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Hydrological assessment and water management study in Norra Bunn

With a focus on fish stock conservation

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Abstract

The focus of this study it to investigate the status of the Norra Bunn lake and the challenges it is facing today then to address these issues accordingly with a focus on water resources management for a better fish stocks conservation.
To achieve the objectives, various literature reviews, data collection from different sources and on-site water samplings are carried out.
The study results show that the lake is suffering from excessive chemical compounds of mercury, mercury associated compounds and polybrominated diphenyl ethers (PBDEs) in fish; oxygen deficiency in the deep water during summer; potentially ongoing brownification development; excessive nutrients load coming from household discharge although there is no strong indication that the lake is affected by eutrophication at the current stage; moderate fish status as a result of moderate population structure of perch and finally the hydropower plant operation disturbs the hydrological regime in the lake that in average 80% of the discharge from the lake is induced by the water extraction.
However, due to the complex nature of each challenge, no direct countermeasure is proposed in this study rather several approaches are proposed to achieve a sustainable fish stocks conservation.

Sammanfattning

Fokus för denna studie är att undersöka statusen för Norra Bunnsjön och de utmaningar den står inför idag med betoning på vattenresurshantering för ett bättre bevarande av fiskbestånden.

För att uppnå målen genomfördes litteraturgranskningar, datainsamling från olika källor och vattenprovtagningar på plats. Resultaten visar att sjön har höga halter av kemiska föroreningar som kvicksilver, kvicksilverassocierade föreningar och polybromerade difenyletrar (PBDE); syrebrist i det djupa vattnet under sommaren; potentiellt pågående utveckling av brunifiering; hög näringsbelastning som kommer från hushållens utsläpp även om det inte finns någon stark indikation på att sjön påverkas av övergödning i nuvarande skede; måttlig fiskstatus som ett resultat av måttlig populationsstruktur av abborre och slutligen stör vattenkraftverksdriften det hydrologiska systemet i sjön. Flera metoder föreslås för att uppnå ett hållbart bevarande av fiskbestånden.

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List of abbreviation

DNM Ditch Network Maintenance
DO Dissolved oxygen
FVOF Fiskevårdsområdesförening
IDW Inverse Distance Weight
TN Total nitrogen
TP Total phosphorus

1. Introduction

1.1. Background & motivations

The lake Bunn is situated in the center part of Sweden about four kilometers southeast of Gränna, within the border of Jönköping region and it belongs to the Röttleån water system that flows into lake Vättern. According to the water information system of Sweden (VISS), the Bunn lake is a mesotrophic lake and it is designated as regionally particularly valuable water for fishing though it is judged to have a low natural value (VISS, n.d.).

Lake Bunn naturally has only one outlet where water discharged into Röttleån river and eventually conveys to Vättern downstream. In the meanwhile, Bunn receives inflow from two lakes upstream, one is lake Ören situated at the East of Bunn and another one is Ruppen situated at the South of Bunn. Additionally, there is another discharge point situated at the southwestmost corner of Bunn and has been extracting water to the Röttle hydropower plant which is owned and operated by Jönköping Energi AB which is situated near Vättern for the electricity production since 1922 (Länsstyrelsen i Jönköpings län, 2014). A map illustrating the layout of Bunn and its natural outlet, inlets, water extraction point are presented in Appendix 1.

In fact, the lake Bunn consists of three pools which are Norra, Mellan and Södra Bunn, in total they have a surface area of 10.18 km^2. In this project, the focus is Norra Bunn and Mellan Bunn which they have a surface area of 7.51 km^2 and a volume of 51 million cubic meters (Anders Svahnberg, 2016). In this study, these two pools together will be referred as Norra Bunn unless otherwise stated and the division of lake Norra Bunn and Södra Bunn is also illustrated in Appendix 1 with a green line.

According to the previous investigation carried out in August 2015 (Länsstyrelsen Jönköping, 2016) the lake Bunn was rich in fish and around 10 different species were caught, such as perch, bream, pike roach, etc. During the investigation, the fish stocks were dominated by perch and roach. However, due to the brownification and potentially undergoing eutrophication development in the lake it is of great interest for the fish conservation association (Fiskevårdsområdesförening, FVOF) of Norra Bunn to understand the comprehensive status of the lake and to manage the lake in a sustainable way for the conservation of fish stocks in the lake, with a focus on the water resources management.

Especially, as a fact that for these relatively small and private owned surface water, there is no clear instruction from the Swedish authority on what is or how should a good fish management plan be. Although it is stated on the website of Swedish Sea and Water authority that there is an ongoing work for a development of a sustainable and common strategy for both professional and sport fishing to balance the environmental ambition with the fish stocks (Swedish Agency Marine and water Management, 2021).

Besides, the current effective fishing regulations such as fishery regulations (FIFS 2004:37) in terms of recreational fishing mainly focuses on regulating the fishing methods, gears, baits, location, species, etc, rather than focusing on a management perspective. Apart from what has been regulated by laws, it is the water owner, in this case the FVOF's responsibility to manage the lake.

Therefore, it is of a great importance that there could be a general plan or guidance for these small lakes to refer to in the future for a better fish stock management.

1.2. Objectives

The main objectives for this project are to firstly investigate the status of the lake in a comprehensive way, in terms of hydrological and ecological aspects. Secondly, it is to recognize the issues that the lake is facing. Finally, it is to address the issues accordingly in terms of fish stocks conservation.

1.3. Approaches

To meet these objectives stated in the previous sub-section, a hydrological assessment of the lake is in need to investigate the hydrological status.

Apart from that, water qualities in the past twenty years should be investigated to have an overall picture about how the water quality has been varying over the years. In addition, water sampling and analyzing at various spots in the lake is also desired to get an overview of the current water status and as an attempt to confirm what had been discovered in the past.

Subsequently, it is also important to identify the issues that need to be addressed prior to the others.

Supplementarily, a general suggestion of the speed limit of ships navigating in the lake is also included. As it is believed that high speeds generated waves might induce negative ecological consequences, such as disturbing the aquatic life and generate sediments transport. However, it would not be a major part of the study, thus the impact of ships will not be quantified and discussed in the text. Hence it is presented in the Appendix 2 instead.

In the end, preliminary suggestions on the water management of Norra Bunn with a focus on maintaining fish stocks will be presented.

2. Data & Methodology

2.1. Data collection & Literature review

To establish a thorough understanding of the project and to assess the hydrological condition in the Norra Bunn lake, this study included various literature review with a focus on the lake, hydrological model, and sustainable water management in terms of fish stock conservation.

Especially, to get a general picture of the fish stocks in the lake, there are several attempts. Firstly, with the object of maintaining fish stocks in the Norra Bunn, it is necessary to get an overview of the fishing volume over the years and the fishing interest of the lake. Therefore, the online fishing reports of Norra Bunn on the Ifiske website were summarized and interpreted from year 2016 to 2020.

Secondly, the fish test report of year 2015 was also studied to obtain information about fish species and potentially some relevant information about fish stocks.

2.2. Hydrological & hydraulic modelling

In order to assess the current hydrological status in the Norra Bunn, a hydrological assessment is needed. During the assessment, mainly the results downloaded from SMHI HYPE model were used and several assumptions were made where data were not available. Moreover, it is noteworthy that there was no calibration or optimization of the results in this study.

Apart from that, all necessary data were collected from accredited sources, such as SMHI, VISS and SUG to build a clear understanding of hydrological model for the lake.

2.2.1. HYPE model

HYPE model is a process-based hydrological model for the simulation of water flows and nutrients from precipitation through land, soil, river and lakes to the outlet. In the model there are mainly three parts to represent the water movements and balance, that is water in soil layers, water in rivers and water in lakes (SMHI, 2013).

Especially, the simulation is highly relying on soil types and landuse in each model domain. Today, the HYPE model is applied to entire Sweden and results of the simulations are updated continuously and are available flow download on the Vattenwebb. Additionally, the model has been applied in Sweden since 2008 (SMHI, n.d.). The water balance in the HYPE model can be illustrated as following:

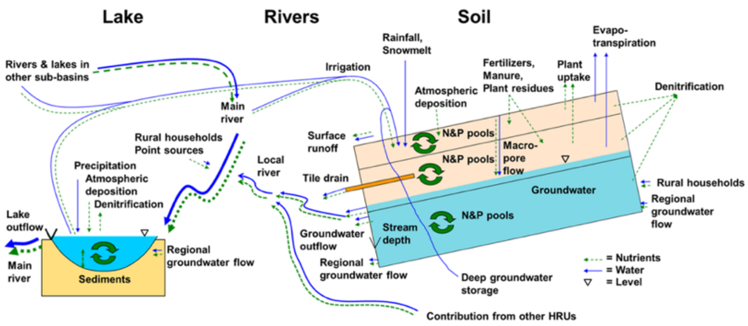

Figure 1: Conceptual illustration processes of water balance in HYPE model (SMHI, 2013).

Bunn lake is modelled by HYPE model as a sub-catchment, the detailed information, model version about the sub-catchment which were used in the model were presented in Appendix 3. Modelling results from 2004 to 2020 were obtained and only data from 2004 to 2019 were used in the hydrological assessment due to the availability of monthly data were not updated for the whole year of 2020 at the time of the assessment, so that a water balance can be made.

It is worth noticing that the results downloaded were meant for the entire sub-catchment of lake Bunn. Nevertheless, Norra Bunn is situated at the downstream direction of the lake, thus the modelling results including flow from upstream, local surface runoff, discharge to the Rötteleån river, local nutrient loads can be directly used for assessments without having to make any modifications.

Although, the detailed data regarding water content in the soil layers including groundwater flows are not included in the results obtained from SMHI though it is modelled. Therefore, a simplification of the hydrological cycle of the lake Bunn sub-catchment was made. That is assuming the imbalance between sum of inflow and outflow from different sources reported in the results sheet is induced by the soil water variation in the form of soil water recharge.

Although in the reality, there might be a small portion of water taking out from the lake for small scale irrigation purpose, it is considered to be negligible.

2.2.2. Water extraction from hydropower plant

The Röttle hydropower plant operating by the lake Vättern and is continuously extracting water from the upper North of Norra Bunn lake. Besides the hydropower plant, there is also a dam called Boget that is regulating the water which is located before the water conveys downstream to the Röttle river. In the HYPE model, the water extracted by hydropower plant and discharged from the Boget was simulated as an entity, however it is not simulated or calibrated with the operational records at the hydropower plant. Consequently, some inconsistencies between the simulated flow and the operational records are expected. Hence, it is important to include water extraction in the water balance of Norra Bunn lake induced by the hydropower plant.

Moreover, the daily average water extraction rate to the hydropower station was available for year 2011-2020, however, during year 2005-2010, there were only monthly and annual power production records available from the Jonköping engeri AB which owns the hydropower station.

Thus, to estimate the flow rate during year 2005 to 2010, the average production efficiency (η= 76.38%) from year 2011 to 2020 was used to back calculate the flow rate, which was used for the production of electricity, see equation 1.

$$P = \rho \times q \times g \times h \times \eta$$

Equation 1: Calculation of power production where P denotes energy production, kilowatt;

ρ denotes the water density, which is 1000 kg/m^3;

g denotes the acceleration of gravity, m/s^2;

h denotes the static head, in this case 108 m was used, unless otherwise stated;

η denotes the power production efficiency, %.

The power production and water extraction rates for year 2011 to 2020 are known, thus an average water production efficiency could be obtained and used to calculate the water extraction rate in 2005 to 2010.

Furthermore, there were no yearly or monthly data available for the water flow at the dam Boget to the Röttleån river for year 2005-2010, thus the flow records from year 2011- 2019 with similar precipitation over the years were used instead. A table of which years were used as a reference is presented in the appendix 4.

2.2.3. Water balance of the sub-catchment

All sources of annual inflow except soil water flow are available from HYPE model results. As a rule of thumb, the water enters the sub-catchment should equal to water leaves the sub-catchment at an equilibrium state. Hence, a simple water balance relationship could be established (Equation 2):

$$Q_{Total\ in} = Q_{Total\ out}$$

Equation 2: Simple water balance equation

where $Q_{Total\ in}$ and $Q_{Total\ out}$ denote the total incoming and outgoing water to the sub-catchment where lake Bunn is located, respectively, m^3/s;

$$Q_{total\ in} = Q_{up} + Q_{precp.} + Q_{ww}$$

Equation 3: Total incoming water to the sub-catchment where Q_{up} denotes the inflow coming from the upstream, in this case, it includes flow from lake Ören and Ruppen,

$Q_{precp.}$ denotes the precipitation over the whole sub-catchment,

Q_{ww} denotes the wastewater coming from the surrounding residential area, in this case, no water consumption variations would be considered, and it is assumed that the discharge from households remains the same crossing the years.

Although the figures for upstream incoming water are not directly available in the simulation results of HYPE, but it can be derived from the equation 4:

$$Q_{up} = Q_{total\ out} - Q_{precp.}$$

Equation 4: Calculation of upstream flow to the lake

In addition, a hydraulic retention time could also be obtained:

$$T = V_{Norra} \div Q_{Out}$$

Equation 5: Calculation of hydraulic retention time

where T denotes the hydraulic retention time, year;

V_{Norra} denotes the volume of Norra and Mellan Bunn, m^3;

Q_{Out} denotes the discharge outflow from the lake, that includes flow to the hydropower plant and flow to the downstream (natural outflow and regulated flow at Boget dam), m^3/a.

2.2.4. Wastewater discharge from private household

According to the residence map around Norra Bunn (see Appendix 5) provided by the Jönköping municipality, there are around 263 households reside in the surroundings area of Norra Bunn. For the estimation of wastewater and nutrients discharge through private sewer, see equation 5, it is assumed that there are 2.2 capita per household (579 residents in total) with a water consumption of 0.15 m3/d per capita and the domestic wastewater contains typically 80 g/m^3 TN and 23 g/m^3 TP. In addition, a discharge coefficient of 0.8 was applied.

$$Q_{ww} = q \times p \times C_{ww}$$

Equation 6: Estimation of domestic wastewater discharge

q denotes the daily water consumption per capita, m3/d;

p denotes the total residents in the surrounding area;

C_{ww} denotes the wastewater discharge coefficient which is 0.8 in this case.

In this way, wastewater and nutrients discharge from the private sewer to the lake remained the same throughout the years and any water consumption variation during different seasons were neglected.

The total out flow from the lake could thus be:

$$Q_{Total\ out} = Q_{evap} + Q_{out} + Q_{Hydro}$$

Equation 7: Total outflow from the sub-catchment

where Q_{evap} denotes the amount of water leaving the sub-catchment in the form of evapotranspiration, m^3/s;

Q_{out} denotes the total water discharge flow from the lake, which is the station corrected flow from HYPE simulation results, including water extraction flow for power production, m^3/s;

Q_{Hydro} denotes the water extraction flow from the lake for power production, m^3/s

2.2.5. Daily precipitation rate

Since the daily precipitation rate is not simulated in the HYPE model, the Inverse Distance Weight (IDW) method is used to calculate the precipitation rate in the middle of Norra Bunn. The IDW method calculates the precipitation based on the weighted distance from the available three meteorological stations (Visingsö A, Högemålen, Ramsjöholm station) which form a triangle around the Norra Bunn, as shown in Appendix 6. The further the distance to the center of Norra Bunn, the lower the weight is.

To simplify the calculation, a power to 1 is chosen for the IDW function. The equation is as shown below:

$$P_{Bunn} = \left[\left(\frac{P_V}{D_V}\right) + \left(\frac{P_H}{D_H}\right) + \left(\frac{P_R}{D_R}\right) / (\left(\frac{1}{D_V}\right) + \left(\frac{1}{D_H}\right) + \left(\frac{1}{D_R}\right)\right]$$

Equation 8: IDW interpolation method for the calculation of precipitation rate

where P_{Bunn}, P_V, P_H, P_R denote the precipitation on top of the center of Norra

station, respectively, mm;

D_V, D_H and D_R denote the distance between Visingsö A, Högemålen and Ramsjöholm station to the center of Norra Bunn, km.

While the distance from Visingsö A, Högemålen and Ramsjöholm station to the center of Norra Bunn are 13.43, 19.57 and 24.94 km accordingly.

2.3. Water quality in the lake

The water quality in the lake Bunn has been monitored and evaluated by Jönköping municipality in two programs. One is part of the recipient control program of lake Vättern where the water sample is taken once a year and certain parameters are measured. Another one is the surface water management program where the lake is evaluated and classified by various criteria in a rather comprehensive way which includes mainly ecological and water chemical classification. For these two programs, the same monitoring station/ sampling point is used, which is located in the middle of Norra Bunn. As a result, these information are considered to be representative to depict the status of Norra Bunn.

2.3.1. Water management program

In the water management program, which is reported and updated regularly on the website of VISS. The information and data were collected from the website and interpreted to get a comprehensive picture of Norra Bunn.

2.3.2. Control program

In the control program, there are data available from 1999 to 2020 which are gathered in the environmental database of SLU website. For the purpose of understanding the development of water quality over the year, data from the database were downloaded and interpreted.

2.3.3. On-site water sampling

To get a current figure of water quality in Norra Bunn, field work was carried out to collect water samples from various spots (see Appendix 7 for sampling points) in the lake and sent to accredited lab for the analysis.

Water sampling

The water samples were taken using a 2-litter Rutter sampler. The water samples were taken at nine different locations with one surface and one bottom samples at the same location where the water is more than 10m deep. In addition, surface samples were taken at approximately 0.5 meter below the water surface and bottom samples were taken at approximately 6m above the lake bottom.

There are prefixed markers on the cable of the sampler where each marker denotes approximately 0.5 meter. As for the bottom samples, the bathymetric contour map of Norra Bunn, which is also the fishing map was taken as a reference. Therefore, it has to be bore in mind that the depth of the bottom sample might not necessary be at six meters above the bottom.

On-site analysis

Water temperature, dissolved oxygen and turbidity was measured with portable devices when the samples were taken.

Among these, temperature was measured by the dissolved oxygen meter (Hanna HI-9146) while measuring for dissolved oxygen, turbidity was measured with turbidity meter (Hanna HI-93703) and pH was measured with a portable pH meter (Eutech waterproof pH testr 20). All the measurements were done according to the instructions.

2.3.4. Status classification

To be able to compare the water sampling results with the existing water quality data, the same Swedish status classification standard (HVMFS 2019:25) which was used in the water management cycles was applied whenever it was applicable. In this study, mainly the classification of Chlorophyll a, nutrients, dissolved oxygen, fish stocks and sight depth were applied or referred to. Among these parameters, most of them were classified based on a scale of EK value which in general is a ratio between reference value and observed value of each assessment criteria or parameter. Each parameter has different classification scale and reference value. Especially, the reference value was calculated for each water bodies. Due to lack of information, it was impossible to calculate the reference values in this study, thus only those available reference values reported in the management cycle were used.

As for dissolved oxygen, the classification scale is based on the dissolved oxygen content in the water. Different classification scales were presented in the following sections where it is relevant.

3. Results & Discussions

3.1. Fishing volume from 2016-2020

To fish in Norra Bunn, it is required that one must have a fishing license and bound with the fishing license are several regulations in the lake, in relation with sport fishing. The regulations include 1) No jet driving in the lake and a boat may not drive faster than 7 knots in restricted area; 2) Only limited fishing gears can be used such as rod and spin; 3) Prohibited fishing in the certain area such as park, garden and area with nets and crayfish; 4) No fishing of crayfish; 5) Retaining size of pike and pikeperch for no less than 50 cm and up to 80 cm for pike and 70 cm for pikeperch; 6) Only two of each fish species one may retain; 7) Only two rods can be fishing at the same time (Södra Bunn FVOF, n.d.).

According to the available fishing reports reported on iFiske (iFiske, 2021), the sport fishing activities were more frequent during April to November. Fishing records were occasionally found during Decembers. The fishing reports normally include fish species, quantities, weight, type of baits, date and approximate locations. As it is stated with the fishing license that there are few regulations However, not all fields are obligatory, and the accuracy of the data was unknown.

Furthermore, it should be pointed out that not all the fishes that were captured in the lake were reported on the website by anglers and the unreported amount could not be quantified. However, it is the only available data source, and the unreported amount of fishing records is believed to be insignificant since the fishing report is obligatory by law.

According to the records from IFiske(iFiske, 2021), there were in total 1563 fishes caught in the lake of which only 662 sets of fish were not returned (75.94% return rate).

It is obvious that in the sport fishing, fish species in the lake were dominated by perch and pike while perchpike, Roach and Carp were also occasionally caught in the lake. A table of summary is as presented below in table 1:

Table 1: Fishing report from 2016-2020 according to records found on the website of iFiske (iFiske, 2021).

Year	**2016**	**2017**	**2018**	**2019**	**2020**	**Sum**	Returned rate, %
Pike	42	104	138	102	301	687	90.83
Perch	18	105	131	265	263	782	61.89
Pikeperch	8	1	19	7	9	44	79.55
Roach	1	11	7	3	19	41	43.90
Carp	-	-	5	-	-	5	100.00
Bream	-	-	-	1	-	1	100.00
Tench	-	-	1	1	-	2	100.00
Salmon	-	-	1	-	-	1	0.00
Sum	69	221	302	379	592	1563	75.94

It is obvious that there was an increasing trend of people's interests in fishing in the Norra Bunn, thus it brought an increasing fishing capacity over the years. While the return rate of perch was the highest (more than 90%) and less than half of the roaches were returned.

Especially for Pike and Perch, there is in general an increasing trend of fish catch over 2016 to 2020, where the capture of perch was almost quintupled in 2017 and the increasing rate differed less than 1% in 2020.

As for pike, there is also a general increasing trend except in 2019 where the increasing rate was negative (-26.09%), though the figure rose again to almost twice (195.10%) of the amount of 2019 in 2020.

As a result of the growth of pike and perch capture over the years, the total figure of fish capacity also increased. The variation of increasing rate was in a range of 56.20% to 220.29%.

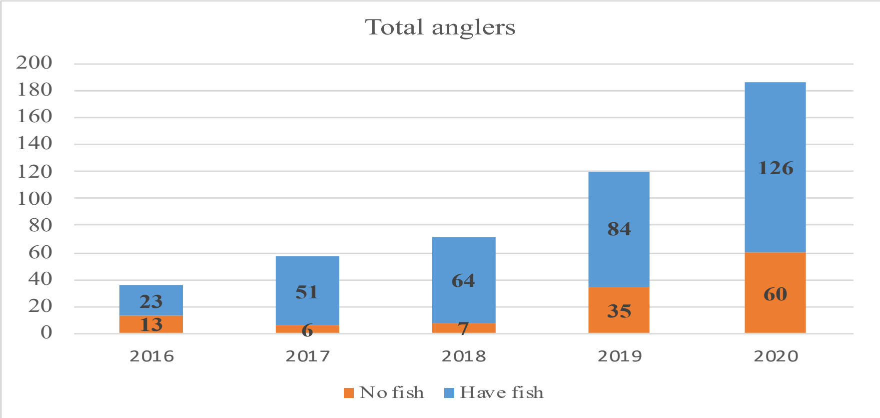

Figure 2: Number of anglers that caught fish and did not catch fish

When looking into the total number of anglers that were fishing in the Norra Bunn over the same time period, the figure of anglers fishing in the Norra Bunn was increased from 36 to 186 per year, though not everyone captured a fish, see figure 2. Moreover, the variation of anglers that captured at least one fish almost complied with the increasing rate of fishing capacity reported above, except for 2017 where the figure of people who caught fishes were increased by 121.74% while the fishing capacity was increased by 220.29%.

Although the sizes of different fishes varied over the years, there is a suspicious reduction of fish sizes for pike, perch, and pikeperch by less than 10% on average from year 2016 to 2020, see table 2. Besides, when taking the fish capture per capita into consideration, it exhibits a similar trend with the fishing capacities that the figure is in general increasing and the dramatic increase was in 2017 where the figure was rising as much as sixfold than in 2016 and the increments for the rest of the years (2018 and 2020) were less than 10%, except for year 2019, where a slightly decline by 4.38%, figure 3.

Table 2: Average weight of fish during the years

Species	2016	2017	2018	2019	2020
Pike	1.79	1.72	1.78	1.46	1.63
Perch	0.30	0.23	0.37	0.15	0.17
Pikeperch	2.44	1.50	0.80	2.57	2.28
Roach	0.05	0.05	0.04[1]	0.03	0.04

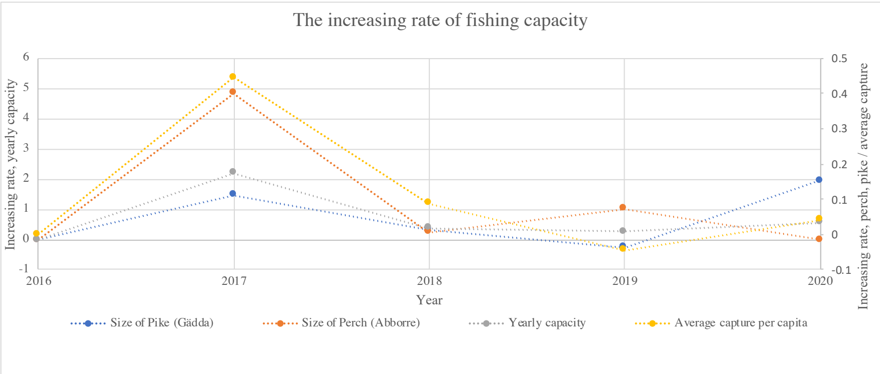

Figure 3: The increase of fish catches over the years (2016 to 2020)

It is known that the preliminary stage of eutrophication in the freshwater is favored for the population of fishes thus the population will rise preliminarily. However, with the proceeding development of eutrophication, it will negatively affect the fish stocks which will eventually lead to a declining fish population due to various reasons, e.g. oxygen depletion in deep water, oxygen supersaturation in upper water layer during summer, over-dense vegetation coverage, etc (Willemsen, 1980).

However, increasing fish captured and slightly decreasing of fish sizes does not necessarily reflect the fish stocks variations in the lake, due to various factors that can affect the captures, such as baits, weather, anglers' experience, fishing methods, location, etc.

[1] This figure is considered to have very poor reliability due to many uncertainties in the online report.

Besides, due to the lack of data and unsupervised data quality, it is hard to draw a solid conclusion that these variations are induced by the potential eutrophication in Norra Bunn based on the data acquired from iFiske.

3.2. Fish test in 2015

The following statement in this section is based on the observations of the fish test report which was carried out in 2015 (Länsstyrelsen Jönköping, 2016) unless otherwise stated.
During the fish test which was carried out in the middle of August for five days (August 11th to 15th), 40 bottom nets and six pelagic nets were used placed in the entire lake Bunn. During the test, it was observed that in bottomed nets the catch was dominated by perch and roach and the total catch was slightly higher than the standard value while the pelagic nets were dominated by roach. In total, 1595 fishes that weighted 63kg in total and 10 species including perch, bream, ruffe, pike, pikeperch, roach, Eutopean smelt, rudd, vendace and tench of which it consisted, were caught. However, there were no catch in the deepest zone in the bottom nets from 12-20 meters and in the pelagic net from 12-18 meters due to the lack of oxygen from the depth of 8 to 10 meters. (abborre, braxen, gers, gädda, gös, mört, nors, sarv, siklöja och sutare.)
Different fish species that were caught at different depth were illustrated in table 3 and the darker color indicates where the species were caught the most except roaches where the fishes with average weight were caught mostly at the depth from 6 to 12 meters.

Table 3: Fish species caught at different depth in the fish test of 2015.

Depths, m	Species caught									
0	Roaches				Ruffe	Pike			Rudd	Tench
3		Bream		Pikeperch						
6			Perch				European smelt			
9								Vendace		
12										

Overall, by assessment of the total biomass, the lake was weakly dominated by carp fish which includes roach and bream. However, it was also recognized that their assessment method in general would

underestimate the stock of pike which is a popular species for sport fishing.
According to the report, the ecological status of the fish community did not change ever since 2005 and was classified as in a good status, based on the assessment method EQR8. It was also concluded in the report that it was unlikely the lake was affected by eutrophication or acidification at that time.
Above all, when comparing the results from fishing test in 2015 and fishing reports on iFiske during 2016 to 2020, there are significant variations, see table 4.

Table 4: Fishing results comparison between fishing test 2015 and fishing records from 2016 to 2020.

Fishing test	2015	2016	2017	2018	2019	2020
Pike						
Quantity	5	42	104	138	102	227
Weight Total, kg	1.59	75.25	179.35	246.25	149.35	371.1
Average, kg	0.32	1.79	1.72	1.78	1.46	1.63
Perch						
Quantity	603	18	105	131	265	263
Weight Total, kg	30.93	5.4	24.58	49.09	39.43	43.65
Average, kg	0.05	0.3	0.23	0.37	0.15	0.17
Pikeperch						
Quantity	18	8	1	19	7	9
Weight Total, kg	0.76	19.5	1.5	15.27	18	20.5
Average, kg	0.04	2.44	1.5	0.8	2.57	2.28
Roach						
Quantity	938	1	11	7	3	19
Weight Total, kg	23.26	0.05	0.6	0.25	0.08	0.7
Average, kg	0.02	0.05	0.05	0.04	0.03	0.04

It is obvious that the fish caught in the fishing test 2015 was in average smaller in size than in the fishing reports from sport fishing while only pike were captured more in sport fishing than in the fishing test. When comparing the quantity of perch, pikeperch and roach, it is clear that the catch in sport fishing was far less than what was caught during the fishing test. The possible causes are, firstly, the sport fishing depth was unlikely to reach as far as the fishing test and cover different depth and area evenly; secondly the baits used for sport fishing were not designed for catching fish fry; anglers might have their own personal preferences or goals in catching a specific species while sport fishing.
Additionally, the results also agreed with the fact that the standard method used in the fishing test would underestimate the population of pike when comparing it with the sport fishing records from the previous section that unlike the fishing test result, the sport fishing volume was dominated by pike and perch judging from the total biomass.

3.3. Hydrological and Hydraulic assessments

3.3.1. Hydrological assessment

In this section, data used in the analysis or assessments were obtained from the HYPE model results for Bunn lake (SMHI and Havs- och vattenmyndigheten, 2021) and operational records obtained from Jönköping Engeri AB (Jönköping Engeri AB, 2021), where hydropower production was relevant, unless otherwise stated.

Inflow to the lake

Based on the results from HYPE model, the main annual inflow to the sub-catchment from various sources were plotted in figure 4. The inflow to the lake consisted mainly two parts which includes inflow from the upstream (including regional groundwater flow), inflow from precipitation (both precipitations generated surface runoff and precipitation on top of the lake).

In general, from 2004 to 2019, the inflow from upstream, which included discharge from Ören lake and Ruppen lake and potential regional groundwater flow varied from 0.35 to 1.41 m^3/s, which took around 41% of the total inflow and was fluctuating in the range of 22% to 51%.

Another source of inflow was precipitation, the annual precipitation varied from 0.89 to 1.52 m^3/s, which made up more than half (59%) of the inflow over the years, and was fluctuating in the range of 49% to 77%.

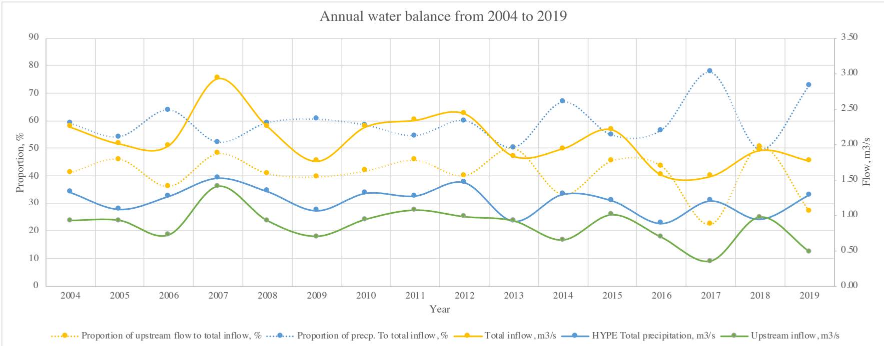

Figure 4: Annual inflows to the lake from various sources, 2004 to 2019.

Nutrient load

In addition, the wastewater discharge into the lake from private households in the surrounding area only accounted for less than 10^{-4} %, thus is not presented in the figure above.

With the assumptions made in the previous section, a consistent daily discharge of water 69.48 m^3/d was yielded which is equivalent to 8.04×10^{-4} m^3/s. Due to the lack of information about applied wastewater treatment processes at each household, it was assumed that at the point of wastewater discharged into the lake, there would be a 40% reduction of total nitrogen and 80% reduction of total phosphorus. Assuming at the point of wastewater discharged into the lake, there would be a 40% reduction of total nitrogen and 80% reduction of total phosphorus.

As a result, there would be approximately 93.32 kg total phosphorus and 973.83kg total nitrogen discharged into the lake on an annually basis. These are rather similar figures with the figures included in the HYPE model where 100 kg and 1181 kg for total phosphorus and total nitrogen discharge coming from households in the area, respectively.

Moreover, total phosphorus and total nitrogen discharged by households accounted for in average 19.98% and 6.59% annual nutrients discharge from the sub-catchment of Bunn, see figure 5. It was obvious that the proportional discharge of nutrients from private sewer to the total local discharge of nutrients varied during the years. The less precipitation of the year, the higher the proportion of private discharged nutrients was. During the driest year (2016) the total phosphorus and total nitrogen discharged by households accounted for 28.77% and 8.79%, accordingly. While the rest of the local nutrient loads came with mainly surface run off that entered the lake. Given the fact that the proportion of wastewater discharge from the private sewers only accounted for less than 10^{-4} % of inflow (including private sewer discharge and surface runoff) within the sub-catchment that was modelled for nutrient loads, the contribution of nutrient loads induced by private sewers is considered as significant.

Subsequently, assuming the private sewer were to be connected to a public sewer system and transported to a wastewater treatment plant, which means that there would be no discharge of nutrients coming from private households. That would be an average reduction of 19.98% total phosphorus and 6.59% total nitrogen.

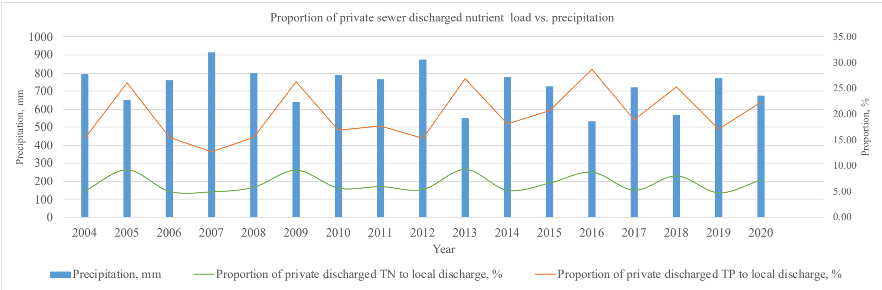

Figure 5: Proportion of private sewer discharged nutrient load vs. precipitation

Outflow from the sub-catchment

The annual total outflow from the sub-catchment was consisted of three main sources and were plotted in figure 6. The first one was the water extraction to the hydropower plant. The second was the water discharge from the outlet of the lake. The last one was the evapotranspiration.

According to the simulation results from HYPE, the water discharge from the lake (natural water flow and hydropower extraction), which was the station corrected discharge, ranged from 0.59 to 2.38 m^3/s, and was accounted for 45% to 66% of the total annual outflow, around 58% in average.

In general, from 2004 to 2019, the outflow to the hydropower plant varied from 0.71 to 1.96 m^3/s, which took around 60% of the total outflow from the sub-catchment, which was in the range of 33% to 81%.

The last main outflow source, evapotranspiration over the sub-catchment was ranging from 0.71 to 0.97 m^3/s and took up around 24.22% of the total outflow.
It is worth noticing that the discharge from the natural outlet of the lake was not presented below as it accounted for only 4% of the total outflow.

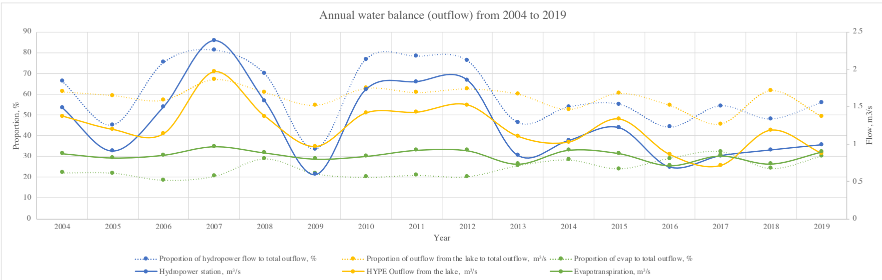

Figure 6: Annual water balance, outflow from 2004 to 2019

It is worth mentioning that, even though the HYPE simulated outflow theoretically also included the water extraction from the lake, however, it could be observed that at some points the simulated outflow was even lower than the water extraction flow. Specifically, the proportion of water extraction accounted for 61% to 131% of the simulated outflow which was in average 103% of the simulated outflow. The reasons for the outbalanced water extraction than the simulated flow are, firstly, the simulated flow was calibrated based on real measurements where it was applicable. However, within this model domain (sub-catchment of Bunn), there was no flow measurement, and the simulated flow was thus calibrated based on the station corrected flow at downstream of the lake where the flow measurements were available. Secondly, the simulated results were after all simulations based on various given information and assumptions, where the changes of conditions in the sub-catchment could not be monitored all the time. Besides, the flow records from the hydropower plan are somewhat more reliable than the simulation. Therefore, there would be occasions that the simulated results do not agree with the reality.

Nevertheless, as a widely applied model, the HYPE simulated results are still considered useful for the illustration of water balance within the sub-catchment and more importantly, to what extend a water component is affecting the lake, even though the exact figures might deviate from what were simulated. In this case, it is clearly presented that the water extraction to the hydropower plant took a significant share of the water budget in the lake.

Water extraction from the hydropower station

The statement in this sub-section was mainly based on the operational records obtained from Jönköping Energi AB, unless otherwise stated. According to the operational records, the water extraction to the hydropower plant was very low in 2009, due to low power production. For the rest of the years during 2004 to 2019, there were always relatively low water extraction during summer and autumn, around May to September or June to November, see figure 7. That was mainly due to the decision made by the Växjö district court on 1998-03-31, that Jonköping Energi AB is responsible to release a minimum discharge of 0.15 m^3/s during the May and October and 0.035 m^3/s during the period of June - September through the regulation dam Boget at the natural outlet.

However, the minimum discharge shall cease when the water level in the lake falls below the lowering limit of 195.55m above the datum(Växjö Tingsrätt, 1998).

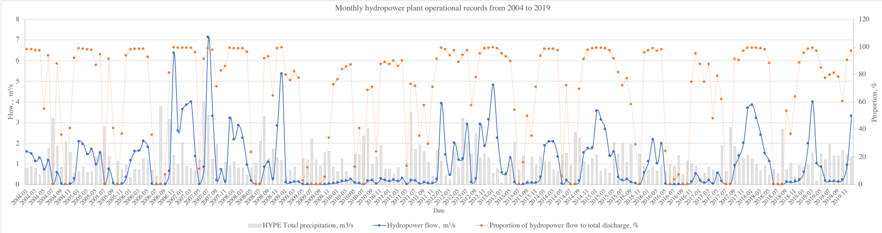

Figure 7: Water extraction to the hydropower plant during 2004 to 2019

Especially, when looking into the water discharged from lake Bunn, the water extraction by the hydropower plant took up from 0% to 99%. That was in average 80 %, excluding when the hydropower plant was not in operation. Thus, it is obvious that the hydropower plant had been taking a significant amount of water from the lake.
On the other hand, the water level at the extraction point in the lake had been monitored the whole time due to the fact that the hydropower plant needed to obey the water permit that the water level could not drop below 195.55m, relative to the datum (Växjö Tingsrätt, 1998). The variation of water levels at the monitoring point which had been monitored during the operation. Though the annual average variation during all the years was less than 1 cm. A maximum variation of 15.6 cm comparing with the day before (2003/06/28). That was due to the fact that the water level fluctuated quite much throughout the years from 2005 to 2020. But one has to bear in mind that the water level variation at the monitoring spot does not mean the water level variation in the lake, it is considered to be less fluctuated in the lake in general.
As an example, the water level variation of year 2012, which was a wet year is illustrated in the figure 8.

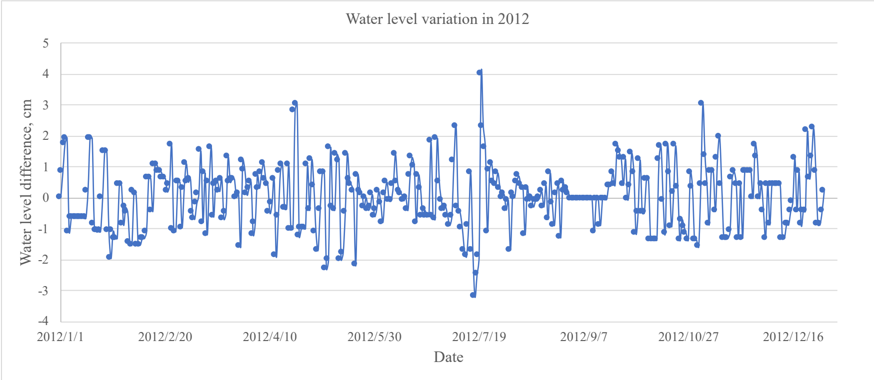

Figure 8: Water level variation in 2012.

Besides, the hydraulic retention time calculated by equation 5 gave a retention time of 1.51 year in average (average flow of 1.07 m^3/s). Although it was hard to determine the hydraulic retention time without the hydropower plant, it was possible to do so with the simulated results from HYPE model. According to the simulation flow as if the lake was not regulated by dam, the annual average flow was 1.38 m^3/s over the years so that a hydraulic retention time of 1.17 year. Hence, there was approximately an increase of hydraulic retention time by 29%.

As a result, the operation of hydropower plant is considered of having a significant impact on the hydrological regime of the lake, though the impact induced by this could not yet be quantified in this study.

3.4. Water quality status:

The water quality in the lake Bunn is monitored by Jönköping municipality in two programs. One is part of the recipient control program of lake Vättern where the water sample is taken once a year and certain parameters are measured. Another one is the surface water management program where water quality is evaluated and classified in a rather comprehensive way which includes ecological and chemical classification.

3.4.1. Water management cycles on VISS

In this section, all the data and classification information presented were obtained from the open information regarding these three water management cycles which are reported on the VISS website (VISS, 2021), unless otherwise stated.

There are currently three management cycles of surface water across Sweden from 2004 to 2021. During all management cycles, there are two main quality requirements including ecological requirement and chemical requirement of surface water. Thus assessments during the management program are also focusing on ecological and chemical status of surface water, which include many assessment parameters under each criteria (VISS, 2021).

In the latest management cycle, which is still active, the targeted environmental standard requirement for the lake Bunn is to achieve good status for both ecological and chemical status. However, during three management cycles, chemical status of surface water never achieved good status, due to excessive mercury, mercury compounds and polybrominated diphenyl ethers (PBDEs). Nevertheless, exceptions were made for these two excessive chemicals and associated compounds in the management cycle 3, of which the contents have exceeded the Swedish limits in all the water bodies in Sweden mainly due to atmospheric deposition. Mercury and its associated compounds in fish are of great because of its toxicity to the fish which could damage the cells, neuro, tissues and subsequently disturb the behavior, growth of the fish which eventually increase the mortality while human will also risk being exposed to mercury by the consumption of mercury accumulated fish (Zheng et al., 2019). In the meanwhile, the widespread PBDEs are of concern due to wide use in industries such as production of flame retardants, its toxicity and its high bio-accumulation (Roberts et al., 2011). As a result, once the PBDEs started to accumulate in fish, it would eventually disturb the reproduction and thyroid of fish (Yu et al., 2015).

A comprehensive summary of majority part of the information reported during the three management cycles are tabulated in Appendix 8.

3.4.2. Significant changes in status and identified issues

Parameters or assessment criteria that had changed significantly during the management cycles are presented in table 5.

Table 5: Parameters of which status had changed during the management program

Parameter	**Status**
Chlorophyll a	From high to Good
Proportion of blue-green algae	High to good, not included in the 3rd cycle
Total biomass	High to good, from cycle 1 to cycle 3.
Fish in lakes (EindexW3)	Moderate, not included in the previous 2 cycles,
Acidification	From high to good in the latest assessment. pH >6.6 is classified as good.
Nutrients	From good to high

The status of chlorophyll a, total biomass and the acidification deteriorated by one level from management cycle one to three due to the increase in the concentration of chlorophyll a, total biomass, and the decrease in pH.
As for the classification of fish status in the lake deteriorated by one level due to the newly introduced classification indicator (EindexW3) was classified as moderate, while the other indicator (EQR8) remained good. Therefore, it does not suggest that the fish stock in the lake had deteriorated between the two management cycles (VISS, n.d.).
However, the newly introduced indicator does suggest that the fish stocks in the lake have been negatively affected. A comparison of different criteria of these two indices are listed in table 6:

Table 6: Assessment criteria of index EQR8 & EindexW3 (Havs- och vattenmyndigheten, 2014)

EQR8	EindexW3
Number of native fish species	Proportion of potentially fish-eating perch (biomass)
Simpson's Dn (diversity index based on number of individuals)	Total number of fish per net
Simpson's Dw (diversity index based on biomass)	Geometric mean length of perch
Relative biomass of native fish species	
Relative number of individuals of native species	
Average weight of the total catch	
Proportion of potentially fish-eating perch fish (biomass)	
Perch / carp fish quota (biomass)	

EK of EindexW3 is calculated by dividing the index value by the median value of the index in reference lakes. The median value for EindexW3 is 0.515 or 0.469 for cold-water fish.

The status of fish reduced to moderate in the latest management cycle where one more fish criteria (EindexW3) was included in the assessment and was classified as moderate status based on the fish test carried out in 2015 (Länsstyrelsen Jönköping, 2016). Furthermore, to understand what had caused this classification of EindexW3, the attempt was made to classify these three criteria including in the index. However, due to lack of detailed information about the fishing test, it was only possible to classify two out of these three criteria but the geometric mean length of perch, while the other two parameters were assessed to have a high. Therefore, it is possible to conclude that it was the length of perch that had a moderate status which had led to a moderate status of EindexW3 index.

While looking at the classification scaling and the calculation of EK value of EindexW3, a reasonable assumption can be made that the length of majority perch caught by the bottom nets during the fish test was below the median length of 124.9 mm. In another word, in terms of the population structure, many perch were small in size

In the latest risk assessment, it is identified that both ecological and chemical assessment in the lake will not achieve good due to, firstly, poor flow condition due to regulated flow and oxygen condition in the lake. Secondly, due to the excessive Polybrominated diphenyl ethers, mercury, and its associated compounds.

Due to the decline of phosphorus content between management cycle one to management cycle three, the nutrient status also improved which led to an increase of classification from good to high.

To summarize, the parameters that do not achieve a good status could be identified and summarized in table 7.

Table 7: Parameters which did not achieve at least a good status in the latest management cycle.

Chemical status	Does not achieve good	
	Mercury and mercury compounds	Does not achieve good chemical surface water status
	Brominated diphenyl ether	
Ecological status	Moderate	
	Fish	Moderate
	Oxygen conditions	Bad
	Hydrological regime	Moderate

According to the management program, eutrophication was identified as an environmental issue for the downstream of lake Bunn, that is the river Röttleån and a detailed requirement for lake Bunn to tackle this issue was also given, see table 8. Thus, a reduction of nutrient discharge is needed even though the lake Bunn does not have the eutrophication problem at the moment.

Table 8: Identified environmental issue in the latest management cycle (2016- 2021).

Identified environmental issue	Requirement
Eutrophication due to loads of nutrients	Phosphorus discharge needed to be reduced by 65 kg/year

3.4.3. Significant stressors

According to the investigation and assessments made in the management program, the significant stressors which affected the water quality were identified as followed: individual sewers (leads to eutrophication in the lake, risk of reduced status is phosphorus.); atmospheric deposition of mercury, mercury compounds and brominated diphenyl; hydropower plant which induced the change of flow and risk reducing the status of hydrological regime and finally, unknown stressor which had led to the poor oxygen condition and the fish stocks were negatively affected according to the fishing test done in 2015.

3.4.4. Status classification in the latest management cycle

Classification of oxygen condition

According to the surface water classification standard of Sweden Oxygen classification was done based on the measurements taken at the deepest water depth in the lake was classified as bad which is the worst within the classification scale, as presented in table 9.

According to the latest assessment in the management cycle, the value is 0.2mg/l which is extremely low comparing with the worst classification threshold which is less than 2mg/l.

Table 9: The classification scale of oxygen concentration in the surface water (Havs- och vattenmyndigheten, 2014)

	Oxygen concentration (mg/l)
Status	**Warm water fish**
High	Oxygen ≥ 7 (8)
Good	≥ 5 Oxygen <7

Moderate	≥ 4 Oxygen < 5
Unsatisfactory	≥ 2 Oxygen < 4
Bad	Oxygen < 2

Classification of nutrients

The classification of nutrient level according to the latest management cycle was classified as high. The classification was determined by the classification (table 10) scale proposed by the Swedish standard.

Table 10: The status classification of total phosphorus in lakes (Hav och Vatten myndigheten, 2014)

Status	**Classification limits (EK value[1])**
High	0.7≤EK
Good	0.5≤EK<0.7
Moderate	0.3≤EK<0.5
Unsatisfactory	0.2≤EK<0.3
Bad	EK<0.2

[1]: The EK value is the ratio between the reference value and observed value, while the reference value is determined for individual water body, in lake Bunn the reference value of total phosphorus is 7.94 µg /l and the observed value is 9.68 µg /l which results in an EK value of 1.22.

3.4.5. The control program

In the control program, there are surface samples and bottom samples taken at the same location but different depth of the lake where the surface samples are taken at half meter below the water surface and the bottom samples are taken at 6 meters above the bottom. For lake Bunn, the sampling point (appendix 9) is located in the middle of Norra Bunn, thus the results from the control program can be used to properly describe the water quality in Norra Bunn. A list of all measured parameters and all the analysis reported in the control program are presented in Appendix 10.

The analysis started earliest in 1893 however the analysis is not continuously and not all parameters were measured in every year, thus the data presented in this section is intermittently while all the negative and zero values are removed.

Among all parameters, those that are most relevant to this project are listed below in table 11:

Table 11: Relevant parameters monitored in the control program

Parameters	
Temperature	TP, μg/l
pH	PO4-P, μg /l
Alkalinity, meq/l	TN, μg /l
Conductivity, mS/m	NO2 and NO3-N
Turbidity	NH4-N, μg /l
TOC, mg/l	SO4, mg/l
Oxygen, mg/l	Chlorophyll a, μg/l
Oxygen saturation, %	Sight depth with and without binoculars

To provide a general view of the water condition in the lake over the year, the maximum, minimum, average and mean values of each parameter is presented in Appendix 11.

Nutrient related parameters

The nutrients condition in the lake, which is mainly described by nitrogen and phosphorus, while the classification of eutrophication in lake Bunn was based on mainly total phosphorus. The nutrients condition from 1982 to 2020 are plotted in figure 9a & 9b where data are available.

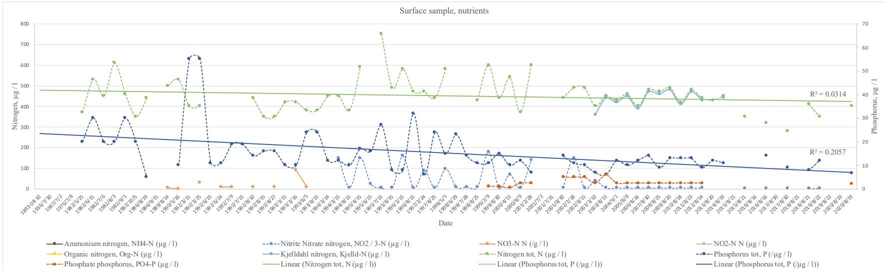

Figure 9a: Nutrients conditions in the surface samples

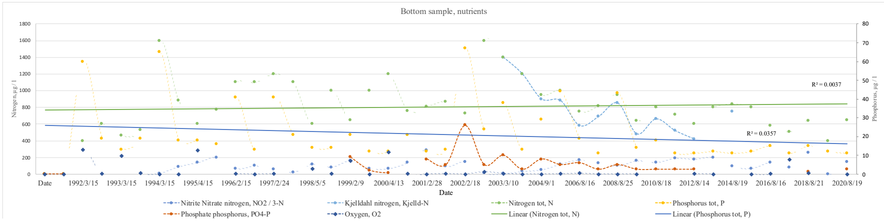

Figure 9b: Nutrients conditions in the bottom samples

As shown in the figures above, even though the data points are fluctuating over years, but with the help of trend line, a slightly decreasing trend of total phosphorus in both surface and bottom samples can be observed while the total nitrogen shows a decreasing trend in the surface samples and an increasing trend in the bottom samples.

The latest three-year average concentration of total phosphorus from 2018 to 2020 was 8.67 µg/l, which yielded a EK value of 0.916 (reference value was 7.94 mg/l) and according to the classification scale presented in table 10, resulting in a nutrient status of high. In the meanwhile, the latest three-year average concentration of total from 2018 to 2020 was 386.67 µg/l.

Relating to the previous section of the nutrients discharge through private sewers, an average reduction of 19.98% total phosphorus and 6.59% total nitrogen would be possible if connecting private sewers to public sewer system. That would result in an average concentration of TP and TN to be 6.94 µg/l and 361.22 µg/l, respectively. Since the status of phosphorus in the lake was already classified as high, thus there would not be a significant improvement for the status of the lake, but a EK value larger than one could be obtained. Though during the classification of status, EK value larger than one will be reset to one.

Although there was no classification for the status of total nitrogen in the surface water, it could still be concluded that the collective wastewater treatment for the private sewer to a wastewater treatment plant would reduce the risk for the future eutrophication development.

Oxygen condition and bio-physical parameters

As for the oxygen condition and bio-physical parameters illustrated in figure 10a & 10b, there was a decreasing trend of oxygen content in both surface and bottom water sample over the years and a rather obvious increasing trend of color and turbidity in both sampling layers, which subsequently leads to a decreasing in the sight depth in the surface layer. Though, the analysis of color was cancelled from 2015 onwards.

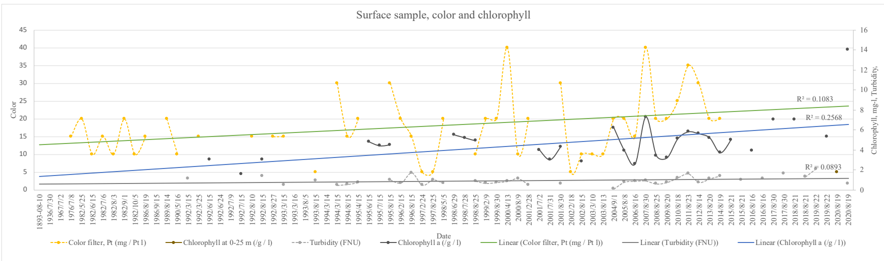

Figure 10a: Color, chlorophyll & sight depth conditions in the surface samples

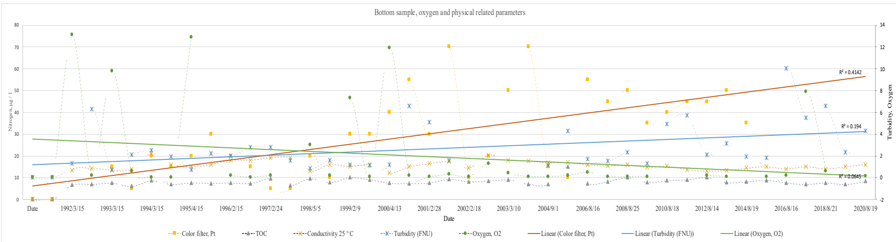

Figure 10b: Color, chlorophyll & sight depth conditions in the bottom samples

In addition to this, one must bear in mind that all these trendlines added for different parameters have very poor R^2 less than 0.2, which means that they are poorly related to the observed data.

Except for the trendline of color which gives a R^2 of 0.41, which means it is a little bit more reliable than the others. As an increasing of color in surface water normally indicates an ongoing brownification process.
The brownification which is mainly a result of increasing dissolved organic carbon or iron in the water, which could be driven by several factors such as climate change, land use change in the surrounding area, atmospheric deposition, etc, (Kritzberg et al., 2020). The increasing of DOC and iron is more commonly seen at places where conifers dominant (Björnerås et al. 2017).
Brownification can at the preliminary stage boost the zooplankton production while subsequently, undermine the photosynthesis and therefore reduce the food supply to fish and zooplankton. Eventually, affect the fish stocks negatively (Williamson et al., 2015).
To cope with brownification in lakes, there are several measures. For instance, improve the structure of forest, that is to convert from conifers dominant to deciduous tree dominant (Kritzberg et al., 2020). Or to control the hydrological connectivity. There are existing ditch network maintenances (DNM) in Sweden, where drainage ditches were dug to improve the production of forest which would lead to decrease DOC concentration to the water, though the extent of it depends on the surface soil type, while the other negative impact to the water quality which might be induced by the DNM such as erosion of suspended solids should be considered at the same time (Kritzberg et al., 2020; Nieminen et al., 2018).
Notwithstanding, the driver of brownification in the Norra Bunn is unclear in this study, thus further study is needed to conduct suitable countermeasures in the area.

When looking deep into the oxygen condition at different depth over years from 1999 to 2018, a rather similar pattern can be observed as shown in figure 11:

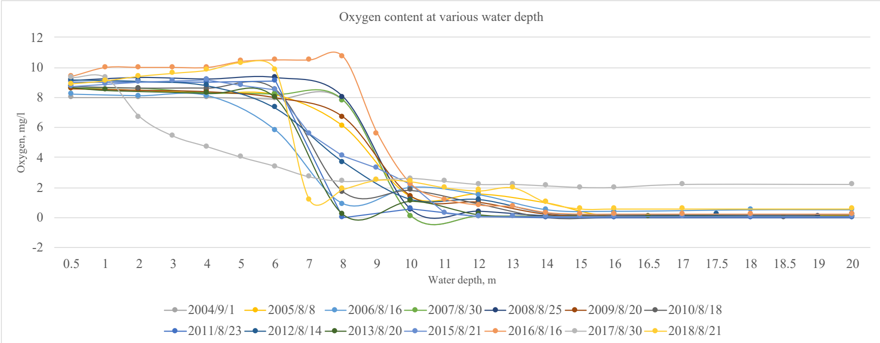

Figure 11: Oxygen content at different depth from 2004 to 2018.

All the samples were taken during the summer where water temperature was in average 13.13 °C and ranging averagely from 18.11 to 7.23°C at different depth. It is obvious that the dissolved oxygen in water dropped significantly after 6 to 8 meters and with a reduction of 96.17% in average (from 8.79 to 0.34 mg/l), i.e., from the depth of 0.5m to the deepest sampling points. While year 2017 is an exception where oxygen content only dropped to around 2.2mg/l after 10 meters and the oxygen content stayed rather stable.

Subsequently, the oxygen content at different depth was compared with water temperature taken at the same time and depth, though there was no significant difference of the water temperature variation with depth in 2017 than the rest of the years, see figure 12.

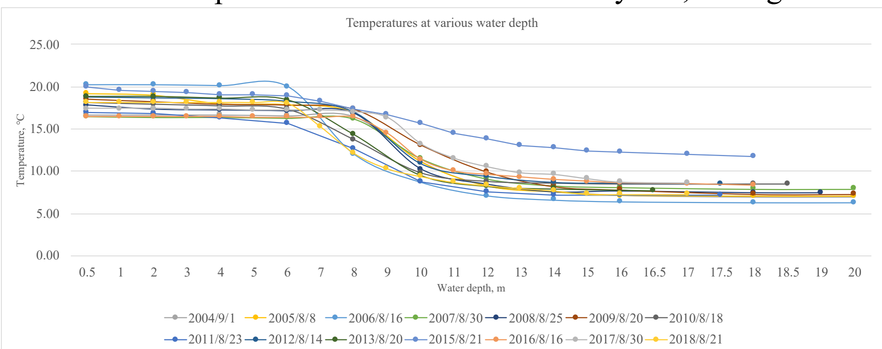

Figure 12: Dissolved oxygen at various depth vs. different temperature from 2004 to 2018

In addition, precipitation from HYPE model for year 2004- 2018 was also compared (see Appendix 12) with the oxygen content, though year 2017 was only a year with a relatively normal precipitation, it had a rather high precipitation during August which was nearly 135 mm. Since there was no daily modelling value for precipitation, IDW calculated daily precipitation was used and at 2017/08/30 there was a very heavy rainfall of 34.69 mm, thus the gradually decreasing oxygen content and higher oxygen content at the bottom was probably be a result of heavy rainfall as suggest in a study carried out by Liu et al. (2020), heavy to medium rainfall can lead to an increasing of penetration depth for dissolved oxygen.

Sight depth

The sight depth of lake Bunn was classified as high during the first and second management cycle, while during the third management cycle it was not classified. However according to the report produced by Jönköping municipality in 2020 (Länsstyrelsen Jönköping, 2016), the status of sight depth in lake Bunn had decreased from moderate ($0.33 \leq EK < 0.50$) in 2018 to unsatisfactory ($0.25 \leq EK < 0.33$) in 2019 which was a decline in depth from 1.9m to 1.6m.

Since the information is missing for the reference value of sight depth in lake Bunn, it is hard to calculate the status of sight depth in 2020 even though a sight depth of 4.2m, which was more than twice the depth of previous two years was observed. Thereby, it could be estimated that the status was supposed to be classified as at least good, of which the EK value would be in the range of $0.50 \leq EK < 0.67$.

3.5. Water sampling in the lake

Water samples were taken at 9 different locations and two samples at surface and bottom respectively were taken at locations where the water is more than 10m deep. Surface samples were taken at approximately 0.5m below the water surface and bottom samples were taken at approximately 6m above the lake bottom.

The on-site measurements of DO, pH and turbidity showed that the dissolved oxygen for all the sampling points achieved a high status

(>=7mg/l) and it did not differ more than 0.5 mg/l from the surface to the bottom at the same sampling point, see Appendix 13 for detailed results.

The pH showed a rather neutral status which was no less than 6.80, with an average pH of 7.14 and the turbidity was in average 1.16 FTU.

There were some water samples that were sent to the accredited ALS lab for the analysis of total nitrogen, total phosphorus, color and chlorophyll a. However, due to administrative error, those samples did not get to be analyzed until 4 days later. All the samples were below the lower detectable limit for total nitrogen (> 1mg/l) and total phosphorus (>0.03 mg/l) except for the surface sample of sampling point 3 which were located at the middle of Mellan Bunn part, and the total nitrogen was 1 mg/l (*Analyscertifikat*, 2021).

Other than that, the results of chlorophyll a tested for two surface samples (sampling point 8 and 9) were 3.2 (EK= 0.985) and 4.8 µg/L (EK= 0.951), respectively and according to the status classification of chlorophyll a, see appendix 14, they are classified as high status. However, the chlorophyll was considered of being degraded by around 40% after 4 days and based the average (4.84 µg/L) result reported in the control program, it was most likely that the value would be higher and the status of chlorophyll a at the time of the sampling should be classified as good or moderate instead.

As for the color, the highest color 34.3 mgPt/l sample was the sample taken at the inflow point to the lake Bunn, which was at the Södra Bunn. While, in average the color of the surface samples (23.39 mgPt/l) excluding the sample at the inflow, was slightly higher than that of the deep samples (22.73 mgPt/l). All the samples had a value of color lower than the most recent results reported in the control program in 2014 where the color was 35 mgPt/l.

In general, the pH, nutrient, oxygen and color at the time of the sampling were in a rather good status. As for turbidity and color, those values were not extraordinary, however these two parameters are not classified in the standard, thus a comparable status classification with other parameters could not be obtained. Nevertheless, the water sample taken in the control program was during summertime while

3.6. Fish and fishing management in lake Vättern

In this section, the statements are mainly based on the review of the report produced by the protection association of Vättern (Vätternvårdsförbundet, 2017), unless otherwise stated.

For lake Vättern, which is the downstream recipient of lake Bunn and has various species (around 32) such as salmon, perch, pike and char, there is a comprehensive management plan for year 2017 to 2022. The management plan was initiated with an extensive background studies, such as the recognition of restricted area, species, activities conducted in the lake, various stakeholders, etc. Furthermore, the fish and fishing management plan in lake Vättern was established in 2009 which had been revised in 2017 and it was a cross-disciplinary collaboration between the FVOF of Vättern, authorities, researchers, fisherman, etc, which depend highly on the involvement of relevant parties to achieve a common goal.

The co-management between various groups facilitated the adaptive management and increased the involvement and responsibility of different groups. The management plan were put together based on the collected comments and proposals from different parties, ranging from individuals to professionals. The objective of the management plan is to act as an advisory document to establish the goals and guidelines for the future fish and fishery, from an ecologically, economically, socially sustainable perspective.

Part of the general goals of the management plan which involves the conservation of fish stocks focus on 1) Certain typical species should at least achieve good conservation; 2) No overexploitation is allowed; 3) No new alien species are allowed; 4) Environmental toxins in fish should be reduced; 5) The tributaries of the lake shall provide passages for the naturally occurring species; 6) Establish thorough understanding of the ecosystem of the lake. Each goal has normally a timeline of five to six years.

Under the general goals, there are sub-goals for improving fish stocks which are based on a comprehensive status assessment of each species and evaluating the withdraw potential of each in terms of professional and sport fishing. The goals are evaluated and followed up using different indicators such as size and age structure, catch per unit in the fishing test, etc.

Likewise, there are also sub-goals for the management of fishing. Since there are both professional and sport fishing, the goals are also set separately for different species for different fishing categories and the goals are also adapted to the fishing and closed season.

Above all, the extensive fishing supervision also plays a significant role in the management plan which involves inspections from various parties, including anglers, authorities, professional fishman, etc. To make sure all the activities comply with the management plan and regulations.

Likewise, the FVOF of Norra Bunn could also initiate such collaborative activities between relevant parties, such as residents, anglers, water owners, landowners, , FVOF of Södra Bunn, Jönköping Engeri AB, Jönköping municipality and researchers. Together with a more extensive understanding of the ecosystem of Norra Bunn or preferably, the whole lake Bunn, it would be possible to identify the issues needed to be tackled and to collect proposals from various groups. Subsequently, the strategy towards each identified problem can be finally decided.

4. Conclusions

To sum up, the Norra Bunn is facing following issues based on available information obtained so far. First of all, it has been experiencing the excessive concentration of mercury, mercury associated compounds and polybrominated diphenyl ethers (PBDE) in fish, however this situation is prevailing in the whole Sweden and is mainly due to atmospheric deposition thus it is considered technically impossible to be addressed at the moment.

Secondly, the lake is suffering from an oxygen deficiency in the deep water which is at some point a depletion in the bottom layer in the lake. About this anoxic and hypoxic zone in the lake, part of the reasons is believed to be phosphorus release from the bottom sediments and nutrients load in the water that had consumed oxygen during the decomposition processes, especially during the summertime. At the time of the water sampling done in this study, it was at the end of April, 28th of April in a sunny day though the air temperature remained low, around 12 Celsius. It can be concluded from the on-site measurements of dissolved oxygen, the content of dissolved oxygen even at the very deep water, which is approximately 12 meters, remained at a high status (the dissolved oxygen was all higher than 7mg/l), according to the status classification.

Therefore, it is almost certain that there is a significant seasonal variation of dissolved oxygen content in the lake, possibly with other chemicals as well. It is thus preferred that in the future, to establish a more comprehensive background of the status of dissolved oxygen in the lake all year around, more frequent samples and analysis should be taken and done. And once the reasons are identified, countermeasures could be taken to improve the condition of dissolved oxygen especially in summer. Especially for the close monitoring water quality changes in terms of the development of color as there is mild trend indicates that the color is increasing with time. And if it is properly monitored and observed, countermeasures then can be taken accordingly.

On the other hand, at this stage there is no solid proof that would suggest there is an ongoing eutrophication development in the lake, the nutrient discharge from the private sewers will need to be taken care of in the future as it is accounted for 19.98% of phosphorus load in the lake. More importantly, the downstream of the lake, Röttleån river is already suffer from eutrophication. A possible suggestion is to collect the wastewater before it discharges to the lake and direct it to a nearby wastewater treatment plant, for instance the one situated at the South of lake Vättern approximately 45 km away from lake Bunn.

And third, there is likely an ongoing brownification in the lake, which resulted in an increasing of color. However, this matter is not studied sufficiently in this study and the stressors for this phenomenon in Norra Bunn is unclear. Consequently, it gets back to the second point that the water quality should be further and more frequently analyzed to propose appropriate actions.

Fourth, the Röttle hydropower plant that has been extracting water from lake is taking up almost 89% of the water discharged from the lake and thus is believed to have significant impact on the hydrological regime of the lake, though the extent of negative impact that would be induced by this flow regulation cannot be quantified in this study. Therefore, it is recommended to carry out more studies in this aspect and to quantify the impact so that it would be possible for an optimized operation of the hydropower plant.

Fifth, the status of fish stocks in the lake did not deteriorate during the last fishing test done in 2015. However, as also suggested in the test, the size of many perch is considered rather small, which makes it important to improve the structure of the fish community by introducing new fishing limit or regulations in Norra Bunn, that is to limit the withdraw of perch of certain number per capita and certain size to increase the presence of larger perch in the lake.

Finally, in order to conserve the fish stocks in the lake effectively in the future, it is important for the FVOF of Norra Bunn to motivate and involve the relevant stakeholders around the lake to participate in the better management of the lake. Preferably, to take reference from the management plan of lake Vättern, that is to involve private water owner, residents, tourists, anglers, researcher, Jönköping

municipality and Jönköping Engeri AB and collect opinions and proposals for a future management goal. Henceforth, it would be possible to draft a management plan once the drivers behind each challenge that the lake are facing today are identified properly.
In addition, the speed limit of boats navigating in the lake proposed in the Appendix 2 is just a result of a preliminary study, hence it could only be served as a reference. If a more accurate or comprehensive strategy is desired, more study is needed, starting from the detailed bathymetric information and bottom material.

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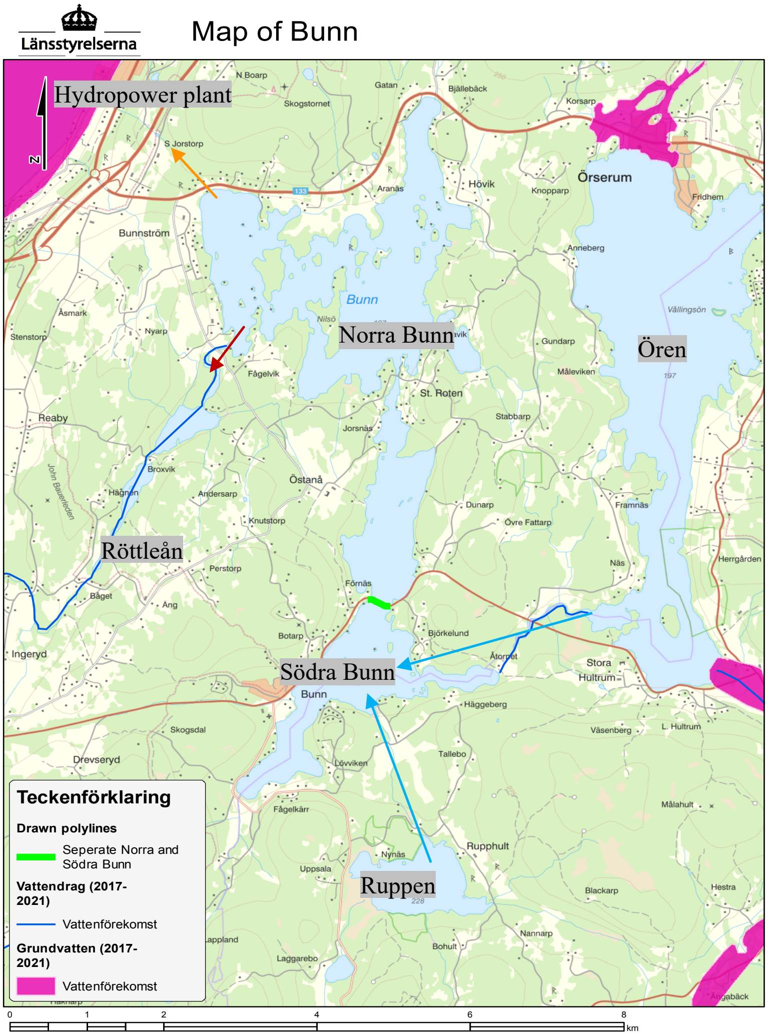
Appendix 1: Map of Bunn besides lake Vättern (Länsstyrelserna, 2020)



Appendix 2: Preliminary approach for a speed limit of ships in the lake.

Preliminary method to determine the speed limit in the lake
To determine a speed limit for driving boats in the lake, a rough hydraulic calculation was carried out. Due to the complex nature of hydraulic conditions of the lake and various aspects to consider when it comes to protect the aquatic ecosystem, the approach to determine the speed limit in the lake in this study is thus, based on the boat velocity calculated by a maximum wave limit. The maximum wave limit was deducted from a known speed limit applied in the lake at several sensitive zones (see appendix 15) which was decided by the Jönköping county (Länsstyrelsen I Jönköping) that a boat speed may not exceed 7 knots (approximately 3.6 m/s) in the restricted area.

In order to get a rough estimation of speed limits of boats navigating in the Norra Bunn, several equations and the dimensions of a common small boat The Egret 167 (Go Downsize, 2020) were used.

$$gH_M / U_{SR}^2 = \beta (F_* - 0.1)^2 (y / L_S)^{-1/3}$$

Equation 9: Calculation of maximum secondary wave height

This equation was proposed by Kriebel and Seeling (2005) to calculate the maximum secondary wave height, where H_M denotes the maximum wave height, m;
U_{SR} denotes the relative ship speed, m/s;
β denotes the empirical coefficient which depends on the hull design.

$$\beta = 1 + 8tanh^3[0.45(L_S / L_E - 2)$$

Equation 10: Calculation of hull design empirical coefficient

$$F_* = F_{LS} \exp\left(\alpha \, d_s / h\right)$$

Equation 11: Modified Froude number

where F_* denotes a modified Froude number;
y denotes the distance from the sailing line, m;
L_s denotes the ship length, m;

h denotes the water depth, m;
L_E denotes entrance length of the ship which is the length from ship bow and the point where the ship hull is at its maximum width, m;
F_{LS} denotes the length and depth-based Froude number, normally applied in deep water, in this case, it is considered that Norra Bunn is rather shallow, thus shallow water Froude number F_h is used instead.

$$F_h = U_{SR}/\sqrt{(g * h)}$$

α denotes a coefficient, where:

$$\alpha = 2.35(1 - C_B)$$

C_B denotes a ship block coefficient, where:
V_s denotes the displacement volume, m^3.

$$C_B = {}^{V_S}/_{L_S B_S d_S}$$

To simplify the calculation, the displacement volume is calculated as if it were a cuboid, thus the C_B is 1.
B_S denotes the width of the ship, m;
d_S denotes ship draft, m;
In order to get a proper distance from the sailing line so that a maximum wave height could be determined, these existing restricted zones combined with the field trip to the were studied and the narrowest location was identified which is under the bridge where the Stabbarp road crosses the lake at the downstream direction of Norra Bunn. The width at that location is approximately 7 meters and the water depth is around the location is 2-4 meters, according to the fishing map of Norra Bunn (Anders Svahnberg, 2016).
Dimensions of a common small boat are listed below (table 12), based on the model *The Egret 167*.

Table 12: Dimensions used in the calculation, based on a model: The Egret 167

L_E, m	Ds, m	L_S, m	B_S, m	U_{SR}, m/s	C_B	α
3.5	0.25	5	2.2	3.60	1.00	0

With the known conditions and equations presented in previous section, at 3.5 meters from the sailing line, water depth of 4 meters and a ship speed of 3.6 m/s, a maximum wave height of 0.53 meter was obtained.

It is worth noticing that the water depth right under the bridge is around 2 meters, however the maximum wave height determined this way subsequently led to a rather fast speed at deeper water where the channel is relatively narrow. Hence maximum wave height was determined by taking the average maximum wave height that obtained with 2 meters (resulted in a maximum wave height of 0.73 meter) and 4 meters (resulted in a maximum wave height of 0.32 meter). As a result, a maximum wave height of 0.53 meter was obtained.
This maximum wave height was used to calculate the speed limit at various water depth and distance from the sailing line. However, since close shore erosion and sediment transport in the very shallow water was not considered, the recommendation of speed limit in this study was only applied from 3.5 meters away from the shoreline and the depth from 2 meters and downwards to 20 meters. Naturally, the deeper and wider the water goes, the smaller the wave the boat could generate.

The distance from the sailing line crossing the lake is roughly in a range of 3.5 meters to 650 meters, assuming the ship is navigating on the centerline. A hypothetical speed limit ranging from 3.6 m/s to 33.15 m/s at depth varying from 4 to 20 meters. However, applying a speed limit over the lake based on different depth and distance to the sailing line at the same time might be difficult for people to follow, speed limits in the range of 3.5 m/s to 10.96 m/s that were calculated at the water depth of 4 meters and a distance from sailing line ranging from 3.5 to 650 meters is thus recommended, see figure 13. In this manner, the lake would be divided into several zones that allow people to follow more easily.

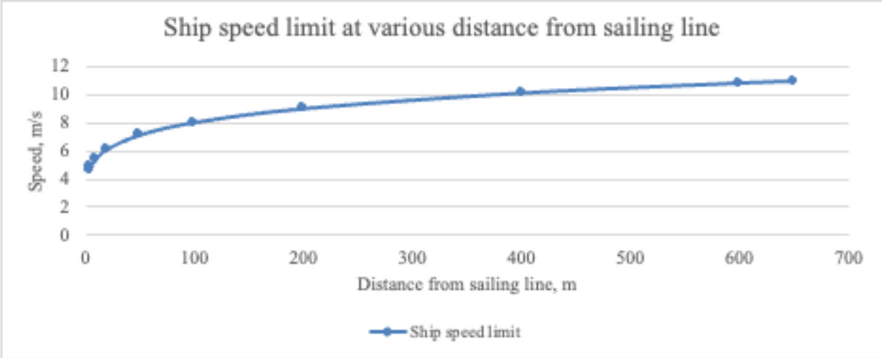


Figure 13: Ship speed limit at various distance from the sailing line at a water depth of 4 meters.

Appendix 3: Basic information about the sub-catchment of Bunn which h HYPE model (SMHI, 2016)

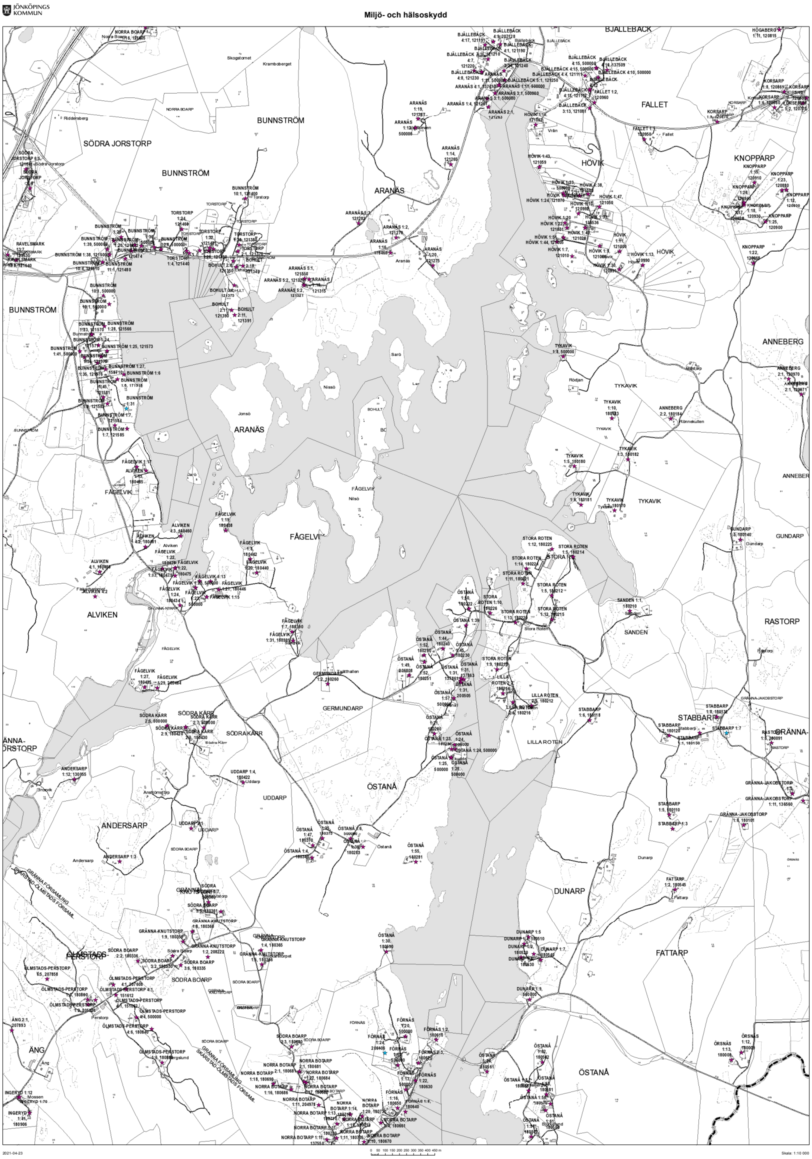
Model information									
HYPE model set:	s-hype2016_version_16_f								
HYPE version:	HYPE_version_5_14_0								
HYPE simulation start:	1976/1/1								
ANSWER Version:	ANSWER_2016_3								
The sub-catchment area									
			Land use			**Soils**			**Loading**
SUBID of the sub-catchment area:	3542		**Lake and watercourses**	17.99%		**Moraine**	28.05%		**Individu drains**
AROID of the sub-catchment area:	643100-142165		**Forest land**	67.20%		**Thin soil and bare mountains**	40.56%		**Sewage treatmen**
Name of the sub-catchment area:	The outlet of the Bottom		**Hedmark and other land**	4.22%		**Peat**	2.60%		**Industry**
Main catchment area:	67. Motal current		**Bare scales and thin soils**	0.00%		**Ice material**	0.16%		
Outlet point, SWEREF99:	469372, 6426769		**Glacier**	0.00%		**Rough soil**	0.56%		
Area [km²]:	54.79		**Marshes and wetlands**	0.10%		**Silt**	0.71%		
Adjustment amplitude [m]:	0.996		**Agricultural land**	9.89%		**Finjord**	0.47%		
Number of dams according to the dust register:	0		**Urban area**	0.49%		**Sandy soils**	3.59%		
Water use (outlet - supply) [m³ / s]:	0		**Hard surfaces**	0.11%		**Easy clay**	5.11%		
Specific flow power [W / m²]:	0					**Middle clay**	0.06%		
						Stiff clay	0.03%		
						Hard surfaces	0.11%		
						Lake and watercourses	17.99%		

Appendix 4: Reference year for the flow at dam Boget during year 2005- 2010, reference taken from year 2011-2019 based on annual precipitation.

(In excel Water balance, tab HYPE yearly value)

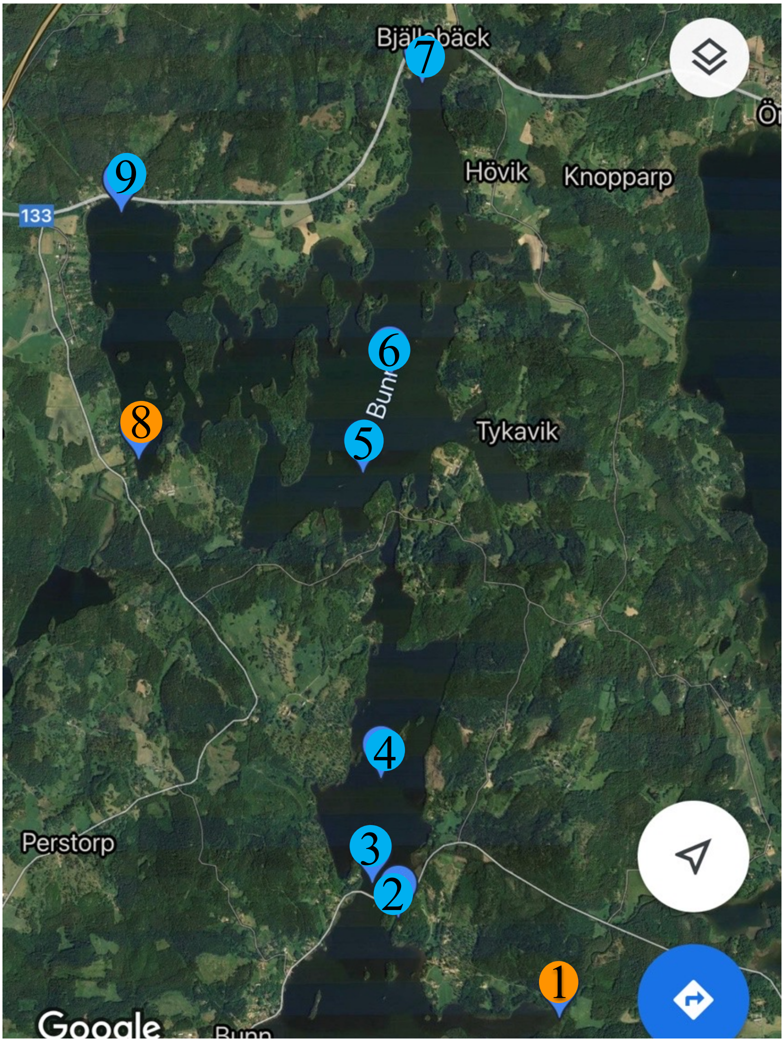
Year	Precipitation, mm	Reference year	Precipitation, mm
2004	761	2014	745
2005	624	2017	692
2006	729	2011	732
2007	876	2012	840
2008	768	2014	745
2009	613	2017	692
2010	754	2014	745

Appendix 5: Residence map in the vicinity of Norra Bunn (Jönköping Kommun, 2021)



Appendix 6: Location of meteorological stations relatively to Norra Bunn for IDW interpolation (OpenStreetMap, n.d.)

Appendix 7: On-site sampling points (Google Maps, 2021)



Appendix 8: Summary of management cycles

Cycle 3				
Ecological status				
Quality requirements				
Good ecological status				
Chemical surface water status				
Quality requirements				
Good chemical surface water status				
Exceptions - Less stringent requirements				
Mercury and mercury compounds Brominated diphenyl ether		Does not achieve good chemical surface water status		
Status				
Ecological status		Moderate		
Origin / descent Natural		Natural		
Chemical status		Does not achieve good		
Ecological status - Biological quality factors				
Phytoplankton		Good		
Nutrient effect phytoplankton		Good		
-Chlorophyll a		Good		
-Proportion of blue-green algae		-		
-Plankton Trophic Index (PTI)		Good		
-Total biomass		Good		
Fish		Moderate		
Fish in lakes (EQR8)		Good		
Phytoplankton		Moderate		
Ecological status - Physical-Chemical quality factors				
Nutrients	High			
Lighting conditions	High			
Oxygen conditions	Bad			
Acidification	Good	Average pH is >6.6		
Special pollutants	Good			
Ecological status - Hydromorphological quality factors				
Connectivity in lakes	No classiication			
Hydrological regime in lakesColor representation of classificationModerate				
	Water level variation in lakes			
	Deviation in winter or summer water level			
	The rate of change in the water level in lakes			
Morphological condi	Not classified			
	Change in the plan form of lakes			
	Bottom substrate in lakes			
	Structures on the shallow water area in lakes			
	The surround	Good		
	The floating	Moderate		
Chemical status				
Priority topicsColor representation of classificationDoes not achieve good				
	Brominated d	Does not achieve good		
	Lead and lea	Not classified		
	Cadmium an	Not classified		
	Mercury and	Does not achieve good		
	Nickel and n	No classification		
Sources of influence				
Diffuse sources - Inc	Significant impact			
Diffuse sources - At	Significant impact			
Change of hydrologi	Significant impact			
Unknown significant	Significant impact			
Identified environmental issue			Requirement	
Eutrophication due to loads of nutrients			Phosphorus discharge needed to be reduced by 65kg/year	
Risk assessment				
Risk that Ecological status / potential will not be achieved in 2027			Risk	Due to flow change and poor oxygen conditions due to loading of organics. The cause for poor oxygen condition is unknown, poor O2 also affects fish.
Risk that Chemical status will not be achieved in 2027			Risk	Due to mercury and brominated diphenyl ethers which are induced by atmospheric deposition

Cycle 2					
Ecological status					
Quality requirements					
Good ecological status					
Chemical surface water status					
Quality requirements					
Good chemical surface water status					
Exceptions - Less stringent requirements					
Mercury and mercury compounds Brominated diphenyl ether		Does not achieve good chemical surface water status			
Status					
Ecological status		Good			
Origin / descent		Natural			
Chemical status		Does not achieve good			
hemical status without excessive substanc		Good			
Ecological status - Biological quality factors					
Phytoplankton		Good			
Nutrient effect phytoplankton		Good			
-Chlorophyll a		-			
-Proportion of blue-green algae		Good			
-Trophic plankton index (TPI)		Unsatisfactory			
-Total biomass		Good			
Fish		Good			
Phytoplankton		Good			
Ecological status - Physical-Chemical quality factors					
General conditions phisical-chemical			Good		
	Nutrients	Good			
	Lighting conditic	High			
	Acidification	High	pH high, risk of acidification is very low, lowest pH was above 7.0		
Special pollutants	Good				
	Non-synthetic su	Good			
		Copper	Good		
		Chromium	Good		
		Zinc	Good		
Ecological status - Hydromorphological quality factors					
Morphological conditic	Not classified				
	The surrounding	Good			
	The floating plar	Moderate			
Chemical status					
Priority topicsColor representation of classificationDoes not achieve good					
		Brominated diphenyl et	Does not achieve good		
	Heavy metals - groupColor representation of classificationDoes not achieve good				
		Lead and lead compour	Good		
		Cadmium and cadmiun	Good		
		Mercury and mercury c	Does not achieve good		
		Nickel and nickel comp	Good		
Sources of influence					
2.6.3 Atmospheric depositionColor representation of classificationSignificant impact					
4. Flow regulation and morphological changesColor representation of classificationSignificant impact					
Environmental problems cycle 2 (2010-2016)					
1. Eutrophication and oxygen-poor conditions					No
1.1 Eutrophication due to nutrient load					No
2. Environmental toxins					Yes
2.1 Pollution of environmental toxins					Yes
3. Acidification					No
4. Changed habitat through physical impact					Yes
4.1 Flow changes					Yes
Risk assessment					
Risk that Ecological status / potential will not be achieved in 2021			Risk		
Risk that Chemical status will not be achieved in 2021			Risk		

Cycle 1				
Ecological status				
Quality requirements				
Good ecological status				
Chemical surface water status				
Quality requirements				
Good chemical surface water status				
Status				
Ecological status		Good		
Origin / descent		Natural		
Chemical status		Good		
Ecological status - Biological quality factors				
Phytoplankton		Good		
Nutrient effect phytoplankton		Good		
Chlorophyll a		High		
-Proportion of blue-green algae		High		
-Trophic plankton index (TPI)		Moderate		
-Total biomass		High		
Fish		Good		
-Fish in lakes (EQR8)		Good		
Species for phytoplankton		Not classified		
Bottom fauna		High		
ASPT		High		
BQI		Not classified		
MILA		High		
Ecological status - Physical-Chemical quality factors				
ral conditions phisical-chemical representation of classification(				
	Nutrients	Good		
	Lighting conditic	High		
	AcidificationCol	Good	No sampling below pH 7.6, 4 samples taken	
Non-synthetic substances		Good	The status is set to Good when the levels for Copper and Chromium are below the limit value even if the levels for Zinc are below the background level	
Ecological status - Hydromorphological quality factors				
Hydromorphology cycle 1 2004-2015,Moderate				
Continuity				
	Presence of artificial obstacles to migrationColor representation of classificationGo			
Hydrological regime lakesColor representation of classificationModerate				
	Prescribed regulatory amplitude for lakesColor representation of classificationMod			
Morphological conditions		Not classified		
	Number of road:	High		
Chemical status				
Priority topicsColor representation of classificationDoes not achieve good				
	Mercury and me	Does not achieve good		
Environmental problems Cycle 1				
1. Eutrophication and oxygen-poor conditions			No	The risk is considered to be small that the status deteriorates due to nutrients.
2. Environmental toxins			Yes	
3. Acidification			No	The risk is considered to be small that the status deteriorates due to acidification.
4.1 Flow changes			Yes	The water body is affected by regulation.
4.2 Connectivity changes			-	
4.3 Morphological changes			-	
5. Alien species			No	
Risk assessment				
Risk that Ecological status / potential will not be achieved in 2015		Risk	The lake currently has good status, but there is a risk that it will not achieve good status in 2015 due to the growing recreational buildings adjacent to the lake. Today there are problems with oxygen deficiency in the groundwater.	
Risk that Chemical status will not be achieved in 2015		Risk	The EC Water Framework Directive (2008/105 / EC) sets the maximum level, ie the permitted level, for mercury in biota at 20 micrograms per kilogram (ug / kg). In Sweden today, mercury exceeds the limit value in all surface water bodies; lakes, streams and coastal waters.	

Appendix 9: Sampling point used in control program (SLU, n.d.)

Note: Sampling point is denoted by the brown flag

Appendix 10: Parameters measured in control program and the comparison with management program

Parameters	Parameters in classification on VISS	Reference value	Observed value reported on VISS	Surface observed value reported on Control program (mean value)	Bottom observed value reported on Control program (mean value)	Comments
Temperature	-		-	17.85	7.40	Profile
pH	Almost nuetral	Not available		7.50	7.30	
Alkalinity, meq/l	Low	0.27	0.69	0.67	0.85	Less than and equal to 1 meq/l is classified as low.
Conductivity, mS/m	-	-	-	14.30	15.20	
Absorbants	-	-	-	0.03, unit missing	0.04	Filtered with 5cm filter
Turbidity				0.87	2.10	FNU
TOC, mg/l				7.90	7.70	
Oxygen, mg/l	Bad	-	0.20	8.85	0.20	Classification scale based on different values
Oxygen saturation, %	-	-	-	94.50	1.00	Profile
TP, µg/l	High	7.94	9.68	12.00	15.00	Nutrient classification is mainly based on TP
PO4-P, µg /l	-	-	-	2.50	3.85	
TN, µg /l	-	-	-	440.00	800.00	
NO2 and NO3-N	-	-	-	10.00	-	
NH4-N, µg /l	-	-	-	-	-	
Ca, mg/l	-	-	-	0.90	18.00	
Mg, mg/l	-	-	-	0.19	2.50	
Cl, mg/l	-	-	-	0.26	10.00	
Na, mg/l	-	-	-	0.27	6.20	
SO4, mg/l	-	-	-	0.33	17.50	
Mercury and mercury compounds, g/kg wet weight	Does not achieve good	20.00		-	-	limited value at 20
Brominated diphenyl ether, g/kg wet weight	Does not achieve good	0.01		-	-	limited value at 0.0085
Chlorofyll a, µg/l	Good	2.50	4.96	4.65	-	
Sight depth without binoculars	-	-	-	3.75	4.20	More than 38 meausrements

Appendix 11: General statistics of parameters measured in the control pr

Surface samples:

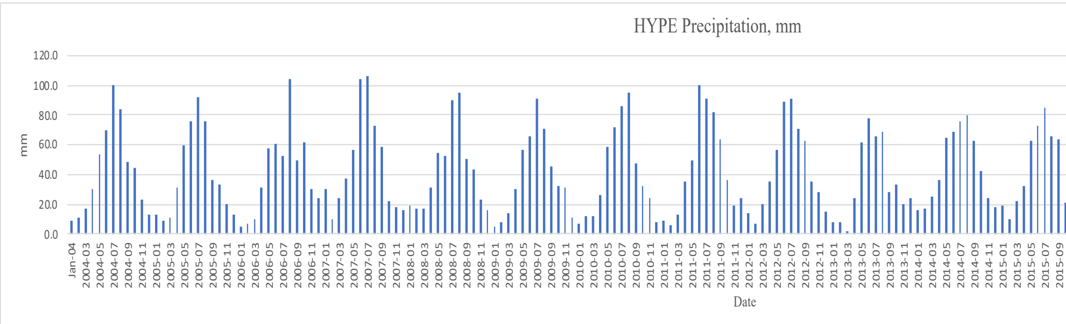
Surface	Sample depth	Sampling temperature	Turbidity	Color filter, Pt	Abs 420/5 filter	TOC	Conductivity 25 ° C	pH	Alkalinity	Nitrite Nitrate nitrogen, NO2 / 3-N	NO3-N	Kjelldahl nitrogen, Kjelld-N	Nitrogen tot, N	Phosphorus tot, P
Unit	(m)	(° C)	(FNU)	(mg / Pt l)		(mg / l)	(mS / m)		(meq / l)	(µg / l)	N (/g / l)	(µg / l)	(µg / l)	(/g / l)
Count	76.00	50.00	37.00	46.00	8.00	53.00	41.00	58.00	57.00	39.00	9.00	12.00	57.00	63.00
Average	0.16	14.69	0.93	17.83	0.05	8.06	14.27	7.55	0.65	35.48	19.33	435.00	451.58	15.07
Max	0.50	25.50	2.10	40.00	0.11	11.00	18.00	8.10	0.79	180.00	90.00	480.00	750.00	55.00
Min	-6.00	0.90	0.10	5.00	0.01	6.30	12.00	7.00	0.44	-1.00	1.00	360.00	280.00	-5.00
Mean	0.50	17.85	0.87	17.50	0.03	7.90	14.30	7.60	0.65	5.00	10.00	440.00	440.00	12.00

Surface	Phosphate phosphorus, PO4-P	DO	Oxygen saturation	Sight depth without binoculars	Depth of field with binoculars	Ca	Mg	Na	K	Cl	SO4	Chlorophyll a	Chlorophyll at 0-25 m	COD Mn	Ca
Unit	(µg / l)	(mg / l)	(percent)	(m)	(m)	(mg / l)	(mg / l)	(mg / l)	(mg / l)	(mg / l)	(mg / l)	(/g / l)	(/g / l)	(mg / l)	(m
Count	27.00	42.00	42.00	55.00	38.00	46.00	46.00	41.00	41.00	41.00	48.00	30.00	1.00	11.00	
Average	1.51	9.47	92.16	3.74	4.11	1497.29	55.09	6.04	1.31	9.60	15.51	4.84	5.00	5.94	
Max	6.00	13.30	110.00	5.10	5.70	18036.00	2432.00	7.00	1.60	13.00	29.00	14.00	5.00	7.00	
Min	-5.00	0.12	1.00	1.60	1.70	15.00	1.34	4.80	1.00	6.60	0.34	1.57	5.00	5.10	
Mean	2.50	8.85	94.50	3.80	4.20	18.00	2.30	6.00	1.40	9.00	15.50	4.65	5.00	5.80	

Bottom samples:

Bottom,	Sample depth	Temperature	Turbidity	Color filter, Pt	Abs 420/5 filter	TOC	pH	Alkalinity	Nitrite Nitrate nitrogen, NO2 / 3-N	Kjelld-N	Nitrogen tot, N	Phosphorus tot, P	Phosphate phosphorus, PO4-P	DO	Oxygen saturation	Sight depth without binoculars	Depth of field with binoculars	Ca
	(m)	(° C)	(FNU)	(mg / Pt l)		(mg / l)		(meq / l)	(µg / l)	(µg / l)	(µg / l)	(µg / l)	(µg / l)	(mg / l)	(percent)	(m)	(m)	(meq / l)
Count	35.00	41.00	37.00	33.00	8.00	41.00	41.00	41.00	37.00	12.00	41.00	41.00	20.00	35.00	34.00	3.00	3.00	10.00
Average	19.57	6.71	2.88	30.61	0.07	8.15	7.29	0.88	112.29	777.50	843.90	22.05	5.43	2.07	14.99	3.93	4.47	0.92
Max	20.00	11.80	10.00	70.00	0.22	15.00	7.80	1.60	290.00	1400.00	1600.00	67.00	26.00	13.10	100.00	4.50	5.00	1.05
Min	16.50	2.00	0.70	5.00	0.03	6.00	6.90	0.60	2.90	420.00	400.00	11.00	0.50	0.05	0.30	3.60	4.10	0.85
Mean	20.00	7.40	2.10	30.00	0.04	7.70	7.30	0.85	100.00	720.00	800.00	15.00	3.85	0.20	1.30	3.70	4.30	0.90

Appendix 12: Monthly precipitation in the sub-catchment of lake Bun results.



Appendix 13: On-site water sampling results

Sampling points		Temperature, °C	DO, mg/L	DO, %	Turbidity, FTU	pH
1	Surface	6.3	9.1	90%	3.09	-
2	Surface	5.9	9.5	92%	1.15	-
	Surface2	5.6	9.2	88%	1.27	-
3	Surface	5.7	8.9	87%	0.67	7.4
	Bottom	4.5	8.7	84%	0.81	7.08
4	Surface	4.6	9.2	89%	0.87	6.85
	Bottom	4.1	8.9	84%	1.51	6.8
5	Surface	6.2	8.7	87%	0.18	7.3
	Bottom	4.2	8.2	83%	0.79	7.2
6	Surface	6.6	8.5	84%	0.88	7.13
	Bottom	4.3	8.4	83%	1.44	7.2
7	Surface	6.1	8.7	86%	0.78	7.17
	Bottom	5.8	8.6	86%	0.91	6.96
8	Surface	8.2	8.6	93%	2.43	7.38
9	Surface	6.5	8.6	87%	1.29	7.16
	Bottom	6.2	8.9	90%	0.49	7.17

Note: Samples marked yellow, were samples taken in the afternoon

Appendix 14: Classification scales for chlorophyll a (Havs- och vattenmyndigheten, 2014)

respektive 3B.

Typ	Status-gräns	Klorofyll *a*	Klorofyll *a*. Gony	EK	EK Gony	Region +humus	Status-gräns	Klorofyll *a*	EK
1MLK	chl_{ref}	2,5	3,2	1	1	1K	chl_{ref}	2,7	1
	H/G	5,0	4,6	0,95	0,93		H/G	4,3	0,97
	G/M	8,5	6,9	0,87	0,82		G/M	8,6	0,90
	M/O	17	10	0,69	0,67		M/O	17	0,75
	O/D	33	16	0,35	0,38		O/D	34	0,46
	chl_{max}	50	24	0	0		chl_{max}	61	0
1GLB	chl_{ref}		16		1	1B	chl_{ref}	10	1
	H/G		31		0,89		H/G	18	0,90
	G/M		47		0,77		G/M	27	0,79
	M/O		70		0,60		M/O	41	0,62
	O/D		100		0,37		O/D	61	0,37
	chl_{max}		150		0		chl_{max}	90	0
1MLB	chl_{ref}	3,0	5,0	1	1	2B	chl_{ref}	8	1
	H/G	6,0	12	0,94	0,87		H/G	12	0,92
	G/M	10	18	0,86	0,77		G/M	18	0,81
	M/O	20	27	0,66	0,61		M/O	27	0,64
	O/D	40	41	0,26	0,36		O/D	41	0,39
	chl_{max}	53	61	0	0		chl_{max}	61	0

Where EKchl = (chlobs– chlmax) / (chlref – chlmax), refer to the first type of 1MLK for Bunn lake for the classification and the column outlined in the red perimeter.

Appendix 15: Speed limited area in Bunn (Länsstyrelsen i Jönköpings län, n.d.)