P-10-25

Monitering Forsmark

Hydrochemical investigations in four calciferous lakes in the Forsmark area

Results from complementary investigations in the Forsmark area, 2008–2009

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Sveriges Vattenekologer AB

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September 2010

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Abstract

The present report documents the results from the first year of hydrochemical investigations in four small, calciferous lakes in the Forsmark area. The aim is to study the water composition and its seasonal variations. The report presents the results from seven sampling occasions between November 2008 and December 2009. In addition to the sampling in the four lakes, water samples were also collected in October 2009 from a lake (Bruksdammen), which is a potential water source. Specifically, the construction and operation of an underground storage facility for high level radioactive waste may result in groundwater-table drawdown. External supply of water may be required to reduce consequences for biodiversity and valuable species. Implementation of such measures requires prior knowledge of the water composition both for potential supplies and for objects that are representative for potential recipients.

The results from the water sampling includes field measurements of redox potential, ORP (*Oxidising Reducing Potential)*, pH, dissolved oxygen, electrical conductivity, salinity, depth, barometric pressure, turbidity, chlorophyll, PAR (*Photosynthetic Active Radiation*) and water temperature, as well as chemical analyses of major constituents and nutrient salts. The analysis of water samples from the possible future water source (Lake Bruksdammen) also includes trace metals.

The results show that, similar to previously investigated lakes and streams in the area, the small lakes are well buffered with high alkalinity, high pH and high calcium concentrations. The low salinity in the lakes further indicates that they are not, or have not recently been, influenced by brackish sea water.

Furthermore, the water compositions show large variation over the year which highlights the importance of year-round sampling. The variation can be explained e.g. by seasonal changes in temperature, ice cover, precipitation and by lake specific parameters such as depth and areal extent, as well as size and geological character of the drainage area. The continued regular sampling will indicate if the seasonal variations follow the same pattern each year.

The observed large seasonal variation indicates that also possible water sources should be sampled according to the same sampling scheme as used here for the four lakes that represent potential recipients. From this information it may be possible to find the period when the water composition of source and recipients is as similar as possible. The transferred water will then require little or no tampering, and the impacts from introducing external water will be as small as possible.

Sammanfattning

Denna rapport dokumenterar det första året av hydrokemiska undersökningar i fyra små, kalkrika sjöar i Forsmarksområdet. Syftet med undersökningen är att studera vattensammansättningen i sjöarna och dess variation över året. I rapporten presenteras resultat från sju provtagningstillfällen under perioden november 2008 till december 2009. Utöver provtagningen i de fyra sjöarna provtogs i oktober 2009 även en sjö som utgör en möjlig distributionskälla. Det planerade byggandet av ett underjordiskt slutförvar för använt kärnbränsle kan leda till avsänkning av grundvattennivån i närområdet och därmed även lägre vattennivå i områdets sjöar. Extern tillförsel av vatten kan bli nödvändigt för att minska konsekvenserna för biodiversiteten och viktiga arter. Om sådana åtgärder ska vidtas krävs kunskap om vattensammansättningar både vad gäller möjliga vattenförsörjnings-alternativ och avseende objekt som kan representera möjliga recipienter.

De erhållna resultaten från de fem sjöarna (inklusive en möjlig vattenkälla) omfattar fältmätningar av ORP (*Oxidising-Reducing Potential*), pH, löst syre, elektrisk konduktivitet, salinitet, djup, barometertryck, turbiditet, klorofyll, PAR (*Photosynthetic Active Radiation*) och vattentemperatur samt kemiska analyser av huvudkomponenter, närsalter och kolföreningar. I den sjö som förslagits som möjlig vattenkälla analyserades även spårmetaller.

Resultaten visar att dessa sjöar, i likhet med tidigare undersökta sjöar och bäckar i Forsmarksområdet, är väl buffrade med hög alkalinitet, högt pH och höga kalciumkoncentrationer. Vidare indikerar den låga salthalten i sjöarna att de inte påverkas eller inte nyligen har påverkats av bräckt havsvatten.

Resultaten visar vidare att vattensammansättningarna varierar mycket över året, vilket tydliggör vikten av regelbunden provtagning under alla årstider. Variationen kan förklaras av årstidsförändringar i till exempel temperatur, istäckning, nederbörd m m samt av sjöspecifika faktorer såsom sjöns djup och areella utbredning liksom avrinningsområdets storlek och geologiska karaktär. Fortsatt regelbunden provtagning kommer att visa om variationerna följer ett återkommande årligt mönster.

De stora årstidsvariationer som observerats indikerar att också möjliga distributionskällor borde provtas enligt samma schema som de fyra sjöar som representerar potentiella recipienter. En sådan information skulle göra det möjligt att identifiera den period då vattensammansättningen i källa och recipient är som mest överensstämmande. Behovet av justering av sammansättning i samband med överföring av vatten till recipienterna skulle därmed minska, liksom den risk för hydrokemisk påverkan på sjöarna som uppkommer vid tillförsel av ett vatten med avvikande hydrokemisk karaktär.

Contents

Introduction

The Swedish Nuclear Fuel and Waste Management Co (SKB, Svensk Kärnbränslehantering AB) has conducted extensive site investigations in the Forsmark area for the purpose of a future permanent underground storage facility (slutförvar) for used nuclear fuel. The investigation phase of the site investigations in Forsmark was finished in June 2007, but some complementary investigations as well as a long-term monitoring programme are still going on /1/.

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

The sampling locations are presented in Figure 2-1. 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 number (AP PF 400-08-005). Only data in databases are accepted for further interpretation and modeling. The data 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.

The aim of this investigation is to study the water compositions in small lakes that are representative for the types of nature objects that may be affected by the construction and operation of an underground storage facility for high level radioactive waste. The construction and operation may result in a lowering of the groundwater table and the lake water levels. External water supply may be an option to reduce consequences for biodiversity and valuable species. Lake Bruksdammen, see Figure 2-1, is a potential source from which water could be distributed. Thus, knowledge of the water composition of both the potential source (Lake Bruksdammen) and objects that are representative for potential recipients is needed in order to assess the hydrochemical consequences of mixing different waters.

The investigations include 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, barometric pressure, turbidity, chlorophyll, PAR (*Photosynthetic Active Radiation)* and water temperature. The sampling and field measurements started in November 2008 and will according to present plans continue to the end of 2010. This document reports results from the seven sampling occasions during 2008–2009. The sampling during 2010 will be reported in a subsequent P-report.

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

Activity plan	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. /2/	SKB MB 900.004	1.0
Mätsystembeskrivning för YSI. Multiparametersystem för vattenmätningar. /3/	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).

2 Methods and performance

2.1 Sampling locations and sampling scheme

The locations of the four studied calciferous lakes (near Lake Bolundsfjärden) and Lake Bruksdammen are presented in Figure 2-1. Table 2-1 lists the location id-codes, coordinates and names together with clarifying comments. The sampling scheme for the period 2008–2009 is given in Table 2-2.

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

Sampling locations	Coordinates (RT90 RHB70)	Name	Comments
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	
PFM005864	16 29 456, 66 97 176	Bruksdammen	Sampled once

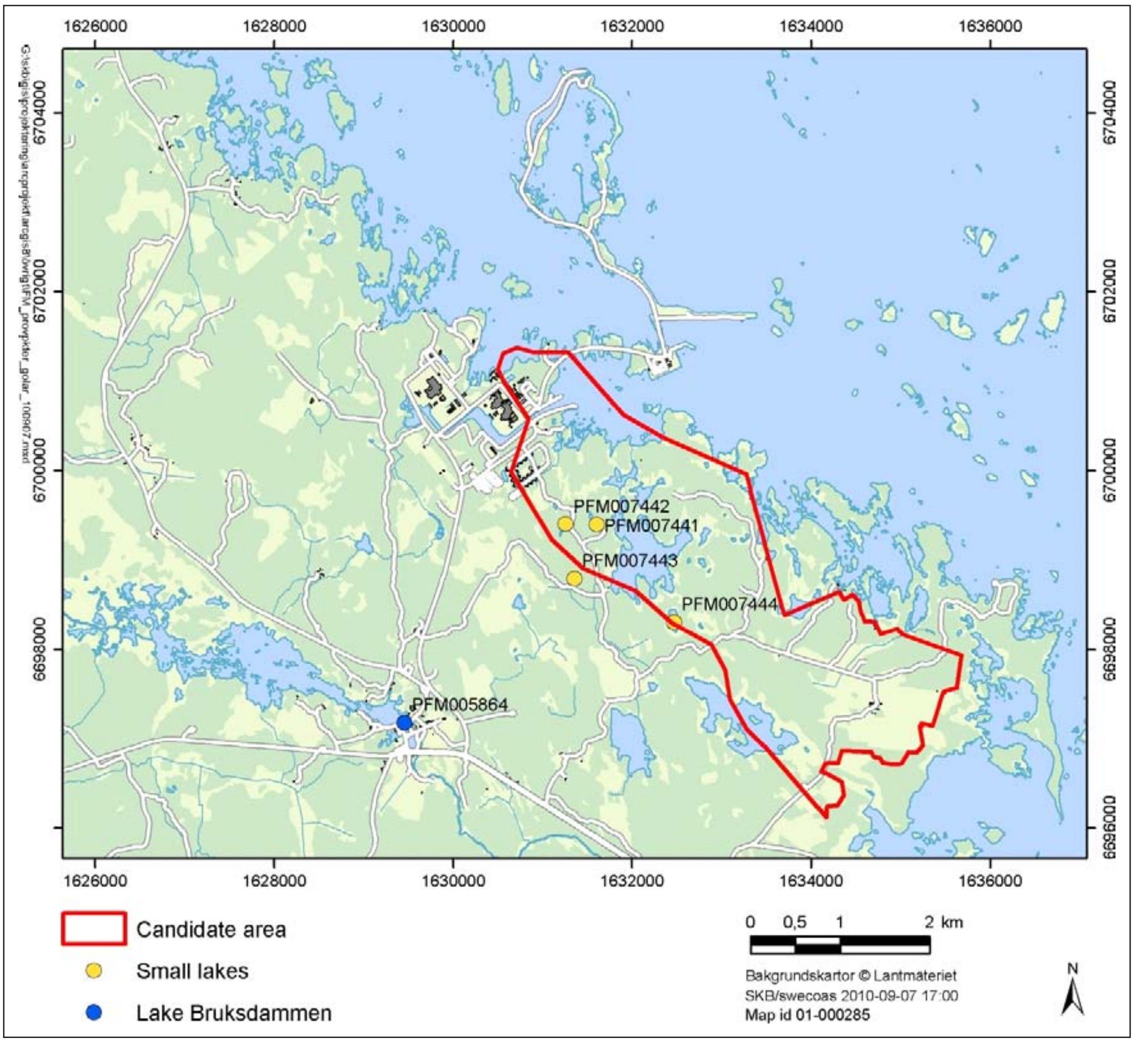

Figure 2-1. Locations of the studied small calciferous lakes and Lake Bruksdammen.

Table 2-2. Sampling scheme for the complementary investigations in four calciferous lakes, 2008–2009.

Year	Month	Week	Class
2008	November	47	3
	December	–	–
2009	January	3	3
	February	–	–
	March	11	3
	April	–	–
	May	20	3
	June	–	–
	July	–	–
	August	33	3
	September	–	–
	October	41	3
	November	–	–
	December	49	3

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 2-2.

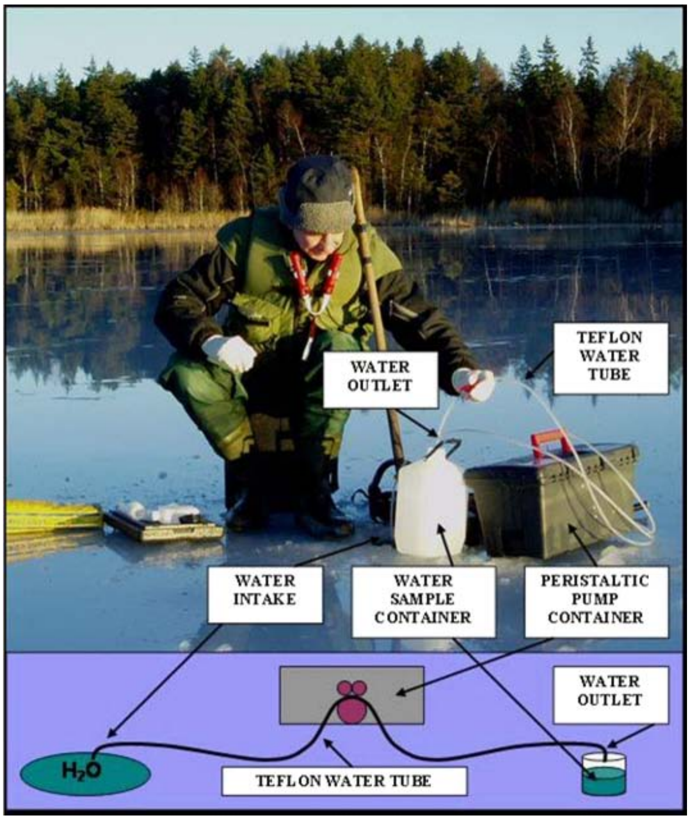

Figure 2-2. *Winter sampling of surface water using the peristaltic pump system (PPS). A schematic presentation of the PPS is also shown.*

2.2.2 Multiparameter sondes

Field measurements were performed using a multiparameter sonde (YSI 6600 EDS). A terminal (YSI 650 MDS) is connected to the sonde through a cable for logging data, Figure 2-3. 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). Table 2-3 lists the parameters measured by the sonde, (used in this investigation).

Table 2-3. Parameters measured by the YSI sonde.

Parameter	YSI 6600 EDS	Parameter	YSI 6600 EDS
Date/time	Yes	Salinity (ppt)	Yes
Temperature (°C)	Yes	Depth (m)	Yes
pH	Yes	Barometric pressure (mm Hg)	Yes
Dissolved oxygen (mg/L)	Yes	Turbidity (NTU)	Yes
ORP (Redox potential, mV)	Yes	Chlorophyll (µg/l)	Yes
Electrical conductivity (mS/cm)	Yes	Light / PAR* (µmoles s^{-1} m^{-2})	Yes

* Photosynthetic Active Radiation

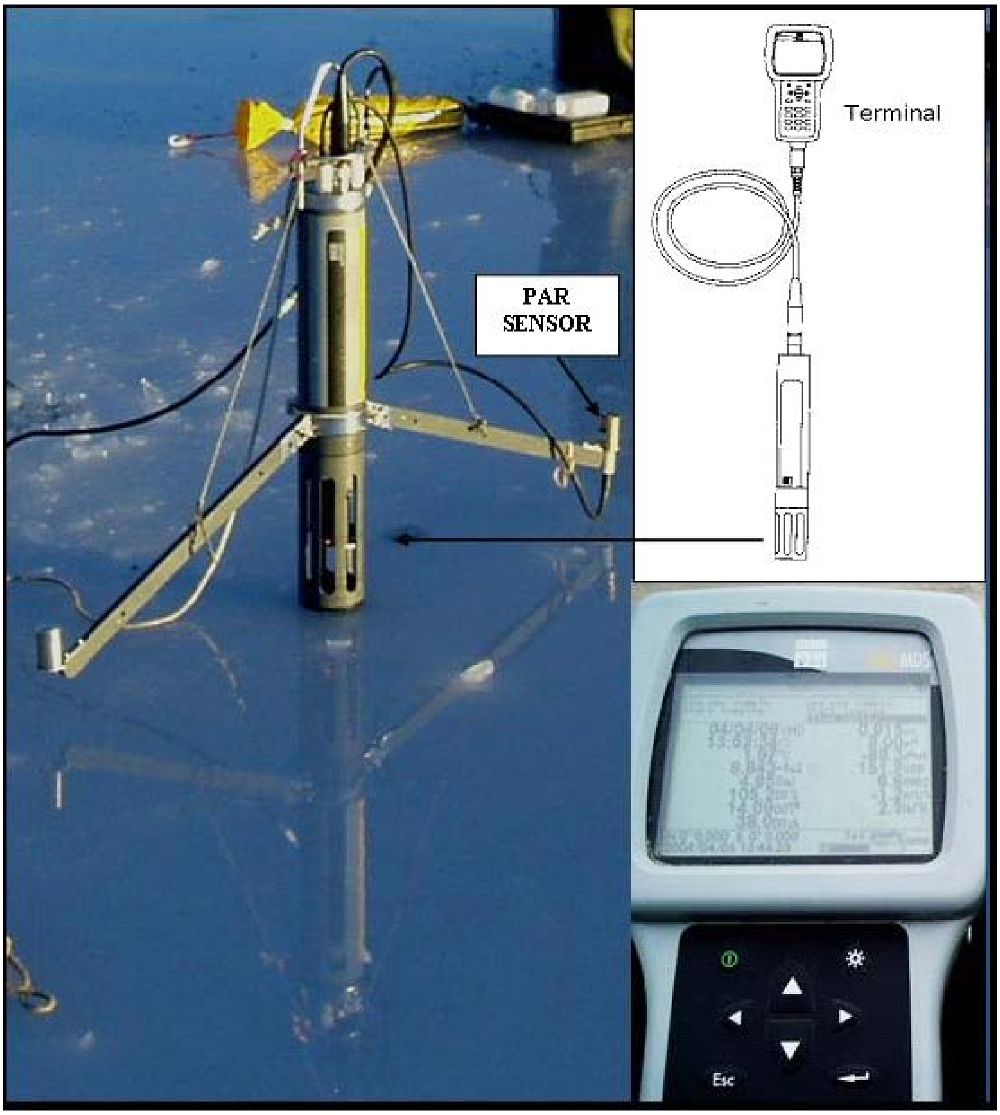

Figure 2-3. *The measurement sonde equipped with a PAR sensor used in the field investigations of surface waters. Also shown is a close up of the terminal during measurements.*

2.2.3 General field equipment

- Ruttner samplers were used as backup if the portable pump system should fail.
- The exact positions of the sampling locations were determined using a GPS (Garmin 172C) with an average accuracy of ± 0.5–1.0 m.
- Disposable filters (Millipore, 0.40 µm, ∅ = 22 mm) were used together with 60 mL syringes to filter specific sample portions of the sampled 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 in 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 sondes 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 labeled 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, SO4_S, Si	Acid washed		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/0.45 µm filter	Fill 80%
25	3	–	Nutrients: NH4, NO2, NO3, PO4		Filtering with syringe/0.45 µm filter	Fill up
100–125[a]	2	Green			Adding 1 ml Mn(II)SO_4 and 2 ml alkalic iodine solution	Fill up and overflow

[a] In week 21, samples in Winkler bottles were collected for oxygen analyses. Sonde measurements showed values below 4 mg/L.

2.3.3 Field measurements

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

2.3.4 Sample treatment and chemical analyses

An overview of analytical methods is given in Appendix 1.

2.3.5 Data handling/post processing

Two field protocols (activity log and sampling protocol) were used. These protocols contain meta data (e.g. id-code, date and time, sample no. and field crew), a few measured data like atmospheric pressure and air temperature, general weather observations and comments on field conditions that may influence the analytical results. These protocols provide basic information for creating activities and activity comments in the Sicada database. The measured parameters and information on 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 for hydrochemical analysis data, 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. The applied hierarchy path "Hydrochemistry/Hydrochemical investigation/Analyses/Water in the database" contains two types of tables, raw data tables and primary data tables (final data tables).

Data on *basic water analyses* are inserted into raw data tables for further evaluation. The evaluation results in a final reduced data set for each sample. These data sets are compiled in a primary data table named "water_composition". 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 ± 5% are considered acceptable (in surface waters ± 10%).

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

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

All results from "biochemical" components and special analyses of trace metals and isotopes" are inserted directly into primary data tables. In those cases where the analyses are repeated or performed by more than one laboratory, a "best choice" notation will indicate those results which are considered most reliable.

An overview of the data management is given in Figure 2-4.

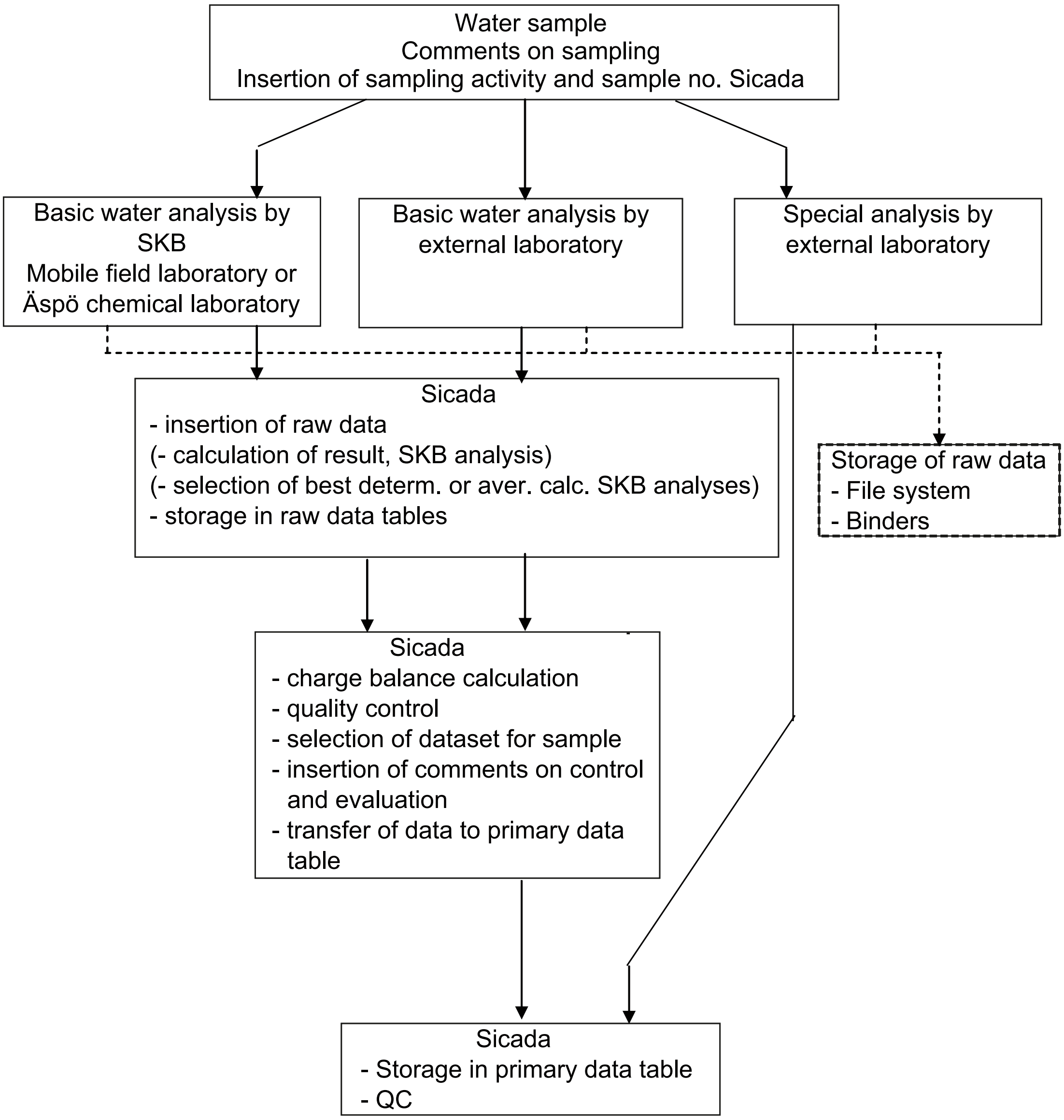

***Figure 2-4.** Overview of data management for hydrochemical data.*

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.

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 V38år04.xls	1 or 2*
Photography	PFM66.jpg	1–4

* Depending on the number of measuring sondes used.

Other relevant information and data

Information about weather conditions and related parameters during the sampling occasions are 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

Sampling was not performed at sampling location PFM007444 during March and May, 2009, since this lake is situated in a bird protection area with restricted access during the spring season. Table 2-6 presents the sampling occasions during the reported period and the reasons for the few omissions are given. Table 2-7 presents some special circumstances that may have effected the field measurements and/or the water sample quality.

Table 2-6. Collected samples and conducted measurements.

Lakes	Year Month Week	08 Nov 47	09 Jan 3	09 Mar 11	09 Maj 20	09 Aug 33	09 Oct 41	09 Dec 49
PFM007441		x	x	x	x	x	x	X
PFM007442		x	x	x	x	x	x	X
PFM007443	Kungsträsket	x	x	x	x	x	x	X
PFM007444	Vambörsfjärden	x	x	o	o	x	x	X
PFM005864	Bruksdammen	–	–	–	–	–	x	–

Explanations and abbreviations:

X: Sample taken.

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

–: No sampling planned.

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

Lakes	Year Month Week	08 Nov 47	09 Jan 3	09 Mar 11	09 Maj 20	09 Aug 33	09 Oct 41	09 Dec 49
PFM007441				Q, W				
PFM007442								
PFM007443	Kungsträsket			W				
PFM007444	Vambörsfjärden							
PFM005864	Bruksdammen							

Explanations to codes/abbreviations:

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

W: Possible contamination of samples due to meltwater on the ice.

3 Results

3.1 Water analyses

3.1.1 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^-. Furthermore, batch measurements of pH and electrical conductivity are included. The basic water analysis data are compiled together with field measurements of pH and water temperature in Appendix 2, Table A2-1. The charge balance errors give an indication of the quality and uncertainty of the analyses of major constituents. None of the 26 samples/datasets show errors exceeding ± 10% but in eight cases the errors exceed ± 5%. The proportions of the major cations and anions in the different lake waters are given in Figures 3-1 to 3-4.

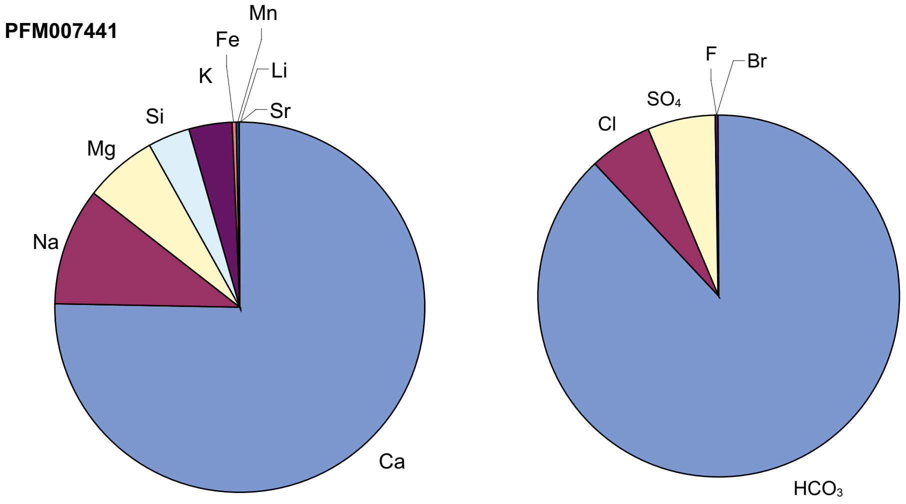

Figure 3-1. *Relative proportions (mean value based on seven sampling occasions) of the major constituents* Na^+*,* K^+*,* Ca^{2+}*,* Mg^{2+}*, Sr,* SO_4^{2-}*,* Cl^-*, Si and* HCO_3^- *as well as the minor constituents* Fe^{2+}*,* Li^+*,* Mn^{2+}*,* Br^- *and* F^- *in lake water from PFM007441.*

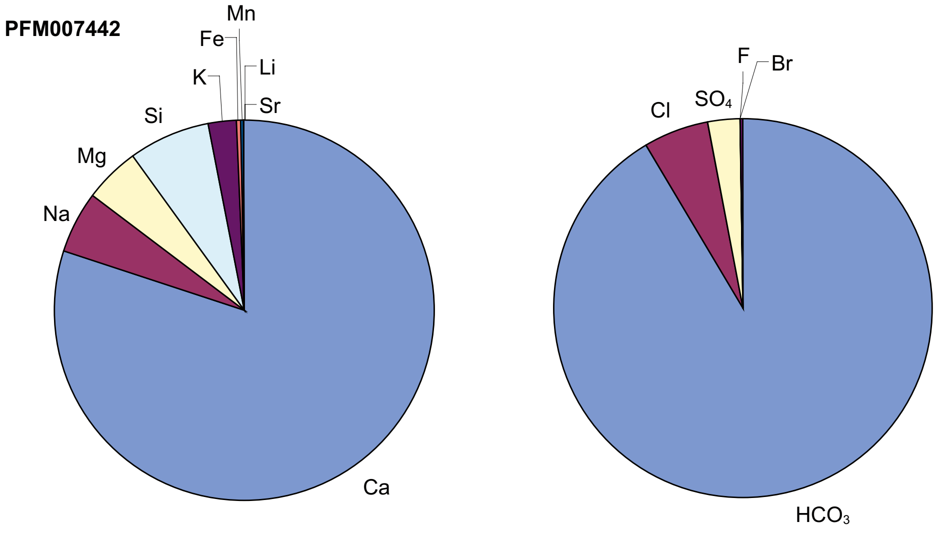

Figure 3-2. *Relative proportions (mean value based on seven sampling occasions) of the major constituents* Na^+*,* K^+*,* Ca^{2+}*,* Mg^{2+}*, Sr,* SO_4^{2-}*,* Cl^-*, Si and* HCO_3^- *as well as the minor constituents* Fe^{2+}*,* Li^+*,* Mn^{2+}*,* Br^- *and* F^- *in lake water from PFM007442.*

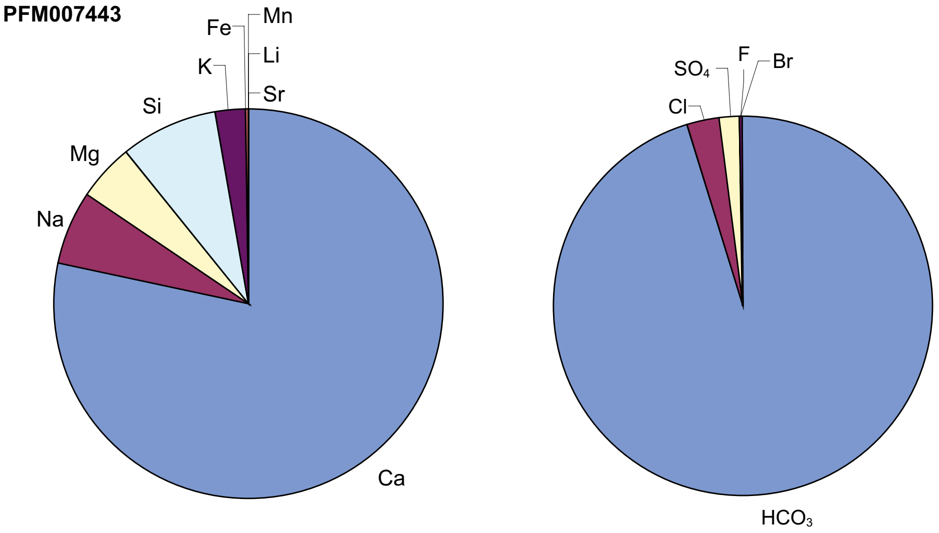

Figure 3-3. *Relative proportions (mean value based on seven sampling occasions) of the major constituents* Na^+, K^+, Ca^{2+}, Mg^{2+}, *Sr*, SO_4^{2-}, Cl^-, *Si and* HCO_3^- *as well as the minor constituents* Fe^{2+}, Li^+, Mn^{2+}, Br^- *and* F^- *in lake water from PFM007443.*

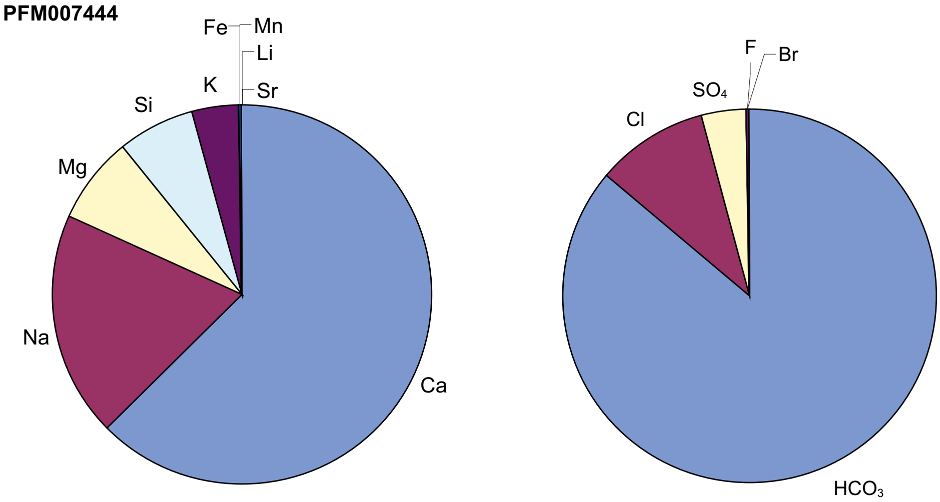

Figure 3-4. *Relative proportions (mean value based on five sampling occasions) of the major constituents* Na^+, K^+, Ca^{2+}, Mg^{2+}, *Sr*, SO_4^{2-}, Cl^-, *Si and* HCO_3^- *as well as the minor constituents* Fe^{2+}, Li^+, Mn^{2+}, Br^- *and* F^- *in lake water from PFM007444.*

Sulphate by ion chromatography and sulphate calculated from total sulphur by ICP are compared in Figure 3-5. The systematic deviation may be due to presence of hydrogen sulphide and other sulphur containing species in the lake waters.

3.1.2 Surface water supplements

The surface water supplements include NH_4-N, NO_2-N, NO_3-N+NO_2-N, tot-N, tot-P, PO_4-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 moles nitrogen to 1 mole 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.

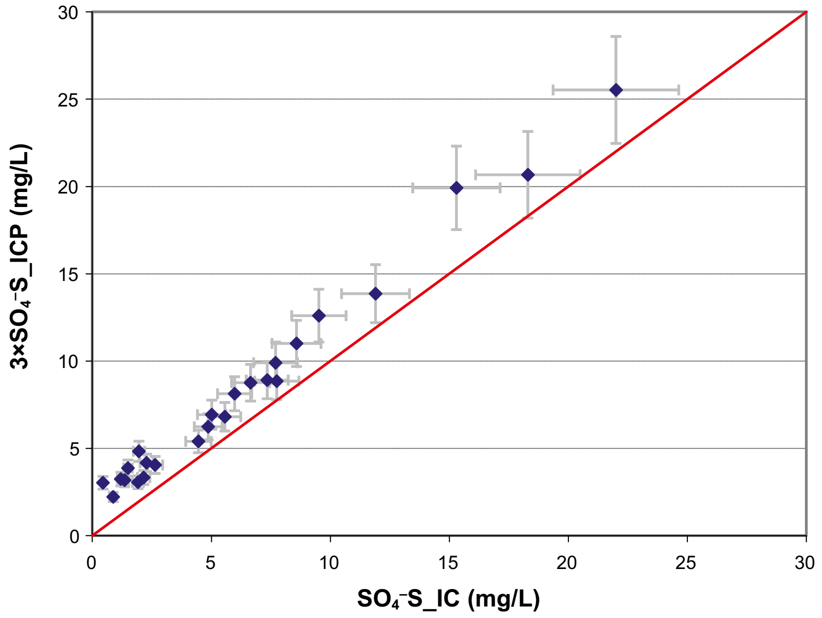

__Figure 3-5.__ Sulphate (SO_4^- by IC) versus sulphate calculated from total sulphur ($3 \times SO_4^-S$) by ICP. The measurement uncertainty (appendix 1) is shown as error bars.

When nitrogen is present in excess, the ratio will be higher than 16, indicating that phosphorus is limiting the growth. Lower ratios indicate 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 phosphorous in the investigated lake waters. As expected all four lakes are phosphorus limited with high concentrations of nitrogen. The highest concentration of nitrogen (>3,000 µg/L) was found in sampling location PFM007441 during March 2009, whereas the highest concentration of phosphorus (>45 µg/L) was found in sampling location PFM007443 during the October sampling in 2009.

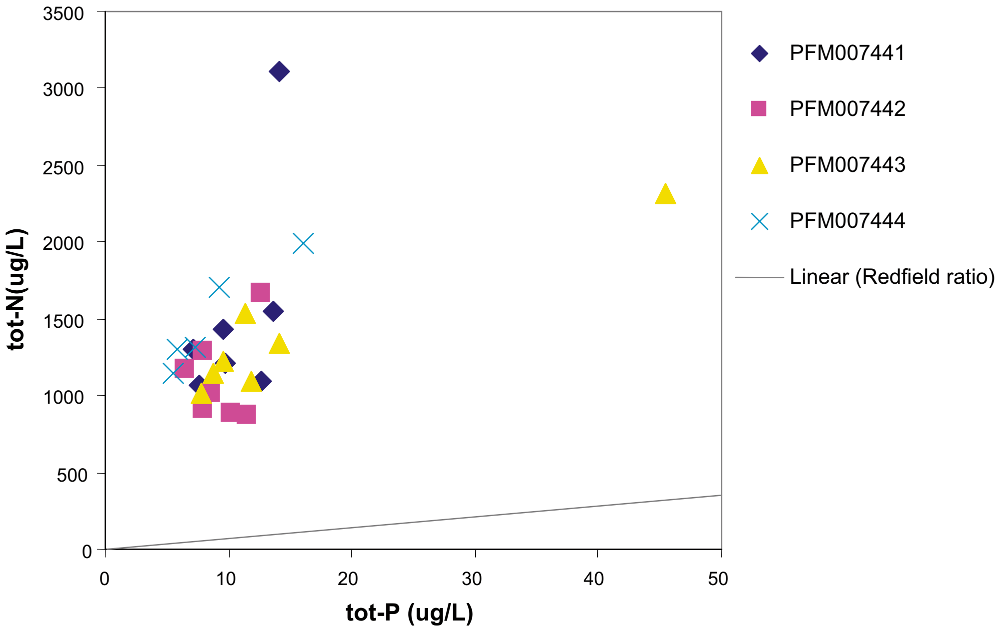

__Figure 3-6.__ The linear relationship between nitrogen and phosphorus in the four investigated lake waters. The Redfield ratio (7:1) is given by the line. Values above and below the line indicate phosphorus limitation and nitrogen limitation, respectively.

3.2 Field measurements

The field measurement data include redox potential, pH, dissolved oxygen, electrical conductivity, salinity, measurement depth, barometric pressure, turbidity, chlorophyll, PAR and water temperature. Measured pH in the four lakes ranges between 6.7 and 8.9. The highest value was measured in sampling location PFM007443 in August and the lowest pH was observed in March in sampling point PFM007442. Figure 3-7 shows the mean pH for the four lakes during the period November 2008–December 2009.

The electrical conductivity (EC) in the four lakes measured between 19 and 67 mS/m. The highest value was observed in sampling location PFM007441 and the lowest in sampling location PFM007443. The salinity in the lakes was low, 0.09–0.32 (per mill.). Figures 3-8 and 3-9 show the mean conductivity and salinity for the lakes during the reported period.

Two sets of data are of lower quality; sonde measurements (YSI 6600 EDS) of chlorophyll and turbidity. The chlorophyll measurements are problematic, possibly due to the fact that humic substances and chlorophyll have similar fluorescence in the wavelength used by the measurement 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 low 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.

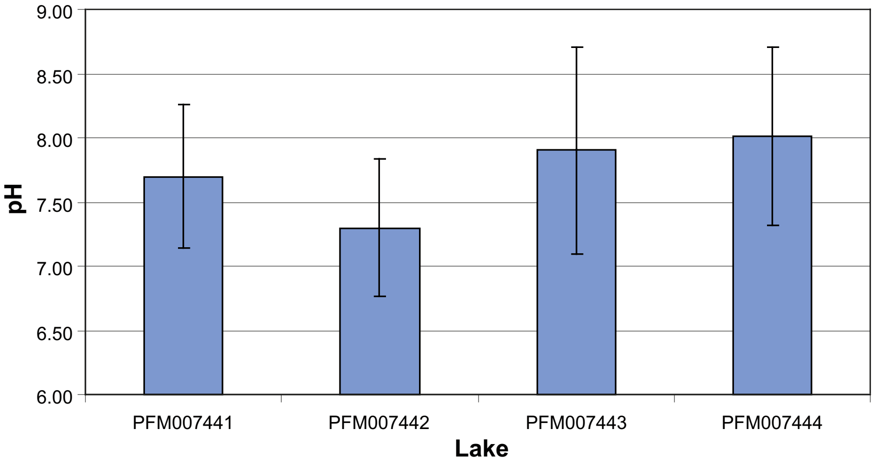

Figure 3-7. *The pH (mean ± stdev) in the four sampling points.*

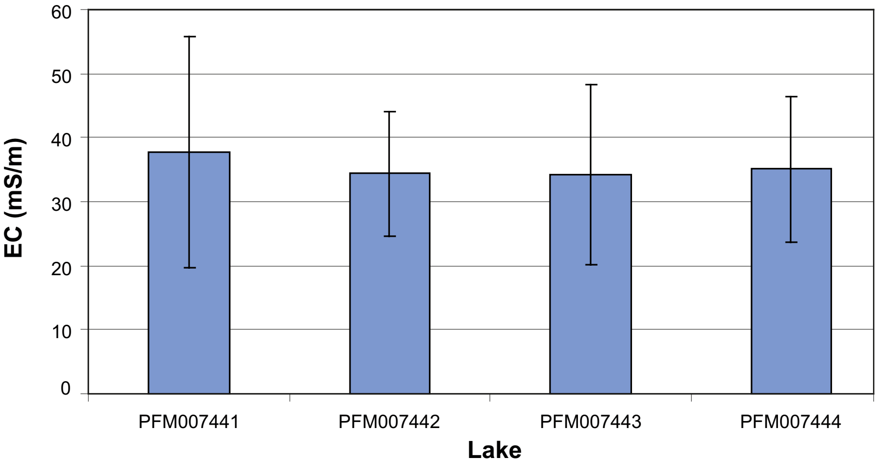

Figure 3-8. *The electrical conductivity in mS/m (mean ± stdev) in the four sampling locations.*

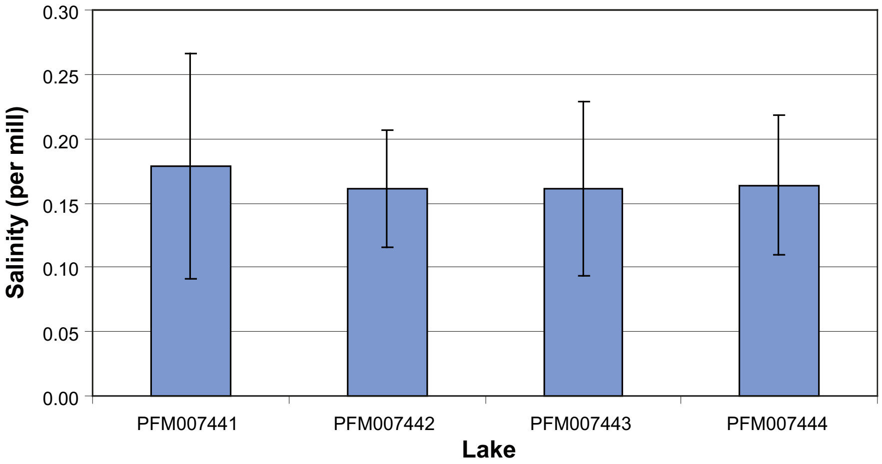

Figure 3-9. *The salinity in per mill. (mean ± stdev) in the four sampling locations.*

3.3 Seasonal variation in water composition

The water composition at a given time is dependent on seasonal differences such as precipitation, ice cover, temperature and primary production, as well as on lake specific factors such as depth and areal extent, and size and geological character of the drainage area. This leads to variations in composition both during the year and 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 3-10). Many other parameters also change during the year. Dissolved oxygen and pH roughly follow the temperature changes with lower values during winter when ice covers the lakes causing winter stagnation in the water circulation, Figures 3-11 and 3-12.

The highest electrical conductivity (EC) values were measured during the winter period, Figure 3-13. Similar patterns are also observed for total organic carbon (TOC), total nitrogen and most of the ions, for example Ca^{2+} and HCO_3^-, Figures 3-14 to 3-22. The highest values of total phosphorus were observed in two of the lakes during October, Figure 3-16. These values were also mirrored by increased concentrations of total nitrogen.

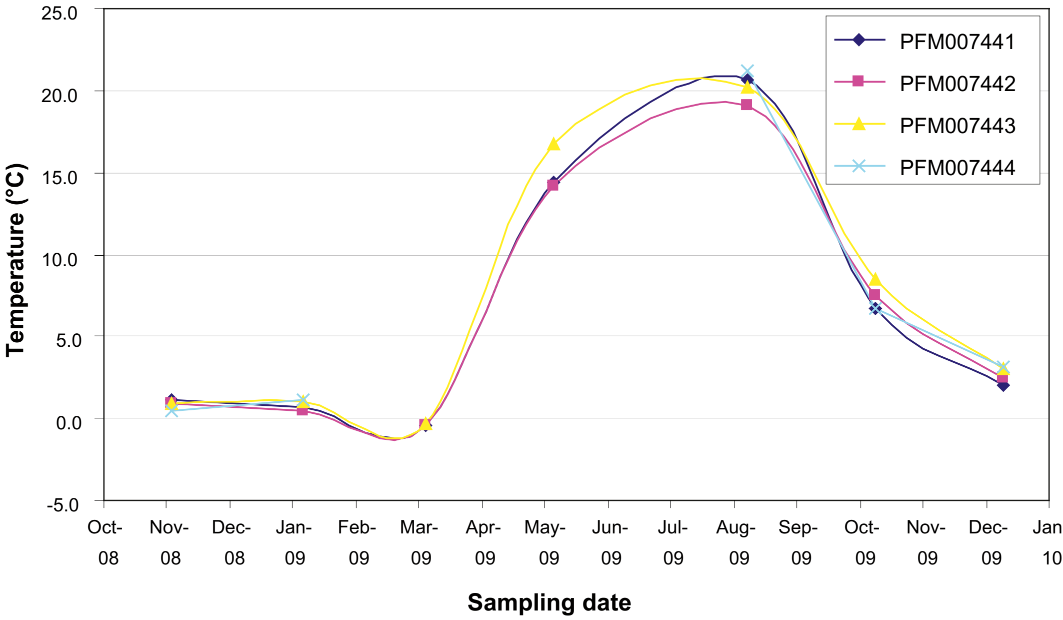

Figure 3-10. *Seasonal variation in water temperature (°C) in the four lakes.*

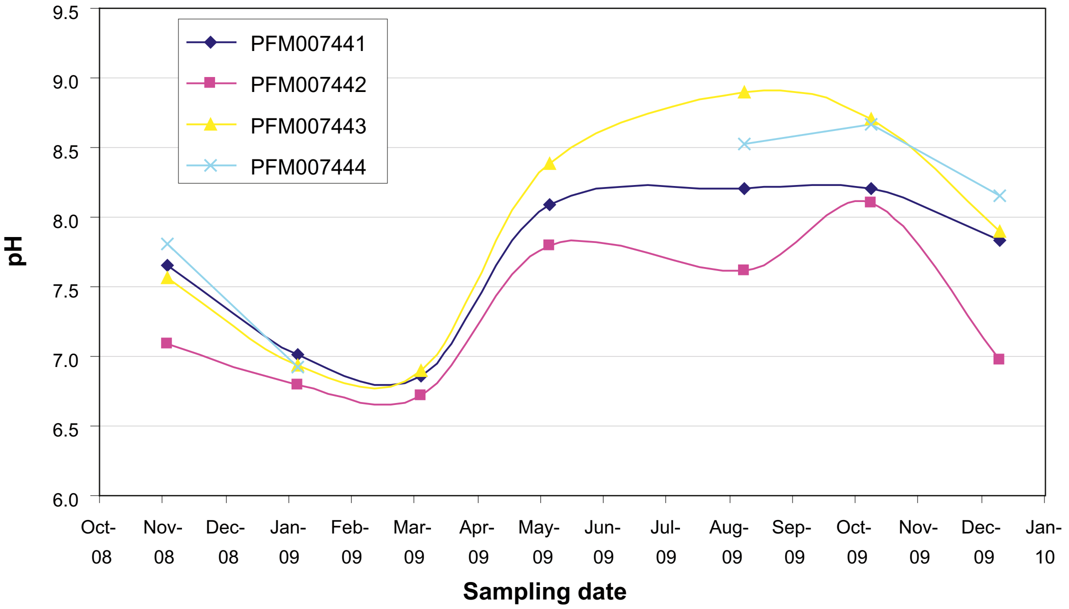

Figure 3-11. *Seasonal variation of pH in the four lakes.*

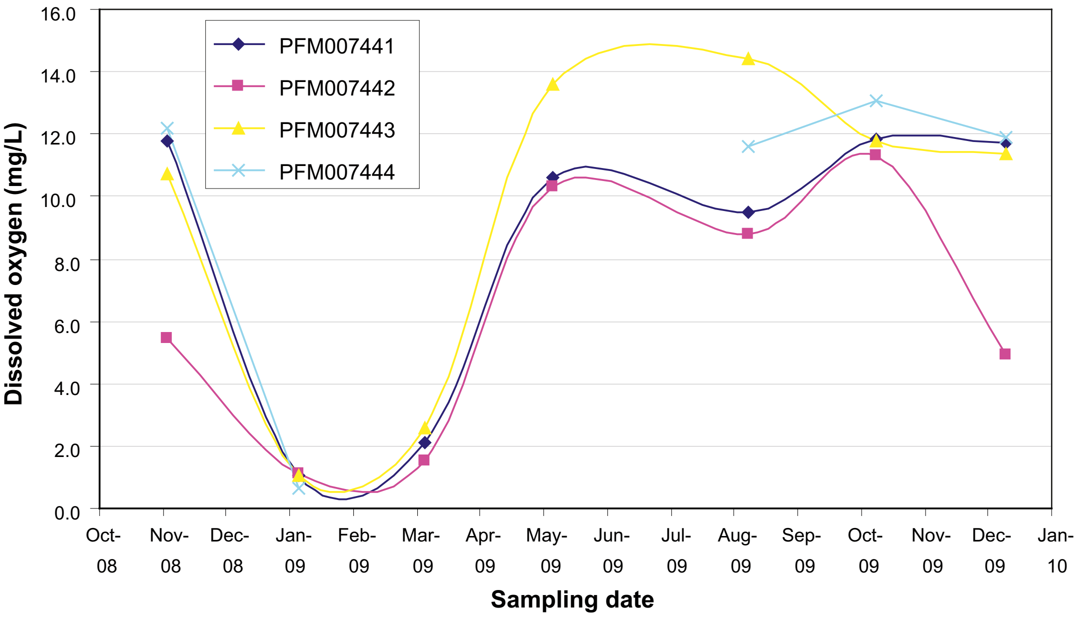

Figure 3-12. *Seasonal variation of dissolved oxygen (mg/L) in the four lakes.*

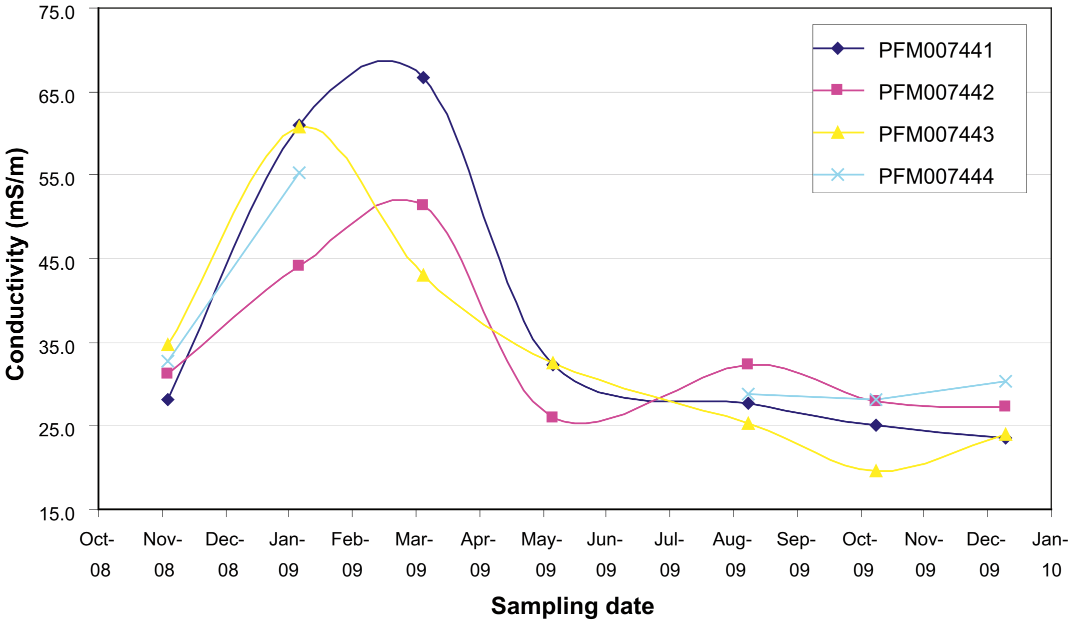

Figure 3-13. Seasonal variation of electrical conductivity (mS/m) in the four lakes.

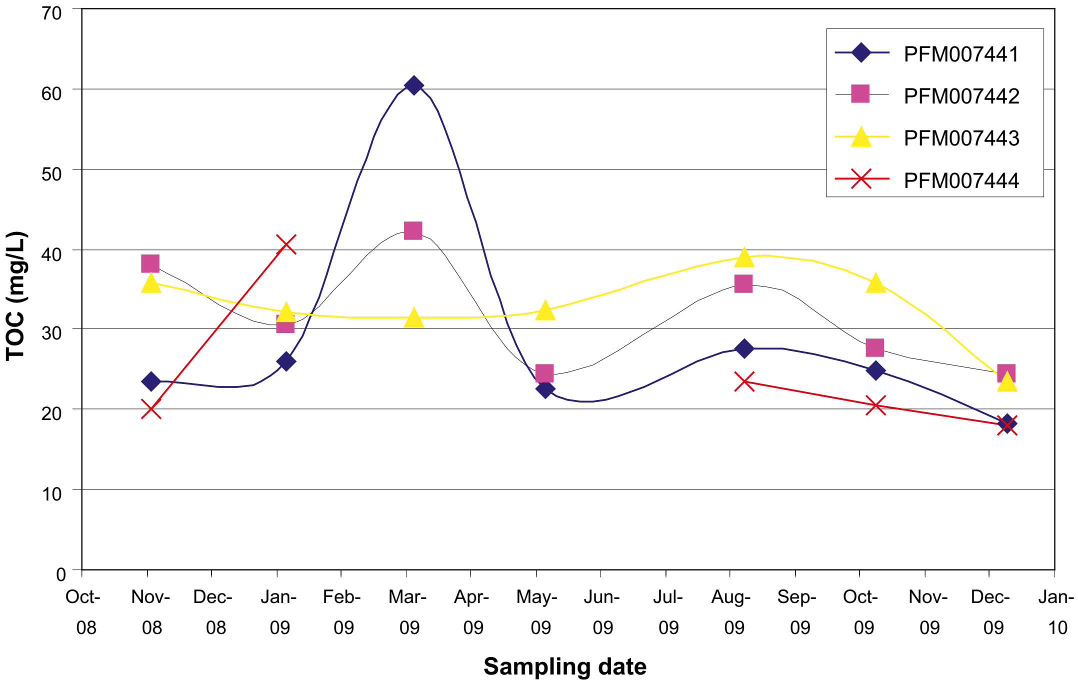

Figure 3-14. Seasonal variation of total organic carbon, TOC (mg/L) in the four lakes.

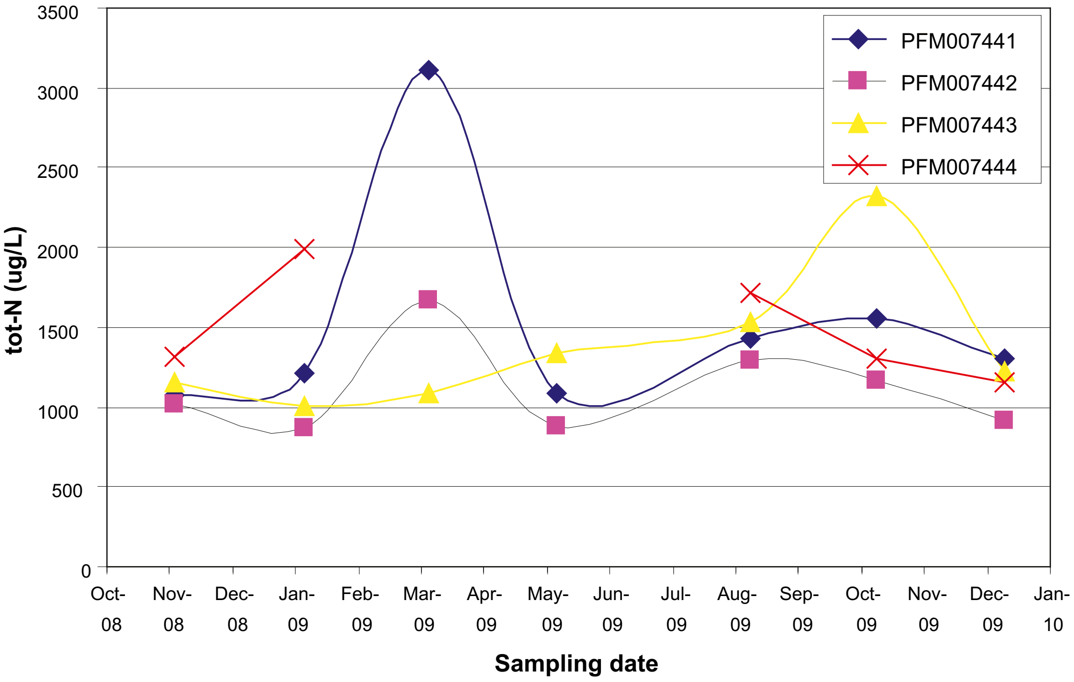

Figure 3-15. *Seasonal variation of total nitrogen (μg/L) in the four lakes.*

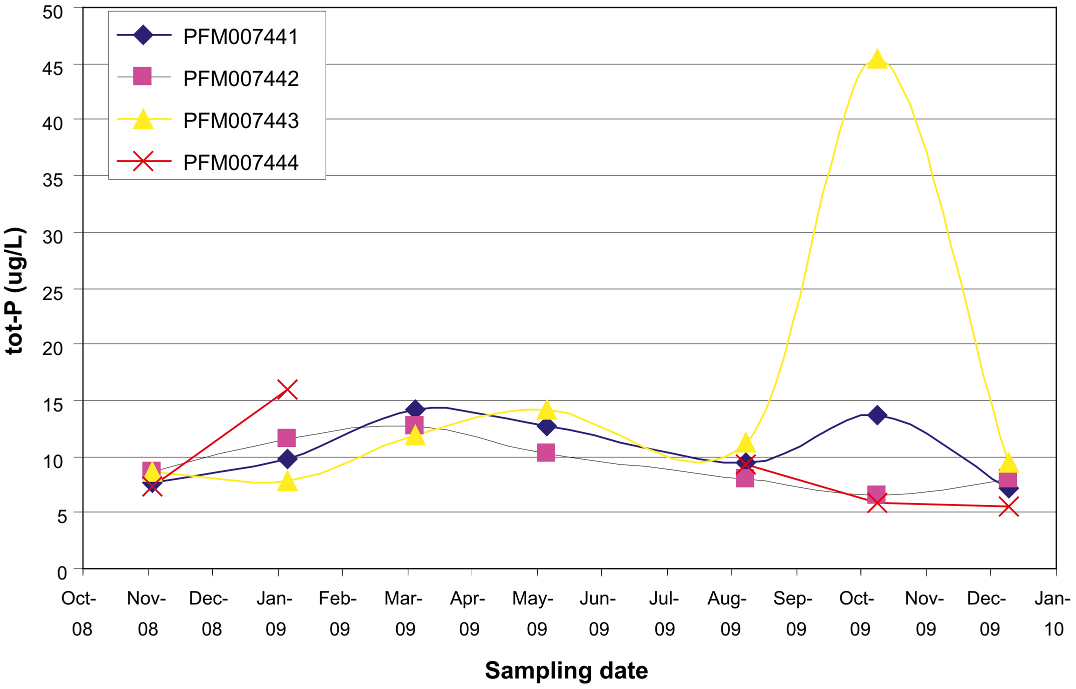

Figure 3-16. *Seasonal variation of total phosphorus (μg/L) in the four lakes.*

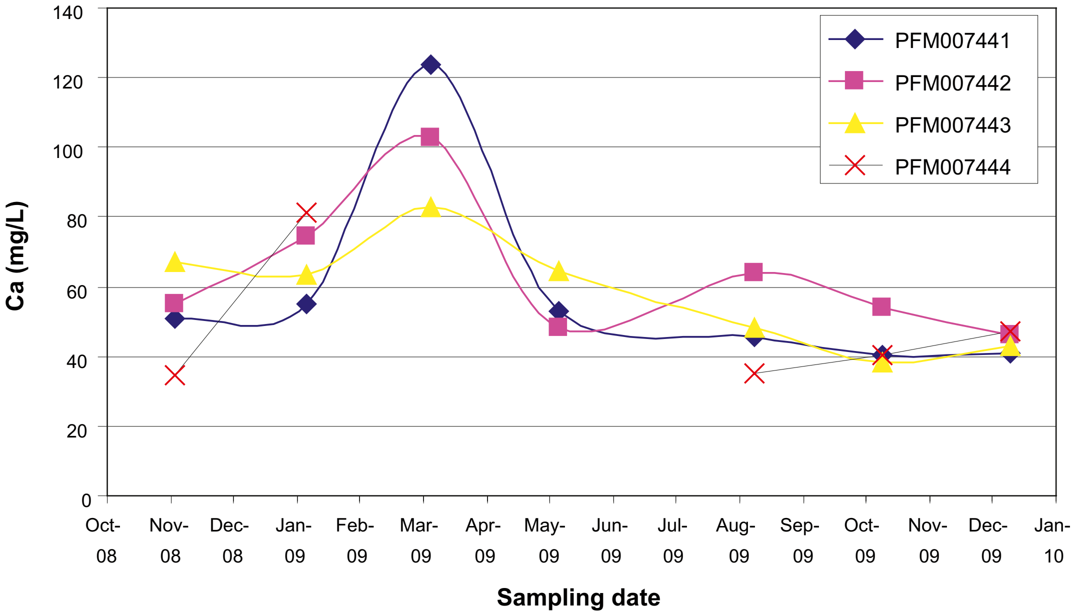

Figure 3-17. *Seasonal variation of Ca^{2+} (mg/L) in the four lakes.*

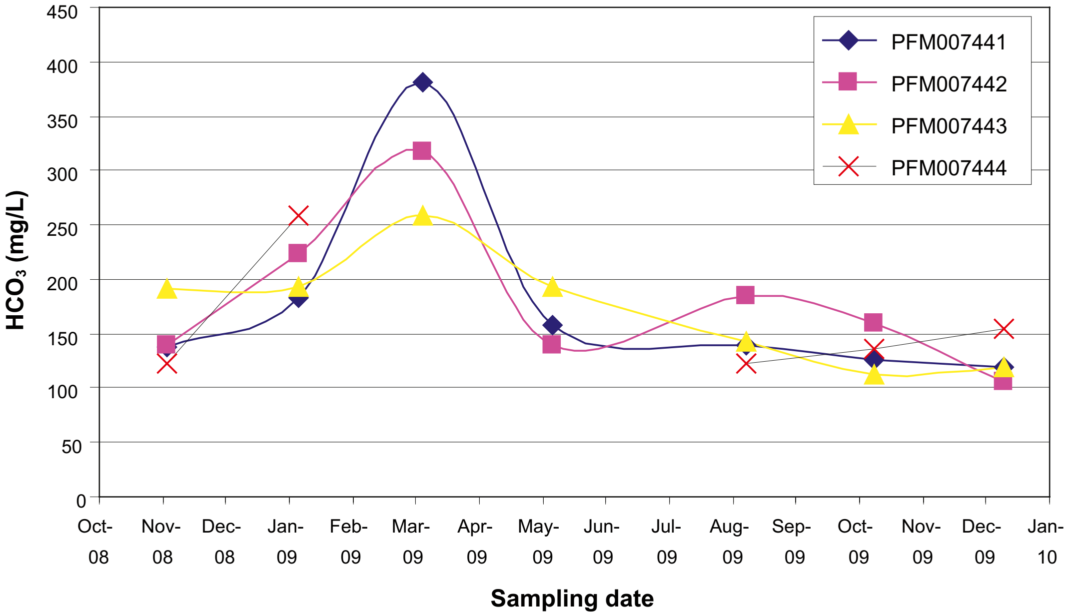

Figure 3-18. *Seasonal variation of HCO_3^- (mg/L) in the four lakes.*

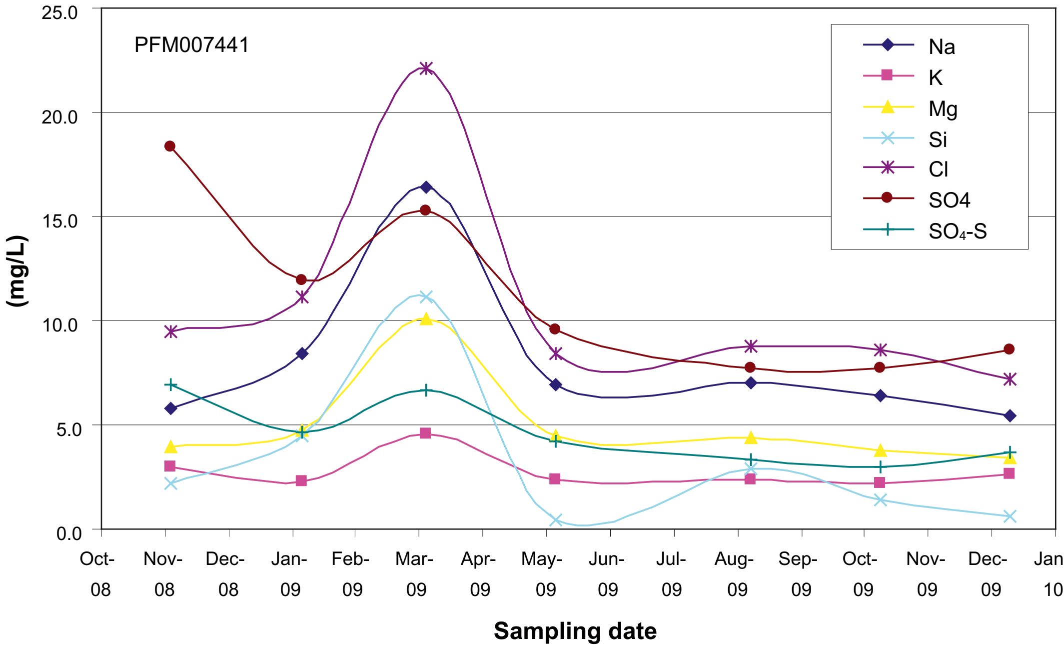

Figure 3-19. *Seasonal variation of* Na^+, K^+, Mg^{2+}, Si^{2+}, Cl^-, SO_4^{2+} *and* SO_4*-S (mg/L) concentrations in sampling location PFM007441.*

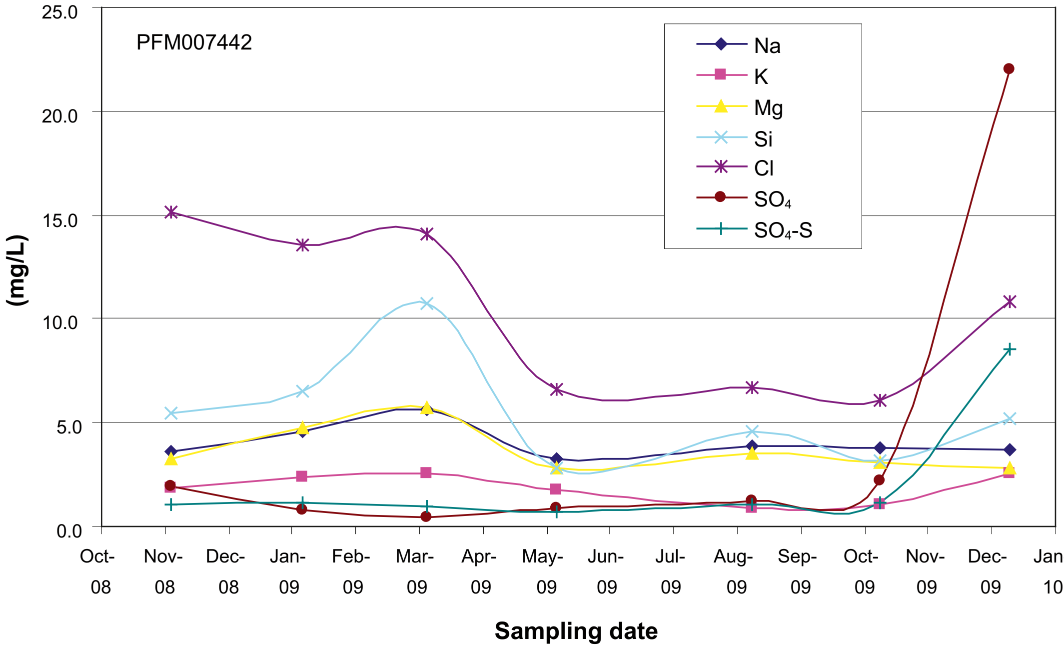

Figure 3-20. *Seasonal variation of* Na^+, K^+, Mg^{2+}, Si^{2+}, Cl^-, SO_4^{2+} *and* SO_4*-S (mg/L) concentrations in sampling location PFM007442.*

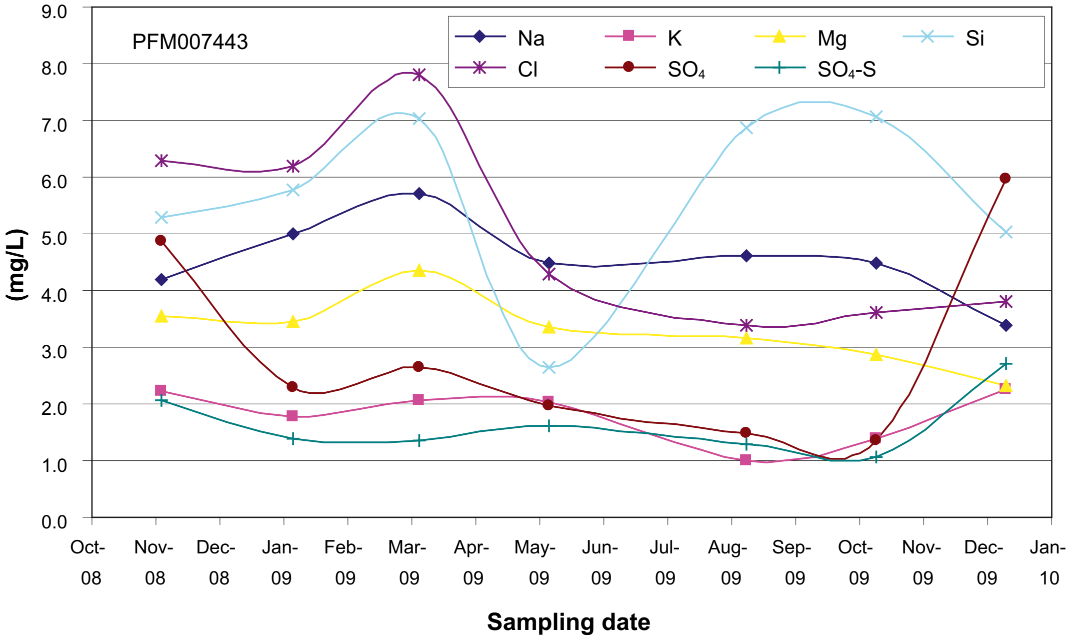

Figure 3-21. *Seasonal variation of Na^+, K^+, Mg^{2+}, Si^{2+}, Cl^-, SO_4^{2+} and SO_4-S (mg/L) concentrations in sampling location PFM007443.*

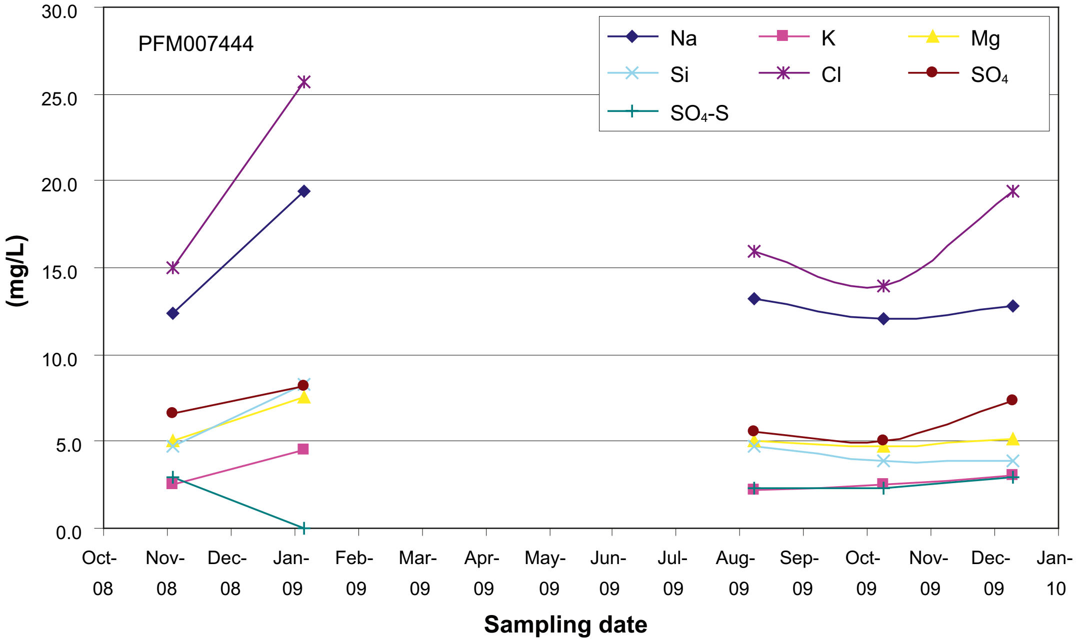

Figure 3-22. *Seasonal variation of Na^+, K^+, Mg^{2+}, Si^{2+}, Cl^-, SO_4^{2+} and SO_4-S (mg/L) concentrations in sampling location PFM007444. Due to restricted access to the lake, no samples were collected in March and May, 2009.*

3.4 Lake Bruksdammen

Lake Bruksdammen (sampling location PFM005864) is a potential source for water to reduce consequences for biodiversity and valuable species during construction and operation of the underground storage facility for used nuclear fuel. The sampling of this lake was performed in October, 2009. The main purpose with the sampling was to rule out high levels of trace metals. Therefore, most of the surface water supplement analyses (for example nutrient salts) were not included.

The proportions of the different cations and anions are presented in Figure 3-23.

The analyses of trace metals include Al, As, Cd, Cr, Cu, Co, Hg, Ni, Zn, Pb, V, Mo, and Ba. The trace metal data are compiled in Appendix 2, Table A2-4.

Common metals in fresh water are Al, Cr, Cu, Co, Ni and Zn. In Lake Bruksdammen aluminum and barium were the most common trace elements, Figure 3-24.

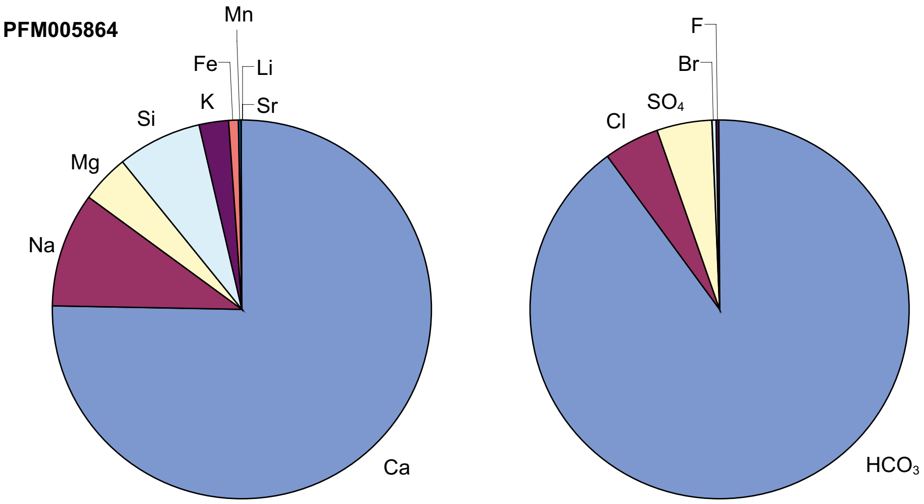

Figure 3-23. *Proportions of the major constituents Na^+, K^+, Ca^{2+}, Mg^{2+}, Sr, SO_4^{2-}, Cl^-, Si and HCO_3^- as well as the minor constituents Fe^{2+}, Li^+, Mn^{2+}, Br^- and F^- in Lake Bruksdammen in October, 2009.*

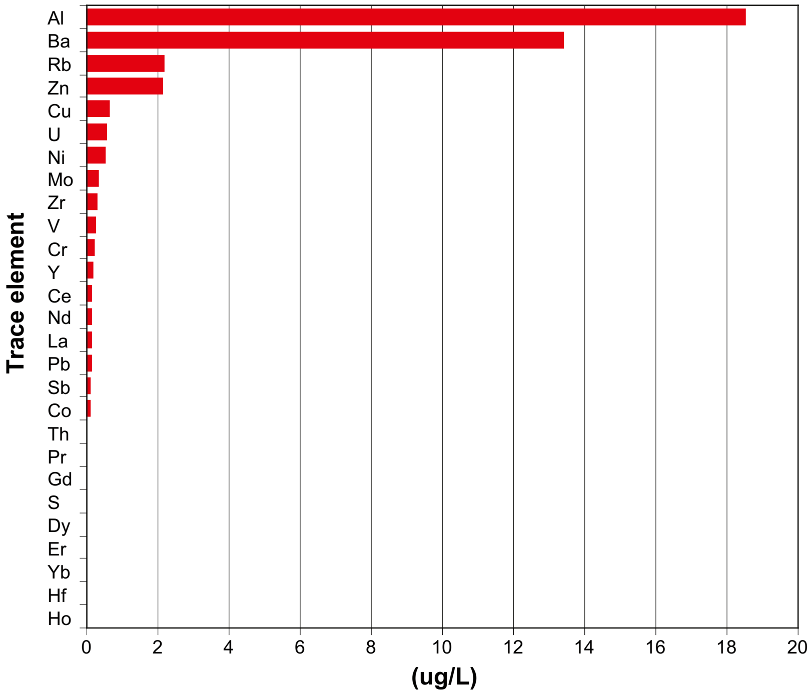

Figure 3-24. *Trace metal concentrations in Lake Bruksdammen in October, 2009.*

Comparision with the four calciferous lakes

The water compositions in Lake Bruksdammen and in the four small lakes (sampling locations PFM007441 to PFM007444) are compared in Figures 3-25 to 3-27. The presented data originate from the sampling in October, 2009.

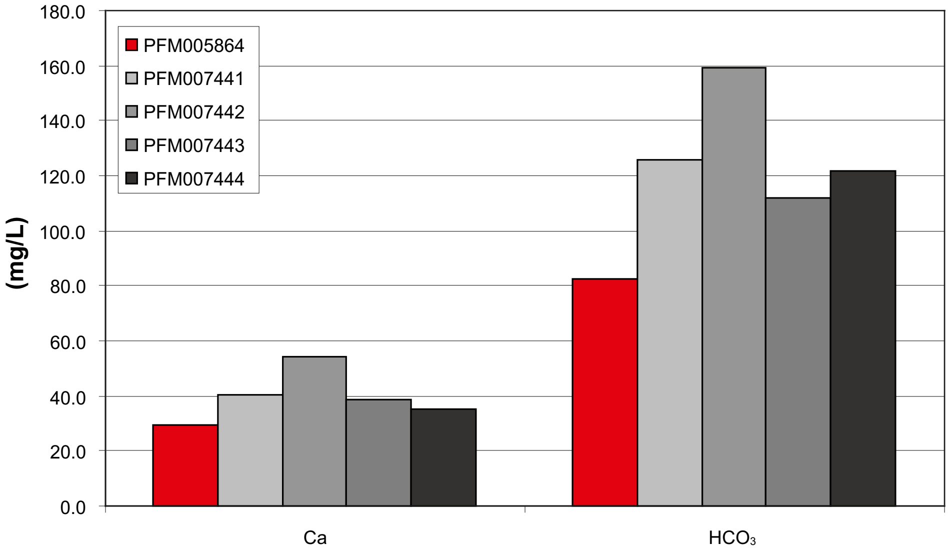

Figure 3-25. *Concentrations of Ca^2 and HCO_3^- in Lake Bruksdammen (PFM005864) and the four lakes (PFM007441 to PFM007444) in October, 2009.*

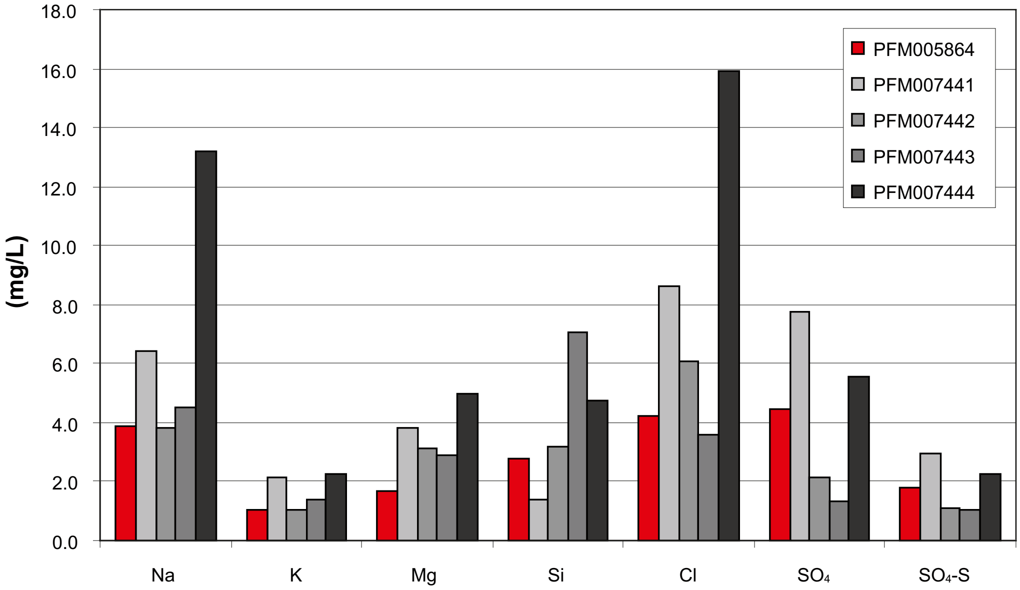

Figure 3-26. *Concentration of Na^+, K^+, Mg^{2+}, S (SO4-S), SO_4^{2-}, Cl^- and Si in Lake Bruksdammen (PFM005864) and the four lakes (PFM007441 to PFM007444) in October, 2009.*

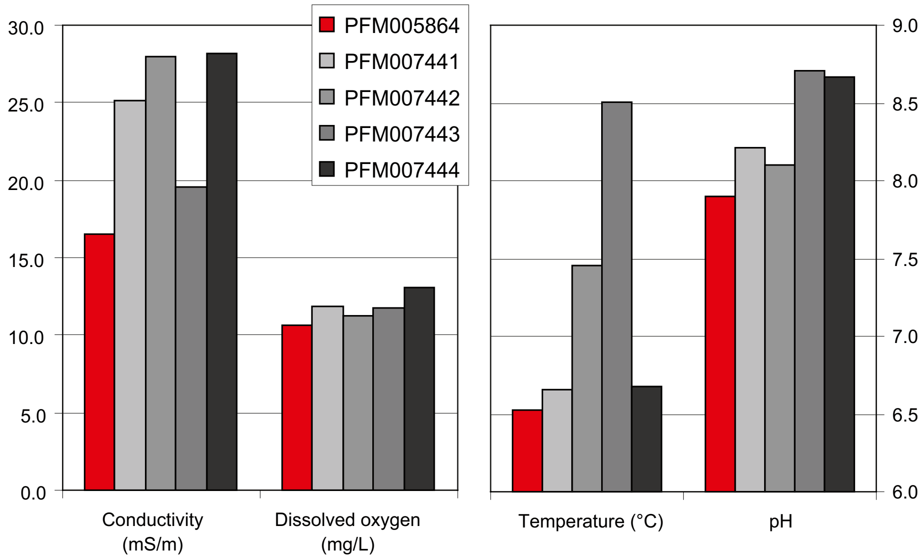

Figure 3-27. Field measurements of electrical conductivity (EC), dissolved oxygen, temperature and pH in Lake Bruksdammen (PFM005864) and the four lakes (PFM007441 to PFM007444) in October, 2009.

4 Summary and discussion

The four small lakes are well buffered with high alkalinity, high pH and high calcium concentrations, and the water compositions are similar to some of those included in the ongoing regular hydrochemical monitoring programme for lakes and streams in the area /2, 3, 4, 5, 6, 7/. However, none of these four lakes showed the high sodium chloride concentrations observed in some of the surface waters in the monitoring programme. This verifies that they are not, or have not recently, been influenced by brackish sea water.

The variation in water composition over the year was large, which may be explained by seasonal changes in temperature, ice cover, precipitation and lake specific parameters such as lake size and drainage area size. The seasonal variations highlight the importance of year round sampling. Continued sampling in the lakes will reveal if the seasonal variation pattern is similar each year.

From the possible future water level restoration point of view, there is a need for water sampling also from Lake Bruksdammen and other possible water sources according to the same sampling scheme as for potential recipients. From this information it may be possible to find a time period when the water composition is the most similar in source and recipient and the impacts from introducing external water will be minimised.

5 References

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

/1/ **SKB 2007.** Forsmark site investigation. Programme for long-term observations of geosphere and biosphere after completed site investigations. SKB R-07-34. Svensk Kärnbränslehantering AB.

/2/ **Nilsson A-C, Karlsson S, Borgiel M, 2003.** Forsmark site investigation. 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.

/3/ **Nilsson A-C, Borgiel M, 2004.** Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, March 2003 to March 2004. SKB P-04-146, Svensk Kärnbränslehantering AB.

/4/ **Nilsson A-C, Borgiel M, 2005.** Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, March 2004 to June 2005. SKB P-05-274, Svensk Kärnbränslehantering AB.

/5/ **Nilsson A-C, Borgiel M, 2007.** Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, July 2005 to June 2006. SKB P-07-95, Svensk Kärnbränslehantering AB.

/6/ **Nilsson A-C, Borgiel M, 2008.** Forsmark site investigation. Sampling and analyses of surface waters. Results from sampling in the Forsmark area, July 2006 to June 2007. SKB P-08-17, Svensk Kärnbränslehantering AB.

/7/ **Qvarfordt S, Borgiel M, Berg C, Nilsson A-C 2008.** Forsmark site investigation. Hydrochemical monitoring of near surface groundwater, surface waters and precipitation. Results from sampling in the Forsmark area, August 2007–December 2007. SKB P-08-55, Svensk Kärnbränslehantering AB.

Appendix 1

Sampling and analytical methods

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^- Cl^-	Mohr-titration IC	≥ 70 0.5 – 70	mg/L	5% 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^- F^-	IC Potentiometric	DL 0.2, RL 0.5 DL 0.1, RL 0.2	mg/L	13% 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% (50–1200 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]	/1/	0.5	µg/L	5%
PON[7]	/1/	0.5	µg/L	5%
POP[7]	/1/	0.1	µg/L	5%
POC[7]	/1/	1	µg/L	4%
Tot-N[7]	/1/	10	µg/L	4%
Tot-P[7]	/1/	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% 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 analysator	0.5	mg/L	8%
TOC	UV oxidation, IR Carbon analysator	0.5	mg/L	10%
$\delta^{2}H$	MS	2	‰ SMOW[7]	0.9 (one standard deviation)
$\delta\ ^{18}O$	MS	0.1	‰ SMOW[7]	0.1 (one standard dev.)
^{3}H	LSC	0.8	TU[8]	0.8
$\delta\ ^{37}Cl$	A (MS)	0.2	‰ SMOC[10]	0.2[17]
$\delta^{13}C$	A (MS)	–	‰ PDB[11]	0.3[17]
^{14}C pmc	A (MS)	–	PMC[12]	0.4[17]
$\delta\ ^{34}S$	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.)

[1] 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.

[2] 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).

[3] Measurement uncertainty reported by the laboratory, generally as ± percent of measured value in question at 95% confidence interval.

[4.v] Reporting limits at electrical cond. 520 mS/m, 1440 mS/m and 3810 mS/m respectively.

[5] Measurement uncertainty at concentrations 100×RL.

[6] Measurement uncertainty at concentrations 10×RL.

[7] Determined only in surface waters. PON, POP and POC refers to Particulate Organic Nitrogen, Phosphorous and Carbon, respectively.

[8] Per mille deviation [16] from SMOW (Standard Mean Oceanic Water).

[9] TU=Tritium Units, where one TU corresponds to a tritium/hydrogen ratio of 10^{-18} (1 Bq/L Tritium = 8.45 TU).

[10] Per mille deviation [16] from SMOC (Standard Mean Oceanic Chloride).

[11] Per mille deviation [16] from PDB (the standard PeeDee Belemnite).

[12] The following relation is valid between pmC (percent modern carbon) and Carbon-14 age: $pmC = 100 \times e^{((1950-y-1.03t)/8274)}$ where y = the year of the C-14 measurement and t = C-14 age.

[13] Per mille deviation [16] from CDT (the standard Canyon Diablo Troilite).

[14] Isotope ratio without unit.

[15] The following expressions are applicable to convert activity to concentration, for uranium-238 and thorium-232: 1 ppm U = 12.4 Bq/kg^{238}U, 1 ppm Th = 3.93 Bq/kg^{232}Th.

[16] Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as: $\delta yI = 1{,}000 \times (K_{sample}-K_{standard})/Kstandard$, where K= the isotope ratio and yI =2H, 18O, 37Cl, 13C or 34S etc.

[17] SKB estimation from duplicate analyses by the contracted laboratory.

Appendix 2

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)
PFM005864	2009-10-07 08:00	2009-10-07 14:00	0.5		16517	6.5	7.90	16.5	0.08	–0.6	10.69	87.0	8.4	–79	989.1
PFM007441	2009-01-14 11:00	2009-01-14 18:00	0.3	0.40	16182	0.7	7.01	61.0	0.29	3.6	1.04	7.2	15.6	13	1,006.6
PFM007441	2009-03-10 11:00	2009-03-10 17:00	0.3	0.50	16223	–0.5	6.86	66.6	0.32	4.3	2.11	14.2	19.1	11	997.9
PFM007441	2009-05-12 13:00	2009-05-12 17:30	0.3	0.40	16267	14.4	8.09	32.2	0.15	–0.7	10.58	103.6	3.8	177	1,024.7
PFM007441	2009-08-11 16:00	2009-08-11 22:00	0.1	0.30	16355	20.6	8.21	27.8	0.13	–1.1	9.48	105.6	3.5	–25	1,005.9
PFM007441	2009-10-07 08:00	2009-10-07 14:00	0.2	0.30	16514	6.7	8.21	25.1	0.12	–0.7	11.84	96.8	2.5	–35	989.1
PFM007441	2009-12-02 07:30	2009-12-02 11:30	0.3	0.35	16625	2.0	7.83	23.5	0.11	–1.2	11.75	85.1	2.6	206	1,014.2
PFM007441	2008-11-18 09:00	2008-11-18 16:30	0.30	0.16	16158	1.1	7.65	28.1	0.13	–1.2	11.77	83.2	6.5	273	989.5
PFM007442	2009-01-15 08:00	2009-01-15 16:00	0.3	0.45	16183	0.5	6.79	44.1	0.21	–1.3	1.10	7.6	15.6	71	1,019.8
PFM007442	2009-03-10 11:00	2009-03-10 17:00	0.2	0.50	16224	–0.4	6.72	51.4	0.24	–1.2	1.53	10.4	13.5	31	998.1
PFM007442	2009-05-12 13:00	2009-05-12 17:30	0.3	0.40	16268	14.2	7.79	25.9	0.12	–1.1	10.33	100.8	8.9	164	1,024.1
PFM007442	2009-08-11 16:00	2009-08-11 22:00	0.1	0.30	16356	19.1	7.61	32.4	0.15	–1.2	8.78	95.0	9.9	1	1,005.7
PFM007442	2009-10-07 08:00	2009-10-07 14:00	0.2	0.25	16515	7.5	8.10	28.0	0.13	–1.1	11.29	94.1	4.8	–61	989.3
PFM007442	2009-12-02 07:30	2009-12-02 11:30	0.3	0.30	16626	2.5	6.97	27.3	0.13	–1.6	4.95	36.2	12.6	215	1,014.1
PFM007442	2008-11-18 09:00	2008-11-18 16:30	0.50	0.14	16159	0.9	7.09	31.3	0.15	–1.0	5.44	38.2	17.6	286	989.7
PFM007443	2009-01-14 11:00	2009-01-14 18:00	0.4	0.50	16181	1.1	6.94	60.7	0.29	0.8	1.05	7.4	24.4	38	1,005.7
PFM007443	2009-03-10 11:00	2009-03-10 17:00	0.3	0.50	16225	–0.3	6.90	43.0	0.20	–1.4	2.60	17.7	10.6	61	998.5
PFM007443	2009-05-12 13:00	2009-05-12 17:30	0.2	0.25	16269	16.8	8.39	32.5	0.16	–0.3	13.59	140.2	3.5	167	1,024.4
PFM007443	2009-08-11 16:00	2009-08-11 22:00	0.1	0.20	16354	20.2	8.90	25.2	0.12	0.5	14.41	159.2	10.0	–28	1,006.2
PFM007443	2009-10-07 08:00	2009-10-07 14:00	0.2	0.20	16516	8.5	8.71	19.6	0.09	0.0	11.80	100.9	3.1	–63	989.6
PFM007443	2009-12-01 14:00	2009-12-01 16:00	0.3	0.30	16624	3.0	7.90	24.0	0.11	–0.6	11.36	84.4	7.2	135	1,006.7
PFM007443	2008-11-18 09:00	2008-11-18 16:30	0.70	0.15	16160	0.9	7.56	34.6	0.16	–1.1	10.72	75.3	17.7	281	982.9
PFM007444	2009-01-14 11:00	2009-01-14 18:00	0.5	0.70	16180	1.2	6.92	55.2	0.26	–0.7	0.63	4.4	14.3	–16	1,004.6
PFM007444	2009-08-11 16:00	2009-08-11 22:00	0.1	0.40	16353	21.3	8.52	28.8	0.14	–0.8	11.63	131.2	4.3	–14	1,007.4
PFM007444	2009-10-06 16:00	2009-10-06 19:00	0.2	0.30	16513	6.7	8.67	28.2	0.13	–1.1	13.09	107.1	1.4	29	1,011.6
PFM007444	2009-12-01 14:00	2009-12-01 16:00	0.3	0.30	16623	3.2	8.15	30.3	0.14	–1.4	11.87	88.6	2.0	115	1,006.1
PFM007444	2008-11-18 09:00	2008-11-18 16:30	0.30	0.10	16161	0.5	7.81	32.7	0.15	–1.3	12.21	84.7	4.0	269	981.6

Sno = Corresponding water sample no.

EC = Electrical conductivity.

NTU = Nephelometric Turbidiy Unit.

ORP = Oxidising Reducing Potential.

* Measurements with low reliability.

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)	Mn (mg/L)
PFM005864	16517	0.5	2009-10-07	6.90	3.9	1.1	29.7	1.7	83	4.2	4.5	1.8	<0.20	<0.20	2.76	0.35	0.035
PFM007441	16182	0.3	2009-01-14	–0.88	8.4	2.3	54.8	4.7	183	11.1	11.9	4.6	<0.20	0.30	4.43	1.10	0.080
PFM007441	16223	0.3	2009-03-10	3.58	16.4	4.5	124.0	10.1	381	22.1	15.3	6.6	<0.20	0.61	11.10	2.65	0.196
PFM007441	16267	0.3	2009-05-12	4.53	6.9	2.3	53.2	4.5	157	8.4	9.5	4.2	<0.20	0.37	0.47	0.12	0.007
PFM007441	16355	0.1	2009-08-11	4.44	7.0	2.4	45.7	4.4	139	8.8	7.7	3.3	<0.20	0.42	2.86	0.12	0.004
PFM007441	16514	0.2	2009-10-07	2.99	6.4	2.2	40.5	3.8	126	8.6	7.8	3.0	<0.20	0.40	1.38	0.03	<0.003
PFM007441	16625	0.3	2009-12-02	4.45	5.4	2.6	40.9	3.4	119	7.2	8.6	3.7	<0.20	0.33	0.60	0.04	<0.003
PFM007441	16158	0.70	2008-11-18	3.85	5.8	3.00	50.9	3.99	137	9.5	18.30	6.89	<0.20	0.33	2.18	0.07	0.0107
PFM007442	16183	0.3	2009-01-15	2.72	4.6	2.4	74.5	4.7	224	13.6	0.8	1.1	<0.20	0.34	6.50	0.63	0.218
PFM007442	16224	0.2	2009-03-10	2.03	5.6	2.5	103.0	5.8	318	14.1	0.5	1.0	<0.20	0.43	10.70	2.17	0.293
PFM007442	16268	0.3	2009-05-12	5.55	3.3	1.8	48.1	2.9	139	6.6	0.9	0.7	<0.20	0.34	2.85	0.09	0.006
PFM007442	16356	0.1	2009-08-11	5.55	3.9	0.9	64.0	3.6	184	6.7	1.2	1.1	<0.20	0.39	4.56	0.20	0.015
PFM007442	16515	0.2	2009-10-07	4.59	3.8	1.0	54.0	3.1	159	6.1	2.2	1.1	<0.20	0.37	3.18	0.05	0.007
PFM007442	16626	0.3	2009-12-02	3.31	3.7	2.6	46.3	2.8	106	10.8	22.0	8.5	<0.20	0.32	5.21	0.13	0.044
PFM007442	16159	0.30	2008-11-18	6.81	3.6	1.88	54.8	3.29	140	15.1	1.92	1.02	<0.20	0.30	5.49	0.32	0.0253
PFM007443	16181	0.4	2009-01-14	3.95	5.0	1.8	63.6	3.4	193	6.2	2.3	1.4	<0.20	0.26	5.76	0.36	0.045
PFM007443	16225	0.3	2009-03-10	2.34	5.7	2.1	82.7	4.3	259	7.8	2.6	1.4	<0.20	0.34	7.04	0.36	0.040
PFM007443	16269	0.2	2009-05-12	4.66	4.5	2.0	64.4	3.4	193	4.3	2.0	1.6	<0.20	0.40	2.66	0.08	0.004
PFM007443	16354	0.1	2009-08-11	6.72	4.6	1.0	48.1	3.2	142	3.4	1.5	1.3	<0.20	0.40	6.87	0.06	<0.003
PFM007443	16516	0.2	2009-10-07	8.28	4.5	1.4	38.5	2.9	112	3.6	1.4	1.1	<0.20	0.38	7.06	0.03	0.005
PFM007443	16624	0.3	2009-12-01	6.26	3.4	2.3	42.9	2.3	119	3.8	6.0	2.7	<0.20	0.30	5.03	0.07	0.007
PFM007443	16160	0.50	2008-11-18	5.65	4.2	2.24	67.2	3.54	192	6.3	4.87	2.08	<0.20	0.33	5.30	0.13	0.0136
PFM007444	16180	0.5	2009-01-14		19.4	4.6	81.5	7.5	259	25.7	8.2	x	<0.20	0.46	8.33	0.23	0.140
PFM007444	16353	0.1	2009-08-11	2.40	12.4	2.5	34.8	5.0	122	15.0	6.7	2.9	<0.20	0.38	4.75	0.00	<0.003
PFM007444	16513	0.2	2009-10-06	3.31	13.2	2.2	35.0	5.0	122	15.9	5.6	2.3	<0.20	0.40	4.72	<0.02	<0.003
PFM007444	16623	0.3	2009-12-01	3.68	12.1	2.5	40.5	4.7	136	14.0	5.0	2.3	<0.20	0.35	3.91	<0.02	<0.003
PFM007444	16161	0.30	2008-11-18	1.77	12.8	3.02	47.2	5.10	155	19.4	7.35	2.97	<0.20	0.36	3.85	0.02	0.0112

Table A2-2. Continued.

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)
PFM005864	16517	0.5	2009-10-07	0.0009	0.036	7.55	7.90	6.5	16.7	16.5
PFM007441	16182	0.3	2009-01-14	<0.0040	0.077	7.09	7.01	0.7	36.9	61.0
PFM007441	16223	0.3	2009-03-10	0.0060	0.164	6.86	6.86	–0.5	68.7	66.6
PFM007441	16267	0.3	2009-05-12	<0.0040	0.072	7.87	8.09	14.4	30.6	32.2
PFM007441	16355	0.1	2009-08-11	<0.0040	0.073	8.11	8.21	20.6	27.4	27.8
PFM007441	16514	0.2	2009-10-07	<0.0040	0.057	8.10	8.21	6.7	25.8	25.1
PFM007441	16625	0.3	2009-12-02	<0.0040	0.055	7.89	7.83	2.0	23.8	23.5
PFM007441	16158	0.70	2008-11-18	<0.0040	0.065	7.84	7.56	0.9	29.3	34.6
PFM007442	16183	0.3	2009-01-15	<0.0040	0.095	6.85	6.79	0.5	40.2	44.1
PFM007442	16224	0.2	2009-03-10	<0.0040	0.124	6.85	6.72	–0.4	54.7	51.4
PFM007442	16268	0.3	2009-05-12	<0.0040	0.061	7.64	7.79	14.2	25.4	25.9
PFM007442	16356	0.1	2009-08-11	<0.0040	0.083	7.74	7.61	19.1	32.3	32.4
PFM007442	16515	0.2	2009-10-07	<0.0040	0.066	8.03	8.10	7.5	28.3	28.0
PFM007442	16626	0.3	2009-12-02	<0.0040	0.057	7.07	6.97	2.5	25.7	27.3
PFM007442	16159	0.30	2008-11-18	<0.0040	0.063	7.40	7.81	0.5	28.5	32.7
PFM007443	16181	0.4	2009-01-14	<0.0040	0.068	7.06	6.94	1.1	34.0	60.7
PFM007443	16225	0.3	2009-03-10	<0.0040	0.082	6.98	6.90	–0.3	44.3	43.0
PFM007443	16269	0.2	2009-05-12	<0.0040	0.069	8.15	8.39	16.8	32.2	32.5
PFM007443	16354	0.1	2009-08-11	<0.0040	0.063	8.84	8.90	20.2	24.4	25.2
PFM007443	16516	0.2	2009-10-07	<0.0040	0.048	8.43	8.71	8.5	20.2	19.6
PFM007443	16624	0.3	2009-12-01	<0.0040	0.048	7.79	7.90	3.0	22.1	24.0
PFM007443	16160	0.50	2008-11-18	<0.0040	0.071	7.81	7.09	0.9	33.7	31.3
PFM007444	16180	0.5	2009-01-14	0.0056	0.122	6.92	6.92	1.2	50.5	55.2
PFM007444	16353	0.1	2009-08-11	<0.0040	0.074	8.37	8.52	21.3	26.5	28.8
PFM007444	16513	0.2	2009-10-06	<0.0040	0.068	8.25	8.67	6.7	26.8	28.2
PFM007444	16623	0.3	2009-12-01	<0.0040	0.073	7.99	8.15	3.2	29.1	30.3
PFM007444	16161	0.30	2008-11-18	<0.0040	0.077	7.82	7.65	1.1	32.4	28.1

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)
PFM005864	16517	2009-10-07	0.5	–	–	–	–	0.0079	–	–	–	5.00
PFM007441	16182	2009-01-14	0.3	0.4070	0.0014	0.0103	1.2100	0.0097	<0.0005	25.90	25.20	5.74
PFM007441	16223	2009-03-10	0.3	1.3300	0.0005	0.0033	3.1100	0.0141	<0.0005	60.50	58.50	9.80
PFM007441	16267	2009-05-12	0.3	0.0169	0.0003	0.0022	1.0900	0.0127	0.0012	22.50	22.30	2.44
PFM007441	16355	2009-08-11	0.1	0.0199	0.0002	0.0071	1.4300	0.0095	<0.0005	27.60	28.00	2.21
PFM007441	16514	2009-10-07	0.2	0.0482	0.0005	0.0199	1.5500	0.0137	0.0007	24.80	24.80	1.16
PFM007441	16625	2009-12-02	0.3	0.2620	0.0018	0.0567	1.3000	0.0072	0.0007	18.30	17.50	1.64
PFM007441	16158	2008-11-18	0.3	0.0272	0.0006	0.0191	1.0700	0.0076	<0.0005	23.50	23.30	2.94
PFM007442	16183	2009-01-15	0.3	0.0705	0.0007	0.0033	0.8700	0.0115	<0.0005	30.50	30.10	5.42
PFM007442	16224	2009-03-10	0.2	0.4700	0.0004	0.0008	1.6700	0.0127	<0.0005	42.20	41.50	8.06
PFM007442	16268	2009-05-12	0.3	0.0113	0.0003	0.0010	0.8790	0.0103	0.0010	24.30	23.90	4.04
PFM007442	16356	2009-08-11	0.1	0.0273	0.0005	0.0106	1.2900	0.0079	<0.0005	35.50	35.20	6.03
PFM007442	16515	2009-10-07	0.2	0.0329	0.0008	0.0284	1.1700	0.0065	<0.0005	27.50	27.80	2.92
PFM007442	16626	2009-12-02	0.3	0.0420	0.0010	0.0220	0.9150	0.0079	<0.0005	24.50	24.30	4.25
PFM007442	16159	2008-11-18	0.5	0.0031	0.0003	0.0004	1.0200	0.0086	<0.0005	38.00	36.70	7.04
PFM007443	16181	2009-01-14	0.4	0.1060	0.0022	0.0147	1.0100	0.0078	<0.0005	32.10	32.80	4.76
PFM007443	16225	2009-03-10	0.3	0.1590	0.0003	0.0073	1.0900	0.0119	<0.0005	31.40	30.40	3.94
PFM007443	16269	2009-05-12	0.2	0.0130	0.0003	0.0008	1.3400	0.0141	0.0019	32.40	30.20	3.96
PFM007443	16354	2009-08-11	0.1	0.0737	0.0004	0.0082	1.5300	0.0113	0.0012	38.90	37.60	4.02
PFM007443	16516	2009-10-07	0.2	0.0905	0.0007	0.0239	2.3200	0.0454	<0.0005	35.80	35.80	2.22
PFM007443	16624	2009-12-01	0.3	0.0759	0.0015	0.0419	1.2200	0.0095	0.0008	23.50	23.40	2.59
PFM007443	16160	2008-11-18	0.7	0.0388	0.0005	0.0084	1.1500	0.0087	<0.0005	35.70	35.00	5.66
PFM007444	16180	2009-01-14	0.5	0.7340	0.0005	0.0035	1.9900	0.0160	<0.0005	40.60	40.60	4.78
PFM007444	16353	2009-08-11	0.1	0.0182	0.0002	0.0064	1.7100	0.0093	<0.0005	23.50	22.80	1.47
PFM007444	16513	2009-10-06	0.2	0.0249	0.0002	0.0005	1.3000	0.0059	<0.0005	20.50	19.80	1.02
PFM007444	16623	2009-12-01	0.3	0.1120	0.0011	0.0289	1.1500	0.0055	<0.0005	17.90	17.60	1.02
PFM007444	16161	2008-11-18	0.3	0.2030	0.0009	0.0284	1.3100	0.0073	0.0007	20.00	20.00	1.74

Table A2-4. Trace metals.

Idcode	**PFM005864**	
Sample no.	**16517**	
Sampling date	**2009-10-07**	
Depth (m)	**0.5**	
Trace element	**Value**	**Unit**
Al	18.500	(ug/L)
Cd	<0.002	(ug/L)
Cr	0.200	(ug/L)
Cu	0.630	(ug/L)
Co	0.060	(ug/L)
Hg	<0.002	(ug/L)
Ni	0.499	(ug/L)
Zn	2.110	(ug/L)
Pb	0.103	(ug/L)
V	0.249	(ug/L)
Mo	0.317	(ug/L)
Ba	13.400	(ug/L)
U	0.535	(ug/L)
Th	0.030	(ug/L)
Sc	<0.050	(ug/L)
Rb	2.150	(ug/L)
Y	0.168	(ug/L)
Zr	0.270	(ug/L)
Sb	0.073	(ug/L)
Cs	<0.030	(ug/L)
La	0.116	(ug/L)
Hf	0.008	(ug/L)
Tl	<0.010	(ug/L)
Ce	0.127	(ug/L)
Pr	0.0298	(ug/L)
Nd	0.1190	(ug/L)
Sm	0.0263	(ug/L)
Eu	<0.0050	(ug/L)
Gd	0.0272	(ug/L)
Tb	<0.0050	(ug/L)
Dy	0.0247	(ug/L)
Ho	0.0057	(ug/L)
Er	0.0174	(ug/L)
Tm	<0.0040	(ug/L)
Yb	0.0159	(ug/L)
Lu	<0.0050	(ug/L)