Selective withdrawal to reduce regulation effects on ice cover downstream outlet of Alta power plant

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Abstract

Alta hydropower station was commissioned in 1987. Alta river was one of the richest salmon rivers in Norway, and there were serious concerns 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 regulation has reduced the ice cover considerably several km downstream the outlet, and the water temperature has been 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 considerably after the regulation. The biologists claim that this partly is caused by less shelter due to the reduced ice cover.

The power station has two intakes, one 10 m below HWL in the reservoir, and another 70 m deeper. The upper intake was planned to be used in summer so that the summer water temperature would be less affected.

From 1987 to 2001 only the lower intake was used in winter. However, by using the upper intake in winter the water temperature of the power plant discharge will be lower, and thus increase the potential for ice cover downstream. This was first tested the winter 2000-01 and the upper intake has been used part of the winter since then. It has been shown that we can obtain discharge water temperatures of 0.2-0.4 °C by using the upper intake. Then the ice coverage increases considerably. This is considered to be advantageous for the fish habitat.

The upper intake can, however, only be used a limited time. When the falling water level in the reservoir is reduced to the level where we have to change to the lower intake the temperature will increase 1 - 2 °C in a short time, and the ice cover upstream Savco lake will melt.

To utilize the reservoir below the upper intake before spring flood the power plant discharge must be increased. This means to forward the spring break-up of the river ice. A challenge here is to do this without causing ice problems in the 40 km ice covered river downstream. This has been tested, and it seems possible to avoid problems if a considerate and close evaluation of the hydrological conditions in late winter and spring is undertaken. The licence for the power plant is being modified to use the upper intake in winter. It seems optimal to plan for a change of intake around April 1. There are strong limitations on reductions in discharge throughout the spring due to the fish habitat.
Introduction

The Alta hydropower station was set into production in 1987 after more than 15 years of planning and investigations of environmental impacts. The Alta power plant has been one of the most controversial cases in Norway, even though the plant is of moderate size and fairly simple in its construction.

The Alta power plant is located in the far north of Norway. The river has a total length of 170 km and is flowing northwards, draining the Finmark plateau, 300-400 m asl, descending through a spectacular canyon and flowing through the Alta valley, towards the Alta fjord, facing the Arctic Ocean (fig 1).

The river was ice covered every winter with ice thicknesses in the range of $\frac{1}{2}$ - 1 m, some times more, depending on the meteorological conditions. In some years the valley had experienced fairly serious ice runs. The river was well known for being one of the richest salmon rivers in Norway, specially known for very large fish, often more than 20 kg. There were serious concerns 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. Due to uncertainties about the consequences a preliminary scheme of regulation was given with the licensing. The environmental investigations have been continued, and have since 2001 been specially focused on measures to increase ice cover. A final scheme is expected to be given in 2007.

Outline of the power plant system

Virdnejavre was originally a natural lake, 11 km long and fairly narrow, with normal water stage 250 m asl. A 120 m tall concrete dam was built across the river approximately 5 km downstream the natural outlet of the lake in a narrow canyon. The natural outlet is forming a threshold in the reservoir. The former lake, Virdnejavre, here called the main basin, holds two thirds of the reservoir.

The highest water level (HWL) is 265 m asl. The lowest water level (LWL) is 245 m asl in the former lake (main basin) and 200 m asl downstream the threshold (lower basin). A tunnel through the threshold enables LWL in the main basin lower than in the former lake. The hydro power station has two intakes in the dam, one 10 m below HWL and one 17 m below LWL in the lower basin.

The storage capacity is 6 % of yearly inflow to the reservoir. The outlet of the power plant is located 2 km downstream the dam, 80 m asl, and 45 km from the outlet of the river in the fjord. The power plant discharge was limited to 30 m$^3$/s in winter and as close as possible to natural flow during the fishing season. The reservoir is filled up in 2-3 weeks during spring flood in early summer.

Originally only one intake to the power station was planned. One had to expect a significant reduction of water temperature in summer time downstream the power plant, which was considered unfavourable for the fish. To minimize this effect the upper intake was built, even though the effect was considered to be marginal.
Fig 1. Location of Alta river and outline of the river from the reservoir to the outlet in the Altafjord. Distance along the river from outlet of the power plant to the fjord is about 40 km.
Winter Hydrological conditions

Before regulation

Before regulation the discharge decreased throughout the fall and winter, and on the average reached a minimum value in the range of 12-18 m$^3$/s towards the end of the winter (fig 2). The water would cool off to freezing in October or November, and then substantial frazil would form. The formation of an ice cover started on stretches with little gradient in the lower part of the river. There was considerable dynamic ice production, with frazil, formation of bottom ice, bottom ice dams and hanging ice dams. Gradually the ice front would move upwards the river. In certain areas leads were kept open all winter due to higher velocity of the water. The extension of these leads varied with the winter weather and the discharge flow. Winter ice runs were reported.

There are only occasional observations of ice cover upstream Savco lake before regulation. We do know that the stretch was ice covered in winter, but we do not know for how long.

The break-up would start with a gradual enlarging of the leads, first in the upper, and southern, part of the river. As the discharge increased, the increase in the water level would cause some broken ice to start drifting. The earliest break-up was reported at the end of April, and the latest the first part of June. Spring ice-runs occurred in connection with extremely fast increase in runoff.

After regulation, using the lower intake in winter

To avoid or reduce possible ice problems, specifically ice runs, the winter discharge was given fairly strict limitations in the licensed operating regime of the power plant. The discharge was to follow the natural inflow to the reservoir throughout the fall until 30 m$^3$/s or lower, a value calculated to be the average regulated discharge for the actual winter (fig 2). There should be no increase in discharge later in the winter. The average winter discharge was calculated according to the reservoir volume and the expected inflow. Due to variations in winter inflow to the reservoir from year to year, discharge from the power plant has varied from 24 m$^3$/s to 30 m3/s, which is the upper allowed limit. The reservoir should be gradually utilized throughout the winter.
Fig 3. Open leads before and after regulation using the lower intake in the middle of winter in an average year. Savco lake is seen in the middle of the figure. The outlet of the power station is at the right margin of the figure.

With this regime the water temperature at the site of the outlet of the power station in the fall and winter is increased. Due to the higher temperature and increased discharge, there has, as expected, hardly been any ice cover after regulation from the outlet of the power station to Savco Lake, with a few and short exceptions in winters with very favourable conditions for ice cover. Shortly downstream Savco lake the water temperature has cooled down to 0°C, and further downstream the winter water temperature is at the freezing point, as it was before regulation. Downstream Savco lake the ice formation has been less influenced until the withdrawal from the reservoir starts, which most often happens in December. From then on, the higher discharge will delay the ice covering. In the lower parts of the river the ice cover is only minor influenced.

The ice decay starts earlier than before regulation due to the larger discharge throughout the winter. The break-up starts in the upper parts and proceeds downwards very similar to the situation before regulation. The ice cover is, however, very dependent on the winter meteorological conditions that do have fairly large annual variations.

Reduction of fish population

After some years with this scheme of regulation the fish investigations indicated a reduction in the fish population, especially in the upper part of the river, from the outlet of the power station to Savco lake. The biologists claimed that this was partly caused by less shelter due to reduced ice cover, and also possibly higher water temperature in winter. On the other hand, somewhat higher winter discharge
than before, especially towards the end of the winter, seemed to have had a positive effect on the fish in the lower regions of the river.

One was then looking into measures to reduce winter water temperature and possibly increase the ice cover. It was decided to investigate possibilities by using the upper intake in winter. This included a new scheme of regulation, and a new temporary permission for trying out this was given by the water authorities.

**Water temperature in the reservoir and in the power plant discharge**

The water temperature and flow pattern in the main basin, on the threshold and in the lower basin was studied by alternatively using the upper and lower intake. Four thermistorstrings were deployed in the reservoir and measured the water temperature at 11 depths down to 50 m depth. In addition the water temperature was measured manually approximately once a month.

The temperature in the Alta river upstream the reservoir drops to the freezing point in late October. At this time, the reservoir is at HWL and the hydro power station runs on the inflow. The reservoir is normally ice covered in late October or November. Within the start of December, an approximately 10 m thick top layer of cold water is established in the main basin. The major part of the flow passing the threshold comes from this layer. In addition the surface current withdraw some warmer water from below the thermocline, which passes the threshold close to the bottom.

**Using the lower intake**

When using the lower intake, a current towards the lower intake is established by the water passing the threshold. This leads to an effective mixing of the water masses in the lower basin, and a decrease in the water temperature here. Therefore, the water temperature decreases throughout the winter in the lower basin, and the vertical temperature differences are only a few tenths of a degree at the end of the winter.

Thus the discharge water temperature also decreases slowly throughout the winter. It has had fairly large differences from year to year, with temperatures ranging between 1 and 0.5 °C the first part of January to temperatures between 0.6 and 0.4 °C the middle of March.

**Using the upper intake**

When using the upper intake the cold inflow water flows in the top layer towards the upper intake. The warmer water from below the thermocline in the main basin is passing the threshold and flowing into the lower basin close to the bottom. It spreads out in the deeper part of the lower basin, gradually mixing with the water above, and hence the temperature increases except in the cold surface layer.

It is obvious that the temperature of the discharge water is considerably closer to the freezing point when using the upper intake. The temperature drops 0.5-0.8 °C when changing from the lower to the upper intake early in the winter. With the upper intake in use the discharge temperature has been between 0.2 and 0.4 °C all seasons.

However, warm water remains in the basin below the upper intake, and due to the flow of warm water close to the threshold and along the deeper part of the lower reservoir, the temperature here even tends to increase somewhat, a few tenths of a degree, during the period with upper intake in use. When the water stage is getting close to 260 m asl it is no longer considered safe to use the upper intake. When opening the lower intake the accumulated warmer water create an increase in discharge
Fig. 4  The assumed flow pattern in the lower part of the Alta reservoir in wintertime when using the lower or the upper intake. Dark blue indicates "warm" water (1-4°C) and light blue indicates "cold" water (0-1°C). HWL and LWL are indicated on the figure.

Water temperature in the range of 1°C. This can be somewhat evened out by using both intakes for a period. The biologists have, however, not considered this "heat-wave" for threatening. Gradually the colder inflow water will replace the warmer bottom water in the lower basin, and the conditions will after 1-2 weeks be very similar to as if the lower intake had been used all winter.

**Increased ice cover from the power plant outlet to Savco lake**

The local air temperature and the water temperature on several locations downstream the power plant are registered. In cold weather the water cools down and there is generally ice formation 1-2 km downstream the outlet, depending on weather and water discharge. Some times, however, there may even be some ice in shallow areas closer to the outlet.

The ice coverage is documented by automatic cameras, and studied closely. One of the views of the automatic camera is shown in fig 6. The ice cover is quantified on 3 locations, P2, P4 and P6 the winters from 2001-02 to 2005-06. In 2005-06 the stretch downstream P6, hidden by a hillside, P8, is covered by a second camera. (fig 7). The results have been graded in 3 classes (for P6 four classes), and the situation the winter 2005-06 is shown in fig.5.

In December 2005 the discharge was still quite high, and reached 30 m³/s towards the end of the month. It was changed to the upper intake in the middle of December, and the water temperature changed from 0.5 to 0.2°C. The weather was quite cold and some shore ice formed fairly soon. More substantial ice cover was formed in connection with cold weather and somewhat reduced discharge in
Fig 5. The results winter season 2005-06. The temperature of the discharge drops from 0.5°C to 0.2°C when changing from lower to upper intake. When changing back to the lower intake the temperature increases to more than 1°C due to emptying the accumulated warmer water in the bottom of the lower basin.

Periods with air temperature below –10°C is shaded blue, it is seen that the water then is cooled off to zero at the measuring site Savco.

The evaluated ice cover at the locations P2, P4, P6 and P8 is illustrated at the bottom of the figure.
the middle of January. The ice cover survived through periods with air temperatures towards 0°C, when the cooling of the discharge water must have been smaller. At the end of March the reservoir had been reduced to 260 m so that the upper intake could no longer be used, and it was changed to the lower intake. The water temperature immediately increased by more than 1°C, and the ice upstream Savco lake disappeared in a few days.

Overall the season 2005 had a fairly good ice cover. With the old regime of regulation, only using the lower intake, it would have been no ice or very marginal ice formation in this area.

The ice formation varies with water temperature, water discharge and weather conditions. As documented the discharge water temperature is reduced by using the upper intake, and enables increased ice formation. The water discharge consists of the inflow and the withdrawal from the reservoir. The inflow depends on the hydrology and do vary somewhat from year to year. The daily withdrawal available depends on the time period one chooses to use the upper intake.

Consequences for ice release downstream Savco lake

The upper intake is closed when the water level is reduced to 260 m. At this point 75% of the reservoir is still left. The challenge now is to utilize the reservoir by increasing the discharge without causing ice problems downstream in the 40 km long still ice covered river.

Additional restrictions from the biological side are:

- reductions in the discharge should be avoided
- if the discharge has to be reduced it must not be lower than the minimum value earlier in the winter, and the changes must be slow

Ideally the reservoir should be close to empty just before the spring flood, which is some time between the last part of April and the first part of June. The capacity of the turbines are 92-96 m³/s for the relevant water stages.

When the lower intake is opened the accumulated warmer water in the lower reservoir is emptied out. The heat capacity in this water is, as pointed out, sufficient to melt the ice down to Savco lake.

The warmer water caused by the change of intake can in some years be traced also downstream Savco lake. The existing open leads, that in the beginning of the breakup mainly are located on stretches with somewhat larger gradient, will increase in size due to increasing discharge and increased radiation at this time of the year. The longer and wider slowflowing stretches in the upper part of the river will mainly open up first. It is essential not to raise the water level so fast that the ice breaks up and starts moving and jamming.

As the available time from the change of intake to the spring flood may be very short, it is important to find out how fast the discharge can be increased without causing ice jams. This has been tested out along with careful observations of the development of the ice situation.

The ice conditions have been inspected regularly along the river throughout the winter season, but sometimes restricted by ice situations that limited travel. The investigations have been intensified, and for the last seasons remote cameras have been used after the change of intake. The cameras have been located on strategic places and moved downstream as the ice release has proceeded.

It is essential that the progression of the ice release is not faster than a thermal release permits, and thus creates as long open leads as possible by a careful increase in discharge.
Fig 6. Near maximum observed ice cover with upper intake in use, January 8, 2003. Location P2 for ice observations is somewhat upstream P4 (to the left of the picture).

Fig 7. Ice cover January 23, 2006. P6 is the river bend in front, P8 is downstream the river bend. Savco lake is seen in the central back of the picture. The lake is ice covered with no snow.
Conclusion

By using the upper intake in winter the water temperature will be lower and thus make it possible for ice to form between the outlet of the power plant and Savco lake. This has improved the conditions for the fish. A new scheme of regulation based on use of the upper intake in winter will be implemented.

The upper intake can be used to utilize 25% of the reservoir. The longer time the upper intake is used the lower the discharge will be in this period. Lower discharge is favourable for ice formation.

In order to utilize the lower part of the reservoir the lower intake must be used from ca April 1. to avoid ice problems downstream Savco lake. The discharge must be increased in such a way that the ice release will be as close to thermal as possible. This has been managed all the seasons the upper intake has been used.

The restrictions from the biological side, that any decrease in discharge before the spring flood should be avoided, put restrictions on the household of the water also after the ice release. The large natural variations in the time of increased inflow requires continuous hydrological observations and calculations until the inflow matches the turbine capacity.

References


Asvall, R. P.: Water temperatures and ice conditions downstream the Alta hydropower reservoir with different intake levels, Proceedings of the 16th International Symposium on Ice, Dunedin, New Zealand 2002

Kvambekk, Å. S.: Water temperatures in the Alta hydropower reservoir with different intake levels, Proceedings of the 16th International Symposium on Ice, Dunedin, New Zealand 2002