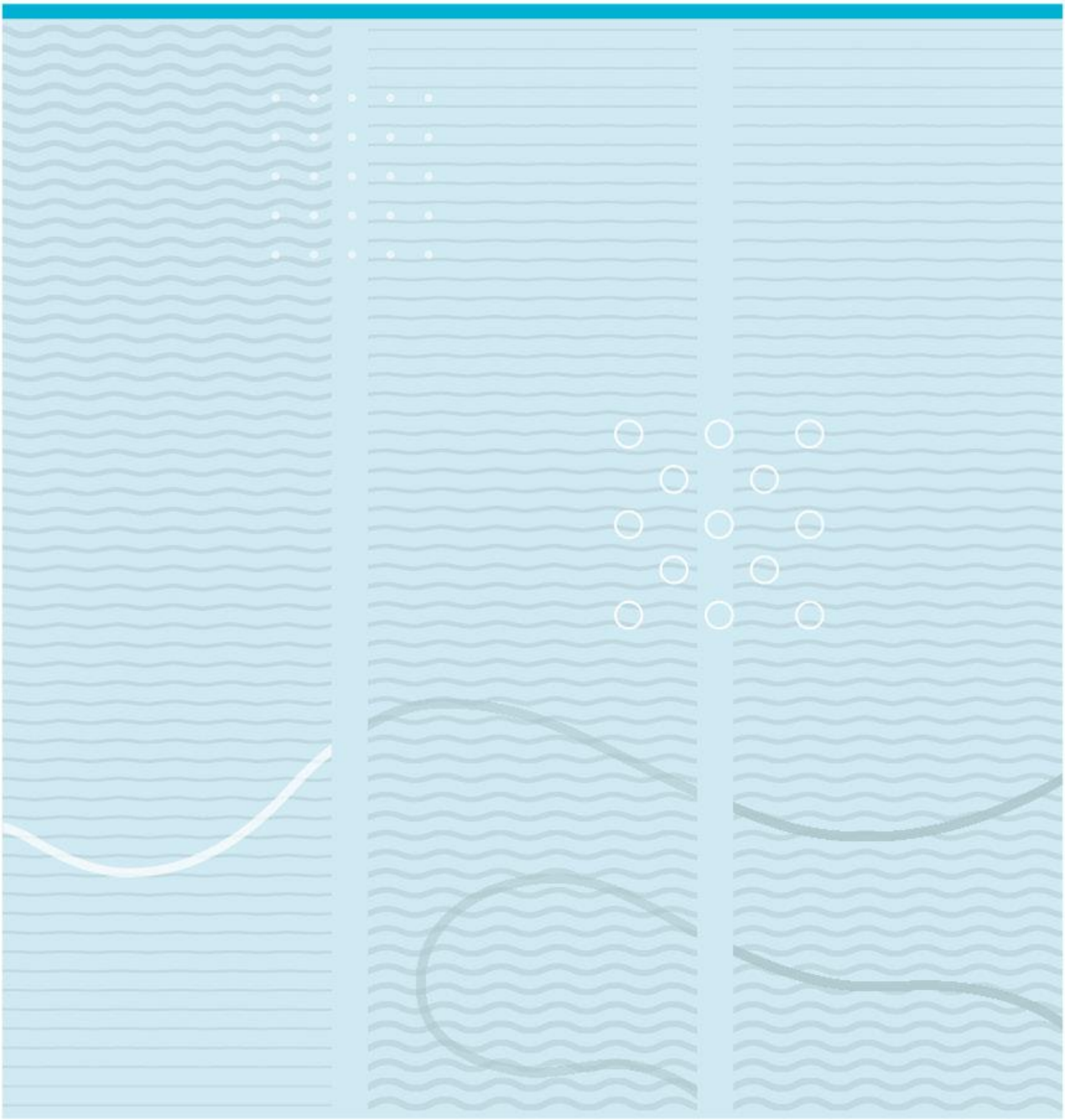
University of South-Eastern Norway
Faculty of Technology, Natural Sciences and Maritime Sciences
Master's Thesis
Study programme: Environmental Sciences
2019-2020

Charles Haakon Carr

Seasonal variations in chlorophyll-a, temperature and major water chemistry close to an open pen fish farm in Lake Fyresvatn - 2019



University of South-Eastern Norway
Faculty of Technology, Natural Sciences and Maritime Sciences
Department of Natural Sciences and Environmental Health
PO Box 235
NO-3603 Kongsberg, Norway

http://www.usn.no

This thesis is worth 60 study points

Abstract

In 2019, seasonal variations in water chemistry, including total phosphorus, total-nitrogen, and chlorophyll-a were investigated in Lake Fyresvatn, Vestfold and Telemark county, to reveal potential local and whole lake effects of open pen fish farming in the lake. The investigation was performed monthly from May to September 2019 at six local stations, 10 m, 100 m, and 1000 m north and south from the fish farm. Integrated water samples were taken in epilimnion (0-6 m), and at one defined hypolimnion depth (20 or 40 m) depending on the station depths. Early July, a bottom fauna investigation was implemented with four transect, 0 m, 10 m and 30 m out from the fish farm. In addition, integrated epilimnion samples (0-12 m) were sampled at the same dates as the local water sampling, near the lake inlet in north and near the lake outlet in south. These data were also compared with corresponding data from 2016, 2017 and 2018. Different statistical analyses were used to reveal possible local and whole lake effects of the fish farm activity.

The concentrations of nutrients (Tot-P: total phosphorous and Tot-N: total nitrogen), in Lake Fyresvatn were low, with subsequent low concentrations of chlorophyll-a (Chl-a) during the investigation period. No significant differences were found between the stations, though one station close to the fish farm (N-10), had somewhat higher phosphorus concentration, and thus reduced ecological status according to EQR values (Ecological Quality Ratio) set by the Norwegian classification system, in accordance with the European water framework directives. Despite significant differences in nutrients and Chl-a between months, it did not alter the lake classification status. Only small effects of the fish farm on the bottom fauna was documented at > 10 m from the pens. The two most common bottom fauna organisms found belongs to the family Chironomidae and the subclass Oligochaeta, the latter primarily within the genus Tubifex. Of the two predominant bottom fauna groups, the Chironomidae individuals are generally far more sensitive to high loads of organic matter and nutrients compared with Oligochaeta. Accordingly, while increasing numbers of Chironomidae individuals were found by increasing distance from the fish farm, the opposite gradient was revealed for Oligochaeta. However, at the edge of the pens (0 m), a decreased number of Oligochaeta was observed compared with at 10 m, where very high numbers of individuals were observed, i.e. > 2000 ind. m^{-2}. This may indicate suboptimal conditions, even for the low oxygen adapted Tubifex individuals, very close to the fish farm.

The EQR values for sight depth, Chl-a, Tot-P and Tot-N, both near the inlet and outlet of Lake Fyresvatn, corresponded to very good to good ecological status in 2019, similar to 2016, 2017, 2018 investigations. The reduction in Tot-N in the lake in 2019 caused a change in the EQR status for this parameter, from good to very good compared to the previous investigated years. Overall, there is so far minor indications of fish farm effects on the water chemistry and Chl-a in Lake Fyresvatn, despite the production volume has increased significantly the last two years. However, as the lakes residence time is ≈ 8 years, it takes time to document the whole lake effects of at date production. Accordingly, further monitoring is needed.

Content

Preface

This master thesis was written as part of the master program at the Institute of Natural Sciences and Environmental Health (INMH), University of South-Eastern Norway.

A special thanks to Espen Lydersen, my main supervisor who has supported me and my fellow student Tarald Tesdal Håland, both in the field and in the laboratory and much more. I also want to thank Frode Bergan (INHM) for water sampling far North and South of Lake Fyresvatn and Karin Brekke Li (INHM) for excellent help in the laboratory. Furthermore, I want to acknowledge Rådgivende Biologer AS for quantitative determination of zoo- and phytoplankton, and the farming company, Telemarkrøye AS, for access to their farm facilities, including boat and for sharing production data. At last, but not least, I want to thank my cohabitant and fellow student Cilie T. Kristiansen for support and patience through master thesis writing, and for 5 great years during our studies at USN.

Bø in Telemark, 15.05.2020
Charles Haakon Carr

1 Introduction

Aquaculture is a large- and increasing industry. It contributes to approximately 40 % of all sea food consumption in the world and is estimated to grow to meet future demands (Bostock et al. 2010). In 2018, Norway produced 1.36 mill. ton aqua cultural fish, a production increase of 3.6 % from 2017 (Fauske 2019, Fiskeridirektortet 2018). The industry provides food to the worlds increasing population, workspace and government revenues. It is also a potential everlasting industry, provided it is done in a sustainable way (Mustafa & Shapawi 2015, Norsk vannforening 2016). In Norway aquaculture production of marine fish species dominates, primarily Atlantic salmon (*Salmo salar*). However, Norway has a vast variety of freshwater environments, with very good natural conditions for inland fish, both for wild fish and fish farming (Lydersen 2015). Currently, 65.8 % of all lakes and rivers in Norway have a good or higher ecological state (Vann-nett 2020).

The growing industry constitutes several environmental concerns and challenges, with regards to nutrient pollution and how to maintain the pristine nature of Norwegian freshwater lakes. Open pen fish farms discharge nutrients (phosphorus and nitrogen) and organic materials into the surrounding aquatic environment, from spillage of fish feed, fish excrement and other excretion products (Kelly 1993, Islam 2005). Phosphorus and nitrogen are biogenic elements, not toxins (Olsen et al., 2008). The increased supply of nutrients can change or increase the biological growth and production, which can lead to resurgence of phytoplankton (algal bloom), also known as eutrophication (Holtan & Åstebøl 1990). Imposed eutrophication can have major consequences on a waterbody's natural biology and water chemistry, with long-term effects (Hongve & Kjensmo 2018). As eutrophication develops, gradual degeneration of the waters functions occurs. The process may create severe build-up of anoxic sediments, toxic algae, decreased biodiversity, changes in species composition and in worst case, lead to widespread death. Eutrophication may not just affect the environment negatively, but also the production in the fish farm as well (Colby et al. 1972, Xiao-e et al. 2008, Mustafa & Shapawi 2015).

Concentrations of chlorophyll-a (Chl-a), total nitrogen (Tot-N), total phosphorus (Tot-P) and sight depth are eutrophication (nutrient) linked parameters used globally to evaluate water quality (Poikane et al. 2010). Nutrient pollution can come from several other human and natural linked sources, that must be taken into consideration when evaluating eventual pollution

(Holtan & Åstebøl 1990). Norway is an EEA member and follow the standards of EU water framework directive (WFD). The Norwegian water management conducts the WFD in Norwegian law and is a guide on processes and criteria on how our water resources should be managed. The main goal is to protect and secure sustainable water use. WFDs environmental objective is that all waterbodies must have a good ecological- and chemical state. In cases were a waterbody is heavily modified, a good potential is the objective. The Ecological state has five condition classes (very good to very bad) and chemical state, just good or bad (Direktoratsgruppen 2018). All waterbodies are classified based on quality elements, physical, chemical and biological parameters. Where the biological quality elements are the ruling factor, while the physical and chemical quality elements are used as a support parameter to adjust the condition class (Pedersen & Green 2013). To be able to evaluate a waterbody, it must be typologized (location, size, depth etc.) and the water body reference values assessed, so the " at present" conditions can be evaluated in light of these scientifically based condition classes (Direktoratsgruppen 2018).

Local conditions in a lake i.e. hydrological and morphological factors can affect the nutrient pollutions, like water exchange rate in the lake e.g. large inflow of water and short residence time can give frequent water replacement in a lake and have a dilutive effect on nutrients. Thus, a lake with frequent water exchange can withstand greater nutrient supply than a similar lake with less frequent water exchange (Lydersen et al. 2017). Over 70 % of Norway's largest watercourses are regulated (≈6000 km^2), mainly for hydroelectrical production (Sørensen et al. 2014, A. Kålås et al., 2010). This normally affects the water level, and residence time of lakes, with subsequently effects on the critical loads of nutrients in lakes. Our study site, Lake Fyresvatn is no exception, with both regulated water bodies upstream and in the lake itself. In Norway, large and deep lakes, like Fyresvatn, are often naturally very nutrient poor, and even more nutrient poor as the regulation *per se* often results in increased residence time, with subsequent increased retention of nutrients in the lake and in the downstream waterbodies. Hydrological load and residence time are therefore crucial factors for all lakes, including Lake Fyresvatn, when assessing effects of increased inputs of nutrients from open pen fish farming (Lydersen et al. 2017, Rognerud et al. 1979, Berge 1987).

In this master thesis, Lake Fyresvatn was investigated in 2019 to asses potential lake impacts of discharged nutrients from an open pen fish farm, Telemarkrøye AS, a farm established in the lake in May 2014 with an annual production permit of around 300-ton of indigenous Arctic charr, *Salvelinus alpinus L*. (Fiskeridirektoratet 2012). Thus, the main goals were to reveal potential seasonal variations in water chemistry, phosphorus (P), nitrogen (N), chlorophyll-a (Chl-a) and bottom fauna close to the fish farm, and potential effects on the whole lake. Whole lake effects have been implemented in the four previous years by the University of South-eastern Norway. As it is mandatory for all fish farms in Norway to monitor and report effects of emissions to the recipient (Akvakulturloven 2013, §11), our results was also given to Rådgivende Biologer AS who was responsible for monitoring lake program on behalf of Telemarkrøye AS (Johnsen et al. 2019).

2 Methods

2.1 Study area

Lake Fyresvatn is a large oligotrophic and calcium poor clearwater lake in Fyresdal municipality in Vestfold and Telemark county. The lake is located 280 m.a.s.l with a surface area of 49.6 km^2 and a volume of 5956 mill. m^3. The catchment area is 878.8 km^2 and is a part of the Arendal watercourse with outlet to the ocean at Arendal, a city in Agder county. The lake has max depth of 377 m and an average depth of 120 m (**Figure 2.1**) making it the 22nd largest and 5th deepest lake in Norway (Lydersen 2015). Residence time of the lake is ≈8 years and a hydrological load of 15.2 m^3 m^2 yr^{-1} (**Table 2.1**). The average annual precipitation the last 4 years (2016-2019) is 1013 mm, based on the nearest weather station Tveitsund.

Table 2.1: Morphological and hydrological data for Lake Fyresvatn (Vann-nett, NVE atlas).

Waterbody id: 019-1274-L							
Surface area km^2	Catchment area km^2	Annual innflow km^3	Volume km^3	Average depth m	max depth m	Recidence time years	Hydrological load m^3 m^2 yr^{-1}
49.63	878.8	0.753	5.956	120	377	7.97	15.2

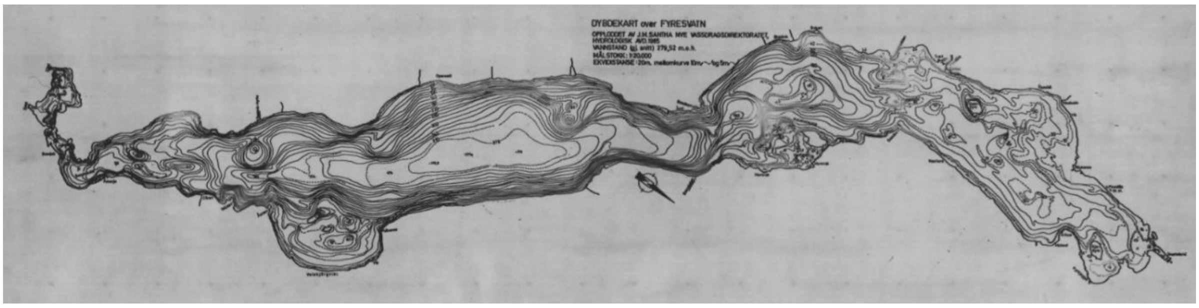


Figure 2.1: Depth map of Lake Fyresvatn from 1965, north towards the right (NVE atlas) (reworked from Johnsen et al. 2019).

The lake is a heavily modified water body, as the lake is hydrological reservoir for hydroelectric production by Momrak kraftlag AS and Finndøla Agder Energi vannkraft AS (Sørensen et al. 2014, NVE 2019). Barriers, sluice, floodgates and morphological changes to the habitat have an impact on regulated water level of 4.5 m, i.e. from 279.65 to 275.15 m a.s.l. (Vann-nett).

Water from Finndøla power plant, comes from several waters that lead down to Gausvatn, which runs out to Fyresvatn in the North-west of the lake (59°11'22.9"N 8°03'25.8"E). The power plant has minimum flow requirements, approx. 1.5 m^3 sec^{-1} at all times, and a yearly average flow of 20 m^3 sec^{-1} (Borgstrøm 1976, Sørensen et al. 2014). Fyresvatn itself is regulated in the South of the lake, at Glomdammen (59°00'33.9"N 8°16'06.0"E), where the surface water is discharged from 2-3 meters depth (Lydersen et al. 2017).

Acid rain has a middle impact on the lake today, but the lake was earlier heavily affected by acid rain, and the lake was limed in 1996, by >1100-ton lime. Accordingly, pH and the acid neutralizing capacity increased. Due to the long residence time of the lake (8 yrs), the effects of this liming are relatively long lasting (Hindar & Larssen 2004).

There is registered one wastewater treatment plant with emission into Lake Fyresvatn, but this plant is shown to have low impact on the lake, **Annex 1** (Norskeutslipp 2018).

Most common fish species in Lake Fyresvatn are Brown trout (*Salmo Trutta*), Whitefish (*Coregonus lavaretus*), and Arctic charr (*Salvelinus alpinus)* (Lydersen 2015). The fish farm (Telemarkrøye AS) is located northwest in the lake, just south from the island Gunnøyne (**Figure 2.2**). The first open pen production of indigenous Arctic charr in Lake Fyresvatn started in May 2014. It started with about 44 000 fish stocked to an annual number of about 200 000 fish the last two years (Johnsen et al. 2019).

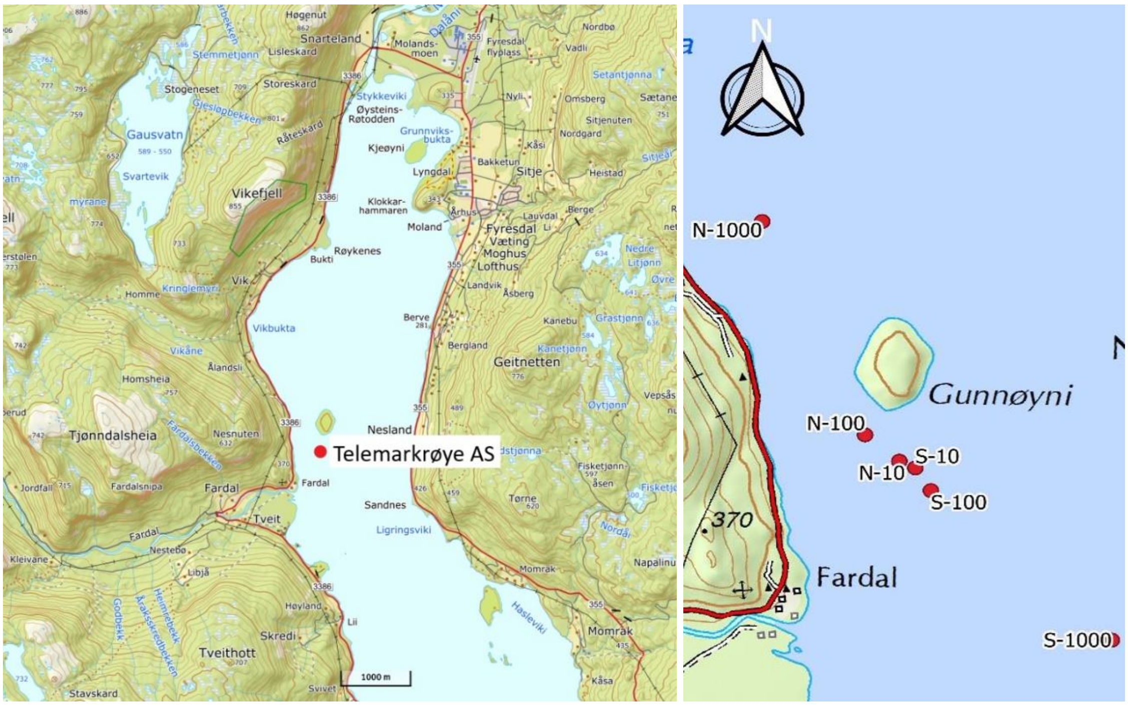


Figure 2.2: Overview of the northern part of Lake Fyresvatn with the fish farm (Telemarkrøye AS) marked, and map of sampling sites N-10, N-100, N-1000, S-10, S-100 and S-1000. Station N means north, S means south, numbers are the distance (m) from the fish farm (modified from Norgeskart, Angelovičová 2018).

2.2 Sampling

The water sampling was done monthly, five times from May to September 2019. Six sites were included, three at different distances (10, 100 and 1000 m) north from the farm, three corresponding sites south from the farm. Accordingly, the sites are named N-10, N-100, N-1000, S-10, S-100 and S-1000. (**Table 2.2**). Data recording in field was implemented with an YSI EXO 2 multiparameter sonde (**Ch. 2.2.1**), while sight depth was measured by a standard secchi disk. Water samples were taken by a Limnos water collector. At the same dates the investigations were implemented close to the farm, another water sampling program was carried out north and south of Lake Fyresvatn by two colleagues from the University of South-eastern Norway. These samples were included in this master thesis. A bottom fauna (**Ch. 2.2.3**) investigation was implemented early July at 12 stations close to the farm, i.e. 4 transects (two south and two north) with 3 sample sites 0, 10 and 30 m from the farm (**Table 2.3**). The sediments were collected by and an Ekman bottom grab.

Table 2.2: Water sampling sites, site depths and 3 different sites (10, 100 and 1000 m) north and south from the fish farm in Lake Fyresvatn 2019.

Station	Distance from Net pen m	Depth m	GPS North	GPS East
N-10	10	40	59.15143	8.06019
N-100	100	20	59.15235	8.05805
N-1000	1000	20	59.15992	8.051483
S-10	10	40	59.15119	8.06119
S-100	100	40	59.15039	8.062167
S-1000	1000	>40	59.14514	8.073487

Table 2.3: Overview of the 12 bottom fauna stations, 3 stations along four different transects in Lake Fyresvatn in 2019. The 3 stations along each transect are located 0, 10 and 30 m away from the fish farm.

Station	Cardinal direction	Dist. Net pen m	GPS North	GPS East	Depth m	Date
1	South-west	0	59 09.055	008 03.593	44.5	02.07.2019
2	South-west	10	59 09.050	008 03.599	45.6	03.07.2019
3	South-west	30	59 09.042	008 03.612	52.0	04.07.2019
4	South-east	0	59 09.072	008 03.634	46.0	02.07.2019
5	South-east	10	59 09.068	008 03.643	48.0	02.07.2019
6	South-east	30	59 09.060	008 03.655	54.0	04.07.2019
7	North-west	0	59 09.061	008 03.583	46.0	03.07.2019
8	North-west	10	59 09.066	008 03.576	42.0	03.07.2019
9	North-west	30	59.09.073	008 03.563	38.0	04.07.2019
10	North-east	0	59 09.079	008 03.630	46.0	02.07.2019
11	North-east	10	59 09.084	008 03.623	43.0	03.07.2019
12	North-east	30	59 09.090	008 03.608	38.0	04.07.2019

2.2.1 YSI EXO 2 Multiparameter Sonde

By the EXO 2 water quality sonde instrument it was possible to record lake depth, conductivity, temperature, turbidity, dissolved O_2, pH, chlorophyll-a and blue green algae. At all six water stations near the fish farm (Table 2.2), the sonde was submerged and all the above-mentioned parameters logged at every meter from 0-12 m, then at every 5th meter down to the bottom. Due to limited cable length, the maximal logging depth was 60 m. The sensors were calibrated with standards before each field day. Data from EXO 2 log was transferred to an excel sheet after each field day. Corresponding sonde was not used at the two stations north and south in Lake Fyresvatn. Here, only water temperature was measured down to 12 m, secchi depth recorded, and water samples collected. The results for turbidity measured with the YSI multiparameter sonde is not implemented in this study, due to turbidity sensor problems.

2.2.2 Water sampling – Limnos water collector

Water samples were collected by a Limnos water collector (volume: 2 L) with a thermometer. Samples were collected at each meter from 0-6 m and one sample near the bottom or at deepest at 40 m (Table 2.2). These samples should represent the hypolimnion water of the lake, while the 0-6 m should represent the epilimnion water of the lake. All water collected from 0-6 m were transferred to a 25 L can. From this mixed 0-6 m water, 0.5 L was transferred to a polyethylene bottle (PE) for water chemistry analysis, while about 3-4 L was transferred to 5 L blue plastic can for Chl-a filtration/analysis. Furthermore, 100 mL was transferred to a brown glass bottle and preserved with 1 mL Lugols solution, for later zoo- and phytoplankton analyses. Water collected from the deepest point was only transferred to 0.5L PE bottle for water chemical analysis. At all depths were water was collected by the Limnos sampler, also the temperature was registered.

Water samples collected, north, close to the inlet, and south, close to the outlet of Lake Fyresvatn were taken from a mixed samples of water from 0, 2, 4, 6, 8, 10, 12 m. In addition, sight depth was measured, and the mixed water was transferred to same type of bottles, as described above for analysis of water chemistry Chl-a and zoo- and phytoplankton. The other sample depth strategy at these two sites rely on the fact that this procedure has been followed at these two station the last 3 years. At all sampling sites we have decided to not follow the

Norwegian management regulations (Direktoratsgruppen 2018), recommending sampling of epilimnion down to twice the sight depth, meaning that samples depth likely will be different at all sampling dates. In addition, as the weather conditions often differ between sampling dates, with large impacts on sight depth recordings, we have decided to take samples from the same depth during all field trips.

2.2.3 **Bottom fauna**

Bottom fauna sampling was implemented at 12 stations near the fish farm using an Ekman bottom grab (areal: 0.152*0,156 m = 0.237 m^2) from 2. to 4. July 2019 (**Table 2.3**, **Figure 2.3**). Five parallel samples were taken at each of the 12 locations, except for station 7 and 11 where only 3 parallel samples were sufficient enough (all 3 samples were similar). Each sample was washed and sieved through a sieve box, to remove small particles as mud and sand. The remaining material was systematically examined for benthos and other interesting organic structures as dead fish eggs, i.e. roe. All benthos and roe were collected and transferred to prenumbered bottles containing 96 % ethanol (**Figure 2.4**), before stored dark and cold (4 °C) until analysed. Sediment consistency, smell and other sediment characteristics were also noted.

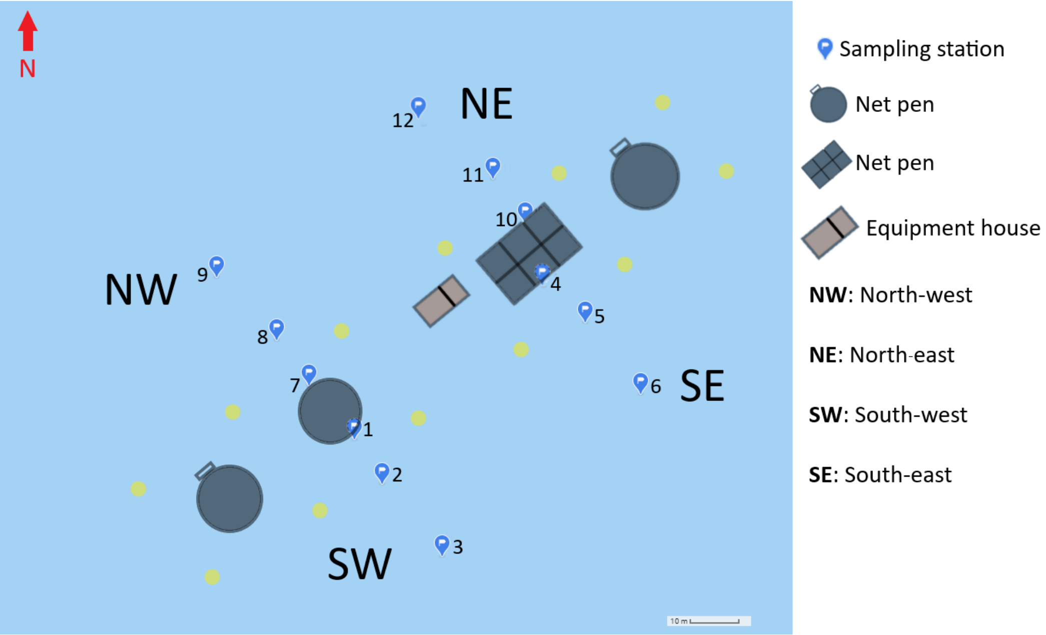


Figure 2.3: Overview of bottom fauna sampling sites and transects, based on GPS coordinates (modified from google maps).

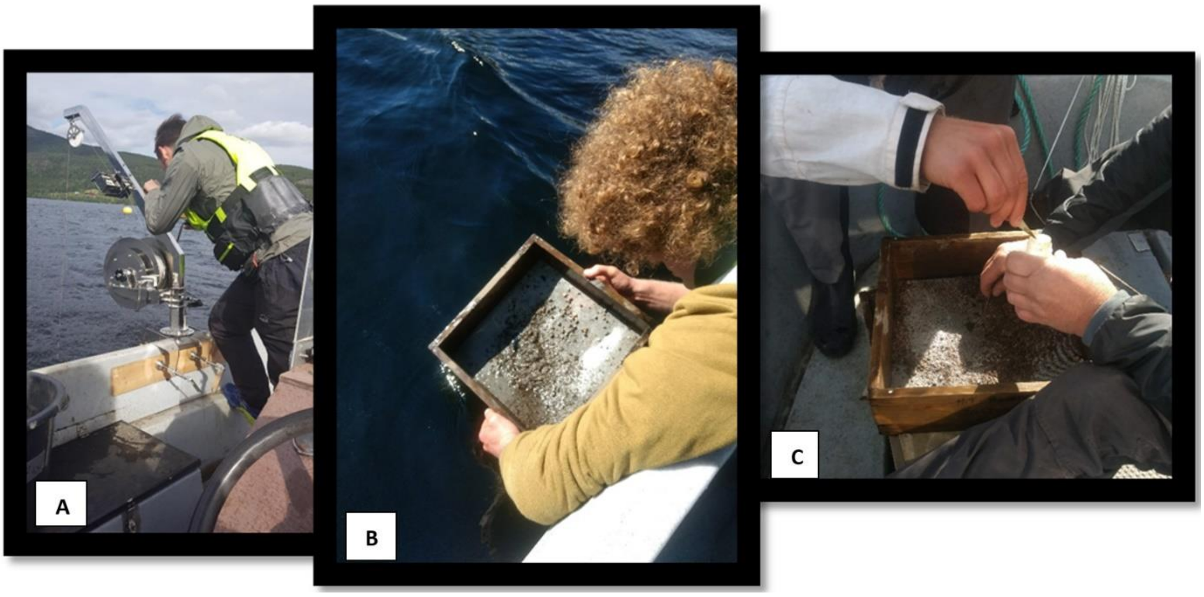


Figure 2.4: Bottom fauna sampling in Lake Fyresvatn, July 2019. A = collecting a sample with the Ekman bottom grab. B = washing of a sample. C = systematically examining for benthos and collecting them. Photo: Charles H. Carr and Tarald T. Håland.

2.3 Laboratory Methods

Directly after field, i.e. the same day, pH, conductivity and turbidity were measured in all water chemistry samples, both from the stations close to the farm and the two stations north and south in Lake Fyresvatn. In addition, a certain, volume (between 1700-2500 mL) of water from each station was filtrated through a 0,45 mm glass microfiber filter (GFC), for later Chl-a measurements. The amount of water filtered differed between months, but identical volumes was filtrated for all station from the same sample day.

After filtration, the filter was folded with filtrate inwards and packed in aluminium foil and freezed down (-18°C) until analysed. The remaining volume in the water chemistry bottles, were also stored cold (4°C) and dark until analysed for the remaining microchemical parameters Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-}, NH_4^{+}, NO_3^{-}, Tot-N (Total Nitrogen), Tot-P (Total Phosphorus), and water colour, the latter due to trouble with our TOC analyser instrument. All analyses were performed according to defined standard methods (**Table 2.4**).

All analyses were carried out at the Department of Nature, Health and Environment (INHM) at USN during October-November 2019, except for the zoo- and phytoplankton analyses implemented by Rådgivende Biologer AS in Bergen (Johnsen et al. 2019).

Table 2.4. Overview of standard water chemistry methods and instruments used for water analyses in Lake Fyresvatnet 2019.

Parameter	Unit	Standard	Equipment
pH	$-\log[H^+]$	NS 4720	PHM210, Meterlab
Conductivity	$\mu S\ cm^{-1}$	NS-ISO 7888	WTW Conductivity meter LF 320
Turbidity	NTU	NS-EN ISO 7027-1:2016	Merck Turbiquant 1100 IR
Colour	$mg\ Pt\ L^{-1}$	NS-EN ISO 7887:2011 C	Perkin Elmer Lambda 25 Spectrophotometer
Total phosphorus (TOT-P)	$\mu g\ P\ L^{-1}$	NS-EN 1189	Perkin Elmer Lambda 25 Spectrophotometer
Total nitrogen (TOT-N)	$\mu g\ N\ L^{-1}$	NS-EN 4743	FIAlab-2500
Chlorophyll-a (Chl-a)	µg L-1	NS-EN ISO 7887:2011 C	Perkin Elmer Lambda 25 Spectrophotometer
Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+	$mg\ L^{-1}$	NS-EN ISO 14911	IC Dionex IC 1100 Ionic chromatography
Cl^-, SO_4^{2-}, NO_3^-	$\mu g\ L^{-1}$	NS-EN 10304-1:2009	IC Dionex IC 1100 Ionic chromatography

Due to uncertainty when measuring Tot-P and Tot-N, two parallel water samples were always analysed. Tot-P concentrations < 5 µg L^{-1} are difficult, i.e. due to problems with accuracy and reproducibility at such low concentrations. In addition, 15 Tot-N and 11 Tot-P samples were reanalysed, as the parallels exhibited large deviations. Reasons for this might be contamination during sampling or analysis preparation. The bottles used in field has never been used before, only rinsed with water from Lake Fyresvatn before sampling.

Identifying Benthos

Identifying bottom fauna (benthos) was done with a magnifier and microscope at USN. Benthos was mainly identified to family (*Chironomidae*) and subclass (*Oligochaeta*) (Økland, 1996). Dead roe from Arctic charr was also registered. Bottom fauna density is defined as individuals m^2. The Ekmann grab has an area of 0.237 m^2, this gives an upscaling factor of 4.22 to be able to specify bottom fauna density as individuals per m^2.

2.4 Statistics

Statistical analyses were performed on Minitab version 18. Since many statistical tests require the data to be normally distributed, the Anderson-Darling normality test (AD test) was used on various parameters. The AD test confirms if the data is normally distributed at p-value > 0.05. One-way analysis of variance (ANOVA) was used for normal distributed data and Kruskal-Wallis for non-normal distributed data, in addition Tukey pairwise comparisons were performed to visualise eventual grouping information based on significance level of variation in means. These analyses were used to find out if there was a statistical difference in water chemistry between the sampling months and between the sampling sites. To check for significant difference between epilimnion and hypolimnion, two-sample t-test was used for normal distributed data and Mann-Whitney U test for non-normal distributed data. Some certain parameters were analysed with simple regressions and regression analysis for variance between the individual parameters and months or years (Whitlock & Schluter 2015).

All parameters and results were calculated with arithmetic average, standard deviation (st.dev), maximum (max), minimum (min) values and correlation matrix for each individual sampling site and month in Excel. Tot-P and Tot-N calculations were based on the lowest analysing value of the two parallels. Major cations and anions were also converted to µekv L^{-1} in order to calculate charge balance and ANC (Acid neutralizing capacity), the latter calculated as the difference between base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and strong acid anions (SO_4^{2-}, NO_3^{-}, Cl^{-}) according to Reuss and Johnson (1986)(**Table 2.5**).

Table 2.5: Parameters with transformed units and formula for transforming from weight concentrations to equivalent concentrations.

Paramter	Original Un	Transfered	Formula
H^+	pH	µekv L^{-1}	10^{-pH} x 10^{6}
Ca^{2+}	mg L^{-1}	µekv L^{-1}	[Ca^{2+}]/40.08 x 2000
Mg^{2+}	mg L^{-1}	µekv L^{-1}	[Mg^{2+}]/24.312 *2000
Na^+	mg L^{-1}	µekv L^{-1}	[Na^+]/22.9898*1000
K^+	mg L^{-1}	µekv L^{-1}	[K^+]/39.102*1000
NH_4^+-N	µg L^{-1}	µekv L^{-1}	[NH_4^+]/18.039*1000
SO_4^{2-}	mg L^{-1}	µekv L^{-1}	[SO_4^{2-}]/96*2000
Cl^-	mg L^{-1}	µekv L^{-1}	[Cl^-]/35.453 * 1000
NO_3^--N	µg L^{-1}	µekv L^{-1}	[NO_3^-] /14
ANC		µekv L^{-1}	(Ca^{2+}+ Mg^{2+}+ Na^++ K^+)-(SO_4^{2-} + Cl^- + NO_3^-)
Σcations		µekv L^{-1}	Σcations
Σanions		µekv L^{-1}	Σanions
CB		µekv L^{-1}	Cations - Anions
CB		%	(CB/(cation+anions)) x 100

Time-weighted means

Time-weighted means (C_m) was calculated for sight depth, water colour, turbidity, Chl-a, Tot-P, Tot-N, pH and conductivity:

$$C_m = \sum \frac{C_n \times t_n}{St_{tot}}$$ (*Equation 1*)

C_n = is the average concentration between two subsequent measurements (C_1+C_2/2),
t_n = is the number of days between the two measurement (t_2-t_1)
st_{tot} = is the total number of days between the first and the last sampling day.

EQR and nEQR

Lake Fyresvatn in defined to represent lake type L-N5 according to the NGIG (Northern geographic intercalibration groups), which are very calcium poor and clear lakes, 200-0 m from the forest boarder. More specifically, a L202d lake based on Norwegian lake types (Direktoratsgruppen 2018). Based on this lake classification, estimation of EQR (Ecological Quality Ratio: ratio between measured value and the expected reference value for the given lake type) (**Table 2.6**) and normalized EQR (nEQR) values (**Equation 2**) were calculated for sight depth, Tot-P, Tot-N, Chl-a, biovolume, phytoplankton trophic Index (PTI), Cyanobacteria (Cyano), pH and ANC in Lake Fyresvatn.

Table 2.6: Overview of the different methods for calculating EQR values for different physical, chemical and biological parameters where (Table references) in the Direktoratsgruppen Veileder 02:2018 the data are taken from. Lake Fyresvatn is defined to be a L-N5 lake according to the NGIG system.

NGIG: L-N5	Norwegian lake type: L202d	
Parameter	Class limit tables	EQR-Method
Sight depth	7.11	Method 1: EQR = obs/ref
Tot-P	7.8	Method 2: EQR = ref/obs
Tot-N	7.10	Method 2: EQR = ref/obs
Chl-a	4.2	Method 2: EQR = ref/obs
Biovolum	4.2	Method 3: EQR = (observed-worst)/(reference-worst)
PTI	4.2	Method 3: EQR = (observed-worst)/(reference-worst)
Cyano	4.2	Method 3: EQR = (observed-worst)/(reference-worst)
pH	7.2	Method 1: EQR = obs/ref
ANC	7.3	Method 3: EQR = (observed-worst)/(reference-worst)

$$nEQR = \left[\left(\frac{EQR - lower\ EQR\ class\ limit}{Upper\ EQR\ limit - lower\ EQR\ limit}\right) \times 0.2\right] + lower\ nEQR\ class\ limit \quad (\textit{Equation 2})$$

nEQR = Normalized EQR
EQR = Not normalized EQR
Lower EQR class limit = Lower not normalized EQR class limit for the relevant class
Upper EQR - lower EQR limit = Class width for non-normalized scale (upper minus lower non-normalized limit value)
0.2 = Standardized classwidth for nomalized scale (upper minus lower normalized EQR class limit)
Lower nEQR class limit = Lower normalized EQR class limit for relevent class (either 0, 0.2, 0.4, 0.6 or 0.8)

P-retention

Relationship between hydrological residence time- and retention of phosphorus in large lakes (R or $P_{Retention}$) (Lydersen et al. 2017, Berge 1987).

$$R = \frac{1}{(1 + T_W^{-0.5})} \quad or \quad R = \frac{1}{1 + \frac{1}{\sqrt{T_W}}} \qquad (\textit{Equation 3 and 4})$$

R = Retention Coefficient or retention coefficient for phosphorus in the lake
Tw = The lakes residence time (years)

3 Results

3.1 Metrological and runoff data

Based on the weather station Tveitsund (**Table 3.1**), located near Lake Fyresvatn, the annual precipitation in 2019 was 1281 mm, somewhat higher than the last 4 years average, i.e 1013mm (**Ch. 2.1**). During the sampling period (May – September 2019), monthly precipitation varied from 83.6 mm in May to 181.9 mm in August. Total precipitation during sampling period was 620.4 mm. Daily average runoff for each month during our sampling period varied from 2.1 m^3 sec^{-1} in June to 3.9 in August. The daily average runoff throughout the whole sampling period was 2.8 m^3 sec^{-1}. Daily runoff had a moderate correlation with precipitation (COR: 0.6, P = 0.00), where runoff increases with increased precipitation ([Runoff]=2.22[Precip.] + 0.15, P=0.00), usually with a delayed response (**Figure 3.1**). Air temperature varied from 8.8 °C in May to 16.2 °C in July. Average wind speeds were 1.5-2.0 m s^{-1}, with predominant wind direction from north and north-west during the colder months (Jan-May and Sep-Dec), while south and south-east dominated during the summer months (Jun-Aug). These wind directions go along the length of the lake (**Table 3.1**).

Table 3.1: Weather data from Tveitsund weather station 2019, monthly and annual results of precipitation (mm), Air temperature (°C), Windspeeds (m/s) and cardinal wind direction (Eklima).

2019 Month	Precipitation mm	Air Temp °C	Windspeed m/s	Wind Direction
Jan	47.2	-1.9	1.8	N/NW ↘
Feb	54.7	1.1	1.7	N↓
Mar	94.5	2	2.0	NW ↘
Apr	54.7	6.1	1.4	N/NE ↙
May	83.6	8.8	2.0	NW ↘
Jun	112.8	13.7	2.0	S↑
Jul	145.6	16.2	1.7	E/SE ↖
Aug	181.9	15.5	1.6	SE ↖
Sep	96.5	10.6	1.8	N/NW ↘
Oct	140.8	4.9	1.4	N
Nov	150.7	0.1	1.5	NW ↘
Dec	117.8	0.6	1.5	E/NE ↙
Annual	1281	6.5	1.7	

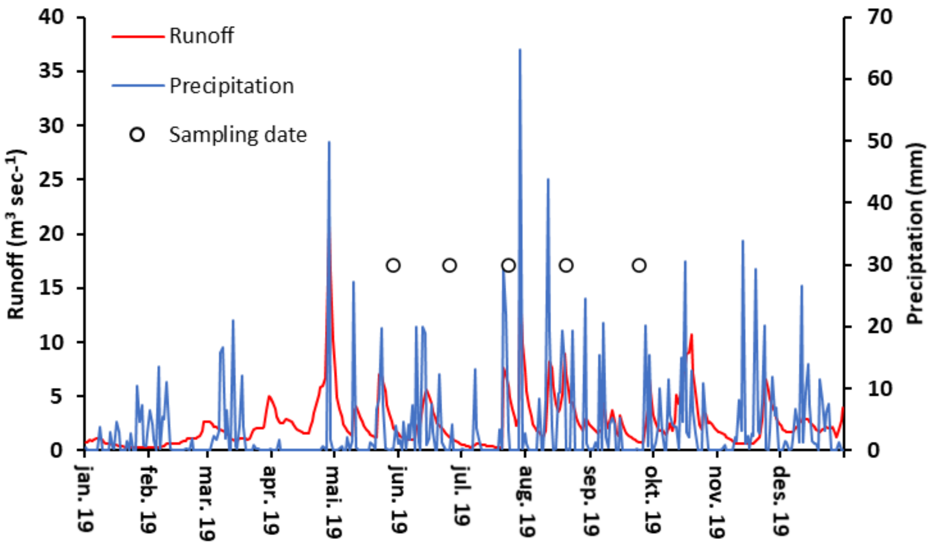


Figure 3.1: Daily average runoff (m^3 sec^{-1}) and precipitation (mm) at the outlet of Lake Fyresvatn (Kilåi bru) 2019. Open circles indicate sampling dates. Data from Kileåi has been received from Klausen E. NVE (per. com.), while precipitation data is taken from the database Eklima.

3.2 Physical, chemical, and biological parameters

The water physical, chemical and biological parameters for each sampling site (North: N-1000, N-100, *N*-10, and South: S-10, S-100, S-1000) are based on mixed values from the epilimnion (0-6 m), and at one defined hypolimnion depth (20-40 m) depending on the various station depths. All statistical test of variance between months or stations (ANOVA/Kruskal-Wallis) are enclosed in **Annex 2-3**. All tests (Two-sample t-test/Mann-Whitney U) between epilimnion and hypolimnion are enclosed in **Annex 4**. Basic statistics, time-weighted means (TWM) and standard deviation (St.dev) in **Annex 5** (A and B).

3.2.1 Physical parameters

The sight depth in Lake Fyresvatn varied from 5.0 m at S-100 in May to 8.2 m at the far south station in September (**Table 3.10**). The sight depth was significantly higher in both July and September (≈7.5 m) compared to the other investigated months (≈6.0 m) (**Table 3.2**). There were no significant differences in sight depth between stations. Average sight depths for all stations were ≈6.7 m.

Table 3.2: Grouping information using One-Way Anova with Tukey pairwise comparisons between sight depth (m) means and sampling months. Means with no sharing letters are significantly different

Sight depth versus months				
Months	N	Mean	Grouping	
September	8	7.46	A	
July	8	7.46	A	
May	8	6.44		B
June	8	6.05		B
August	8	6.00		B

The turbidity was low during our survey in Lake Fyresvatn (**Table 3.10** and **3.11**), ranging from 0.14 NTU at several sites in September to 0.89 NTU at station N-10 in June, both measured in hypolimnion. Turbidity was significantly higher in epilimnion (0.33 NTU) compared to hypolimnion (0.27 NTU). September was significantly lower (0.21 NTU) compared to the other months (> 0.30 NTU). There were no significant variations in turbidity between stations.

Water colour was also generally low in Lake Fyresvatn, varying from 10-30 mg Pt L^{-1}, but average was significantly higher in epilimnion, 17.0 mg Pt L^{-1}, compared to hypolimnion, 15.2 mg Pt L^{-1} (**Table 3.10** and **3.11**). In both epilimnion and hypolimnion, it was a tendency of increasing water colour by time, i.e. from May to September (**Figure 3.2**). The water colour was significantly higher in July, August and September, compared to May and June (**Table 3.3**).

Table 3.3: Grouping information using One-Way Anova with Tukey pairwise comparisons between water colour (mg Pt L^{-1}) means and sampling months. Means with no sharing letters are significantly different.

Water Colour(mg Pt L^{-1}) versus months					
Month	N	Mean	Grouping		
Aug	8	18.91	A		
Sept	8	18.23	A		
Jul	8	17.22	A	B	
Jun	8	16.45		B	
May	8	14.61			C

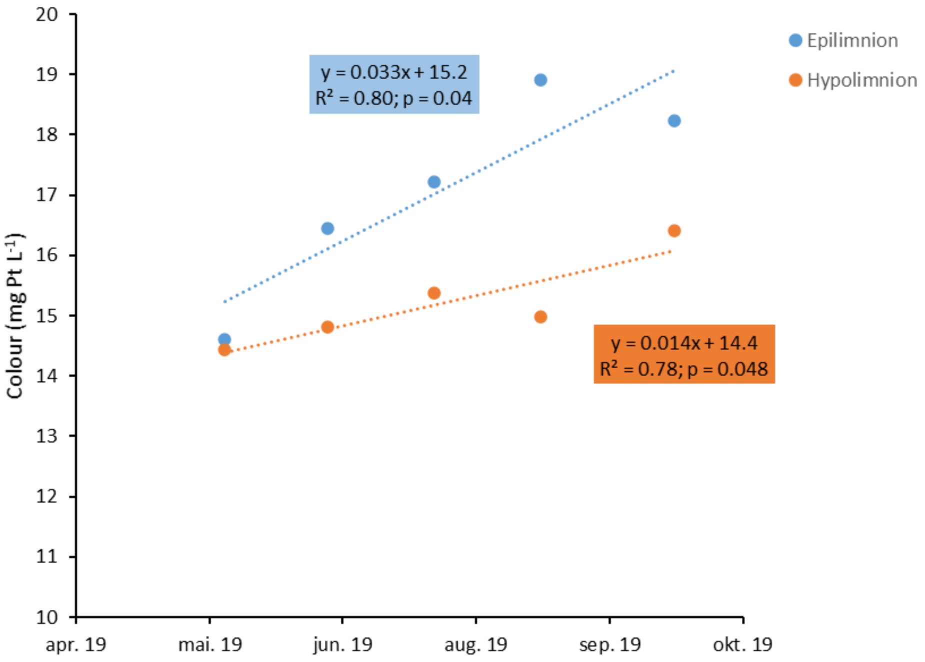


Figure 3.2: Change in water colour (mg Pt L^{-1}) by time in Lake Fyresvatn in 2019, based on monthly averages for all stations.

3.2.2 **Chemical parameters**

The conductivity in Lake Fyresvatn was very low. During the investigation period, lowest measured conductivity (10.0 µS cm^{-1}) was measured in September at several stations, and in both epilimnion and hypolimnion. The highest conductivity (12.6 µS cm^{-1}) was measured in August, in epilimnion at the far north station (**Table 3.10** and **3.11**). Statistically, conductivity was significantly higher in hypolimnion (11.2 µS cm^{-1}) compared to epilimnion (10.8 µS cm^{-1}), despite minor differences.

Epilimnion pH ranged from 5.6 (N-10, in May) to 6.4 in July at both the far north and the far south stations (**Table 3.10** and **3.11**). Compared to the local stations, average pH was significantly higher at both (north and south) those sites (pH = 6.2), compared to station N-10 (pH = 5.8) close to the fish farm. The remaining stations did not differ significantly from other stations, all exhibiting an average pH of ≈ 6.0. Average monthly pH was significantly higher in July (pH = 6.2) compared to May (pH =5.9), while the remaining months were not significantly different from the other months (**Table 3.4**). There were no significant differences in pH between epilimnion and hypolimnion water during the investigated period (pH ≈ 6.0), (**Table 3.10 and 3.11**).

Table 3.4: Grouping information using One-Way Anova with Tukey pairwise comparisons between pH means, sampling stations and months. Means with no sharing letters are significantly different.

pH versus stations					pH versus months				
Station	N	Mean	Grouping		Month	N	Mean	Grouping	
South	5	6.2	A		July	8	6.2	A	
North	5	6.2	A		Sept	8	6.1	A	B
S-10	5	6.1	A	B	Aug	8	6.1	A	B
S-1000	5	6.1	A	B	June	8	6.1	A	B
S-100	5	6.1	A	B	May	8	5.9		B
N-1000	5	6.1	A	B					
N-100	5	6.0	A	B					
N-10	5	5.8		B					

Calcium (Ca^{2+}) varied from 0.93 mg L^{-1} (S-100 in August) to 1.06 mg L^{-1} far north station in May (**Table 3.10** and **3.11**). Though small, the Ca^{2+} concentrations significantly varied between months, with the highest concentration in May (1.01 mg L^{-1}), followed by June, September and July (0.97 mg L^{-1}), and lowest in August (0.95 mg L^{-1} (**Table 3.5**). No significant differences in the Ca^{2+} concentrations were revealed, neither between stations, nor between epilimnion and hypolimnion.

Table 3.5: Grouping information using One-Way Anova with Tukey pairwise comparisons between calcium (Ca^{2+}) means and months. Means with no sharing letters are significantly different.

Calcium (Ca^{2+}) versus months					
Month	N	Mean	Grouping		
May	8	1.01	A		
June	8	0.98	A	B	
Sept	8	0.97	A	B	
July	8	0.96		B	C
Aug	8	0.94			C

The remaining major cations showed no significant variations between neither stations, nor months or depths (**Table 3.10** and **3.11**). The magnesium (Mg^{2+}) concentrations varied from 0.17- 0.18 mg L^{-1}. Sodium (Na^{+}) ranged from 0.66 mg L^{-1} (N-1000 in July) to 0.72 mg L^{-1} at several stations in May (N-10, N-1000, S-100, S-1000 and south). Potassium (K^{+}) ranged from 0.16 mg L^{-1} at several station and months to 0.23 mg L^{-1} at the station far north in May.

The concentrations of ammonium (NH_4^+) was generally low, and thus often under the detection limit for the method (< 50 µg L^{-1}).

Sulphate (SO_4^{2-}) varied from 1.13 µg L^{-1} at S-100 in August to 3.44 µg L^{-1} at S-10 in May, both in epilimnion. Despite small differences, the SO_4^{2-} concentrations were significantly higher in hypolimnion, 1.70 µg L^{-1}, compared to epilimnion, 1.60 µg L^{-1} (**Table 3.10** and **3.11**). SO_4^{2-} exhibited no significant differences between neither stations nor months.

Chloride (Cl^-) ranged from 1.60 µg L^{-1} at N-100 in May to 2.23 µg L^{-1} at N-10 in June (**Table 3.10** and **3.11**). Cl^- was significantly higher in epilimnion (1.75 µg L^{-1}) compared to hypolimnion (1.67 µg L^{-1}).

Nitrate (NO_3^-) ranged from 30 µg L^{-1} at N-10 in June to 194 µg L^{-1} at S-10 in June (**Table 3.10** and **3.11**). The NO_3^- concentrations were significantly higher in both the far north and the far south station (170 µg L^{-1}) compared with station N-10 and S-10, located close to the fish farm (140 µg L^{-1}). Even though not significant, NO_3^- showed an increasing time pattern from May (146 µg L^{-1}) to September (168 µg L^{-1}). There were no significant differences in NO_3^- between epilimnion and hypolimnion.

The acid neutralization capacity (ANC) ranged from -23.6 µekv L^{-1} (S-10) to 19.0 µekv L^{-1} at station N-1000, both measured in May (**Table 3.10** and **3.11**). ANC was significantly higher at the stations located north from the fish farm (7.8 µekv L^{-1}) compared to the stations located south from the farm (0.7 µekv L^{-1}), with exception of station S-100 (8.9 µekv L^{-1}). There was no significant difference in ANC neither between months nor between epilimnion and hypolimnion.

To validate the chemical data, we also did a charge balance calculation. Deviation from 0 is given in %, i.e. CB%. CB% exhibited a small percentage higher amounts of cations compared with anions. The best CB% (closest to 0) was revealed at the far north and south stations (CB%: +0.3 %), while the highest deviation was revealed at station N-10 (CB%: +0.7 %). The overall average CB% was + 0.5 %, indicating high data quality. Both epilimnion and hypolimnion exhibited identical charge balances. Monthly CB % ranged from +0.5 % in August to +0.7 % in June (**Table 3.6**, **3.7** and **3.8**)

Table 3.6: Major cations and anions converted to equivalent concentrations (µekv L^{-1}), and charge balance calculations (CB = Cations – Anions) in epilimnion at each station.

Epilimnion	2019	Charge Balance								
Parameter	**Unit**	**North**	**N-1000**	**N-100**	**N-10**	**S-10**	**S-100**	**S-1000**	**South**	**Average**
H^+	µekv L^{-1}	0.7	0.9	1.1	1.5	0.8	0.8	0.8	0.7	0.9
Ca^{2+}	µekv L^{-1}	50.1	48.5	48.1	48.4	48.7	48.3	48.4	50.1	48.8
Mg^{2+}	µekv L^{-1}	14.8	14.6	14.6	14.7	14.7	14.6	14.7	14.8	14.7
Na^+	µekv L^{-1}	30.0	30.0	29.9	30.3	29.8	29.7	30.0	30.4	30.0
K^+	µekv L^{-1}	5.1	4.4	4.2	4.3	4.5	4.4	4.3	4.8	4.5
NH_4^+-N	µekv L^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO_4^{2-}	µekv L^{-1}	31.5	29.5	28.4	31.6	42.3	29.0	37.1	37.6	33.4
Cl^-	µekv L^{-1}	48.3	48.5	48.1	51.8	49.5	48.4	50.2	49.6	49.3
NO_3^--N	µekv L^{-1}	11.5	10.9	10.5	9.6	10.2	10.7	12.3	12.8	11.1
ANC	µekv L^{-1}	8.9	8.6	9.9	4.7	-4.4	8.9	-2.1	0.1	4.3
Σcations	µekv L^{-1}	100.8	98.4	97.9	99.2	98.5	97.9	98.2	100.8	99.0
Σanions	µekv L^{-1}	100.1	97.5	96.9	97.7	97.7	97.0	97.4	100.1	98.1
CB	µekv L^{-1}	0.7	0.9	1.1	1.5	0.8	0.9	0.8	0.7	0.9
CB	%	0.3	0.5	0.6	0.7	0.4	0.4	0.4	0.3	0.5

Table 3.7: Major cations and anions converted to equivalent concentrations (µekv L^{-1}), and charge balance calculations (CB = Cations – Anions) in hypolimnion at each station.

Hypolimnion	2019	Charge Balance						
Parameter	**Unit**	**N-1000**	**N-100**	**N-10**	**S-10**	**S-100**	**S-1000**	**Average**
H^+	µekv L^{-1}	0.8	1.0	1.3	1.1	1.1	1.0	1.0
Ca2+	µekv L^{-1}	48.9	48.7	49.5	48.9	48.9	48.9	49.0
Mg2+	µekv L^{-1}	14.7	14.7	14.8	14.7	14.6	14.7	14.7
Na+	µekv L^{-1}	30.4	30.6	31.2	30.8	30.8	30.7	30.8
K+	µekv L^{-1}	4.3	4.3	4.3	4.4	4.3	4.3	4.3
NH4+-N	µekv L^{-1}	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SO42-	µekv L^{-1}	29.1	34.0	36.8	38.3	33.8	36.7	34.8
Cl-	µekv L^{-1}	48.1	47.9	49.0	46.2	48.3	42.9	47.1
NO3--N	µekv L^{-1}	11.2	12.4	7.9	10.4	12.2	13.2	11.2
ANC	µekv L^{-1}	10.0	3.9	6.0	4.0	4.3	5.8	5.7
Σcations	µekv L^{-1}	99.2	99.2	101.1	99.9	99.7	99.7	99.8
Σanions	µekv L^{-1}	98.4	98.2	99.8	98.9	98.6	98.7	98.8
CB	µekv L^{-1}	0.8	1.0	1.4	1.1	1.1	1.0	1.1
CB %	%	0.4	0.5	0.7	0.5	0.5	0.5	0.5

Table 3.8: Major cations and anions converted to equivalent concentrations (µekv L^{-1}), and charge balance calculations (CB = Cations – Anions) for each sampling month.

Monthly	2019	Charge Balance					
Ions	**Unit**	**May**	**June**	**July**	**August**	**September**	**Average**
H^+	µekv L^{-1}	1.2	1.0	0.9	1.1	1.1	1.0
Ca^{2+}	µekv L^{-1}	49.4	48.9	48.3	48.2	48.6	48.7
Mg^{2+}	µekv L^{-1}	14.7	14.6	14.5	14.8	14.9	14.7
Na^+	µekv L^{-1}	30.9	30.0	30.3	30.2	30.4	30.4
K^+	µekv L^{-1}	4.2	4.3	4.3	4.4	4.4	4.3
NH_4^+-N	µekv L^{-1}	0.0	0.0	0.0	0.0	0.0	0.1
SO_4^{2-}	µekv L^{-1}	36.8	37.2	30.4	30.3	34.8	33.9
Cl^-	µekv L^{-1}	48.2	47.3	48.9	48.2	48.5	48.2
NO_3^--N	µekv L^{-1}	10.8	9.3	10.6	11.6	12.5	11.0
ANC	µekv L^{-1}	3.5	4.1	7.5	7.5	2.4	5.0
Σcations	µekv L^{-1}	100.6	99.0	98.4	98.8	99.4	99.2
Σanions	µekv L^{-1}	99.3	97.9	97.4	97.5	98.2	98.1
CB	µekv L^{-1}	1.3	1.1	1.0	1.2	1.2	1.2
CB	%	0.6	0.7	0.6	0.5	0.6	0.6

3.2.3 **Tot-P, Tot-N and Chl-a**

The total phosphorus (Tot-P) concentrations were generally low, ranging from 0.98 µg L^{-1} in June to 11.26 µg L^{-1} in May, both in hypolimnion at station N-1000. (**Table 3.10** and **3.11**). Station N-10 (closest to the fish farm) exhibited the highest Tot-P average concentration (5.18 µg L^{-1}), but not significantly higher than the other stations (≈ 3.0 µg L^{-1}). There were also no significant differences in Tot-P neither between months, nor depths.

Total nitrogen (Tot-N) was also generally low during the sampling months, ranging from 83 µg L^{-1} (N-10) to 200 µg L^{-1} (S-100), both measured in July in hypolimnion (**Table 3.10** and **3.11**). There was no significant difference between the depths, in epilimnion and hypolimnion. There were no significant differences in Tot-N neither between months, nor stations. Average Tot-N in Lake Fyresvatn was ≈140 µg L^{-1}.

The chlorophyll-a (Chl-a) concentrations were generally very low, ranging from 0.09 µg L^{-1} at the far north station in May, to 1.35 µg L^{-1} at station N-100 in August (**Table 3.10**). The concentrations of Chl-a were significantly higher in August (1.03 µg L^{-1}), followed by June (0.85 µg L^{-1}), September and July (≈0.70 µg L^{-1}), and lowest in May, 0.21 µg L^{-1} (**Table 3.9**). There were no significant differences in Chl-a between stations.

Table 3.9: Grouping information using One-Way Anova with Tukey pairwise comparisons between Chl-a means (µg L^{-1}) and sampling months. Means with no sharing letters are significantly different.

		Chl-a versus months			
Month	N	Mean	Grouping		
Aug	8	1.03	A		
Jun	8	0.85	A	B	
Sept	8	0.69		B	
Jul	8	0.67		B	
May	8	0.21			C

Table 3.10: Maximum, minimum and average values of central physical, chemical and biological parameters in the epilimnion water at different stations in Lake Fyresvatn during May to September 2019.

2019	**North**	**N-1000**	**N-100**	**N-10**	**S-10**	**S-100**	**S-1000**	**South**
Epilimnion	min-max	min-max	min-max	min-max	min-max	min-max	min-max	min-max
0-6 m	average	average	average	average	average	average	average	average
Sigth depth	5.5 ± 7.5	5.4 ± 7.0	6.0 ± 7.8	5.5 ± 7.7	6.0 ± 7.5	5.0 ± 8.0	6.0 ± 7.8	6.1 ± 8.2
m	6.6	6.2	6.8	6.6	6.9	6.5	6.7	7.3
Colour	13.7 ± 20.3	15.9 ± 19.1	15.2 ± 18.6	14.5 ± 19.0	13.9 ± 18.8	13.6 ± 18.3	16.6 ± 20.8	13.2 ± 18.2
mg Pt L^{-1}	18.3	17.4	16.8	16.9	16.3	16.5	18.0	16.5
Turbidity	0.21 ± 0.6	0.21 ± 0.37	0.21 ± 0.50	0.21 ± 0.48	0.21 ± 0.37	0.22 ± 0.34	0.21 ± 0.37	0.21 ± 0.20
NTU	0.42	0.31	0.38	0.35	0.31	0.29	0.31	0.27
pH	6.0 ± 6.4	5.8 ± 6.2	5.8 ± 6.1	5.6 ± 6.1	6.0 ± 6.3	5.9 ± 6.3	5.9 ± 6.4	6.1 ± 6.4
pH	6.2	6.1	6.0	5.8	6.1	6.1	6.1	6.2
ANC	1.9 ± 16.8	-3.1 ± 19.0	-3.2 ± 17.8	-0.2 ± 17.8	-23.6 ± 11.7	0.8 ± 14.1	-10.8 ± 5.5	-2.8 ± 3.6
µekv L^{-1}	8.9	8.6	9.9	4.7	-4.4	8.9	-2.1	0.1
Conductivety	10 ± 12.6	10.0 ± 11.0	10.0 ± 12.3	10.0 ± 11.8	10.0 ± 11.5	10.0 ± 11.7	10.0 ± 11.4	10 ± 11.2
mS cm^{-1}	11.3	10.6	11.0	11.1	10.8	10.8	10.7	10.9
Chl-a	0.09 ± 0.80	0.14 ± 0.98	0.14 ± 1.35	0.16 ± 1.04	0.20 ± 1.21	0.16 ± 1.26	0.15 ± 1.04	0.43 ± 0.65
mg L^{-1}	0.60	0.74	0.75	0.69	0.72	0.70	0.74	0.57
Tot-P	1.74 ± 3.41	0.98 ± 11.26	1.23 ± 2.82	1.99 ± 7.60	1.86 ± 2.34	1.20 ± 8.26	1.76 ± 2.82	1.73 ± 7.44
mg L^{-1}	2.28	4.11	2.06	5.19	2.13	3.13	2.15	3.97
Tot-N	130 ± 186	121 ± 161	124 ± 158	130 ± 160	85 ± 149	109 ± 150	133 ± 186	100 ± 181
mg L^{-1}	151	134	141	143	126	133	159	149
Ca^{2+}	0.96 ± 1.06	0.95 ± 1.01	0.94 ± 0.97	0.94 ± 0.99	0.95 ± 1.01	0.93 ± 1.00	0.95 ± 1.00	0.96 ± 1.02
mg L^{-1}	1.01	0.97	0.96	0.97	0.98	0.97	0.97	1.00
Mg^{2+}	0.18 ± 0.18	0.17 ± 0.18	0.18 ± 0.18	0.18 ± 0.18	0.18 ± 0.18	0.18 ± 0.18	0.18 ± 0.18	0.18 ± 0.18
mg L^{-1}	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Na^{+}	0.66 ± 0.71	0.66 ± 0.72	0.67 ± 0.71	0.67 ± 0.72	0.67 ± 0.70	0.67 ± 0.72	0.68 ± 0.72	0.68 ± 0.72
mg L^{-1}	0.69	0.69	0.69	0.70	0.69	0.68	0.69	0.70
K^{+}	0.17 ± 0.23	0.16 ± 0.18	0.16 ± 0.18	0.16 ± 0.18	0.17 ± 0.18	0.16 ± 0.18	0.16 ± 0.18	0.18 ± 0.20
mg L^{-1}	0.20	0.17	0.17	0.17	0.18	0.17	0.17	0.19
NH_4^{+}-N	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
mg L^{-1}	< 50	< 50	< 50	< 50	< 50	< 50	< 50	< 50
SO_4^{2-}	1.26 ± 1.66	1.20 ± 1.78	1.16 ± 1.79	1.28 ± 1.66	1.26 ± 3.44	1.13 ± 1.71	1.44 ± 2.08	1.61 ± 1.97
µg L^{-1}	1.51	1.42	1.37	1.52	2.03	1.39	1.78	1.80
Cl^{-}	1.64 ± 1.77	1.62 ± 1.78	1.60 ± 1.80	1.68 ± 2.23	1.70 ± 1.79	1.66 ± 1.79	1.73 ± 1.82	1.72 ± 1.79
µg L^{-1}	1.71	1.72	1.70	1.84	1.75	1.72	1.78	1.76
NO_3^{-}-N	144 ± 169	135 ± 179	134 ± 165	130 ± 175	33 ± 194	134 ± 168	159 ± 188	169 ± 188
µg L^{-1}	161	152	147	135	143	150	172	179

Table 3.11: Maximum, minimum and average values of central physical, chemical and biological parameters in the hypolimnion water at different stations in Lake Fyresvatn during May to September 2019.

2019	**N-1000**	**N-100**	**N-10**	**S-10**	**S-100**	**S-1000**
Hypolimnion	min-max	min-max	min-max	min-max	min-max	min-max
20-40 m	average	average	average	average	average	average
Colour	14.3 ± 18.6	14.3 ± 18.6	12.8 ± 15.7	13.5 ± 16.9	14.2 ± 18.3	13.6 ± 15.6
mg Pt L^{-1}	15.85	15.55	14.46	15.24	15.34	14.78
Turbidity	0.15 ± 0.31	0.22 ± 0.37	0.28 ± 0.89	0.18 ± 0.30	0.14 ± 0.30	0.14 ± 0.28
NTU	0.24	0.31	0.47	0.23	0.22	0.19
pH	6.0 ± 6.2	5.9 ± 6.1	5.7 ± 6.0	5.7 ± 6.1	5.9 ± 6.0	5.9 ± 6.1
pH	6.1	6.0	5.9	6.0	6.0	6.0
ANC	-2.7 ± 14.1	-5.6 ± 11.5	-2.5 ± 14.0	-5.0 ± 16.0	-3.2 ± 14.2	-3.3 ± 13.4
μekv L^{-1}	10.0	3.9	6.0	4.0	4.3	5.8
Conductivety	10 ± 11.4	10 ± 11.7	10 ± 11.8	10 ± 12	10 ± 12.4	10 ± 12
μS cm^{-1}	11.02	11.12	11.26	11.24	11.36	11.28
Tot-P	1.25 ± 6.36	1.43 ± 2.42	1.43 ± 3.45	2.17 ± 6.08	1.25 ± 6.88	1.48 ± 2.78
μg L^{-1}	2.60	1.80	2.43	3.11	2.96	2.03
Tot-N	121 ± 137	121 ± 138	83 ± 140	114 ± 182	145 ± 200	119 ± 151
μg L^{-1}	130	126	122	151	163	141
Ca^{2+}	0.97 ± 0.99	0.96 ± 0.99	0.97 ± 1.02	0.96 ± 0.99	0.97 ± 0.99	0.97 ± 0.99
mg L^{-1}	0.98	0.98	0.99	0.98	0.98	0.98
Mg^{2+}	0.18 ± 0.18	0.18 ± 0.18	0.18 ± 0.18	0.18 ± 0.18	0.17 ± 0.18	0.18 ± 0.18
mg L^{-1}	0.18	0.18	0.18	0.18	0.18	0.18
Na^+	0.68 ± 0.73	0.68 ± 0.72	0.69 ± 0.74	0.68 ± 0.72	0.69 ± 0.71	0.69 ± 0.72
mg L^{-1}	0.70	0.70	0.72	0.71	0.71	0.71
K^+	0.17 ± 0.17	0.15 ± 0.18	0.16 ± 0.18	0.17 ± 0.19	0.15 ± 0.18	0.16 ± 0.17
mg L^{-1}	0.17	0.17	0.17	0.17	0.17	0.17
NH_4^+-N	n.a	n.a	n.a	n.a	n.a	n.a
μg L^{-1}	< 50	< 50	< 50	< 50	< 50	< 50
SO_4^{2-}	1.28 ± 1.78	1.41 ± 2.02	1.30 ± 2.63	1.26 ± 2.52	1.27 ± 1.90	1.64 ± 1.84
μg L^{-1}	1.40	1.63	1.77	1.84	1.62	1.76
Cl^-	1.64 ± 1.79	1.65 ± 1.76	1.29 ± 2.26	1.37 ± 1.71	1.66 ± 1.76	1.36 ± 1.75
μg L^{-1}	1.70	1.70	1.74	1.64	1.71	1.52
NO_3^--N	146 ± 181	165 ± 184	14 ± 181	28 ± 196	146 ± 189	176 ± 204
μg L^{-1}	157	174	110	145	171	185

3.2.4 **YSI Results**

The YSI multiparameter sonde monthly table results (averages of all stations), are enclosed in **Annex 6**.

Water temperatures variations were small (0.2°C) between our six sampling sites near the fish farm. The significant difference in hypolimnion temperatures between stations rely on the fact that maximum depth at station N-100 and N-1000 was 20 m compared with the other stations with hypolimnion depth > 40 m. The surface water (0-6 m) temperature ranged from 6.0 °C in May to 15.8 °C in August. In May and June there was no distinct thermocline, while in July, a distinct thermocline was established at about 8-10 m, while in August an even more distinct thermocline was established at about 10 m. In September, the water temperature started to fall, from 15.8 °C (in August) to 11.0 °C in September, and the thermocline is deepening and far less distinct (**Figure 3.3**).

Dissolved O_2 (mg L^{-1}) was lowest in July and August in epilimnion (≈9.1 mg L^{-1}), with increasing O_2 at about 10 m depth (≈ 10.0 mg L^{-1}). May, June and September were very similar, with minor variation in O_2 through the whole water column (≈ 11.0 mg L^{-1}). Bottom water O_2 concentrations were ≈ 11.0 mg L^{-1} through all months (**Figure 3.3**). When the YSI sonde hit the sediment, O_2 concentrations dropped significantly, > 1.0 mg L^{-1} (**Annex 6**).

YSI Conductivity in epilimnion (0-6 m), ranged from 9.8 µS cm^{-1} at S-100 in August to 12.7 µS cm^{-1} at S-100 in June, and showed a significant correlation with measured conductivity in epilimnion ([Measured Cond.]= -11.69[YSI Cond.] + 2.07, P = 0.00; COR: 0.70, P = 0.00). The YSI conductivity exhibited the lowest values in September (≈10.2 µS cm^{-1}), same as measured conductivity, but May and June as highest (11.0 µS cm^{-1}), were highest monthly average for measured conductivity was in August. YSI Conductivity was not significantly different between stations, nor between epilimnion and hypolimnion. Average YSI conductivity was ≈10.7 µS cm^{-1} (**Figure 3.3**).

YSI pH in epilimnion (0-6 m) showed minor variations between months, ranging from 5.6 in May to 5.9 in August. In hypolimnion (20-40 m) pH varied from 5.3 to 5.6 between the months (**Figure 3.3**). There were no significant differences in pH between stations, nor depths (epilimnion vs hypolimnion). Comparison of pH measurements between YSI (recorded) and pH (measured), showed significantly lower pH by the YSI recorder compared with the measured pH, measured by pH meter at the laboratory.

YSI Chl-a in epilimnion (0-6 m), ranged from 0.42 µg L^{-1} at both S-100 and S-1000 in May to 1.55 µg L^{-1} S-1000 in June, and showed a very significant correlation with measured Chl-a in epilimnion ([Measured Chl-a] = -0.099[YSI Chl-a] + 0.846, P = 0.00; COR: 0.87, P = 0.00). The YSI Recorded Chl-a data showed significantly higher values in June compared with August, the opposite of what was measured in the laboratory on the epilimnion water (**Table 3.9** and **3.12**). Most likely reason for this, was that we did not rinse the sonde in distilled water between stations, as the sonde also was recording down into the sediments at all sites with depth < 40-45 m. The YSI data did not exhibit significant differences in Chl-a between stations. Combined with the low ANC in lake Fyresvatn, the primary production (Chl-a) showed to have a small impact on pH in epilimnion (**Figure 3.3**).

Table 3.12: Grouping information using One-Way Anova with Tukey pairwise comparisons between YSI recorded Chl-a means (µg L^{-1}) and sampling months. Means with no sharing letters are significantly different.

YSI Chl-a versus months						
Month	N	Mean	Grouping			
June	6	1.43	A			
August	6	1.26		B		
September	6	0.89			C	
July	6	0.81			C	
May	6	0.47				D

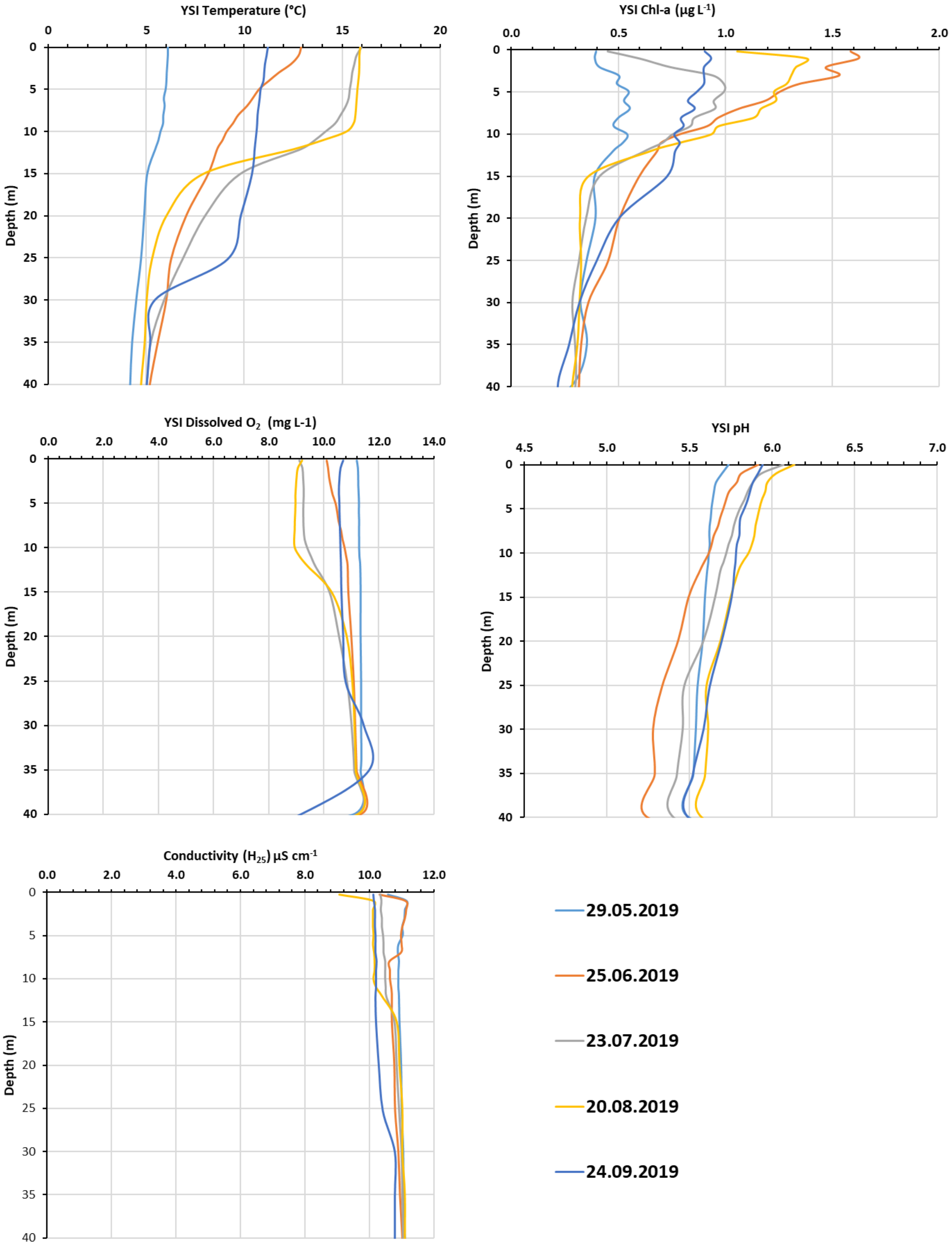


Figure 3.3: Depth profiles for Water temperature, Chl-a, dissolved O_2, pH and conductivity (average of all sampling sites), based on the YSI multiparameter sonde. The colours describe the different months.

3.2.5 **Hydrology and phosphorus**

According to **Equation 3 or 4** (see above), the lake residence time (T_w) in lake Fyresvatnet is ≈ 8 years, which means that about 74 % of the phosphorus in the lake will be retained in the lake, i.e. precipitate and subsequently incorporated in the lake sediment (**Figure 3.4**).

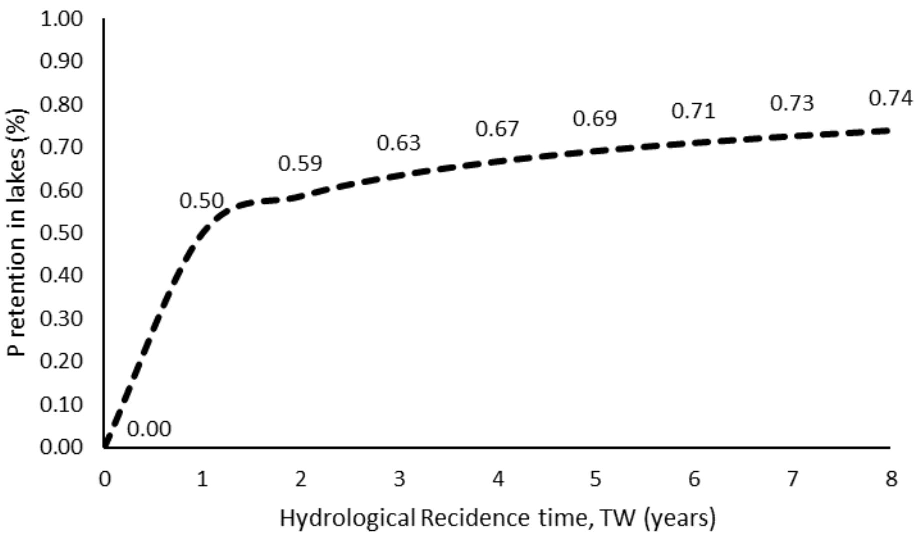


Figure 3.4: The relationship between hydrological residence time- and retention of phosphorus in lakes.

3.2.6 **Ecological quality reference - EQR & nEQR 2019**

Ecological quality reference (EQR) and normalised ecological quality reference (nEQR) values were calculated based on time-weighted means (TWM) for sight depth, Tot-P, Tot-N, Chl-a, pH and ANC (**Annex 6**). EQR calculation for biovolume (algae volume), phytoplankton trophic index (PTI) and cyanobacteria (cyano) were based on normal means, provided from Rådgivende Biologer AS (*Johnsen et al. 2019)* using Equations presented in **Table 2.5** and **Equation 2.**

All nEQR calculations in **Table 3.14**, showed Very good condition, except for Tot-P at station N-10, characterized with to Good (nEQR 0.786). Station N-10 also had the lowest Site x̄nEQR of 0.929, but still overall classified as Very good. With all stations and parameters combined, the lakes water quality (x̄nEQR = 0.98) of Lake Fyresvatn was characterized as Very good in 2019.

Table 3.14: EQR and nEQR values for sight depth, Tot-P and Tot-N, based on time-weighted mean concentrations in epilimnion (0-6m) at all sampling sites in Lake Fyresvatn 2019. Blue = Very good conditions. Green = Good condition.

2019	Water quality										
Lake type 202d	Secchi depth m	EQR Sight depth	nEQR Sight depth	Tot-P µg L^{-1}	EQR Tot-P	nEQR Tot-P	Tot-N µg L^{-1}	EQR Tot-N	nEQR Tot-N	Site x̄nEQR	x̄nEQR
North	6.4	1.01	**1.000**	2.14	1.40	**1.000**	151	0.99	**0.996**	**0.999**	0.98
N-1000	6.2	0.98	**0.929**	3.26	0.92	**0.960**	134	1.12	**1.000**	**0.963**	
N-100	6.7	1.06	**1.000**	2.12	1.42	**1.000**	141	1.06	**1.000**	**1.000**	
N-10	6.6	1.05	**1.000**	5.18	0.58	**0.786**	142	1.05	**1.000**	**0.929**	
S-10	6.8	1.08	**1.000**	2.13	1.41	**1.000**	126	1.20	**1.000**	**1.000**	
S-100	6.6	1.04	**1.000**	2.79	1.08	**1.000**	132	1.14	**1.000**	**1.000**	
S-1000	6.7	1.06	**1.000**	2.17	1.38	**1.000**	162	0.93	**0.964**	**0.988**	
South	7.1	1.13	**1.000**	4.31	0.70	**0.848**	145	1.03	**1.000**	**0.949**	

EQR and nEQR calculations for the phytoplankton parameters, Chl-a, biovolume, PTI and cyano is present in **Table 3.15**. The nEQR calculations of Chl-a showed Very good condition at all stations. Also, the nEQR calculations for Biovolume (algaevolume) showed Very good condition at all stations. nEQR calculations for PTI varied from good to bad. Station S-10 (nEQR: 0.605) and South (nEQR: 0.616) correspond to Good condition, while station N-10 with an nEQR of 0.270 corresponds to Bad condition. The remaining stations (North, N-1000, N-100, S-100 and S-1000) showed Moderate condition for PTI (nEQR 0.423 - 0.491).

The nEQR calculations for Cyano showed Very good condition at all stations varying from 0.989 to 1.000. By summing up the 4 biological assed parameters (x̄nEQR) for all sites, Lake Fyresvatn is evaluated to have a Good biological status (x̄nEQR: 0.615 – 0.775, average 0.72).

Table 3.15: EQR and nEQR values for the biological parameters (phytoplankton): Chl-a is based on time-weighted mean concentrations in epilimnion (0-6m), biovolume (algae volume in epilimnion), PTI (phytoplankton trophic index in epilimnion) and cyano (cyanobacteria in epilimnion) in Lake Fyresvatn in 2019. Analyses of biovolume, PTI and Cyano were implemented by Rådgivende Biologer. Blue = Very good condition; Green = Good conditions; Yellow = Moderate conditions; Orange = Bad conditions.

2019	Phytoplankton													
Lake Type 202d	Chl-a µg L^{-1}	EQR Chl-a	nEQR Chl-a	Biovolum mg L-1	EQR Biovolum	nEQR Biovolum	PTI x̄	EQR PTI	nEQR PTI	Cyano mg L-1	EQR Cyano	nEQR Cyano	Site x̄nEQR	x̄nEQR
North	0.66	1.97	**1.000**	0.157	0.98	**0.837**	2.28	0.78	**0.480**	0	1.00	**1.000**	**0.713**	**0.72**
N-1000	0.81	1.61	**1.000**	0.144	0.99	**0.882**	2.3	0.77	**0.457**	0	1.00	**1.000**	**0.709**	
N-100	0.84	1.54	**1.000**	0.13	0.99	**0.931**	2.33	0.76	**0.423**	0	1.00	**1.000**	**0.700**	
N-10	0.77	1.70	**1.000**	0.142	0.99	**0.889**	2.45	0.70	**0.270**	0.011	1.00	**0.989**	**0.615**	
S-10	0.80	1.64	**1.000**	0.169	0.98	**0.800**	2.17	0.83	**0.605**	0.008	1.00	**0.992**	**0.768**	
S-100	0.79	1.64	**1.000**	0.154	0.98	**0.848**	2.27	0.79	**0.491**	0.008	1.00	**0.992**	**0.719**	
S-1000	0.81	1.60	**1.000**	0.12	1.00	**0.965**	2.28	0.78	**0.480**	0	1.00	**1.000**	**0.734**	
South	0.57	2.26	**1.000**	0.165	0.98	**0.810**	2.16	0.84	**0.616**	0.007	1.00	**0.993**	**0.775**	

All nEQR calculation for pH showed Good conditions (nEQR 0.683 – 0.796), while ANC ranged from Bad (nEQR: 0.202-0.203). to Very bad (nEQR: 0) conditions (**Table 3.16**), Very bad at station S-10 and S-1000. Altogether, the nEQR for acidification status in Lake Fyresvatn in 2019 was 0.46, corresponding to Moderate acidification condition.

Table 3.16: EQR and nEQR values of pH and ANC based on time-weighted means in epilimnion (0-6 m) at all stations (N-10, N-100, N-1000, S-10, S-100, S-1000, north and south) in Lake Fyresvatn in 2019. Green = Good conditions; Yellow = Moderate condition; Orange = Bad condition; Red =Very bad condition.

2019	Acidification							
Lake Type	pH	EQR	nEQR	ANC	EQR	nEQR	Site	
202d	x̄	pH	pH	x̄	ANC	ANC	x̄nEQR	x̄nEQR
North	6.2	0.95	**0.796**	8.9	0.15	**0.203**	**0.499**	**0.46**
N-1000	6.1	0.93	**0.759**	8.6	0.14	**0.203**	**0.481**	
N-100	6.0	0.92	**0.731**	9.9	0.16	**0.203**	**0.467**	
N-10	5.8	0.90	**0.683**	4.7	0.08	**0.202**	**0.442**	
S-10	6.1	0.94	**0.777**	-4.4	-0.07	**0.000**	**0.389**	
S-100	6.1	0.93	**0.765**	8.9	0.15	**0.202**	**0.483**	
S-1000	6.1	0.93	**0.766**	-2.1	-0.04	**0.000**	**0.383**	
South	6.2	0.95	**0.796**	0.1	0.001	**0.202**	**0.499**	

3.3 Compared with previous years: 2016, 2017, 2018 and 2019

Climate data from Tveitsund weather station (**Table 3.17**), located near lake Fyresvatn, shows that the air temperature (C°) was higher during the sampling period in 2018 (May-October), compared to the other investigated years (2016, 2017 and 2019). Years with warmer months during their sampling period compared to 2018, were September 2016 (13.5 C°) and August 2019 (15.5 C°). Regarding monthly average precipitation (mm), 2019 exhibited the highest rainfall during that years sampling period (124 mm, average of May-September), followed by 2018 (66 mm, average of May-October), 2017 (116 mm, average of June-October) and 2016 that exhibited the least rainfall (61 mm, average of June-October). **Figure 3.5** shows variation in runoff (m^3 sec^{-1}) and precipitation (mm) between years 2016, 2017, 2018 and 2019. The annual daily average runoff in 2017 and 2019 (2.5 m^3 sec^{-1}) were significantly higher compared to the other years, with lowest in 2016 (1.8 m^3 sec^{-1}). 2017 exhibited the highest daily average runoff during the sampling period (3.7 m^3 sec^{-1}), followed by 2019 (2.8 m^3 sec^{-1}), 2018 (1.4 m^3 sec^{-1}) and 2016 (1.2 m^3 sec^{-1}).

Table 3.17: Monthly and annual average air temperatures (C°) and precipitation (mm) from 2016 to 2019 at Tveitsund weather station, located near Lake Fyresvatn (Eklima). Sampling months are marked grey. Note: no data from Tveitsund from 19.07.17 to 31.07.17.

	Air Temp °C				Precip. mm			
Month	**2016**	**2017**	**2018**	**2019**	**2016**	**2017**	**2018**	**2019**
Jan	-4.5	-0.5	-1.4	-1.9	92.2	43.1	143.7	47.2
Feb	-0.9	-1.4	-4.4	1.1	74.8	72.7	77.6	54.7
Mar	1.6	1.6	-3.9	2	85.5	62.0	26.8	94.5
April	4.3	4.5	4.4	6.1	60.0	49.9	30.6	54.7
May	11.1	10.9	13.8	8.8	78.1	81.7	46.3	83.6
Jun	15.1	14.0	16.6	13.7	52.8	141.3	43.7	112.8
Jul	15.2	14.7	20.7	16.2	91.0	12.5	44.4	145.6
Aug	14.2	13.8	14.5	15.5	76.8	80.5	75.0	181.9
Sep	13.5	10.8	11.2	10.6	54.4	187.4	158.0	96.5
Oct	5.1	6.8	7.0	4.9	30.5	158.8	33.7	140.8
Nov	0.7	1.6	3.0	0.1	81.8	88.2	128.6	150.7
Dec	2.1	-0.9	-0.4	0.6	55.8	49.7	98.5	117.8
Yearly	6.5	6.3	6.8	6.5	834	1028	907	1281

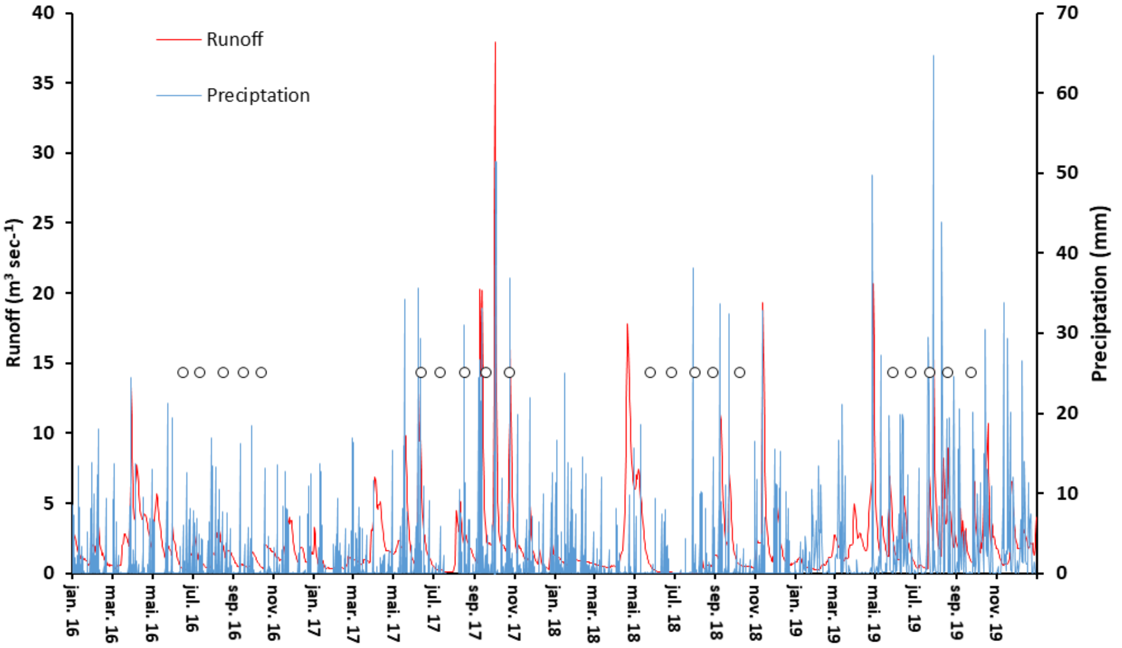


Figure 3.5: Daily average runoff (m^3 sec^{-1}) and precipitation (mm) at the outlet of Lake Fyresvatn (Kilåi bru) from 2016 to 2019. Open circles indicate sampling dates. Data from Kileåi has been received from Klausen E. NVE (pers. com.), while precipitation data is taken from the database Eklima.

The parameters selected to compare between the years are primarily focused on sight depth, Chl-a, Tot-N and Tot-P from far north and south stations based on mixed samples of 0-12 m, from the years 2016, 2017, 2018 and 2019. Year 2016 and 2017 only have data from far north and south stations in lake Fyresvatn. To show the difference in selected parameters between the years, a table with time-weighted mean concentrations (TWMC), average concentration, standard deviation (st.dev), median, maximum (max) and minimum (min) values are presented below (**Table 3.18**).

The lowest sight depth measured during the period 2016 - 2019 was 5.0 m (station far north, in June 2017, while det highest sight depth (8.5 m) was measured at station far south in August 2016. The sight depth is shown to be significantly higher in the south (7.3 m) compared to north (6.5 m) in Lake Fyresvatn, and with small variations during the period at the far south station. At the north station, both 2016 and 2018 showed significantly higher sight depths compared to 2017 and 2019, with the highest average sight depth (7.0 m) recorded in 2018, the lowest (5.8 m) in 2017.

All years, the highest Tot-N concentrations were recorded at far north station, with the highest value measured (410 µg L^{-1}) in October 2017 and lowest (100 µg L^{-1}) in August 2019. The average concentration of Tot-N in 2019 (≈150 µg L^{-1}) was much lower compared to previous years, i.e. ≈ 300 µg L^{-1} in 2016 and 2017 and ≈ 250 µg L^{-1} in 2018. The decrease was not found to be statistically significant (**Figure 3.6**).

For Tot-P, the concentrations varied from 0.50 µg L^{-1} in 2016 (June) to 35.1 µg L^{-1} in 2017 (September), both measured at the far north station. Tot- P in 2016 were significantly lower compared to the other years (2017, 2018 and 2019), all samples were 1.0 µg L^{-1} or lower, while 2017 exhibited significantly higher Tot-P values. In 2016, Tot-P was analysed at NMBU, while in 2017 Tot-P was analysed at INHM, but with large analytical challenges. In both 2018 and 2019 with more comparable data (2.0-4.0 µg L^{-1}), the Tot-P analyses were performed at INHM, using new sampling bottles. Large challenges are expected with Tot-P analyses in lakes with very low Tot-P values (< 5.0 µg L^{-1}), which are normally present in Lake Fyresvatn.

The Chl-a concentrations varied from 0.26 µg L^{-1} in August 2016 at station far north to 1.42 µg L^{-1} in August 2016 at station far south. Both 2016 and 2018 exhibited the highest Chl-a TWMC in the south, while 2017 and 2019 had their highest Chl-a TWMC in the north.

Overall, 2018 had the highest Chl-a average concentrations (0.89 µg L^{-1}), followed by 2016 (0.82 µg L^{-1}), 2019 (0.66 µg L^{-1}) and 2017 (0.65 µg L^{-1}).

Table 3.18: Time-weighted mean concentrations (TWMC), average, standard deviations (St.dev), median, maximum and minimum values for sight depth (m), Chl-a (µg L^{-1}), Tot-N (µg L^{-1}) and Tot-P (µg L^{-1}) from the site far North and far South in Lake Fyresvatn from 2016 to 2019.

	Fyresvatn North				**Fyresvatn South**			
	2016	**2017**	**2018**	**2019**	**2016**	**2017**	**2018**	**2019**
	Sight depth m	Sight depth m	Sight depth m	Sight depth m	Sight depth m	Sight depth m	Sight depth m	Sight depth m
TWMC:	6.9	5.8	7.0	6.4	7.3	7.4	7.3	7.1
Average:	6.9	5.7	7.0	6.6	7.1	7.3	7.4	7.3
Stdev:	0.4	0.4	0.0	0.8	0.9	0.5	0.5	0.9
Median:	7.0	6.0	7.0	6.3	7.0	7.0	7.3	7.5
Max:	7.5	6.0	7.0	7.5	8.5	8.0	8.0	8.2
Min:	6.5	5.0	7.0	5.5	6.0	6.9	7.0	6.1
	Chl-a µg L^{-1}	Chl-a µg L^{-1}	Chl-a µg L^{-1}	Chl-a µg L^{-1}	Chl-a µg L^{-1}	Chl-a µg L^{-1}	Chl-a µg L^{-1}	Chl-a µg L^{-1}
TWMC:	0.60	0.65	0.74	0.66	0.82	0.60	0.89	0.57
Average:	0.58	0.63	0.69	0.60	0.82	0.59	0.81	0.57
Stdev:	0.24	0.16	0.19	0.29	0.36	0.18	0.39	0.09
Median:	0.54	0.68	0.68	0.70	0.71	0.64	0.73	0.59
Max:	0.85	0.76	0.90	0.80	1.42	0.73	1.33	0.65
Min:	0.26	0.34	0.51	0.09	0.45	0.28	0.45	0.43
	Tot-N µg L^{-1}	Tot-N µg L^{-1}	Tot-N µg L^{-1}	Tot-N µg L^{-1}	Tot-N µg L^{-1}	Tot-N µg L^{-1}	Tot-N µg L^{-1}	Tot-N µg L^{-1}
TWMC:	305	342	257	151	297	285	253	142
Average:	299	341	258	151	304	288	249	145
Stdev:	55	64	19	26	39	36	30	29
Median:	296	360	261	135	299	302	261	143
Max:	380	410	274	186	343	331	270	175
Min:	247	268	234	130	246	243	205	100
	Tot-P µg L^{-1}	Tot-P µg L^{-1}	Tot-P µg L^{-1}	Tot-P µg L^{-1}	Tot-P µg L^{-1}	Tot-P µg L^{-1}	Tot-P µg L^{-1}	Tot-P µg L^{-1}
TWMC:	0.64	16.40	2.45	2.14	0.58	5.20	1.92	4.31
Average:	0.70	15.54	2.58	2.28	0.60	5.00	1.89	3.97
Stdev:	0.21	12.45	1.10	0.66	0.14	3.00	0.84	2.34
Median:	0.70	12.59	2.32	2.10	0.50	4.00	1.85	3.01
Max:	1.00	35.10	4.13	3.41	0.80	10.30	2.93	7.44
Min:	0.50	5.01	1.55	1.74	0.50	2.80	0.93	1.73

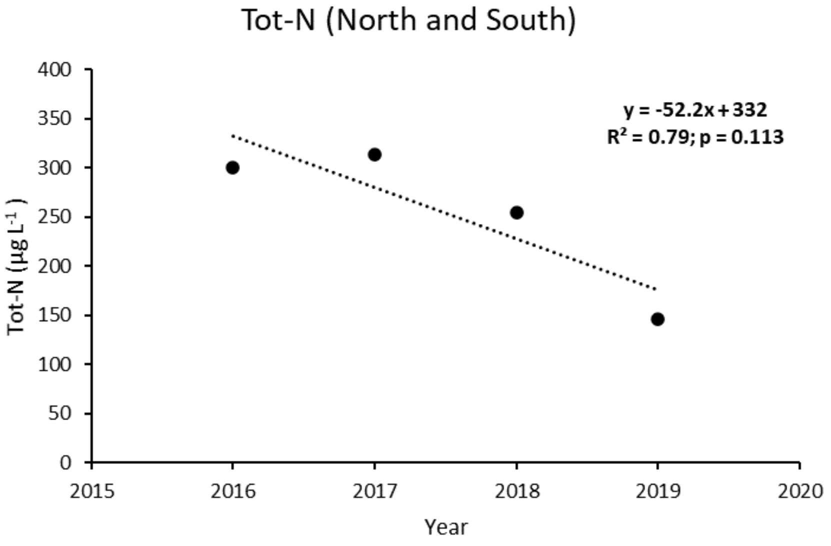


Figure 3.6: Tot-N regression from 2016-2019, with TWMC from North and South.

3.3.1 EQR estimation between the years 2016, 2017, 2018 and 2019

Ecological quality reference (EQR) values are calculated using time-weighted means (TWM) for sight depth, Tot-P, Tot-N and Chl-a for the years 2016, 2017, 2018 and 2019 (**Table 3.18**) using Equations presented in **Table 2.5** and **Equation 2.** Overall, the EQR estimations show moderate to very good to good conditions.

Table 3.19: EQR and nEQR values of sight depth, Tot-P, Tot-N and Chl-a based on time-weighted mean concentrations from epilimnion (mixed samples of 0-12 m) at the sampling sites far north and far south in Lake Fyresvatn from 2016 to . Blue = Very good condition; Green = good condition; Yellow = moderate condition.

2016 - 2019		**Eutrophication**													
Lake type Year	202d Site	Secchi depth m	EQR Sight depth	nEQR Sight depth	Tot-P µg L^{-1}	EQR Tot-P	nEQR Tot-P	Tot-N µg L^{-1}	EQR Tot-N	nEQR Tot-N	Chl-a µg L^{-1}	EQR Chl-a	nEQR Chl.a	Site x̄nEQR	x̄nEQR
2016	North	6.9	1.10	**1.000**	0.64	4.69	**1.000**	305	0.49	**0.713**	0.60	2.17	**1.000**	**0.928**	**0.91**
2017	North	5.8	0.92	**0.735**	16.4	0.18	**0.405**	342	0.44	**0.671**	0.65	2.00	**1.000**	**0.703**	
2018	North	7	1.11	**1.000**	2.45	1.22	**1.000**	257	0.58	**0.787**	0.74	1.76	**1.000**	**0.947**	
2019	North	6.4	1.02	**1.000**	2.14	1.40	**1.000**	151	0.99	**0.996**	0.66	1.97	**1.000**	**0.999**	
2016	South	7.3	1.16	**1.000**	0.58	5.17	**1.000**	297	0.51	**0.724**	0.82	1.59	**1.000**	**0.931**	
2017	South	7.4	1.17	**1.000**	5.2	0.58	**0.785**	285	0.53	**0.741**	0.60	2.17	**1.000**	**0.881**	
2018	South	7.3	1.16	**1.000**	1.92	1.56	**1.000**	253	0.59	**0.794**	0.89	1.46	**1.000**	**0.949**	
2019	South	7.1	1.13	**1.000**	4.31	0.70	**0.848**	145	1.03	**1.000**	0.57	2.26	**1.000**	**0.962**	

3.3.2 EQR estimation between 2018 and 2019

Ecological quality reference (EQR) values are calculated using time-weighted means (TWM) for sight depth, Tot-P, Tot-N and Chl-a for 2018 and 2019 (**Annex 5** and **7**) using Equations presented in **Table 2.5** and **Equation 2**. The comparison only represents the 6 stations close to the fish farm (N-1000, N-100, N-10, S-10, S-100, S-1000). Overall, the EQR estimations show Good to Very good conditions.

Table 3.20: EQR and nEQR values of sight depth, Tot-P, Tot-N and Chl-a based on time-weighted means from mix samples 0-6 m at Sampling sites N-1000, N-100, N-10, S-10, S-100 and S-1000 from year 2018 and 2019. Blue = very good and green = good.

2018 - 2019								**Eutrophication**							
Lake Type	202d	Secchi depth	EQR	nEQR	Tot-P	EQR	nEQR	Tot-N	EQR	nEQR	Chl-a	EQR	nEQR	Site	
Year	Site	m	Sight depth	Sight depth	µg L^{-1}	Tot-P	Tot-P	µg L^{-1}	Tot-N	Tot-N	µg L^{-1}	Chl-a	Chl.a	x̄nEQR	x̄nEQR
2018	N-1000	8.1	1.29	**1.000**	4.03	0.74	**0.872**	241	0.62	**0.810**	0.73	1.78	**1.000**	**0.921**	**0.96**
2019	N-1000	6.2	0.98	**0.929**	3.26	0.92	**0.960**	134	1.12	**1.000**	0.81	1.61	**1.000**	**0.972**	
2018	N-100	8.1	1.29	**1.000**	3.86	0.78	**0.889**	251	0.60	**0.798**	0.83	1.57	**1.000**	**0.922**	
2019	N-100	6.7	1.06	**1.000**	2.12	1.42	**1.000**	141	1.07	**1.000**	0.84	1.54	**1.000**	**1.000**	
2018	N-10	7.5	1.19	**1.000**	3.41	0.88	**0.940**	258	0.58	**0.790**	0.74	1.76	**1.000**	**0.921**	
2019	N-10	6.6	1.05	**1.000**	5.18	0.58	**0.786**	141	1.06	**1.000**	0.77	1.70	**1.000**	**0.972**	
2018	S-10	7.7	1.22	**1.000**	3.16	0.95	**0.975**	267	0.56	**0.770**	0.72	1.81	**1.000**	**0.936**	
2019	S-10	6.8	1.08	**1.000**	2.13	1.41	**1.000**	126	1.20	**1.000**	0.80	1.64	**1.000**	**1.000**	
2018	S-100	7.8	1.24	**1.000**	3.83	0.78	**0.892**	252	0.60	**0.796**	0.77	1.69	**1.000**	**0.922**	
2019	S-100	6.6	1.04	**1.000**	2.79	1.08	**1.000**	132	1.14	**1.000**	0.79	1.64	**1.000**	**1.000**	
2018	S-1000	8.3	1.32	**1.000**	3.35	0.90	**0.948**	254	0.59	**0.790**	0.88	1.48	**1.000**	**0.934**	
2019	S-1000	6.7	1.06	**1.000**	2.17	1.38	**1.000**	162	0.93	**0.964**	0.81	1.60	**1.000**	**0.991**	

3.3.2.1 Earlier results, before the fish farm was established

EQR calculations Tot-P and Tot-N from 1982, 1993, 1994, 1996 and 1997 (**Table 3.21**) rely on various sampling sites, mostly taken from different sites in the mid area and northern area of Lake Fyresvatn, and with varying number of sampling per year. These EQR calculation were made in order to compare and post fish farm conditions in Lake Fyresvatn. Overall, the pre fish farm conditions in Lake Fyresvatn based on EQR estimates were Very good to Good. **Figure 3.7** shows SO_4^{2-}, Ca^{2+} and pH concentrations from 1978 – 2019.

Table 3.21: Variations in EQR and nEQR values of Tot-P and Tot-N from different sampling sites in Lake Fyresvatn during the pre fish farm period, i.e. from 1982 to 1997 (Resa database NIVA, **Annex 8**). Blue = Very good; Green = Good.

1982 - 1997						Tot-P and Tot-N					
Lake Type	202d	Location		Tot-p	EQR	nEQR	Tot-N	EQR	nEQR	Site	
Source	Year	North	East	µg L-1	Tot-P	Tot-P	µg L-1	Tot-N	Tot-N	x̄nEQR	x̄nEQR
NIVA	1982	6551000	451500	2.67	1.13	1.00	323	0.46	0.69	0.85	0.90
NIVA	1993	6555199	447900	2.35	1.28	1.00	243	0.62	0.89	0.94	
NIVA	1994	6555199	447955	2.87	1.05	1.00	260	0.58	0.78	0.89	
NIVA	1996	6555199	447900	1.50	2.00	1.00	254	0.59	0.79	0.90	
NIVA	1997	6555199	447900	1.00	3.00	1.00	248	0.60	0.82	0.91	

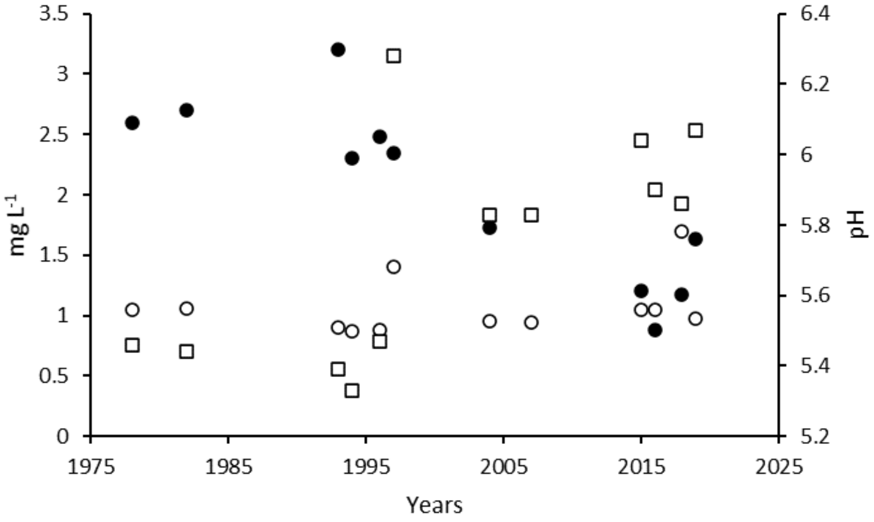


Figure 3.7: Concentrations of SO_4^{2-} (●), Ca^{2+} (○) and pH (□) in Lake Fyresvatn from 1978 – 2019. Table data can be found in **Annex 7** and **8** (Resa database NIVA; Lydersen et al. 2017, Angelovičová 2018).

3.4 Bottom Fauna and sediment description

All bottom fauna results for Fyresvatn 2019 are enclosed in **Annex 10**. Assembled data is presented in **Table 3.22** while densities (ind. m^2) along the four transects from the fish farm are visualised in **Figure 3.8**.

The highest density of Oligochaeta was found at station 7 (North-West transect at 0 m) were the average density (3 parallel samples) was 2279 per m^2. The lowest density of Oligochaeta was at station 10 (North-east transect at 0 m distance) were the average density (5 parallel samples) was 8 per m^2. Station 7 stands out from the other three transects at 0 m distance. Without station 7 included, the lowest densities of Oligochaeta was at 0 m from the fish farms net pen (59 ind. m^2), followed by the highest concentrations at 10 m distance (2033 ind. m^2) and then lower at 30 m distance (297 ind. m^2). With station 7 included, the density is highest at 0 m distance (2338 per m^2) and decreases outwards.

The highest density of Chironomidae was found at station 12 (North-east transect at 30 m distance) were the average density (5 parallel samples) was 67 ind. m^2. The lowest density of Chironomidae was found at stations 1, 7, 10 (all 0 m distance) and station 5 (10 m distance) with 0 ind. m^2. At station 4 (South-east transect at 0 m distance) we found 8 Chironomidae ind. m^2, this stands out from the other three stations at 0 m distance, were the density was 0 ind. m^2. On average, the density of Chironomidae increases with the distance from the fish farm.

Table 3.22: Bottom fauna stations, station depths, distance from the fish farms, density (ind. m^{-2}) of bottom fauna organisms (Oligochaeta and Chironomidae) and Arctic charr roe from the investigation in Lake Fyresvatn in 2019.

Station	Depth m	Dist. Net pen m	Oligochaeta Imago ind. m^2	Chironomidae Larvae ind. m^2	Arctic Char roe ind. m^2
1	45	0	17	0	329
2	46	10	307	17	0
3	52	30	30	59	0
4	46	0	34	8	160
5	48	10	107	0	8
6	54	30	25	42	0
7	46	0	2279	0	295
8	42	10	584	17	0
9	38	30	59	59	0
10	46	0	8	0	810
11	43	10	1036	14	0
12	38	30	183	67	0
1, 4, 7, 10	46	0	2338	8	1594
2, 5, 8, 11	45	10	2033	48	8
3, 6, 9, 12	46	30	297	228	0

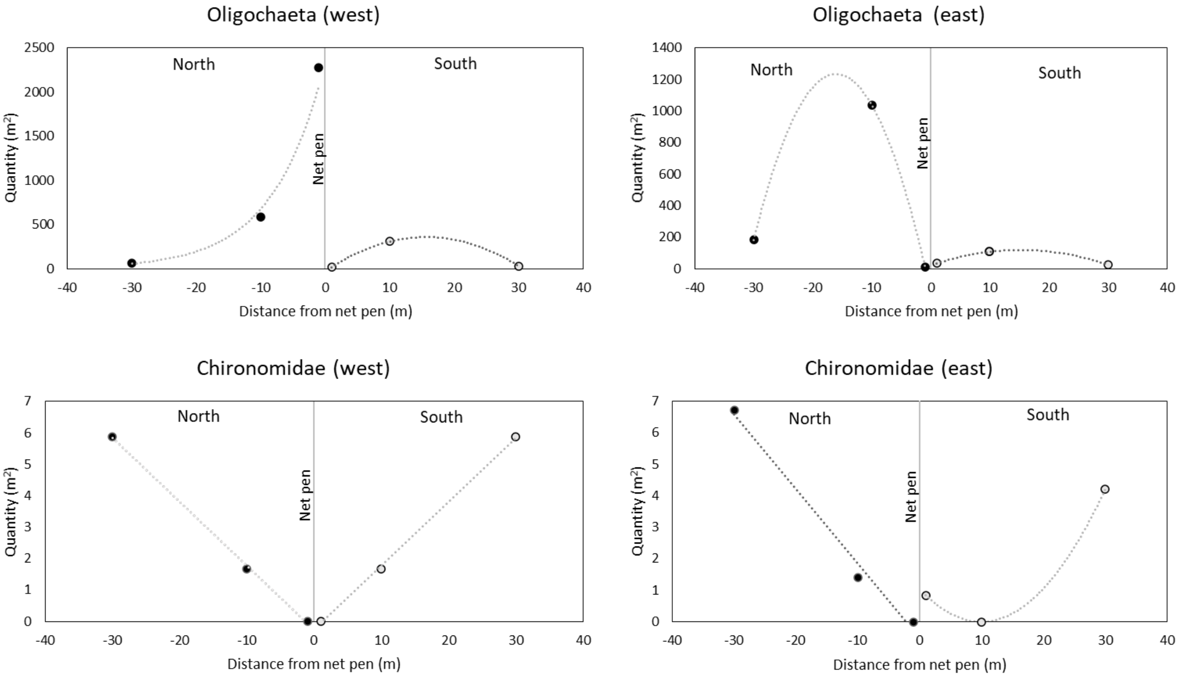


Figure 3.8: Density (ind. m^2) of Oligochaeta and Chironomidae at two north facing transects (one east and one west on the fish farm) and two south facing transects (one east and one west on the fish farm). Along the transects samples are withdrawn at a distance of 0 m, 10 and 30 m from the edge of the fish farm pens. South-west includes stations 1, 2 and 3; North-west includes stations 7, 8 and 9; South-east includes stations 4, 5 and 6; North-east includes station 10, 11 and 12 (Note different Y axis values on Oligochaeta).

Sediment description

Sediments take 0 m from the fish farm pens consisted of sludge with some sand and gravel. After sieving the sediments, the retained material contained slime, a lot of dead Arctic charr roe and food pellets. All samples smelled of sewage. South-east transect at 0m (station 4) had no food pellets, less sewage smell and the only site where Chironomidae individuals were found at the 4 stations located 0 m from the pens. North-west transect at 0 m (station 7) had a more varied sediment with more sand and was where we found the highest density of Oligochaeta. North-east transect at 0 m (station 10) had the most sewage smell out of all of them, with a lot of food pellets, dead arctic char roe and least benthos found.

Sediments 10 m from the fish farms net pen consisted mainly of sand and gravel, with some oxidized iron (Fe^{3+}). We found no food pellets, but at station 5 we found some arctic char roe. There was no sewage smell from the sediments at these distances and was here we found the most benthos at three out of the four transects i.e. 10 m distance.

Sediments 30 m from the fish farms net pen consisted of sand, gravel and rocks, with a lot of oxidized iron (Fe^{3+}). We found no food pellets or arctic char roe, and there was no sewage smell.

4 Discussion

All lakes are supplied with nutrients from natural runoff, and many lakes are affected by additional nutrient runoff from sewage and agriculture (Holtan & Åstebø, 1990). The effect of extra nutrients will vary greatly from lake to lake, but in most cases the lake will become more nutritious (Rognerud 1979, Berge 1987, Johnsen et al. 2019). With the extra impact from the fish farm makes Lake Fyresvatn an interesting lake to investigate, where one knows little of the impact with regards to the fish farm, and when including the water regulations.

Like most lakes in Norway, Lake Fyresvatn is a deep and naturally nutrient poor lake, and when affected by regulated waters upstream, maybe even more nutrient poor. These water regulations might cause changes to the residence time (T_w), compared to what natural T_w would be in these waters. This can result in higher P-retention and that less phosphorus (P) runs in to Fyresvatn. These regulations do not just affect the nutrients and T_w but also the variation in the lakes upper water layers (Epilimnion) especially in summertime, with regards to water temperature and the lakes stratification (Kirillin & Shatwell 2016). Water from the magazine is drained from the depths, which is colder than surface water. The impact can result in colder surface water in Lake Fyresvatn compared to what the natural temperature would be (Lydersen et al., 2017). The colder water can have a positive "impact" with regards to the production of Arctic Charr, which is stenothermal and thrives in colder temperatures, preferably $< 12°C$ (Sæther et al. 2016, Olk et al. 2019). Studies have shown that Arctic Char egg fertilisation in colder water temperatures (2-8 °C) have a higher survival rate, compared to eggs fertilised in higher temperatures (Krieger & Olson 1988, Atse et al. 2002).

During our survey period (May - September) the surface water temperature in Lake Fyresvatn was not higher than 15.8°C, which is similar to temperatures measured from previous surveys, with exception of 2018, which had an abnormally hot summer (Lydersen et al. 2017, Angelovičová 2018). Summer stagnation usually occurs in June in Lake Fyresvatn, while in 2019, summer stagnation was not observed until July. Lake autumn turn-over normally occurs once during October (Lydersen et al. 2017). Our sampling period ended in September, were the thermocline was deepening and far less distinct, which can indicate a transition to the autumn turn-over (**Figure 3.3**).

The low water colour and turbidity both categorizes the lake as clear (Direktoratsgruppen, 2018), which corresponds with the long sight depth, as well as a long photosynthetic depth (Dodds & Whiles 2010), typically found in oligotrophic lakes. Since we did not have the opportunity to measure TOC (total organic carbon), water colour can be used to estimate an approximate humus content. The highest water colour average was 18.3 mg Pt L^{-1}, which corresponds to the lake having a low humus content (TOC 2-5 mg L^{-1}), (Direktoratsgruppen, 2018). The monthly increase of water colour might due to increased Chl-a (**Figure 3.2**), (Carvalho et al. 2009). Rognerud et al. (1979) established a strong relationship between sight depth and Chl-a, for deep and clear lakes in Norway. The correlation shows an inverse relationship, were increased Chl-a concentrations is usually accompanied by decreased sight depth. But as the nutrient concentrations in 2019 were low, did this result in a low algal bloom (Chl-a) during the summer months, which also matches the long sight depth.

In oligotrophic lakes phosphorus (P) is usually the best predictor for algal growth, with P:N ratios > 1:12. As P is in a shorter supply than nitrogen (N) for algae growth. Tot-P and Chl-a also have well established empirical positive relationships, which are widely used (Dillion & Rigler 1974, Rognerud et al. 1979, Prairie et al. 1989).

The results from 2019 had a P:N ratio > 1:12, where both Tot-P and Tot-N concentrations were generally low. Tot-N was relatively stable throughout the whole lake, while Tot-P was higher north from the fish farm. The combined water quality (EQR) in Lake Fyresvatn 2019 was characterized as Very good (**Table 3.14**). The only outlier was the higher Tot-P concentrations at station N-10, where the concentration was characterized as Good. This might imply that this station is more affected by the fish farm compared to the others. Statistically, this was not shown to be significantly higher compared to the other stations but did however have an impact on the EQR calculations. Based on the empirical relationships between Tot-P and Chl-a, one could expect higher Chl-a concentrations at station N-10, this was not the case. The Chl-a was lower at station N-10 compared to several other stations with lower measured Tot-P. Although, there are uncertainties associated with Tot-P measurements in lakes where concentrations are very low i.e. accuracy (Lydersen et al. 2019). Another important factor regarding P, is how much of the P is bioavailable (dissolved phosphate), were the dissolved P can be utilized by the algae directly and varies between different supply sources. From fish farms it is estimated to be 30-40 %, from wastewater up to 65-70 % and agriculture 30 % (Braaten et al. 1992).

Chl-a was as expected, highest during the warmer months (June-September), (Caravalho et al. 2009). Although, measured Chl-a in July had a decrease in epilimnion (0-6 m). The YSI Chl-a depth profile shows lower Chl-a concentrations in the first 3 m, and higher at 4-10 m depth. Regarding our mix samples (0-6 m), the first 3 m may have diluted the higher concentrations 4-6 m depth (**Figure 3.3**). The conditions (EQR) for the four biological quality elements (**Table 3.15**). Chl-a, biovolume (algae volume) and cyanobacteria results were characterized as Very good, but due to high PTI scores, the summarized nEQR was lowered to Good, because of "one-out-all-out-principle" (Direktoratsgruppen, 2018). The worst PTI score was calculated at station N-10, were the highest concentrations of Tot-P was observed. Phytoplankton taxa can be a very useful indicator for environmental conditions and can give a suggestive clue to the water quality (Brettum 1989, Carvalho et. Al. 2008). The PTI is a biological quality element used as an indicator for eutrophication, were in this case the PTI does not correspond with the measured nutrient concentrations (Tot-P and Tot-N) in Lake Fyresvatn 2019.

4.1 Compared with previous years

Based on EQR calculations from earlier years (**Table 3.19**), the parameters that have had any significant effect or change on the lakes condition is Tot-P and Tot-N. The Tot-N concentrations in 2019 have reduced by almost half of the Tot-N concentrations from previous years (2016, 2017 and 2018). Rådgivende Biologer AS, did their own field survey in September (2019) in Lake Fyresvatn, that confirmed the low Tot-N concentrations, with a control sample (Johnsen et al., 2019). This decrease has changed the condition for Tot-N from good to very good condition in 2019. Tot-P concentrations were significantly higher in 2017, where conditions were characterized as Good and Moderate. There is a chance that these samples might have been contaminated, as its unlikely that the concentrations were this high, and we would expect to see an increase in Chl-a values, which was not the case. All other years the Tot-P has been much lower and characterized to Very good conditions. Both sight depth and Chl-a has been stable between the years with no changes in condition and have continuously been characterized to very good conditions.

Comparing stations close to the fish farm 2018-2019 (**Table 3.20**), Tot-N shows the same decrease in concentration, and all sampling sites have gone from good to Very good, with exception of station N-1000 in 2018 which already had a Very good condition. Regarding Tot-P, only station N-10 has gone from Very good to Good condition 2019.

Previous data of Tot-P and Tot-N, from years (1982, 1993, 1994, 1996 and 1997) before the fish farm was established, showed an overall Very good condition in Lake Fyresvatn. There have been minor changes in Tot-P, with a small increase in 2019 since those years. Tot-N has decreased since then (**Table 3.22**). Even though these samples have been taken at varied sampling sites and dates, Lake Fyresvatn is a large lake and is wind exposed. The dominating wind directions go along the length of the lake (**Table 3.1**), which can suggest that the surface water is well circulated and that the physical, chemical and biological parameters are similar from north to south, especially above the thermocline (Meromictic),(Kleiven 2017, Bengtsson 1978). Which Johnsen et al. (2019) also mentioned in their report.

But, as the production in the fish farm has increased significantly the last two years, and the residence time (T_w) in lakes Fyresvatn is ≈ 8 years, implies a long response time, and we might not see the effects before ≈ 8 years. The estimated retention time related to phosphorus, withholds 74 % of all the P emitted into Lake Fyresvatn (**Figure 3.4**), were most of the P is permanently stored in sediment (Søndergaard 2007, Lydersen 2017). However, the sediment is an integral part of the lake system and serves as a buffer against changes in external P supply (Molversmyr & Andersen 2006). P can be released from sediment under reduced conditions (low Eh). Complexes P bindings (e.g. iron phosphate hydroxide) dissolve ($Fe^3 \rightarrow Fe^2$). Phosphate that has dissolved under reduced conditions in hypolimnion, can come up to the surface during circulation periods, spring and fall (Skiple & Bratli 1997). Although, there is no signs of being reduced conditions on the lakebed in Lake Fyresvatn. The concentrations of SO_4^{2-} and NO_3^- (oxidized states) were higher in hypolimnion compared to epilimnion. Bottom water O_2 conditions were relatively good (**Annex 12**), together with the presence of Oxidized iron (Fe^{3+}) suggests good conditions near the lakebed. O_2 is one of the primary determinants of redox (Eh), and the presence of O_2 tells us that the Eh is high and indicates an oxidizing environment (Walter & Dodds 2010).

4.2 Acidification

The ion composition in the Lake Fyresvatn (2019) resulted in a low acid neutralization capacity (ANC) and again the low pH. The overall acidification EQR calculation in lake Fyresvatn was assessed as Moderate and is mainly due to the low ANC that varied from Bad to Very bad, while all pH measurements were assessed as Good (**Table 3.16**). It is apparent that Fyresvatn receives much of its ions from atmospheric input, besides P and calcium (Ca^{2+}). The geology in the aera mainly consists of acidic and low weatherable bedrock such as diuretic to granitic gneiss that offer a low buffer capacity (Jansen 1986, Klempe 1992, Johnsen et al. 2019).

Earlier Fyresvatn was heavily affected by acid rain, mainly from anthropogenic SO_2-gas in from of sulfuric acid (H_2SO_4), (Myhre 2015, Lydersen et al. 2017). Data from back to 1978 (**Figure 3.7**) show that the SO_4^{2-} concentrations were highest in 1993 and has since then decreased significantly (Hindar & Larssen 2004). The lowest concentration measured since then was in 2016, with a 73 % decrease of SO_4^{2-}. In 2019, the SO_4^{2-} concentrations have increased from 2016, but still a 49 % decrease from 1993. Even though SO_4^{2-} has increased 2019, the pH seems to be stable. The Ca^{2+} has changed marginally over the same time period and had its peak in 1997 during the liming projects. Today the effect of the liming in the water has almost disappeared and is considered to be close to not limed (Høgberget et al. 2018). The acidification level in Lake Fyresvatn in 2019, does not seem to have any effect on the biology, including the fish.

4.3 Bottom fauna

The fish farm (Telemarkrøye AS) has produced ≈250-ton fish in total since established in 2014. The last two years (2018 and 2019) the fish farm has produced ≈ 80 tons annually (**Annex 11**). The discharge of nutrients in the upper layers (epilimnion) can affect the phytoplankton, where photosynthesis takes place. Although, most of the discharge from the fish farm is released under the thermocline and the photic zone, where particulate nutrients sink to the lakebed and accumulate (Olsen et al. 2008). Bottom fauna was investigated to assess direct local impact from the fish farms activity. In general, the environmental impact on the lakebed is greatest directly, and in the near vicinity of the fish farm, normally confined within 1 km.

The effect, however, depends on location, locality conditions, water flow and production density, as higher productions accumulate more organic material to the sediment. The concerning impact is the development of anoxic sediments, reduced conditions (low Eh) and toxic gasses that can decrease the benthic diversity. This happens when the bottom fauna is fed with more organic material than what they are capable to consume, and the organic material accumulates. The oxygen demand in these enriched sediments can be five to ten times higher than non-enriched sediments (Wu 1995).

The two most common bottom fauna organisms found belongs to the family Chironomidae and the subclass Oligochaeta, the latter primarily within the genus *Tubifex*. Of the two predominant bottom fauna groups, the Chironomidae individuals are generally far more sensitive to high loads of organic matter and nutrients compared with Oligochaeta (Lydersen, pers. Com.). Accordingly, increasing numbers of Chironomidae individuals were found by increasing distance from the fish farm, the opposite gradient was revealed for Oligochaeta (Figure 3.8). On average Oligochaeta was highest at 0 m distance, due to 1 transect, which was significantly higher compared to the other 3, at 0 m distance from the net pen (Table 3.22). In general, the densities were higher at 10 m distance. The fact that the densities of Oligochaeta varied, may be related to the position of the fish farm, and that this changes due to weather (wind) and water flow.

In the Sediments 0 m from the fish farms net pen mainly consisted of sludge and dissolved food pellets, with a strong sewage smell. Where a lot of dead Arctic charr was also observed.
At 10 m from the net pen, the impact from the fish farm was reduced significantly, we found Arctic charr Roe at one station but no food pellets. At 30 m distance, the impact on bottom fauna seemed to be minimal, and there were no signs from the fish farm at all, and that 30 m distance results might indicate natural bottom fauna in the lake.
Compared to survey done in 2017 (Lydersen et al. 2017), who did one transect north and one south, the densities were similar for both Oligochaeta and Chironomidae. Only difference is that we did not find any sign of caddisfly larva (*Trichoptera*) or their houses in 2019, which Lydersen et al. (2017) found in their survey.

The fact that the lowest density in general was at 0 m from the fish farm might indicate suboptimal conditions, even for the low oxygen adapted and pollutant tolerant Oligochaeta (Fischer & Beeton 1975). At 10 m distance where the highest densities were found, might suggest non-fatal conditions i.e. low Eh or toxic environments (high values of H_2S or butyric acid) in the sediment, even though this was not analysed.

5 Conclusion

Overall, there is so far minor indications of fish farm effects on the water chemistry and Chl-a in Lake Fyresvatn, despite the production volume has increased significantly the last two years. Though these production volumes are not high, considering the size of the lake. The discharge and concentrations levels of nutrient (phosphorus and nitrogen) do not increase the algae growth (Chl-a, phytoplankton and cyanobacteria) to critical levels or suggest signs of eutrophication. The condition characterization of Tot-P, Tot-N and Chl-a shows that the conditions in the lake are Very good. However, as the lake residence time is ≈ 8 years, it takes time to document the whole lake effects of current production volume. Most of the discharge from the fish farm is released under the thermocline and the photic zone, were particulate nutrients sink to the lakebed. There were some indicators that the bottom fauna was affected by the accumulation of nutrient and organic matter discharged from the fish farm, even for the low oxygen adapted Tubifex. The less tolerant of the two species (Chironomidae) observed was found at increasing density further away from the fish farm. The more tolerant species (Oligochaeta) was observed in higher densities close to, with decreasing density away from the fish farm. Accordingly, further monitoring is needed.

References

Akvakulturloven (2013), § 11. *Miljøovervåking, Lov om akvakultur,* LOV-2005-06-17-79.

Angelovičová M. (2018). *Local, seasonal variations in chlorophyll-a and water chemistry close to an open pen fish farm in Lake Fyresvatn 2018*. Unpublished, Master thesis, USN, Bø. 54 pages.

Atse C. B., Audent C., de la Noüe J. (2002). *Effects of temperature and salinity on the reproductive success of Arctic charr, Salvelinus alpinus (L.): egg composition, milt characteristics and fry survival*. Aquaculture Research 33: 299–309. ISSN: 1355-557X; E-ISSN: 1365-2109.

Braaten B., Johnsen T., Källqvist T., Pedersen A. (1992). *Biologisk tilgjengelighet av næringssalttilførsler til det marine miljø fra fiskeoppdrett, landbruksavrenning og kommunalt avløpsvann*. NIVA-rapport nr. 2877, 160 pages, ISBN 82-577-2191-3.

Bengsston L. (1978). *Wind induced circulation in Lakes*. Hydrology Research volum 9, issue 2: Nordic Hydrology, pp.75-94. DOI: 10.2166/nh.1978.0007

Berge D. (1987). *Fosforbelastning og respons i grunne og middels grunne innsjøer. Hvordan man bestemmer akseptabelt trofinivå og akseptabel fosforbelastning i sjøer med middeldyp 1,5-15m*. Norsk institutt for vannforskning, NIVA-rapport 0-85110, nr 2001. 44 pages.

Borgstrøm R. (1976). *Skjønn Nisse rog Fyresvatn ovenforliggende reguleringers virkning på fisket i Nisser, Borstadvatn og Fyresvatn/Drang. Fra laboratorium for ferskvannøkologi og innlandsfiske*. Zoologisk Museum, Universitetet i Oslo, Rapport 27. 55 pages.

Bostock J., Brendan McAndrew B., Randolph Richards R., Kim Jauncey K., Trevor Telfer T., Lorenzen K., David Little D., Lindsay Ross L., Handisyde N., Iain Gatward L., Corner R. (2010). *Aquaculture: global status and trends*. Part of Philosophical Transactions of the Royal Society B. ISSN: 0962-8436, E-ISSN: 1471-2970, DOI: 10.1098/rstb.2010.0170.

Brettum P. (1989). *Alger som indikator på vannkvalitet: planteplankton*. NIVA-rapport nr. 2344, 111 pages. ISBN: 82-577-1627-8.

Carvalho L., Solimini A., Phillips G., Berg M., Pietiläinen O-P., Lyche S. A., Poikane S., Mischkle U. (2008). *Chlorophyll reference conditions for European lake types used for intercalibration of ecological status*. Aquatic ecology Vol.42, page. 203-2011. SSN: 1386-2588; E-ISSN: 1573-5125. DOI: 10.1007/s10452-008-9189-4.

Carvalho L., Solimini A., Phillips G., Pietiläinen O-P., Moe J., Cardoso A., Lyche S. A., Ott I., Søndergaard M., Tartari G. and Rekolainen S. (2009). *Site-specific chlorophyll reference conditions for lakes in Northern and Western Europe*. Hydrobiologia, 2009, Vol.633(1), pp.59-66.

Colby P. J., Spangler G. R., Hurley D. A., McCombie A. M. (1972). *Effects of eutrophication on salmonid communities in oligotrophic lakes*. Journal of the Fisheries Research Board of Canada 29, 975-983.

Dillion P. J. & Rigler F. H. (1974). *The phosphorus-chlorophyll relationship in lakes*. Association for the sciences of Limnology and Oceanography (ASLO)/ Volume 19, issue 5. Page: 767-773. DOI: 10.4319/lo.1974.19.5.0767.

Direktoratsgruppen (2018). *Vanndirektivet, Klassifisering av miljøtilstand i vann, Økologisk og kjemisk klassifisering for kystvann, grunnvann, innsjøer og elver*. Veileder 2:2018 – Revised February 2018.

Dodds W. K. and Whiles M. R. (2010). *Freshwater Ecology: Concepts and Environmental Applications of Limnology - 2nd edition*. Chapter 3, pp.52-61. Elsevier Science & Technology. E-ISBN: 9781282878495.

Eklima. *Vær- og klimadata fra historiske data til sanntisobservasjoner*. Metrologisk institutt, data base. Sited and downloaded data from URL: http://sharki.oslo.dnmi.no/portal/page?_pageid=73,39035,73_39049&_dad=portal&_schema=PORTAL

Fauske M. (2019). *Statistikk for akvakultur 2018, Foreløpige tall pr. Mai 2019*. Rapport Fiskeridirektoratet, 46 pages. Arkivnummer: 19/138.

Fischer J. & Beeton A. (1975). *The effect of dissolved oxygen on the burrowing behavior of Limnodrilus hoffmeisteri (Oligochaeta)*. Hydrobiologia, 1975, Vol.47(2), pp.273-290

Fiskeridirektorate*t (2018). Statistikk for akvakultur 2017, Foreløpige tall pr. Mai 2018*. Rapport Fiskeridirektoratet, 49 pages.

Fiskeridirektoratet (2012). *Informasjon om akvakulturtillatelse; Telemarkrøye AS*, Tillatelsenr: TKF 003.

Hindar & Larssen (2004). *Forsuringsutvikling og behov for ytterligere kalking i Arendals-vassdraget*. Norsk institutt for vannforskning, Rapport LNR 4873-2004, page 10. ISBN: 82-577-4558-8; ISSN: 1894-7948.

Holtan H. & Åstebøl S. (1990). *Hånbok i innsamling av data om forurensningstilførseler til vassdrag og fjorder.* NIVA Jordforsk, 53 pages. ISBN: 82-577-1818-1.

Hongve D. & Kjensmo J. (2018), *Eutrofiering.* Store Norske Leksikon, Last update 20.02.18. Sited from URL: https://snl.no/eutrofiering [08.02.2020]

Høgberget R., Håvardstun J., Skancke L. B. (2019). Driftskontroll av kalkdoseringsanlegg i Arendalsvassdraget År 2018. NIVA rapport: 7395-2019, 18 pages. ISBN 978-82-577-7130-0; ISSN 1894-7948.

Islam S. (2005). *Nitrogen and phosphorus budget in coastal and marine cage aquaculture and impacts of effluent loading on ecosystem: review and analysis towards model development*. Part of Marine Pollution Bulletine, Vol.50, Page 48-61. ISSN: 0025-326X; E-ISSN: 1879-3363. DOI: 10.1016/j.marpolbul.2004.08.008

Jansen I. J. (1986). *Kvartærgeologi: jord og landskap i Telemark gjennom 11000 år: beskrivelse til kvartærgeologisk kart i målestokk 1:250000*. Institutt for naturanalyse Bø, 87 pages. ISBN: 8273940039.

Johnsen G. H. (2016). *Dokumentasjonsgrunnlag for søknad om oppdrett av ørret og røye i Sirdalsvatn*. Rådgivende Biologer AS. Rapport 2285, 21 pages.

Johnsen G. H, Wathne I. and Lydersen E. (2019). *Overvåkning av Fyresvatnet for Telemarkrøye AS I 2019.* Rådgivende Biologer AS, Rapport 3001, 43 pages. ISBN: 978-82-8308-674-4.

Kelly L. (1993). *Release rates and biological availability of phosphorus released from sediments receiving aquaculture wastes*. Hydrobiologia, 1993, Vol.253, Page 367-372. Institute of Aquaculture, Scotland. E-ISSN: 1573-5117, DOI: 10.1007/BF00050762.

Kirillin G. and Shatwell T. (2016). *Generalized scaling of seasonal thermal stratification in lakes*. Part of Earth-Science Reviews Vol. 161, page 179-190. ISSN: 0012-8252; E-ISSN: 1872-6828.

Kleiven S. (2017). Ferskvannsøkologi - Vannets fysiske egenskaper, Kap 10 og 11., Teaching material from freshwater ecology subject at college in South-Eastern Norway (HSN), spring 2017.

Klempe H. (1992). Grunnvann og GiN-Kartlegging I Telemark. Vannforeningen: Vann-1C-92, page 220-228.

Krieger K. G and Olson R. N. (1988). *Some factors involved in gamete quality in Arctic charr (Salvelinus alpinus) broodstock of the Nanyuk Lake strain*. Proceedings of the Aquaculture International Congress, Vancouver. p 74.

Kålås J. A., Henriksen S., Skjelseth S., Viken Å. (2010). *Environmental conditions and impacts for red list species, Fresh water.* Artsdatabanken page. 97 – 106. ISBN: 978-82-92838-28-0.

Lydersen E. (2015). Kartlegging av kunnskap og kompetanse innen ferskvannsfisk og ferskvannsfiske i Telemark, Forstudie. HSN Bø, vannpotalen. 38 pages.

Lydersen E., Holtan M., Olk T. R., Aarnes T. A., Økelsrud A., Stabell T., (2017). *Limnologiske undersøkelser i Fyresvatn 2016/2017 med focus på Telemarkrøye AS sitt anlegg I Fyresvatn*. Høgskolen i sørøst-Norge, Bø. 30 pages. Unpublished.

Mhyre A. (2015). *Klima, energi og miljø*. Universitetsforlaget, Oslo. 2end edition. Cha. 11, Sur nedbør, page 237-248. ISBN: 9788215024127.

Molversmyr Å. & Andersen T. (2006). *Kartlegging og vurdering av interngjødsling I Frøylandsvatnet*. Iris-rapport: 2006/017. ISBN: 82-490-0429-9.

Mustafa S. & Shapawi R. (2015). Aquaculture ecosystems, adaptability and sustainability. John Wiley & Sons, Ltd, UK. Page 140-163. ISBN: 9781118778548

Norsk vannforening (2016). *Vanndirektivet og Fiskeoppdrett*. Volum 4, årgang 51. Page 355-357.

Norskeutslipp, *(2018). Fyresdal avløpsrenseanlegg utslipp 2014-2018; P-Tot, N-Tot, BOD5 and COD tons per year (TPY),* miljødirektoratet, Sited 20 from URL: https://www.norskeutslipp.no/no/Diverse/Virksomhet/?CompanyID=8894 [08.01.20]

NVE Atlas, search: "Fyresvatnet", vatnløpenummer 1274, vassdragsnummer 019.DB1, Dybdekart, berskrivelse, detaljer. Sited: from URL: https://atlas.nve.no/Html5Viewer/index.html?viewer=nveatlas# [08.01.20]

NVE (2019), *Utbygd vannkraft*, Vannkraftverk med eier (installert effekt større eller lik 1 MW). NVE, hydropower plant nr. 82 and nr. 1607, Kart.

NVE, personal communication in e-mail, from Eva klausen

Olk T. R., Thorarensen H. T, Jeuthe H., Wollebæk J., Lydersen E. (2019). *Brood-stock management and early hatchery rearing of Arctic charr (Salvelinus alpinus (Linnaeus)).* Norwegian open research archives (NORA). 29 pages. ISSN: 1753-5123; ISSN: 1753-5131; E-ISSN: 1753-5131.

Olsen L. M., Homer M. and Olsen Y. (2008). *Perspectives of nutrient emission from fish aquaculture in coastal waters: Literature review with evaluated state of knowledge*. The Fishery and Aquaculture Industry Research Fund, 68 pages. DOI: 10.13140/RG.2.1.1273.8006

Pedersen A. & Green N. (2013). *Vanndirektivet – Kystvann, Hvordan evaluere vannkvalitet.* Vannforeningen, Innlegg fra møter i forening. Vann 04 2013. Page. 543 - 550.

Prairie Y. T., Duarte C. M. and Klaff J. (1989). *Unifying Nutrient–Chlorophyll Relationships in Lakes*. Canadian Journal of Fisheries and Aquatic Sciences, 1989, 46(7): 1176-1182. DOI: /10.1139/f89-153

Reuss, J.O., and Johnson, D.W. (1986) Acid deposition and the acidification of soils and waters. Ecological Studies 59, Springer-Verlag, New York, 119 pages.

Rognerud S., Berge D. and Johannessen M. (1979). *Telemarksvassdraget Hovedrapport fra undersøkelsene I perioden 1975-1979*. NIVA-Rapport 0-70112, 82 pages. ISBN: 82-577-0202-1; ISSN: 1894-7948.

Skiple A. & Bratli J. L (1997). Overvåkning og tilstandsklassifisering av Borrevannet 1992-1996. Revidert tiltaksplan for 1997. Norsk institutt for vannforskning, NIVA-rapport;3803, 67 pages. ISBN: 82-577-3379-2.

Sæther B-S., Siikavuopio S., Jobling M. (2016). *Environmental conditions required for intensive farming of Arctic charr (Salvelinus alpinus (L.))*. Hydrobiologia 783: 347–359. SSN: 0018-8158; E-ISSN: 1573-5117.

Søndergaard, M. (2007). *Nutrient dynamics in lakes – with emphasis on phosphorus, sediment and lake restorations*. Doctoral dissertation, National Environmental Research Institute, University of Aarhus, 269 pages. ISBN: 978-87-7772-986-7, E-ISSN: 1600-0048.

Sørensen J., Brodtkorb E., Haug I., Fjellanger J., (2014). *Vannkraftkonsesjoner som kan revideres innen 2022 Nasjonal gjennomgang og forslag til prioritering*. NVE Rapport nr: 49/2013. Page. 49-51, 77-78.

Vann-nett, (2020). Faktaark; Norge; Tilstand; Innsjø og elver. Sited from URL: https://www.vann-nett.no/portal/#/area/1/NorwayID [15.03.2020]

Vann-nett, Fyresvatnet, vannforekomstID: 019-1274-L. Sited: from URL: https://www.vann-nett.no/portal/#/waterbody/019-1274-L [08.01.2020]

Walter K. & Whiles M. R. (2010). *Freswater Ecology: concepts and environmental applications of limnology*. Academic Press, Amsterdam, 2nd ed. Chapter 12, page 289-320. ISBN: 9780123747242

Whitelock M. C and Schluter D. (2015). *The Analysis of biological data*. W.H Freeman and Company, 2nd ed, 818 pages. ISBN: 9781319154219.

Wu R. S. S. (1995). *The environmental impact of marine fish culture: Towards a sustainable future*. Marine Pollution Bulletin. Page 159-166. ISSN: 0025-326X; E-ISSN: 1879-336

Xiao-e Y., Xiang W., Hu-lin H., Zhen-li H. (2008). *Mechanisms and assessment of water eutophication.* Journal of Zhejinang University Science B. page. 197-209. ISSN: 1673-1581; E-ISSN: 1862-1783.

Økland J. & Økland K. A. (1996). *Dyreliv i vann og vassdrag: artsmangfold i farger*. Oslo: Cappelen, 8th ed. Page 17 and 52. ISBN: 8202159997.

Annex

LIST:

Annex 1: wastewater treatment plants yearly emissions to Lake Fyresvatn

Annex 2: Statistical testing between sampling months

Annex 3: Statistical testing between sampling stations

Annex 4: Statistical testing between epilimnion and hypolimnion

Annex 5: Time weighted mean concentrations 2019 (A and B)

Annex 6: YSI multiparameter sonde table results

Annex 7: Results from survey in Lake Fyresvatn 2018

Annex 8: Results from surveys in Lake Fyresvatn 1978-2016.

Annex 9: Results from survey of Fyresvatn 2019 (A, B and C)

Annex 10: Bottom fauna results 2019

Annex 11: Historical data for Telemarkrøye AS production 2014 to November 2019

Annex 12: Bottom water O_2 (mg L^{-1}) Classification

Annex 1: wastewater treatment plants yearly emissions to Lake Fyresvatn

Tot-P, Tot-N, biological oxygen demand and chemical oxygen demand emissions from Fyresdal wastewater treatment plant into lake Fyresvatn in tons per year (TPY) (norskeutslipp.no).

Year	Tot-P TPY	Tot-N TPY	BOD5 TPY	COD TPY
2014	0.027	n.a	10.491	19.153
2015	0.022	n.a	4.551	8.096
2016	0.006	n.a	1.531	4.027
2017	0.002	2.756	0.335	2.457
2018	0.005	2.052	2.262	4.473

Annex 2: Statistical testing between sampling months

Statistical testing between each individual parameter and the sampling months (May-September) in Lake Fyresvatn 2019. An Anderson-darling normality test (AD-test) was used to confirm if the data was normally distributed, at p-value > 0.05. One-way ANOVA was used for normally distributed data and Kruskal-Wallis for non-normally distributed data. Green highlighted areas are p-values are <0.05.

Months	**AD Normality test P-value**	**ANOVA F-Value**	**Kruskal-Wallis H-Value**	**P-Value**
pH	0.086	4.75	-	0.00
ANC	0.308	0.47	-	0.76
Ca^{2+}	0.041	2.18	22.91	0.00
SO_4^{2-}	<0.005	1.16	4.59	0.33
NO_3^-	<0.005	0.5	3.49	0.479
Sight depth	<0.005	15.23	20.22	0.00
Turbidity	0.020	6.23	19.30	0.00
Colour	<0.005	13.32	25.14	0.00
Chl-a	0.028	25.86	25.78	0.00
Tot-P	<0.005	0.72	6.06	0.20
Tot-N	0.205	0.22	-	0.93
YSI Temp.	<0.005	4819	27.58	0.00
YSI Chl-a	0.023	159.5	25.31	0.00
YSI O_2	<0.005	637	27.87	0.00
YSI Cond.	<0.005	0.304	6.11	0.30
YSI pH	0.838	14.29	-	0.00

Annex 3: Statistical testing between sampling stations

Statistical testing between each individual parameter and the sampling stations in 2019, were Anderson-darling normality test (AD-test) was used to confirm if the data was normally distributed, at p-value > 0.05. One-way ANOVA was used for normally distributed data and Kruskal-Wallis for non-normally distributed data. Green highlighted areas are p-values are <0.05.

Stations	AD Normality test	ANOVA	Kruskal-Wallis	
	P-value	F-Value	H-Value	P-Value
pH	0.086	2.89	-	0.02
ANC	0.205	2.66	-	0.03
Ca^{2+}	0.041	8.68	8.86	0.26
SO_4^{2-}	<0.005	2.22	15.5	0.03
NO_3^-	<0.005	1.02	14.38	0.05
Sight depth	<0.005	0.61	4.47	0.72
Turbidity	0.020	1.59	8.14	0.32
Colour	<0.005	0.61	4.55	0.72
Chl-a	0.023	0.19	4.39	0.73
Tot-P	<0.005	1.41	7.44	0.39
Tot-N	0.326	1.32	-	0.27
YSI Temp.	<0.005	0	0.3	0.99
YSI Chl-a	0.023	0.02	0.49	0.99
YSI O_2	<0.005	0.02	0.57	0.99
YSI Cond.	<0.005	8.64	16.48	0.00
YSI pH	0.838	0.63	-	0.68

Annex 4: Statistical testing between epilimnion and hypolimnion

Statistical testing between epilimnion (0-6 m) and hypolimnion (20-40 m) in Lake Fyresvatn 2019. An Anderson-darling normality test (AD-test) was used to confirm if the data was normally distributed, at p-value > 0.05. The two-sample t-test was used for normally distributed data and Mann-Whitney U test for non-normally distributed data. Green highlighted areas are p-values are <0.05.

	Epilimnion AD Normality test P-value	Hypolimnion AD Normality test P-value	Both deths stacked AD Normality test P-value	Two-sample t-test t-value	Mann-whitney U test W-value	P-Value
Cond	0.145	<0.005	<0.005	-	748	**0.01**
Colour	0.331	<0.005	0.023	-	1178	**0.00**
Turb	0.019	<0.005	<0.005	-	1117	**0.00**
Tot-P	<0.005	<0.005	<0.005	-	998	0.22
Tot-N	<0.005	0.207	<0.005	-	946	0.65
pH	0.252	0.012	0.006	-	981	0.33
ANC	0.337	0.024	0.05	-	891	0.73
Ca^{2+}	0.246	0.155	<0.005	-	0.86	0.67
Mg^{2+}	-	-	-	-	-	**-**
Na^+	0.048	<0.005	<0.005	-	676	**0.00**
K^+	0.612	0.622	0.849	0.4	-	0.69
NH_4^+	-	-	-	-	-	-
SO_4^{2-}	<0.005	0.018	<0.005	-	798	**0.09**
Cl^-	<0.005	<0.005	<0.005	-	1102	**0.01**
NO_3^-	<0.005	<0.005	<0.005	-	767	**0.03**

Annex 5: Time weighted mean concentrations calculations (TWMC), 2019

5.A Statistical data based on the physical, chemical and biological analysis from all sampling sites in ***epilimnion*** *(0-6 m) in Lake Fyresvatn 2019. Time-weighted mean concentrations (TWMC), averages, standard deviation (st.dev), median, maximum (max) and minimum (min) values for the parameters Sight depth (m), Colour (mg Pt L^{-1}), Turbidity (NTU), Chl-a (µg L^{-1}), Tot-P (µg L^{-1}), Tot-N (µg L^{-1}), pH and Conductivity (µS Cm^{-1}).*

2019	North	N-1000	N-100	N-10	S-10	S-100	S-1000	South
0-6m	**Sight depth**	**Sight depth**	**Sight depth**	**Sight depth**	**Sight depth**	**Sight depth**	**Sight depth**	**Sight depth**
	m	m	m	m	m	m	m	m
TWMC:	6.4	6.2	6.7	6.6	6.8	6.6	6.7	7.1
Average:	6.6	6.2	6.8	6.6	6.9	6.5	6.7	7.3
Stdev:	0.8	0.6	0.8	1.0	0.8	1.2	0.7	0.9
Median:	6.3	6.1	6.5	6.1	7.5	6.0	6.5	7.5
Max:	7.5	7.0	7.8	7.7	7.5	8.0	7.8	8.2
Min:	5.5	5.4	6.0	5.5	6.0	5.0	6.0	6.1
0-6m	**Colour**	**Colour**	**Colour**	**Colour**	**Colour**	**Colour**	**Colour**	**Colour**
	mg Pt L^{-1}	mg Pt L^{-1}	mg Pt L^{-1}	mg Pt L^{-1}	mg Pt L^{-1}	mg Pt L^{-1}	mg Pt L^{-1}	mg Pt L^{-1}
TWMC:	18.93	17.44	17.02	17.15	16.51	16.74	18.12	16.79
Average:	18.34	17.38	16.79	16.92	16.30	16.47	17.98	16.45
Stdev:	2.70	1.36	1.21	1.94	2.25	1.86	1.88	2.11
Median:	19.20	16.83	16.77	17.28	16.50	16.41	16.74	17.71
Max:	20.27	19.10	18.58	19.00	18.78	18.25	20.76	18.18
Min:	13.74	15.93	15.22	14.50	13.88	13.59	16.59	13.20
0-6m	**Turbidity**	**Turbidity**	**Turbidity**	**Turbidity**	**Turbidity**	**Turbidity**	**Turbidity**	**Turbidity**
	NTU	NTU	NTU	NTU	NTU	NTU	NTU	NTU
TWMC:	0.44	0.31	0.38	0.35	0.32	0.29	0.32	0.28
Average:	0.42	0.31	0.38	0.35	0.31	0.29	0.31	0.27
Stdev:	0.14	0.06	0.12	0.10	0.06	0.07	0.06	0.04
Median:	0.45	0.32	0.37	0.37	0.31	0.34	0.33	0.30
Max:	0.60	0.37	0.50	0.48	0.37	0.34	0.37	0.30
Min:	0.21	0.21	0.21	0.21	0.21	0.22	0.21	0.21
0-6m	**Chl-a**	**Chl-a**	**Chl-a**	**Chl-a**	**Chl-a**	**Chl-a**	**Chl-a**	**Chl-a**
	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}
TWMC:	0.66	0.81	0.84	0.77	0.80	0.79	0.81	0.57
Average:	0.60	0.74	0.75	0.69	0.72	0.70	0.74	0.57
Stdev:	0.29	0.35	0.43	0.34	0.36	0.42	0.35	0.09
Median:	0.70	0.88	0.75	0.70	0.70	0.63	0.79	0.59
Max:	0.80	0.98	1.35	1.04	1.21	1.26	1.04	0.65
Min:	0.09	0.14	0.14	0.16	0.20	0.16	0.15	0.43
0-6m	**Tot-P**	**Tot-P**	**Tot-P**	**Tot-P**	**Tot-P**	**Tot-P**	**Tot-P**	**Tot-P**
	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}
TWMC:	2.14	3.11	2.12	5.18	2.13	2.79	2.17	4.31
Average:	2.28	4.11	2.06	5.19	2.13	3.13	2.15	3.97
Stdev:	0.66	4.09	0.72	2.77	0.19	2.90	0.43	2.34
Median:	2.10	3.07	2.32	6.41	2.20	1.94	1.96	3.01
Max:	3.41	6.28	2.82	7.60	2.34	8.26	2.82	7.44
Min:	1.74	0.98	1.23	1.99	1.86	1.20	1.76	1.73
0-6m	**Tot-N**	**Tot-N**	**Tot-N**	**Tot-N**	**Tot-N**	**Tot-N**	**Tot-N**	**Tot-N**
	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}
TWMC:	151	134	141	142	126	132	162	145
Average:	151	134	141	143	126	133	159	149
Stdev:	26	16	15	14	24	16	21	31
Median:	135	127	139	136	131	139	164	150
Max:	186	161	158	160	149	150	186	181
Min:	130	121	124	130	85	109	133	100
0-6m	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**	**pH**
	pH	pH	pH	pH	pH	pH	pH	pH
TWMC:	6.17	6.08	5.99	5.84	6.12	6.10	6.10	6.19
Average:	6.16	6.05	5.97	5.83	6.11	6.07	6.07	6.17
Stdev:	0.14	0.15	0.11	0.18	0.11	0.15	0.15	0.14
Median:	6.14	6.07	5.99	5.82	6.10	6.03	6.03	6.10
Max:	6.40	6.24	6.10	6.05	6.27	6.28	6.28	6.40
Min:	6.03	5.81	5.80	5.63	5.98	5.87	5.87	6.06
0-6m	**Cond.**	**Cond.**	**Cond.**	**Cond.**	**Cond.**	**Cond.**	**Cond.**	**Cond.**
	µS Cm^{-1}	µS Cm^{-1}	µS Cm^{-1}	µS Cm^{-1}	µS Cm^{-1}	µS Cm^{-1}	µS Cm^{-1}	µS Cm^{-1}
May	11.40	11.00	11.10	11.80	11.40	11.00	11.10	11.20
June	11.30	10.80	10.80	11.40	11.50	11.70	11.40	11.20
July	11.30	10.80	10.70	11.60	10.80	10.80	10.80	11.20
August	12.60	10.40	12.30	10.80	10.40	10.40	10.40	10.70
September	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00

5.B Statistical data based on the physical, chemical and biological analysis from all sampling sites in ***hypolimnion*** *(20-40 m) in Lake Fyresvatn 2019. Time-weighted mean concentrations (TWMC), average, standard deviation (st.dev), median, maximum (max) and minimum (min) values for the parameters Colour (mg Pt L^{-1}), Turbidity (NTU), Tot-P (µg L^{-1}), Tot-N (µg L^{-1}) and Conductivity (µS Cm^{-1}).*

2019	**N-1000**	**N-100**	**N-10**	**S-10**	**S-100**	**S-1000**
20-40m	**Colour** mg Pt L^{-1}	**Colour** mg Pt L^{-1}	**Colour** mg Pt L^{-1}	**Colour** mg Pt L^{-1}	**Colour** mg Pt L^{-1}	**Colour** mg Pt L^{-1}
TWMC:	15.62	15.41	14.57	15.22	15.40	14.88
Average:	15.85	15.55	14.46	15.24	15.34	14.78
Stdev:	1.58	1.78	1.11	1.22	1.70	0.88
Median:	15.65	14.89	14.85	15.11	14.51	15.05
Max:	18.42	18.63	15.66	16.93	18.30	15.63
Min:	14.28	14.27	12.79	13.53	14.17	13.58
20-40m	**Turbidity** NTU	**Turbidity** NTU	**Turbidity** NTU	**Turbidity** NTU	**Turbidity** NTU	**Turbidity** NTU
TWMC:	0.24	0.32	0.50	0.23	0.23	0.20
Average:	0.24	0.31	0.47	0.23	0.22	0.19
Stdev:	0.06	0.06	0.25	0.05	0.06	0.05
Median:	0.24	0.33	0.41	0.20	0.21	0.18
Max:	0.31	0.37	0.89	0.30	0.30	0.28
Min:	0.15	0.22	0.28	0.18	0.14	0.14
20-40m	**Tot-P** µg L^{-1}	**Tot-P** µg L^{-1}	**Tot-P** µg L^{-1}	**Tot-P** µg L^{-1}	**Tot-P** µg L^{-1}	**Tot-P** µg L^{-1}
TWMC:	2.31	1.76	2.42	2.89	3.00	1.98
Average:	2.60	1.80	2.43	3.11	2.96	2.03
Stdev:	2.12	0.42	0.85	1.67	2.36	0.54
Median:	1.75	1.74	2.42	2.37	1.73	1.96
Max:	6.36	2.42	3.45	6.08	6.88	2.78
Min:	1.25	1.36	1.43	2.17	1.25	1.48
20-40m	**Tot-N** µg L^{-1}	**Tot-N** µg L^{-1}	**Tot-N** µg L^{-1}	**Tot-N** µg L^{-1}	**Tot-N** µg L^{-1}	**Tot-N** µg L^{-1}
TWMC:	130	125	118	146	164	141
Average:	130	126	122	151	163	141
Stdev:	8	7	22	29	23	14
Median:	134	124	125	155	153	149
Max:	137	138	140	182	200	151
Min:	121	121	83	114	145	119
20-40m	**pH** pH	**pH** pH	**pH** pH	**pH** pH	**pH** pH	**pH** pH
TWMC:	6.08	6.01	5.86	5.99	5.95	5.99
Average:	6.08	6.02	5.87	5.97	5.97	6.00
Stdev:	0.06	0.07	0.12	0.14	0.08	0.06
Median:	6.05	6.03	5.90	6.00	6.00	6.01
Max:	6.18	6.11	6.02	6.12	6.04	6.07
Min:	6.04	5.93	5.73	5.73	5.88	5.92
20-40m	**Cond.** µS cm-1	**Cond.** µS cm-1	**Cond.** µS cm-1	**Cond.** µS cm-1	**Cond.** µS cm-1	**Cond.** µS cm-1
TWMC:	11.1	11.2	11.4	11.3	11.4	11.4
Average:	11.0	11.1	11.3	11.2	11.4	11.3
Stdev:	0.6	0.7	0.7	0.8	0.9	0.8
Median:	11.2	11.2	11.5	11.5	11.4	11.5
Max:	11.4	11.7	11.8	12.0	12.4	12.0
Min:	10.0	10.0	10.0	10.0	10.0	10.0

Annex 6: YSI multiparameter sonde table results

Monthly YSI Multiparameter sonde results (average of all stations). Temperature, Chl-a, Dissolved O_2 (mg L^{-1}), pH, conductivity (H_{25}) and O_2 %. Note: at 45m depth, the YSI sonde hit sediments at most stations.

Date	**29.05.2019**	**25.06.2019**	**23.07.2019**	**20.08.2019**	**24.09.2019**
Detpth	Temp.	Temp.	Temp.	Temp.	Temp.
m	**°C**	**°C**	**°C**	**°C**	**°C**
0	6.1	12.9	16.0	15.9	11.2
1	6.1	12.8	15.7	15.9	11.1
2	6.1	12.4	15.6	15.9	11.0
3	6.0	11.8	15.5	15.8	11.0
4	6.0	11.2	15.5	15.8	11.0
5	6.0	10.8	15.4	15.8	10.8
6	5.9	10.4	15.3	15.7	10.8
7	5.9	10.1	15.2	15.7	10.7
8	5.9	9.7	14.9	15.7	10.7
9	5.9	9.4	14.6	15.6	10.7
10	5.7	9.1	14.1	15.2	10.6
11	5.6	8.9	13.6	14.0	10.6
12	5.5	8.6	12.9	12.6	10.5
15	5.1	8.1	9.8	7.9	10.4
20	4.9	7.0	8.0	6.1	9.8
25	4.7	6.3	6.9	5.3	9.1
30	4.5	6.0	5.9	5.0	5.4
35	4.3	5.6	5.2	4.9	5.2
40	4.2	5.2	5.0	4.7	5.0
45	4.2	4.9	4.7	4.7	4.8

Date	**29.05.2019**	**25.06.2019**	**23.07.2019**	**20.08.2019**	**24.09.2019**
Detpth	Chl-a	Chl-a	Chl-a	Chl-a	Chl-a
m	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}
0	0.4	1.6	0.5	1.1	0.9
1	0.4	1.6	0.6	1.4	0.9
2	0.4	1.5	0.7	1.3	0.9
3	0.5	1.5	0.9	1.3	0.9
4	0.5	1.3	1.0	1.3	0.9
5	0.5	1.3	1.0	1.2	0.9
6	0.5	1.2	0.9	1.2	0.8
7	0.6	1.1	1.0	1.2	0.9
8	0.5	1.0	0.9	1.1	0.8
9	0.5	0.9	0.8	1.0	0.8
10	0.5	0.8	0.8	0.9	0.8
11	0.5	0.7	0.7	0.8	0.8
12	0.5	0.7	0.6	0.6	0.8
15	0.4	0.6	0.4	0.4	0.7
20	0.4	0.5	0.4	0.3	0.5
25	0.4	0.5	0.3	0.3	0.4
30	0.3	0.4	0.3	0.3	0.3
35	0.4	0.3	0.3	0.3	0.3
40	0.3	0.3	0.3	0.3	0.2
45	0.0	0.3	0.2	0.3	0.3

Date	**29.05.2019**	**25.06.2019**	**23.07.2019**	**20.08.2019**	**24.09.2019**
Detpth	O_2	O_2	O_2	O_2	O_2
m	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
0	11.2	10.1	9.1	9.2	10.7
1	11.2	10.2	9.2	9.1	10.6
2	11.2	10.2	9.3	9.0	10.6
3	11.3	10.3	9.3	9.0	10.5
4	11.3	10.3	9.3	9.0	10.5
5	11.3	10.4	9.3	9.0	10.6
6	11.3	10.5	9.3	9.0	10.6
7	11.3	10.5	9.3	8.9	10.6
8	11.3	10.6	9.3	8.9	10.6
9	11.3	10.7	9.3	8.9	10.6
10	11.3	10.8	9.4	9.0	10.6
11	11.3	10.8	9.6	9.1	10.6
12	11.3	10.9	9.7	9.4	10.6
15	11.3	10.9	10.2	10.3	10.6
20	11.3	11.0	10.6	10.8	10.7
25	11.4	11.1	10.9	11.0	10.8
30	11.4	11.1	11.0	11.1	11.4
35	11.3	11.2	11.1	11.2	11.6
40	11.0	11.3	11.2	11.2	9.1
45	0.6	0.9	4.4	5.2	5.3

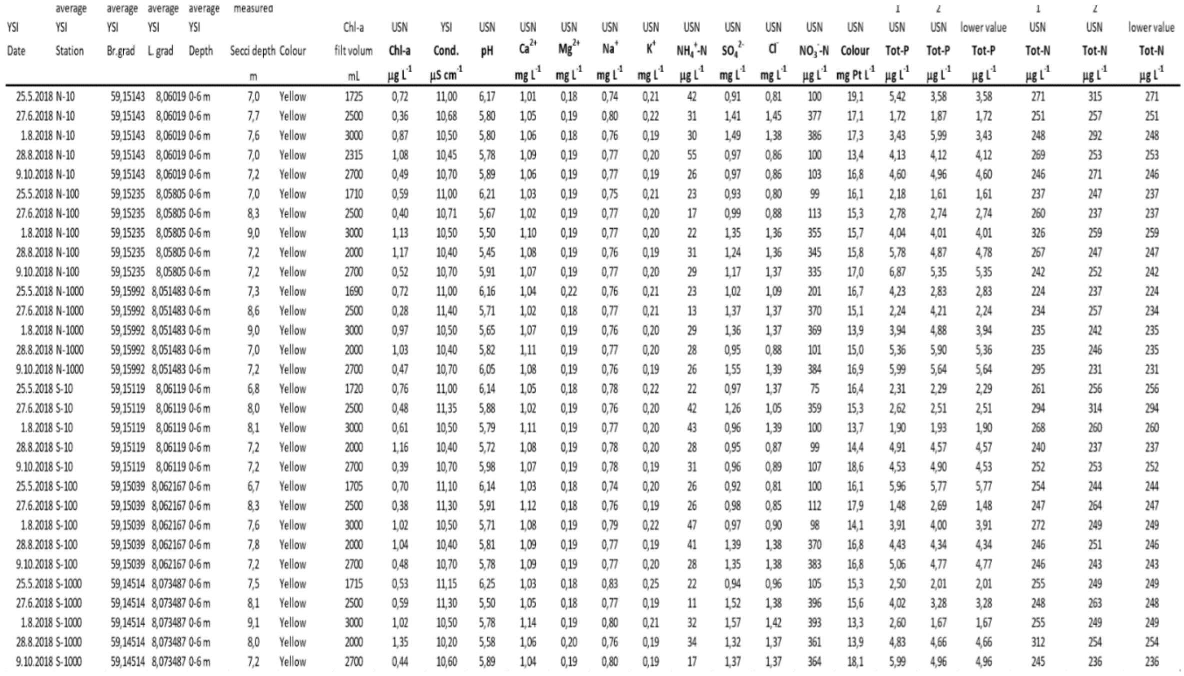
Date	**29.05.2019**	**25.06.2019**	**23.07.2019**	**20.08.2019**	**24.09.2019**
Detpth	pH	pH	pH	pH	pH
m					
0	5.7	5.9	6.1	6.1	5.9
1	5.7	5.8	5.9	6.0	5.9
2	5.7	5.8	5.9	6.0	5.9
3	5.7	5.7	5.9	6.0	5.9
4	5.6	5.7	5.8	5.9	5.9
5	5.6	5.7	5.8	5.9	5.8
6	5.6	5.7	5.8	5.9	5.8
7	5.6	5.7	5.8	5.9	5.8
8	5.6	5.7	5.8	5.9	5.8
9	5.6	5.6	5.7	5.9	5.8
10	5.6	5.6	5.7	5.9	5.8
11	5.6	5.6	5.7	5.8	5.8
12	5.6	5.6	5.7	5.8	5.8
15	5.6	5.5	5.7	5.8	5.8
20	5.6	5.4	5.6	5.7	5.7
25	5.6	5.3	5.5	5.6	5.6
30	5.5	5.3	5.5	5.6	5.6
35	5.5	5.3	5.4	5.6	5.5
40	5.5	5.3	5.4	5.6	5.5
45	6.5	6.3	6.0	6.2	6.0

Date	**29.05.2019**	**25.06.2019**	**23.07.2019**	**20.08.2019**	**24.09.2019**
Detpth	H_{25}	H_{25}	H_{25}	H_{25}	H_{25}
m	µS cm^{-1}	µS cm^{-1}	µS cm^{-1}	µS cm^{-1}	µS cm^{-1}
0	10.6	10.3	10.4	8.6	10.1
1	11.2	11.1	10.4	10.1	10.2
2	11.1	11.1	10.4	10.1	10.2
3	11.1	11.1	10.4	10.1	10.2
4	11.0	11.0	10.4	10.1	10.2
5	11.0	11.0	10.4	10.1	10.2
6	10.9	11.0	10.5	10.1	10.2
7	10.9	11.0	10.5	10.2	10.2
8	10.9	10.6	10.5	10.2	10.2
9	10.9	10.6	10.5	10.2	10.2
10	10.9	10.6	10.5	10.1	10.2
11	10.9	10.7	10.5	10.2	10.2
12	10.9	10.7	10.5	10.4	10.2
15	10.9	10.7	10.8	10.9	10.2
20	11.0	10.8	10.9	10.9	10.3
25	11.0	10.8	20.0	12.3	10.4
30	11.1	10.9	11.0	11.0	10.8
35	11.1	11.0	12.8	11.1	10.8
40	11.1	11.0	12.8	11.1	10.8
45	906.0	339.4	250.1	250.2	159.9

Date	**29.05.2019**	**25.06.2019**	**23.07.2019**	**20.08.2019**	**24.09.2019**
Detpth	O_2	O_2	O_2	O_2	O_2
m	%	%	%	%	%
0	90.0	95.8	92.4	93.0	97.4
1	90.6	95.9	93.1	91.5	96.4
2	90.4	95.4	93.1	91.0	95.9
3	90.4	94.7	93.0	90.8	95.7
4	90.4	94.2	93.0	90.5	95.6
5	90.4	94.1	92.7	90.4	95.4
6	90.2	93.9	92.6	90.2	95.4
7	90.3	93.7	92.3	90.0	95.3
8	90.2	93.5	91.9	89.9	95.3
9	90.2	93.4	91.7	89.5	95.3
10	90.0	93.3	91.6	89.1	95.3
11	89.7	93.4	91.9	88.6	95.3
12	89.4	93.2	92.0	88.5	95.2
15	88.9	92.4	90.2	86.7	95.1
20	88.4	90.8	90.0	87.1	94.4
25	88.1	90.1	89.0	87.3	93.7
30	87.7	89.6	88.4	87.2	90.6
35	87.2	89.0	87.6	87.2	91.5
40	86.8	88.5	87.4	87.0	71.3
45	4.4	6.9	2.9	6.4	10.8

Annex 7: Results from survey in Lake Fyresvatn 2018

Results from survey of Lake Fyresvatn 2018 (Angelovičová M. 2018).



	average	average	average	average	measured															1	2		1	2	
YSI	YSI	YSI	YSI	YSI			Chl-a	USN	YSI	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	lower value	USN	USN	lower value
Date	Station	Br.grad	L grad	Depth	Secci depth	Colour	filt volum	**Chl-a**	**Cond.**	**pH**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**NH_4^+-N**	**SO_4^{2-}**	**Cl^{-}**	**NO_3^--N**	**Colour**	**Tot-P**	**Tot-P**	**Tot-P**	**Tot-N**	**Tot-N**	**Tot-N**
					m		mL	**µg L^{-1}**	**µS cm^{-1}**		**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**mg Pt L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**
25.5.2018	N-10	59,15143	8,06019	0-6 m	7,0	Yellow	1725	0,72	11,00	6,17	1,01	0,18	0,74	0,21	42	0,91	0,81	100	19,1	5,42	3,58	3,58	271	315	271
27.6.2018	N-10	59,15143	8,06019	0-6 m	7,7	Yellow	2500	0,36	10,68	5,80	1,05	0,19	0,80	0,22	31	1,41	1,45	377	17,1	1,72	1,87	1,72	251	257	251
1.8.2018	N-10	59,15143	8,06019	0-6 m	7,6	Yellow	3000	0,87	10,50	5,80	1,06	0,18	0,76	0,19	30	1,49	1,38	386	17,3	3,43	5,99	3,43	248	292	248
28.8.2018	N-10	59,15143	8,06019	0-6 m	7,0	Yellow	2315	1,08	10,45	5,78	1,09	0,19	0,77	0,20	55	0,97	0,86	100	13,4	4,13	4,12	4,12	269	253	253
9.10.2018	N-10	59,15143	8,06019	0-6 m	7,2	Yellow	2700	0,49	10,70	5,89	1,06	0,19	0,77	0,19	26	0,97	0,86	103	16,8	4,60	4,96	4,60	246	271	246
25.5.2018	N-100	59,15235	8,05805	0-6 m	7,0	Yellow	1710	0,59	11,00	6,21	1,03	0,19	0,75	0,21	23	0,93	0,80	99	16,1	2,18	1,61	1,61	237	247	237
27.6.2018	N-100	59,15235	8,05805	0-6 m	8,3	Yellow	2500	0,40	10,71	5,67	1,02	0,19	0,77	0,20	17	0,99	0,88	113	15,3	2,78	2,74	2,74	260	237	237
1.8.2018	N-100	59,15235	8,05805	0-6 m	9,0	Yellow	3000	1,13	10,50	5,50	1,10	0,19	0,77	0,20	22	1,35	1,36	355	15,7	4,04	4,01	4,01	326	259	259
28.8.2018	N-100	59,15235	8,05805	0-6 m	7,2	Yellow	2000	1,17	10,40	5,45	1,08	0,19	0,76	0,19	31	1,24	1,36	345	15,8	5,78	4,87	4,78	267	247	247
9.10.2018	N-100	59,15235	8,05805	0-6 m	7,2	Yellow	2700	0,52	10,70	5,91	1,07	0,19	0,77	0,20	29	1,17	1,37	335	17,0	6,87	5,35	5,35	242	252	242
25.5.2018	N-1000	59,15992	8,051483	0-6 m	7,3	Yellow	1690	0,72	11,00	6,16	1,04	0,22	0,76	0,21	23	1,02	1,09	201	16,7	4,23	2,83	2,83	224	237	224
27.6.2018	N-1000	59,15992	8,051483	0-6 m	8,6	Yellow	2500	0,28	11,40	5,71	1,02	0,18	0,77	0,21	13	1,37	1,37	370	15,1	2,24	4,21	2,24	234	257	234
1.8.2018	N-1000	59,15992	8,051483	0-6 m	9,0	Yellow	3000	0,97	10,50	5,65	1,07	0,19	0,76	0,20	29	1,36	1,37	369	13,9	3,94	4,88	3,94	235	242	235
28.8.2018	N-1000	59,15992	8,051483	0-6 m	7,0	Yellow	2000	1,03	10,40	5,82	1,11	0,19	0,77	0,20	28	0,95	0,88	101	15,0	5,36	5,90	5,36	235	246	235
9.10.2018	N-1000	59,15992	8,051483	0-6 m	7,2	Yellow	2700	0,47	10,70	6,05	1,08	0,19	0,76	0,19	26	1,55	1,39	384	16,9	5,99	5,64	5,64	295	231	231
25.5.2018	S-10	59,15119	8,06119	0-6 m	6,8	Yellow	1720	0,76	11,00	6,14	1,05	0,18	0,78	0,22	22	0,97	1,37	75	16,4	2,31	2,29	2,29	261	256	256
27.6.2018	S-10	59,15119	8,06119	0-6 m	8,0	Yellow	2500	0,48	11,35	5,88	1,02	0,19	0,76	0,20	42	1,26	1,05	359	15,3	2,62	2,51	2,51	294	314	294
1.8.2018	S-10	59,15119	8,06119	0-6 m	8,1	Yellow	3000	0,61	10,50	5,79	1,11	0,19	0,77	0,20	43	0,96	1,39	100	13,7	1,90	1,93	1,90	268	260	260
28.8.2018	S-10	59,15119	8,06119	0-6 m	7,2	Yellow	2000	1,16	10,40	5,72	1,08	0,19	0,78	0,20	28	0,95	0,87	99	14,4	4,91	4,57	4,57	240	237	237
9.10.2018	S-10	59,15119	8,06119	0-6 m	7,2	Yellow	2700	0,39	10,70	5,98	1,07	0,19	0,78	0,19	31	0,96	0,89	107	18,6	4,53	4,90	4,53	252	253	252
25.5.2018	S-100	59,15039	8,062167	0-6 m	6,7	Yellow	1705	0,70	11,10	6,14	1,03	0,18	0,74	0,20	26	0,92	0,81	100	16,1	5,96	5,77	5,77	254	244	244
27.6.2018	S-100	59,15039	8,062167	0-6 m	8,3	Yellow	2500	0,38	11,30	5,91	1,12	0,18	0,76	0,19	26	0,98	0,85	112	17,9	1,48	2,69	1,48	247	264	247
1.8.2018	S-100	59,15039	8,062167	0-6 m	7,6	Yellow	3000	1,02	10,50	5,71	1,08	0,19	0,79	0,22	47	0,97	0,90	98	14,1	3,91	4,00	3,91	272	249	249
28.8.2018	S-100	59,15039	8,062167	0-6 m	7,8	Yellow	2000	1,04	10,40	5,81	1,09	0,19	0,77	0,19	41	1,39	1,38	370	16,8	4,43	4,34	4,34	246	251	246
9.10.2018	S-100	59,15039	8,062167	0-6 m	7,2	Yellow	2700	0,48	10,70	5,78	1,09	0,19	0,77	0,20	28	1,35	1,38	383	16,8	5,06	4,77	4,77	246	243	243
25.5.2018	S-1000	59,14514	8,073487	0-6 m	7,5	Yellow	1715	0,53	11,15	6,25	1,03	0,18	0,83	0,25	22	0,94	0,96	105	15,3	2,50	2,01	2,01	255	249	249
27.6.2018	S-1000	59,14514	8,073487	0-6 m	8,1	Yellow	2500	0,59	11,30	5,50	1,05	0,18	0,77	0,19	11	1,52	1,38	396	15,6	4,02	3,28	3,28	248	263	248
1.8.2018	S-1000	59,14514	8,073487	0-6 m	9,1	Yellow	3000	1,02	10,50	5,78	1,14	0,19	0,80	0,21	32	1,57	1,42	393	13,3	2,60	1,67	1,67	255	249	249
28.8.2018	S-1000	59,14514	8,073487	0-6 m	8,0	Yellow	2000	1,35	10,20	5,58	1,06	0,20	0,76	0,19	34	1,32	1,37	361	13,9	4,83	4,66	4,66	312	254	254
9.10.2018	S-1000	59,14514	8,073487	0-6 m	7,2	Yellow	2700	0,44	10,60	5,89	1,04	0,19	0,80	0,19	17	1,37	1,37	364	18,1	5,99	4,96	4,96	245	236	236

Annex 8: Results from surveys in Lake Fyresvatn 1975-2016

Results from survey of Lake Fyresvatn 1978-2016 (Lydersen et al. 2017; NIVA, Resa database).

	UTM	**UTM**	**UTM**	**Dato**	**Siktedyp**	**pH**	**H^+**	**KOND**	**$Alk_{målt}$**	**Alk_{korr}**	**Tot-N**	**NO_3-N**	**TOC**	**Cl**	**SO_4**	**Al**	**Al/R**	**Al/Il**	**LAL**	**Ca**	**K**	**Mg**	**Na**	**Tot-P**	**Chl-a**	**Kilde**
	N	Ø	Sone		m		µekv L^{-1}	mS m^{-1}	µmol L^{-1}	µmol L^{-1}	µg L^{-1}	µg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	µg L^{-1}	
Fyresvatn	6551000	451500	32	okt. 78		5,46	3,47					125	2,20	0,90	2,60	130				1,05	0,27	0,20	0,92			Niva, Resa database
	6551000	451500	32	mar. 82		5,35	4,42				345	155		1,08	2,73	73				0,95	0,17	0,20	0,73	3,00		Niva, Resa database
	6551000	451500	32	mai. 82		5,53	2,94	1,56				153		1,13	2,67	56				0,91	0,22	0,21	0,80			Niva, Resa database
	6551000	451500	32	aug. 82		5,49	3,23	1,60			283	140		0,90	2,68	62				0,98	0,18	0,22	0,75	1,83		Niva, Resa database
	6551000	451500	32	nov. 82		5,44	3,60	1,60			340	143		1,13	2,73	87				0,99	0,20	0,20	0,73	3,17		Niva, Resa database
Fyresvatn	6555199	447900	32	aug. 93		5,41	3,86	1,67			284	185	1,76	1,40	3,04		122	55	67	0,89	0,22	0,19	0,83			Niva, Resa database
Fyresvatn	6541330	457955	32	okt. 93		5,41	3,89	1,82			205	170	1,26	1,40	3,30		115	40	75	0,90	0,15	0,20	0,82	2,20		Niva, Resa database
	6541330	457955	32	des. 93		5,36	4,37	1,55			240	180	1,83	1,40	3,00		100	35	65	0,92	0,14	0,20	0,77	<2.5		Niva, Resa database
	6541330	457955	32	apr. 94		5,35	4,47	1,53			220	195	1,43	1,50	2,50		150	55	95	0,90	0,17	0,20	0,83	<2.5		Niva, Resa database
	6541330	457955	32	mai. 94		5,24	5,75	1,83			260	210	2,92	1,40	1,80		150	75	75	0,83	0,15	0,19	0,88	<2.5		Niva, Resa database
	6541330	457955	32	jun. 94		5,39	4,07	1,74			300	180	2,03	1,50	2,70		125	70	55	0,89	0,18	0,21	0,82	3,60		Niva, Resa database
Fyresvatn	6555199	447900	32	sep. 96		5,47	3,35	1,48	34	6	254	175	1,68	1,33	2,48		86	29	57	0,88	0,16	0,21	0,83	1,50		Niva, Resa database
	6555199	447900	32	des. 97		6,28	0,52	1,63	59	27	248	178	1,70	1,35	2,35		68	43	25	1,40	0,18	0,20	0,83	1,00		Niva, Resa database
	6550000	453000	32	jul. 04		5,83	1,48	1,29		< 20					1,73					0,95				2,50		Nilssen, Wærvågen, 2009
Fyresvatn	Vik		32	nov. 07		5,90	1,26	1,35	38	7							42	20	22	0,94						Aquateam, 2007, utenfor Vik
Fyresvatn	Breivik		32	jul. 15	8,0						320		2,70											12	0,40	Faun AS, analysert av Eurofins
	Breivik		32	aug. 15	9,0						240		3,20											< 3	0,80	Faun AS, analysert av Eurofins
	Breivik		32	sep. 15	5,5						460		4,10											8,5	1,50	Faun AS, analysert av Eurofins
	Breivik		32	okt. 15	6,0	5,80					490		3,90											5,7	1,20	Faun AS, analysert av Eurofins
Fyresvatn S	6543013	458484	32	jun. 15		6,04	0,91	1,11		25	373	124	2,70	0,83	1,21					1,05	0,18	0,26	0,79	6	0,44	USN, Tot-P analysert på NIVA
Fyresvatn N	6560330	447374	32	jun. 16	7,0	5,26	5,50	1,08		26	250	95	2,27	0,87	1,00					1,04	0,14	0,34	0,75	1,0	0,47	HSN, Tot-P analysert på NMBU
	6560330	447374	32	jul. 16	7,0	5,99	1,02	1,16		22	380	101	2,31	0,92	1,02					1,04	0,40	0,36	0,76	0,7	0,86	HSN, Tot-P analysert på NMBU
	6560330	447374	32	aug. 16	6,5	5,90	1,26	1,06		25	247	92	2,35	0,87	0,96					1,04	0,14	0,38	0,75	0,5	0,26	HSN, Tot-P analysert på NMBU
	6560330	447374	32	sep. 16	7,5	6,03	0,93	1,07		24	320	98	2,38	0,87	0,95					1,05	0,13	0,38	0,74	**<0,5**	0,45	HSN, Tot-P analysert på NMBU
	6560330	447374	32	okt. 16	6,5	6,02	0,95	1,13		21	296	104	2,40	0,89	0,98					1,09	0,15	0,40	0,76	0,8	0,78	HSN, Tot-P analysert på NMBU
Fyresvatn S	6542648	458392	32	jun. 16	7,0	6,00	1,00	1,09		34	299	113	2,20	0,89	1,08					1,05	0,15	0,35	0,75	**<0,5**	0,71	HSN, Tot-P analysert på NMBU
	6542648	458392	32	jul. 16	7,0	5,96	1,10	1,09		27	294	99	2,24	0,87	1,03					1,02	0,16	0,36	0,74	**<0,5**	0,85	HSN, Tot-P analysert på NMBU
	6542648	458392	32	aug. 16	8,5	6,03	0,93	1,07		24	246	104	2,26	0,88	1,03					1,03	0,14	0,38	0,75	0,5	1,42	HSN, Tot-P analysert på NMBU
	6542648	458392	32	sep. 16	7,0	6,00	1,00	1,13		29	337	95	2,30	0,88	1,02					1,06	0,14	0,38	0,74	0,7	0,54	HSN, Tot-P analysert på NMBU
	6542648	458392	32	okt. 16	6,0	5,93	1,17	1,07		27	343	102	2,35	0,90	1,05					1,05	0,16	0,39	0,76	0,8	0,69	HSN, Tot-P analysert på NMBU

Annex 9: Results from survey of Fyresvatn 2019

9.A*: All results from survey of Lake Fyresvatn, May – September in 2019.*

Epilimnion results (0-6 m) close to the fish farm 10 m, 100 m and 1000 m distance.

	average	average	average	average	measured			USN	USN	lab	median	lab		lab		lab											1.0	2.0	Gj.nitt	1	2	Gj.nitt	
YSI	YSI	YSI	YSI	YSI			Chl-a	median YSI	average YSI	USN	YSI	USN	median YSI	USN	median YSI	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	
Dato	Stasjon	Br.grad	L.grad	Dyp	Secci depth	Colour	filt volum	**Chl-a**	**Chl-a**	**Chl-a**	**Cond.**	**Cond.**	**pH**	**pH**	**Turb.**	**Turb.**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**NH_4^+-N**	**SO_4^{2-}**	**Cl^{-}**	**NO_3^--N**	**TOC**	**Farge**	**Tot-P**	**Tot-P**	**Tot-P**	**Tot-N**	**Tot-N**	**Tot-N**	**Org-N**
					m		mL	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µS cm^{-1}**	**µS cm^{-1}**			**FTU**	**NTU**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**	**mg L^{-1}**	**µg L^{-1}**	**mg L^{-1}**	**mg Pt L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**	**µg L^{-1}**
29.05.2019	N-10	59.1514267	8.06019	0-6	5.5	grønnlig gul	2500	0.47	0.48	0.16	10.90	11.80	5.67	5.63	-0.67	0.48	0.99	0.18	0.72	0.18	0.00	1.60	1.68	164		14.5	6.4	6.4	6.4	128	136	132	-32
29.05.2019	N-100	59.1523467	8.05805	0-6	6.5	grønnlig gul	2500	0.49	0.47	0.14	10.80	11.10	5.64	5.80	-0.65	0.5	0.97	0.18	0.71	0.16	0.00	1.21	1.60	134		15.2	1.3	1.1	1.2	159	146	153	19
29.05.2019	N-1000	59.1599167	8.05148333	0-6	umulig		2500	0.49	0.49	0.14	11.90	11.00	5.64	5.81	-0.71	0.32	1.01	0.18	0.72	0.16	0.00	1.25	1.62	141		15.9	6.3	16.2	11.3	131	141	136	-5
29.05.2019	S-10	59.15119	8.06119	0-6	7.5	grønnlig gul	2500	0.55	0.52	0.2	11.00	11.40	5.70	6.04	-0.53	0.35	1.01	0.18	0.70	0.18	0.00	3.44	1.77	33		13.9	2.1	2.3	2.2	132	124	128	95
29.05.2019	S-100	59.15039	8.06216667	0-6	5.0	grønnlig gul	2500	0.42	0.42	0.16	10.90	11.00	5.61	5.87	-0.68	0.34	1.00	0.18	0.72	0.18	0.00	1.71	1.68	168		13.6	1.6	2.3	1.9	135	148	142	-27
29.05.2019	S-1000	59.1451367	8.07348667	0-6	umulig		2500	0.40	0.42	0.15	10.80	11.10	5.64	6.02	-0.69	0.33	1.00	0.18	0.72	0.17	0.00	1.80	1.75	177		16.7	1.8	1.7	1.8	135	192	164	-13
25.06.2019	N-10	59.1514267	8.06019	0-6	6.1	brunlig gul	2000	1.44	1.38	0.92	10.60	11.40	5.72	5.97	-0.71	0.29	0.98	0.18	0.70	0.16	0.00	1.55	2.23	30		15.4	7.9	7.1	7.5	120	139	130	100
25.06.2019	N-100	59.1523467	8.05805	0-6	6.0	brunlig gul	2000	1.37	1.47	0.78		10.80	5.83	6.10	-0.72	0.31	0.97	0.18	0.69	0.16	0.00	1.45	1.75	154		16.4	2.9	2.8	2.8	137	140	139	-15
25.06.2019	N-1000	59.1599167	8.05148333	0-6	5.4	brunlig gul	2000	1.40	1.46	0.97	10.50	10.80	5.79	6.07	-0.73	0.37	0.98	0.18	0.71	0.18	0.00	1.45	1.76	154		16.8	3.2	3.0	3.1	123	130	127	-28
25.06.2019	S-10	59.15119	8.06119	0-6	6.1	brunlig gul	2000	1.33	1.35	0.83	10.90	11.50	5.69	5.98	-0.69	0.31	0.99	0.18	0.69	0.17	0.00	2.11	1.74	194		14.2	2.4	2.3	2.3	143	119	131	-63
25.06.2019	S-100	59.15039	8.06216667	0-6	6.0	brunlig gul	2000	1.42	1.37	0.95	12.70	11.70	5.72	6.03	-0.76	0.34	0.97	0.18	0.68	0.17	0.00	1.64	1.79	162		16.4	2.0	2.8	2.4	152	147	150	-12
25.06.2019	S-1000	59.1451367	8.07348667	0-6	6.5	brunlig gul	2000	1.67	1.55	1.04	10.50	11.40	5.71	6.08	-0.75	0.31	0.98	0.18	0.68	0.18	0.00	1.98	1.82	172		16.7	2.9	2.8	2.8	143	143	143	-29
23.07.2019	N-10	59.1514267	8.06019	0-6	7.7	brunlig gul	2000	0.96	0.89	0.64	10.40	11.60	6.02	5.82	-0.82	0.37	0.97	0.18	0.70	0.17	0.00	1.28	1.75	146		17.3	7.2	8.0	7.6	158	153	156	9
23.07.2019	N-100	59.1523467	8.05805	0-6	7.8	brunlig gul	2000	0.93	0.86	0.75	10.40	10.70	5.83	5.99	-0.8	0.37	0.97	0.18	0.67	0.17	0.00	1.79	1.80	165		16.8	1.8	0.9	1.4	142	135	139	-27
23.07.2019	N-1000	59.1599167	8.05148333	0-6	6.6	brunlig gul	2000	0.86	0.77	0.72	10.40	10.80	5.88	6.24	-0.81	0.29	0.95	0.17	0.66	0.17	0.00	1.20	1.72	135		16.5	0.0	1.9	1.0	159	162	161	25
23.07.2019	S-10	59.15119	8.06119	0-6	7.5	brunlig gul	2000	0.92	0.80	0.64	10.40	10.80	5.76	6.27	-0.8	0.31	0.96	0.18	0.67	0.17	0.00	1.26	1.70	142		16.5	2.1	2.4	2.2	140	30	85	-56
23.07.2019	S-100	59.15039	8.06216667	0-6	8.0	brunlig gul	2000	0.92	0.76	0.51	10.40	10.80	5.78	6.28	-0.81	0.22	0.97	0.18	0.67	0.16	0.00	1.25	1.72	134		16.1	1.3	1.1	1.2	115	162	139	5
23.07.2019	S-1000	59.1451367	8.07348667	0-6	7.8	brunlig gul	2000	0.82	0.78	0.79	10.40	10.80	5.85	6.37	-0.795	0.33	0.96	0.18	0.68	0.17	0.00	1.60	1.78	162		16.6	2.7	1.0	1.9	167	172	170	8
20.08.2019	N-10	59.1514267	8.06019	0-6	6.0	brunlig gul	1700	1.34	1.29	1.04	10.20	10.80	6.02	5.70	-0.69	0.4	0.94	0.18	0.67	0.17	0.00	1.49	1.74	160		19.0	1.9	2.1	2.0	116	155	136	-24
20.08.2019	N-100	59.1523467	8.05805	0-6	6.0	brunlig gul	1700	1.29	1.26	1.35	10.10	12.30	5.95	5.99	-0.70	0.49	0.94	0.18	0.67	0.17	0.00	1.16	1.67	136		18.6	2.2	2.5	2.3	141	175	158	22
20.08.2019	N-1000	59.1599167	8.05148333	0-6	6.0	brunlig gul	1700	1.12	1.21	0.98	10.10	10.40	5.90	6.06	-0.71	0.34	0.95	0.18	0.67	0.17	0.00	1.40	1.72	152		18.5	2.1	2.1	2.1	112	129	121	-31
20.08.2019	S-10	59.15119	8.06119	0-6	6.0	brunlig gul	1700	1.33	1.29	1.21	10.10	10.40	6.01	6.15	-0.71	0.37	0.95	0.18	0.67	0.17	0.00	1.66	1.76	177		18.8	1.9	1.9	1.9	143	155	149	-28
20.08.2019	S-100	59.15039	8.06216667	0-6	6.0	brunlig gul	1700	1.22	1.24	1.26	10.10	10.40	5.89	6.15	-0.73	0.34	0.93	0.18	0.67	0.17	0.00	1.13	1.66	136		18.3	1.9	1.9	1.9	113	105	109	-27
20.08.2019	S-1000	59.1451367	8.07348667	0-6	6.0	brunlig gul	1700	1.32	1.28	0.96	10.10	10.40	5.99	5.92	-0.74	0.37	0.95	0.18	0.68	0.17	0.00	1.44	1.73	159		20.8	2.2	1.7	2.0	217	155	186	27
24.09.2019	N-10	59.1514267	8.06019	0-6	7.5	brunlig gul	2000	0.88	0.84	0.7	10.30	10.00	5.90	6.05	-0.12	0.21	0.97	0.18	0.68	0.16	0.00	1.66	1.79	175		18.5	2.6	2.3	2.4	147	173	160	-15
24.09.2019	N-100	59.1523467	8.05805	0-6	7.5	brunlig gul	2000	0.86	0.87	0.72	10.20	10.00	6.09	5.98	-0.11	0.21	0.97	0.18	0.69	0.18	0.00	1.21	1.69	145		16.9	2.8	2.3	2.6	122	125	124	-21
24.09.2019	N-1000	59.1599167	8.05148333	0-6	7.0	brunlig gul	2000	1.12	1.14	0.88	10.10	10.00	5.77	6.09	-0.12	0.21	0.96	0.18	0.68	0.18	0.00	1.78	1.78	179		19.1	3.5	2.7	3.1	133	118	125	-54
24.09.2019	S-10	59.15119	8.06119	0-6	7.5	brunlig gul	2000	0.8	0.81	0.7	10.20	10.00	5.81	6.10	-0.12	0.21	0.97	0.18	0.70	0.18	0.00	1.69	1.79	170		18.2	2.0	2.1	2.0	133	141	137	-33
24.09.2019	S-100	59.15039	8.06216667	0-6	7.5	brunlig gul	2000	0.85	0.82	0.63	10.20	10.00	5.80	6.03	-0.12	0.22	0.97	0.18	0.69	0.17	0.00	1.23	1.72	151		18.0	9.4	7.1	8.3	132	122	127	-24
24.09.2019	S-1000	59.1451367	8.07348667	0-6	7.0	brunlig gul	2000	0.85	0.86	0.74	10.10	10.00	5.84	5.99	-0.11	0.21	0.97	0.18	0.69	0.16	0.00	2.08	1.81	188		19.1	2.9	1.7	2.3	150	116	133	-55

9.B Hypolimnion results (20-40 m) close to the fish farm 10 m, 100 m and 1000 m distance.

YSI Dato	average YSI Stasjon	average YSI Br.grad	average YSI L. grad	average YSI Dyp	median YSI **Cond.** **µS cm^{-1}**	lab USN **Cond.** **µS cm^{-1}**	median YSI **pH**	lab USN **pH**	median YSI **Turb.** **FTU**	lab USN **Turb.** **NTU**	USN **Ca^{2+}** **mg L^{-1}**	USN **Mg^{2+}** **mg L^{-1}**	USN **Na^{+}** **mg L^{-1}**	USN **K^{+}** **mg L^{-1}**	USN **NH$_4^+$-N** **µg L^{-1}**	USN **SO$_4^{2-}$** **mg L^{-1}**	USN **Cl^{-}** **mg L^{-1}**	USN **NO$_3^-$-N** **µg L^{-1}**	USN **TOC** **mg L^{-1}**	USN **Farge** **mg Pt L^{-1}**	1.0 USN **Tot-P** **µg L^{-1}**	2.0 USN **Tot-P** **µg L^{-1}**	Gj.nitt USN **Tot-P** **µg L^{-1}**	1 USN **Tot-N** **µg L^{-1}**	2 USN **Tot-N** **µg L^{-1}**	Gj.nitt USN **Tot-N** **µg L^{-1}**	**Org-N** **µg L^{-1}**
29.05.2019	N-10	59.1451367	8.07348667	40	11.10	11.30	5.56	6.02	-0.69	0.28	0.97	0.18	0.72	0.16	0.00	1.85	1.77	174		12.8	1.9	1.7	1.8	147	124	136	-39
29.05.2019	N-100	59.1451367	8.07348667	20	11.00	11.10	5.60	6.04	-0.68	0.35	0.99	0.18	0.72	0.16	0.00	2.02	1.76	183		14.3	1.9	2.0	2.0	139	136	138	-46
29.05.2019	N-1000	59.1451367	8.07348667	20	11.00	11.20	5.59	6.05	-0.68	0.28	0.99	0.18	0.69	0.17	0.00	1.29	1.70	146		15.7	2.0	2.0	2.0	130	145	137	-9
29.05.2019	S-10	59.1451367	8.07348667	40	11.10	11.60	5.42	5.99	-0.73	0.20	0.99	0.18	0.72	0.17	0.00	1.26	1.68	135		15.0	2.7	2.5	2.6	206	158	182	47
29.05.2019	S-100	59.1451367	8.07348667	40	11.10	11.60	5.56	6.04	-0.74	0.25	0.98	0.18	0.71	0.15	0.00	1.90	1.74	181		15.3	2.5	4.4	3.5	145	150	148	-33
29.05.2019	S-1000	59.1451367	8.07348667	40	11.00	11.50	5.54	6.03	-0.74	0.16	0.98	0.18	0.69	0.16	0.00	1.84	1.75	182		13.6	2.4	2.3	2.3	143	132	138	-44
25.06.2019	N-10	59.1451367	8.07348667	40	11.10	11.70	5.28	5.94	-0.68	0.89	1.02	0.18	0.69	0.18	0.00	2.63	1.29	24		14.0	3.7	3.2	3.4	129	118	124	100
25.06.2019	N-100	59.1451367	8.07348667	20		11.70	5.51	5.99	-0.74	0.37	0.97	0.18	0.68	0.16	0.00	1.64	1.71	172		15.4	3.1	1.7	2.4	170	148	159	-13
25.06.2019	N-1000	59.1451367	8.07348667	20	10.80	11.10	5.53	6.05	-0.72	0.31	0.97	0.18	0.68	0.17	0.00	1.33	1.64	155		14.3	1.8	1.7	1.8	130	138	134	-21
25.06.2019	S-10	59.1451367	8.07348667	40	11.00	11.10	5.32	6.02	-0.68	0.30	0.96	0.18	0.68	0.17	0.00	2.52	1.37	28		16.9	2.4	2.3	2.3	143	208	176	148
25.06.2019	S-100	59.1451367	8.07348667	40	11.00	12.40	5.27	5.89	-0.78	0.30	0.99	0.18	0.69	0.18	0.00	1.29	1.66	146		14.2	1.5	1.0	1.3	155	152	153	8
25.06.2019	S-1000	59.1451367	8.07348667	40	11.00	11.60	5.16	5.96	-0.79	0.28	0.98	0.18	0.69	0.17	0.00	1.80	1.38	176		14.2	1.9	1.0	1.5	150	148	149	-27
23.07.2019	N-10	59.1451367	8.07348667	40	11.20	11.80	5.54	5.90	-0.6	0.46	0.99	0.18	0.74	0.16	0.00	1.38	2.26	14		14.8	2.1	2.7	2.4	72	94	83	69
23.07.2019	N-100	59.1451367	8.07348667	20	10.80	11.20	5.62	6.11	-0.81	0.29	0.96	0.18	0.71	0.15	0.00	1.50	1.65	177		14.5	1.5	1.4	1.5	79	167	123	-54
23.07.2019	N-1000	59.1451367	8.07348667	20	10.90	11.40	5.64	6.18	-0.81	0.24	0.97	0.18	0.71	0.17	0.00	1.28	1.67	150		16.0	1.3	1.2	1.3	112	129	121	-29
23.07.2019	S-10	59.1451367	8.07348667	40	11.00	11.50	5.14	6.12	-0.77	0.2	0.97	0.18	0.71	0.17	0.00	1.95	1.71	196		13.5	3.3	1.0	2.2	103	157	130	-66
23.07.2019	S-100	59.1451367	8.07348667	40	11.00	11.40	5.43	5.88	-0.83	0.21	0.97	0.17	0.71	0.17	0.00	1.27	1.68	152		18.3	7.7	6.1	6.9	219	181	200	48
23.07.2019	S-1000	59.1451367	8.07348667	40	11.00	11.30	5.53	6.01	-0.84	0.18	0.97	0.18	0.71	0.17	0.00	1.79	1.36	204		15.1	1.9	3.7	2.8	122	116	119	-85
20.08.2019	N-10	59.1451367	8.07348667	40	11.10	11.50	5.63	5.73	-0.82	0.41	0.98	0.18	0.72	0.17	0.00	1.30	1.66	158		15.0	1.4	1.5	1.4	123	127	125	-34
20.08.2019	N-100	59.1451367	8.07348667	20	11.10	11.60	5.73	5.93	-0.81	0.33	0.98	0.18	0.72	0.18	0.00	1.41	1.67	165		14.9	1.2	1.6	1.4	127	121	124	-41
20.08.2019	N-1000	59.1451367	8.07348667	20	11.10	11.40	5.66	6.04	-0.86	0.15	0.99	0.18	0.73	0.17	0.00	1.30	1.73	152		14.9	1.7	1.5	1.6	118	152	135	-17
20.08.2019	S-10	59.1451367	8.07348667	40	11.10	12.00	5.46	6.00	-0.79	0.18	0.99	0.18	0.72	0.19	0.00	1.57	1.71	174		15.1	2.5	2.2	2.4	117	111	114	-59
20.08.2019	S-100	59.1451367	8.07348667	40	11.10	11.40	5.62	6.00	-0.83	0.21	0.98	0.18	0.71	0.17	0.00	1.82	1.74	187		14.5	1.9	1.5	1.7	117	173	145	-42
20.08.2019	S-1000	59.1451367	8.07348667	40	11.10	12.00	5.62	5.92	-0.83	0.2	0.99	0.18	0.72	0.17	0.00	1.76	1.74	187		15.5	1.1	2.1	1.6	114	186	150	-37
24.09.2019	N-10	59.1451367	8.07348667	40	10.80	10.00	5.56	5.77	-0.17	0.29	0.99	0.18	0.72	0.18	0.00	1.68	1.71	181		15.7	3.2	2.9	3.1	147	133	140	-41
24.09.2019	N-100	59.1451367	8.07348667	20	10.30	10.00	5.80	6.03	-0.12	0.22	0.98	0.18	0.70	0.18	0.00	1.60	1.70	174		18.6	1.8	1.7	1.7	120	123	121	-52
24.09.2019	N-1000	59.1451367	8.07348667	20	10.30	10.00	5.73	6.09	-0.14	0.23	0.97	0.18	0.69	0.17	0.00	1.78	1.79	181		18.4	6.3	6.4	6.4	121	n.a	121	-60
24.09.2019	S-10	59.1451367	8.07348667	40	10.80	10.00	5.44	5.73	-0.16	0.25	0.98	0.18	0.71	0.17	0.00	1.89	1.71	192		15.6	6.0	6.1	6.1	145	164	155	-38
24.09.2019	S-100	59.1451367	8.07348667	40	10.80	10.00	5.49	6.02	-0.15	0.14	0.98	0.18	0.71	0.17	0.00	1.81	1.76	189		14.5	1.3	1.7	1.5	162	171	166	-23
24.09.2019	S-1000	59.1451367	8.07348667	40	10.80	10.00	5.46	6.07	-0.19	0.14	0.98	0.18	0.71	0.17	0.00	1.64	1.38	177		15.6	1.8	2.1	2.0	158	144	151	-27

9.C *Epilimnion results (0-12 m) at far north and south stations.*

Dato	Station	m		mL	µg L^{-1}		µS cm^{-1}	NTU	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	mg L^{-1}	mg L^{-1}	µg L^{-1}	mg L^{-1}	mg Pt L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}	µg L^{-1}
		Secci depth	Colour	filtvolum	Chl-a	pH	Kond	Turb	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	NH$_4^+$-N	SO$_4^{2-}$	Cl$^-$	NO$_3^-$-N	TOC	Farge	Tot-P	Tot-P	Tot-P	Tot-N	Tot-N
		measured																			gj.snitt		
				Chl-a	USN	USN			USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN	USN
29.05.2019	Fyresvatn N	7.3	gulig grønn	2500	0,09	6.10	11.40	0.45	1.06	0.18	0.70	0.23	n.a	1.59	1.70	167		13.7	3.54	3.28	3.41	144	122
25.06.2019	Fyresvatn N	6.2	gulig grønn	2000	0,80	6.14	11.30	0.46	0.99	0.18	0.69	0.21	n.a	1.26	1.64	144		20.3	1.72	1.77	1.74	190	181
23.07.2019	Fyresvatn N	6.3	brunlig gul	2000	0,62	6.40	11.30	0.60	1.01	0.18	0.71	0.21	n.a	1.46	1.72	158		20.2	2.08	2.12	2.10	126	135
20.08.2019	Fyresvatn N	5.5	gulig brun	1700	0,79	6.03	12.60	0.39	0.96	0.18	0.66	0.17	n.a	1.60	1.73	169		19.2	1.85	2.03	1.94	134	137
24.09.2019	Fyresvatn N	7.5	gulig grønn	2000	0,70	6.14	10.00	0.21	1.01	0.18	0.69	0.18	n.a	1.66	1.77	164		18.3	2.40	1.96	2.18	170	174
29.05.2019	Fyresvatn S	7.5	gulig grønn	2500	0,64	6.10	11.20	0.21	1.01	0.18	0.70	0.18	n.a	1.84	1.76	184		13.2	3.31	2.70	3.01	158	141
25.06.2019	Fyresvatn S	6.1	gulig grønn	2000	0,54	6.09	11.20	0.30	1.01	0.18	0.68	0.19	n.a	1.93	1.75	184		15.4	7.12	7.76	7.44	175	187
23.07.2019	Fyresvatn S	8.0	gulig grønn	2000	0,65	6.40	11.20	0.30	1.02	0.18	0.72	0.20	n.a	1.97	1.72	188		17.7	2.51	2.43	2.47	143	144
20.08.2019	Fyresvatn S	6.5	gulig grønn	1700	0,59	6.19	10.70	0.30	0.96	0.18	0.70	0.18	n.a	1.61	1.78	169		18.2	4.23	6.20	5.21		100
24.09.2019	Fyresvatn S	8.2	gulig grønn	2000	0,43	6.06	10.00	0.23	1.02	0.18	0.70	0.18	n.a	1.66	1.79	172		17.8	1.84	1.62	1.73	163	174

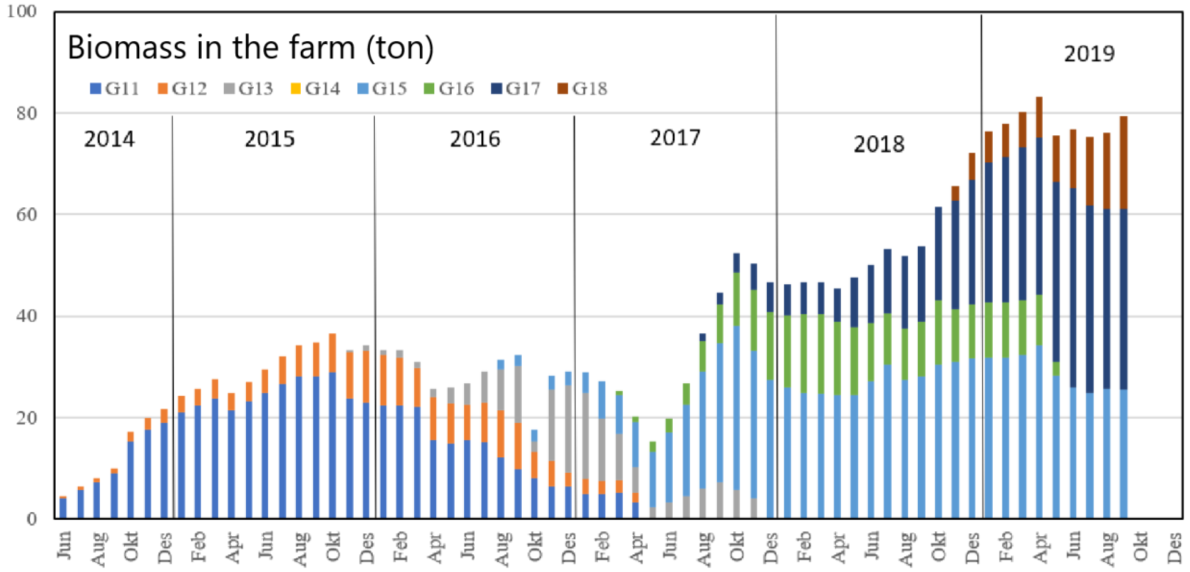
Annex 10: Bottom fauna results 2019

Results from the bottom fauna survey in Fyresvatn, in July 2019. Five parallel samples were taken at 12 different stations along four transects with different distance from the fish pen edge (0, 10, and 30 m) of the fish farm. South-west transect includes stations 1, 2 and 3; North-west transect includes stations 7, 8 and 9; South-east transect includes stations 4, 5 and 6; North-east transect includes station 10, 11 and 12.

Station	Sampling Date	GPS North	GPS East	Depth m	Oligochaeter egg ant. m^{-2}	Oligochaeter voksne ant. m^{-2}	Chironomider larver ant. m^{-2}	Igler voksen ant. m^{-2}	Røye egg ant. m^{-2}	Vårfluer hus ant. m^{-2}	Chironomider hus ant. m^{-2}	Rundorm i oligochaet ant. m^{-2}
1	02.07.2019				0	4.2	0	0	50.4	0	0	0
1	02.07.2019				0	4.2	0	0	8.4	0	0	0
1	02.07.2019				0	12.6	0	0	84	0	0	0
1	02.07.2019				0	21	0	0	12.6	0	0	0
1	02.07.2019				0	42	0	0	8.4	0	0	0
1	**02.07.2019**			**44.5**	**0**	**16.8**	**0**	**0**	**32.76**	**0**	**0**	**0**
2	03.07.2019				0	138.6	0	0	0	0	0	0
2	03.07.2019				0	327.6	0	0	0	0	0	0
2	03.07.2019				0	621.6	8.4	0	0	0	0	0
2	03.07.2019				0	357	0	0	0	0	0	0
2	03.07.2019				0	88.2	0	0	0	0	0	0
2	**03.07.2019**			**45.6**	**0**	**306.6**	**1.68**	**0**	**0**	**0**	**0**	**0**
3	04.07.2019				0	4.2	0	0	0	0	0	0
3	04.07.2019				0	4.2	4.2	0	0	0	0	0
3	04.07.2019				0	54.6	4.2	0	0	0	0	0
3	04.07.2019				0	88.2	12.6	0	0	0	0	0
3	04.07.2019				0	0	8.4	0	0	0	0	0
3	**04.07.2019**			**52.0**	**0**	**30.24**	**5.88**	**0**	**0**	**0**	**0**	**0**
4	02.07.2019				0	16.8	0	0	29.4	0	0	0
4	02.07.2019				0	50.4	0	0	25.2	0	0	0
4	02.07.2019				0	25.2	0	0	0	0	0	0
4	02.07.2019				0	8.4	0	0	12.6	0	0	0
4	02.07.2019				0	67.2	4.2	0	12.6	0	0	0
4	**02.07.2019**			**46.0**	**0**	**33.6**	**0.84**	**0**	**15.96**	**0**	**0**	**0**
5	02.07.2019				0	8.4	0	0	0	0	0	0
5	02.07.2019				0	180.6	0	0	0	0	0	0
5	02.07.2019				0	0	0	0	0	0	0	0
5	02.07.2019				0	29.4	0	0	0	0	0	0
5	02.07.2019				0	315	0	0	4.2	0	0	0
5	**02.07.2019**			**48.0**	**0**	**106.68**	**0**	**0**	**0.84**	**0**	**0**	**0**
6	04.07.2019				0	33.6	4.2	0	0	0	0	0
6	04.07.2019				0	8.4	0	0	0	0	0	0
6	04.07.2019				0	54.6	12.6	0	0	0	0	0
6	04.07.2019				0	25.2	0	0	0	0	0	0
6	04.07.2019				0	4.2	4.2	0	0	0	0	0
6	**04.07.2019**			**54.0**	**0**	**25.2**	**4.2**	**0**	**0**	**0**	**0**	**0**
7	03.07.2019	te forreste	Mye dyr		0	3360	0	0	0	0	0	0
7	03.07.2019	ye forrest	Lite dyr		0	117.6	0	0	88.2	0	0	0
7	03.07.2019	te forreste	Mye dyr		0	3360	0	0	0	0	0	0
7	03.07.2019				0	0	0	0	0	0	0	0
7	03.07.2019				0	0	0	0	0	0	0	0
7	**03.07.2019**			**46.0**	**0**	**2279.2**	**0**	**0**	**29.4**	**0**	**0**	**0**
8	03.07.2019				0	659.4	0	0	0	0	0	0
8	03.07.2019				0	407.4	0	0	0	0	0	0
8	03.07.2019				0	541.8	4.2	0	0	0	0	0
8	03.07.2019				0	701.4	0	0	0	0	0	0
8	03.07.2019				0	609	4.2	0	0	0	0	0
8	**03.07.2019**			**42.0**	**0**	**583.8**	**1.68**	**0**	**0**	**0**	**0**	**0**
9	04.07.2019				0	29.4	4.2	0	0	0	0	0
9	04.07.2019				0	25.2	4.2	0	0	0	0	0
9	04.07.2019				0	88.2	16.8	0	0	0	0	0
9	04.07.2019				0	37.8	4.2	0	0	0	0	0
9	04.07.2019				0	113.4	0	0	0	0	0	0
9	**04.07.2019**			**38.0**	**0**	**58.8**	**5.88**	**0**	**0**	**0**	**0**	**0**
10	02.07.2019				0	4.2	0	0	159.6	0	0	0
10	02.07.2019				0	37.8	0	0	100.8	0	0	0
10	02.07.2019				0	0	0	0	33.6	0	0	0
10	02.07.2019				0	0	0	0	84	0	0	0
10	02.07.2019				0	0	0	0	25.2	0	0	0
10	**02.07.2019**			**46.0**	**0**	**8.4**	**0**	**0**	**80.64**	**0**	**0**	**0**
11	03.07.2019				0	903	4.2	0	0	0	0	0
11	03.07.2019				0	1041.6	0	0	0	0	0	0
11	03.07.2019				0	1163.4	0	0	0	0	0	0
11	03.07.2019				0	0	0	0	0	0	0	0
11	03.07.2019				0	0	0	0	0	0	0	0
11	**03.07.2019**			**43.0**	**0**	**1036**	**1.4**	**0**	**0**	**0**	**0**	**0**
12	04.07.2019				0	79.8	16.8	0	0	0	0	0
12	04.07.2019				0	109.2	0	0	0	0	0	0
12	04.07.2019				0	260.4	12.6	0	0	0	0	0
12	04.07.2019				0	239.4	0	0	0	0	0	0
12	04.07.2019				0	226.8	4.2	0	0	0	0	0
12	**04.07.2019**			**38.0**	**0**	**183.12**	**6.72**	**0**	**0**	**0**	**0**	**0**

Annex 11: Historical data for Telemarkrøye AS production 2014 to November 2019

Historical data for Telemarkrøye AS production 2014 to November 2019. Standing biomass (fish) in the farm, in ton (Johnsen et al., 2019).



Annex 12: Bottom water O_2 (mg L^{-1}) Classification

Class limits for oxygen (O_2 mg L^{-1}) in clear water lakes, for lake types L-N1 (L102, L105a, and L106), low land lakes. Source: Direktoratsgruppen, 2018. Table 7.15 page. 116.

Class limits for Oxygen in Lakes	Clear water types: L-N1 (L102, L106a, L106)					
Parameter	Ref	Very good	Good	Moderate	Bad	Very bad
O_2 (mg L^{-1}) Percentile 50	14	>12	12-9	9-5	5-2	>2
O_2 (mg L^{-1}) Percentile 5	12	> 9	9-5	5-2	2-1	< 1

Bottom water oxygen (O_2 mg L^{-1}) conditions for all station (N-10, N-100, N-1000, S-10, S-100 and S-1000) close to the fish farm in Lake Fyresvatn 2019.

Stations Depth	N-10 40 m	N-100 20 m	N-1000 20 m	S-10 40 m	S-100 40 m	S-1000 40 m	Summed Condition
O_2 (mg L^{-1}) Percentile 50	11	11	11	11	11	11	Good
O_2 (mg L^{-1}) Percentile 5	11	11	10	11	11	11	