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River ice implications related to water power production in Norway

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Water power production is very important in Norway, as nearly 99% of the electricity production is based on water power. During the last century the major part of the potential water power not excluded from development by political decisions was developed. Now the focus is on developing smaller plants.

From the very first water regulations done in the country the implications of changes in ice conditions were recognized and evaluated. In the permits for regulations and schemes of water discharge the expected changes in ice conditions were taken into account, and most often followed up with close and long term observations and measurements.

Today increased focus on variable price on power day and night is unfavorable for the ice conditions, especially if the discharge is located on a river.

A summary of selected ice problems and efforts how to handle them is included. So is also a summary of anticipated climatic changes relevant for the ice conditions.

1. The background

Ice on lakes and rivers is a part of nature in most parts of Norway. The geography is such that there are large gradients in elevation from low coastland areas to high mountainous areas, narrow valleys with steep slopes, and wider valleys with more moderate slopes. The large gradients and seasonal variations in climate impact both runoff and ice conditions. The long coast is facing the North Sea and the Arctic Ocean. The Gulf-stream sweeps the western coast from south to north, contributing to a change from maritime to continental climate going inland from the coast. The Gulf-stream also reduces the north – south gradient, and contributes to the existence of ice-free fjords along the coast. The lowest winter temperatures are found in the interior fairly close to the Swedish border in the southern part and in the interior of the Finmark plateau in the northern part. All of which promotes the formation of ice in rivers and lakes, most all over the country, except in a narrow rim along the south-western coast. There are, however, large regional variations.

Most ice covered rivers and lakes have a history of being safe and easy travelling routes. Regular winter traffic on ice is today mostly for leisure purposes. Knowledge of ice, its occurrence and quality, has always been of great importance. Ice runs and winter flooding has always been well known phenomenon in many areas. The gradual introduction of water power had often considerable implications on ice conditions as compared before. This paper comments briefly on these implications.

2. The power development, the legal framework, and the new power market

The first development of hydro power in Norway started in the 1870's, then with power production mainly for light purposes. The first municipal power supply system was established in the town of Hammerfest, on Norway's arctic coast. The town had electrical streetlights in 1890, said to be the first place in the world. Gradually more power stations with intake reservoirs were built, with the major development taking place after the turn of the century.

Throughout the 20.th century hydro power plants were built all over the country. A number of these, built in the period up to 1940, were for the time among the largest hydro power stations in the world. Another period of constructing large power plant systems was from the middle towards the end of the 20.th century.

Today the period of the larger power developments is over, to a large extent determined by environmental considerations and political decisions. The main focus is now on developing smaller plants located in smaller unregulated streams.

The need for a legal framework for utilizing hydro power was soon recognized and established. The impact on the affected local population, and their rightful share of the benefits of the hydro power development had to be taken care of, including compensation for negative influence on the environment. Rules and guidelines were developed, as experiences were gained.

In 1991 a new market based energy law was implemented in Norway. The aim was to achieve more efficient use of electricity production by means of market forces. The new law established an open power market for the whole country. All private households could now choose where to buy electricity, independent of their homestead.

This new market had, however, some effects on the running of the individual plants. As there are short and long-term variations in electricity, prices and demand varying by the hour, there are now more short-time variations in hydro power production, and thus water discharge, than before. This, of course, is unfavorable for the ice conditions, especially when the discharge is located on a river. The open market now includes a large part of Europe as well, so that trade of electricity across borders have increased. Large subsea power cables now connect the Norwegian grid to the European grid.

3. Early ice investigations and experiences

It was early foreseen that water regulation influenced the ice conditions in lakes and rivers, first that the length of the season and also the bearing capacity of the ice was reduced with increasing winter discharge. Observations of ice formation in turbulent water and formation of bottom ice were also performed, and experiences started coming in.

A major occurrence was extensive ice-runs in the Glomma river in the southeast of the country in the late 1920's, which raised concerns about the possible influence of increased winter discharge from the newly regulated lake Aursunden at the head of the river basin. To investigate this a governmental commission was appointed. A basic study of the heat exchange and ice formation was performed under the leadership of Dr Olav Devik, then associate professor at The Norwegian Technical University. This commission initiated further studies of super cooled water films, the existence of frazil ice, and the formation of bottom ice.

Ice runs were also frequent in many other rivers these winters. The commission concluded that the formation and breakdown of ice dams during these winters were not so different between regulated and not regulated comparable rivers. The consequences, however, were much more serious for the regulated rivers with increased winter flow. Problems connected to flooding and icing was more serious in the regulated rivers. Based on these findings stricter regulations were enforced on the discharge from the reservoir.

The existence of frazil and bottom ice has been known in these areas "as long as man can remember". However, the scientific explanation for its formation had long been discussed. Again Dr Devik made his mark. He was one of the first to realize the importance of super cooling of water, and to measure it. He detected super cooled water films that had been forced underneath obstacles in the water, fundamental for the explanation of how bottom ice and bottom ice dams forms. He based his measurements of super cooling on radiation from the surface, and thus was able to measure temperature in very thin layers.

The majority of ice problems connected to water power development is caused by increased winter discharge. This was early realized, and observations and investigations of ice conditions were soon mandatory parts of the planning of power development. Ice investigations are also often performed as a part of the work of the water courts, to decide on compensation for changes connected to the power development.

4. Summary of selected ice problems and how they have been handled

4.1 The problem of stabilizing ice conditions with increased winter discharge (Glomma)

As mentioned above the lake Aursunden in the very upper part of the Glomma watercourse was regulated to provide winter water to power stations in the lower part of the river, and taken into use in 1924. From the very beginning this increase in winter discharge caused ice problems. On the slow flowing areas the ice was no longer safe for travelling, and in the more swift stretches there were frequently ice-runs and jamming. To reduce ice runs and jamming, special restrictions have been laid on the winter discharge.

The vulnerable river stretch is now inspected regularly in the ice forming season. To avoid ice runs the discharge is kept low in the fall and early winter, and should not be increased, and then gradually, before the river is stabilized and bottom ice dams are emptied.

4.2 The problem of extreme frazil formation and flooding (Einunna)

In situations with extreme frazil production the storing volume for frazil may be too small. When the water velocity decreases the frazil will be stored along the river. When there is an icecover downstream the frazil producing area, the river often is being blocked by frazil so that adjacent area is flooded. A threatened area is Einunna in the higher mountain plateau in the central part of southern Norway. “Warm”water is released from a reservoir, along a fairly swift stream, onto a more slow flowing area with adjacent farmhouses. In extreme weather with low temperatures and snowfall frazil is produced and the increase in water stage is very fast. Drifting snow into the open river contributes to the problems.

Remote observations of weather and hydrology are established at the site, to enable quick action if the water stage so that the farmhouses are being threatened. Local adjustments of the river bed and in the discharge to increase ice cover have so far not given any satisfactory results.

4.3 The problem of unexpected stops of power stations

Downstream reservoirs, between intakes and outlet of power stations, the discharge in the river is normally small and limited to a restricted low water flow. Often there is a considerable volume of ice and snow accumulated in these river sections. A sudden outburst of water here might cause ice run and jamming. This may happen when the power station suddenly stops for some reason.

This was the case last winter in the Orkla river. The intake reservoir is quite small and the water travelling time from the next reservoir upstream is ca 6 hours. The water overflowing the dam created an ice run that created a 3 km long jam. Fortunately there was no serious damage by the ice in this case. The stop was due to delivery problems for the power. As the reservoir was full and there is no by-pass arrangement in this station, the overflow could not be avoided.

With extreme weather conditions the racks in the intakes in the reservoirs may be clogged by frazil. This has happened in Bardu river. The intake reservoir is most often ice covered, but was by this occasion broken up due to extreme wind conditions. The temperature was low, frazil ice clogged the rack, and the power station stopped. In this case it was possible to hold back the water from overflowing. In the river downstream the outlet of the power station the water diminished and the surface ice here stranded. A controlled and gentle increase in discharge, when the racks were cleared off, and the power station could run again, avoided further ice problems downstream.

From Høyegga dam in the Glomma river the water is diverted to the neighbouring valley. Downstream the dam there is a restricted fairly low winter discharge, and the river is ice covered in winter. The power station stopped and the water overflowed the dam. It was possible only for a very short time to reduce the overflow. Part of the overflowing water froze on top of the existing ice cover and the ice thickness increased considerably. This happened in January and the power station was out of function throughout the spring flood. This was a vulnerable situation as ice runs in this area was quite common before the diversion. Measures to reduce the ice thickness were discussed. Fortunately the weather conditions were very favourable for the situation and the ice melted off gently.

In all the cases mentioned there has been only one turbine installed in the power station. In the last example a second turbine would have solved the problem. That is not the case when the stop is caused by intake or delivery problems. Then only a bypass turbine will solve the problem if the inflow to the reservoir can not be stopped.

4.4 Changed ice conditions in reservoirs

Increased flow through lakes will create larger open areas at inlets and outlets. The increased through flow will increase the areas of weaker ice in sounds, and new sounds may occur as the water level drops, and thus also be subjected to weakening of the ice. New open areas and areas with weakened ice will also occur by inlets and outlets of tunnels and power stations. The deeper parts of the reservoirs will only have minor changes in ice thickness. When there is a large change in water level throughout the winter season, a rim of crevassed ice will ground along the shore, especially on steep and rough areas. Short time variations in water level may give overall unsafe ice

When the ice has sufficient strength ice covered lakes are relatively safe and easy winter roads. Leisure use of ice has been more and more popular, both by local people and tourists. Knowledge of the ice conditions are of great importance for safety reasons. Information of weakened ice caused by water power development is therefore published on the internet.

4.5 Selective withdrawal to reduce effects on water temperature and ice coverage, to reduce effects on salmon (Alta)

Alta river is one of the richest salmon rivers in Norway, and there were serious concerns about how the power plant would influence ice conditions and fish habitat in the river. Extensive investigations of possible environmental impacts were therefore performed during the planning stage. Before regulation the river was ice covered except for limited leads. As expected the ice cover was nearly absent several km downstream the outlet, and the water temperature was somewhat lower in summer and slightly higher in fall and winter. The investigations on water temperature, ice conditions and fish population have continued after commissioning to document changes caused by the power development. The amount of fish near the power station outlet was reduced. The biologists claimed that this partly was caused by less shelter due to the reduced ice cover. One was therefore looking for compensating measures.

There is an upper (near surface) and a lower (near bottom) intake to the power plant. The upper intake was built to reduce the water temperature changes during summer. It was investigated to use the upper intake in winter to reduce temperature in the discharged water. By doing this the discharge water has been somewhat colder, and part of the upper reach of the river has been ice covered in cold periods. This has proved to be advantageous for the fish habitat.

The upper intake can, however, only be used a limited time. When the water level in the reservoir is reduced 15 m the lower intake must be used to avoid air induction. Then the temperature increases 1 - 2 ^{o}C in a short time, due to the configuration of the reservoir, and the ice cover will melt in this upper reach. To extend the period of potential for ice formation the release from the reservoir is kept fairly low. This lower discharge is favourable for ice formation in the whole river, also further downstream. A reasonable time for change of intake is now found to be early April. At the corresponding water stage, limited by the location of the upper intake, only 25 % of the reservoir is utilized.

To utilize the reservoir storage below the upper intake before spring flood the power plant discharge must be increased. This means that the spring break-up of the river ice must be started artificially. A challenge here has been to find a gentle way of increasing the discharge without causing ice problems in the 40 km ice covered river downstream. A method has been tested, and found satisfactory, and will be included in the final scheme of regulation for the plant.

5. Influence of climatic changes

Winter climate in Norway is expected to be warmer winter climate all over the country. The major impacts on the ice cover in rivers and lakes based on downscaled scenarios are:

- Only a few days shorter ice period in the most continental part of the country.
- The ice period decreases more towards the coast.
- Larger differences between years.
- More frequent ice runs with possible jamming at new places.
- Increased area along the coast with seldom ice.
- Longer stretch free of ice downstream large lakes.
- The lake ice will be thinner in the maritime regime, but less change in the continental regime.

The length of the ice season is particularly sensitive to length of time with freezing temperatures, and the amount of snow fall. Mild spells and heavy rainfall in the winter can trigger ice jamming and ice runs when an ice cover has developed. The downscaled scenarios of global warming indicate that the projected changes in temperature will differ regionally in Norway. More unstable ice conditions are expected along the coast and maritime areas from the south and as far north as to the arctic circle. The effect on ice will be somewhat different on rivers than on lakes.

The areas where the ice runs and jamming starts will shift to higher altitudes, moving the maritime ice cover further inland. This can cause a possibility of damages at other locations than those suffering from ice runs in the past. The season with the risk of ice runs will be shorter, but the year to year variability will be high. Extreme winter rainfall events after the ice has formed can cause severe ice runs.