BACHELOR THESIS

Excessive plant growth in Lake Hafslovatnet, Western Norway

Can human interference in the watershed and climate change (temperature) be the cause of the noticed increase of water plants in Lake Hafslovatnet, Western Norway, since 1983?

by

Amarens de Wolff

Fig. 1 Front Picture: Uprooted plant fragments floating in Lake Hafslovatnet on 29 October 2015 (own photo)

Environmental sciences at Van Hall Larenstein University of Applied Sciences, the Netherlands

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van hall larenstein university of applied sciences

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Bachelor thesis
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Preface

Dear reader,

Before you lies the thesis 'Excessive Plant growth in Lake Hafslovatnet, Western Norway'. It has been written for my bachelor study Environmental sciences at Van Hall Larenstein, University of applied sciences. The subject was provided by T. Dale from Høgskulen i Sogn og Fjordane University college. In 2017-2018 Høgskulen I Sogn og Fjordane is going to merge together with other universities in West Norway to form Høgskulen på Vestlandet (Western Norway University of applied sciences). This thesis has been written before this time period, and therefore uses the old university name. This thesis would not have been the same without the information and data that was provided. Therefore I would like to thank the following persons:
I. Lavoll from NVE region Vest for giving information about the flood prevention activities in the river Størelvi at Veitastrond. Furthermore R. Løland, also from NVE region Vest for providing a huge dataset and graphs of the water level and water flow rate at lake Veitastrondvatnet. I.M. Slinde (Luster municipality) for finding large amounts of water quality data, used for drink water production, for both Lake Veitastrondvatnet and Hafslovatnet. H. Bremer from Bremerfjøsen Hafslo for finding more results from Hafslovatnet and Veitastrondvatnet. All the international students of the 'From mountain to Fjord' minor at the Høgskulen I Sogn og Fjordane have my thanks for all their hard work to collect data during excursions over the years (2008-2015 and still going).

The following supervisors deserve my thanks: E. Leunissen and J. van Belle (Van Hall Larenstein) for their patience, expertise and guidance to guide me to the end of this bachelor thesis.
Matthias Paetzel (Høgskulen i Sogn og Fjordane) for two things: first for lending his fingers to make a good photo of plants covered with oxidised iron and second for his role in managing late application forms and advise for my thesis. And not to forget the invitations to join 'From mountain to fjord excursions' which were a lot of fun. T. Dale (Høgskulen i Sogn og Fjordane) deserves a very big thank you and *Tusen takk* for his enthusiastic supervision in Norway, the field trips, his help with digging up interesting information from all kinds of sources and for keeping me motivated when I was lost in the process of making the thesis and his patience as it took some time for me to finish this thesis. *Tusen takk for en hyggelig samarbeid i Norge.* I will always have good memories of my time in Sogndal.

Lastly I would like to thank the From Mountain to Fjord groups of 2014 and 2015. The group of 2014 made the stay during the minor great and made me want to come back. The group of 2015 has my thanks for their welcome in the group, all its fun during my stay and making the second stay as great as the year before. My best friends R. Schipper and M. Baijens deserve my thanks as well for supporting me during the process, cheering me up, talking to me and providing a place to have a break by helping out around the farm. Finally my last thanks goes to my family for their support, reading concept versions and providing chocolate and tea.

Amarens de Wolff
25-08-2017

Abstract

Lake Hafslovatnet is part of a water system which lies in the county Sogn og Fjordane in Western Norway. At the base of this system lies the glacier Austerdalsbreen. Its meltwater passes, combined with normal precipitation, one river, one large lake and two small lakes before it passes Lake Hafslovatnet. This oligotrophic lake is the last location before the water flows into the fjords. Since the 1980s users of this lake noticed excessive growth of water plants in the lake, which began to interfere with recreational activities. There have been previous studies investigating the plant growth problem. Nonetheless the problem is still occurring to some extend nowadays. The purpose of this study was to analyse possible effects that could have caused the excessive plant growth that has been observed in Lake Hafslovatnet after the regulation of this lake and Lake Veitastrondvatnet in 1983. Therefore the following research question was formulated: *Can human interference in the watershed and climate change (temperature) be the cause of the noticed increase of water plants in Lake Hafslovatnet, western Norway, since 1984?*

The research was realized by gathering relevant information from literature combined with the analysis of hydrological, hydrographical and own data. The focus was laid on better understanding the role of the hydrology in the plant growth problem. With the literature research data was combined into a large dataset of hydrological and chemical parameters, which has not been done before. The data was statistically analysed with a Change point analysis and a (non) seasonal Mann-Kendall trend test.

With CTD measurements a better basic understanding of the present and recent hydrographic and hydrological structure of the lakes has been acquired. It shows that Lake Hafslovatnet has a two layered epilimnion when the lake is stratified. Furthermore it receives colder water at its inlet than at the outlet. Some small increasing trends in hydrological and chemical data were found: Turbidity, pH and iron. Yearly summarized air temperatures had two detected increasing trends for to low altitude stations (Lærdal and Fjærland). One increasing trend was found with a seasonal Mann-Kendall trend test on monthly averaged values. The yearly summarized water temperature had an increasing trend, and the separate tested months resulted in April and October both having an increasing trend. Two changes were similar for air as for water temperatures (1997/1998 and 1993 / 1992).Between the 1960's and ca 1990 the most alterations in the water system were made. The scattered data did not show clear connections to certain dates, but indicated some changed conditions in the system. The analysis revealed some different factors that were involved. These factors could be local (altering the two rivers Storelvi and Heggestadelvi, building a bypass tunnel, hydroelectric power plant) and global (regulation, changes in air or water temperature, beach erosion, changes in hydrological or chemical parameters etc).

With this investigation it is clear that there could be many more factors involved in the plant growth problem compared to the factors discussed in previous papers. One of these factors could be related to the bypass tunnel built for the regulation. A second factor could be beach erosion, taking place at Lake Veitastrondvatnet, Lake Tverrbergvatnet and Lake Straumane. To verify both factors, additional research is needed. Finally it is important to keep measuring to maintain the long term datasets.

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1 Introduction

Lake Hafslovatnet lies in the county of Sogn og Fjordane, Western Norway (see fig 3, chapter 2.1.1). The lake and its area have a rich geological history including its creation.

In general, the orogeny of the west Norwegian mountains goes back roughly 425-415 million years ago (Jones & Blake, 2003). In this age two continents called Laurentia (Greenland) and Baltica (among which Norway) collided together pushing the Baltica plate upwards creating the Caledonian mountains (Fossen & Dunlap, 1998). Over millions of years erosion of the mountains transformed them to gently shaped hills (Bryhni, 2015). During the Alpine orogeny around 100 – 66 million years ago (Moores & Fairbridge, 1998) the land north of the collision was lifted up including the area of Norway, called Tertiary uplift or Paleogene / Neogene uplift (Holtedahl, 1975).

Water started to flow into low areas, cracks and fault lines to the sea, creating rivers in the landscape. In the last 2.6 million years glacial and interglacial periods occurred on Earth (Imbrie & Imbrie, 1979). During ice ages, glaciers advanced following the riverbeds, eroding the riverbeds even deeper. In interglacial periods, rivers took over the erosion process from the glaciers. As a result, the landscape got large valley systems. Some valleys close to shore were flooded during a period of sea level rise, creating the fjords that still exist in the present. The higher parts of the valleys were not flooded and some parts were filled with melt and rain water creating fresh water lakes (M. Paetzel, personal communication). Aa (1982) has given a precise description of the geological events in the area of Lake Hafslovatnet. The present water system where Lake Hafslovatnet is part of still has a small glacier at its base, followed by a deep and long lake (Lake Veitastrondvatnet), two shallower lakes (Lake Tverrbergvatnet and Lake Straumavatnet) and Lake Hafslovatnet itself, before the water is drained into the Barsnesfjords via the river Årøy.

Lake Hafslovatnet is an oligotrophic lake (Rørslett, Hvoslef, & Faafeng, 1986) and has softer beaches like margins, whereas upstream, Lake Veitastrondvatnets' beaches consist of rocks and steep mountainsides. Next to Hafslovatnet lies Hafslo, a small town whose inhabitants use the lake for the production of drinking water and recreational purposes like fishing and other activities (Anonymous (1), 2000). The western part of Hafslovatnet is protected as a bird sanctuary since 1991 (Larsen, 2001). At the outlet of Hafslovatnet lies the Årøy hydroelectric water power plant, which was built in 1983. Since the power plant was taken into operation, the water level of both lakes have been regulated. Lake Veitastrondvatnet is regulated at a maximum level of 171 m above sea level with 2.5 m variation. At the outlet, water passes by the natural draining system via a dived tunnel. Within the tunnel, a regulation hatch ensures that the right amount of water passes through. Lake Hafslovatnet has a maximum level at 169 m a.s.l. with only 1.5 m variation (Schedel, 2015).

In the early 1980s, the users of Lake Hafslovatnet started to notice that the amount of aquatic vegetation was growing fast in comparison with previous years. The increased growth began to interfere with user activities (Mjelde, Brandrud, & Lindstrøm, 1992) for example fishermen and boat users (Rørslett, Hvoslef, & Faafeng, 1986) (Larsen, 2001). At the power plant, a grid before the water inlet was installed to keep plant material out of the turbines. Once in a while a mechanical arm will lift up all gathered plant material (T. Dale, pers. communication).

In 1979 and 1980 vegetation of the whole watershed of Årøyelvi (including Hafslovatnet) was investigated and mapped (Evensen, 1981) to assess the possible future impact of building the Årøy hydroelectric power plant at the outlet of Hafslovatnet. Large quantities of some plant species, among which *Callitriche hamulata* and Myriophyllum *alterniflorum,* were reported.

A second aquatic vegetation survey of Hafslovatnet and upstream was done byRørslett, Hvoslef and Faafeng. In 1984 a large domination of *Callitriche hamulata* was seen in Hafslovatnet. In 1985 there was a sudden decrease in water vegetation. The large amount of reported *Callitriche hamulata* was only seen in some parts and in lesser numbers. Lots of dead plant material was found at some distance from the shore at depths greater than four meters in the southwestern part of Hafslovatnet. The cause of the collapse of the growth could not be explained with certainty, but was guessed as a natural phenomenon (Rørslett, Hvoslef, & Faafeng, 1986).

In the years 1985 – 1989 the vegetation recovered and a large population of aquatic plants was reported. Therefore in 1990 another aquatic plant investigation and discussion of possible causes related to the plant growth was carried out by Mjelde, Brandrud and Lindstrøm. In fig. 2 the area with massive occurrence of aquatic plants is shown based on the results in 1990. Investigations showed that both acidification and increased nutrient supply were not influencing the plant growth. The areas where most plants were seen occurred in areas where the water flow is high in comparison with other locations. This paper mentioned that: “*Equalized water levels over the year with reduced water levels in the summer (reduced flood peaks) and increased water levels in the winter, with a reduced period of ice cover, is favourable for the development of water vegetation. In particular, it appears that the combination of lack of draining in late winter and shortened periods with ice cover has led to massive growth of vegetation.”* [Cited from Mjelde, Brandrud, & Lindstrøm, 1992]. The mentioned changes were also likely to be the cause of the problem in the 1980’ies. *Callitriche hamulata* and *Myriophyllum alterniflorum* were again mentioned in their conclusion as the strongest growing species. Advised was to lower the levels under the minimum height (167.5 m above sea level) to 167.2 m) a.s.l. at the end of winter or ideally during the winter itself to increase the mortality rate by freezing. This measure prevents the plant to grow perennial and therefore restrains the amount of growing plants in the system (Mjelde, Brandrud, & Lindstrøm, 1992).

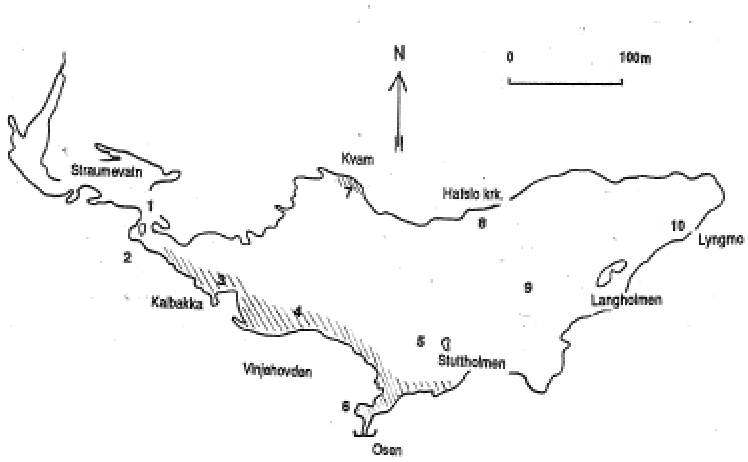


Fig. 2 Area of Lake Hafslovatnet with problematic growth of aquatic vegetation in 1990 marked with oblique lines (Mjelde, Brandrud, & Lindstrøm, 1992)

In 1994 this recommendation was applied and documented by Mjelde and Brandrud. The water level of the lake was lowered with one meter beneath 167.5 m a.s.l. in late winter of 1994. The conditions of that period were normal with cold temperatures and ice. After reinvestigating the lake the number of dominating species (*Callitriche hamulata* and *Myriophyllum alterniflorum*) were reduced. It was still unknown what was causing the reduction, low water levels or a cold winter. An estimation how long it would take for aquatic plants to build up massive populations with warm winters and high water levels was determined to be two to four years. Advised was to monitor plant build up together with information about temperature and periods of ice to see if one or both factors could influence the growth (Mjelde & Brandrud, 1994).

In 2003 Hindar, Johansen, Andersen and Saloranta conducted a thorough investigation of the aquatic plant *Juncus bulbosus*. Over the years, lakes in southern and southwestern Norway were reported having excessive growth of aquatic plants. Mostly *Juncus bulbosus* was growing in large numbers. This plant is linked to hydroelectric power plants (regulation of water levels and ice formation) and liming (supply of calcium on sediment surface) with changed nutrient availability for plants. In the paper statistical analysis was done with the available data to see what factors influenced the growth of this plant. Stream velocity proved to be the most influential regarding the degree of plant coverage. Beside the stream velocity other significant factors found were a general increasing time trend, air and water summer temperature, altitude and dissolved organic matter (Hindar, Johansen, Andersen, & Saloranta, 2003).

Since 1994 no investigation or vegetation mapping was done until 2015. In this year *Juncus bulbosus* Moe, Evardsen, Mjelde and Friberg concluded that they found no *Juncus bulbosus* beyond the bird protection area. In the area there was in general more vegetation than outside the area. Beside *Juncus bulbosus* several other taller species were high in abundance as well at some locations. The southern part of Lake Hafslovatnet, which was identified as a problem area in 1990 had no problematic plant growth in 2015. Their conclusion was: *"Our recommendation is therefore to postpone any planned mechanical or other removal measures, and then resurvey the vegetation once more in 2-3 years, to see if bulbous rush has increased in abundance and/or coverage. After this, one can assess whether removal measures are really necessary and/or desirable, and if so, what kind of measures should be initiated."* [Cited from: Moe, Edvardsen, Mjelde, & Friberg, 2015]

Between the start of investigations of 1979 to 2015, several different interventions were carried out to see if these had effect on the plant growth. As described before, there had been an experiment with lowering the water levels in wintertime and increasing it in spring to freeze and remove the plants (Mjelde & Brandrud, 1994). Another solution used was to remove water plants and a layer of soil to fight off any new growing plants and delaying settlements of new plants (Rørslett, Hvoslef, & Faafeng, 1986) (Mjelde, Brandrud, & Lindstrøm, 1992). Table 1 shows the plant species that have been mentioned in research papers (between 1980 and 2015).

Table 1 Overview of identified aquatic plants causing excessive plant growth in Lake Hafslovatn from the time it was noticed in the 1980's up until 2015. (1) (Dijkstra, 2017) (2) (Mjelde, Brandrud, & Lindstrøm, 1992)

Scientific name [2]	English name[1]	Norwegian name[2]	Dutch name[1]
Callitriche hamulata	Intermediate Water-Starwort	Klovasshår	Haaksterrenkroos
Juncus bulbosus	Common bulbous rush	Krypsiv	Knolrus
Myriophyllum alterniflorum	Alternate Water-milfoil	Vanlig Tusenblad	Teer vederkruid
Sparganium angustifolium	Floating bur-reed	Flotgras	Drijvende egelskop

1.1 Purpose

In general this thesis will try to find out why the water plants started to grow so extensively that users of the lake started to experience problems. Growth of water plants can be directly and indirectly influenced by several factors. For example a high nutrient concentration in the water can have a positive effect on the growth. Processes that cause an increase of the nutrient concentration influence the growth rate indirectly. In the introduction it became clear that earlier investigations have looked into the plant growth problem and some causes and solutions were presented. But still in 2015 increases have been reported.

Although biological factors are of great importance to truly understand the present system of Hafslovatnet and the plant growth, this thesis focussed on getting a better understanding of the hydrological situation as this part is equally important. Therefore the main focus of this thesis is to gather relevant information from literature and combine it with the analysis of hydrological, hydrographical and own data, in order to better understand the role of the hydrology in the plant growth problem for both the past and present.

The purpose of this study was to analyse possible effects that could have caused the excessive plant growth that has been observed in Lake Hafslovatnet after the regulation of this lake and Lake Veitastrondvatnet in 1983.

1.2 Research questions

The main question of this thesis is presented below together with its sub-questions and hypothesises. The sub questions were narrowed down further into working hypothesises.

Main question:

Can human interference in the watershed and climate change (temperature) be the cause of the noticed increase of water plants in Lake Hafslovatnet, Western Norway, since 1983?

Main Hypothesis

Human influences and changes in climate (temperature) have contributed to the increase of water plants in both Hafslovatnet and Straumavatnet.

Sub questions

1. **What is known about the present hydrological, hydrographical and chemical conditions in Lake Hafslovatnet?**

2. **Has the temperature (changed by climate) altered hydrographical, hydrological or chemical conditions in the watershed of Lake Hafslovatnet resulting in increased plant growth?**
   H2.1 The temperature of the air and water has changed
   H2.2 There is a changed ice cover period detectable in the air or water temperatures

3. **Has human interference in the past changed hydrological, hydrographical or chemical conditions in the watershed of Lake Hafslovatnet resulted in increased plant growth?**
   H3.1 The parameters pH, oxygen, turbidity, secchi depth, 'fargetall', conductivity, temperature and nutrients like phosphour, iron, silica, and nitrogen have changed after the regulation of Lake Hafslotvatnet and Lake Veitastrondvatnet in 1983.

   H3.2 The deepening and straightening of Storelvi and Heggestadelvi in combination with extensive draining of the farmland in the Veitastrond area between 1960 and 1990 changed the parameters turbidity and the concentration of iron (Fe) in the rivers feeding into Lake Veitastrond and subsequently into Lake Hafslovatnet.

   H3.3: Human alteration in the water system between Lake Veitastrondvatnet and Lake Hafslovatnet by building a dived tunnel (around 1983), allowing subsurface water from Lake Veitastrondvatnet to bypass the natural surface water outflow to Lake Hafslovatnet, thus possibly changing the parameters temperature, density, nutrients and turbidity in the water flowing into Tverrbergvatnet Straumavatnet and Lake Hafslovatnet.

   - H3.3.1 With a dived (ca. 1-7 meter below normal water level in Lake Veitastrondvatnet.) water tunnel instead of a natural surface outlet, water below the surface and partly below the euphotic zone in Lake Veitastrondvatnet will be passed through, resulting in colder water, a higher turbidity and possibly higher nutrient transport to Tverrbergvatnet, Straumavatnet and Hafslovatnet.

   H3.4: Regulation changed the normal height fluctuations in the lakes Hafslovatnet and Veitastrondvatnet and thus changed hydrographical, hydrological and chemical conditions in the watershed like water level, water flow, surface area, beach erosion, turbidity, Secchi depth and possible nutrients by erosion

   - H3.4.1 Regulation changed the hydrographical conditions water level, stream velocity and surface area
   - H3.4.2 Regulation changed the hydrological and chemical conditions temperature turbidity, secchi depth and nutrients
   - H3.4.3. The regulation has caused increased beach erosion in Lake Veitastrondvatnet, Lake Tverrbergvatnet, Lake Straumane, and possibly Lake Hafslovatnet

2 Background information

2.1 The watershed of Lake Hafslovatnet

Here the area belonging to the watershed of Lake Hafslovatnet is briefly described, from the start of the main water source to its end in the fjords.

2.1.1 Geographic location

The watershed of Hafslovatnet is located in the county Sogn og Fjordane in western Norway. The total size of the watershed is around 451km^2. Here streams, rivers and lakes all discharge water (precipitation and meltwater) into the fjords. From the fjords the water is transported to the open sea.

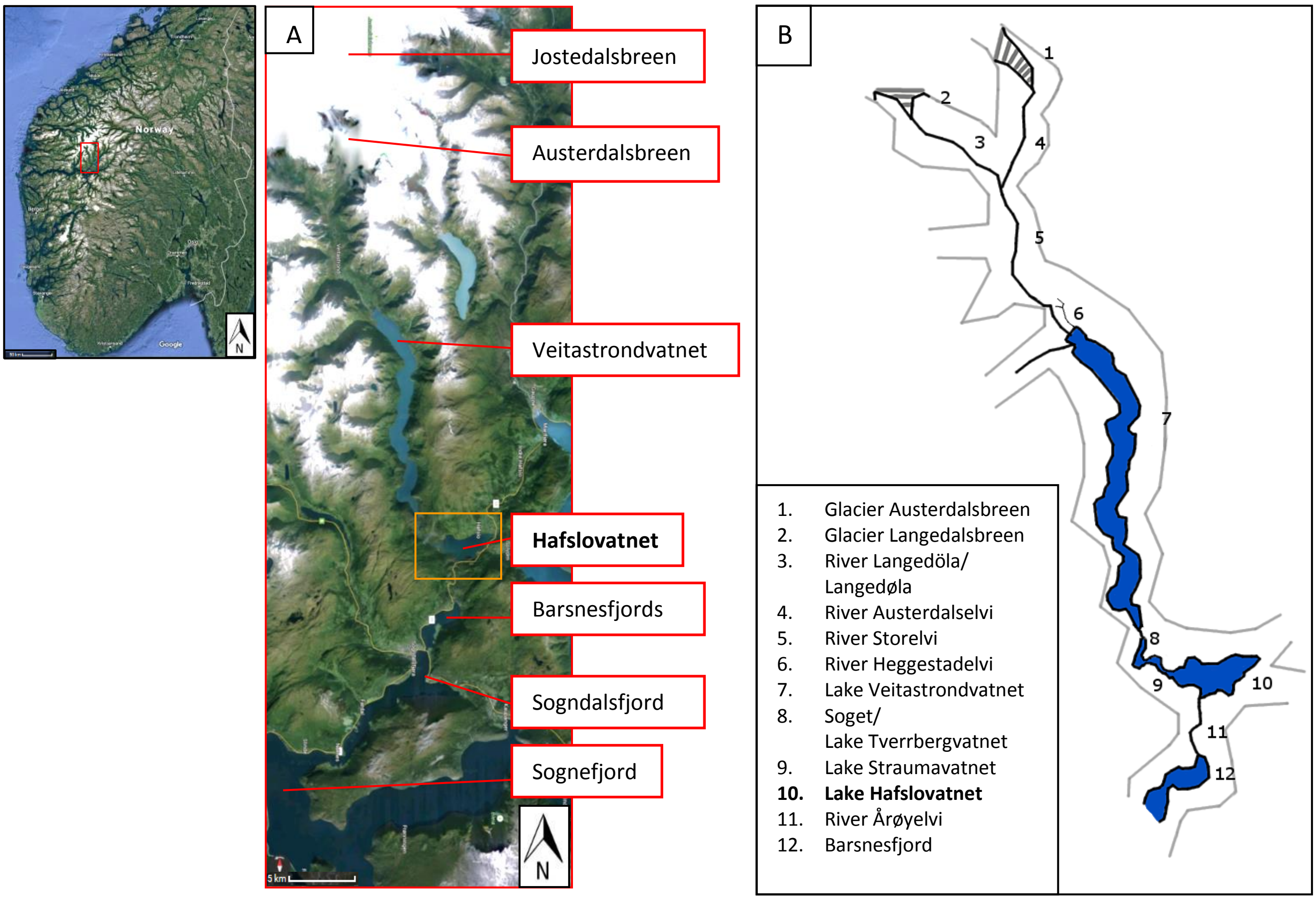


Fig. 3 Satellite (A) and schematic (B) overview of the whole water system of Lake Veitastrondvatnet and Lake Hafslovatnet. The area lies in West Norway along the Sognefjord. Satellite image retrieved from Google maps 2016 on 20-12-2015

2.1.2 Description

The main source of the watershed starts at the Jostedal ice cap (called Jostedalsbreen). It is the largest main land glacier of Europe and covers an area of 474 km^2. From Jostedalsbreen glacier arms reach into the valleys (Anonymous (2)). One of these side glaciers is the Austerdalsbreen (1). This glacier has two glacier arms called Odinsbreen and Torsbreen, and one interrupted glacier arm which has the name Lokebreen (Wikipedia (2), 2016). Meltwater from the Austerdalsbreen leaves the glacier at the front. The amount of water is big enough to form the river Austerdalselvi (4). At the end of the valley, Tungastølen, the Austerdalselvi meets the Langedøla river (3). This river contains meltwater from the

Langedalsbreen (a strong interrupted glacier) and has different water properties.

Table 2 Translation of common Norwegian words in names

Norwegian water names in a nutshell	
Breen	Glacier
Vatnet	Water (lake)
Elvi	river

The combined rivers continue as the Storelvi (5) which eventually flows past the village Veitastrond into Lake Veitastrondvatnet. A second rain fed river (Heggestadelvi, 6) is flowing through farmland and the town before it enters Veitastrondvatnet as well (fig. 4). Changes to both rivers have been made. The once meandering Storelvi has been deepened and made straight around the area of the village. For over 5640 m has been worked on in phases between 1962 and the 1990'ies (I. M. Slinde pers. comm. 2015). Beside this, the river was reinforced with a dike to improve protection of the village against floods. Water from farmland is drained into Heggestadelvi. Possible lowered ground water levels could have caused extensive draining of iron rich water into the river.

By altering the river and controlling the water level around the farm land, deep ground water wells up alongside the land and is transported to the river. The river shows a strong coloration which looked like oxidised iron (fig. 5).

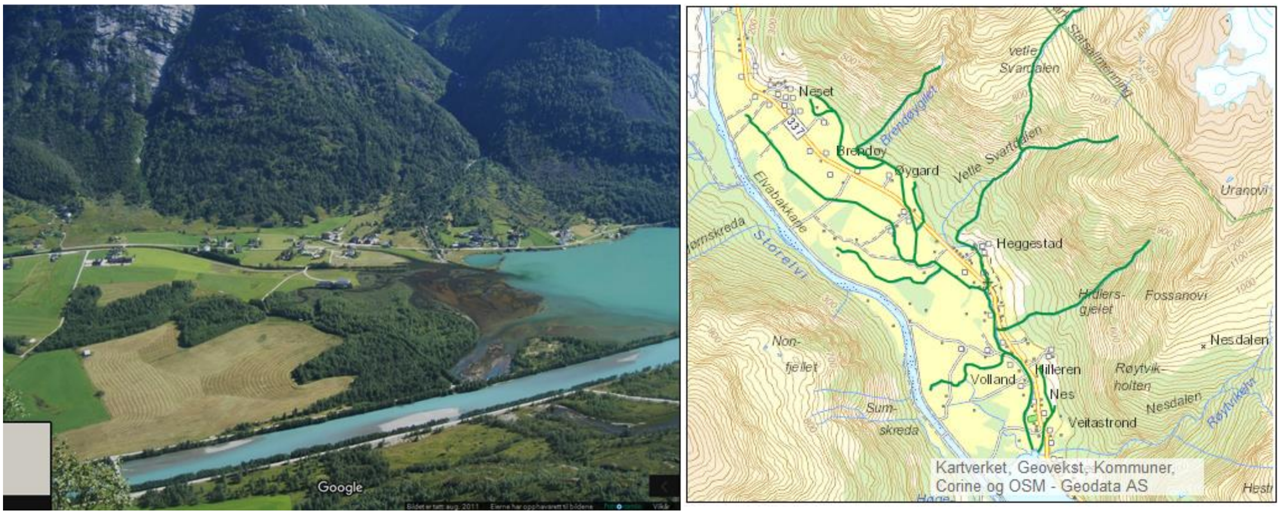


Fig. 4 Heggestadelvi (brownish, add arrow) and Storelvi (add arrow) both flowing into Veitastrondvatnet. Right fig.: Heggestadelvi and its tributaries highlighted in green. Left: retrieved from Google maps 2016 on 20-12-2015. Right: (Vann-Nett, 2017) In between the outlet of Heggestadelvi and Storelvi one may see the old delta

Fig. 5 Left fig.: Impression of Heggestadelvi and farmland at Veitastrond. Middle and Right picture were taken at the bridge. Middle and right fig.: Both showing the color of oxidized iron and settled material on plants growing along the river (own pictures)

Lake Veitastrondvatnet (7)

Fig. 6 Dam at outlet Veitastrondvatnet

This lake is a deep, narrow (1.2 km) and long (19 km) lake surrounded by mountains. It lies 172m above sea level. It is an oligotrophic lake with high turbidity. It receives glacial melt water and precipitation. Both sides of the lake have mostly rocky shores. Veitastrondvatnet is regulated at a level of 171 m a.s.l. and the height is allowed to vary 2.5 meter (Schedel, 2015). The town Veitastrond is situated north of the lake alongside the Storelvi. Situated on river sediments and old glacial floodplain its soil is fertile and used for livestock and grass production. Water from Veitastrondvatnet flows through the connecting lakes Tverrbergsvatnet (8) and Straumavatnet (9) before it enters Lake Hafslovatnet. At the outlet of Veitastrond (called Soget), a dam was put with an overflow system and a tunnel underneath (see fig 6). Outgoing water can be regulated in the tunnel itself. (see appendix 8.13 for a depth contour map)

Lake Hafslovatnet (8)

Compared to Veitastrondvatnet, Hafslovatnet is a shorter (5.5 km) but wider lake (1.8 km) (Søhoel, 2010). This lake also has oligotrophic conditions. It lies 168 m above sea level and is regulated at a level of 169 m with 1.5 m variation (Schedel, 2015).The water from Veitastrond enters in the western part of the lake. This area has also been assigned as a sanctuary for birds in 1991 (Larsen, 2001). At the eastern side lies a town called Hafslo. At the south-west part of the lake the water is used for the production of electricity. Before the hydroelectric power plant was built in 1983, the water ran through the Årøy-river into the Barsnesfjords. Now most of the water is gathered at the beginning of the river and directed to large water turbines through a tunnel. In front of the water inlet the water depth is shallow (±1-1.5m), letting only the surface water enter into the tunnel. The temperature in the water running through the turbine thus roughly represents the temperature in the surface waters of Lake Hafslovatnet.

In the figure below a more detailed map of the lake is shown (fig. 7).

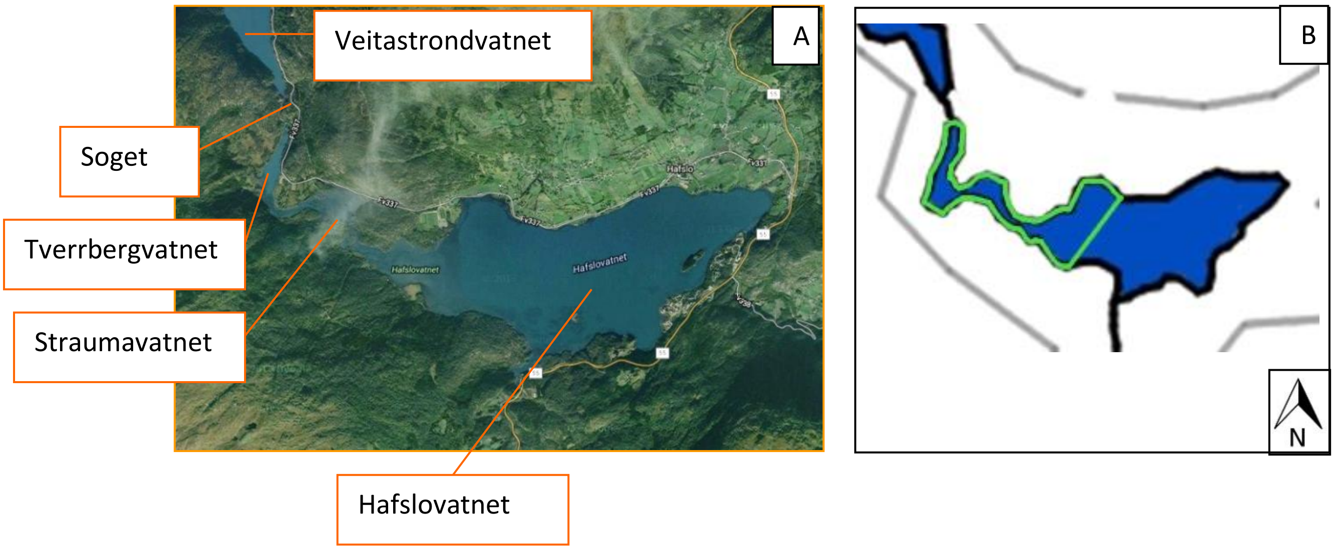


Fig. 7 Satellite (A) and schematic overview (B) of the area. In green the contour of the bird protection area is shown. Satellite image retrieved from Google maps 2016 on 20-12-2015

The depth contour lines of Hafslovatnet (fig. 8) show that at the inlet of the lake in the west the water depth is very shallow (1-3 m) as well as at the outlet in the south. Further to the east the depth increases with a steep gradient to a maximum of 80m. After that, there is a large area with depths between 30 to 60m. Along the edges the water is shallow. However at the north side of the lake there are quick steeper gradients in depth than at the south. Another detailed depth contour map can be found in Appendix 8.13

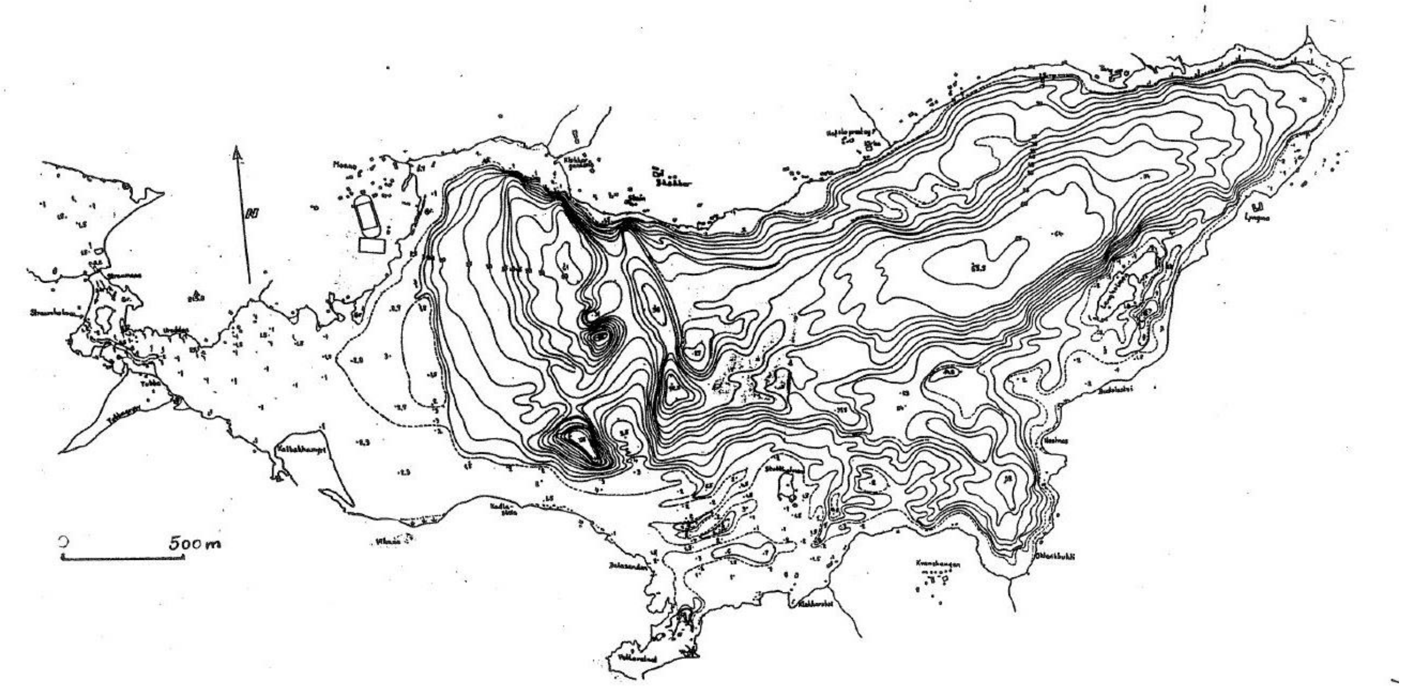


Fig. 8 Depth contour map of Hafslovatnet (Mjelde, Brandrud, & Lindstrøm, 1992)

Barsnesfjords, Sogndalsfjord and Sognefjord

The freshwater from Lake Hafslovatnet enters the fjord system at the Barsnesfjord. It consists of two basins; the Inner and Outer Barsnesfjord. The two basins are separated by a threshold (underwater ridge).They are connected to the Sogndalsfjord, which runs along the town Sogndal. Later it flows over in the Norafjord (small part, but most Norwegians call it still Sogndalsfjord) and at last connects to the main Sognefjord.

Fig. 9 (A) Glacier Austerdalsbreen with Odinsbreen (left) and Torsbreen (right). (B) Storelvi with meltwater from Austerdalsbreen. (C) Meeting point between meltwater from Austerdalsbreen and Langedalsbreen (own pictures)

Fig. 10 (A) Impression of lake Veitastrondvatnet. (B) Lake Hafslovatnet seen from Lyngmo camping to the east. (C) Lake Hafslovatnet in eastern direction (own pictures)

2.2 Activities around Lake Hafslovatnet

Land use

In the area of Hafslovatnet and Veitastrondvatnet there are a lot of farms. Along Hafslovatnet there are seven registered farms, whereof four are producing milk. There is almost no grass production and no registered use of pesticides (Anonymous (1), 2000). Within the last 50 years effects of increased nutrient input were noticed in Norway and action was taken to reduce the use of for example fertilizers.

Drinking water

Besides recreational use of the lake the town Hafslo also withdraws water for drinking water use. Per day 2400 m^3 water is extracted from the lake (about 0.028 m^3/s). Before it is used by the inhabitants of Hafslo, the water is treated to ensure a good quality (Anonymous (1), 2000).

Hydroelectric power production

Norway has a lot of opportunity to collect energy from hydroelectric power plants. High amounts of precipitation and natural height differences from mountains create chances to use hydroelectric power production. Since 1943, Lake Hafslovatnet has been regulated to enable energy production. The electricity is generated by a hydroelectric power plant (4 GW) at the outlet of Hafslovatnet (Årøy river). Rørslett describes in his paper that from late October to the end of April the water was blocked by a special non-permanent structure to hold the water. In the other months the water could follow a natural pattern (Rørslett, Hvoslef, & Faafeng, 1986).

Since 1983, a second and larger plant was set up with two bigger turbines. Combined they produce around 350 GWh per year. This power plant almost does not use any extra water storage for its production, however water level regulation of Hafslovatnet (1.5 m) meter and Veitastrondvatnet (2.5 m) is taking place all year round. Because the power plant only has the lakes as it reservoirs, it still depends on the seasons (high water availability in summer, low in winter). This type of power plant is therefore called a river hydroelectric power plant. The electricity production process itself can also not be stopped as new water comes into the water system almost continually. If the water input is too high, the extra water can be released through the old Årøy riverbed. The 1.6 km long tunnel from the lake until the outlet is not reaching the fjord directly. Instead the last bit of the river was kept for salmons to enable them to swim further inland (Årøy Hydroelectric water power plant pers. communication).

2.3 Identified problematic aquatic plants in Lake Hafslovatnet

In general

Aquatic plants are plant species that are adapted to live in soils saturated with water, half in the water or totally submerged. Based on this morphological principle there are six separate types: Amphiphytes, Isoetids, Elodeids, Helophytes, Nymphaeids and Pleuston.

The Amphiphytes can live both above the water line and submerged beneath the water surface whereas Isoetids can only live beneath the water surface during their life cycle. They are connected by roots to the water bottom. Similar to Isoetids are the Elodeids, except their flowers will rise above the water surface. Helophytes also have roots that attach them to the bottom, but have leaves above the water surface. Nymphaeids are similar to Helophytes but their leaves are floating on the water surface. The last group, called Pleuston, do not use/have roots and float freely over the water surface (Westlake, Květ, & Szczepański, 1998) . Evensen, who described the vegetation in the watershed of Hafslovatnet, mentioned four of six types: Isoetids, Elodeids, Helophytes and Nymphaeids (Evensen, 1981). The four most mentioned species in papers are discussed below. Pictures can be seen in fig. 11.

Callitriche hamulata

Callitriche hamulata falls under the elodeids (Evensen, 1981). It likes to grow at sunny to slightly shaded places in bright fresh water. Low water temperatures are favoured and the water has to be slightly acidic. Both still as well as flowing water is no problem, however Evensen found them mostly at locations with running water. *Callitriche hamulata* prefers oligotrophic to mesotrophic conditions. Furthermore the soil it grows on is sand or a mix between sand, silt and clay (Dijkstra (1), 2017).

Juncus bulbosus

Juncus bulbosus is also sometimes mentioned as *Juncus suspinus (synonym)*. This species can be classified within the Amphiphytes as it is known to grow both on land as well as in water. On land it needs wet, nutrient poor and acidic soil. In the water it favours shallow fresh water and can both be found in still water as well as in flowing water. (Dijkstra (2), 2017).

Depending where *Juncus bulbosus* grows, the forms can be morphologically very different. It has a thick bottom and several leaves which are formed in a rosette. When forming new sprouts, a new rosette with leaves grows out. The growth rate can be very high and it is able to form large clusters of plant material (Moe, Edvardsen, Mjelde, & Friberg, 2015).
Thorough statistical research by Hindar, Johansen, Andersen and Saloranta in 2003 concluded from a variety of different factors that flow speed is the most important factor influencing the degree of cover by *Juncus bulbosus*. The second most important factor was that an independent time trend explained a lot of the found variations between factors. Other factors that were found to possibly influence the cover were: summer temperature of both air and water, amount of organic carbon and the water level itself. *Juncus bulbosus* grows well both at a low flow rate (<10 cm/s) and at a high rate (~50 cm/s). In order to grow well, it has to attach its roots in sand/pebble or finer material (mud). When the plant has optimal growing conditions, the growth rate can reach up to 1 m per year. Its optimum depth is 0.5-1.5 meter, but can also be at 2.5-3 meters deep. They are perennial plants but can die if they get frozen. Because the species is able to grow at low light intensities, it can have a long growing season in Norway. It prefers low pH values but can also survive at higher values. NH_4 is the best N-source for *Juncus bulbosus*, because together with CO_2 it has the best growth results. Even

with low P concentrations it is able to form large clusters and generate a high amount of biomass (Hindar, Johansen, Andersen, & Saloranta, 2003).

Myriophyllum alterniflorum

Myriophyllum alterniflorum falls under the Elodeids (Evensen, 1981). It grows at sunny places in mostly bright, shallow fresh water. The conditions are preferred to be slightly acidic. Still and flowing water are both places where *Myriophyllum alterniflorum* can grow. However, Evensen (1981) found this plant mostly in still waters. It prefers mostly oligotrophic but can be found in mesotrophic conditions as well. The soil must mostly consist of sand (Dijkstra (3), 2017).

Sparganium angustifolium

Sparganium angustifolium falls under the Nymphaeids (Evensen, 1981). It likes to grow at sunny places in shallow, fresh water in slow moving streams. It prefers slightly acidic and mesotrophic conditions. They favour soil that consists of peat or peaty sand. (Dijkstra (4), 2017)

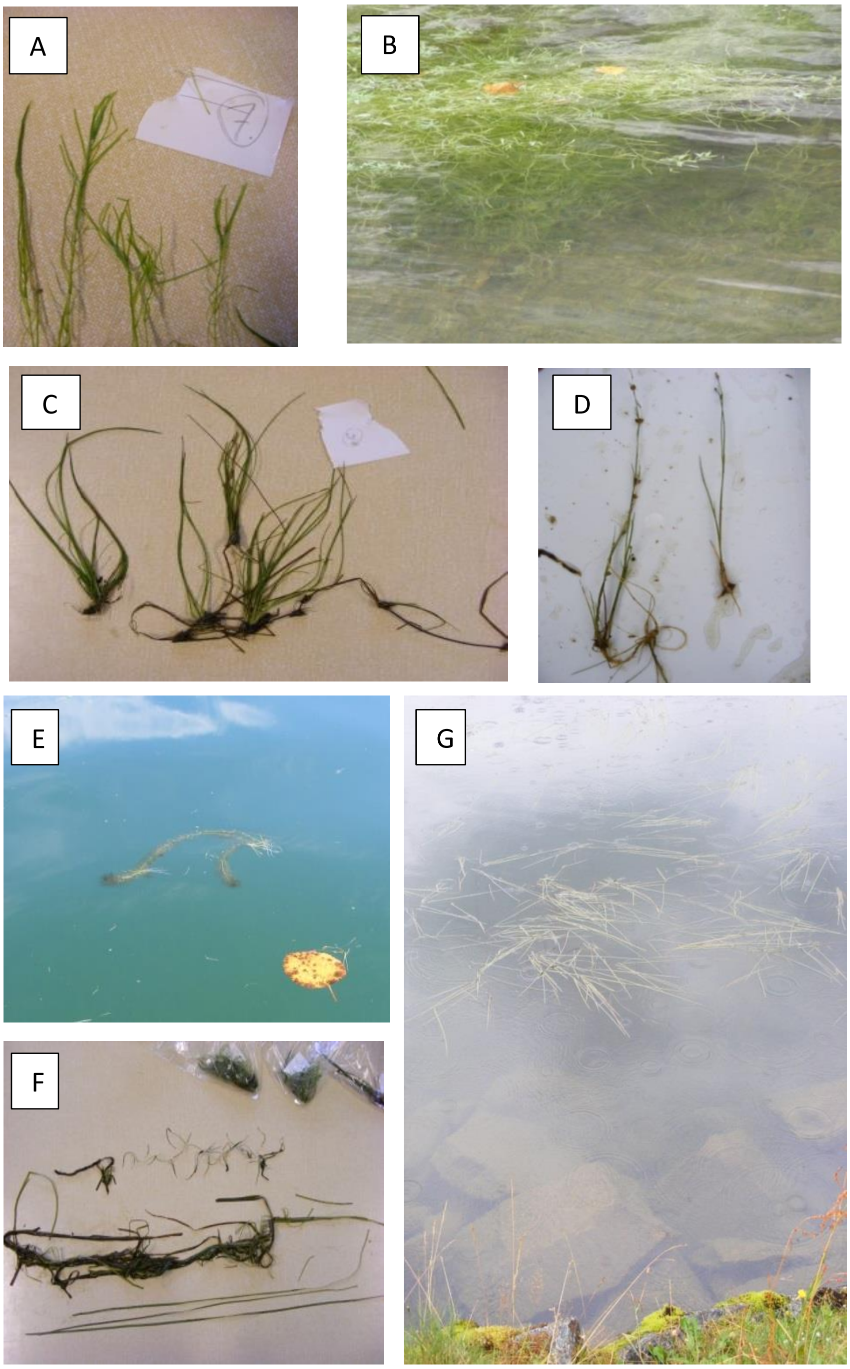


Fig. 11 Pictures of: A. *Callitriche hamulata* (October) B. *Callitriche hamulata* in the water at Tverrbergvatnet (October) C. Juncus bulbosus, found floating along Straumane edge (October) D. *Juncus bulbosus*, found floating in Hafslovatnet (August)
E. *Myriophyllum alterniflorum* (September) found floating in Hafslovatnet F. *Sparganium angustifolium*, found at Straumavatnet (October) G. *Sparganium angustifolium*, found in Lake Hafslovatnet (August). Size of plants in A, C and Dca 10-20 cm. In B the yellow fig.s are birch leaves of ca 4-5 cm size.

3 Material and Methods

3.1 Literature research

The material and methods used can be divided into two parts. The first part of the thesis is based on results from a literature research. A lot of different papers were collected with various subjects about lake conditions, history and field research of Hafslovatnet and other lakes and rivers upstream. The goal was to create an overview of available data and information which was used as a basis for the research questions. A great part of the acquired papers were investigations into the fish population of the lakes and contained interesting data about the hydrology and chemistry of the investigated water systems. The complete dataset with its sources can be found in the appendix 8.8 to 8.11. Other papers focussed on the plant growth problem, investigated growth conditions of *Juncus bulbosus*, sediment rates and papers about glacier movements between Sogndal and Jostedalsbreen.

In table 3, a short summary of all data that was provided for the thesis is given with a short description of the author/organisation and a short description of what kind of data. All data from papers are referred to in the appendix and bibliography:

Table 3 Overview over provided data and their sources

Author	**Name dataset**	**Description**
Høgskulen i Sogn og Fjordane, "From mountain to fjord" courses 2008-2015, under supervision of M. Paetzel and T. Dale, unpublished	CTD data: 2008-2015	River surface + lake hydrography (**+ B. Deventer**)
Høgskulen i Sogn og Fjordane, excursions Norwegian students, unpublished	Utefag Hafslo 2010 Utefag Hafslo 2011	Hydrological data of two Norwegian excursions
NVE (Norges Vassdrag- og Energidirektorat) – R. Løland	Waterlevel 1900 – 2015 Waterflow – Graph	Water level Waterflow
NVE/Sognekraft Årøy kraftverk	Temperature Årøy 1985-2015	Temperature at outlet power plant
Luster kommune, Va-ingeniør I.M. Slinde	Chemical analysis drink water production Veitastrondsvatnet and Hafslovatnet	Water chemistry
Eklima (2014)	Homogenized air temperature	Datasets from weather stations close to the research area

3.2 General conditions

Hydrological parameters

A CTD device (Conductivity, Temperature and Depth meter) was used for a continuous vertical measurement from surface to bottom. The CTD (model SD 204, SAIV A/S) measured depth, temperature, conductivity, density (is noted in sigma-t. Density is (sigma-t value / 1000) + 1.000 = density in g/cm^3), sound velocity, chlorophyll a, oxygen (saturation in %) and turbidity.

With the Rutner water sampler loose measurements of 2, 6, 10, 25 and 35 m deep were sampled. Of those samples, the temperature (thermometer), oxygen levels (OxyGuard Handy Delta), pH (PHM 80 portable pH meter) and the conductivity (ATC HI 3291, Hannah Instruments) were measured. Turbidity samples were collected in brown bottles which were determined later with a spectrophotometer at the laboratory. At the same location the Secchi depth (Secchi Disk) was measured. All the mentioned hydrological parameters were taken in the surface water bodies from Austerdalsbreen to Lake Hafslovatnet. Table 4 shows all locations and their station numbers. The location of station 1 was at the same location as used in the horizontal structure measurements (explained in the following section).

Table 4 Explanation of the measurement stations of hydrological parameters

Name	Station
Glacier Austerdalsbreen	Station 1
River Austerdalselvi (Tungastølen)	Station 2
River Langedøla (plain above bridge)	Station 3
River Storelvi (below bridge)	Station 4
Lake Veitastrondvatnet (surface)	Station 5
Lake Hafslovantnet (Surface)	Station 6

The oxygen probe of the CTD requires daily calibration of the electrode in order to guarantee accurate measurements. This was not done and therefore many of the oxygen values are in general probably showing somewhat too low or too high values. But relative values still show correct values, meaning higher concentrations in the surface layers and some lower at deeper depths (T. Dale pers. Communication). The density in the CTD graphs are noted in Sigma-T. This is a numerical simplification to express the density. The formula is as follows:

Sigma-t: (Density (g/cm^3) -1.000) x 1000

An example would be a density of 1.027 g/cm^3, which would result in a sigma-t of 27. A density below 1.000 results in a negative sigma-t (T. Dale, personal communication).

Horizontal structure of the hydrography in Lake Hafslovatnet

For the horizontal cross-section 5 locations in Lake Hafslovatnet were sampled (fig. 12). At Station 4 five measurements were taken (Table 5). This station was planned to be at the location where the depth of the lake reaches up to 89 meters deep, to investigate conditions at the deepest part. During the fieldtrip this location could not be found after 5 attempts. The deepest at Station 4 was chosen for the analysis.

A generalized visualisation of the cross section, based on the CTD graphs was made to illustrate differences between the stations. In order to draw, it the values were categorized and assigned colours. This categorization was based on the highest and lowest measured values and divided by the amount of desired categories (11). Per category, the temperature covers a rise of 0.5 °C, the turbidity a rise of 0.2 FTU and the chlorophyll a 0.6 µg/l. After determining the categories, each got a specific colour ranging from purple (low) to dark red (high).

Table 5 Table with the locations and GPS labels of the stations. Red stations were not used in the analysis of the thesis.

Station	Latitude	Longitude	Date
Station 5	61,30471836	7,14580631	29-9-2015 11:13
Station 4	61,30135562	7,16080531	29-9-2015 12:21
Station 4	61,30128228	7,16003601	29-9-2015 12:38
Station 4	61,30095673	7,16308141	29-9-2015 13:00
Station 4	61,30020973	7,15851889	29-9-2015 13:21
Station 4	61,30047267	7,16090513	29-9-2015 13:40
Station 7	61,29658540	7,16953657	29-9-2015 14:27
Station 2	61,30405895	7,18576997	29-9-2015 15:10
Station 1	61,30831235	7,20494776	29-9-2015 16:23

Fig. 12 Measurement locations in Lake Hafslovatnet. Lines indicate the stations and orientation of the horizontal cross-section with the CTD (Google Maps, 2015)

3.3 Climate in the area surrounding Lake Veitastrondvatnet and Lake Hafslovatnet.

The air temperature dataset of weather stations was requested from Eklima (Norwegian Meteorlogical Institute, 2016). There were no stations within the area of the villages Hafslo, Veitastrond or the lakes. Therefore stations further away had to be selected. Beside the distance from the area, also the altitude was chosen as a criteria. The altitude of Veitastrondvatnet is 172 m and Hafslovatnet 168 m. There were no close stations which had a similar altitude. Therefore of the four stations two had to have a low altitude and two a high altitude. The last criteria was the time of operation, as in the 1980s the problem was noticed. In fig. 13 the four chosen stations are given.

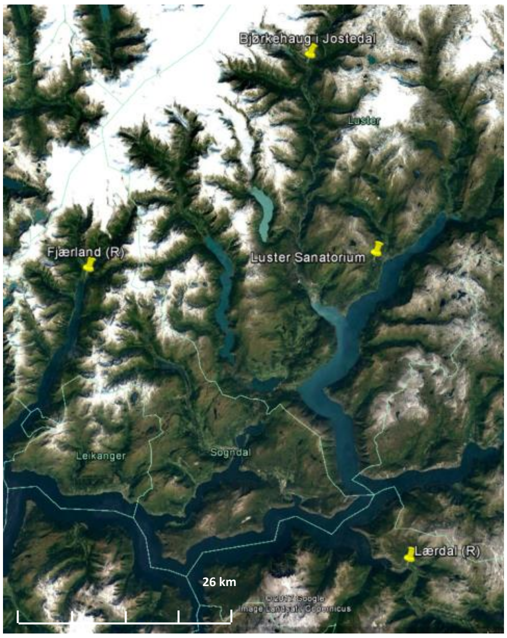


Fig. 13 The yellow dots indicate the location of the stations. (R) means reconstructed time series
* the data was until December 2015 instead of 2009 which was given with the dataset

Table 6 (Below) Information chosen weather stations

Stations				
St.nr.	Name	Operates from	Operates until	Altitude
54110	LÆRDAL (R)	1869	2009*	2
55820	FJÆRLAND (R)	1921	2009*	3
55430	BJØRKEHAUG I JOSTEDAL	1963	2004	305
55350	LUSTER SANATORIUM	1901	1973	484

Table 6 contains information of the chosen stations. The '(R)' stands for reconstructed station time series, meaning that for both locations, more than one station was combined into one dataset. The temperature values in the dataset were given every month per year and were homogenized. That means that the datasets of the stations were corrected for non-climatic changes like relocation of the station or changed measurement instruments (Wikipedia, 2016). The data range starts from 1950 and reaches until 2015. Because the monthly values per year resulted in an unclear graph, it was decided to summarize the monthly values to values per year.

The water temperature data set was provided by the owners of the Årøy power plant: A/S Sognekraft. The measurements were taken just after the outlet of the power plant. The dataset can say something about the conditions of Hafslovatnet because the inlet of water to the power plant is at the transition from the lake to the old Årøy riverbed. Knowing from the depth contour lines that the area is shallow (circa 1 - 3m) mainly surface water is entering the power plant. Since the start of the hydroelectric production the water temperature was measured, providing a dataset from 1985 until 2015. The measurements are daily but some periods have some small gaps. For the results the values were summarized per year and per month for every year to better visualize possible changes in temperature. In appendix 8.1 a correction table is shown for the yearly values. If there were more than 100 missing days the year was removed from the analysis. For the monthly summarized values the same principle was used, but then the maximum was set on a maximum of 20 days per month. Those values were not removed, but the missing days were plotted in a graph (appendix 8.2).

3.4 Hydrological and chemical parameters

Observations on various parameters that were found in many papers and unpublished reports that were used in this thesis are summarized in table 7.

While searching papers for data a lot of times the parameter “Fargetall” in mg Pt/l. was often mentioned. It is described as a colour scale that measures the amount of humus (which gives a yellow to brown colouration in the water), iron and manganese (CICERO, et al., 2008). The colour is compared to standard coloured glass discs which stand for different colour scale numbers or to standardized dilution potions. The description those of APHA Colour or Hazen scale which is based on Pt/Co solutions (Hunterlab, 2015). In this thesis the word colouration is used with mg Pt/l as unit. For statistical analysis the NO3 values where recalculated to N-NO3 values.

Table 7 Overview of the measurements of various parameters found in papers and unpublished reports, as well as measured during field work

Part	
Hydrological parameters	**Chemical parameters**
Temperature	Orthophosphate (P – ortho)
pH	Total phosphor (P – total)
Oxygen (mg/l and %)	Nitrate (NO3)
Conductivity	Sulfate (SO4)
Colouration (mg Pt/l)	Calcium (Ca)
Turbidity	Silicon (Si)
Secchi depth	Iron (Fe)
	Magnesium (Mg)
	Sodium (Na)
	Potassium (K)
	Aluminium total reactable (Al - tot. reactable)
	Aluminium

3.5 Statistical analysis

For the analysis two tests were run according to the paper (Hobæk, et al., 1998). A non-parametric (seasonal and non-seasonal) Mann-Kendall test and a change point analysis test.

The **Mann-Kendall test** – Is a non-parametrical test used to identify a trend in a series even if there is a seasonal component in the series (Addinsoft, 2017). When the dataset contained data present in all months and contained multiple years, the seasonal trend test was run. If this was not the case, the non-seasonal trend test was run instead. Both tests used a continuity correction. When data is binominal (not continuous) instead of nominal (continuous) this correction can be used to approximate a normal distribution (Weisstein, 2017). The outcome (change P) is two tailed.

The datasets were tested two times. The first time all the measurements were included in the test while the second time only measurements from zero to six m deep were taken. In this way changes at the surface, where the plants are growing, are taken into account. Assumed was that plants grow from zero to three m deep and have to deal with a varying water level between 0.8 and 1 m. But not only plants but also other small organisms like algae are influenced by changes on hydrology and chemistry level. Most of the photosynthetic organisms are mostly in the photic zone. The average secchi depth over all the years was 5.6 meter. Therefore a depth from zero to six m was chosen.

The **Change point analyzer** (version 2.3 on http://www.variation.com, Taylor Enterprises 1997-2016) detects if a change in the analysed dataset took place. As result a table and a graph is produced. In the graph with blue back grounds the detected changes are shown. In the table a lot more information is given (see table 8).

Table 8 Explanation and example of the results table when completing a change point analysis with the analyzer tool

Titles	Year	Confidence interval	Confidence level	From	To	Level
Meaning	Estimation of year when change happened	Confidence interval for the time of change	How confident is the analysis that the change actually occurred	Prior to the change the average temperature was	After the change the average temperature was	Indication of the importance of the change lv 1 means change has been detected first and is the best visible in the plot figure.
Example	1962	(1953, 1970)	97 %	5.2442	4.6612	2

Significance tests were based on the same settings as the paper of Hobæk, et al and the standart setting of the Change point analyser to use Bootstraps (1000 times) without replacements with MSE Estimates (Hobæk, et al., 1998). The confidence level was 95% before detected changes were included in the table.

4. Results

4.1 Present conditions in the water system

Before the climatic and historical data are discussed, first it is important to get a general overview of present conditions in the water system to be able to compare data later on. First Lake Hafslovatnet is discussed before following the stream upwards to Lake Veitastrondvatnet and the rivers up to the glacier Austerdalsbreen.

4.1.1 The general vertical structure of the hydrology and chemistry of Lake Hafslovatnet

To see what a general structure in summertime is like, a graph was made with the results of a CTD measurement (of 2015) in the north east part of Lake Hafslovatnet. The different parameters (temperature, oxygen saturation, turbidity, chlorophyll a and density) are plotted against the depth. The change in parameters can give information about how the lake is behaving from the surface to the bottom.

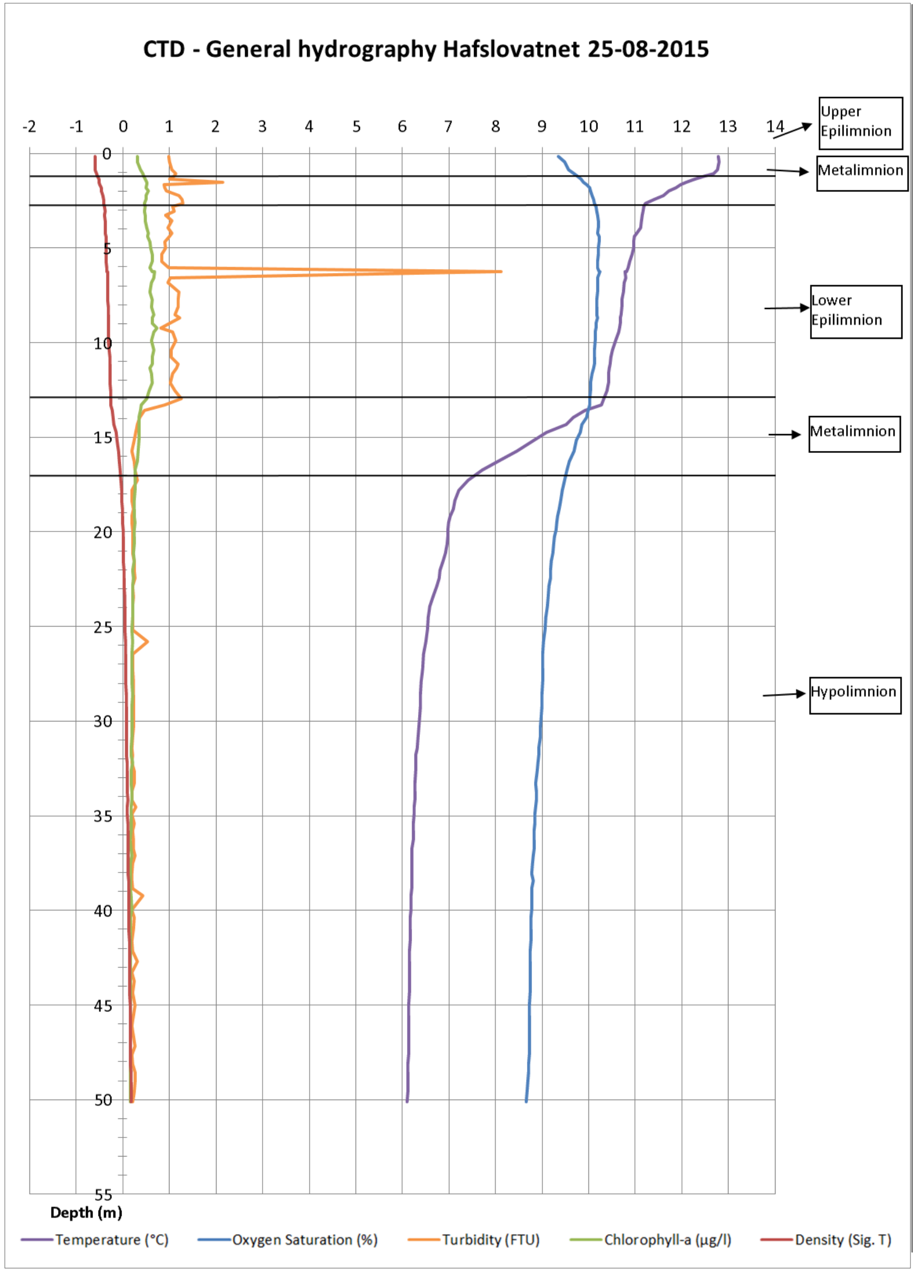
In the figure below (fig. 14) one of the results from CTD measurements is presented. Looking at the graph and its plotted parameters, it seems that there are several patterns present. The first parameter, temperature, starts around 13 °C and drops in two steps; first to 11 °C and then to 7 – 6 °C. Likewise, the density is increasing in two steps. However the pattern of the density is not as clear as the temperature. In the right figure the pattern is made more visible as only the density is shown.

In this figure the density follows a similar pattern as described at the parameter temperature. A decrease in temperature means an increase in density. In the graph two increases are clearly visible. Both parameters point out that a stratification of the lake in 2015 is present: an upper epilimnion, a metalimnion (both thermocline (temperature) and pycnocline (density) are present), a lower epilimnion and a second, but less clear metalimnion. They are all above the hypolimnion, the lowest layer in a stratified water mass.

While keeping in mind that the oxygen values are likely to be lower (discussed in the methods) the pattern of oxygen saturation starts around 95% and increases at the same time the temperature decreases. In the lower epilimnion both temperature and saturation levels are stable and reach above 100% (between 100-102%). If photosynthesis is stronger than the respiration or is leaving the specific depth, a saturation of over 100% can be achieved.

The next parameter, turbidity, has a higher FTU level until it reaches a depth of approximately 13/14m. After this depth the FTU drops sharply to almost zero. Levels of chlorophyll a start lower at the surface and increase a few meters deeper. It has a higher concentration until 13 meters before the concentration lowers.

The CTD measurements X showed that patterns were present and parameters could be related to each other: temperature and density, temperature and oxygen, turbidity and chlorophyll a and the oxygen and the chlorophyll a concentration.



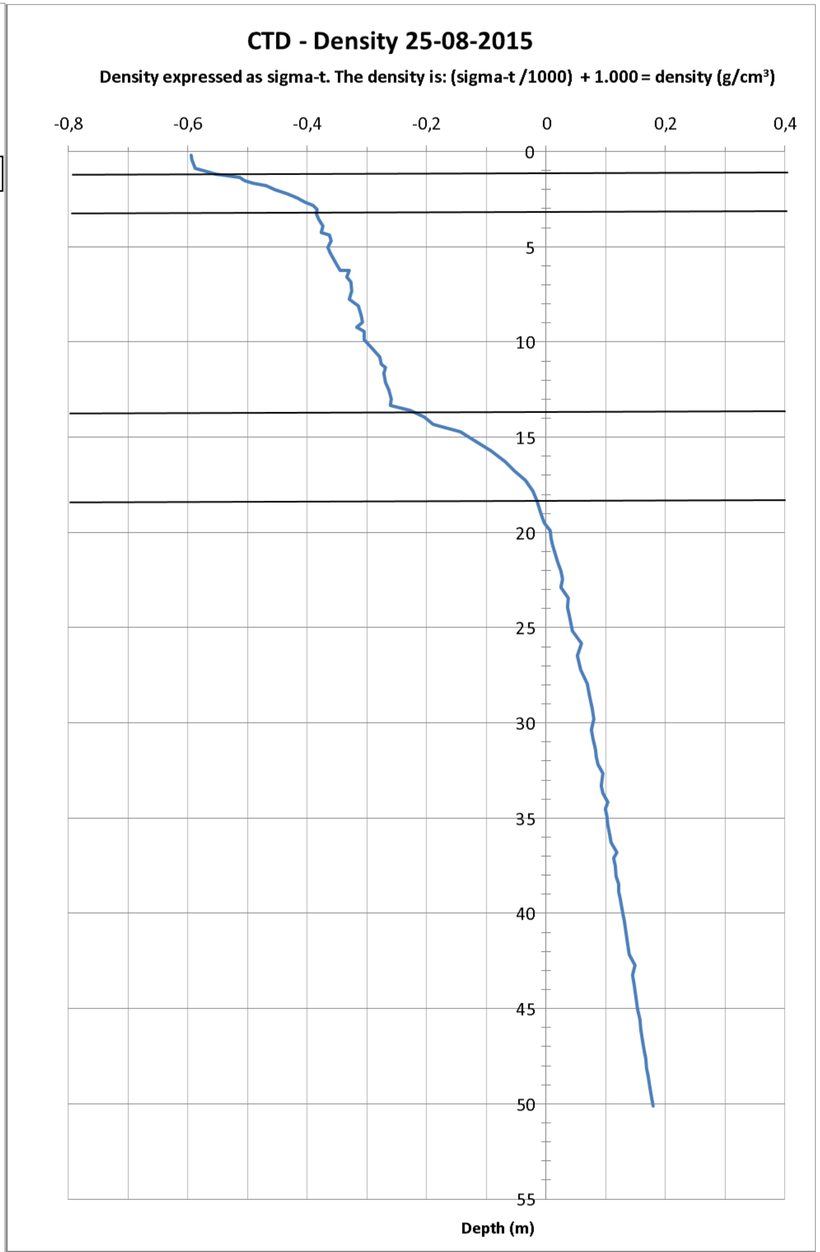


Fig. 14

Left fig.:
CTD graph of Hafslovatnet close to Lyngmo camping. The temperature, oxygen saturation, turbidity, chlorophyll a and the density are shown. The oxygen must be multiplied by ten to get the actual saturation

Right fig.:
CTD Density graph which is expressed in sigma-t. To get to the density (g/cm^3) divide sigma-t by 1000 and add 1.000

(M2F HISF 2015)

4.1.2 Lateral variations of the hydrography of Lake Hafslovatnet

In order to understand if the observed patterns of fig. 14 are similar at different locations, some additional samples were taken during a second field trip (see Methods). This section is divided into two parts: The cross –sections from east to west and from north to south. Per part the separate CTD measurements per station are presented first and subsequently a figure is shown which visualizes differences between the stations.

Cross-section: from east to west

Both Station 1 and Station 2 (fig. 15) had one of the deepest CTD measurements: 50 m and 53 m respectively. Their graphs show similar results for the parameters temperature, oxygen, chlorophyll a and turbidity. The temperature drops quickly in the first few meters before the decline becomes less steep. Between 15-20 m there is a second metalimnion before it almost levels out. Both oxygen saturation levels slightly increase before they slowly decrease again. The chlorophyll a concentration is high in the first 10-15 m after which it drops to almost zero. The turbidity slowly rises until 17 -20 m before it drops to a low level.

At station 4 the measurement reached 37 m below the water surface. This location has shallower water depth than the other stations. The temperature has a less pronounced transition between 0 and 2 m but the second metalimnion is coinciding with the other two stations. The oxygen saturation has a similar pattern. The chlorophyll a starts to increase later and drops at a deeper depth. The turbidity has also a lower concentration at the surface, before it increases. The decrease seems to take place at the same depth as the other two stations.

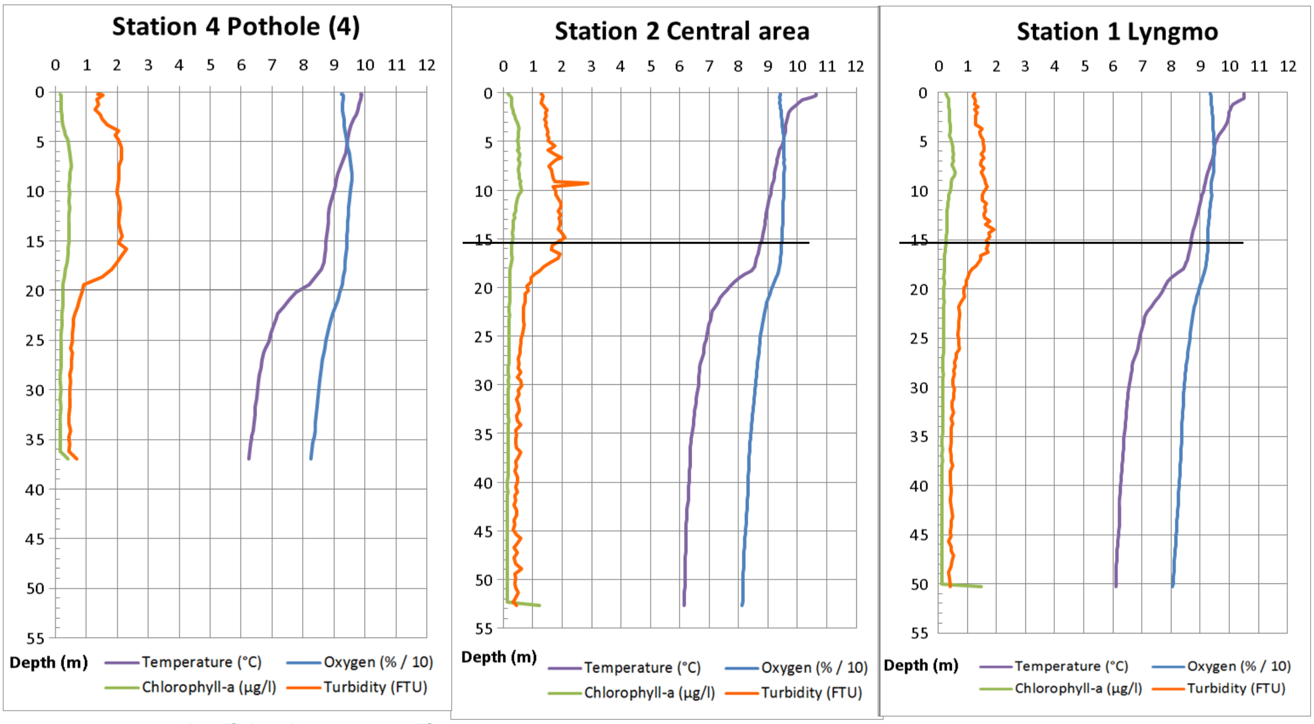


Fig. 15 CTD graphs of the three stations from west to east.

In fig. 17 and 18, generalized figures of the most interesting parameters (temperature, turbidity and chlorophyll a) and the data of the three stations were combined. A timetable with the time of measurements is provided in tables 9 and 10.The values were divided into several categories, each parameter has its own category (explained in the method) in order to make the graphs comparable with each other and visualize differences. Light purple stands for low concentrations as dark red stands for high concentrations. The last two parameters were not linear interpolated due to the large differences and low amount of measurements.

Cross-section: From west to east
The first fig. (16, left) shows that the temperature for station 2 and station 1 are very similar, except station 2 and station 1 have the red and dark red category (10 – 10.5 and 10.5 – 11 °C). Station 4 has the coldest surface layer and lacks the two warmest categories. This difference points out that, considering the timing of the measurements (table 9 and 10), the patterns can differ at the surface. The sun had more time to heat the water before the measurements of station 1 and 2. In general the patterns of all stations are similar from surface to bottom.

The turbidity is different for the three stations. In general, station 4 has the largest area containing the colours yellow to red which means a higher concentration (between 1.4 and 2.0 FTU) while station 1 has the smallest area. Another interesting fact is that the turbidity is not the highest at the surface but several meters deep and more to the east, the area of low concentrations increases. At lower depths the turbidity is similar for all stations.

The chlorophyll a concentrations also has a lower concentration at the surface and a higher concentration several meters deeper. Here station 2 seems to have the largest area with a high concentration but the differences are less pronounced as the turbidity values. In the CTD graphs (fig. 14) the oxygen saturation followed the chlorophyll a concentrations, meaning that the saturation increased as the concentration became higher and the saturation decreased as the concentration became lower.

Cross-section: From north to south
The resulting graphs from the second cross-section is shown on page 34 (fig. 18). Both station 5 and station 7 were very shallow with a maximum depth of 2 m. Because those two stations are at the inlet and outlet of Hafslovatnet, they were also connected with station 4 to see the circumstances halfway.

At station 5 the incoming water from Veitastrondvatnet is around 8.5 °C. The oxygen saturation is high reaching almost up to 100%. The turbidity is high with values between 2 and 3 FTU. The chlorophyll a concentration seems to be very low, except a high peak between 0.8 and 1.2 meter. This may be due to a piece of plant material drifting around.

Station 7 is located at the outlet of Lake Hafslovatnet. The temperature of the water is warmer with temperatures slightly above and below 10 °C. Oxygen saturation levels show a small increase from around 90% to almost 100%. The turbidity has values below 2 FTU. The chlorophyll a is low and does not show any noticeable changes.

The last station, station 4, has water temperatures of 10°C and does not show any visible variation in depth. Oxygen saturation is also stable with a level between 90 and 100 %. The turbidity values are around 1.5 FTU. The chlorophyll a concentration is low and also does not show any changes in concentration. Comparing the three stations, there can be seen that the temperature and the turbidity of station 5 (inlet) and station 7 (outlet) are different from each other. At the inlet the water is colder and is more turbid, while at the outlet the water is warmer and is less turbid. The chlorophyll a concentration and oxygen saturation levels did not show large differences.

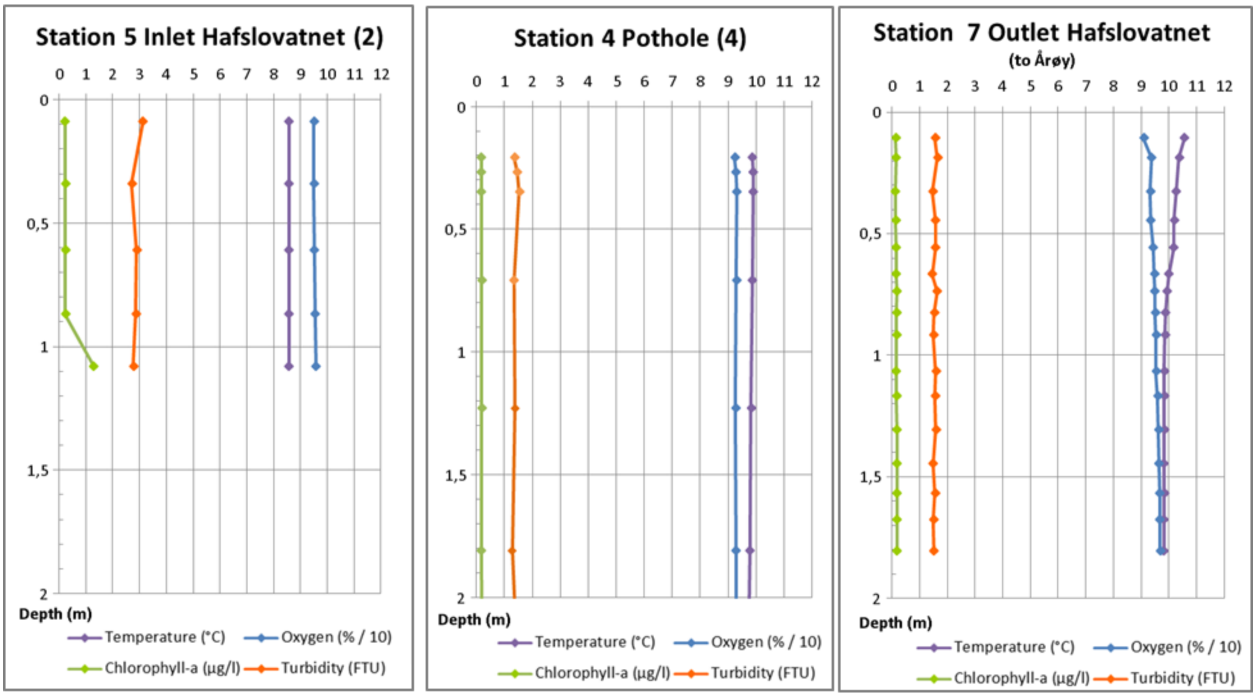


Fig. 16 CTD graphs of the three stations from north to south (St. 5 south near outlet of Lake Hafslovatnet, St. 7. Near inlet to Lake Hafslovatnet)

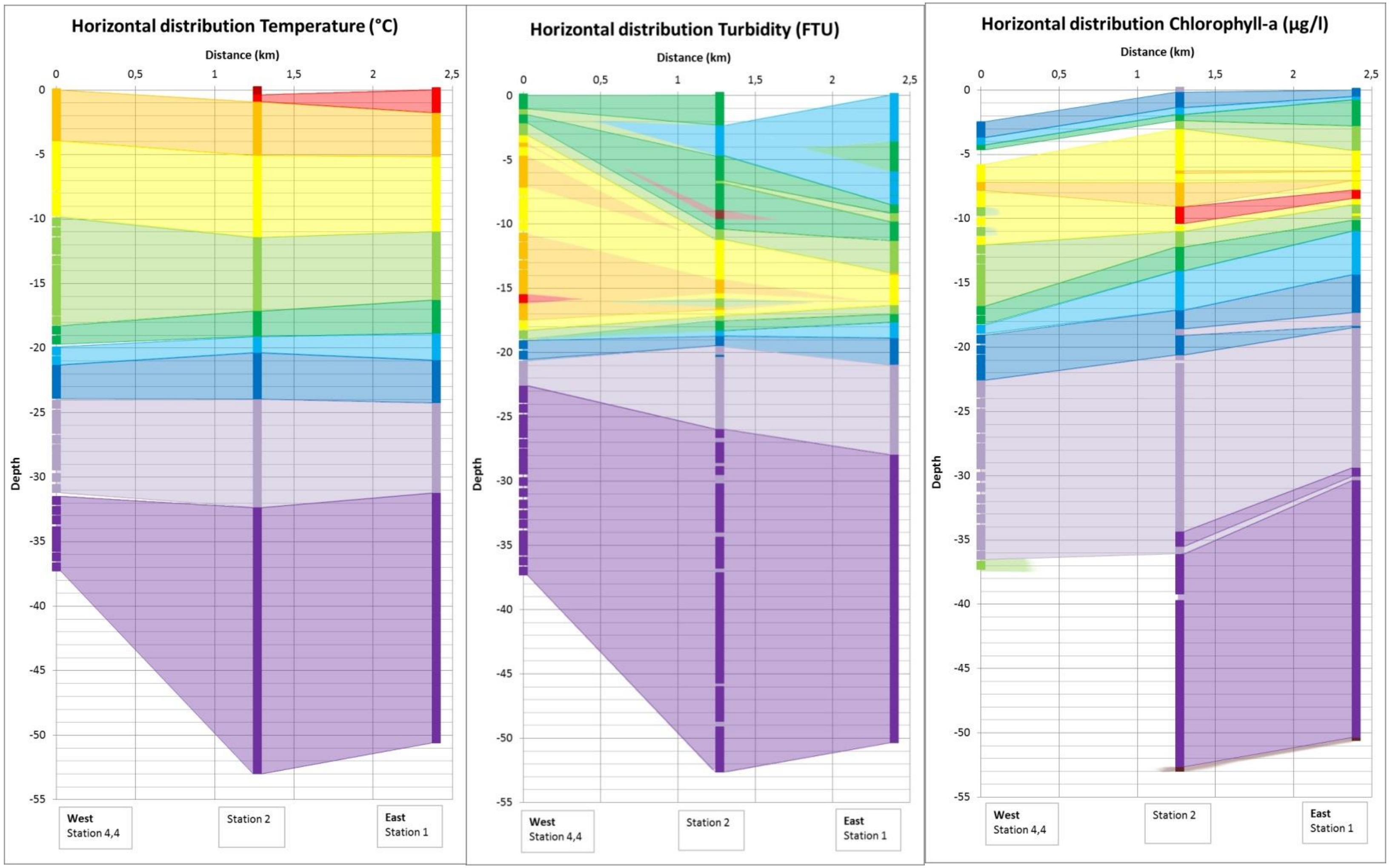


Table 9 Time table with the station numbers and the time during the day when the measurements were made

Station nr.	Time
Station 7	15:25
Station 5	12.12
Station 4.4	13:57
Station 2	16:12
Station 1	17:26

Fig. 17 Visualization of the temperature, turbidity and chlorophyll-a from west to east for stations 4.4, 2 and 1. See color codes below.

Parameter I scale											
Temperature (°C)	5,5-6	6,5-7	7-7,5	7,5-8	8-8,5	8,5-9	9-9,5	9,5-10	10-10,5	10,5-11	
Turbidity (FTU)	0,2-0,4	0,4-0,6	0,6-0,8	0,8-1,0	1,0-1,2	1,2-1,4	1,4-1,6	1,6-1,8	1,8-2,0	2,0-2,2	>2,2
Chlorophyll a (µg/l)	0,10-0,16	0,16-0,22	0,22-0,28	0,28-0,34	0,34-0,40	0,40-0,46	0,46-0,52	0,52-0,58	0,58-0,64	0,64-0,70	>0,70

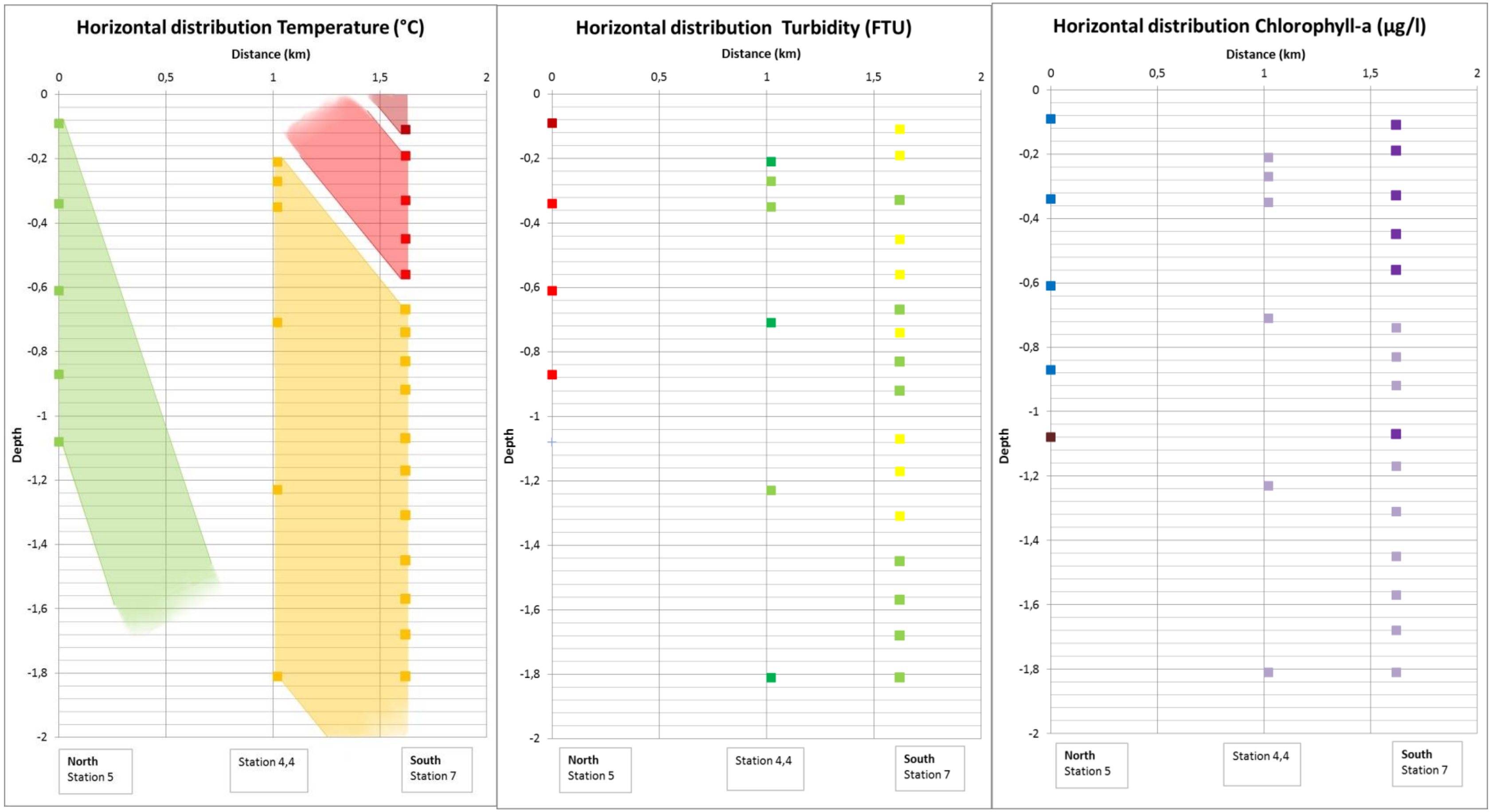


Table 10 Time table with the station numbers and the time the measurements were made

Station nr.	Time
Station 7:	15:25
Station 5:	12:12
Station 4,4:	13:57
Station 2:	16:12
Station 1:	17:26

Fig. 18 Visualization of the temperature, turbidity and chlorophyll-a from north to south at stations 5, 4,4 and 7. See colour codes below

Parameter I scale											
Temperature (°C)	5,5-6	6,5-7	7-7,5	7,5-8	8-8,5	8,5-9	9-9,5	9,5-10	10-10,5	10,5-11	
Turbidity (FTU)	0,2-0,4	0,4-0,6	0,6-0,8	0,8-1,0	1,0-1,2	1,2-1,4	1,4-1,6	1,6-1,8	1,8-2,0	2,0-2,2	>2,2
Chlorophyll a (µg/l)	0,10-0,16	0,16-0,22	0,22-0,28	0,28-0,34	0,34-0,40	0,40-0,46	0,46-0,52	0,52-0,58	0,58-0,64	0,64-0,70	>0,70

4.1.3 Recent hydrological and chemical CTD parameters of Lake Hafslovatnet

Now that some general patterns have been identified, in this paragraph a time series of yearly data will be shown. These measurements were taken every year in late August (2008 – 2015) at a location close to station 1 (camping Lyngmo) (see fig. 19 on the next page).

Temperature

All the temperature distributions seem to follow the same stratification pattern, with some degree of variation. At some years there is an upper epilimnion visible, but in other years it is less visible or not recognizable at all. Between 3 and 5m all temperatures decline quickly before flattening out (lower epilimnion). Between roughly 10-15 meters the temperatures drop again and straighten out (hypolimnion). When comparing the years, the year 2008 stands out as it starts with a drop in temperature instead of a stable layer, but then it shows an upper epilimnion around the same depths as the other years and has the earliest transition to the hypolimnion. In 2014 the hypolimnion was the coldest of all years, while in 2015 the hypolimnion was the warmest of all years. Other years differ in their similarity to either 2014 or 2015. The lower epilimnion temperatures show a variety around 2°C but the hypolimnion of all the years are very close to each other.

Turbidity

Despite only three years of turbidity measurements the results do seem to show a pattern. The turbidity is high in the upper and lower epilimnion and lowers when the depth increases further and reaches the hypolimnion. In 2008 and 2014 the turbidity is slightly lower at the surface and increases with the depth until it drops to low levels at 12-14 meters. The year 2015 has a completely different pattern. It has a stable turbidity value from the surface until 14m (start of metalimnion to the hypolimnion) without increases or decreases but definitely lower than the other years. The two large peaks are probably an error in the measurements or it is possible that there was a piece of material that passed along the CTD’s turbidity probe.

Oxygen

The percentage of oxygen saturation shows that all years have a good saturation level in the surface layers. Further down all saturation levels increase and decrease in the hypolimnion.

Chlorophyll a

Chlorophyll a concentrations in all years start with low concentrations in the first meters before they rise. The high peaks are all occurring between 3 and 11m. Further down the concentrations are declining. Only in 2010 the chlorophyll a concentration was already very high at the surface and did not increase further. The years 2009, 2012 and 2013 all have a high concentration at the end of the measurements caused by the CTD sinking into the sediment layer.

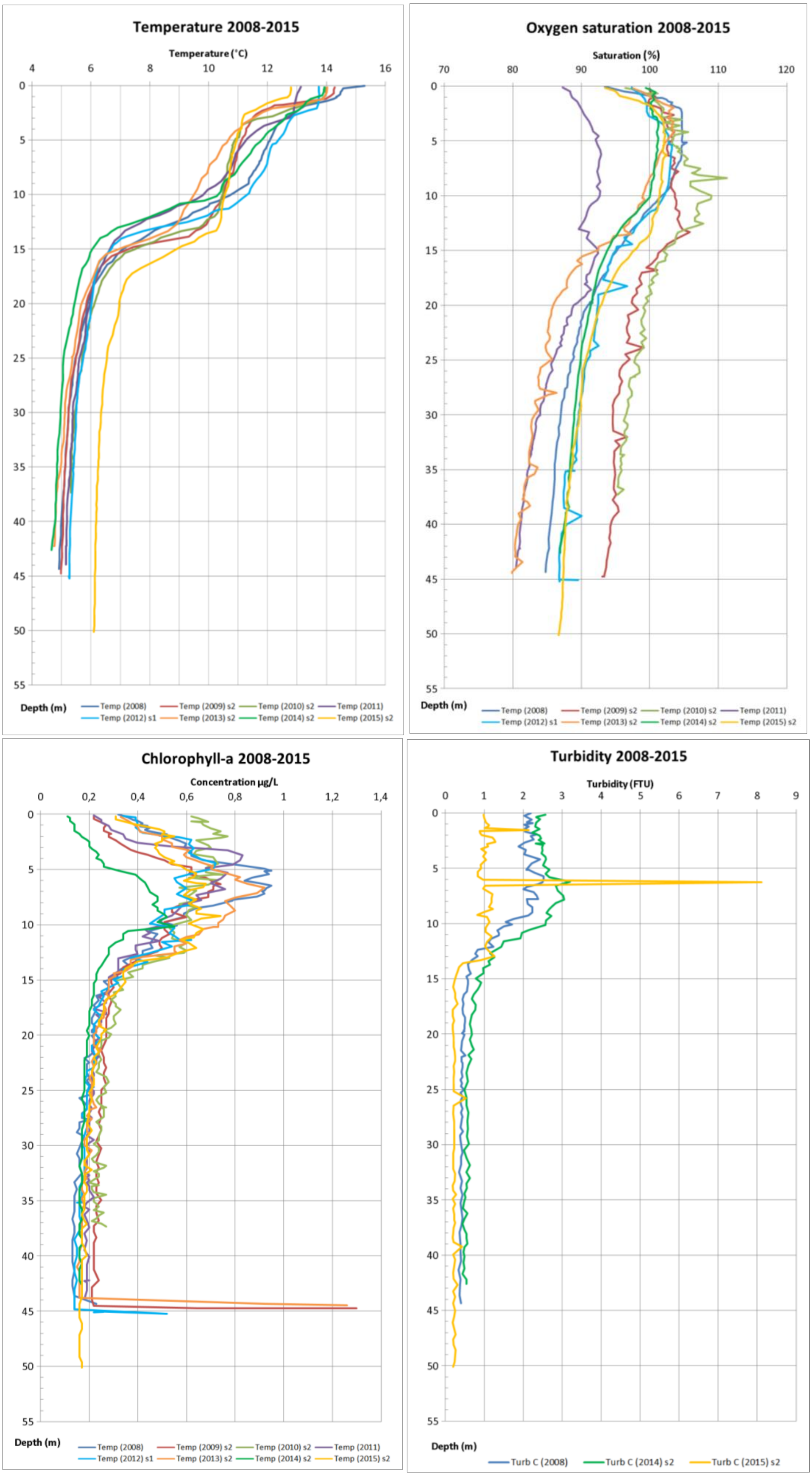


Fig. 19 Graphs showing measurements for four parameters in Lake Hafslovatn in the period between 2008 and 2015. Measurements were all taken at station 1 (east end of lake, near Lyngmo Camping) at the end of August by students (Høgskulen i Sogn og Fjordane, unp.)

4.1.4 The general vertical structure of the hydrology and chemistry of Lake Veitastrondvatnet

From the lake Veitastrondvatnet only one CTD measurement has been taken. This was taken in 2011 by M2F students and is presented in fig. 20 below. To see if there are differences, the CTD graph from Hafslovatnet is shown as well. Both include the temperature (°C), oxygen saturation (%), density (Sigma-T) and chlorophyll a concentration (µg/l).

The temperature in Veitastrondvatnet decreases quickly at first before it declines less steep further downwards. Between 30 and 40 m it seems that there is a slightly steeper decrease before levelling out again. The oxygen at the surface starts around 90%, increases to almost 100% around 3-4 m before it drops again to 85-90%. The chlorophyll a value is rising with a peak round 4 m before dropping again to almost zero. The graph shows a low density at the surface which increases over depth.

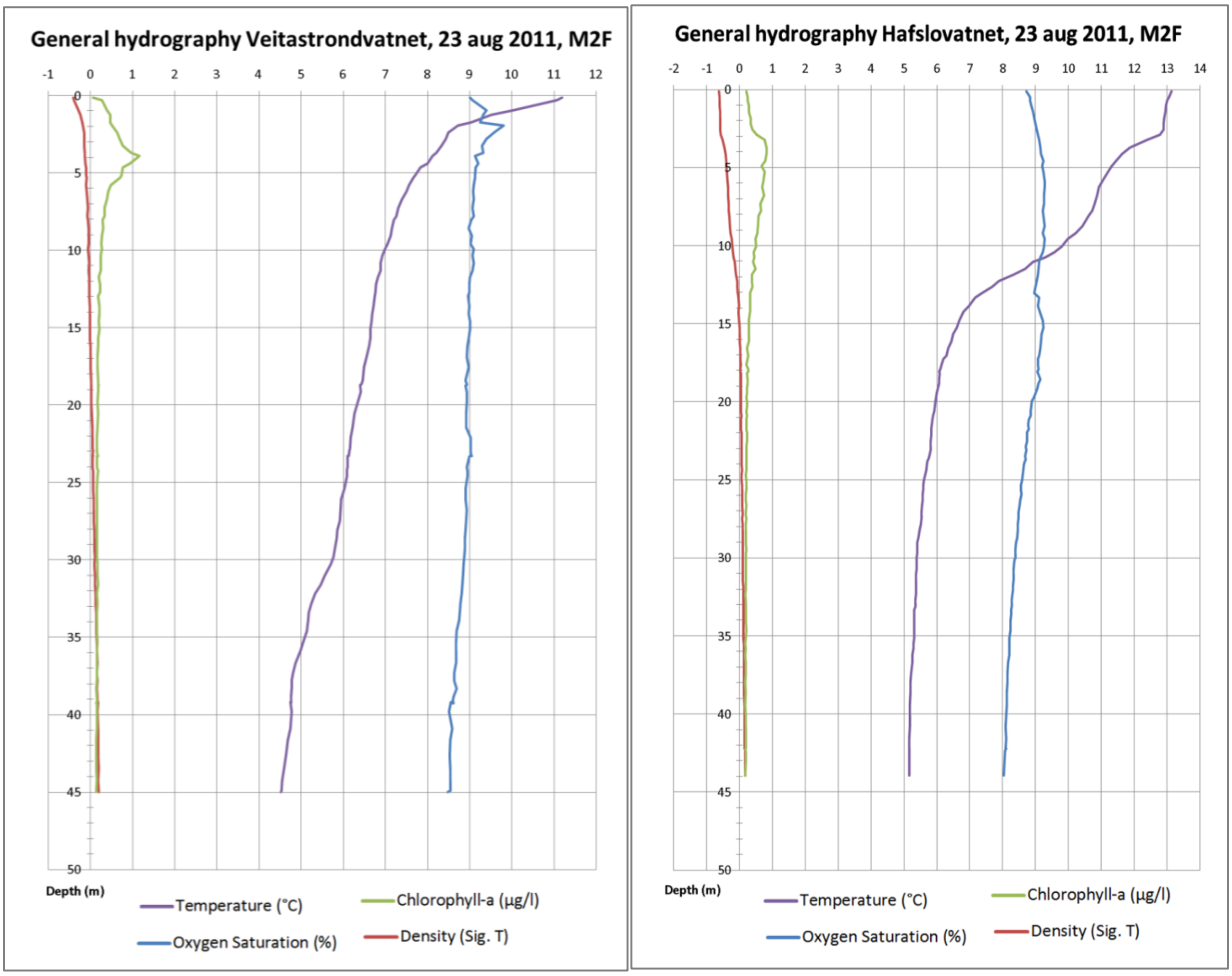


Fig. 20 CTD graphs of Lake Veitastrondvatnet (left) and Lake Hafslovatnet (right) in late August in 2011. In the graph the temp (C), density (sigma t), oxygen (% saturation) and chlorophyll (µg chl. a/l) is shown

The CTD of Lake Hafslovatnet in 2011 shows an upper and lower epilimnion and the hypolimnion. The second metalimnion to the hypolimnion is present as well with the first around 4-7 m and the second between 10 and 15 m. The distance between the two layers are shorter than the CTD graph of 2015. The oxygen is slightly rising from around 89% to 94% and drops slowly to 80%. The chlorophyll a concentration peaks at 3 m and slowly drops to lower numbers as the depths increases. The density shows, just readable, two increasing steps just like the temperature.

Comparing the two graphs with each other (there can be seen that) both the temperature and the structure differs. Lake Veitastrondvatnet has a colder temperature than Lake Hafslovatnet over the whole sampled section of the water column. Thus this illustrates that in comparison, cold water from Lake Veitastrondvatnet passes through the system to Lake Hafslovatnet which has warmer surface temperatures. Furthermore an adjustment has been made at the outlet of Lake Veitastrondvatnet altering the depth of the water passing through. This will be further discussed in paragraph 4.3.3. Beside the temperature, the structure of the lakes differs as well. At Lake Hafslovatnet, the epilimnion and first metalimnion are more obvious than in Lake Veitastrondvatnet. There is only a metalimnion at the surface that can be seen and a hypolimnion at the bottom, because the water there reaches almost 4 °C, which is the densest water possible. At 30 m in Veitastrondvatnet there could be a start of a metalimnion to the hypolimnion while at Hafslovatnet this transition is much clearer and starts at 10 m depth. However, Lake Veitastrondvatnet is a lot deeper than Hafslovatnet. It has more locations with depths around 100 m, which could explain the difference.

Until so far the CTD graphs have resulted in the following observations. The general graph of August 2015 has shown that Lake Hafslovatnet has a two layered epilimnion. Lateral variations are present in the lake as well (September 2015). At the inlet to the lake in the northwest the incoming water is colder and has a higher turbidity than at the outlet in the south. From west to east the stratification and especially the upper epilimnion is less pronounced than in the east. This stratification pattern can be found back in the yearly measurements (August) while each years varies a little. Therefore this is very likely to take place over a longer period, probably very soon after stratification sets in and stops as soon the water starts to turn over in autumn.

Fig. 21 Front at Straumane entering Lake Hafslovatnet. First photo was taken on 10 June 2010 and the second one on 9 July 2010 (T.Dale)

4.1.5 River measurements: surface gradients from the Austerdals glacier to Lake Hafslovatnet.

These last measurements are taken from rivers upstream of Hafslovatnet and Veitastrondvatnet (table 11). The measurements of the following parameters were taken:

Temperature, turbidity, pH, conductivity and oxygen (saturation and mg/l). Only the temperature and the turbidity were tested with a trend test as those two parameters had the most results and showed the highest r-square values (see fig. 22 and appendix 8.3).

Table 11 Location names of the stations. Note that Station 3 is at another river branch joining with the main river from station 2 a little upstream from station 4.

Name	Station
Glacier Austerdalsbreen	Station 1
River Austerdalselvi (Tungastølen)	Station 2
River Langedøla (plain above bridge)	Station 3
River Storelvi (below bridge)	Station 4
Lake Veitastrondvatnet (surface)	Station 5
Lake Hafslovatnet (Surface)	Station 6

Temperature

The temperature graph shows very clearly that the further away from the glacier the stations are, the warmer the water gets. Only station 3 (another river branch) has a higher temperature than station 4, which results in an average temperature at station 4. There are no clear increases or decreases visible. When tested with the non-seasonal Mann-Kendall trend test there was one significant detection (P 0.004 and a Sen's slope of 0.317) at station 1, which is the glacier Austerdalsbreen. All other stations did not have significant detections (see appendix).

Turbidity

The turbidity is very high at the first station, but over the years has been decreasing before increasing again in 2015. The turbidity at the other stations is much lower than at the first station. Station 3 has less turbid water than station 2, due to the different water sources. Also here station 4 is the sum of station 2 and 3. A non-seasonal Mann kendall trend test did not result in any significant detections (see appendix).

Secchi depth

Comparing the secchi depth graph with the turbidity graph it can be seen that the opposite pattern is occuring, because the lower the secchi depth gets, the higher the turbitiy is.

pH

The pH values all show fluctuations between a value of 6 and 7.5 since the start of the measurements. It seems that if in one year the pH is lower, all stations have a lower value when compared with other years.

Conductivity

Measurements of conductivity show that the conductivity (µS/cm) is very low for a freshwater lake. In the upper graph the conductivity was only measured between 2012 and 2015. Station 1 (close to the glacier) shows a large variation in conductivity; being in the middle of the measurements, then having the highest peak before being the lowest of the stations. Stations 2 to 4 (rivers) are all very close to each other and show almost the same pattern. The last two stations 5 and 6, Veitastrondvatnet and Hafslovatnet, both have a large variation and show different conductivity values. Station 6 starts high and drops to a low conductivity as station 5 is lower but rises. In the second graph the patterns are different, station 1 to 4 which are all close to the glacier, show lower conducitvity values than the last stations 5 and 6.

Oxygen

The percentage shows even a very high percentage at station 1 in comparison to the other ones.

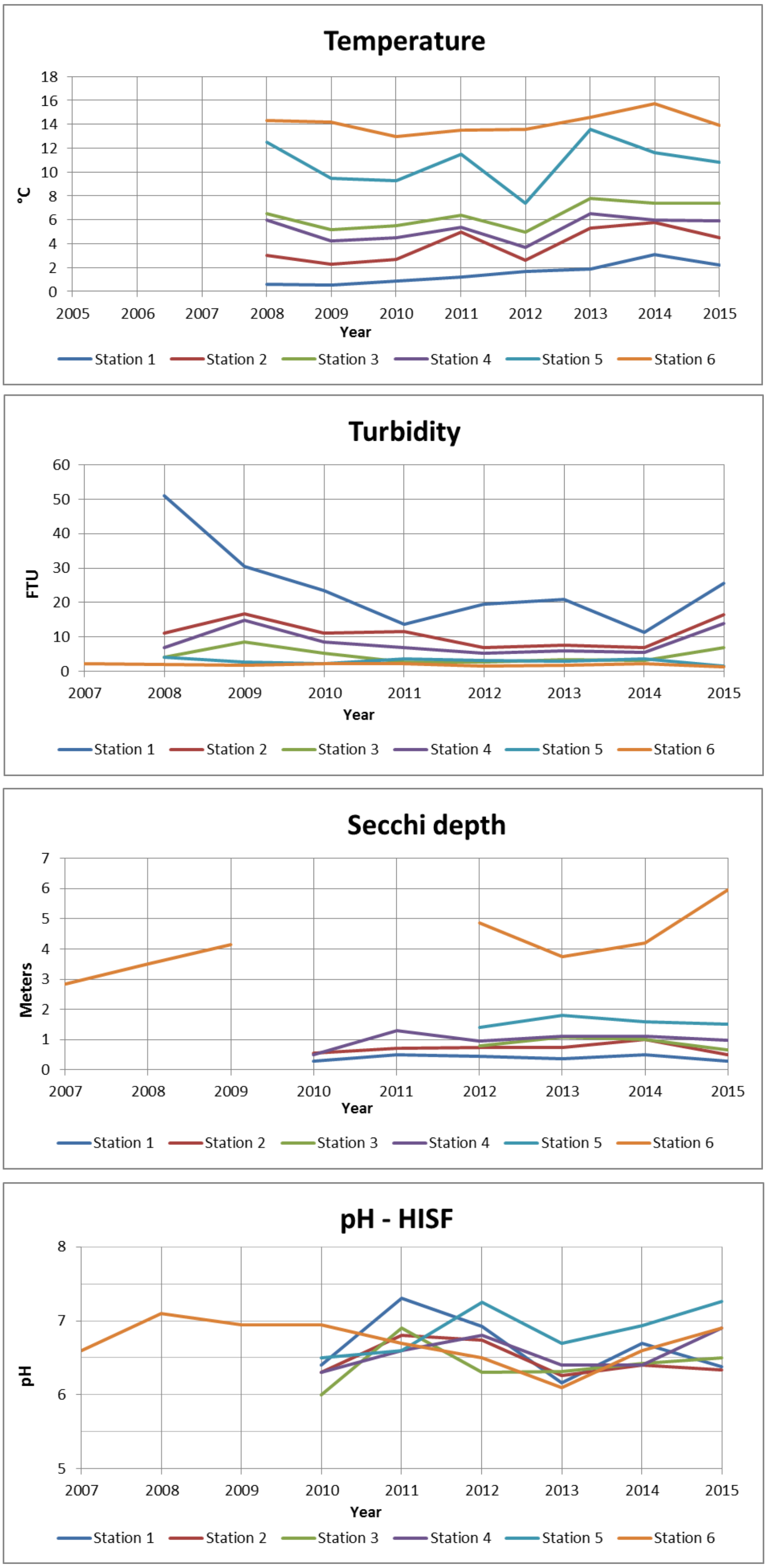


Fig. 22 Four graphs with temperature, turbidity, secchi depth and pH measurements. As shown in table 11 the station numbers belong to the following locations: Glacier Austerdalsbreen (1), River Austerdalselvi (2), River Langedøla (3), River Storelvi (4), Lake Veitastrondvatnet (5) and Lake Hafslovatnet (6). All graphs in appendix 8.4.

4.2 Temperature (Climate change)

In this subchapter the influence of climate on the water system is investigated. Only air and water temperature records were analysed.

4.2.1 Air and water temperature

In the introduction the general climate of Hafslo was described as a subpolar oceanic climate (Cfc) meaning the climate is warm and temperate (Peel, Finlayson, & McMahon, 2007) (Climate-date). Temperature datasets from stations close to the research area were selected to see yearly temperature variations in the area.

Air temperature from weather stations

In the following fig. (23), yearly averages of four different weather stations are shown. Table 12 on the next page summarizes important meta data of the used stations. There is a difference in yearly temperatures between the lower altitude stations ('Lærdal' and 'Fjærland') and the high altitude stations ('Luster sanatorium' and 'Bjørkehaug i Jostedal'). The higher the altitude, the lower the temperatures are. All stations show the same pattern with similar high and low peaks. Between 1982 and 1985 there was a high peak in temperature especially visible in blue (Bjørkehaug I Jostedal station) but at the low altitude stations this peak seems less extreme in comparison with other years.

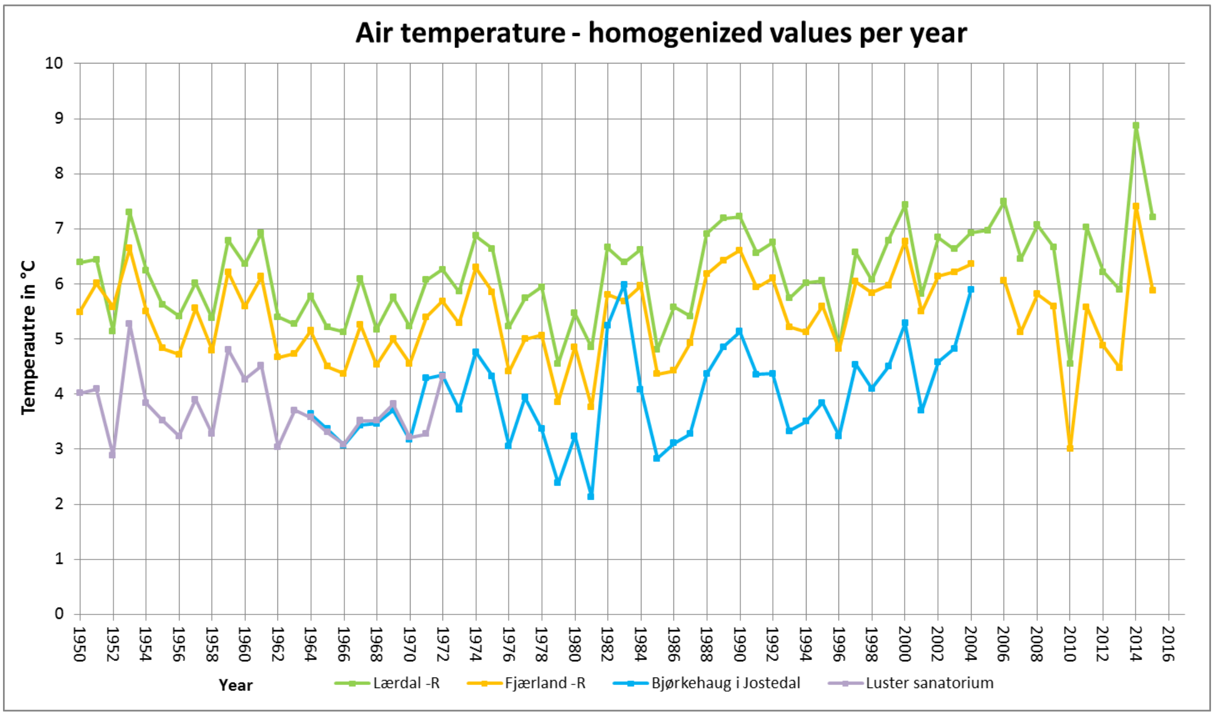


Fig. 23 Air temperature of four weather stations close to Hafslovatnet (Norwegian Meteorlogical Institute, 2016) with yearly data. The data were homogenized: corrected for non-climatic changes.–R means reconstructed time series

Trend tests / Statistical trend analysis

The first statistical trend test (Mann-Kendall trend test) of the yearly values pointed out that only Lærdal (P 0,003) and Jostedal (P 0,007) had a significant increasing trend (low increase) (see table 12). However when testing the monthly values of the four stations with the same test, only Lærdal had a significant (low) increase (P 0,013).

Table 12 Result of Mann-Kendall trend test for the air temperature. Yearly values mean one averaged temperature per year. Monthly values mean one value per month.

Yearly values (non seasonal MK test) With continuity correction	Chance P	Sen's slope	Confidence interval
Lærdal R	0.003	0.016	0.013; 0.019
Fjærland R	0.131	0.008	0.005; 0.011
Bjørkehaug i Jostedal	0.007	0.03	0.026; 0.033
Luster Sanatorium	0.291	-0.023	-0.030; -0.016

Monthly values (Seasonal MK test period = 12) With continuity correction	Chance P	Sen's slope
Lærdal R	0.013	0.02
Fjærland R	0.053	0.025
Bjørkehaug i Jostedal	0.309	0.022
Luster Sanatorium	0.060	-0.037

The second statistical test (change point analysis) resulted in two stations having significant detected changes (Lærdal and Fjærland). Results can be seen in fig. 24 and table 13. The most important change at Lærdal was in 1962 when the temperature dropped from 5.2 to 4.6 °C. It has a high confidence level (97%) but a very large confidence interval (1953-1970). This means that the moment of change cannot be pinpointed exactly to one year. The smallest confidence interval is 12 years, estimated around 1988 but the change is rated less important. At Fjærland the most important change is detected in 1988, but also had the highest confidence interval.

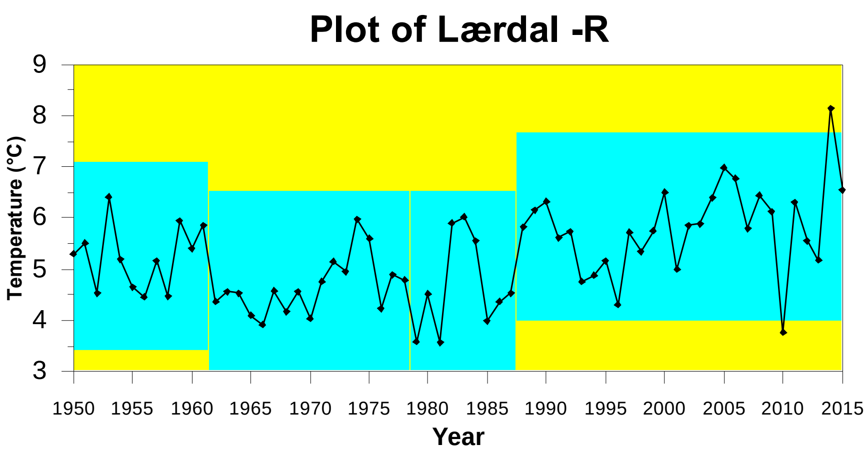


Fig. 24 Results of a change-point analysis. The figures are visually showing changes while the tables contain more detailed information. Every month was a season (12) and bootstrap was 1000 with no replacements. The level indicates importance change and visibility in the plotted graph.

Table 13 Table of significant changes for the air temperature at Lærdal. The test was carried out with a 90% confidence level and bootstrap = 1000 without replacements

Year	Confidence interval	Confidence level	From	To	Level
1962	(1953, 1970)	97 %	5.2442	4.6612	2
1979	(1963, 1987)	99 %	4.6612	4.6785	5
1988	(1984, 1996)	93 %	4.6785	5.8173	5

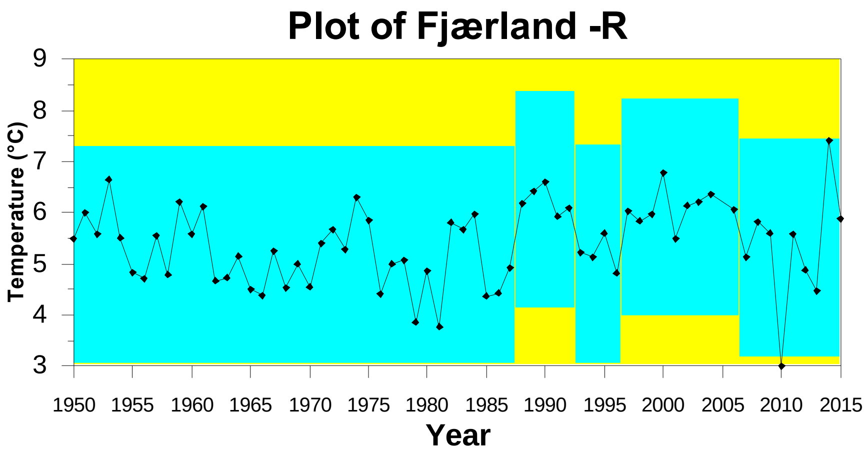


Fig. 25 Result Change point analysis of reconstructed time series at Fjærland

Table 14 Table of significant changes for the air temperature at Fjærland. The test was carried out with a 90% confidence level and bootstrap of 1000 without replacements

Year	Confidence interval	Confidence level	From	To	Level
1988	(1976, 1988)	97 %	5.1716	6.25	1
1993	(1993, 1993)	96 %	6.25	5.1925	5
1997	(1997, 1998)	99 %	5.1925	6.1033	4
2007	(2006, 2015)	99 %	6.1033	5.3078	2

Water temperature at the Årøy power plant outlet

The water temperatures at the outlet of the Årøy hydroelectric power plant are presented in Fig. 26. Although these temperatures were taken after the water travelled through the power plant, it gives an indication of the surface temperatures (1-3 meters) in Lake Hafslovatnet. Next to the temperature also a graph was made with the number of days without measurements (see Appendix 8.5). In years in which there were no missing days (2006 - 2009) the average water temperature was between 6 and 7 °C. In Appendix 8.6 the water temperatures are also plotted per week and sorted out per year to visualize differences in seasonal patterns between the years.

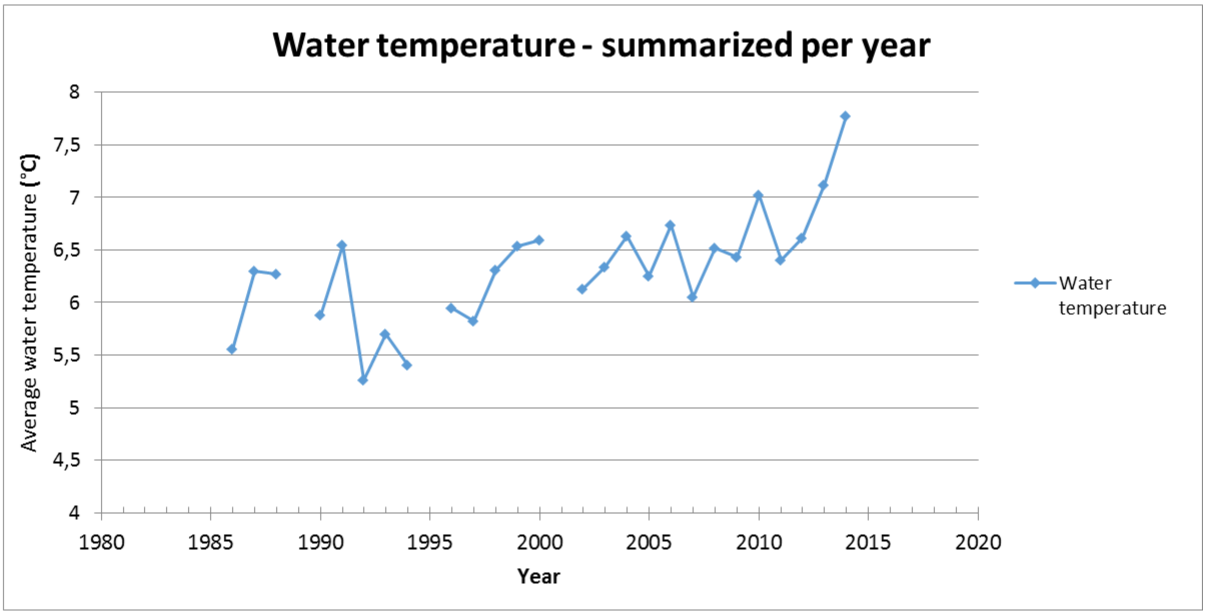


Fig. 26 Results of the water temperature measured at the outlet of the Årøy hydroelectric water power plant. The values are yearly values.

Analysis with Mann-Kendall trend test and change point analysis water temperature

The Mann-Kendall trend test for the water temperature of Lake Hafslovatnet summarized per year resulted in a significant small increasing trend (P 0,000; Sen's slope 0,049, measured in water leaving the turbine in the power plant).

A change point analysis of the yearly summarized data resulted in two detected changes in the trend (See fig. 27 and table 15). The strongest change was found in 1998 (confidence interval 1998, 1999) where a change from 5.62 °C to 6.58 °C was detected. However, both these years had a lot of missing data (see Appendix 8.5).

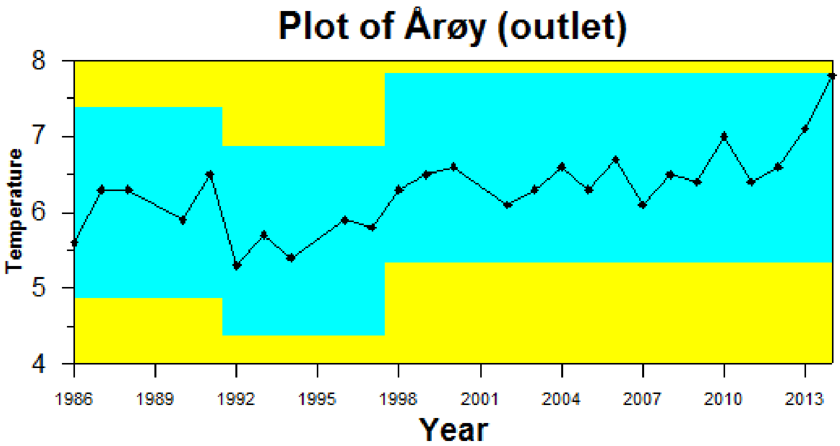


Fig. 27 Result Change point analysis at the outlet of the Årøy hydroelectric power plant

Table 15 Table of significant changes for the water temperature at Årøy. The test was carried out with a 90% confidence level and bootstrap of 1000 without replacements

Year	Confidence interval	Confidence level	From	To	Level
1992	(1988, 1996)	92 %	6.12	5.62	2
1998	(1998, 1999)	98 %	5.62	6.5812	1

A second Mann-Kendall trend analysis on monthly summarized water temperatures with the seasonal Mann-Kendall trend test also got and the outcome that showed a significant trend (P 0,060; Sen's slope 0,032). The months were also separately tested, those results are shown in table 16.

Table 16 Result of Mann-Kendall trend test. Every month was tested separately

Mann Kendall trend test (non seasonal) with continuity correction			
Month	**Chance P**	**Sen's slope**	**Notes**
January	0,488	-0,008	] -0,010 ; -0,005 [
February	0,211	-0,007	] -0,009 ; -0,006 [
March	0,381	0,012	] 0,008; 0,015 [
April	0,087	0,026	] 0,022; 0,032 [
May	0,012	0,103	] 0,089; 0,115 [
June	0,278	0,045	[0,030; 0,066 [
July	0,381	0,037	[0,022; 0,047 [
August	0,123	0,047	] 0,034; 0,058 [
September	0,087	0,048	] 0,041; 0,054 [

October	0,034	0,028	] 0,023; 0,031 [
November	0,129	0,029	] 0,020; 0,036 [
December	0,866	0,003	] -0,005 ; 0,009 [

4.2.2 Ice cover period

In the introduction, a brief overview of previous studies was described. One of the subjects was the effect of ice on the amount of plant material in Lake Hafslovatnet. The height of the water level was mentioned as a factor but also the timing of ice formation and the timing of ice breakup in spring could be of importance.

The water temperatures at the Årøy outlet are an indicator of the water temperatures close to the surface of Lake Hafslovatnet. Eight months of the water temperature were examined: February – May and October – December, as in this period the ice melts away and the winter ice starts to grow. Between April - May and October – November the difference in average temperature were large (fig. 29). All months are included in appendix 8.7.

Analysis with Mann-Kendall trend test and change point analysis

Looking back at the tested months in table 16, there are only two months which had a significant increasing trend. These are May (P 0,012) and October (P 0,034). Both also had an increase in their trends, whereof May had the largest: 0,103 against 0,028 in October.

A change point analysis resulted in two months with significant changes (fig. 28 and table 17): April (2 detections) and May in standard deviation (1 detection). The results show that there was a decrease in trend of the temperature around 1993 (1989-1996) and 2003 (2002-2009).

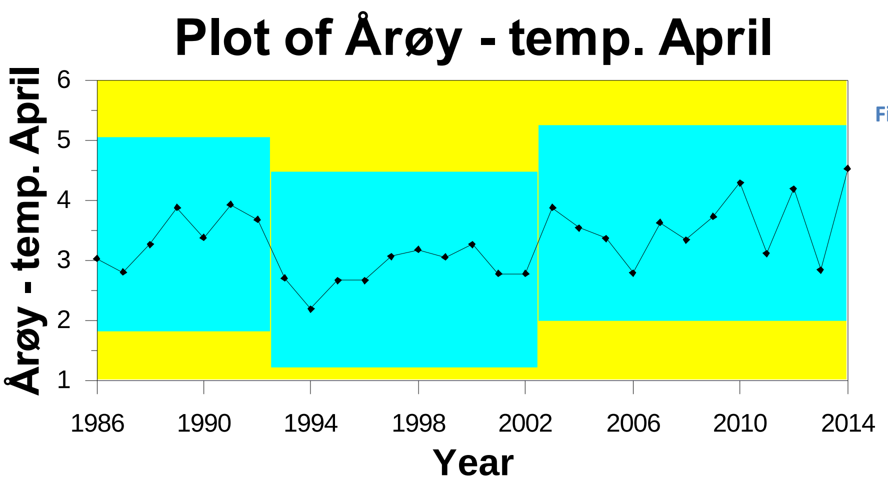


Fig. 28 Result Change point analysis for April

Year	Confidence interval	Confidence level	From	To	Level
1993	(1989, 1996)	98 %	3.4357	2.848	2
2003	(2002, 2009)	97 %	2.848	3.6175	3

Table 17 Table of significant changes for the water temperature in April. The test was carried out with a 90% confidence level and bootstrap of 1000 without replacements

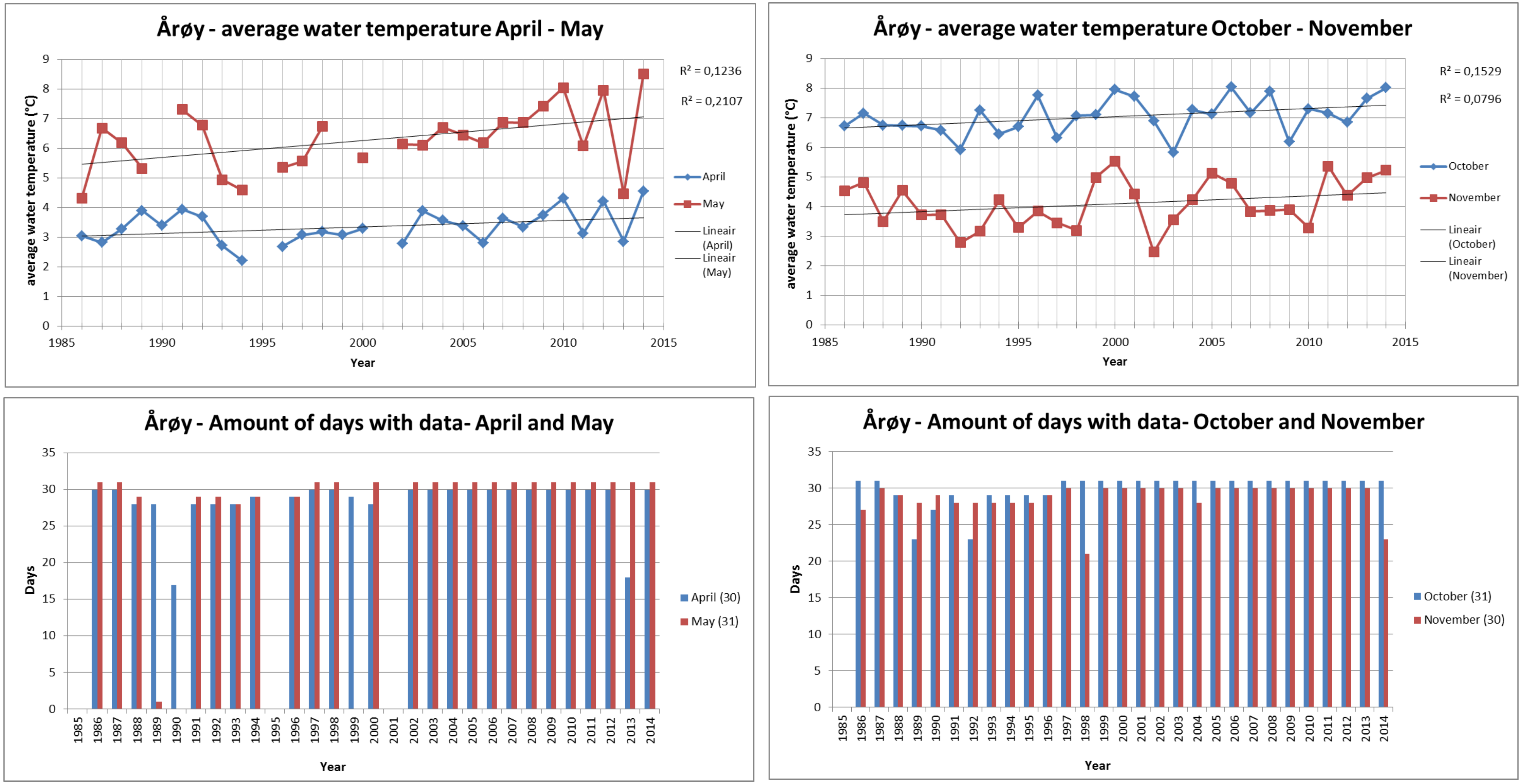


Fig. 29 Water temperatures at Årøy outlet plotted in years per month in the upper two graphs. In the lower two graphs the number of days with data is shown.

4.3 Human interferences in the water system

In this subchapter, human interference in the water system is investigated. Over the last 50 to 70 years changes have been (locally) made in the water system. As introduced in the introduction these were the regulation of the water height and thus the variation of both lakes, the construction of the flood protection of Storelvi at Veitastrond, the extensive draining of the farmland into Heggestadelvi at Veitastrond and the construction of a bypass at the outlet of Veitastrondvatnet. When talking about changes in the water system the year 1983 is an important year. In this year the hydroelectric power plant was taken into production and thus the regulation had to be in order. Most people believe the start of the Årøy hydroelectric power plant brought changes to the water system and inhabitants and users started to notice the increased plant growth close.

Adjustments in the water system

In the introduction, a brief overview was given about the kind of adjustments and constructions that were built. These could have effects in the water system. First hydrological and chemical parameters are presented to see if parameters have changed. Then possible effects of the alterations are discussed. There are four hypotheses which each have a different subject:

4.3.1 Hydrological and chemical results over time at Lake Hafslovatnet

Before discussing the artificial adjustments in the water system, the parameters which could have changed over the years will be discussed. In the introduction, the increased plant growth was discussed. Water level and winter with ice were mentioned as a possible factor in controlling the plant population. The focus of this section (4.3.1) adds to the story by looking at hydrological and chemical measurements in the lakes Hafslovatnet and Veitastrondvatnet, that were found in papers and own collected data. A complete overview of the dataset can be found in the appendix (8.8 – 8.11).

4.1.1.1 Hydrological measurements

First the hydrological results will be presented. This consist of the parameters temperature, conductivity, turbidity and secchi depth. These are shown below. Furthermore the colouration is part of the hydrology as well but these are not shown in the graphs. In all graphs a line has been put in to mark 1983 to see if there are changes before and after this year.

Temperature

Most of the data of the parameter temperature (fig 30) was collected between 2008 and 2015. In the graph the differences per category are very clear. The warmer temperatures are closer to the surface than the colder ones. There is not enough data to see differences before and after 1983 as there is not much data available before 1983 and the air temperature graph showed a peak in the temperature around 1980-1985 in comparison with the other years. The r-square of the 0-2 m depth is very low (0.0322). The other depths do have a higher r-square, whereof the 10 to 15 m (r-square 0.2233), 20 to 25 m(r-square 0.5234) and >30 m (r-square 0.2317) had the three highest r-squares. Especially the measurements between 20 and 25 m suggest an increase in temperature. But this could depend on when the measurements were taken.

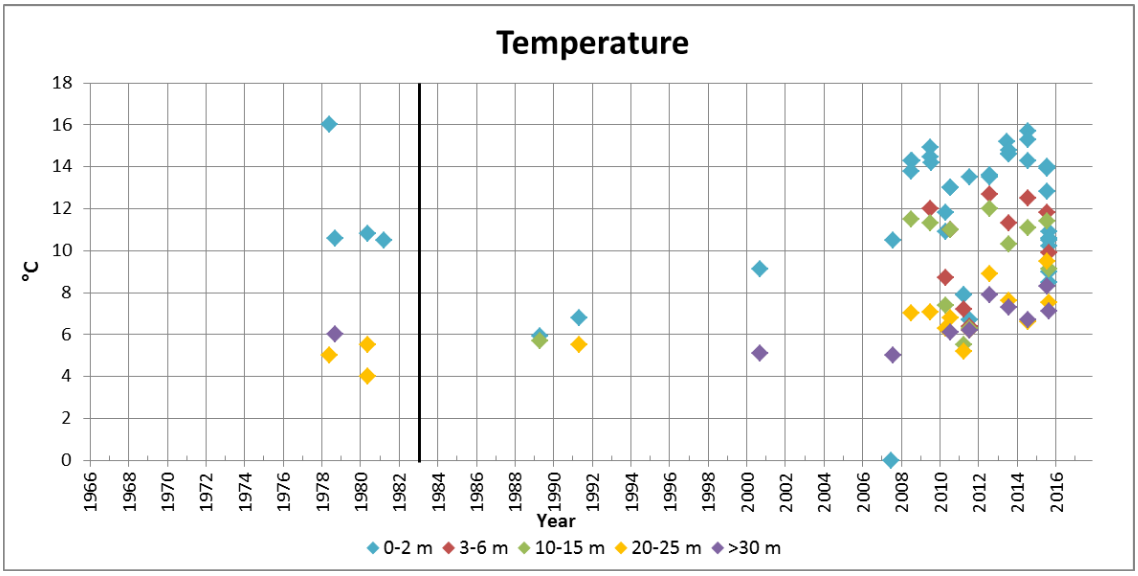
Conductivity

In recent years deeper conductivity measurements were made than in the past. There is no increase or decrease visible in the data and the r-square (1E-04). There are some high values that seem to be a lot higher than most other values and all those higher values are from the category 0-2 m.

Turbidity and secchi depth

Both the turbidity and the secchi depth (fig. 31) express how turbid the water is. There are almost no documented values before 1983 for both parameters. The turbidity of the surface water seems to have increased slowly although there is a lot of variation between the measurements. Looking at the different depths, the results show that deep depths have a lower turbidity than shallower depths. The r-square was not high with 0.2149.

The secchi-depth is clearly showing a decrease (thus increase in turbidity of the water) but there are not a lot of measurements before 1983. It does have the highest r-square of 0.6113.



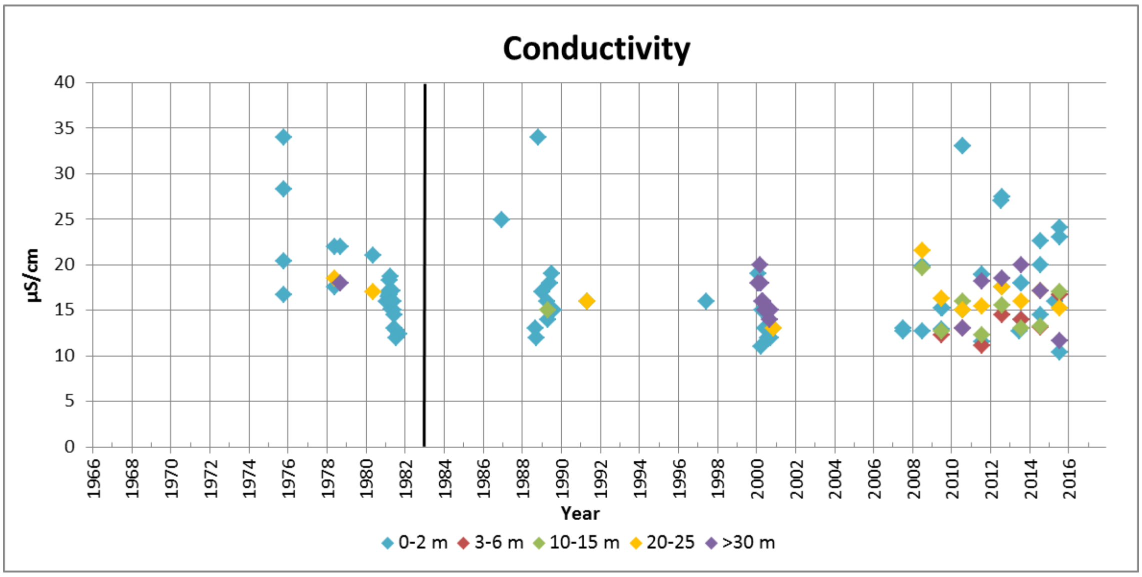
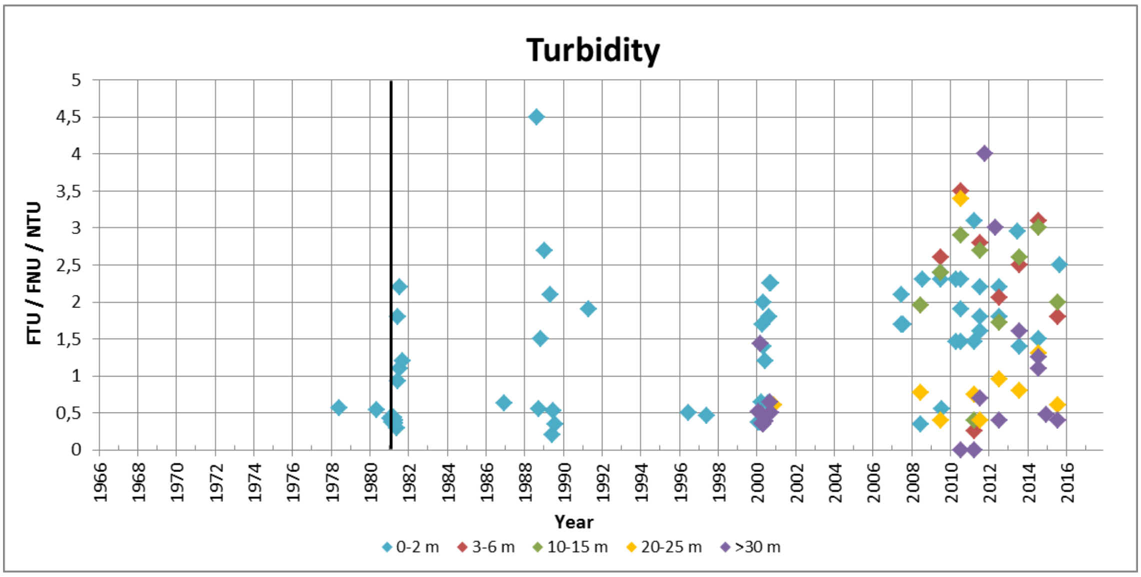


Fig. 30 Conductivity (µS/cm) in Lake Hafslovatnet in the period 1976 - 2015. Data found in papers and unpublished reports presented in graphs per parameters and ordered by depth



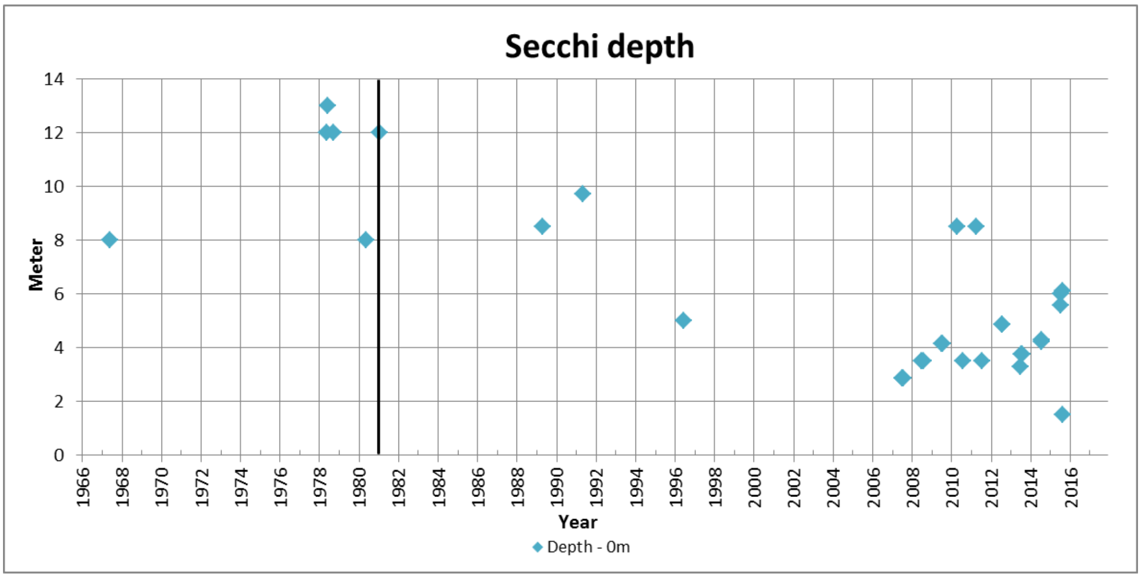


Fig. 31 Secchi depths (m) and Turbidity (FTU/FNU /NTU) in Lake Hafslovatnet. Data found in papers presented in graphs per parameters and ordered by depth

4.1.1.2 Chemical measurements

The chemical parameters discussed here are the pH, Oxygen, Ortho Phosphates, Total Phosphates, Nitrate (NO3), Sulphate (SO4), Calcium (Ca), Silicon (Si), Iron (Fe), Magnesium (Mg), Sodium (Na), Potassium (K), Aluminium (Al), Total reactable Aluminium (Al tot) and Chlorine (Cl). Because there was a lot of data for the PH (fig. 32) it is described in the same way as the hydrological parameters. The oxygen can be found in appendix 8.12 and nutrients are only described and compared with the Norwegian version of the Water Framework Directive to compare these numbers with its classifications.

PH

The graph (fig. 32), shows that there is some data before the year 1983. However, most data is from after this year. Most data that was measured was taken from the surface of Hafslovatnet. In more recent years, data of deeper depths was retrieved as well. Of the surface values there are three measurements that are below a pH of 6: two times in 1981 (pH of 5.13 and 5.78) and one in 1987 (pH 5.8). The time of measurements was May in 1981 and January in 1987. Around the 1960s and 1970s there were difficulties with acidic rain, also in Norway, causing lakes and rivers to get a low pH (5-6). After that period, when knowledge of the problem and the cause increased, a big effort was made to reduce the acidification of the environment. In Enge & Lura 2003 the conclusion was that the acidification of waters and soils clearly was reduced (Enge & Lura, 2003). More recent values in Hafslovatnet also show that the pH has been increasing and is mostly between 6.4 and 7.0 with some exceptions. Beside surface values also deeper depths were measured. In the graph it is visible that water in greater depths has a lower pH than at the surface.

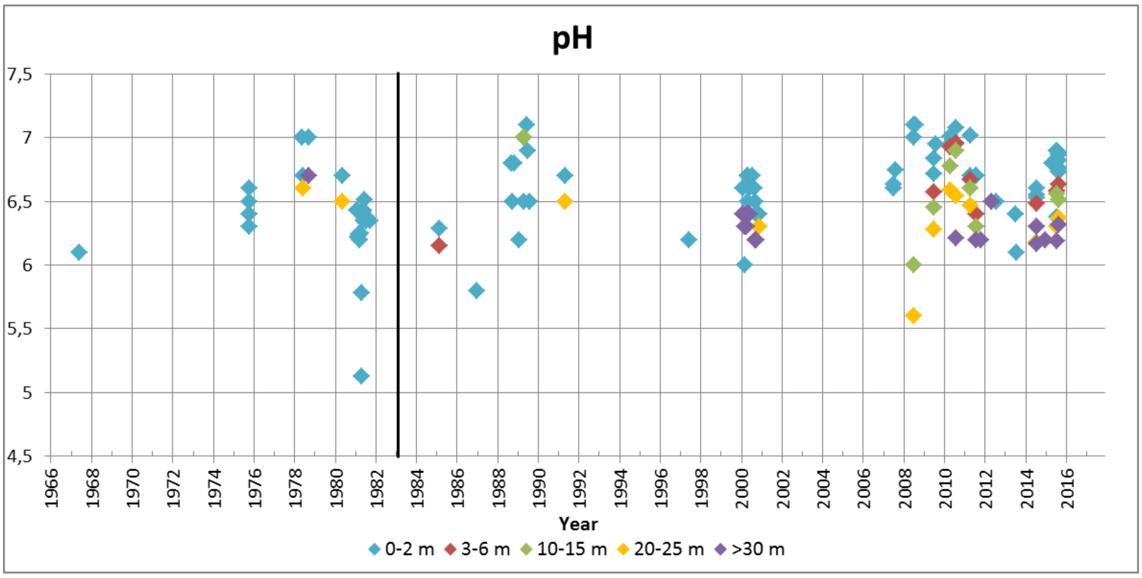


Fig. 32 Oxygen results found for Lake Hafslovatnet in papers during the literature research.

Oxygen

Despite that there were not a lot of oxygen measurements (appendix 8.12), it can be said that oxygen levels are high. The oxygen saturation stays above 90% while concentrations stay above 10 mg/l (numbers below 6 mg/l start to indicate that some oxygen relying organisms start to experience difficulties).These numbers are fitting very well for an oligotrophic lake.

Macro nutrients: Phosphates, Nitrate and Potassium

The most important nutrients for plant growth will be described shortly below. None of the measurements were taken just before and after 1983 or 1984 (start hydroelectric power plant and break down of plant population).Therefore only changes before and after these two events can be found. But general changes in concentrations can be found.

Orthophosphate and total phosphor

For plants, phosphorus is very important for growth and for metabolic reactions (Behar, 1997). There was not a lot of data available for both phosphorus types. Total phosphates are mentioned in the Norwegian classification system for environmental quality of fresh water (Andersen, et al., 1997). Below 7 µg P/l the classification is rated as very good. All measurements before 1997 very likely had another classification, therefore this classification is only used to compare numbers The total phosphor concentration was a lot higher than the reference value in 1988-1989, where some measurements of 23 and 53 µg P/l were measured. The conditions were, according to the classification, varying between good and bad. The orthophosphates concentrations were low. In

1978 there were measurements that were below the detection range and measurements of 1 and 3 µg P/l. Orthophosphates are the only phosphates that can be directly taken up by an organism.

Nitrogen and Nitrate

Another important nutrient for plants is nitrogen. Aquatic plants use nitrogen in the form of NO_3^- for building proteins (Behar, 1997). The reference value in Andersen, et al 1997 (0.3 mg N/l) results in a very good quality. Most data were however measured in mg NO_3/l, and therefore all measurements were recalculated to mg N/l to be able to compare them to the reference value. All measurements stay below the reference and therefore they are pointing to a very good quality. This also points to an oligotrophic lake as this type has low nutrient numbers. Taken into account that there are only four measurements before 1983, it cannot be said if the values are representative for that time. If it was, the values seem to have higher peaks than in recent years.

Potassium

There was no reference value for Potassium. The measured concentrations in the dataset did not show any clear increases or decreases.

Other macro nutrients: Sulfur, Calcium and Magnesium

These nutrients weren't measured much either, and did not show visible increases and decreases. Of sulfur only measurements as SO_4 were found.

Micro nutrients: Iron, Sodium, Chlorine, Silicon and Aluminum

Almost all parameters all had data available before 1983. Some had only data after this year. Comparing them with more recent measurements did not reveal any increases or decreases as all concentrations were close to each other, with varying higher and lower measured concentrations.

4.3.1.1 Mann-Kendall trend tests

Besides examining the data in general, the dataset was also analysed by a (non-seasonal) Mann-Kendall trend Test to see if significant trends could be found in the data. The result of this test is shown in the tables 18 to 20.

In table 16 there were four significant trends detected: temperature, colouration and turbidity. All of them have a very slightly increasing trend, except the colouration, which is lowering. Table 17, which only contains measurements from 0 to 6 m deep, has a different outcome. There only the coloration and turbidity have a detected trend. The slopes of the detected trends are stronger than the first analysis. This difference is very likely caused as some parameters change over the depth of the water, like the temperature; water at a greater depth is expected to have a lower temperature due to the density. When excluding depth as factor by only taking the upper part of the water (in this case 0 to 6 m) this effect has been strongly reduced. In the previous section it became clear that the turbidity seemed to increase and the secchi depth to decrease. The statistical test has confirmed his observation.

The results for the chemical parameters are summarized in table 19 and 20. A non-seasonal trend test for the chemical parameters resulted in five detected trends: pH (slight increase), Ortho-Phosphate (zero increase), Nitrogen (increase), Magnesium (decrease) and Sodium (decrease). Silicon did not have enough data to test. The increasing trend of the pH makes sense. In the past problems with acidification were happening but have been improved, resulting in an increase in pH numbers over time. In table 20 the second test with only the shallow depths of the same parameters are shown. The test resulted in the same detected trends, however instead of nitrogen now iron got a detected increasing trend.

Table 18 Statistical analysis of hydrological parameters containing all depths. Green means there has been found a significant increasing or decreasing trend. Red means no trend has been found. The sen's slope indicates the slope of the trend.

All depths - Non seasonal trend test Hafslovatnet			
Parameter	**P value (two tailed)**	**Sen's slope**	**Confidence interval Sen's slope**
Temperature	0,010	0,033	0,025; 0,043
Conductivity (µS/cm)	0,089	-0,016	-0,025; -0,008
Colouration	0,009	-0,048	-0,071; -0,033
turbidity	< 0,0001	0,012	0,010; 0,014
Secchi depth	0,111	-0,128	-0,162; -0,100

Table 19 Statistical analysis of hydrological parameters containing measurements between 0 and 6 m deep. Green means there has been found a significant increasing or decreasing trend, red means there has not. The sen's slope indicates the slope of the trend.

0 – 6 meter - Non seasonal trend test Hafslovatnet			
Parameter	**P value (two tailed)**	**Sen's slope**	**Confidence interval Sen's slope**
Temperature	0,576	0,018	0,000; 0,032
Conductivity (µS/cm)	0,095	-0,033	-0,044 ; -0,020
Colouration	0,001	-0,136	-0,188 ; -0,099
turbidity	< 0,0001	0,026	0,023; 0,029
Secchi depth	x	x	x

Table 20 Statistical analysis of chemical parameters containing measurements of all depths. Green means there has been found a significant increasing or decreasing trend, red means there has not. The sen's slope indicates the slope of the trend.

All depths – Non seasonal trend test Hafslovatnet			
Parameter	**P value two tailed**	**Sen's slope**	**Confidence interval Sen's slope / Notes**
pH	0,040	0,001	0,001; 0,002
Oxygen (mg/l)	0,090	-0,03	-0,038; -0,028
Oxygen (%)	0,071	0,714	0,649; 0,720
Ortho Phosphates	0,019	0	0
Total Phosphates	0,680	0,208	0,131; 0,325
Nitrogen N-NO_3	0,000	0,003	0,003; 0,003
Sulphate - SO4	0,339	-0,23	-0,235; -0,190
Calcium - Ca	0,363	-0,026	-0,030; -0,022
Silicon - Si	x	x	x
Iron - Fe	0,424	x	0
Magnesium - Mg	0,004	-0,006	-0,006; -0,006
Sodium - Na	0,001	-0,026	-0,026 ; -0,025
Potassium - K	0,227	-0,008	-0,010; -0,008
Aluminium - Al	0,310	-1,167	-1,408; -0,831
Total reactable	0,585	-0,002	-0,003 ; -0,002

Aluminium - Al tot			
Chlorine - Cl	0,548	-0,095	-0,114 ; -0,084
all parameters: - 1997 became 1-7-1997 - 2007 and 2013: 1-8-2007 and 24-8-2013 - Below detection range, f.ex. <5 etc. is 0 - Similar date (two times the same date, was not accepted by test) added one day			

Table 21 Statistical analysis of chemical parameters containing measurements between 0 and 66m deep. Green means there has been found a significant increasing or decreasing trend, red means there has not. The sen's slope indicates the slope of the trend.

0 -6 meter – Non seasonal trend test Hafslovatnet			
Parameter	**P value two tailed**	**Sen's slope**	**Confidence interval Sen's slope / Notes**
pH	<0,0001	0,005	0,004; 0,005
Oxygen (mg/l)	0,079	-0,11	-0,153 ; -0,088
Oxygen (%)	0,454	0,5	0,473; 0,547
Ortho Phosphates	0,033	0	0
Total Phosphates	0,482	0,6	0,430; 0,758
Nitrogen – N-NO_3	0,187	0,003	0,002; 0,004
Sulphate - SO_4	0,339	-0,23	-0,235; -0,190
Calcium - Ca	0,065	-0,04	-0,043 ; -0,036
Silicon - Si	x	x	X
Iron - Fe	0,043	0,002	0,002; 0,003
Magnesium - Mg	0,004	-0,006	-0,006; -0,006
Sodium - Na	0,001	-0,026	-0,026 ; -0,025
Potassium - K	0,227	-0,008	-0,010; -0,008
Aluminium - Al	0,310	-1,167	-1,408; -0,831
Total reactable Aluminium - Al tot	0,566	-0,011	-0,012 ; -0,009
Chlorine - Cl	0,548	-0,095	-0,114 ; -0,084
all parameters: - 1997 became 1-7-1997 - 2007 and 2013: 1-8-2007 and 24-8-2013 - Below detection range, f.ex. <5 etc. is 0 - Similar date (two times the same date, was not accepted by test) added one day			

4.3.2 Hydrological and chemical results over time at Lake Veitastrondvatnet

For Lake Veitastrondvatnet less data was found as for Lake Hafslovatnet. Despite this, some things can be concluded (for the numbers see appendix).

4.3.2.1 Hydrological measurements

The temperature was decreasing with an increasing depth in September 1981 and October 1984. In August 2011, the temperatures were a lot higher and also deeper down it dropped less and was still 6.9 at 38mdeep. All surface measurements from HISF show that there is variation between 7 and 15 °C. The conductivity is low and is in the same range as Hafslovatnet. The measured turbidity over depth shows that values are higher in the shallower parts (in the case of 1984 it was 20m) and lower in the deeper parts. Surface values are varying over years and months. The second depth measurements had higher values than 1984 and here again are the highest values deeper down and not at the surface. The small amount of Secchi depth measurements seem to indicate a decrease in measurements.

4.3.2.2 Chemical measurements

The pH has increased over all depths since the early measurements, caused by preventing acidic rain. The oxygen shows high saturation levels except 1984 were it stays the same over the depth.

Macro and micro Nutrients

Orthophosphate and total phosphor

Also Veitastrondvatnet did not have a lot of measurements of phosphorus. The orthophosphates were well below 7 µg P/l as reference (Norwegian classification system). The total phosphor exceeded this reference with 1 µg P/l in 1991.

Nitrogen and Nitrate

The nitrate measurements were measured here in mg/l. With the reference of 0.3 mg N/l most measurements stayed well below this classification.

The values are only higher than the reference value in 1975, but since 2000 both measurements are lower than 0.3 mg N /l.

Calcium, Silicon, Iron, Magnesium, Sodium, Potassium and Aluminium

These parameters had a few measurements and did not show any large increases or high measurements.

4.3.2.1 Mann-Kendall trend tests

As for Lake Hafslovatnet, also Lake Veitastrondvatnet was tested with the (non-seasonal) Mann-Kendall trend test. Those results are presented in tables 21 to 24.

In table 20 it can be seen that there are two detected trends for the parameters temperature and colouration. The temperature has an increasing trend and the colouration a decreasing trend. Comparing these two with the results from Hafslovatnet it seems that the slopes of the trends are stronger in Veitastrondvatnet than in Hafslovatnet. When only testing the measurements between 0 and 6m deep (table 22) the pH instead of the temperature has a detected increasing trend, while the colouration has an even higher slope.

Table 22 Statistical analysis of hydrological parameters containing measurements of all depths. Green means there has been found a significant increasing or decreasing trend, red means there has not. The sen's slope indicates the slope of the trend.

All depths - Non seasonal trend test Veitastrondvatnet			
Parameter	**P value two tailed**	**Sen's slope**	**Interval**
Temperature	0,011	0,194	0,177; 0,224
Conductivity (µS/cm)	0,411	-0,06	-0,099; -0,041
Colouration	0,002	-0,242	-0,250; -0,200
turbidity	0,095	0,09	0,078; 0,100
Secchi depth	0,419	-0,2	-0,202; -0,145

Table 23 Statistical analysis of hydrological parameters containing measurements between 0 and 6m deep. Green means there has been found a significant increasing or decreasing trend, red means there has not. The sen's slope indicates the slope of the trend.

0 – 6 meter - Non seasonal trend test Veitastrondvatnet			
Parameter	**P value two tailed**	**Sen's slope**	**Interval**
Temperature	0,063	0,266	0,234; 0,331
Conductivity (µS/cm)	0,674	-0,057	-0,100 ; -0,009
Colouration	0,046	-0,775	-0,804 ; -0,724
turbidity	0,324	0,107	0,078; 0,124
Secchi depth	0,419	-0,2	-0,202; -0,145

Not all chemical parameters in table 23 and 24 could be tested with the Mann-Kendall trend test. Those that could be tested all resulted in having no significant trends, except the pH for the 0 to 6m analysis. A significantly increasing trend was detected.

Table 24 Statistical analysis of chemical parameters containing measurements of all depths. Green means there has been found a significant increasing or decreasing trend, red means there has not. The sen's slope indicates the slope of the trend.

All depths – Non seasonal trend test Veitastrondvatnet			
Parameter	**P value two tailed**	**Sen's slope**	**Interval**
pH	0,060	0,018	0,015; 0,022
Oxygen (mg/l)	0,675	0	X
Oxygen (%)	0,446	-0,071	-0,167; 0,000
Ortho Phosphates	0,146	-0,107	-0,123 ; -0,095
Total Phosphates	x	x	x
Nitrate - NO3	0,263	-0,367	-0,419 ; -0,265
Sulphate - SO4	0,734	-0,18	-0,200 ; -0,160
Calcium - Ca	x	x	x
Silicon - Si	x	x	x
Iron - Fe	x	x	x
Magnesium - Mg	x	x	x
Sodium - Na	0,734	0,115	0,106; 0,124
Potassium - K	x	x	x
Total reactable Aluminium - Al tot	X	x	x
Chlorine - Cl	1,000	0,023	0,008; 0,039
All parameters: - 9-6-09-1981 became 7-09-1981 - 1997 word 1-7-1997 - 2007 and 2011 became 28-8-2007 and 28-8-2011 - Below detection range, f.ex. <5 etc. is 0			

Table 25 Statistical analysis of chemical parameters containing measurements between 0 and 6m deep. Green means there has been found a significant increasing or decreasing trend, red means there has not. The sen's slope indicates the slope of the trend.

0 – 6 meter – Non seasonal trend test Veitastrondvatnet			
Parameter	**P value two tailed**	**Sen's slope**	**Interval**
pH	0,001	0,057	0,052; 0,061
Oxygen (mg/l)	0,454	0,343	0,312; 0,367
Oxygen (%)	0,566	1,4	1,260; 1,960
Ortho Phosphates	0,272	-0,2	-0,250 ; -0,180
Total Phosphates	x	x	x
Nitrate - NO3	0,649	-0,963	-1,123 ; -0,841
Sulphate - SO4	0,734	-0,18	-0,200 ; -0,160
Calcium - Ca	x	x	x
Silicon - Si	x	x	x
Iron - Fe	x	x	x
Magnesium - Mg	x	x	x
Sodium - Na	0,734	0,115	0,106; 0,124
Potassium - K	x	x	x
Total reactable Aluminium - Al tot	X	x	x
Chloride - Cl	1,000	0,023	0,008; 0,039
All parameters: - 9-6-09-1981 became 7-09-1981 - 1997 word 1-7-1997 - 2007 and 2011 became 28-8-2007 and 28-8-2011 - Below detection range, f.ex. <5 etc. is 0			

4.3.3 Manipulations of the rivers Storelvi and Heggestadelvi

In the area of Veitastrond, between 1962 and the 1990'ies, adjustments and repairs have been made on the two rivers Storelvi and Heggestadelvi. At the river Storelvi, over 5640m had been straightened. Furthermore, a flood prevention dam was build built partially on both sides of the river to reduce flooding episodes. In addition, a threshold was established. From length profiles it is probable that down the river the bottom was partially lowered. There are no known measurements before and after adjustments (personal communication, NVE). A comparison of two aerial photos from 1955 and 1966 shows significant changes in banks in those then years (Bogen, 1981).
The farmland around the river Heggestadelvi has been altered in such a way that (probably by lowering the ground water level) extensive draining of water to the river was realized. With the water a lot of iron is transported as well.

In the statistical analyses for Veitastrondvatnet there were no significant trends found for turbidity (effect of altering Storelvi) or iron (effect of altering Heggestadelvi and its water source) but there was a decreasing trend for colouration.

4.3.4 Water dam with tunnel

At the outlet of Lake Veitastrondvatnet to Tverrbergvatnet a small water dam was planned around 1976 and built around the same time as the hydroelectric power plant. The small dam blocks the natural water outlet and lets water pass through via a separate tunnel. Inside the tunnel, a regulation hatch (fig. 33) enables to regulate the amount of water passing through the tunnel to ensure the right water level needed for the hydroelectric production at Lake Hafslovatnet (Berdal, 1976). The entrance of the tunnel lies 1 – 7 m below the water surface.

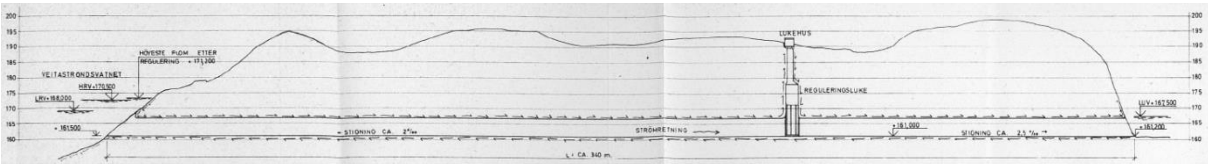


Fig. 33 Plans of the water tunnel and its regulation hatch in 1976 (Berdal, 1976). The heights are mentioned in the text below

In fig. 33 a schematic plan of the water tunnel is shown. The tunnel entrance lies between 161.5 m and 167.85 m, thus the entrance is 6.35 m high. The lowest regulation height of the water level is 168.0m and the highest level is 170.50m. This means that at the lowest allowed water level, water from around 0,15 – 6,5 m deep will flow through the tunnel. At the highest allowed water level (2.5 m higher) water from 2.5 – 9 m deep is passed through. The average secchi depth from the collected dataset in Lake Veitastrondvatnet is 2,51m. With a conversion factor (varies between 2 and 3 depending on turbid or clear conditions) the euphotic depth can be calculated (T Dale, pers. Communication). Using this factor the euphotic depth can be between 5.02 (x2) and 7.53(x3) meters. Because of the rather turbid conditions the euphotic depth will be likely more close to 5,02m. This means that even at the lowest allowed water level a part of the inflowing water will be water below the euphotic zone of Lake Veitastrondvatnet.

In the first part of this chapter CTD measurements were shown and compared to a location in Lake Hafslovatnet and with the two lakes (Hafslovatnet and Veitastrondvatnet). Comparing the CTD of the two lakes showed that Lake Veitastrondvatnet had a lower surface temperature and one clear metalimnion while Lake Hafslovatnet had a higher surface temperature and two metalimnions. The horizontal cross-sections pointed out that the measurements closest to the inlet of Lake Hafslovatnet surface were different from the rest. The surface temperature was lower whereas the other two stations were warmer. The turbidity and chlorophyll a concentration were not high at the surface but their peaks occurred meters lower.

The temperature in Lake Hafslovatnet had a significant trend (slight increase), but only if all depths were used (same for lake Veitastrondvatnet). The turbidity had for both tests (all depths and 0-6m) a significant trend (slight increase). Of the nutrients, the following three had significant detections: Orthophosphates (no increase or decrease), Magnesium (small decrease) and Sodium (small decrease). Both turbidity as well as the nutrients did not have a detected trend in Lake Veitastrondvatnet.

4.3.4 Regulation in Lake Veitastrondvatnet and Hafslovatnet

Before the regulation in 1983 the water system of Hafslovatnet followed a natural run off pattern. The height depended on the amount of meltwater from the glaciers and precipitation in the area and the residence time along the way. Following the rivers to the lakes, the water was stored there naturally for some time before it reached the Årøy river to the fjords. Nowadays the water level is regulated by a dam and the inlet of the power plant. With these two constructions the amount of water can be controlled by letting the lakes hold on to the incoming water longer than usual, but within maximum regulation heights.

4.3.4.1 Seasonal variations in the water level in Lake Veitastrondvatnet before and after the regulation in 1983

Since regulation the seasonal variation has changed. In fig. 34 data about the water level from Veitastrondvatnet since the 1970s are plotted into two graphs. The upper graph shows that before the regulation took place, the water level had a larger variation (3.5 – 4m) than the variation after regulation (2 – 2.5m). Since 1996 the noted height was changed from meters (related to a measuring pole see fig. 35) to meters above sea level. Those values are shown in the lower graph. It shows the same variation as in the upper graph (2 – 2.5m in regulated conditions). In the years 2010 and 2011 the variations seems to be larger (3), but 2013 – 2014 are lower again (2.5m).

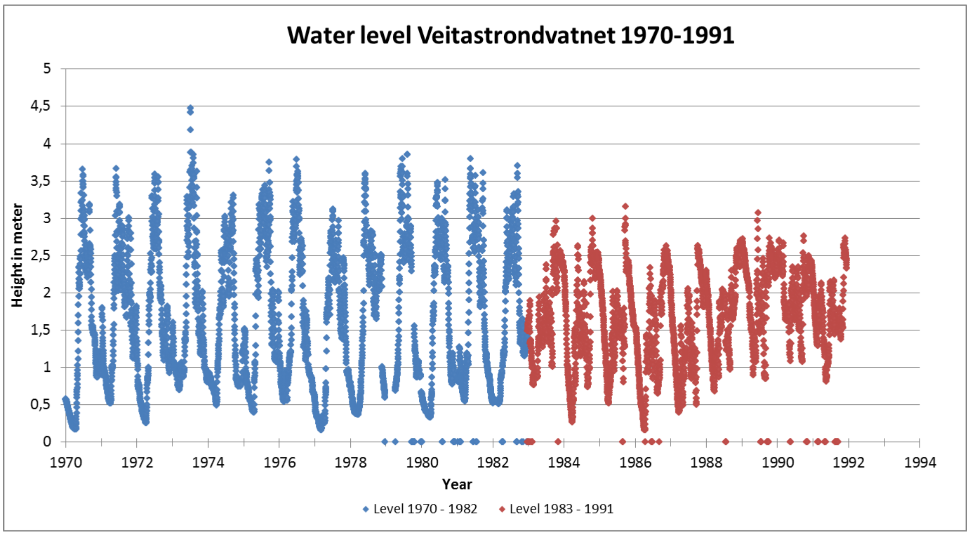


Fig. 35 Example of measurement pole at Straumavatnet to measure the water level

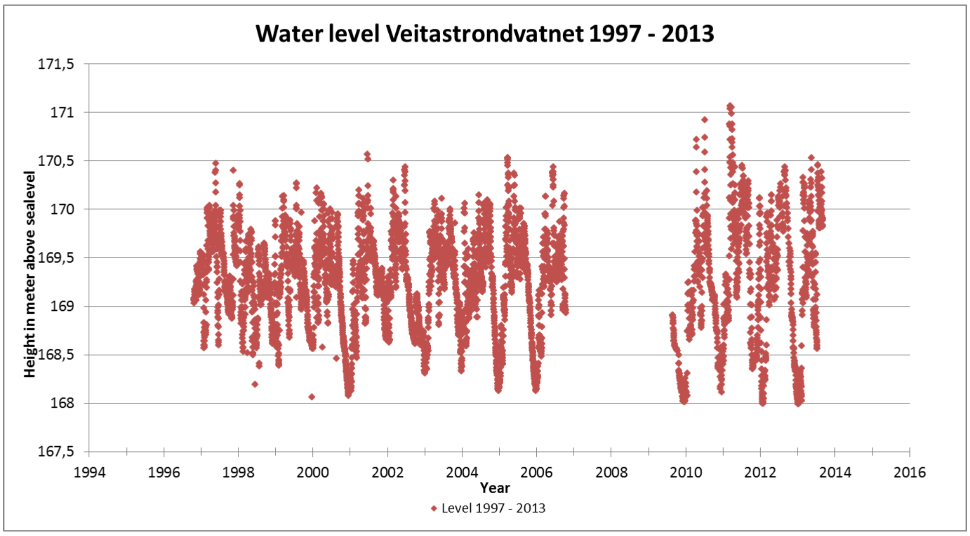


Fig. 34 Two graphs containing data about water level at the outlet of Veitastrondvatnet (at Soget). The first graph contains data before regulation and after regulation. The second figure contains the data since changing from meters to meters above sea level. Data was provided by *Norges vassdrags- og energidirektorat* (NVE)

Beside the provided water level measurements at the outlet of Veitastrondvatnet the following fig. (fig. 36) shows the water level height over one year as an average of all measurements since 1900 –

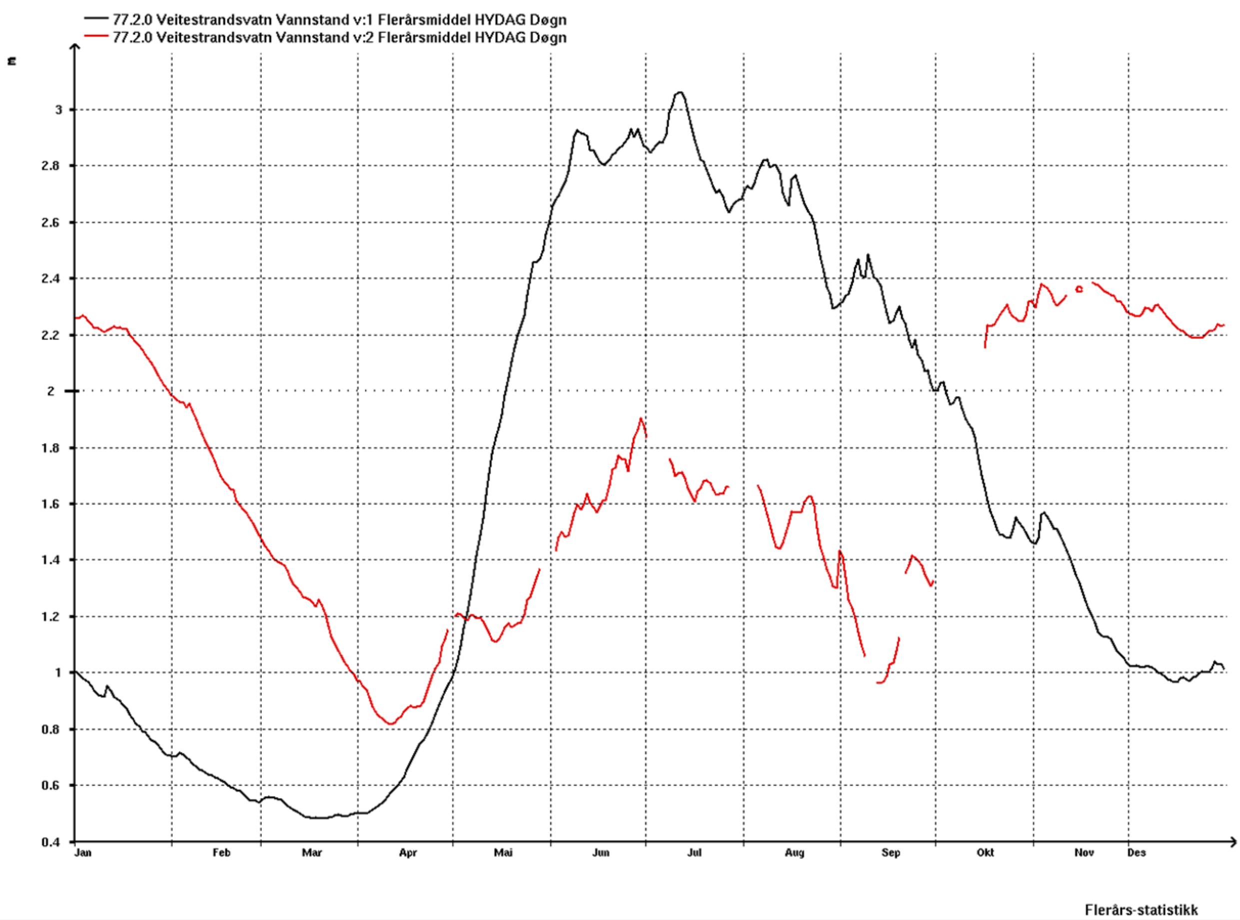


Fig. 36 Average water level measurements per month before regulation (black) and after regulation (red) at the outlet of Veitastrondvatnet (at Soget). The Y-axis shows the height in meters and the x-axis shows the months. (NVE)

1983 and the average between 1983 and 2014 (NVE). The water level is higher from October to April and lower from April to October. The variation in water level over one year is smaller.

4.3.4.2 Water flow

With the regulation of the water level a change in water flow is possible. In fig. 37, like fig. 36, a general water flow pattern over one year has been made. The data is from Lake Veitastrondvatnet. From November to April the amount of transported water per second is low while between May and October the flow is high. When comparing the graph with the one in fig. 36, the similarity of the pattern with the unregulated water level pattern stands out. If assumed that the flow speed is related to the water level, the new flow speed (after regulation in 1983) is similar to the new water level pattern as well. Thus the flow pattern should have changed too. Meaning that a lower volume of water is passed on into the water system in summer than in winter time.

The water flow is defined as the volume of water passing a location per time unit, or volume (m^3) /time (sec). The speed of the water plays a role in the water flow as it defines the distance water travels per second, or distance (m) / sec. As water from Lake Veitastrondvatnet passes the lakes

Tverrbergvatnet and Straumane before entering Lake Hafslovatnet where the water is regulated again, a (likely) changed flow through these two lakes in between can have altered their water speeds. However if a change in flow influences the speed of the water at lake Tverrbergvatnet and Straumane is difficult to say. The water speed is partly related to the amounts flowing in but as well to the water level in Lake Hafslovatnet. Depending on the level differences between lakes Veitastrondvatnet and Hafslovatnet and the flow it is likely to assume that the water speed will increase somewhat when the water flow increases as well.

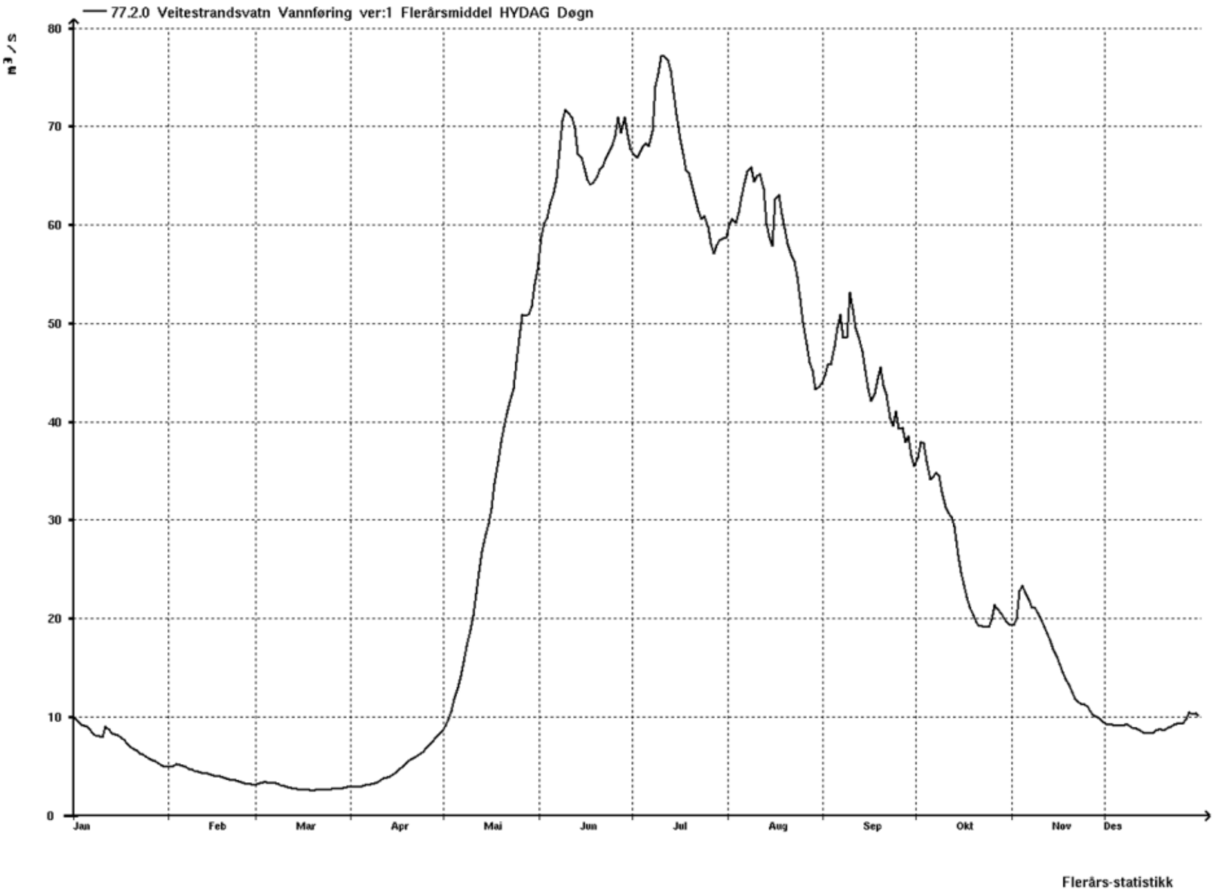


Fig. 37 Water flow showing the average flow per month at the outlet point Soget from Veitastrondvatnet before regulation. On the y-axis the water flow is shown in m^3/s and on the x-axis the months are shown. (NVE)

4.3.4.3 Beach erosion

While exploring Straumane and Tverrbergvatnet (6 Oct. 2015) some marked signs of beach erosion were present along the edges. The first thing noticed were edges with a soil layer atop a layer with rocks (moraine like, see fig. 38 A) where water had carved out gaps between the rocks and the soil (fig 38 B and C). This could mean that at some point, soil was eroded away from underneath the surface. The soil is still kept together due to the dense roots of the plants on the top of the layer. Even large roots and parts of trees are visible where the old soil around has completely eroded away. An owner of a recreational house had reinforced the beach to prevent further erosion (fig. 38 D and E). There had been a time when sediments could settle and even vegetation like moss, grass and trees could grow. A change in several processes could have altered the condition causing erosion by the water, which are the water level, water flow and water speed. This results in more terrestrial sediment, which is taken with the water downstream which can contribute to a higher turbidity and

nutrient level in the water. In spring time clouds of muddy water along the few soft bottom beaches in Lake Veitastrondvatnet can be seen (T. Dale, pers. Communication) suggesting that beach erosion is still taking place in Lake Veitastrondvatnet, more than 40 years after the regulation.
Looking at the water level fluctuations the range has become smaller after regulation. However, the sign of erosion does not comply with this fact. Before 1983 the water could variate to a much higher level, meaning there was a higher change of water reaching the altitude of the eroded gaps. If the water could go higher than the gaps and this was created after the regulation, fewer trees would be growing close to the water edge. Therefore, it is likely that the water height at the lakes Straumane and Tverrbergvatnet experience, despite the lowered variations, now more often a higher water level, a higher water flow (more water movement) and a higher water velocity than before. Or that these factors happen at a moment when the water level is staying longer on one level.

Fig. 38 Five photos taken along the edges of Tverrbergvatnet and Straumavatnet. A. shows the layer containing rocks and the upper soil layer with plants. B. shows another spot were the two layers have a clear separation. C. Shows the depth of the gap. The yellow notebook has the size of an A4 paper. D. shows remains of roots of trees and the line were the erosion has not yet taken place. E. Shows that this home owner took measurements against erosion by the water. (A-C own photo's; D and E by T. Dale)

5 Conclusion

At the beginning of this thesis the following main question was introduced: *Can human interference in the watershed and climate change (temperature) be the cause of the noticed increase of water plants in Lake Hafslovatnet, western Norway, since 1984?* This was investigated by looking at all the collected data about the hydrography, hydrology and chemistry of the lake from 1967 until 2014. First the results will be discussed per sub question. After this the thesis will be concluded by answering the main question.

5.1 Answering the sub questions

What is known about the present hydrographical hydrological, and chemical conditions in Lake Hafslovatnet?

CTD measurements and loose measurements of the rivers upstream, together with information provided in the introduction give a general understanding of the recent hydrographical, hydrological and some chemical conditions in the watershed. The CTD of the 25th of August 2015 shows that there is a two layered epilimnion in Lake Hafslovatnet. Within the second epilimnion the turbidity, chlorophyll a and oxygen saturation are higher than in the upper epilimnion or the hypolimnion. Yearly measurements in late August since 2008 show that, with some variation, the same structure is present. This means that this is a situation that is robust enough to happen each year. Further sampling in Lake Hafslovatnet in late September showed that this typical structure is present all over the lake. Differences can be seen in temperature, turbidity and chlorophyll a from east to west and north to south. The incoming water from the bypass tunnel in Lake Veitastrondvatnet to Lake Hafslovatnet is colder and denser than the surface water of Hafslovatnet. This can very likely be the cause of the two layered epilimnion as the cold, dense water sinks below the surface water in Lake Hafslovatnet. Visual observations of fronts at the inlet support this theory (fig. 21 in chapter 4) and can explain why the highest turbidity and chlorophyll a are not found at the surface but at some meters below the surface. Further away from the inlet to Lake Hafslovatnet the differences between the two epilimnions are also less pronounced showing that water starts to mix slowly as it gets more time to heat up. Measurements from the Glacier Austerdalsbreen to Lake Hafslovatnet showed that at the glacier the temperatures are lowest and slowly heats up on its way downstream. Furthermore the turbidity was highest at the glacier, which makes sense as the glacier erodes the mountain rock. The pH did not show a clear pattern.

Has the temperature changed (by climate) and altered hydrographical, hydrological or chemical conditions in the watershed of Lake Hafslovatnet resulting in increased plant growth?

There is no strong indication that the water temperature shortly before or after 1983 changed due to climate change, when the increased plant growth was noticed. But the air temperatures of Fjærland and the water temperatures do have two detected changes around the same time: in 1993/1992 and 1997/1998. Here a change in the water temperature could have been caused by a rise or drop in air temperature but cannot have contributed to the growth back in the 1980s. This could suggest that the excessive plant growth is possibly not due to climate change. However the results do suggest that around April, May and October the air temperature is increasing, resulting in a shorter ice cover period and causing a longer growth season for the plants. However an increased growth season of some weeks is probably not sufficient enough to explain the large increase in plant growth alone. However despite reduced ice cover there is no evidence found in the used dataset for an elongated stratification period, unlike the paper from Hobæk, et al., 1998.

Analysis of the air temperature resulted in the following detections: at station Lærdal (low altitude) three detected changes with the change point analysis were found. With 91% confidence the most important change occurred in 1962 when the average yearly temperature before and after the change went from 5.2 °C to 4.7 °C. Although the (95%) confidence interval could not be pinpointed very exactly, it is most likely that this change was caused by the winter of 1962-1963, which was one of the coldest winters of the twentieth century for many countries, among which in Europe (O'Connor, 1963) . The other detected changes (1979 and 1988), rated less important but still detected, both had changes where the average temperature increased. With the Mann-Kendall trend test a significant trend (P 0.003) was detected and the trend had a small increase (sen's slope of 0.016). The seasonal Mann-Kendall trend test was applied to monthly averaged values. Here again a trend was detected (P 0.013, sen's slope 0.02). This means that at this low altitude station since 1979 changes resulted in an increase in temperature and over the whole dataset an increasing trend in the yearly average air temperature are present. The second station Fjærland (low altitude), situated in a valley below a glacier in similar way as Veitastrond, had four detected changes whereof the two most important changes occurred in 1988 (97% confidence) and 2007 (99% confidence). In 1988 the differences before and after the detected change was an increase in temperature (5.1 °C to 6.25 °C) while in 2007 the change was a decrease (6.1 °C to 5.3 °C). However here was no trend detected with the Mann-Kendall trend test. Bjørkehaug i Jostedal (high altitude) had no detected changes. It did have a detected slight increasing trend with the Mann-Kendall trend test for the average yearly values (P 0.007, Sen's slope 0.03). The last station, Luster sanatorium (high altitude) had no significant changes or trends. Based on these results it seems that changes in temperature are stronger at lower altitudes than at higher results. Around the time of the noticed plant growth problem (somewhere between 1980 and 1984) only the station at Lærdal had detected changes around this time period, while Fjærland had more recent detections. As Lake Hafslovatnet lies between these two altitudes it is not clear whether it has experienced similar influences found at either of the two lower altitude weather stations or at the higher altitude stations.

The average yearly water temperature at the outlet of the Årøy hydroelectric power plant has two significant changes. The first detected change happened in 1992 (92% Confidence) and the water temperature after the change decreased. The second more important change was in 1998 (98% confidence) where the temperature increased. A significant (slight) increasing trend (P 0.000 sen's slope 0.049) of the average yearly water temperature was detected with the Mann-Kendall trend test. The average monthly values were tested with a seasonal Mann-Kendall trend test. An increasing trend in the water temperature was detected as well (P 0.060; sen's slope 0.032).
Testing the months separately with the Mann-Kendall trend test resulted in two significant increasing trends in May (P 0.012 sen's slope 0.103) and October (P 0.034 sen's slope 0.028). Change point analysis found significant changes in April. The detected changes in water temperature however cannot be connected to the plant growth problem in the 1980s. The two detected trends in May and October suggest that the water temperatures have in general become warmer for a longer period.

Has human interference in the past changed hydrological, hydrographical or chemical conditions in the watershed of Lake Hafslovatnet resulting in increased plant growth?

Human interference has taken place over many years. Heavy alterations in the area of Veitastrond and Hafslo however have taken place over the past 50 to 70 years. Most changes identified and discussed in this thesis were carried out roughly between the 1960s to 1983. These consists of canalisation and build of flood protection, changes made in the course of the rivers and extensive draining of farmland in the area of Veitastrond. Furthermore the construction of a bypass tunnel at the outlet of Veitastrondvatnet and the placement of the hydro-electric power plant in 1983 at the outlet of Hafslovatnet.

First, the analyses of the hydrological data resulted in some significant increasing trends. No connection to 1983 could be found. Table 24 shows more detected trends for Lake Hafslovatnet than for Lake Veitastrondvatnet. The pH for both lakes has an increasing trend. As mentioned before in the past acidic precipitation caused the pH of waterbodies to be drastically lowered. Since action was taken the pH has risen to more normal, slightly acidic values. The coloration has a decreasing trend for both lakes. Humic acids, iron and manganese, that influence the water color probably have decreased. Furthermore Lake Hafslovatnet had an increasing trend for the turbidity. Measurements of the last years already suggested a decreasing secchi depth and increasing turbidity. The trend test has confirmed these observations. An increase in turbidity could be caused by many factors: there could be more glacier erosion of the mountain, increased terrestrial organic material transported by precipitation, the alterations of the rivers Storevli and Heggestadelvi at Veitastrond, erosion of the beaches at Straumane (increasing terrestrial organic material and nutrients), sedimentation in the lakes, light penetration and at last could be influenced by the amount of algae in the water. There was no detected trend in Lake Veitastrondvatnet, while it lies upstream, meaning that the increase is caused by less data for Lake Veitastrondvatnet or factors happening between this lake and Lake Hafslovatnet.

Table 26 Trends of the analyzed hydrological and chemical measurements by the Mann-Kendall trend test. The dataset contained all collected data out of papers, researches and own measurements and can be viewed in Appendix 8.8 – 8.11.

Hafslovatnet 0 – 6 meter	
Parameter	**Mann-Kendall trend test (non-seasonal)**
pH	Increasing trend
Coloration	Decreasing trend
Turbidity	Increasing trend
Chemistry	
Ortho-phosphates	zero, but trend
Iron (Fe)	Increasing trend
Magnesium (Mg)	Decreasing trend
Sodium (Na)	Decreasing trend
Veitastrondvatnet 0 – 6 meter	
Parameter	**Mann-Kendall trend test (non-seasonal)**
pH	Increasing trend
Coloration	Decreasing trend
Chemistry	
-	

Manipulations to straighten, partially lowering the river Storelvi and realizing flood prevention dikes at Veitastrond are likely to have brought changes into the water system especially during and close after finishing the alterations. From the beginning of these manipulations in the period 1962 – 1990 are no hydrological and/or chemical measurements available, but around 1980 it is not clear when and which alteration was worked on. Changes that these alterations have brought are very likely to be the transport of colder water and a larger transport of sediments from the glacier as the residence time in the river has shortened.

Regulation of the water level has caused the variation and general pattern per year to change since 1983. The major change before and after regulation is the water level variation. Before the level was low in winter, high in spring and summer and lower again in autumn. Now the summer levels are lower and the winter levels are higher. The amount of water passing through the water system and the water level are controlled by the bypass tunnel with the regulation hatch at Veitastrondvatnet and the hydroelectric power plant at Hafslovatnet.

The water flow pattern over one year was very similar to the water level pattern before regulation. The amount of transported water per second depends among other things the allowance of water to be passed. When more water has to be stored in for example Lake Veitastrondvatnet the regulation hatch in the bypass tunnel could be lowered to let less water pass through, immediately changing the flow. Therefore it is likely that the flow after regulation is also similar to the new water level pattern.

It is not clear when the found beach erosion at Straumane started to take place, but in fig. 38 could be seen that it has been present for a while as tree roots at the water edge were visible. Observations in spring when clouds of muddy water along the soft bottom beaches (T. Dale, pers. communication) indicate that there is still transportation of sediments present. However how much of sediment transportation is natural in a system with running water is not known. The turbidity in Lake Hafslovatnet does have a detected increasing trend, and records of the secchi depth showed a decrease. The only nutrient that had an increasing trend was iron. This nutrient has a far better probability of entering the water system at Heggestadelvi than originating from the eroded soil.

5.2 General conclusions and recommendations

With CTD measurements a better basic understanding of the hydrographic (or hydrological) structure of the lakes has been acquired. In addition to this, the present investigation collected data from various scattered sources, which was not yet done by other researchers. With all these data now available it became possible to see that there could be many more factors involved in the plant growth problem compared to the factors discussed in previous papers.

One of these factors could be related to the bypass tunnel build in connection to the regulation. This tunnel now allows to send colder, denser and more turbid water from below the euphotic zone in Lake Veitastrondvatnet to Lake Hafslovatnet via the shallow areas of Lake Tverrbergvatnet and Straumane. Lake Hafslovatnet has a two layered epilimnion during the summer months. The deeper epilimnion is probably caused by the cold, dense and turbid water that submerges the upper epilimnion in Lake Hafslovatnet when it meets the warmer, less dense surface water of Lake Hafslovatnet. Since much of the water coming via the bypass tunnel probably is drained from below the euphotic zone in Lake Veitastrondvatnet, it is likely to assume that the bypass water contains more nutrients compared to the amounts of nutrients in the surfaces water in Lake

Veitastrondvatnet that previously drained into Lake Hafslovatnet. This assumedly nutrient richer water, partly coming from below the euphotic zone in Lake Veitastrondvatnet could explain the increased plant growth in Lake Tverrbergvatnet, Straumane and Lake Hafslovatnet. This mechanism could thus partly explain both the increased plant growth as well as the decreased Secchi depth observed in the water after the regulation. The decreased Secchi depth could reflect an increased growth of phytoplankton in the lower epilimnion.

Beach erosions in Lake Veitastrondvatnet, Lake Tverrbergvatnet and Straumane following the regulation, could also have contributed to the decreased Secci depth by releasing more particles to the water masses. But beach erosion in itself could not have caused the excessive plant growth. However if the eroded material also releases nutrients to the waters, then beach erosion could partly stimulate growth of both plant and phytoplankton. The extensive draining in the farmland of Veitastrond releasing increased amounts of at iron (and possibly other elements) could also be involved in the increase growth.

However, there is one important difference in the possible impacts of the bypass tunnel on the one hand, and the beach erosions and draining on the other hand. It is likely that the effects of the beach erosion and the draining will decrease with time, whereas the effect of the bypass tunnel probably will not decrease with time.

There are two increasing trends detected in air and water temperatures, but cannot be linked to each other or to the year 1983. Therefore it cannot be said that climate change has altered hydrographical, hydrological or chemical conditions in the watershed. However it has to be kept in mind that the water input of this water system is partially glacier water. When air temperatures are high close to the glacier, it will release colder melt water into the system, which counteracts the increased air temperature. There is a clear connection between human interference and water level in Veitastrondvatnet. To answer the main question, human interference can have played a part in the plant growth problem by altering hydrological conditions and with less certainty chemical/nutrient conditions in the water system.

To verify the “nutrient addition from the bypass tunnel”-hypothesis it is recommended to study the nutrient depth distribution (nitrate, phosphate, iron) in all the involved water masses (Lake Veitastrondvatnet, bypass tunnel, Lake Tverrbergvatnet, Straumane and Lake Hafslovatnet) over the growth seasons for 3 years.

It is also suggested to carry out a study to see if the regulation has change the general seasonal pattern in the current speed in the water going from Lake Veitastrondvatnet to Lake Hafslovatnet as this could have a positive effect on the plant growth. However, a changed current speed pattern could probably not explain the decreased secchi depth.

A final suggestion to further studies is to continue adding new data to these (some already large) datasets. Especially larger data sets are very valuable for long term analysis and documentation of possible changes.

6 Discussion

The purpose of this study was to analyze possible effects that could have caused the excessive plant growth that has been observed in Lake Hafslovatnet after the regulation of this lake and Lake Veitastrondvatnet in 1983. The thesis did not address the biological side of this problem as data collection resulted in so much different kind of information the subject of the thesis was narrowed down to the hydrography, hydrology and chemistry (nutrients).

The analysis has revealed some different factors that could be involved. These factors could be local, such as alterations of the two rivers Storelvi and Heggestadelvi, construction of a bypass tunnel and hydroelectric powerplant) and/or global, such as regulations, changes in air or water temperature, beach erosion, changes in hydrological or chemical parameters etc. Known from literature about the problem is that acidification is not the cause of the excessive plant growth here. Areas with the highest density of plants had a higher water flow. Reduced periods with ice and a later winter draining were mentioned as important factors (Mjelde, Brandrud, & Lindstrøm, 1992). After testing it was unclear whether a cold winter or low water level reduced the plant growth (Mjelde & Brandrud, 1994). The flowrate together with water level regulation are triggers for the excessive growth (Hindar, Johansen, Andersen, & Saloranta, 2003) (Moe, Edvardsen, Mjelde, & Friberg, 2015). The water level data provided by NVE and the flow rate (Sellevold, Orvedal, & Orvedal, 2012) backs up the conclusions from other studies. Furhtermore an increased sediment rate was reported in Lake Hafslovatnet (Sønstegaard, 2002 unp.) which could point at the beach erosion or that since regulation the water gets more change to settle and allow sedimentation before the inlet instead of in the fjords. Sønstegaard studied some sediment cores from Lake Hafslovatnet and these seemed to indicate an increased sedimentation rate since the 1980s. This could support increased sediment load to Lake Hafslovatnet following the river regulations upstream Lake Veitastrond as well as the observed beach erosions in Lake Veitastrondvatnet, Lake Tverrbergvatnet and Straumane. This research adds a basic understanding of the past and present conditions in the watershed and a general understanding of the recent structure in Lake Hafslovatnet.

Besides research and investigations also mechanical removal of plants and soil have been carried out, reducing the plant growth for some time. The plant community has been described in several papers as well to identify which plant species were occurring in high numbers and which were not. With this information an indication of the circumstances best suitable for these species could be achieved. This thesis adds to the other researches by looking at what kind of changes have been detected providing some additional information about the grow conditions.

7 Literature

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8 Appendix

8.1 Correction Årøy water temperature yearly data

Overview missing measurement days at the outlet of the Årøy hydroelectric power plant. Under 265 days with measurements per year were not allowed and not taken with in the analysis.

Year	Unc. Av. Water temp	Counted days	Normal count days	Change	Cor. Av. water temp
1985	1,2	20	31	11	
1986	5,6	362	365	3	5,56
1987	6,3	358	365	7	6,30
1988	6,3	331	366	35	6,27
1989	3,3	193	365	172	
1990	5,9	292	365	73	5,88
1991	6,5	339	365	26	6,55
1992	5,3	289	366	77	5,27
1993	5,7	340	365	25	5,70
1994	5,4	342	365	23	5,41
1995	4,0	174	365	191	
1996	5,9	334	366	32	5,94
1997	5,8	350	365	15	5,82
1998	6,3	342	365	23	6,31
1999	6,5	278	365	87	6,53
2000	6,6	338	366	28	6,60
2001	8,8	193	365	172	
2002	6,1	335	365	30	6,13
2003	6,3	349	365	16	6,33
2004	6,6	364	366	2	6,64
2005	6,3	345	365	20	6,26
2006	6,7	365	365	0	6,74
2007	6,1	365	365	0	6,05
2008	6,5	366	366	0	6,52
2009	6,4	365	365	0	6,44
2010	7,0	341	365	24	7,03
2011	6,4	337	365	28	6,40
2012	6,6	359	366	7	6,62
2013	7,1	294	365	71	7,11
2014	7,8	327	365	38	7,78

8.2 Correction Årøy water temperature monthly data

Overview of missing measurement days split up per month. Mach, May and December had the least days with measurements.

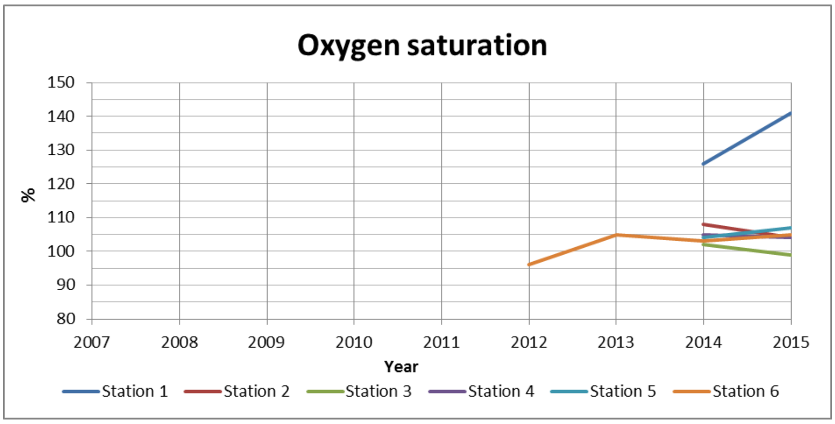
Month	Amount days	Count days	Difference	%	Difference %
January	899	784	115	87,2	12,8
February	812	728	84	89,7	10,3
March	899	738	161	82,1	17,9
April	870	770	100	88,5	11,5
May	899	732	167	81,4	18,6
June	870	757	113	87,0	13,0
July	899	820	79	91,2	8,8
August	899	802	97	89,2	10,8
September	870	795	75	91,4	8,6
October	899	867	32	96,4	3,6
November	870	834	36	95,9	4,1
December	899	760	139	84,5	15,5
Total count:	10585	9387	1198	-	-

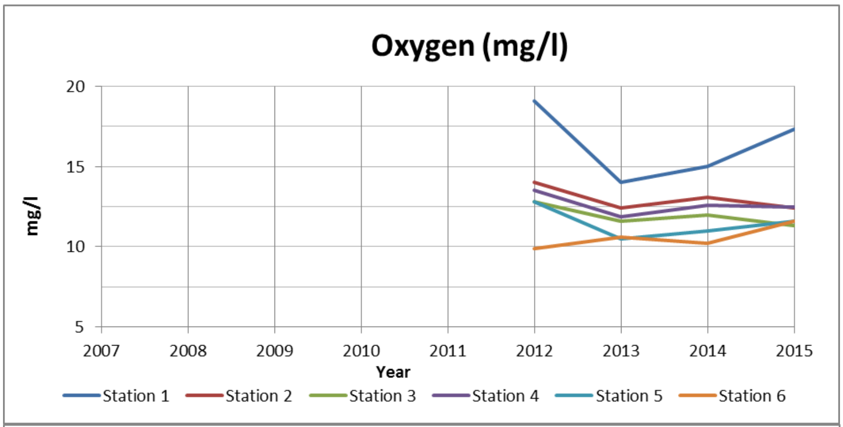
8.3 Table R-square

R-square values				
Station number	Station name	Temp	Turb	pH
Station 1	Glacier Austerdalsbreen	0,8291	0,4242	0,1158
Station 2	River Austerdalselvi (Tungastølen)	0,4868	0,0378	0,1132
Station 3	River Langedøla (plain above bridge)	0,1313	0,0028	0,0382
Station 4	River Storelvi (below bridge)	0,3783	0,0224	0,1948
Station 5	Veitastrond (surface)	0,0119	0,2095	0,4767
Station 6	Hafslovann (Surface)	0,1162	0,2226	0,1345

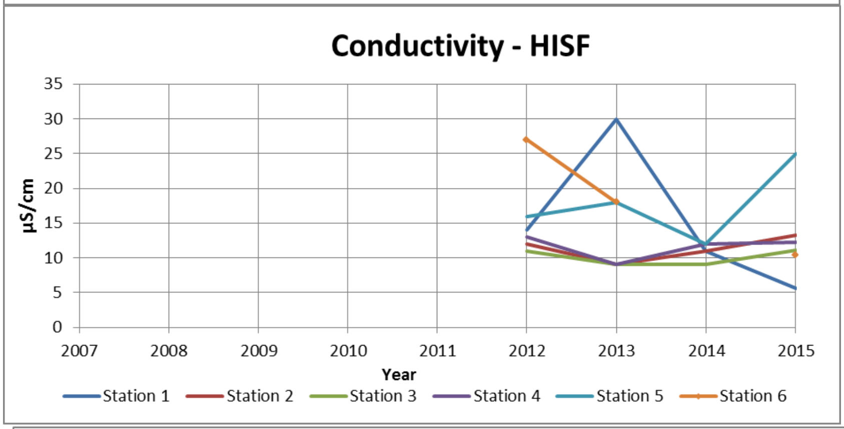
8.4 River measurements: The other parameters

The pH measurements of mr. Berndt have been excluded as the values were regarded to be too high for plausible measurements

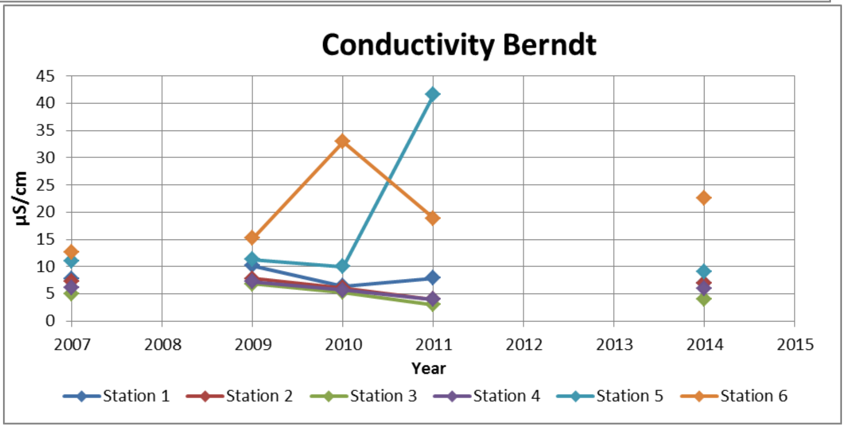




Oxygen (mg/l)
mg/l
20
15
10
5
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6



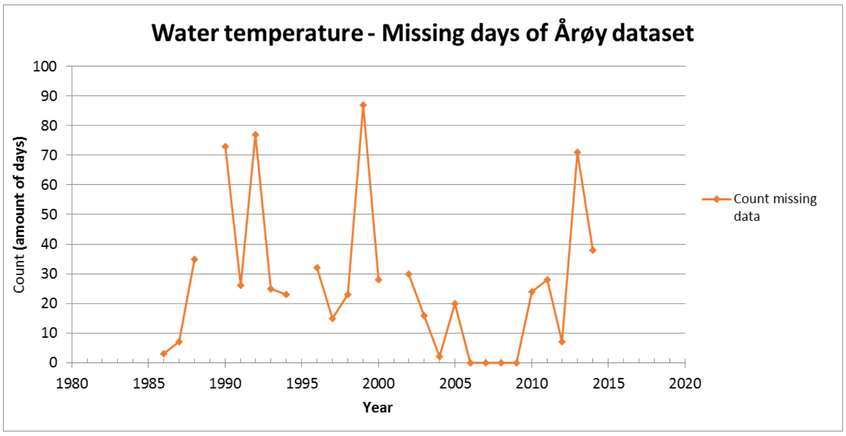
Conductivity - HISF
µS/cm
35
30
25
20
15
10
5
0
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6

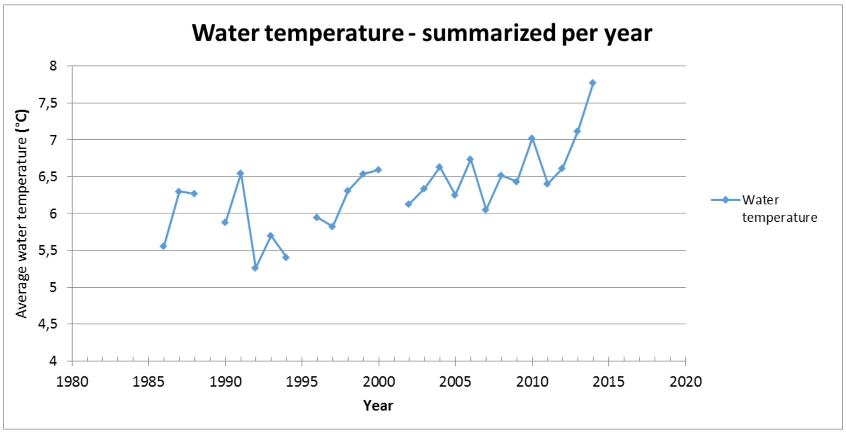


Conductivity Berndt
µS/cm
45
40
35
30
25
20
15
10
5
0
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
Station 1
Station 2
Station 3
Station 4
Station 5
Station 6

8.5 Water temperature – temperature graph and missing days Årøy dataset graph

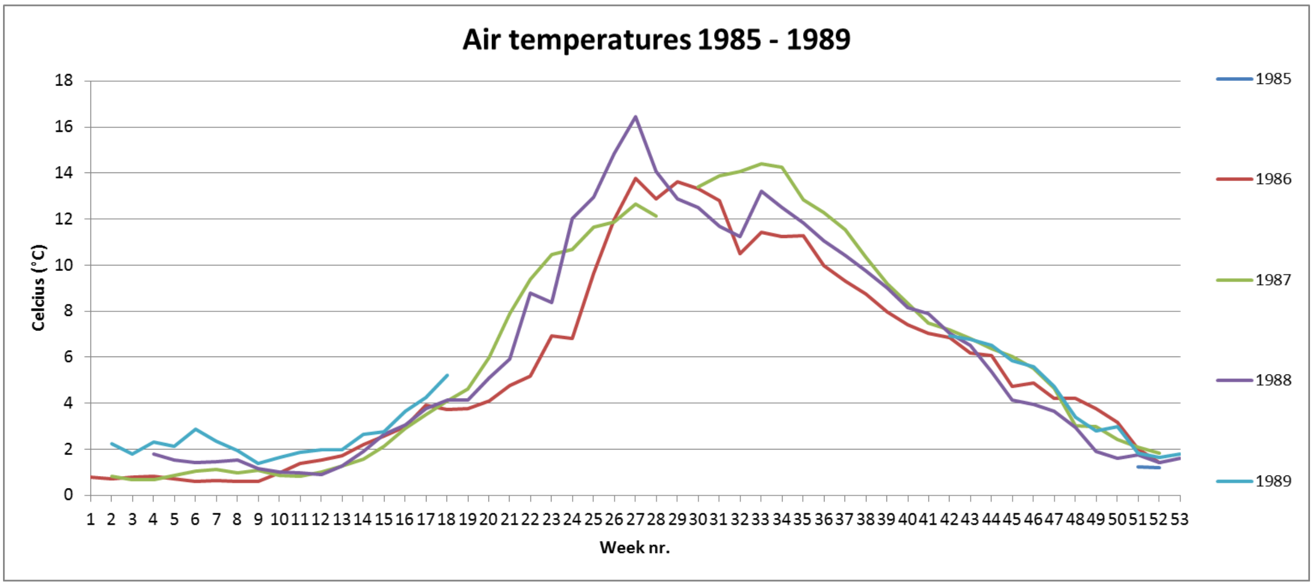
The average water temperature graph with the missing day's count. The graph beneath it is the measured temperatures for comparison.

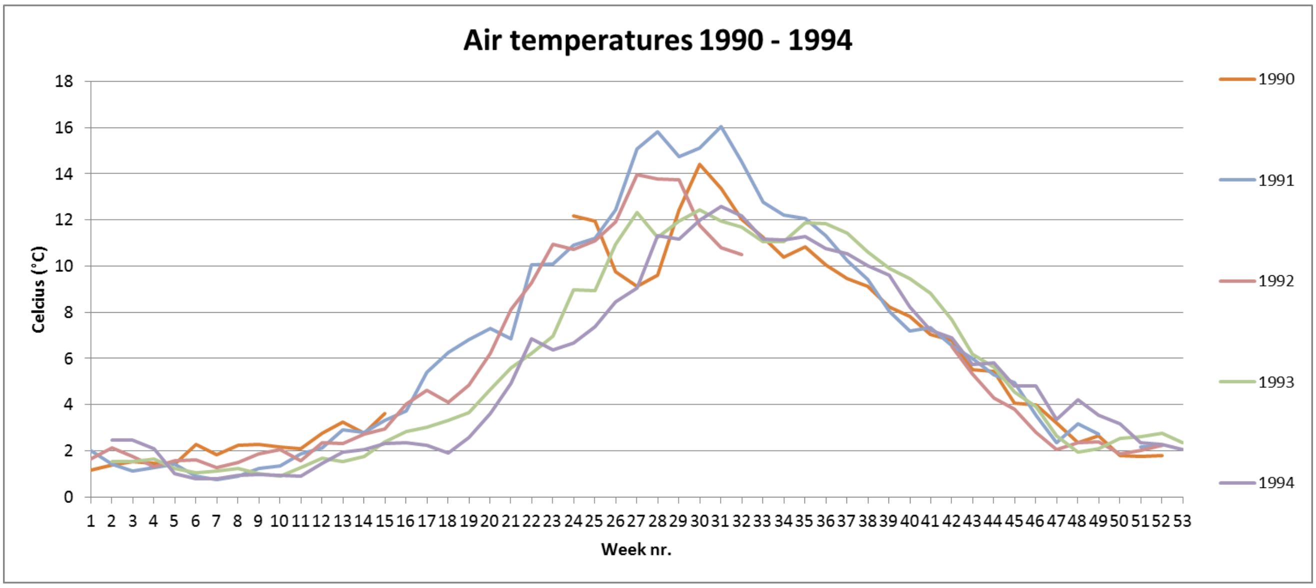


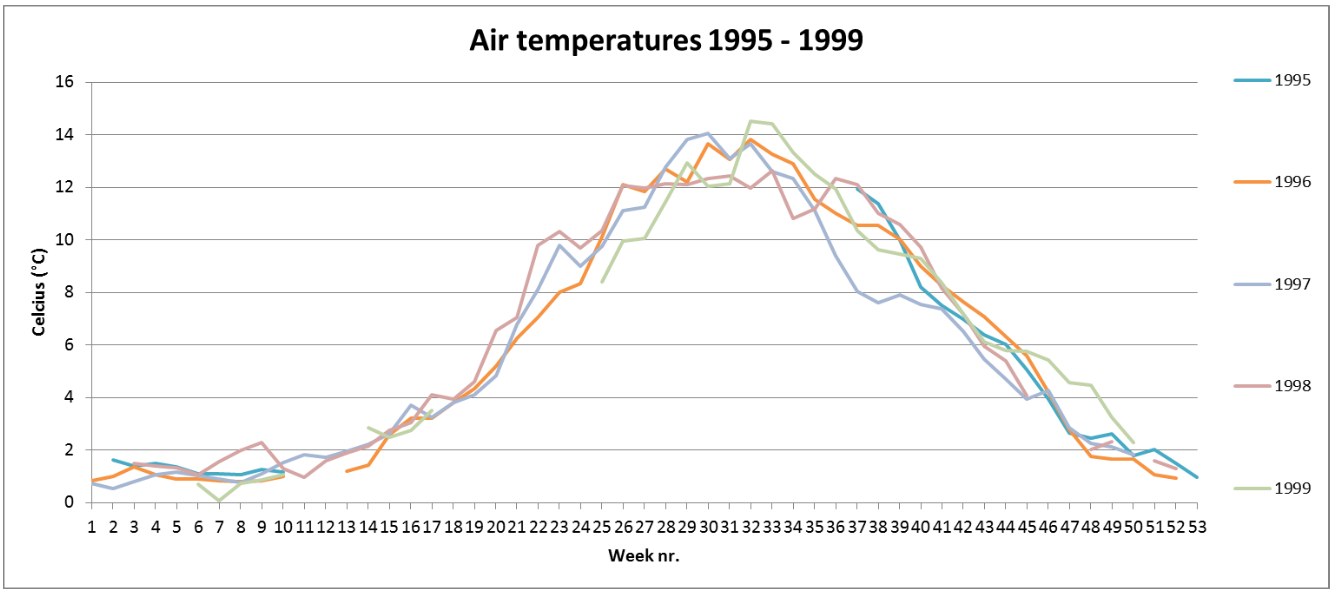


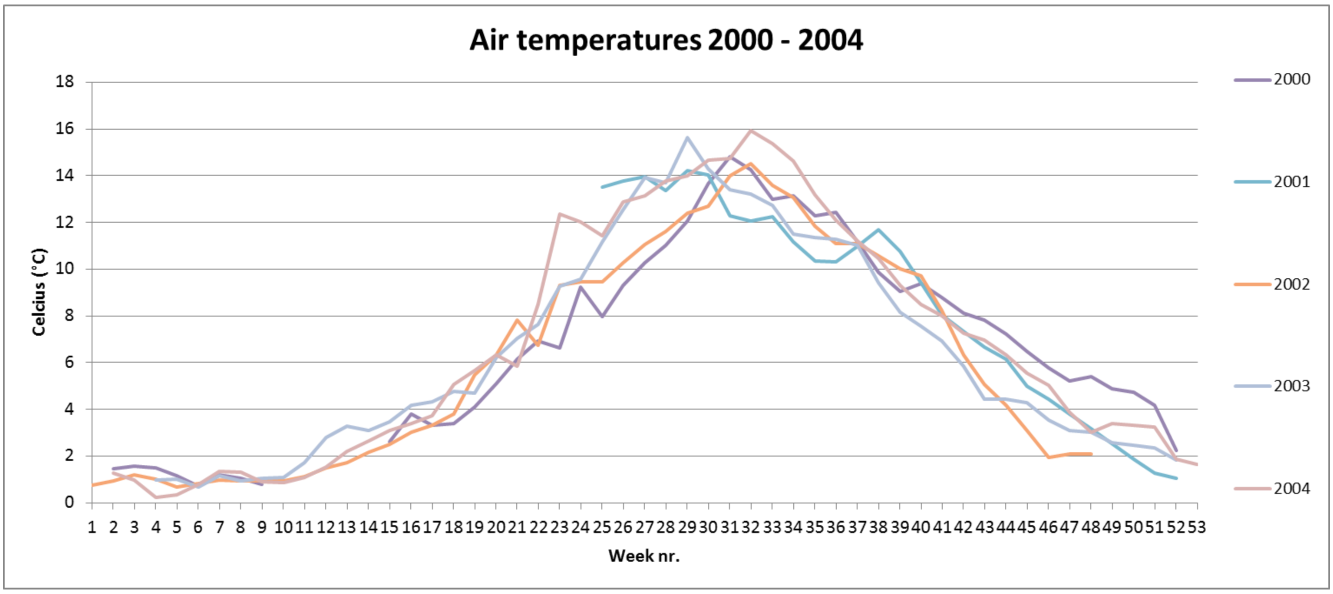
8.6 Water temperatures sorted per week per year

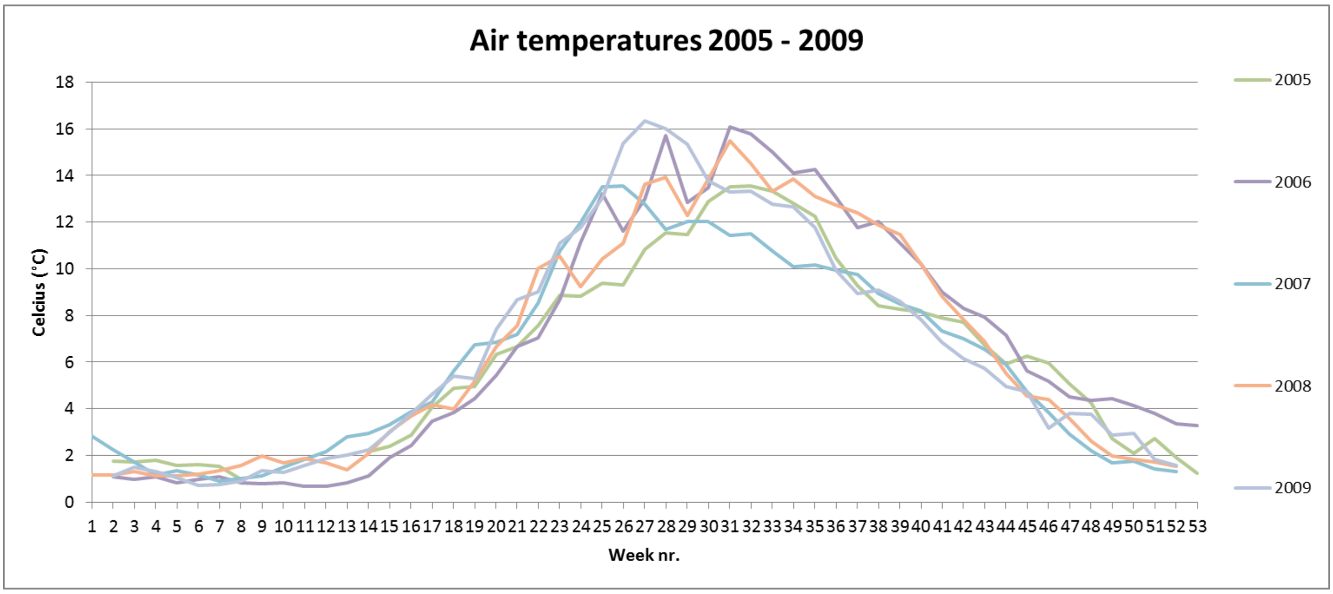
Each year shown are the water temperatures per week sorted out per year. Here differences between the seasons are visible.

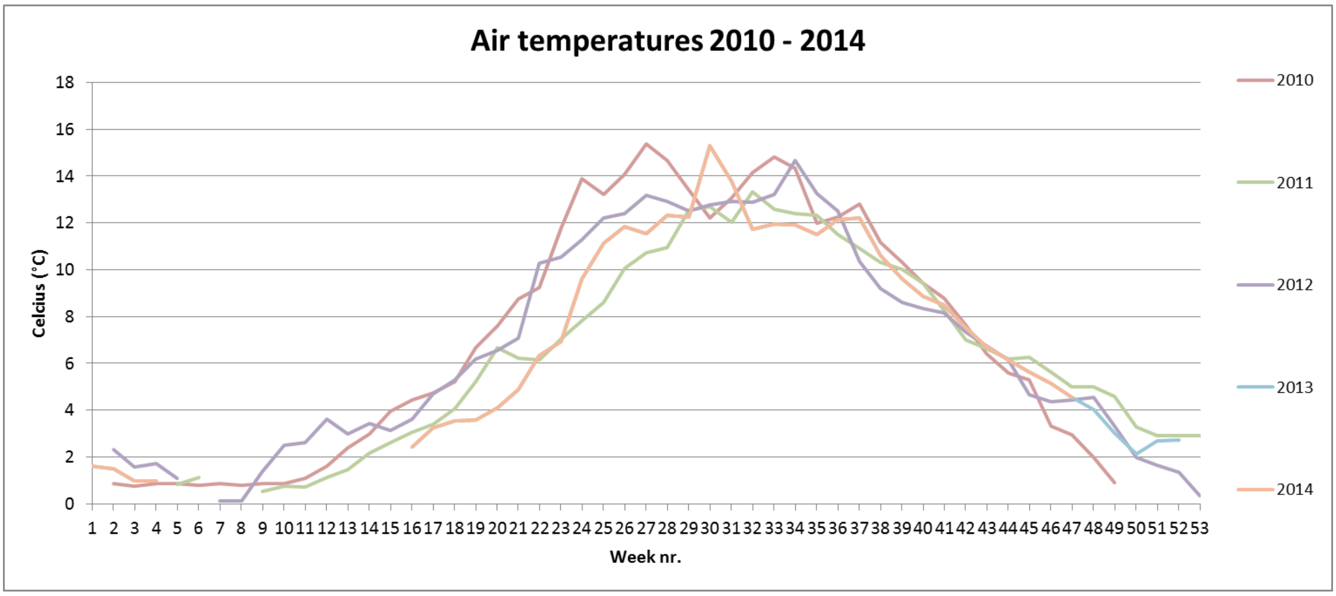



Air temperatures 1990 - 1994
Celcius (°C)
Week nr.
1990
1991
1992
1993
1994


Air temperatures 1995 - 1999
Celcius (°C)
Week nr.
1995
1996
1997
1998
1999

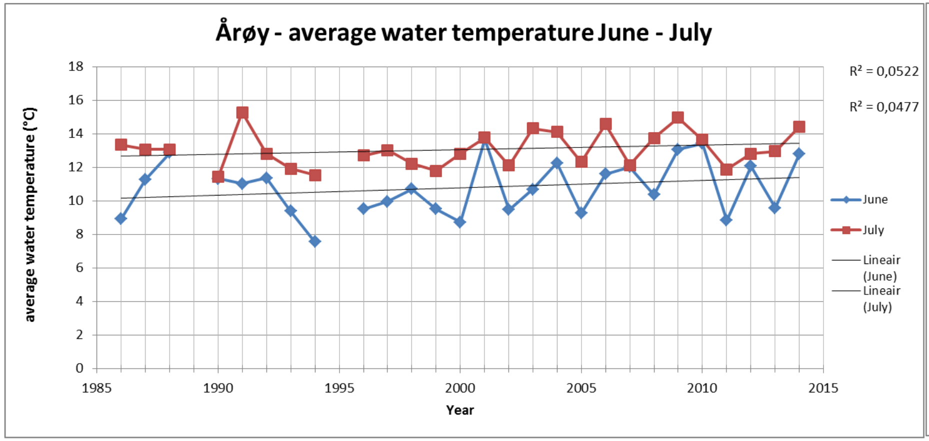

Air temperatures 2000 - 2004
Celcius (°C)
Week nr.
2000
2001
2002
2003
2004

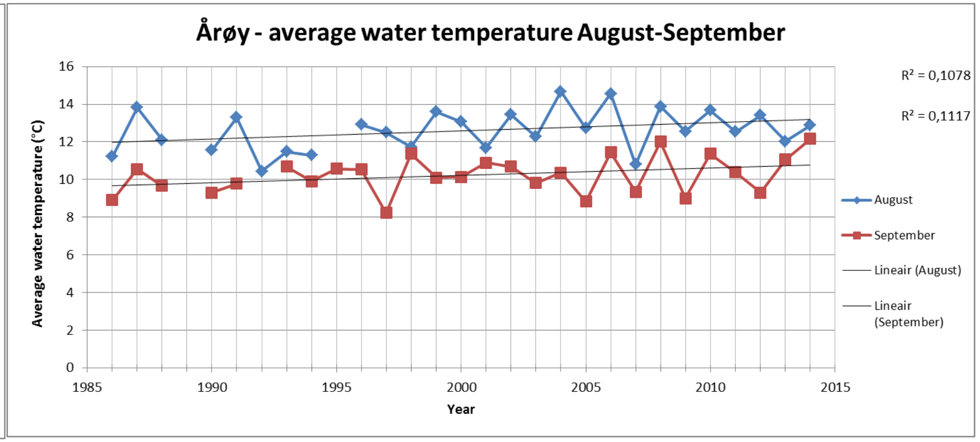

Air temperatures 2005 - 2009
Celcius (°C)
Week nr.
2005
2006
2007
2008
2009

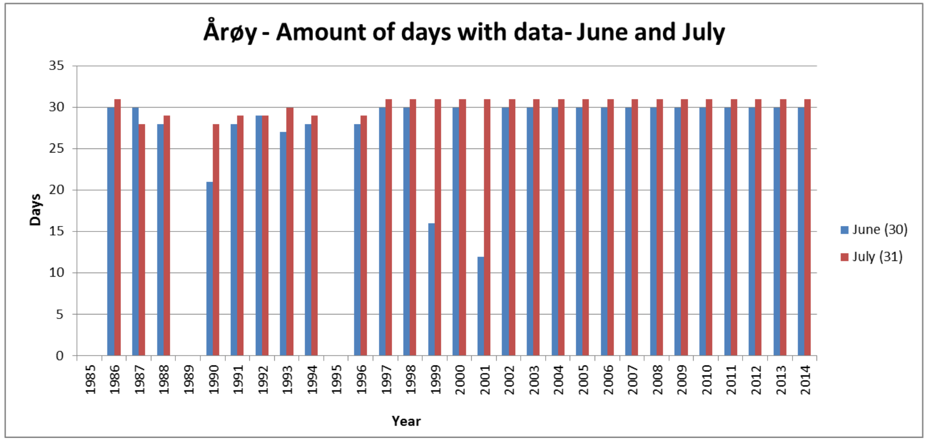

Air temperatures 2010 - 2014
Celcius (°C)
Week nr.
2010
2011
2012
2013
2014

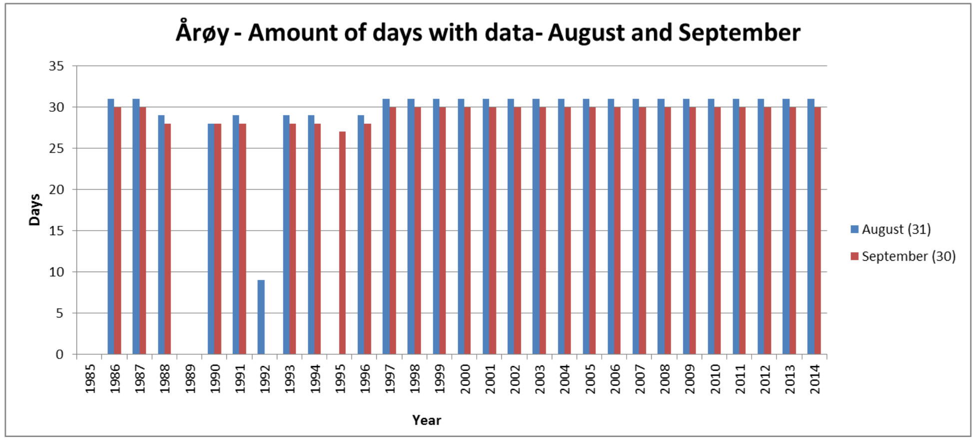
8.7 Water temperatures split out per month per year

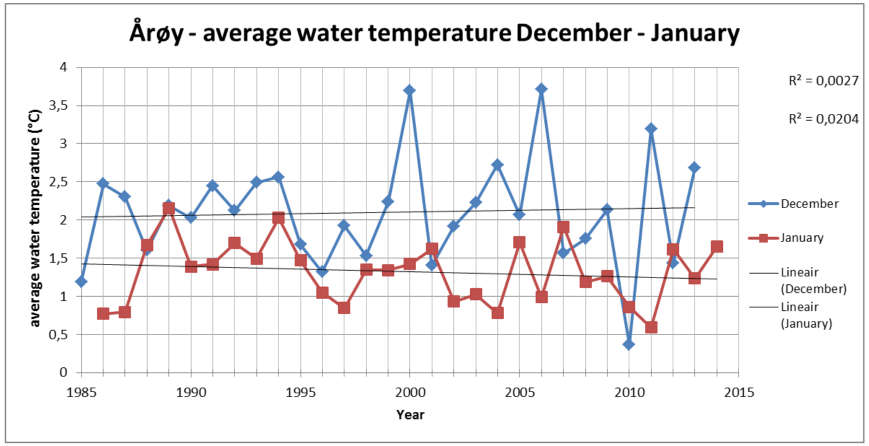
As in the previous appendix here the water temperatures are shown per month. Differences in average month temperature are visible in these graphs



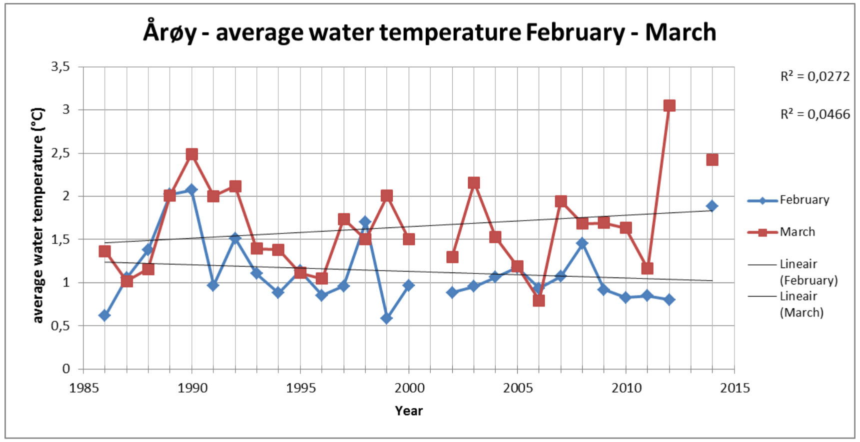




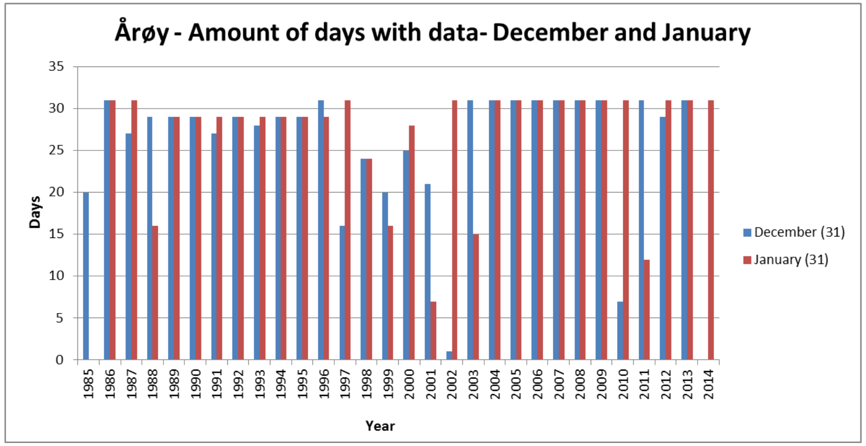




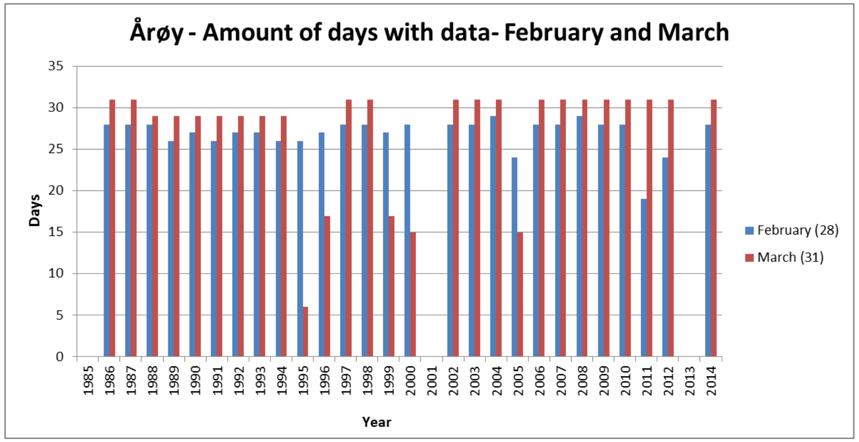
Årøy - average water temperature December - January
average water temperature (°C)
Year
R² = 0,0027
R² = 0,0204
December
January
Lineair (December)
Lineair (January)



Årøy - average water temperature February - March
average water temperature (°C)
Year
R² = 0,0272
R² = 0,0466
February
March
Lineair (February)
Lineair (March)



Årøy - Amount of days with data- December and January
Days
Year
December (31)
January (31)



Årøy - Amount of days with data- February and March
Days
Year
February (28)
March (31)

8.8 Hydrology – Hafslovatnet and the sources of the information

Here all the collected data and their sources are listed. In the final appendix (x) the literature list can be found.

Date	Depth (m)	Temperature (°C)	pH	Oxygen (mg/L)	Oxygen (%)	Conductivity (µS/cm)	Fargetall	Turbidity (FTU/FNU/NTU)	Secchi depth (m)	Reference
06-1967	0		6,1						8	(Lunder, 1967)
22-10-1975	0		6,6			20,4	5			(Statens Institutt for Folkehelse, 1975)
22-10-1975	0		6,5			34	<5			(Statens Institutt for Folkehelse, 1975)
22-10-1975	0		6,3			28,3	5			(Statens Institutt for Folkehelse, 1975)
22-10-1975	0		6,4			16,7	5			(Statens Institutt for Folkehelse, 1975)
1978	0		7			22			12	(Sivertsen, Data Hafslovatnet, 1981)
5-6-1978	0	16	6,7	9,6-12,4	100	17,5			13	(Sivertsen, Data Hafslovatnet, 1981) 1-10 06-1978
5-6-1978	25	5	6,6	10,8-11,6	90-100	18,5				(Sivertsen, Data Hafslovatnet, 1981) 1-10 06-1978
20-09-1978	0	10,6	7		100	22			12	(Sivertsen, Data Hafslovatnet, 1981)
20-09-1978	deep	6	6,7		90	18				(Sivertsen, Data Hafslovatnet, 1981)
23-5-1980	0	10,8	6,7	12,2	106	21			8	(Sivertsen, Data Hafslovatnet, 1981) 19-25 05-1980
23-5-1980	20	5,5	6,5	12,2	98	17				(Sivertsen, Data Hafslovatnet, 1981) 19-25 05-1980
23-5-1980	25	4								(Sivertsen, Data Hafslovatnet, 1981) 19-25 05-1980
02-1981	0		6,43			16			12	(Sivertsen, Data Hafslovatnet, 1981)
20-02-1981	0		6,43			15,9	14	0,56		(Dalan, Lund, & Roen, 1981)
03-1981	0		6,22			17				(Sivertsen, Data Hafslovatnet, 1981)
10-03-1981	0		6,24			16,5	16	0,54		(Dalan, Lund, & Roen, 1981)
23-03-1981	0		6,2			18,3	14	0,42		(Dalan, Lund, & Roen, 1981)
04-1981	0		6,24		90-100	17				(Sivertsen, Data Hafslovatnet, 1981)
03-04-1981	0	10,5	6,24			16,7	12	0,37		(Dalan, Lund, & Roen, 1981)
10-04-1981	0		6,25			18,7	16	0,45		(Dalan, Lund, & Roen, 1981)
05-1981	0		5,78			16				(Sivertsen, Data Hafslovatnet, 1981)
05-05-1981	0		**5,13**			15,1	102	0,44		(Dalan, Lund, & Roen, 1981)
27-05-1981	0		6,43			17,1	16	0,44		(Dalan, Lund, & Roen, 1981)
06-1981	0		6,42			15				(Sivertsen, Data Hafslovatnet, 1981)
10-06-1981	0		6,35			16	15	0,4		(Dalan, Lund, & Roen, 1981)

25-06-1981	0		6,51			14,5	9	0,36		(Dalan, Lund, & Roen, 1981)
07-1981	0		6,38			13				(Sivertsen, Data Hafslovatnet, 1981)
30-07-1981	0		6,38			12,8	7	0,3		(Dalan, Lund, & Roen, 1981)
08-1981	0		6,35			12				(Sivertsen, Data Hafslovatnet, 1981)
26-09-1981	0		6,35			12,4	20	0,93		(Dalan, Lund, & Roen, 1981)
08-03-1985	1		6,29							(Sivertsen, 1985)
08-03-1985	3		6,15							(Sivertsen, 1985)
6-1-1987	0		5,8			24,9	5	1,8		(Sogn offentlige kjøt- og næringsmiddelkontroll , 1987)
14-09-1988	0		6,8			13	5	2,2		(Sognlab til Hafslo grunneigarlag, 1989)
12-10-1988	0		6,5			12	5	1,1		(Sognlab til Hafslo grunneigarlag, 1989)
11-11-1988	0		6,8			34	5	1,2		(Sognlab til Hafslo grunneigarlag, 1989)
03-02-1989	0		6,2			17	5	0,63		(Sognlab til Hafslo grunneigarlag, 1989)
26-04-1989	0		6,5			16	5	4,5		(Sognlab til Hafslo grunneigarlag, 1989)
10-05-1989	1	5,9	7	12,1	100	14			8,5	(Sivertsen, 1989)
10-05-1989	15	5,7	7	12,1	100	15				(Sivertsen, 1989)
20-06-1989	0		7,1			18	5	0,55		(Sognlab til Hafslo grunneigarlag, 1989)
19-07-1989	0		6,9			19	5	1,5		(Sognlab til Hafslo grunneigarlag, 1989)
22-08-1989	0		6,5			15	10	2,7		(Sognlab til Hafslo grunneigarlag, 1989)
15-5-1991	1	6,8	6,7	12,5		16	7,5		9,7	(Sivertsen, 1991)13-16 05-1991
15-5-1991	20	5,5	6,5	11,6		16	9			(Sivertsen, 1991)13-16 05-1991
7-7-1996	0								5	(Hobæk, 1998)
1997	0		6,2			16	2	0,20		(Urdal & Sølsnæs, Fiskeressursar i regulerte vassdrag i Sogn og Fjordane., 1997)
29-02-2000	0		6,6	14,3		19	8	0,53		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
29-02-2000	30		6,4	11,5		18	6	0,51		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
28-03-2000	0		6	15,4		18	<3	0,35		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
28-03-2000	30		6,3	11,2		20	5	1,44		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
26-04-2000	0		6,4	14,3		11	5	0,5		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
26-04-2000	30		6,3	11,9		18	6	0,49		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)

10-05-2000	0		6,5	11,7		15	7	0,46		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
10-05-2000	30		6,4	11,8		16	7	0,36		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
23-05-2000	0		6,7			15	5	0,37		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
23-05-2000	0		6,7	11,9		15	5	0,37		(Næringsmiddeltilsynet for Sogn, 2000)
23-05-2000	30		6,4			16	6	0,34		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
23-05-2000	30		6,4	11,9		16	6	0,34		(Næringsmiddeltilsynet for Sogn, 2000)
27-06-2000	0		6,6	11,6		13	6	0,64		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
27-06-2000	30		6,4	11,8		15	7	0,38		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
21-08-2000	0		6,7			12	4	1,7		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
11-09-2000	0		6,6			12	4	2		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
02-10-2000	0	9,1	6,5			12	6	1,4		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
02-10-2000	30	5,1	6,2			14	6	0,65		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
24-10-2000	0		6,4			12	4	1,2		(Næringsmiddeltilsynet for Sogn, 2000)
24-10-2000	30		6,2			15	5	0,5		(Næringsmiddeltilsynet for Sogn, 2000)
11-12-2000	0		6,4			13	6	0,63		(Næringsmiddeltilsynet for Sogn, 2000)
11-12-2000	20		6,3			13	12	0,61		(Næringsmiddeltilsynet for Sogn, 2000)
31-07 / 2-08 2007	0	11,9	6,5			13	2	1,8	3,0	(Gladsø, 2008)
08-2007	0		6,6			12,7		2,25	2,85	(Høgskulen i Sogn og Fjordane, unp.)
08-2007	0		6,63					2,25	2,85	(Høgskulen i Sogn og Fjordane, unp.)
28-08-2007	0	10,5	6,75						2,85	(Høgskulen i Sogn og Fjordane, unp.)
28-08-2007	50	5								(Høgskulen i Sogn og Fjordane, unp.)
08-2008	0	14,3	7,1			12,7			3,5	(Høgskulen i Sogn og Fjordane, unp.)
08-2008	2	13,8	7			19,9		2,1		(Høgskulen i Sogn og Fjordane, unp.)
08-2008	6									(Høgskulen i Sogn og Fjordane, unp.)
08-2008	10	11,5	6			19,7		1,95		(Høgskulen i Sogn og Fjordane, unp.)

08-2008	25	7	5,6			21,6		0,77		(Høgskulen i Sogn og Fjordane, unp.)
08-2008	37									(Høgskulen i Sogn og Fjordane, unp.)
1-9-2008	0	14,3	7,1					2,1	3,5	(Høgskulen i Sogn og Fjordane, unp.)
08-2009	0	14,9	6,84			15,2		1,7	4,15	(Høgskulen i Sogn og Fjordane, unp.)
08-2009	2	14,45	6,72			12,9		1,9		(Høgskulen i Sogn og Fjordane, unp.)
08-2009	6	12	6,57			12,3		2,6		(Høgskulen i Sogn og Fjordane, unp.)
08-2009	10	11,3	6,45			12,7		2,4		(Høgskulen i Sogn og Fjordane, unp.)
08-2009	25	7,05	6,28			16,3		0,4		(Høgskulen i Sogn og Fjordane, unp.)
08-2009	37									(Høgskulen i Sogn og Fjordane, unp.)
24-8-2009	0	14,2	6,95			15,2		1,7	4,15	(Høgskulen i Sogn og Fjordane, unp.)
20-5-2010	0	11,8	7,01						8,5	(Høgskulen i Sogn og Fjordane, unp.)
20-5-2010	2	10,9	6,95							(Høgskulen i Sogn og Fjordane, unp.)
20-5-2010	6	8,7	6,93							(Høgskulen i Sogn og Fjordane, unp.)
20-5-2010	10	7,4	6,78							(Høgskulen i Sogn og Fjordane, unp.)
20-5-2010	25	6,3	6,59							(Høgskulen i Sogn og Fjordane, unp.)
20-5-2010	37									(Høgskulen i Sogn og Fjordane, unp.)
23-8-2010	0	13	6,95			33		2,3		(Høgskulen i Sogn og Fjordane, unp.)
24-8-2010	0	13	6,95			33		2,3	3,5	(Høgskulen i Sogn og Fjordane, unp.)
24-8-2010	2	13	7,08			15		2,5		(Høgskulen i Sogn og Fjordane, unp.)
24-8-2010	6	11	6,96			13		3,5		(Høgskulen i Sogn og Fjordane, unp.)
24-8-2010	10	11	6,9			16		2,9		(Høgskulen i Sogn og Fjordane, unp.)
24-8-2010	25	6,8	6,54			15		3,4		(Høgskulen i Sogn og Fjordane, unp.)
24-8-2010	37	6,1	6,21			13		***B**		(Høgskulen i Sogn og Fjordane, unp.)
12-5-2011	0	7,9	7,02					0,55	8,5	(Høgskulen i Sogn og Fjordane, unp.)
12-5-2011	2	7,9	6,7					0,35		(Høgskulen i Sogn og Fjordane, unp.)
12-5-2011	6	7,2	6,67					0,25		(Høgskulen i Sogn og Fjordane, unp.)
12-5-2011	10	5,5	6,6					0,4		(Høgskulen i Sogn og Fjordane, unp.)
12-5-2011	25	5,2	6,47					0,75		(Høgskulen i Sogn og Fjordane, unp.)
22-8-2011	0	13,5	6,7			18,9		2,3		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	0	6,7	6,7			18,9		2,3	3,5	(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	2	6,7	6,7			11,5		2,4		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	6	6,4	6,4			11,1		2,8		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	10	6,3	6,3			12,3		2,7		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	25	6,2	6,2			15,4		0,4		(Høgskulen i Sogn og Fjordane, unp.)

23-8-2011	38	6,2	6,2			18,2		0,7		(Høgskulen i Sogn og Fjordane, unp.)
14-11-2011	30		6,2				6	4		(Sognlab, 2011)
5-6-2012	30		6,5				7	3		(Sognlab, 2012)
27-8-2012	0	13,6	6,5	9,9	96	27		1,46	4,85	(Høgskulen i Sogn og Fjordane, unp.)
28-8-2012	0	13,6				27,5		1,46	4,85	(Høgskulen i Sogn og Fjordane, unp.)
28-8-2012	2	13,5				17,5		1,46		(Høgskulen i Sogn og Fjordane, unp.)
28-8-2012	6	12,7				14,5		2,06		(Høgskulen i Sogn og Fjordane, unp.)
28-8-2012	10	12				15,5		1,72		(Høgskulen i Sogn og Fjordane, unp.)
28-8-2012	25	8,9				17,5		0,95		(Høgskulen i Sogn og Fjordane, unp.)
28-8-2012	37	7,9				18,5		0,4		(Høgskulen i Sogn og Fjordane, unp.)
30-07-2013	0	15,2	6,4			12,7	4	1,6	3,3	(Schedel, 2015)
26-8-2013	0	14,6	6,1	10,6	105	18		1,8	3,75	(Høgskulen i Sogn og Fjordane, unp.)
27-8-2013	0	14,6				18		1,8	3,75	(Høgskulen i Sogn og Fjordane, unp.)
27-8-2013	2	14,8				14		1,9		(Høgskulen i Sogn og Fjordane, unp.)
27-8-2013	6	11,3				14		2,5		(Høgskulen i Sogn og Fjordane, unp.)
27-8-2013	10	10,3				13		2,6		(Høgskulen i Sogn og Fjordane, unp.)
27-8-2013	25	7,6				16		0,8		(Høgskulen i Sogn og Fjordane, unp.)
27-8-2013	37	7,3				20		1,6		(Høgskulen i Sogn og Fjordane, unp.)
25-8-2014	0	15,7	6,6	10,2	103	22,6		2,2	4,2	(Høgskulen i Sogn og Fjordane, unp.)
26-8-2014	0	15,3	6,55			20		2,95	4,3	(Høgskulen i Sogn og Fjordane, unp.)
26-8-2014	2	14,3	6,53			14,5		3,1		(Høgskulen i Sogn og Fjordane, unp.)
26-8-2014	6	12,5	6,48			13,1		3,1		(Høgskulen i Sogn og Fjordane, unp.)
26-8-2014	10	11,1	6,3			13,2		3		(Høgskulen i Sogn og Fjordane, unp.)
26-8-2014	25	6,6	6,18			17,1		1,3		(Høgskulen i Sogn og Fjordane, unp.)
26-8-2014	30		6,3				5	1,1		(Sognlab, 2014)
26-8-2014	37	6,7	6,17			17,1		1,25		(Høgskulen i Sogn og Fjordane, unp.)
02-02-2015	30		6,2				5	0,47		(Sognlab, 2015)
01-06-2015	0		6,8			16	<3			(Sognlab, 2015)
24-8-2015	0	13,9	6,9	11,6	105	10,41		1,4	5,59	(Høgskulen i Sogn og Fjordane, unp.)
25-8-2015	0	14	6,9			23,05		1,5	6	(Høgskulen i Sogn og Fjordane, unp.)
25-8-2015	2	12,8	6,38			24,06		2,2		(Høgskulen i Sogn og Fjordane, unp.)
25-8-2015	6	11,8	6,58			16,7		1,8		(Høgskulen i Sogn og Fjordane, unp.)
25-8-2015	10	11,4	6,56			17		2		(Høgskulen i Sogn og Fjordane, unp.)
25-8-2015	25	9,5	6,3			15,25		0,6		(Høgskulen i Sogn og Fjordane, unp.)

25-8-2015	37	8,3	6,19			11,7		0,4		(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	0	8,5	6,87						**1,5**	(Høgskulen i Sogn og Fjordane, unp.) **(Secchi depth: *B)**
29-9-2015	1	9	6,82							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	0	10,5	6,76							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	1	10,2	6,73							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	0	10,9	6,88							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	2	10,6	6,73							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	6	9,9	6,63							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	10	9,1	6,51							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	25	7,5	6,37							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	35	7,1	6,32							(Høgskulen i Sogn og Fjordane, unp.)
29-9-2015	0								6,1	(Høgskulen i Sogn og Fjordane, unp.)
*B = Bottom; measurement device hit bottom, could influence measurement										

8.9 Hydrology – Veitastrondvatnet and the sources of the information

Date	Depth (m)	Temperature (°C)	pH	Oxygen (mg/L)	Oxygen (%)	Conductivity (µS/cm)	Fargetall	Turbidity (FTU/FNU/NTU)	Secchi depth (m)	Reference
06-1967	0		5,8							(Lunder, 1967)
16-09-1981	2	8,5	6	11,3	100	14	5			(Hovland, Karlsen, Mortensen, & Solberg, 1982)
16-09-1981	40	4,7	5,9	11,7	94	18	5			(Hovland, Karlsen, Mortensen, & Solberg, 1982)
16-09-1981	76	4,6	5,9	11,6	93	21	5			(Hovland, Karlsen, Mortensen, & Solberg, 1982)
31-10-1984	1	4,7		9,4	73					(Christiansen & Mjøen, 1985)
31-10-1984	2	4,7	6,2	9,4	73	13,8	8	1,3		(Christiansen & Mjøen, 1985)
31-10-1984	5	4,7	6,27	9,2	72	13,7	7	1,25		(Christiansen & Mjøen, 1985)
31-10-1984	10	4,7	6,26	9,4	73	13,7	7	1,25		(Christiansen & Mjøen, 1985)
31-10-1984	15	4,7		9,4	73					(Christiansen & Mjøen, 1985)
31-10-1984	20	4,7	6,3	9,4	73	13,6	7	1,2		(Christiansen & Mjøen, 1985)
31-10-1984	25	4,3	5,99	9,4	72	16,8	7	0,6		(Christiansen & Mjøen, 1985)

31-10-1984	31	4		9,4	72					(Christiansen & Mjøen, 1985)
31-10-1984	55		6,16			16,1	7	0,55		(Christiansen & Mjøen, 1985)
31-10-1984	120		6,1			16,3	6	1,75		(Christiansen & Mjøen, 1985)
04-06-1991	0		6,6			18	5	0,53		(Næringsmiddeltilsynet for Sogn, 1991)
09-07-1996	0		6,2			15,3	3	0,20	3,5	(Urdal & Sølsnæs, Fiskeressursar i regulerte vassdrag i Sogn og Fjordane., 1997); (Hobæk, 1998)
09-07-1996	0								5	(Urdal & Sølsnæs, Fiskeressursar i regulerte vassdrag i Sogn og Fjordane., 1997)
30/31-07-2007	0	9,5	6,5			12	2	2,3	1,4 - 1,7	(Gladsø, 2008)
2007	0					11				(Høgskulen i Sogn og Fjordane, unp.)
1-9-2008	0	15,5						4,2		(Høgskulen i Sogn og Fjordane, unp.)
24-8-2009	0	9,5				11,3		2,8		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2010	0	9,3	6,5			10		2,25	1,25	(Høgskulen i Sogn og Fjordane, unp.)
22-8-2011	0	11,5	6,6			41,6		3,65		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	0	11,5	6,6			41,6		3,65	2,5	(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	2	9,8	6,7			11,1		4		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	6	8,5	6,6			11		4,95		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	10	7,9	6,5			11,2		4,7		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	25	7,8	6,3			11,6		5,05		(Høgskulen i Sogn og Fjordane, unp.)
23-8-2011	38	6,9	6,3			14,2		4		(Høgskulen i Sogn og Fjordane, unp.)
27-8-2012	0	7,4	7,25	12,8		16		3,25	1,4	(Høgskulen i Sogn og Fjordane, unp.)
3-6-2013	30		5,7				<3			(Sognlab, 2013)
14-08-2013	0		6,4			10,9	4	2,8	5	(Schedel, 2015)
26-8-2013	0	13,6	6,7	10,5		18		3	1,8	(Høgskulen i Sogn og Fjordane, unp.)
11-11-2013	0		6,1			14	<3	0,1		(Sognlab, 2013)
03-03-2014	30		6				<3	0,88		(Sognlab, 2014)
12-05-2014	30		6,2			18	<3			(Sognlab, 2014)
3-6-2014	30		5,7				3			(Sognlab, 2014)
25-8-2014	0	11,6	6,93	11	104	10,5		3,54	1,6	(Høgskulen i Sogn og Fjordane, unp.)
1-6-2015	30		5,7				<3			(Sognlab, 2015)
24-8-2015	0	10,8	7,26	11,6	107	25		1,5	1,5	(Høgskulen i Sogn og Fjordane, unp.)

8.10 Chemistry – Hafslovatnet and the sources of information

Year	Dept h	P-ortho Ortho phosphates	P - total Total phosphates	NO3	SO4	Ca	Si	Fe	Mg	Na	K	Al	Al - Tot. Total reactable	Cl	Reference
	m	ug P/L	ug P/L	mg/L	mg SO4 /L	mg/L	mg/L	mg fe/L	mg/L	mg/L	mg/L	µg/l	mg/L	mg/L	
06-1967	0					2,5									(Lunder, 1967)
22-10-1975	0			0,1	2,5			0,02						1,1	(Statens Institutt for Folkehelse, 1975)
22-10-1975	0			0,61	3,5			0,03						3,2	(Statens Institutt for Folkehelse, 1975)
22-10-1975	0			0,41	3			0,15						2,2	(Statens Institutt for Folkehelse, 1975)
22-10-1975	0			0,09	3			0,05						0,7	(Statens Institutt for Folkehelse, 1975)
1-10 06-1978	0	0-10													(Sivertsen, 1981)
1-10 06-1978	25	0-8													(Sivertsen, 1981)
20-09-1978	0	1													(Sivertsen, 1981)
20-09-1978	deep	3													(Sivertsen, 1981)
20-02-1981	0					1,67			0,21	0,96	0,37	28			(Dalan, Lund, & Roen, 1981)
10-03-1981	0					1,87			0,19	0,77	0,44	31			(Dalan, Lund, & Roen, 1981)
23-03-1981	0					1,76			0,2	0,87	0,46	15			(Dalan, Lund, & Roen, 1981)
03-04-1981	0					1,88			0,15	0,77	0,36	63			(Dalan, Lund, & Roen, 1981)
10-04-1981	0					1,92			0,19	0,87	0,62	70			(Dalan, Lund, & Roen, 1981)
05-05-1981	0					0,88			0,25	1,12	0,5	249			(Dalan, Lund, & Roen, 1981)
27-05-1981	0					1,29			0,19	0,84	0,51	14			(Dalan, Lund, & Roen, 1981)
10-06-1981	0					1,68			0,15	0,74	0,64	24			(Dalan, Lund, & Roen, 1981)
25-06-1981	0					1,59			0,14	0,69	0,39	18			(Dalan, Lund, & Roen, 1981)
30-07-1981	0					1,44			0,16	0,69	0,37	24			(Dalan, Lund, & Roen, 1981)
26-09-1981	0					1,27			0,11	0,64	0,46	11			(Dalan, Lund, & Roen, 1981)
8-03-1985	1		<1												(Sivertsen, 1981)
	3		6,5												(Sivertsen, 1981)
6-1-1987	0		0	0				0							(Sogn offentlige kjøt- og

															næringsmiddelkontroll , 1987)
14-09-1988	0		10												(Sognlab til Hafslo grunneigarlag, 1989)
12-10-1988	0		5												(Sognlab til Hafslo grunneigarlag, 1989)
11-11-1988	0		53												(Sognlab til Hafslo grunneigarlag, 1989)
03-02-1989	0		8												(Sognlab til Hafslo grunneigarlag, 1989)
26-04-1989	0		17												(Sognlab til Hafslo grunneigarlag, 1989)
20-06-1989	0		13												(Sognlab til Hafslo grunneigarlag, 1989)
19-07-1989	0		23												(Sognlab til Hafslo grunneigarlag, 1989)
22-08-1989	0		8												(Sognlab til Hafslo grunneigarlag, 1989)
10-05-1989	1		6												(Sivertsen, 1981)
	15		7												(Sivertsen, 1981)
1997	0				2,77	1,51	0,53		0,14	0,71	0,33		18		(Urdal & Sølsnæs, Fiskeressursar i regulerte vassdrag i Sogn og Fjordane., 1997)
29-02-2000	0			0,2		2,1		0,032					0,035		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
28-03-2000	0			0,15		1,2		0,02					0,024		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
26-04-2000	0			0,089				0,031							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
10-05-2000	0			0,15				0,034							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
23-05-2000	0			0,12 mg N/l				0,031							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
23-05-2000	0			0,12				0,031							(Næringsmiddeltilsynet for Sogn, 2000)
27-06-2000	0			0,084				0,04							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
21-08-2000	0			<0,05				0,11							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
11-09-2000	0			0,051				0,13							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
02-10-2000	0			0,068				0,092					0,064		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
24-10-2000	0			0,068 mg N/l				0,082					0,059		(Næringsmiddeltilsynet for Sogn, 2000)
29-02-2000	30			0,18		2		0,031					0,027		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)

28-03-2000	30			0,19		1,9		0,029					0,028		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
26-04-2000	30			0,23				0,048							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
10-05-2000	30			0,15				0,028							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
23-05-2000	30			0,15 mg N/l				0,031							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
23-05-2000	30			0,15				0,031							(Næringsmiddeltilsynet for Sogn, 2000)
27-06-2000	30			0,11				0,031							(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
02-10-2000	30			0,12				0,047					0,043		(ISIS Rådgivande Ingeniørar og Arkitektar, 2000)
24-10-2000	30			0,12 mg N/l				0,038					0,042		(Næringsmiddeltilsynet for Sogn, 2000)
11-12-2000	0			0,10 mg N/l				0,041					0,035		(Næringsmiddeltilsynet for Sogn, 2000)
11-12-2000	20			0,10 mg N/l				0,036					0,036		(Næringsmiddeltilsynet for Sogn, 2000)
31-07 / 2-08 2007	0			0,08	2		0,63 1		0,14	0,47	0,27			0,72	(Gladsø, 2008)
2008	0	0,2		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2009	0	0		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2009	2	0		0,75											(Høgskulen i Sogn og Fjordane, unp.)
2009	6	0		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2009	10	0,1		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2009	25	0,1		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2009	37	0,1													(Høgskulen i Sogn og Fjordane, unp.)
2010	0	0		0											(Høgskulen i Sogn og Fjordane, unp.)
2010	2	0		0											(Høgskulen i Sogn og Fjordane, unp.)
2010	6	0		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2010	10	0		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2010	25	0,5		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2010	37	0,5		0,5											(Høgskulen i Sogn og Fjordane, unp.)
2011	0	0		1											(Høgskulen i Sogn og Fjordane, unp.)
2011	2	0		1											(Høgskulen i Sogn og Fjordane, unp.)

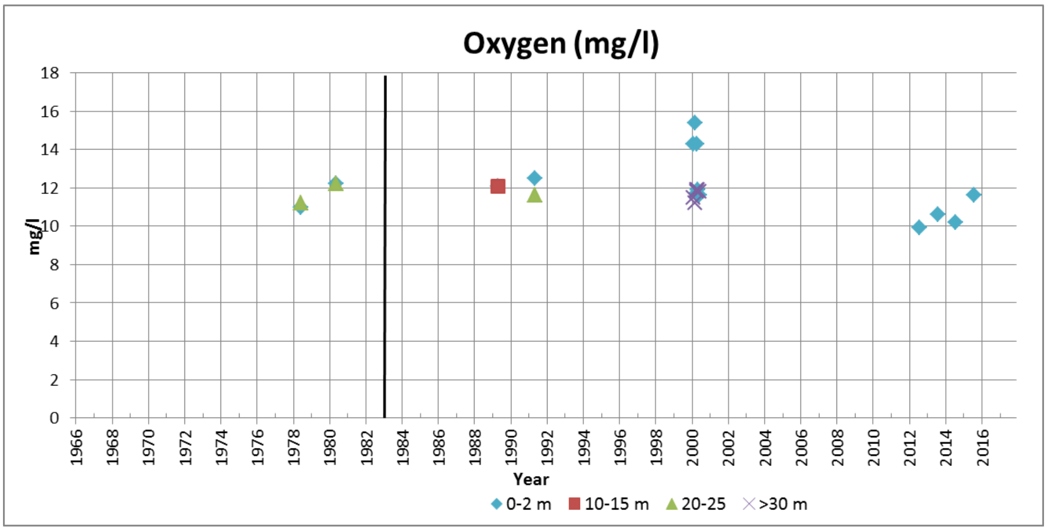
2011	6	0		1											(Høgskulen i Sogn og Fjordane, unp.)
2011	10	0		1											(Høgskulen i Sogn og Fjordane, unp.)
2011	25	0		1											(Høgskulen i Sogn og Fjordane, unp.)
2011	37	0		1											(Høgskulen i Sogn og Fjordane, unp.)
2013	0			0,029		1,4			0,14	0,64	0,35		<8,0	0,74	(Schedel, 2015)
28-8-2014	0	0		0,5											(Høgskulen i Sogn og Fjordane, unp.)
02-02-2015	0							<0,0							(Sognlab, 2015)
01-06-2015	0							10						1	(Sognlab, 2015)

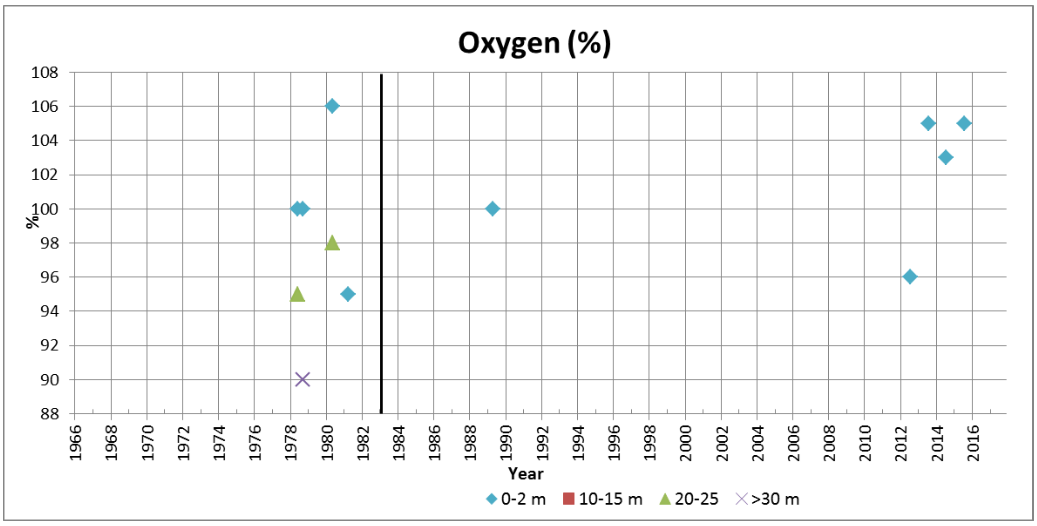
8.11 Chemistry – Veitastrondvatnet and the source of information

Year	Depth	P-ortho	P-total	NO3	SO4	Ca	Si	Fe	Mg	Na	K	Al	Cl	Reference
		Orthofos-fates	Total fosfates									total reactable		
	m	ug P/L	ug P/L	ug/L	mg SO4 /L	mg /L	mg /L	mg /L	mg /L	mg /L	mg /L	ug/L	mg/L	
06-1967	0					2.0								(Lunder, 1967)
9-6 09-1981	2	0,8		4,6										(Hovland, Karlsen, Mortensen, & Solberg, 1982)
9-6 09-1981	40	1,4		10,3										(Hovland, Karlsen, Mortensen, & Solberg, 1982)
9-6 09-1981	76	1,4		11										(Hovland, Karlsen, Mortensen, & Solberg, 1982)
31-10-1984	2	2												(Christiansen & Mjøen, 1985)
01-11-1984	6	1,7												(Christiansen & Mjøen, 1985)
02-11-1984	9	3,3												(Christiansen & Mjøen, 1985)
03-11-1984	19	<1												(Christiansen & Mjøen, 1985)
04-11-1984	28	<1												(Christiansen & Mjøen, 1985)
05-11-1984	56	<1												(Christiansen & Mjøen, 1985)
06-11-1984	122	1,7												(Christiansen & Mjøen, 1985)
4-6-1991	0		8 µg/l											(Næringsmiddeltilsynet for Sogn, 1991)
09-07-1996	0													(Urdal & Sølsnæs, Fiskeressursar i regulerte vassdrag i Sogn og Fjordane., 1997); (Hobæk, 1998)
1997	0			78	2,87	1,46	0,56		0,14	0,66	0,3	19	0,82	(Urdal & Sølsnæs, Fiskeressursar i

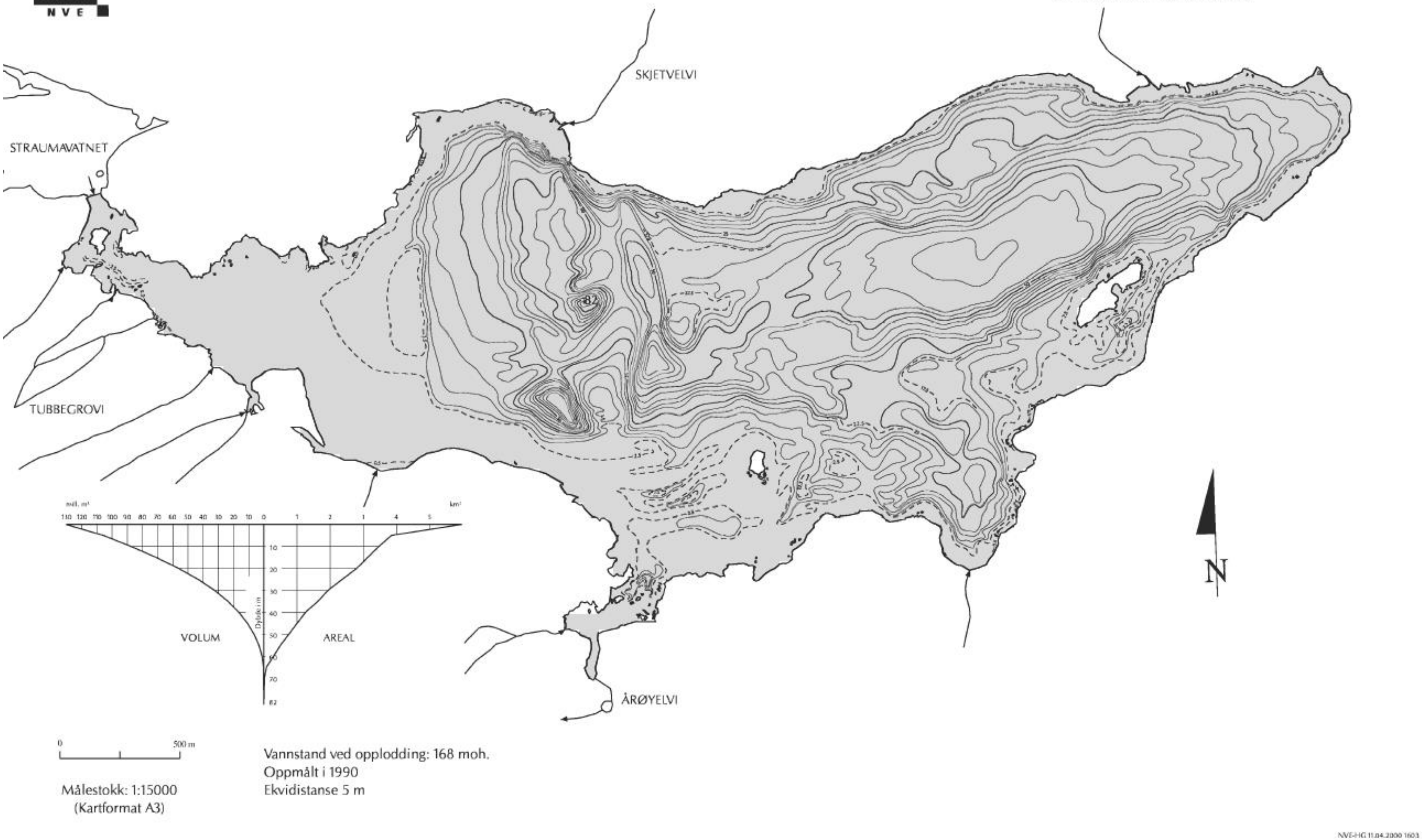
														regulerte vassdrag i Sogn og Fjordane., 1997)
30/31-07-2007	0			70	1.80		0.657		0.14	0.44	0.27		0.620	(Gladsø, 2008)
2011	0	0		0.75										(Høgskulen i Sogn og Fjordane, unp.)
2011	2	0		0.75										(Høgskulen i Sogn og Fjordane, unp.)
2011	6	0		1										(Høgskulen i Sogn og Fjordane, unp.)
2011	10	0		1										(Høgskulen i Sogn og Fjordane, unp.)
2011	25	0		1										(Høgskulen i Sogn og Fjordane, unp.)
2011	38	0.1		1										(Høgskulen i Sogn og Fjordane, unp.)
14-08-2013	0			18	1,7	1,2			0,14	0,59	0,35	<8,0	0,58	(Schedel, 2015)
11-11-2013	0							0,015						(Sognlab, 2013)
12-5-2014	30			0,111	2,09			0,02		0,9		11	1,08	(ALS labatorygroup Norway , 2014)

8.12 Additional graphs



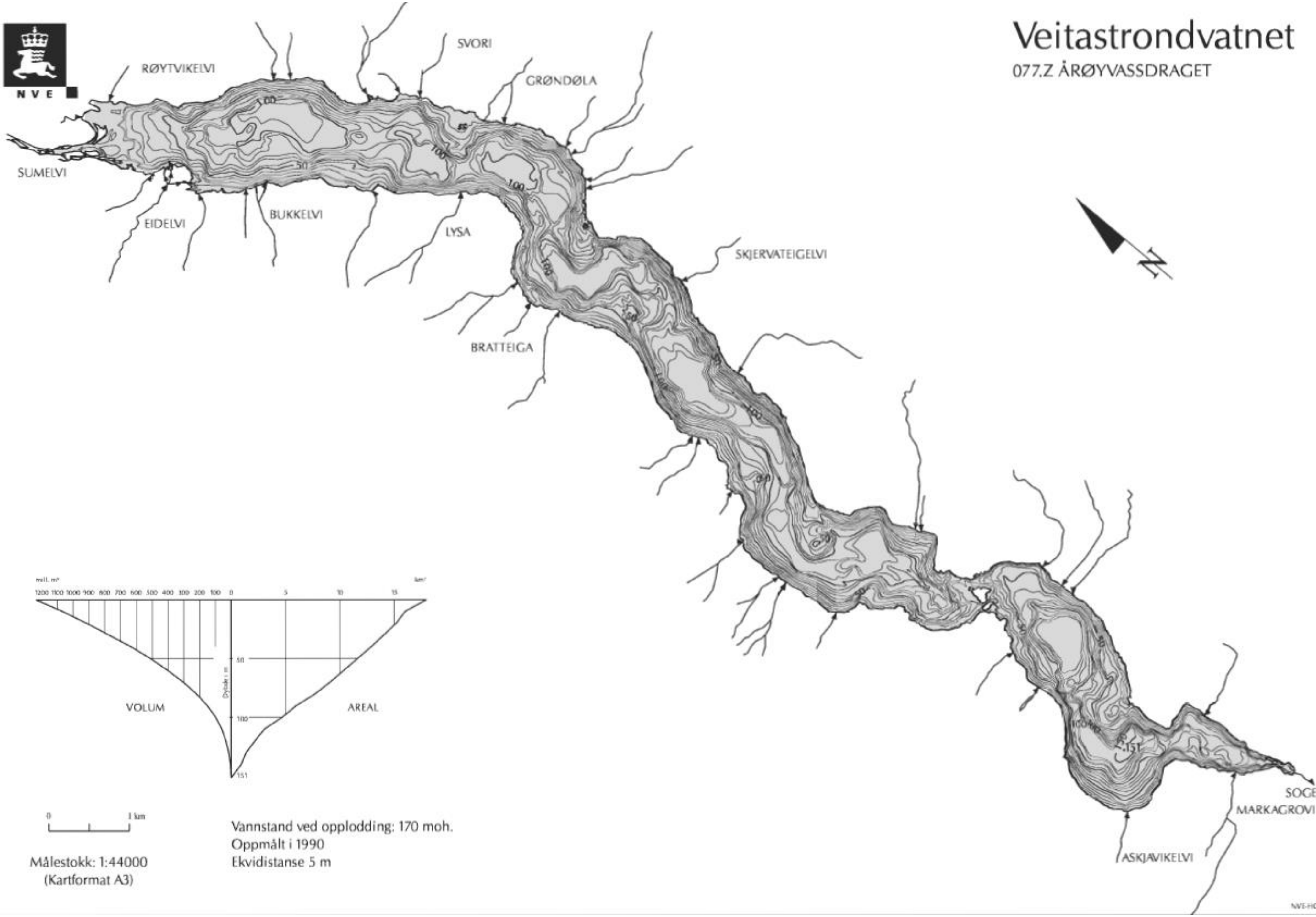


8.13 Depth contour maps Hafslovatnet and Veitastrondvatnet



Veitastrondvatnet

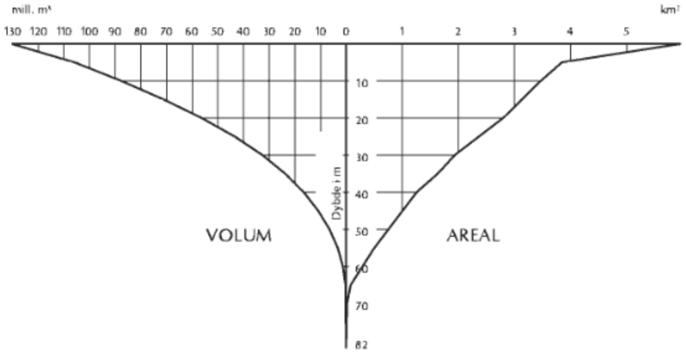
077.Z ÅRØYVASSDRAGET



0 1 km

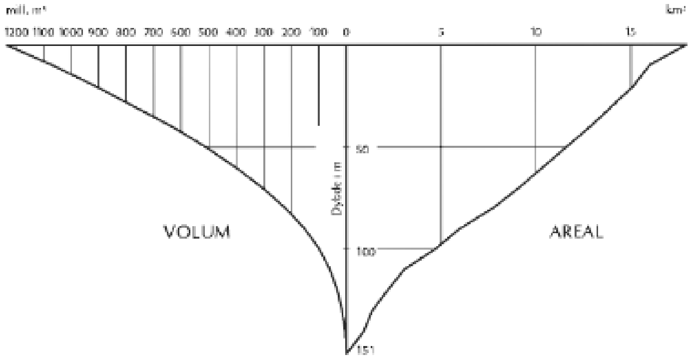
Målestokk: 1:44000
(Kartformat A3)

Vannstand ved opplodding: 170 moh.
Oppmålt i 1990
Ekvidistanse 5 m



Vannstand ved opplodding: 168 moh.
Oppmålt i 1990

Hafslovatnet



Vannstand ved opplodding: 170 moh.
Oppmålt i 1990
Ekvidistanse 5 m

Veitastrondvatnet

8.14 Schematic representation of the bypass tunnel

Schematic representation of the bypass tunnel and the effect of a regulated water level. Based on building scheme of engineer Berdal ,1976. Heights shown are relative to the sea level.