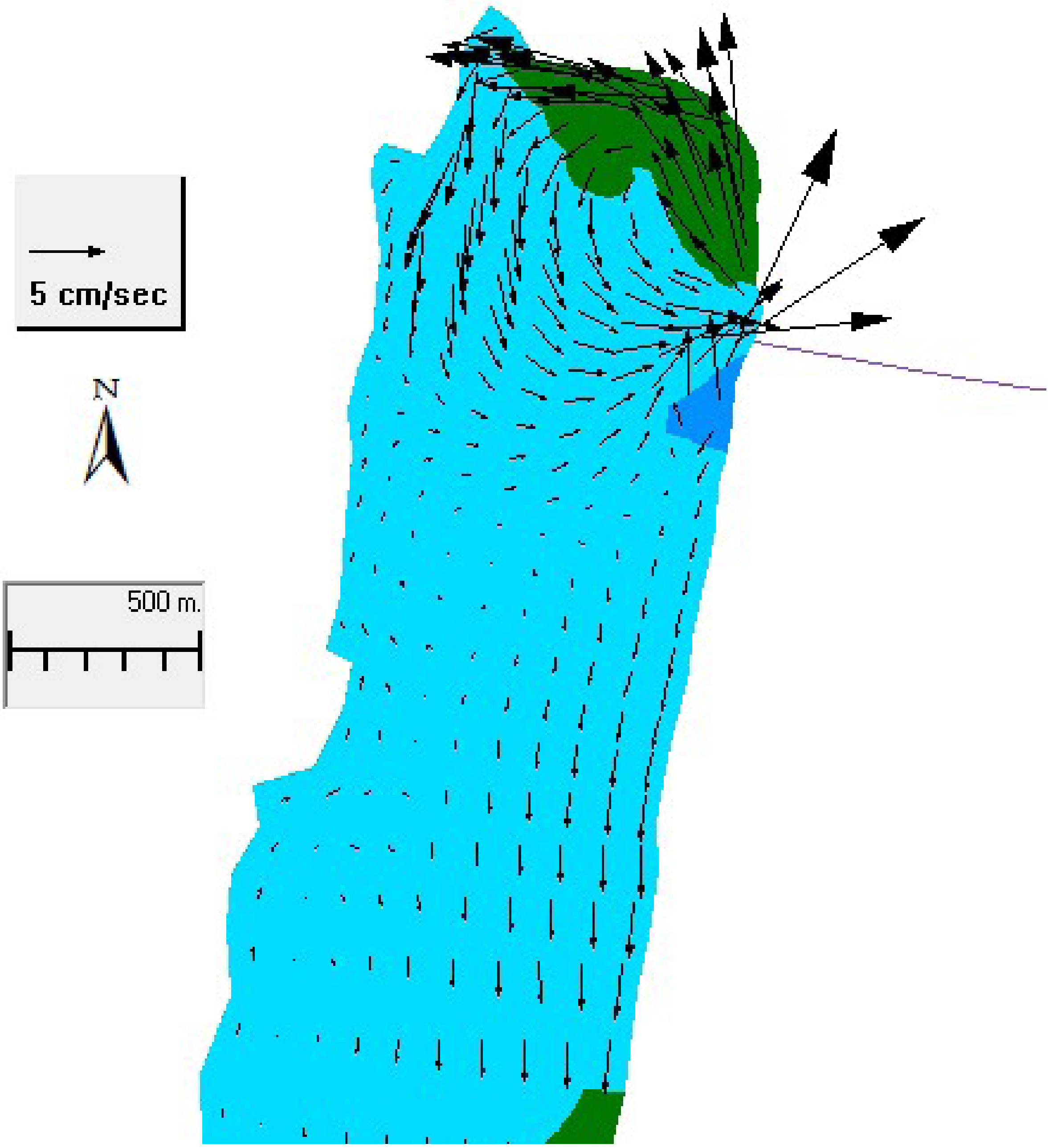
REPORT SNO 6326-2012

Hydro-peaking at Tonstad power plant in Norway Modelled effects on currents, temperatures and ice cover



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Abstract

This study has analysed the impacts on the physical conditions in the reservoirs of Sira-Kvina's Tonstad hydropower plant by simulating an intensive day-night peaking regime and compare this with today's production regime (i.e a simplified regime without any peaking, called 'base-line'). The simulated scenarios must, however, be considered as being an extension of today's typical hydropeaking regime rather than a scenario for how the future use of the Norwegian hydropower as 'a battery' to Europe might be. In Tonstad, hydropeaking was simulated by pumping water from Sirdalsvatn to Homstølvatn during night-time and releasing the water for production the following day. Hydropeaking led to considerably changes in water level in the upstream reservoir Homstølvatn, estimating the typical daily fluctuations to be 3.5 meters. The daily water level changes in the downstream reservoir (Sirdalsvatn) were simulated to approx. 0.75 meters. Hydropeaking increased the current speed, in particular in the areas close to the inlet/outlet of the Tonstad hydropower plant (in both Sirdalsvatn and Homstølvatn). The vertical mixing was increased throughout the reservoirs. In Sirdalsvatn the hydropeaking led to reduced temperatures near the surface and increased temperatures at greater depths due to increased vertical mixing, especially during the autumn and the first part of the winter. The circulation period was delayed and prolonged by a week or two. The increased hydropeaking resulted in a shorter period with ice cover in both Sirdalsvatn and Homstølsvatn, and in particular in the areas close to the inlet/outlet structures. Larger daily fluctuations in water level will most likely lead to more frequent ice break-ups along the shores.

4 keywords, Norwegian	4 keywords, English
1. Effekt-kjøring	1. Hydropeaking
2. Vannstand, strømning, temperatur, is	2. Water level, current, temperature, ice cover
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Hydropeaking at Tonstad power plant in Norway

Modelled effects on currents, temperatures and ice cover

Preface

The European energy sector undergoes significant changes due to climate change and the need to shift from fossil-based energy production to renewable energy production. The increased share of renewable energy production, to a large extent based on the non-regulated wind and solar power, will need a back-up system delivering energy to the consumers in periods of low production from the non-regulated sources. Reservoir-based hydropower, possibly also equipped with pumping facilities, can act as a back-up ("battery") by providing such services. In an inter-connected European power system the Norwegian reservoirs, assumed to hold around 50% of the total European reservoir capacity, could play an important role in balancing power production and consumption in Europe in the future.

The EnviPEAK-project was launched as one of the main activities in CEDREN (Centre for Environmental Design of Renewable Energy, www.cedren.no) in 2009. Most of the research activities in EnviPEAK are related to environmental impacts from hydropeaking in rivers and not directly connected to the concept of balancing non-regulated renewable energy production in a large scale, as this will be based on pumping and production between large recipients (large reservoirs, lakes and fjords).

The study reported herein is, however, one of the few studies in EnviPEAK focusing on environmental impacts in reservoirs and lakes. This study was carried out in southern Norway in the power system operated by Sira-Kvina ('Tonstad'). A similar study is currently being carried out in Statkraft's Ulla-Førre power system and is planned to be finished later in 2012. Furthermore, we would like to draw the attention to a partly finalised and partly on-going regional feasibility study on 'South-eastern Norway as a battery' (project titled 'HydroBalance'), covering technical, environmental and social aspects of realising Spouth-east Norway as a 'green battery'.

As well as the present report, the study from Ulla-Førra and all other publicly open reports produced by CEDREN are or will be made accessible via the 'Publication' part of the CEDREN Web site (http://www.cedren.no/Allpublications.aspx).

Tor Haakon Bakken is project leader for EnviPEAK-project, while Torulv Tjomsland has been responsible for this study on Sira-Kvina's Tonstad hydropower system.

Oslo, July 31st, 2012

Torulv Tjomsland and Tor Haakon Bakken

Contents

Summary

Introduction

The main objective of this study has been to model and analyse the hydro-dynamic effects in reservoirs/lakes introduced by an intensive hydropeaking regime in the Tonstad hydropower system, located in the south-eastern part of Norway. This included simulating the changes in water level, water temperature, water currents and ice formation in the reservoirs part of this hydropower system.

Tonstad hydropower plant is owned by Sira-Kvina kraftselskap AS and is today equipped with 2 generation units, called Tonstad 1& 2. The hydropower plant collects water from two neighbouring catchments, named Sira and Kvina, with the two reservoirs Ousdalsvatn in Sira and Homstølvatn in Kvina. The water is released from Tonstad 1 & 2 into the downstream reservoir Sirdalsvatn. The outlet of the plant is in the northern end of Lake Sirdalsvatn, which basically consists of three basins divided by two barriers.

The proposed and simulated hydropeaking regime implies pumping water from the downstream Sirdalsvatn to the upstream reservoir Homstølvatn during night-time and release water for production during day-time. To facilitate such a regime with pumping and and dramatically ioncreaed production capacity, a new tunnel and power plant (Tonstad 3) has to be constructed and included in the model setup.

In order to simulate the propsed pumping/hydropeaking regime a model package named GEMSS was applied. GEMSS is developed by ERM's Surface Group in Exton, Pennsylvania, USA. In this study, 3D hydrodynamic part of the modeling tool was applied, which supports simulation of water current, temperature, ice cover and transport of conservative matters in three dimensions.

The model was configured for a base-line scenario (no hydropeaking) and a second scenario with hydropeaking. The defined hydropeaking scenario involved pumping of 270 m^3/s from Sirdalsvatn to Homstølvatn during the night (14 hours) and then releasing the water for electricity production 10 hours the following day. By pumping the water back into Homstølsvatn, 650 m^3/s of water was available for hydropower production during the peak periods (day-time), being a dramatic increase from a constant flow of 170 m^3/s, representing the present situation (base-line scenario). This daily pumping/production regime was simulated identically all days throughout the year. The purpose was to study seasonal differences with and without hydropeaking.

Effects of hydropeaking

Water level

The water level in Homstølvatn increased approx. 3.5 m during the 14 hours with pumping and decreased to the original level again during the following 10 hours with production (release). The water level in Sirdalsvatn increased approx. 0.75 meters during the production period and decreased to the original level during the following pumping period.

Water currents

The dense water (holding 4^o C) from the bottom of the upstream reservoir of Homstølsvatn (Nesjen, see illustration in figure 2) enters Homstølvatn at the surface, descends towards the bottom and moves towards the intake tunnel. Especially near the bottom, these currents/velocities were reversed during the pumping period. The pumped water from Sirdalsvatn was dispersed almost from the surface to the bottom. Most of the water pumped during the night returned through the power plant the following day.

In Sirdalsvatn the hydropeaking with increased water flows out of the Tonstad power plant led to increased water current velocities. During the pumping period, currents were reversed in the direction of the intake. According to the simulations, the hydropeaking scenario led to interior waves and greater vertical mixing in all parts of the lake.

Water temperatures

In Homstølvatn the effects of hydropeaking could be found during the period May-September, compared to the base-line scenario. Near the bottom, just below level of the intake tunnel, hydropeaking resulted in a temperature increase in up to 3 ^{o}C. Above the tunnel, the effects were opposite. The rest of the year the differences from the base-line scenario were small.

In Sirdalsvatn the hydropeaking led to higher temperatures at greater depths and reduced temperatures near the surface. The effects were greatest in periods with unstable vertical profiles, i.e. during the circulation period in the autumn/first part of the winter. The period of cooling during autumn/winter was delayed and prolonged by a week or two, the vertical circulation became deeper and the circulation period was delayed. Even as the vertical mixing reduced the temperature diffences between surface and bottom, the surface temperatures were still higher than in the current scenario in part of October - November due to the delayed and prolonged circulation.

In the center of Sirdalsvatn and at depths less than 20 meters, hydropeaking led to reduced temperatures during the summer period (May-August) and increased temperatures in the period from September to April. The changes in temperatures from the base-line to a situation with hydropeaking were, however, normally less than 2 ^{o}C. These increased temperatures were caused by vertical mixing. At 50 meters depth, the temperatures are approximately 4 ^{o}C the whole year.

In the southern end of Sirdalsvatn, the upper 20 meters shows a similar pattern of water temperature changes as in the center of the lake, i.e reduced temperatures in the summer and increased temperatures in the rest of the year. The temperature changes in the surface layer with and without pumping are, however, greater than in the center of the lake, which maybe can be explained due to the fact that without pumping, the thermocline in the southern part is generally better developed than in the northern and center part of the lake.

Basically, the hydropeaking seems to affect the top layer throughout the lake. At 50 meters depth, the temperatures are to a very limited extent affected by hydropeaking.

Ice cover

Strong currents near the tunnel outlets are expected to lead to reduced ice cover formation both in Sirdalsvatn and Homstølvatn. An additional outlet from Tonstad 3 will increase the ice free area locally and extend the area with weak ice cover.

In both Sirdalsvatn and Homstølvatn hydropeaking resulted in a shorter period with ice cover. The ice formation may be delayed more than one month and the break up is expected to take place a couple of weeks earlier. This can be explained by the increased vertical mixing followed by winter temperatures slightly above 0 ^{o}C.

Daily water level fluctuation of 3.5 meters in Homstølvatn may lead to a more frequent break up of the ice cover along the shores. The same phenomenon also may be expected in Sirdalsvatn due to daily fluctuations, simulated to be approx. 0.75 meters.

1. Introduction

1.1 Objectives

The main objective of this study was to model and analyse hydro-dynamic changes introduced by the hydropeaking regime, by use of Tonstad hydropower system as the case. The hydro-dynamic variables analysed were water level, water currents (velocity and direction), water temperature and ice formation.

1.2 Power plants and area description

Tonstad hydropower plant and its regulated waters are located in the southern part of Norway, **Figure 1**. The plant is owned by Sira-Kvina kraftselskap AS and is today equipped with 2 generation units, called Tonstad 1& 2. Tonstad is located in Sira catchment, but the hydropower plant collects water from both Sira and its neighbouring catchment, named Kvina. The two reservoirs closest to the plant are Ousdalsvatn and Homstølvatn, located in Sira and in Kvina, respectively. The two reservoirs have equal HRL (highest regulated water level). In periods with no production, water from the reservoir with highest water level flows into the other. The water is released from Tonstad 1 & 2 into the downstream reservoir Sirdalsvatn, **Figure 2** and **Figure 3**. The outlet of the plant is in the northern end of Lake Sirdalsvatn, which basically consists of three basins divided by two barriers.

Sirdalsvatn consists of three basins divided by two barriers, **Figure 4** and **Figure 5**. The northern sill at a depth of 40 meters, is located 7 km south of Tonstad. The second sill at a depth of 25 meters, is located 5 km upstream from outlet in the southern end. The northern part of the reservoir holds the deeper parts of the lake, and depths around 120 meters are common. The basin in the middle has depths approaching 100 meters.

The depths in the other reservoirs (upstream the plant) Nesjen, Homstølsvatn and Ousdalsvatn go slightly beyond the lowest regulated level, see **Table 1**. Nesjen and Ousdalsvatn receive surface water from the upstream catchment while Homstølvatn receives most of the water almost directly from the bottom of Nesjen.

The diameter of the tunnels through Tonstad 1& 2 are approx. 10 meters and the outflows to Sirdalsvatn are between 8 and 18 meter below HRL. In order to realize the idea of intensive hydropeaking as simulated in this study, new tunnels need and a new plant (Tonstad 3) need to be constructed. According to the plants, such a tunnel with be excavated with a dialmeter of 12 mters. The outflow in Sirdalsvatn is planned to be located 300 m south of the existing outlet and 10-22 m below HRL. The tunnel through this new plant will be used for both pumping to Homstølvatn and production.

Today the daily fluctuations of the water level in Ousdalsvatn are small. In Homstølvatn around 20 % of the days in the period 2000-2005 had a daily water level change less than 1 meter. Both of the reservoirs Ousdalsvatn and Homstølvatn normally have relative constant water level a few meters below HRL. The reservoirs seldom are emptied to levels near LRL.

Table 1. Reservoirs and basic characteristic values.

	HRL	LRL	Regulation	Surface area
Reservoir	**m.a.s.l.**	**m.a.s.l.**	**meters**	**km^2**
Nesjen	715.0	677.0	38.0	15.96
Homstølsvatn	496.6	471.0	25.6	2.89
Ousdalsvatn	496.6	482.0	14.6	1.19
Sirdalsvatn	49.5	47.5	2.0	19.34

The current electro-mechanical installation of Tonstad power plant may produce 960 MW, which is the single plant with the second largest capacity in Norway. The maximum water flow is 254 m^3/s. Mean water flow through the power plant during the winter is ca. 150 m^3/s. This discharge is gradually reduced to about 50 m^3/ in the middle of the summer. Mean yearly flow is ca.135 m^3/s, with 75 m^3/s and 60 m^3/s originating from Ousdalsvatn and Homstølvatn, respectively; see **Figure 6** - **Figure 9**.

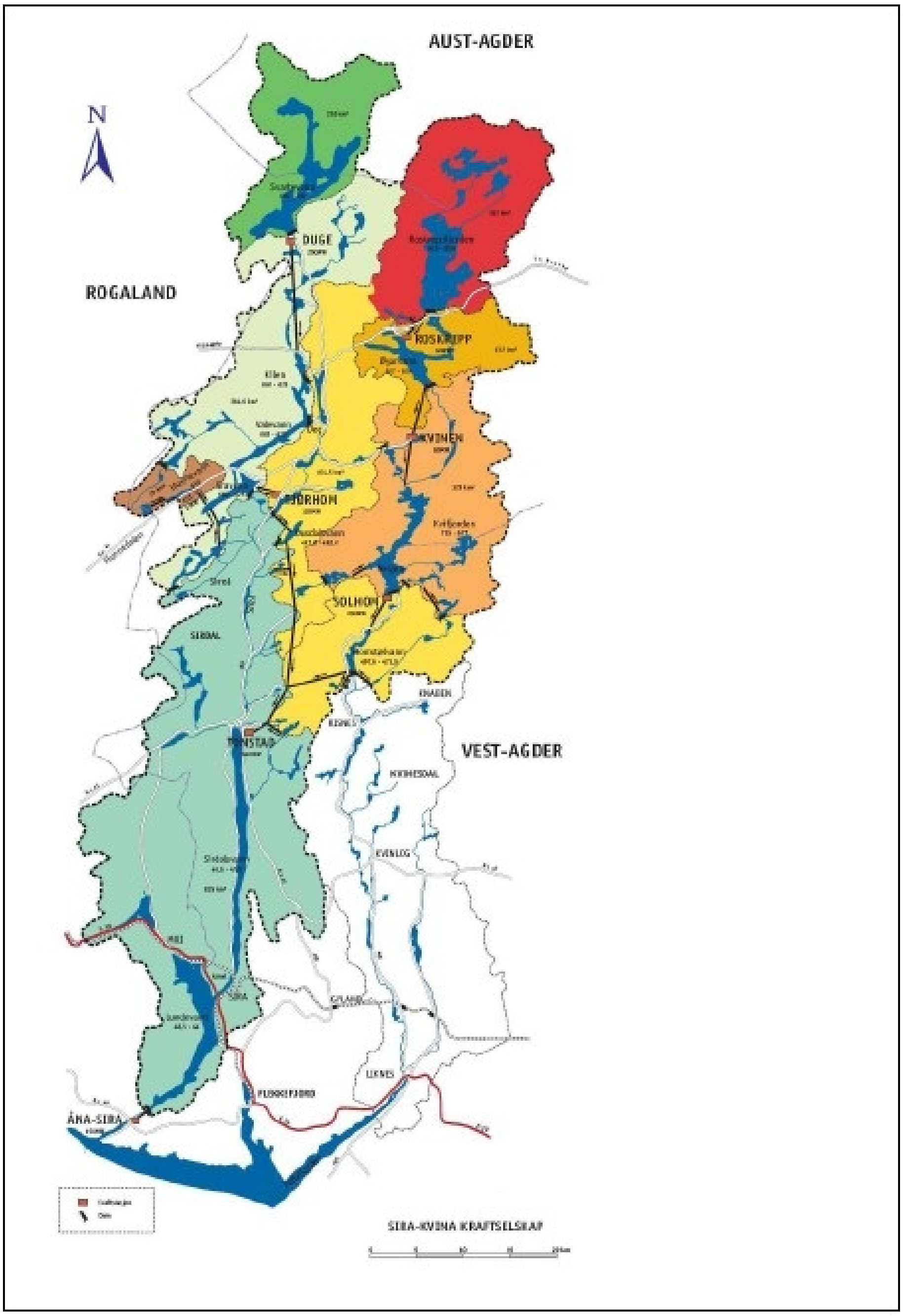


Figure 1. Tonstad 1& 2 hydropower plant is located in the northern end of the downstream reservoir Sirdalsvatn. Tonstad collects water from Sira catchment to the west of the regulated scheme, and from neighbour catchment Kvina in the eastern part of the scheme. Tonstad 1& 2 hydropower and its regulated catchments are located in plant the southern part of Norway.

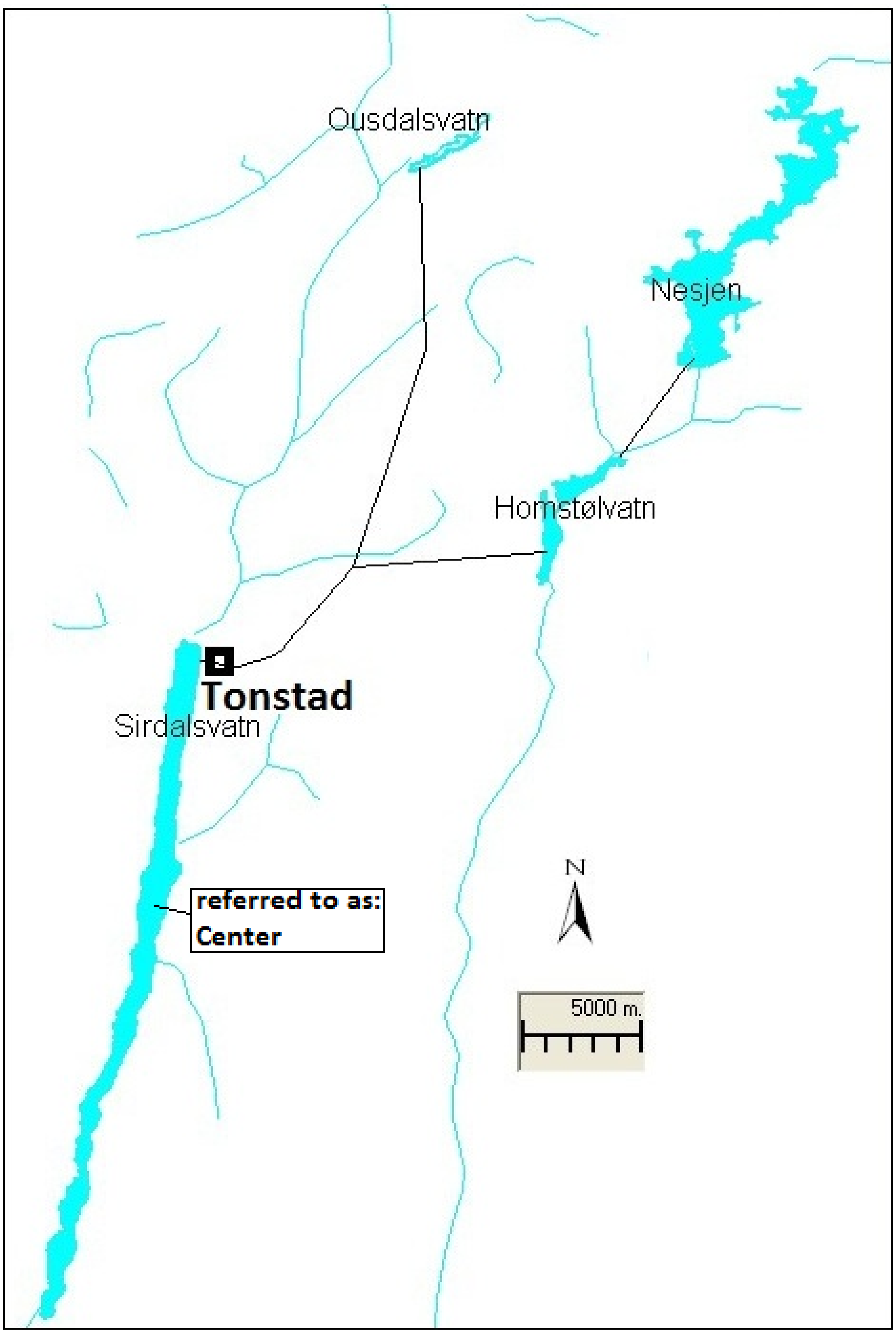


Figure 2. Tonstad 1& 2 hydropower plant, with outflow to Lake Sirdalsvatn, receives water from the reservoirs Ousdalsvatn and Homstølvatn. Ousdalsvatn is part of the Sira catchment (West), while Homstølvatn is located in the neighbour catchment to the East, namely Kvina.

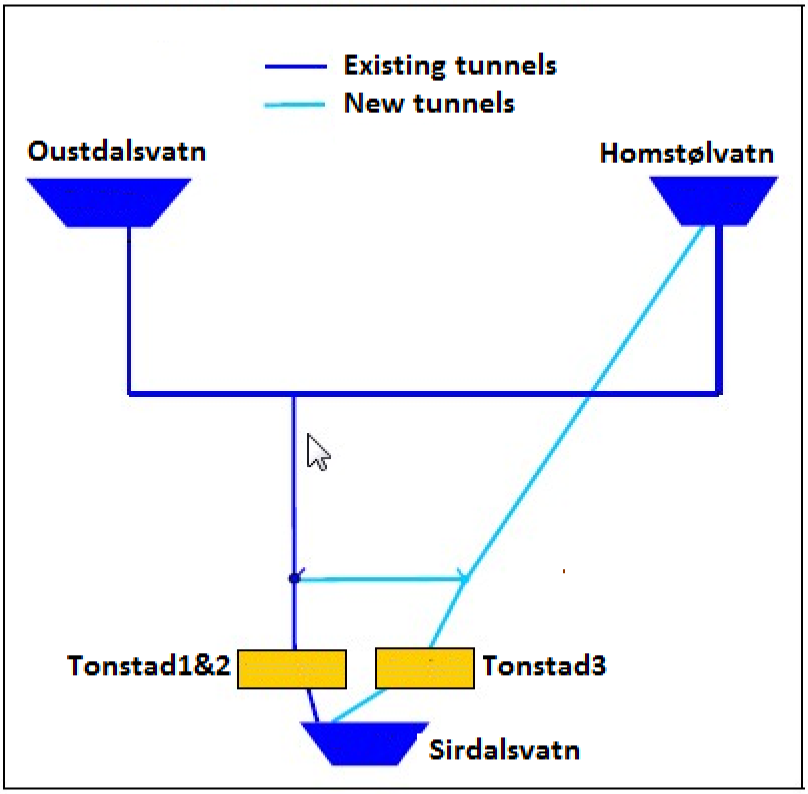


Figure 3. Water is drained from the reservoirs Ousdalsvatn and Homstølvatn into Tonstad power plants (current installation is Tonstad 1 & 2) via tunnels, and released into the downstream Sirdalsvatn, when no pumping facilities are installed. To accomodate a future intensive hydropeaking regime, the new plant Tonstad 3 is planned, which will be equipped with reversible turbines and the tunnel through this new plant will hence be used for both pumping to Homstølvatn and production (Magnell et al. 2007).

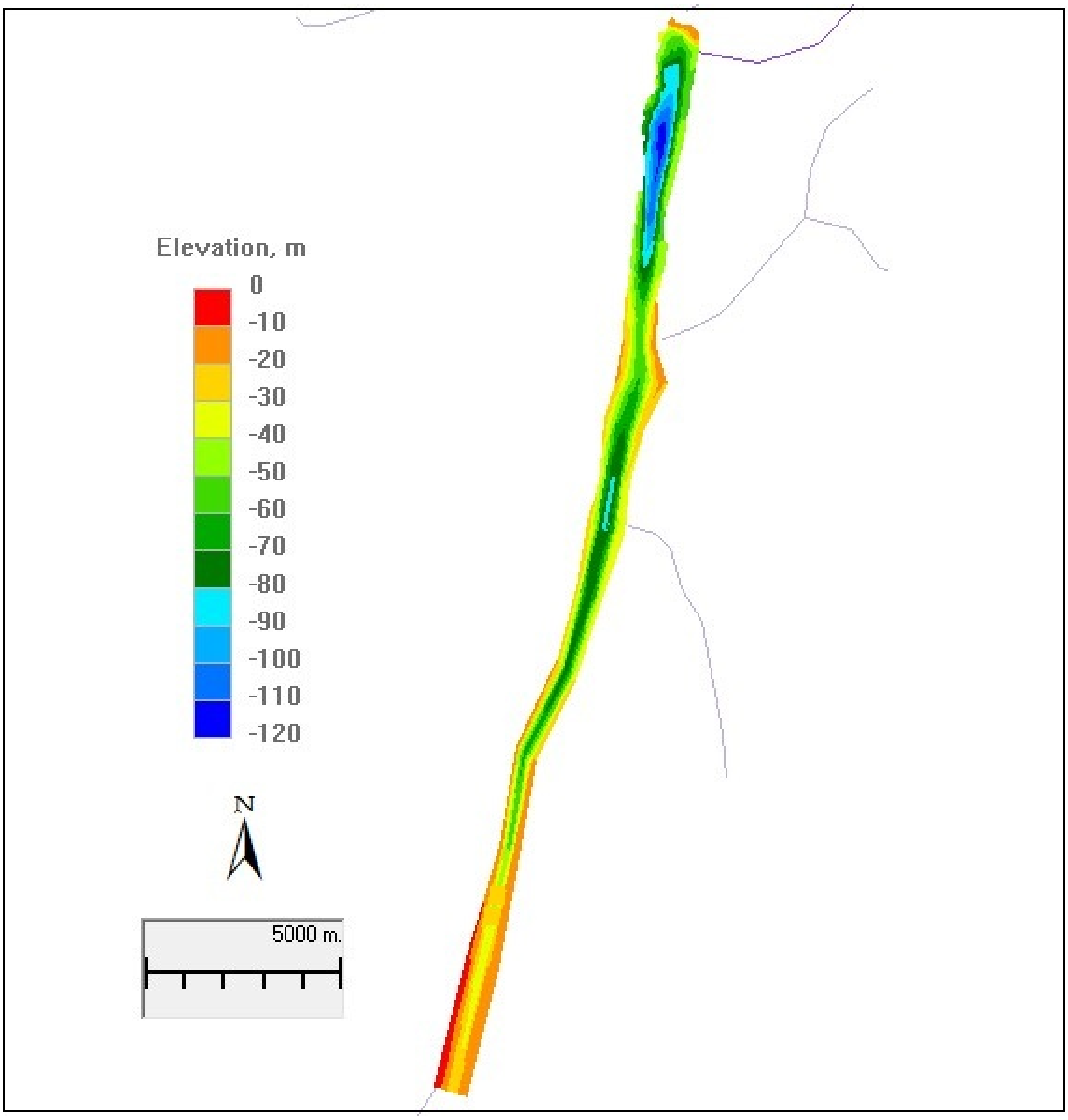


Figure 4. The map illustrates the bathymetric model/map of Sirdalsvatn, as used in the model. Sirdalsvatn consists of three basins divided by two sills.

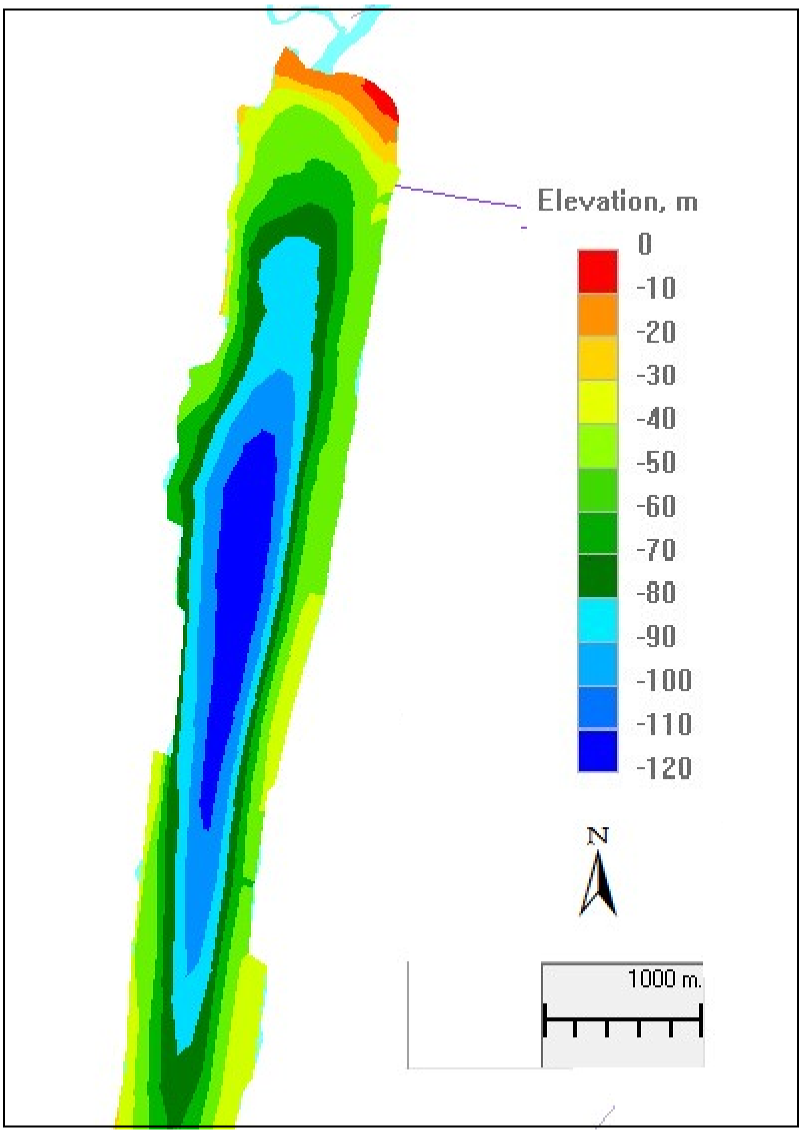


Figure 5. The figure shows the bathymetric map map of the northern part of Sirdalsvatn.

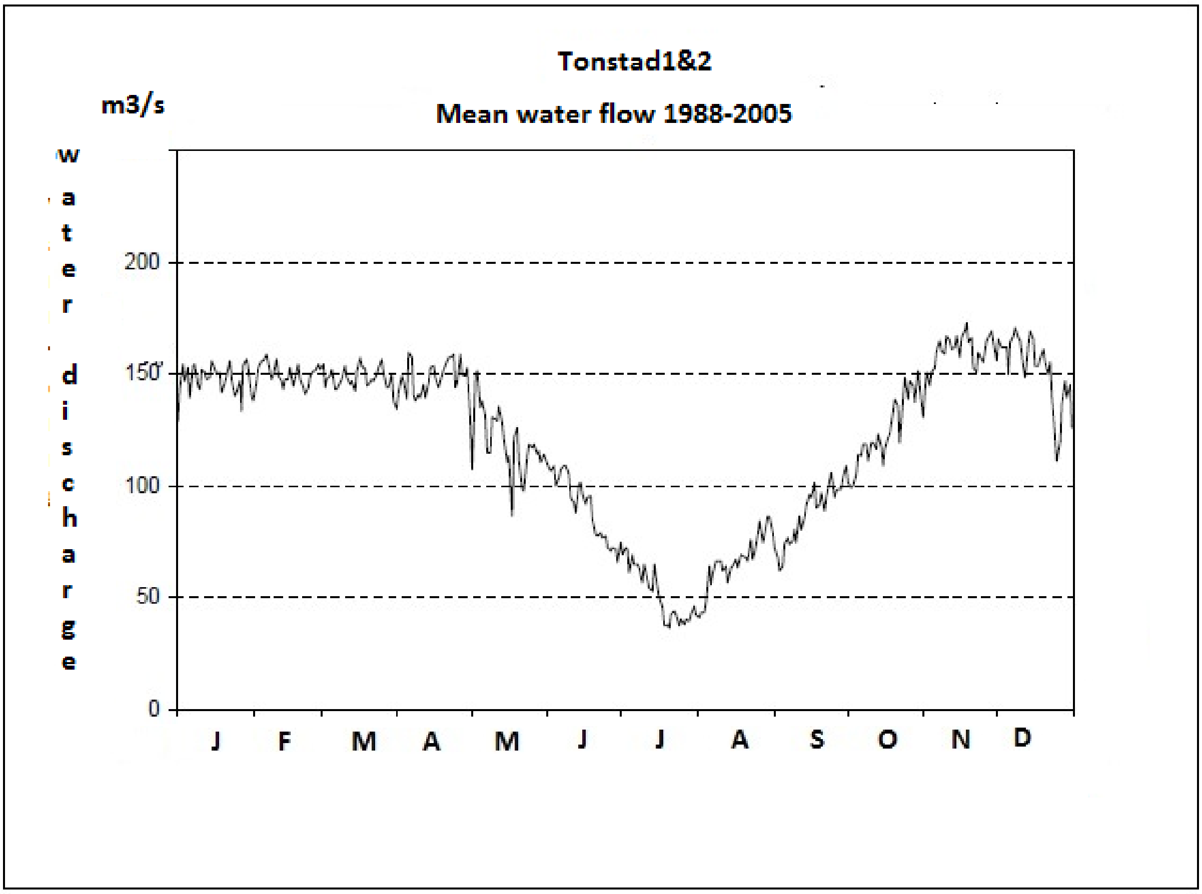


Figure 6. Mean water flow through Tonstad power plant in the period 1988-2005 (Magnell et al. 2007)

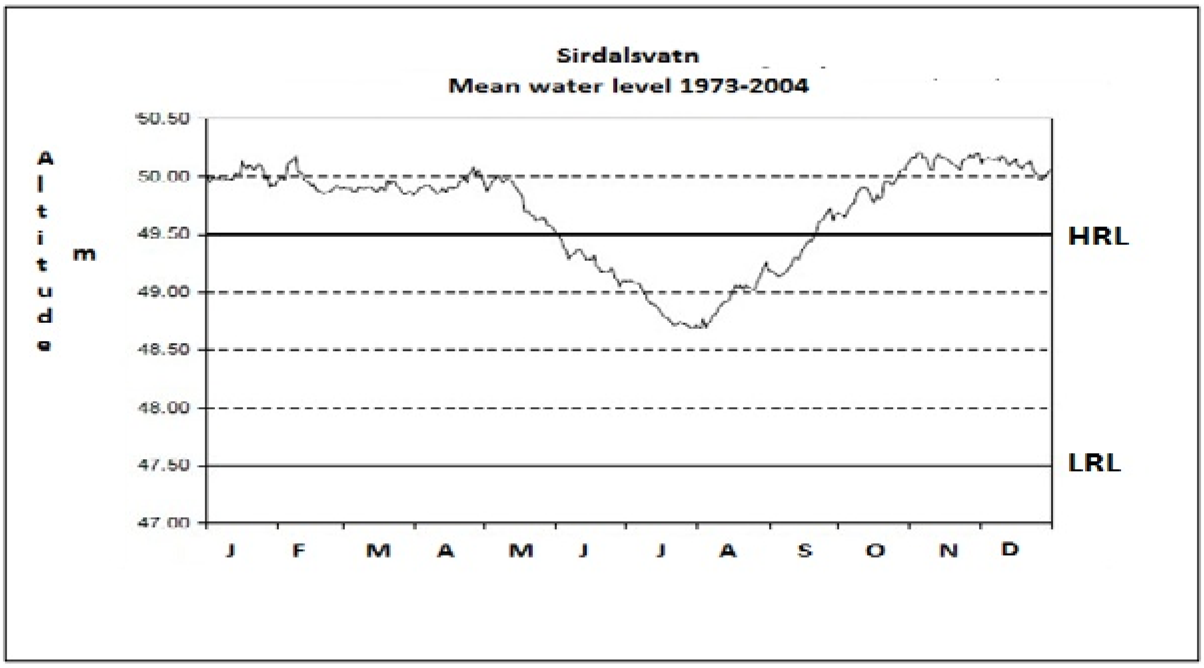


Figure 7. Lake Sirdalsvatn is regulated by 2 meters. Most of the year the water level close to the highest regulated water level (Magnell et al. 2007).

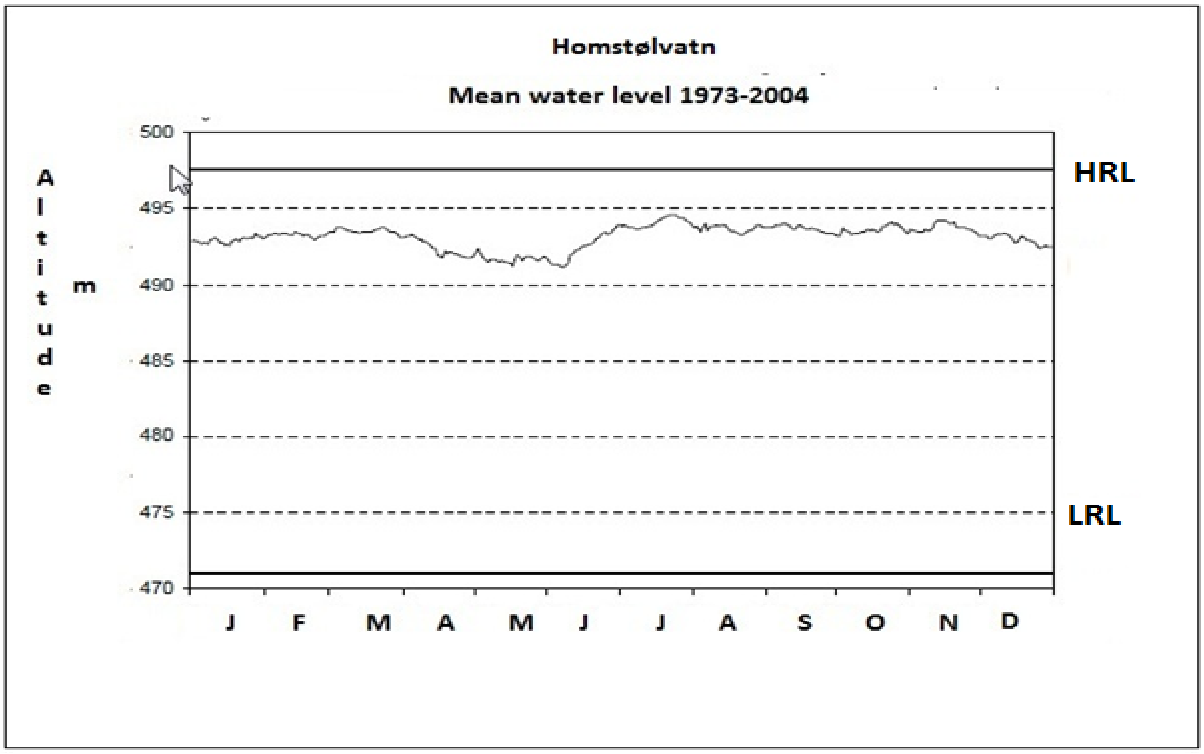


Figure 8. The water level has been rather stable to around 5 meters below highest regulated water level (Magnell et al. 2007).

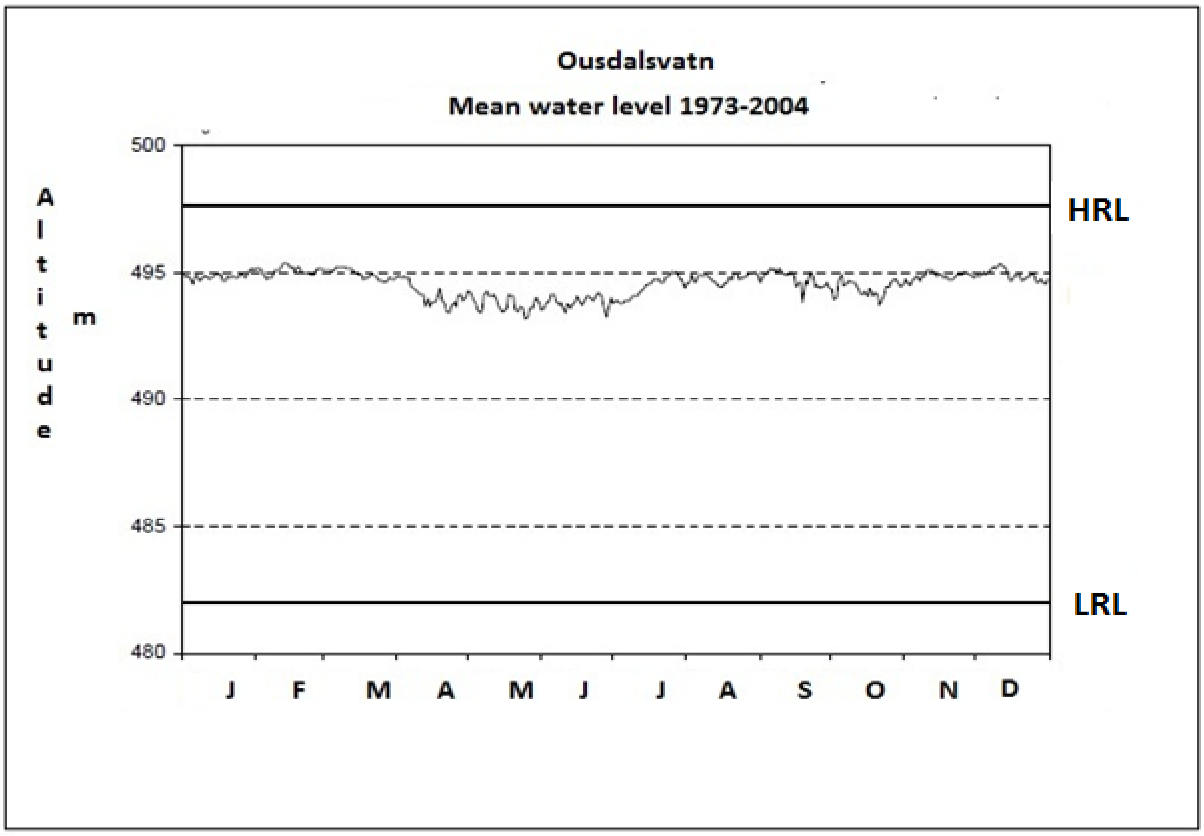


Figure 9. The water level has been rather stable to around 3meters below highest regulated water level (Magnell et al. 2007).

1.3 Methods

In order to simulate the proposed hydropeaking swcenario, a model package named GEMSS (Generalized Environmental Modelling System for Surface waters) was applied. The model package is been developed by ERM's Surface water Modeling Group in Exton, Pennsylvania, http://www.erm-smg.com. The central part of the modeling tool is the hydrodynamic module. Modules to simulate sediment transport, water quality, oil spill, etc. can be added to the hydro-dynamic module and buold on the basic hydro-dynamic calculations.

In this study water water, water current/velocities, water temperature, ice cover and transport of conservative matters were simulated with use of the 3-dimentional version of the model. The model simulated the situation in the reservoirs with and without hydropeaking.

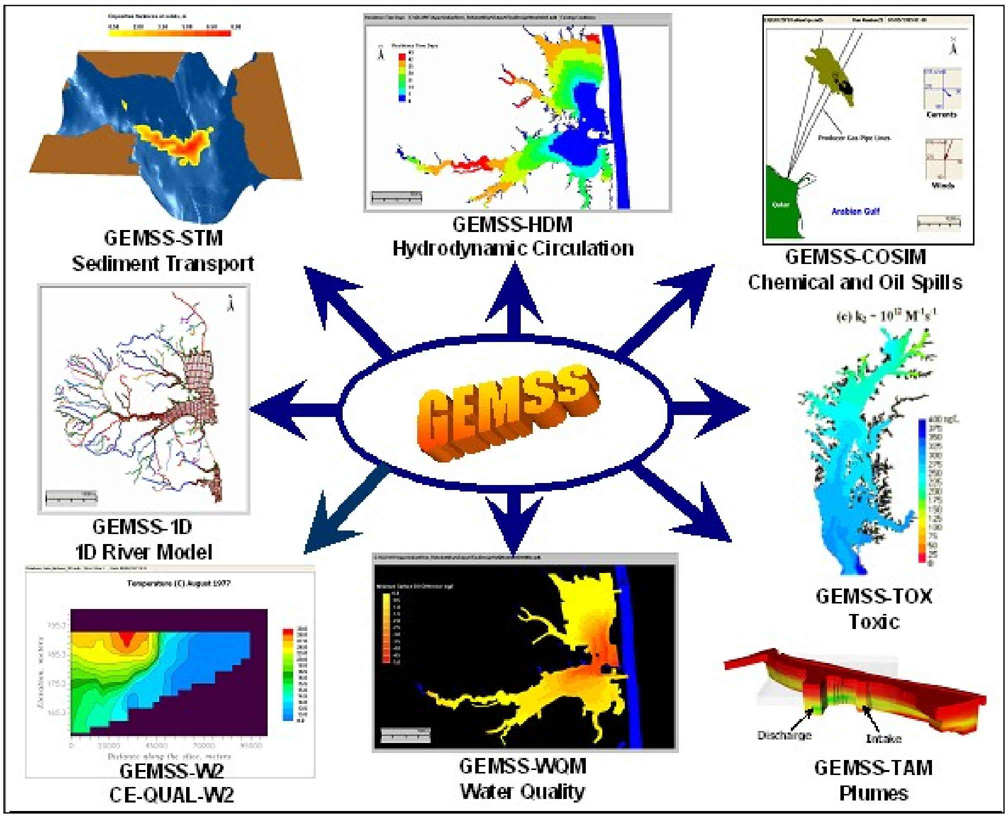


Figure 10. The model package named GEMSS was used in this study and water current/velocities, temperature and transport of conservative matters were simulated. GEMSS is developed by ERM's Surface Group in Exton, Pennsylvania, USA.

2. Simulation of the current situation (base-line)

2.1 Data

Data on water discharges, water levels, reservoirs, tunnels etc. was received from the hydropower company Sira-Kvina kraftselskap AS. Climate data for the simulation period (2008), i.e air temperature, dew point temperature, wind velocity, wind direction, air pressure and cloud cover, were obtained with 6 hours resolution were collected from the meteorological station 42920 Tjørhom, , operated by the Norwegian Meteorological Institute. Station 42920 is Tjørhom located a few kilometres north of the reservoir Ousdalsvatn at an altitude of approx. 500 meters above sea level

The available hydrological information was insufficient to describe the water exchanges beween the reservoirs Ousdalsvatn and Homstølvatn.

Two modelling grids were prepared for the reservoir Sirdalsvatn, while the detailed grid covered only the northern part of the reservoir, which also was considered the most interesting as the the largest changes were expected to happen there. For the other reservoirs the same grids were used for all calculations, see **Figure 10 - Figure 13**. The detailed grid was also only used for the calculation of the shorter periods (a week), while the less detailed grid was used for the calculations of longer periods (year) in order to save computational resources.

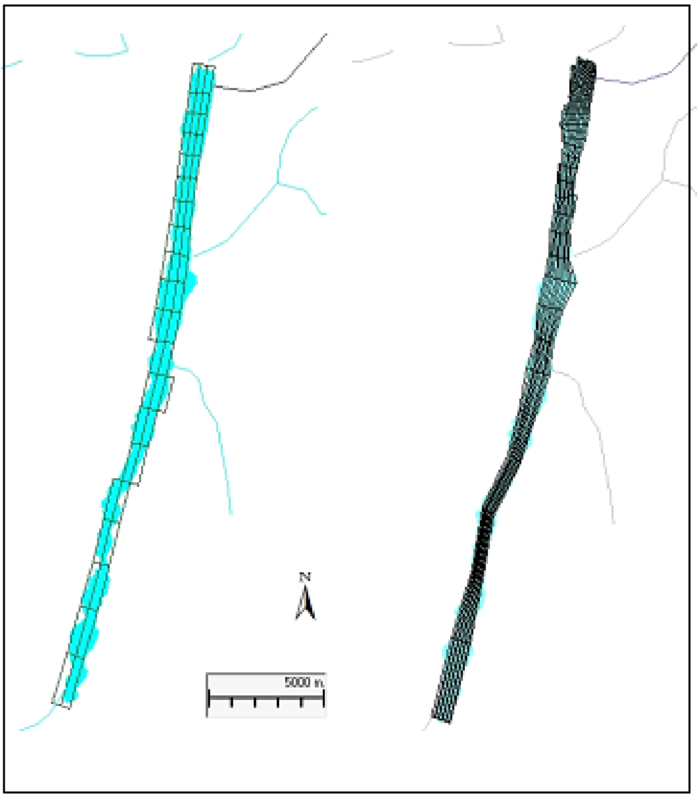


Figure 11. Two modelling grids were prepared for Sirdalsvatn. The less detailed grid was used for calculations covering longer time periods (year). The most detailed grid was used for calculation of shorter time periods (week).

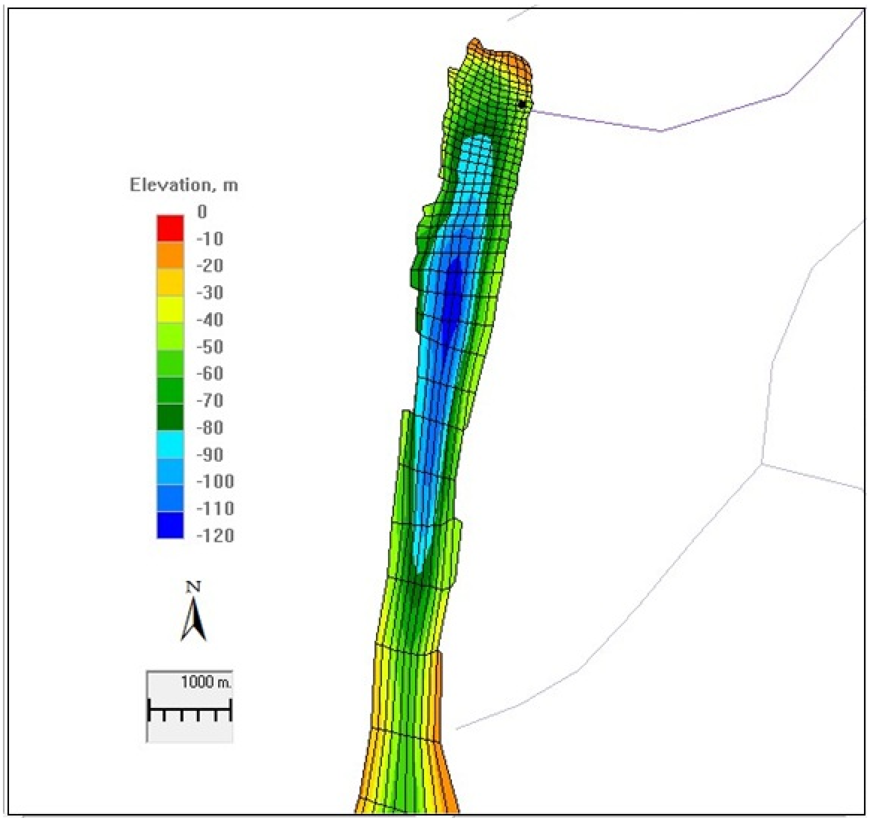


Figure 12. The grid was more detailed (finer spatial resolution) near the power plant outlet.

Figure 13. The same grid resolution was used for Nesjen, Homstølvatn and Ousdalsvatn for all simulations.

2.2 Current situation (base-line)

The outlet from the hydropower plant is 8-18 meters below HRL in Sirdalsvatn and the discharge was 200 m^3/s during the simulations. The water flow in the river Sira into reservoir Ousdalsvatn in the northern part was set to 7 m^3/s, which is equal to the yearly mean value.

A representative subset of the modelled water currents in Sirdalsvatn can be inspected in the **Figure 14 –Figure 17**. The water flowing out from the power plant moved across the lake from east to west, and a return current was established in the northern end. The differences in current patterns were small between the surface and 10 meter beneath the surface.

During the summer, temperatures decrease towards deeper waters which results in more stable vertical conditions. During autumn/winter the vertical temperature profile gradually approached 4 ^{o}C throughout the water column, which in turn leads to a vertical circulation of the water mass. This phenomenon affected to some extent the currents, as the currents on deep water were greater in the circulation periods than during the summer. In the surface layer the magnitude of the currents were slightly higher under summer conditions.

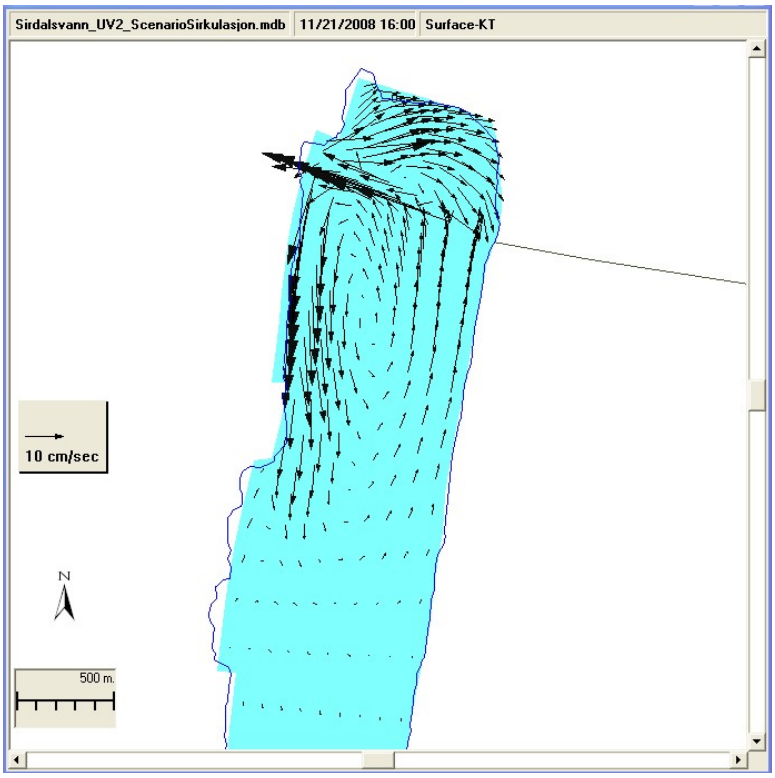
The currents in the northern part of Lake Sirdalsvatn are dominated by the outflow from the power plant. The surface currents in this area were relative stable in spite of fairly strong wind in the magnitude of 4 m/s in different directions, see **Figure 18 - Figure 21**. The effect of the wind on the water currents became noticeable from approximately one kilometre south of the tunnel outflow.

The outlet of water from the reservoir Ousdalsvatn, located 6-15 meter beneath HRL, holds water with temperatures close to the same as the surface water entering Ousdalsvatn. The throughput is large compared to the volume of the reservoir, which results in small temperature differences between outflowing and inflowing water, and the reservoir 'behaves much like a river' with high temperatures during the summer and close to 0 ^{o}C during the winter.

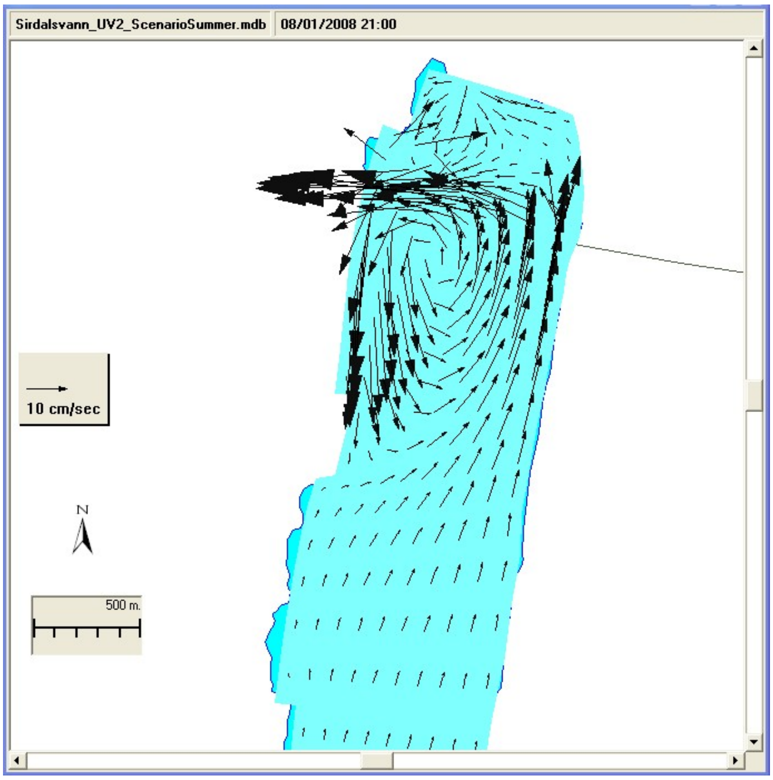
The reservoir Nesjen receives surface water from the upstream rivers. The outlet is located 30-38 meters beneath HRL and feeds the downstream reservoir Homstølvatn with water holding a temperature around 4 ^{o}C throughout the year, **Figure 23**.

The water from the bottom of the reservoir Nesjen with higher density enters reservoir Homstølvatn at the surface in the northern part, descends and moves along the bottom towards the outlet tunnel 18-26 m beneath HRL, **Figure 24**.

As there were very limited data for calibration and verification available, the results from the model simulations could not be controlled. However, the the current pattern near the power plant outflow in northern end of Sirdalsvatn was in accordance with qualitative observations of people with knowledge about the area and the scattered current measurements (Magnell et al. 2007).

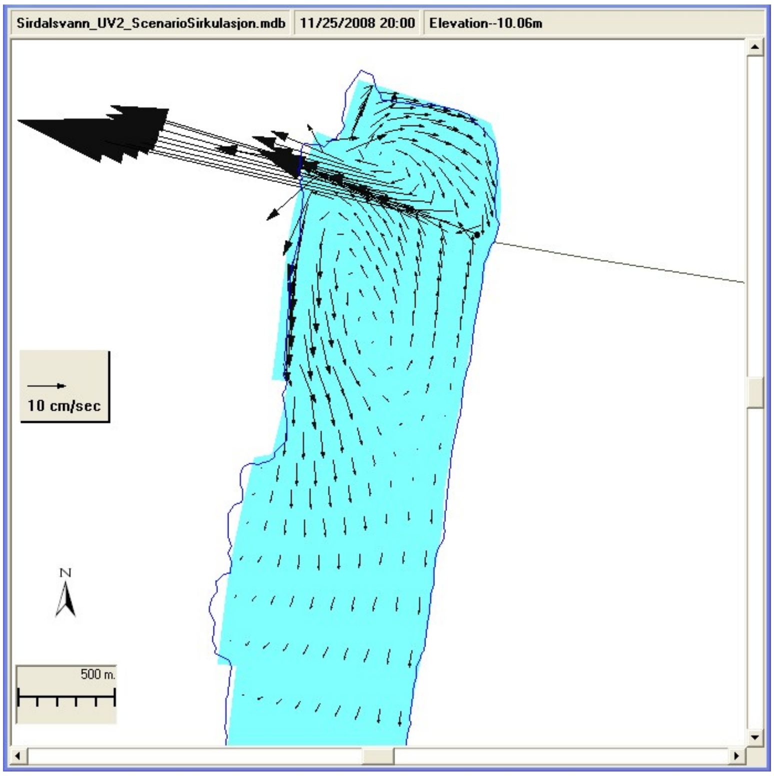


Circulation pattern in the surface during a period with vertical circulation (Autumn/Winter).

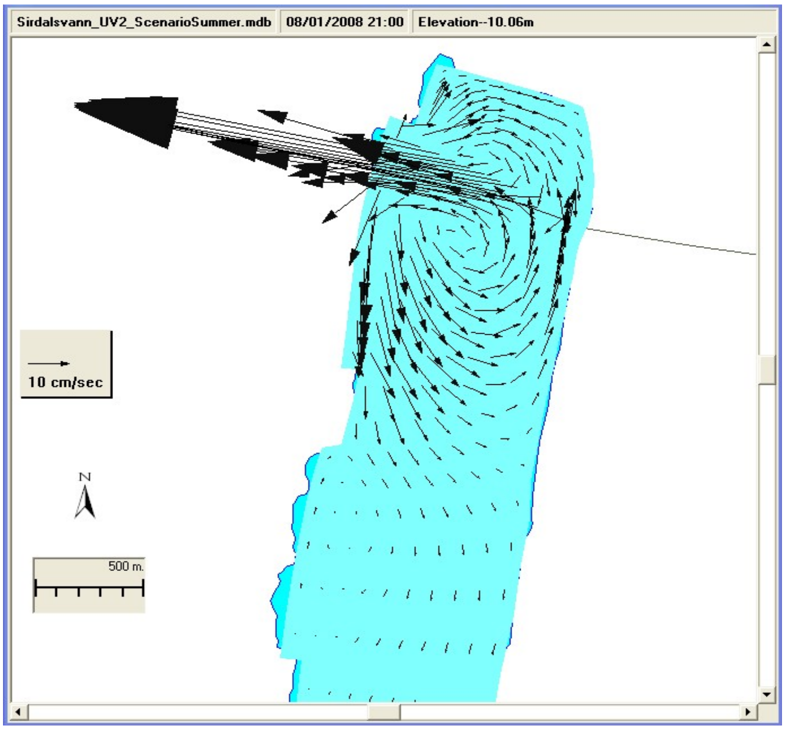


Circulation pattern in the surface during a period with layered profile (Summer).

Figure 14. The figure presents the circulation pattern in the northern end of Sirdalsvatn in circulation periods (autumn/winter) and periods representing layered vertical profile (summer). The main current pattern was the same.

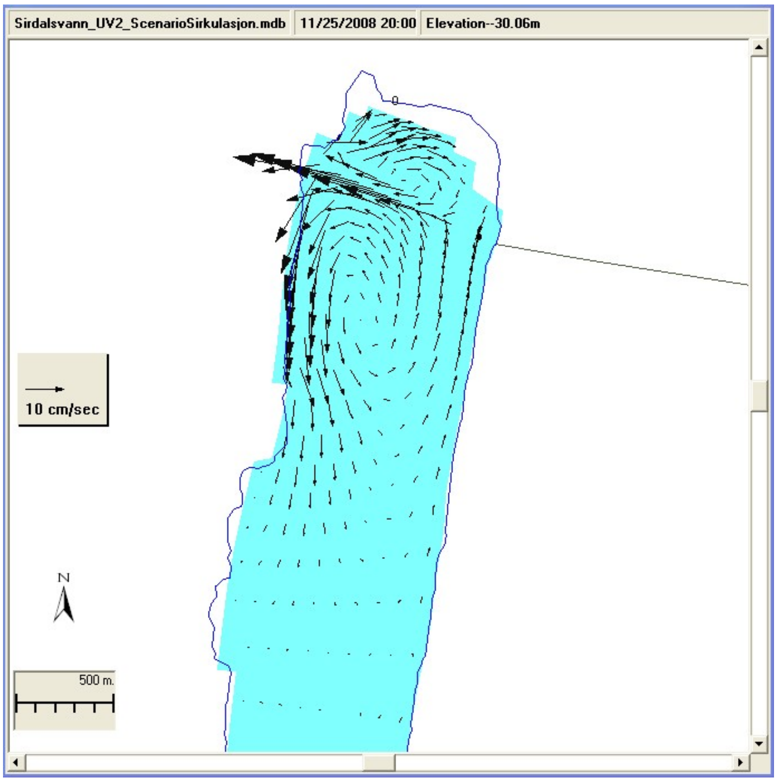


Circulation pattern at 10 meters depth during a period with vertical circulation (Autumn/Winter).

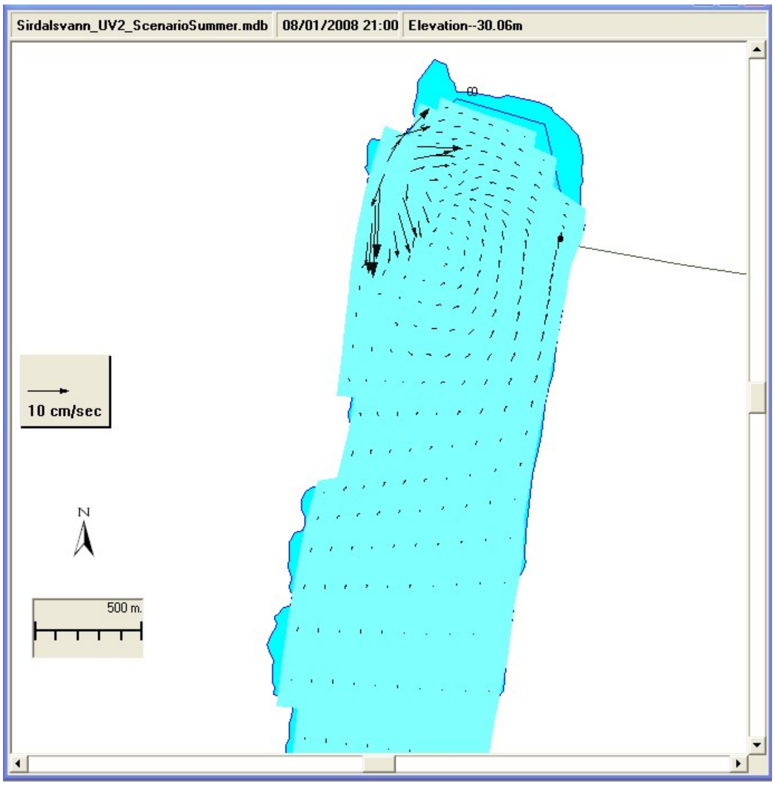


Circulation pattern at 10 meters depth during a period with layered profile (Summer).

Figure 15. The figure shows the currents at 10 meter depth in the northern end of Sirdalsvatn, which were similar to the surface circulation pattern.

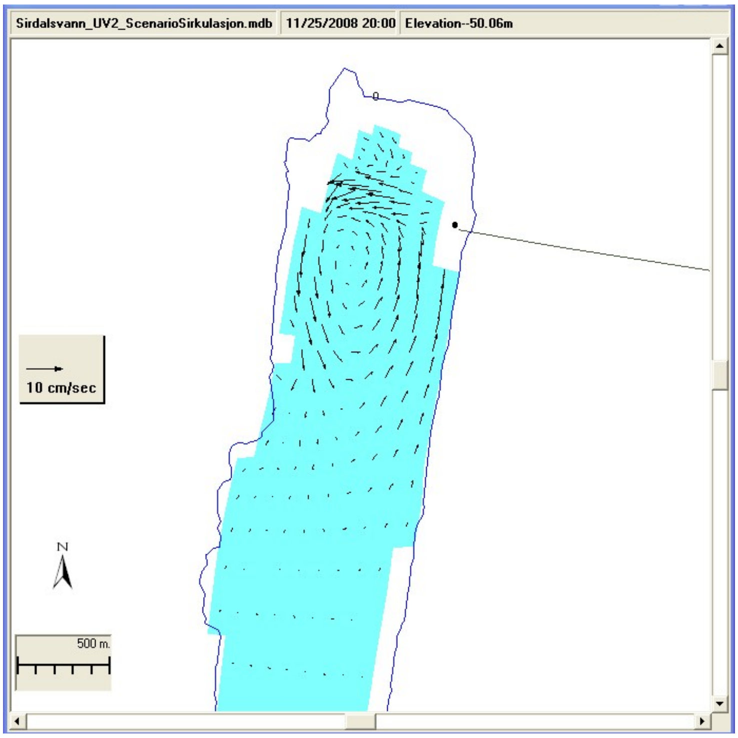


Circulation pattern at 30 meters depth during a period with vertical circulation (Autumn/Winter).

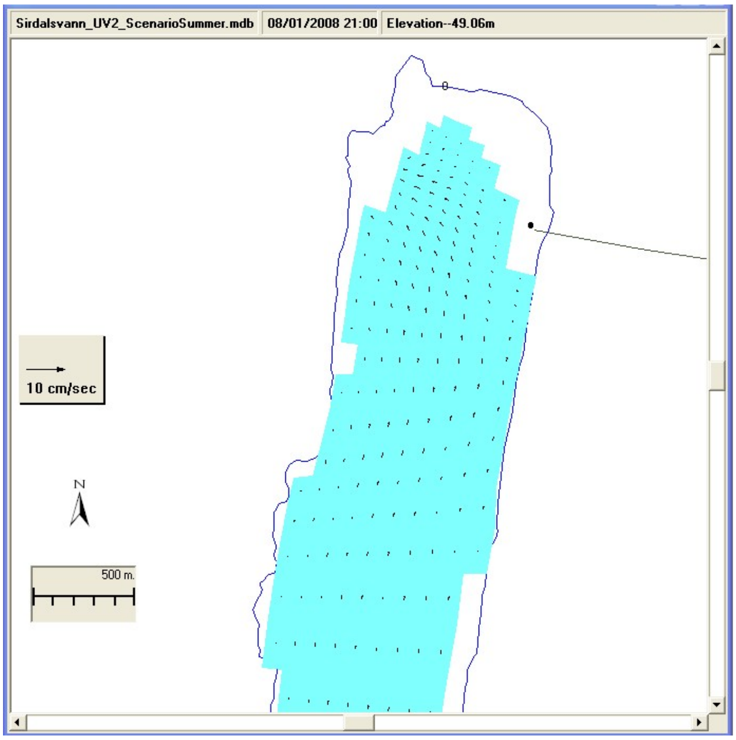


Circulation pattern at 30 meters depth during a period with layered profile (Summer).

Figure 16. The figure presents the circulation pattern in the northern end of Sirdalsvatn. The current velocities on 30 m depth were larger during periods with vertical circulating. During the summer higher temperature gradients reduced movements at greater depths.



Circulation pattern at 50 meters depth during a period with vertical circulation (Autumn/Winter).



Circulation pattern at 50 meters depth during a period with layered profile (Summer).

Figure 17. The figure illustrates the situation in the northern end of Sirdalsvatn. At 50 m the power plant still coursed circulating movements during periods with unstable vertical conditions.

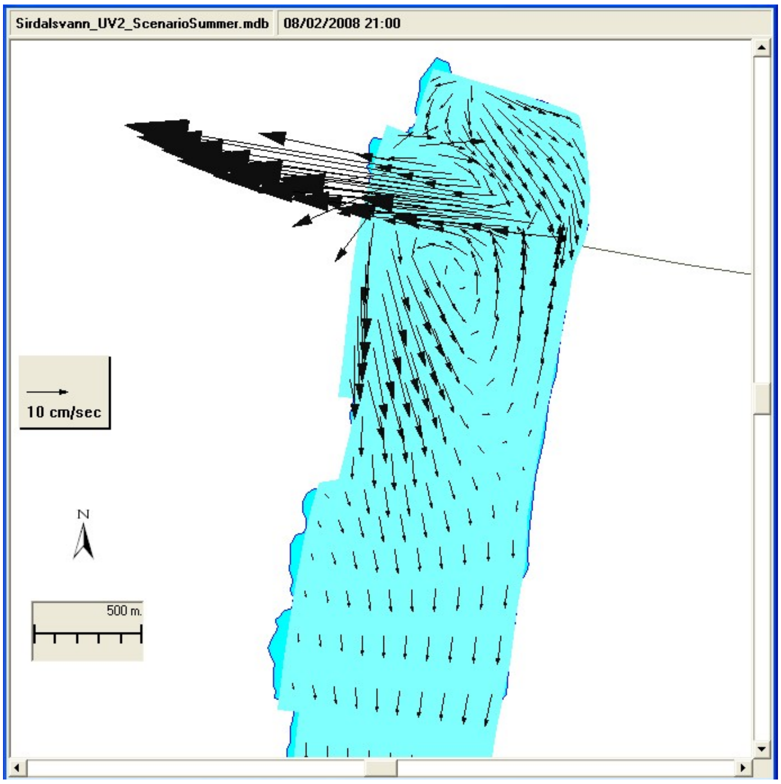


Figure 18. Surface currents during the Summer with 4 m/s wind from North.

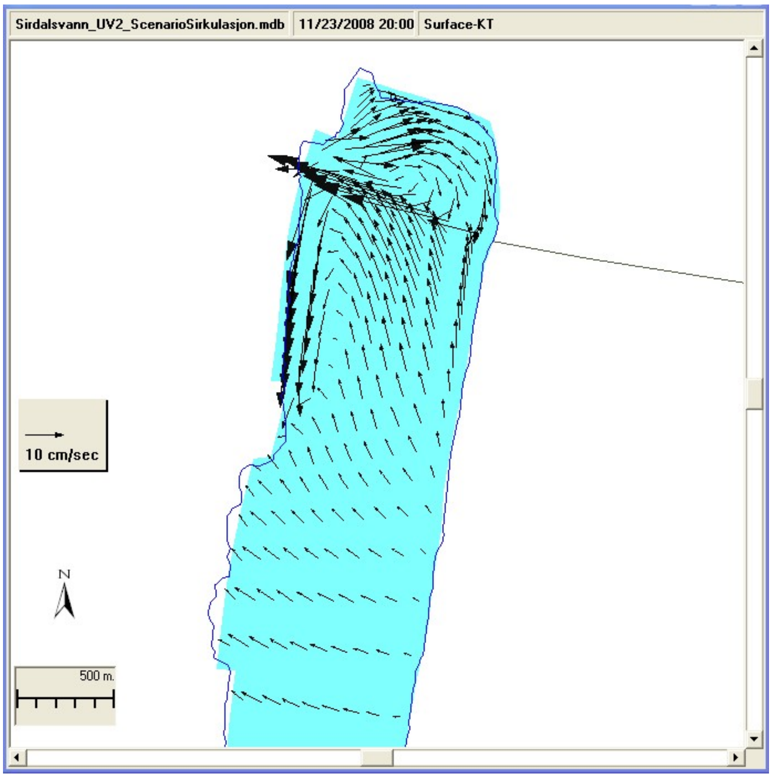
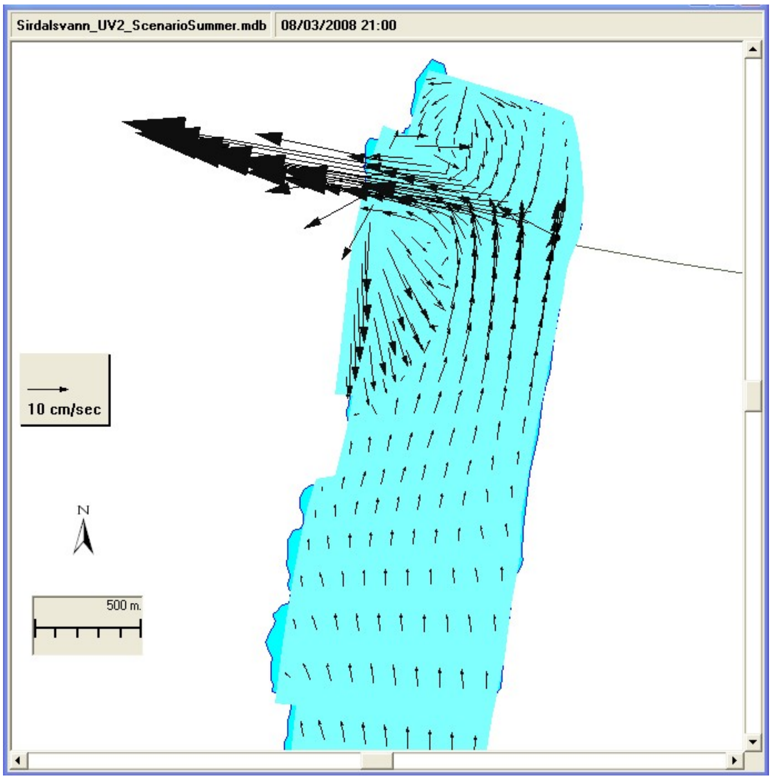
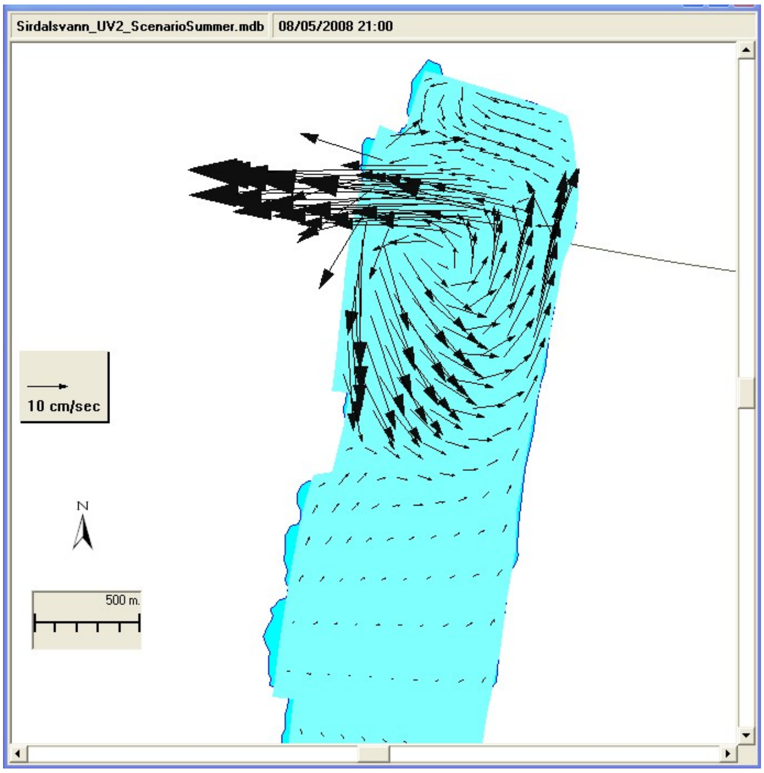


Figure 19. Surface currents during the Summer with 4 m/s wind from East.



Sirdalsvann_UV2_ScenarioSummer.mdb 08/03/2008 21:00

Figure 20. Surface currents during the Summer with 4 m/s wind from South.



Sirdalsvann_UV2_ScenarioSummer.mdb 08/05/2008 21:00

Figure 21. Surface currents during the Summer with 4 m/s wind from West.

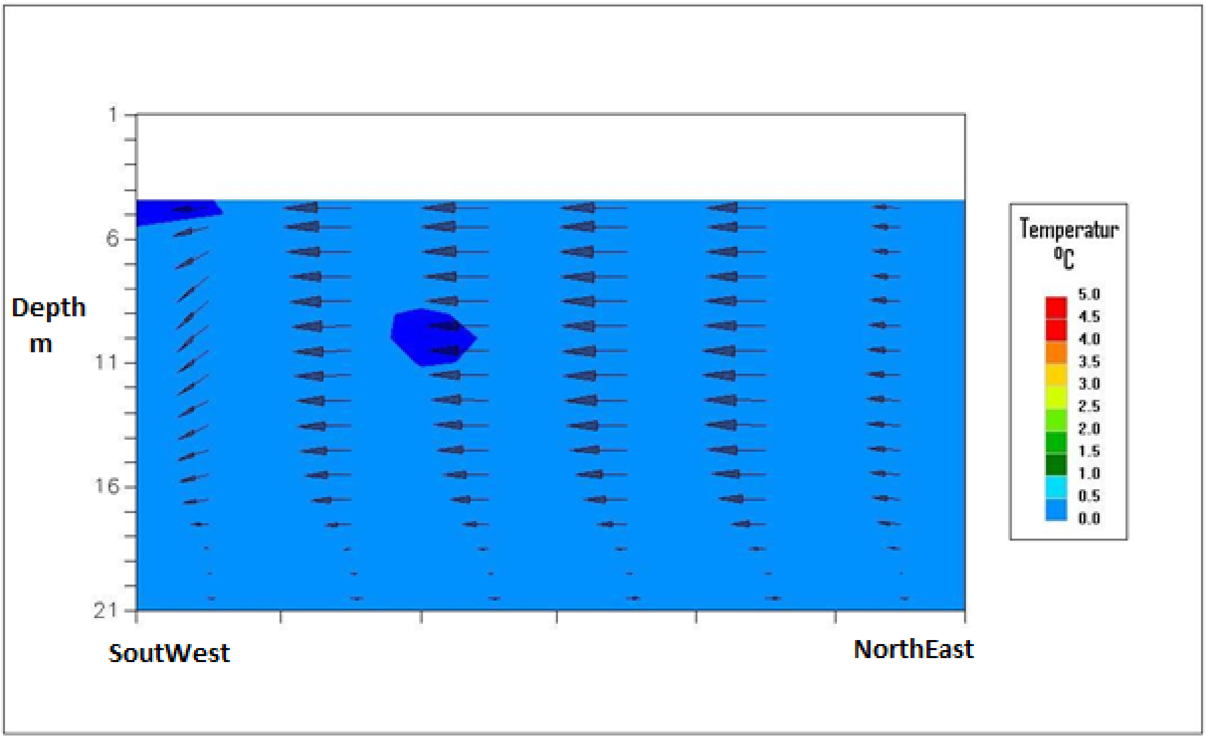


Figure 22. The inflow to the reservoir Ousdalsvatn is surface water from the upstream river, and outlet of the reservoir is located between 6-15 meters beneath HRL. As the throughput is large compared to the volume of the reservoir the reservoir 'behaves much like a river' and the temperature differences within the reservoir are small. The figure shows a slice of the reservoir, and the depth is presented along the Y-axis and the modelled temperatures from south-west to north-east are presented along the X-axis.

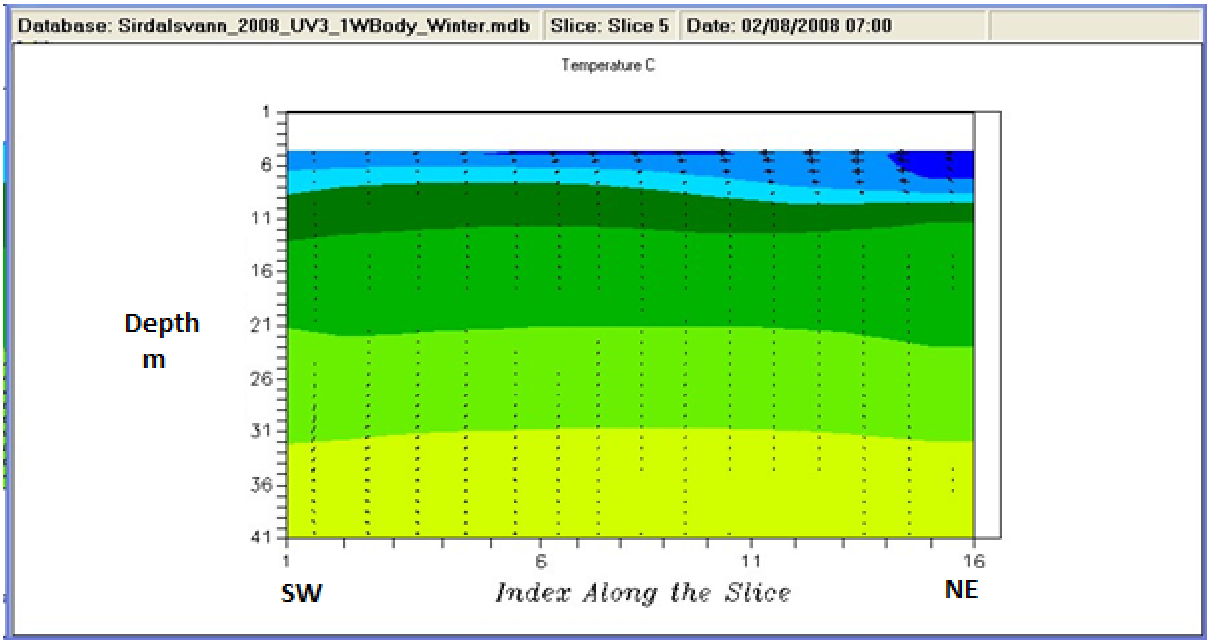
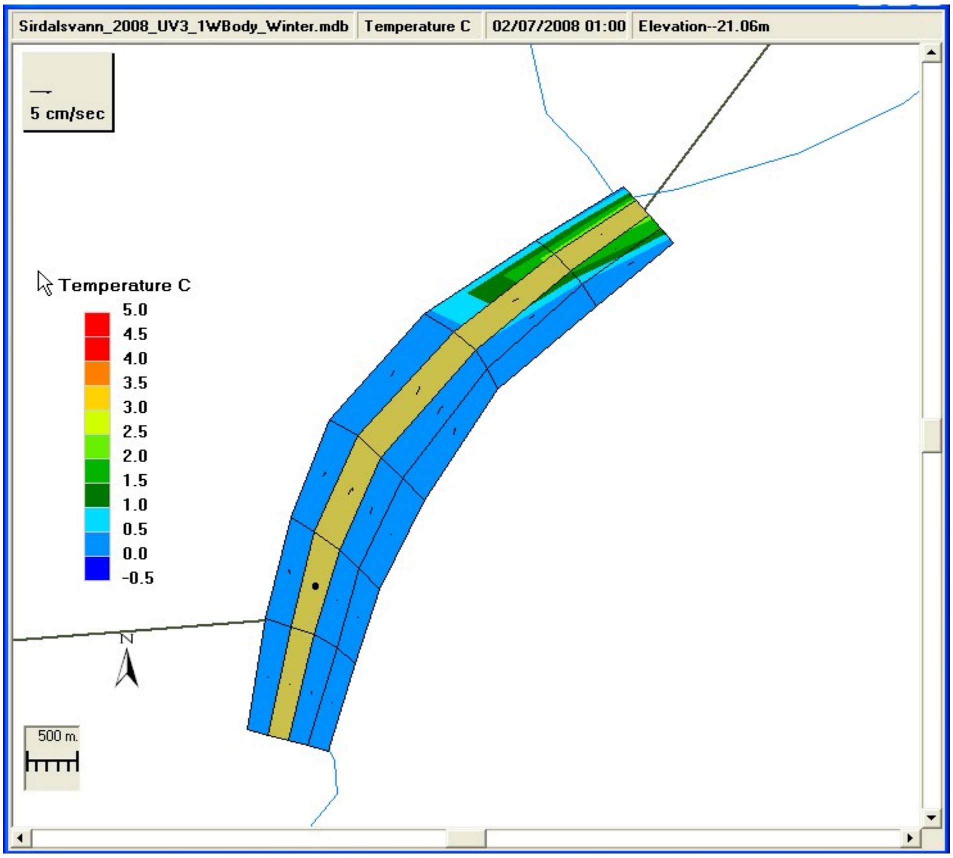
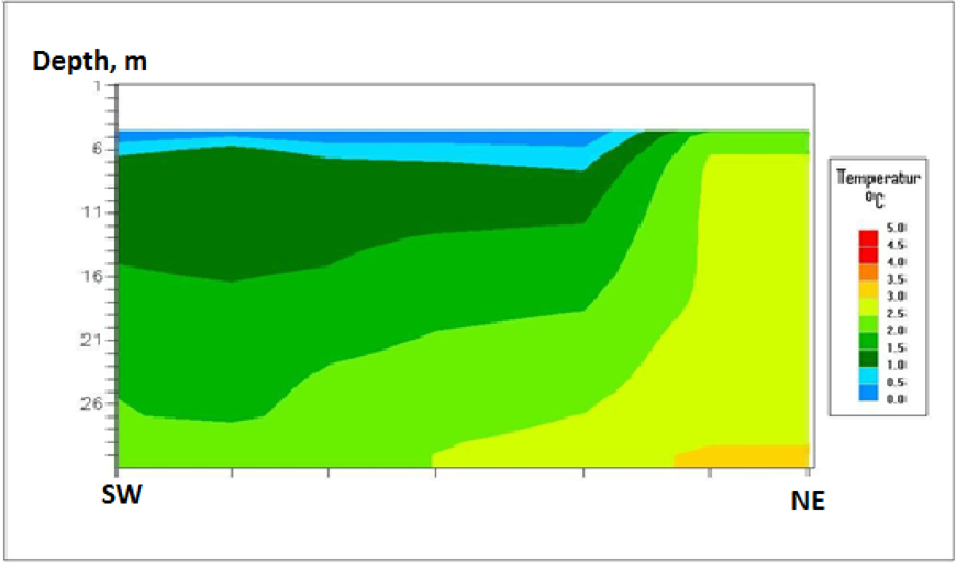

Database: Sirdalsvann_2008_UV3_1WBody_Winter.mdb | Slice: Slice 5 | Date: 02/08/2008 07:00

Figure 23. Temperatures in a length-depth profile. The reservoir Nesjen receives surface water from the upstream rivers. The outflow, located 30-38 meters beneath HRL, delivers water with temperatures around 4 °C to the downstream reservoir Homstølvatn throughout the year.



Sirdalsvann_2008_UV3_1WBody_Winter.mdb | Temperature C | 02/07/2008 01:00 | Elevation--21.06m

Temperatures in reservoir Homstølvatn at 21 meters below HRL. The brown slice indicates the location of the depth-slidce presented in the next figure.



Length-depth sliceof temperatures in reservoir Homstølvatn at the location of the brown slice shown in the preceding figure.

Figure 24. The main inflow to the reservoir Homstølvatn comes from the bottom of the upstream reservoir Nesjen. The denser water from the bottom of the reservoir Nesjen enters at the surface in the northern part of Homstølsvatn, dive and move along the bottom towards the outlet tunnel 18-26 m beneath HRL.

3. Simulated hydropeaking

3.1 Scenario description

The hydropeaking scenario for Tonstad Hydropower system was defined the following way:

Table 2. The table specifies the water flows between the reservoirs/HHP during a 24 hour-cycle.

Hour no.	**Release from Ousdalsvatn to Tonstad HPP [m^3/s]**	**Release from Homstølsvatn to Tonstad HPP [m^3/s]**	**Release from Ousdalsvatn to Homstølsvatn HPP [m^3/s]**	**Pumping from sirdalsvatn to Homstølsvatn [m^3/s]**
0-10	100	0	0	270
10-20	100	550	0	0
20-24	100	0	0	270

For the hydropeaking scenario, a total discharge through the power plants for the 10 hour production period was 650 m^3/s. In the period with no peaking production, 100 m^3/s of water enter Tonstad from Ousdalsvatn. In the base-line scenario ('current situation') a constant discharge/release of 170 m^3/s from the upstream reservoirs were inserted into the model.

During the night-time, lasting for 14 hours from 20 o'clock in the evening and 10 o'clock in the morning, 270 m^3/s was pumped from Sirdalsvatn by Tonstad 3 to Homstølvatn, **Figure 25**. This volume was used for power production during a 10-hours period the following day. The pumped water would then contribute with a flow 380 m^3/s during the peak period. A daily mean inflow of 70 m^3/s from Nesjen into Homstølvatn resulted in 170 m^3/s through the power plants during the 10 hours production period. From Ousdalsvatn 100 m^3/s was continuously used for production.

The hydropeaking scenario described in this section represents most likely a simplification of the operational strategy compared to what a future operation of the Tonstad system will be. However, the purpose was to study typical effects of hydropeaking effects during various seasons and the described scenario would hence represent a possible way of operating the system within a day-night production regime.

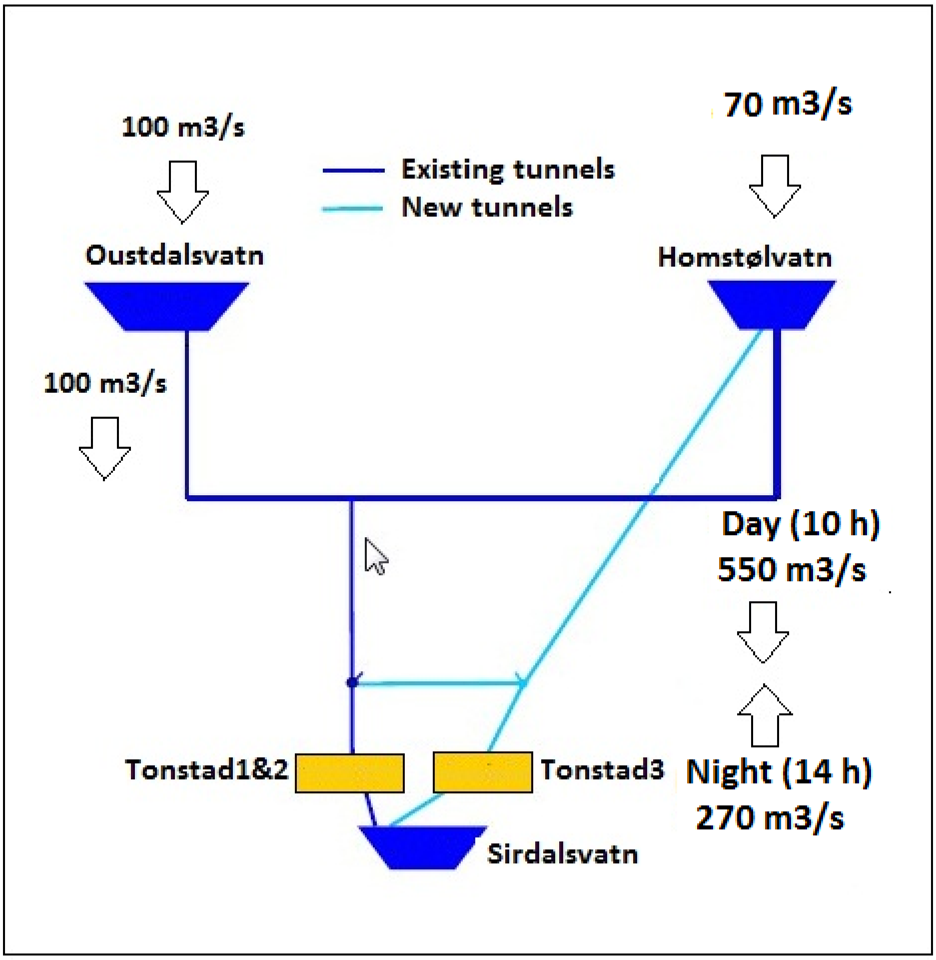


Figure 25. During a 10-hours day-time period (from 10 o'clock in the morning to 20 o'clock in the evening) 100 m^3/s of water were released from Ousdalsvatn and 550 m^3/s from Homstølvatn for power production. This volume of water was equally distributed between Tonstad 1& 2 and Tonstad 3. Water was pumped back to Homstølsvatn during night-time (14 hours – from 20 o'clock in the evening to 10 o'clock the next morning). Tonstad 3 pumped 270 m^3/s from Sirdalsvatn to Homstølvatn during the pumping period (night-time). 100 m^3/s was constantly released from Ousdalsvatn for power production in Tonstad.

During the production period the water was equally divided between Tonstad 1& 2 and Tonstad 3. During the pumping period, water from Ousdalsvatn was released into Tonstad 1& 2 only, and water entering Homstølvatn from upstream was temporarily stored in the reservoir.

The water level at the start of the simulations was 1 m below HRL in all reservoirs. For Ousdalsvatn and Nesjen no changes in water level took place during the simulation period (water levels constant). In Homstølvatn the water level decreased during the production period, while the water level in Sirdalsvatn raised.

The outlet from Tonstad 3 was was located 300 m south of the existing outlet and 10 - 22 m below HRL. This is slightly deeper than the outlet from Tonstad 1& 2 which is 8 and 18 m beneath HRL.

To study differences between the “current situation" (base-line), the model was first configured to simulate power production with a constant water flow through the power plant set to 170 m^3/s. The inflow from the river Sira into Ousdalsvatn weas set to a constant value of 7 m^3/s, representing the mean annual flow. The mean discharge out of the southern end of Sirdalsvatn was 177 m^3/s.

The scenarios were run for one year with climate conditions as observed in 2008 without wind; therefor the “current scenario” (base-line) was not exactly like the real conditions in 2008. The reason for removing the effects from the wind was to study differences between the two scenarios and isolate the effects of hydropeaking.

3.2 Water level

The simulation results showed that the water level in Homstølvatn decreased 3.5 meters during the 10 hours with production (water released from Homstølsvatn). The reservoir was filled back to the original level again during the following 16 hours-period with pumping,

The water level in Sirdalsvatn raised 0.75 meters during the 8 hours production period and deceased/lowered to the original level during the following pumping period.

The other reservoirs reservoirs involved in the study (Ousdalsvatn and Nesjen) were assumed to be kept at a more or less constant level during the whole simulation period, and hence did not experience any water level fluctuations.

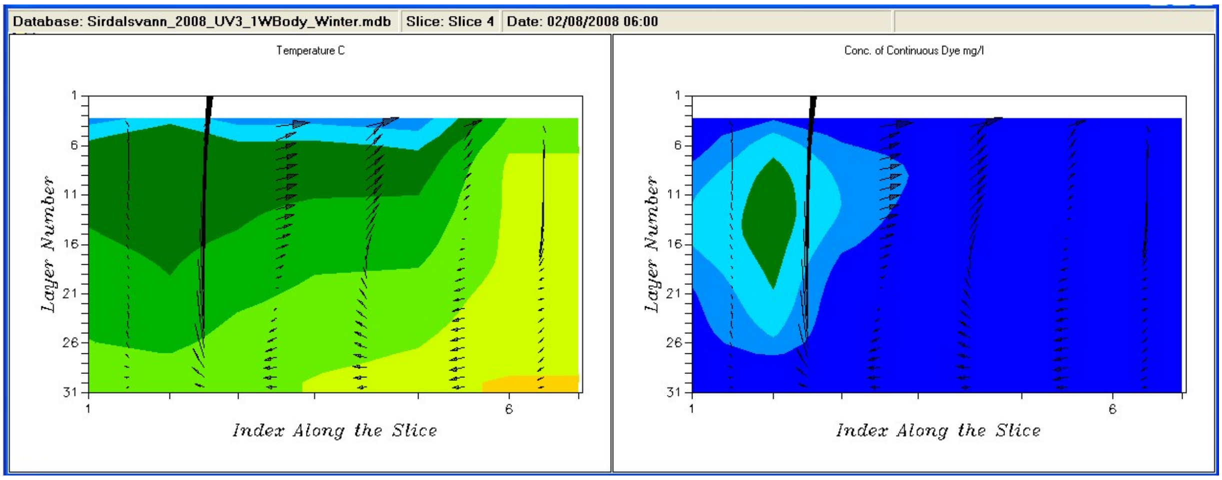
3.3 Water currents

Figure 26 show how the warm water with high density (near 4°C) from the bottom of Nesjen enters Homstølvatn at the surface, descends downwards and moves towards the intake tunnel. By pumping, the water moved away from the tunnel mainly in the upper part. The pumped water from Sirdalsvatn is distributed almost from top to bottom. The dye-figures indicate that most of the water pumped during the night is returned through the power plant the following day.

Results from Sirdalsvatn in February are shown in **Figure 27 - Figure 29**. The hydropeaking scenario increased the water flows through the power plants, which led to slightly increased current velocities in the lake. The main current pattern was the same as in the “today scenario” (base-line); however the outflow was distributed over a larger area as the new outlet from Tonstad 3 was located 300 meters south of the Tonstad 1& 2. After releaving the outlet, the water moved across the lake. Thereafter one part moved southwards. The other part moved northwards along the northern shore towards the outlet again. The return movement/flow was weaker than in the base-line simulations. During the pumping period, currents were reversed in the direction of the outlet (inlet) in Sirdalsvatn, despite the constant inflow of 100 m^3/s to Sirdalsvatn from Tonstad 1& 2, **Figure 30 - Figure 31**.

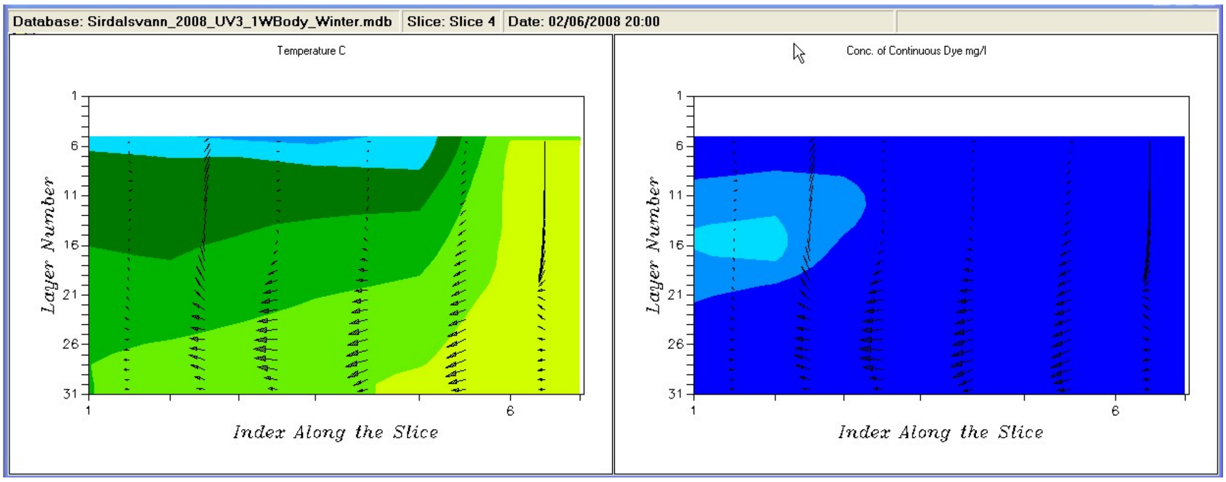
The water currents 12 meters beneath HRL were very close to identical to the surface layer. At a depth of 24 meters below HRL (below the tunnels), the currents were considerably more smooth and stable. It was a tendency to downwards currents near the tunnels and upwards further out (westwards).

The inflow from the power plants mainly influenced the surface layers in February,



Database: Sirdalsvann_2008_UV3_1WBody_Winter.mdb | Slice: Slice 4 | Date: 02/08/2008 06:00

Reservoir Homstølvatn at the end of a pumping period in February.



Database: Sirdalsvann_2008_UV3_1WBody_Winter.mdb | Slice: Slice 4 | Date: 02/06/2008 20:00

Reservoir Homstølvatn at the end of a production period in February.

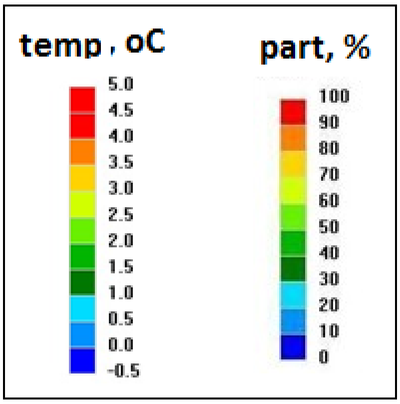


Figure 26. The figures to the left (temperatures) show how the warm water with high density (near 4^{o}C) from the bottom of Nesjen enters Homstølvatn at the surface, descends downwards and moves towards the intake tunnel. By pumping, the water moved away from the tunnel mainly in upper part of the reservoir. The right figures (dye) show where water pumped from Sirdalsvatn during the last pumping cycle is located. The pumped water from Sirdalsvatn is distributed almost from top to bottom. The dye-figures indicate that most of the water pumped during the night is returned through the power plant the following day.

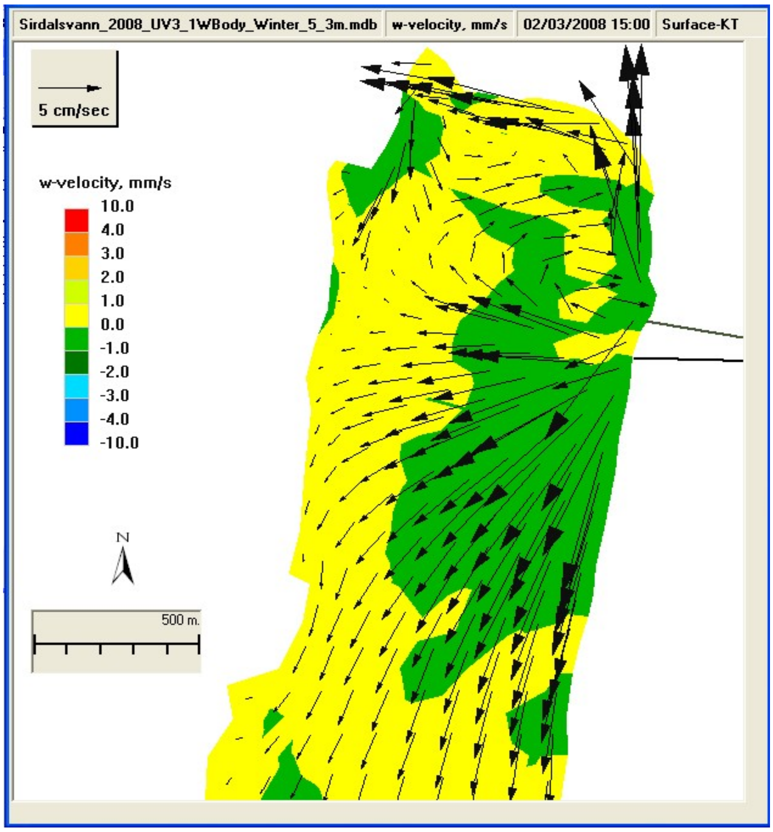


Figure 27. Water currents at the surface in Sirdalsvatn during the hydropeaking period (day-time). Vertical velocities/w-velocities are positive downwards.

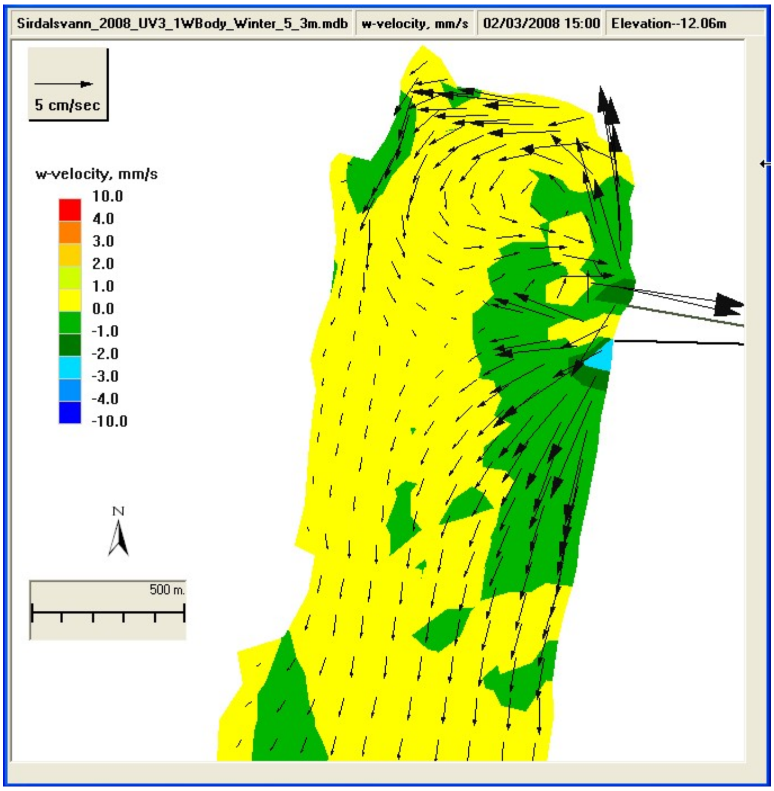


Figure 28. Water currents in Sirdalsvatn during the production period (hydropeaking) at 12 meters depths beneath HRL (w-velocity/vertical velocities are positive downwards).

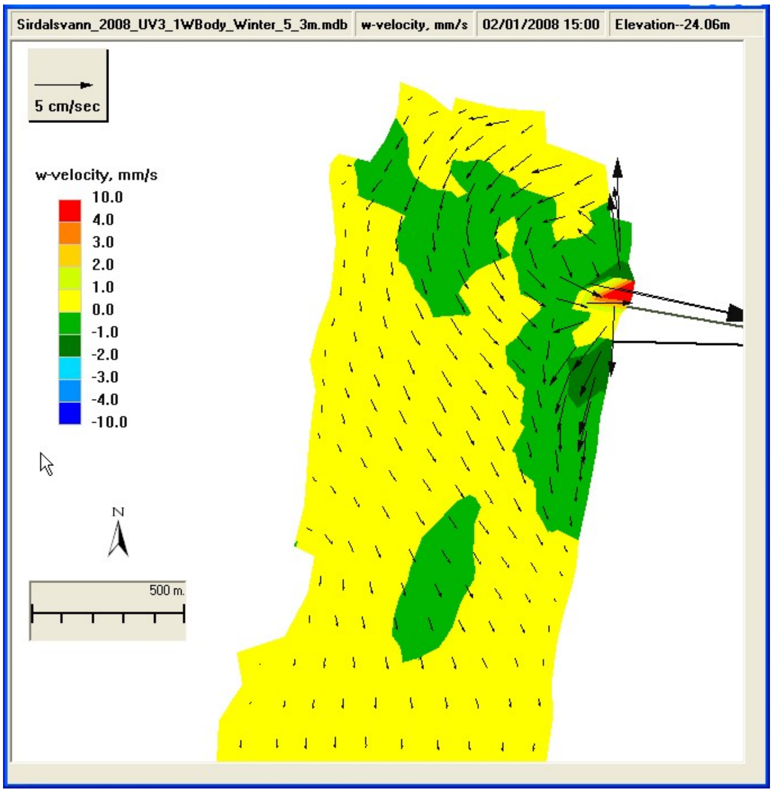


Figure 29. Water currents in Sirdalsvatn at a depth 24 meters below HRL during the hydropeaking period (w-velocity/vertical velocities are positive downwards).

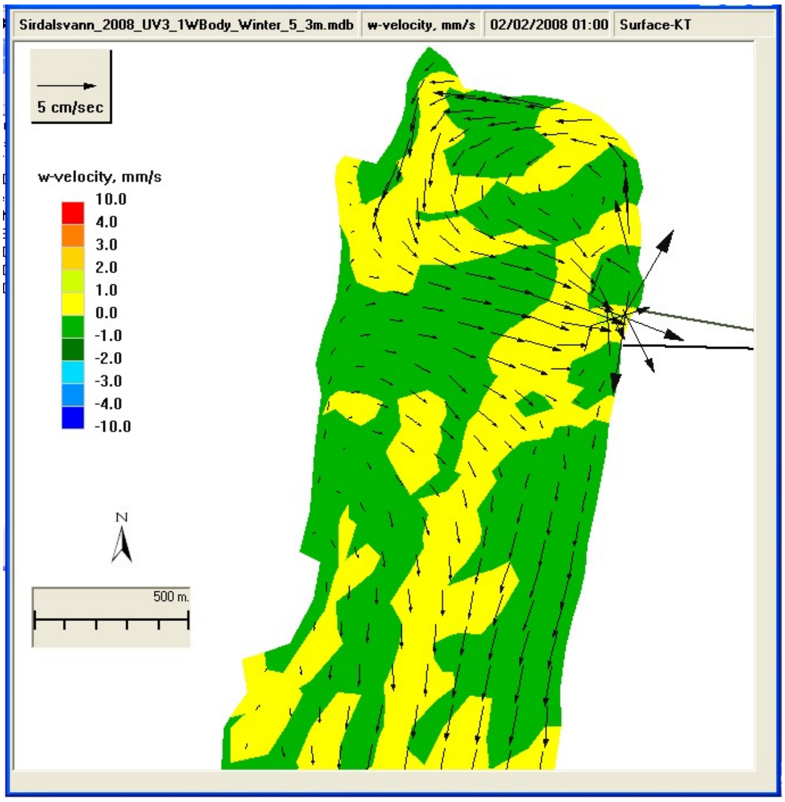


Figure 30. Water current at surface of Sirdalsvatn when pumping takes place (w-velocity/vertical velocities are positive downwards).

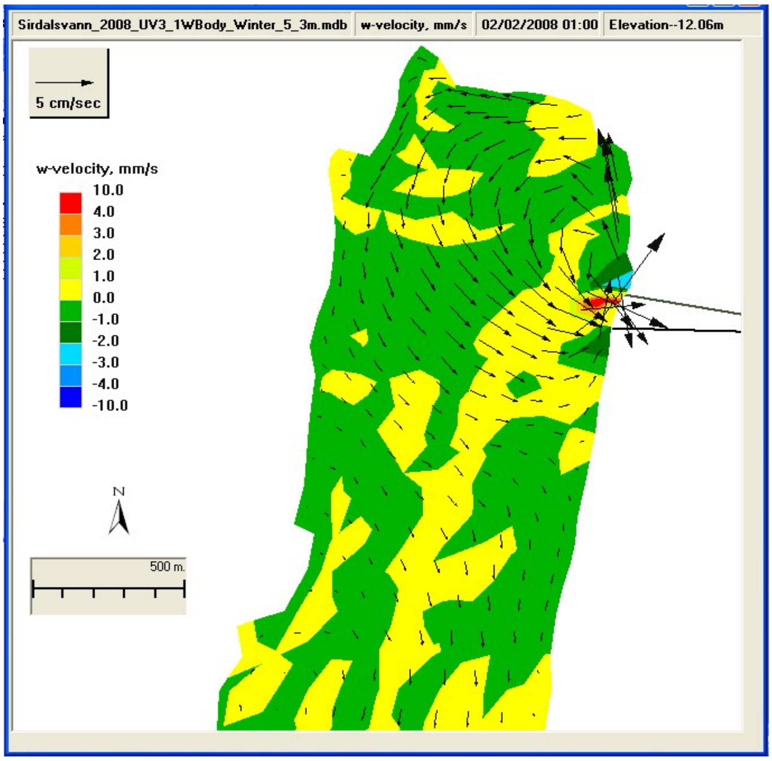


Figure 31. Water currents in Sirdalsvatn at 12 meters depths beneath HRL. During pumping periods the water mainly moved in the direction of the outlet/inlet in Sirdalsvatn (w-velocity/vertical velocities are positive downwards).

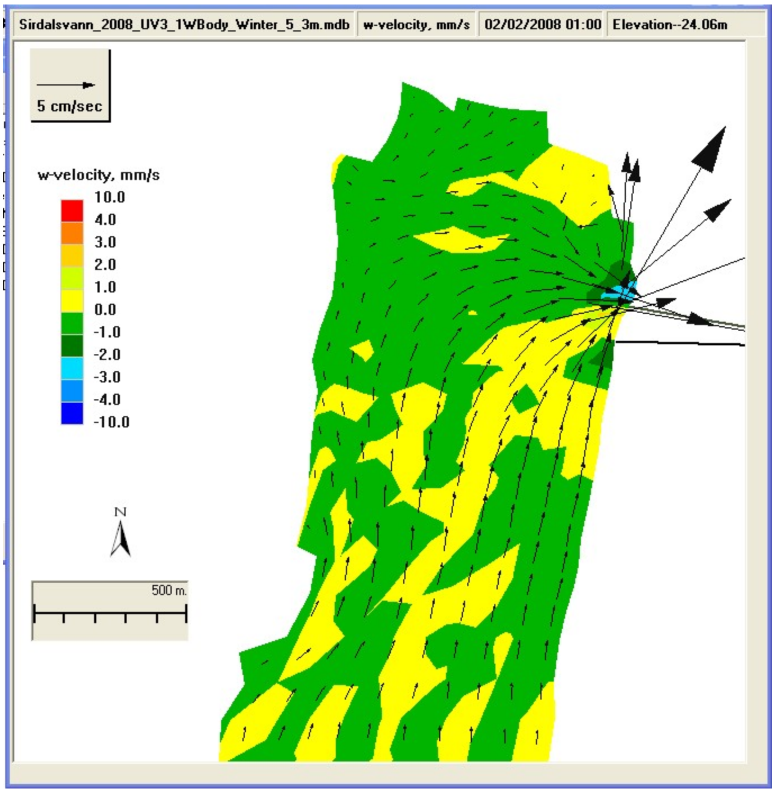
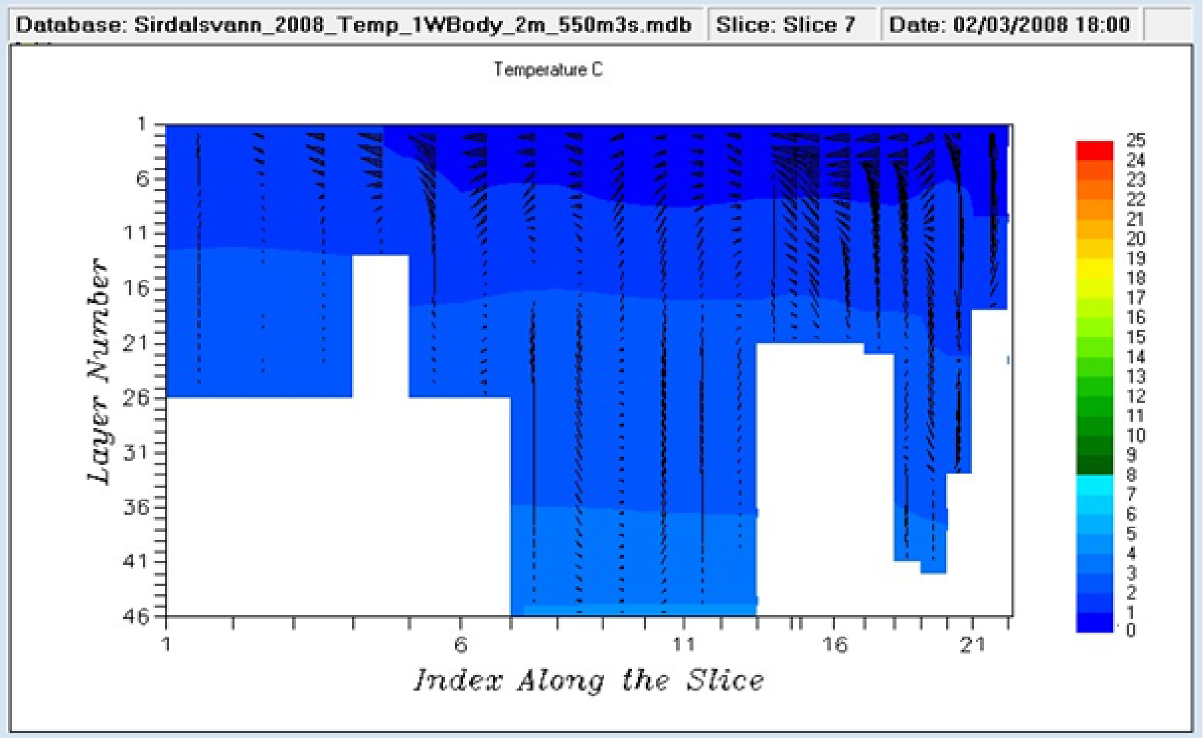


Figure 32. Water currents in Sirdalsvatn at 24 meters depths beneath HRL. During pumping periods the water moved in the direction of the most southern tunnel (w-velocity /vertical velocities are positive downwards).

Studying the length profile of the lake, the inflow from the power plants mainly influenced the surface layers in February, **Figure 33**, The inflow from the power plants mainly influenced the layers below the surface in October as during most of the year, **Figure 34**.

Hydropeaking caused higher velocities and greater vertical mixing than in the base-line scenario, but the main current patterns were similar, **Figure 34** - **Figure 35**. The outflow from the power plants during the production period resulted in southwards currents below the surface. Pumping resulted in northward return currents in surface layers towards the intake tunnel. The high water flow and changing flow directions led to interior waves and vertical mixing, **Figure 36** - **Figure 42**.



Database: Sirdalsvann_2008_Temp_1WBody_2m_550m3s.mdb

Slice: Slice 7

Date: 02/03/2008 18:00

Figure 33. The figure shows results from a hydropeaking period in February. The inflow from the power plants mainly influenced the surface layers this time of the year. Please note the scale indexes. In the depth direction each layer is 2 meters. In the length direction the grid lengths increase southwards.

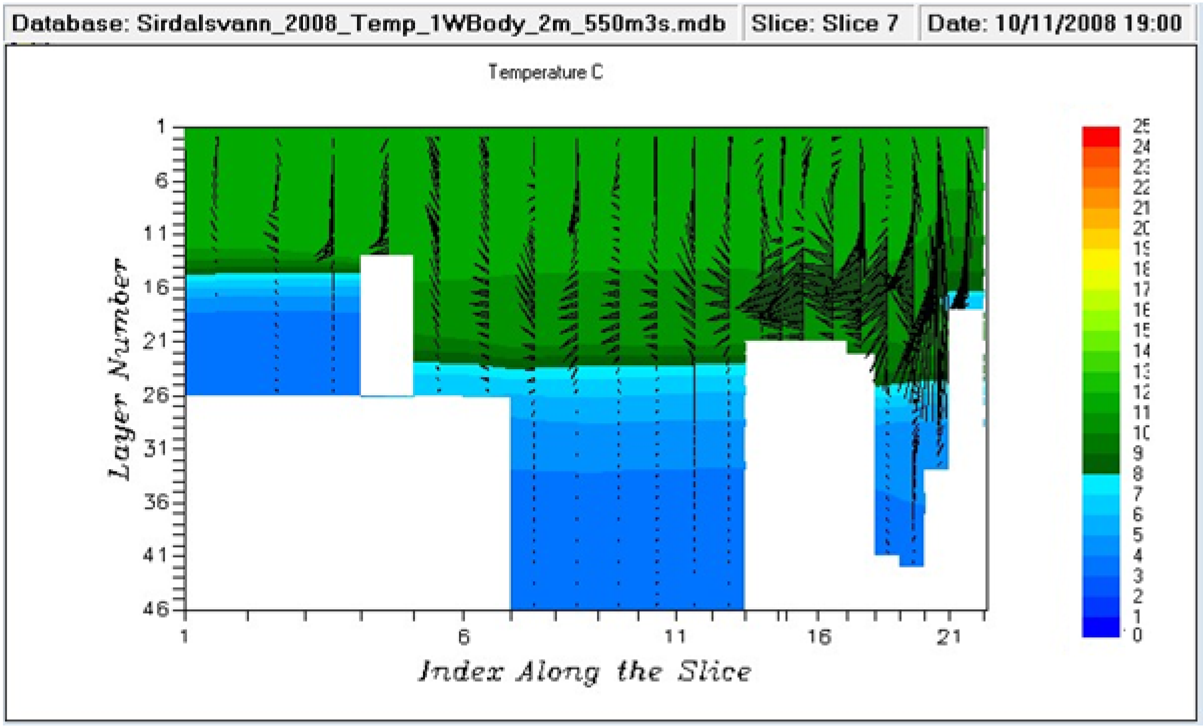


Figure 34. The figure shows results from a hydropeaking period in October. The inflow from the power plans mainly influenced the layers below the surface in this time of the year.

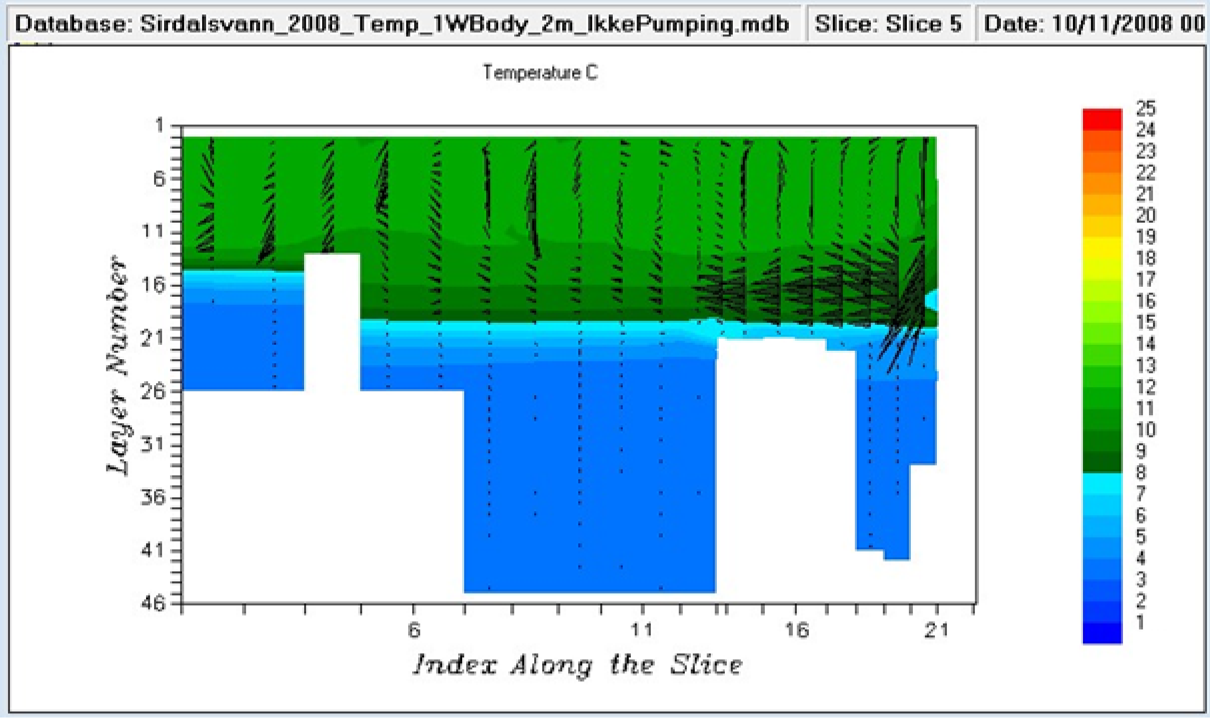
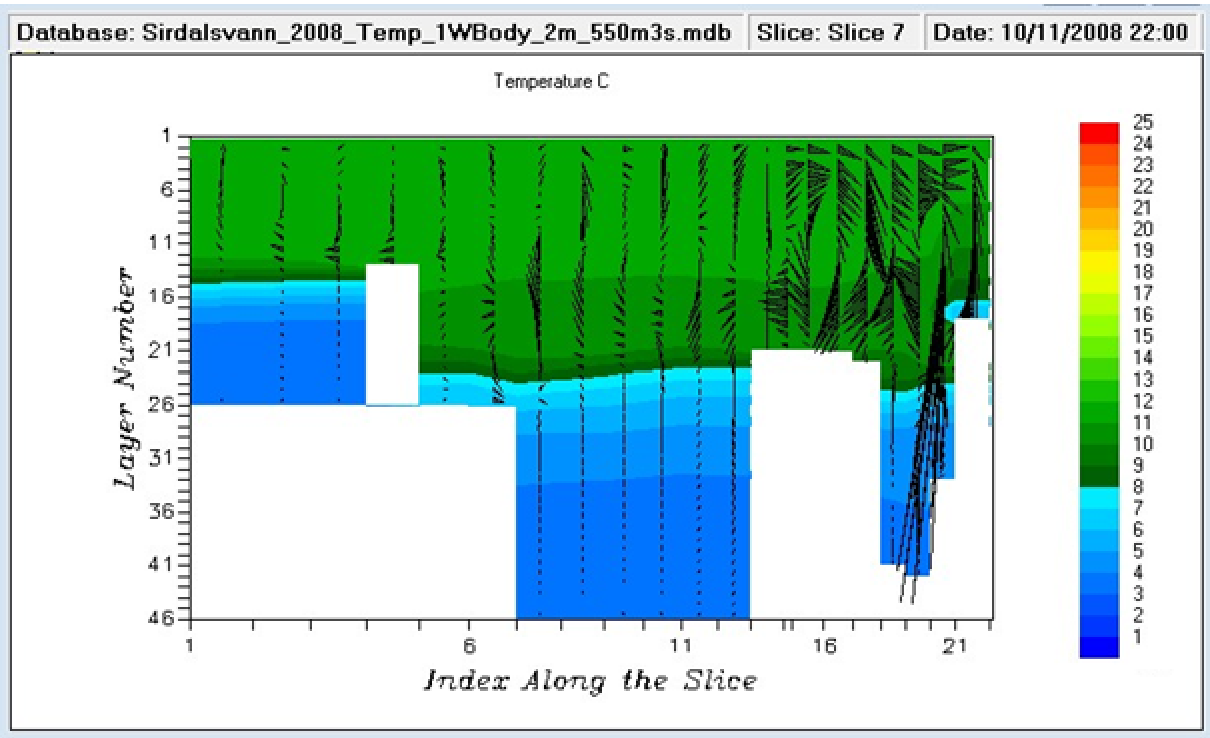


Figure 35. The figure shows results from a period without hydropeaking in October. The velocities are reduced, but the main current patterns are similar. The vertical mixing was less than with hydropeaking. The figure presents a XZ-slice, i.e a slice from south (left) to north.

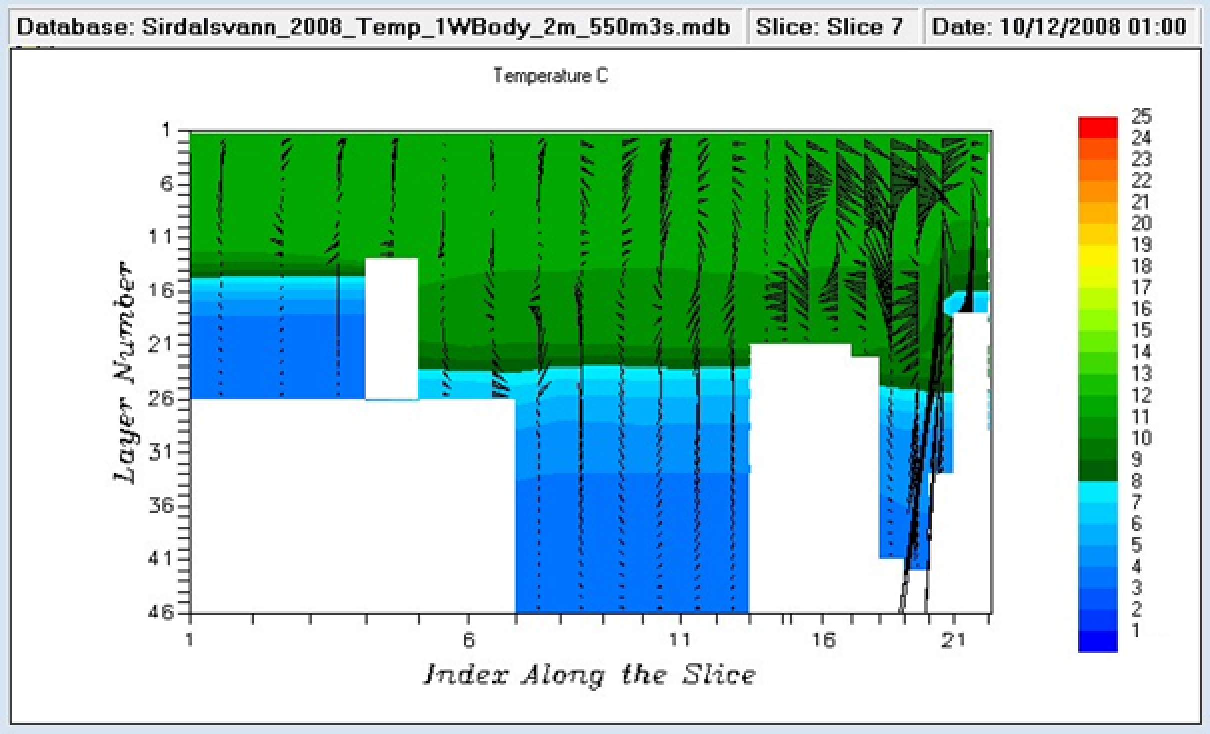


Database: Sirdalsvann_2008_Temp_1WBody_2m_550m3s.mdb

Slice: Slice 7

Date: 10/11/2008 22:00

Figure 36. Water temperature and currents during a puming period (time: 22:00). Currents move towards the intake tunnel in the surface layers (0 – 20 m) and in opposite direction below (20 – 40 m).

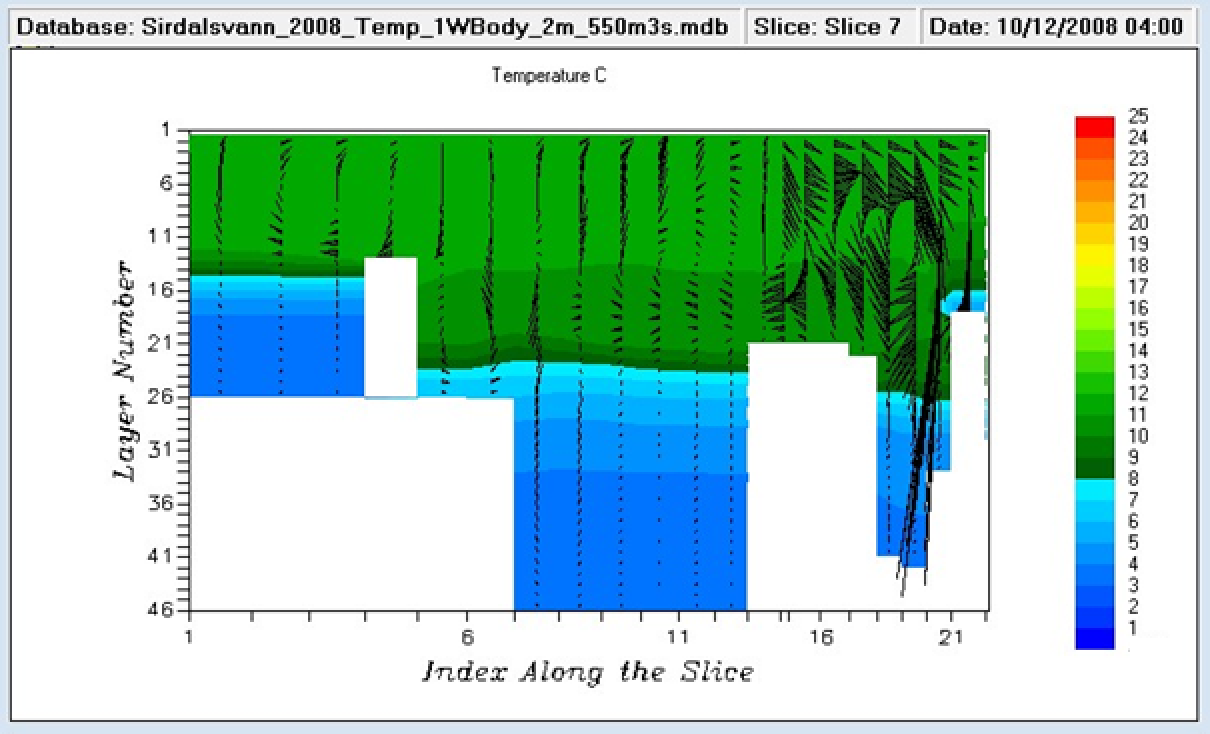


Database: Sirdalsvann_2008_Temp_1WBody_2m_550m3s.mdb

Slice: Slice 7

Date: 10/12/2008 01:00

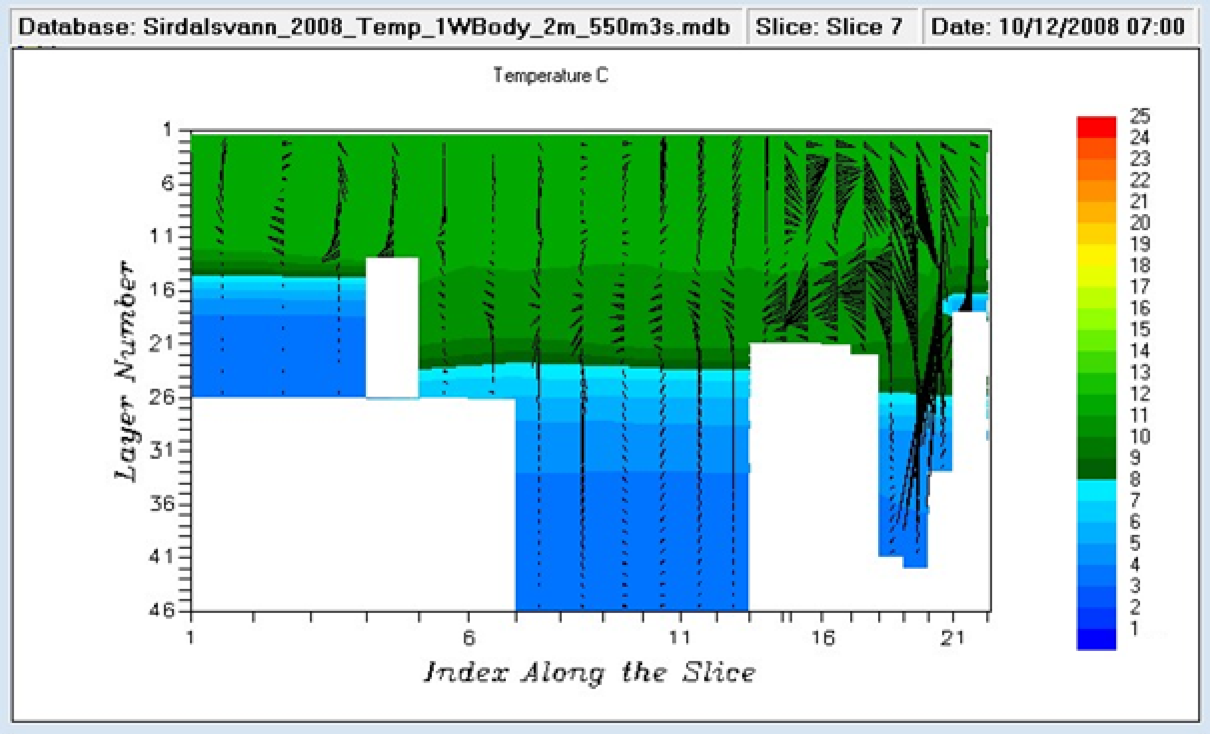
Figure 37. Water temperature and currents during a puming period (time: 01:00).


Database: Sirdalsvann_2008_Temp_1WBody_2m_550m3s.mdb

Slice: Slice 7

Date: 10/12/2008 04:00

Figure 38. Water temperature and currents during a puming period (Time: 04:00). The peaking led to interior waves.


Database: Sirdalsvann_2008_Temp_1WBody_2m_550m3s.mdb

Slice: Slice 7

Date: 10/12/2008 07:00

Figure 39. Water temperature and currents during a puming period (Time: 07:00).

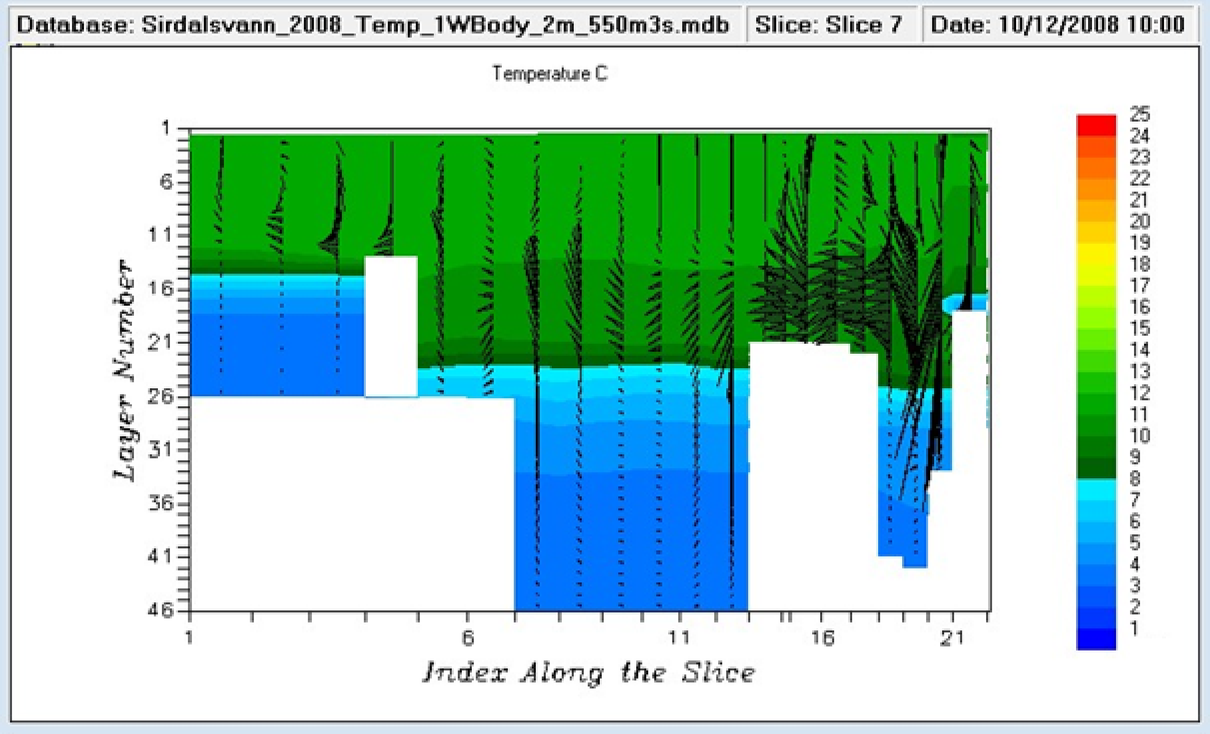


Figure 40. Water temperature and currents during a production period (Time: 10:00). The production water mainly flow southwards between 20 and 40 meter below the surface. The thendency continued through the outlet of the lake.

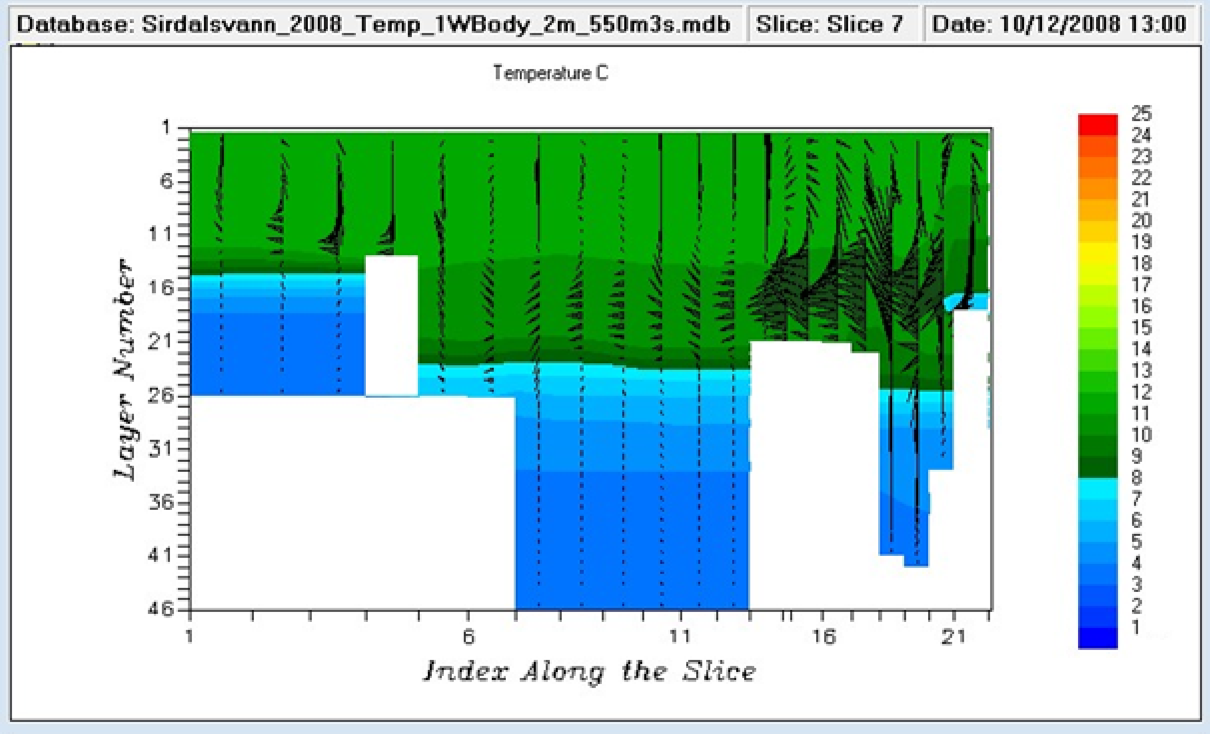


Figure 41. Water temperature and currents during a production period (Time: 13:00).

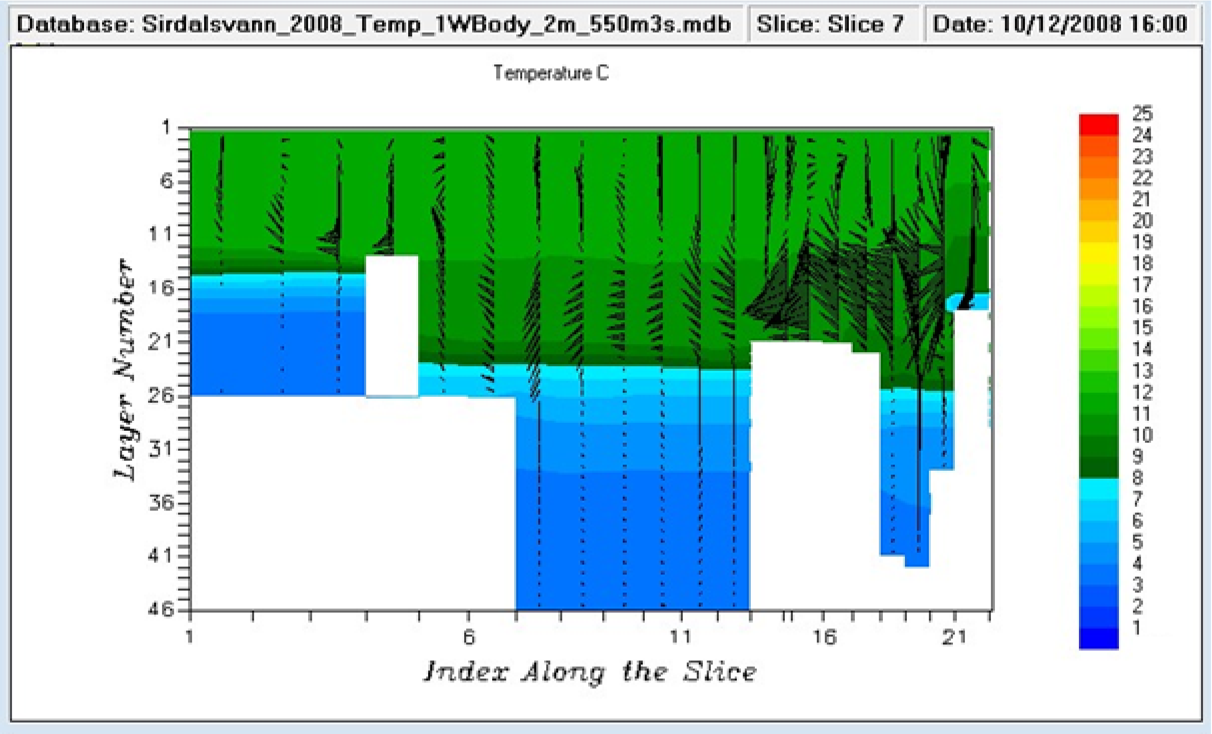


Figure 42. Water temperature and currents during a production period (Time: 16:00).

The preceding figures are examples of results from a daily cycle in October with production and pumping. The outflow from the power plants during the production period resulted in southward currents beneath the surface. Pumping resulted in northward return currents in surface layers and in the direction of the intake tunnel. The high water flow and changing flow directions led to interior waves and vertical mixing.

3.4 Temperature

Ousdalsvatn and Nesjen are not influenced by pumping and we, hence, expect no noticeable changes from the current situation. Maximum temperatures on the surface of the two reservoirs are near 25 °C. The smaller lake Ousdalsvatn reacts more quickly on climate changes during the year. There are small differences between temperatures from surface to 20 meters depth/bottom during the period with decreasing temperatures autumn and winter,
Figure 43.

In Homstølvatn effects of hydropeaking could be found during the period May-October. The rest of the year the differences were small. Near the bottom, and just below level of the intake tunnel, hydropeaking resulted in increased temperatures approaching 3 °C. Above the tunnel the effects were opposite. Hydropeaking led to increased mixing in the vertical direction. The hydropeaking generally caused slightly lower surface temperature and higher bottom temperatures,
Figure 44 - Figure 45.

Surface temperatures in the center of Sirdalsvatn are similar or lower as in Homstølvatn, **Figure 46**. At larger depths (20 meters), the temperatures in Sirdalsvatn were higher during summertime with hydropeaking. These results (especially at 20 meters depth) are explained by how Homstølvatn is influenced by bottom water from Nesjen which led to cooling during the summer and warming during the winter.

Current temperatures in Sirdalsvatn, near the power plant outlets at Tonstad, got higher summer temperatures than in the center of the lake, especially at 20 meters depth, **Figure 47**. The reason seems to be high temperatures in the water received through the power plant, especially from Ousdalsvatn.

Effects of hydropeaking on water temperatures in Sirdalsvatn are shown in **Figure 48 - Figure 56**.

An East-West slice in Sirdalsvatn at Tonstad shows a marked temperature gradient in February from near zero at the surface to 4 ^{o}C near the bottom. A small layer with high temperature gradients was located near the intake tunnel due to vertical movements in the direction of the intake tunnel, **Figure 48**.

In Sirdalsvatn by Tonstad, hydropeaking caused colder water near the surface during summer and warmer water during the period with decreasing temperatures in the autumn/winter. The circulation period became prolonged, **Figure 52 - Figure 56**.

In the center of Sirdalsvatn and above 20 meters, hydropeaking led to lowered temperatures during summertime (May-August) and higher temperatures the rest of the year, **Figure 50** and **Figure 52 - Figure 56** . The differences were normally less than 2 ^{o}C. 50 meters below the surface, the temperatures are in the base-line scenario approx. 4 ^{o}C the whole year. At this depth, hydropeaking led to increased temperatures during the period July-October with up to 4 ^{o}C. The differences in deep water indicate that hydropeaking affected the vertical mixing of the water column at larger depths. The cooling during autumn/winter was delayed by about a week and the vertical circulation became deeper. The circulation period also became prolonged by a couple of weeks. During the winter, hydropeaking generally led to slightly higher temperatures.

In the southern end of Sirdalsvatn, the differences in the upper 20 meters showed a similar pattern as in the center of the lake. However, the differences withtin the surface layer, with and without pumping, were greater than in the middle of the lake, **Figure 50** and **Figure 52 - Figure 56**. Without pumping the thermocline was better developed than in the northern and center part of the lake.

Hydropeaking seems to affect the whole top layer throughout the lake. In the middle basin of Sirdalsvatn most of the vertical profile was affected. The vertical movement due to pumping seemed not to affect deep water areas south of the barrier in any noticeable way.

Basically the hydropeaking led to increased temperatures at greater depths and reduced temperatures near the surface in Sirdalsvatn. The effects were greatest in periods with unstable vertical profiles, i.e. during the circulation period in the autumn and first part of the winter. Even as the vertical mixing reduced the temperature diffences between surface and bottom, the surface temperatures were still higher than in the current scenario in part of October - November due to the delayed and prolonged circulation, **Figure 49**.

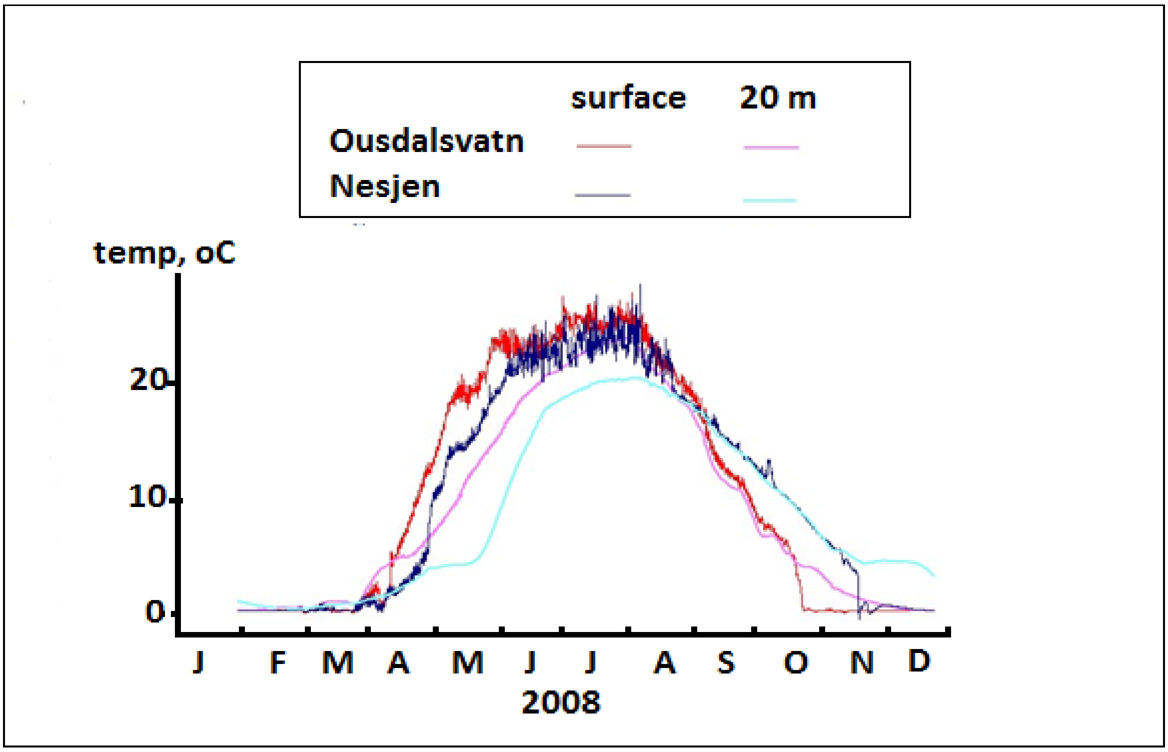


Figure 43. The maximum temperatures on the surface of Ousdalsvatn and Nesjen are near 25 °C. The smaller lake Ousdalsvatn reacts more quickly on climate changes during the year. There are small differences between temperatures from surface to 20 meters during the period with decreasing temperatures autumn and winter. Ousdalsvatn and Nesjen are not directly affected by the pumping/hydropeaking.

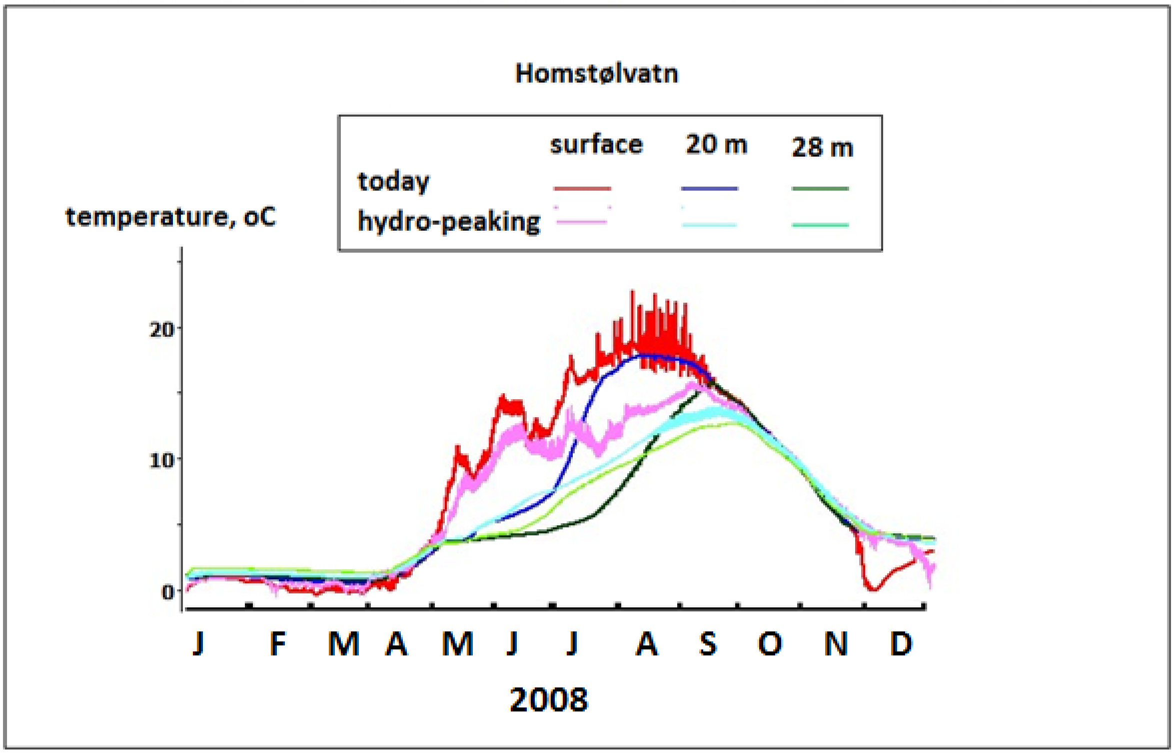
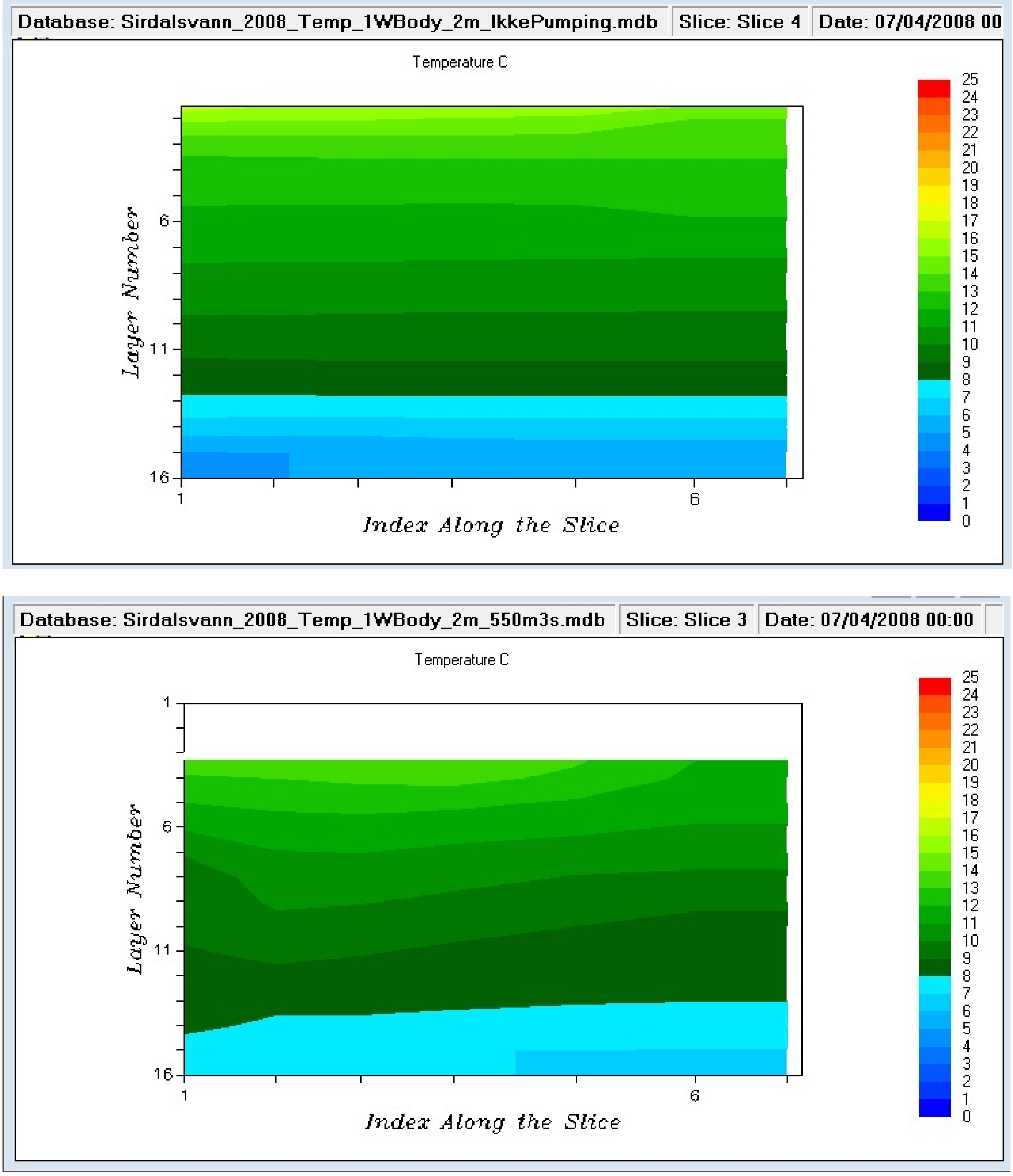


Figure 44. The figure presents the results from Homstølsvatn. In the period May-September, effects of hydropeaking could be found, the rest of the year the differences are small. Near the bottom, just below level of the intake tunnel, hydropeaking resulted in temperature increases with up to 3 °C. Above the tunnel the effects were opposite. Be aware of that the surface layer is the top layer and varies up to 3.5 meters during a day. The other levels are fixed and refer to highest regulated water level (HRL). A fixed level of 20 meter without pumping, are here seen together with a curve representing depths close to 5 meters deeper. The daily variations, which may be more than 2 °C, also are affected of that phenomenon in addition to water exchange between the reservoirs.



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Slice: Slice 4

Date: 07/04/2008 00

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Slice: Slice 3

Date: 07/04/2008 00:00

Figure 45. In Homstølvatn hydropeaking led to increased mixing in the vertical direction. The upper part presents the results of the base-line scenario for July, while the lower part of the figure shows the scenario with hydropeaking. Generally, the result show slightly lower surface temperature and higher bottom temperatures with hydropeaking.

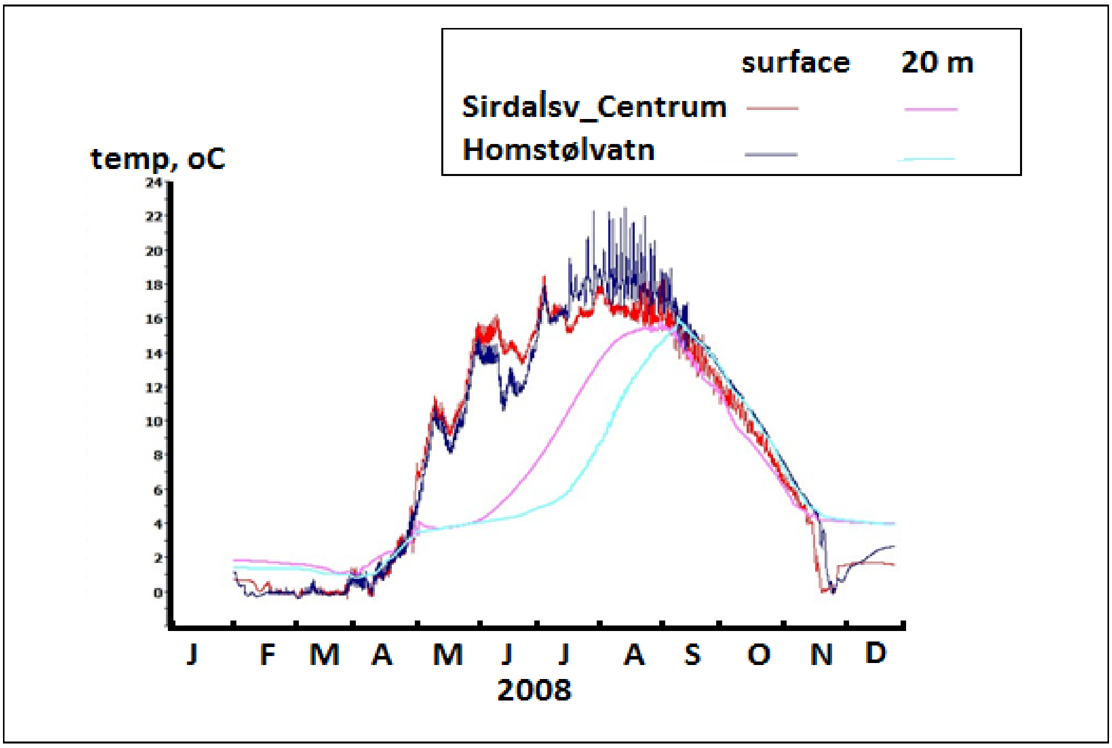

Figure 46. Surface temperatures in the center of Sirdalsvatn (indicated by location "Center" in figure 2) and Homstølvatn are in the base-line scenario fairly similar. At greater depth, 20 meters, the temperatures in Sirdalsvatn were higher during summertime. The phenomena, especially at 20 meters, are connected to how Homstølvatn is influenced by bottom water from Nesjen which led to cooling during summer and warming during winter.

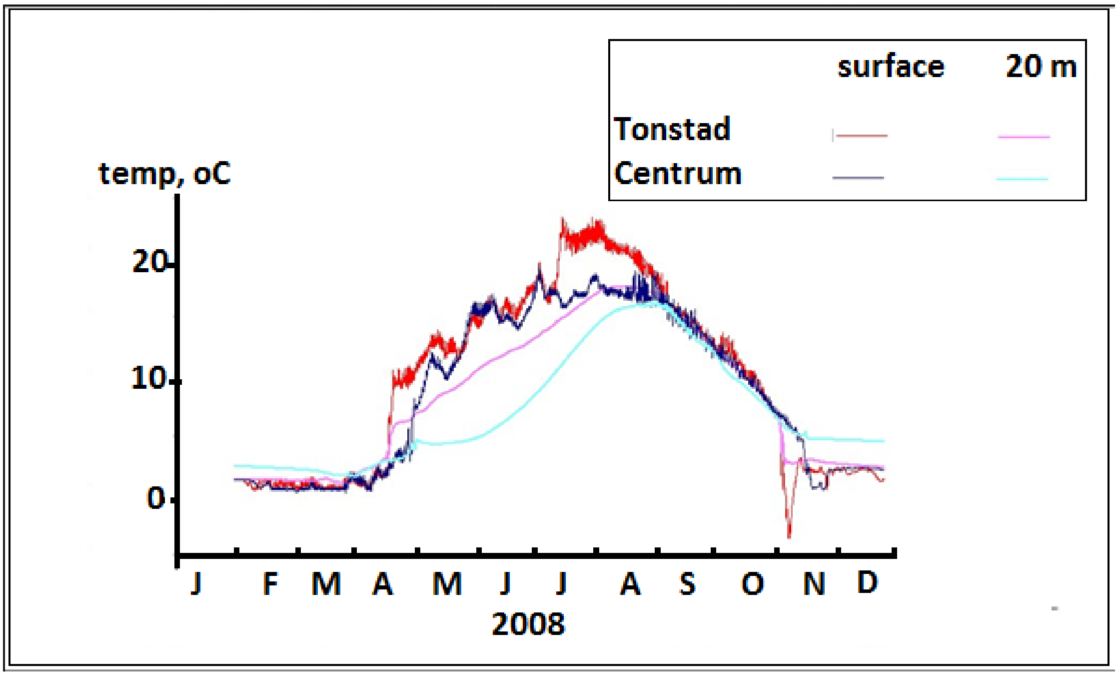

Figure 47. The figure presents water temperatures in Sirdalsvatn by Tonstad and centrum (indicated by location "Center" in figure 2), without any pumping (base-line). The temperatures in Sirdalsvatn by the power plant outlets at Tonstad, have higher summer temperatures than in the center of the lake, especially at 20 meters depth. The reason seems to be high temperatures of the water received through the power plant, especially from Ousdalsvatn.

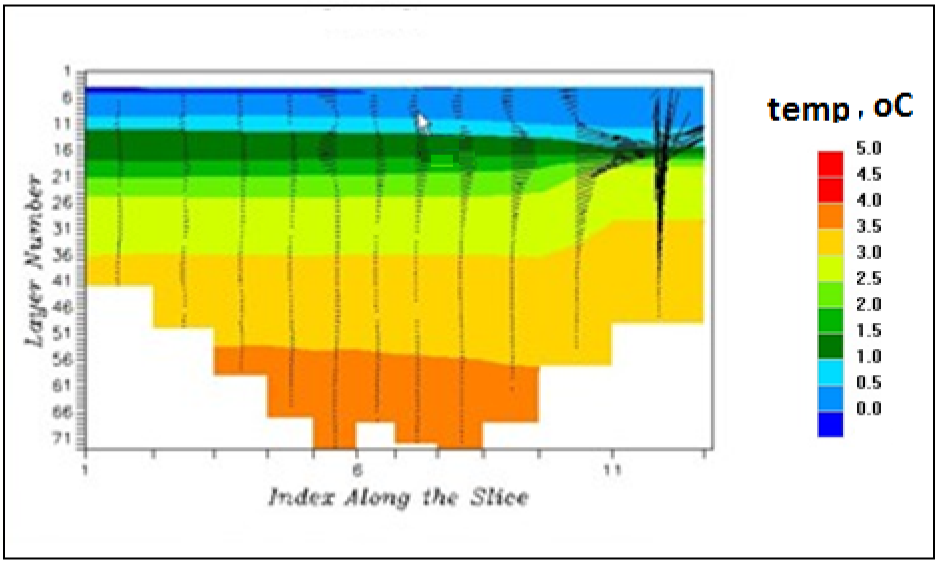

Figure 48. An East-West slice in Sirdalsvatn at Tonstad in February shows a marked temperature gradient from near zero on the surface to 4 ^{o}C near the bottom. A small layer with high temperature gradient was located near the intake tunnel due to movements in the direction of the inlet.

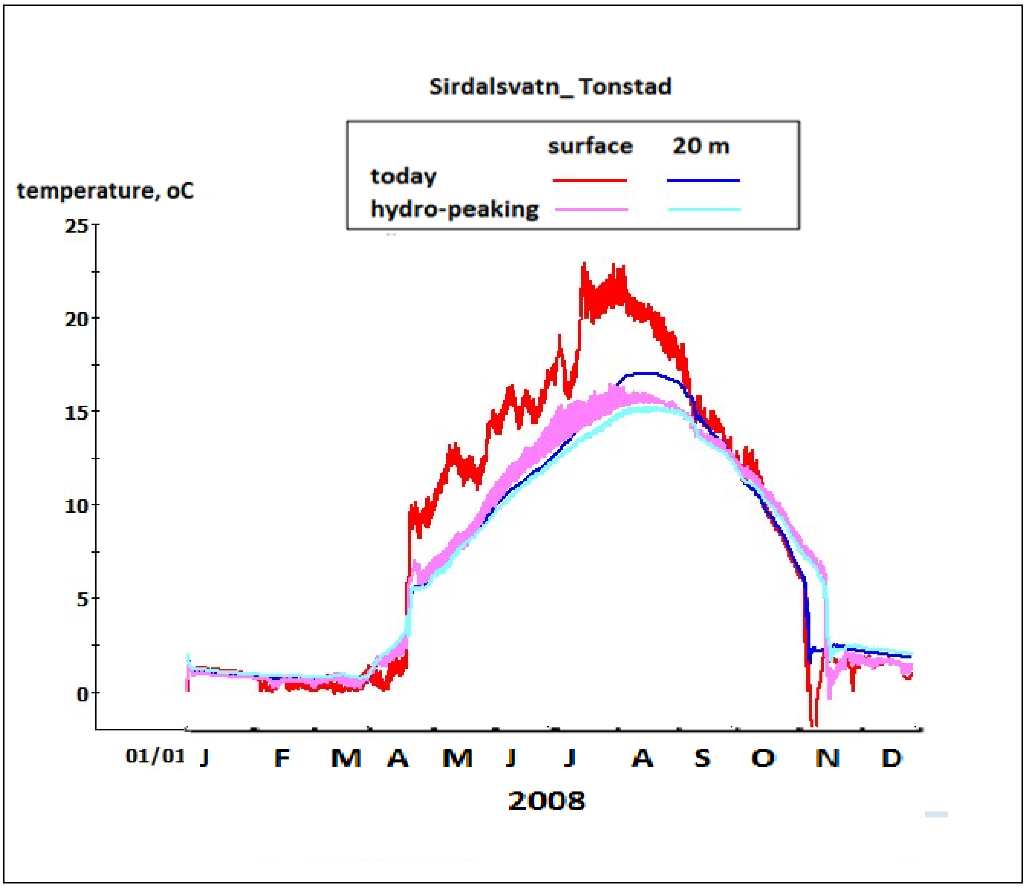

Figure 49. Temperatures in Sirdalsvatn by Tonstad, with and without hydropeaking. Hydropeaking led to colder water near surface during the summer and warmer during the period with decreasing temperatures autumn/winter. The circulation period was prolonged.

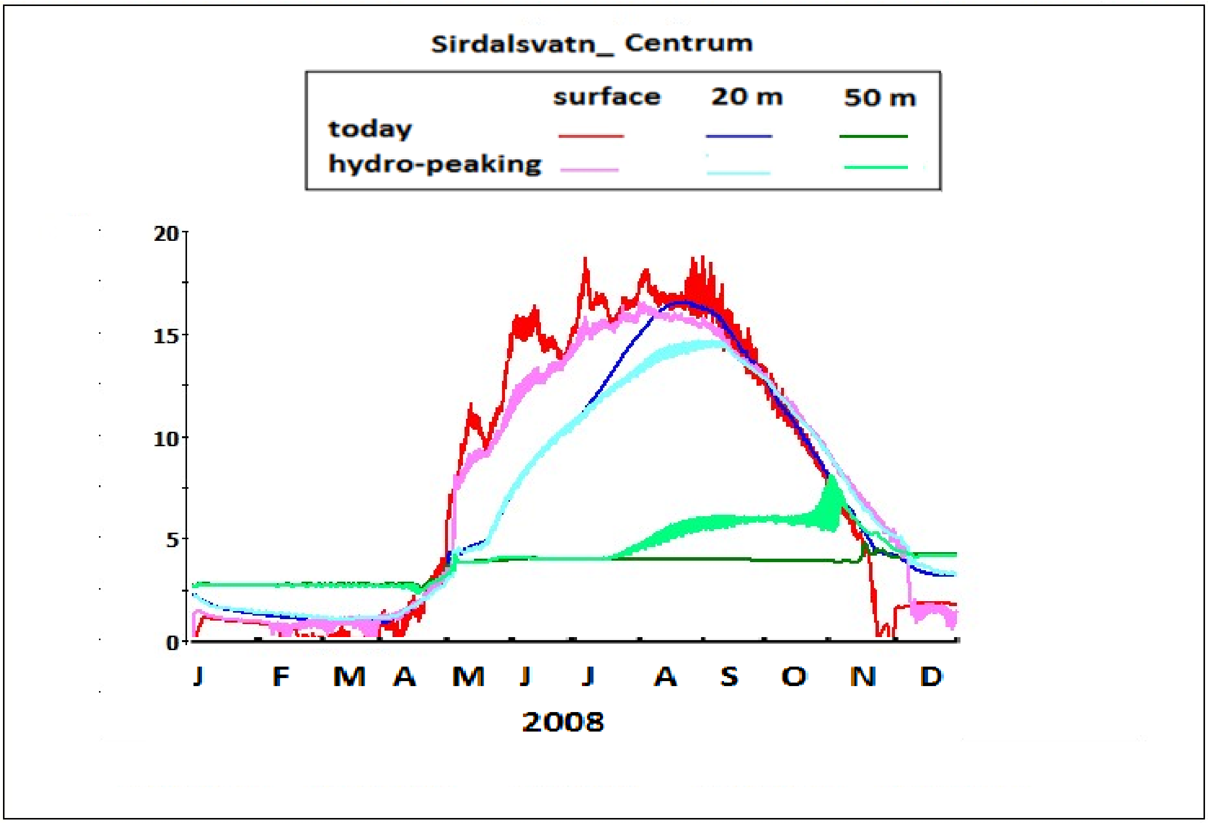

Figure 50. Temperatures in the centre of Sirdalsvatn (indicated by location "Center" in figure 2), with and without hydropeaking. Above 20 meters hydropeaking led to reduced temperature during the summer (May-August), with the opposite situation the rest of the year. Hydropeaking led to decreased temperatures in the period July-October with up to 4 ^{o}C. The cooling during autumn/winter was delayed by about a week or two. The vertical circulation became deeper and the circulation period became delayed and prolonged.

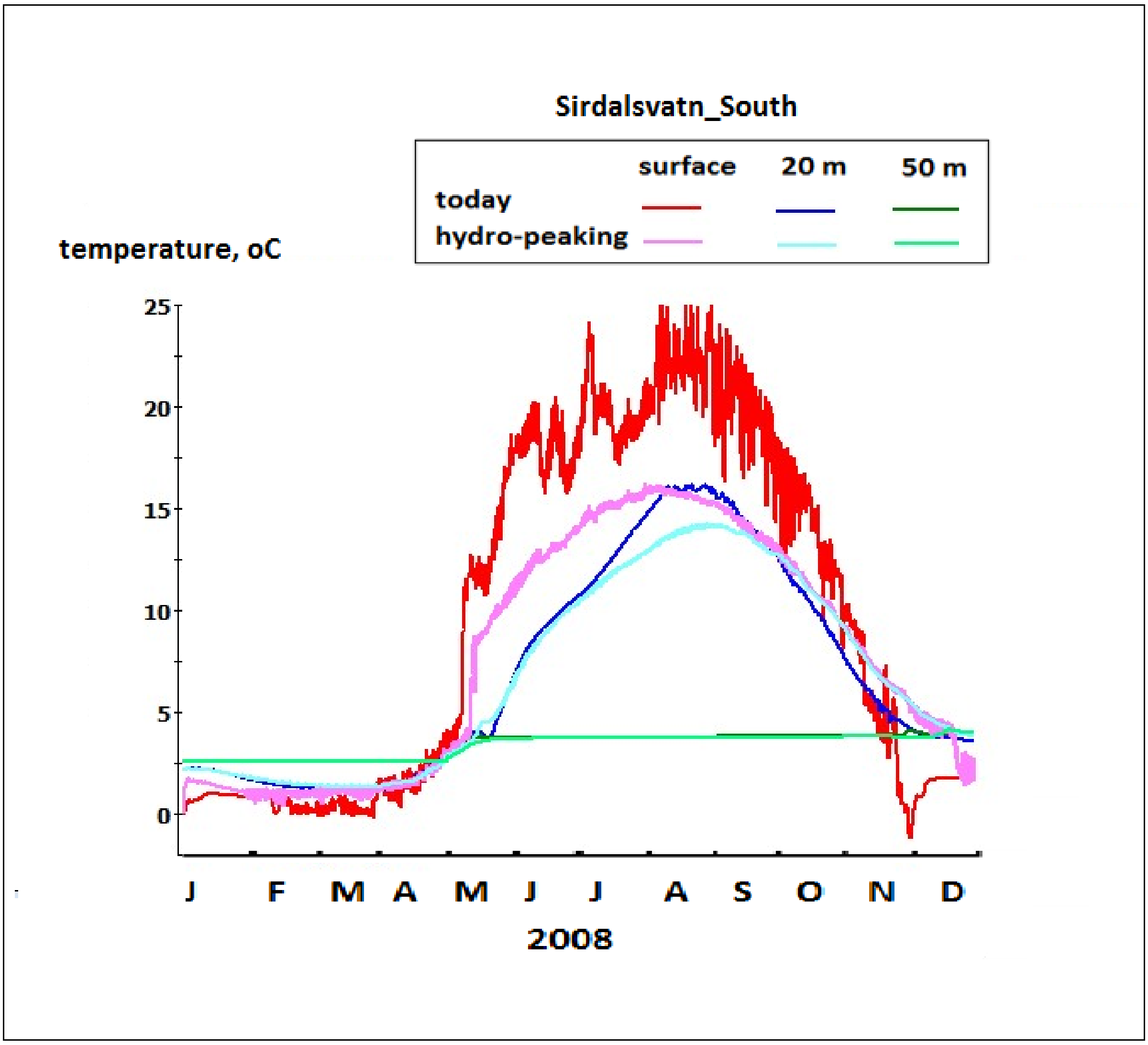

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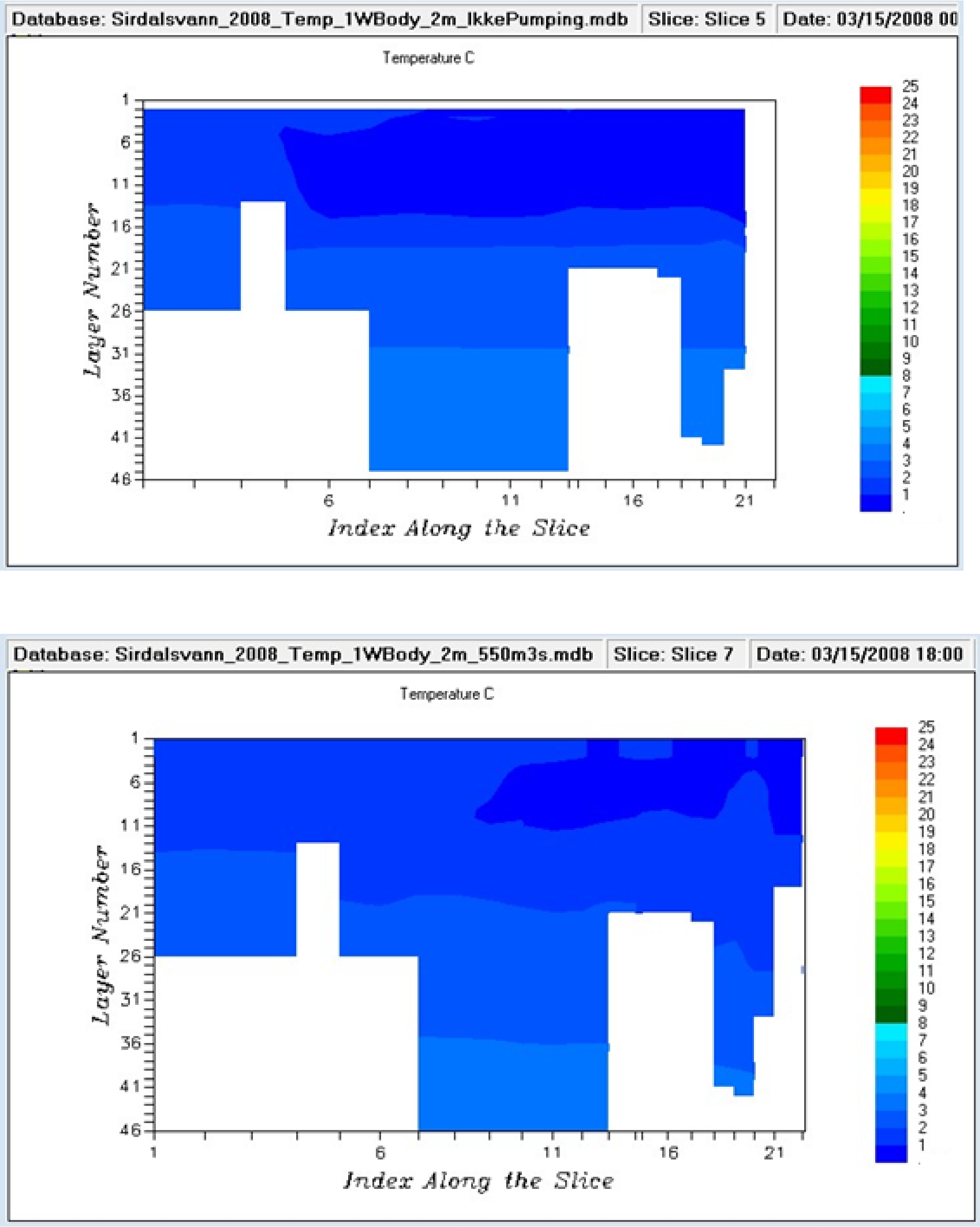
Figure 51. The figure shows temperatures in the southern part of Sirdalsvatn, with and without hydropeaking. In this part of the reservoir, the differences in the upper 20 meters showed similar patterns as in the center of the reservoir. The vertical movements due to hydropeaking did not affect the deepest areas south of the barrier in any noticeable way.



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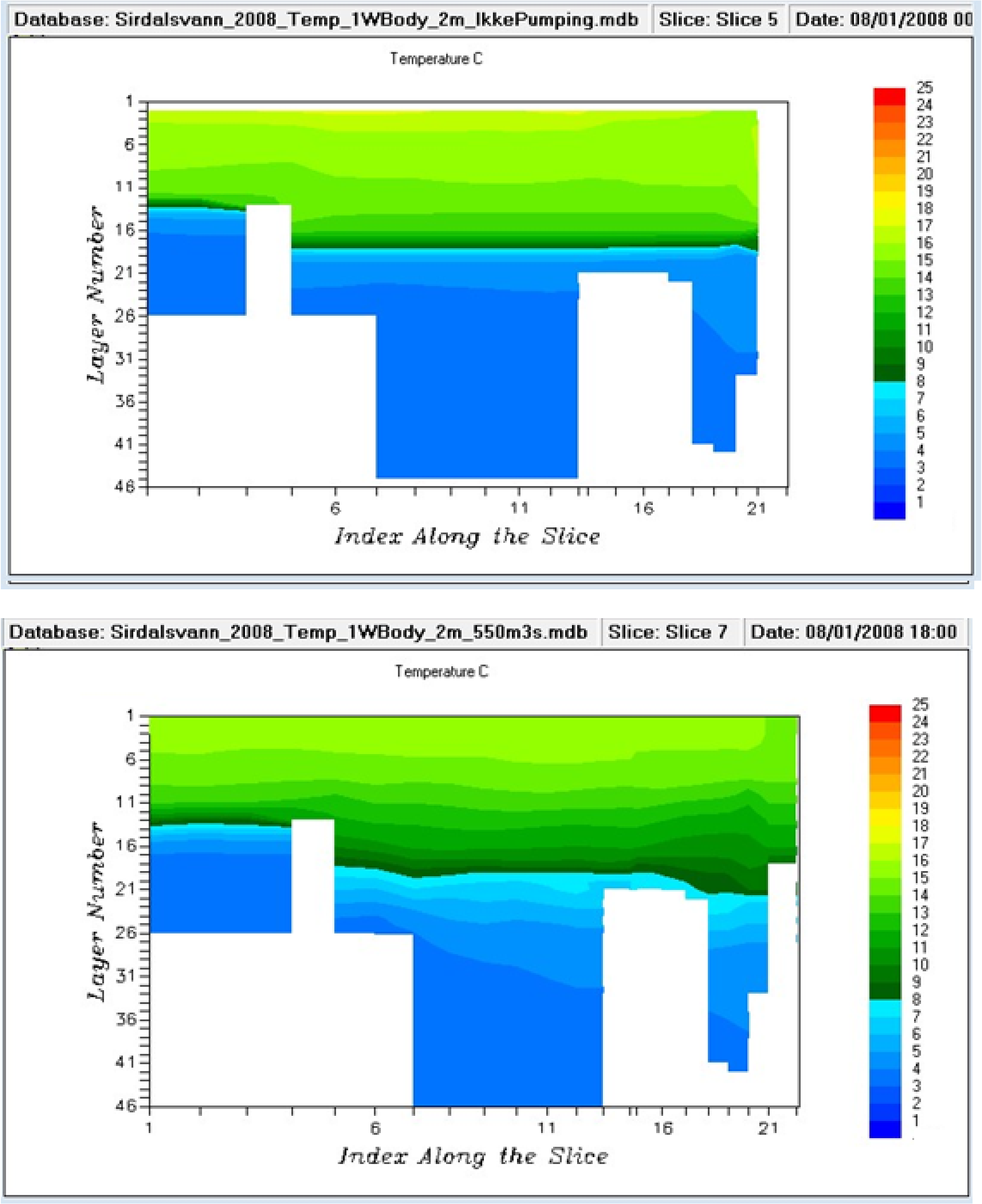
Database: Sirdalsvann_2008_Temp_1WBody_2m_550m3s.mdb | Slice: Slice 7 | Date: 03/15/2008 18:00

Figure 52. The figure shows temperatures in Sirdalsvatn in March, without (upper part) and with pumping/hydropeaking (lower part). Hydropeaking led to colder water on larger depths and slightly higher values near surface in Sirdalsvatn. The reasons are greater vertical movement, greater transport of water from top to bottom with reduced temperature differences as the outcome.



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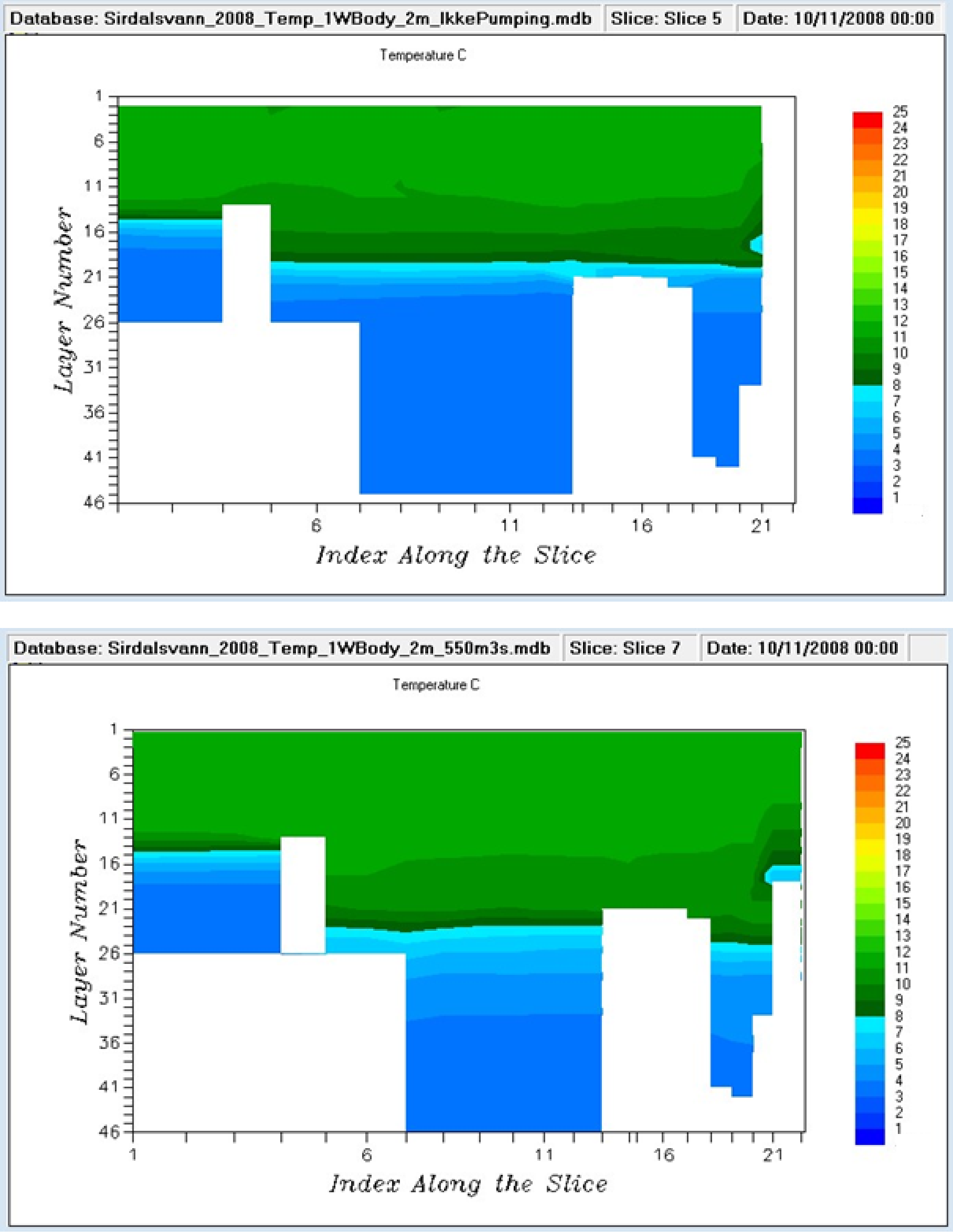
Database: Sirdalsvann_2008_Temp_1WBody_2m_550m3s.mdb | Slice: Slice 7 | Date: 08/01/2008 18:00

Figure 53. The figure shows temperatures in Sirdalsvatn in August, without (upper part) and with pumping/hydropeaking (lower part). Hydropeaking led to warmer water on greater depths and slightly reduced values near the surface in Sirdalsvatn. The reasons are greater vertical movement, greater transport of water from top to bottom with reduced temperature differences as the outcome.



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Database: Sirdalsvann_2008_Temp_1WBody_2m_550m3s.mdb
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Date: 10/11/2008 00:00

Figure 54. The figure shows temperatures in Sirdalsvatn in October, without (upper part) and with pumping/hydropeaking (lower part). The hydropeaking led to increased temperatures on larger depths and reduced temperatures near the surface in Sirdalsvatn. The effects were greater than for the summer situation.

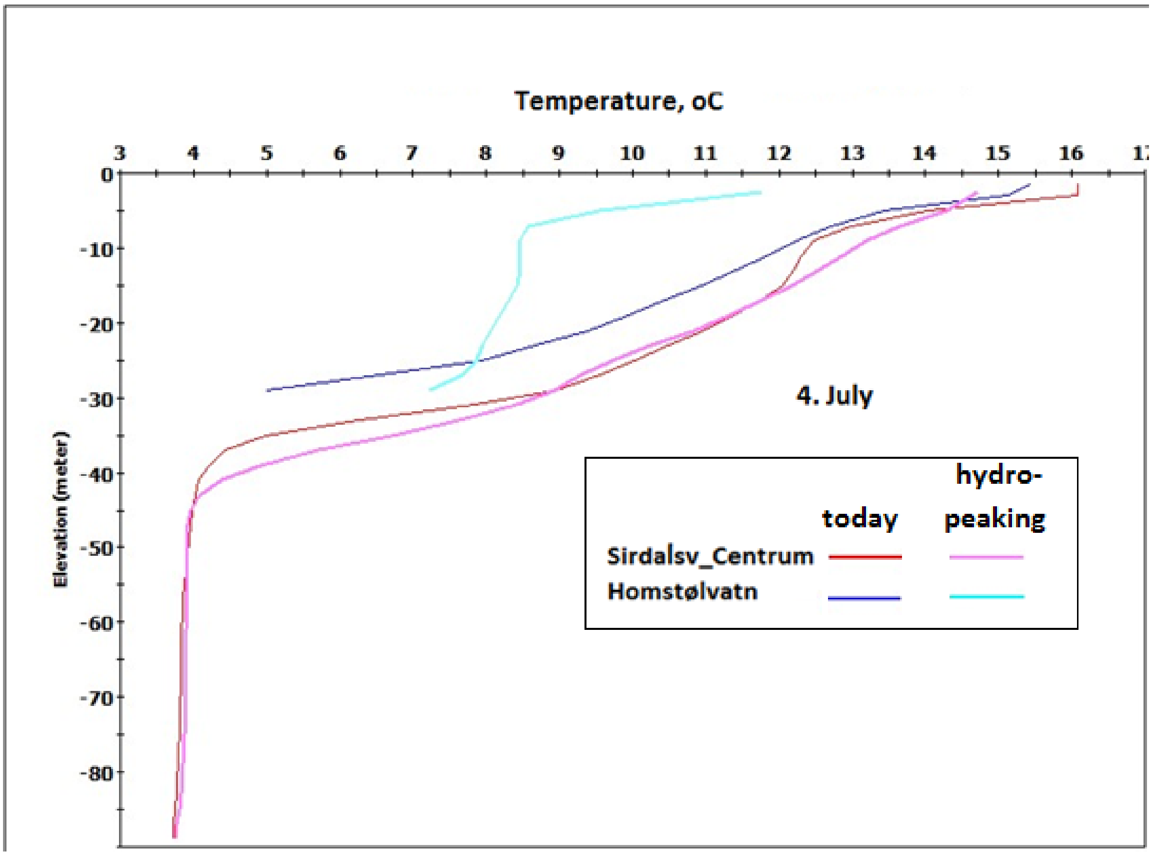

Figure 55. Hydropeaking/pumping in Homstølvatn led to lower surface temperatures and higher temperatures near the bottom in July. In the center of Sirdalsvatn the differences were small. The location Sirdalsv_Centrum is referred to as location "Center" in figure 2.

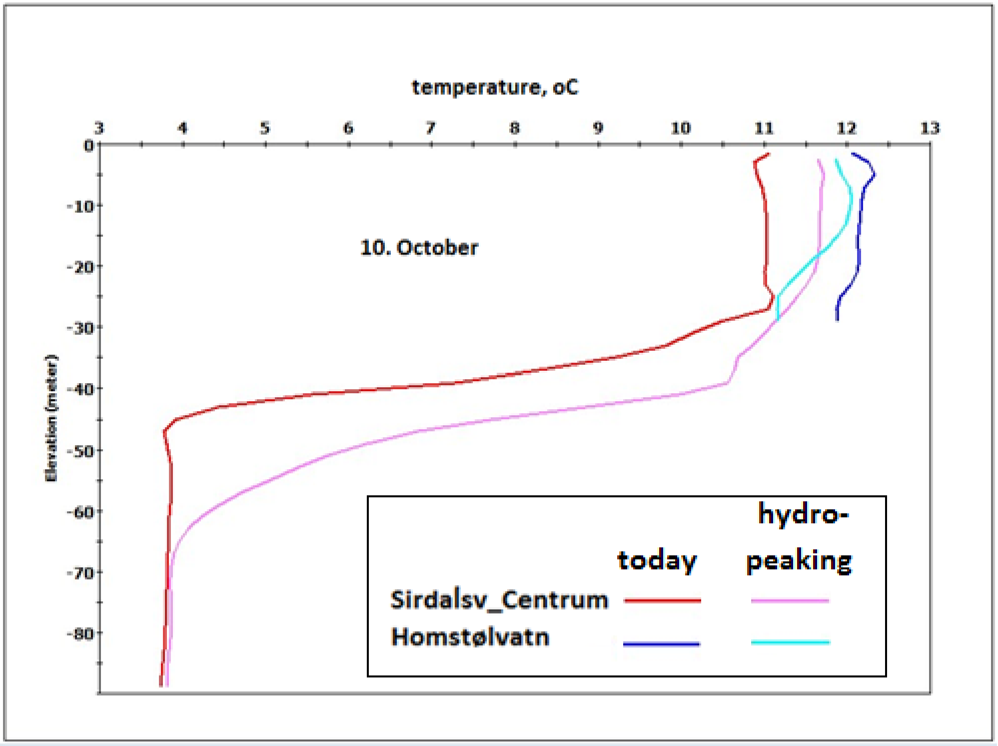

Figure 56. In October hydropeaking caused higher temperatures both in Homstølvatn and center of Sirdalsvatn. The location Sirdalsv_Centrum is referred to as location "Center" in figure 2.

3.5 Ice cover

Ice cover was modeled for 2008 with and without hydropeaking. Basically, the simulations of ythe hydropeaking scenarios show strong currents near the tunnel outlets causing reduced ice cover formations. An additional outlet from Tonstad 3 will further increase the ice free area or areas with weak ice cover, **Figure 57**.

More detailed, the results from base-line scenario simulations show ice free conditions during the period February 17th – December 2nd, while the areas close to the inlets/intake and outlets tend to have longer ice-free periods. With hydropeaking the ice cover breaks up a couple of weeks earlier than in the base-line scenario and was established more than one month later than without hydropeaking/pumping. The results were similar in both Sirdalsvatn and Homstølvatn.

Due to large water level variations (3.5 meters daily changes), reduced ice cover along the shores must be expected. The model was, however, not able to predict such effects explicitly.

The same climate input data (see details in section 2.1) was used for both Sirdalsvatn and Homstølvatn with altitude corrections, despite of a difference in altitude of 450 meters. This introduces uncertainty in the predictions of both the dates of the ice formation/break-up and the length of the ice-covered periods for all reservoirs and both scenarios. However, the basic finding is that it seems like hydropeaking causes a shorter period with ice cover.Especially in Sirdalsvatn the prolonged circulation period and slightly higher winter temperatures led to later ice cover formation and earlier break up. In the smaller reservoir, Homstølvatn, the vertical mixture and high velocities due to reversing water flow were more dominant.

As the ice cover is formed when the water temperature drops to 0° C, the predictions of the ice cover formation are very sensitive to the precision in the water temperature calculations at low temperatures. The simulations of hydropeaking gave more days with water temperatures slightly above 0° C, hence leading to shorter periods with ice cover.

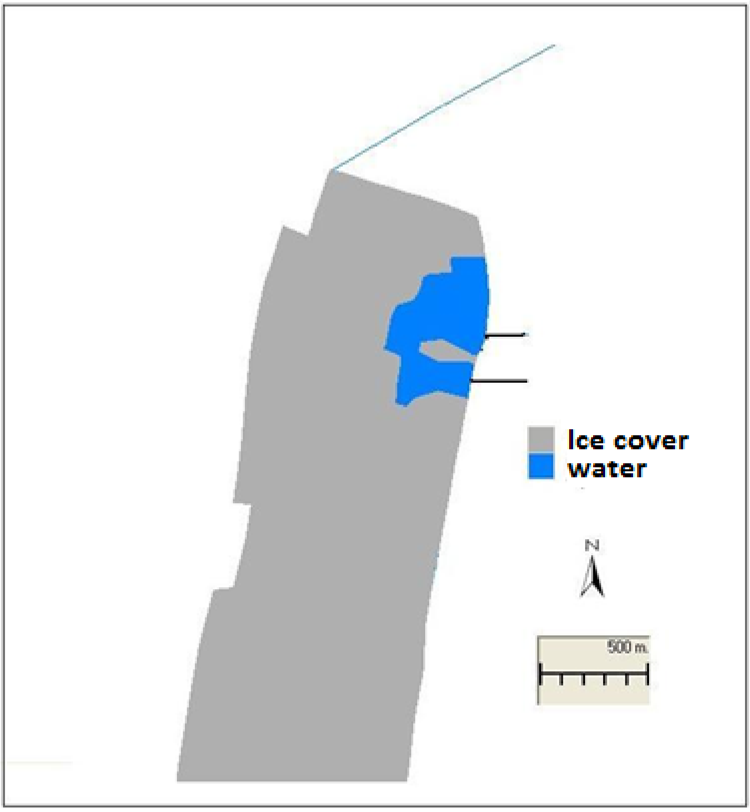

Figure 57. Strong currents near the tunnel caused reduced ice cover formation. An additional outlet from Tonstad 3 will increase the ice free areas.

3.6 Discussion

In order to model and analyse the effect on the hydro-dynamic conditions in the Tonstad-system, a number of simplifications and assumptions had to be made;

1. The hydropeaking scenario was run with constant hydropeaking throughout the year as the purpose was to study effects of hydropeaking effects during various seasons.
2. The base-line scenario was simulated with a stable/constant water flow through the power plant, intended to represent today's production regime. In reality, the power plant produces already some peak power.
3. To isolate hydropeaking effects from wind effects, wind forcing was not included in the scenarios. Inclusing of wind forcing will introduce currents and vertical mixing of water, possibly redicing the effects from hydropeaking.

These simplifications will affect the precision of the model results, i.e increase the uncertainty, and the scenario results should be interpreted as 'effects on the hydro-dynamic conditions hydropeaking may cause'. Without support in a systematic uncertainty assessment, the authors believe that the results should be considered conservative, in the meaning that the impacts are probably not larger than those presented in this report.

The scenario was run with constant hydropeaking throughout the year. Hydrological and economical reasons etc. may lead to reduced number of days with hydropeaking. The effects described below will be reduced by shorter duration of hydropeaking.

In the hydropeaking scenario the water flow from Nesjen to Homstølvatn was set to constant over the year, i.e constant production in Nesjen hydropower plant. A more likely scenario for the power production might be that also this power plant will to some extent will be used for hydropeaking. This will change inflow regime to Homstølsvatn from constant to a flow determined by the production regime in the upstream plant. If so, the water level changes in Homstølvatn will be smaller than presented in this report, i.e less than the simulated 0.5 meters per pumping-production cycle.

During the last few years, the mean water level in Sirdalsvatn has been approx. 0.5 meters higher than HRL during the winter. In our scenarios hydropeaking increased this water level by approx. 0.75 meters. If this is an unacceptable impact, this could possibly be mitigated by increasing the outflow from the reservoir.

The hydropeaking resulted in increased vertical mixing in Sirdalsvatn which in turn led to reduced temperature differences in the vertically in the water column. The increase of temperatures on great depths late summer and autumn are interesting findings as well as the delay in temperature decrease in the upper parts during autumn/winter.

From the simulation results it seems like the extensive hydropeaking regime and large volumes of inflowing/outflowing water in the Sirdalsvatn might introduce interior waves. This might reduce the period with ice cover. The model probably handles this reasonable well, but it should, however, be noted that small errors could lead to temperatures slightly above zero, which, of course, will affect the computation of ice.

Finaly and not least, it should be underlined that the model results from GEMSS were never compared with observations of hydro-dynamic variables, as relevant calibration data was not available prior to setting up the hydropeaking scenario simulation. Without any calibration, the goodness-of-fit of the model could not be analysed nor quanfified. The confidence in the model results hence rely on to what extent the governing equations for our purpose is represented in the model code, the quality of the input data and the model setup, and the skills of the operator/modeler.

3.7 Conclusions

The conclusions from simulating a future scenario of a day-night hydropeaking regime in Tonstad hydropower system are;

- The simulated hydropeaking regime introduced large and daily fluctuations in Homstølvatn, i.e. a daily fluctuation of approx. of 3.5 meters. The daily fluctuations in Sirdalsvatn are simulated to be approx. 0.75 meters.
- Hydropeaking increased the current speed and changed the current pattern, especially near the inlet/outlet tunnels in Sirdalsvatn and Homstølvatn.
- In Sirdalsvatn the hydropeaking led to reduced temperatures near the surface and increased temperatures on greater depths due to increased vertical mixing, in particular during the autumn and the first part of the winter. The circulation period was delayed and prolonged by a week or two.
- In Sirdalsvatn hydropeaking resulted in shorter period with ice cover. In both Sirdalsvatn and Homstølvatn reduced ice cover formation in the areas near the hydropower outlet, is probably

due to increased current velocities. Furthermore, rapid water level changes may break up a continuous ice cover along the shores.

- The GEMSS-tool proved to simulate a future realistic day-night hydropeaking regime in a reasonable way, thus qualifying for being a suitable tool for quantifying hydro-dynamic impacts of hydropeaking between reservoirs. Such a statement could, however, not be directly supported by traditional calibration/verification procedure (as such data was not available), but is based on the authors' scientific judgements and the modeller's prior experience with GEMSS and a number of similar tools.

4. References

ERM. Model developer: http://www.erm-smg.com.

Magnell, J-P., Kvambekk, A., Berg, G. og Gaut, A. 2007. Tilleggsinstallasjon med mulighet for pumping i Tonstad kraftverk. 54 sider. Rapportnr. 139581-01, SWECO GRØNER, Oslo.

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