

Forsmark site investigation

Hydrochemical investigations in four calciferous lakes in the Forsmark area

Results from the second year of a complementary investigation in the Forsmark area

Susanne Qvarfordt, Sveriges Vattenekologer AB

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December 2011

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors. SKB may draw modified conclusions, based on additional literature sources and/or expert opinions.

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Abstract

The present report documents the results from the second year of hydrochemical investigations in four small, calciferous lakes in the Forsmark area in order to study the lake water compositions.

The construction of a permanent storage facility for used nuclear fuel may result in a lowering of the ground water level and also lake surface water levels. Restoration of habitats by adding water may be an option to reduce possible negative consequences induced by a lower water level on biodiversity and valuable species. Thus, knowledge of the water composition is needed.

This report presents the results from six sampling occasions during January to December 2010. The results from the sampling of the four lakes includes field measurements of redox potential (ORP), pH, dissolved oxygen, electrical conductivity, salinity, depth, atmospheric pressure, turbidity, chlorophyll and water temperature, as well as chemical analyses of major constituents and nutrient salts.

The four investigated small lakes are well buffered with high alkalinity, high pH and high calcium concentrations. This is in accordance with results from the ongoing monitoring programme of lakes and streams in the area and with the results from the previous sampling period (2008–2009).

The results show both seasonal and inter-annual variation in the analysed parameters. This can be explained by seasonal changes and annual differences in temperature, ice-cover, precipitation etc and lake specific parameters such as lake size and drainage area. The variation highlights the importance of both year round sampling and continued sampling for several years when discussing the water composition.

Sammanfattning

Rapporten dokumenterar det andra året av hydrokemiska undersökningar i fyra små, kalkrika sjöar i Forsmarksområdet för att studera sjöarnas vattensammansättning.

Byggandet av ett slutförvar för använt kärnbränsle kan leda till en lägre grundvattennivå och därmed även lägre vattennivå i sjöarna i området. Tillförsel av vatten i syfte att återställa habitat kan bli ett alternativ för att minska konsekvenserna av en lägre vattennivå på biodiversitet och viktiga arter. Därför behövs information om vattensammansättningen i sjöarna.

I denna rapport presenteras resultat från sex provtagningstillfällen under perioden januari till december 2010. De erhållna resultaten från sjöarna omfattar fältmätningar av ORP (*Oxidising Reducing Potential*), pH, löst syre, elektrisk konduktivitet, salinitet, djup, atmosfärstryck, turbiditet, klorofyll och vattentemperatur samt kemiska analyser av huvudkomponenter, närsalter och kolföreningar.

Resultaten visar att de fyra sjöarna, i likhet med tidigare undersökta sjöar och bäckar i Forsmarksområdet, är väl buffrade med hög alkalinitet, högt pH och höga kalciumkoncentrationer.

Resultaten visar även stor variation i analyserade parametrar både under året och mellan de två undersökningsåren, vilket tydligt visar hur viktigt det är att provta vid flera tillfällen under året och även under flera år. Variationen kan förklaras av årstidsförändringar i t ex temperatur, istäckning och nederbörd, samt skillnader i sjöarnas egenskaper när det gäller t ex storlek och avrinningsområde.

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1 Introduction

The Swedish Nuclear Fuel and Waste Management Co (SKB, Svensk Kärnbränslehantering AB) have conducted extensive site investigations in the Forsmark area for the purpose of a future permanent repository for used nuclear fuel. The investigation phase of the site investigations in Forsmark was finished in June 2007, but some complementary investigations still continue as well as a long-term monitoring programme (SKB 2007).

The long-term monitoring programme includes sampling and hydrochemical analyses of surface waters from four lakes, four streams and one shallow sea bay. The complementary investigation reported in this document includes sampling of surface waters from four small, shallow calciferous lakes and their surrounding marshlands (rikkärr).

The aim of this complementary investigation is to analyse the chemical water compositions of the lakes. The construction of a repository may result in a lowering of the groundwater level. Restoration of habitats by adding water may be an option to reduce consequences induced by a lower ground water level on biodiversity and valuable species. Thus, knowledge of the water composition is needed.

The investigation of the lakes includes sampling for chemical analysis as well as direct measurements of physical and chemical parameters such as ORP (Oxidising Reducing Potential), pH, dissolved oxygen, electrical conductivity, salinity, measurement depth, atmospheric pressure, turbidity, chlorophyll and water temperature. The sampling and field measurements started in November 2008. This document reports results from the six sampling occasions during 2010.

The sampling locations are presented in the map in Figure 2-1 as well as with photos in Figures 1-1, 1-2, 2-2, 2-5 and 3-7. The controlling documents for the activities are listed in Table 1-1. The activity plans and the method descriptions are SKB's internal controlling documents. Original data from the reported activities are stored in the primary database Sicada. Data are traceable in Sicada by the activity plan numbers (AP PF 400-08-005). Only data in databases are accepted for further interpretation and modelling. The results presented in this report are regarded as copies of the original data. Data in the database may be revised, if needed. However, such revision of the database will not necessarily result in a revision of this report, although major revisions are the normal procedure for a P-report. Minor revisions are normally presented as supplements, available at www.skb.se.



Figure 1-1. The shallow Lake PFM007442.

Table 1-1. Controlling documents for performance of the activity.

Activity plans	Number	Version
Kompletterande hydrokemisk undersökning i fyra kalkgölar i Forsmarksområdet, 2008–2009.	AP PF 400-08-005	1.0
Method descriptions	Number	Version
Metodbeskrivning för ytvattenprovtagningar vid platsundersökningar.	SKB MB 900.004	1.0
Mätsystembeskrivning för YSI. Multiparametersystem för vattenmätningar.	SKB MD 910.001	1.0

Water sampling and measurement procedures are also described in SKB PIR-04-06, “Metodik för provtagning av ekologiska parametrar i sjöar och vattendrag”, and SKB PIR-04-12, ”Översikt över provhanterings- och analysrutiner för vattenprov” (SKB internal documents).



Figure 1-2. Lake PFM007444.

2 Methods and performance

2.1 Sampling locations and sampling scheme

This complementary investigation included four small, calciferous lakes near Lake Bolundsfjärden. The sampling locations are presented in Figure 2-1. Table 2-1 lists the location id-codes, coordinates and names. The sampling scheme for 2010 is given in Table 2-2.

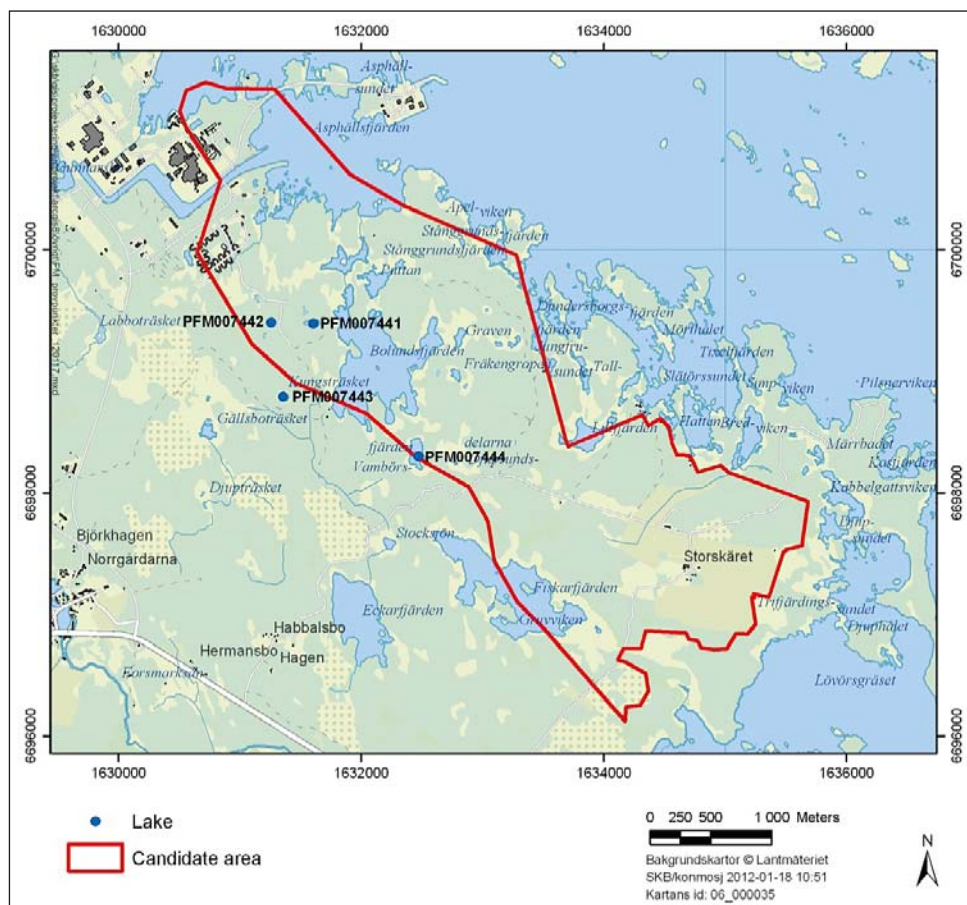


Figure 2-1. Sampling locations for the complementary investigations in four small, calciferous lakes.

Table 2-1. Sampling locations (Id-code, coordinates and name).

Sampling locations	Coordinates (RT90 RHB70)	Name
PFM007441	16 31 606, 66 99 396	
PFM007442	16 31 259, 66 99 402	
PFM007443	16 31 357, 66 98 792	Kungsträsket
PFM007444	16 32 472, 66 98 302	Vambörsfjärden

Table 2-2. Sampling scheme for the complementary investigations in four calciferous lakes during 2010.

Year	Month	Week	Class
2010	January	3	3
	February	–	–
	March	11	3
	April	–	–
	May	21	3
	June	–	–
	July	–	–
	August	32	3
	September	–	–
	October	41	3
	November	–	–
	December	49	3



Figure 2-2. Water sampling in Lake PFM007444.

2.2 Equipment

2.2.1 Sampling equipment

Water samples were collected using an online pumping setup consisting of an electrical peristaltic pump system, PPS (ASF Thomas SR 10/100, powered by 12 VDC, 7 Ah cells), connected to a 4 m long Teflon-tube (FEP 140) of 5 mm inner diameter. The sampling equipment is presented in Figure 2-3.

2.2.2 Multiparameter sondes

Field measurements were performed using a multi parameter sonde (YSI 6600 EDS). A terminal (YSI 650 MDS) is connected to the sonde through a cable for logging data (Figure 2-4). Calibration of the sonde was carried out according to the measurement system description SKB MD 910.003 (SKB internal controlling document, see Table 1-1). A smaller sonde (YSI 600QS) is kept as a backup. Table 2-3 describes the parameters measured by the sondes.

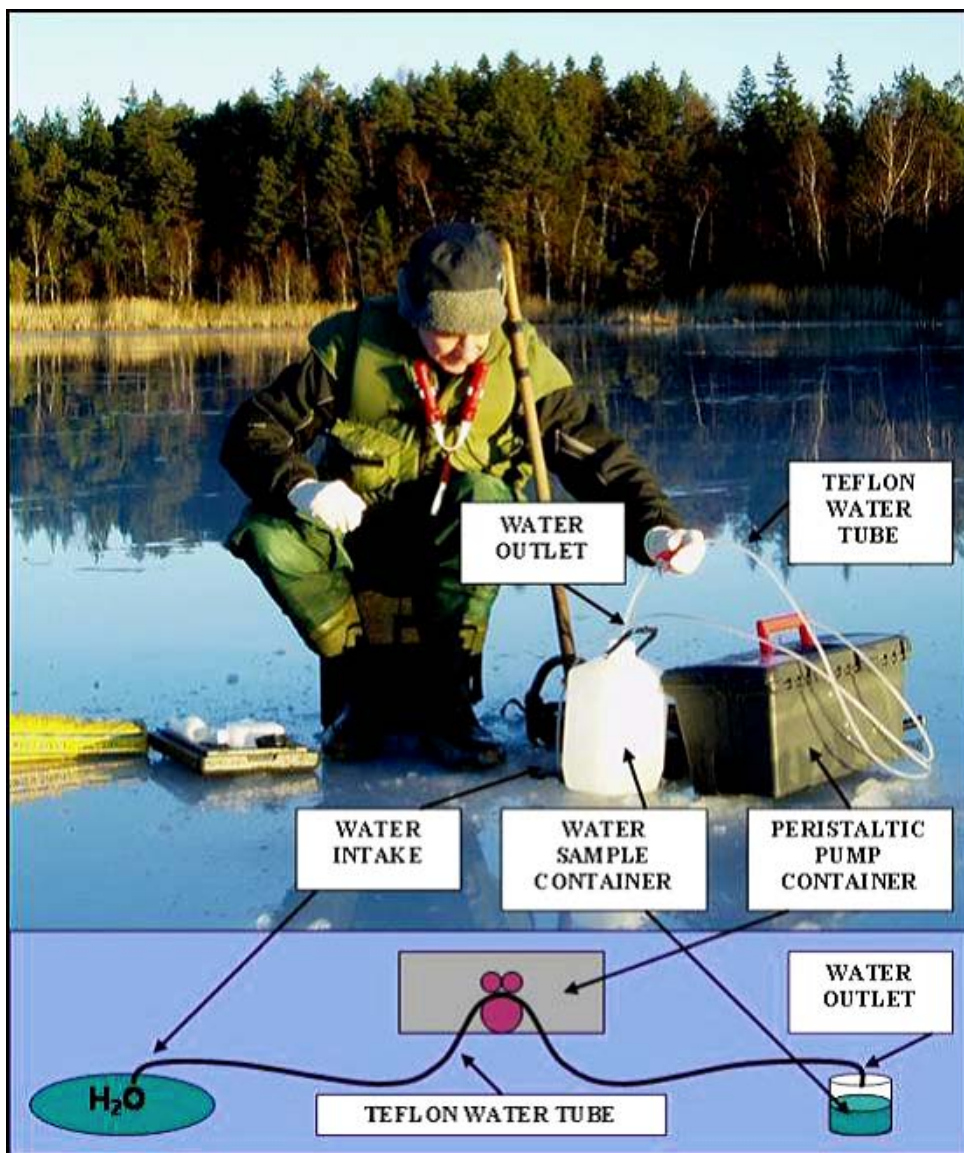


Figure 2-3. Winter sampling of surface water using the peristaltic pump system (PPS). A schematic presentation of the PPS is also shown.

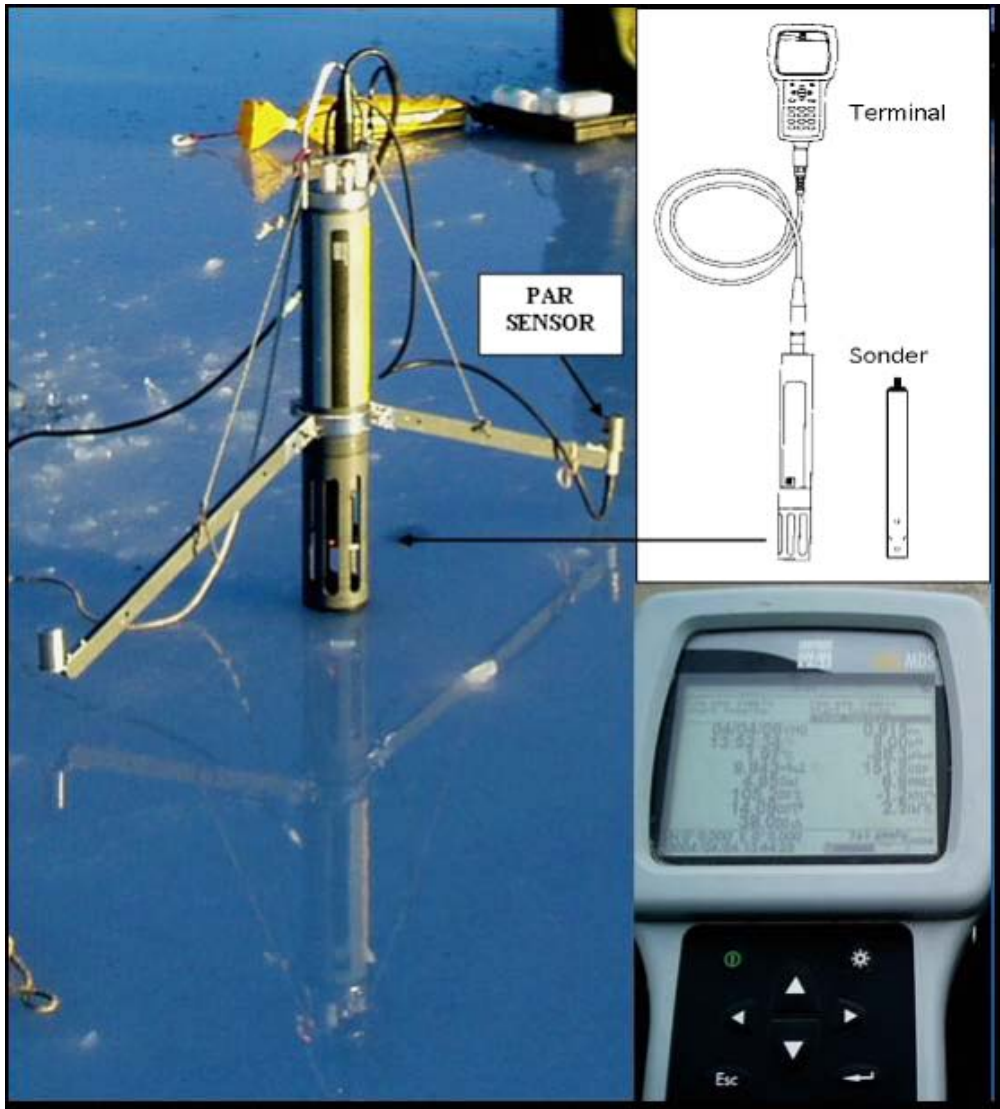


Figure 2-4. The measurement sonde equipped with a PAR sensor used in the field investigations of surface waters. The smaller sonde (YSI 600QS) in the schematic presentation is a backup. Also shown is a close up of the terminal during measurements.



Figure 2-5. Sampling in Lake PFM007443.

Table 2-3. Parameters measured by the two YSI sondes.

Parameter	YSI 6600 EDS	YSI 600 QS
Date/time	Yes	Yes
Temperature (°C)	Yes	Yes
pH	Yes	Yes
Dissolved oxygen (mg/L)	Yes	Yes
ORP (Redox potential, mV)	Yes	Yes
Electrical conductivity (mS/cm)	Yes	Yes
Salinity (ppt)	Yes	Yes
Depth (m)	Yes	Yes
Barometric pressure (mm Hg)	Yes	Yes
Turbidity (NTU)	Yes	No
Chlorophyll (µg/l)	Yes	No
Light / PAR* (µmoles s ⁻¹ m ⁻²)	Yes	No

* Photosynthetic Active Radiation.

2.2.3 General field equipment

- Ruttner samplers were used as backup if the portable pump system should fail.
- The exact locations of the sampling location positions were determined using a GPS (Garmin 172C) with an average accuracy of +/- 0.5–1.0 m.
- Disposable filters (Millipore, 0.40 µm, Ø = 22 mm) were used together with 60 mL syringes to filter specific sample portions of sample water in the field.

2.3 Performance

2.3.1 Presampling preparations

Prior to sampling, the sample bottles were cleaned (according to the routines for respective SKB-class sampling), labeled and packed in insulated boxes/bags. Acid additions were made in advance to bottles intended for trace metal analyses; these were placed in separate plastic bags to avoid contamination. The peristaltic pump system (PPS), including the Teflon tubes, was washed using acid (0.5 M HCl) and rinsed with deionised water before use. The equipment was kept well protected in plastic bags or in tight containers. Calibration of the sonde was performed according to the measurement system description SKB MD 910.003.

2.3.2 Water sampling

Water samples were collected using the peristaltic pump system (PPS). Lake water was sampled from 0.1–0.5 m depth depending on depth and vegetation in the lakes. The PPS and sample bottles were rinsed with water from the sampling locations prior to filling, except for bottles with acid additions. The disposable filters (Millipore) were rinsed with sample water before filtering and sampling commenced. To avoid contamination, the field crew wore rubber gloves and great care was taken not to contaminate bottles or equipment. Bottles and samples containing added acid were handled and stored separately to avoid contaminating other sample portions.

Each sample consisted of several sample portions labelled with the same sample number. The preparation of the sample portions in the field differed depending on their use. Details on collected sample portions, components to be analysed and sample preparations are summarised in Table 2-4.

Table 2-4. Sample volumes, components and preparation of samples.

Bottle volume (mL)	Number of bottles	SKB labels	Analyses	Comments	Preparation in field	Filling instructions
250	1	Green	pH, EC, Alkalinity, color determination			Fill up
250	1	Green, Anj.	Cl, SO ₄ , Br, F			Fill up
125	1	Red, HK	Major cations, SO ₄ _S, Si	Acid washed, added acid		Fill up
100	1	Green, Br				Fill up
100	1	Green, N/P	Tot-N, tot-P			Fill 80%
25	1	Green, T	TOC			Fill 80%
25	1	Green, D	DOC		Filtering with syringe/0.40 µm filter	Fill 80%
25	3	–	Nutrients: NH ₄ , NO ₂ , NO ₃ , PO ₄		Filtering with syringe/0.40 µm filter	Fill up
100–125 ^{a)}	2	Green	Dissolved oxygen (for O ₂ <4 mg/L)		Addition of 1 ml Mn(II)SO ₄ and 2 ml alkalic iodine solution	Fill up and overflow

a) Winkler samples were taken when sonde measurements of oxygen showed values below 4 mg/L.

2.3.3 Field measurements

The multi parameter sonde was used for measurements of pH, water temperature, atmospheric pressure, ORP, turbidity, electrical conductivity, salinity, dissolved oxygen and chlorophyll.

2.3.4 Sample treatment and chemical analyses

An overview of analytical methods, detection limits and measurement uncertainties is given in Appendix 1.

2.3.5 Data handling/post processing

Two field protocols (activity log and sampling protocol) contain metadata (id-code, date, time, sample no., field crew etc), a few measured data and weather observations as well as comments on field conditions which may influence the analytical results. The field protocols supply basic information for creating activities and activity comments in the SKB Sicada database. In addition, the few measured parameters and weather conditions, noted on the sampling protocol, are stored as data tables in Sicada.

Furthermore, eventual deviations from the sampling programme or from the normal routines are also documented in special reports/comment files. The comment files are stored in the Sicada file archive.

Chemical analytical data

The following routines for quality control and data management are generally applied to data from hydrogeochemical analysis, independent of sampling method or sampling object.

Several components are determined by more than one method and/or laboratory. Moreover, control analyses by an independent laboratory are performed as a standard procedure on each fifth or tenth collected sample.

All analytical results were stored in the Sicada database, including duplicates and results from more than one laboratory and/or method. The results are evaluated to produce a final reduced dataset with one value for each analysed constituent/parameter and each sample. Each selected value is labelled Y in a connected column in the Sicada data tables. The omitted values are retained in the tables but they are labelled N. The evaluation is based on:

- Comparison of the results from different laboratories and/or methods. The analyses are repeated if a large disparity is noted (generally more than 10%).

- Calculation of charge balance errors. Relative errors within $\pm 5\%$ are considered acceptable (in surface waters $\pm 10\%$).

$$\text{relative error}(\%) = 100 \times \frac{\sum \text{cation}(\text{equivalents}) - \sum \text{anions}(\text{equivalents})}{\sum \text{cation}(\text{equivalents}) + \sum \text{anion}(\text{equivalents})}$$

- General expert judgement of plausibility based on earlier results and experiences.

Field measurement data

The logged data from sonde measurements are exported digitally from the YSI Terminal 650–MDS to the specified Sicada data table. The original raw data file, calibration file and calibration protocol from each sonde, as well as photographs and comments on sampling and measurements, are stored in the Sicada file archive, see Table 2-5.

Other relevant information and data

Information about weather conditions and related parameters during the sampling occasions is compiled in a separate table in Sicada called “Weather_data” which contains the following columns:

Air temperature	Wind velocity	Runoff/Water flow
Cloudiness	Wind direction	Water depth
Precipitation	Light penetration (lakes and sea)	Snow/ice depth

These data are not presented in this report.

2.3.6 Nonconformities

Lake PFM007444 is situated in a bird protection area with restricted access and was not sampled during March and May. The backup sonde was used in August which meant that there are no field values for turbidity and chlorophyll from that occasion. Table 2-6 shows conducted and omitted sampling locations during the reported period. Table 2-7 presents observations and circumstances that may have had an effect on the field measurements and quality of the water samples.

Table 2-5. File types stored in the Sicada file archive.

Type of file	Example of file name	No. per sampling session
Raw data file	L580438.dat	1 or 2*
Comments	Noterat V38.doc	1
Calibration data file	000113CF.txt	1 or 2*
Calibration protocol	Stora sonden V38är04.xls	1 or 2*
Photography	PFM66.jpg	1–4

* Depending on the number of measuring sondes used.

Table 2-6. Collected samples and conducted measurements.

Lakes	Year Month Week	10	10	10	10	10	10
		Jan 3	Mar 11	Maj 21	Aug 32	Oct 41	Dec 49
PFM007441		x	x	x	x	x	x
PFM007442		x	x	x	x	x	x
PFM007443	Kungsträsket	x	x	x	x	x	x
PFM007444	Vambörsfjärden	x	o	o	x	x	x

Explanations and abbreviations:

X: Sample taken.

O: No sample due to restricted access in a bird protection area.

Table 2-7. Noted circumstances that may have an effect on the results.

Lakes	Year Month Week	10 Jan 3	10 Mar 11	10 Maj 21	10 Aug 32	10 Oct 41	10 Dec 49
PFM007441		Z	ZY		S		Z
PFM007442		Z	ZYQ		S		Z
PFM007443	Kungsträsket	Z	ZYQ		S		Z
PFM007444	Vambörsfjärden	Z			S		

Explanations to codes/abbreviations:

S: Backup sonde was used, no values for turbidity and chlorophyll.

Q: Risk for incorrect sonde values Turbidity and Chlorophyll, due to plants and/or particles in the water.

Z: Two Winkler samples collected as the oxygen concentration was below 4.0 mg/L.

Y: Two hydrogen sulfide samples collected as the oxygen concentration was below 4.0 mg/L.

3 Results

3.1 General

The investigation period from January to December 2010 includes water samples and field measurements from six sampling occasions. The data are compiled in the attached Appendices and stored in the Sicada database where they are traceable by the activity plan number. Furthermore, the accompanying field documentation is quite extensive. The same four lakes were previously sampled on seven occasions between November 2008 and December 2009 (Qvarfordt et al. 2010).

Previous investigations in Forsmark have shown that freshwaters in the area are generally well buffered with high alkalinity, high pH and high calcium concentrations (Nilsson et al. 2003, Nilsson and Borgiel 2004, 2005, 2007, 2008, Qvarfordt et al. 2008). In addition, waters affected or recently affected by brackish sea water still show high sodium chloride concentrations.

3.2 Water analyses

3.2.1 Major components

The basic water analyses include the major constituents Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Sr , S , SO_4^{2-} , Cl^- , Si and HCO_3^- , as well as the minor constituents Fe^{2+} , Li^+ , Mn^{2+} , Br^- and F^- . In all four lakes, Ca^{2+} and HCO_3^- were the most common cation and anion (Figures 3-1, 3-2, 3-3, 3-4). The large proportions of these two ions are explained by the limestone rich surroundings in the Forsmark area.

Sulphate by ion chromatography and sulphate calculated from total sulphur by ICP are compared in Figure 3-5. The comparison shows systematically somewhat higher values by ICP AES. The reason may be presence of other sulphur-containing species, but it may also be due to analytical error since the differences are almost within the measurement uncertainties.

The charge balance errors give an indication of the quality and uncertainty of the analyses of major constituents. None of the 22 samples/datasets show imbalances exceeding $\pm 10\%$ but in five cases the errors exceed $\pm 5\%$.

The basic water analysis data are compiled together with field and laboratory measurements of pH, EC and water temperature in Appendix 2, Table A2-2.

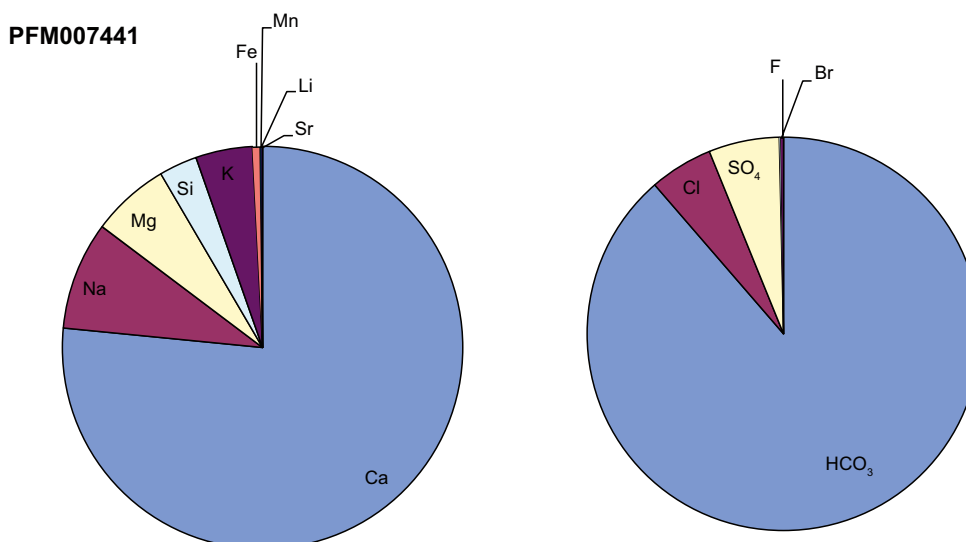


Figure 3-1. Relative proportions (mean value based on six sampling occasions) of the major constituents Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Sr , S , SO_4^{2-} , Cl^- , Si and HCO_3^- as well as the minor constituents Fe^{2+} , Li^+ , Mn^{2+} , Br^- and F^- in lake water from PFM007441.

PFM007442

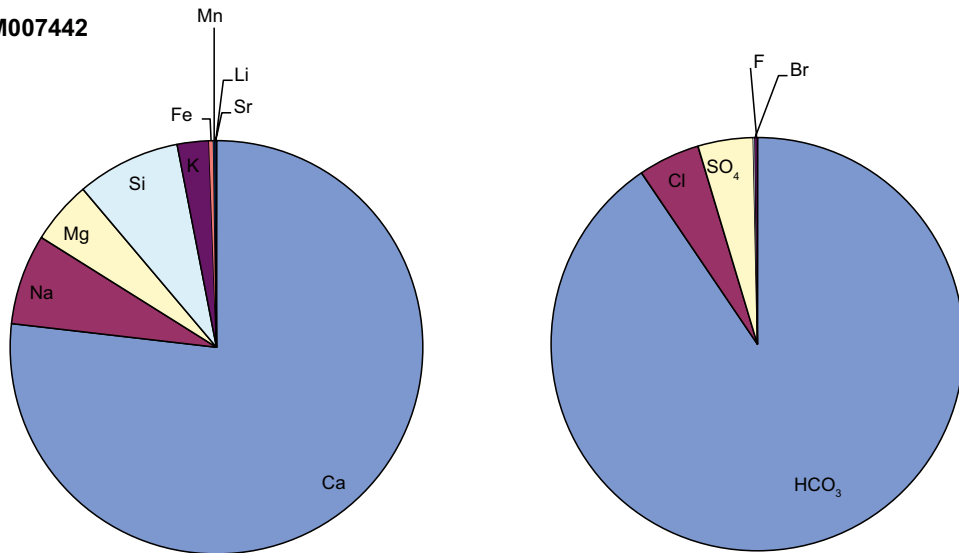


Figure 3-2. Relative proportions (mean value based on six sampling occasions) of the major constituents Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Sr , S , SO_4^{2-} , Cl^- , Si and HCO_3^- as well as the minor constituents Fe^{2+} , Li^+ , Mn^{2+} , Br^- and F^- in lake water from PFM007442.

PFM007443

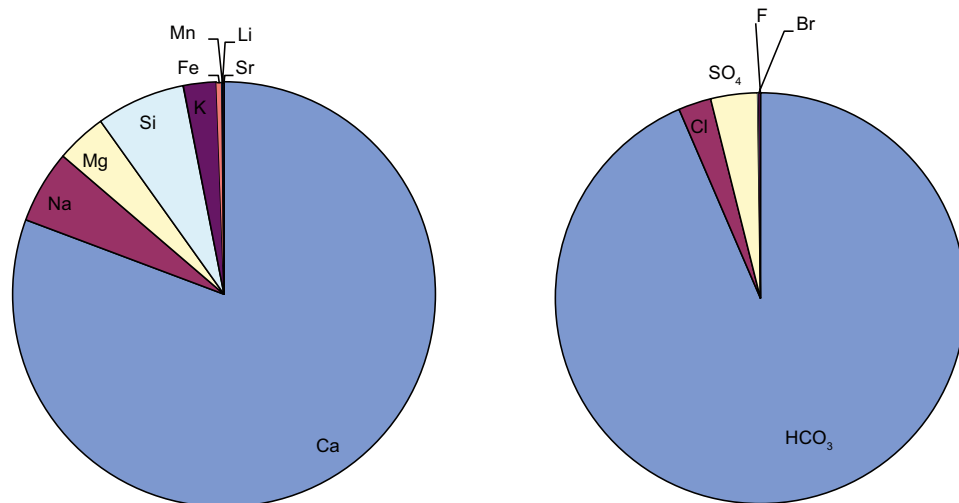


Figure 3-3. Relative proportions (mean value based on six sampling occasions) of the major constituents Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Sr , S , SO_4^{2-} , Cl^- , Si and HCO_3^- as well as the minor constituents Fe^{2+} , Li^+ , Mn^{2+} , Br^- and F^- in lake water from PFM007443.

PFM007444

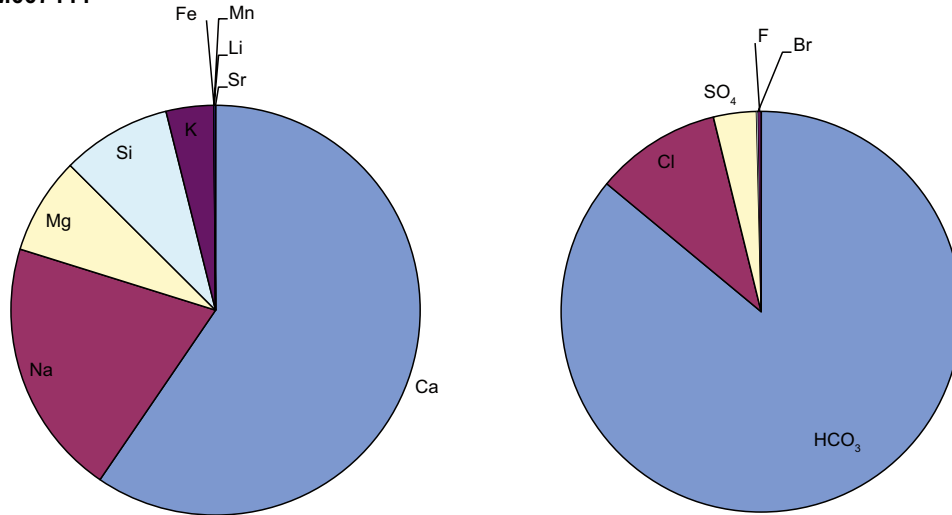


Figure 3-4. Relative proportions (mean value based on six sampling occasions) of the major constituents Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Sr , S , SO_4^{2-} , Cl^- , Si and HCO_3^- as well as the minor constituents Fe^{2+} , Li^+ , Mn^{2+} , Br^- and F^- in lake water from PFM007444.

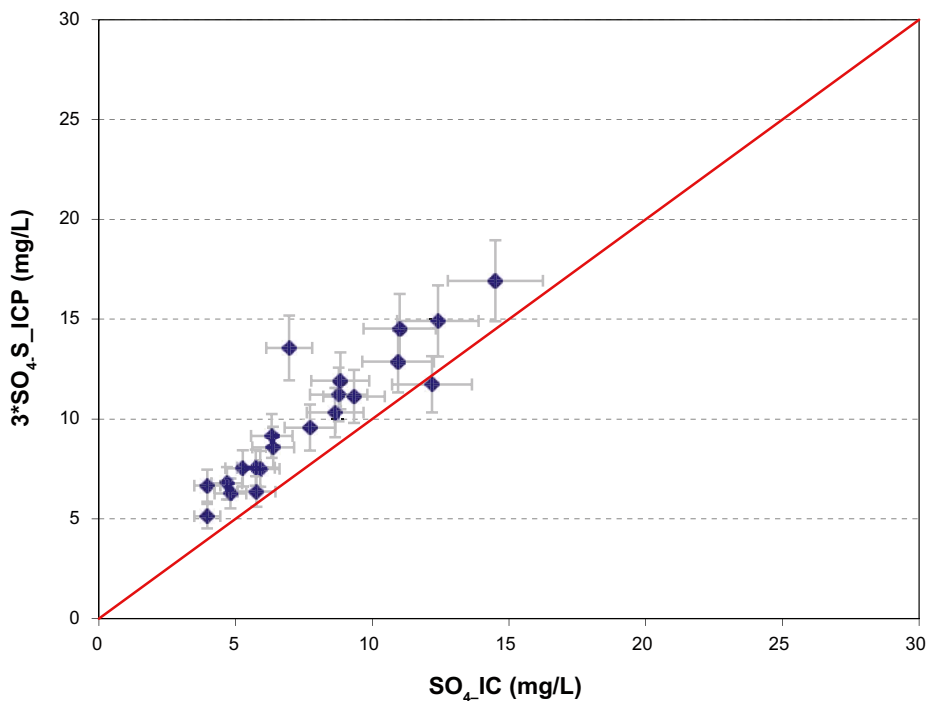


Figure 3-5. Sulphate (SO_4^- by IC) versus sulphate calculated from total sulphur ($3 \times \text{SO}_4^- \text{S}$) by ICP. The measurement uncertainty (Appendix 1) is shown as error bars. The data represent all six sampling occasions and all four lakes.

3.2.2 Surface water supplements

The surface water supplements included $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N} + \text{NO}_2\text{-N}$, tot-N, tot-P, $\text{PO}_4\text{-P}$, TOC, DOC and also dissolved oxygen. The analytical data are compiled in Appendix 2, Table A2-3.

The nutrients, nitrogen and phosphorus, are often the limiting factors for the primary production. Primary producers such as plants and phytoplankton use nitrogen and phosphorus in a ratio of about 16 mol nitrogen to 1 mol phosphorous (also known as the Redfield ratio) or 7:1 in terms of mass. A ratio deviating from 16 (or 7) indicates that the primary production is limited by either nitrogen or phosphorus.

When nitrogen is present in excess the ratio will be higher than 16, indicating that lack of phosphorus is limiting the growth, whereas lower ratios indicates nitrogen limitations, which may favour growth of blue green algae able to use nitrogen from the air. In fresh water, phosphorus is usually the limiting nutrient whereas in the oceans it is usually nitrogen.

Figure 3-6 shows the relationship between nitrogen and phosphorus in the surface water of the investigated lakes. As expected, all four lakes are phosphorus limited with high concentrations of nitrogen. During 2009 the highest concentration of nitrogen (>3,000 µg/L) was found in March in Lake PFM007441 whereas the highest concentration of phosphorus (>45 µg/L) was found in October in Lake PFM007443.

In 2010, high concentrations of nitrogen were observed in March in lakes PFM007441 and PFM007443 (>3,000 µg/L and >5,000 µg/L). The very high nitrogen concentration in Lake PFM007443 coincided with high concentration of phosphorus (27 µg/L). High concentrations of phosphorus were also found in Lake PFM00742 (22 µg/L) in March although the highest concentration (36 µg/L) was observed in Lake PFM007444 in January.

The nitrogen concentration was otherwise in the range 860–1,990 µg/L in the lakes. The lowest concentrations were generally noted in Lake PFM00742 and the highest in Lake PFM00741. The phosphorus concentration was generally in the range 6–14 µg/L. The lowest concentrations were generally observed in Lake PFM00742 and the highest in lakes PFM00741 and PFM00743.

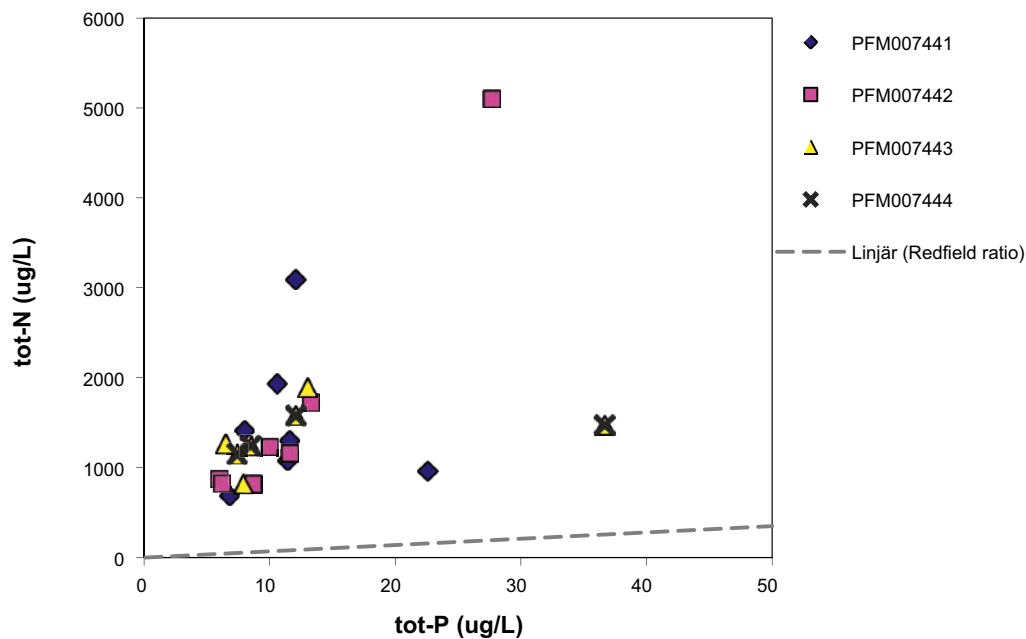


Figure 3-6. The relationship between nitrogen and phosphorus in the surface water of the four investigated lakes. The Redfield ratio (7:1) is indicated. Values above and below the line indicate phosphorus limitation and nitrogen limitation, respectively.



Figure 3-7. Winter sampling in Lake PFM007441.

3.3 Field measurements

The field measurement data included redox potential, pH, dissolved oxygen, electrical conductivity, salinity, measurement depth, atmospheric pressure, turbidity, chlorophyll and water temperature. Measured pH in the four lakes varied between 6.8 and 8.9. The highest value was measured in Lake PFM007441 in August and the lowest pH was observed in January in Lake PFM007442. Generally, Lake PFM007442 showed lower pH values compared to the other lakes. Figure 3-8 show the mean pH for the four lakes during the period January–December 2010.

If compared to the previous sampling period, Lake PFM007443 showed a similar high pH also in August 2009 and Lake PFM007442 showed the lowest pH in March 2009.

The electrical conductivity (EC) in the four lakes was between 17 and 67 mS/m (Figure 3-9). The highest value was observed in Lake PFM007443 and the lowest in Lake PFM007441 in contrast to the previous sampling period when PFM007441 showed the highest value and PFM007443 the lowest. The salinity in the lakes was low 0.08–0.32 (per mille). Figures 3-9 and 3-10 show the mean EC and salinity for the lakes during this reported sampling period.

Two sets of data are of lower quality; sonde measurements (YSI 6600 EDS) of chlorophyll and turbidity. The chlorophyll measurements have been problematic, possibly due to the fact that humus substances and chlorophyll have similar fluorescence in the wavelength used by the sonde. Since the inland waters show high concentrations of humic substances and the sonde interprets humus as chlorophyll, the amount of chlorophyll tends to be overestimated. The turbidity measurements performed in lakes often display negative values. This may be due to bad probe sensitivity in clear waters (turbidity weak waters). Comments on the lower quality of chlorophyll and turbidity data, as well as explanations to these circumstances, are stored in the Sicada database. The field measurement data are compiled in Appendix 2, Table A2-1.

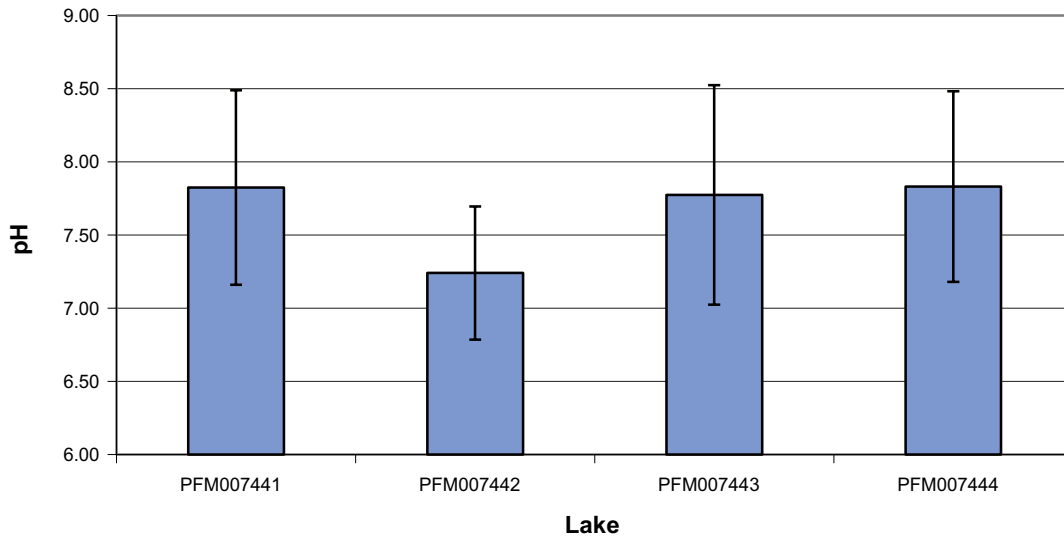


Figure 3-8. Measured pH (mean \pm stdev) in the four lakes.

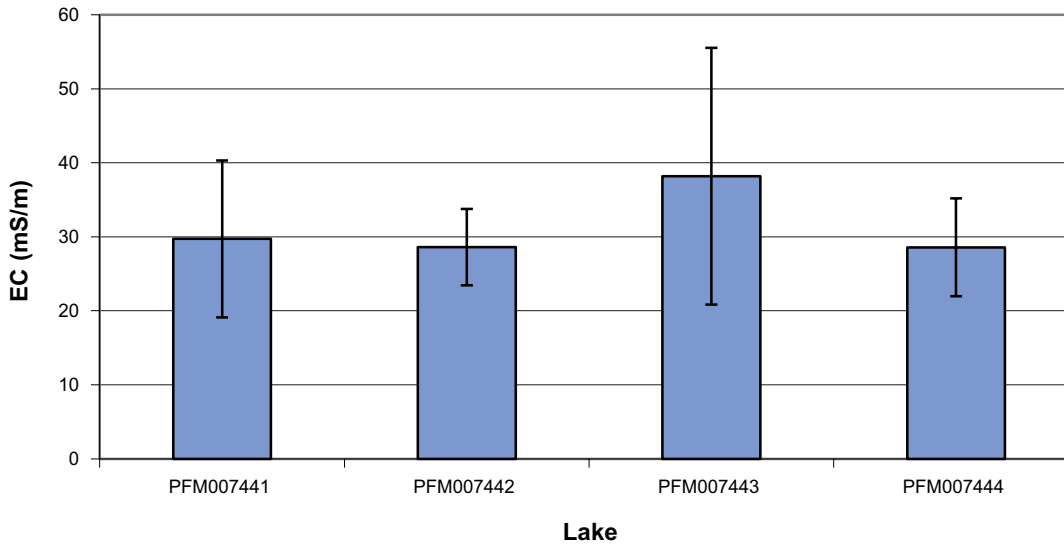


Figure 3-9. Measured electrical conductivity (EC) (mean \pm stdev) in the four lakes.

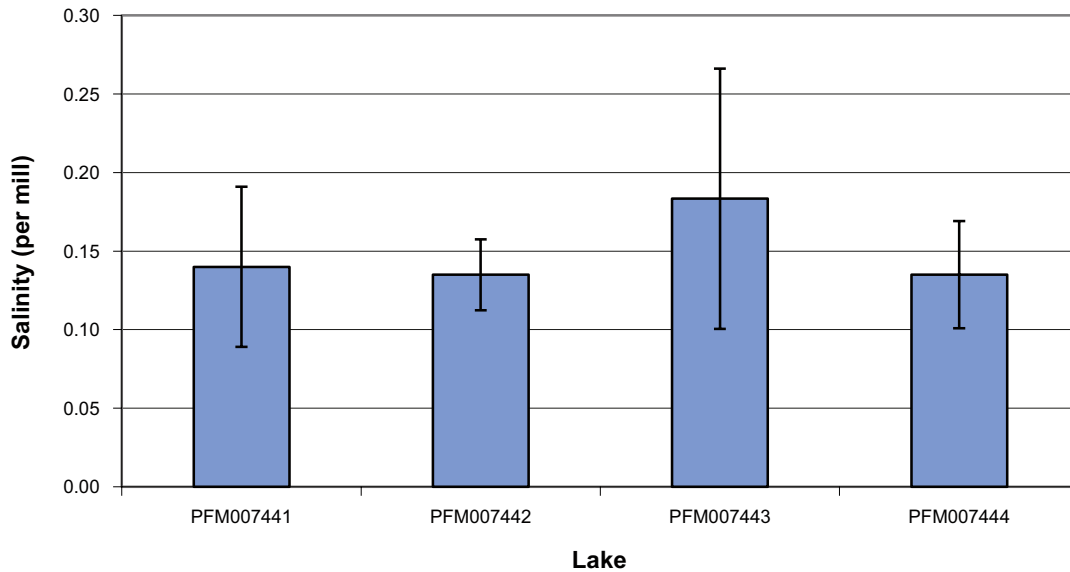


Figure 3-10. Salinity (mean ± stdev) in the four lakes.

3.4 Seasonal variation in water composition

The water composition at a given occasion is dependent on seasonal differences such as precipitation, ice-cover, temperature etc together with the size of the lake and drainage area, depth, primary production etc. This leads to both seasonal variations in the water composition and variations between water bodies.

Obvious seasonal effects are changes in water temperature with below or near zero temperatures during winter and up to ca 20°C in the summer (Figure 3-11). Many other parameters also change during the year. Both pH and dissolved oxygen roughly follow the temperature changes with lower values during winter when ice often covers the lakes causing winter stagnation in the water circulation (Figures 3-12, 3-13).

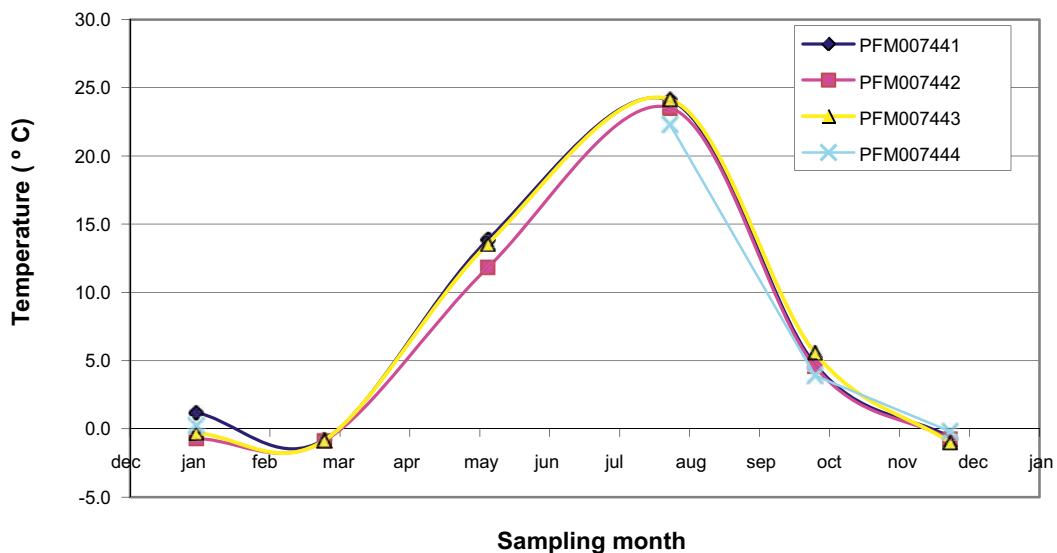


Figure 3-11. Seasonal variation of water temperature (°C) in the four lakes during 2010.

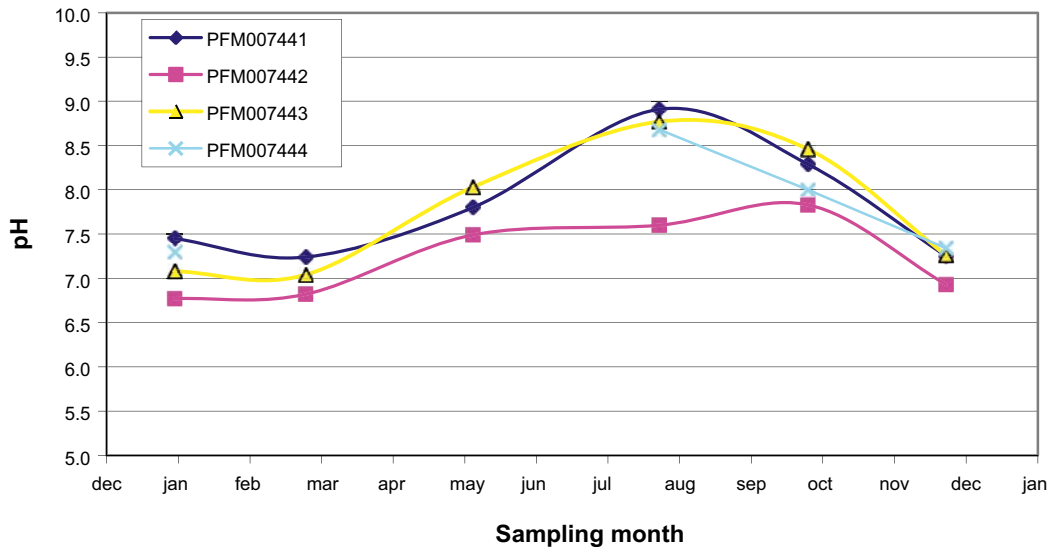


Figure 3-12. Seasonal variation of pH in the four lakes during 2010.

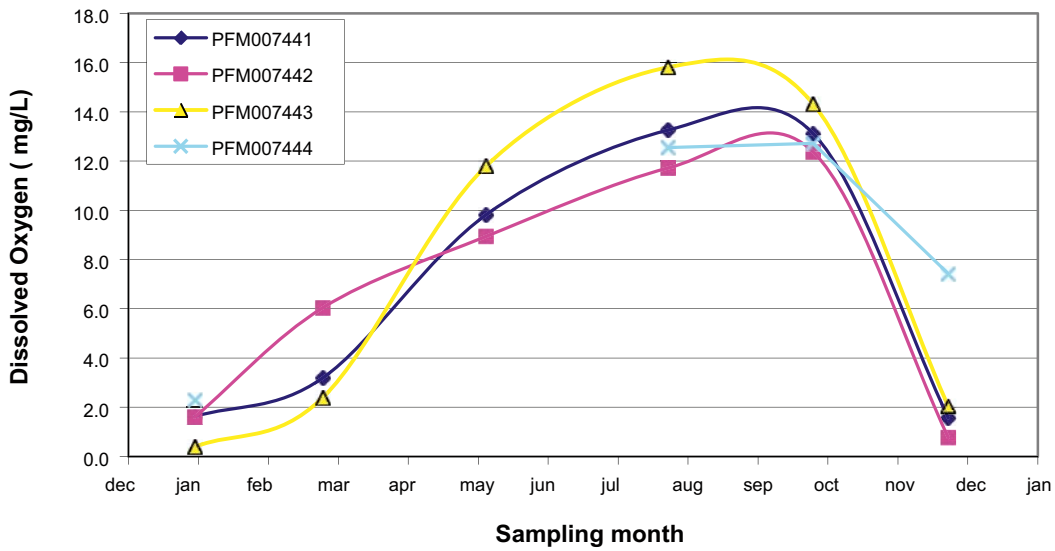


Figure 3-13. Seasonal variation of dissolved oxygen (mg/L) in the four lakes during 2010.

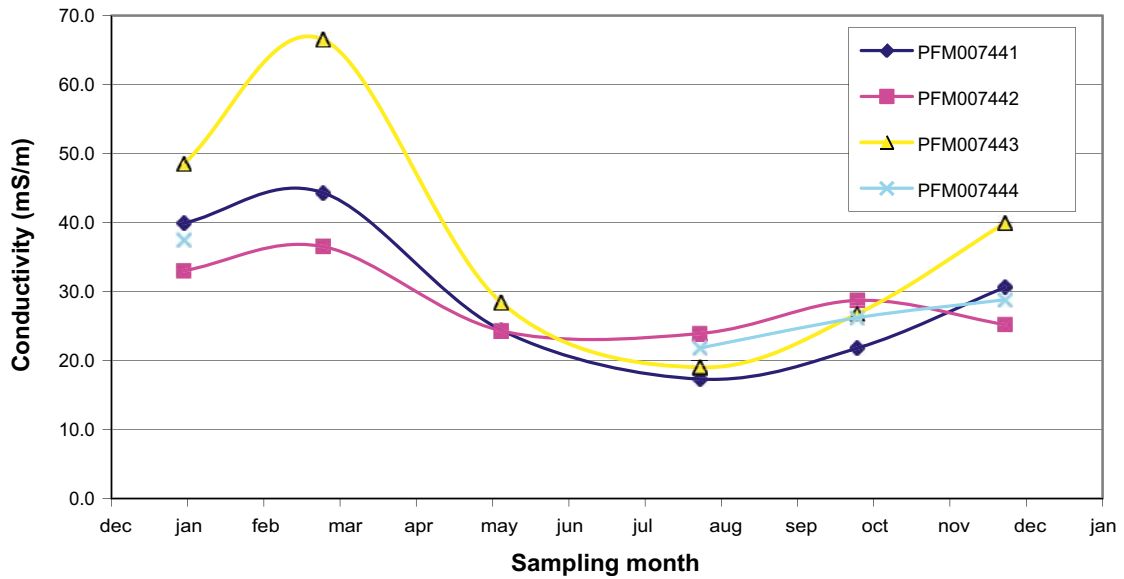


Figure 3-14. Seasonal variation of electrical conductivity (mS/m) in the four lakes during 2010.

The electrical conductivity (EC), which estimates the amount of total dissolved salts, or the total amount of dissolved ions in the water, was high during the winter period. The highest values were noted in March (Figure 3-14). This pattern is also seen in the seasonal variation of total organic carbon (TOC) (Figure 3-15), total nitrogen (Figure 3-16) and total phosphorus (Figure 3-17). The highest value of total phosphorus was however noted in Lake PFM0007444 in January (Figure 3-17).

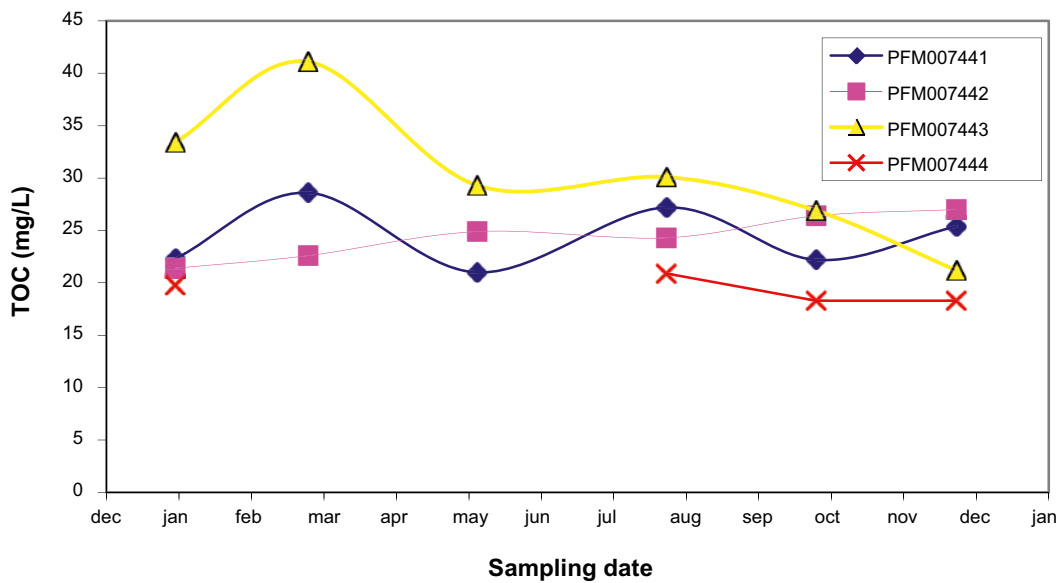


Figure 3-15. Seasonal variation of total organic carbon, TOC (mg/L) in the four lakes.

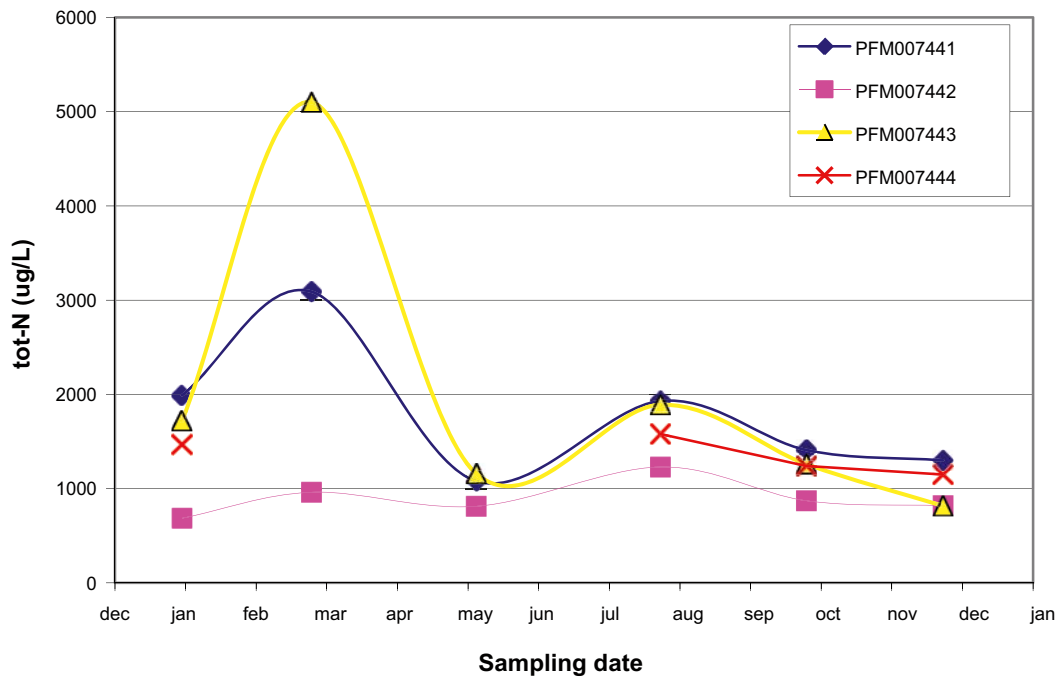


Figure 3-16. Seasonal variation of total nitrogen ($\mu\text{g/L}$) in the four lakes.

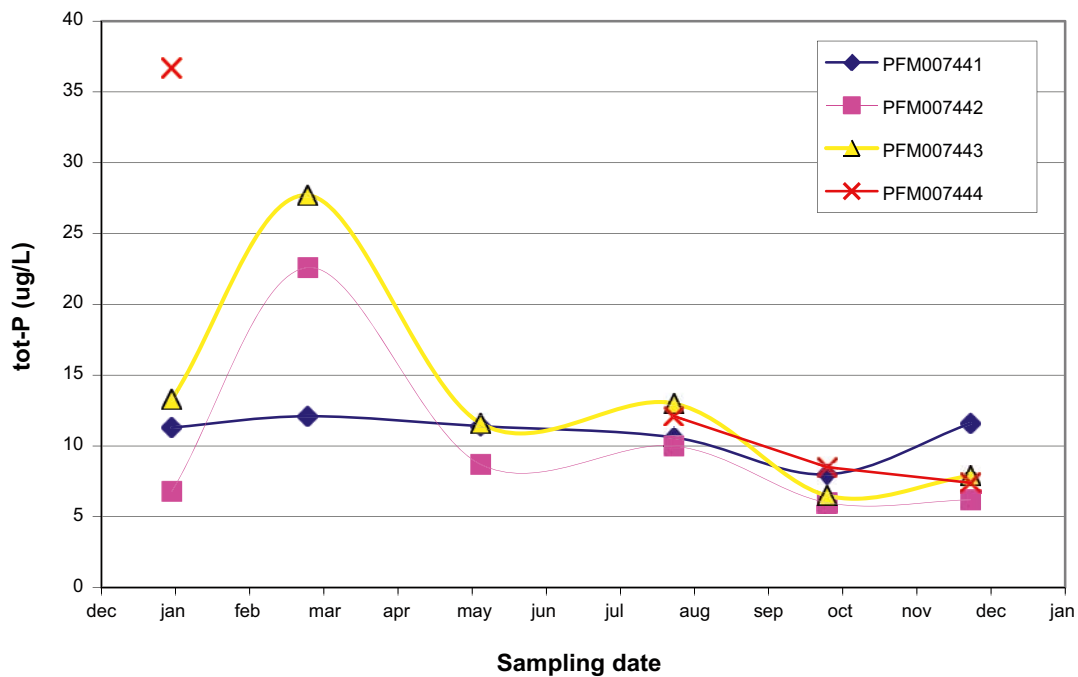


Figure 3-17. Seasonal variation in total phosphorus ($\mu\text{g/L}$) in the four lakes.

3.5 Annual and seasonal variation

In Appendix 3, Figures A3-1 to A3-16, the results are compared for some of the constituents/parameters from the two years of sampling (2009 and 2010). The comparisons show that both seasonal and annual variation can be large, but generally the seasonal pattern is similar between years. The presented constituents/parameters include temperature, pH, conductivity (EC), dissolved oxygen, total organic carbon (TOC) and dissolved organic carbon (DOC), as well as total nitrogen and total phosphorus.

4 Summary and discussion

The four investigated small lakes are well buffered with high alkalinity, high pH and high calcium concentrations. This is in accordance with results from the ongoing monitoring programme of lakes and streams in the area and with the results from the previous sampling period (2008–2009) (Qvarfordt et al. 2010).

The results show both seasonal and inter-annual variation in the analysed parameters. This can be explained by seasonal changes and annual differences in temperature, ice-cover, precipitation etc and lake specific parameters such as lake size and drainage area. The variation highlights the importance of both year round sampling and continuing sampling for several years.



Figure 4-1. Winter sampling in Lake PFM007441.

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

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Nilsson A-C, Borgiel M, 2008. Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, July 2006–June 2007. SKB P-08-17, Svensk Kärnbränslehantering AB.

Nilsson A-C, Karlsson S, Borgiel M, 2003. Forsmark site investigations. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, March 2002 to March 2003. SKB P-03-27, Svensk Kärnbränslehantering AB.

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Qvarfordt S, Borgiel M, Berg C, 2010. Monitoring Forsmark. Hydrochemical investigations in four calciferous lakes in the Forsmark area. Results from complementary investigations in the Forsmark area, 2008–2009. SKB P-10-25, Svensk Kärnbränslehantering AB.

Analytical methods, reporting limits and measurement uncertainties

Table A1-1. Analytical methods, reporting limits and measurement uncertainties.

Component	Method ¹	Reporting limits (RL), detection limits (DL) or range ²	Unit	Measurement uncertainty ³
pH	Potentiometric	3–10	pH unit	±0.1
EC	Electrical Conductivity meas.	1–150 150–10,000	mS/m	5% 3%
HCO ₃	Alkalinity titration	1	mg/L	4%
Cl ⁻	Mohr- titration	≥ 70	mg/L	5%
Cl ⁻	IC	0.5–70		8%
SO ₄	IC	0.5	mg/L	12%
Br ⁻	IC	DL 0.2, RL 0.5	mg/L	15%
Br	ICP SFMS	0.001, 0.004, 0.010 ⁴	mg/L	25% ⁵
F ⁻	IC	DL 0.2, RL 0.5	mg/L	13%
F ⁻	Potentiometric	DL 0.1, RL 0.2		12%
I ⁻	ICP SFMS	0.001, 0.004, 0.010 ⁴	mg/L	25% ⁵
Na	ICP AES	0.1	mg/L	13%
K	ICP AES	0.4	mg/L	12%
Ca	ICP AES	0.1	mg/L	12%
Mg	ICP AES	0.09	mg/L	12%
S(tot)	ICP AES	0.16	mg/L	12%
Si(tot)	ICP AES	0.03	mg/L	14%
Sr	ICP AES	0.002	mg/L	12%
Li	ICP AES	0.004	mg/L	12.2%
Fe	ICP AES	0.02	mg/L	13.3% ⁶
Fe	ICP SFMS	0.0004, 0.002, 0.004 ⁴	mg/L	20% ⁶
Mn	ICP AES	0.003	mg/L	12.1% ⁵
Mn	ICP SFMS	0.00003, 0.00004, 0.0001 ⁴	mg/L	53% ⁶
Fe(II), Fe(tot)	Spectrophotometry	DL 0.006, RL 0.02	mg/L	0.005 (0.02–0.05 mg/L) 9% (0.05–1 mg/L) 7% (1–3 mg/L)
HS ⁻	Spectrophotometry, SKB	SKB DL 0.006, RL 0.02	mg/L	25%
HS ⁻	Spectrophotometry, external laboratory	0.01	mg/L	0.02 (0.01–0.2 mg/L) 12% (>0.2 mg/L)
NO ₂ as N	Spectrophotometry	0.1	µg/L	2%
NO ₃ as N	Spectrophotometry	0.2	µg/L	5%
NO ₂ +NO ₃ as N	Spectrophotometry	0.2	µg/L	0.2 (0.2–20 µg/L) 2% (> 20 µg/L)
NH ₄ as N	Spectrophotometry, SKB	11	µg/L	30% (11–20 µg/L) 25% (20–50 µg/L) 12% (50–1,200 µg/L)
NH ₄ as N	Spectrophotometry, external laboratory	0.8	µg/L	0.8 (0.8–20 µg/L) 5% (> 20 µg/L)
PO ₄ as P	Spectrophotometry	0.7	µg/L	0.7 (0.7–20 µg/L) 3% (> 20 µg/L)
SiO ₄	Spectrophotometry	1	µg/L	2.5% (>100 µg/L)
O ₂	Iodometric titration	0.2–20	mg/L	5%
Chlorophyll a, c pheopigment ⁷	Spectrophotometry	0.5	µg/L	5%
PON ⁷	Elemental analysator	0.5	µg/L	5%
POP ⁷	Special laboratory method	0.1	µg/L	5%
POC ⁷	Elemental analysator	1	µg/L	4%
Tot-N ⁷	Spectrophotometry	10	µg/L	4%
Tot-P ⁷	Spectrophotometry	0.5	µg/L	6%
Al,	ICP SFMS	0.2, 0.3, 0.7 ⁴	µg/L	17.6% ⁶
Zn	ICP SFMS	0.2, 0.8, 2 ⁴	µg/L	15.5, 17.7, 25.5% ⁶
Ba, Cr, Mo,	ICP SFMS	0.01, 0.04, 0.1 ⁴	µg/L	Ba 15% ⁴ , Cr 22% ⁵ Mo 39% ⁶
Pb	ICP SFMS	0.01, 0.1, 0.3 ⁴	µg/L	15% ⁶

Component	Method ¹	Reporting limits (RL), detection limits (DL) or range ²	Unit	Measurement uncertainty ³
Cd	ICP SFMS	0.002, 0.02, 0.5 ⁴	µg/L	15.5% ⁶
Hg	ICP AFS	0.002	µg/L	10.7% ⁶
Co	ICP SFMS	0.005, 0.02, 0.05 ⁴	µg/L	25.9% ⁶
V	ICP SFMS	0.005, 0.03, 0.05 ⁴	µg/L	18.1% ⁶
Cu	ICP SFMS	0.1, 0.2, 0.5 ⁴	µg/L	14.4% ⁶
Ni	ICP SFMS	0.05, 0.2, 0.5 ⁴	µg/L	15.8% ⁶
P	ICP SFMS	1, 5, 40 ⁴	µg/L	16.3% ⁶
As	ICP SFMS	0.01 (520 mS/m)	µg/L	59.2% ⁶
La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu	ICP SFMS	0.005, 0.02, 0.05 ⁴	µg/L	20%, 20%, 25% ⁶
Sc, In, Th	ICP SFMS	0.05, 0.2, 0.5 ⁴	µg/L	25% ⁶
Rb, Zr, Sb, Cs	ICP SFMS	0.025, 0.1, 0.25 ⁴	µg/L	15%, 20%, 20% ⁵ 25% ⁶
Tl	ICP SFMS	0.025, 0.1, 0.25 ⁴	µg/L	14.3% ^{5 and 6}
Y, Hf	ICP SFMS	0.005, 0.02, 0.05 ⁴	µg/L	15%, 20%, 20% ⁵ 25% ⁶
U	ICP SFMS	0.001, 0.005, 0.01 ⁴	µg/L	13.5%, 14.3%, 15.9% ⁵ 19.1%, 17.9%, 20.9% ⁶
DOC	UV oxidation, IR Carbon analyser	0.5	mg/L	8%
TOC	UV oxidation, IR Carbon analyser	0.5	mg/L	10%
δ ² H	MS	2	‰ SMOW ⁷	0.9 (one standard deviation)
δ ¹⁸ O	MS	0.1	‰ SMOW ⁷	0.1 (one standard dev.)
³ H	LSC	0.8	TU ⁸	0.8
δ ³⁷ Cl	A (MS)	0.2	‰ SMOC ¹⁰	0.2 ¹⁷
δ ¹³ C	A (MS)	–	‰ PDB ¹¹	0.3 ¹⁷
¹⁴ C pmc	A (MS)	–	PMC ¹²	0.4 ¹⁷
δ ³⁴ S	MS	0.2	‰ CDT ¹³	0.4 (one standard dev.)
⁸⁷ Sr/ ⁸⁶ Sr	TIMS	–	No unit (ratio) ¹⁴	0.00002
¹⁰ B/ ¹¹ B	ICP SFMS	–	No unit (ratio) ¹⁴	–
²³⁴ U, ²³⁵ U, ²³⁸ U, ²³² Th, ³⁰ Th	Alfa spectr.	0.0001	Bq/L ¹⁵	≤5% (Counting statistics uncertainty)
²²² Rn, ²²⁶ Ra	LSS	0.015	Bq/L	≤5% (Count. stat. uncert.)

- Many elements may be determined by more than one ICP technique depending on concentration range. The most relevant technique and measurement uncertainty for the concentrations normally encountered in groundwater are presented. In cases where two techniques were frequently used, both are displayed.
- Reporting limits (RL), generally 10×standard deviation, if nothing else is stated. Measured values below RL or DL are stored as negative values in SICADA (i.e. – RL value and – DL value).
- Measurement uncertainty reported by the laboratory, generally as ± percent of measured value in question at 95% confidence interval.
- Reporting limits at electrical cond. 520 mS/m, 1,440 mS/m and 3,810 mS/m respectively.
- Measurement uncertainty at concentrations 100×RL.
- Measurement uncertainty at concentrations 10×RL.
- Determined only in surface waters. PON, POP and POC refers to Particulate Organic Nitrogen, Phosphorous and Carbon, respectively.
- Per mille deviation¹⁶ from SMOW (Standard Mean Oceanic Water).
- TU=Tritium Units, where one TU corresponds to a tritium/hydrogen ratio of 10⁻¹⁸ (1 Bq/L Tritium = 8.45 TU).
- Per mille deviation¹⁶ from SMOC (Standard Mean Oceanic Chloride).
- Per mille deviation¹⁶ from PDB (the standard PeeDee Belemnite).
- The following relation is valid between pmC (percent modern carbon) and Carbon-14 age: pmC = 100 × e^{(-1950-y-1.031)(8274)} where y = the year of the C-14 measurement and t = C-14 age.
- Per mille deviation¹⁶ from CDT (the standard Canyon Diablo Troilite).
- Isotope ratio without unit.
- The following expressions are applicable to convert activity to concentration, for uranium-238 and thorium-232: 1 ppm U = 12.4 Bq/kg²³⁸U, 1 ppm Th = 3.93 Bq/kg²³²Th.
- Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as: δ‰ = 1,000 × (K_{sample} – K_{standard}) / K_{standard}, where K = the isotope ratio and ‰ = ²H, ¹⁸O, ³⁷Cl, ¹³C or ³⁴S etc.
- SKB estimation from duplicate analyses by the contracted laboratory.

Field measurements and analytical data

Table A2-1. Field measurements

Idcode	Start date yyyy/mm/dd hh:mm	Stop date yyyy/mm/dd hh:mm	Measured depth (m)	Water depth (m)	Sno	Temp. (° C)	pH	EC* (mS/m)	Salinity (per mill)	Turb* (NTU)	O2 diss. (mg/l)	O2 (%)	Chlorophyll (ug/l)	ORP (mV)	Atm. Pressure (hPa)
PFM007441	2010-01-20 10:30	2010-01-20 18:00	0.38	0.40	16633	1.19	7.45	39.9	0.19	-0.6	1.62	11.5	4.5	-87	1,034.9
PFM007441	2010-03-16 08:00	2010-03-16 14:30	0.35	0.40	16664	-0.79	7.24	44.3	0.21	0.3	3.19	21.4	3.7	75	1,008.3
PFM007441	2010-05-25 10:00	2010-05-25 15:00	0.26	0.35	16724	13.86	7.80	24.4	0.12	-1.3	9.82	95.0	3.8	182	996.7
PFM007441	2010-08-11 13:00	2010-08-11 19:00	0.10	0.30	16785	24.08	8.91	17.3	0.08	a	13.26	157.8		85	1,016.5
PFM007441	2010-10-12 16:00	2010-10-12 19:30	0.21	0.4	16825	4.76	8.29	21.8	0.10	-1.2	13.12	102.2	4.3	-127	1,016.0
PFM007441	2010-12-09 15:00	2010-12-09 19:30	0.30	0.4	16930	-0.61	7.25	30.6	0.14	-1.9	1.57	10.6	7.2	45	1,000.3
PFM007442	2010-01-20 10:30	2010-01-20 18:00	0.22	0.25	16634	-0.71	6.77	33.0	0.15	-0.7	1.60	10.7	9.7	-96	1,034.7
PFM007442	2010-03-16 08:00	2010-03-16 14:30	0.28	0.30	16665	-0.89	6.82	36.5	0.17	4.0	6.04	40.3	27.6	73	1,009.8
PFM007442	2010-05-25 10:00	2010-05-25 15:00	0.26	0.35	16725	11.82	7.49	24.3	0.12	-1.5	8.94	82.7	10.3	181	997.1
PFM007442	2010-08-11 13:00	2010-08-11 19:00	0.10	0.20	16786	23.53	7.60	23.9	0.11	a	11.72	138.0		128	1,016.3
PFM007442	2010-10-12 16:00	2010-10-12 19:30	0.21	0.3	16827	4.57	7.83	28.7	0.14	-1.7	12.37	95.8	9.3	-108	1,015.8
PFM007442	2010-12-09 15:00	2010-12-09 19:30	0.23	0.3	16931	-0.76	6.93	25.2	0.12	-2.1	0.77	5.1	12.0	-48	1,000.8
PFM007443	2010-01-20 10:30	2010-01-20 18:00	0.17	0.20	16636	-0.32	7.08	48.5	0.23	0.0	0.39	2.6	21.0	-109	1,034.5
PFM007443	2010-03-16 08:00	2010-03-16 14:30	0.26	0.30	16663	-0.84	7.04	66.5	0.32	1.9	2.39	16.0	13.9	32	1,007.5
PFM007443	2010-05-25 10:00	2010-05-25 15:00	0.21	0.30	16723	13.56	8.03	28.4	0.14	-1.1	11.80	113.5	8.1	180	996.2
PFM007443	2010-08-11 13:00	2010-08-11 19:00	0.10	0.15	16784	24.15	8.77	19.0	0.09	a	15.81	188.4		90	1,016.1
PFM007443	2010-10-12 16:00	2010-10-12 19:30	0.21	0.3	16826	5.59	8.46	26.8	0.13	-1.1	14.32	113.9	6.5	-111	1,015.9
PFM007443	2010-12-09 15:00	2010-12-09 19:30	0.23	0.3	16929	-0.99	7.26	39.9	0.19	-0.7	2.04	13.6	11.9	-43	999.0
PFM007444	2010-01-20 10:30	2010-01-20 18:00	0.38	0.50	16635	0.25	7.30	37.5	0.18	-1.3	2.29	15.8	3.3	-87	1,034.5
PFM007444	2010-08-11 13:00	2010-08-11 19:00	0.10	0.30	16783	22.31	8.68	21.8	0.10	a	12.55	144.5		88	1,016.2
PFM007444	2010-10-13 08:00	2010-10-13 12:00	0.22	0.3	16828	3.91	8.00	26.2	0.12	-1.2	12.72	96.9	3.5	-142	1,013.3
PFM007444	2010-12-10 08:00	2010-12-10 11:30	0.28	0.5	16932	-0.19	7.34	28.8	0.14	-1.8	7.42	50.5	2.8	86	1,002.6

Sno = Corresponding water sample no
EC = Electrical conductivity

NTU = Nephelometric Turbidity Unit
ORP = Oxidising Reducing Potential

* Measurements with low reliability.
a = Measurements were made with the backup sonde YSI 600QS.

Table A2-2. Compilation of hydrochemical data from water analyses.

Idcode	Sample (no.)	Depth (m)	Sampling date (yyyy-mm-dd)	RCB (%)	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	HCO ₃ ⁻ (mg/L)	Cl ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	SO ₄ ^{-S} (mg/L)	Br (mg/L)	F ⁻ (mg/L)	Si (mg/L)	Fe (mg/L)
PFM007441	16633	0.4	2010-01-20	0.6	6.8	3.2	57.4	4.3	186	9.0	8.8	3.7	-0.20	0.34	1.52	0.53
PFM007441	16664	0.4	2010-03-16	-2.2	3.2	4.2	73.4	5.7	242	12.7	9.3	3.7	-0.20	0.36	3.95	1.35
PFM007441	16724	0.3	2010-05-25	2.3	5.4	1.9	41.5	3.3	122	6.8	11.0	4.8	-0.20	0.33	0.63	0.10
PFM007441	16785	0.1	2010-08-11	5.7	6.2	2.0	26.3	3.2	74	7.5	8.8	4.0	-0.20	0.41	3.40	0.08
PFM007441	16825	0.2	2010-10-12	4.1	5.5	2.5	34.7	3.1	103	6.6	8.6	3.4	-0.20	0.35	0.25	0.04
PFM007441	16930	0.3	2010-12-09	4	5.4	3.2	51.8	3.9	149	8.7	10.9	4.3	-0.20	0.37	1.68	0.19
PFM007442	16634	0.2	2010-01-20	2.6	5.1	1.3	44.9	3.0	124	7.3	14.5	5.6	-0.20	0.27	4.94	0.18
PFM007442	16665	0.3	2010-03-16	3.9	5.9	1.3	58.3	3.8	171	8.5	7.7	3.2	-0.20	0.28	7.08	0.56
PFM007442	16725	0.3	2010-05-25	3.5	3.5	1.5	45.2	2.7	131	7.5	3.3	1.9	-0.20	0.30	3.55	0.10
PFM007442	16786	0.1	2010-08-11	5.3	3.8	1.5	43.9	2.9	119	7.8	6.4	2.9	-0.20	0.36	5.82	0.09
PFM007442	16827	0.2	2010-10-12	5.3	4.5	2.2	54.4	3.2	156	8.0	4.0	1.7	-0.20	0.34	4.64	0.08
PFM007442	16931	0.2	2010-12-09	2.7	4.3	1.7	47.8	3.2	147	6.2	4.7	2.3	-0.20	0.26	5.09	0.32
PFM007443	16636	0.2	2010-01-20	1.6	4.7	2.0	67.8	3.4	202	6.0	12.4	5.0	-0.20	0.22	7.50	1.36
PFM007443	16663	0.3	2010-03-16	4.7	7.0	3.5	151.0	5.3	432	8.7	7.0	4.5	-0.20	0.21	13.90	0.42
PFM007443	16723	0.2	2010-05-25	4.4	4.1	1.6	56.3	2.8	163	3.8	6.3	3.1	-0.20	0.33	4.34	0.09
PFM007443	16784	0.1	2010-08-11	6.7	4.7	1.7	34.1	2.7	99	4.4	4.0	2.2	-0.20	0.39	4.13	0.03
PFM007443	16826	0.2	2010-10-12	5.4	4.3	2.6	52.3	2.9	151	4.6	5.9	2.5	-0.20	0.34	1.38	0.03
PFM007443	16929	0.2	2010-12-09	1.6	4.2	1.6	57.3	3.0	170	6.1	12.2	3.9	-0.20	0.32	3.93	0.16
PFM007444	16635	0.4	2010-01-20	1.7	13.8	2.9	51.3	5.4	178	16.3	5.7	2.5	-0.20	0.36	4.71	0.05
PFM007444	16783	0.1	2010-08-11	3.2	13.1	2.1	25.2	4.6	91	15.8	5.3	2.5	-0.20	0.39	7.71	-0.02
PFM007444	16828	0.2	2010-10-13	3.7	13.2	2.2	35.5	4.8	123	15.2	4.8	2.1	-0.20	0.36	5.13	-0.02
PFM007444	16932	0.3	2010-12-10	-1.5	11.0	2.3	38.1	4.6	141	15.5	5.8	2.1	-0.20	0.37	4.25	0.03

RCB = Relative Charge Balance error.

pH_L = lab. pH.

pH_F = field pH.

Temp_F = water temperature in the field.

EC_L= Electrical Conductivity measured in lab.

EC_F= Electrical Conductivity measured in field.

Table A2-2. Compilation of hydrochemical data from water analyses.

Mn (mg/L)	Idcode	Sample (no.)	Depth (m)	Sampling date (yyyy-mm-dd)	Li (mg/L)	Sr (mg/L)	pH_L	pH_F	Temp_F (° C)	EC_L (mS/m)	EC_F (mS/m)
0.12	PFM007441	16633	0.4	2010-01-20	0.0042	0.072	7.36	7.45	1.2	34.7	39.9
0.12	PFM007441	16664	0.4	2010-03-16	-0.0040	0.089	7.25	7.24	-0.8	44.4	44.3
0.01	PFM007441	16724	0.3	2010-05-25	-0.0040	0.057	7.74	7.80	13.9	25.3	24.4
0.00	PFM007441	16785	0.1	2010-08-11	-0.0040	0.049	8.86	8.91	24.1	18.9	17.3
0.00	PFM007441	16825	0.2	2010-10-12	-0.0040	0.050	8.02	8.29	4.8	21.1	21.8
0.09	PFM007441	16930	0.3	2010-12-09	-0.0040	0.061	7.06	7.25	-0.6	29.2	30.6
0.05	PFM007442	16634	0.2	2010-01-20	-0.0040	0.056	6.73	6.77	-0.7	25.9	33.0
0.24	PFM007442	16665	0.3	2010-03-16	-0.0040	0.073	6.83	6.82	-0.9	31.9	36.5
0.01	PFM007442	16725	0.3	2010-05-25	-0.0040	0.059	7.36	7.49	11.8	24.6	24.3
0.01	PFM007442	16786	0.1	2010-08-11	-0.0040	0.065	7.87	7.60	23.5	23.8	23.9
0.01	PFM007442	16827	0.2	2010-10-12	-0.0040	0.070	7.46	7.83	4.6	28.9	28.7
0.17	PFM007442	16931	0.2	2010-12-09	-0.0040	0.056	6.94	6.93	-0.8	27.4	25.2
0.22	PFM007443	16636	0.2	2010-01-20	-0.0040	0.071	6.83	7.08	-0.3	37.3	48.5
0.18	PFM007443	16663	0.3	2010-03-16	-0.0040	0.133	7.23	7.04	-0.8	69.7	66.5
0.00	PFM007443	16723	0.2	2010-05-25	-0.0040	0.061	7.97	8.03	13.6	28.9	28.4
0.00	PFM007443	16784	0.1	2010-08-11	-0.0040	0.053	9.10	8.77	24.2	17.3	19.0
0.00	PFM007443	16826	0.2	2010-10-12	-0.0040	0.061	8.16	8.46	5.6	26.9	26.8
0.04	PFM007443	16929	0.2	2010-12-09	-0.0040	0.055	7.01	7.26	-1.0	31.9	39.9
0.02	PFM007444	16635	0.4	2010-01-20	-0.0040	0.086	7.31	7.30	0.3	35.2	37.5
0.00	PFM007444	16783	0.1	2010-08-11	-0.0040	0.065	8.69	8.68	22.3	21.9	21.8
0.00	PFM007444	16828	0.2	2010-10-13	-0.0040	0.072	7.84	8.00	3.9	26.2	26.2
0.02	PFM007444	16932	0.3	2010-12-10	-0.0040	0.067	7.11	7.34	-0.2	28.6	28.8

RCB = Relative Charge Balance error.

pH_L = lab. pH.

pH_F = field pH.

Temp_F = water temperature in the field.

EC_L= Electrical Conductivity measured in lab.

EC_F= Electrical Conductivity measured in field.

Table A2-3. Surface water supplements.

Idcode	Sample (no.)	Sampling date (yyyy-mm-dd)	Depth (m)	NH ₄ _N (mg/L)	NO ₂ _N (mg/L)	NO ₃ _N+NO ₂ _N (mg/L)	N TOT (mg/L)	P TOT (mg/L)	PO ₄ _P (mg/L)	TOC (mg/L)	DOC (mg/L)	Abs. coeff. (1/m)
PFM007441	16633	2010-01-20	0.4	0.7860	0.0013	0.0548	1.9900	0.0113	-0.0005	22.30	21.80	2.07
PFM007441	16664	2010-03-16	0.4	1.5900	0.0036	0.1010	3.0900	0.0121	0.0007	28.60	26.90	4.51
PFM007441	16724	2010-05-25	0.3	0.0244	0.0003	0.0024	1.0800	0.0114	0.0014	21.00	21.20	2.64
PFM007441	16785	2010-08-11	0.1	0.0040	-0.0002	0.0013	1.9300	0.0106	-0.0005	27.20	26.60	
PFM007441	16825	2010-10-12	0.2	0.0085	-0.0002	0.0014	1.4100	0.0080	-0.0005	22.20	21.20	1.42
PFM007441	16930	2010-12-09	0.3	0.0923	0.0005	0.0227	1.3000	0.0116	-0.0005	25.40	25.40	3.99
PFM007442	16634	2010-01-20	0.2	0.0209	0.0003	0.0055	0.6860	0.0068	-0.0005	21.40	20.90	2.89
PFM007442	16665	2010-03-16	0.3	0.1930	0.0007	0.0250	0.9620	0.0226	0.0006	22.60	21.80	5.97
PFM007442	16725	2010-05-25	0.3	0.0057	0.0003	0.0003	0.8130	0.0087	0.0006	24.90	24.50	4.46
PFM007442	16786	2010-08-11	0.1	0.0330	-0.0002	0.0016	1.2300	0.0100	-0.0005	24.30	21.10	
PFM007442	16827	2010-10-12	0.2	0.0065	0.0003	0.0014	0.8720	0.0060	-0.0005	26.40	25.80	4.00
PFM007442	16931	2010-12-09	0.2	0.0128	-0.0002	0.0276	0.8200	0.0062	-0.0005	27.00	26.70	5.18
PFM007443	16636	2010-01-20	0.2	0.6310	0.0013	0.0040	1.7200	0.0133	-0.0005	33.40	32.30	4.72
PFM007443	16663	2010-03-16	0.3	3.3700	0.0036	0.0789	5.1000	0.0277	0.0018	41.10	41.20	3.94
PFM007443	16723	2010-05-25	0.2	0.0090	0.0002	0.0014	1.1600	0.0116	0.0016	29.30	28.40	4.38
PFM007443	16784	2010-08-11	0.1	0.0065	-0.0002	0.0017	1.8900	0.0130	-0.0005	30.10	30.00	
PFM007443	16826	2010-10-12	0.2	0.0160	0.0002	0.0013	1.2600	0.0065	-0.0005	26.90	26.60	2.66
PFM007443	16929	2010-12-09	0.2	0.0602	0.0003	0.0297	0.8170	0.0079	-0.0005	21.20	20.40	3.82
PFM007444	16635	2010-01-20	0.4	0.3440	0.0009	0.0281	1.4700	0.0367	-0.0005	19.80	19.50	1.39
PFM007444	16783	2010-08-11	0.1	0.0139	-0.0002	0.0011	1.5800	0.0121	-0.0005	20.90	19.80	
PFM007444	16828	2010-10-13	0.2	0.0202	-0.0002	0.0023	1.2400	0.0085	-0.0005	18.30	18.20	1.06
PFM007444	16932	2010-12-10	0.3	0.0704	0.0004	0.0239	1.1500	0.0074	-0.0005	18.30	17.50	2.16

Comparison of seasonal patterns from 2009 and 2010 (temperature, pH, conductivity (EC), dissolved oxygen, total organic carbon (TOC), dissolved organic carbon (DOC), total nitrogen and total phosphorus)

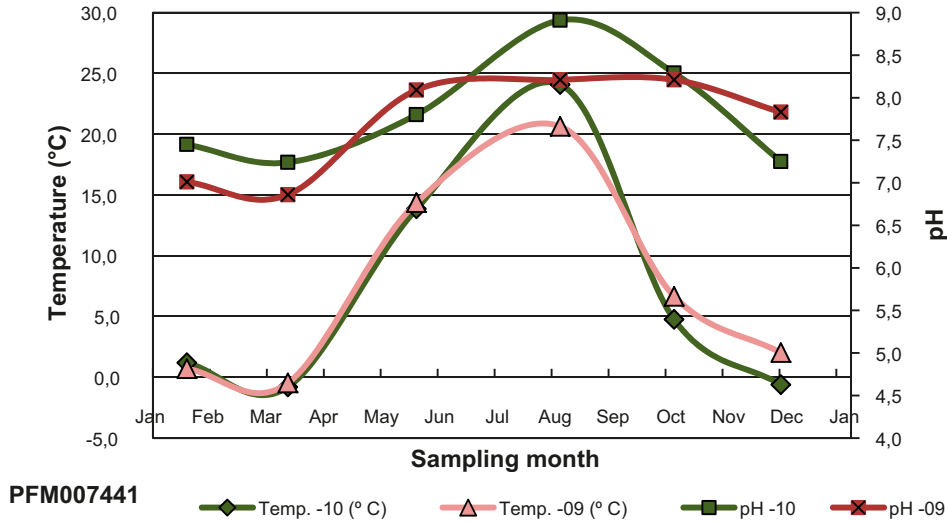


Figure A3-1. Annual and seasonal variation in temperature and pH in Lake PFM007441 during 2009 and 2010.

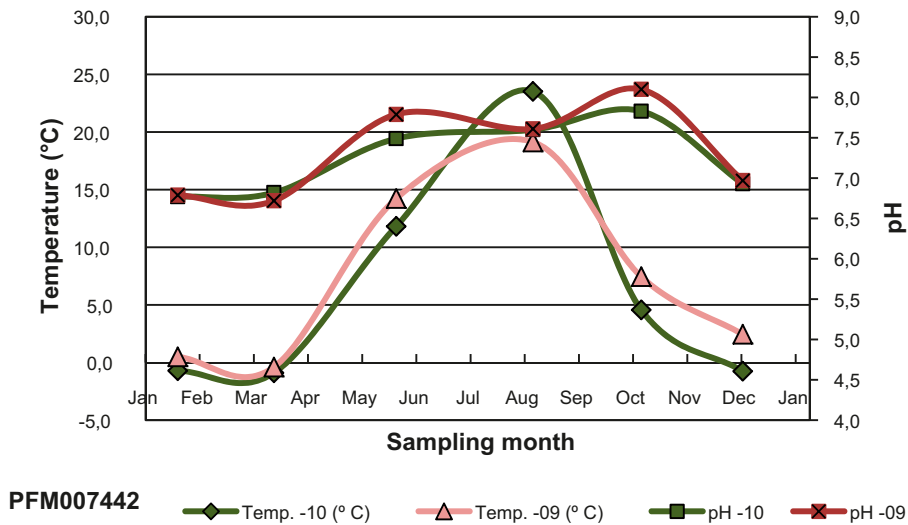
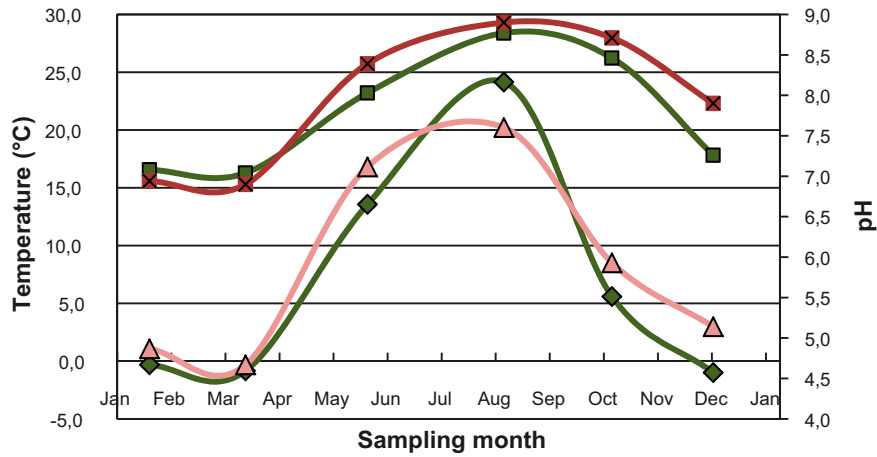
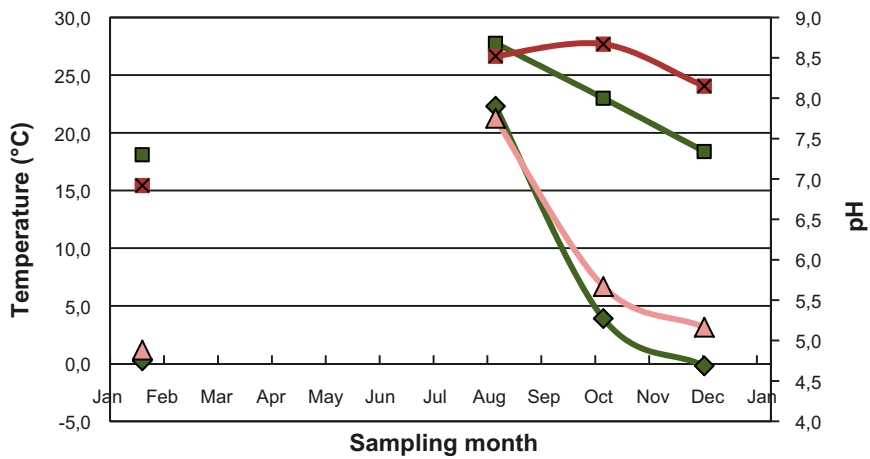


Figure A3-2. Annual and seasonal variation in temperature and pH in Lake PFM007442 during 2009 and 2010.



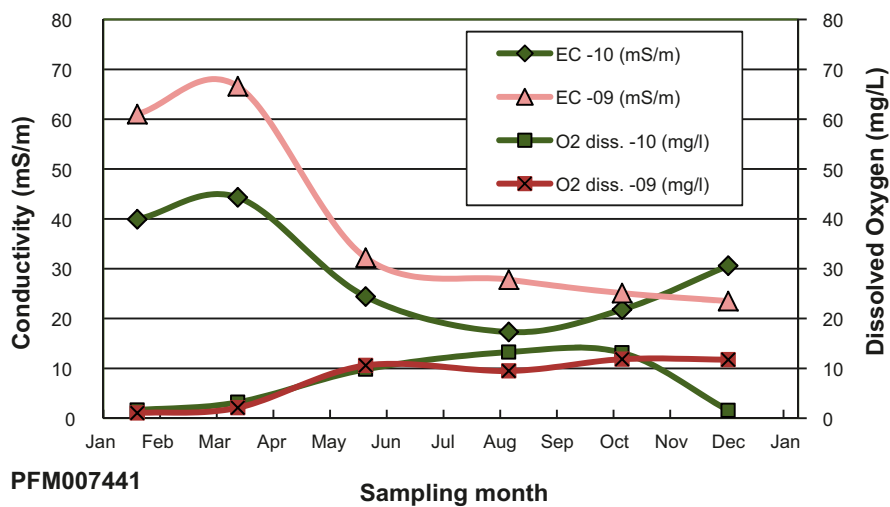
PFM007443 ◆ Temp. -10 (°C) ▲ Temp. -09 (°C) ■ pH -10 × pH -09

Figure A3-3. Annual and seasonal variation in temperature and pH in Lake PFM007443 during 2009 and 2010.



PFM007444 ◆ Temp. -10 (°C) ▲ Temp. -09 (°C) ■ pH -10 × pH -09

Figure A3-4. Annual and seasonal variation in temperature and pH in Lake PFM007444 during 2009 and 2010.



PFM007441

Figure A3-5. Annual and seasonal variation in conductivity (EC) and dissolved oxygen in Lake PFM007441 during 2009 and 2010.

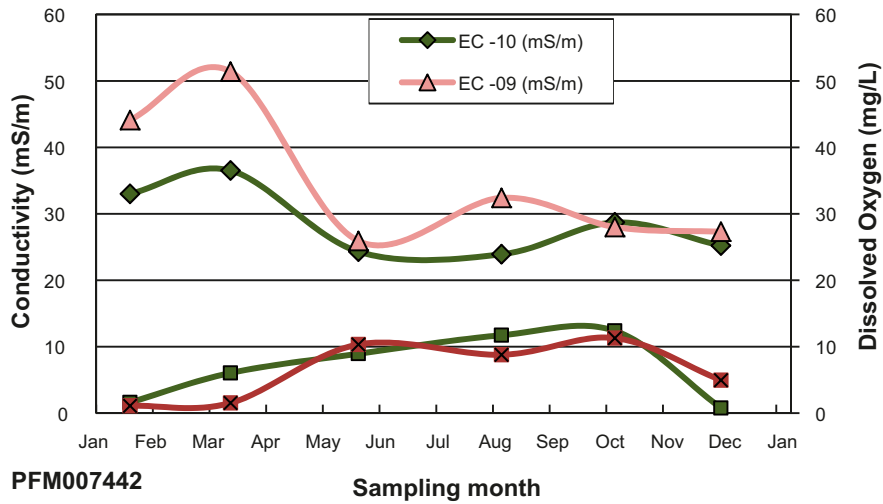


Figure A3-6. Annual and seasonal variation in conductivity (EC) and dissolved oxygen in Lake PFM007442 during 2009 and 2010.

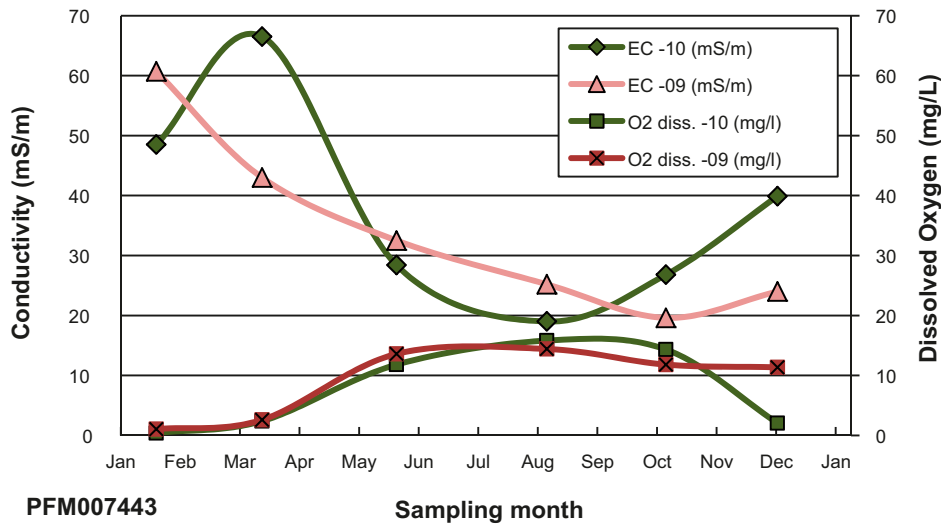


Figure A3-7. Annual and seasonal variation in conductivity (EC) and dissolved oxygen in Lake PFM007443 during 2009 and 2010.

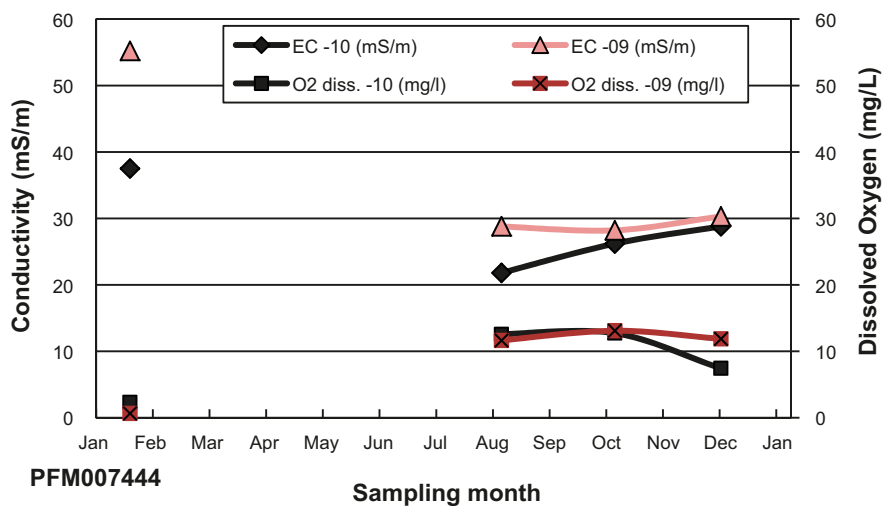
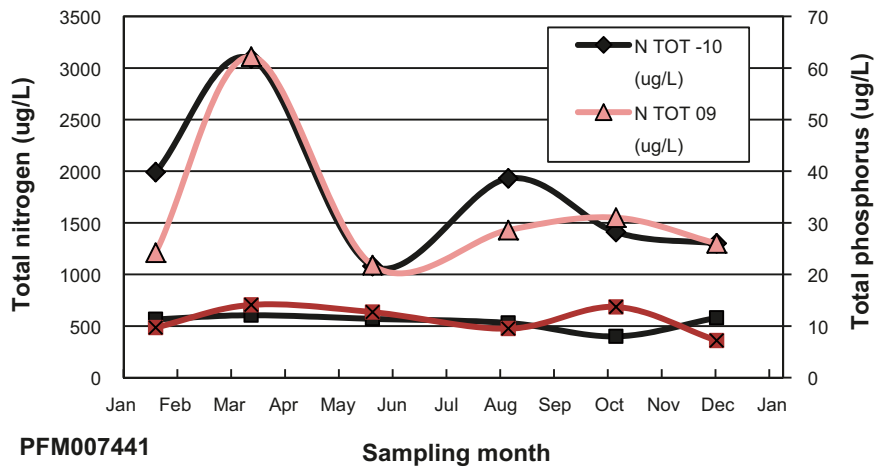
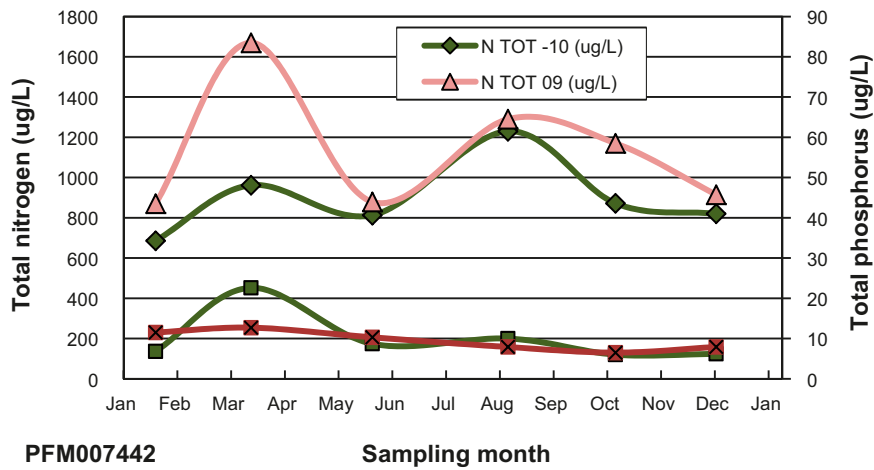


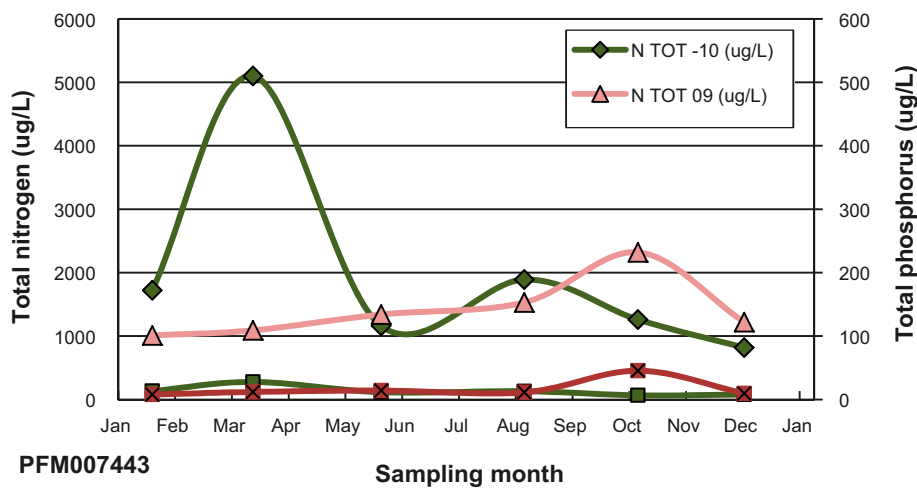
Figure A3-8. Annual and seasonal variation in conductivity (EC) and dissolved oxygen in Lake PFM007444 during 2009 and 2010.



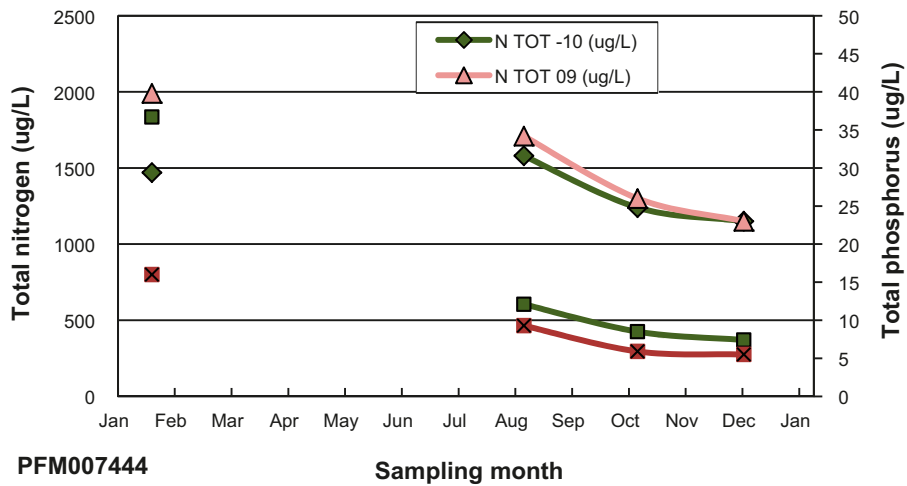
PFM007441 **Sampling month**
Figure A3-9. Annual and seasonal variation in total nitrogen and total phosphorus in Lake PFM007441 during 2009 and 2010.



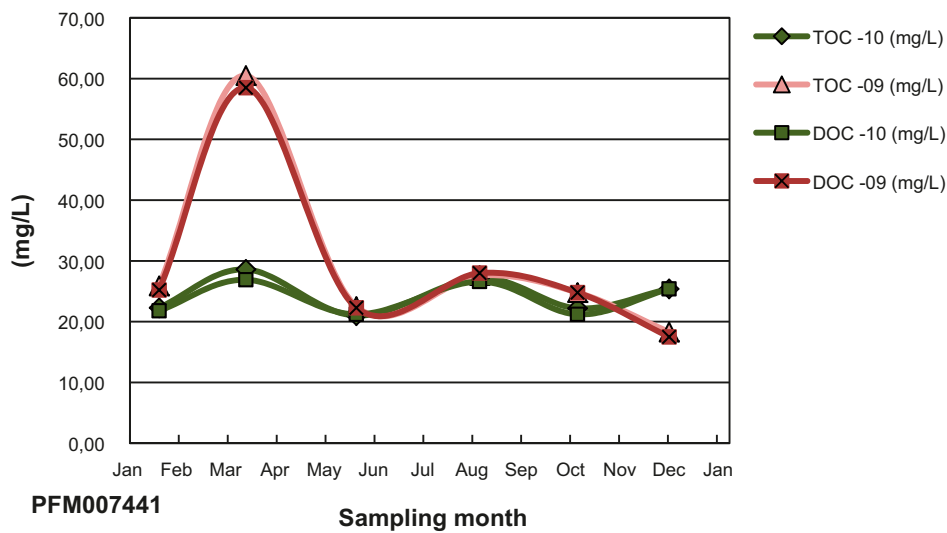
PFM007442 **Sampling month**
Figure A3-10. Annual and seasonal variation in total nitrogen and total phosphorus in Lake PFM007442 during 2009 and 2010.



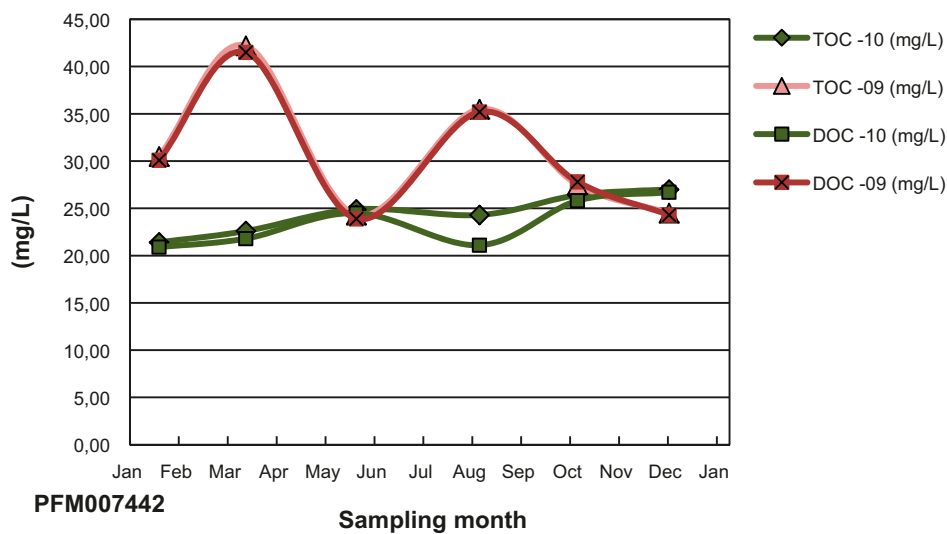
PFM007443 **Sampling month**
Figure A3-11. Annual and seasonal variation in total nitrogen and total phosphorus in Lake PFM007443 during 2009 and 2010.



PFM007444 **Sampling month**
Figure A3-12. Annual and seasonal variation in total nitrogen and total phosphorus in Lake PFM007444 during 2009 and 2010.



PFM007441 **Sampling month**
Figure A3-13. Annual and seasonal variation in total organic carbon (TOC) and dissolved organic carbon (DOC) in Lake PFM007441 during 2009 and 2010.



PFM007442 **Sampling month**
Figure A3-14. Annual and seasonal variation in total organic carbon (TOC) and dissolved organic carbon (DOC) in Lake PFM007442 during 2009 and 2010.

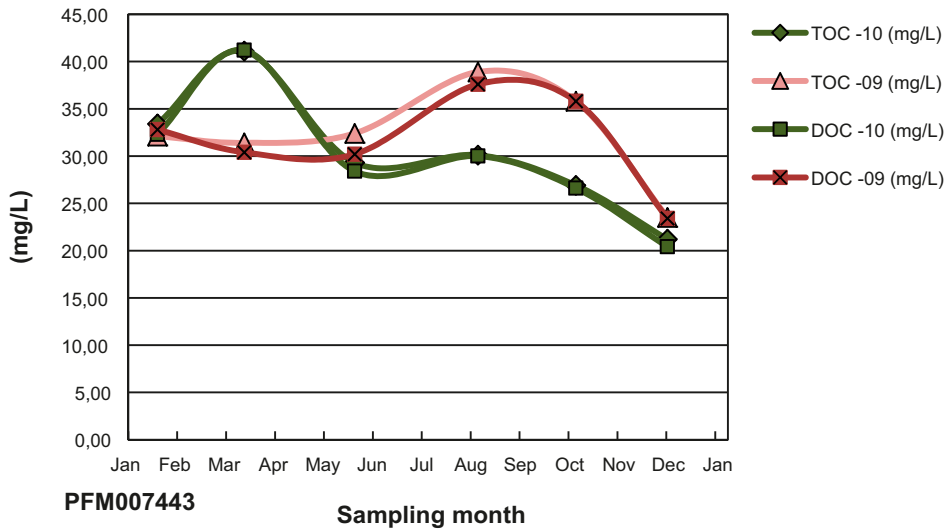


Figure A3-15. Annual and seasonal variation in total organic carbon (TOC) and dissolved organic carbon (DOC) in Lake PFM007443 during 2009 and 2010.

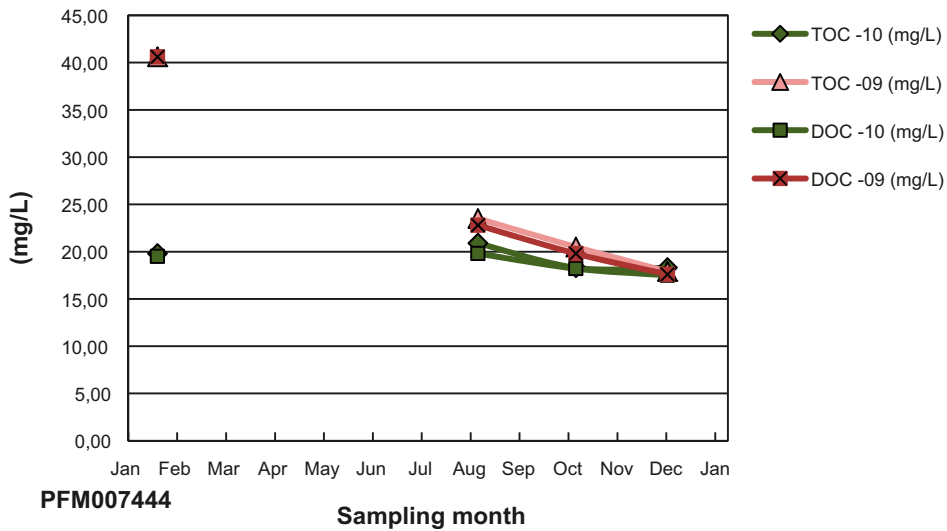


Figure A3-16. Annual and seasonal variation in total organic carbon (TOC) and dissolved organic carbon (DOC) in Lake PFM007444 during 2009 and 2010.