

Monitoring TCM 2020 - Aquatic



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Summary Aquatic monitoring of three lakes, including drinking water sources, located in close vicinity to the Technology Centre Mongstad (TCM) was conducted to look for traces of amine-discharges from CO ₂ capture activities. Lake water was collected in January 2020, just after the completion of a longer test campaign at TCM, and analysed for the presence of amines, nitrosamines, and nitramines, in addition to selected water chemical parameters (pH, total organic carbon, phytoplankton biomass (chlorophyll A), and nutrient content and composition). Results from the lakes were compared to results from two reference lakes and to results previously obtained during earlier monitoring work. In conclusion, no traces of amine-discharges from TCM was detected: finding no amines, nitrosamines, nor nitramines at or above their respective analytical limits for quantification, and no clear trends of increase in any of the chemical parameters anticipated to be sensitive to amine-discharges.

Four keywords 1. Monitoring 2. CO ₂ capture 3. Amines 4. Drinking water	Fire emneord 1. Overvåkning 2. CO ₂ fangst 3. Aminer 4. Drikkevann
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Monitoring TCM 2020 - Aquatic

Preface

The monitoring of aquatic environment around Mongstad 2020 was conducted by the Norwegian Institute for Water Research (NIVA) on commission from Technology Centre Mongstad (TCM) DA.

Audun Drageset, TCM, was the contact person for the project and he is thanked for his good collaboration.

The field work was conducted by Espen Lund and Cathrine Brecke Gundersen, and also with contribution from Vibeke Namtvedt (TCM). Analyses of amines, nitrosamines, and nitramines were conducted by SINTEF Industry with Kai Vernstad as the contact person. General water chemistry was determined by NIVA laboratory.

Merete Grung was responsible for the quality assurance of the work and the project.

Oslo, 09.06.2020

Cathrine Brecke Gundersen

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Summary

The *Monitoring TCM 2020 – Aquatic* assessed selected lakes in the vicinity of Technology Centre Mongstad (TCM) for traces of amine-discharges from ongoing CO₂ capture activities. Excess input of amines to a lake may influence the natural nutrient status (leading to e.g. increased phytoplankton growth). Moreover, amines emitted atmospherically can degrade to form the carcinogenic- and potentially carcinogenic nitrosamines and nitramines, respectively.

The studied lakes constituted three raw drinking water sources located in close proximity to TCM (Lakes *Kvernhusvatn*, *Rotevatnet*, and *Storavatnet*). In addition, two reference lakes were included for comparison (one located on the west-coast and one in Eastern Norway). Samples were collected during January 2020, after the completion of a long test campaign at TCM. The samples were analysed for concentrations of amines, nitrosamines, and nitramines. In addition, several water chemical parameters that are known to be sensitive to changes in the nutrient status of lakes were also analysed. The parameters covered pH, total organic carbon, phytoplankton biomass (measured as chlorophyll A), total phosphorous and nitrogen, nitrate, and ammonium. The study was a continuation of previous monitoring work investigating the same parameters in the same lakes during the years 2011, 2013, 2014, and 2016.

In conclusion, no traces of amine-related discharges from TCM were detected in any of the studied lakes. No amines, nitrosamines, nor nitramines were measured at or above their respective analytical limits of quantification. Levels of the water chemical parameters, sensitive to amine-discharges, were compared to previous measurements, finding no clear trends of increase (or decrease).

Interestingly, the results contrasts with the findings from 2016 when two amines were detected in all lakes (including the reference lakes). In 2016, the samples were collected during autumn (October) when amines are likely to be produced from the degradation of organic material, which is contrary to the overall low biological activity during winter (January). Hence, we hypothesize that this is a result of seasonal variation in the natural sources and dynamics of amines.

This clearly shows that future research should focus on understanding the dynamics of sources to naturally occurring amines, in addition to improve the analytical methods for determination of nitrosamines and nitramines at lower concentrations.

Sammendrag

Tittel: Overvåkning TCM 2020 - Akvatisk

År: 2020

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Utvalgte innsjøer ble undersøkt for amin-utslipp fra pågående CO₂ fangst ved Teknologisenteret Mongstad (TCM). Økt tilførsel av aminer til en innsjø kan påvirke den naturlige næringsstatusen (kan for eksempel føre til økt vekst av fytoplankton). I tillegg kan aminer som slippes ut via luft brytes ned til henholdsvis kreftfremkallende- og mulig kreftfremkallende nitrosaminer og nitraminer.

Innsjøene som ble studert var tre drikkevannskilder nærliggende TCM (*Kvernhusvatn*, *Rotevatnet*, and *Storavatnet*) og to referanse-innsjøer til sammenlikning (en på Vestlandet og en på Østlandet). Prøvetakingen ble utført i januar 2020, etter at en lengre test kampanje på TCM var avsluttet. Vannprøvene ble analysert for konsentrasjoner av aminer, nitrosaminer og nitraminer, i tillegg til flere vannkjemiske parametere som er følsomme til endringer i næringsstatusen til en innsjø. Parameterne inkluderte pH, totalt organisk karbon, fytoplankton biomasse (målt som klorofyll a), total fosfor og nitrogen, nitrat og ammonium. Studiet var en videreførelse av tidligere utført overvåkningsarbeid der de samme parameterne ble undersøkt i innsjøene i årene 2011, 2013, 2014 og 2016.

Det ble ikke funnet noen spor av amin-relaterte utslipp fra TCM i noen av de undersøkte innsjøene. Hverken aminer, nitrosaminer eller nitraminer ble målt til nivåer tilsvarende- eller høyere enn kvantifiseringsgrenen til de respektive analysemetodene. For de vannkjemiske parameterne, som er følsomme til økt amin-relatert utslipp, ble nivåene sammenliknet med tidligere målte verdier uten å finne noen tegn til stigning (eller nedgang).

Årets resultater viste avvik fra 2016-undersøkelsen ved at det da ble funnet to aminer i alle innsjøene (inkludert referansevannene). I 2016 ble imidlertid prøvetakingen gjennomført om høsten (oktober) som er den tiden i løpet av året det kan forventes forhøyede nivåer av naturlig forekommende aminer fra nedbrytning av organisk materiale. Det står i kontrast til den generelt lave biologiske aktiviteten om vinteren, som var tidspunktet for årets prøvetaking (Januar). Vår hypotese er at det avvikende resultatet mellom de to årene skyldes sesongvariasjoner i naturlige kilder og prosessering av aminer.

Dette viser at fremtidig forskning bør fokusere på å øke forståelsen av kildedynamikken til naturlig forekommende aminer, i tillegg til å forbedre de analytiske metodene som brukes til å bestemme nitrosaminer og nitraminer ved lave konsentrasjoner.

1 Introduction

Technology for CO₂ capture is expected to become an important tool in the combat of climate change (IPCC, 2014). The principle is to isolate CO₂ from the flue gas of large-scale point emitters and to subsequently either store the concentrated CO₂ safely underground or to reuse it in some industrial process (e.g. algae production). Currently, the most feasible way of capturing CO₂ is by using amines (Rochelle, 2009; Wang et al., 2011). However, concern is raised since amines can be co-emitted with the cleaned flue gas and thereby introduced to the nearby environment. Moreover, the amines can be atmospherically degraded to form the carcinogenic- and potentially carcinogenic nitrosamines and nitramines, respectively (Reynolds et al., 2012).

All three compound groups of *amines*, *nitrosamines*, and *nitramines* are very hydrophilic, and are thus expected to reside in the aqueous phase after being deposited on ground. While some amines are naturally present in surface waters at low levels (< 10 µg L⁻¹), excess input can interfere with the natural balance by constituting a nitrogen-rich nutrient. The amines are likely taken up in the nitrogen cycle, to be transformed and utilized by aquatic microorganisms. Natural sources of amines to freshwaters include degradation of organic materials/organisms and faeces from e.g. birds (Poste et al., 2014, and references therein). Anthropogenic sources, other than CO₂ capture, can be runoff from agricultural areas. Nitrosamines and nitramines are not expected to be ubiquitous in the environment and are of major concern for potentially ending up in drinking water sources. The Norwegian Institute of Public Health (NIPH) has recommended a safety limit of 4 ng L⁻¹ for the sum of nitrosamines and nitramines in drinking water (Låg et al., 2011).

Technology Centre Mongstad (TCM) is the world's largest centre for development of CO₂ capture technology and has been in operation since 2012. Strict emission regulations must be followed, and monitoring of the nearby environment is routinely conducted focusing on the amines and corresponding degradation products. A baseline study was conducted in 2011 to establish background levels of amines, nitrosamines, and nitramines in aquatic and terrestrial compartments, as well as characterizing the natural status of the area (Grung et al., 2012). The region is influenced by its close proximity to the coast which shows up e.g. as high levels of seawater ions (sodium, calcium, and magnesium) in surface freshwaters. During recent years, the environmental monitoring has focused on a selection of lakes that serves as drinking water sources to the local population. The three lakes, *Kvernhusvatn*, *Rotevatnet*, and *Storavatnet* were identified with the highest risk of receiving amine discharges from TCM, after consulting atmospheric dispersion and deposition modelling (Karl et al., 2011). The lakes are naturally oligotrophic, meaning they are low in nutrients and organic carbon, which can cause them to be especially sensitive to a small excess input of nutritious compounds like amines. Through the TCM initiated environmental monitoring programme, the lakes have been sampled a total of four times (including the 2011 baseline study) and analysed for presence of amines, nitrosamines, and nitramines, in addition to selected water chemical parameters. The chemical parameters were selected for being sensitive to excessive input of nutrients such as amines and includes nitrogen- and phosphorous content as well as phytoplankton biomass (Chlorophyll A.) and pH. To be able to account for naturally present amines and seasonal fluctuations in the selected parameters, reference lakes that cannot receive emissions from TCM have been included for comparison.

From the monitoring conducted so far, no traces of amine emissions from TCM has been found in any of the lakes. In 2016, the presence of two amines (*MEA*; *monoethanolamine* and *AMP*; *2-amino-2-methyl-1-propanol*) was confirmed in all lakes investigated, but with levels higher in the reference

lakes compared to the drinking water sources in close vicinity to TCM (Grung et al., 2017). Levels of MEA were found to range from 1.6 to 2.1 $\mu\text{g L}^{-1}$ in the drinking water lakes, and from 0.7 to 3.5 $\mu\text{g L}^{-1}$ in the two reference lakes (one at the west- and one in eastern Norway). AMP was measured from 0.22 to 0.30 $\mu\text{g L}^{-1}$ in all lakes investigated. The samples were collected during the fall (October) which is likely the time of the year in which degradation of organic material, produced during the summer, is at its highest. Neither nitrosamines nor nitramines have ever been detected in any of the lakes.

Regarding the environmental monitoring studies, it should be mentioned that the results from the early work is associated with high uncertainties due analytical challenges related to the determination of amines, nitrosamines, and nitramines. While during the recent years the reliability of the analytical results has reached a satisfactory limit, the sensitivity of the methods used to determine nitrosamines and nitramines is still not sufficient to be able to measure at the NIPH recommended limit.

The objective of the 2020 aquatic monitoring was to assess levels of amines, nitrosamines, and nitramines in the three drinking water source lakes, Lakes *Kvernhusvatn*, *Rotevatnet*, and *Storavatnet* and to compare the results with the two reference lakes *Storavatnet26964* (located on the west-coast) and *Langtjernet* (located in Eastern Norway) and to the previously obtained results from earlier monitoring work. Sampling was conducted in January 2020, just after the completion of a long test campaign at TCM.

2 Methods

2.1 Water sampling sites, sampling procedure, and spiking

2.1.1 Lake Water Sampling Sites

The lakes that were sampled are listed in Table 1 including names, location, size, and identification number. In Figure 1, the location of the lakes is indicated by a map. Lakes *M02 Kvernhusvatn*, *M50 Rotevatnet*, and *M51 Storavatnet2125* are drinking water sources located in close vicinity to TCM. Lakes *M52 Storavatnet26964* and *O01 Langtjernet* are included as reference lakes. The first is also at the west-coast, but far south from TCM and thus not receptive of amine discharges, while the latter is at the eastern part of Norway. These are the same lakes as included in the 2016 survey (Grung et al., 2017).

Table 1: Overview of the lakes sampled.

ID	Name	¹ Municipality (county)	Lake area (km ²)	Altitude (m)	Latitude	Longitude	NVE no
M 02	Kvernhusvatn	Gulen (Vestlandet)	0.01	33	60.8599	5.0114	175749
M 50	Rotevatnet	Alver (Vestlandet)	0.07	34	60.7543	5.0824	26224
M 51	Storavatnet 2125	Alver (Vestlandet)	1.96	20	60.6599	5.2592	2125
M 52	Storavatnet 26964	Øygarden (Vestlandet)	0.14	24	60.1800	5.0543	26964
O 01	Langtjernet	Flå (Viken)	0.23	516	60.3727	9.7263	7272

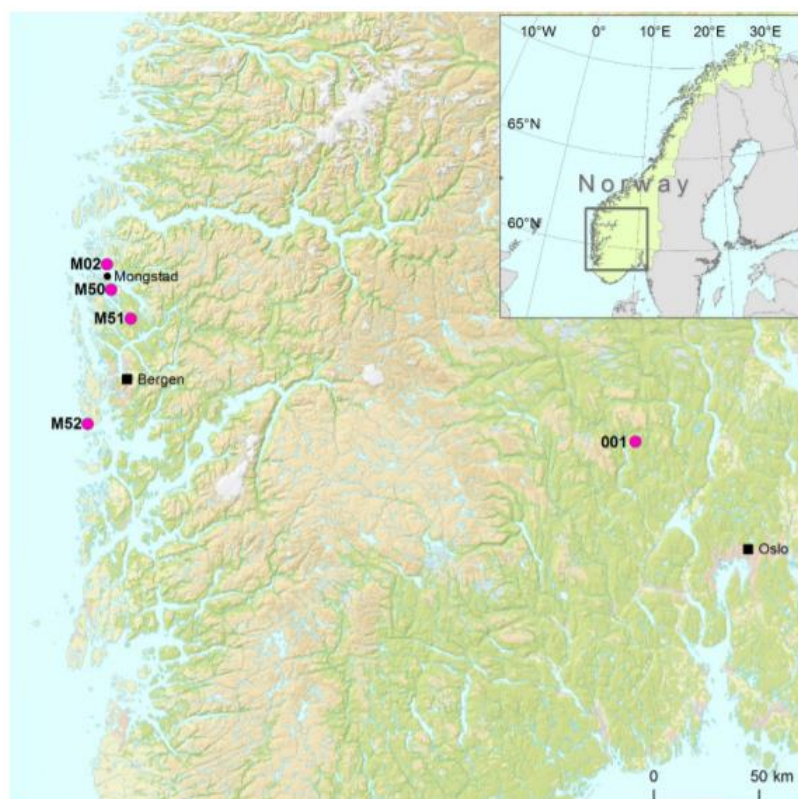


Figure 1: Map showing the location of the sampled lakes. From Grung et al. (2017).

¹ From 01.01.2020

2.1.2 Lake Water Sampling

Water samples were collected from the lakes during the second half of January 2020, just after a longer test campaign at TCM had finished. Hypothetically, the timing of the sampling would allow emissions to accumulate in the environment while limiting time for degradation. The reference lake *Langtjernet* was sampled the 23rd of January, the drinking water sources *Rotevatnet* and *Storavatnet2125* and the reference lake *Storavatnet26964* were sampled on the 28th of January, and the drinking water source lake *Kvernhusvatn* on the 29th of January. Photos of the lakes taken the day of sampling are presented in **Figure 2**.

Water was collected from 0.1 - 0.5 m below the surface from the outlet of the lake, according to the following procedure: the sample container was rinsed three times with the lake water before the sample was collected. At each site, two different water samples were collected, one for amine/nitrosamine/nitramine and another for general water chemistry determination, in addition to filtrate for the determination of Chlorophyll A. The samples for amine/nitrosamine/nitramine analysis was sampled in acid washed amber glass bottles (250 mL, DURAN[®] borosilicate glass, ISO 4796-1, VWR) equipped with cap liner (silicone, PTFE-coated, DURAN[®]), as recommended by EPA Method 521. Sample for general water chemistry determination was sampled in PPTe bottles.



Figure 2: Photos of the sampled lakes from the respective day of sampling. From top left: *M02 Kvernhusvatnet*, *M50 Rotevatnet*, *M51 Storavatnet 2125*, *M52 Storavatnet 26964*, and *O01 Langtjernet*. Photo: Espen Lund, NIVA.

2.1.3 Sample Conservation Procedure

The samples to be measured for amines, nitrosamines, and nitramines were acid-conserved in two steps to avoid chemical formation of nitrosamines from potentially present amines and nitrite, and biodegradation of any of the analytes. The procedure was a refined version of the one used for the 2016 survey (Grung et al., 2017), building on recommendations from EPA Method 607, and was finalised in close cooperation with both TCM and SINTEF Industry laboratories.

The sample conservation was conducted as follows:

1. To 200 mL water sample, 0.5 mL sulfonic acid (12.5 g L^{-1}) (ACS reagent, 99.3%, Sigma-Aldrich) was added to a final concentration of 0.03 g L^{-1} . This was done to quench nitrosamine formation from amines and nitrite in the sample (EPA Method 607). The sample was mixed gently and allowed to react for a minimum of 10 minutes.
2. Sulphuric acid (2.5 M) was added to the sample to obtain a final pH of approximately 2.3. The pH was confirmed using a portable pre-calibrated pH-meter (WTW pH 330 – Redox SensoLyt Pt T2019). Optimally, the pH should be as close to 2 as possible, to reduce biological activity, while not going below 2.0 to ensure maximum compatibility with the analytical method (SINTEF Industry, personal communication).

2.1.4 Chlorophyll A sample preparation procedure

For the determination of Chlorophyll A, 1000 mL of sample was filtrated through GF/F filters. The filters were kept frozen using dry ice until arrival at the laboratory.

2.1.5 Spiking of samples

Two additional water samples were collected from the reference lake, *Storavatnet 26964* to be spiked with known amounts of the two amines, AMP and piperazine (PZ). The samples were subject to the same sample conservation as the other samples. Spiking was conducted by TCM laboratory. Final concentrations amounted to 284.7 ng L^{-1} AMP and 272.1 ng L^{-1} PZ in control sample 1 and 287.5 ng L^{-1} AMP and 274.8 ng L^{-1} PZ in control sample 2. Results from analysis were satisfactory with recovery of 98% for PZ in both control samples and 99 and 100% for AMP in the two control samples, respectively.

2.1.6 Shipment of samples

Packaging and shipping of the samples from TCM to SINTEF Industry laboratory was carried out by personnel at TCM. The samples were shipped the 29th of January and arrival was confirmed the next day.

2.2 Chemical Analyses

2.2.1 Determination of amines, nitrosamines, and nitramines

Determination of amines, nitrosamines, and nitramines was conducted by SINTEF Industry laboratory. The specific molecules included are listed in Table 2 including name, abbreviation, CAS-no, and concentration limit of quantification (LOQ) for the method. A liquid chromatograph – triple quadrupole mass spectrometer (LC-TQMS) was used for the analyses, equipped with electrospray ionisation (ESI) for the determination of amines and atmospheric pressure ionisation (APCI) for the nitrosamines and nitramines. Different LC columns were used for the three compound groups (amines: Ascentis Express phenyl-hexyl, 15 cm x 4.6 mm, 2.7 μm , nitrosamines: Supelco Ascentis express, phenyl-hexyl 4.6 x 150 mm, and nitramines: Ascentis Express RP-Amide, 15 cm x 4.6 mm, 2.7 μm).

Table 2: Overview of the analyte amines, nitrosamines, and nitramines including the limit of quantification (LOQ) of the method.

Group	Name	Abbr.	CAS-no	LOQ (ng L ⁻¹)
Amine	2-amino-2-methylpropanol	AMP	124-68-5	50
	Monoethanolamine	MEA	141-43-5	100
	Piperazine	Pz	116-85-0	
Nitrosamine	N-Nitrosodiethanolamine	NDELA	116-54-7	10
	Nitrosopiperidine	NPIP	100-75-4	
	N-Nitroso-n-dibutylamine	NDBA	924-16-3	
	Nitrosodiethylamine	NDEA	55-18-5	
	Nitrosodimethylamine	NDMA	62-75-9	
	Nitroso N-Methylethylamine	NMEA	10595-95-6	
	Nitrosomorpholine	NMOR	59-89-2	
	Nitrosodi-N-Propylamine	NDPA	621-64-7	
	Nitrosopyrrolidine	NPYR	930-55-2	
	Nitrosopiperazine	NPz	5632-47-3	100
Nitramine	2-(nitroamino)ethanol	MEA-NO ₂	74386-82-6	100
	2-methyl-2-(nitroamino)propan-1-ol	AMP-NO ₂	1239666-60-4	
	1-nitropiperazine	Pz-NO ₂	42499-41-2	500

2.2.2 Water chemistry

Determination of major chemical components was carried out at NIVA, in line with previous monitoring and baseline work (Grung et al., 2012; Grung et al., 2017; Poste et al., 2015). The parameters chosen are summarized in Table 3. All analyses were accredited. Note that Tot-N was determined at Eurofins.

Table 3: Water chemistry parameters analysed.

Code	Analyte	Method	LOD	Unit
pH	pH	Potentiometry	-	-
Tot-P	Total phosphorous	Automated photometry	1	$\mu\text{g P L}^{-1}$
Tot-N	Total nitrogen	Eurofins internal method	10	$\mu\text{g N L}^{-1}$
NH₄	Ammonium	Ion chromatography	2	$\mu\text{g N L}^{-1}$
NO₃	Nitrate	Ion chromatography	2	$\mu\text{g N L}^{-1}$
TOC	Total organic carbon	Oxidation to CO ₂ with UV/persulphate (IR detection)	0.10	mg C L^{-1}
Cl	Chloride	Ion chromatography	0.005	mg L^{-1}
SO₄	Sulphate	Ion chromatography	0.005	mg L^{-1}
Na	Sodium	Ion chromatography	0.002	mg L^{-1}
Chl.a	Chlorophyll a	Methanol extraction + spectrophotometry	0.31	$\mu\text{g L}^{-1}$

3 Results and Discussion

3.1 Presence of amines, nitrosamines, and nitramines

To look for traces of amine-discharges from TCM, the lakes were analysed for a range of different amines, nitrosamines, and nitramines relevant to CO₂ capture. No amines, nitrosamines, nor nitramines were detected in any of the lakes (including the reference lakes) at levels at or above their respective method limit of quantification (Table A-1 in Appendix). This contrasted to the findings from 2016 in which the two amines, MEA and AMP were detected at low levels in all lakes. Since the levels were higher in the reference lakes than in the lakes close to TCM, the source was depicted to be natural, e.g. from decaying organic materials. The cause of the deviating results between the 2016 and 2020 studies is hypothesized to result from seasonal variation. While in 2016, the samples were collected during the autumn (October), with typical high decay rates of organic material, the samples in 2020 were collected mid-winters (January) with overall low biological activity. Although the results from the two years cannot be directly compared to each other, the results from this year's mid-winter sampling provide valuable insight into the seasonal variation of naturally sourced amines. Another aspect to the low biological activity during winter is that potential uptake- and transformation processes of amines are low. Thus, mid-winter could constitute the season with highest likelihood of retrieving amines emitted from TCM.

Note that the methods used to measure nitrosamines and nitramines were not sufficiently sensitive to measure at the low levels that have been predicted by the atmospheric dispersion and deposition modelling (ng - $\mu\text{g L}^{-1}$) (Karl et al., 2011)

3.2 Lake Water Chemistry

In Figures 3, 4, and 5 results for the water chemical parameters measured in the lake waters are graphically presented and compared to the results from the four previous aquatic monitoring assessments: October 2011 - Baseline study (Grung et al., 2012), November 2013 and April 2014 - Measuring amines in Norwegian surface waters (Poste et al., 2015), and October 2016 - Monitoring TCM 2016 – Aquatic (Grung et al., 2017). The results from this 2020 survey are also presented numerically in Table A-2 in Appendix.

3.2.1 Status

Overall, the three raw drinking water lakes and the one reference lake from the west-coast (*Storavatnet2125*, *Rotevatnet*, *Kverhusvatnet*, and *Storavatnet26964*) were similar in pH, TOC (Figure 3), nutrient levels (Figure 4), and ionic composition (Figure 5). The pH was slightly acidic (5.7 - 6.2) and the TOC was low to moderate (1.9 - 4.7 mg C L⁻¹), which is typical for this region. In accordance with previous years, the lakes were characterised as oligotrophic (clear water with low nutrient levels and productivity) on the basis of total phosphorus and phytoplankton biomass measurements (Tot P: 2 – 10 $\mu\text{g P L}^{-1}$ and Chl.A.: 0.48 – 0.74 $\mu\text{g L}^{-1}$). Levels of total nitrogen ranged from 110 to 390 $\mu\text{g N L}^{-1}$. The highest was in Lake *Storavatnet2125* which was reflected by an elevated level of nitrate (180 $\mu\text{g NO}_3\text{-N L}^{-1}$) when compared to the other lakes (25 - 47 $\mu\text{g NO}_3\text{-N L}^{-1}$). The source of nitrate can be both of natural and anthropogenic origin, but the exact source is difficult to pin-point without further investigations. Levels of ammonium were all over low, ranging from 7 to 27 $\mu\text{g NH}_4\text{-N L}^{-1}$. The proximity of the lakes to the coast is clearly reflected in the ionic composition of the water, being high in sodium (Na: 6-11 mg L⁻¹), chloride (Cl: 10-20 mg L⁻¹), and sulphate (SO₄: 1-3 mg L⁻¹).

The reference lake in East-Norway (*Langtjernet*) is distinct by its higher TOC level (13 mg C L^{-1}) and markedly lower concentration of the seawater-associated ions (Na: 0.62 mg L^{-1} , Cl: 0.25 mg L^{-1} , SO_4 : 0.67 mg L^{-1}). This is as expected for a lake from a forested catchment rich in organic soils and located further away from the coast. The nutrient status of Lake *Langtjernet* can also be characterized as oligotrophic ($3 \text{ } \mu\text{g P L}^{-1}$ and $\text{Chl.A} < 0.31 \text{ } \mu\text{g L}^{-1}$).

3.2.2 Trends

From the relatively infrequent measurements conducted it is difficult to identify trends of significant increase or decrease, and especially also when considering potential influence from seasonal variation. However, tendencies of change with time might be observable.

Of greatest interest with regards to tracing amine-discharges from TCM are the nitrogen fractions (Figure 4). While the levels appear to be relatively stable in most lakes, an increase in certain nitrogen species was observed for Lake *Kvernhusvatnet*, located just north of TCM. This year's level of nitrate and ammonium were six and five times higher, respectively, than the median of the four preceding measurements. Interestingly, at the same time, the level of total nitrogen was three times lower than the median of the four preceding measurements. This indicates a shift in the distribution of nitrogen species in Lake *Kvernhusvatnet* at the time of the 2020 sampling compared to the previous. During this year sampling, we observed the water level of the lake to be markedly higher compared to the previously conducted sampling. Winter is typically associated with high precipitation and January 2020 had more than twice the normal precipitation (met.no). With the lake being surrounded by agricultural activities, the intense rain may have flushed nitrogen fertilisers into the lake, thereby altering the nitrogen distribution. None of the other parameters relevant to identify discharge from TCM (e.g. pH, Chl. A.) showed any clear tendencies of increase or decrease with time. For sodium and chloride, an increasing trend was observed which can be associated with the use of road salt for de-icing of the nearby roads.

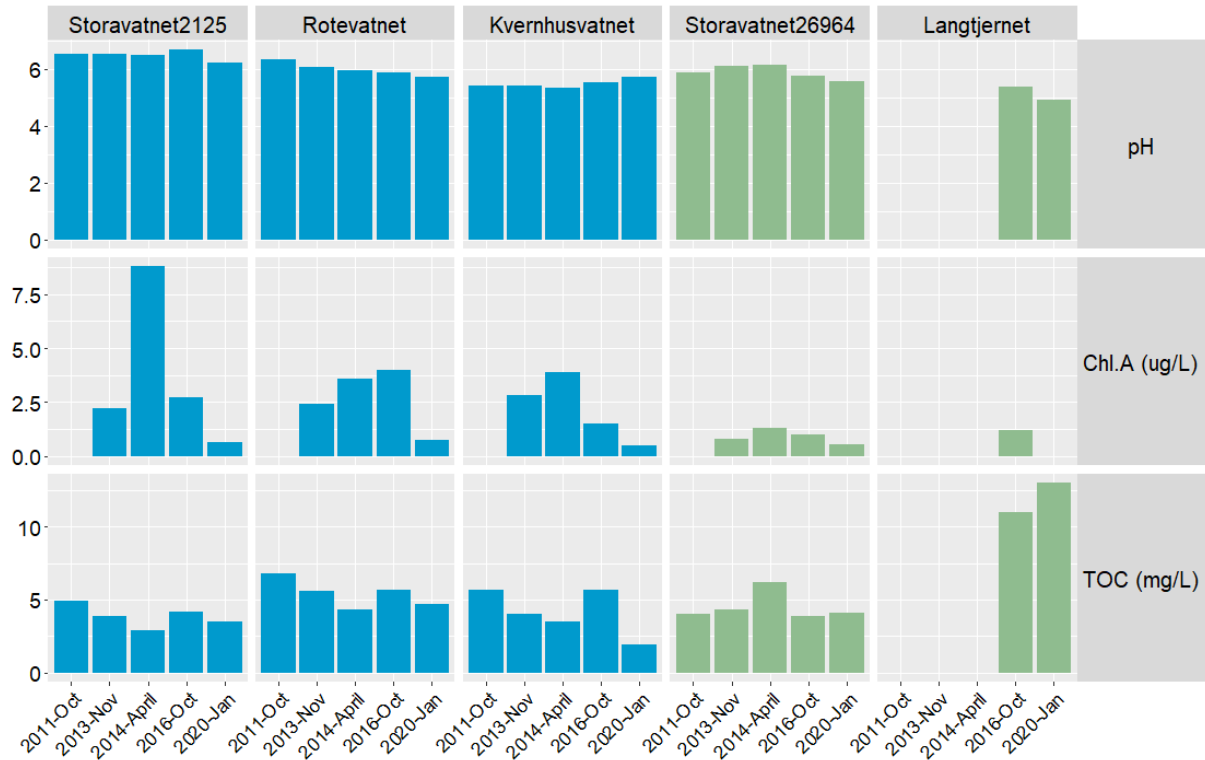


Figure 3: Levels of pH, Chlorophyll A (Chl.A; measure for phytoplankton biomass), and total organic carbon (TOC) measured in the lakes Storavatnet2125, Rotevatnet, Kverhusvatnet, and Storavatnet26964, and Langtjernet during the total of five monitoring work conducted. Raw drinking water lakes are in blue while the reference lakes are in green.

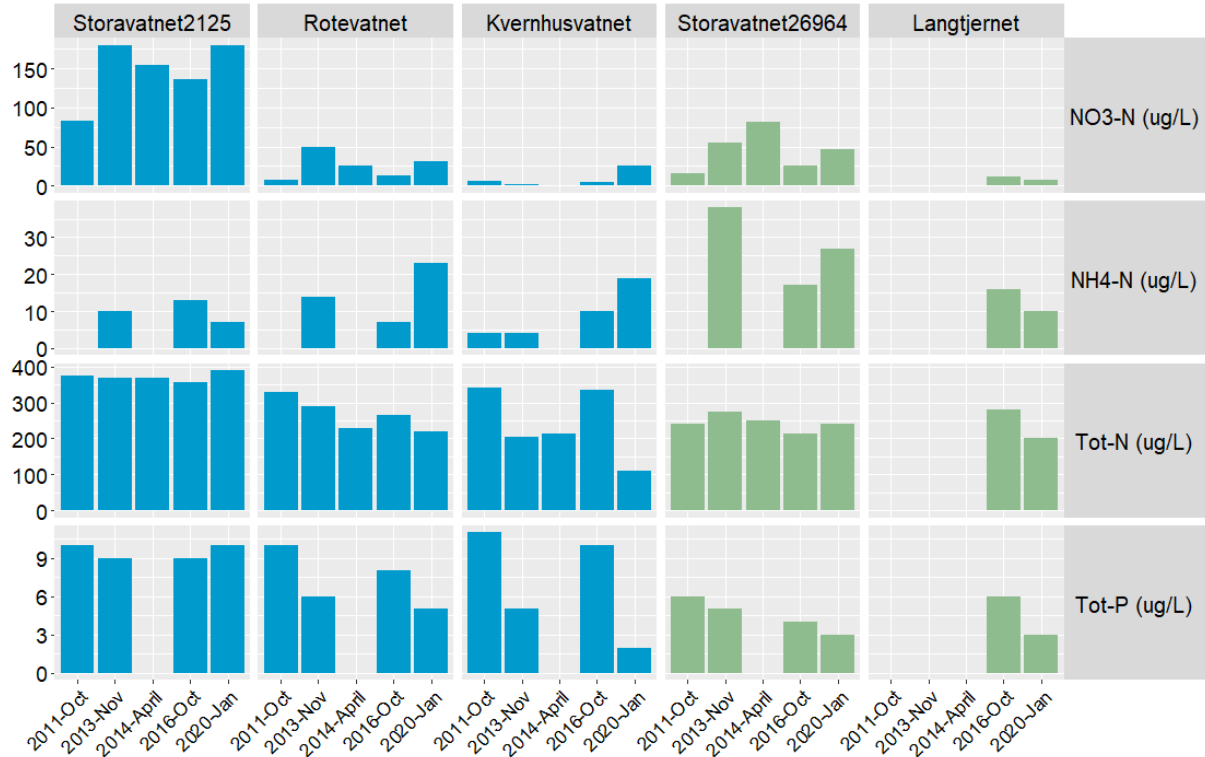


Figure 4: Levels of nitrate (NO₃-N), ammonium (NH₄-N), total nitrogen (Tot-N), and total phosphorous (Tot-P) measured in the lakes Storavatnet2125, Rotevatnet, Kverhusvatnet, and Storavatnet26964, and Langtjernet during the total of five monitoring work conducted. Raw drinking water lakes are in blue while the reference lakes are in green.

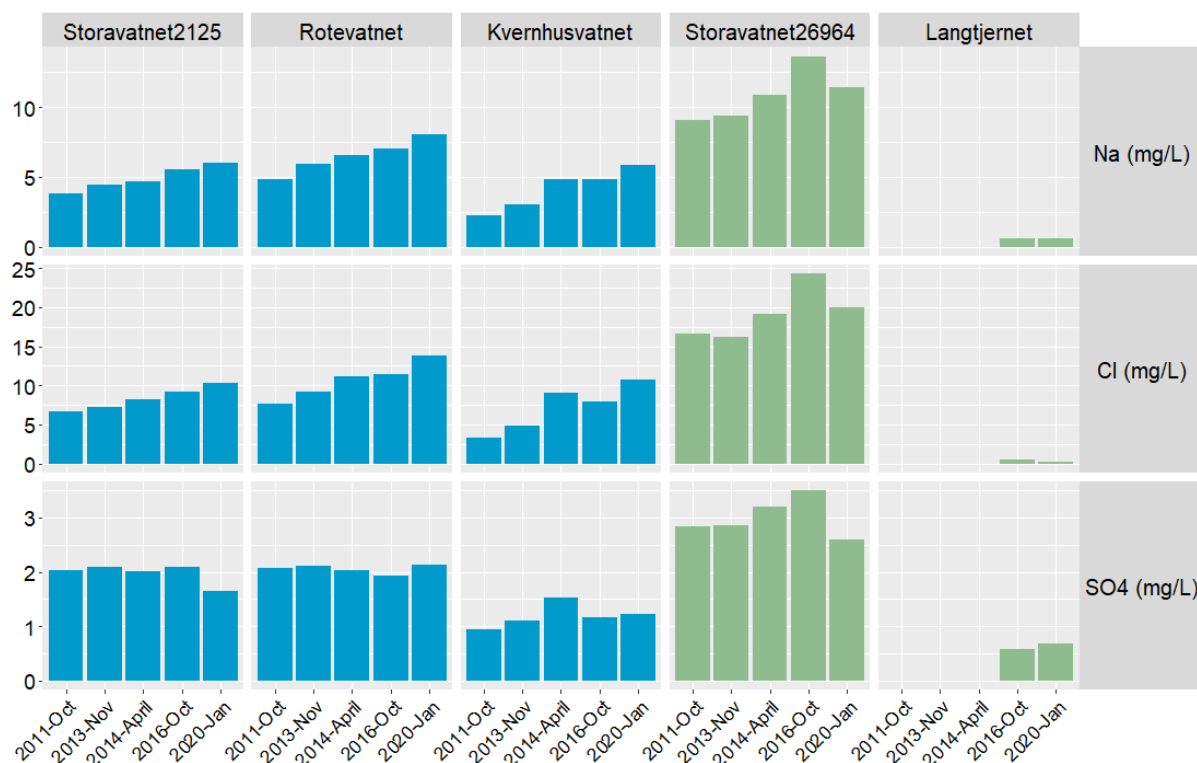


Figure 5: Levels of sodium (Na), chloride (Cl), and sulphate (SO₄) measured in the lakes Storavatnet2125, Rotevatnet, Kverhusvatnet, and Storavatnet26964, and Langtjernet during the total of five monitoring work conducted. Raw drinking water lakes are in blue while the reference lakes are in green.

4 Conclusion

Three lakes, serving as raw water drinking sources, have been assessed for potential influence from amine-discharges from CO₂ capture activities at the nearby TCM.

In conclusion, no traces of amine-related emissions from TCM could be detected in any of the lakes investigated. None of the amines, nitrosamines, nor nitramines were detected in any of the lakes at levels at or above the quantification limit of their respective analytical methods. Amines are considered as highly nutritious compounds and may rapidly be taken up- and transformed by the nitrogen cycle. Lake water levels of selected water chemical parameters, including pH, phytoplankton biomass (Chl. A.), and nutrient content and speciation, were compared to reference lakes and to results from previous monitoring work, finding no clear indications of excess nitrogen input. One exception was Lake *Kvernhusvatn* in which the current concentration of nitrate and ammonia was several times higher than observed during the previous years, while the level of total nitrogen was lower. This indicated a shift in the dynamics of the nitrogen species rather than an excess input of nitrogen to the lake. The intense precipitation occurring during winter 2020 may have caused the increase in nitrate and ammonium by flushing the agricultural regions surrounding the lake.

Seasonal variation may also explain the discrepancy in the results of amines when comparing the current observed absent amines to the low levels found in all lakes in 2016. The absence of amines in the current assessment is attributed to the overall low biological activity during winter.

At the same time as demonstrating the lack of influence from CO₂ capture on the nearby lakes, the current assessment has contributed with valuable insight into potential seasonal variation in the natural sources and dynamics of amines. To further explore this, future studies should be conducted with more frequent sampling. Finally, the analytical methods for the determination of nitramines and nitrosamines should be improved to be able to measure at the low levels expected to result from CO₂ capture activities.

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Appendix A.

Table A-1: Results from the determination of amines, nitrosamines, and nitramines in the lake waters showing no detection above the respective methods limit of quantification presented.

Group	Abbr.	Drinking water			Reference	
		Storavatnet 2125	Rotevatnet	Kvernhusvatn	Storavatnet26964	Langtjernet
Amines (ng L ⁻¹)	AMP	< 50	< 50	< 50	< 50	< 50
	MEA	< 100	< 100	< 100	< 100	< 100
	Pz	< 100	< 100	< 100	< 100	< 100
Nitrosamines (ng L ⁻¹)	NDELA	< 10	< 10	< 10	< 10	< 10
	NPIP	< 10	< 10	< 10	< 10	< 10
	NDBA	< 10	< 10	< 10	< 10	< 10
	NDEA	< 10	< 10	< 10	< 10	< 10
	NDMA	< 10	< 10	< 10	< 10	< 10
	NMEA	< 10	< 10	< 10	< 10	< 10
	NMOR	< 10	< 10	< 10	< 10	< 10
	NDPA	< 10	< 10	< 10	< 10	< 10
	NPYR	< 10	< 10	< 10	< 10	< 10
	NPz	< 100	< 100	< 100	< 100	< 100
Nitramines (ng L ⁻¹)	MEA-NO ₂	< 100	< 100	< 100	< 100	< 100
	AMP-NO ₂	< 100	< 100	< 100	< 100	< 100
	Pz-NO ₂	< 500	< 500	< 500	< 500	< 500

Table A-2: Results for the water chemical parameters measured in the lake water.

Abbr.	Drinking water			Reference	
	Storavatnet2125	Rotevatnet	Kvernhusvatn	Storavatnet26964	Langtjernet
pH	6.2	5.72	5.71	5.56	4.92
TOC (mg L ⁻¹)	3.5	4.7	1.9	4.1	13
Na (mg L ⁻¹)	6.01	8.02	5.84	11.4	0.62
Cl (mg L ⁻¹)	10.3	13.8	10.8	20	0.25
SO ₄ (mg L ⁻¹)	1.64	2.13	1.22	2.59	0.67
NH ₄ -N (µg L ⁻¹)	7	23	19	27	10
NO ₃ -N (µg L ⁻¹)	180	31	25	47	8
Tot-N (µg L ⁻¹)	390	220	110	240	200
Tot-P (µg L ⁻¹)	10	5	2	3	3
Chl.A (µg L ⁻¹)	0.65	0.74	0.48	0.54	NA

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