Norwegian University
of Life Sciences

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Temporal and Spatial GIS Visualizations and Statistics of Near-Term DOC Changes in Ten Norwegian Lakes,
Based on the Climatic Factors Precipitation and Temperature

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Environment and Natural Resources

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GIS-visualiseringer og statistikk over fremtidige DOC-forandringer i ti norske innsjøer, i tid og rom, basert på klimafaktorene nedbør og temperatur.

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Environment and Natural Resources

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Human pollution and modifications of the environment and climate are now so pervasive that no aquatic environment of the biosphere is unaltered in some manner by these disturbances.

– Robert G. Wetzel

Abstract

The colour of lakes several places in the Northern hemisphere has been increasing the last few decades; this brownification is affecting aquatic life, drinking water facilities and the carbon cycle. It is closely linked to the reduced acid rain enhancing the concentrations of dissolved organic carbon (DOC). However, now that the amounts of sulphate (SO_4^{2-}) in Norwegian lakes are starting to stabilize, there is still an increasing trend in DOC values, possibly caused by increased temperature and precipitation. The climate is changing, and at the same time geographic information systems (GIS) are constantly improving. Having future climate change predictions for Norway, calculated by the Intergovernmental Panel on Climate Change (IPCC), together with today's GIS programs, there are many possibilities to model future scenarios.

In this thesis, the goal was to assess DOC changes in ten Norwegian lakes, differing in location and water chemistry, based on near future air temperature and precipitation predictions of IPCC's scenario RCP4.5; as well as to use GIS models to spatially visualize the relative production of allochthonous DOC reaching lakes within the catchment areas. This was possible by using existing data on the correlation between temperature and total organic carbon (TOC: in these lakes mainly DOC), in addition to dividing precipitation by SO_4^{2-} concentrations, before and after stabilization, to see the effects of precipitation amounts. Four lakes were considered precipitation dependent, and all ten lakes showed continuous positive trends in predicted TOC values to the year 2025 and further increases stabilizing towards year 2075. Hence, it seemed that future climate change is likely to cause increased DOC concentrations in Norwegian lakes. The specific temporal and spatial increases within each catchment area were possible to show through graphs and GIS models.

Due to the strongly decreased SO_4^{2-} values, continuous monitoring of DOC/ TOC values in Norwegian (as well as other similar European) lakes are important. Further research on the effects of the climatic parameters precipitation and temperature are needed to find more answers concerning if and how these are affecting the levels in general, and at specific sites. Furthermore, when it comes to GIS as tools for visualizations and statistical calculations the possibilities are numerous and this thesis only show a glimpse of the part GIS can play in water management and research.

Sammendrag

De siste tiårene har det flere steder i Nord-Amerika og i Europa blitt observert en stadig økning av fargetall i innsjøer. Dette påvirker både ferskvannsflora- og fauna, drikkevannsfasiliteter og det globale karbonkretsløpet. De stadig brunere innsjøene har vist seg å henge sammen med den reduserte sure nedbøren i disse områdene som har ført til økende konsentrasjoner av løst organisk materiale (DOC). Selv om sulfat-konsentrasjonene (SO_4^{2-}) i norske innsjøer har stabilisert seg de siste årene, har ikke den økende DOC-trenden gjort det samme, noe som muligens skyldes økt temperatur og nedbørsmengder. Fremtidige klimaforandringer i Norge, beregnet ut i fra FNs klimapanels (IPCCs) tall, sammen med nåtidens GIS-programmer, gir rom for mange muligheter når det gjelder å fremstille fremtidige scenario.

Målet for denne oppgaven var å vurdere DOC-forandringer i ti norske innsjøer fordelt utover landet og med ulik vannkjemi, ved bruk av IPCC sin prediksjon RCP4.5 av lufttemperatur og nedbørmengde i nær fremtid. I tillegg skulle GIS-modeller brukes for å visualisere hvor i nedbørfeltet de største relative endringer i produksjon av alloktone tilførsler av DOC til innsjøene ville være. Dette var gjennomførbart grunnet eksisterende data angående sammenhengen mellom temperatur og totalt organisk karbon (TOC: hvorav mesteparten er DOC), i tillegg til muligheten for å dele opp nedbør med tanke på SO_4^{2-}-konsentrasjoner før og etter stabilisering, for å se påvirkningen fra nedbørsmengder. Fire innsjøer ble regnet som nedbørsavhengige, samtidig som alle ti viste seg å fortsette den positive TOC-trenden til 2025, for så å gradvis stabilisere seg mot 2075. Ut i fra dette ble det tolket at klimaforandringer i nær fremtid vil kunne føre til økte konsentrasjoner av DOC i norske innsjøer. De spesifikke økningene, både når det gjaldt tidsaspektet og den romlige fordelingen innenfor hvert nedbørsfelt, var mulig å fremstille ved bruk av grafer og GIS-modeller.

På grunn av den observerte nedgangen av SO_4^{2-}-konsentrasjoner, bør overvåkingen av DOC/ TOC i norske (så vel som lignende europeiske) innsjøer fortsette og overvåkes. I tillegg trengs det mer forskning på hvilken rolle temperatur og nedbør har når det gjelder disse fremtidige mengdene generelt, og i enkelt-innsjøer. Når det gjelder GIS som visualiserings- og statistikk-verktøy er mulighetene mange og denne masteroppgaven er kun et glimt av rollen de kan (og bør) få i videre vannforvaltning- og forskning.

Preface

This is a master's thesis in the study program Environment and Natural Resources within the specialisation Limnology and Water Resources, at the Department of Environmental Sciences at the Norwegian University of Life Science. The aim was to provide temporal and spatial GIS visualizations and statistics of near-term DOC changes in ten Norwegian lakes, based on IPCC's predicted future precipitation and temperatures. Working on this thesis over the last year has been an existing journey where I am especially grateful for learning more about the possibilities of GIS in water management and research.

I would like to thank my fellow students through all my years in Ås, and the professors at the faculty, for being a part of making me ready to become a Master of Science. This includes my co-supervisor Gunnhild Riise and especially my supervisor Ståle Haaland who has been of great support, helping me throughout the year whenever needed.

I would also like to thank Torgrim Sund and Ivar Svare Holand at Nord University for teaching me the basics (and more) of GIS giving me the start I needed to learn the hydrologic parts on my one, as well as good discussions on the subject. Thanks to The Norwegian Environment Agency, Gesa A. Weyhenmeyer and Øyvind Garmo for providing helpful information and necessary data.

Finally, my grateful thanks are extended to family and friends for all support, and to my parents for letting me stay in their cabin to finish my thesis – probably giving me the most beautiful view one could have from a workplace.

____

Kari Anne Solberg
Kvål, 14 February 2017

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Abbreviations

AR5 – IPCC's assessment report number 5

Cl – Chloride (Cl^-)

DEM – Digital Elevation Model

DOC – Dissolved organic carbon

DOM – Dissolved organic matter

GIS – Geographic information systems

HMW – High molecular weight

IPCC – Intergovernmental Panel on Climate Change

KNMI – The Royal Netherlands Meteorological Institute

LMW – Low molecular weight

MD – The Norwegian Environment Agency

MET Norway – The Norwegian Meteorological Institute

NIVA – The Norwegian Institute for Water Research

NVE – The Norwegian Water Resources and Energy Directorate

POM – Particulate organic matter

RCP – Representative concentration pathways

SO_4 – Sulphate (SO_4^{2-})

TOC – Total organic carbon

WFD – Water Framework Directive

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1. Introduction

The concentrations of organic matter of lakes several places in the Northern hemisphere have been increasing the last few decades, closely linked to the decline in acid rain (Monteith et al. 2007). However, now that the amounts of SO_4 in Norwegian lakes are starting to stabilize, there is still an increasing trend in organic matter, possibly caused by increased temperature and precipitation (Weyhenmeyer & Karlsson 2009). Affecting the aquatic life, drinking water facilities and the carbon cycle, future concentrations are of interest (e.g. Algesten et al. 2004; Thrane et al. 2014; Wetzel 2001). The climate is changing, and at the same time geographic information systems (GIS) are constantly improving (Haaland et al. 2016; IPCC 2014). Having future climate change predictions for Norway based on scenarios from the Intergovernmental Panel on Climate Change (IPCC), together with today's GIS programs, there are many possibilities to model future scenarios – of which some will be presented in this thesis.

1.1. Organic matter

Organic matter in lakes includes various stages of degradation of plants, animals and microorganisms, and plays an important role in the carbon cycle (Algesten et al. (2004). In lakes, organic matter can be of either autochthonous or allochthonous origin (Wetzel 2001). Autochthonous organic matter is produced within the lake (i.e. plankton, aquatic macrophytes, fish, etc.), whereas allochthonous organic matter is produced within the lake's catchment. The quality of the allochthonous organic matter, and how much is transported to the lake, depend on factors such as types of catchment soil and vegetation, climate and land use (Allan & Castillo 2007).

Organic matter and its organic carbon content is often categorized by operationally defined size fractions, labelled particulate and dissolved organic matter (POM and DOM, respectively) (Wetzel 2001). These fractions are separated by size using filtration methods where POM > 0.45 µm; most of the organic matter is detritus: non-living (Figure 1). In lentic and lotic systems, the dissolved fraction (≤ 0.45 µm) often dominates, and for lakes the ratio DOM:POM normally lies between 6:1 and 10:1, being highest in oligotrophic lakes (Allan & Castillo 2007; Wetzel 2001).

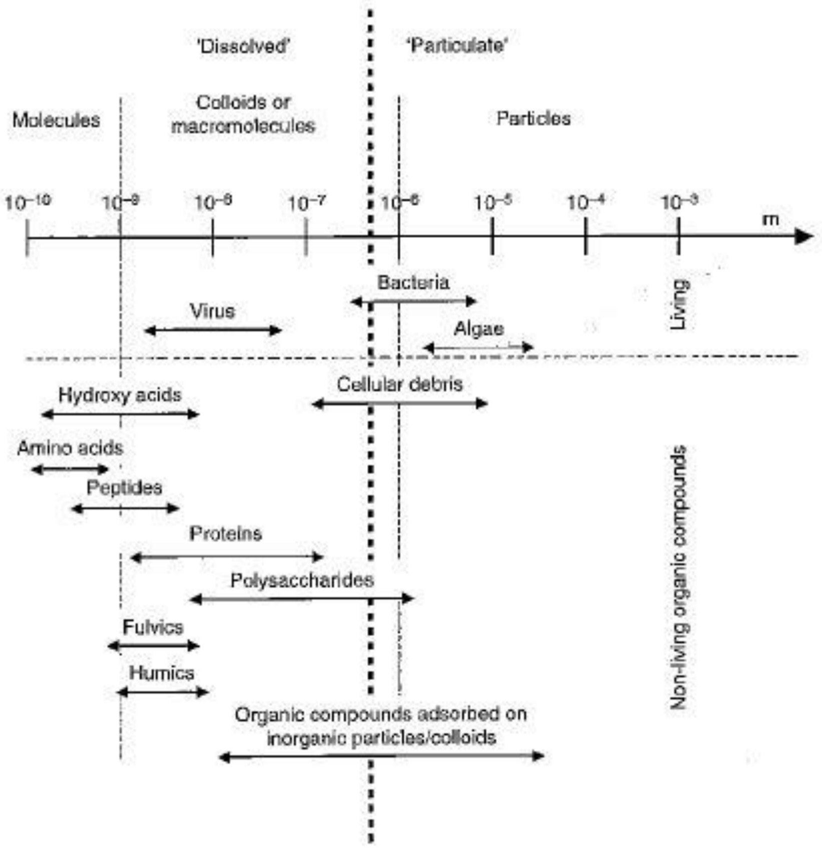

Figure 1. Overview of the composition of total organic carbon, divided into dissolved and particulate by size, as well as non-living and living. From Tranvik and von Wachenfeldt (2009) who developed it from Stumm W and Morgan JJ (1996). Aquatic Chemistry: Chemical Equilibria and Rates in Natural Waters. *New York: Wiley.*

The sum of the fractions of organic matter are referred to as total organic matter (Wetzel 2001). To emphasize that it is of a natural origin, and to distinguish it from organic matter of anthropogenic origin, such as plastics, the letter N for natural is often added (NOM, PNOM, DNOM). However, the fractions are also very often presented as the C-content: TOC, DOC and POC (often in mg C/l), due to the high content of C in organic matter (often about 50 %) and the easy use of TOC-analyzers. TOC and DOC will frequently be used in this thesis.

Organic matter in lakes can also be divided into humic and non-humic matter (Wetzel 2001). Non-humic substances are mainly of low molecular weight (LMW) and labile, causing high flux rates and thus low concentrations in aquatic systems. Humic matter on the other hand makes up 70-80 % of the organic matter in water and soils; have high molecular weight (HMW); come mainly from plants; and are hard to degrade further, thus resulting in these flux rates being low.

The humic matter consists of both weak and stronger acids (fulvic and humic), causing negative sites where cations can attach (Steinberg 2003; Wetzel 2001). This can lead to binding of metals, either strong as for e.g. mercury (Hg), lead (Pb), iron (Fe) and aluminium (Al), or weak (e.g. Ni; Zn; Cd), and thence possible transport of these through washout of dissolved organic matter from soils to water (Lawlor & Tipping 2003). As a weak acid-base system, dissolved humic matter also represents an important buffer system in lakes (Wetzel 2001). However, it has been shown that the acid neutralizing capacity (ANC) of lakes needs to be higher with increasing concentrations of organic matter for fish (trout) being able to reproduce (Lydersen et al. 2004). This latter is because a part (about a third) of the organic acids act as strong acids.

An important feature of humic matter in lakes is its ability to absorb light (UV and short waved visual, blue-green light), causing a so-called brownification of lakes (Graneli 2012; Wetzel 2001). The light absorption is due to longer conjugated systems (chromophores, pigments) within the humic structure (Shapiro 1957; Steinberg 2003), and also due to humic matters' ability of complexation with ferrous Fe-colloids (Poulin et al. 2014). HMW-fractions of humic matter absorb light most efficiently, due to its higher content of conjugated systems.

There are many aspects around brownification of lakes. Brownification might benefit algae through the protection of UV radiation, but will also reduce the light penetration needed for photosynthesis (e.g. Kirk 1976; Thrane et al. 2014). The brownification also represents challenges for drinking water facilities (Ødegaard 2013). The focus regarding lake brownification in this thesis will be on its present climate drivers precipitation and temperature.

1.1.1. Precipitation

1.1.1.1. Precipitation chemistry

Precipitation consists of several ions, and the composition, and thence effects on the reached watersheds, vary (Allan & Castillo 2007). Some of the precipitation causes acidification of soils and waters. This acid precipitation is sometimes caused by anthropogenic sulphur, either as wet (SO_4) or dry (SO_2) depositions, originating from the combustion of fossil fuel/ biomass and/ or sulphide ore smelting. Other causes for acid precipitation could be anthropogenic emissions of nitrogen oxides (NO_x) and ammonia (NH_3) through fossil fuel combustion and fertilizing, or natural emissions of NO_x, NH_3 and several sulphur species; natural sources for these nitrogen and sulphur species are e.g. the ocean, wetlands and microbial activities (VanLoon & Duffy 2011).

Acidification of soils and lakes, caused by anthropogenic sulphur emissions, was recognized in several parts of the Northern hemisphere in the 1960s and 1970s, leading to aims of decreasing the emissions (Allan & Castillo 2007). The acid rain problems were most apparent in the eastern part of North America and parts of Europe. The decline in measured SO_4 levels in lakes in these areas has been continuous since the 1980s, this also goes for Norway where the catchments of this thesis are situated (e.g.Monteith et al. 2007; Skjelkvåle et al. 2005; Wright & Jenkins 2001).

Simultaneously, a brownification of lakes in these places have been observed (Graneli 2012). The increase seems to be linked mainly to the decreasing amounts of sulphur emissions and sea-salts (Evans et al. 2005; Haaland et al. 2010; Monteith et al. 2007). This could mean that the decrease monitored these last decades is in fact a return of the original colours (Evans et al. 2006). In Norway, though some parts are still struggling with recovering, most lakes (93 %) are classified as the classes good or better (see section 1.1.3) according to WFD (Austnes et al. 2016).

Opposite to organic matter, acid precipitation and sea-salts can mobilize metals. For NaCl, this happens through cation exchange, colloidal dispersion and aqueous complexes; the first being the most important and all depending on the pH, hardness and alkalinity of water (Amundsen et al. 2008; Bäckström et al. 2004). What effect this mobilization has on fish and other aquatic life depend on the amounts and types of metals. Sea-salts in soils increase the ionic strength, thus enhancing the solubility of DOC; and in waters they are most important in lakes close to the sea or under marine level (Evans et al. 2006; Haaland et al. 2012). As mentioned, the sea-salt depositions, also in Norway, has declined during the same period as SO_4; this is probably due to the heavy storm events being fewer the last decades than during the years around 1990 (Skjelkvåle et al. 2007).

1.1.1.2. Precipitation amounts

Though the main drivers of the colour increases seen the last decades are decreasing sulphur and sea-salt depositions (1.1.1.1), there can also be other important factors. E.g., Evans et al. (2005) found that the correlation between DOC and SO_4 in 22 UK Acid Waters Monitoring Network (AWMN) lakes was not strong enough to say that the brownification in all the lakes was caused only by the decline in acid depositions. He argues that the lakes which have had the most changes in sulphur depositions show DOC levels affected by this, whilst the other show correlation to climate changes.

Several studies support that there are other factors than SO_4 and sea-salts, though not as important and varying from site to site (e.g. Evans et al. 2005; Weyhenmeyer & Karlsson 2009). In many of these, no or weak relationships between TOC, DOC, colour and precipitation amounts are found. When looking at variations during the year, however, stronger correlations have been seen (Canham et al. 2004). And studies have emphasized the difference of DOC loadings in wet and dry climate (de Wit et al. 2016; Schindler et al. 1997). Haaland et al. (2010) also found that when measurements from four Norwegian lakes were modelled using precipitation chemistry (SO_4 + Cl) and quantity, strong positive correlations occurred for yearly precipitation and colour in the lakes (explaining up to 94 % of the variation in colour). These trends were not seen before this separation: then the ions explained 80 % of the increased water colour, whilst the yearly amounts of precipitation (mm) did not seem to be very important (r^2=0,29).

Transport of DOC from soils due to precipitation and the subsequent runoff, is especially important in the growth season because this is when the concentration of soil DOC is at its highest (Haaland & Mulder 2009). Increased amounts of precipitation can lead to altered waterways, temporary or permanently, plausibly causing increased discharge of organic matter from the upper soils; this has most effect in deep soils (Haaland & Mulder 2009; Hongve et al. 2004). In addition, heavy rain and flood leads to more of the upper soil layers being drained; this is also the part of the soil with highest concentrations of organic matter.

1.1.2. Temperature

Temperature affects DOC levels in waters and soils through several pathways due to its role in temporal and spatial runoff, production and degradation (e.g. Evans et al. 2006; Futter et al. 2011; Monteith et al. 2007; Wetzel 2001). In a study on 1041 boreal Swedish lakes, Weyhenmeyer and Karlsson (2009) found non-linear correlations between TOC levels and both lake-specific mean annual air temperature and the main growing and runoff season. These two factors gave more significant results than factors such as altitude and longitude.

In an experiment by Wright and Jenkins (2001), five catchments in Southern Norway were studied over a 17 year long period; three of the catchments being reference sites and the remaining two having a roof all over the canopy. The latter two were inside greenhouses where the climate was changed in different ways, in addition to the precipitation being cleaned for acid depositions. Some of the years one of them (named KIM) got increased temperature and CO_2 levels; these years showed that the TOC levels still increased, though lacking the yearly variation (high during summer; low during winter). This was caused by the winter temperature being held higher than the freezing point; thus, leading to more runoff during winter than the other years.

The microbial degradation of organic matter is also increased by temperature (Wetzel 2001). In addition, the increased temperature due to climate change has led to altered precipitation and evapotranspiration patterns causing both lower and higher DOC levels than before depending on location; more in section 1.2.

1.1.3. Water management

The WFD focusing on getting lakes back to their original biological and chemical states based on so-called references lakes, has increased the focus on lakes' situations and anthropogenic pressure (2000/60/EC 2000). The WFD is implemented in Norway through a water regulation (Vannforskriften) (FOR-2006-12-15-1446 2006).

The general DOC increases in Norwegian lakes also apply for drinking water, causing several potential problems regarding health and costs (e.g. Hongve et al. 2004). As mentioned (1.1) DOC absorbs UV radiation; in waterworks where UV radiation is used as a step in the water treatment these particles may therefore cause inadequate treatment, plausibly preventing the disinfection of the drinking water (Ødegaard 2013). Furthermore, if chloride is used for disinfection in water where organic matter is present, some of it will oxidize the organic matter leading to a need for more added chloride. In addition to reducing the effects of the treatments, DOC and chloride can lead to health issues, due to bi-products such as trihalomethanes (e.g. chloroform).

Depending on amounts of DOC, the water may also get unwanted taste, smell (if chloride is added) and colour, as well as damages to the water pipes (Ødegaard 2013). The negative sites in humic substances (see 1.1) are also potential indirect causes for health issues if binding considerable amounts of toxic metals, pesticides etc., harmful for humans.

1.2. Climate Change and IPCC

In the future, the climate change is predicted to increase the yearly temperature, the yearly precipitation and extreme precipitation events in Europe, regardless the scenario (IPCC 2013a). Regarding temperature, the strongest increases over the last decades have been seen in Scandinavia; whereas the future extreme precipitation are likely to increase for all seasons in the north of Europe (Kovats et al. 2014). This makes Norway a country with future increases in all these climate parameters. The temperature increases get higher with latitude, and in Norway there will also be a larger increase during winter than summer (Hanssen-Bauer et al. 2015). Locally there will also be decreasing temperatures and precipitation.

The CO_2 increases may lead to more DOC due to its positive effect on plant productivity (Wetzel 2001). Altered temperatures and precipitation patterns will some places lead to droughts and thence less DOC, whilst other places could get more DOC caused by increased precipitation and especially more often and severe heavy rain events.

IPCC has presented four different scenarios, depending on different amounts and trends in future emissions of greenhouse gases, in their Fifth Assessment Report (AR5) (IPCC 2013a; IPCC 2014).The scenarios are described as representative concentration pathways (RCPs) and are RCP2.6; RCP4.5; RCP6.0; and RCP8.5. The scenario used in this thesis' method is RCP4.5. This refers to a radiative forcing threshold of 4.5 W/ m^2 not being crossed, and stabilizing in 2100; it also includes a peak of global emissions in 2040 stabilizing after 2080 (IPCC 2013b; Thomson et al. 2011).

1.3. GIS

Geographic information systems (GIS) are used to describe, understand, calculate and visualize geographic attributes and spatial data (Rød 2015). Since the start in Canada in the 1960's, these systems have evolved and spread, and are now essential tools in most disciplines around the world considering geospatial data. In today's GIS program, such as QGIS and ArcGIS, it is possible to find and present features as e.g. land use, temperature, waterways and flow directions, depending on the available data sources (ESRI; QGIS). The Norwegian Mapping Authority has opened several data types for the public online, including digital elevation models (DEMs) and different types of topography data for the entire country (Kartverket 2017). In addition to allowing calculations and visualization of data representing the present and the past, not only temporally, but also spatially (with fine resolution), GIS open the opportunity of modelling the future.

1.4. Aim of the thesis

The aim of this thesis is to assess DOC changes in ten Norwegian lakes based on near future air temperature and precipitation predictions by the IPCC; and to use GIS models to spatially visualize the relative production of allochthonous DOC within the catchment areas.

1.5. Hypothesis

My hypothesis is that future climate change may cause increased DOC concentrations in Norwegian lakes; and GIS models can be used to spatially visualize the relative production of allochthonous DOC reaching lakes within specific catchment areas.

2. Method

2.1. Study sites

The ten lakes chosen for this work are located all over Norway, with different latitudes, longitudes and altitudes, as well as being both inland and near-coast locations (Figure 2); namely Botnevatnet; Isebakktjern; Grytsjøen; Kapervatnet; Lille Djupvatnet/ Nuvttejávrrit; Movatnet; Røyravatnet; Stavsvatn; Storbørja; and Store Øyvannet. They were all a part of a dataset of 78 Norwegian lakes (2.2.1), and the selection was based, in addition to geography, on trends and magnitude of the concentrations of the measured chemical compounds (Cl; SO_4; TOC), conductivity and the ratio lake:catchment area, to ensure variation.

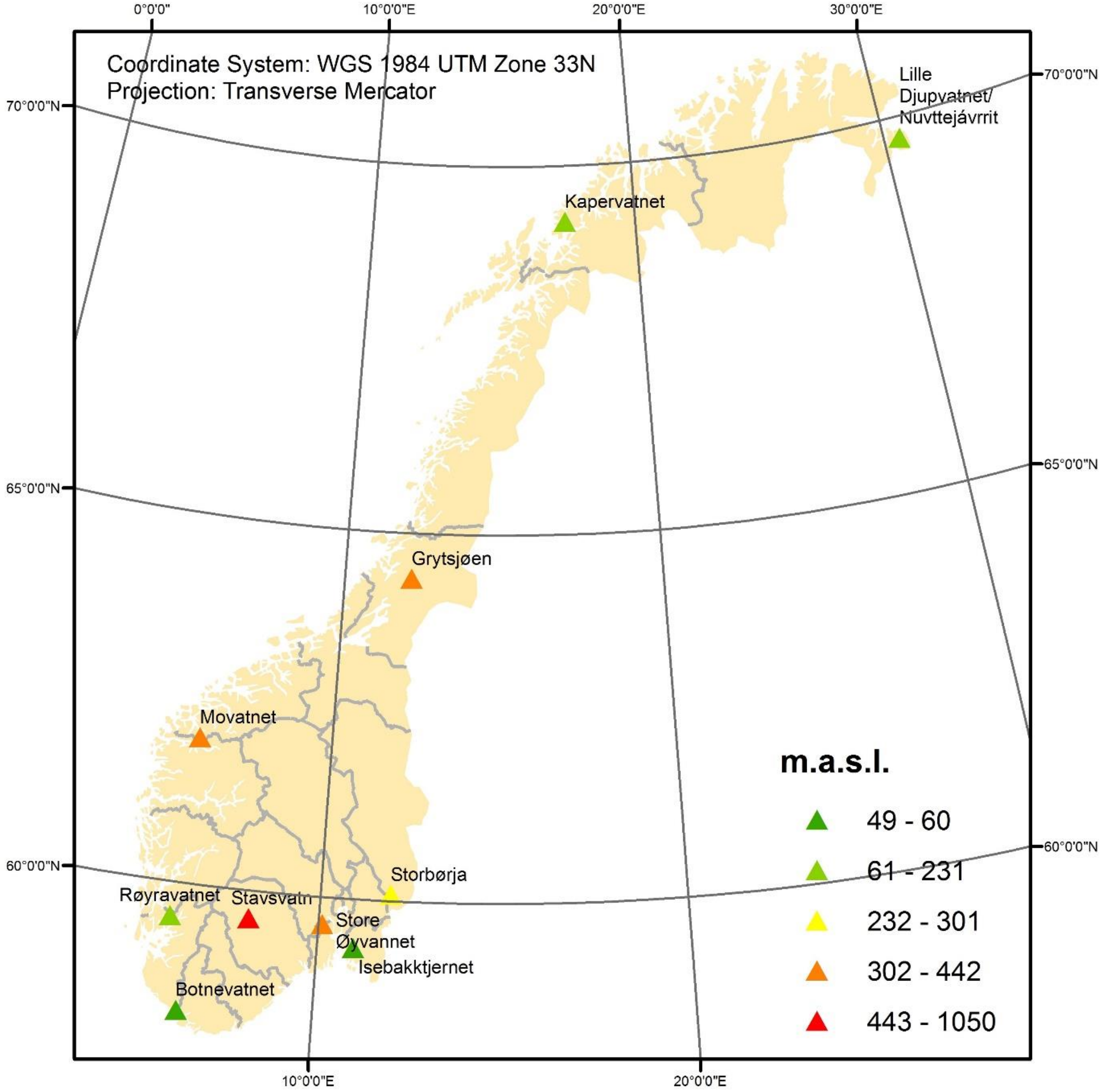

Figure 2. The locations of the ten Norwegian lakes chosen for this study. Data from The Norwegian Mapping Authority (N5000) and NVE (Norwegian Lake Database).

2.2. Data sets

2.2.1. Lake samples

The ten lakes were chosen from a set of 78 reference lakes the Norwegian Institute for Water Research (NIVA) has monitored from 1986 to 2014 (no samples from 2013) for the Norwegian Environment Agency (MD) (Appendix A). Originally, these were a part of a set of 1000 lakes chosen for the program *Monitoring long-range transboundary air pollution*, aiming for monitoring regional, yearly and long-term changes in acidification of Norwegian lakes (Garmo et al. 2015; Henriksen et al. 1987). During the next decades, several surveys gradually reduced the number of these lakes, until the 84 lakes still being monitored were chosen in 2004: including the 78 reference lakes (Garmo et al. 2015; Schartau et al. 2005; Skjelkvåle et al. 1996). The samples have been taken yearly during the time after autumn circulation has started. The guidelines have been to take the samples in the outlets, also when using helicopters; however, where this was not possible the samples were taken from the shore (Henriksen et al. 1987).

2.2.2. Historical precipitation and temperature

Monthly precipitation values for each watershed were downloaded from The Norwegian Meteorological Institute's (MET Norway's) freely available data for the nearest relevant stations with adequate time series (MET Norway 2016a; MET Norway 2016d). Due to different sampling dates (MD data set) from year to year (varying from September to November), precipitation from May to October was calculated and used in further analysis (Appendix B). This was to increase the reliability of the statistics regarding correlations between precipitation and TOC also when sampling dates differ. All the calculations regarding temperature and precipitation were executed in MATLAB, ArcPy and Excel.

In addition, monthly precipitation and annual temperature data for Norway in the normal period 1961-1990 was downloaded as 1000x1000 m grid data (MET Norway 2016b; MET Norway 2016c).

2.2.3. Predicted future precipitation and temperature

Predicted future precipitation and temperature changes for the catchments were based on IPCC's RCP 4.5 scenario of the AR5 (IPCC 2014). The maps in Annex I (IPCC 2013a) uses the reference period 1986-2005 and projects estimates for the periods 2016-2035; 2046-2065; 2081-2100. This is not compatible with the normal period used as reference in this thesis (2.2.2) and the preferable data was therefore derived from The Royal Netherlands Meteorological Institute's (KNMI's) Climate Explorer's Climate Change Atlas (KNMI 2016). This Atlas uses the data from AR5 Annex I to project a map of the wanted area and years by allowing to change the parameters of their script. For this report, the mean annual temperature changes from 1990 to 2025 and 2075 were calculated using the RCP 4.5 scenario and the reference period 1971-1990 (1961-1990 was not available).

The percentage precipitation changes for the months May to October at the precipitation dependent lakes (see 2.3.3) were found using the same procedure as described for temperature (Note: here the normal period 1961-1990 could, and therefore was, used).

2.2.4. Digital elevation models

Digital elevation models (DEMs) for areas covering the ten catchments were downloaded online (freely available) from The Norwegian Mapping Authority (Kartverket 2016a). The DEMs are raster data with cells holding information about the elevation of the earth's surface; the specific DEMs used in this analysis have 10 meters xy-resolution, and an approximate z-resolution of 2-6 meters. Where the catchments covered several DEMs, these were merged.

2.3. Model approach

2.3.1. Flow directions, flow accumulation and watershed delineation

The delineation and visualization of the catchments, and the flow directions of the water within, were derived from the 10x10 m grid DEMs using ArcGIS software (ArcMap 10.4, ESRI, Redlands, CA, USA). Some cells in the DEMs have no flow direction: all the surrounding cells have higher elevation values. Though these sinks can be natural, such as kettle lakes (Artsdatabanken 2016), they are usually caused by inaccuracies in the raster, due to measurements or the ten meter resolution (O'Callaghan & Mark 1984). All the sinks were filled up to the level of the neighbouring cell with the lowest elevation values, to ensure that they would not disturb the further steps and cause incorrect results.

An eight-direction (D8) flow model (Greenlee 1987; Jenson & Domingue 1988) was used to find the flow directions in the raster. Using this method, each cell is given one of eight possible values, representing the direction depending on which of the neighbouring cells has the steepest gradient. This is calculated using Equation 1.

Equation 1. Calculation of the gradient to be used in the D8-method. Modified from Jenson and Domingue (1988).

$$gradient = \frac{change\ in\ elevation\ values}{distance\ between\ the\ cell\ centres} \times 100$$

The flow directions of the cells in the rasters were then applied when calculating how many upstream cells each cell was gaining water from, resulting in flow accumulation rasters with the assigned values. The method is further described in Jenson and Domingue (1988).

To be able to delineate the watersheds, pour points were manually placed in the most accumulated pixel near the outlet of the respective lake, using the accumulation raster (with a threshold) and The Norwegian Lake Database (NVE 2016a). To make sure the manually placed pour points were indeed at the cells with the highest accumulation values, the nearest cells were searched and the pour points were snapped to the cells with the highest value. Together with the flow direction rasters, the pour point of each lake was used to calculate which cells of the raster drained to the outlet of the lakes; thus, resulting in the lakes' watershed rasters. To ensure adequate catchment results, they were cross-checked with The Norwegian Water Resources and Energy Directorate's (NVE's) watersheds in the NVE Atlas (NVE 2016b) (larger units than the results in this thesis) and The Norwegian Mapping Authority's topographic map Norgeskart (Kartverket 2016b).

Several thresholds in the flow accumulation rasters were made, and checked up against the same maps as for the catchments (only this time with rivers in the NVE Atlas) to see which gave the best representation of the normal water flow. A threshold of 500 was found to be representative for all lakes; hence, all cells gaining water from at least 500 upstream cells are visualized in the watershed rasters showing stream flow (3.1). To only show these specific cells of high accumulation, their value was set to 1, whilst the others were given the value NoData, and thus not displayed.

Hill shaded DEM-rasters, NVE's lake database (NVE 2016a) and 1:50 000 data for vegetation cover, land use and buildings were added to better visualize the topography of the areas and increase the local understanding of where in the watersheds possible hazards and relevant changes are likely to occur.

2.3.2. Temperature modelling

The catchment area feature was extended and added 100 random points, which then was given values from the temperature raster with mean annual temperatures from the normal period 1961-1990 (1000x1000 m grid). The points were then exact interpolated to 10x10 m grid using a Thin-plate spline function, as explained by Hoar and Nychka (2008). When extracting the downscaled temperature raster with the watershed area, the raster was snapped to the filled DEM raster to align the output cells, using bilinear interpolation.

The downscaled temperature raster was adjusted for altitude by applying an environmental lapse rate (Equation 2). For minimal data processing the slope for the relation between temperature and altitude used, was taken directly from Livingstone et al. (1999) who found this to be -0.6 °C per 100 m.

Equation 2. Raster calculation for adjusting the downscaled temperature rasters by applying the environmental lapse rate found by Livingstone et al. (1999).

$$Adjusted\ temp.raster = Downscaled\ temp.raster + \left(0.06 \times (Mean\ DEM - DEM)\right)$$

For more accurate temperature results one could e.g. use additional factors or find the slope in the specific area by using the Parameter-elevation Regressions on Independent Slopes Model (PRISM), see e.g. Hoar and Nychka (2008). By using the PRISM, or other methods in a GIS or statistical program, one also gets the intercept of the linear regression: i.e. what the temperature is at sea level. Due to not having such data, as well as giving a less time and data processing demanding method, a simplification was made in this model, by using the average height of the catchment area as a reference when applying the slope. The reason for choosing the whole area instead of the original 1000 x 1000 m grids, was that the former proved to give the smoothest result. Thus, though it may not give as correct temperature values as possible, it does give a good visualization of the temperature distribution. In addition, it appeared to be representative enough to show where the changes may have the biggest impacts.

The downscaled and adjusted temperatures for the normal period 1961-1990 were used to model future temperatures for 2025 and 2075 by adding the increase (2.2.3) with simple raster calculations. Minimum, mean and maximum values of the output rasters, as well as the reference raster, were extracted and assessed in the further calculations of future TOC levels (2.3.4).

2.3.3. Precipitation vs TOC

The calculated precipitation (mm) for the years between 1986 and 2014 (not including 2013) holding valid values was for each lake tested towards TOC looking at both quality and quantity of the precipitation.

First, looking at only the precipitation amounts and TOC levels there were no significant trends. However, when looking at only the last years positive correlations were spotted. The reason for deciding to test this was the decline in SO_4 levels seen in Norwegian lakes over the last decades, getting closer to stabilizing the last years, thus not having the same impact on TOC as before. These findings resulted in the further calculations being done with precipitation values divided by the chemistry parameter SO_4.

Plotting the precipitation (divided by quality) against TOC, and adding linear trend lines, it came clear that as the SO_4 levels declined the precipitation amounts had more impact on the TOC levels in most lakes. However, the statistical significance was low due to few years with low/ stabilized SO_4 values for all the lakes, in addition to only one TOC sample per year. That said, these are the data for Norwegian lakes available at this date, and considering that this thesis' focus is on testing methods and showing possibilities of GIS modelling, the lakes with $r^2 > 0.50$ were chosen for future TOC calculations depending on precipitation.

2.3.4. Future TOC predictions

Due to the decision to use precipitation values from May to October, these six months' grids (1961-1990) were summed with simple raster calculations. From the resulting raster, values for the lakes considered to be precipitation dependent when it comes to TOC values were extracted. Then, the percentage increases, according to the IPCC results (2.2.3), were added for the years 2025 and 2075 to find the values (mm) for these years.

For the precipitation dependent lakes the p values were also added. Then the slope of the trend line for the years with lowest SO_4 values was used for predicting future TOC levels, since the SO_4 values are likely to continue the decline or stay as low as today. These results were added to the increase caused by temperature. For the lakes considered non-dependent on precipitation only the TOC increase related to temperature was calculated.

The percentage increase of TOC per degree (°C) was derived from the nonlinear correlation found in Swedish lakes by Weyhenmeyer and Karlsson (2009). For each catchment, the temperature values for the normal period 1961-1990 and the spatial minimum, mean and maximum values calculated for the years 2025 and 2075 (2.3.2) were used to find the percentage increases; these were further added to the TOC values of 2014. For the four lakes considered precipitation dependent, the TOC increases caused by precipitation were added to the values derived from the temperature increases.

After all calculations were done, the historical (1986-2014) and predicted (2025 and 2075) TOC values were plotted in graphs, showing temporal and spatial (minimum, mean and maximum) values in the catchments.

3. Results

3.1. Catchments

Figures Figure 3 to Figure 12 show the ten delineated watersheds with their accumulation rasters given a threshold = 500 to show the most important waterways. Lakes, vegetation cover, land use and buildings are also added, giving a more complex overview of the catchment area and possible effects on the water draining to the lakes. The scales are approximately the same to visualize the relative sizes and underlying hill shaded DEMs are included for better perception of the terrain.

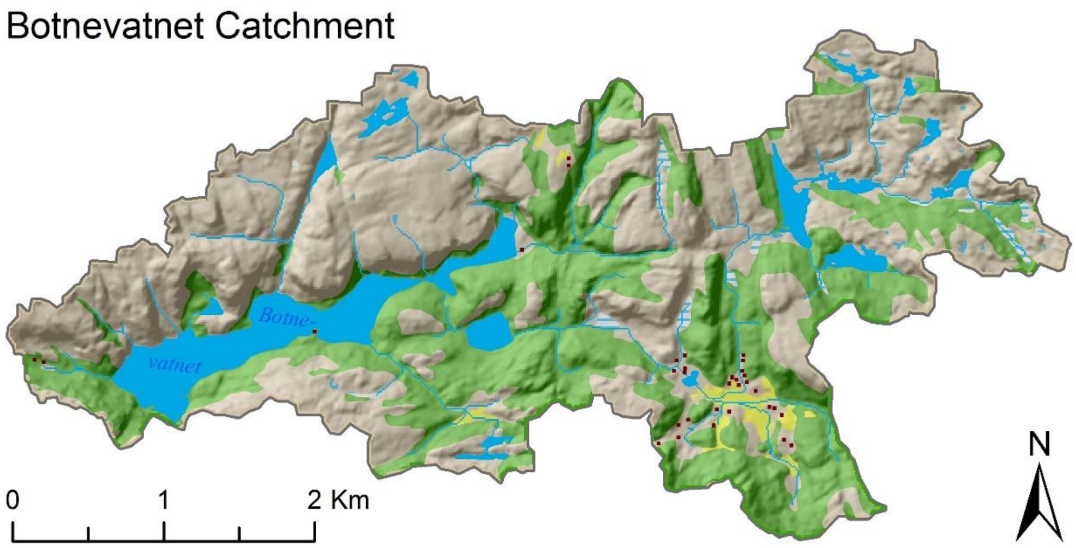

Figure 3. The delineated catchment for the lake Botnevatnet, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

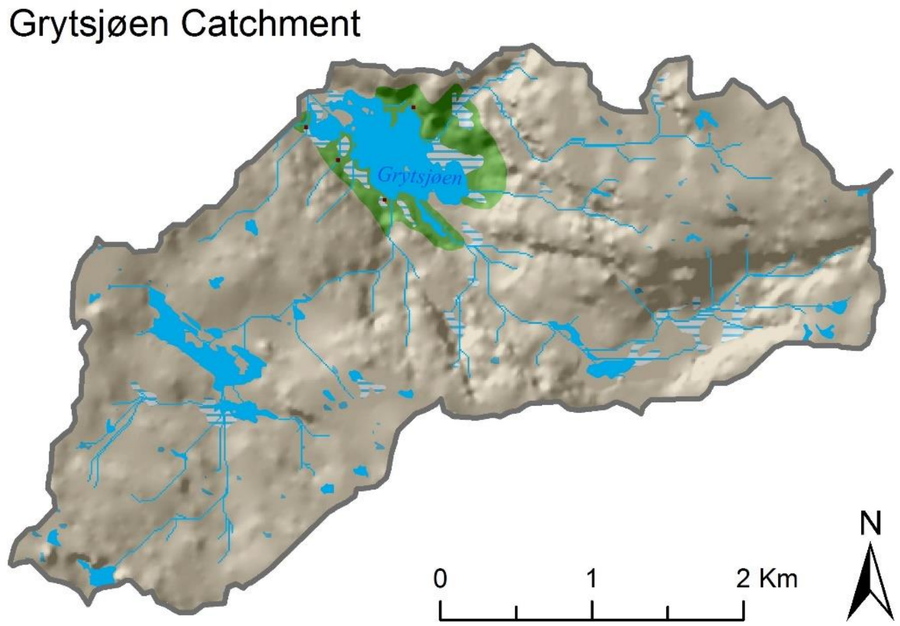

Figure 4. The delineated catchment for the lake Grytsjøen, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

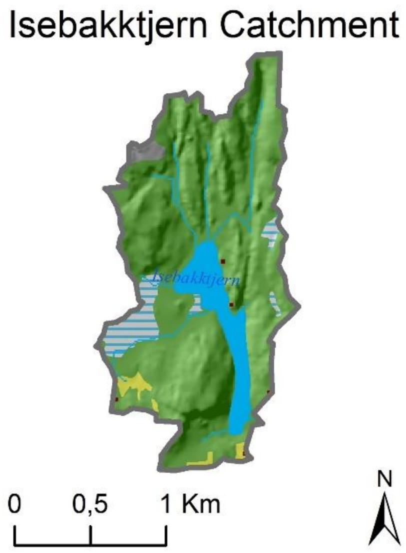

Figure 5. The delineated catchment for the lake Isebakktjern, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

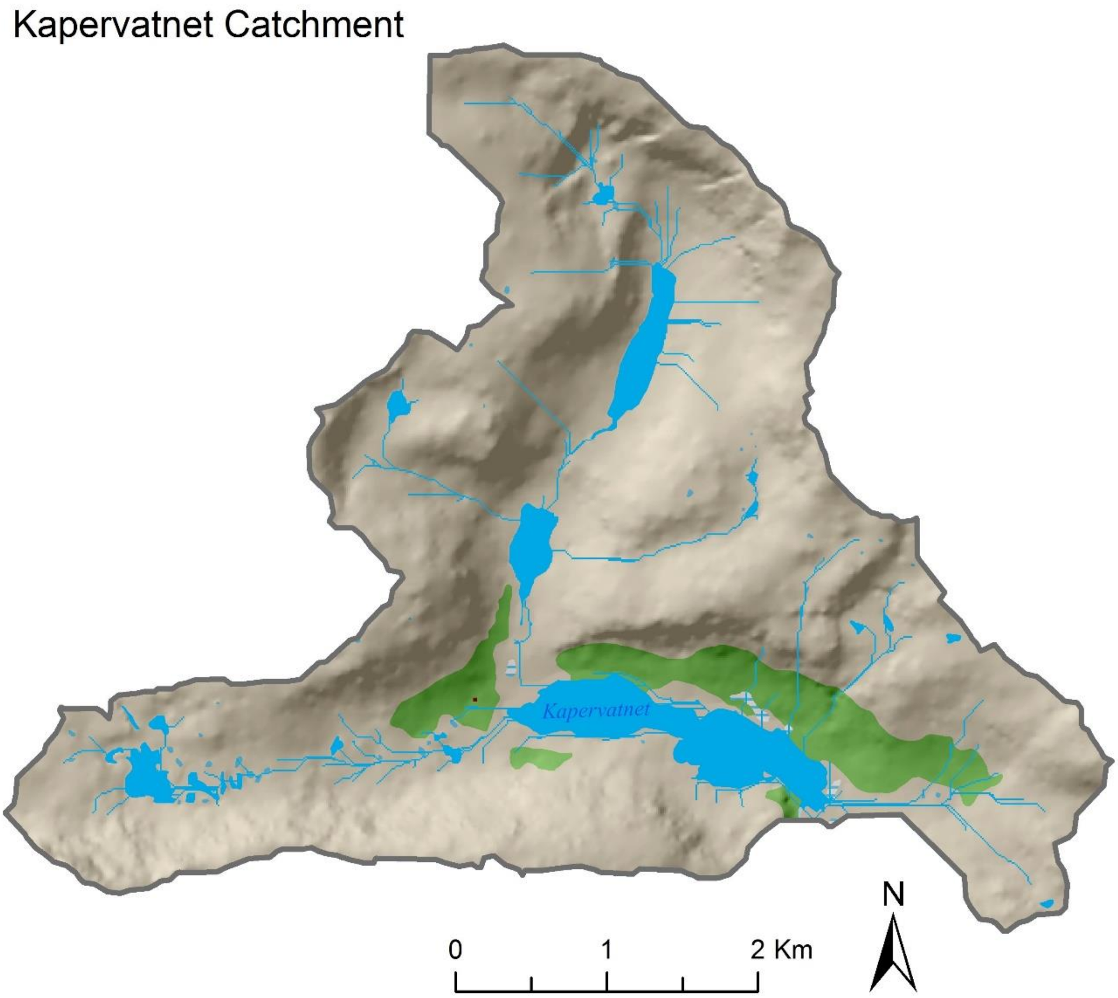

Figure 6. The delineated catchment for the lake Kapervatnet, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

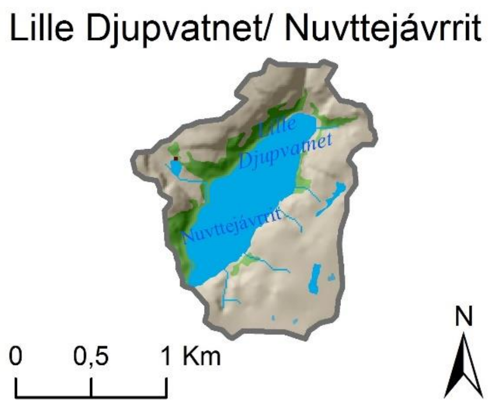

Figure 7. The delineated catchment for the lake Lille Djupvatnet/ Nuvttejávrrit, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

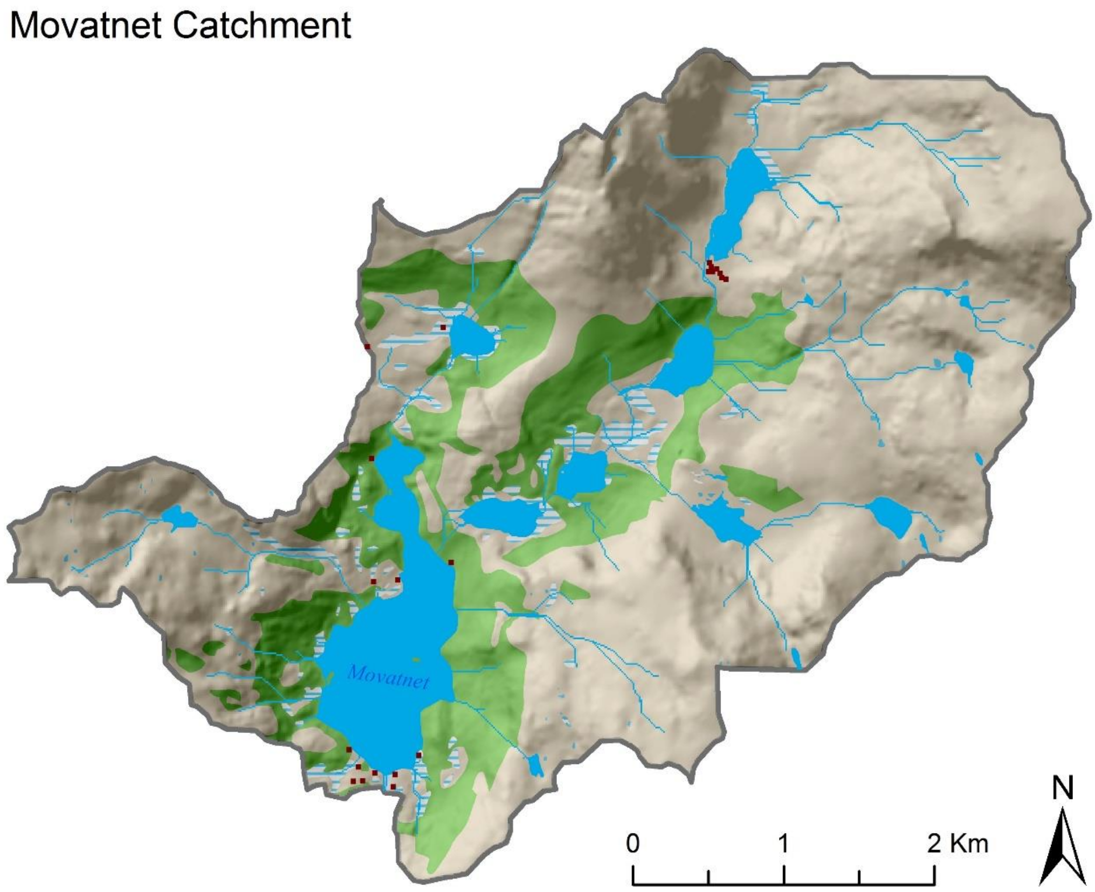

Figure 8. The delineated catchment for the lake Movatnet, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

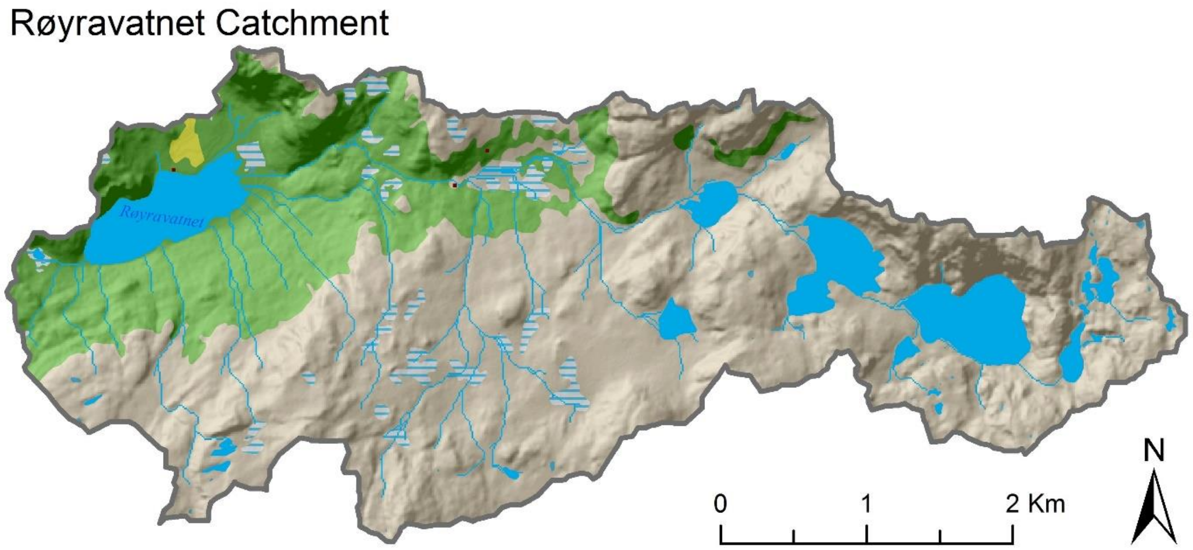

Figure 9. The delineated catchment for the lake Røyravatnet, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

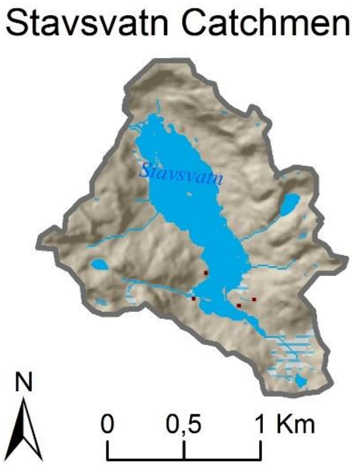

Figure 10. The delineated catchment for the lake Stavsvatn, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

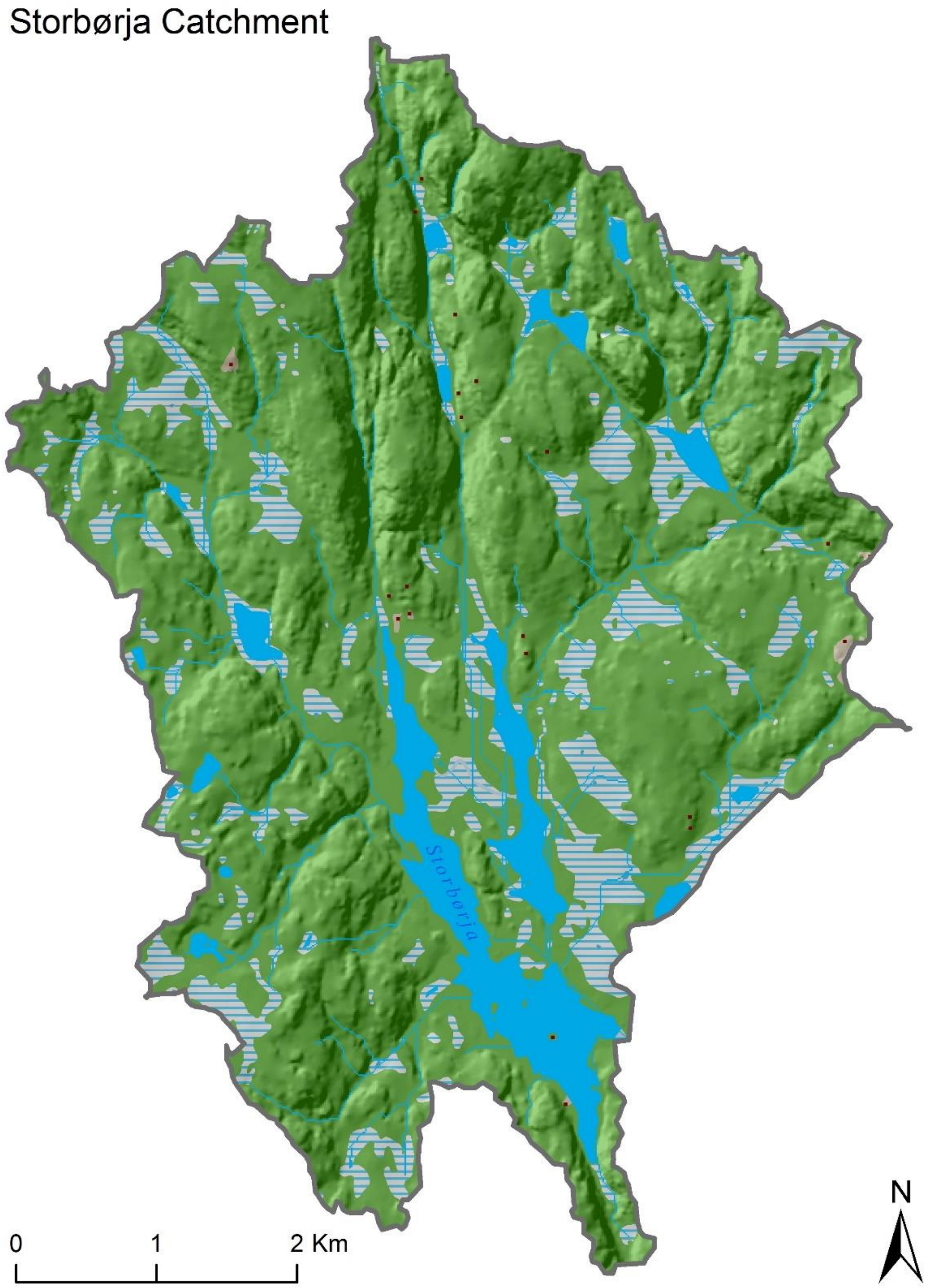

Figure 11. The delineated catchment for the lake Storbørja, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

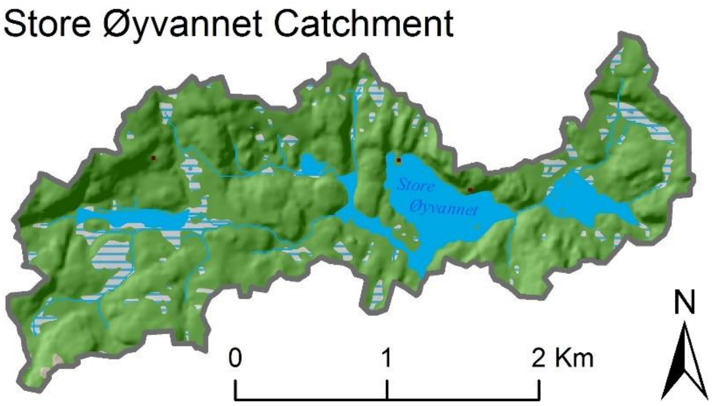

Figure 12. The delineated catchment for the lake Store Øyvannet, including the accumulation raster with threshold=500, vegetation, land use and buildings. Data from The Norwegian Mapping Authority (DEM; N50) and NVE (Norwegian Lake Database).

The Figure 3 to Figure 12 show little to no settlement in the catchments, and agricultural areas only in three: Botnevatnet, Isebakktjern and Røyravatnet. This is due to MD's database lakes being used as reference lakes for acid deposition measurements, and hence should be as little human impacted as possible. There is still differences between the lakes in size, catchment area, catchment: lake ratio and vegetation cover.

To give a statistical overview, information concerning lake area, catchment area and the ratio catchment:lake area, found in ArcMap, is put together in Table 1.

Table 1. Information concerning the ten lakes and their catchments.

Lake	Catchment area (km^2)	Lake area (km^2)	Catchment:lake ratio
Botnevatnet	12,30	0,67	18,36
Grytsjøen	11,96	0,38	31,47
Isebakktjern	2,30	0,20	11,50
Kapervatnet	19,81	0,70	28,30
Lille Djupvatnet/ Nuvttejávrrit	1,85	0,42	4,40
Movatnet	20,32	1,03	19,73
Røyravatnet	16,03	0,43	37,28
Stavsvatn	2,39	0,41	5,83
Storbørja	30,64	1,16	26,41
Store Øyvannet	5,20	0,36	14,44

3.2. Precipitation vs TOC

Linear trend lines in Figure 13 to Figure 22 (a) show the correlations between precipitation amounts (mm; May - October) and TOC levels (mg C/ L), divided by SO_4 values, for the years in the time period

1986 to 2014 holding sufficient data. The trend line equations and r^2 values are also presented. Figure 13 to Figure 22 (b) show the SO_4 values from 1986 to 2014.

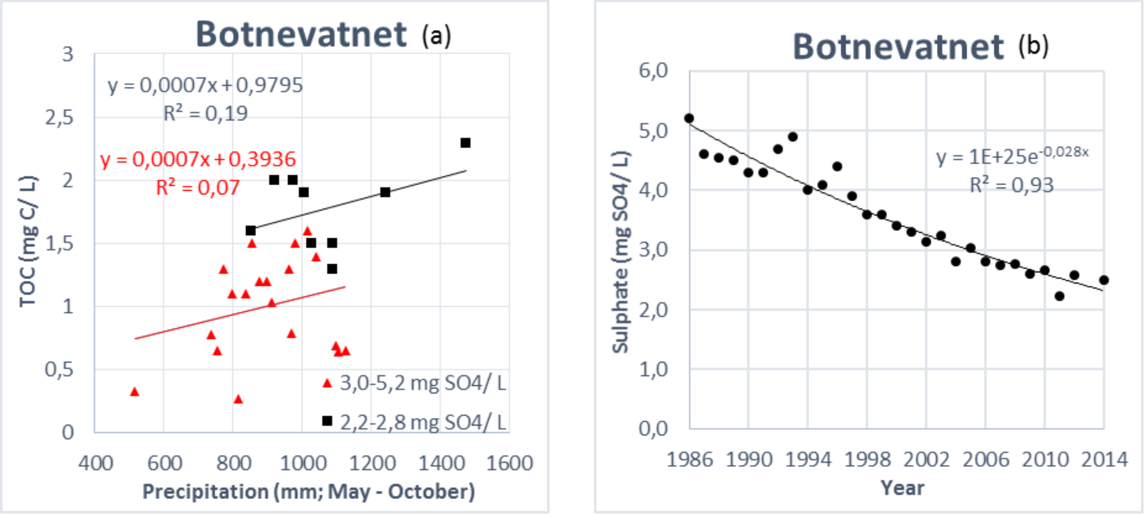

Figure 13. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) in the period 1986-2012 and 2014 in the lake Botnevatnet. Data from MET Norway (2016a) and MD's dataset (1986-2014).

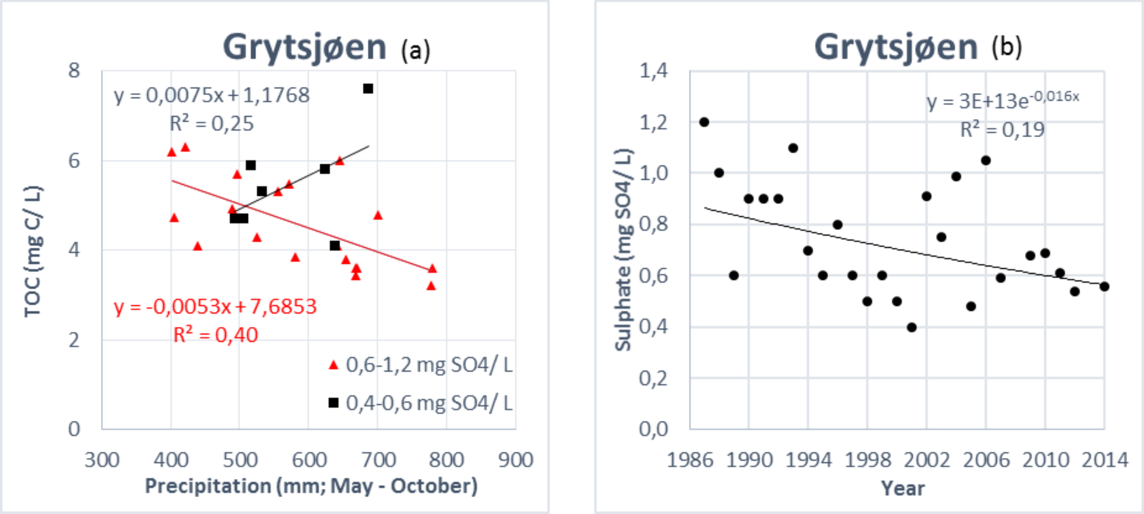

Figure 14. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Grytsjøen. Data from MET Norway (2016a) and MD's dataset (1986-2014).

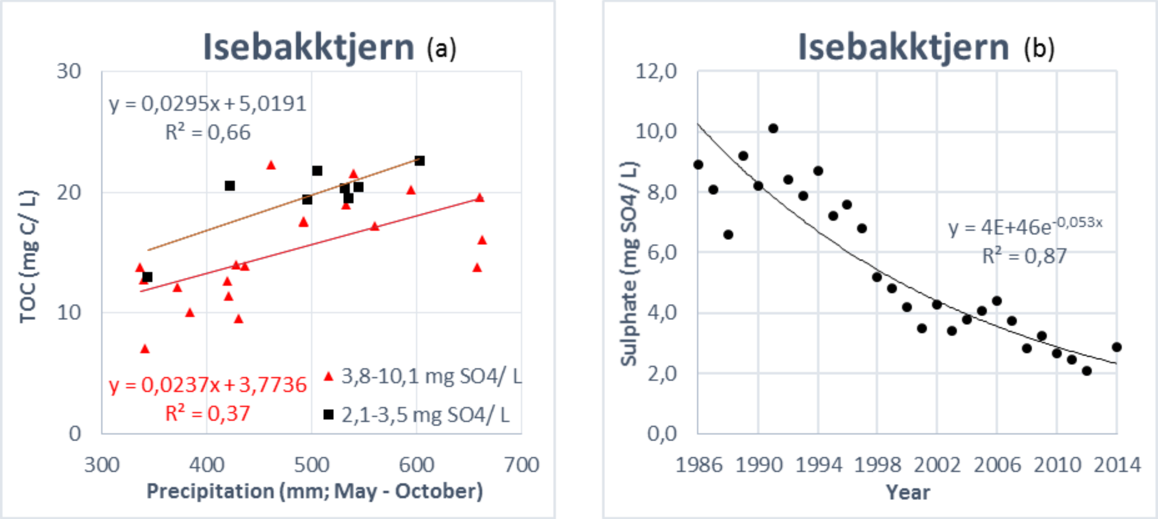

Figure 15. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Isebakktjern. Data from MET Norway (2016a) and MD's dataset (1986-2014).

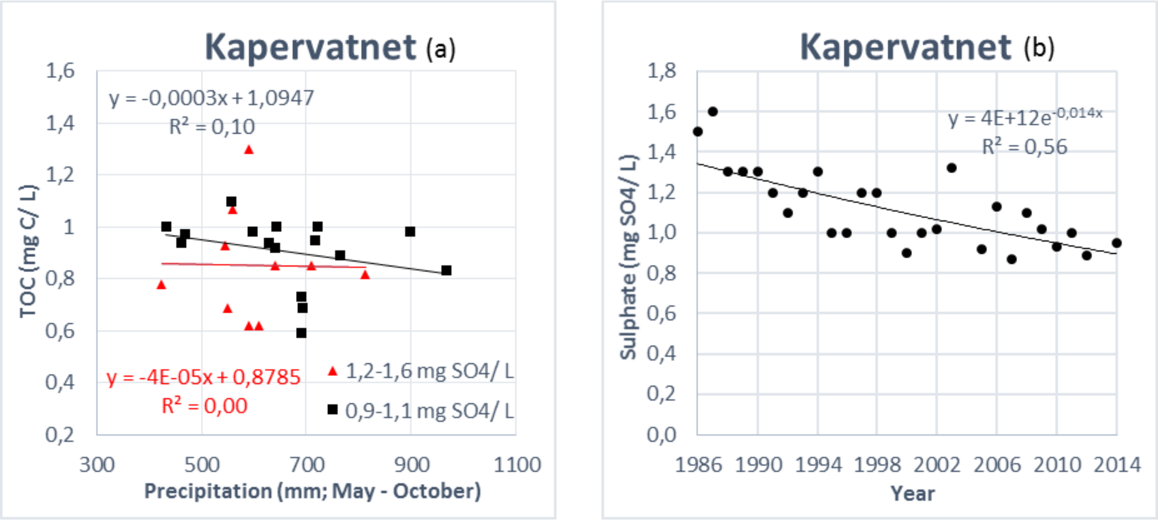

Figure 16. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Kapervatnet. Data from MET Norway (2016a) and MD's dataset (1986-2014).

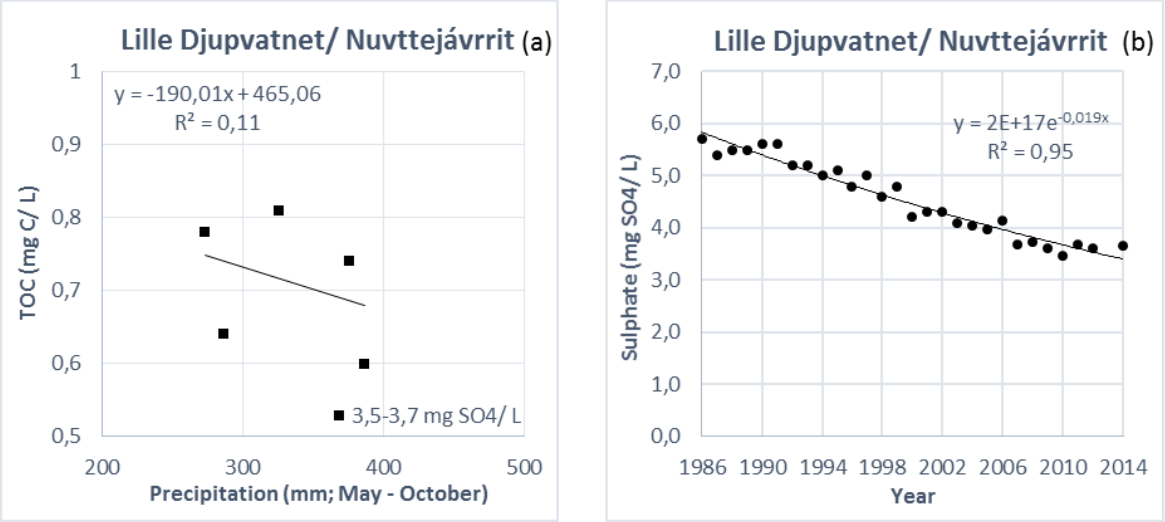

Figure 17. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Lille Djupvatnet/ Nuvttejávrrit. Data from MET Norway (2016a) and MD's dataset (1986-2014).

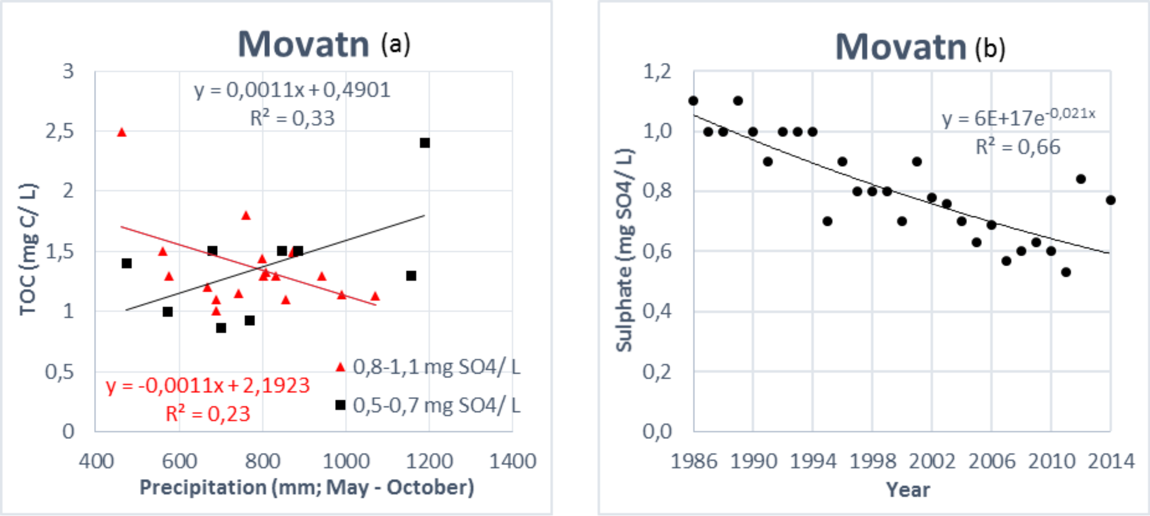

Figure 18. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Movatn. Data from MET Norway (2016a) and MD's dataset (1986-2014).

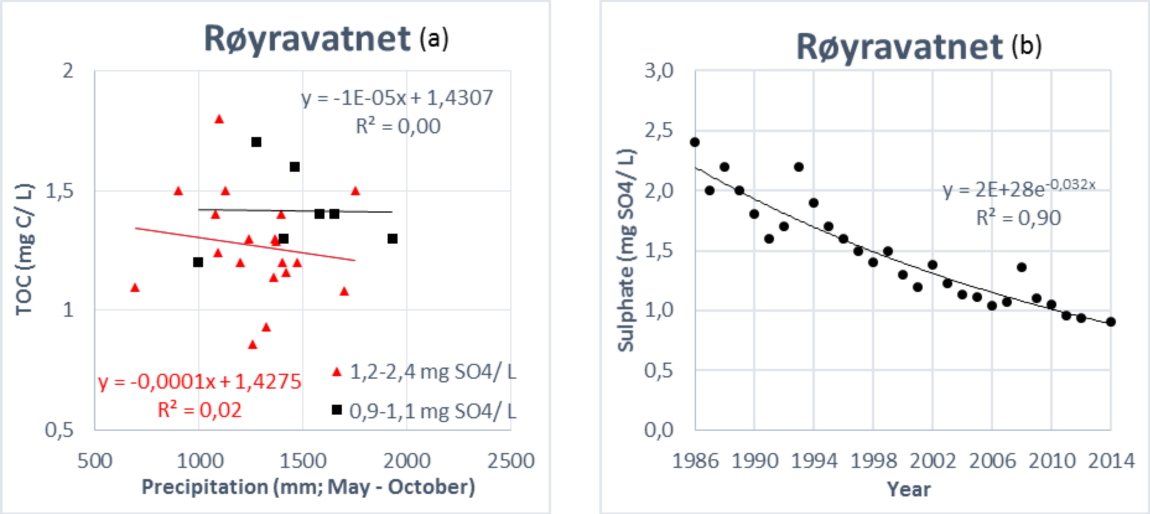

Figure 19. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Røyravatnet. Data from MET Norway (2016a) and MD's dataset (1986-2014).

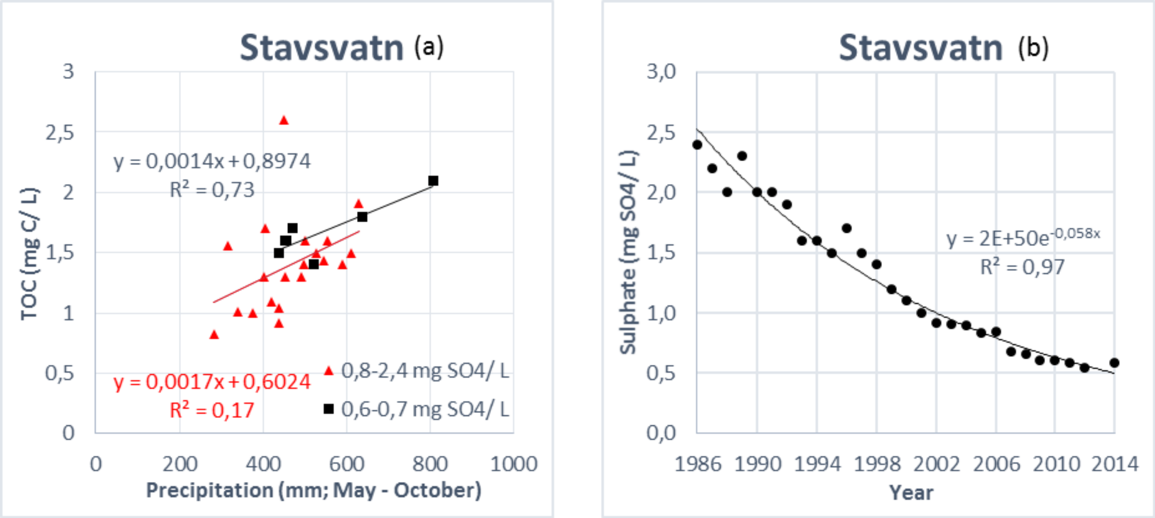

Figure 20. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Stavsvatn. Data from MET Norway (2016a) and MD's dataset (1986-2014).

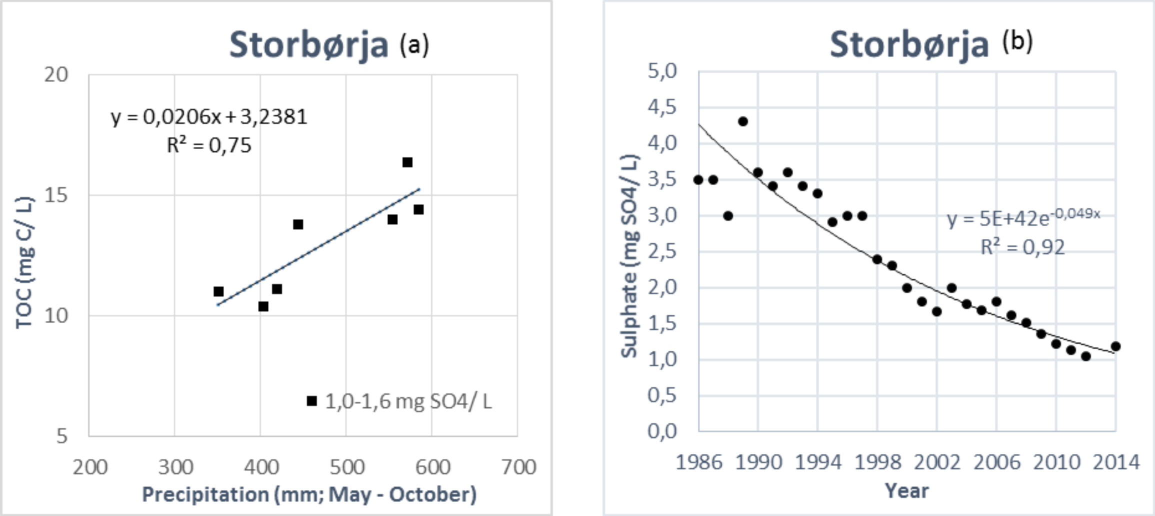

Figure 21. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Storbørja. Data from MET Norway (2016a) and MD's dataset (1986-2014).

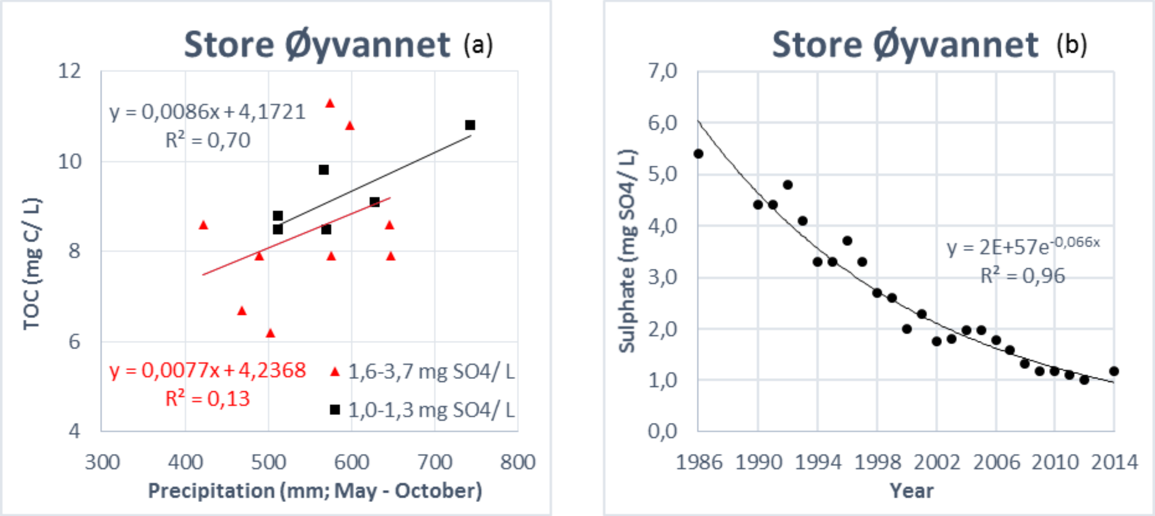

Figure 22. Precipitation vs. TOC for available years; black regression lines representing the years with low and (nearly) stabilized SO_4 values; red regression lines years with higher SO_4 vales (a) and SO_4 values (b) for the period 1986-2012 and 2014 in the lake Store Øyvannet. Data from MET Norway (2016a) and MD's dataset (1986-2014).

All the lakes had a decrease in SO_4 values from 1986 to 2014. The decrease was most significant in those with values higher than 1.6 mg/ L. The lakes Grytsjøen, Movatnet and Kapervatnet had the lowest starting values and the lowest significance in decrease. The levels seem to be stabilizing towards the last years, and most lakes had concentrations between 0.6 and 1.2 mg/ L in 2014, whilst Botnevatnet and Isebakktjern had somewhat higher levels: 2.5 and 2.9 respectively. Lille Djupvatnet/ Nuvttejávrrit did not have the same steep slope as the other lakes starting with relatively high SO_4 values, and still had 3.7 mg SO_4/ L in 2014.

As explained in sections 2.2.3 and 2.2.4, these last years with stabilized SO_4 values were chosen to see the correlation between measured TOC and precipitation (black regression lines in Figure 13 to Figure 22 (a)). The years with higher SO_4 concentrations were also added (red regression lines) for all years holding sufficient precipitation data, to show possible changes. In seven of the lakes a positive correlation between precipitation amounts and TOC was seen in the samples with the lowest SO_4 values; whether the correlation was positive or negative in the other samples varied. However, only four of them had $r^2>0.50$ for the trend lines with the lowest SO_4 values, and were therefore considered to be precipitation dependent for the further calculations. These are given in Table 2 along with r^2 and p values.

Table 2. The four lakes where TOC was considered precipitation dependent, with r^2 and p values.

Lake	r^2	p value
Isebakktjern	0,66	0,014
Stavsvatn	0,73	0,014
Storbørja	0,75	0,012
Store Øyvannet	0,70	0,039

All these lakes had p values < 0.05 and the trend lines from the regression analysis between precipitation and TOC were therefore considered statistically significant. Due to these trend lines representing recent years with SO_4 values that seem to be stabilizing, thus considered to stay approximately the same for the future years calculated, the slopes are used in the predictions without alterations.

3.3. Future precipitation and temperature

The precipitation values found for years 2025 and 2075, as well as the normal period 1961-1990, for the four precipitation dependent lakes are shown in Table 3. These results were used in the further calculations of future TOC levels (3.4). All the lakes will get increased precipitation amounts according to the scenario, and the percentage increases will be larger between 1961-1990 and 2025 than between 2025 and 2075.

Table 3. Future precipitation (May-October; mm) from the normal period 1961-1990 (MET Norway 2016b) according to RPC4.5 (IPCC 2013a; KNMI 2016).

Lake	1961-1990	2025	2075
Isebakktjern	487	513	519
Stavsvatn	559	590	597
Storbørja	478	507	513
Store Øyvannet	538	568	575

To show the present and future temperature distribution and changes in Norway according to the annual mean temperatures for the normal period 1961-1990 and IPCC's scenario RCP 4.5, the increases were added to the grid for the normal period (Figure 23). All of Norway will get higher mean annual temperature values, and the changes increase with latitude.

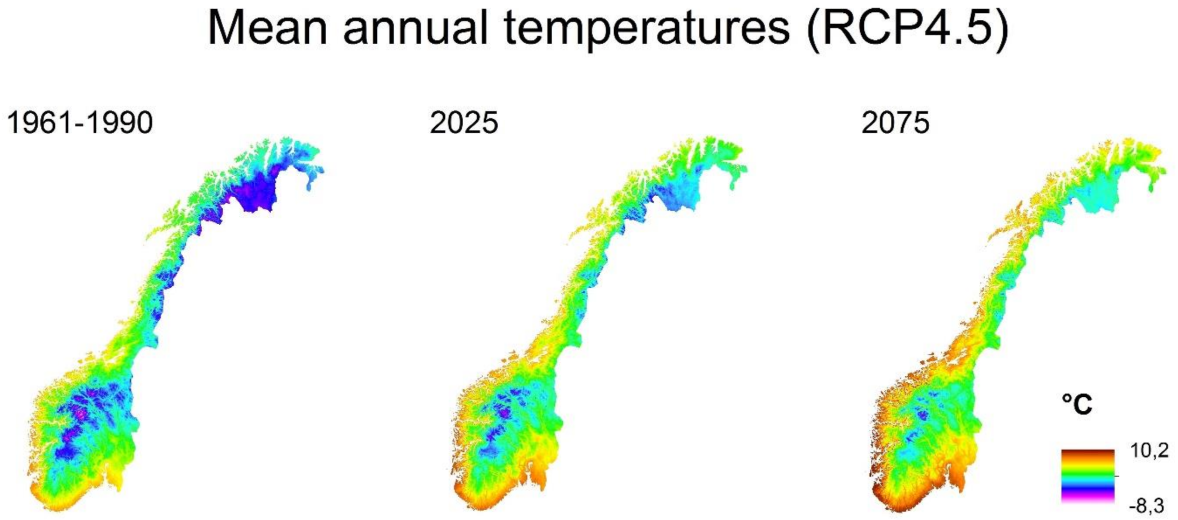

Figure 23. Mean annual temperatures (℃) for the normal period 1961-1990 (MET Norway 2016c) and years 2025 and 2075 according to scenario RCP 4.5 (IPCC 2013a; KNMI 2016).

The local temperature rasters, after downscaling, adjusting for altitude, and adding predicted increases (2.3.2) for all catchments, are shown in Figure 24 to Figure 33. The temperature scale for each catchment is set to be the same for the three periods to better visualize the increases. For more information concerning relative and absolute sizes see section 3.1. For exact values of the pixels holding the minimum, mean and maximum temperatures for each watershed and period, see Appendix C.

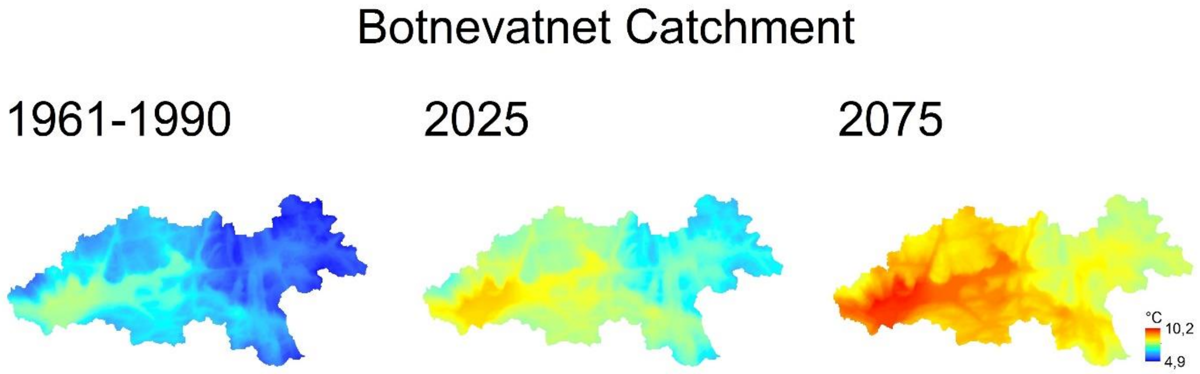

Figure 24. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Botnevatnet (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

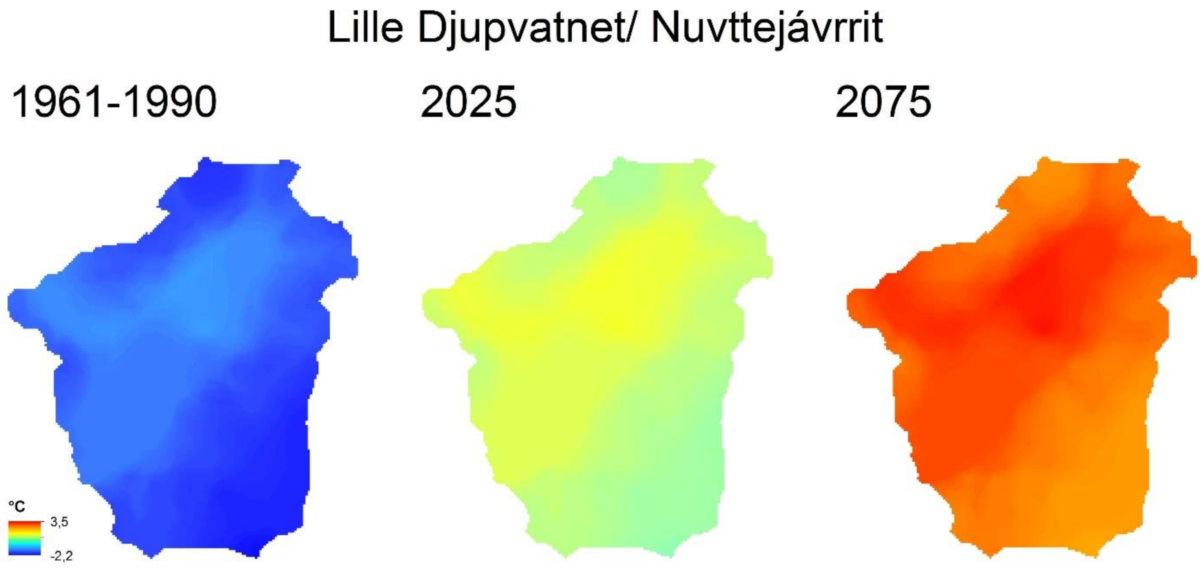

Figure 25. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Lille Djupvatnet/ Nuvttejávrrit (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

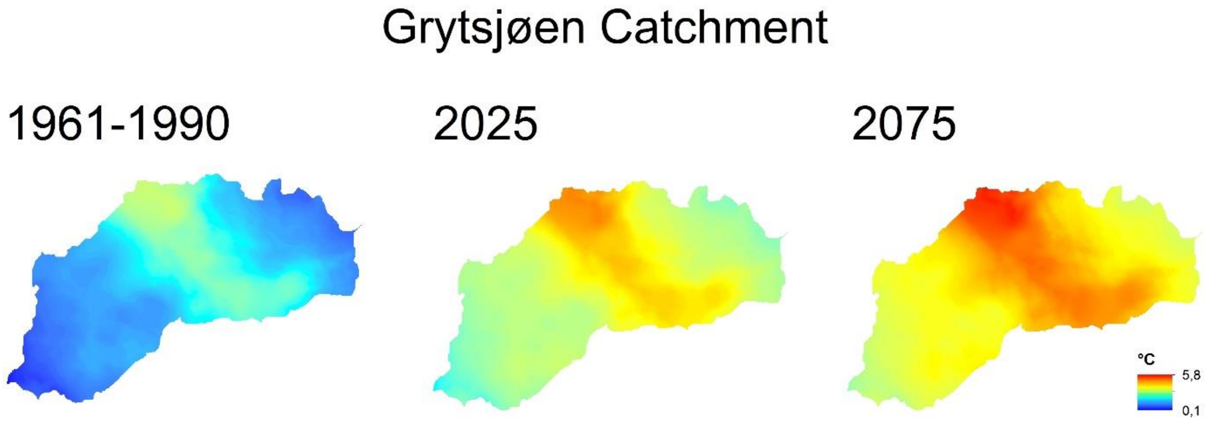

Figure 26. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Grytsjøen (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

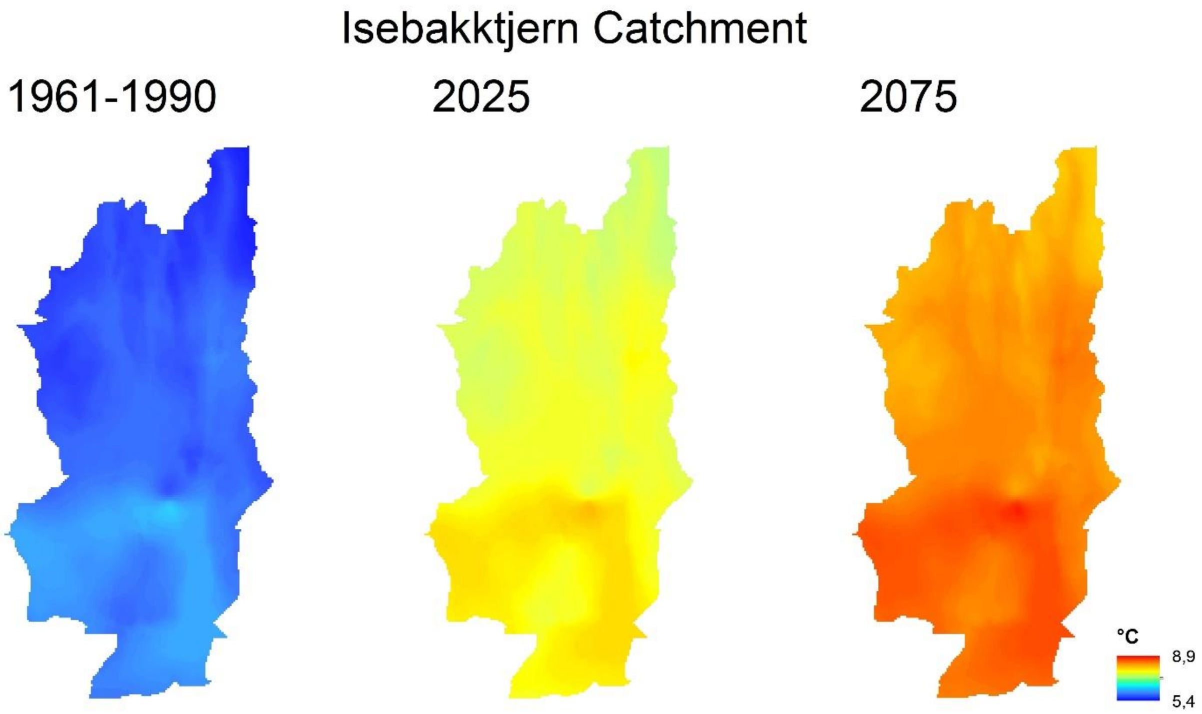

Figure 27. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Isebakktjern (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

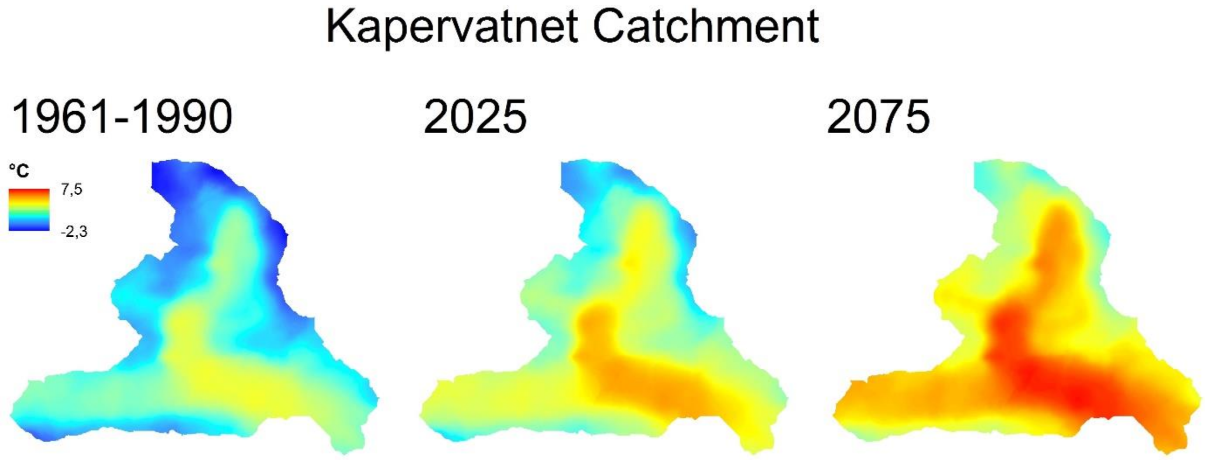

Figure 28. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Kapervatnet (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

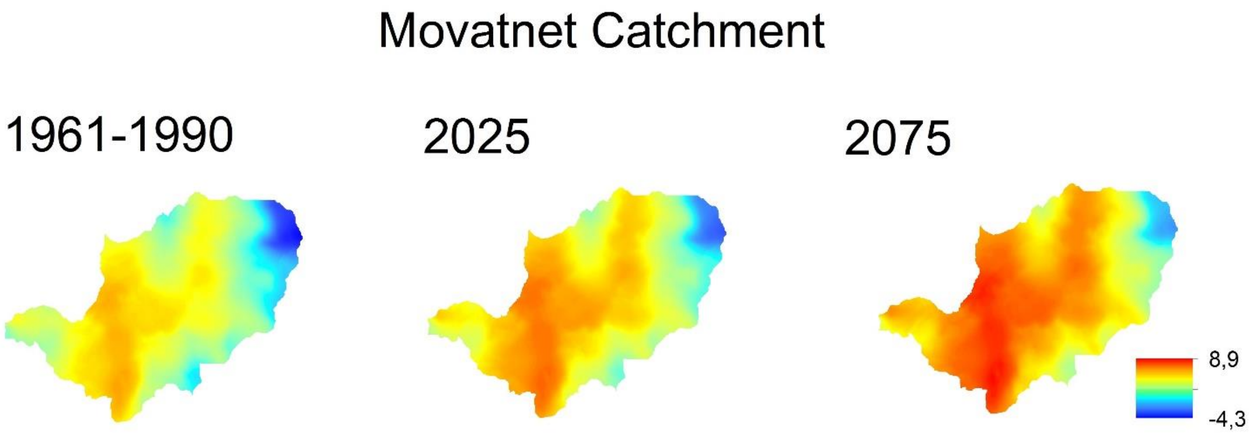

Figure 29. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Movatnet (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

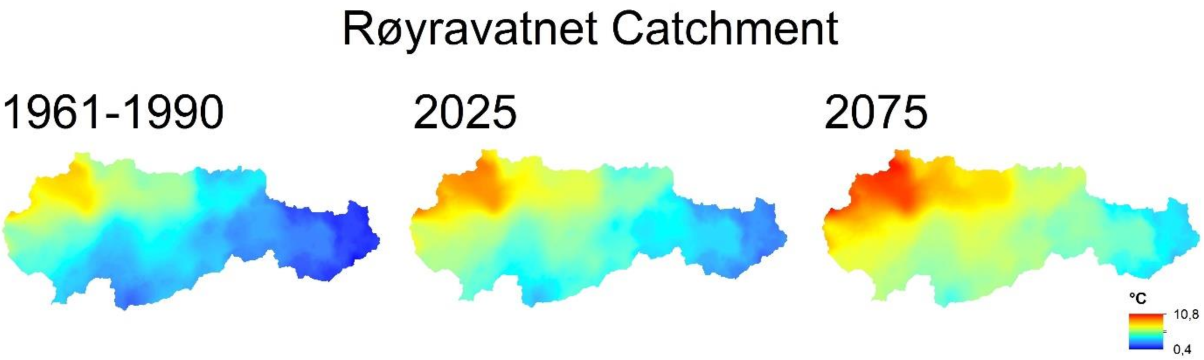

Figure 30. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Røyravatnet (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

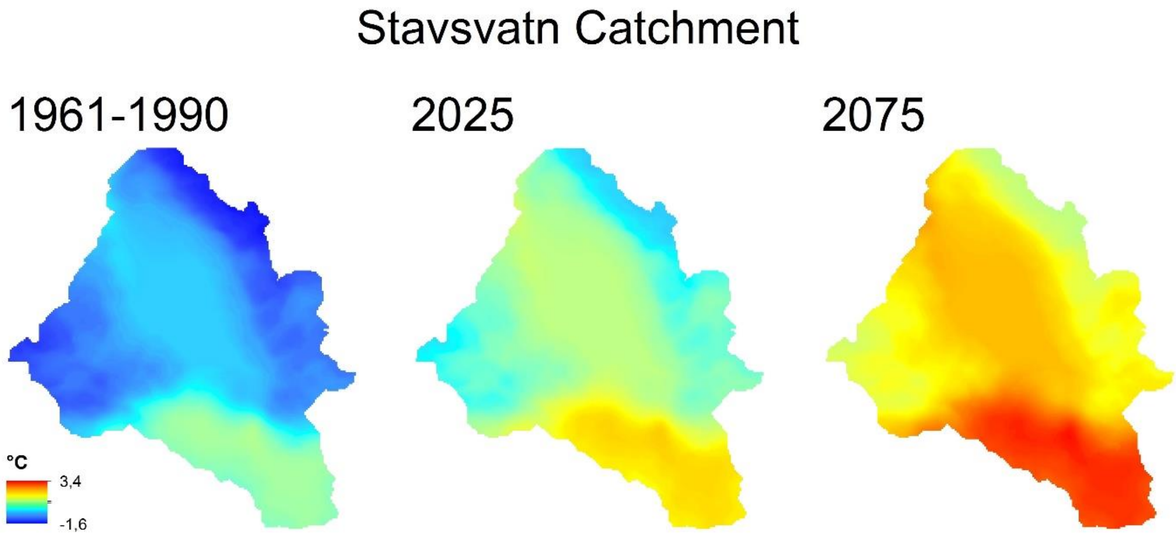

Figure 31. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Stavsvatn (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

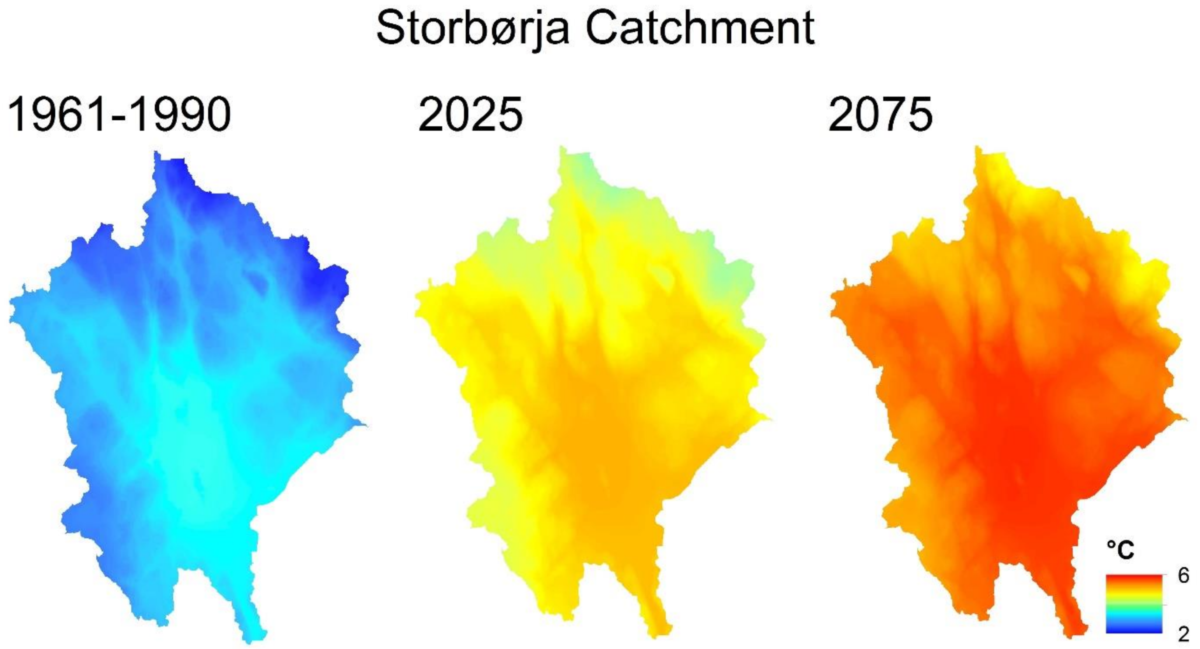

Figure 32. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Storbørja (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

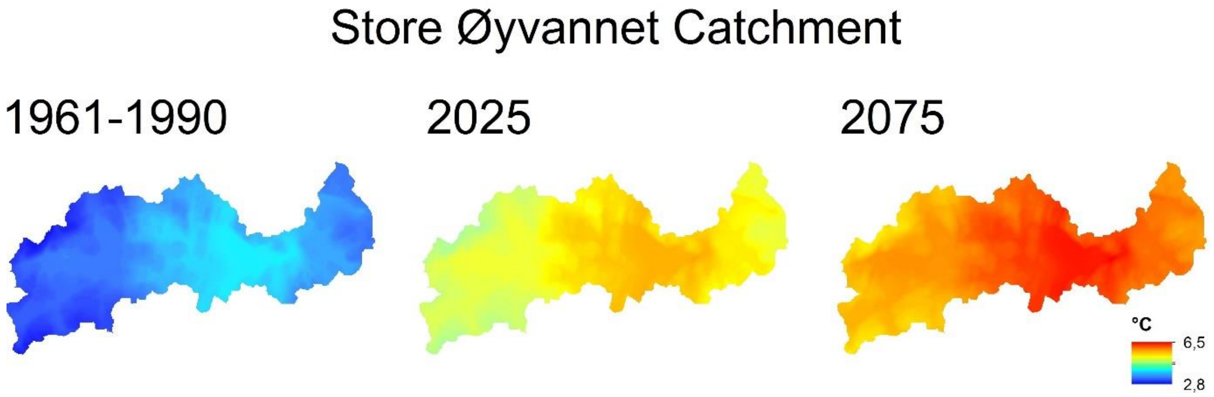

Figure 33. The downscaled, adjusted and predicted temperature rasters for the normal period 1961-1990 and years 2025 and 2075 for the delineated catchment of the lake Store Øyvannet (based on data from IPCC (2013a), KNMI (2016) and MET Norway (2016c)).

The temperature rasters can be coupled with interesting layers from the catchments (3.1); for an example, see Appendix D. Seen together with the graphs of future TOC (3.4) such maps give room for more precise spatial water management. What parameters one want to calculate or visualize depend on the purpose (water management; public information; specific or relative results, etc.).

3.4. Future TOC

The available measurements from 1986 to 2014 for all the lakes were plotted to show graphs of the historical change in TOC. These are shown in Figure 34 to Figure 43, together with trend lines for the results of future levels up to 2075, based on the values predicted for 2025 and 2075 (as described in section 2.3.4). This was done for the minimum, mean and maximum temperature, within each lake's watershed, with the calculated spatial reference values for the normal period 1961-1990 (see figures in section 3.3). The alterations caused by precipitation increases are also included in the graphs for the four lakes considered precipitation dependent (Table 3).The increasing trends are likely to stabilize towards the end of this period (Hanssen-Bauer et al. 2015), which also the results for 2025 and 2075 show (Appendix C).

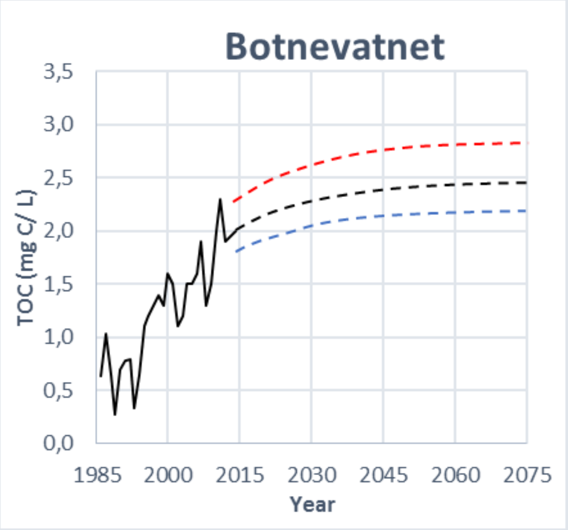

Figure 34. Historical (MD 1986-2014) and calculated future spatial TOC values for Botnevatnet (RCP4.5).

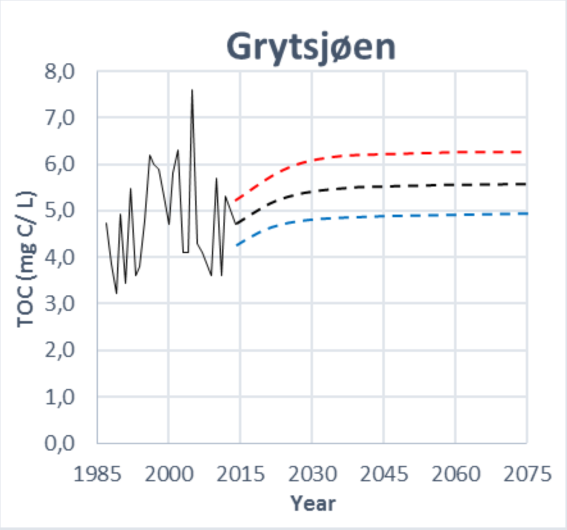

Figure 35. Historical (MD 1986-2014) and calculated future spatial TOC values for Grytsjøen (RCP4.5).

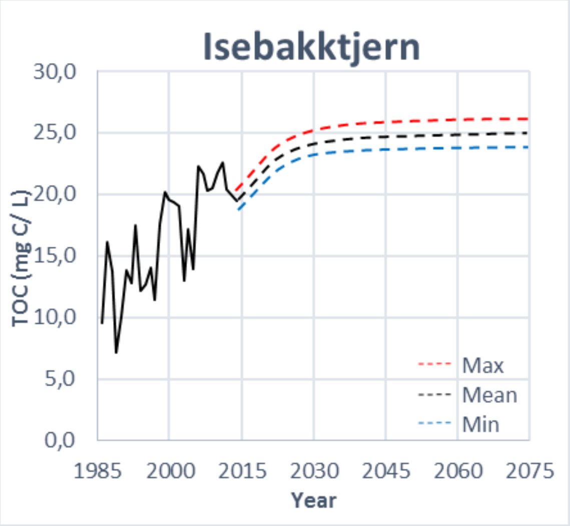

Figure 36. Historical (MD 1986-2014) and calculated future spatial TOC values for Isebakktjern (RCP4.5).

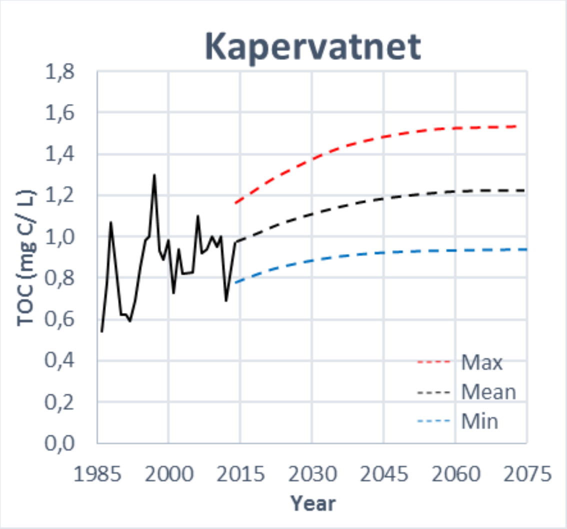

Figure 37. Historical (MD 1986-2014) and calculated future spatial TOC values for Kapervatnet (RCP4.5).

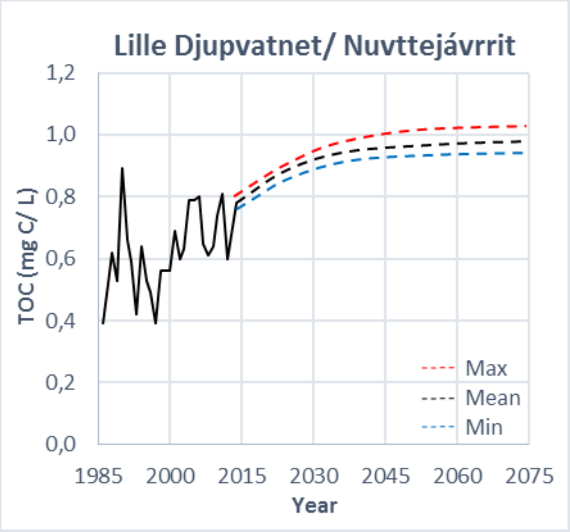

Figure 38. Historical (MD 1986-2014) and calculated future spatial TOC values for Botnevatnet (RCP4.5).

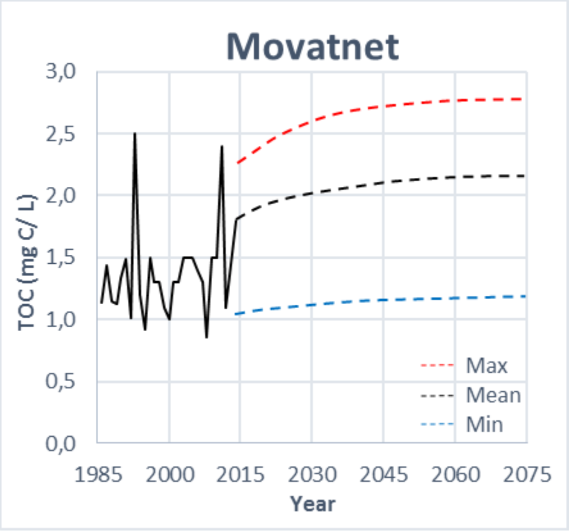

Figure 39. Historical (MD 1986-2014) and calculated future spatial TOC values for Movatnet (RCP4.5)

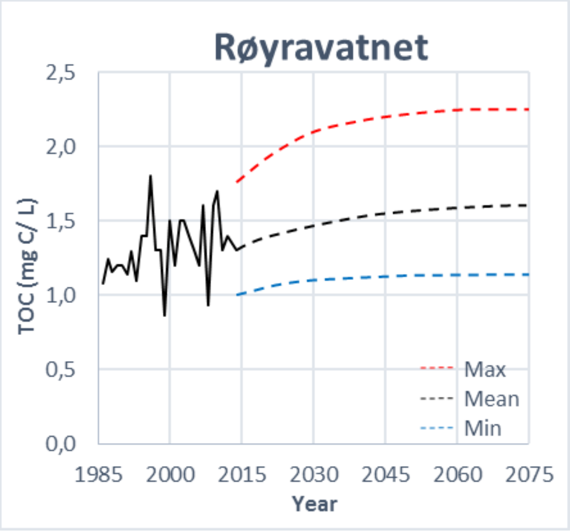

Figure 40. Historical (MD 1986-2014) and calculated future spatial TOC values for Røyravatnet (RCP4.5).

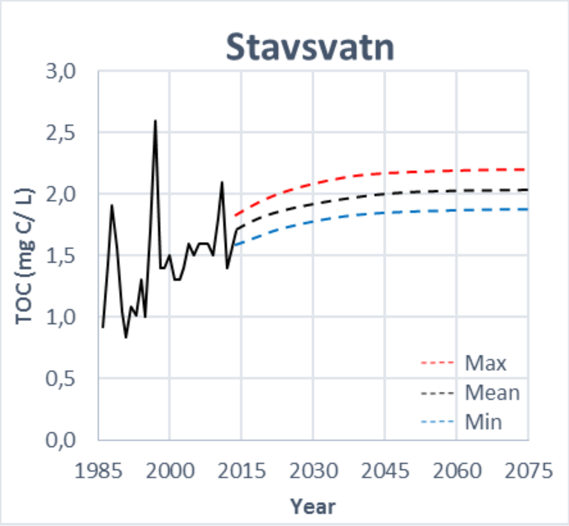

Figure 41. Historical (MD 1986-2014) and calculated future spatial TOC values for Stavsvatn (RCP4.5).

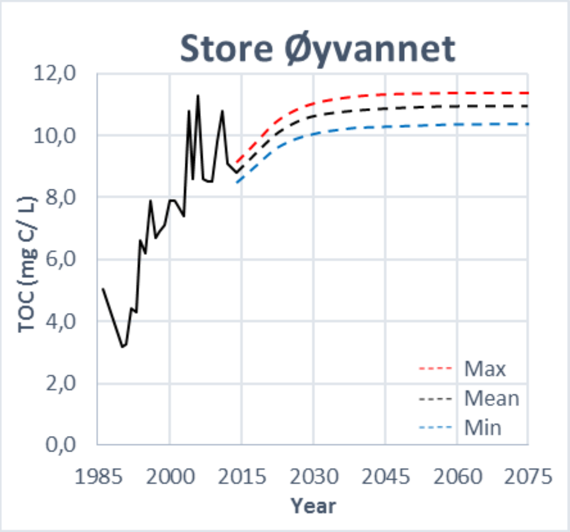

Figure 42. Historical (MD 1986-2014) and calculated future spatial TOC values for Store Øyvannet (RCP4.5).

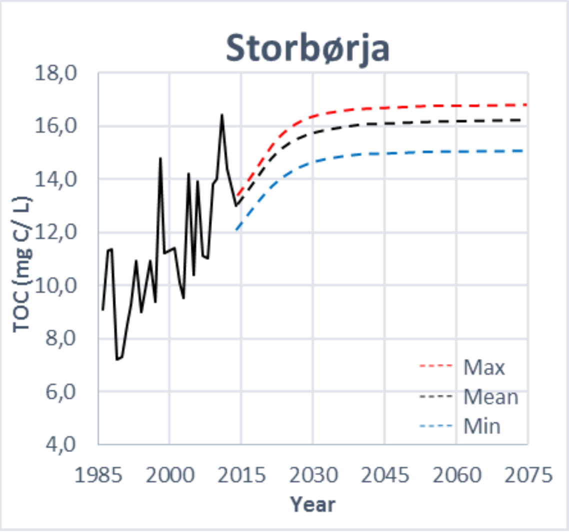

Figure 43. Historical (MD 1986-2014) and calculated future spatial TOC values for Storbørja (RCP4.5).

The increase in mg TOC/ L is largest in the lakes with the highest starting values (Isebakktjern; Storbørja; Store Øyvannet). These, in addition to Stavsvatn, are also the lakes considered to be precipitation dependent. This implies that the largest increases in DOC will occur in the lakes with high values today, though other lakes may also get considerable increases.

The graphs also show that there is often an important difference in the spatial contributions of DOC to the lakes. In several of the catchments, the difference between the minimum and maximum values are relatively high, either in concentration (e.g. Grytsjøen; Isebakktjern; Storbørja) or in percent as for Kapervatnet, Movatnet and Røyravatnet. The maximum levels also increase more rapidly than the minimum, leading to an increasing difference through the years. This means that the warmest areas of the watersheds not only contribute most to the lake DOC concentrations; they also get a relatively more important role in future years.

4. Discussion

4.1. Data

The measurements from MD are taken in the period September - December (Appendix A) when the lakes normally are circulating, giving a holomixis of the water and thus the chemical compounds and therefore concentration values representative for the lakes.

The data for future temperature and precipitation values were extracted from KNMI's Climate Change Atlas due to more detailed maps than the ones found in Annex I of AR5, as well as more possibilities in choosing years (IPCC 2013b; KNMI 2016). All predicted future data are linked to variable uncertainty, also when addressing a specific scenario. This is always emphasized in IPCC's and others' models and statistics (e.g. Collins et al. 2013; Hanssen-Bauer et al. 2015) and should also be taken into account for all results in this thesis, even more due to the temperature downscaling. It is also important to keep in mind that the predictions of future climate are always improving, as was also seen in some extend from IPCC's AR4 to AR5 (IPCC 2014), and the newest models should always be used to ensure the best possible results.

It would be beneficial with even finer resolution than provided from IPCC, since the changes will differ among the regions of Norway (Hanssen-Bauer et al. 2015). MET Norway, NVE and Uni Research have made such maps available online at Norsk klimaservicesenter (2016), but these data are not available in GIS file formats; this is something they are working on at the moment and will be ready in 2017 (Hygen 2016, pers. comm.). When using the method described here, such data, or similar for other countries, should be applied when possible.

The difference in precipitation increases for May to October in 2025 vs. 2075 is low in the predictions used here for the four lakes considered precipitation dependent. These are all located in the south-east of Norway, where precipitation increases in general will be lower than in more northern latitudes (Hanssen-Bauer et al. 2015). In addition, the maps at Norsk klimaservicesenter (2016) support the low differences, showing that in some places precipitation will decrease in the summer months, sometimes making up for the increase in the autumn.

4.2. Modelling

During the work on the GIS parts of the method (2.3.1; 2.3.2), scripts (ArcPy) were made, making it possible to run the same methods for all lakes. This include the filling of sinks in the DEMs; delineation of watersheds; downscaling of temperature rasters; and all other aspects of the GIS modelling shown in this thesis. Such scripts make the execution of tasks easier in several ways; it can be run outside the GIS program (here: Python (command line)) reducing the processing time (e.g. the accumulation rasters are even then relatively time-consuming) as well as the risk of crashing the GIS program. It is also especially useful when modelling several lakes as here. Furthermore, it is possible to make cartographic models which can be run in the GIS program (e.g. Omran et al. 2016).

4.2.1. Hydrological modelling

The output results of the catchments were cross-checked towards the NVE Atlas (NVE 2016b). This Atlas does not have the watersheds for all lakes; however, it does give an idea of whether the outputs of this study are likely to be correct or not. The aim of this paper is not as much giving exact, perfect delineated watersheds as it is using a straightforward method, with no more data processing than necessary to get an approximately correct result. One can always use more parameters and several data processing steps to try to get a more accurate result; however, the risk of missing out on or inserting wrong parameters, misunderstanding the results and enhancing the errors does increase as well as the preparation and processing time. Moreover, the focus in this study was on methods and trends, and few well-chosen parameters are also considered to be an advantage possibly giving more correct results (Skaugen & Onof 2014).

Though it is possible to get more accurate watersheds and waterways by using finer resolution than 10 x 10 x 2-6 m (Rød 2015), the results show that the accuracy after filling the DEMs are good enough for the visualization and the results are considered appropriate for this thesis. Note that finer resolution would cause more data processing and a partly aim of this thesis is to show a method not too processing and time demanding and with only the most important details.

The watershed delineations clearly show which areas are draining to the lakes and can be used for visualization and planning as well as for statistics. Together with the underlying layers it shows what the most important streams are flowing through and past, considering vegetation cover, land use and nearby buildings. This gives a comprehensive view of today’s situation for each catchment area and room for understanding and predicting possible present and future threats related to DOC production and transport from the catchments to the lakes (Allan & Castillo 2007; Canham et al. 2004).

This study includes lakes varying in altitude, latitude and longitude, as well as levels of SO_4, Cl and TOC (Figure 2; Appendix A). Considering this, the method could possibly be applied to lakes all over Norway. However, the lakes, all being part of MD’s reference lakes are not considerably affected by anthropogenic pressure such as agriculture and waste water (Garmo et al. 2015); this should therefore also be taken into account if using a similar method to lakes affected by other human impacts than atmospheric depositions and climate change.

4.2.2. Temperature modelling

The fine resolution of the temperature rasters for the predicted future values (Figure 24 to Figure 33) show that one can use GIS modelling, together with statistics, to visualize where in the watersheds the most important changes will occur. Looking at interesting layers, such as those in section 3.1, it can be used in evaluation of where and if e.g. restrictions are needed, and when planning future land use or similar management projects.

In other cases where it will be more interesting to look at other lakes, or calculating with other future climate scenarios, the method will still be valid; one would simply change the parameters. A necessity is however that similar data are available; for Norwegian lakes this would often be the case because temperature and precipitation data, as well as DEMs etc. are freely available online (Kartverket 2017; MET Norway 2016a). Therefore, this method could be used for multiple reasons and with a variety of input parameters, also in other countries than Norway (remembering to also change the environmental lapse rate if needed (Livingstone et al. 1999)), where a part of the goal is to spatially visualize the changes in a catchment area.

In addition to showing the results as rasters as done in this report, it is also possible to go directly into the GIS program used for getting the results and find the exact values for specific points or do other analysis such as finding all areas with a specific temperature (Omran et al. 2016; Rød 2015). As shown in the example from Movatnet (Appendix D) one could overlay the waterways to see where the changes caused by temperature will be largest, and based on other layers and statistics consider which streams are contributing most to the DOC of the respective lake. This could e.g. be done by simple visualization as here; by marking out the most important streams or areas; or doing statistical calculations.

As explained in section 2.3.2, the temperature downscaling, including adjusting for altitude, gives results that are good for visualization and representative enough though not as correct as possible. Moreover, and most important in this case, the resulting rasters show that it is indeed possible to model future DOC levels at local scales and give a spatial visualization of the changes.

4.3. Future TOC levels

4.3.1. Precipitation

The results in Figure 13Figure 22 (b) clearly show that all ten lakes have had a decreasing trend of SO_4 concentrations from 1986, which is a well known phenomena in Norway linked to the decreasing sulphate depositions through acid rain (e.g. Skjelkvåle et al. 2005; Wright & Jenkins 2001).

In all the ten lakes, SO_4 levels had decreased and TOC levels increased. The slope for SO_4 decrease was not as steep for Lille Djupvatnet/ Nuvttejávrrit as the rest, probably due to the northeast location of the lake (see Figure 2) where the sulphur depositions have other main source locations giving more acid rain here than further south (VanLoon & Duffy 2011).

Though parameters as vegetation and soil cover is not considered in the future calculations of organic carbon levels for the lakes in this thesis, it is clear from previous work (Allan & Castillo 2007), and to some extent the results given here, that they do play an important part. However, there are mentioned disadvantages of including many parameters, and in addition precipitation and temperature affects most of the pathways and processes including DOC (Allan & Castillo 2007; Wetzel 2001); thus, always calculating the impact of precipitation for each lake, these two parameters are thought to give a good description on how DOC levels will change in the future.

Of the four lakes found to have precipitation dependent TOC values according to the «standards» set in this thesis (2.3.3), three were the ones with highest TOC levels, as well as amounts of forest and wetland in the watersheds (Storbørja, Store Øyvannet and Isebakktjern). All four lakes differ in regard to size, catchment area and catchment:lake area ratio (Table 1), and are located in different parts of south-east Norway. This is a region in Norway were the RCP4.5 scenario implies a small increase in total precipitation for the months May to October (Hanssen-Bauer et al. 2015; IPCC 2013b; Norsk klimaservicesenter 2016) and hence the TOC increase caused by precipitation may not play an important role. However, it is a factor that must be considered, not only for these lakes, but also for other Norwegian lakes due to difference in the role of precipitation now; the possibility of the role changing with decreasing future SO_4 values; and the regional and local distribution of precipitation changes (somewhere also having decreasing values in this period) (Norsk klimaservicesenter 2016).

Although the lakes may be going back to their original pre-industrial colours (Evans et al. 2006), the increasing DOC concentrations could continue without acid rain, due to increasing precipitation amounts (and temperature: section 4.3.2). That said, my results also show that this correlation is not an absolute; each lakes must therefore be calculated to see whether or not it is precipitation dependent, and if so, in what degree. Another issue when it comes to the specific calculations of future TOC increases caused by precipitation for the four lakes considered to be precipitation dependent, is that the few years of low SO_4 values indicate that levels may decrease somewhat for the nearest years (de Wit et al. 2016). This is not taken into account in the calculations and should therefore be further tested in the near future, and recalibrated when using this method in the following years if values were in fact not completely stabilized.

Heavy-rain events and floods are not considered in the method of this study. Nonetheless, they do play an important part (see 1.1.1.2) in transport of organic matter from soils, and the increasing frequency thought to occur in Norway based on climate models will make them even more important (Hanssen-Bauer et al. 2015). It is however important to mention that in some locations high rainfall may at times counteract the increased lake DOC concentrations from allochthonous inputs due to increased flushing rates leading to the discharge from the lake being larger (Boyer et al. 1996; Canham et al. 2004). This could also be some of the reason for some of the lakes in this study not being considered precipitation dependent.

When it comes to precipitation chemistry, it is important to keep in mind the role of possible sea-salts in the precipitation (1.1.1.1). Though the effects of SO_4 are thought to be ruled out by the division (before and after stabilization), natural occurring sea-salts could also interfere with the results, especially in southern Norwegian near-coast locations (Haaland et al. 2010; Schartau et al. 2009; Wright & Jenkins 2001). In addition, some of the regression lines with weak correlation may be caused by the catchment characteristics, as little vegetation and soils, leading to less difference in DOC drained by precipitation (Gergel et al. 1999; Haaland & Mulder 2009); thus, as one might expect, precipitation amounts seem to play a larger part in watersheds with high frequency of organic soil layers.

Several studies undertaken before the stabilization of SO_4 concentrations in European lakes do not emphasize precipitation as a key factor for DOC changes, though possible impacts are mentioned (e.g. Evans et al. 2005; Evans et al. 2006; Weyhenmeyer & Karlsson 2009). This thesis, and the results of Haaland et al. (2010), does however show clearer trends – probably due to the possibility to separate precipitation by chemistry and using years with stabilized SO_4 values. The results are also supported by a recent report by de Wit et al. (2016), estimating that the increased precipitation will indeed play a key role in future DOC levels in Fennoscandia. They also add another aspect – dry vs. wet climate; by dividing by mean precipitation amounts they found clear trends which were positive for the dry places and thence gradually declined towards the wettest areas.

As explained in sections 1.1.1.2 and 1.1.2, the most important period for the impact of precipitation on DOC transport is during the growing season, when DOC concentrations in discharge are highest (Haaland & Mulder 2009). Thus, focusing on the precipitation amounts from May to October is considered reasonable for the calculations in this thesis, since this mostly includes the main growing and runoff season in Norway when production and transport is at its maximum (Tollan 1972), and starting four to seven months before sample takings.

Not all precipitation goes to runoff: some infiltrates deeper soils and groundwater, and some is lost to the atmosphere by evapotranspiration (evaporation + transpiration) (Hendriks 2010). With the changing climate, also the relation between evapotranspiration and precipitation is altered in various ways around the globe, and for Norway this is predicted to lead to more precipitation in relation to evapotranspiration (Kirtman et al. 2013); thence, giving the precipitation an even larger role in the future due to more runoff also in percentage. The water balance could also be altered by land-use change (evaporation) within catchment areas and by changes in storage in areas were the temperatures exceeds 0 °C leading to less snow and also altered runoff patterns from these areas (Hendriks 2010).

4.3.2. Temperature

The experiment by Wright and Jenkins (2001) where a Norwegian catchment showed increased TOC levels with increased temperature (without the present of acid depositions) is highly relevant to the changing climate in Norway. Especially the winters are getting warmer (Hanssen-Bauer et al. 2015), causing longer periods with temperatures above 0 °C and hence more runoff; potentially causing more transport of DOC than now, even with stabilized sulphur depositions (Hendriks 2010). And with the increasing temperatures also the growing season will prolong – an important reason for the trend Weyhenmeyer and Karlsson (2009) found causing enhanced TOC values.

The temperature rasters show that it is possible to visualize the temperatures within a watershed, with fine resolution by downscaling and adjusting for altitude; and then use these to find future temperature changes by using predicted increases. By understanding how TOC levels in lakes for these regions are related to temperature (Weyhenmeyer & Karlsson 2009) this gives the possibility to show future changes both with maps and statistics. The spatial statistics can also be used to show with graphs when and where the most important relative changes is likely to occur according to the chosen scenario.

The slope of temperature increases in Norway will be increasing with latitude (Figure 23; Hanssen-Bauer et al. (2015)). However, the DOC levels are generally lower in the north, and highest in the south-east areas, and due to the trend that Weyhenmeyer and Karlsson (2009) found to be nonlinear, the highest increases may still be seen in the south of Norway. Moreover, general regional trends may not be enough when engaging in issues at specific locations (e.g. drinking water sources), and each lake and its catchment area should be seen individually. The nonlinear correlation between temperature and TOC also cause clear differences within the catchments seen in the graphs of future spatial and temporal TOC values (Figure 34 to Figure 43); the maximum levels increase more rapidly than the minimum, leading to an increasing difference through the years.

4.4. Water management

Many subjects can be, and has been, discussed regarding whether or not the DOC increases are positive or negative. E.g. metal binding and transport can be both positive and negative for aquatic life depending on which metals (toxic or essential) are transported or mobilized/ immobilized (e.g. Hongve et al. 2012 on Hg), and whether or not the monitored trends in coloration of lakes are simply a return to the original states (e.g. Erlandsson et al. 2011). This said, the DOC changes to come in the future in the Norwegian lakes where SO_4 concentrations are stabilizing, will be caused by a changing climate (4.3) caused by increased greenhouse gas emissions through anthropogenic activities.

In what extent climate factors will affect the DOC levels is yet to be seen, and similar studies as this thesis should continue with the somewhat still decreasing SO_4 levels and the changing climate conditions. The future precipitation and temperature changes are also varying largely between scenarios, depending on future emissions (IPCC 2013a; IPCC 2014). However, all scenarios are showing increase in global temperatures, precipitation and heavy rain events, and this is also the predictions for Norway, though locally decreased precipitation and temperature and hence DOC production and transport, will occur (Hanssen-Bauer et al. 2015; Norsk klimaservicesenter 2016).

The implementation of the WFD in Norway has given more focus on the status of lakes and streams. Predictions at local scales give the possibility of more specific and effective water management within watersheds. Possible decreasing DOC levels can be located, and for the lakes getting increased levels the severity can be predicted and if needed, e.g. for drinking waters, counter-actions and adaptions can be done to prepare for the brownification.

This study show how the increasing DOC and the effects of precipitation and temperature can be predicted and visualized both temporal and spatial within watersheds. However, the possibilities are numerous and this thesis only partly show the role GIS can play in water management and research.

5. Conclusion

This thesis showed that it was possible to spatially visualize the relative production of allochthonous DOC within specific catchments, using the same method in GIS for all ten lakes. The output results of watersheds and waterways for all the lakes were successful, as well as the local distribution of temperatures, including future increases according to the IPCC scenario RCP4.5.

By dividing precipitation by chemistry, to avoid most of the interference from SO_4, it was possible to determine which lakes were considered precipitation dependent; these were the four lakes Stavsvatn, Isebakktjern, Storbørja and Store Øyvannet, whereof the three latter had the highest TOC values of the ten. Together with existing predicted future precipitation values from IPCC, these trends could be used for calculating the effects of near-term future precipitation amounts of TOC values.

Using spatial air temperature values from the catchment areas, together with correlations between temperature and TOC, also these changes were possible to calculate. Thus, adding the effects of precipitation where relevant, it was possible to show through graphs and GIS models what the temporal and spatial TOC increases (in these lakes mainly DOC) would be, in local scales. According to the predictions used in this thesis, all ten lakes would continue to have an increasing trend of DOC in near future, stabilizing towards the end of the tested period (year 2075), supporting the hypothesis that future climate change may cause increased DOC concentrations in Norwegian lakes.

The method outlined in this study is thought to have an advantage for use in water management due to few parameters, mostly freely available data and minimal processing demanding operations; moreover, it is applicable for other lakes and scenarios by adding equivalent inputs.

Due to the decreased SO_4 values, now stabilized or nearly stabilized, continuous monitoring of DOC/ TOC values in Norwegian (as well as other similar European) lakes are important. Further research on the effects of the climatic parameters precipitation and temperature are needed to find more accurate answers concerning if and how these are correlated in general and at specific sites. Furthermore, when it comes to GIS as tools for visualizations and statistical calculations the possibilities are numerous and this thesis only show a glimpse of the part GIS can play in water management and research.

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Appendices

Appendix A. Sampling data for the parameters pH, conductivity, alkalinity, Cl, SO_4 and TOC for all ten lakes; including sampling dates, county and Norwegian Lake Database numbers. All sampling dates available for the period 1986-2014 are added. Based on data from the Norwegian Environment Agency's data set on reference lakes (1986-2014).

Lake	NVE VatnLnr/ Norwegian Lake Database number	County	Sampling date	pH	Conductivity mS/ m	Alkalinity mmol/ L	Cl mg/ L	SO4 mg/L	TOC mg/ L
Botnevatnet	21797	Vest-Agder	10.28.1986	4,88	5,06	NoData	8,5	5,2	0,64
Botnevatnet	21797	Vest-Agder	11.3.1987	4,89	2,14	NoData	7,9	4,6	1,03
Botnevatnet	21797	Vest-Agder	11.1.1988	4,87	4,12	NoData	9,3	4,55	0,65
Botnevatnet	21797	Vest-Agder	10.6.1989	4,84	6,10	NoData	10,7	4,5	0,27
Botnevatnet	21797	Vest-Agder	10.9.1990	4,82	6,05	NoData	11,2	4,3	0,69
Botnevatnet	21797	Vest-Agder	10.31.1991	4,81	5,88	NoData	10,4	4,3	0,78
Botnevatnet	21797	Vest-Agder	9.26.1992	4,87	5,35	NoData	9,4	4,7	0,79
Botnevatnet	21797	Vest-Agder	10.26.1993	4,80	7,14	NoData	15	4,9	0,33
Botnevatnet	21797	Vest-Agder	10.21.1994	4,90	5,51	0,022	11,8	4	0,65
Botnevatnet	21797	Vest-Agder	11.2.1995	4,91	5,60	0,020	11,2	4,1	1,1
Botnevatnet	21797	Vest-Agder	11.5.1996	4,99	4,59	0,026	9	4,4	1,2
Botnevatnet	21797	Vest-Agder	11.23.1997	4,90	5,04	0,021	10,2	3,9	1,3
Botnevatnet	21797	Vest-Agder	11.11.1998	5,10	4,21	0,027	7,6	3,6	1,4
Botnevatnet	21797	Vest-Agder	12.2.1999	5,21	4,33	0,030	8,4	3,6	1,3
Botnevatnet	21797	Vest-Agder	12.18.2000	4,90	5,80	0,019	11,9	3,4	1,6
Botnevatnet	21797	Vest-Agder	11.26.2001	5,09	4,49	0,028	9,1	3,3	1,5
Botnevatnet	21797	Vest-Agder	11.17.2002	5,19	4,45	0,026	9,6	3,14	1,1
Botnevatnet	21797	Vest-Agder	11.23.2003	5,12	4,30	0,026	8,9	3,25	1,2
Botnevatnet	21797	Vest-Agder	10.15.2004	5,26	3,72	0,029	7,19	2,8	1,5
Botnevatnet	21797	Vest-Agder	11.29.2005	5,05	5,21	0,026	11,1	3,04	1,5
Botnevatnet	21797	Vest-Agder	11.22.2006	5,14	4,27	0,028	8,57	2,81	1,6
Botnevatnet	21797	Vest-Agder	12.19.2007	5,47	5,04	0,036	10,5	2,75	1,9
Botnevatnet	21797	Vest-Agder	10.17.2008	5,41	4,96	0,031	10,5	2,76	1,3
Botnevatnet	21797	Vest-Agder	10.17.2009	5,36	5,20	0,030	11,3	2,61	1,5
Botnevatnet	21797	Vest-Agder	10.15.2010	5,67	4,00	0,036	8,3	2,67	2
Botnevatnet	21797	Vest-Agder	10.14.2011	5,69	3,55	0,037	7,21	2,24	2,3
Botnevatnet	21797	Vest-Agder	10.12.2012	5,64	4,84	0,028	10,3	2,58	1,9
Botnevatnet	21797	Vest-Agder	10.11.2014	5,79	3,74	0,004	7,52	2,5	2
Grytsjøen	40322	Nord-Trøndelag	10.18.1987	5,67	1,52	0,040	2,4	1,2	4,74
Grytsjøen	40322	Nord-Trøndelag	10.26.1988	5,55	1,73	0,037	2,8	1	3,86
Grytsjøen	40322	Nord-Trøndelag	10.30.1989	5,40	1,63	0,027	3	0,6	3,23
Grytsjøen	40322	Nord-Trøndelag	10.11.1990	5,46	1,72	0,031	2,7	0,9	4,92
Grytsjøen	40322	Nord-Trøndelag	10.22.1991	5,62	1,33	0,040	2,3	0,9	3,43

Lake	NVE VatnLnr/ Norwegian Lake Database number	County	Sampling date	pH	Conductivity mS/ m	Alkalinity mmol/ L	Cl mg/ L	SO4 mg/L	TOC mg/ L
Grytsjøen	40322	Nord-Trøndelag	10.21.1992	5,62	1,82	0,037	3,2	0,9	5,48
Grytsjøen	40322	Nord-Trøndelag	11.9.1993	5,26	2,04	NoData	4	1,1	3,6
Grytsjøen	40322	Nord-Trøndelag	10.19.1994	5,48	1,33	0,040	2,3	0,7	3,8
Grytsjøen	40322	Nord-Trøndelag	9.19.1995	5,86	1,26	0,049	2	0,6	4,8
Grytsjøen	40322	Nord-Trøndelag	10.6.1996	5,76	1,57	0,048	2,5	0,8	6,2
Grytsjøen	40322	Nord-Trøndelag	10.5.1997	5,46	1,67	0,040	2,9	0,6	6
Grytsjøen	40322	Nord-Trøndelag	9.20.1998	5,92	1,18	0,053	1,6	0,5	5,9
Grytsjøen	40322	Nord-Trøndelag	10.10.1999	5,88	1,26	0,053	1,7	0,6	5,3
Grytsjøen	40322	Nord-Trøndelag	10.8.2000	5,88	1,14	0,040	1,6	0,5	4,7
Grytsjøen	40322	Nord-Trøndelag	10.7.2001	5,97	1,12	0,050	1,4	0,4	5,8
Grytsjøen	40322	Nord-Trøndelag	10.9.2002	5,69	1,86	0,046	3,48	0,91	6,3
Grytsjøen	40322	Nord-Trøndelag	11.10.2003	5,72	1,93	0,041	3,88	0,75	4,1
Grytsjøen	40322	Nord-Trøndelag	11.27.2004	5,60	2,15	0,038	4,52	0,99	4,1
Grytsjøen	40322	Nord-Trøndelag	8.31.2005	5,71	1,35	0,042	1,98	0,48	7,6
Grytsjøen	40322	Nord-Trøndelag	11.12.2006	5,58	2,08	0,041	3,94	1,05	4,3
Grytsjøen	40322	Nord-Trøndelag	10.21.2007	5,55	1,74	0,036	3,33	0,59	4,1
Grytsjøen	40322	Nord-Trøndelag	11.8.2009	5,64	1,74	0,036	3,47	0,68	3,6
Grytsjøen	40322	Nord-Trøndelag	11.28.2010	5,76	1,63	0,050	2,51	0,69	5,7
Grytsjøen	40322	Nord-Trøndelag	11.27.2011	5,49	1,62	0,035	3	0,61	3,6
Grytsjøen	40322	Nord-Trøndelag	11.11.2012	5,86	1,57	0,044	2,64	0,54	5,3
Grytsjøen	40322	Nord-Trøndelag	11.10.2014	5,79	1,48	0,010	2,57	0,56	4,7
Isebakktjern	5844	Østfold	10.15.1986	5,50	5,29	0,051	6,6	8,9	9,55
Isebakktjern	5844	Østfold	10.27.1987	4,53	5,44	NoData	5	8,1	16,1
Isebakktjern	5844	Østfold	10.26.1988	4,82	5,02	NoData	6	6,6	13,76
Isebakktjern	5844	Østfold	10.25.1989	5,15	5,98	NoData	7,6	9,2	7,12
Isebakktjern	5844	Østfold	10.22.1990	5,05	6,39	NoData	9,3	8,2	10,07
Isebakktjern	5844	Østfold	10.31.1991	4,89	6,85	NoData	9,6	10,1	13,8
Isebakktjern	5844	Østfold	10.29.1992	5,12	6,24	NoData	9	8,4	12,8
Isebakktjern	5844	Østfold	11.1.1993	4,75	5,98	NoData	7,8	7,9	17,5
Isebakktjern	5844	Østfold	10.28.1994	5,24	5,27	0,047	7,3	8,7	12,2
Isebakktjern	5844	Østfold	10.20.1995	5,39	5,17	0,051	7,1	7,2	12,7
Isebakktjern	5844	Østfold	10.9.1996	5,30	5,60	0,051	8,2	7,6	14
Isebakktjern	5844	Østfold	11.4.1997	5,85	5,75	0,066	9,2	6,8	11,4
Isebakktjern	5844	Østfold	10.12.1998	5,48	4,61	0,059	6,6	5,2	17,6
Isebakktjern	5844	Østfold	10.15.1999	4,98	4,25	0,038	4,4	4,8	20,2
Isebakktjern	5844	Østfold	11.8.2000	4,74	4,79	0,015	6,2	4,2	19,6
Isebakktjern	5844	Østfold	11.7.2001	5,24	4,00	0,050	5,7	3,5	19,4
Isebakktjern	5844	Østfold	11.4.2002	4,94	4,33	0,034	5,67	4,29	19
Isebakktjern	5844	Østfold	10.30.2003	5,86	3,87	0,080	5,33	3,43	13
Isebakktjern	5844	Østfold	12.5.2004	4,90	4,79	0,028	7,65	3,77	17,2

Lake	NVE VatnLnr/ Norwegian Lake Database number	County	Sampling date	pH	Conductivity mS/ m	Alkalinity mmol/ L	Cl mg/ L	SO4 mg/L	TOC mg/ L
Isebakktjern	5844	Østfold	10.27.2005	5,44	6,00	0,052	11,4	4,06	13,9
Isebakktjern	5844	Østfold	11.2.2006	5,10	5,14	0,052	7,17	4,42	22,3
Isebakktjern	5844	Østfold	11.15.2007	5,47	5,15	0,062	8,06	3,75	21,6
Isebakktjern	5844	Østfold	11.4.2008	4,99	5,15	0,037	8,68	2,85	20,3
Isebakktjern	5844	Østfold	11.3.2009	5,69	5,03	0,072	8,15	3,25	20,5
Isebakktjern	5844	Østfold	11.6.2010	5,14	4,22	0,048	6,11	2,68	21,8
Isebakktjern	5844	Østfold	11.3.2011	5,20	3,81	0,048	5,19	2,47	22,6
Isebakktjern	5844	Østfold	11.6.2012	4,81	4,08	0,014	5,84	2,08	20,4
Isebakktjern	5844	Østfold	10.30.2014	5,45	4,67	0,031	7,4	2,88	19,5
Kapervatnet	50879	Troms	9.28.1986	6,10	1,49	0,038	2,9	1,5	0,54
Kapervatnet	50879	Troms	10.17.1987	6,18	1,90	0,044	3,5	1,6	0,78
Kapervatnet	50879	Troms	10.22.1988	5,87	2,39	0,053	4,9	1,3	1,07
Kapervatnet	50879	Troms	10.14.1989	6,10	1,70	0,036	2,9	1,3	0,85
Kapervatnet	50879	Troms	10.12.1990	5,94	1,47	0,034	2,4	1,3	0,62
Kapervatnet	50879	Troms	9.23.1991	6,10	1,40	0,034	2,4	1,2	0,62
Kapervatnet	50879	Troms	9.19.1992	6,21	1,37	0,042	2,4	1,1	0,59
Kapervatnet	50879	Troms	9.27.1993	6,05	1,84	0,048	3,6	1,2	0,69
Kapervatnet	50879	Troms	9.28.1994	6,09	1,60	0,046	3,1	1,3	0,85
Kapervatnet	50879	Troms	9.28.1995	6,27	1,21	0,050	2,2	1	0,98
Kapervatnet	50879	Troms	10.7.1996	5,96	1,49	0,049	2,8	1	1
Kapervatnet	50879	Troms	10.3.1997	6,07	2,08	0,049	4,5	1,2	1,3
Kapervatnet	50879	Troms	9.29.1998	6,24	1,46	0,048	2,7	1,2	0,93
Kapervatnet	50879	Troms	10.1.1999	6,11	1,36	0,045	2,4	1	0,89
Kapervatnet	50879	Troms	9.25.2000	6,22	1,09	0,042	1,7	0,9	0,98
Kapervatnet	50879	Troms	9.26.2001	6,30	1,76	0,043	3,6	1	0,73
Kapervatnet	50879	Troms	9.26.2002	6,14	1,88	0,050	4,03	1,02	0,94
Kapervatnet	50879	Troms	10.8.2003	6,09	1,73	0,046	2,98	1,32	0,82
Kapervatnet	50879	Troms	10.4.2005	6,19	1,78	0,045	3,79	0,92	0,83
Kapervatnet	50879	Troms	9.28.2006	6,17	1,41	0,052	2,43	1,13	1,1
Kapervatnet	50879	Troms	9.27.2007	6,30	1,33	0,053	2,2	0,87	0,92
Kapervatnet	50879	Troms	10.3.2008	6,19	1,84	0,051	3,74	1,1	0,94
Kapervatnet	50879	Troms	10.6.2009	6,26	1,97	0,049	4	1,02	1
Kapervatnet	50879	Troms	9.29.2010	6,40	1,26	0,054	1,99	0,93	0,95
Kapervatnet	50879	Troms	10.5.2011	6,41	1,61	0,061	2,88	1	1
Kapervatnet	50879	Troms	10.10.2012	6,18	1,19	0,048	1,92	0,89	0,69
Kapervatnet	50879	Troms	10.23.2014	6,22	1,54	0,014	2,9	0,95	0,97
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.26.1986	5,22	3,24	NoData	4,9	5,7	0,39
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.25.1987	5,17	4,11	NoData	4,5	5,4	0,52
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.29.1988	5,27	3,46	NoData	4,7	5,5	0,62

Lake	NVE VatnLnr/ Norwegian Lake Database number	County	Sampling date	pH	Conductivity mS/ m	Alkalinity mmol/ L	Cl mg/ L	SO4 mg/L	TOC mg/ L
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.20.1989	5,17	3,45	0,021	4,6	5,5	0,53
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.20.1990	5,14	3,65	NoData	4,7	5,6	0,89
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.21.1991	5,21	3,56	0,023	5	5,6	0,66
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.22.1992	5,31	3,39	0,028	5,2	5,2	0,59
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.16.1993	5,40	3,25	0,028	5,4	5,2	0,42
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.7.1994	5,32	3,23	0,029	5,2	5	0,64
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.18.1995	5,39	3,17	0,033	5,1	5,1	0,53
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.25.1996	5,44	3,21	0,032	5,1	4,8	0,49
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.16.1997	5,37	3,18	0,026	5,4	5	0,39
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.2.1998	5,54	3,26	0,034	5,4	4,6	0,56
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.22.1999	5,52	3,15	0,033	5,2	4,8	0,56
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.3.2000	5,52	3,01	0,029	5,3	4,2	0,56
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.1.2001	5,64	2,91	0,033	4,6	4,3	0,69
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.23.2002	5,67	2,91	0,034	4,77	4,32	0,6
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.25.2003	5,81	3,03	0,037	5,23	4,08	0,63
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.25.2004	5,72	2,98	0,034	5,05	4,04	0,79
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.27.2005	5,76	2,98	0,036	5,15	3,97	0,79
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	11.1.2006	5,57	3,01	0,037	5,31	4,13	0,8
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.3.2007	5,91	2,90	0,036	4,97	3,69	0,65
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.11.2008	5,96	2,88	0,042	4,91	3,73	0,61
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.1.2009	6,02	2,92	0,039	4,82	3,61	0,64
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	9.3.2010	6,01	2,80	0,032	4,59	3,47	0,74
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.15.2011	5,99	2,78	0,040	4,69	3,69	0,81
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.6.2012	5,83	2,65	0,033	4,5	3,61	0,6
Lille Djupvatnet/ Nuvttejávrrit	64217	Finnmark	10.2.2014	6,09	2,86	0,009	4,76	3,66	0,78
Movatnet	1935	Sogn og Fjordane	10.15.1986	5,85	1,14	0,034	1,9	1,1	1,14
Movatnet	1935	Sogn og Fjordane	10.18.1987	5,78	1,22	0,037	1,8	1	1,44
Movatnet	1935	Sogn og Fjordane	11.11.1988	5,74	1,19	0,038	1,8	1	1,15
Movatnet	1935	Sogn og Fjordane	10.22.1989	5,70	1,50	0,026	2,4	1,1	1,13
Movatnet	1935	Sogn og Fjordane	10.31.1990	5,76	1,28	0,033	2,3	1	1,33
Movatnet	1935	Sogn og Fjordane	10.24.1991	5,89	1,20	0,040	2,1	0,9	1,49
Movatnet	1935	Sogn og Fjordane	10.29.1992	5,86	1,49	0,035	2,8	1	1,01
Movatnet	1935	Sogn og Fjordane	11.11.1993	5,80	1,35	0,041	2,5	1	2,5
Movatnet	1935	Sogn og Fjordane	10.29.1994	5,88	1,11	0,042	2,1	1	1,2

Lake	NVE VatnLnr/ Norwegian Lake Database number	County	Sampling date	pH	Conductivity mS/ m	Alkalinity mmol/ L	Cl mg/ L	SO4 mg/L	TOC mg/ L
Movatnet	1935	Sogn og Fjordane	9.17.1995	6,12	0,76	0,044	1,2	0,7	0,92
Movatnet	1935	Sogn og Fjordane	11.20.1996	5,89	1,11	0,045	1,8	0,9	1,5
Movatnet	1935	Sogn og Fjordane	10.15.1997	5,88	1,16	0,045	2	0,8	1,3
Movatnet	1935	Sogn og Fjordane	11.17.1998	5,98	1,08	0,044	1,7	0,8	1,3
Movatnet	1935	Sogn og Fjordane	10.27.1999	5,96	1,00	0,049	1,6	0,8	1,1
Movatnet	1935	Sogn og Fjordane	10.16.2000	6,10	0,99	0,037	1,7	0,7	1
Movatnet	1935	Sogn og Fjordane	12.4.2001	5,95	1,51	0,044	3	0,9	1,3
Movatnet	1935	Sogn og Fjordane	10.19.2002	6,01	1,14	0,042	2,09	0,78	1,3
Movatnet	1935	Sogn og Fjordane	10.17.2003	6,00	1,21	0,046	2,08	0,76	1,5
Movatnet	1935	Sogn og Fjordane	10.26.2004	6,01	1,06	0,045	1,69	0,7	1,5
Movatnet	1935	Sogn og Fjordane	11.25.2005	5,91	1,03	0,043	1,71	0,63	1,5
Movatnet	1935	Sogn og Fjordane	10.24.2006	6,15	0,99	0,050	1,51	0,69	1,4
Movatnet	1935	Sogn og Fjordane	10.29.2007	5,90	1,13	0,038	2,14	0,57	1,3
Movatnet	1935	Sogn og Fjordane	10.4.2008	6,22	1,02	0,044	1,68	0,6	0,86
Movatnet	1935	Sogn og Fjordane	10.10.2009	6,09	1,23	0,038	2,22	0,63	1,5
Movatnet	1935	Sogn og Fjordane	10.10.2010	6,25	0,95	0,050	1,35	0,6	1,5
Movatnet	1935	Sogn og Fjordane	10.12.2011	5,83	1,27	0,040	2,41	0,53	2,4
Movatnet	1935	Sogn og Fjordane	10.20.2012	5,80	1,95	0,043	4,09	0,84	1,1
Movatnet	1935	Sogn og Fjordane	10.13.2014	6,34	1,33	0,020	2,13	0,77	1,8
Røyravatnet	22548	Rogaland	10.17.1986	5,14	2,05	NoData	3	2,4	1,08
Røyravatnet	22548	Rogaland	10.31.1987	4,98	2,20	NoData	3,4	2	1,24
Røyravatnet	22548	Rogaland	10.16.1988	5,06	2,22	NoData	3	2,2	1,16
Røyravatnet	22548	Rogaland	11.3.1989	4,87	2,55	NoData	3,5	2	1,2
Røyravatnet	22548	Rogaland	10.22.1990	4,97	2,44	NoData	3,9	1,8	1,2
Røyravatnet	22548	Rogaland	11.13.1991	4,96	2,33	0,021	3,6	1,6	1,14
Røyravatnet	22548	Rogaland	10.20.1992	5,11	1,96	NoData	3	1,7	1,29
Røyravatnet	22548	Rogaland	10.18.1993	5,09	2,40	0,024	4,4	2,2	1,1
Røyravatnet	22548	Rogaland	10.21.1994	5,11	2,01	0,026	3,7	1,9	1,4
Røyravatnet	22548	Rogaland	11.3.1995	5,02	2,04	0,024	3,2	1,7	1,4
Røyravatnet	22548	Rogaland	10.23.1996	5,22	1,69	0,031	2,4	1,6	1,8
Røyravatnet	22548	Rogaland	11.5.1997	5,18	2,11	0,032	4	1,5	1,3
Røyravatnet	22548	Rogaland	11.2.1998	5,36	1,66	0,032	2,8	1,4	1,3
Røyravatnet	22548	Rogaland	12.27.1999	5,04	2,73	0,023	5,3	1,5	0,86
Røyravatnet	22548	Rogaland	11.9.2000	5,25	1,73	0,026	2,8	1,3	1,5
Røyravatnet	22548	Rogaland	12.1.2001	5,32	1,72	0,031	3	1,2	1,2
Røyravatnet	22548	Rogaland	11.5.2002	5,39	1,84	0,028	3,34	1,38	1,5
Røyravatnet	22548	Rogaland	11.16.2003	5,56	1,42	0,034	2,25	1,23	1,5
Røyravatnet	22548	Rogaland	10.27.2004	5,42	1,67	0,033	3,08	1,13	1,4
Røyravatnet	22548	Rogaland	11.29.2005	5,27	1,63	0,030	2,77	1,11	1,3
Røyravatnet	22548	Rogaland	11.26.2006	5,25	1,64	0,028	2,86	1,04	1,2

Lake	NVE VatnLnr/ Norwegian Lake Database number	County	Sampling date	pH	Conductivity mS/ m	Alkalinity mmol/ L	Cl mg/ L	SO4 mg/L	TOC mg/ L
Røyravatnet	22548	Rogaland	11.5.2007	5,41	1,64	0,032	3,01	1,07	1,6
Røyravatnet	22548	Rogaland	11.3.2008	5,89	2,79	0,054	4,38	1,36	0,93
Røyravatnet	22548	Rogaland	11.13.2009	5,57	1,83	0,032	3,46	1,1	1,6
Røyravatnet	22548	Rogaland	11.19.2010	5,65	1,51	0,041	2,57	1,05	1,7
Røyravatnet	22548	Rogaland	11.15.2011	5,62	1,64	0,036	3,02	0,96	1,3
Røyravatnet	22548	Rogaland	11.5.2012	5,53	1,57	0,034	2,77	0,94	1,4
Røyravatnet	22548	Rogaland	11.24.2014	5,57	1,52	0,000	2,78	0,91	1,3
Stavsvatn	13194	Telemark	9.25.1986	5,85	1,02	0,037	0,6	2,4	0,92
Stavsvatn	13194	Telemark	10.30.1987	5,63	1,10	0,036	0,4	2,2	1,44
Stavsvatn	13194	Telemark	10.4.1988	5,65	1,00	0,039	0,4	2	1,91
Stavsvatn	13194	Telemark	9.27.1989	5,68	1,33	0,040	1	2,3	1,56
Stavsvatn	13194	Telemark	10.6.1990	5,79	1,05	0,038	0,7	2	1,04
Stavsvatn	13194	Telemark	9.26.1991	6,01	1,05	0,039	0,7	2	0,83
Stavsvatn	13194	Telemark	9.28.1992	5,90	1,10	0,051	0,7	1,9	1,09
Stavsvatn	13194	Telemark	9.23.1993	6,12	1,09	0,052	0,8	1,6	1,01
Stavsvatn	13194	Telemark	9.28.1994	6,00	1,08	0,050	0,6	1,6	1,3
Stavsvatn	13194	Telemark	9.18.1995	6,00	0,87	0,048	0,5	1,5	1
Stavsvatn	13194	Telemark	10.22.1996	5,87	1,01	0,047	0,6	1,7	1,7
Stavsvatn	13194	Telemark	9.16.1997	5,92	0,98	0,051	0,6	1,5	2,6
Stavsvatn	13194	Telemark	9.21.1998	6,05	0,90	0,051	0,5	1,4	1,4
Stavsvatn	13194	Telemark	10.8.1999	6,18	0,87	0,050	0,5	1,2	1,4
Stavsvatn	13194	Telemark	10.9.2000	6,05	0,82	0,042	0,4	1,1	1,5
Stavsvatn	13194	Telemark	10.5.2001	6,18	0,75	0,050	0,4	1	1,3
Stavsvatn	13194	Telemark	10.10.2002	6,26	0,76	0,055	0,47	0,92	1,3
Stavsvatn	13194	Telemark	10.2.2003	6,14	0,76	0,051	0,34	0,91	1,4
Stavsvatn	13194	Telemark	10.10.2004	6,21	0,77	0,050	0,29	0,9	1,6
Stavsvatn	13194	Telemark	10.2.2005	6,23	0,79	0,054	0,38	0,84	1,5
Stavsvatn	13194	Telemark	10.22.2006	6,23	0,82	0,056	0,39	0,85	1,6
Stavsvatn	13194	Telemark	10.14.2007	6,23	0,76	0,052	0,36	0,68	1,6
Stavsvatn	13194	Telemark	11.15.2008	6,63	0,86	0,076	0,41	0,66	1,6
Stavsvatn	13194	Telemark	11.21.2009	6,37	0,75	0,053	0,33	0,61	1,5
Stavsvatn	13194	Telemark	10.23.2010	6,34	0,74	0,058	0,32	0,61	1,8
Stavsvatn	13194	Telemark	10.16.2011	6,09	0,79	0,056	0,29	0,59	2,1
Stavsvatn	13194	Telemark	10.21.2012	6,08	0,75	0,062	0,33	0,55	1,4
Stavsvatn	13194	Telemark	10.20.2014	6,33	0,73	0,030	0,36	0,59	1,7
Storbørja	368	Hedmark	10.16.1986	5,14	2,02	NoData	1,2	3,5	9,09
Storbørja	368	Hedmark	10.21.1987	4,82	2,40	NoData	1,1	3,5	11,3
Storbørja	368	Hedmark	10.25.1988	4,80	2,29	NoData	0,9	3	11,36
Storbørja	368	Hedmark	10.18.1989	5,16	2,14	NoData	1,2	4,3	7,19

Lake	NVE VatnLnr/ Norwegian Lake Database number	County	Sampling date	pH	Conductivity mS/ m	Alkalinity mmol/ L	Cl mg/ L	SO4 mg/L	TOC mg/ L
Storbørja	368	Hedmark	10.23.1990	5,24	2,24	NoData	1,6	3,6	7,31
Storbørja	368	Hedmark	10.18.1991	5,22	2,32	NoData	1,9	3,4	8,53
Storbørja	368	Hedmark	10.21.1992	5,32	2,30	0,041	1,7	3,6	9,29
Storbørja	368	Hedmark	10.26.1993	5,17	2,19	0,030	1,6	3,4	10,9
Storbørja	368	Hedmark	10.14.1994	5,29	1,88	0,040	1,3	3,3	9
Storbørja	368	Hedmark	10.20.1995	5,31	1,85	0,042	1,2	2,9	9,8
Storbørja	368	Hedmark	10.18.1996	5,33	2,04	0,041	1,3	3	10,9
Storbørja	368	Hedmark	10.27.1997	5,32	1,96	0,045	1,5	3	9,4
Storbørja	368	Hedmark	10.26.1998	5,49	2,03	0,058	1,4	2,4	14,8
Storbørja	368	Hedmark	10.12.1999	5,27	1,75	0,041	1,1	2,3	11,2
Storbørja	368	Hedmark	10.31.2000	4,97	1,98	0,028	1,3	2	11,3
Storbørja	368	Hedmark	11.1.2001	5,10	1,69	0,040	1,1	1,8	11,4
Storbørja	368	Hedmark	10.15.2002	5,47	1,50	0,046	1,01	1,66	10,1
Storbørja	368	Hedmark	10.17.2003	5,47	1,61	0,047	1,03	1,99	9,5
Storbørja	368	Hedmark	9.23.2004	5,03	1,86	0,032	1,12	1,78	14,2
Storbørja	368	Hedmark	10.26.2005	5,46	1,71	0,045	1,4	1,69	10,4
Storbørja	368	Hedmark	11.8.2006	5,11	1,88	0,039	1,4	1,8	13,9
Storbørja	368	Hedmark	10.31.2007	5,25	1,78	0,037	1,44	1,62	11,1
Storbørja	368	Hedmark	10.22.2008	5,35	1,65	0,043	1,31	1,52	11
Storbørja	368	Hedmark	10.23.2009	5,21	1,76	0,040	1,35	1,36	13,8
Storbørja	368	Hedmark	10.12.2010	5,24	1,68	0,042	1,12	1,22	14
Storbørja	368	Hedmark	10.24.2011	5,10	1,73	0,036	1,03	1,13	16,4
Storbørja	368	Hedmark	10.27.2012	5,18	1,66	0,036	1,2	1,04	14,4
Storbørja	368	Hedmark	10.24.2014	5,45	1,51	0,012	1,14	1,18	10,4
Store Øyvannet	5742	Vestfold	10.17.1986	5,32	2,20	0,025	1,2	5,4	5,03
Store Øyvannet	5742	Vestfold	10.15.1990	5,10	2,50	NoData	1,9	4,4	3,16
Store Øyvannet	5742	Vestfold	10.1.1991	5,70	2,25	0,031	1,8	4,4	3,28
Store Øyvannet	5742	Vestfold	10.4.1992	5,30	2,43	0,022	2,2	4,8	4,4
Store Øyvannet	5742	Vestfold	9.27.1993	5,40	2,21	0,038	1,9	4,1	4,3
Store Øyvannet	5742	Vestfold	10.17.1994	5,42	1,92	0,046	1,5	3,3	6,6
Store Øyvannet	5742	Vestfold	10.19.1995	5,29	1,87	0,040	1,5	3,3	6,2
Store Øyvannet	5742	Vestfold	10.23.1996	5,32	2,12	0,040	1,6	3,7	7,9
Store Øyvannet	5742	Vestfold	10.15.1997	5,68	2,03	0,053	1,7	3,3	6,7
Store Øyvannet	5742	Vestfold	10.22.1998	5,65	1,82	0,046	1,4	2,7	6,9
Store Øyvannet	5742	Vestfold	11.22.1999	5,44	1,74	0,042	1,1	2,6	7,1
Store Øyvannet	5742	Vestfold	12.18.2000	5,31	1,75	0,036	1,4	2	7,9
Store Øyvannet	5742	Vestfold	11.8.2001	5,55	1,66	0,044	1,2	2,3	7,9
Store Øyvannet	5742	Vestfold	10.21.2002	5,88	1,57	0,056	1,19	1,76	7,7
Store Øyvannet	5742	Vestfold	10.17.2003	5,97	1,54	0,060	0,98	1,8	7,4
Store Øyvannet	5742	Vestfold	11.19.2004	5,59	1,81	0,052	1,4	1,97	10,8

Lake	NVE VatnLnr/ Norwegian Lake Database number	County	Sampling date	pH	Conductivity mS/ m	Alkalinity mmol/ L	Cl mg/ L	SO4 mg/L	TOC mg/ L
Store Øyvannet	5742	Vestfold	11.22.2005	5,74	1,78	0,052	1,6	1,97	8,6
Store Øyvannet	5742	Vestfold	11.6.2006	5,45	1,80	0,052	1,49	1,79	11,3
Store Øyvannet	5742	Vestfold	11.14.2007	5,90	1,66	0,055	1,38	1,59	8,6
Store Øyvannet	5742	Vestfold	11.3.2008	5,80	1,53	0,055	1,15	1,32	8,5
Store Øyvannet	5742	Vestfold	10.29.2009	5,87	1,54	0,060	1,17	1,19	8,5
Store Øyvannet	5742	Vestfold	10.22.2010	5,73	1,52	0,048	1,02	1,19	9,8
Store Øyvannet	5742	Vestfold	10.21.2011	5,76	1,51	0,060	1,05	1,11	10,8
Store Øyvannet	5742	Vestfold	10.13.2012	6,15	1,57	0,058	1,24	1,02	9,1
Store Øyvannet	5742	Vestfold	10.19.2014	5,89	1,55	0,025	1,34	1,17	8,8

Appendix B. Calculated precipitation data (mm; May-October) from the chosen weather stations for each lake. All available values for the period 1986-2012 and 2014 are added; years holding insufficient data are given values "NoData". The Norwegian Lake Database numbers are also added. Based on data from MET Norway (2016a).

Lake	NVE VatnLnr/ Norwegian Lake Database number	Weather Station	Year	Precipitation mm; May-October
Botnevatnet	21797	Flekkefjord	1986	1104,5
Botnevatnet	21797	Flekkefjord	1987	912,2
Botnevatnet	21797	Flekkefjord	1988	1125,3
Botnevatnet	21797	Flekkefjord	1989	813,7
Botnevatnet	21797	Flekkefjord	1990	1097,2
Botnevatnet	21797	Flekkefjord	1991	734,9
Botnevatnet	21797	Flekkefjord	1992	970,7
Botnevatnet	21797	Flekkefjord	1993	516,5
Botnevatnet	21797	Flekkefjord	1994	755
Botnevatnet	21797	Flekkefjord	1995	838,4
Botnevatnet	21797	Flekkefjord	1996	877,4
Botnevatnet	21797	Flekkefjord	1997	773
Botnevatnet	21797	Flekkefjord	1998	1039,3
Botnevatnet	21797	Flekkefjord	1999	960,9
Botnevatnet	21797	Flekkefjord	2000	1014,9
Botnevatnet	21797	Flekkefjord	2001	980,7
Botnevatnet	21797	Flekkefjord	2002	798,5
Botnevatnet	21797	Flekkefjord	2003	897,4
Botnevatnet	21797	Flekkefjord	2004	1085,7
Botnevatnet	21797	Flekkefjord	2005	856
Botnevatnet	21797	Flekkefjord	2006	852,1
Botnevatnet	21797	Flekkefjord	2007	1005,5
Botnevatnet	21797	Flekkefjord	2008	1088,4
Botnevatnet	21797	Flekkefjord	2009	1025,6
Botnevatnet	21797	Flekkefjord	2010	974
Botnevatnet	21797	Flekkefjord	2011	1474,3
Botnevatnet	21797	Flekkefjord	2012	1241,5
Botnevatnet	21797	Flekkefjord	2014	919,2
Grytsjøen	40322	Unnset	1986	NoData
Grytsjøen	40322	Unnset	1987	405,8
Grytsjøen	40322	Unnset	1988	579,9
Grytsjøen	40322	Unnset	1989	778,2
Grytsjøen	40322	Unnset	1990	488,6
Grytsjøen	40322	Unnset	1991	668,1
Grytsjøen	40322	Unnset	1992	571
Grytsjøen	40322	Unnset	1993	669,6
Grytsjøen	40322	Unnset	1994	654,2
Grytsjøen	40322	Unnset	1995	699,9

Lake	NVE VatnLnr/ Norwegian Lake Database number	Weather Station	Year	Precipitation mm; May-October
Grytsjøen	40322	Unnset	1996	402,6
Grytsjøen	40322	Unnset	1997	644,3
Grytsjøen	40322	Unnset	1998	516,1
Grytsjøen	40322	Unnset	1999	556,2
Grytsjøen	40322	Unnset	2000	505,6
Grytsjøen	40322	Unnset	2001	623,5
Grytsjøen	40322	Unnset	2002	420,7
Grytsjøen	40322	Unnset	2003	640,6
Grytsjøen	40322	Unnset	2004	438,6
Grytsjøen	40322	Unnset	2005	686,9
Grytsjøen	40322	Unnset	2006	524,4
Grytsjøen	40322	Unnset	2007	637,8
Grytsjøen	40322	Unnset	2008	NoData
Grytsjøen	40322	Unnset	2009	668,4
Grytsjøen	40322	Unnset	2010	497,3
Grytsjøen	40322	Unnset	2011	779,8
Grytsjøen	40323	Unnset	2012	532,1
Grytsjøen	40324	Unnset	2014	492,2
Isebakktjern	5844	Rygge	1986	430
Isebakktjern	5844	Rygge	1987	663,2
Isebakktjern	5844	Rygge	1988	658,6
Isebakktjern	5844	Rygge	1989	340,6
Isebakktjern	5844	Rygge	1990	383,9
Isebakktjern	5844	Rygge	1991	336,5
Isebakktjern	5844	Rygge	1992	339,8
Isebakktjern	5844	Rygge	1993	492,9
Isebakktjern	5844	Rygge	1994	372,1
Isebakktjern	5844	Rygge	1995	419,4
Isebakktjern	5844	Rygge	1996	428,5
Isebakktjern	5844	Rygge	1997	421,2
Isebakktjern	5844	Rygge	1998	492,8
Isebakktjern	5844	Rygge	1999	595,3
Isebakktjern	5844	Rygge	2000	660,1
Isebakktjern	5844	Rygge	2001	496,3
Isebakktjern	5844	Rygge	2002	532,7
Isebakktjern	5844	Rygge	2003	343,9
Isebakktjern	5844	Rygge	2004	560,2
Isebakktjern	5844	Rygge	2005	435,9
Isebakktjern	5844	Rygge	2006	461,7
Isebakktjern	5844	Rygge	2007	539,7
Isebakktjern	5844	Rygge	2008	531,5
Isebakktjern	5844	Rygge	2009	422,1

Lake	NVE VatnLnr/ Norwegian Lake Database number	Weather Station	Year	Precipitation mm; May-October
Isebakktjern	5844	Rygge	2010	505
Isebakktjern	5844	Rygge	2011	603,1
Isebakktjern	5844	Rygge	2012	545,3
Isebakktjern	5844	Rygge	2014	535,8
Kapervatnet	50879	Grunnfarnes	1986	NoData
Kapervatnet	50879	Grunnfarnes	1987	424,4
Kapervatnet	50879	Grunnfarnes	1988	558,5
Kapervatnet	50879	Grunnfarnes	1989	710
Kapervatnet	50879	Grunnfarnes	1990	589,9
Kapervatnet	50879	Grunnfarnes	1991	610
Kapervatnet	50879	Grunnfarnes	1992	691,8
Kapervatnet	50879	Grunnfarnes	1993	549,3
Kapervatnet	50879	Grunnfarnes	1994	639,6
Kapervatnet	50879	Grunnfarnes	1995	896,9
Kapervatnet	50879	Grunnfarnes	1996	720,7
Kapervatnet	50879	Grunnfarnes	1997	590
Kapervatnet	50879	Grunnfarnes	1998	544,6
Kapervatnet	50879	Grunnfarnes	1999	764,6
Kapervatnet	50879	Grunnfarnes	2000	596,5
Kapervatnet	50879	Grunnfarnes	2001	689,9
Kapervatnet	50879	Grunnfarnes	2002	627,8
Kapervatnet	50879	Grunnfarnes	2003	813,2
Kapervatnet	50879	Grunnfarnes	2004	NoData
Kapervatnet	50879	Grunnfarnes	2005	967,2
Kapervatnet	50879	Grunnfarnes	2006	557,2
Kapervatnet	50879	Grunnfarnes	2007	639,9
Kapervatnet	50879	Grunnfarnes	2008	462,1
Kapervatnet	50879	Grunnfarnes	2009	643,5
Kapervatnet	50879	Grunnfarnes	2010	716,9
Kapervatnet	50879	Grunnfarnes	2011	432,1
Kapervatnet	50879	Grunnfarnes	2012	692,8
Kapervatnet	50880	Grunnfarnes	2014	469,1
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1986	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1987	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1988	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1989	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1990	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1991	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1992	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1993	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1994	NoData

Lake	NVE VatnLnr/ Norwegian Lake Database number	Weather Station	Year	Precipitation mm; May-October
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1995	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1996	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1997	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1998	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	1999	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2000	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2001	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2002	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2003	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2004	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2005	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2006	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2007	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2008	NoData
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2009	286,3
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2010	375,2
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2011	325,9
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2012	386,7
Lille Djupvatnet/ Nuvttejávrrit	64217	Svanvik	2014	272,9
Movatnet	1935	Nymark	1986	989,6
Movatnet	1935	Nymark	1987	800,7
Movatnet	1935	Nymark	1988	743
Movatnet	1935	Nymark	1989	1072,1
Movatnet	1935	Nymark	1990	808,2
Movatnet	1935	Nymark	1991	873,4
Movatnet	1935	Nymark	1992	688,9
Movatnet	1935	Nymark	1993	462,6
Movatnet	1935	Nymark	1994	669,1
Movatnet	1935	Nymark	1995	768,4
Movatnet	1935	Nymark	1996	562,7
Movatnet	1935	Nymark	1997	942,6
Movatnet	1935	Nymark	1998	831,4
Movatnet	1935	Nymark	1999	689,7
Movatnet	1935	Nymark	2000	573,9
Movatnet	1935	Nymark	2001	802
Movatnet	1935	Nymark	2002	575
Movatnet	1935	Nymark	2003	873,6
Movatnet	1935	Nymark	2004	846,5
Movatnet	1935	Nymark	2005	885,3
Movatnet	1935	Nymark	2006	473,8
Movatnet	1935	Nymark	2007	1158,5
Movatnet	1935	Nymark	2008	699,9

Lake	NVE VatnLnr/ Norwegian Lake Database number	Weather Station	Year	Precipitation mm; May-October
Movatnet	1935	Nymark	2009	885,9
Movatnet	1935	Nymark	2010	680
Movatnet	1935	Nymark	2011	1190,1
Movatnet	1935	Nymark	2012	856,6
Movatnet	1935	Nymark	2014	760,1
Røyravatnet	22548	Hundseid	1986	1699
Røyravatnet	22548	Hundseid	1987	1094,4
Røyravatnet	22548	Hundseid	1988	1418,1
Røyravatnet	22548	Hundseid	1989	1475,5
Røyravatnet	22548	Hundseid	1990	1196,4
Røyravatnet	22548	Hundseid	1991	1362,2
Røyravatnet	22548	Hundseid	1992	1372,2
Røyravatnet	22548	Hundseid	1993	693,9
Røyravatnet	22548	Hundseid	1994	1078,2
Røyravatnet	22548	Hundseid	1995	1395,1
Røyravatnet	22548	Hundseid	1996	1097,7
Røyravatnet	22548	Hundseid	1997	1243,2
Røyravatnet	22548	Hundseid	1998	1366
Røyravatnet	22548	Hundseid	1999	1260
Røyravatnet	22548	Hundseid	2000	1129,3
Røyravatnet	22548	Hundseid	2001	1401,6
Røyravatnet	22548	Hundseid	2002	899,9
Røyravatnet	22548	Hundseid	2003	1751,7
Røyravatnet	22548	Hundseid	2004	1581,8
Røyravatnet	22548	Hundseid	2005	NoData
Røyravatnet	22548	Hundseid	2006	999,4
Røyravatnet	22548	Hundseid	2007	1459,7
Røyravatnet	22548	Hundseid	2008	1323,6
Røyravatnet	22548	Hundseid	2009	NoData
Røyravatnet	22548	Hundseid	2010	1277
Røyravatnet	22548	Hundseid	2011	1930,5
Røyravatnet	22548	Hundseid	2012	1651,6
Røyravatnet	22548	Hundseid	2014	1406,7
Stavsvatn	13194	Rauland	1986	437,7
Stavsvatn	13194	Rauland	1987	547,2
Stavsvatn	13194	Rauland	1988	629,3
Stavsvatn	13194	Rauland	1989	316,7
Stavsvatn	13194	Rauland	1990	438,7
Stavsvatn	13194	Rauland	1991	282,1
Stavsvatn	13194	Rauland	1992	421,4
Stavsvatn	13194	Rauland	1993	340,8

Lake	NVE VatnLnr/ Norwegian Lake Database number	Weather Station	Year	Precipitation mm; May-October
Stavsvatn	13194	Rauland	1994	402,7
Stavsvatn	13194	Rauland	1995	375,3
Stavsvatn	13194	Rauland	1996	406,4
Stavsvatn	13194	Rauland	1997	451,7
Stavsvatn	13194	Rauland	1998	498,3
Stavsvatn	13194	Rauland	1999	518,5
Stavsvatn	13194	Rauland	2000	610,7
Stavsvatn	13194	Rauland	2001	490,8
Stavsvatn	13194	Rauland	2002	453,6
Stavsvatn	13194	Rauland	2003	590,7
Stavsvatn	13194	Rauland	2004	554,2
Stavsvatn	13194	Rauland	2005	526,5
Stavsvatn	13194	Rauland	2006	499,8
Stavsvatn	13194	Rauland	2007	455,4
Stavsvatn	13194	Rauland	2008	452,6
Stavsvatn	13194	Rauland	2009	438,1
Stavsvatn	13194	Rauland	2010	638,5
Stavsvatn	13194	Rauland	2011	807,9
Stavsvatn	13194	Rauland	2012	521,7
Stavsvatn	13194	Rauland	2014	470
Storbørja	368	Kongsvinger	1986	NoData
Storbørja	368	Kongsvinger	1987	NoData
Storbørja	368	Kongsvinger	1988	NoData
Storbørja	368	Kongsvinger	1989	NoData
Storbørja	368	Kongsvinger	1990	NoData
Storbørja	368	Kongsvinger	1991	NoData
Storbørja	368	Kongsvinger	1992	NoData
Storbørja	368	Kongsvinger	1993	NoData
Storbørja	368	Kongsvinger	1994	NoData
Storbørja	368	Kongsvinger	1995	NoData
Storbørja	368	Kongsvinger	1996	NoData
Storbørja	368	Kongsvinger	1997	NoData
Storbørja	368	Kongsvinger	1998	NoData
Storbørja	368	Kongsvinger	1999	NoData
Storbørja	368	Kongsvinger	2000	NoData
Storbørja	368	Kongsvinger	2001	NoData
Storbørja	368	Kongsvinger	2002	NoData
Storbørja	368	Kongsvinger	2003	NoData
Storbørja	368	Kongsvinger	2004	NoData
Storbørja	368	Kongsvinger	2005	NoData
Storbørja	368	Kongsvinger	2006	NoData
Storbørja	368	Kongsvinger	2007	419,1

Lake	NVE VatnLnr/ Norwegian Lake Database number	Weather Station	Year	Precipitation mm; May-October
Storbørja	368	Kongsvinger	2008	350,5
Storbørja	368	Kongsvinger	2009	443,3
Storbørja	368	Kongsvinger	2010	554,2
Storbørja	368	Kongsvinger	2011	571,6
Storbørja	368	Kongsvinger	2012	584,4
Storbørja	368	Kongsvinger	2014	403
Store Øyvannet	5742	Galleberg	1986	NoData
Store Øyvannet	5742	Galleberg	1990	NoData
Store Øyvannet	5742	Galleberg	1991	NoData
Store Øyvannet	5742	Galleberg	1992	NoData
Store Øyvannet	5742	Galleberg	1993	NoData
Store Øyvannet	5742	Galleberg	1994	NoData
Store Øyvannet	5742	Galleberg	1995	503,1
Store Øyvannet	5742	Galleberg	1996	489,3
Store Øyvannet	5742	Galleberg	1997	468,8
Store Øyvannet	5742	Galleberg	1998	NoData
Store Øyvannet	5742	Galleberg	1999	NoData
Store Øyvannet	5742	Galleberg	2000	647
Store Øyvannet	5742	Galleberg	2001	575,1
Store Øyvannet	5742	Galleberg	2002	NoData
Store Øyvannet	5742	Galleberg	2003	NoData
Store Øyvannet	5742	Galleberg	2004	598,7
Store Øyvannet	5742	Galleberg	2005	421,6
Store Øyvannet	5742	Galleberg	2006	574
Store Øyvannet	5742	Galleberg	2007	645,6
Store Øyvannet	5742	Galleberg	2008	512,2
Store Øyvannet	5742	Galleberg	2009	570
Store Øyvannet	5742	Galleberg	2010	567,2
Store Øyvannet	5743	Galleberg	2011	743
Store Øyvannet	5744	Galleberg	2012	628,5
Store Øyvannet	5745	Galleberg	2014	511,9

Appendix C. All spatial temperature values (℃) for each catchment area's minimum, maximum and mean value; calculated for the normal period 1961-1990, year 2025 and year 2075, using data from IPCC (2013b); KNMI (2016); MET Norway (2016c); The Norwegian Mapping Authority (DEM).

Normal period 1961-1990:

Lake	MIN	MAX	MEAN
Botnevatnet	4,91	7,66	6,17
Grytsjøen	0,17	3,24	1,68
Isebakktjern	5,47	6,33	5,88
Kapervatnet	-2,27	3,93	1,32
Lille Djupvatnet/ Nuvttejávrrit	-2,17	-1,05	-1,56
Movatnet	-4,27	6,34	3,16
Røyravatnet	0,48	8,28	3,78
Stavsvatn	-1,54	0,87	-0,36
Storbørja	2,05	3,40	3,00
Store Øyvannet	2,84	4,00	3,50

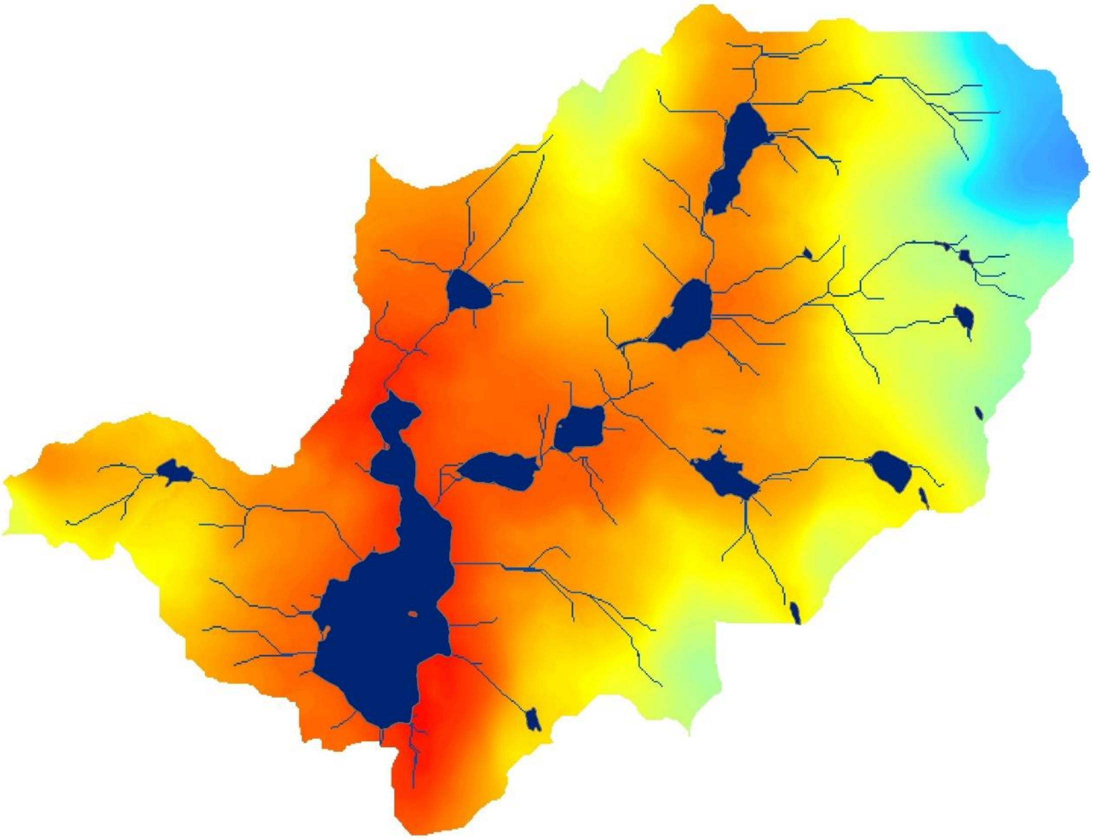
Year 2025:

Lake	MIN	MAX	MEAN
Botnevatnet	6,16	8,91	7,42
Grytsjøen	1,92	4,99	3,43
Isebakktjern	7,22	8,08	7,63
Kapervatnet	-0,52	5,68	3,07
Lille Djupvatnet/ Nuvttejávrrit	0,33	1,45	0,94
Movatnet	-3,02	7,59	4,41
Røyravatnet	1,73	9,53	5,03
Stavsvatn	-0,29	2,12	0,89
Storbørja	3,80	5,15	4,75
Store Øyvannet	4,59	5,75	5,25

Year 2075:

Lake	MIN	MAX	MEAN
Botnevatnet	7,41	10,16	8,67
Grytsjøen	2,67	5,73	4,18
Isebakktjern	7,97	8,83	8,38
Kapervatnet	1,23	7,43	4,82
Lille Djupvatnet/ Nuvttejávrrit	2,33	3,45	2,94
Movatnet	-1,77	8,84	5,66
Røyravatnet	2,98	10,78	6,28
Stavsvatn	0,96	3,37	2,14
Storbørja	4,55	5,90	5,50
Store Øyvannet	5,34	6,50	6,00

Appendix D. Movatnet catchment with the calculated temperature raster for 2075 overlaid by the accumulation raster with a threshold = 500 and all the lakes (based on data from The Norwegian Mapping Authority (DEM); NVE (Norwegian Lake Database); IPCC (2013b); KNMI (2016); MET Norway (2016c)).



To show some of the possibilities mentioned in section 3.3, an example from Movatnet catchment was added in this Appendix, with its flow accumulation raster holding a threshold showing the most important waterways, added on top of the temperature raster. The threshold could also be decreased to show where the water flows during heavier rainfall events.

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