

Report

P-17-39

June 2018



Hydrochemical monitoring of near surface groundwater and surface waters

Results from the sampling period January–December 2015

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SVENSK KÄRNBRÄNSLEHANTERING

ISSN 1651-4416

SKB P-17-39

ID 1688211

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Sveriges Vattenekologer

Keywords: Surface waters, Near surface groundwaters, Chemical sampling, Chemical analysis, Water composition, AP SFK-10-082.

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Abstract

This report presents the hydrochemical monitoring of near surface groundwaters and surface waters in Forsmark during the sampling period January to December 2015.

Near surface groundwaters were sampled and analysed four times during this period. The samples were collected from five shallow soil monitoring wells and one BAT-pipe.

Sampling of surface waters (streams, lakes and a shallow sea bay) was performed once per month (except July) in the four streams and once per season (four times) in the lakes and the sea bay included in the monitoring programme. Water from an extra sampling object (the outlet of Lake Biotestsjön) was collected once per month (except July) for tritium analyses in order to check for possible tritium contamination from the nuclear power plant.

The results from the near surface groundwater and surface water monitoring include field measurements of redox potential (ORP), pH, dissolved oxygen, electrical conductivity and water temperature, as well as chemical analyses of major constituents, nutrient salts, trace metals and isotopes. For surface waters, the field measurements also include depth and turbidity.

Generally, the new data confirm the knowledge and conclusions from the earlier investigation periods. The characters of the near surface groundwaters in the monitoring programme generally remain unchanged also this year.

Surface waters in the lakes and streams in the Forsmark area are well buffered with high alkalinity, high pH and high calcium concentrations. The proportions of the major ions in the sampled freshwaters and the shallow sea bay were similar to previous years, showing no major changes, also, the concentrations of total nitrogen and total phosphorus were similar to previous years. However, a slightly elevated concentration of Na^+ and Cl^- indicate a salt water inflow into Bolundsfjärden. Previous data indicates periodic tritium contamination from the adjacent nuclear power plant in water samples from near the cooling water outlet. Slightly elevated tritium values were also found in the June and September samples 2015.

Sammanfattning

Rapporten dokumenterar den hydrokemiska övervakningen av ytnära grundvatten och ytvatten i Forsmarksområdet under provtagningsperioden januari till december 2015.

Provtagning och analyser av ytnära grundvatten från fem jordborrhål samt ett BAT-rör utfördes vid fyra tillfällen under 2015.

Ytvatten provtogs en gång per månad (utom i juli) i fyra bäckar samt fyra gånger per år (en gång per årstid) i tre sjöar och en grund havsvik. En extra provpunkt vid utloppet av Biotestsjön provtogs en gång per månad (utom i juli) i syfte att kontrollera eventuell kontaminering av tritium från kärnkraftverket.

De erhållna resultaten från ytnära grundvatten och ytvatten omfattar fältmätningar av ORP (redox-potential), pH, löst syre, elektrisk konduktivitet och vattentemperatur samt kemiska analyser av huvudkomponenter, närsalter, kolföreningar, spårelement och isotoper. För ytvatten mäts även djup, atmosfärstryck och turbiditet.

Årets data bekräftar generellt slutsatser från tidigare undersökningsperioder. Ytvattnet i sjöar och bäckar i Forsmarksområdet är väl buffrade med hög alkalinitet, högt pH och höga kalciumkoncentrationer. Koncentrationen av de vanligaste jonerna i de provtagna sötvattnen och havspunkten liknade föregående år och visar därmed inga större förändringar under året. Något förhöjda koncentrationer av natrium och kalium indikerar dock ett möjligt saltvattensinflöde i Bolundsfjärden. Under juni och september uppmättes något förhöjda halter av tritium i proverna nära kylvattenutsläppet från kärnkraftverket (Biotestsjön).

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1 Introduction

The site investigations in Forsmark were finished in June 2007 (SKB 2001, 2005) and a less intensive phase commenced when a prolonged monitoring programme was established (SKB 2007). This document reports the performance and results for near surface groundwater and surface waters during the period January to December 2015. The monitoring has been ongoing, in one form or another, since 2001 and is today governed by the monitoring programme from 2007 (SKB 2007).

The sampling objects for near surface groundwater in soil include shallow monitoring wells and wells/pipes equipped with BAT-filter tips (a special sampling system described in Section 2.3.3). The different sampling objects are presented in Table 2-1 and a map showing their location is presented in Figure 2-1. The surface water sampling sites include lake waters, stream waters and one sea water location (shallow bay) in the Forsmark area. The sampling locations are presented in Figure 3-1 and Table 3-1.

The monitoring activities include sampling and chemical analyses as well as field measurements. The controlling documents for the activities are listed in Table 1-1. The activity plans and 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 SFK 10-082). Only data in the database 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.



Figure 1-1. Sampling near surface groundwater from the well SFM0023 in January.

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

Activity plans	Number	Version
Hydrokemisk monitoringsprogram för gölar, ytvatten och ytnära grundvatten januari 2015 till juni 2016.	AP SFK 10-082	1.0
Method descriptions	Number	Version
Metodbeskrivning för ytvattenprovtagningar vid platsundersökningar.	SKB MB 900.004	2.0
Mätsystembeskrivning för YSI. Multi parametersystem för vattenmätningar.	SKB MD 910.003	1.0
Provtagning och Provhantering	SKB MD 452.001	8.0

Water sampling and measurement procedures are also described in SKB PIR-04-09 “Metodik för provtagning av ekologiska parametrar i hav”, SKB PIR-04-06, “Metodik för provtagning av ekologiska parametrar i sjöar och vattendrag”, and SKB PIR-04-12, ”Översikt över provhanters- och analysrutiner för vattenprov” (SKB internal documents).

2 Near surface groundwaters

2.1 Objectives and scope

An extensive, two-year-long sampling campaign designed to characterise near surface groundwaters in different types of environments within the candidate area (SKB 2001) was followed by a reduced monitoring programme in July 2005 (SKB 2005). The site investigation of the candidate area was concluded in June 2007 but the monitoring programme (SKB 2007) will continue until the construction of the repository for spent nuclear fuel starts and during the construction and operation phase. This in order to monitor the water composition and obtain long time-series of data, first to create a base-line describing the natural variations and second to follow changes caused by the construction and operation of the repository.

During the reported period, January–December 2015, the sampling locations (stand pipes) within the monitoring programme were sampled at four occasions, in January, April, August and October. The five monitoring wells (stand pipes) and the pipe equipped with a BAT-filter tip are all located in the prioritised north-western part of the area where the storage facility will be built.

The activity includes water sampling for chemical analysis as well as direct measurements in the field of parameters such as ORP (redox potential), pH, dissolved oxygen, electrical conductivity (EC) and water temperature. The analytical protocol includes major constituents, nutrient salts, silica, carbon species as well as isotopes and trace metals, see Tables 2-2 and 2-3.

2.2 Sampling objects

The monitoring programme for near surface groundwater includes five stand pipes and one BAT-pipe. The wells/pipes are of the following types:

1. Single stand pipes made of HDPE located close to drill sites.
2. Double and single stand pipes made of HDPE. Double pipes means that one of the pipes is equipped with a permanently installed sensor for logging the groundwater pressure and the other pipe is intended for hydrochemical sampling.
3. Stand pipes installed in the sediment below the water layer in Lake Bolundsfjärden (Figure 1-1). These pipes are made of ordinary, non-stainless iron. Stand pipes located in till below fen are of the same type.
4. Pipes equipped with BAT-filter tips as described in Section 2.3.3.

For pipe types 1) to 3), the positions of the filter/screen part, and for type 4) the position of the BAT-filter tip, correspond to the upper and lower section limits (Secup and Seclow) in the Sicada database. The section limits refer to the top of the stand pipe (Top of Casing/TOC).

The sampled monitoring wells and their stand pipe types are listed in Table 2-1. The locations of the different sampling objects are displayed in Figure 2-1. Total depths and filter/screen depths, as well as coordinates for the different stand pipes, are given in Berg et al. (2015) together with outlines of the different pipe types.

Table 2-1. List of sampling objects, type of sampling and type of object.

Idcode	Comments on sampled object	Type*
SFM0001	Stand pipe connected to drill site	A
SFM0023	Stand pipe in sediment below water surface (iron pipe)	C
SFM0032	Double-pipe for chemistry	B
SFM0037	Double-pipe for chemistry	B
SFM0049	Double-pipe for chemistry	B
SFM0051	BAT-system, drill site 1	D

* Code used to distinguish between different types of soil monitoring wells/stand pipes included in the monitoring programme, see Berg et al. (2015).

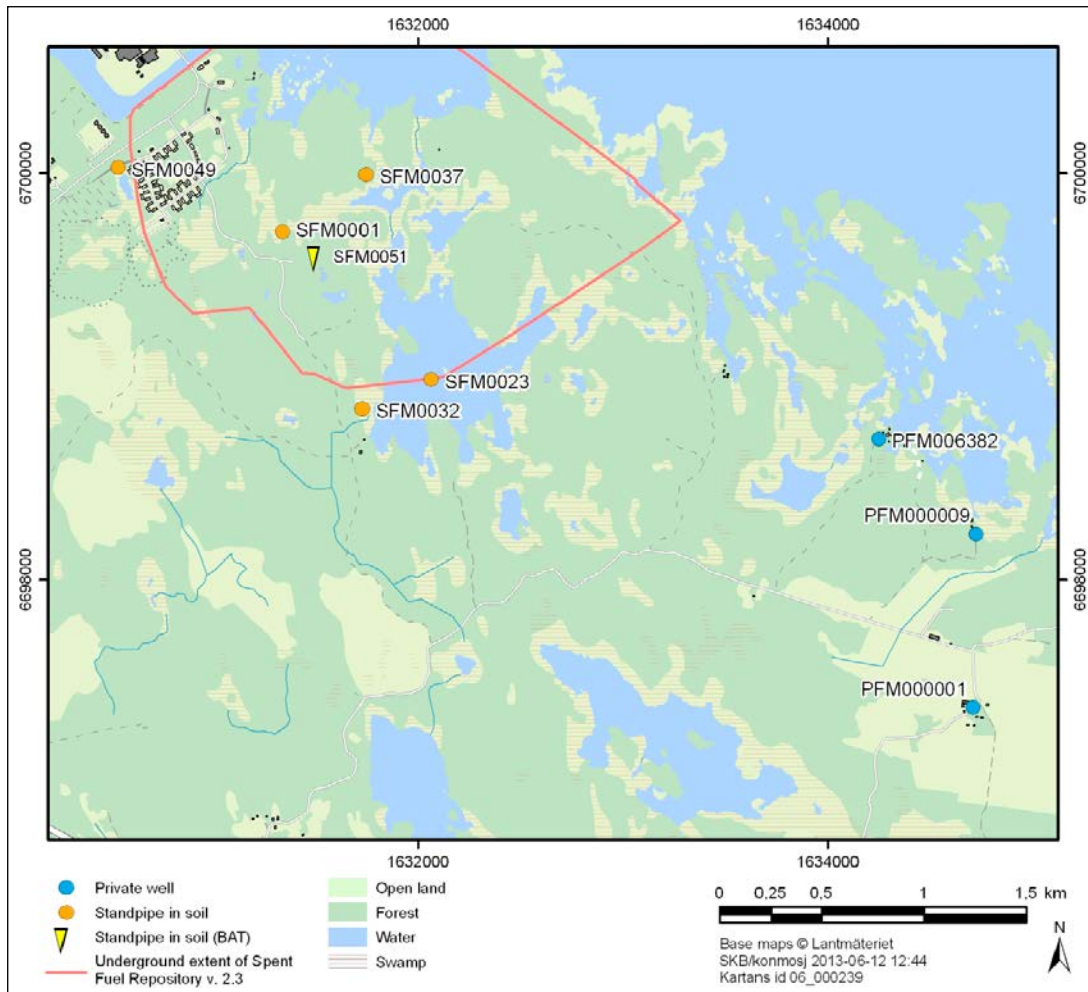


Figure 2-1. Location of the different types of soil monitoring wells included in the monitoring programme for near surface groundwater.

2.3 Equipment

2.3.1 Sampling equipment

Groundwater samples from the shallow monitoring stand pipes in soil were collected using pump setups, each one consisting of a submersible electrical pump (12V, Awimex) connected to a 5–10 m long polyamide-tube (Tecalan) of 8 mm diameter. Manually operated electrical regulators were used to adjust the water flow to a maximum of 1 litre/minute. Disposable filters (0.45 µm, Ø = 22 mm) were used for filtration of some sample portions. The filters were fitted to 60 ml syringes. A separate pump set-up was used for the stand pipe made from standard iron, i.e. pipe SFM0023, in order to minimize the risk of contaminating other samples.

2.3.2 Multi-parameter sondes

Field measurements were conducted with a multi-parameter sonde, InSitu Troll9500, Figure 2-2, which also includes a comparison of filed setup with the sonde used previous years, YSI 600 QS (until April 2013). A hand-held PC is connected to the sonde through a cable for logging and initial field control of data.



Figure 2-2. The multi parameter sonde used in 2015, Troll9500, to the right and the sonde used until April 2013, YSI 600 QS, to the left for comparison of set-up.

The measured parameters in near surface groundwaters included pH, water temperature, oxygen, ORP (redox potential) as well as electrical conductivity. The measurements were conducted in a flow-through cell, Figure 2-2.

2.3.3 BAT-equipment

Water sampling in the stand pipe equipped with a BAT-filter tip was performed with a GeoN BAT-type groundwater sampler. The sampler carries an evacuated and hermetically closed glass sample container, 500 mL, and a vial. The vial is fitted with a cap with a rubber disc, similar to the disc in the filter tip. The needle of the sampler, which is “double-ended”, penetrates through the two rubber discs, thus connecting the filter tip to the vial cap, see Figure 2-3. Due to the vacuum in the vial, water will be sucked from the aquifer, through the filter and the needle, into the vial.

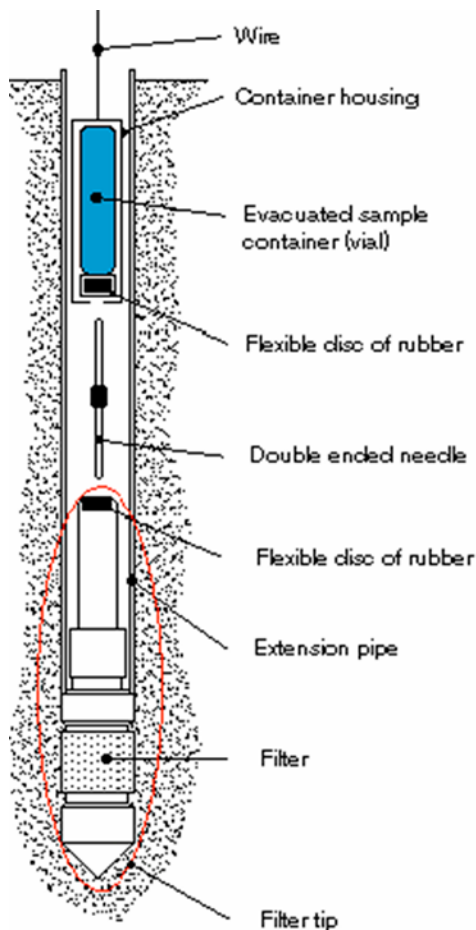


Figure 2-3. Outline of BAT-sampler system and the BAT-filter tip.

2.4 Performance

2.4.1 Sampling programme

Sampling schedule

The sampling schedule for the sampling programme is given in Table 2-2. The bottles were filled and the analyses were performed according to the different SKB chemical classes (class 3 and class 5, respectively) as summarised in Table 2-3.

Presampling preparations

Prior to the sampling campaigns, sample bottles were labelled and packed in insulated boxes/bags. Acid additions were made in advance to bottles intended for trace metal and iron analyses as well as acidified archive samples. Bottles with nitric acid added were put in a separate plastic bag and kept outside the box away from the other sample bottles in order to avoid contamination. The pump setups were washed and rinsed with deionised water before use and all parts of equipment were kept well protected in plastic bags or in tight containers. Calibration of the sondes was performed according to the measurement system description (the operator's manual for TROLL9500, Rev. 007, 2009).

Table 2-2. Sampling schedule January 2015–December 2015.

Year	Month	Week	Sampling object*	Sampling and analysis class and options
2015	January	3	Shallow monitoring wells, A, B, C BAT-pipe, D	SKB class 5 SKB class 5
2015	April	17	Shallow monitoring wells, A, B, C BAT-pipe, D	SKB class 3 SKB class 3
2015	August	32	Shallow monitoring wells, A, B, C BAT-pipe, D	SKB class 5 SKB class 5
2015	October	41	Shallow monitoring wells, A, B, C BAT-pipe, D	SKB class 3 SKB class 3

* The sampling object types A, B, C and D are defined in Table 2-1.

Table 2-3. Sample portions/bottles and preparation procedures for class 3 and class 5.

Bottle volume (mL)	Number of bottles	Components	Preparation
100	1	Br, I	
100	1	Deuterium ² H, ¹⁸ O	–
250	2	Anions (Br, SO ₄ , Cl, F), Alkalinity, pH, Electric conductivity	–
500	1	Tritium, ³ H	–
100	1	Tot-N, Tot-P	–
100	1	TOC	–
250	2	Archive samples	–
25	4	Ammonia, NO _x , Silicate, Phosphate	Filtering with syringe/0.4 µm filter
100	2	DOC, DIC	Filtering with syringe/0.4 µm filter
125	1	Major constituents; cations ^{1a} and S, Si. Environmental metals ^{*1b} , trace metals ^{*1c}	Acid addition (1 mL conc. HNO ₃) Filtering with syringe/0.4 µm,
100	2	Archive samples	Acid addition (1 mL conc. HNO ₃) Filtering with syringe/0.4 µm,
250	1	Fe(II)/Fetot	Acid addition (2.5 mL conc. HCl) Filtering with 0.4 µm filter,
Winkler bottles 125	2	HS	0.5 ml ZnAc + 0.5 ml NaOH and mix

■ Class 3 and 5.

■ Class 5.

* Only class 5 samples.

^{1a} Na, K, Ca, Mg, Si, Fe, Mn, Li, Sr.

^{1b} Al, As, Ba, B, Cd, Co, Cr, Cu, Hg, Mo, Ni, P, Pb, V, Zn.

^{1c} Sc, Rb, Y, Zr, I, Sb, Cs, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, U, Th.

Sampling and measurements

The groundwater sampling procedure described below was generally applied in the groundwater pipes and wells, except for the BAT-pipe.

First, the groundwater level in the pipe was established by sounding and the water volume of the pipe was calculated. The pump with its connected tube was lowered carefully in order to prevent dirt from entering the pipe. The water inlet of the submersible pump was lowered to the filter/screen section of the pipe or just above. Pumping was then performed at a maximum flow rate of one litre per minute. The pumped water was disposed of at least 10 m away from the sampling object where it filtrated back into the ground. The pumping phases were as follows:

- Exchange of water volume in pipe and tubes: The water volume was exchanged three to five times (depending on the exchange/recovery time) prior to the actual sampling.
- Field measurement: A flow-through cell was connected to the pump setup and measurements were performed with the multi parameter sonde. The results were recorded when the electrodes and sensors in the flow-through cell showed stable values (minimum 10 minutes). A judgement of the plausibility of the values was made in the field and accepted values were noted in the field protocol and logged on the hand-held PC.
- Sampling: All sample bottles, except the ones with added acid, were rinsed three times with sample water before they were filled. Disposable filters were used for filtration of water portions for major components, trace metals, Fe, nutrients and DOC/DIC. Each filter was rinsed with sample water (approx. 20 mL) before the sample portion/filtrate was collected. Bottles containing acid were the last ones to be filled in order to prevent acid contamination in the other sample portions. Disposable plastic gloves were used during the sampling. The samples were transported back from the field in insulated bags.

Sampling performance using the BAT-system

Sampling of the BAT-filter tip pipe followed the sampling schedule for the regular shallow soil pipes. The approximate time to fill one 500 mL container in SFM0051 was 15 minutes.

A total of four or five sample containers were filled from the BAT-pipe in order to obtain enough water for the analyses. In order to exchange the water volume in the BAT-pipe before sampling, the first sample container filled was not used for any analyses. The use of the sample volumes and the analyses performed are listed in Table 2-5.

2.4.2 Sample handling and analyses

Table 2-4 lists the collected samples during the reported period. Measurements/analyses of pH_(lab), electrical conductivity_(lab) and alkalinity as well as spectrophotometric analyses of total iron and ferrous iron (Fe+II) were conducted immediately at the site laboratory. An overview of sample treatments and analytical routines for major constituents, minor anions, trace metals and isotopes is given in Appendix 1. The routines are applicable independent of sampling method or type of sampling object.

Table 2-4. List of collected samples during the period January to December 2015 (X = collected sample).

Id code	Name or location	Week/ Year				Sum (X)
		3/15	17/15	32/15	41/15	
Soil wells						
SFM 0001	Drill site 1	X	X	X	X	4
SFM 0023	Bolundsfjärden	X	X	X	X	4
SFM 0032	SV-Bolundsfjärden	X	X	X	X	4
SFM 0037	N-Bolundsfjärden	X	X	X	X	4
SFM 0049	Bostadsområdet	X	X	X	X	4
BAT pipes						
SFM0051	Drill site 1	X	X	X	X	4
Sum (X)		6	6	6	6	24

Table 2-5. Sample containers and analyses, bat pipe SFM0051.

Sample container no.	Analyses and determinations			Total volume
1–2	Chloride, bromide, fluoride and sulphate by IC. (200 mL+50 mL)	Alkalinity titr, pH and EC. (150 mL)	$\delta^2\text{H}$, $\delta^{18}\text{O}$ (100 mL)	500 mL
3	Tritium (500 mL)			Approx. 500 mL
4	Fe (+II), (Fe(tot)) (200 mL)	Major constituents, trace elements, $^{10}\text{B}/^{11}\text{B}$ by ICP AES/MS (125 mL)	5 mL of HCl was added to the container prior to sampling.	325 mL

2.4.3 Nonconformities

Only the field measurements are reported from the sampling location SFM0023. The analytical data for the water samples have been excluded and will be error marked in the Sicada database. This is due to unreliable data. The exclusion of these data is due to highly variable water quality both during the sampling and between each sampling occasions. The differences in water quality can e.g. be observed during the sampling. The water colour is shifting from clear to black. Also, the charge balance error is rarely acceptable. The bad water quality is probably due to the corroded iron stand pipe at this site. The pipe needs fixing to obtain reliable results.

In October, the O₂ probe on the multi parameter sonde malfunctioned and the dissolved oxygen values was therefore disregarded.

Furthermore, the private wells (PFM000001, PFM000009 and PFM006382) were not sampled during year 2015.

2.5 Results

2.5.1 Field measurements

The pH, electrical conductivity, dissolved oxygen, oxygen saturation, water temperature and redox potential (ORP) results from the field measurements are presented in Appendix 2.

pH-measurement

Field measurements of pH are plotted against the corresponding laboratory values in Figure 2-4. The data show good agreement between field and laboratory measurements although some deviation is expected due to different water temperatures and the time delay between field and laboratory measurements.

Electrical conductivity

Electrical conductivity values from the field are plotted versus corresponding laboratory values in Figure 2-5. The values show good agreement between field and laboratory measurements.

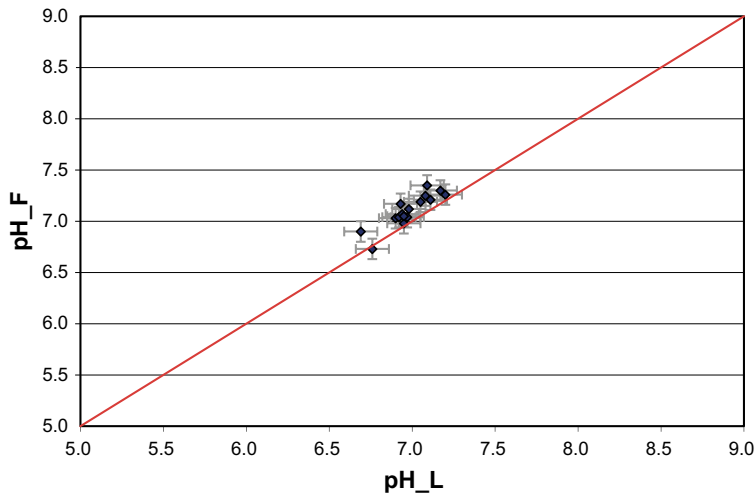


Figure 2-4. Field-pH (pH_F) values versus laboratory-pH (pH_L) values. Field-pH and laboratory-pH values are measured at prevailing water temperature and at 25° C respectively. The measurement uncertainty (Appendix 1) is shown as error bars.

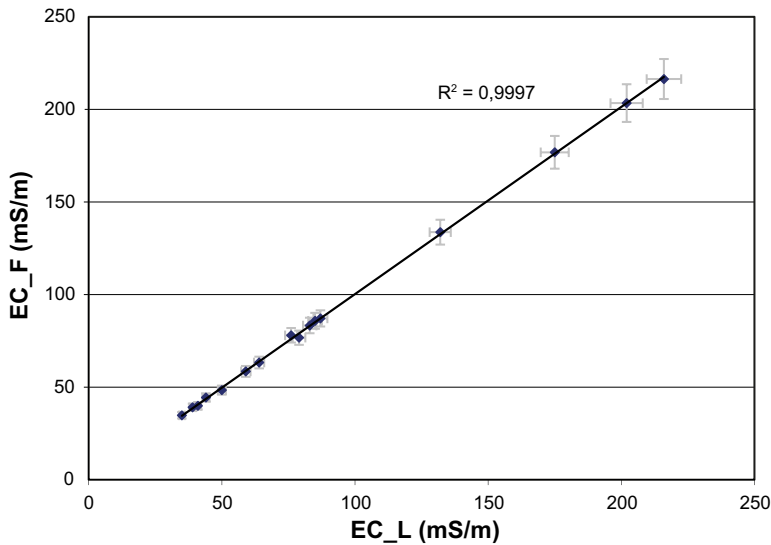


Figure 2-5. Electrical conductivity (25° C). Field measurements (EC_F) versus laboratory values (EC_L). The measurement uncertainty (Appendix 1) is shown as error bars.

Dissolved oxygen

The measurements of dissolved oxygen were checked in April 2005 by comparison with results from laboratory analyses (Nilsson and Borgiel 2005). This control showed that, generally, the field measurement values were somewhat higher, especially at oxygen concentrations below 4 mg/L. Field measurements of dissolved oxygen are presented in Appendix 2.

ORP-measurements and redox conditions

ORP-measurements (Oxidation Reduction Potential) have been conducted using the multipurpose measurement sonde. The recorded ORP-values should be used with great caution and merely considered as an indication of the redox conditions in the waters. Measured ORP-values are presented in Appendix 2.

2.5.2 Water analyses

Basic components

The basic water analyses include the major constituents Na, K, Ca, Mg, Sr, S, SO_4^{2-} , Cl^- , Si and HCO_3^- as well as the minor constituents Fe, Li, Mn, Br, F, I and HS^- . Furthermore, batch measurements of pH and electrical conductivity are included. The basic water analysis data are compiled in Appendix 2. The charge balance error provides an indication of the quality and uncertainty of the analyses of major constituents and, the charge balance error was calculated for all samples according to the formula below.

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

Relative errors within 5 % are considered acceptable. All samples collected in 2015 showed acceptable errors (less than/within ± 5 %). However, note that, due to unreliable data, the samples from sampling well SFM0023 has been excluded.

Differences in flow rate may result in different water characteristics in the duplicate samples which may result in a large charge balance error. Duplicate analyses by a second laboratory or another method are conducted regularly for some of the analysed constituents as a further check of the reliability of the analyses.

The bromide analyses are often uncertain, for example the detection limit of bromide by ion chromatography (<0.2 mg/L) is often too high for fresh waters. Therefore, duplicate analyses by ICP (bromine) have been performed for most samples.

Surface water supplements

Shallow groundwater analysis includes the surface water supplements/options $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N} + \text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, tot-N, tot-P, $\text{PO}_4\text{-P}$, TOC, DOC and DIC. The analytical data are compiled in Appendix 2. The DIC values should be used with care and bicarbonate values (by alkalinity titration) are considered more reliable.

The concentrations of the different nitrogen, phosphorous and carbon compounds may show seasonal variation depending on decomposition processes and varying redox conditions also in shallow groundwaters, however, this variation is more pronounced in surface waters. The graphs in Figure 2-7 show the variations of total nitrogen, ammonium and phosphate in the sampled groundwater from four soil-pipes included in the long-term monitoring programme (data from soil-pipe SFM0023 was excluded in 2015).

The results from 2015 show concentrations within the previously recorded variations for each sampling location, except for well SFM0049. Here the concentrations of total nitrogen were lower during April 2015 compared to previous years (Figure 2-7).



Figure 2-6. Sampling of near surface groundwater at the sampling well SFM0001.

Trace metals

The analyses of trace and rare earth metals include Al, As, Sc, Cd, Cr, Cu, Co, Hg, Ni, Zn, Pb, V, U, Th, Rb, Y, Zr, Mo, In, Sb, Cs, Ba, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. The data are compiled in Appendix 2.

These elements are generally present at low concentrations in the groundwater and the risk for contamination is high. Especially data on common metals such as Al, Cr, Cu, Co, Ni and Zn must be used with caution. Trace metals are not analysed in the iron stand pipe SFM0023 in Lake Bolundsfjärden because of contamination from the iron pipe.

Isotopes

Isotope determinations including the stable isotopes δD , and $\delta^{18}O$ as well as the radioactive isotope 3H (TU) are compiled in Appendix 2.

2.6 Summary and discussion

The characters of the near surface groundwater in the monitoring programme generally remain unchanged. The chemical investigation routines for near surface groundwater are well established after several years of field work, reporting and data administration and this year of the long-term monitoring programme has passed without any major nonconformities or surprises. However, the groundwater analyses data from the stand pipe in Lake Bolundsfjärden (SFM0023) was excluded from this report and will also be error marked in the Sicada database. The reason for this is the low water quality, resulting from the bad condition of the iron stand pipe in the well.

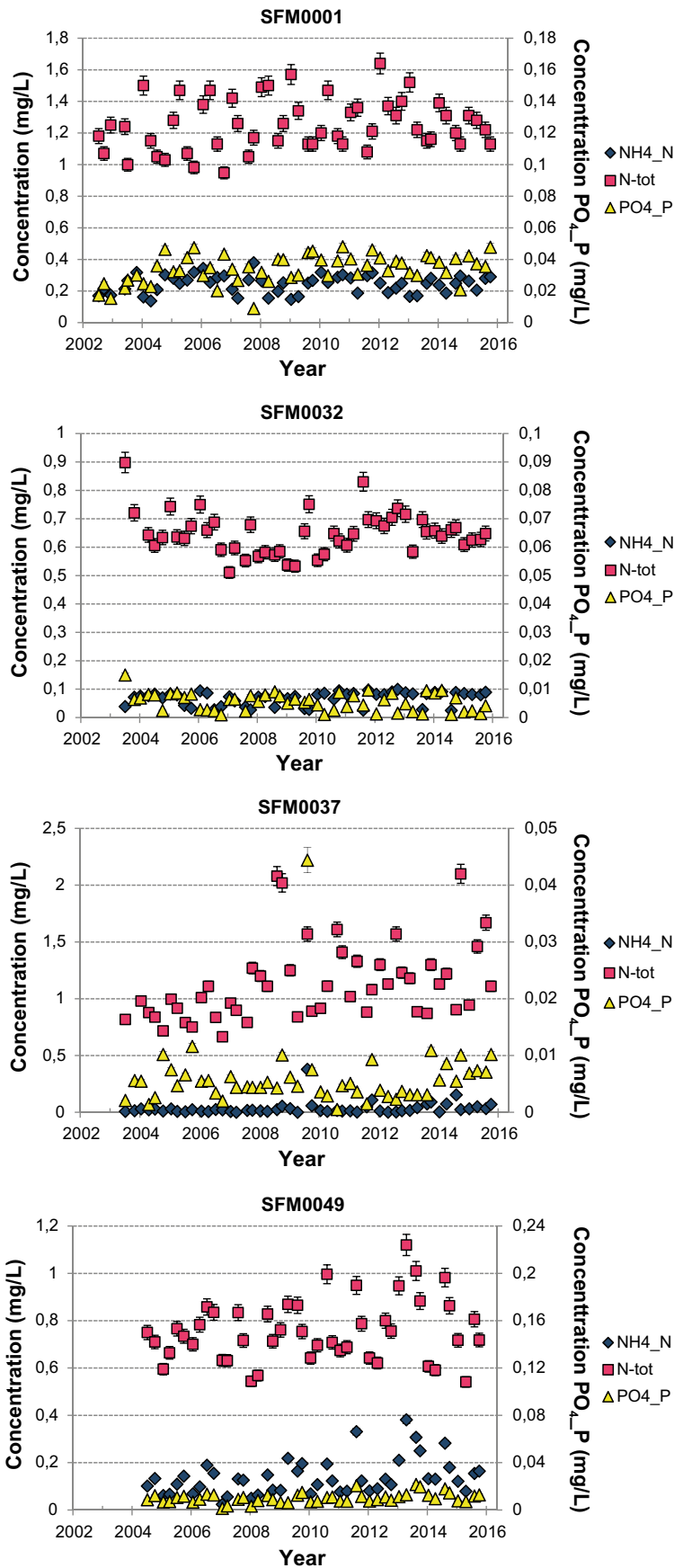


Figure 2-7. Ammonium, total nitrogen and phosphate concentrations plotted versus sampling date for the sampling wells SFM0001, SFM0032, SFM0037 and SFM0049. Note the different scales and that the phosphate concentration is given on the secondary Y-axis. The measurement uncertainty is shown as error bars.

3 Surface waters

3.1 Objectives and scope

Sampling and analyses of surface waters in the Forsmark area began in 2002 during the site investigation phase. After the site investigations, the surface water monitoring programme continued and focused on sampling locations in the prioritised north-western part of the Forsmark candidate area (SKB 2007). The monitoring programme was reviewed and modified in 2010. The modifications of the programme have resulted in reduced sampling frequency in the lakes and sea and fewer isotope determinations but also extended sampling in the streams adding environmental metals to the analytical programme at every sampling occasion.

The main objectives are to obtain long time-series of data to create a base-line, describing the natural variations. This in order to allow identification of eventual perturbation effects from SKB activities during the future construction and operation of the repository for nuclear waste.

The programme includes sampling of water for chemical analysis as well as direct field measurements of physical and chemical parameters such as ORP (Oxidation Reduction Potential), pH, dissolved oxygen, EC, measurement depth, turbidity and water temperature.

The extent of the sampling varied at different occasions. The streams were sampled at eleven occasions (once per month, except for July) and the lake and sea sampling locations at four occasions (once per season) during the reported time period. Analyses of major constituents, surface water supplements (nutrient salts etc) and trace elements were conducted frequently (once a month) while extended analyses, including also isotopes were performed once per season, i.e. in January, April, August and late September/early October.

3.2 Sampling locations and sampling schedule

The monitoring programme includes four lakes, one shallow sea bay location and four streams. Furthermore, a location close to the outlet of cooling water from the nuclear power plant is sampled in order to monitor possible tritium contamination.

The sampling locations are presented in Figure 3-1. Table 3-1 lists the location id-codes, the coordinates and the names together with clarifying comments. The sampling schedule for 2015 is given in Table 3-2.

Table 3-1. Sampling locations (Id-code, coordinates, name and comments).

Sampling locations	Coordinates (RT90 RHB70)	Name	Comments
Lakes			
PFM000074	16 29 854, 66 99 393	Labboträsket	
PFM000097*	16 31 814, 66 99 868	Norra bassängen	* Only field measurements
PFM000107	16 32 065, 66 99 031	Bolundsfjärden	
PFM000117	16 31 946, 66 97 118	Eckarfjärden	
Shallow sea bays and sea location			
PFM000062	16 31 921, 67 00 605	SV Forslingens grund	
PFM000082	16 32 528, 67 01 336		Alternative to PFM00062
PFM102269	16 31 405, 67 04 412	Cooling water outlet, Lake Biotestsjön	Check of tritium contamination
Streams			
PFM000066	16 29 343, 66 99 064	Öster Gunnarsboträsket	
PFM000068	16 31 641, 66 98 735	Kungsträsket	
PFM000069	16 31 510, 66 98 440	Bolundsskogen	
PFM000070	16 32 061, 66 97 319	Norr Eckarfjärden	

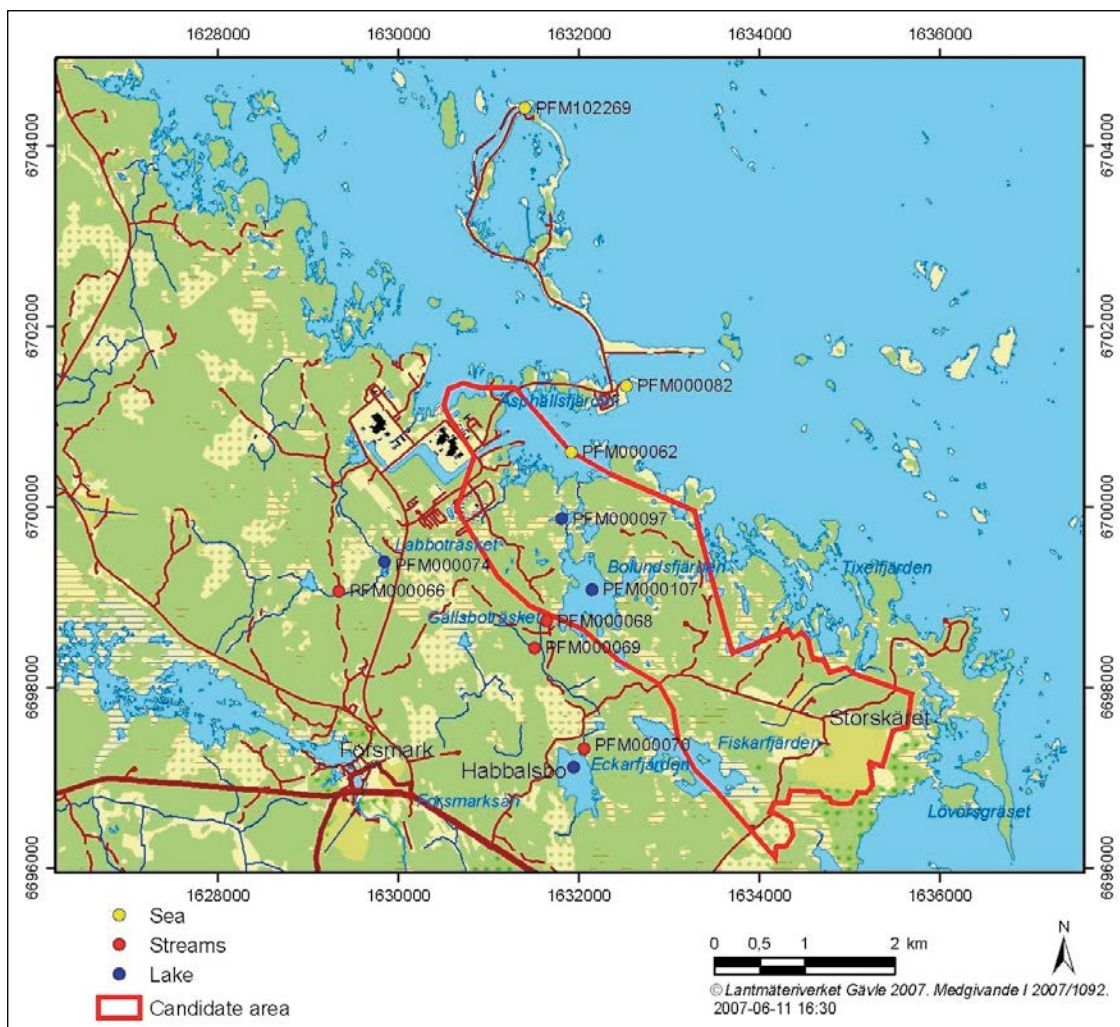


Figure 3-1. Sampling locations within the monitoring programme. One location constitutes an alternative for a regular sampling position (see Table 3-1).

Table 3-2. Surface water sampling schedule from January to December 2015. Sampling occasions in bold characters include lake and sea locations.

Year	Month	Week	Programme type*
2015	January	3	E
2015	February	7	M
2015	March	12	M
2015	April	17	E
2015	May	21	M
2015	June	26	M
2015	August	32	E
2015	September	35	M
2015	September–October	41	E
2015	November	45	M
2015	December	49	M

* M = main programme (SKB class 3 including surface water supplements), E = extended programme (SKB class 5 including surface water supplements).



Figure 3-2. Field sampling at PFM000068 in January 2015.

3.3 Equipment

3.3.1 Sampling equipment

Water samples were collected using a pump setup consisting of an electrical peristaltic pump system, Solinst, model 410, connected to 4–8 m long Teflon-tubes (FEP 140) of 5 mm inner diameter. The sampling equipment is presented in Figure 3-3.



Figure 3-3. Winter sampling of surface water using the peristaltic pump system (PPS). A schematic presentation of the PPS is shown below the photo. Photo from the sampling at PFM00062.

3.3.2 Multi-parameter sondes

Field measurements have been conducted with a multi-parameter sonde, InSitu Troll9500 since April 2013. The replacement of the old sonde, YSI 6600 EDS to the new sond resulted in less field parameters, see Table 3-3. A hand-held PC is connected to the sonde through a cable for logging and initial field control of data.

Table 3-3. Parameters measured by the old YSI sonde and the new TROLL9500.

Parameter	YSI 6600 EDS	TROLL9500
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	No
Turbidity (NTU)	Yes	Yes
Chlorophyll (µg/l)	Yes	No
Light / PAR* (µmoles s ⁻¹ m ⁻²)	Yes	No

* Photosynthetic Active Radiation.

3.3.3 General field equipment

- Ruttner samplers were used as back up if the portable pump system should fail.
- The exact positions of the sampling locations were determined using a GPS (Garmin GPSmap 78s) with an average accuracy of ±0.5–1.0 m.
- Water depth in the lakes and sea was measured using an echo sounder (Plastimo, Echotest, LCD digital sounder) with an accuracy of ±0.05 m.
- Water transparency was estimated using a Secchi disc and an aqua scope.
- Disposable filters (Millipore, 0.40 µm, Ø = 22 mm) were used together with 60 mL syringes to filter specific sample portions of the sampled water in the field.
- A stopwatch, a water-filled plastic bottle (50 mL) and measuring-tape were used for flow/runoff estimates in stream waters.

3.4 Performance

3.4.1 Presampling preparations

Prior to sampling, the sample bottles were labelled and packed in insulated boxes/bags. Acid additions were made in advance to the bottles intended for iron and trace metal analyses as well as the acidified archive samples. The bottles with added acid were placed in separate plastic bags outside the box/bag to avoid contamination. The peristaltic pump system, 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 (the operator's manual for TROLL9500 Rev.007, 2009).

3.4.2 Water sampling

Water samples were collected using the peristaltic pump system. Lake and sea water samples were collected close to the surface at 0.5 m depth. When the lake and sea sampling locations were covered with ice, water was also collected from approximately 0.5 m above the lake or sea bottom, in order to sample water both above and below the stratification. Stream water samples were collected at approximately 0.1 m depth. The peristaltic pump and sample bottles were rinsed with water from the sampling locations prior to collecting samples, except for bottles with acid additions. The disposable filters were rinsed with sample water before filtering and sampling commenced. The field crew wore rubber gloves to avoid contamination and great care was taken not to contaminate bottles or equipment. Bottles and samples with added acid were handled and stored separately to avoid contaminating other sample portions.

Each sample consists of several sample portions labelled with the same sample number. The preparation of the sample portions in the field differs depending on their use. Details on collected sample portions, components to be analysed and sample preparations are summarised in Table 3-4.



Figure 3-4. Water sampling and field measurements at the site PFM000070.

Table 3-4. Sample volumes, components and preparation of samples.

Bottle volume (mL)	Number of bottles	Analyses	Comments	Preparation in field
250	1	pH, EC, Alkalinity, color determination		
250	1	Cl, SO ₄ , Br, F		
100	1	Br		
125	1	Major cations, SO ₄ , S, Si, Environmental metals	Acid washed	Filtering with syringe/0.4 µm filter
2000	1	PON, POP, POC, Chlorophyll a, c and pheophytin	Filtrated in laboratory	
100	1	Tot-N, tot-P		
100	2	DIC, DOC		Filtering with syringe/0.4 µm filter
100	1	TOC		
25	2	Nutrients: NH ₄ , NO ₂ , NO ₃ , PO ₄		Filtering with syringe/0.4 µm filter
1000	1	Suspended matter		
100	1	I	The same bottle as for Br above.	
125	1	Trace metals	Acid washed, the same bottle as for major cations above.	
25	3	Nutrients: NH ₄ , NO ₂ , NO ₃ , PO ₄		Filtering with syringe/0.4 µm filter
100	1	Deuterium, ¹⁸ O		
500	1	Tritium, ³ H		
100	2	Archives	Acid washed	Filtering with syringe/0.4 µm filter
250	2	Archives		
5000	1	Archives*		

■ Main programme, 11 times per year in streams, 4 times per year in lakes and sea.

■ Extended programme four times per year.

* Archives sample to compensate for cancelled isotope analyses.

3.4.3 Field measurements

The multi-parameter sonde was used for measurements of pH, water temperature, ORP, turbidity, electrical conductivity and dissolved oxygen. Light penetration was measured with a Secchi disc at lake and sea sampling locations according to the Swedish standard BIN SR 111. Photo documentation of stream waters was performed to facilitate evaluation of the investigation data. Photos were taken at each stream water sampling location. Depth profiles were logged at lake and sea sampling locations with measurements logged at every metre from the surface to the bottom, see Table 3-5.

Table 3-5. Logging depths at the sampling locations in the lakes and in the shallow sea bay.

Sampling locations	Name	Logging depth (m)					
		0.5	1	1.5	2	2.5	3
Lakes							
PFM000074	Labboträsket	X					
PFM000097	Norra bassängen	X					
PFM000107	Bolundsfjärden	X	X				
PFM000117	Eckarfjärden	X	X	X			
Shallow sea bays							
PFM000062	SV Forslingens grund	X	X		X		X

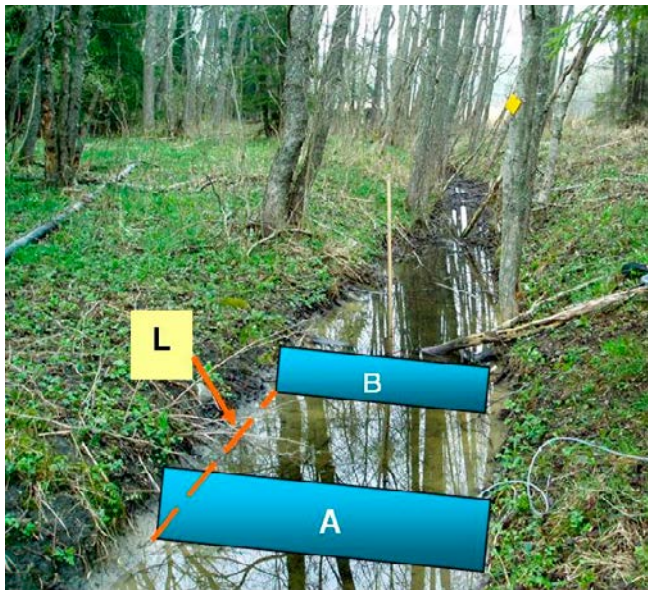


Figure 3-5. Schematic presentation for estimating water runoff in natural stream waters (see text for explanation).

A simple “floating bottle” method (Johansson 2005) was used to measure water flow/runoff in the streams as a complement to the regular method using discharge weirs and gauges. The cross-section mean area of the stream was estimated, forming a rectangle, see Figure 3-5. The time for the bottle (close to neutral in weight in water) to float the distance (L) from point A to B was measured with a stopwatch. This procedure was repeated three times in each stream. The average water velocity (m/s) multiplied with the average area (m²) resulted in a rough water runoff estimate (m³/s).

3.4.4 Sample treatment and chemical analyses

An overview of sample treatment and analytical methods is given in Appendix 1. The routines are applicable independently of sampling method or type of sampling object.

3.4.5 Data handling/post processing

A field protocol established during sampling/measuring contains the metadata (id code, date, time, sample no., field crew etc.), as well as a few measured data and weather observations and other comments on field conditions that may influence the analytical results. The field protocols supply the basic information for creating activities and activity comments in the Sicada database and also information that describes the sampling conditions for further storage in database tables. 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, see Table 3-6.

Field measurement data

The logged data from field measurements are exported digitally from the hand-held PC to the specified Sicada data table. The original data file, as well as photographs and comments on sampling and measurements, are stored in the Sicada file archive, Table 3-6.

Table 3-6. File types stored in the Sicada file archive.

Type of file	Example of file name	No. per sampling session
Data file	YTv40_15_data.xls	1 or 2*
Comments	Noterat V40-15.doc	1
Calibration data file	SN51029 2015-10-01 171308 pH.HTML	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 describing the sampling conditions are compiled in a separate Table in Sicada called “Weather_data” which contains the columns listed below. These data are not presented in this report but are useful information together with information from measurements on other activities within the monitoring programme, when evaluating data.

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

3.4.6 Nonconformities

Some nonconformities have been reported during this sampling period, January–December 2015. The flow measurements in the streams were not always performed due to the ice conditions, dry conditions or too much water vegetation. Collected samples and reasons for deviations from the programme are compiled in Tables 3-7 and 3-8.

There have been problems with the sondes since week 21 and they have mainly been connected to the O₂ probe on the sonde. Therefore, no O₂ measurements were conducted during week 21. During the weeks 26, 35, 41 and 45 a backup O₂ probe (Hach) was used for the oxygen measurements. A backup sonde was used for the field measurements during the weeks 32 and 35. However, this sonde cannot measure depth or turbidity. No field measurements were made during week 49 due to technical problems with all the sondes.



Figure 3-6. Sampling in the cooling water outlet (PFM102269).

Table 3-7. Collected samples and conducted measurements. Explanations and abbreviations.

	Year	15	15	15	15	15	15	15	15	15	15	15		
	Week	3	7	12	17	21	26	32	35	41	45	49	Sum	
Sea														
	Name													
PFM000062	SV-Forslingen	X			X			X		X			4	
PFM000082	Alt PFM62													
PFM102269	Utlopp Biotesten	Y*	Y*	Y*	Y*	Y*	Y*	Y*	Y*	Y*	Y*	Y*	11	
Stream														
PFM000066	Ö-Gunnarsbo	X	X	X	X	X	X	X	X	X	X	X	Y	11
PFM000068	Kungsträsket	X	X	X	X	X	X	X	X	X	X	X	Y	11
PFM000069	Bolundsskogen	X	X	X	X	X	X	X	X	X	X	X	Y	11
PFM000070	N-Eckarfjärden	X	X	X	X	X	X	X	G	X	X	X	Y	10
Lakes														
PFM000074	Labboträsket	X			X			X		X			4	
PFM000097	N. bassängen	B	B	C	B	B	B	B	B	B	B	C	9	
PFM00107	Bolundsfjärden	XX			X			X		X			5	
PFM00117	Eckarfjärden	XX			X			X		X			5	
	Sum water samples	11	5	5	9	5	5	9	4	9	5	5		

Y: Sample taken, no field measurements.

X: Sample and field measurements taken.

B: No sample, only field measurements with sonde.

C: No measurement due to weak ice.

G: Dry conditions, no measurements or samples.

* Only tritium and anions samples.

Table 3-8. Comments on measurements/water sampling.

	Year	15	15	15	15	15	15	15	15	15	15	15	
	Week	3	7	12	17	21	26	32	35	41	45	49	
Sea													
	Name												
PFM000062	SV-Forslingen												
PFM000082	Alt PFM62												
PFM102269	Utlopp Biotesten												
Stream													
PFM000066	Ö-Gunnarsbo						F		G	F	F		
PFM000068	Kungsträsket	C	C				F	F	F	F	F		
PFM000069	Bolundsskogen	C	Z						F		F		
PFM000070	N-Eckarfjärden	C			F		F	B	G	F	F	F	
Lakes													
PFM000074	Labboträsket												
PFM000097	N. bassängen												
PFM00107	Bolundsfjärden	A											
PFM00117	Eckarfjärden	A											

Explanations to codes/abbreviations:

A: Two samples collected. Surface and bottom water sampled separately due to winter stagnation in lake.

B: Too much water vegetation, no flow measurement.

C: Frozen water, no flow measurement.

F: Flow rate to low, no flow measurement.

G: Dry conditions, no measurements or samples.

Z: Samples collected app 10 m from original sampling point due to ice.

3.5 Results

3.5.1 General

The surface water investigation period from January to December 2015 includes 61 water samples and 88 field loggings of measurements from the regular sampling locations in streams, lakes and sea. In addition to the results from the regular sampling objects, eleven tritium results have been obtained from the location close to the cooling water outlet into Lake Biotestsjön. Furthermore, the accompanying field documentation is quite extensive. The data are compiled in the attached appendices and stored in the Sicada database where they are traceable by the activity plan number.

Fresh waters in the Forsmark area are well buffered with high alkalinity, high pH and high calcium concentrations. In addition, waters affected or recently affected by brackish sea water still show high sodium chloride concentrations. The relationship between the position of the coastline and the salinity of the water samples collected at the sampling locations in the area has been demonstrated in Nilsson et al. (2003). Furthermore, a detailed evaluation of surface water data from March 2002 to March 2004 was presented in Sonesten (2004). A summary of the results from the surface water monitoring during 2005–2009 is available in Nilsson et al. (2010).

The results presented and compiled in this section are restricted to field work performed between January 2015 and December 2015.

3.5.2 Water analyses

Major components

The basic water analyses include the major constituents Na, K, Ca, Mg, Sr, S, SO_4^{2-} , Cl^- , Si and Alkalinity as well as the minor constituents Fe, Li, Mn, Br, F^- , and I. Furthermore, batch measurements of pH and EC are included. The basic water analysis data are compiled together with field measurements of pH and water temperature in Appendix 3.

The charge balance errors, see section 2.5.2 for calculation formula, give an indication of the quality and uncertainty of the analyses of major constituents. All samples were within the acceptable errors for surface water ($\pm 10\%$). For four samples collected in May 2015 the charge balance could not be calculated due to missing alkalinity results (laboratory at site not in use).

Surface water supplements

The surface water supplements include $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}+\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, tot-N, tot-P, $\text{PO}_4\text{-P}$, TOC, DOC and DIC. The analytical data are compiled in Appendix 3. The DIC values should be used with care and bicarbonate values by alkalinity titration, are considered more reliable.

Isotopes

The isotope data including the stable isotopes δD , $\delta^{18}\text{O}$, as well as the radioactive isotope tritium (^3H) are compiled in Appendix 3.

Tritium

It is suspected that the natural content of tritium and ^{14}C isotopes may have been enhanced at different occasions due to the adjacent nuclear power plant (Nilsson and Borgiel 2005). Very high tritium concentrations, above 100 TU, have been recorded in samples from the cooling water outlet PFM102269 in July 2005, January and May 2008, October 2010 and April 2011. Slightly elevated values have also been noted in 2006, 2007, 2009, 2011 and 2013. During 2015, slightly elevated tritium values were observed in the samples from June and September, Figure 3-7.

Tritium contents were analysed in water from the regular stream, lake and sea sampling locations in January, April, August and October. Tritium content in the water from the regular sampling points ranged from 6.5 to 10.2 TU (8.4 ± 0.35 TU; mean $\pm 95\%$ confidence interval) compared to between 7.7 and 26.1 TU at the site near the cooling water outlet.

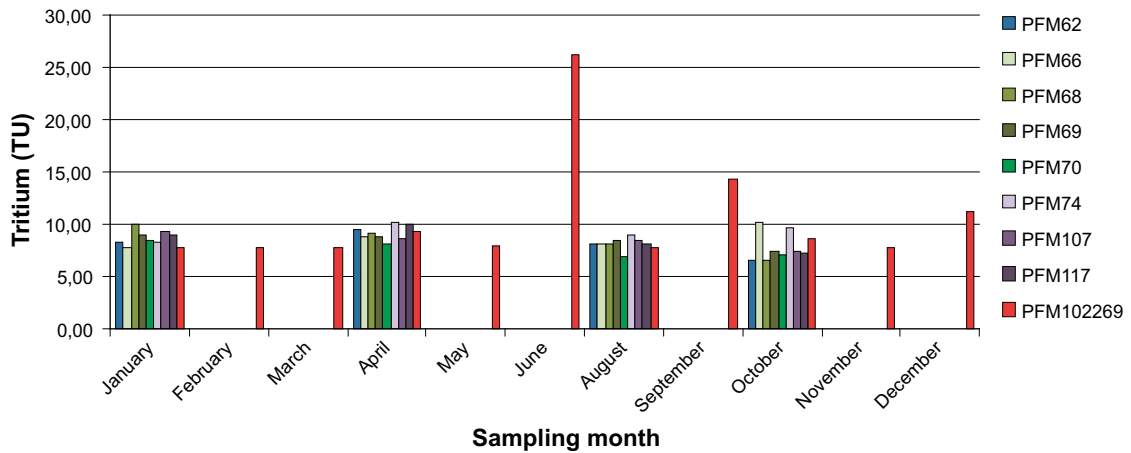


Figure 3-7. Results from tritium analyses sampled during 2015. The red bar represents the additional sampling location near the cooling water outlet, PFM102269.

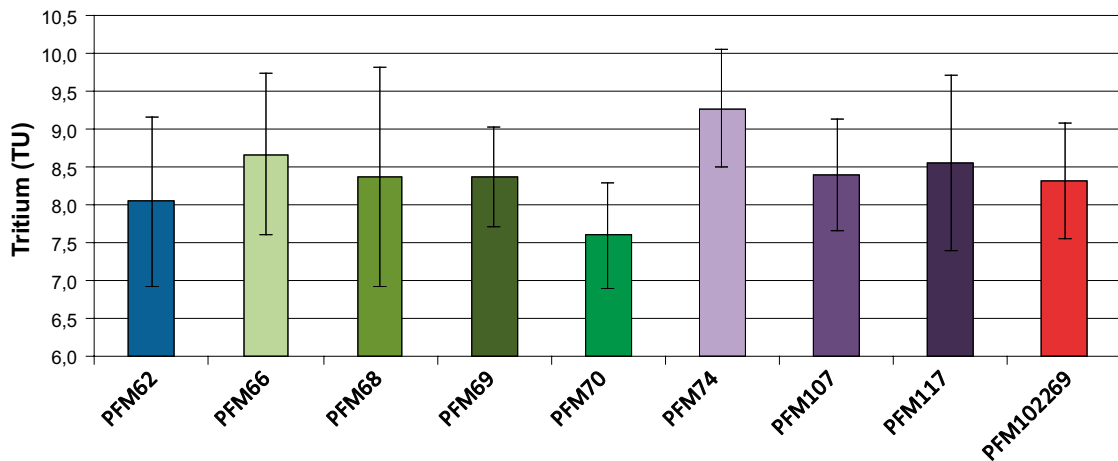


Figure 3-8. Tritium content per sampling location based on the sampling in January, April, August and October 2015 when all locations were sampled (mean \pm 95 % confidence interval). The red bar represents the additional sampling location near the cooling water outlet, PFM102269. PFM000062 is the sea site and PFM000074, PFM000107 and PFM000117 are the lakes. PFM000066, PFM000068, PFM000069 and PFM000070 are streams.

Comparison of tritium contents obtained in January, April, August and October, when all locations were sampled, show that the lowest mean tritium contents were found in the stream location, PFM000070, and in the sea sampling location, PFM000062, Figure 3-8.

Trace metals

The analyses of trace and rare earth elements include Al, As, Sc, Cd, Cr, Cu, Co, Hg, Ni, Zn, Pb, V, U, Th, Rb, Y, Zr, Mo, In, Sb, Cs, Ba, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. The trace element data are compiled in Appendix 3.

These elements are generally present at low concentrations in the water and the risk for contamination is high. Especially data on common metals like Al, Cr, Cu, Co, Ni and Zn must be used with caution. Generally, the distribution of data is location specific but outliers do exist.

3.5.3 Field measurements

The field measurement data including redox potential, pH, dissolved oxygen, electrical conductivity, measurement depth, turbidity and water temperature are compiled in Appendix 3. The water flow rate estimations by the float method (Johansson 2005) are of low accuracy compared to measurements using discharge weirs and gauges. They were performed in order to allow comparison between early data obtained when there was no other available method and new data from installed measurement stations, Appendix 3.

3.5.4 Water composition

The major cations in freshwater and sea water are generally calcium, magnesium, sodium and potassium. Sulphate and chloride are the major anions in sea water and in freshwater also bicarbonate gives a large contribution. The relative proportions between these major constituents differ between sea water and freshwater and also between different freshwater bodies, Figures 3-9 and 3-10. Comparisons of the mean concentrations of these ions at the different sampling locations during year 2008–2015 generally show little variation, Figure 3-11 and 3-12.

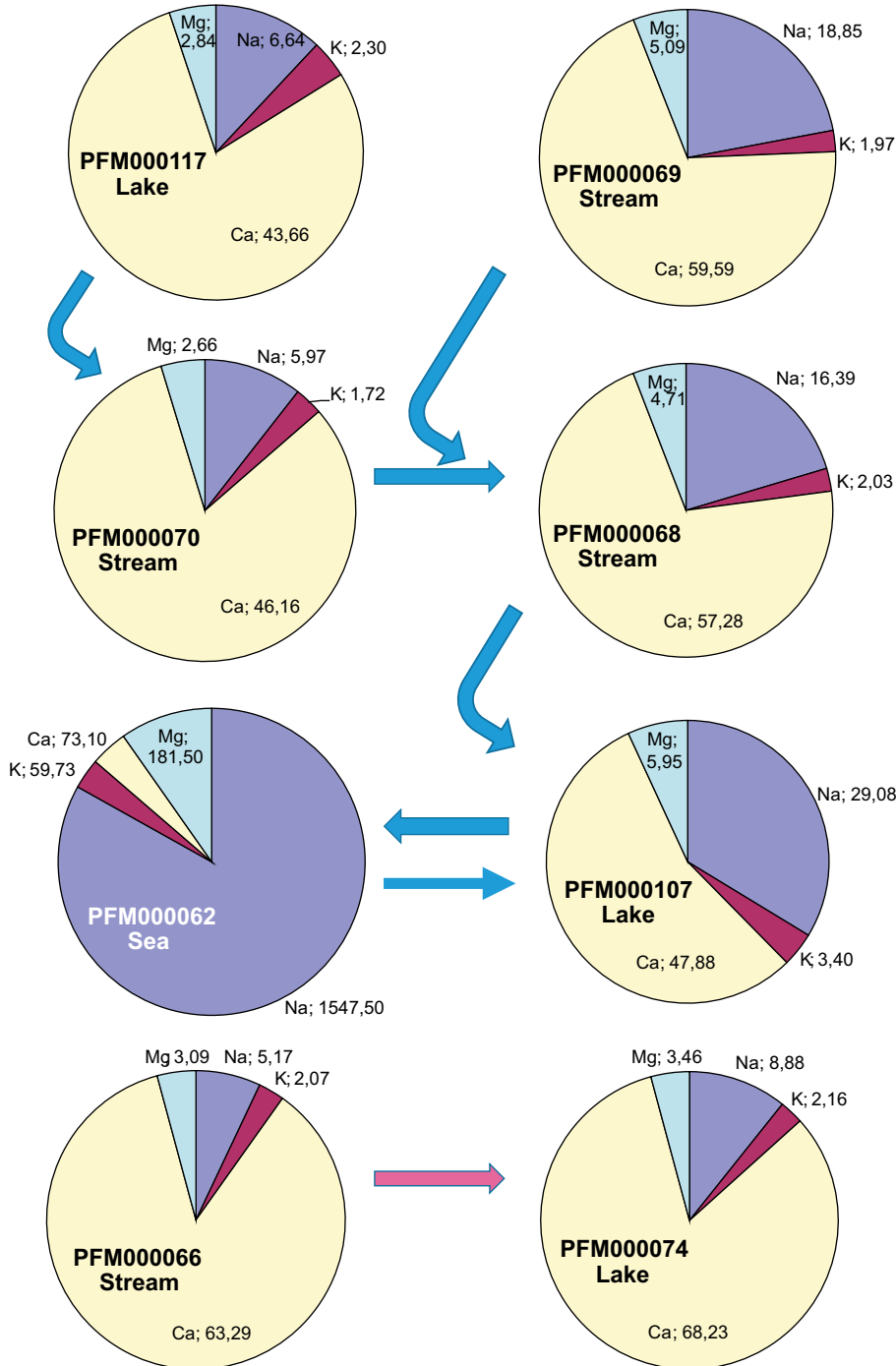


Figure 3-9. Relative proportions of the cations Na^+ , K^+ , Ca^{2+} , Mg^{2+} based on average values during the sampling period 2015. The average values (mg/L) are displayed behind each cation in the diagrams. The arrows show the path of the surface water between the lakes and streams. Occasional inflow of sea water into Lake Bolundsfjärden (PFM 000107) is indicated by a dashed arrow. The Lake Labboträsket (PFM000074) and the stream PFM000066 belong to a different catchment area.

The largest variation in these major constituents is seen in Lake Bolundsfjärden, PFM000107, especially for the ions Na^+ and Cl^- . Lake Bolundsfjärden is characterised by irregular inflow of seawater, which explains the varying concentrations. The concentrations of ions Na^+ and Cl^- were comparatively high in 2008 indicating a recent influx of seawater. Also, in 2012 and 2015 the concentrations were higher indicating seawater inflow.

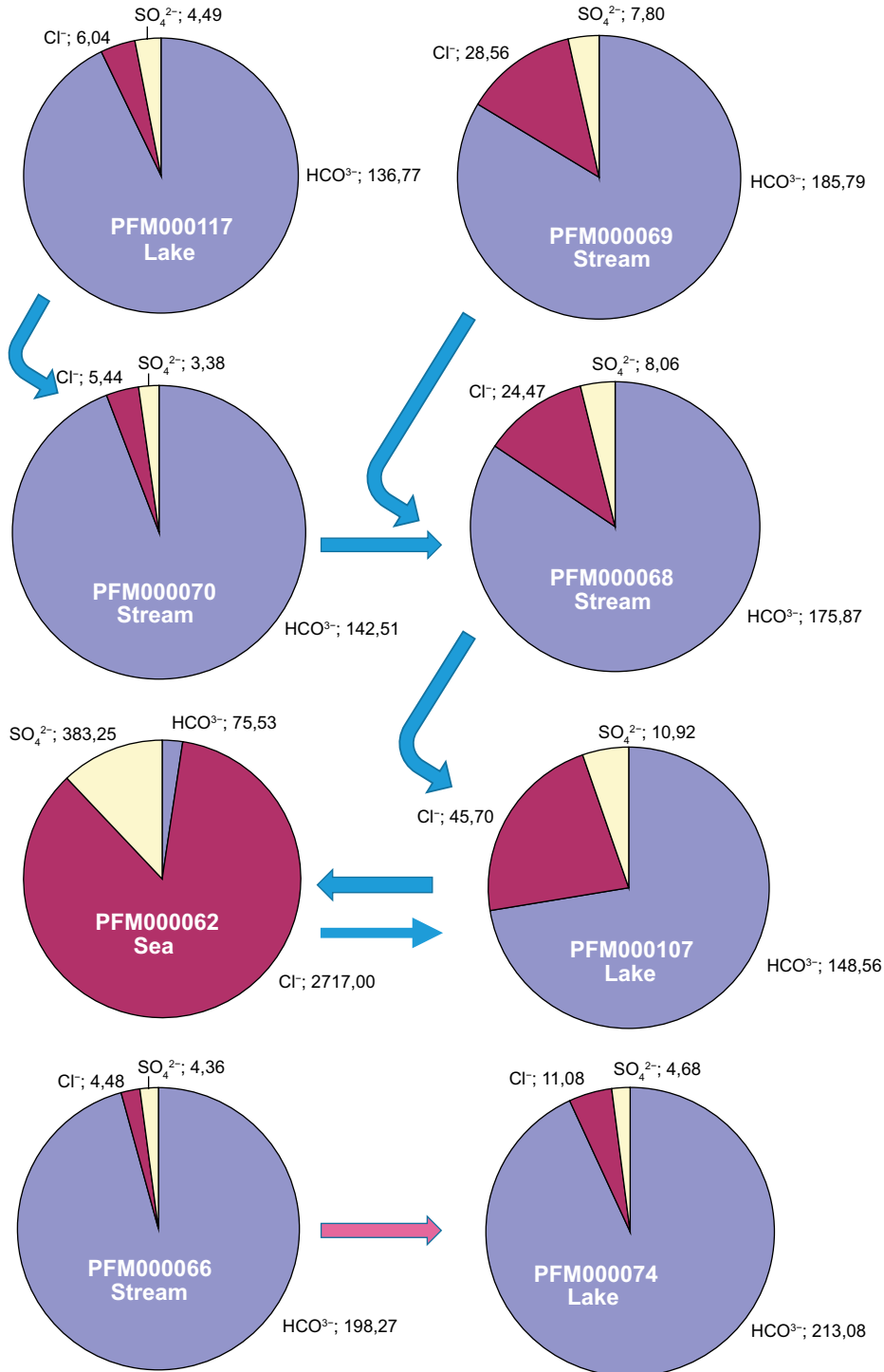


Figure 3-10. Relative proportions of the anions Cl^- , HCO_3^- and SO_4^{2-} based on the average values (given in the diagrams in mg/L) during the sampling period 2015. The arrows show the flow path of the surface water between the lakes and streams. Occasional inflow of sea water into Lake Bolundsfjärden (PFM 000107) is indicated by a dotted arrow. The Lake Labbotträsket (PFM000074) and the stream PFM000066 belong to a different catchment area.

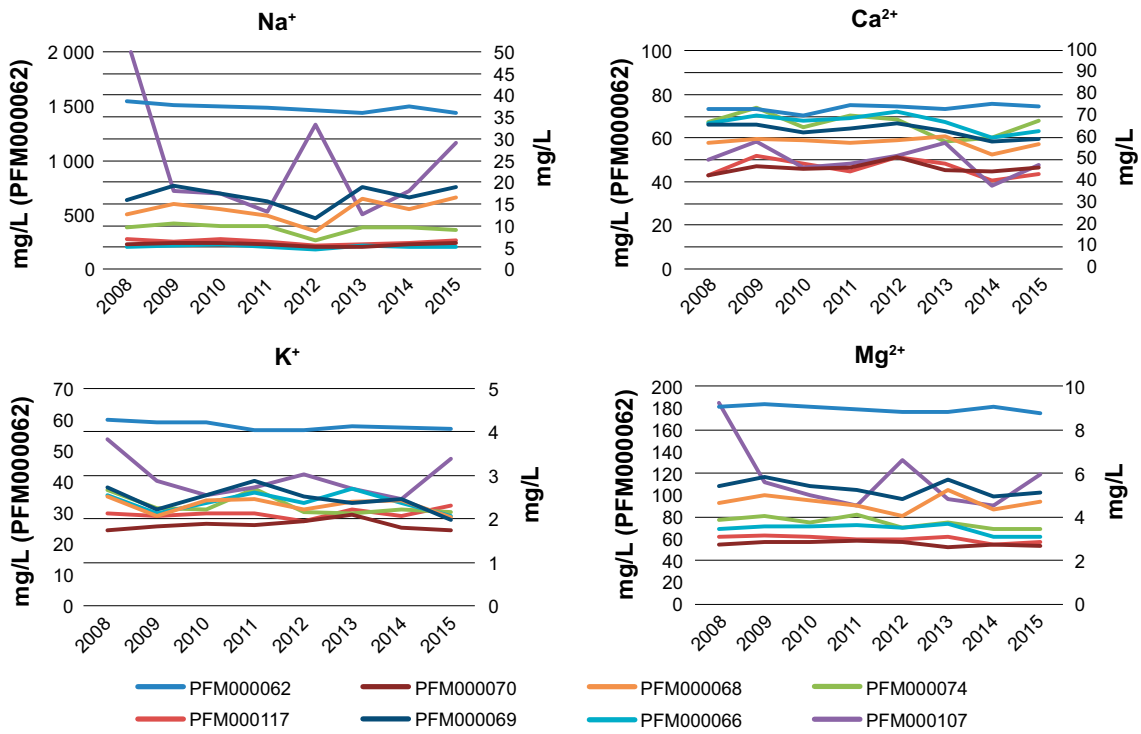


Figure 3-11. Mean concentrations of the cations Na^+ , K^+ , Ca^{2+} , Mg^{2+} during the years 2008–2015 at the sampling locations in the three lakes (PFM000074, PFM000107 and PFM000117) the four streams (PFM000066, PFM000068, PFM000069 and PFM000070) and the sea (PFM000062).

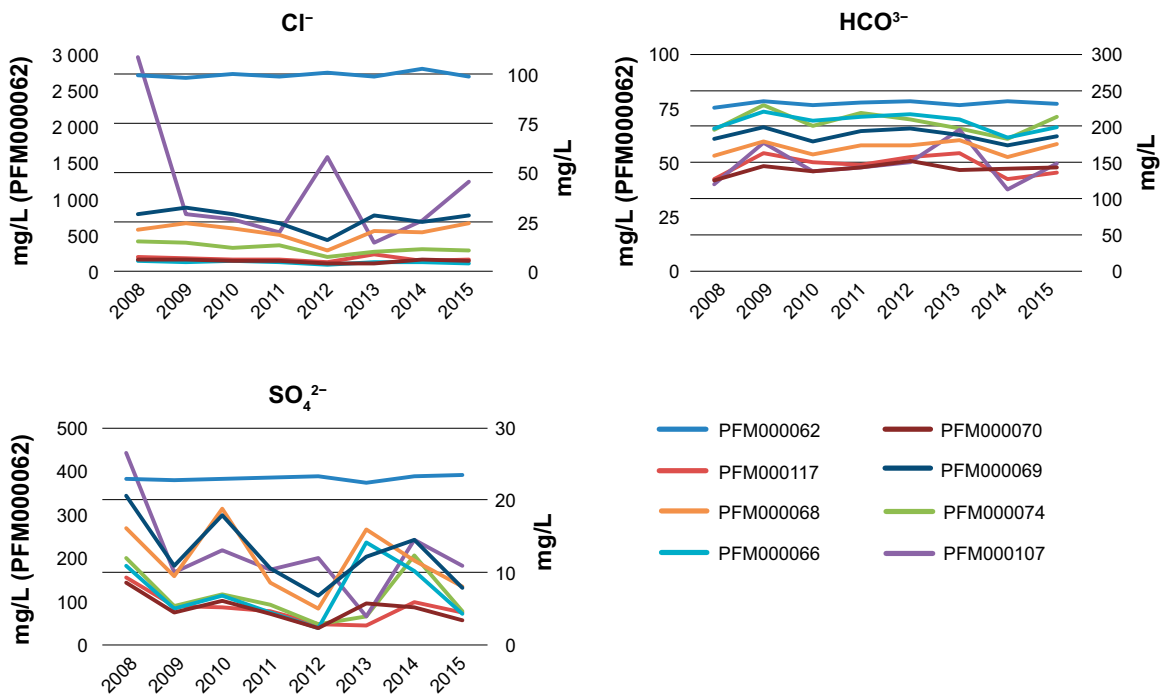


Figure 3-12. Mean concentrations of the anions Cl^- , HCO_3^- and SO_4^{2-} during the years 2008–2015 at the sampling locations in the three lakes (PFM000074, PFM000107 and PFM000117) the four streams (PFM000066, PFM000068, PFM000069 and PFM000070) and the sea (PFM000062).



Figure 3-13. Field measurements at site PFM000068.

3.5.5 The NP-ratio in the surface water

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 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 3-14 shows the relationship between nitrogen and phosphorous in the surface water of the investigated streams, lakes and coastal bays in the Forsmark area. The lakes and streams are phosphorus limited with high concentrations of nitrogen. The coastal bay in the Baltic Sea, PFM000062, is also phosphorous limited although the ratio is much lower.

Comparisons of the mean concentrations of total nitrogen and total phosphorus during years 2008–2015 generally show little variation between the different years, Figure 3-15. The largest variation is seen for phosphorus in Lake Eckarfjärden, PFM000117, but there is no increasing or decreasing trend over the years.

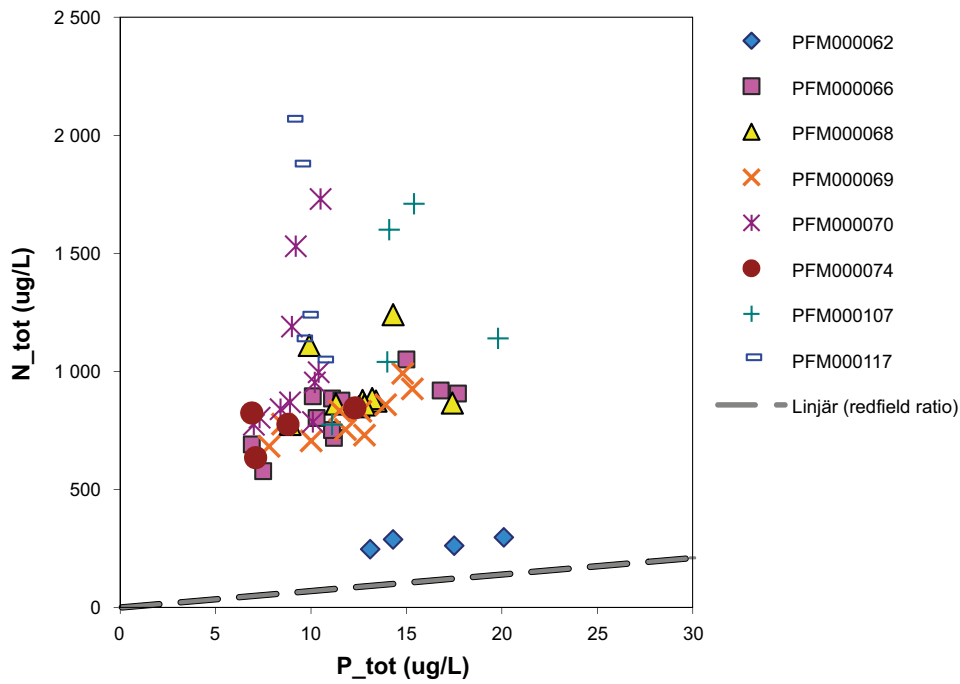


Figure 3-14. The relationship between nitrogen and phosphorus in the surface water of the investigated streams, lakes and coastal bays in the Forsmark area. The Redfield ratio (7:1) is indicated. Values above and below the line indicate phosphorus limitation and nitrogen limitation, respectively.

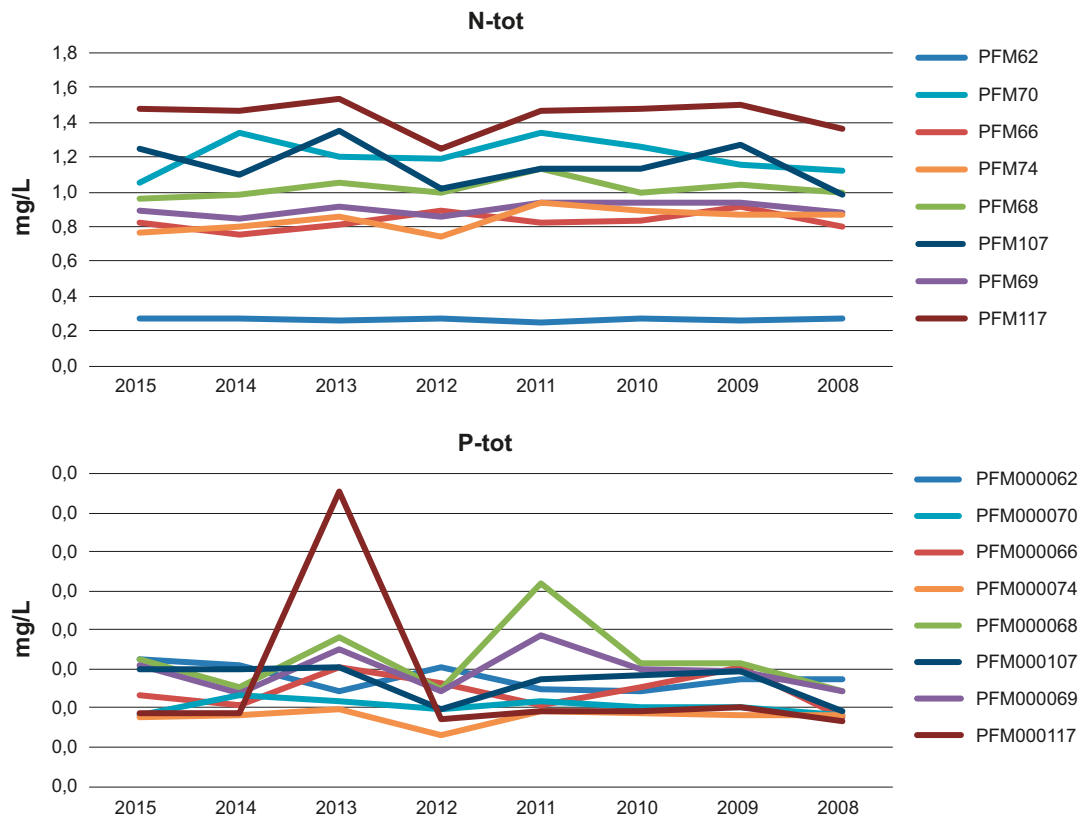


Figure 3-15. Mean concentrations of total nitrogen (N-tot) and total phosphorus (P-tot) during the years 2008–2015 at the sampling locations in the sea bay (PFM000062), four streams (PFM000066, PFM000068, PFM000069 and PFM000070) and three lakes (PFM000074, PFM000107 and PFM000117).

3.6 Summary and discussion

The chemical investigation routines for surface waters are well established and this period of the long-term surface water monitoring programme has passed without any major nonconformities or surprises.

The main experiences and conclusions from surface water sampling and analyses during the sampling period January to December 2015 are summarised below:

- Previous data indicates periodic tritium contamination from the adjacent nuclear power plant in water samples from near the cooling water outlet. Slightly elevated tritium values were also found in the June and September samples 2015.
- The proportions of the major ions in the sampled freshwaters and the shallow sea bay were similar to previous years. However, in 2015 the concentration of Na^+ and Cl^- in Lake Bolundsfjärden, PFM000107, were higher compared to 2013 and 2014, indicating a seawater inflow.
- The concentrations of total nitrogen and total phosphorus in the sampled freshwaters and shallow sea bay were similar to previous years.



Figure 3-16. Field measurements and water sampling at site PFM000066.

References

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

Berg C, Borgiel M, Qvarfordt S, 2015. Hydrochemical monitoring of near surface groundwaters, surface waters and precipitation. Results from the sampling period January 2011– December 2011 in the Forsmark area. SKBdoc 1386267 ver 1.0, Svensk Kärnbränslehantering AB.

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Sampling and analytical methods

Table A-1. 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.	2–150 150–10 000	mS/m	5 % 3 %
HCO ₃	Alkalinity titration	2	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 % ⁵
Mn	ICP AES	0.003	mg/L	12.1 % ⁵
Mn	ICP SFMS	0.00003, 0.00004, 0.0001 ⁴	mg/L	53 % ⁵
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	mg/L	2 %
NO ₃ as N	Spectrophotometry	0.2	mg/L	5 %
NO ₂ +NO ₃ as N	Spectrophotometry	0.2	mg/L	0.2 (0.2–20 mg/L) 2 % (>20 mg/L)
NH ₄ as N	Spectrophotometry, SKB	11	mg/L	30 % (11–20 mg/L) 25 % (20–50 mg/L) 12 % (50–1 200 mg/L)
NH ₄ as N	Spectrophotometry external laboratory	0.8	mg/L	0.8 (0.8–20 mg/L) 5 % (>20 mg/L)
PO ₄ as P	Spectrophotometry	0.7	mg/L	0.7 (0.7–20 mg/L) 3 % (>20 mg/L)
SiO ₄	Spectrophotometry	1	mg/L	2.5 % (> 100 mg/L)
O ₂	Iodometric titration	0.2–20	mg/L	5 %
Chlorophyll a, c pheopigment ⁷	/1/	0.5	mg/L	5 %
PON ⁷	/1/	0.5	mg/L	5 %
POP ⁷	/1/	0.1	mg/L	5 %
POC ⁷	/1/	1	mg/L	4 %
Tot-N ⁷	/1/	10	mg/L	4 %
Tot-P ⁷	/1/	0.5	mg/L	6 %
Al _i	ICP SFMS	0.2, 0.3, 0.7 ⁴	mg/L	17.6 % ⁶
Zn	ICP SFMS	0.2, 0.8, 2 ⁴	mg/L	15.5, 17.7, 25.5 % ⁶
Ba, Cr, Mo,	ICP SFMS	0.01, 0.04, 0.1 ⁴	mg/L	Ba 15 % ⁴ , Cr 22 % ⁵ Mo 39 % ⁶

Component	Method ¹	Reporting limits (RL), detection limits (DL) or range ²	Unit	Measurement uncertainty ³
Pb	ICP SFMS	0.01, 0.1, 0.3 ⁴	mg/L	15 % ⁶
Cd	ICP SFMS	0.002, 0.02, 0.5 ⁴	mg/L	15.5 % ⁶
Hg	ICP AFS	0.002	mg/L	10.7 % ⁶
Co	ICP SFMS	0.005, 0.02, 0.05 ⁴	mg/L	25.9 % ⁶
V	ICP SFMS	0.005, 0.03, 0.05 ⁴	mg/L	18.1 % ⁶
Cu	ICP SFMS	0.1, 0.2, 0.5 ⁴	mg/L	14.4 % ⁶
Ni	ICP SFMS	0.05, 0.2, 0.5 ⁴	mg/L	15.8 % ⁶
P	ICP SFMS	1, 5, 40 ⁴	mg/L	16.3 % ⁶
As	ICP SFMS	0.01 (520 mS/m)	mg/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	mg/L	20 %, 20 %, 25 % ⁶
Sc, In, Th	ICP SFMS	0.05, 0.2, 0.5 ⁴	mg/L	25 % ⁶
Rb, Zr, Sb, Cs	ICP SFMS	0.025, 0.1, 0.25 ⁴	mg/L	15 %, 20 %, 20 % ⁵ 25 % ⁵
Tl	ICP SFMS	0.025, 0.1, 0.25 ⁴	mg/L	14.3 % ^{5,6}
Y, Hf	ICP SFMS	0.005, 0.02, 0.05 ⁴	mg/L	15 %, 20 %, 20 % ⁵ 25 % ⁶
U	ICP SFMS	0.001, 0.005, 0.01 ⁴	mg/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 %
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, ²³⁰ 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 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 deviation¹⁶ 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 deviation¹⁶ from SMOC (Standard Mean Oceanic Chloride).
- ¹¹ Per mille deviation¹⁶ from PDB (the standard PeeDee Belemnite).
- ¹² The following relation is valid between pmC (percent modern carbon) and Carbon-14 age: pmC = 100 × e^(1950-y-1.031y/8274) where y = the year of the C-14 measurement and t = C-14 age.
- ¹³ Per mille deviation¹⁶ 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/kg²³⁸U, 1 ppm Th = 3.93 Bq/kg²³²Th.
- ¹⁶ Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as: δy = 1000×(K_{sample}-K_{standard})/K_{standard}, where K = the isotope ratio and y = ²H, ¹⁸O, ³⁷Cl, ¹³C or ³⁴S etc.
- ¹⁷ SKB estimation from duplicate analyses by the contracted laboratory.

Near surface groundwater

Table A2-1. Field measurements.

Idcode	Measuring date yyyy/mm/dd hh:mm	Sample no	Water temp. (°C)	pH	EC (mS/m)	ORP (mV)	O ₂ diss. (mg/L)	Oxygen (%)
SFM0001	2015-01-14 14:55	30408	4.2	7.21	176.8	-120	-0.03	-0.2
SFM0001	2015-04-21 10:25	30445	5.4	7.30	133.7	-240	-0.16	-1.2
SFM0001	2015-08-06 10:13	30584	8.2	7.35	203.4	-100	-0.15	-1.2
SFM0001	2015-10-06 11:22	30653	8.6	7.26	216.4	-150	x	x
SFM0023	2015-01-15 09:00	30410	4.3	8.32	328.5	-260	0.06	0.5
SFM0023	2015-04-23 08:45	30449	9.0	7.92	165.9	-200	0.10	0.8
SFM0023	2015-08-06 08:15	30588	15.5	7.93	221.4	-250	-0.06	-0.6
SFM0023	2015-10-08 08:00	30655	10.3	8.18	220.7	-260	x	x
SFM0032	2015-01-13 09:56	30406	2.2	7.25	85.8	-110	0.10	0.7
SFM0032	2015-04-21 14:53	30446	5.5	7.19	76.7	-150	-0.11	-0.9
SFM0032	2015-08-06 13:56	30586	11.2	7.17	83.3	-100	-0.15	-1.3
SFM0032	2015-10-06 14:46	30654	9.9	7.04	87.1	-120	x	x
SFM0037	2015-01-13 14:38	30407	0.6	7.03	78.0	-80	0.18	1.3
SFM0037	2015-04-22 10:36	30447	5.5	7.04	58.5	-160	0.08	0.6
SFM0037	2015-08-05 15:20	30585	12.7	7.12	48.4	-40	0.84	7.7
SFM0037	2015-10-06 09:36	30652	9.7	6.98	63.3	-80	x	x
SFM0049	2015-01-15 11:33	30409	1.1	7.07	44.4	-30	0.01	0.1
SFM0049	2015-04-22 14:34	30448	4.2	7.05	34.8	-140	-0.18	-1.4
SFM0049	2015-08-06 15:57	30587	12.7	6.90	39.1	-80	-0.15	-1.3
SFM0049	2015-10-05 16:04	30651	11.8	6.73	39.9	-160	x	x

x = No field measurement due to problem with O₂ probe.

A2.1 Compilation of water analysis data

Table A2-2a. Water composition.

Id code	Secup	Seclow	Date yyyy-mm-dd	Sam- ple No.	RCB %	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO ₃ mg/L	Cl mg/L	SO ₄ mg/L	SO ₄ -S mg/L	Br mg/l	F ⁻ mg/L	Si mg/L	Fe mg/L	Mn mg/L	Li mg/L	Sr mg/L	pH	EC (lab)	HS ⁻	I ⁻
	m	m																			(lab)	mS/m	mg/L	mg/L
SFM0001	3.80	4.80	2015-01-14	30408	2.2	230.0	17.30	97.8	36.60	481.2	242.9	133.90	46.50	1.640	0.69	7.82	3.45	0.23	0.018	0.409	7.11	175.0	0.097	0.0212
SFM0001	3.80	4.80	2015-04-21	30445	0.2	157.0	12.70	82.1	25.40	389.8	173.0	100.10	31.90	0.743	0.63	6.83	2.68	0.18	0.011	0.288	7.17	132.0		0.0092
SFM0001	3.80	4.80	2015-08-06	30584	-1.0	264.0	18.60	100.0	39.60	517.9	314.0	163.10	53.80	1.240	0.70	7.97	3.18	0.23	0.019	0.427	7.09	202.0	0.085	0.0132
SFM0001	3.80	4.80	2015-10-06	30653	2.2	329.0	22.70	101.0	44.30	526.8	350.6	177.70	64.20	1.480	0.87	8.60	3.12	0.24	0.022	0.459	7.20	216.0		0.0136
SFM0032	1.94	2.94	2015-01-13	30406	-0.4	32.9	6.11	122.0	10.60	363.2	58.2	51.10	16.90	1.920	0.66	6.24	2.49	0.21	0.008	0.256	7.08	85.0	0.046	0.0269
SFM0032	1.94	2.94	2015-04-21	30446	0.4	26.6	5.45	124.0	9.70	360.3	50.4	43.40	13.90	0.454	0.63	5.76	2.44	0.20	0.006	0.227	7.05	79.0		0.0060
SFM0032	1.94	2.94	2015-08-06	30586	0.4	29.4	6.46	129.0	10.50	381.1	57.8	43.40	14.00	0.347	0.67	6.91	2.81	0.22	0.008	0.251	6.93	83.0	0.081	0.0079
SFM0032	1.94	2.94	2015-10-06	30654	3.5	39.5	7.61	138.0	12.00	380.1	67.7	43.50	15.40	0.655	0.68	8.11	3.30	0.26	0.010	0.286	6.97	87.0		0.0123
SFM0037	1.10	2.10	2015-01-13	30407	0.4	30.1	5.22	109.0	14.70	355.5	26.9	68.10	24.00	0.301	0.54	6.01	2.09	0.20	0.007	0.247	6.90	76.0	0.333	0.0098
SFM0037	1.10	2.10	2015-04-22	30447	1.4	18.7	3.94	94.0	9.74	317.6	19.1	20.60	7.34	0.156	0.61	7.23	1.71	0.14	0.005	0.172	6.92	59.0		0.0047
SFM0037	1.10	2.10	2015-08-05	30585	3.1	18.3	3.04	80.1	7.98	215.8	10.7	61.60	21.60	0.112	0.52	4.40	0.42	0.13	0.005	0.152	6.98	50.0	<0.019	0.0042
SFM0037	1.10	2.10	2015-10-06	30652	-2.1	28.7	3.42	109.0	11.60	366.2	17.3	66.90	24.80	0.128	0.52	6.74	1.21	0.22	0.008	0.211	6.95	64.0		0.0028
SFM0049	2.90	3.90	2015-01-15	30409	0.2	17.6	3.13	62.0	5.26	207.1	27.1	6.91	3.25	0.082	0.35	5.41	0.67	0.10	0.002	0.098	6.94	44.0	0.175	0.0032
SFM0049	2.90	3.90	2015-04-22	30448	1.1	12.3	2.93	52.0	4.10	168.1	19.8	5.96	2.14	0.054	0.35	4.31	0.46	0.07	<0.004	0.074	6.95	35.0		0.0022
SFM0049	2.90	3.90	2015-08-06	30587	1.6	16.7	3.36	57.8	4.49	196.9	23.3	1.37	0.99	0.077	0.39	4.18	0.70	0.09	<0.004	0.090	6.69	39.0	0.222	0.0070
SFM0049	2.90	3.90	2015-10-05	30651	3.7	17.7	3.10	63.0	4.92	197.2	25.2	1.40	1.97	0.072	0.37	4.88	0.85	0.10	<0.004	0.096	6.76	41.0		0.0039
SFM0051	4.32	4.48	2015-01-12	30405	-0.1	7.1	4.19	109.0	7.38	358.3	14.5	13.90	5.92	0.279	0.57	7.74	5.41	0.22	0.005	0.171	7.15	63.0		0.0154
SFM0051	4.32	4.48	2015-04-20	30444	2.6	7.8	3.80	118.0	7.39	360.4	19.4	14.10	4.76	0.206	0.52	6.63	5.59	0.23	0.004	0.169	7.22	64.0		0.0121
SFM0051	4.32	4.48	2015-08-06	30583	1.3	6.9	4.18	121.0	7.68	375.7	21.6	14.50	5.01	0.124	0.53	9.35	6.05	0.24	0.005	0.180	7.14	64.0		0.0087
SFM0051	4.32	4.48	2015-10-05	30650	3.3	7.7	4.73	127.0	8.20	369.0	20.8	14.20	5.38	0.204	0.53	8.18	6.20	0.25	0.006	0.190	7.44	64.0		0.0133

Table A2-2b.Surface water supplements.

Id code	Secup m	Seclow m	Date yyyy-mm-dd	Sample No.	NH ₄ -N mg/L	NO ₂ -N mg/L	NO ₃ -N+NO ₂ -N mg/L	NO ₃ -N mg/L	N-tot mg/L	P-tot mg/L	PO ₄ -P mg/L	SiO ₂ -Si mg/L	TOC mg/L	DOC mg/L	DIC mg/L
SFM0001	3.80	4.80	2015-01-14	30408	0.263	0.0005	0.0006	<0.0003	1.310	0.044	0.0422	8.13	34.3	34.1	88.8
SFM0001	3.80	4.80	2015-04-21	30445	0.206	0.0005	0.0007	0.0003	1.280	0.039	0.0372	7.32	34.7	34.8	76.0
SFM0001	3.80	4.80	2015-08-06	30584	0.280	0.0009	0.0014	0.0005	1.220	0.049	0.0355	7.89	28.9	29.1	97.1
SFM0001	3.80	4.80	2015-10-06	30653	0.290	0.0005	0.0014	0.0009	1.130	0.052	0.0477	7.91	26.6	26.6	99.2
SFM0032	1.94	2.94	2015-01-13	30406	0.085	0.0003	0.0005	<0.0003	0.609	0.012	0.0020	6.48	18.3	18.2	67.2
SFM0032	1.94	2.94	2015-04-21	30446	0.081	<0.0002	0.0004	0.0003	0.625	0.011	0.0024	6.06	18.2	18.2	65.2
SFM0032	1.94	2.94	2015-08-06	30586	0.080	0.0005	0.0004	<0.0003	0.627	0.012	0.0014	6.90	17.6	17.6	66.7
SFM0032	1.94	2.94	2015-10-06	30654	0.090	0.0009	0.0009	<0.0003	0.648	0.014	0.0042	7.46	18.1	18.1	72.1
SFM0037	1.10	2.10	2015-01-13	30407	0.032	0.0005	0.0010	0.0005	0.945	0.021	0.0069	6.22	29.1	29.4	70.4
SFM0037	1.10	2.10	2015-04-22	30447	0.050	0.0003	0.0008	<0.0003	1.460	0.050	0.0074	7.77	34.5	34.1	65.7
SFM0037	1.10	2.10	2015-08-05	30585	0.034	0.0008	0.0033	0.0025	1.670	0.130	0.0071	4.38	35.6	33.6	37.9
SFM0037	1.10	2.10	2015-10-06	30652	0.071	0.0004	0.0013	0.0009	1.110	0.180	0.0102	6.33	29.5	28.5	56.3
SFM0049	2.90	3.90	2015-01-15	30409	0.121	0.0009	0.0113	0.0104	0.717	0.014	0.0077	5.78	21.6	21.3	40.1
SFM0049	2.90	3.90	2015-04-22	30448	0.079	0.0008	0.0060	0.0051	0.541	0.011	0.0071	4.69	16.4	16.5	31.4
SFM0049	2.90	3.90	2015-08-06	30587	0.154	<0.0002	<0.0003	0.0004	0.806	0.018	0.0118	4.25	21.6	21.6	36.7
SFM0049	2.90	3.90	2015-10-05	30651	0.164	<0.0002	0.0006	0.0004	0.718	0.018	0.0127	4.59	19.3	19.2	40.3
SFM0051	4.32	4.48	2015-01-12	30405						0.017					
SFM0051	4.32	4.48	2015-04-20	30444						0.014					
SFM0051	4.32	4.48	2015-08-06	30583						0.021					
SFM0051	4.32	4.48	2015-10-05	30650						0.019					

Table A2-2c. Isotopes I.

Id code	Secup m	Seclow m	Date yyyy-mm-dd	Sample No.	δ D (‰ SMOW)	Tritium (TU)	$\delta^{18}O$ (‰ SMOW)
SFM0001	3.80	4.80	2015-01-14	30408	-76.7	7.80	-11.22
SFM0001	3.80	4.80	2015-04-21	30445	-78.0	8.70	-11.22
SFM0001	3.80	4.80	2015-08-06	30584	-71.9	6.10	-9.28
SFM0001	3.80	4.80	2015-10-06	30653	-74.3	7.00	-10.63
SFM0032	1.94	2.94	2015-01-13	30406	-82.0	7.80	-11.95
SFM0032	1.94	2.94	2015-04-21	30446	-82.5	9.20	-12.04
SFM0032	1.94	2.94	2015-08-06	30586	-80.5	7.00	-11.51
SFM0032	1.94	2.94	2015-10-06	30654	-79.8	7.00	-11.49
SFM0037	1.10	2.10	2015-01-13	30407	-76.9	8.40	-11.57
SFM0037	1.10	2.10	2015-04-22	30447	-74.8	8.60	-10.87
SFM0037	1.10	2.10	2015-08-05	30585	-63.7	8.40	-9.19
SFM0037	1.10	2.10	2015-10-06	30652	-63.6	9.50	-9.44
SFM0049	2.90	3.90	2015-01-15	30409	-80.4	8.70	-11.75
SFM0049	2.90	3.90	2015-04-22	30448	-80.3	9.20	-11.39
SFM0049	2.90	3.90	2015-08-06	30587	-67.7	7.10	-9.19
SFM0049	2.90	3.90	2015-10-05	30651	-66.2	9.70	-8.98
SFM0051	4.32	4.48	2015-01-12	30405	-85.0	7.60	-12.32
SFM0051	4.32	4.48	2015-04-20	30444	-84.5	7.20	-12.44
SFM0051	4.32	4.48	2015-08-06	30583	-81.3	9.30	-11.71
SFM0051	4.32	4.48	2015-10-05	30650	-81.5	7.40	-11.81

Table A2-2d. Trace metals I.

Id code	Secup m	Seclow m	Date yyyy/mm/dd	Sample No.	Al µg/L	Cd µg/L	Cr µg/L	Cu µg/L	Co µg/L	Hg µg/L	Ni µg/L	Zn µg/L	Pb µg/L	V µg/L	Mo µg/L	Ba µg/L	Se µg/L
SFM0001	3.80	4.80	2015-01-14	30408	77.5	<0.002	0.432	0.282	0.136	<0.002	0.773	1.340	0.278	2.340	0.996	55.7	<0.5
SFM0001	3.80	4.80	2015-04-21	30445													<0.5
SFM0001	3.80	4.80	2015-08-06	30584	22.6	0.006	0.304	0.138	0.096	<0.002	0.420	0.949	0.039	2.080	1.230	58.8	<0.5
SFM0001	3.80	4.80	2015-10-06	30653													<0.5
SFM0032	1.94	2.94	2015-01-13	30406	123.0	0.003	0.254	0.339	0.093	<0.002	0.593	1.840	0.387	1.390	1.910	68.1	<0.5
SFM0032	1.94	2.94	2015-04-21	30446													<0.5
SFM0032	1.94	2.94	2015-08-06	30586	15.1	0.005	0.191	0.138	0.077	<0.002	0.498	<0.2	0.020	1.400	1.770	67.2	<0.5
SFM0032	1.94	2.94	2015-10-06	30654													<0.5
SFM0037	1.10	2.10	2015-01-13	30407	126.0	<0.002	0.454	0.775	0.196	0.005	1.550	3.270	0.403	1.350	0.548	62.5	<0.5
SFM0037	1.10	2.10	2015-04-22	30447													<0.5
SFM0037	1.10	2.10	2015-08-05	30585	48.3	0.050	0.388	2.230	0.441	0.002	2.070	5.630	1.500	3.140	2.290	48.0	<0.5
SFM0037	1.10	2.10	2015-10-06	30652													<0.5
SFM0049	2.90	3.90	2015-01-15	30409	36.1	0.003	0.162	0.545	0.189	<0.002	0.355	7.870	0.587	0.548	0.229	37.4	<0.5
SFM0049	2.90	3.90	2015-04-22	30448													<0.5
SFM0049	2.90	3.90	2015-08-06	30587	36.8	0.002	0.260	0.193	0.126	<0.002	0.251	0.899	0.122	1.210	0.105	33.2	<0.5
SFM0049	2.90	3.90	2015-10-05	30651													<0.5
SFM0051	4.32	4.48	2015-01-12	30405	97.6	<0.002	4.050	0.235	0.108	<0.002	2.390	1.330	0.268	2.280	0.569	83.0	<0.5
SFM0051	4.32	4.48	2015-04-20	30444	49.7	0.002	18.100	0.309	0.211	<0.002	8.990	1.830	0.077	2.200	0.619	79.8	<0.5
SFM0051	4.32	4.48	2015-08-06	30583	95.3	0.004	11.400	2.360	0.202	<0.002	6.340	2.300	0.204	2.460	0.777	86.3	<0.5
SFM0051	4.32	4.48	2015-10-05	30650	180.0	0.010	0.993	0.343	0.088	<0.002	0.805	1.580	0.137	2.550	0.569	95.2	<0.5

Table A2-2e. Trace metals II.

Idcode	Secup m	Seclow m	Date yyyy/mm/dd	Sample No.	U µg/L	Th µg/L	Sc µg/L	Rb µg/L	Y µg/L	Zr µg/L	Sb µg/L	Cs µg/L	La µg/L	Hf µg/L	Tl µg/L	Ce µg/L
SFM0001	3.80	4.80	2015-01-14	30408	3.2400	0.2940	0.1450	3.140	3.180	8.050	0.0523	<0.03	2.140	0.1300	<0.01	5.140
SFM0001	3.80	4.80	2015-04-21	30445												
SFM0001	3.80	4.80	2015-08-06	30584	4.1500	0.3090	0.1220	3.630	2.650	19.700	0.0509	<0.03	1.600	0.2140	<0.01	3.940
SFM0001	3.80	4.80	2015-10-06	30653												
SFM0032	1.94	2.94	2015-01-13	30406	8.6200	0.0870	0.0754	1.870	1.510	4.500	0.0333	<0.03	0.925	0.0761	<0.01	1.670
SFM0032	1.94	2.94	2015-04-21	30446												
SFM0032	1.94	2.94	2015-08-06	30586	8.3400	0.1120	0.0799	2.160	1.720	10.400	0.0296	<0.03	0.783	0.1330	<0.01	1.420
SFM0032	1.94	2.94	2015-10-06	30654												
SFM0037	1.10	2.10	2015-01-13	30407	10.0000	0.1820	0.1120	3.000	2.930	3.330	0.0901	<0.03	1.760	0.0764	<0.01	3.010
SFM0037	1.10	2.10	2015-04-22	30447												
SFM0037	1.10	2.10	2015-08-05	30585	9.5100	0.3160	0.1300	4.870	2.940	5.930	0.0932	<0.03	2.380	0.1070	0.02	4.360
SFM0037	1.10	2.10	2015-10-06	30652												
SFM0049	2.90	3.90	2015-01-15	30409	0.7490	0.0662	<0.05	2.730	0.718	0.390	0.0732	<0.03	0.908	0.0113	<0.01	1.640
SFM0049	2.90	3.90	2015-04-22	30448												
SFM0049	2.90	3.90	2015-08-06	30587	0.2370	0.2070	0.1050	4.320	1.000	0.381	0.0450	<0.03	1.440	0.0157	<0.01	2.980
SFM0049	2.90	3.90	2015-10-05	30651												
SFM0051	4.32	4.48	2015-01-12	30405	0.8080	0.1720	0.0888	0.948	0.934	8.260	0.0428	<0.03	0.469	0.1030	<0.01	0.940
SFM0051	4.32	4.48	2015-04-20	30444												
SFM0051	4.32	4.48	2015-08-06	30583	0.7990	0.2080	0.1120	1.060	1.040	15.600	0.0427	<0.03	0.520	0.1550	<0.01	1.080

Table A2-2e continued.

Idcode	Secup m	Seclow m	Date yyyy/mm/dd	Sample No.	Pr µg/L	Nd µg/L	Sm µg/L	Eu µg/L	Gd µg/L	Tb µg/L	Dy µg/L	Ho µg/L	Er µg/L	Tm µg/L	Yb µg/L	Lu µg/L
SFM0001	3.80	4.80	2015-01-14	30408	0.5130	2.110	0.4390	0.0519	0.4630	0.0691	0.4420	0.0964	0.2980	0.0429	0.2840	0.0479
SFM0001	3.80	4.80	2015-04-21	30445												
SFM0001	3.80	4.80	2015-08-06	30584	0.4000	1.580	0.3240	0.0378	0.3860	0.0618	0.3880	0.0946	0.2480	0.0394	0.2710	0.0320
SFM0001	3.80	4.80	2015-10-06	30653												
SFM0032	1.94	2.94	2015-01-13	30406	0.2040	0.830	0.1610	0.0181	0.1720	0.0261	0.1680	0.0418	0.1370	0.0206	0.1400	0.0257
SFM0032	1.94	2.94	2015-04-21	30446												
SFM0032	1.94	2.94	2015-08-06	30586	0.1810	0.716	0.1550	0.0208	0.1930	0.0316	0.2050	0.0534	0.1620	0.0257	0.1860	0.0315
SFM0032	1.94	2.94	2015-10-06	30654												
SFM0037	1.10	2.10	2015-01-13	30407	0.4020	1.630	0.3480	0.0392	0.3750	0.0578	0.3700	0.0880	0.2730	0.0401	0.2740	0.0453
SFM0037	1.10	2.10	2015-04-22	30447												
SFM0037	1.10	2.10	2015-08-05	30585	0.5630	2.020	0.4170	0.0503	0.4640	0.0709	0.4240	0.1060	0.2890	0.0445	0.2910	0.0481
SFM0037	1.10	2.10	2015-10-06	30652												
SFM0049	2.90	3.90	2015-01-15	30409	0.1940	0.752	0.1460	0.0171	0.1350	0.0188	0.1090	0.0225	0.0697	0.0103	0.0656	0.0116
SFM0049	2.90	3.90	2015-04-22	30448												
SFM0049	2.90	3.90	2015-08-06	30587	0.2880	1.200	0.2370	0.0308	0.2110	0.0330	0.1600	0.0348	0.0928	0.0150	0.0864	0.0147
SFM0049	2.90	3.90	2015-10-05	30651												
SFM0051	4.32	4.48	2015-01-12	30405	0.1140	0.471	0.1040	0.0101	0.1120	0.0178	0.1150	0.0279	0.0958	0.0159	0.1160	0.0218
SFM0051	4.32	4.48	2015-04-20	30444												
SFM0051	4.32	4.48	2015-08-06	30583	0.1380	0.543	0.1160	0.0120	0.1290	0.0216	0.1360	0.0349	0.1120	0.0203	0.1440	0.0193

Appendix 3

Surface waters

Table A3-1. Field measurements.

Id code	Measuring date yyyy-mm-dd hh:mm	Measured depth (m)	Water depth (m)	Sno*	Temp. (°C)	pH	EC** (mS/m)	Turb (NTU***)	O ₂ diss. (mg/l)	O ₂ sat. (%)	ORP**** (mV)
PFM000062	2015-01-13 09:39	0.50	4.00	30402	1.3	7.99	901.3	3.8	14.10	104.3	170
PFM000062	2015-01-13 09:39	1.00	4.00		1.3	7.96	902.2	3.7	14.19	105.0	170
PFM000062	2015-01-13 09:39	2.00	4.00		1.3	7.96	902.9	3.4	14.23	105.2	170
PFM000062	2015-01-13 09:39	3.00	4.00		1.3	7.96	903.0	4.4	14.25	105.3	170
PFM000062	2015-04-20 14:28	0.50	4.30	30428	6.9	8.44	853.6	3.5	12.74	109.0	200
PFM000062	2015-04-20 14:28	1.00	4.30		6.9	8.43	853.8	3.1	12.82	109.6	190
PFM000062	2015-04-20 14:28	2.00	4.30		7.0	8.44	853.8	5.0	12.86	110.0	190
PFM000062	2015-04-20 14:28	3.00	4.30		7.0	8.45	853.7	3.8	12.88	110.4	190
PFM000062	2015-08-04 09:10	0.50	3.80	30569	17.1	8.17	872.7		9.84	103.3	180
PFM000062	2015-08-04 09:10	1.00	3.80		17.1	8.17	872.5		9.84	103.3	180
PFM000062	2015-08-04 09:10	2.00	3.80		17.1	8.17	872.5		9.90	103.9	180
PFM000062	2015-08-04 09:10	3.00	3.80		17.1	8.17	873.5		9.90	103.9	170
PFM000062	2015-10-05 14:51	0.50	4.00	30634	12.6	8.02	883.6	1.3	10.83	100.4	150
PFM000062	2015-10-05 14:51	1.00	4.00		12.6	8.03	883.8	1.3	10.82	100.3	150
PFM000062	2015-10-05 14:51	2.00	4.00		12.6	8.04	883.7	1.4	10.82	100.3	150
PFM000062	2015-10-05 14:51	3.00	4.00		12.5	8.04	883.8	1.6	10.80	100.2	150
PFM000066	2015-01-14 11:55	0.10	0.39	30404	0.3	7.36	42.2	0.6	3.85	26.8	80
PFM000066	2015-02-09 13:50	0.10	0.45	30416	0.2	7.22	35.0	0.5	4.66	32.4	90
PFM000066	2015-03-16 13:10	0.10	0.35	30423	2.0	7.37	27.4	0.9	5.60	40.8	120
PFM000066	2015-04-21 13:50	0.10	0.32	30433	8.8	7.73	32.5	1.4	8.83	76.8	120
PFM000066	2015-05-20 10:55	0.10	0.35	30555	11.2	7.69	30.6	1.3			110
PFM000066	2015-06-22 13:10	0.10	0.25	30562	12.7	7.33	30.6	12.6	4.95	47.0	10
PFM000066	2015-08-04 11:35	0.10	0.31	30571	15.7	7.41	30.3		4.42	43.8	110
PFM000066	2015-08-30 11:00	0.10	0.05	30598	14.1	7.60	33.6		4.01	39.1	50
PFM000066	2015-10-06 11:55	0.10	0.30	30639	7.5	7.52	34.0	0.5	6.37	52.2	90
PFM000066	2015-11-02 11:30	0.10	0.30	30665	6.7	7.27	35.5	134.4	3.26	26.6	0
PFM000066	2015-11-30 13:25	0.10	0.21	30705							
PFM000068	2015-01-12 15:55	0.10	0.52	30399	-0.1	7.43	40.7	4.5	2.81	19.4	40
PFM000068	2015-02-09 10:40	0.10	0.70	30413	0.0	7.24	32.4	0.9	3.93	27.1	90
PFM000068	2015-03-16 10:15	0.10	0.65	30420	0.6	7.37	25.5	0.8	7.96	55.9	110
PFM000068	2015-04-21 10:10	0.10	0.61	30432	5.3	7.57	33.8	3.5	7.81	62.2	100
PFM000068	2015-05-20 08:25	0.10	0.58	30552	8.6	7.50	31.0	1.5			150
PFM000068	2015-06-22 09:50	0.10	0.43	30559	11.2	7.55	41.3	1.3	6.85	62.9	160
PFM000068	2015-08-03 15:00	0.10	0.35	30567	13.8	7.50	36.6		7.35	69.8	110
PFM000068	2015-08-29 17:00	0.10		30596	15.6	7.52	46.1		2.05	20.8	170
PFM000068	2015-10-06 10:30	0.10	0.45	30637	7.4	7.83	40.2	0.9	17.92	64.7	200
PFM000068	2015-11-02 09:30	0.10	0.40	30662	6.7	7.18	45.4	1.2	3.48	29.5	150
PFM000068	2015-11-30 11:10	0.10	0.62	30703							
PFM000069	2015-01-12 17:10	0.10	0.17	30400	-0.1	7.47	49.6	11.1	0.67	4.6	20
PFM000069	2015-02-09 11:10	0.10	0.42	30414	0.0	7.21	39.8	0.5	1.61	11.1	70
PFM000069	2015-03-16 10:45	0.10	0.36	30421	0.8	7.32	31.3	0.4	4.72	33.4	100
PFM000069	2015-04-21 09:30	0.10	0.20	30431	5.0	7.56	35.5	1.1	6.24	49.4	110
PFM000069	2015-05-20 08:50	0.10	0.14	30553	8.2	7.42	36.6	1.2			100
PFM000069	2015-06-22 10:20	0.10	0.07	30560	11.3	7.55	41.2	1.3	7.59	69.5	100
PFM000069	2015-08-04 10:40	0.10	0.15	30570	12.4	7.50	37.3		6.94	64.0	100
PFM000069	2015-08-30 09:30	0.10	0.05	30597	12.4	7.61	45.8		5.12	48.6	-10
PFM000069	2015-10-06 11:05	0.10	0.08	30638	7.2	7.64	39.5	2.4	8.91	72.5	140
PFM000069	2015-11-02 10:05	0.10	0.05	30663	6.6	7.45	44.5	2.0	7.65	62.2	130
PFM000069	2015-11-30 11:40	0.10	0.15	30704							

Table A3-1 continued.

Id code	Measuring date yyyy-mm-dd hh:mm	Measured depth (m)	Water depth (m)	Sno*	Temp. (°C)	pH	EC** (mS/m)	Turb (NTU***)	O ₂ diss. (mg/l)	O ₂ sat. (%)	ORP**** (mV)
PFM000070	2015-01-12 18:37	0.10	0.25	30401	0.4	7.67	29.6	0.7	10.48	73.1	90
PFM000070	2015-02-09 12:10	0.10	0.27	30415	0.9	7.41	26.6	0.5	6.60	46.7	120
PFM000070	2015-03-16 11:25	0.10	0.28	30422	4.9	7.45	18.9	3.8	7.12	56.1	140
PFM000070	2015-04-21 08:30	0.10	0.11	30430	6.3	7.92	26.8	1.2	8.89	72.7	130
PFM000070	2015-05-20 09:50	0.10	0.18	30554	12.1	7.81	25.0	2.1			110
PFM000070	2015-06-22 11:00	0.10	0.05	30561	14.9	7.21	26.8	418.7	3.31	32.7	100
PFM000070	2015-08-04 14:00	0.10	0.10	30573	18.5	7.34	25.0		5.13	53.9	110
PFM000070	2015-08-30 10:05	0.10									
PFM000070	2015-10-05 17:05	0.10	0.05	30636	9.3	7.37	27.1	7.1	5.91	50.6	90
PFM000070	2015-11-02 11:00	0.10	0.05	30664	8.0	7.36	28.2	19.9	4.35	36.6	50
PFM000070	2015-11-30 14:10	0.10	0.14	30706							
PFM000074	2015-01-13 11:25	0.50	1.00	30403	0.6	7.24	42.0	0.5	1.72	12.1	-90
PFM000074	2015-04-21 14:50	0.50	0.85	30434	10.0	7.76	36.0	0.4	9.05	81.1	160
PFM000074	2015-08-03 15:50	0.50	0.90	30568	15.5	7.16	35.3		3.48	34.4	140
PFM000074	2015-10-06 14:30	0.50	0.92	30640	9.7	7.68	39.8	1.0	7.61	65.7	170
PFM000097	2015-01-13 13:55	0.50	1.00		1.0	7.19	727.8	3.2	6.64	48.4	40
PFM000097	2015-02-10 09:40	0.50	0.77		1.2	7.19	81.7	2.4	1.54	11.1	-100
PFM000097	2015-03-17 08:20	0.50									
PFM000097	2015-04-21 12:00	0.50	0.78		10.6	8.54	52.8	0.8	12.39	112.5	150
PFM000097	2015-05-20 14:40	0.50	0.85		16.3	8.76	47.6	1.8			110
PFM000097	2015-06-22 15:20	0.50	0.71		19.8	8.70	54.1	3.2	12.56	137.4	110
PFM000097	2015-08-04 14:50	0.50	0.95		22.4	8.94	44.7		13.20	149.8	80
PFM000097	2015-08-29 16:00	0.50	0.85		20.0	9.13	55.4		13.58	149.2	120
PFM000097	2015-10-07 09:00	0.50	0.73		6.2	8.47	45.0	0.5	12.20	95.9	110
PFM000097	2015-11-03 07:50	0.50	0.76		5.5	8.22	47.6	0.7	11.61	91.9	190
PFM000097	2015-12-01 10:50	0.50									
PFM000107	2015-01-12 13:40	0.50	1.80	30397	2.5	7.45	40.6	0.6	2.00	14.8	160
PFM000107	2015-01-12 13:40	1.00	1.80	30398	3.2	7.22	57.8	6.8	0.78	5.9	-60
PFM000107	2015-04-20 13:00	0.50	1.90	30427	8.7	8.57	44.9	0.6	12.19	105.8	190
PFM000107	2015-04-20 13:00	1.00	1.90		8.7	8.58	44.9	0.5	12.22	106.0	190
PFM000107	2015-08-03 14:19	0.50	1.80	30566	19.7	9.16	37.7		11.34	122.1	90
PFM000107	2015-08-03 14:19	1.00	1.80		19.7	9.16	37.7		11.46	123.3	90
PFM000107	2015-10-05 12:20	0.50	1.80	30633	10.9	8.38	39.3	0.9	11.50	102.7	170
PFM000107	2015-10-05 12:20	1.00	1.80		10.9	8.47	39.3	0.8	11.44	102.2	170
PFM000117	2015-01-14 09:40	0.50	2.20	30411	1.8	7.98	29.5	0.5	10.73	77.9	90
PFM000117	2015-01-14 09:40	1.00	2.20		3.5	7.77	30.0	0.5	6.77	51.5	100
PFM000117	2015-01-14 09:40	1.50	2.20	30412	4.3	7.61	30.9	0.5	4.87	37.9	100
PFM000117	2015-04-20 15:40	0.50	2.10	30429	9.1	8.61	26.7	2.0	12.20	106.8	170
PFM000117	2015-04-20 15:40	1.00	2.10		9.0	8.61	26.7	1.0	12.30	107.6	170
PFM000117	2015-04-20 15:40	1.50	2.10		9.0	8.61	26.7	0.9	12.37	108.0	170
PFM000117	2015-08-04 13:10	0.50	2.20	30572	20.6	8.78	21.1		10.96	120.0	140
PFM000117	2015-08-04 13:10	1.00	2.20		20.6	8.79	21.1		11.18	122.4	140
PFM000117	2015-08-04 13:10	1.50	2.20		20.4	8.84	21.0		11.83	128.9	140
PFM000117	2015-10-05 15:45	0.50	2.00	30635	11.6	8.60	22.0	1.0	11.63	105.4	160
PFM000117	2015-10-05 15:45	1.00	2.00		11.6	8.62	22.0	1.4	11.63	105.5	160
PFM000117	2015-10-05 15:45	1.50	2.00		11.5	8.62	22.0	1.0	11.59	105.1	160

* Sno = Corresponding water sample no.

** EC = Electrical conductivity.

*** NTU = Nephelometric Turbidity Unit.

**** ORP = Oxidising Reducing Potential.

Table A3-2. Water flow measurements.

Id code	Start date	Stop date	Simple flow rate* (m³/s)	Code** / Comment
PFM000068	2015-01-12 15:55	2015-01-12 16:10		C
PFM000069	2015-01-12 17:10	2015-01-12 17:25		C
PFM000070	2015-01-12 18:37	2015-01-12 18:49		C
PFM000066	2015-01-14 11:55	2015-01-14 12:10	0.047	L
PFM000068	2015-02-09 10:40	2015-02-09 11:00		C
PFM000069	2015-02-09 11:10	2015-02-09 11:30	0.078	L
PFM000070	2015-02-09 12:10	2015-02-09 12:30	0.072	L
PFM000066	2015-02-09 13:50	2015-02-09 14:10	0.075	L
PFM000068	2015-03-16 10:15	2015-03-16 10:35	0.197	L
PFM000069	2015-03-16 10:45	2015-03-16 10:55	0.086	L
PFM000070	2015-03-16 11:25	2015-03-16 11:40	0.083	L
PFM000066	2015-03-16 13:10	2015-03-16 13:30	0.136	L
PFM000070	2015-04-21 08:30	2015-04-21 08:45		F
PFM000069	2015-04-21 09:30	2015-04-21 09:50	0.054	L
PFM000068	2015-04-21 10:10	2015-04-21 10:30	0.112	L
PFM000066	2015-04-21 13:50	2015-04-21 14:10	0.036	L
PFM000068	2015-05-20 08:25	2015-05-20 08:40	0.281	L
PFM000069	2015-05-20 08:50	2015-05-20 09:05	0.035	L
PFM000070	2015-05-20 09:50	2015-05-20 10:10	0.038	L
PFM000066	2015-05-20 10:55	2015-05-20 11:10	0.054	L
PFM000068	2015-06-22 09:50	2015-06-22 10:10		F
PFM000069	2015-06-22 10:20	2015-06-22 10:40	0.008	L
PFM000070	2015-06-22 11:00	2015-06-22 11:20		F
PFM000066	2015-06-22 13:10	2015-06-22 13:30		F
PFM000068	2015-08-03 15:00	2015-08-03 15:20		F
PFM000069	2015-08-04 10:40	2015-08-04 11:00	0.032	L
PFM000066	2015-08-04 11:35	2015-08-04 11:55	0.070	L
PFM000070	2015-08-04 14:00	2015-08-04 14:15		B
PFM000068	2015-08-29 17:00	2015-08-29 17:20		F
PFM000069	2015-08-30 09:30	2015-08-30 09:50		F
PFM000070	2015-08-30 10:05	2015-08-30 10:25		G
PFM000066	2015-08-30 11:00	2015-08-30 11:20		F
PFM000070	2015-10-05 17:05	2015-10-05 17:30		F
PFM000068	2015-10-06 10:30	2015-10-06 10:50		F
PFM000069	2015-10-06 11:05	2015-10-06 11:20	0.008	L
PFM000066	2015-10-06 11:55	2015-10-06 12:15		F
PFM000068	2015-11-02 09:30	2015-11-02 09:50		F
PFM000069	2015-11-02 10:05	2015-11-02 10:20		F
PFM000070	2015-11-02 11:00	2015-11-02 10:20		F
PFM000066	2015-11-02 11:30	2015-11-02 11:50		F
PFM000068	2015-11-30 11:10	2015-11-30 11:20	0.112	L
PFM000069	2015-11-30 11:40	2015-11-30 12:00	0.025	L
PFM000066	2015-11-30 13:25	2015-11-30 13:40	0.028	L
PFM000070	2015-11-30 14:10	2015-11-30 14:30		F

* Simple flow rate = based on simple "floating bottle" method.

**** Code description**

- | | |
|--|---|
| A Blocked flow; no measurement. | I Measurement not possible, see protocol. |
| B Too much water vegetation, no measurement. | K Comment missing. |
| C Water completely frozen, no measurement. | L Flow rate value available. |
| D Too much ice, no measurement. | M Low water level. |
| E Flow rate too high, no measurement. | N Lake, Sea, no measurement. |
| F Flow rate too low, no measurement. | O Too much wind, no measurement. |
| G Dry conditions, no measurements. | P Stationary water. |
| H Measurement not possible, estimated value. | |

Table A3-3c. Isotopes.

Idcode	Sample no.	Sampling date (yyyy-mm-dd)	Depth (m)	$\delta^2\text{H}$ ‰ SMOW1)	^3H TU1)	$\delta^{18}\text{O}$ ‰ SMOW1)
PFM000062	30402	2015-01-13	0.50	-60.5	8.20	-8.32
PFM000062	30428	2015-04-20	0.50	-61.1	9.40	-8.52
PFM000062	30569	2015-08-04	0.50	-58.7	8.00	-7.84
PFM000062	30634	2015-10-05	0.50	-58.9	6.60	-7.90
PFM000066	30404	2015-01-14	0.10	-82.2	7.70	-12.18
PFM000066	30433	2015-04-21	0.10	-81.3	8.70	-11.87
PFM000066	30571	2015-08-04	0.10	-68.4	8.10	-9.43
PFM000066	30639	2015-10-06	0.10	-66.8	10.20	-9.34
PFM000068	30399	2015-01-12	0.10	-77.7	9.90	-11.19
PFM000068	30432	2015-04-21	0.10	-80.0	9.10	-11.54
PFM000068	30567	2015-08-03	0.10	-68.5	8.00	-9.36
PFM000068	30637	2015-10-06	0.10	-67.8	6.50	-9.37
PFM000069	30400	2015-01-12	0.10	-82.2	8.90	-12.11
PFM000069	30431	2015-04-21	0.10	-82.6	8.70	-12.06
PFM000069	30570	2015-08-04	0.10	-69.2	8.50	-9.43
PFM000069	30638	2015-10-06	0.10	-68.0	7.40	-9.39
PFM000070	30401	2015-01-12	0.10	-71.3	8.40	-9.66
PFM000070	30430	2015-04-21	0.10	-72.1	8.00	-9.93
PFM000070	30573	2015-08-04	0.10	-58.2	6.90	-7.07
PFM000070	30636	2015-10-05	0.10	-57.7	7.10	-7.20
PFM000074	30403	2015-01-13	0.50	-83.2	8.30	-12.22
PFM000074	30434	2015-04-21	0.50	-80.7	10.10	-11.58
PFM000074	30568	2015-08-03	0.50	-69.1	9.00	-9.52
PFM000074	30640	2015-10-06	0.50	-67.5	9.70	-9.50
PFM000107	30397	2015-01-12	0.50	-71.8	9.20	-10.15
PFM000107	30398	2015-01-12	1.00	-72.9	8.70	-10.34
PFM000107	30427	2015-04-20	0.50	-75.1	8.60	-10.39
PFM000107	30566	2015-08-03	0.50	-51.3	8.40	-5.59
PFM000107	30633	2015-10-05	0.50	-48.5	7.40	-5.14
PFM000117	30411	2015-01-14	0.50	-67.4	8.90	-9.02
PFM000117	30412	2015-01-14	1.50	-67.5	9.50	-9.16
PFM000117	30429	2015-04-20	0.50	-72.3	10.00	-9.71
PFM000117	30572	2015-08-04	0.50	-56.4	8.10	-6.47
PFM000117	30635	2015-10-05	0.50	-51.2	7.20	-5.57
PFM102269	30396	2015-01-13	0.50		7.70	
PFM102269	30417	2015-02-09	0.50		7.70	
PFM102269	30424	2015-03-16	0.50		7.70	
PFM102269	30435	2015-04-21	0.50		9.30	
PFM102269	30556	2015-05-20	0.50		7.90	
PFM102269	30563	2015-06-22	0.50		26.10	
PFM102269	30574	2015-08-03	0.50		7.70	
PFM102269	30600	2015-08-30	0.50		14.20	
PFM102269	30641	2015-10-06	0.50		8.60	
PFM102269	30666	2015-11-02	0.50		7.70	
PFM102269	30707	2015-11-30	0.50		11.20	

Table A3-3d. Trace metals.

Idcode	Sample no.	Sampling date	Depth	Al	Cd	Cr	Cu	Co	Hg	Ni	Zn	Pb	V	Mo	Ba	Se
		(yyyy-mm-dd)	(m)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
PFM000062	30402	2015-01-13	0.50	4.85	0.0223	0.3330	0.815	0.0573	< 0.002	0.787	1.970	0.3970	0.234	1.510	17.40	<0.5
PFM000062	30428	2015-04-20	0.50	<0.3	<0.02	0.0521	0.563	0.0205	0.134	0.714	<0.8	<0.1	0.137	1.340	15.10	<3.0
PFM000062	30569	2015-08-04	0.50	13.80	0.0203	0.2320	0.592	0.0230	<0.002	0.915	3.360	<0.1	0.251	1.290	17.80	4.52
PFM000062	30634	2015-10-05	0.50	1.30	<0.02	<0.04	0.778	<0.02	<0.002	1.280	1.350	<0.1	0.221	1.530	18.10	<3.0
PFM000066	30404	2015-01-14	0.10	10.80	0.0021	0.1800	0.691	0.2060	0.002	0.674	1.090	0.0664	0.275	0.335	30.10	<0.5
PFM000066	30416	2015-02-09	0.10	14.20	<0.002	0.1660	0.933	0.0778	<0.002	0.606	1.310	0.0414	0.195	0.438	23.90	<0.5
PFM000066	30423	2015-03-16	0.10	14.90	0.0060	0.1730	1.080	0.0634	<0.002	0.533	0.996	0.0315	0.195	0.450	17.20	<0.5
PFM000066	30433	2015-04-21	0.10	9.65	<0.002	0.1210	0.646	0.0703	<0.002	0.463	1.410	0.0374	0.248	0.524	23.00	<0.5
PFM000066	30555	2015-05-20	0.10	5.80	<0.002	0.1070	0.660	0.0583	<0.002	0.464	0.378	0.0309	0.189	0.463	18.40	<0.5
PFM000066	30562	2015-06-22	0.10	17.20	<0.002	0.0566	3.570	0.0668	<0.002	0.380	2.020	0.1090	0.292	0.423	19.10	<0.5
PFM000066	30571	2015-08-04	0.10	47.70	0.0031	0.1380	0.646	0.0682	0.003	0.434	1.740	0.2170	0.317	0.452	25.20	<0.5
PFM000066	30598	2015-08-30	0.10	6.46	<0.002	0.1740	0.389	0.0900	<0.002	0.461	1.570	0.0337	0.257	0.328	28.30	<0.5
PFM000066	30639	2015-10-06	0.10	6.11	<0.002	0.1790	0.233	0.0634	<0.002	0.476	4.610	0.0217	0.268	0.279	22.50	<0.5
PFM000066	30665	2015-11-02	0.10	6.59	<0.002	0.1340	0.378	0.0967	<0.002	0.539	1.250	0.0278	0.197	0.271	31.70	<0.5
PFM000066	30705	2015-11-30	0.10	5.36	<0.002	0.0963	0.464	0.0623	<0.002	0.438	1.450	0.0271	0.164	0.371	23.20	<0.5
PFM000068	30399	2015-01-12	0.10	24.30	0.0022	0.2270	0.624	0.2570	0.006	0.746	1.990	0.0984	0.270	0.248	28.20	<0.5
PFM000068	30413	2015-02-09	0.10	27.10	0.0039	0.2400	0.963	0.1260	0.003	0.757	1.700	0.0588	0.264	0.504	20.20	<0.5
PFM000068	30420	2015-03-16	0.10	24.30	0.0081	0.2390	1.040	0.0733	0.003	0.612	1.360	0.0458	0.253	0.720	15.80	<0.5
PFM000068	30432	2015-04-21	0.10	16.40	<0.002	0.1860	0.609	0.1260	<0.002	0.697	1.570	0.0463	0.285	0.709	21.80	<0.5
PFM000068	30552	2015-05-20	0.10	16.20	0.0023	0.1910	0.513	0.0732	0.002	0.619	0.614	0.0620	0.195	0.420	17.00	<0.5
PFM000068	30559	2015-06-22	0.10	19.20	<0.002	0.0879	0.201	0.1070	<0.002	0.447	1.270	0.0633	0.374	0.263	21.30	<0.5
PFM000068	30567	2015-08-03	0.10	22.50	0.0050	0.1730	0.424	0.0811	<0.002	0.578	0.913	0.0705	0.344	0.378	24.00	<0.5
PFM000068	30596	2015-08-29	0.10	14.80	0.0049	0.1640	0.345	0.4040	0.002	0.598	2.210	0.0938	0.338	0.321	36.20	<0.5
PFM000068	30637	2015-10-06	0.10	13.10	<0.002	0.1650	0.324	0.0804	<0.002	0.395	1.920	0.0955	0.240	0.245	21.10	<0.5
PFM000068	30662	2015-11-02	0.10	11.60	<0.002	0.1330	0.380	0.1540	<0.002	0.419	2.780	0.0471	0.190	0.279	31.00	<0.5
PFM000068	30703	2015-11-30	0.10	15.40	0.0022	0.1180	0.742	0.0663	<0.002	0.646	1.680	0.0495	0.220	0.605	22.70	<0.5
PFM000069	30400	2015-01-12	0.10	25.60	<0.002	0.2410	0.576	0.1940	0.004	0.833	2.060	0.1060	0.286	0.211	34.50	<0.5
PFM000069	30414	2015-02-09	0.10	17.50	0.0035	0.2880	0.897	0.0994	0.003	0.792	3.620	0.0600	0.210	0.735	28.00	<0.5
PFM000069	30421	2015-03-16	0.10	18.30	0.0081	0.2380	1.180	0.0528	<0.002	0.682	1.450	0.0468	0.190	1.120	19.50	<0.5
PFM000069	30431	2015-04-21	0.10	13.60	<0.002	0.1650	0.511	0.0621	<0.002	0.509	0.490	0.0297	0.186	0.781	22.30	<0.5
PFM000069	30553	2015-05-20	0.10	14.40	0.0026	0.1240	0.426	0.0583	0.002	0.507	0.335	0.0537	0.192	0.488	20.30	<0.5

Idcode	Sample no.	Sampling date	Depth	Al	Cd	Cr	Cu	Co	Hg	Ni	Zn	Pb	V	Mo	Ba	Se
		(yyyy-mm-dd)	(m)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)	(ug/L)
PFM000069	30560	2015-06-22	0.10	24.60	<0.002	0.1270	0.209	0.0585	<0.002	0.357	0.907	0.0763	0.331	0.236	20.60	<0.5
PFM000069	30570	2015-08-04	0.10	35.20	0.0034	0.1510	0.417	0.0520	<0.002	0.447	1.410	0.1430	0.275	0.366	25.20	<0.5
PFM000069	30597	2015-08-30	0.10	13.50	0.0035	0.1710	0.394	0.1040	<0.002	0.541	2.370	0.0840	0.287	0.416	29.00	<0.5
PFM000069	30638	2015-10-06	0.10	15.60	<0.002	0.1720	0.256	0.0651	<0.002	0.396	4.040	0.0466	0.270	0.211	21.30	<0.5
PFM000069	30663	2015-11-02	0.10	11.80	0.0021	0.1420	0.414	0.0645	<0.002	0.383	1.740	0.0656	0.213	0.285	29.70	<0.5
PFM000069	30704	2015-11-30	0.10	11.00	<0.002	0.0845	0.431	0.0484	<0.002	0.374	0.954	0.0482	0.169	0.556	19.70	<0.5
PFM000070	30401	2015-01-12	0.10	17.20	0.0030	0.1700	0.835	0.0843	0.004	0.516	2.430	0.0730	0.287	0.366	21.30	<0.5
PFM000070	30415	2015-02-09	0.10	30.60	0.0037	0.1980	0.856	0.0597	0.003	0.555	1.530	0.0516	0.272	0.354	18.80	<0.5
PFM000070	30422	2015-03-16	0.10	34.90	0.0065	0.2150	0.918	0.0426	0.003	0.513	1.200	0.0547	0.243	0.309	11.90	<0.5
PFM000070	30430	2015-04-21	0.10	7.73	<0.002	0.0496	0.825	0.1020	<0.002	0.527	0.611	0.0352	0.221	0.295	17.80	<0.5
PFM000070	30554	2015-05-20	0.10	5.60	0.0032	0.1100	0.582	0.0502	<0.002	0.271	0.323	0.0453	0.210	0.293	12.70	<0.5
PFM000070	30561	2015-06-22	0.10	13.20	<0.002	0.0565	0.141	0.0800	<0.002	0.199	0.981	0.0617	0.224	0.059	18.70	<0.5
PFM000070	30573	2015-08-04	0.10	83.90	<0.002	0.1440	0.420	0.0929	<0.002	0.238	1.780	0.3760	0.332	0.074	22.10	<0.5
PFM000070	30636	2015-10-05	0.10	5.92	<0.002	0.1190	0.176	0.1230	<0.002	0.206	2.030	0.0241	0.148	0.054	17.90	<0.5
PFM000070	30664	2015-11-02	0.10	6.24	<0.002	0.0919	0.173	0.1890	<0.002	0.247	1.600	0.0431	0.121	0.081	24.90	<0.5
PFM000070	30706	2015-11-30	0.10	3.04	<0.002	0.0555	0.341	0.0346	<0.002	0.147	1.030	0.0248	0.154	0.260	13.00	<0.5
PFM000074	30403	2015-01-13	0.50	10.70	<0.002	0.1380	0.552	0.0842	<0.002	0.519	1.150	0.0586	0.200	0.249	28.60	<0.5
PFM000074	30434	2015-04-21	0.50	34.40	<0.002	0.1430	0.743	0.0432	<0.002	0.483	1.290	0.1570	0.241	0.510	25.40	<0.5
PFM000074	30568	2015-08-03	0.50	17.10	0.0045	0.0748	0.619	0.0588	<0.002	0.525	1.770	0.0674	0.477	0.436	28.20	<0.5
PFM000074	30640	2015-10-06	0.50	5.45	<0.002	0.1790	0.329	0.0532	<0.002	0.429	3.900	0.0303	0.185	0.285	25.00	<0.5
PFM000107	30397	2015-01-12	0.50	18.50	0.0040	0.2370	0.753	0.1080	0.004	0.642	1.530	0.0887	0.279	0.538	28.30	<0.5
PFM000107	30398	2015-01-12	1.00	21.40	<0.002	0.2500	0.577	0.1710	0.006	0.677	1.370	0.1200	0.327	0.357	31.60	<0.5
PFM000107	30427	2015-04-20	0.50	7.06	0.0038	0.1000	0.623	0.0589	<0.002	0.376	0.824	0.0631	0.267	0.567	16.30	<0.5
PFM000107	30566	2015-08-03	0.50	16.30	0.0046	0.0949	0.518	0.0778	<0.002	0.314	0.824	0.1560	0.473	0.647	13.90	<0.5
PFM000107	30633	2015-10-05	0.50	5.53	0.0033	0.1090	0.477	0.0660	<0.002	0.280	1.460	0.0529	0.238	0.528	12.90	<0.5
PFM000117	30411	2015-01-14	0.50	15.00	<0.002	0.1790	0.863	0.0524	0.003	0.401	1.010	0.0477	0.253	0.373	22.10	<0.5
PFM000117	30412	2015-01-14	1.50	16.20	<0.002	0.1690	0.751	0.0725	<0.002	0.435	2.060	0.0592	0.232	0.316	24.50	<0.5
PFM000117	30429	2015-04-20	0.50	8.72	<0.002	0.0913	0.683	0.0472	<0.002	0.324	1.130	0.0295	0.254	0.303	15.50	<0.5
PFM000117	30572	2015-08-04	0.50	76.50	0.0021	0.1110	0.740	0.0612	0.003	0.288	1.160	0.3660	0.582	0.418	15.00	<0.5
PFM000117	30635	2015-10-05	0.50	2.26	<0.002	0.1090	0.623	0.0728	<0.002	0.271	2.050	0.0146	0.309	0.387	13.90	<0.5

SKB is responsible for managing spent nuclear fuel and radioactive waste produced by the Swedish nuclear power plants such that man and the environment are protected in the near and distant future.

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