developments, but also on the altitude distribution of the glacier. The general conclusion to be drawn from the rough estimates presented here is that by these climate scenarios nearly all glaciers in Norway will experience net melt. This will give reduced glacier volume and areal extent. Initially the effect on runoff will be a significant increase in total runoff and particularly in summer runoff. The effect will be largest on glaciers in the continental climate regime. This is a transient effect; as the glacier areas decrease and the small glaciers and snowfields disappear the ultimate effect will be reduced summer runoff, especially during dry summers.

The effect on costal glaciers with high altitude accumulation areas is more uncertain. Summer runoff will increase, but the calculations for Engabreen show that this is nearly compensated by the increase in winter precipitations, and that such glaciers may stay close to equilibrium. The balance between winter precipitation and summer melt is a sensitive one, and regional variations in the precipitation changes could even give growing glaciers. Glaciologists are inclined to expect higher precipitation increases in maritime areas than those indicated by these scenarios, referring to observations from the Antarctic peninsula (Peel & Mulvaney, 1988) and Alaska (Mayo, 1989), where temperature increases have been accompanied by strong enough precipitation increases to give pronounced glacier growth.

3.3 Conclusions

By the given scenarios all Norwegian glaciers will give a higher water yield and increased summer runoff. Most glaciers will have negative mass balance, resulting in reduced volume and area. This effect will be most pronounced on small glaciers and snow fields in continental climate regimes. When the glacierized areas are significantly reduced, the ultimate effect will be reduced summer runoff, most pronounced in dry summers.

High altitude glaciers in maritime climates with high precipitation might keep their volume and even grow.

4 WATER TEMPERATURE AND ICE CONDITIONS

4.1 Water temperature

The water temperature in rivers and lakes is the result of a complicated energy balance between water, atmosphere and soil. In unregulated Norwegian rivers without large lakes observations however show that there is a close correspondence between air temperature and water temperature when the catchment is free from snow (and glaciers). In this case, the water temperature is a little below the smoothed daily mean air temperature in the summer months. If snow is melting in parts of the catchment, the melt water will have a temperature close to zero, and the overall water temperature will be strongly influenced by the portion of melt water in runoff.

These considerations indicate that the water temperature will increase approximately proportionally to the air temperature in the snow free part of the year. In addition the snow free period will increase considerably (one to two months), resulting in a larger increase in water temperature than air temperature during the present snow melt period. Fig 4.1 illustrates these effects.

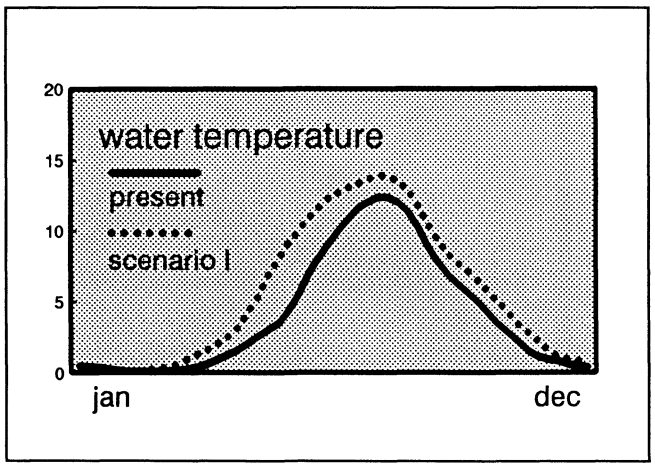


Fig. 4.1 Water temperature changes, river Vosso

In catchments with high glacier coverage, the water temperature might decrease in the summer months due to higher proportion of glacier melt water in runoff (chapter 3).

The temperature conditions in deep lakes and rivers downstream such lakes are governed by the seasonal variations of the thermal and dynamic processes of the lakes. The effects of climate changes on such systems are best studied with the help of dynamic lake models with water temperature and ice cover simulations. Such simulations have not been done for this study.

4.2 Ice conditions on rivers and lakes

4.2.1 General considerations

Norwegian water courses are completely or to some extent ice covered most winters. Time and pattern of freezing up varies from winter to winter, and is only partly determined by weather conditions. The most stable ice conditions are usually found in central southern Norway and in the two northernmost counties Troms and Finnmark. In the costal rivers unstable ice conditions are common even past the polar circle.

The ice conditions influence several user interests, the most important traditionally being recreation and timber transport. A long season with stable ice cover is usually preferred. In many rivers ice jams are quite frequent; such jams impair the transport possibilities and may cause damage by flooding and erosion.

The main factors to influence the ice conditions are:

- air temperature
- radiative energy transfer; clear nights can give ice cover even if the air temperature is above zero
- wind conditions; wind stir of water can delay and even prevent ice cover formation
- water discharge; variations in water discharge can break up ice cover
- water speed; water speed strongly influence ice formation processes - high speed and turbulence give frazil and bottom ice production
- snow depth; insulating snow cover slows ice thickness growth
- river topology and topography; slope, sequence of rapids, pools and lakes influence cooling processes and ice formation
- river regulation; discharge variations and water draw depth in reservoirs can have dramatic effects on ice conditions

4.2.2 Effects of climate change

Climate change will of course influence the ice conditions. The present discussions are based on winter temperature scenarios given in chapter 1 (3.5 degrees increase) and the runoff simulation in chapter 2.

A winter air temperature increase of 3.5 degrees will certainly decrease the ice cover season dramatically. Most costal rivers and lakes will normally be without stable ice cover north to the Troms county. In inland areas of central Norway more unstable ice conditions, and higher frequency of winter ice jams can be expected. Spring breakup ice jams will be reduced. The deep lakes will probably stay ice free most winters. In the northern counties Troms and Finnmark the ice conditions will be less influenced, but even here the frequency of winter ice jams may increase.

For shallow lakes a Finnish study (Kuusisto, 1989) indicates a reduction of ice cover season length with two months, about the same as the expected reduction of snow cover season. The number of years without lake ice cover will increase strongly in southern Finland.

Less snow depth may to some extent counteract the effects of higher air temperature on ice growth after the initial freeze up.

5 EROSION AND SEDIMENT TRANSPORT

5.1 General considerations

A catchment is a dynamic system where it is possible to identify a large number of processes which individually influences sediment transport. Climate and the hydrological regime is main external control on this system, and influence both the erosion processes and the flow of eroded material through the river system. There are many different sources of eroded material.

The glaciers are the most productive sediment sources in Norwegian catchments. The sediment yield of the marine clays are however of the same magnitude as some of the less erosion intensive glaciers. The forested till areas normally have a much lower production, but the sediment yield can increase strongly if the vegetational cover is damaged.

The erosion and sediment transport processes are generally not so well known and described that they can by modeled by physically based models on catchment scale. Assessment of climate change impact on erosion processes thus has to rely on empirical relations and qualitative appraisals.

Two circumstances are important:

- Erosion processes are climate dependent but not necessarily discharge dependent. Production is to a large extent controlled by processes outside the water course system.

- The river channels are transport systems for eroded material and are partly formed by this material. Their shape is largely influenced by hydrological regime and the sediment yield. Changes in these factors will influence the channel erosion and sedimentation processes and thereby the channel form.

Increased sediment production in the upper parts of a catchment can often result in increased channel erosion in the lower river reaches due to equilibrium offset.

There are several examples illustrating that climate change in postglacial time has induced river channel changes. A runoff increase in the Glomma river in sub-atlantic time (1680 B.P.) led to a straightening of the meandering river channel at Flisa. The changes took place over a period of several hundred years (Beisland, 1983).

5.2 Regional changes

Southern Norway can be classified in a number of fluvial regions. The rivers within each region will have similar reactions on external influences. There are not enoughobservations from northern Norway to allow a regional classification for this part of the country. The following description of possible climate change effects on fluvial processes are based on this regionalization.

5.2.1 Glacier region

The glaciers erode by frostshattering and by abrasion of the bedrock with ice embedded blocks. The material is flushed out to the river systems by melt water flow through changing drainage systems.

The heavy erosion and sediment production by the large valley glaciers around the ice caps Jostedalsbreen, Folgefonn, Hardangerjøkulen and Svartisen have a strong influence on the rivers. The glacierized catchments in the central mountains form another group where the sediment load of the rivers is the sum of the sediment load of many smaller glaciers.

The sediment production from glaciers may amount to 50000 - 100000 tons per year from the largest valley glaciers. Isolated cirque glaciers and plateau glaciers have a much lower production; characteristic values are 100 - 200 tons per year.

Climate change will effect the glacier erosion and sediment production in several ways:

- Higher melt rates will influence the release of eroded material through the subglacial drainage system.

- Changed melt rates will influence the glacier dynamics and induce changes in the drainage system, and thereby the release of embedded eroded material.

- Changes in glacier volume, area and sliding speed will influence the processes of erosion. These reactions are much slower than the effects on sediment flushing.

- Changes in glacier front position influence to what extent the eroded material is deposited locally or carried to the river system. Local front advancement can convey earlier deposits to the rivers.

The climate scenarios indicate increased glacier runoff, due to increased melt and summer precipitation. This will result in increased release of eroded material. Observations from Nigardbreen glacier indicate the transport of suspended sediment is 30 - 40 per cent higher than normal in years with high melt.

The scenarios also indicate that most glaciers will melt back. The conditions locally will decide what effect this will have on the sediment transport from each glacier meltwater stream. Observations of glaciers melting completely down indicate that such events may release large amount of eroded material from the exposed glacier sole.

Reduced glacier volume and area will result in reduced erosion rates, and in the long run reduced material transport. Even small glaciers are of large importance as material sources in the Norwegian fluvial regimes. As the glacier melt water runoff contribution dwindles, the material release will be concentrated to high precipitation events.

5.2.2 Western fjords

This region comprises the rivers in the fjord districts without large valley glaciers. Many have small glaciers within their catchments, glaciers which might melt completely down, with results as indicated in 5.2.1. There are few observations from this regions. Due to the expected increase in discharge and flood frequency the erosion and sediment transport will probably increase.

5.2.3 Mountain areas

Outside the glacier catchments it is difficult to estimate the changes of material transport in this regions, as the observations are very scarce. Vegetation reduces erosion in these areas, but is very vulnerable to damages, and regains lost ground very slowly. Large vegetation changes are expected due to climatic change in highland areas (Holten, 1990). Such effects would be partly due to direct climatic influence, partly to hydrological influences such as reduced snow cover and increased soil moisture deficit.

5.2.4 Central inland

In the forest areas of eastern Norway the natural erosion is relatively low. Outside the clay areas the main sediment sources are erosion in tills or glaciofluvial deposits. Modern forestry practices represent in many areas a heavy landscape wear factor; causing increased surface runoff and floods. Use of heavy machinery damages surface cover, especially in mild winters without frozen ground and protective snow cover.

In areas with deep loose deposits gullies are results of and the source of intense erosion. The opening of gullies can be caused by climate change, probably mainly through vegetation changes or

increased groundwater levels. Large floods involving intense rainfall are often the direct cause of gully formation. Such gullies might close again, but may also stay open and increase in size and activity.

In addition to increasing the sediment load which may represent an ecological problem and change the river channel system, the torrents may also represent an hazard by increasing the risk of landslides. The largest historical flood in this area, "Storofsen" 1789, did as much damage through gullying and landslides as through inundations. In addition, the fisheries in the largest lake of Norway, Mjøsa, was damaged for many years due to devastating amounts of suspended sediment loads.

5.2.5 Clay areas

Runoff simulations based on the climate scenarios indicate increased winter floods. In the marine clay areas of eastern Norway such floods can increase the suspended sediment loads considerably. Data from the Leira river from the extremely mild winter of 1990 show a suspended transport of 5700 tons during 4 days in February (catchment area 260 km^2). This is nearly as much as the total transport during 1989. In the period January 10 to February 9 the suspended load in the Glomma river was measured to 250000 tons, the same amount as an average year total (Vollner, 1990). During these episodes the soil was partly frozen, but not snow covered. Heavy rain caused large surface runoff and intense erosion, especially on plowed fields.

Top soil loss is only one of the problems caused by such events. The high loads will also reduce water quality and cause adverse ecological effects in the rivers and estuaries. The effects on river morphology already mentioned could cause channel instability, altered river profiles and changes of flooding levels.

5.3 Conclusions

The changes in the hydrological regime caused by the climate scenarios will generally give increased sediment yield.

The longterm glacier erosion may decrease, but the short term release of eroded material will lead to higher sediment loads in meltwater rivers. The increase in sediment yield is expected to be highest in the clay areas of eastern Norway, caused by higher winter runoff rates and less protective snow cover. Soil loss and water quality problems will increase. Total sediment yield to the Oslo fjord and Skagerak will increase.

Agricultural and forestry practices will strongly influence erosion rates. Vegetation changes caused by climatic change and other environmental changes such as acid precipitation and air pollution may affect erosion, especially in high mountain areas.

Increased erosion will be accompanied by increased loads of particulate nutrients, heavy metals and pesticides, from natural and man made sources. This would accentuate the adverse environmental impacts of the suspended sediment load.

6 WATER QUALITY

As mentioned in the previous chapter, water quality could be reduced due to increased suspended sediment load and the attached loads of particulate nutrients, heavy metals and pesticides. On a broader scale, the Norwegian Institute for Water Research, NIVA, in a parallel study for the Norwegian Interministerial Climate Policy Study has investigated the effects on water quality and aquatic ecology (Gulbrandsen & al., 1990). The main fields covered in this study is the effects of climate change on

- eutrophication of fresh water
- acidification of fresh water
- eutrophication of costal waters

The most serious eutrophication effects are expected on shallow lakes, especially mesoeutrophic to eutrophic systems in agricultural areas. Deep lakes are not expected to be seriously affected.

River acidification may increase due to increased decomposition of organic substance in the deep humus of the Norwegian coniferous forests, a decomposition that would lead to a dramatic increase in release of nitrogen, carbon and phosphorous.

Negative effects in costal waters are expected to be caused by increased nitrogen supply, from increased farm land erosion and humus decomposition. This would increase the danger of algae bloom incidents.

7 FLOODS AND FLOOD DAMAGE

7.1 General considerations

Flood damage occur when the water level in rivers and lakes rises above the confines of the water channel, or the discharge surpasses the capacity of culverts, bridges and pipes. In a river system in its natural state, the bankfull level will usually be exceeded on the average ten to fifty years out of hundred, ie with recurrence interval of two to ten years. In a flooding situation, the damage will usually increase sharply with water level; inundated area, water depth, duration of submergence and water speed will all increase. If the relationship between water level and damage, and the probability distribution of water stage are known, it is possible to determine the probability distribution of damage. The expected annual damage is the mean value of this distribution.

Flood prevention measures can be aimed at reducing the damage at a given flood level (flood zoning, forecasting, embankments) or reducing the discharge and/or the stage (river regulation, channel improvement etc).

Large floods can have serious economical and social consequences. "Storofsen" in 1789, the largest flood in historical time in central Norway killed 80 people, destroyed 3000 farm houses and large area of prime farm land, and started off an emigration to northern Norway. The recurrence interval was probably of the order of 1000 years (Beldring & al, 1990).

The largest flood in recent years was the combined storm, flood and floodtide in October 1987. The flood had a recurrence interval of 100 years or more over an area of 4000 km^2 (Engen, 1988). The damages caused by the flood is probably of the order of 500 M NOK.

The statistics on flood damages are far from comprehensive, but data collected during the last decade from governmental agencies and insurance companies seem to indicate that the direct economic losses are of the order of 100 M NOK per year (Sand, 1986; Andersen 1990). The total costs to individuals and society are larger, and some assessments are in the order of 500 - 1000 M NOK (Skretteberg, 1989).

7.2 Climate change impact

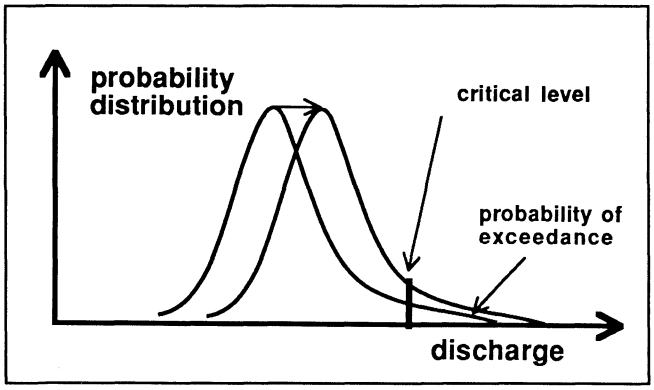


Fig. 7.1 Moderate increase of flood discharges may result in larger increase of flood frequency (area below probability distribution).

As discussed in chapter 2, there are reasons to expect that the spring melt flood will decrease, while the autumn and winter floods will increase. As the large rivers in eastern Norway to a large extent was protected by extensive flood works during the sixties, most of the damage is now caused by rain floods in small and medium sized rivers. The majority of the population live in the costal zone where the rain floods dominate. We can therefore expect the increase in damages caused by rain floods summer, autumn and winter far to outweigh the reduction in damages caused by the spring melt floods. The small catchments in urban areas are especially vulnerable, and in this context the prediction by Blindheim & al (1990) that more of the precipitation can be expected as showers, is certainly a cause for concern.

In the densely populated areas the runoff simulations indicate increases in the flood discharges of a given recurrence period of 5 to 30 per cent. The frequency of floods above a given level will increase more, as the probability (area under the probability distribution) increases rapidly as we move away from the tail (fig 7.1). For Norwegian flood regimes, an increase of the flood discharges of 15 per cent corresponds roughly to a doubling of number of floods above the critical

level. A qualified guess would thus be that the economic losses due to increased flood damages would double under the given scenarios, if no countermeasures were taken.

7.3 Dam safety

Design and construction of Norwegian dams are controlled by regulations issued by the Norwegian Water Resources and Energy Administration in 1981 (NVE, 1986), and design floods are calculated by methods based partly on flood frequency analysis, partly on rainfall estimates (Sælthun & Andersen, 1986; Førland & Kristoffersen, 1989). The design criterium for normal operation of spillways is the 1000 year flood, while the overall dam safety is controlled against the Probable Maximum Flood (PMF), calculated from Probable Maximum Precipitation (PMP) values.

There are, as underlined in chapter 2, large uncertainties connected to estimates of changes in extreme flood values. The runoff simulations do however give some indications. Catchments that today are clearly dominated by the spring flood, even at dam design flood levels should not expect increased flood estimates. Where the autumn floods are critical, or close to being critical, it is reason to expect increased estimates. The simulations, which probably are rather conservative, display increases up to 30 per cent for design flood (1000 year flood), more caused by longer flood season than increased rainfall.

The PMF is closely connected to the PMP estimates, and so far the effect of climate change on PMP values has not been evaluated. For small catchments where summer rains are critical the PMF value will largely vary proportionally to the PMP, with the possibility of some reduction due to increased soil moisture deficit, if this is considered in the calculations. For most catchments autumn rains combined with snow melt is critical. For such catchments, the main effect will be the prolonging of the flood season, and the increased probability of winter rains combined with meltdown of rather large snow storages. For spring floods, the PMP rainfall is usually combined with the melting of a snow storage with 30 year recurrence interval. The melt contribution will be reduced enough to give a total reduction of PMF values for spring situations.

The summer floods are critical for catchments with high glacier coverage, and for the catchments the extreme floods will clearly increase due to the combination of more precipitation and higher melt rates. The effect will in due time be offset by the reduction in glacier area.

Dams are designed for a long technical lifetime, and will certainly experience climate changes. They are also expensive structures that are not easily redesigned to comply with changing climatic loads or governmental regulations. This indicates that dams which are build or revised today should probably be designed with some regard to possible future changes. As these changes can only be assessed with large uncertainty, an optimal design would take them into consideration as an increased load uncertainty, and with increased design safety factors as a consequence (Gottschalk & Sælthun, 1990).

Climate change does not happen overnight, and dams that are safe today, are not unsafe tomorrow. But if they are not dramatically overdesigned, they can not be classified as hydrologically safe for all future. This indicates that existing dams should be reclassified at intervals if they are situated in regions where climate change induces increased flood risks.

7.4 Design under uncertainty

Hydrological uncertainty has traditionally not been given much consideration in hydraulic design. By and large the future hydrologic loads have been thought to be perfectly characterized by a historic data series of thirty years or so. Except in design of dam structures and spillways, little attention has been given to robust designs, ie designs that can take future variations in environmental loads or changes in operating circumstances without deterioration of safely levels or economical value.

Even without the advent of climate change, the natural climatic variability, as demonstrated for instance by fig 1.1, is so large that it should be considered in design methods. As we now are facing even larger changes in flood and runoff regimes, all planning and hydraulic designs with expected lifetime more than ten years should certainly take into consideration the full impact of uncertainty inherent in future loads. This applies to the construction of dams, bridges, urban drainage systems, to master plans with flood zoning schemes and so on.

7.5 Floods from glacier dammed lakes

Glaciers can at times dam water in side valleys or against mountain sides. These lakes will grow until they break through the ice dam and release the stored water abruptly. Such natural dam breaks will usually result in very large floods; discharges up to 100000 m^3/s has been reported. In Norway such floods have caused major disasters in the valleys of Simadal and Jostedal.

Glacier dammed lakes are frequently created when the glacier is out of equilibrium; advancing or retreating. A rapid retreat due to temperature increase could lead to development and subsequent release of such lakes in relatively short time. Several minor lakes are known today. At the moment, they do not represent any large hazard, but they could develop quickly given the right climatic conditions.

8 HYDROPOWER PRODUCTION

8.1 General comments

The Norwegian electricity production system is nearly 100 per cent based on hydropower, which makes it very sensitive to longterm variations in runoff. High inflows that can not be stored in the reservoirs result in dump energy for the domestic market or export, or has to be spilled due to limitations on productions capacity or export transmission capacity. In dry years the domestic thermal reserves are very limited.

At first glance, the climate change scenarios of increased precipitation and mild winters, seem favorable for hydropower production. As shown in chapter 2, the runoff increase is less than the precipitation increase due to increased evapotranspiration, but the most important parts of the country for energy production show a net increase in runoff, even in the low scenario.

The changes in seasonal distribution of runoff, with higher winter flows and reduced spring flood, are generally advantageous, as this reduces the demand for seasonal storage, and reduces flood spill, especially in the run-of-the-river power plants. The operation of the reservoirs changes when the need for seasonal storage is reduced; the extra storage capacity available is used for flood spill reduction, and to some extent to provide longterm storage.

As the runoff simulations are based on data from the last 30 years, we have not introduced any changes in the year-by-year variability. Such changes would greatly influence the firm power level of the Norwegian system.

8.2 Power production simulations

To test and to illustrate the effects of climate changes, the operation of a regional hydropower production and distribution company, "Bergenshalvøens Kommunale Kraftselskap" (BKK), was simulated. The annual production of the company is approximately 5 TWh. Their standard production planning model VANSIMTAP, developed at the Norwegian Electric Power Research Institute, was used. The BKK system was simulated as an isolated system. The simulations were carried out by the Power Pool of Norway, in cooperation with the Norwegian Water Resources and Energy Administration and BKK (Mørk, 1990).

The simulations are based on the six simulated runoff series for the Vosso river; two, present and scenario 1, for each of the three elevation bands. Each reservoir is assigned to the series corresponding to the mean altitude of its catchment. Then the current situation is simulated, using these series and the best historical estimate of mean catchment inflow as input data. For scenario 1, a relationship between runoff change and altitude is established, based on the hydrological simulations. The increase in runoff varies from 2.5 per cent at 250 m asl to 5.6 per cent at 1250 m asl. Then the yield of each catchment is adjusted according to this altitude dependency, and the data series describing scenario 1 is used as inflow series.

The firm power demand was adjusted by existing models, to take into account the changes of seasonal demand profile due to higher winter temperatures.

Total change in energy inflow (runoff weighted by reservoir elevation) was 3.3 per cent. The total energy production increased by 4.5 per cent. The extra gain was due to better seasonal inflow distribution which improved reservoir operation and reduced flood spill. The storage to inflow ratio is lower for BKK than the national average, and flood spills are higher.

The seasonal distribution of energy production was greatly improved; the large production of dump energy in spring was avoided with the altered runoff regime, as shown in fig. 8.1. The operation of the reservoirs was also changed; the annual winter drawdown was reduced, and more water was carried over from wet to dry years, even in this somewhat poorly regulated system.

Firm power production levels are not estimated realistically by isolated system simulations; nationwide or even Nordic system simulations are needed for calculation of firm power levels and assured supply. Because, however, there is less need for reservoir capacity to provide seasonal regulation there is an increase capacity available for year-to-year carry over, and thus an increase in total firm power level - provided the year-by-year variability of inflow does not increase.

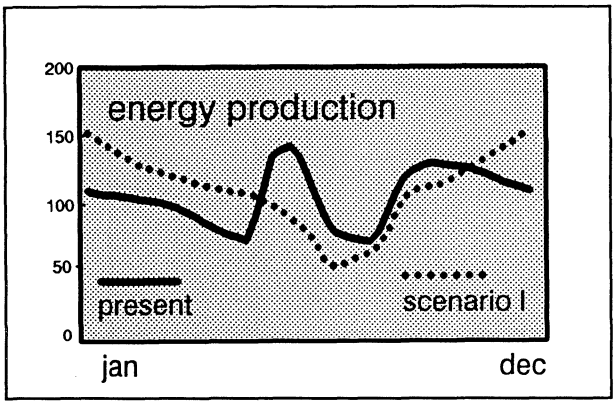


Fig. 8.1 Seasonal distribution of total energy production in BKK hydropower system.

8.3 Conclusions

It is of course bold to draw general conclusions from isolated system simulations covering only 5 per cent of the national electricity production. Using the indications provided by these simulations and information about the production system, and the estimates of regional change in runoff given in chapter 2, some general comments can be made.

The runoff conditions found in the BKK system are probably representative for approximately 35 per cent of the national production system. The conditions found in the costal areas of mid-Norway as represented by the Øyungen catchment is also quite similar, but with a somewhat higher runoff increase. This region represents about 10 per cent of the total production. The regions represented by the Tovdal river in southern Norway and the Forra river in inland mid-Norway have a somewhat lower runoff increase, but are otherwise not very different from the Vosso runoff regime. These two regions account for approximately 30 per cent of the total production.

The central mountain region, as represented by the Otta river, shows small changes in both total runoff change and seasonal distribution of runoff. The production in these areas is about 15 per cent of the total production. Eastern Norway, as represented by the Flisa river, and continental northern Norway, represented by the Alta river, will have reduced runoff according to scenario 1. These regions have a relatively low share of total energy production, approximately 10 per cent.

An estimate for the total system, based on such considerations, indicates that in scenario 1, the increase in total production will be in order of 2 - 3 per cent; about one fifth of this being reduced flood spill. Taking the precipitation change (7.5 per cent increase) as given, the main uncertainty in this estimate is caused by the uncertainty in evapotranspiration assessments. Calculations have not been made for the high scenario (16.5 per cent precipitation increase), but the average runoff increase is in the order of 10 per cent for this scenario. For the high scenario, the flood spill losses will probably rise again if the capacity of the production system is unaltered.

As mentioned above, the mild winters will reduce the demand for energy for heating. Empirical models are available for the estimation of this effect . The Power Pool of Norway calculated the reduced demand in 1989, which had very mild winter months, to be 2.5 TWh. The longterm effect on the electricity sector is, however, uncertain, as the balance between the energy sources may shift according to price, political decisions and customer preferences. The mild winter of 1989/90 saw a surprisingly high consumption of electrical energy, probably because the consumers found it convenient to use electric heaters for the light heating necessary.

9 OTHER EFFECTS

9.1 Agriculture, forestry

The agricultural sector will certainly be strongly influenced by the water related effects of climate change. As mentioned in chapter 5, erosion may become a major environmental problem in central farming areas. This will probably necessitate changes in agricultural practices, which today to a large extent is based on the anticipation of a cold winter with stable snow cover.

Due to earlier snowmelt, the growing season will be significantly longer, and the soil will be ready for cultivation approximately one month earlier. Early and less snow melt combined with higher evapotranspiration will lead to increased soil moisture deficit, as illustrated in chapter 2. This will increase the demand for irrigation significantly. As this will coincide with reduced summer low water flow, small rivers in inland agricultural areas may experience water shortage and increased water quality problems.

Reduced snow cover may influence the winter survival of some cultures.

9.2 Recreation

The changes in discharge, water temperature, and water quality will influence the fresh water fauna (Holten, 1990). This will of course affect fresh water fisheries, both recreational and professional. The changes in river and lake ice cover will also influence recreational fishing.

The season with permanent snow cover will be significantly shorter, and snow conditions generally poorer. The possibility to ski regularly activity will be reduced in the lowland areas around the population centers, and the season of ski centers much shorter in low and middle altitudes. The ski activities will focus on the snow rich high mountain areas.

While the ski possibilities will be impaired, the hiking season in the mountains will become longer. The areas are earlier snow free, and the spring flood will be reduced, giving easier access in June and July.

The operation of hydropower reservoirs will be changed, this may influence the recreational use of these reservoirs.

9.3 Water supply

Surface water supply systems will hardly be seriously affected by shortages, except systems with poor storage capacity, which can get problems in dry summers. Irrigation and industrial water supply directly from rivers can be affected in small inland rivers. Impaired water quality (Gulbrandsen & al, 1990), may become a problem in domestic water supply systems.

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APPENDIX

Table A.1
Simulations for western Norway
Reference catchment: 062.Z Bulken, river Vosso

	1000 - 1500			500 - 1000			0 - 500		
	pres	SC1	%	pres	SC1	%	pres	SC1	%
precipitation	2050	2200	+ 7	2050	2200	+ 7	2050	2200	+ 7
evapotransp.	100	155	+55	155	255	+65	280	390	+40
runoff	1950	2055	+ 5	1895	1945	+ 3	1770	1810	+ 2
Jan, l/s km^2	10	41	+310	22	71	+225	52	86	+65
Feb "	7	26	+270	14	46	+230	34	58	+70
Mar "	6	32	+430	17	59	+250	48	71	+50
Apr "	10	53	+430	30	59	+100	58	46	-20
May "	130	140	+ 10	125	70	- 45	91	28	-70
Jun "	200	100	- 50	140	40	- 70	50	22	-55
Jul "	110	54	- 50	73	31	- 60	30	25	-15
Aug "	62	46	- 25	45	36	- 20	31	32	+ 5
Sep "	81	77	- 5	71	69	- 5	61	63	+ 5
Oct "	74	80	+ 10	75	78	+ 5	72	74	+20
Nov "	39	70	+ 80	58	84	+ 45	75	89	+20
Dec "	16	60	+280	36	85	+135	67	92	+35
spring flood (1/2 - 31/7):									
mean l/s km^2	345	260	- 25	240	235	0	205	245	+20
std.dev. "	75	65	- 15	50	100	+100	75	125	+65
1000 yr flood	775	630	- 20	525	810	+ 50	635	960	+50
autumn flood (1/8 -31/1):									
mean l/s km^2	255	330	+ 25	255	330	+ 30	290	340	+20
std.dev. "	80	90	+ 15	75	95	+ 25	95	115	+25
1000 yr flood	715	845	+ 20	685	875	+ 30	835	1000	+20
annual flood (1/1 - 31/12):									
mean l/s km^2	360	345	- 5	280	350	+ 25	305	370	+20
std.dev. "	65	75	+ 15	60	85	+ 45	79	120	+50
1000 yr flood	730	775	+ 5	625	835	+ 35	760	1060	+40
all seasons:									
mean l/s km^2	360	345	- 5	280	350	+ 25	305	370	+20
1000 yr flood	775	845	+ 10	685	875	+ 30	835	1060	+25
winter low fl (1/10 - 31/5):				1/10 - 30/4:					
mean l/s km^2	4.1	7.5	+ 85	5.3	7.4	+ 40	6.7	8.1	+20
std.dev. "	0.8	3.1	+290	1.3	3.1	+160	2.5	3.3	+30
summer low fl (1/6 - 30/9):				1/5 - 30/9:					
mean l/s km^2	21.9	7.4	- 65	14.9	9.6	- 35	10.3	6.8	-35
std.dev. "	7.9	3.0	- 60	7.0	3.5	- 50	4.8	2.9	-40
snow cover:									
days > 25 %	285	225	-60	245	180	-65	185	100	-85
soil moisture deficit, growing season (1/5 - 31/8):									
mean:	5	10	+ 5	15	30	+15	40	55	+15
days > 50 mm	0	0	0	2	12	+10	35	75	+40
groundwater storage, mm:									
winter	55	70	+15	60	80	+20	75	80	+15
spring	60	80	+20	95	85	-10	85	80	- 5
summer	95	85	-10	85	75	-10	70	60	-10
autumn	80	85	+ 5	80	90	+10	85	85	0

Table A.2
Simulations for central mountains
Reference catchment: 002.DHZ Lalm, river Otta

	1000 - 1500			500 - 1000			0 - 500		
	pres	SC1	%	pres	SC1	%	pres	SC1	%
precipitation	935	1005	+ 7	840	905	+ 7	700	755	+ 7
evapotransp.	75	120	+60	160	225	+40	255	320	+30
runoff	860	835	+ 3	680	680	0	445	435	- 2
Jan, l/s km^2	4	9	+125	6	17	+180	13	23	+ 75
Feb "	4	6	+ 50	4	12	+200	9	17	+ 90
Mar "	3	7	+135	5	14	+180	11	20	+ 80
Apr "	2	11	+450	6	27	+350	22	16	- 25
May "	34	87	+155	74	58	- 20	37	9	- 75
Jun "	136	87	- 35	79	21	- 75	11	5	- 55
Jul "	65	30	- 55	21	11	- 50	7	5	- 30
Aug "	23	17	- 25	10	9	- 10	6	5	- 15
Sep "	22	23	+ 5	16	16	0	8	7	- 10
Oct "	18	27	+ 50	20	24	+ 20	13	12	- 10
Nov "	8	16	+100	12	24	+100	15	19	+ 25
Dec "	5	12	+140	8	25	+210	17	26	+ 55
spring flood (1/2 - 31/7):									
mean l/s km^2	230	180	- 20	170	105	- 40	70	67	- 5
std.dev. "	50	50	0	46	36	- 20	32	46	+ 45
1000 yr flood	515	465	- 20	435	310	- 30	255	330	+ 30
autumn flood (1/8 -31/1):									
mean l/s km^2	71	89	+ 25	55	94	+ 70	64	89	+40
std.dev. "	30	45	+ 50	33	60	+ 80	47	56	+20
1000 yr flood	245	345	+ 40	245	440	+ 80	335	410	+25
annual flood (1/1 - 31/12):									
mean l/s km^2	230	185	- 20	170	130	- 25	88	110	+ 25
std.dev. "	50	49	0	46	47	0	38	52	+ 35
1000 yr flood	515	465	- 10	435	440	- 10	305	410	+ 35
all seasons:									
mean l/s km^2	230	185	- 20	170	130	- 25	88	110	+ 25
1000 yr flood	515	465	- 10	435	440	0	335	410	+ 25
winter low fl (1/10 - 31/5):							1/10 -30/4:		
mean l/s km^2	1.7	3.2	+ 90	2.4	4.1	+ 95	3.5	3.7	+ 5
std.dev. "	0.3	0.9	+200	0.7	0.9	+ 30	0.9	1.1	+ 20
summer low fl (1/6 - 30/9):							1/5 - 30/9:		
mean l/s km^2	8.3	6.5	- 25	4.9	4.6	- 10	3.5	2.6	- 25
std.dev. "	4.3	2.8	- 35	1.5	1.2	- 20	0.8	0.7	- 10
snow cover:									
days > 25 %	290	245	-45	250	205	-45	190	120	-70
soil moisture deficit, growing season, mm (1/5 - 31/8):									
mean:	10	12	+ 2	25	40	+15	70	95	+25
days > 50 mm	0	0	0	15	50	+25	90	115	+25
groundwater storage, mm:									
winter	25	45	+20	35	55	+20	45	55	+10
spring	25	50	+25	35	60	+25	50	50	0
summer	70	65	- 5	60	50	-10	45	35	-10
autumn	55	60	+ 5	50	55	+ 5	45	40	5

Table A.3
Simulations for eastern Norway
Reference catchment: 002.GZ Knappom, river Flisa

	1000 - 1500			500 - 1000			0 - 500		
	pres	SC1	%	pres	SC1	%	pres	SC1	%
precipitation	675	725	+ 7	675	725	+ 7	675	725	+ 7
evapotransp.	100	145	+45	180	245	+35	245	315	+30
runoff	575	580	+ 1	495	480	- 3	430	410	- 5
Jan, l/s km^2	3	6	+50	4	10	+150	6	12	+100
Feb "	3	4	+40	3	8	+165	5	11	+120
Mar "	2	4	+70	3	10	+235	5	12	+140
Apr "	3	14	+370	8	28	+250	21	22	+ 5
May "	55	64	+15	67	32	-55	45	15	-65
Jun "	65	35	-45	32	16	-50	17	12	-30
Jul "	25	21	-15	14	13	- 5	12	11	-10
Aug "	16	16	0	11	11	0	10	10	0
Sep "	18	18	0	14	14	0	12	12	0
Oct "	16	18	+10	14	15	+ 5	13	13	0
Nov "	7	10	+45	8	12	+50	9	12	+35
Dec "	5	9	+80	6	13	+115	8	14	+75
spring flood (1/2 - 31/7):									
mean l/s km^2	165	130	- 20	145	82	- 45	92	63	-30
std.dev. "	42	40	- 5	45	33	- 25	34	33	- 5
1000 yr flood	405	360	- 10	405	270	- 35	285	250	-15
autumn flood (1/8 -31/1):									
mean l/s km^2	44	54	+ 20	41	52	+ 25	37	52	+40
std.dev. "	25	38	+ 50	31	38	+ 25	33	35	+ 5
1000 yr flood	185	270	+ 40	220	270	+ 25	225	250	+15
annual flood (1/1 - 31/12):									
mean l/s km^2	165	134	- 20	147	91	- 40	97	75	-25
std.dev. "	42	39	- 5	43	33	- 25	34	36	+ 5
1000 yr flood	405	355	- 10	395	280	- 30	290	280	- 5
all seasons:									
mean l/s km^2	165	134	- 20	147	91	- 40	97	75	-25
1000 yr flood	405	360	- 10	405	280	- 30	290	280	- 5
winter low fl (1/10 - 31/5):				1/10 - 30/4:					
mean l/s km^2	1.8	2.6	+ 45	2.0	3.5	+ 75	2.6	3.7	+40
std.dev. "	0.3	0.6	+ 50	0.4	1.1	+175	0.7	1.2	+70
summer low fl (1/6 - 30/9):				1/5 - 30/9:					
mean l/s km^2	5.3	5.4	0	4.1	4.2	0	4.0	3.6	-10
std.dev. "	2.3	2.1	- 10	1.4	1.1	-20	1.3	0.9	-30
snow cover:									
days > 25 %	245	210	-35	220	175	-45	185	125	-60
soil moisture deficit, growing season, mm (1/5 - 31/8):									
mean:	20	25	+ 5	40	50	+10	65	80	+15
days > 50 mm	1	3	+ 2	40	60	+20	85	110	+35
groundwater storage, mm:									
winter	30	35	+15	30	45	+15	35	45	+10
spring	30	30	0	35	50	+15	45	50	+ 5
summer	50	55	+ 5	45	45	0	45	40	- 5
autumn	50	55	+ 5	45	50	+ 5	45	45	0

Table A.4
Simulations for northern Norway, inland
Reference catchment: 212.Z Masi, river Alta

	1000 - 1500			500 - 1000		
	pres	SC1	%	pres	SC1	%
precipitation	490	525	+ 7	490	525	+ 7
evapotransp.	100	145	+45	155	205	+30
runoff	390	380	- 3	335	320	- 5
Jan, l/s km^2	3	3	+ 20	3	5	+ 65
Feb "	2	2	+ 20	2	4	+100
Mar "	2	2	+ 20	2	4	+100
Apr "	1	2	+100	2	9	+350
May "	13	31	+140	29	29	0
Jun "	52	38	-25	32	15	-55
Jul "	30	20	-35	16	12	-25
Aug "	18	16	-11	13	13	0
Sep "	12	12	0	10	11	+10
Oct "	7	9	+30	8	10	+25
Nov "	4	6	+50	5	8	+60
Dec "	3	4	+35	4	6	+50
spring flood (1/2 - 31/7)						
mean l/s km^2	120	105	-15	91	56	-40
std.dev. "	32	28	-10	25	26	+ 5
1000 yr flood	305	265	-15	235	205	-15
autumn flood (1/8 - 31/1)						
mean l/s km^2	29	28	- 5	22	23	+ 5
std.dev. "	16	17	+ 5	13	14	+ 5
1000 yr flood	120	125	+ 5	95	105	+10
winter low fl (1/9 - 15/6):						
mean l/s km^2	1.1	1.5	+35	1.4	2.5	+80
std.dev. "	0.2	0.3	+50	0.3	0.6	+100
summer low fl (16/6 - 31/8):						
mean l/s km^2	11.0	9.3	-15	7.6	5.9	-20
std.dev. "	5.5	5.3	- 5	4.5	2.7	-40
snow cover:						
days > 25 %	275	245	-30	240	205	-35
soil moisture deficit, growing season, mm (1/5 - 31/8):						
mean:	25	30	+ 5	35	45	+10
days > 50 mm	1	12	+11	20	50	+30
groundwater storage, mm:						
winter	20	20	0	20	30	+10
spring	35	40	+ 5	40	50	+10
summer	55	55	0	50	50	0
autumn	35	40	+ 5	40	45	+ 5

Table A.5
Simulations for mid-Norway, coast
Reference catchment: 138.Z lake Øyungen

	1000 - 1500			500 - 1000			0 - 500		
	pres	SC1	%	pres	SC1	%	pres	SC1	%
årsnedbør	3075	3310	+ 7	2505	2700	+ 7	1655	1780	+ 7
fordampning	30	80	+180	110	185	+70	235	315	+35
avløp	3045	3230	+ 6	2395	2515	+5	1420	1465	+3
Jan l/s km2	11	39	+255	18	52	+190	29	55	+90
Feb "	7	33	+170	12	49	+310	27	53	+100
Mar "	8	34	+325	14	49	+250	30	52	+75
Apr "	9	61	+580	29	81	+180	62	60	+5
May "	71	153	+115	140	146	+5	102	30	-70
Jun "	297	273	-10	260	107	-60	35	18	-50
Jul "	266	152	-45	113	55	-50	22	21	-5
Aug "	149	92	-40	61	50	-18	20	21	+5
Sep "	145	140	-3	104	104	0	57	59	+5
Oct "	101	131	+30	97	110	+15	65	68	-5
Nov "	23	67	+190	39	76	+95	47	58	+25
Dec "	17	60	+255	28	78	+280	45	65	+45
spring flood (1/2-31/7)									
mean: l/s km2	620	630	+2	500	500	0	290	320	+10
std.avv. "	98	150	+50	95	145	+50	87	105	+20
1000 års flom	1100	1370	+25	970	1215	+25	720	840	+15
autumn flood (1/8-31/1)									
mean: l/s km2	550	625	+15	460	535	+15	315	360	+15
std.avv. "	150	185	+25	145	150	+2	105	105	+0
1000 års flom	1290	1540	+20	1175	1275	+10	835	880	+ 5
annual flood (1/12-31/12)									
mean: l/s km2	645	705	+10	540	580	+10	345	390	+15
std.avv. "	120	175	+50	120	170	+40	105	110	+5
1000 års flom	1235	1570	+25	1135	1420	+25	865	935	+10
alle sesonger									
mean: l/s/km2	645	705	+10	540	580	+10	345	390	+15
1000 års flom	1235	1570	+25	1175	1420	+20	865	935	+10
winter low fl (1/10-31/5)				(1/10-30/4)					
mean:	2.8	5.0	+80	3.5	6.1	+75	5.2	7.1	+40
std.avv	1.2	1.6	+35	1.4	1.6	+15	1.7	1.7	0
summer low fl (1/6-30/9)				(1/5-30/9)					
mean:	22.0	15.7	-30	10.1	9.6	-5	6.7	5.7	-15
std.avv	9.3	5.6	-40	3.7	2.1	-20	2.0	1.9	-5
snow cover:									
days > 25 %	365	275	-90	270	205	-65	200	145	-55
soil moisture deficit, growing season, mm (1/5-31/8)									
mean:	1	2	+1	4	9	+5	19	26	+7
days > 50 mm	0	0	0	0	0	0	1	1	0
groundwater storage, mm:									
winter	15	30	+15	20	35	+15	30	35	+5
spring	35	50	+15	45	45	+0	40	35	-5
summer	55	50	-5	45	45	-0	30	30	-0
autumn	35	40	+5	35	45	+10	35	40	+5

Table A.6
Simulations for mid-Norway, inland
Reference catchment: 124.AZ Høggås bru, river Forra

	1000 - 1500			500 - 1000			0 - 500		
	pres	SC1	%	pres	SC1	%	pres	SC1	%
precipitation	1430	1535	+ 7	1430	1535	+ 7	1430	1535	+ 7
evapotransp.	75	135	+80	150	230	+55	240	330	+40
runoff	1355	1400	+ 3	1280	1305	+ 2	1190	1205	+ 1
Jan, l/s km^2	6	13	+115	10	28	+140	22	38	+75
Feb "	5	10	+100	8	28	+250	21	37	+75
Mar "	4	10	+150	9	29	+220	24	37	+55
Apr "	4	21	+425	17	56	+230	50	40	-20
May "	68	140	+105	140	74	-45	74	25	-65
Jun "	200	115	-40	105	37	-65	33	27	-20
Jul "	92	51	-45	41	37	-10	32	31	- 5
Aug "	45	38	-15	32	34	+ 5	28	29	+ 5
Sep "	44	55	+25	50	54	+10	46	46	0
Oct "	27	45	+60	43	50	+15	44	45	0
Nov "	10	20	+100	18	33	+85	29	36	+25
Dec "	7	16	+130	13	37	+185	29	43	+50
spring flood (1/2 - 31/7):									
mean l/s km^2	435	335	-25	325	250	-25	225	220	- 5
std.dev. "	87	71	-20	71	71	0	62	70	+10
1000 yr flood	935	740	-20	730	655	-10	580	620	+ 5
autumn flood (1/8 -31/1):									
mean l/s km^2	205	250	+20	225	270	+20	235	265	+15
std.dev. "	55	72	+40	66	73	+10	66	82	+25
1000 yr flood	520	665	+25	605	690	+15	615	735	+20
annual flood (1/1 - 31/12):									
mean l/s km^2	435	345	-15	330	290	-15	250	270	+10
std.dev. "	87	67	-20	68	70	+ 5	59	74	+25
1000 yr flood	935	730	-20	720	690	- 5	590	695	+15
all seasons:									
mean l/s km^2	435	345	-15	330	290	-10	250	270	+10
1000 yr flood	935	740	-20	730	690	- 5	615	735	+20
winter low fl (1/10 - 31/5):				1/10 - 30/4:					
mean l/s km^2	3.0	4.8	+ 60	4.5	7.1	+60	6.7	7.8	+15
std.dev. "	0.5	1.1	+120	1.0	1.3	+30	1.3	1.2	-10
summer low fl (1/6 - 30/9):				1/5 - 30/9:					
mean l/s km^2	9.9	8.8	- 10	8.1	8.5	+ 5	8.2	7.8	- 5
std.dev. "	3.5	1.7	- 50	1.3	0.9	-30	0.9	0.9	0
snow cover:									
days > 25 %	305	245	-60	260	195	-65	195	110	-85
soil moisture deficit, growing season, mm (1/5 - 31/8):									
mean:	10	15	+ 5	25	40	+15	55	75	+20
days > 50 mm	0	1	+ 1	10	35	+25	75	100	+25
groundwater storage, mm:									
winter	50	65	+15	60	80	+20	75	80	+ 5
spring	35	60	+25	55	80	+25	70	80	+10
summer	75	85	+10	80	85	+ 5	80	80	0
autumn	80	85	+ 5	85	90	+ 5	85	85	0

Table A.7
Simulations for southern Norway
Reference catchment: 020.Z Flaksvatn, Tovdal river

	1000 - 1500			500 - 1000			0 - 500		
	pres	SC1	%	pres	SC1	%	pres	SC1	%
precipitation	1350	1455	+ 8	1350	1455	+ 8	1350	1455	+ 8
evapotransp.	110	150	+35	230	310	+35	340	430	+25
runoff	1240	1305	+ 5	1120	1145	+ 2	1010	1025	+ 1
Jan, l/s km^2	5	10	+100	9	27	+200	25	34	+35
Feb "	4	6	+ 50	6	20	+235	19	30	+60
Mar "	3	6	+100	6	23	+285	24	32	+35
Apr "	4	22	+450	25	48	+90	45	28	-40
May "	110	145	+ 30	135	57	-60	45	26	-60
Jun "	150	67	-55	48	20	-60	16	15	- 5
Jul "	38	31	-20	21	21	0	16	17	+ 5
Aug "	38	42	-15	30	33	+10	26	28	+10
Sep "	41	42	+10	34	35	+ 5	29	31	+ 5
Oct "	50	57	+15	52	54	+ 5	49	50	0
Nov "	20	43	+115	44	59	+35	55	58	+ 5
Dec "	7	19	+170	17	35	+105	33	40	+20
spring flood (1/2 - 31/7):									
mean l/s km^2	340	270	-20	235	165	-30	145	140	- 5
std.dev. "	75	65	-15	54	60	+10	54	47	+15
1000 yr flood	770	640	-15	545	510	-10	455	410	+10
autumn flood (1/8 -31/1):									
mean l/s km^2	185	225	+20	205	245	+20	220	225	+ 5
std.dev. "	75	95	+25	105	125	+20	120	125	+ 5
1000 yr flood	615	770	+25	805	960	+20	905	940	+ 5
annual flood (1/1 - 31/12):									
mean l/s km^2	345	295	-15	260	260	0	235	240	+ 5
std.dev. "	73	70	- 5	79	110	+40	105	115	+10
1000 yr flood	765	695	-10	715	890	+25	835	900	+10
all seasons:									
mean l/s km^2	345	295	-15	260	260	0	235	240	+ 5
1000 yr flood	770	770	0	805	960	+20	905	940	+ 5
winter low fl (1/10 - 31/5):				1/10 - 30/4:					
mean l/s km^2	2.3	3.6	+ 55	3.5	5.1	+45	5.0	5.5	+10
std.dev. "	0.3	0.8	+165	0.8	1.0	+20	1.1	1.1	0
summer low fl (1/6 - 30/9):				1/5 - 30/9:					
mean l/s km^2	8.4	7.8	-10	5.8	5.2	-10	4.7	4.5	- 5
std.dev. "	4.6	3.9	-15	2.6	1.5	-40	1.3	1.4	+10
snow cover:									
days > 25 %	245	215	-30	205	160	-45	150	75	-75
soil moisture deficit, growing season, mm (1/5 - 31/8):									
mean:	10	15	+ 5	30	40	+10	50	60	+20
days > 50 mm	2	3	+ 1	20	35	+15	55	70	+25
groundwater storage, mm:									
winter	40	60	+10	50	60	+10	60	70	+10
spring	35	55	+20	55	70	+20	65	65	0
summer	65	65	0	60	60	0	55	55	0
autumn	65	70	+ 5	65	70	+10	65	65	0

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