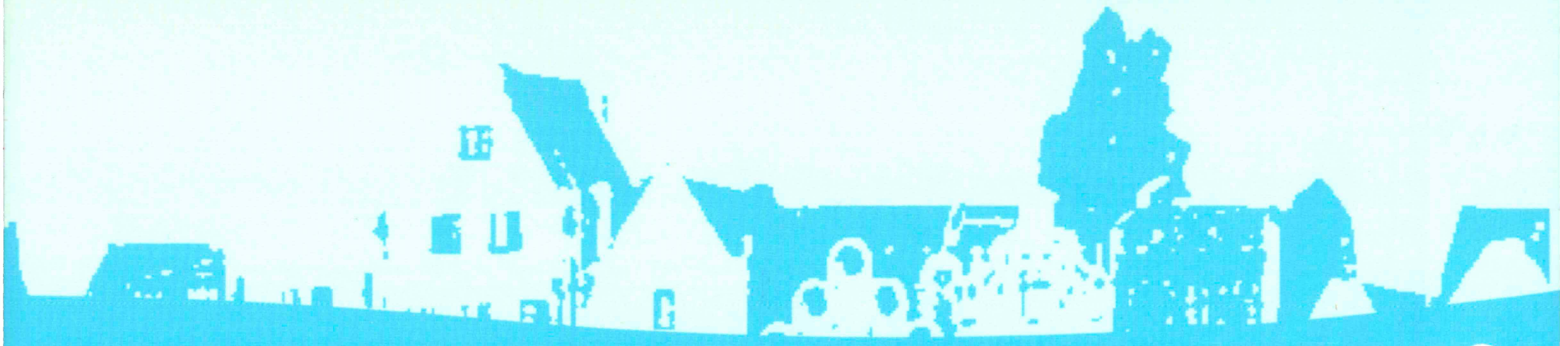


LIVING WITH FLOODS

Norwegian
Water Resources and
Energy Directorate

NVE

"Living with Floods" is a summary of the key results of a Norwegian research programme on floods – HYDRA – which focused on how human activity affects flood conditions in river basins. This report is a translation of the programme's Norwegian-language report for the general public.

The autumn and winter before Christmas 1994 were cold in Eastern Norway, with less than normal precipitation. Although the snow did not arrive until the new year, it fell in great quantities. In April, nearly one and a half times as much snow as normal was recorded, and as late as the middle of May new snow fell at as low as 500 metres. At the end of May, the weather warmed up quickly, accompanied by heavy rainfall. Together with rapid snow melt, this led to 100-year floods, in some areas to 200-year floods, in the Glomma River Basin. Although there were floods in other river basins of Eastern Norway, none were as severe as in the Glomma River Basin.

Damage from the 1995 floods has been estimated at NOK 1.8 billion (approx. USD 200 million). Seven hundred people were evacuated from their homes, 140 sq. km of farmland was inundated and 100 km of main roads and 470 km of railways were blocked as a result of the flood. One person perished, and many were in danger as they struggled against the flood waters.

After the 1995 flood, the Government appointed a commission by royal decree to report on measures for reducing society's vulnerability to floods. The commission submitted its report in August 1996 "Tiltak mot flom" ("Measures against floods"), Norwegian Official Reports (NOU) 1996:16.

Prior to the flood in 1995, the Norwegian Water Resources and Energy Directorate (NVE) initiated a research programme on floods – HYDRA. HYDRA's working hypothesis was that the sum of all human interventions in the form of land use, hydropower regulation, flood protection measures, etc., may have increased the risk of flooding. Most of the studies in HYDRA were done in the Glomma River Basin owning to the ample information basis from the 1995 flood in this river basin (map on the last page).

BACKGROUND PICTURE: THE 1995 FLOOD IN THE GLOMMA RIVER.
PHOTO: JON ARNE EIE

Experts and the public usually have differing perceptions of what floods are. Experts associate the term "flood" with a certain water flow level in a river, whereas most people speak of floods when rivers overflow their banks. In Norway, rain, often in combination with snow melt, is the chief cause of floods.

Floods

Most people generally speak of floods when rivers overflow their banks, creating a risk of damage or injury. Experts have a somewhat different definition of floods. They speak of floods when the water flow is of a certain magnitude, even though this need not lead to inundation. The water level may also be high and certain areas may be inundated without the water flow being particularly large. Blocked drainage outlets and the accumulation of river ice are conditions that can make a river overflow its banks. Especially in densely populated areas intense precipitation and/or rapid snow melt may lead to inundation even though the water flow in the river basin is not of flood-level proportions.

Mean flood, ten-year-flood, and hundred-year-flood

Flood experts keep statistics on floods, often using the term mean flood in such contexts. The mean flood is the average of the largest water flow every year during a given observation period. NVE issue flood warnings only when the expected water flows exceed the same magnitude as a mean flood in the river basin.

Statistics show that we may expect floods of various magnitudes at regular intervals. The magnitude is indicated by the recurrence interval, which is the average number of years that pass between each time an equally large or larger flood occurs. This interval indicates the probability of having a flood of a certain magnitude. For example, there is a 1% chance of a hundred-year-flood and a 10% chance of a ten-year-flood in any given year. Although it is important to remember that the chance of a hundred-year-flood is equally great every year, this chance is small, only 1 %.

Spring and autumn floods

Norwegian river basins differ widely owing to major variations in topography, precipitation and climate. The highest precipitation occur along the coast in Western and Northern Norway as well as in mountain areas. In areas near glaciers in Western Norway, annual precipitation levels of over 5000 mm have been measured. In contrast, about 200 mm has been measured in upper parts of the Glomma River Basin.

Most rivers in Norway have two flood seasons, spring and autumn.

Spring floods are most often the result of snow melt or a combination of melt and precipitation. These floods are typical of large inland river basins in Eastern Norway, Northern Norway and in the mountains.

Autumn floods are a result of precipitation, and are common along the coast.

Causes of floods

The main cause of the major floods in Norway is rain, often combined with snow melt. Meteorological conditions such as the distribution of precipitation and temperature levels have the greatest influence over a flood's magnitude. The capacity that vegetation, surface features, bedrock, lakes, rivers and streams have for storing water is also important.

People also influence flood conditions. We do this through the intensive development of areas near rivers and by removing forests and other vegetation. The release of greenhouse gases is a more indirect means of influencing flood conditions. This leads to a rise in temperature, which may create extensive changes in the weather. One result of this may be an increase in the frequency of hurricanes, major floods, forest fires and landslides. One may therefore say that people themselves have a responsibility for both the causes and the effects of floods.

NVE WARNING LEVELS:

Flood: *Water flow between a mean flood and a ten-year-flood*
Major flood: *Water flow between a ten-year-flood and a hundred-year-flood*
Extreme flood: *Water flow greater than a hundred-year-flood*

Are major floods harmful to people and the environment? Most would probably answer "yes" to this question. The reason for this is that we see it from our perspective as human beings. For us, major floods will undoubtedly lead to damage to buildings, roads and farmland. For the natural environment, the situation is different. A river basin is a system that is always changing, and floods make up a natural part of this system. If the physical, chemical and biological conditions change because of a flood, the river basin itself and the life in the river basin will adapt to these new conditions. Although floods result in environmental changes, the environment is not damaged by them. Not until man-made assets are destroyed by floods is it correct to speak of damage.

CONSEQUENCES FOR PEOPLE

For people, loss of life and material damage are the most important consequences of floods. A large part of the flood damage in Norway is caused by inundation, erosion and landslides, conditions which often occur when smaller rivers overflow and find new channels. Danger to human life is greatest during floods in small rivers of this kind. In such cases, the floods come quickly, without warning and often in combination with landslides. Inundation of alluvial plains along major river basins often leads to damage to buildings, infrastructure and farmland. However, in such river basins, there is more time to implement damage-reducing measures, because the floods do not develop as quickly as in smaller rivers.

Loss of human life

In wealthy countries, it is often material damage that predominates, whereas inundation in poor parts of the world has far greater consequences, because people often live very densely on the alluvial plains that are inundated. This results in many lives being lost during floods and many having to be evacuated and losing their entire livelihoods. Forty per cent of all deaths caused by natural disasters are due to floods. Ninety-five per cent of these deaths occur in developing countries. In recent times it is rare for human life to be lost in floods in Norway. In the Gaula River, as many as 500 people died in a flood in 1345, and during the great flood in the Glomma River in 1789 ("Storofsen") 68 people lost their lives.

Material damage

The trend towards an ever higher standard of living has meant that we have invested great economic resources in land and buildings, often in areas near rivers. Rivers have been magnets for human activity throughout the ages. Rivers overflowing their banks or establishing new channels have cost society a great deal. In 1987–1988, NOK 300 million (approx. USD 34 million) was paid out by insurance companies to compensate for flood damage. The damage from the last major flood, "Vesleofsen" in 1995, amounted to around NOK 1.8 billion (approx. USD 200 million).

One can distinguish between direct and indirect economic damage from floods. Direct damage means damage to buildings, roads, railways and farmland. Indirect damage arises because of physical or economic linkages in society. Such damage involves, for example, interruptions to lines of communication, lost industrial production or business income and delays.

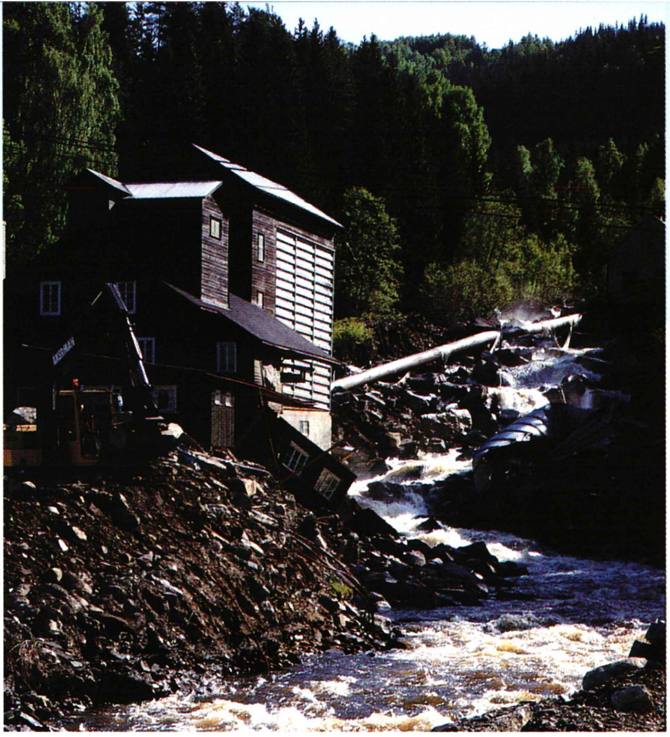
CONSEQUENCES FOR THE ENVIRONMENT

Large water flows result in higher water levels, greater water depths and higher flow speed. These physical changes impact living conditions for individual species, biological communities and entire ecosystems in lakes, rivers and wetlands. Because these organisms live in an environment in which floods make up a natural part of evolution, they will adapt to the new conditions the floods create. Some communities are also dependent on floods in order to exist.

Shaping the river basin environment

Episodes of high water flow are important for those processes that shape the river basin environment. It is a characteristic of flood episodes that erosion is intensified in upper parts of the river basin. Material is deposited further downstream where the velocity of the water decreases. This occurs either on the alluvial plain, in delta areas in lakes or in the eustaries. In areas where the velocity of the water is high, the river may also establish new courses.

It is the mean flood (approx. two years' recurrence interval) that influences the shape of the river course the most. Larger floods



TOP: FLOOD DAMAGE IN THE MOKSA, A TRIBUTARY OF THE GLOMMA RIVER, IN 1995. PHOTO: ANNE HAUGUM.
BOTTOM: EMBANKMENT FAILURE WITH ENSUING EROSION DAMAGE IN THE GLOMMA RIVER NEAR ELVERUM. PHOTO: FOTONOR AS.

Economic losses resulting from extreme weather in 1998 (USD million) with the principal cause in parentheses

China	*32 000 (inundation)*
USA	*16 000 (severe summer heat and drought, forest fires, hurricanes, tornadoes)*
Bangladesh	*5 000 (floods)*
UK	*5 000 (winter storms)*
Japan	*3 000 (floods, landslides, tropical storms and typhoons)*

are required to impact the shape of the alluvial plains. In the delta area in the northern part of Lake Øyeren approx. 30 cm. of sediment was deposited on the alluvial plain during the 1995 flood. In this area, the 1995 flood was estimated to be a 100–200-year flood. The deposits of sediment on the alluvial plains along the Glomma River during the 1995 flood varied. Where the river broke through the flood protection works between Elverum and Kongsvinger, up to two metres of sand was deposited.

It is not only the magnitude of the flood that determines the amount of erosion or sedimentation. It is also important for loose material to be available for the river to erode. Many river basins appear to have little loose material in their catchment areas. During a flood, however, large sources of sediments may be exposed, rendering the transport of material in a river basin extreme. One important consequence of this is that the river becomes filled up with sediment and that the river assumes a new course.

In general the largest supply of sedimentation to Norwegian rivers comes from glacial river basins. Glacial rivers carry a lot of material all year round. The amount of material transported during floods and during normal conditions therefore need not differ so much. During a flood in Jostedalen in 1979, the transport of material in the Nigardselva River was measured at about 9600 tonnes in the course of two days of flooding. This is equal to the amount of material normally carried by the Nigardselva in the course of one year.

In contrast to glacial river basins, the supply of sediment from forest river basins is slight in normal conditions. The reason for this is that the coniferous forests in the lowlands of Southern Norway bind the soil together, thus protecting against erosion. During floods, however, the amount of material transported can be extreme, because the river gains access to moraine material that it otherwise cannot reach. The material transport capacity of the Atna River is a good example of this. During the 1995 flood the amount of material transported by this river was as great as the amount the river has transported over the last 40 years.

Although processes such as erosion and sedimentation help shape the landscape of the river basin, they also impact upon the biological environment. During a flood, the upper parts of the river basin will experience greater erosion. This leads to higher turbidity in the water and less light, which in turn affects the living conditions of plants and animals. Loose material will be deposited in the lower parts of the river basin, which may also create problems because plants and fish larvae are covered by gravel and sand.

Water quality

When erosion increases during floods, more material is carried into the rivers, often increasing the concentration of particles. During major floods the particles are mostly inorganic (sand and gravel). However, the amount of organic particles also increases during floods. "Vesleofsen" in the Glomma River and in the Drammenselva River in 1995 is a good example of this. In these river basins the concentration of phosphorus increased by up to fifty times its typical winter concentration. Even though large quantities of nutrients are leached out, and the amount of environmental toxins also may increase during floods, the quantities of water are so great that the concentrations are not dramatically high. Extreme chemical conditions will therefore not necessarily coincide with major water flow. The chemical and hydrological situation before a flood will often be much more important for the water chemistry than the magnitude of the water flow during the flood. For example, the amount of sulphates, nitrates (acid precipitation) and chlorides (sea salts) in snow or rain may be far more important for the water chemistry than the water flow.

Fish, bottom animals and aquatic plants

Physical changes resulting from high water flows impact the organisms living in the river basin. Here one can distinguish between short-term and long-term effects. Short-term effects are related to the flood episode itself, whereas long-term effects

◀ THE DELTA AT THE NORTHERN END OF THE LARGE LAKE, RANDSFJORDEN, SOUTH-EASTERN NORWAY. PHOTO: NVE.

cover the period after the flood and up until the communities have adapted to the new conditions.

The time it takes to adapt to the new conditions varies. For some communities this may take several years, while other communities can adapt quickly. For the population of Hunder trout in Lake Mjøsa it took two years before their condition and growth returned to the level corresponding to that before the flood in 1995. The massive addition of material into Lake Mjøsa made light conditions in the lake poor, which meant that the Hunder trout did not grow as quickly as before the flood.

All the animal and plant communities studied during and after the 1995 flood were affected by the flood episode itself. The death of plants and animals in flowing water was due to erosion and increased drifting of bottom animals, the silting over of salmon yolk-sac larvae before they emerged from the gravel and the erosion and silting over of aquatic vegetation. In the Gaula River the 1995 flood resulted in, among other things, the density of the 1995 brood of salmon being reduced by 70–90 % in the middle and lower parts of the river basin as compared with the upper parts. The reason for this was that the moraine material that the Gaula River was carrying from the upper reaches of the river basin was deposited in the middle and lower parts of the river. At the time when this happened, the salmon fry were still down in the gravel. Owing to the amount of material that was deposited, the salmon fry died in the gravel. It appears that the time of the flood itself is important for the magnitude of the flood's biological effect. The flood in the Gaula River in 1997 is a good example of this. This flood occurred a few weeks later than the 1995 flood and did not produce a corresponding failure in salmon recruitment. The salmon fry had already emerged from the gravel before the 1997 flood and were therefore not affected to the same degree as during the 1995 flood.
In lakes and lowland river basins in alluvial plains, floods may lead to an increase in access to nutrients because the rivers carry lots of nutrients into the lakes. Alluvial plains become inundated, with many fish species roaming across these inundated areas. This produces a larger area for fish and some bottom animals to live in, which means they are less likely to be prey for others. For species that benefit from floods, the densities of individuals after the flood may be higher. This has been observed for perch in lowland river basins.

The most important physical factor leading to mortality during floods is erosion in the river bottom and along the riverbanks. This leads to the washing out and drifting of organisms and to sedimentation in lower segments of the river basin. Roted plants or organisms that do not move much can easily die in a flood. The plant *Potamogeton perfoliatus*, which is a typical plant in Lake Øyeren and very important as food for fish and birds, was greatly affected by the 1995 flood. The reason was turbid water and sediment covering the plants. Other plants benefited from the flood, probably because they were able to adapt quickly to rapid changes in light and sedimentation conditions. *Sparganium angustifolium* is an example of a plant that exhibited increased prevalence in Lake Øyeren after the 1995 flood.

Once the flood episode is over, a number of processes begin for the communities to adapt to the new conditions created by the flood. There is no simple relationship between floods and biological diversity. Both the frequency and magnitude of floods as well as the shape of the river basin are conditions that will affect the composition of species and their environment. In general, it may be said that river basins that are constantly subjected to floods will have a higher percentage of species with short life cycles and have a greater share of biological communities in early stages of development.

Floods are important for maintaining a balance among species. If there were no floods, pioneer species would be outcompeted because they do not thrive under stable conditions.

River basins have always been important as a basis for human life. River basins have been important as food sources and transportation arteries, for floating timber and generating power. Areas near rivers, especially alluvial plains, have been magnets for human activity. Here the soil is easily cultivated and fertile, and access to water is good.

Along river basins, the developed areas gradually became valuable building sites. The areas near river basins became attractive land for industry, housing, roads and railways, agriculture and establishing cities and towns. There was close access to river transport and the land was easy to build on and provided fine sites for laying out roads. The intensive use of the areas along the watercourses has made us more susceptible to floods today than previously. In addition, the economic consequences of floods are much greater today.

All actions that people have taken in and near rivers and lakes affect flood conditions. In HYDRA, researchers looked at the significance that hydropower regulation, built-up areas and the state of the forests have for flooding in the Glomma River Basin. In addition they studied how flood protection works, measures to reduce flood damage, affect flood conditions.

HYDROPOWER REGULATION

In Norway, large reservoirs have been built for generating electricity. In Central Europe, it is common to use such reservoirs to control floods, and in other parts of the world reservoirs are important for irrigation. Regulation reservoirs have proved to be the most effective flood-control measure that HYDRA has evaluated. The reservoirs are drawn down over the course of the winter to generate power. This means that the flood-control potensial is greatest for spring floods.

The Glomma, Skien and Drammen River Basins, which are all regulated and have regulation capacities of 16 %, 44 % and 34 % respectively, have experienced fewer floods in the 1900s than in the 1800s. The magnitude of the floods has also decreased. The reason for this is that the regulation reservoirs, which were built in the 1900s for power production, have had a moderating effect on floods.

Flood control in the Glomma River Basin

The regulation reservoirs in the Glomma River Basin can store approx. 16 % of all the water that the river basin carries to the sea yearly. Corresponding figures from other regulated river basins in Eastern and Southern Norway are 30–55 %. River basins with such a high percentage of reservoirs rarely experience damage during spring floods. There appears to be a clear connection between a high reservoir percentage in a river basin and minimal flood damage, especially for spring floods.

Existing regulations

Data from the flood in the Glomma River Basin in 1995 form the basis for studies of how existing regulations can control floods. Ahead of the 1995 flood, Lake Osensjøen and Lake Mjøsa, among others, were drawn down to ensure capacity in the regulation reservoirs for the flood one knew was coming. The HYDRA programme studied the effects that these measures have on flood control.
Analyses from the 1995 flood show that the regulations in the river basin had a clear flood-moderating effect. The greatest moderation was achieved in the Glomma river, with 1 m at Elverum and 2.3 m in Lake Øyeren. In the Lågen River, the water level was reduced by 0.4 m at Otta and in Lake Mjøsa.

Additional regulations

Implementing further regulations of lakes in the Glomma River Basin may result in a greater degree of flood control than exists today. Data from the eight largest floods in the 1900s have been used to study the moderating effect of additional regulations.

The flood control potensial appears to be greater in the Glomma River than in the Lågen River, because the former has greater storage capacity in lakes.

By lowering Lake Mjøsa by 1.75 m with the aid of a pump power station, a flood moderation of 0.85 m can be achieved for a flood as large as the 1995 flood. In addition, the water level in Lake Øyeren would be 1.0 m lower than that observed in 1995.

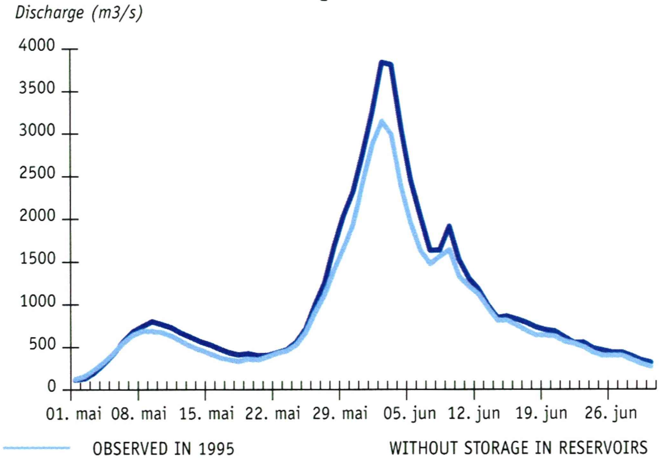
In both the Glomma River and the Lågen River, the additional regulations may result in an average reduction in the water level of up to 0.75 m.

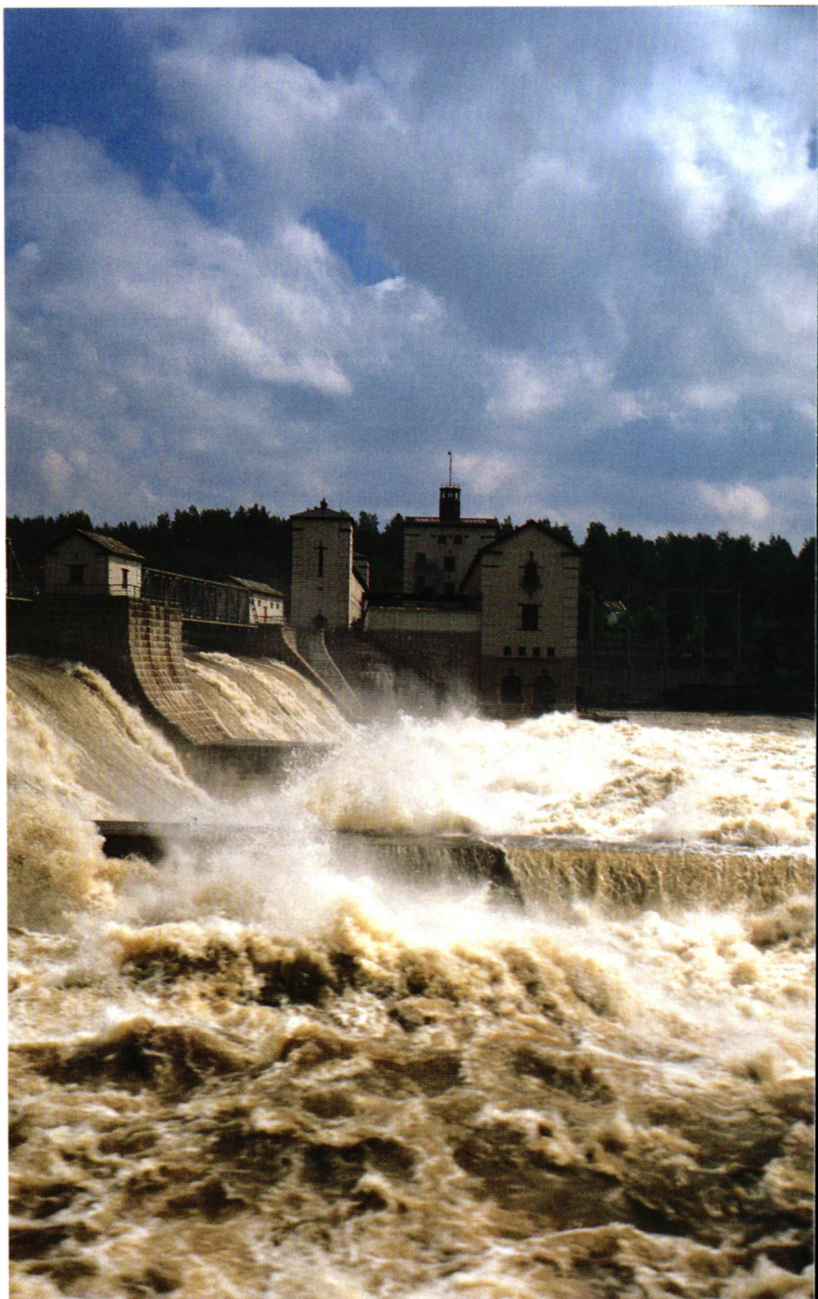
No assessment has been done of the consequences these additional regulations will have on other user interests in the river basin. This will be necessary before any additional regulations can be implemented. Nor has there been any assessment of the costs of giving priority to the use of regulation reservoirs for flood control rather than power production.

BUILT-UP AREAS

The trend towards increasing densities in towns and built-up areas means that increasingly large areas are being transformed into impervious surfaces. This prevents the infiltration of water into the soil, resulting in greater and faster surface runoff. This rapid runoff from impervious surfaces can worsen a flood. As a rule of thumb, one can say that in an area of dense forest, only 20 % of precipitation ends up as surface runoff, whereas the corresponding figure for highly urbanised areas can be up to 90 %. In the

The 1995 flood in Glomma at Elverum with and without the effect of regulated reservoirs





TOP: SUNDET, EIDSVOLL ON THE VORMA RIVER DURING THE 1995 FLOOD. PHOTO: JON ARNE EIE
BOTTOM: THE RÅNÅSFOSS POWER STATION ON THE GLOMMA RIVER. PHOTO: AKERSHUS ENERGY COMPANY

Glomma River Basin, however, the effect of impervious surfaces is scarcely measurable. The main reason is that the built-up areas in the river basin's catchment make up a tiny part of the total catchment area.

Increased runoff

The result of increased runoff from impervious surfaces is that flood crets occur more quickly, are higher and more pronounced and produce inundation and erosion damage. In addition, the rapid runoff can lead to the leaching out of pollutants into rivers and streams. Increased surface runoff due to urbanisation will also reduce the replenishment of groundwater, reducing the hight of the water table.

The runoff has changed for twenty-five built-up areas in the Glomma River Basin catchment after the built-up areas came into existence. The models show that runoff on average has increased by 22 % compared with the situation before development.

The local effects of increased runoff can be great. For the Glomma River Basin as a whole, increased runoff resulting from the establishment of impervious surfaces, will impact floods only slightly. The reason for this is that built-up areas constitute only 0.5 % of the total area of the catchment. For smaller river basins, where built-up areas constitute a greater share of the catchment, increased runoff from impervious surfaces may have a greater impact on flood conditions.

Pollution

The chief sources of pollution from built-up areas during floods are:

- the discharge of untreated sewage from damaged pumping stations, treatment plants and spillways
- erosion and leaching of landfills, disposal sites and sedimentation ponds
- dislodging of and damage to oil, paraffin and chemical tanks
- seepage of chemicals from warehouses and storage areas

The effects of pollution from these point sources are water supply problems, infectious diseases and health risks in connection with clean-up. Among point sources chemical discharge from tanks, disposal sites or transport are considered the most hazardous. However, the risk of such discharge occurring in a flood situation is, however, so small that the total risk should be perceived as moderate.

The leaching of nutrients and environmental toxins from more diffuse sources increases drastically during floods. The great dilution during a flood means that concentrations of pollutants from these sources are seldom dramatic. The risk of high concentrations is greatest in small river basins. Although Norwegian water works often use surface water from such small river basins, the Norwegian settlement pattern means that there are seldom hazardous point sources upstream of these intakes.

FORESTS

It has not been possible to demonstrate any change in flood conditions in the Glomma River Basin attributable to changes in the state of forests from 1920 to 1990. The main reason is that the changes in the state of forests have not been large enough to impact flooding in the river basin.

A forested area will have less runoff than a corresponding area without forests, since forests give off water through evaporation. This occurs both because water evaporates from the trees themselves, but also because snow and rain lying on the vegetation evaporate more readily. In addition, forests have a greater ability to absorb water than cultivated land, for example. This means that forests reduce runoff on the ground and may therefore have a moderating effect on a flood.

In the Glomma River Basin, researchers have studied how changes in the state of forests from 1920 to 1990 have impacted runoff in the two areas, Lake Osensjøen and Flisa. These areas were

selected as representative for the kind of forestry that has been practised in the period after 1900. The areas were also selected because of great forest coverage and because researchers believed that any hydrological changes would be highly visible here. The result of their work shows that the changes in the state of forests during this period has had little impact. Only a slight reduction in runoff from the two areas from 1920 to 1990 was recorded. On the basis of these results, researchers believe that changes in forestry practices have not produced changes in flood conditions for the rest of the Glomma region. The basis for this judgement is data showing that changes in forest conditions have gone in the same direction for the rest of the catchment area, though in most areas the changes in the state of forests have been less extensive than in the Flisa and Osen areas.

The results from the Glomma River Basin are not proof that changes in forest conditions cannot lead to hydrological impacts; on the contrary, this is well known from a number of studies in many countries. If large swathes of forest had been chopped down in the Glomma River Basin catchment area, this would have led to increased runoff and therefore impacted flood conditions. The conclusion from the Glomma River Basin is that changes in the state of forests are not of sufficiant magnitude to impact flooding. Even though the forest has become denser and thus led to greater absorption of water and less runoff, clear-cutting, which began in the 1950s, has led to less absorption of water and greater runoff. The total impact on runoff is slight.

FLOOD PROTECTION WORKS

Flood protection works are dikes built along river basins to keep water from inundating land areas. On the basis of information from the 1995 flood in the Glomma River Basin, researchers found that flood protection works have relatively little impact on the magnitude of floods. However, flood protection works result in the water attaining a greater velocity, causing flood to develop more quickly downstream.

Damming up

In the Glomma River Basin, researchers studied the effect of flood works in Alvdal and along a stretch between Elverum and Kongsvinger. The results show a damming up of the water level in areas with flood protection works, with most damming up being recorded upstream of Kirkenær. For this area, the flood protection works resulted in a water level 0.5 m higher that would have been the case without flood protection works. Downstream of Kirkenær the damming-up effect quickly disappears.

More rapid development of floods

Although flood protection works have little impact on the magnitude of floods, they have a greater impact on how floods develop over time in the river basin. Flood protection works increase the velocity of the water, causing flood peaks to be transmitted more quickly down the river. Because of flood protection works, the culmination of the 1995 flood came approx. 10 hours earlier to the Kirkenær area and approx. 20 hours earlier to Kongsvinger than would have been the case if there had been no flood protection works in these areas. The more rapid development of floods will be a challenge for both flood warning and emergency services in the river basin, since one has less time to plan contingency measures.

◀ THE GLOMMA RIVER AT LAUTA DURING THE 1995 FLOOD. PHOTO: JON ARNE EIE.

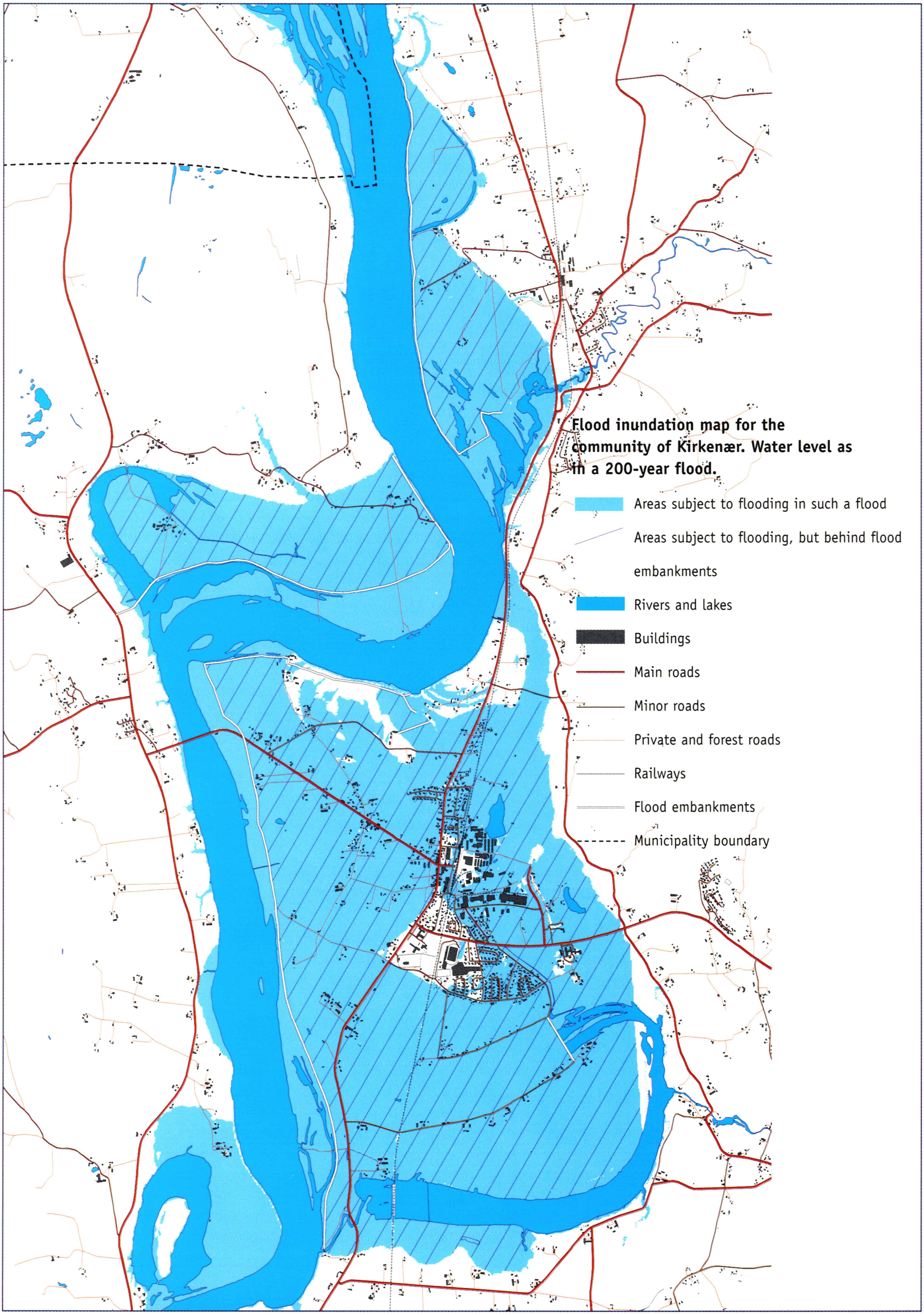
HUMAN ACTIVITIES AND FLOODS IN THE GLOMMA RIVER BASIN

To study how regulation reservoirs, flood protection works, built-up areas and changes in the state of forests in the aggregate impact floods in a river basin, researchers have developed a model, called the HYDRA River Basin Model. This is an overall model that ties together all the subordinate models used to simulate how human activity affects floods. Although the HYDRA River Basin Model has been tested in the Glomma River Basin, it can be applied to and used in other river basins as well.

The main results from the analysis of the Glomma River Basin using the HYDRA River Basin Model are that:

- flood conditions in the Glomma River Basin have changed as a result of human impact
- human impact has led to reduced floods in the river basin
- the main reason for reduced floods is that regulation reservoirs, built for hydro power generation, have moderated the floods
- urbanisation causes an increase in floods locally, though mostly on a small scale
- the impact of urbanisation is almost not measurable in the main river basin
- flood protection works imply a slight local increase in water level and a slight increase in water flow downstream of the flood protection works
- impacts of flood protection works of any significance are primarily along the stretch from Elverum to Kongsvinger, where the largest flood works are located
- changes in the forestry and the state of forests have not led to measurable changes in floods

It is important to underscore that these results apply to the Glomma River Basin. Although some of the conclusions can probably be applied to other large, regulated river basins, for small river basins the results of human impacts may have a completely different outcome from that in the Glomma River Basin. Since the catchment area of the Glomma River Basin covers 13 % of the land area of Norway, man-made impacts would have to be relatively major before manifesting themselves in such a large river basin.


Flood inundation map for the community of Kirkenær. Water level as in a 200-year flood.
Areas subject to flooding in such a flood
Areas subject to flooding, but behind flood embankments
Rivers and lakes
Buildings
Main roads
Minor roads
Private and forest roads
Railways
Flood embankments
Municipality boundary

In the future, flood protection measures will be less technical than today. Land-use planning, preparedness and flood warnings will be important tools for reducing flood damage in the future. Of technical measures, regulation reservoirs, built for hydro power generation, can be important for controlling floods. This assumes that power producers can be required to use the reservoirs for this purpose.

Floods in the future

Increases in population, industrialisation and car traffic lead to increases in emissions of CO_2, methane gas and other greenhouse gases that give rise to global warming. In the past century the mean global annual temperature has risen by 0.5° C. Climatologists maintain that if this trend continues, the increase in temperature may lead to extensive changes in the weather. This may lead to a future in which we may experience more hurricanes, major floods and landslides.

One does not need to go further back in time than to the 1300s before one can see that climatic changes clearly affect hydrological conditions and therefore floods. "The Little Ice Age", lasting from approximately 1300 to the end of the 1800s, is a good example of this. This was a period marked by cooling over large parts of the world. The average temperature in Norway fell by approx. 1° C during this cold period. At high latitudes and in mountain areas, glaciers grew rapidly. In the valleys around the Jostedal Glacier, historical writings show that the lower temperature and advance of glaciers led to poorer harvests and ruined fields as a result of floods, landslides and avalanches. Many had to abandon their farms because they lost their entire livelihoods.

Flood protection in the future

Over the ages there has been a major emphasis on technical protection measures, such as flood protection works, canalisation and or measures to lower water levels. The paramount aim has been to protect land and buildings from flood damage. Over time greater focus has been directed at the socio-economic and environmental consequences of flood protection measures, which will probably influence the choice of protection methods in the future. Internationally, but also in Norway, people today are turning to non-technical measures. Land-use planning, improved preparedness/warning and alternative ways of dealing with surface water are examples of such measures. There will also be a need for technical flood protection measures in the future. Of such measures, regulation reservoirs, built for hydro power generation, will be important for controlling floods.

Land-use planning

Through the Planning and Building Act, the Norwegian municipalities have a responsibility to ensure that land is managed in a way that does not cause hazards. One important topic in municipal planning will therefore be to ascertain which areas are flood-prone. Flood inundation maps are a tool for municipalities in this effort. A flood inundation map shows the areas one may expect will be inundated during floods of various magnitudes, for example, ten-year-floods and fifty-year-floods. In a separate project, NVE has identified the most flood-prone stretches in the country, and flood inundation maps are now being prepared for these areas.

HYDRA has contributed to an improvement in the methods for preparing flood inundation maps. In addition, maps have been drawn for recurrence intervals of 10 years, 50 years and 100–200 years for a number of the large alluvial plains along the Glomma River.

Placing restrictions on land use in Norway may present problems. The topography of Norway gives Norwegians limited access to areas suited to housing, industry and agriculture as well as infrastructure. In addition, there has been political pressure to preserve agricultural land for maintaining a degree of self-sufficiency and the current level of activity in agriculture and affiliated service industries.

In the future, municipalities, which are responsible for land-use planning, will face new challenges in protecting flood-prone areas. The trend towards non-technical measures will continue unabated – a particularly favourable development as far as both good economics and environmental policy are concerned. This development will require knowledge and the ability to readjust among municipalities, landowners, and not least national and regional public administration.

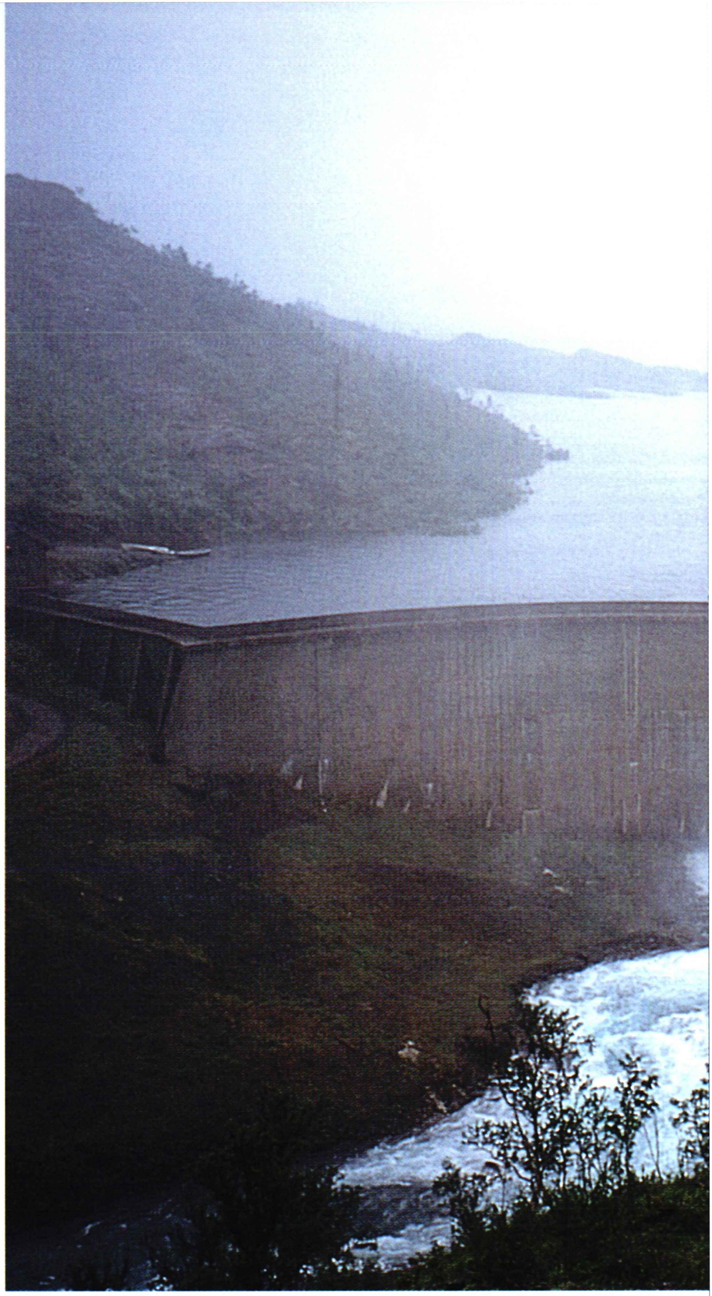
Today we have ample knowledge about areas susceptible to floods, rockslides, etc. It is therefore important for municipalities to draw on this information when engaging in land-use planning.

Reservoirs
Using reservoirs for controlling floods has proved to be the most effective measure of those evaluated by HYDRA. Under the assumption that the power producers can be required to use their regulation reservoirs to suppress floods, these reservoirs will be important for reducing flood damage in the future.

If climatic trends move towards warmer and wetter winters, there will be less need to store water over time. In such a situation, power producers will, to a certain extent, no longer have to weigh finances against flood control, because the value of storing water will not be present to the same degree as today. This may make it easier to use the regulation reservoirs for flood control.

An assessment of the flood control effect of a number of additional regulations (twelve projects) in the Glomma River Basin shows that there is a considerable potential for flood control, particularly in the Glomma branch.

By realising the additional regulations one can discount major flood damage in the Glomma River from floods of magnitudes up to the 1995 flood. In the Otta and Lågen Rivers and Lake Mjøsa, however, the flood control effect of the additional regulations are not as great. Here we must still expect flood damage in connection with major summer and autumn floods, even though the floods are smaller than the 1995 flood.



Alternative management of surface water
The problems arising from increased runoff from urban and built-up areas may be reduced to a certain extent by implementing best management practice (BMP). The most common method of BMP is to delay the water on its way back to the river basin, either by having the water infiltrate the ground or by storing it in ponds or pools on or below the surface of the ground. For smaller rivers and streams, even a rather slight delay may possibly have a substantial effect. However, BMP is little suited to suppressing floods in large river basins because they would require large reservoir capacity.

In the USA and Canada, BMP is widely used to reduce the risk of flood damage and reduce pollution of river basins. In Norway, BMP is still perceived as a new technique, even though the method has been employed in some areas. Early in the 1980s, best management practice was put in place in several residential areas of Bergen, Bærum and Oslo municipalities. Today nearly

THE SPILLWAY OF A RESERVOIR DAM (HOLMVASSDAMMEN) IN NORTHERN NORWAY.
PHOTO: ARNE H. ERLANDSEN.

The organisational structure and distribution of responsibilities on a regional level have in principle been set forth in a Royal Decree of 12 December 1997 –"Guidelines for regional co-ordinating responsibilities during crises and disasters in peacetime". The county governor is the regional co-ordinator in a crisis situation. Although the police may take the initiative in a mobilisation phase, they resume regular police duties once the crisis organisation is functioning. Participation of the Armed Forces is regulated by a Royal Decree of 13 February 1998 – "Instructions for the Armed Forces' support of the Police in peacetime". At a municipal level, the situation is less clear, especially since no contingency plans exist. The municipality, through the Emergency Planning Council, or other emergency crisis organisation, is the natural leader at the incident site. Nevertheless it may be appropriate, as at the county level, for the police to assume responsibility in an introductory and start-up phase.

35 000 people are connected to BMP systems in Norwegian cities and towns.

Flood warning and crisis management

Flood warning

A proper flood warning is a warning that provides a detailed prediction of the situation that will arise in a river basin. Proper warnings make it possible to implement measures to reduce harm to living things and damage to material goods in and near river basins.

NVE has the responsibility for issuing warnings for floods, major floods and extreme floods. Flood warnings are issued when the water flow is expected to reach a certain magnitude. Although floods need not lead to inundation, they may result in inundation with a risk of injury and damage. Inundations may occur locally, even if there is not a flood in the river basins. This can be due to the blockage of culverts or other drains. Particularly in urban areas intense rain showers and/or snow melt may lead to flooding without there being flood water flows in the river basins. Although it is not possible for NVE to forecast such local flooding, NVE will inform municipalities and county governors to the greatest extent possible of conditions that increase the risk of such events. Nor is it possible to predict flooding due to local and intense rain showers, since it is quite coincidental where the showers hit. Nevertheless, it is possible to issue warnings for local flooding and erosion due to rapid snow melt and/or sustained and intense precipitation over a limited area, but which is still not enough to provide the basis for a flood warning. In such cases NVE will issue a "Local Flooding Warning".

It is important that the warning reaches the county and municipal emergency services as quickly as possible. That is why routines have been established for issuing warnings and requiring a receipt for warnings received. The public also has access to flood warnings on the national teletext service.

Preparedness and emergency management

Through preparedness the extent of damage from flooding will be reduced. Once a flood has arrived, the major challenge is to manage it properly. Important tools for managing floods are the preparation of plans detailing how to deal with floods and, in particular, training for such eventualities.

Proper plans should contain information on organisation and participation. Furthermore, there should be explicit instructions regarding equipment, personnel and evacuation. It is particularly important to have planned how information should be relayed to and from an "emergency organisation". Preparedness plans have little value if training for such crisis situations is not carried out regularly.

If in a crisis situation it is expedient to reinforce or open flood protection works, it is extra important for the plan to contain explicit instructions for how this work is to be done. Such instructions should be formulated and updated for all flood protection works. It is especially important to focus on the safety of the personnel working in the area.

Environmentally friendly flood protection measures

The intensive use of alluvial plains for settlement, agriculture and infrastructure quickly resulted in a need for protecting these areas from floods and flood damage. For this reason, a number of flood protection measures have been implemented involving physical interventions both directly in the river channel and in adjacent areas. A number of negative environmental effects have been recorded in connection with these measures, for example, changes in runoff conditions, homogeneous biotopes, changes in species diversity and species composition. Consequently, a need has arisen to undo the environmental damage of existing flood protection measures and to develop methods for preventing in so far as it is possible the negative effects arising from new protection measures.

Restoration/Rehabilitation/Remedial measures

Restoring river basins is often used as a collective term for measures whose aim is to improve the conditions in river basins that have been subject to various forms of intervention or impacts. The reasons why such measures are implemented and the aims of these measures and their extent may vary.

A number of restorative measures, whose aim is to improve environmental conditions in river basins, also have a flood control effect and can therefore be used in river basin areas where flood protection is needed. Common to these measures is the fact that they disturb or spoil river basin functions to a lesser extent than traditional flood protection measures (e.g. canalisation and flood protection works built right up alongside the course of rivers). The most important environmentally-friendly flood protection measures are flood works built farther from rivers, the re-establishment of wetlands (natural storage areas) and artificial storage areas. In addition, there are anti-erosion measures such as thresholds, current deflectors, sedimentation ponds, stabilisation ponds, erosion protection of riverbanks, reducing the steepness of riverbanks and maintaining vegetation in the river profile. Although these measures are in themselves not direct environmental measures, they may render it unnecessary to implement more comprehensive flood-prevention measures. Seen this way, these measures have an environmental stamp.

In the future it will be important to see restoration and rehabilitation as long-term processes in which a number of smaller measures can be implemented in isolation, though with a view to achieving a common goal for the entire catchment area.

In establishing any flood-prevention measure, a cost/benefit analysis should, in principle, be performed. This is a socio-economic assessment designed to determine whether the measure is profitable. One problem with such analyses is that many of the factors that make up the analysis are difficult to put a price on, e.g. environmental consequences. In the future, the focus should be on establishing quantitative indicators for environmental consequences such as, for instance, valuable biotopes, wetlands and beach zones. Not until environmental consequences are given a price is it possible to perform a real assessment on an equal footing with the other factors in the cost/benefit analysis.

Restoration – re-establishing natural processes and functions in connection with ecosystems in the water and in boundary zones along the river basin, i.e. trying to revert to the conditions before the intervention. Restoration is, as a rule, an ideal goal that is seldom attained.

Rehabilitation – partial reversion to structure and function before the intervention. This is a practical approach in which certain properties/characteristics are selected in an effort to improve them.

Remedial measures – any improvement in environmental quality in an area where interventions previously have taken place. The remedy is either based on considerations of a single species, or is designed to make conditions better adapted for special user interests.

WEIRS IN THE GJENGEDAL WATERCOURSE IN WESTERN NORWAY. PHOTO: OLIANNE EIKENÆS

HYDRA REPORTS

- The Flood is Coming ... Final Report from HYDRA
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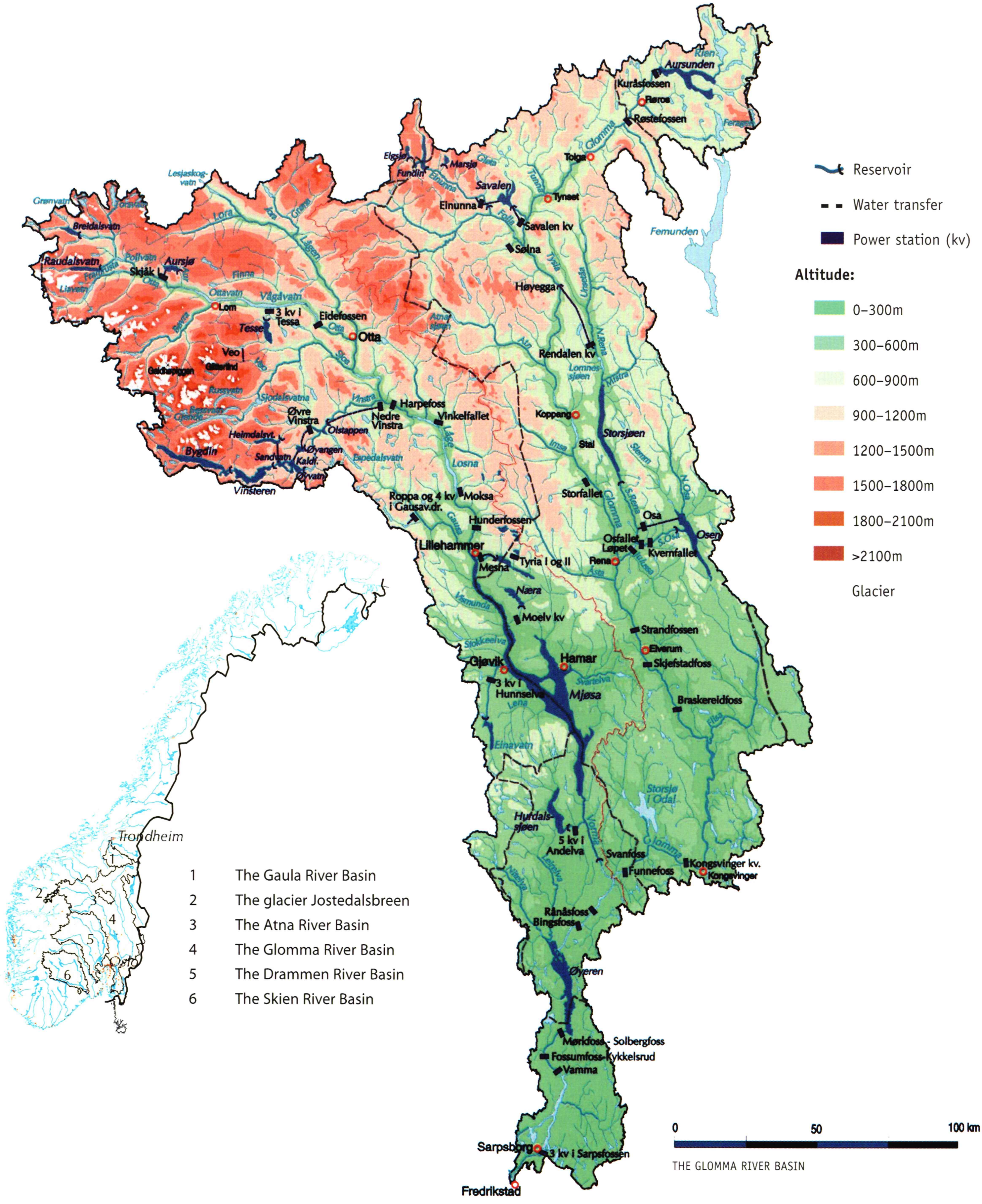

Reservoir
Water transfer
Power station (kv)
Altitude:
0–300m
300–600m
600–900m
900–1200m
1200–1500m
1500–1800m
1800–2100m
>2100m
Glacier
Trondheim
1 The Gaula River Basin
2 The glacier Jostedalsbreen
3 The Atna River Basin
4 The Glomma River Basin
5 The Drammen River Basin
6 The Skien River Basin
0
50
100 km
THE GLOMMA RIVER BASIN
Aursunden
Kuråsfossen
Røros
Røstefossen
Tolga
Glomma
Tynset
Savalen
Einunna
Savalen kv
Sølna
Femunden
Høyegga
Rendalen kv
Koppang
Storsjøen
Stai
Storfallet
Osa
Osen
Osfallet
Løpet
Kvernfallet
Rena
Lillehammer
Mesna
Tyria I og II
Hunderfossen
Moksa
Losna
Vinkelfallet
Harpefoss
Nedre Vinstra
Øvre Vinstra
Olstappen
Otta
Eidefossen
Lom
Skjåk
Raudalsvatn
Breidalsvatn
Bygdin
Vinsteren
Veo
Galdhøpiggen
Glittertind
Næra
Moelv kv
Strandfossen
Elverum
Skjefstadfoss
Gjøvik
Hamar
Mjøsa
Braskereidfoss
Einavatn
Storsjø i Odal
Hurdalssjøen
5 kv i Andelva
Vorma
Svanfoss
Funnefoss
Kongsvinger kv.
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