P-06-217

Forsmark site investigation

Hydrochemical characterisation in borehole KFM09A

Results from the investigated section at 785.1–792.2 m

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September 2006

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Keywords: Groundwater, Measurements on-line, In situ sampling, Measurements in situ, Redox potential, Chemical analyses, Isotope determinations, AP PF 400-06-026.

Abstract

Complete chemical characterisation is the most extensive chemical investigation method performed in core drilled boreholes. The method entails pumping, measurements on-line and regular water sampling for chemical analyses in isolated borehole sections during approximately three weeks per section at a flow rate of between 50 and 200 mL/min.

The method has been used in a section from borehole KFM09A at 785.1–792.2 m borehole length (vertical depth 676.2–682.3 m). The results include on-line measurements of redox potential, pH, dissolved oxygen, electrical conductivity and water temperature in the borehole section, together with chemical analyses of major constituents, trace metals and isotopes.

In this borehole, inorganic colloids, humic and fulvic acids and dissolved gas were not investigated due to malfunction of the equipment.

The water composition was stable during the pumping and sampling periods and the chloride concentration amounted to 14,800 mg/L. The pH-values (on-line and from lab) were rather high (8.1–8.2). Only one redox electrode (the platinum electrode at the surface) measured reasonable and stable values. The Eh-value (–229 mV) for the groundwater from the borehole section is therefore highly uncertain.

Sammanfattning

Fullständig kemikarakterisering är den mest omfattande kemiska undersökningsmetoden för kärnborrhål. Metoden innebär pumpning, mätning on-line och regelbunden vatten-provtagning för kemiska analyser i avgränsade borrhålssektioner under cirka tre veckor per sektion med ett pumpflöde på mellan 50 och 200 mL/min.

Metoden har utförts i en sektion av borrhålet KFM09A vid 785,1–792,2 m borrhålslängd (vertikalt djup 676,2–682,3 m). Resultaten omfattar mätningar on-line av redoxpotential, pH, löst syre, elektrisk konduktivitet och vattentemperatur i borrhåls-sektionen liksom kemiska analyser av huvudkomponenter och spårelement.

I detta borrhål undersöktes inte oorganiska kolloider, humus- och fulvosyror samt lösta gaser på grund av problem med utrustning.

Vattensammansättningen var stabil under pump/provtagningsperioden och kloridkoncentrationen uppgick till 14 800 mg/L. pH-värdena (on-line och på lab) var ganska höga (8,1–8,2). Endast en redoxelektrod (platinaelektroden vid ytan) mätte rimliga och stabila värden. Eh-värdet (–229 mV) för grundvattnet från borrhålssektionen är därför högst osäkert.

Contents

1 Introduction

This document reports the performance and results of the activity Complete Chemical Characterisation in borehole KFM09A within the site investigation programme at Forsmark /1/. The work was conducted according to the activity plan AP PF 400-06-026 with some exceptions, see Nonconformities. The report presents hydrogeochemical data from fieldwork carried out during April to May 2006.

The controlling documents for the activity are listed in Table 1-1. The activity plan, the method description and the measurement system descriptions constitute SKB's internal controlling documents. The obtained data from the activity are reported to the database SICADA, where they are traceable by the activity plan number.

Borehole KFM09A is a non-telescopic and non-chemistry type core drilled borehole /2/. Its location together with other current boreholes within the investigation area is shown in Figure 1-1. Figure 1-2 presents a detailed map of drill sites DS7 and DS9 showing the locations of KFM09A and other nearby situated percussion-drilled boreholes. KFM09A is at ground surface inclined at 59°, in the direction towards south-west. The borehole is core drilled with a diameter of 77.3 mm. The design of borehole KFM09A is presented in Appendix 1.

Water sampling, using new sampling equipment (SLT) suited for low hydraulic transmissivity fractures, was also planned according to the activity plan. However, the tests in this borehole were not technically successful and a description of the performance is reported in Appendix 2.

The cleaning procedures of all equipment used in the borehole, during and after drilling, were performed according to the lowest level (level 1) in the cleaning instructions in MD 600.004 (Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning).

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

Activity plan	**Number**	**Version**
Fullständig kemikaraktärisering med mobilt fältlaboratorium i KFM09A.	AP PF 400-06-026	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för fullständig kemikaraktärisering med mobilt fältlaboratorium.	SKB MD 430.017	2.0
Measurement system descriptions	Number	Version
Instruktion för rengöring av borrutrustning och viss markbaserad utrustning.	SKB MD 600.004	1.0
Mätsystembeskrivningar för mobil kemienhet allmän del, slangvagn, borrhålsutrustning, mobil ytChemmac och dataapplikation.	SKB MD 434.004 SKB MD 434.005 SKB MD 434.006 SKB MD 434.007 SKB MD 433.018	1.0 1.0 1.0 1.0 1.0
Mätsystembeskrivning för fraktionering av humus- och fulvosyror	SKB MD 431.043	1.0
Mätsystembeskrivning för uppkoncentrering av humus- och fulvosyror.	SKB MD 431.044	
Instructions		
Provtagning och analys-kemilaboratorium.	SKB MD 452.001-019	–

Figure 1-1. The investigation area at Forsmark (approximately the area inside the black square) including the candidate area selected for more detailed investigations with the currently completed core drilled boreholes.

Figure 1-2. Locations and projections on the horizontal plane of the cored boreholes KFM09 and surrounding boreholes at drill sites DS9 and DS7.

2 Objectives and scope

Complete chemical characterisation is the most extensive chemical investigation method performed in core drilled boreholes. The method is carried out in order to obtain as much information as possible about the chemical conditions in the groundwater from individual water-bearing fractures or fracture zones. Considerable effort is put into obtaining representative samples from a limited rock volume. Careful pumping and continuous control of the pressure in the sampled borehole section, as well as above the section, is maintained in order to minimise the risk of mixing with groundwaters from other fracture systems.

A decision has been made to prioritise the north-western part of the Forsmark candidate area for the continuing investigations /3/. So far, representative chemical data from borehole sections at depths greater than 200 m are scarce from this part of the area. The reason for sampling in this non-chemistry borehole is the presence of highly saline water found at a borehole length below 700 m. This was shown by a strong attenuation of the borehole radar signal, /4/ as well as the results from the hydrochemical logging of the borehole /5/. Thus, it was found to be of interest to investigate further the water chemistry of the deepest parts of this borehole.

The analytical programme was carried out according to SKB chemistry class 4 and class 5 including all options, complemented with analyses of barium, boron and phosphorous /1/. Furthermore, pH, redox potential (Eh) and water temperature were measured using flow-through cells in the borehole section as well as at the ground surface. The flow-through cell at the surface also measured electrical conductivity and dissolved oxygen.

3 Background

3.1 Flushing water history

Tap water from the facility for washing of vehicles close to drill site DS9 was used as flushing water to drill borehole KFM09A and its chemical composition was checked once during use /2/. The core drilling of the 799.67 m long borehole consumed 861 m^3 of flushing water. The volume of returned water from the borehole was only 1.0 m^3 partly due to that no air lift pumping was conducted during drilling. The design of the borehole does not allow contemporary air lift pumping. However, seven repeated flushings with nitrogen gas were conducted subsequent to the drilling and an additional water volume (approximately 12.5 m^3) was exchanged.

Automatic dosing equipment to introduce Uranine was installed in the water line which supplies flushing water to the drilling head. The Uranine concentration in the flushing water and returned water was checked regularly and a total of 92 samples of each sample type were analysed. The average concentration in the flushing water amounted to 0.161±0.039 mg/L. The Uranine concentrations in the flushing water and in the returned water are presented in Figure 3-1. The diagram displays an unacceptably large variation in the Uranine concentration of the flushing water. A possible explanation is that at some sampling occasions, the sample might have been collected just after the dosing equipment and not close to the drilling machine as it should be. A water budget, presenting the amount of Uranine added to the borehole via the flushing water and the estimated amount recovered in the return water, is given in Table 3-1.

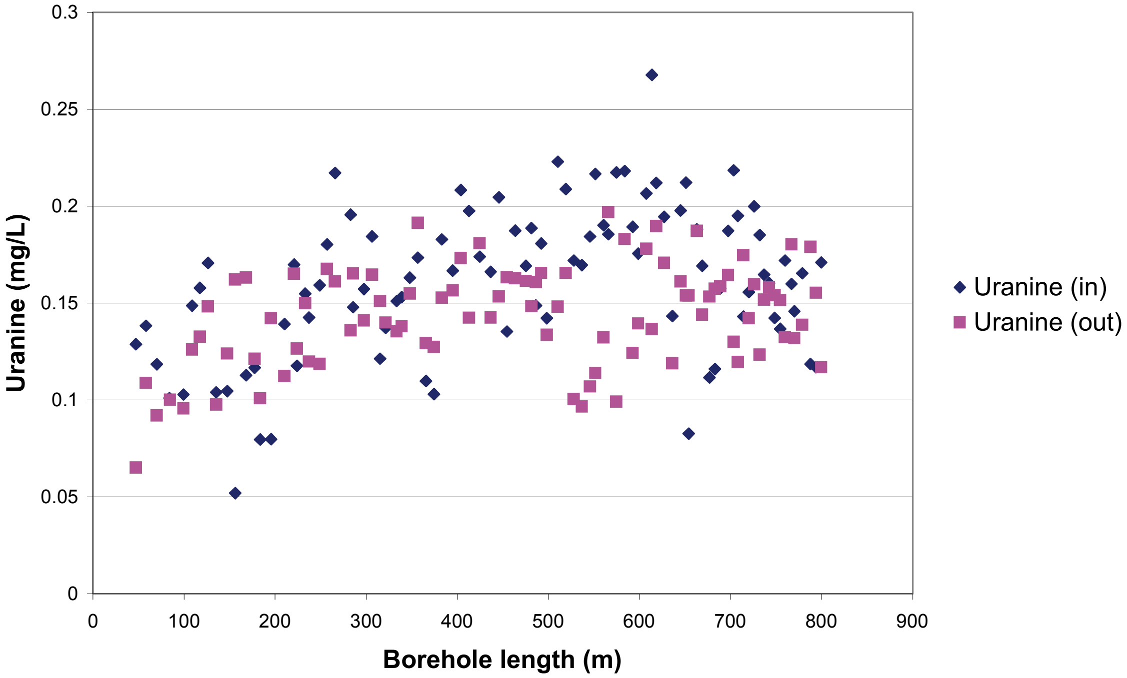


Figure 3-1. Uranine concentrations in the flushing water and in the recovered water versus borehole length.

Table 3-1. Amount of Uranine added to KFM09A via the flushing water during core drilling and the amount recovered in the returned water.

Uranine	(g)
Added, according to the log book.	138
Added, calculated from the average Uranine concentration and the total volume of flushing water.	138
Recovered, estimated from the average Uranine concentration and the total volume of returned water.	0.15

The very good agreement between the amount of Uranine added according to the log book and the amount calculated from the average Uranine concentration is most likely just a coincident. The Uranine budget in Table 3-1 suggests that most of the flushing water was lost to the borehole and the adjacent host bedrock during drilling. However, the subsequent nitrogen flushing should have improved, to some extent, the recovery of flushing water and also of drilling debris.

3.2 Previous events and activities in the borehole

The borehole KFM09A is not specially intended for complete hydrochemical characteri-sation. Due to this, the cleaning procedures of all equipment used in the borehole, during and after drilling, were performed according to the lowest level (level 1) in the cleaning instructions in MD 600.004. The more equipment used in the borehole, the greater is the risk of contamination and effects on, for example the in situ microbiological conditions. The activities/investigations performed in KFM09A prior to the chemistry campaign are listed in Table 3-1 below.

Table 3-2. Activities performed in KFM09A in connection to the chemical characterisation.

Activities performed	Date of completion	Length or section (m)	Comment
Core drilling	2005-10-27	0.00–799.67	Drinking water from the tap was the source of flushing water for core drilling of KFM09A. Flushing water volume = 861 m^3. Return water volume = 1,036 m^3 /2/.
Flushing water treatment	2005-10-27	47.08–799.67	Automatic dosing of Uranine was used during drilling of KFM09A. In this way there was no need for an in-line storage tank placed after the UV-system /2/.
Water sampling	2005-10-05	100–515	SKB class 3, Sample no. 8972.
Geophysical logging	2005-11-11	0– 799.18	/4/
BIPS-logging	2005-11-06	7.00–792.00	/6/
Injection tests	2005-12-21	7.80–791.00	/7/
Hydrochemical logging	2006-03-07	0–795	Sample nos. 12201 to 12216 /5/.
Hydrochemical characterisation	2006-05-02	785.1–792.2	Presented in this report.

4 Equipment

4.1 The mobile field laboratory

The mobile field laboratories used by SKB for water sampling and downhole measurements consist of a laboratory unit, a separate computer unit (MYC), a hose unit with downhole equipment and a Chemmac measurement system. The different parts of the system are described in the SKB internal controlling documents SKB MD 434.004, 434.005, 434.006, 434.007 and SKB MD 433.018 (Mätsystembeskrivningar för mobil kemienhet allmän del, slangvagn, borrhålsutrustning, mobil ytChemmac och dataapplikation), cf. Table 1-1.

The Chemmac measurement facilities include communication systems, measurement application and flow-through cells with electrodes and sensors at the ground surface (surface Chemmac) and downhole (borehole Chemmac).

The downhole equipment comprises inflatable packers, pump, borehole Chemmac and the in situ sampling unit (PVP), allowing measurement (borehole Chemmac) and sampling in situ in the borehole section (PVP sampling unit).

The mobile units used for the investigation of borehole KFM09A consisted of the hose unit S3. A sketch of the arrangement at drill site DS9 is displayed in Figure 4-1. The laboratory unit L3 was employed for analytical work but was located close to the core mapping facility and not at drill site DS9.

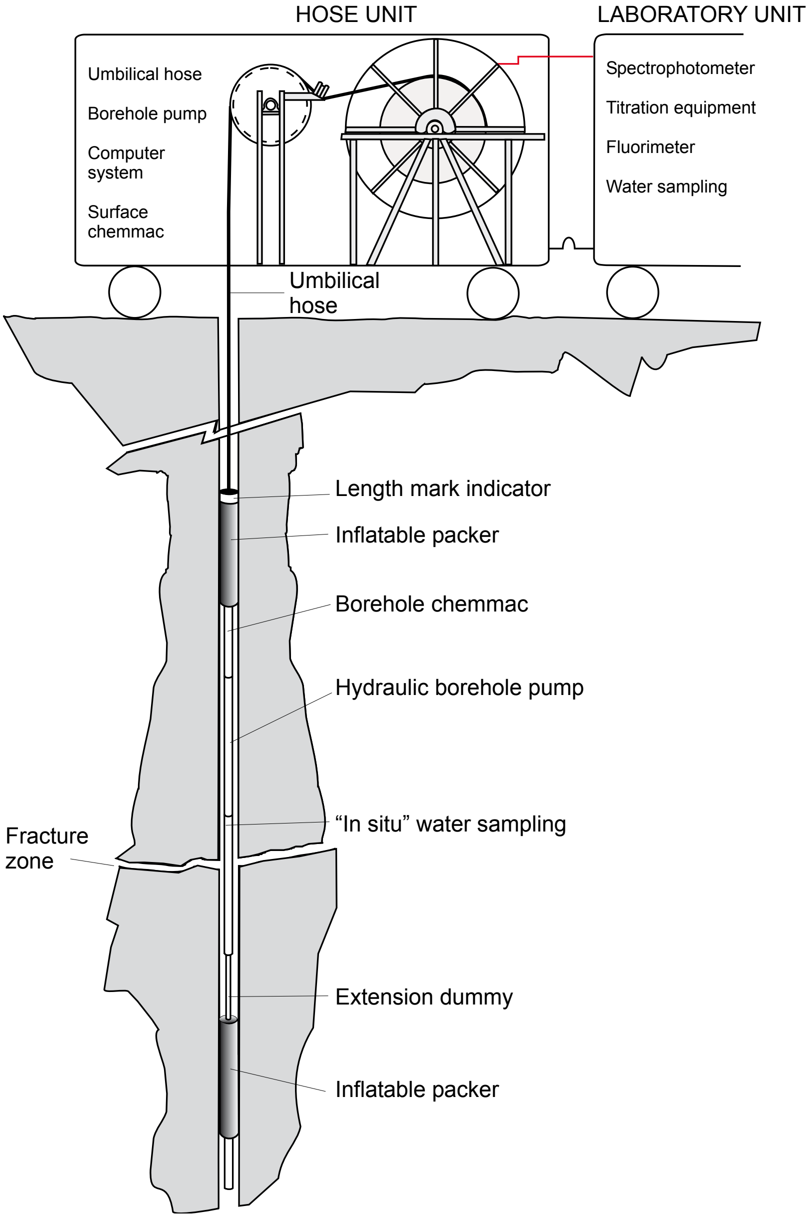


***Figure 4-1.** The mobile laboratory including laboratory unit, hose unit and downhole equipment. The configuration of the downhole units in the borehole can be varied depending on desired section length. However, the in situ water sampler must always be positioned first in the sample water path.*

5 Performance

5.1 Overview of field work procedure

A short chronological summary of the different steps that constitute the chemical characterisation of groundwater in one borehole section is given below.

The preparations conducted before the downhole equipment is lowered in the borehole include:

- Cleaning of the inside of the umbilical hose (the sample water channel) with de-ionised and de-oxygenated water. Finally, the sample water channel is filled with de-ionised and de-oxygenated water prior to lowering.

- Cleaning and preparation of the four sample containers (PVB) belonging to the in situ water sampling unit (PVP). The containers/vessels are cleaned on the outside using 70% denatured ethanol and on the inside using chlorine dioxide. One of the containers is used for microbe sampling and sterile conditions are desirable. The containers are purged with nitrogen gas and a small nitrogen gas pressure is maintained in the containers. The magnitude of the pressure depends on the depth of the section to be sampled and in this case an overpressure of 5 bars was used.

- Calibration of the pH and redox electrodes in the downhole Chemmac equipment.

The different downhole units are assembled during lowering of the equipment down the borehole and the following steps are taken:

- Calibration of the umbilical hose length is conducted at least once for each borehole. For this purpose, a length mark detector unit (caliper) is mounted together with the ordinary downhole equipment. The length mark detector indicates length calibration marks milled into the borehole wall at almost every 50 m along the borehole /2/. At each indication, a reading is made of the corresponding length mark on the umbilical hose. The correct distance to each length mark is obtained from the SICADA database.

When the pump is started and the packers are inflated at the desired positions in the borehole, a pumping and measurement period begins. Typical measures taken and activities carried out during this period are:

- Calibration of the pH and redox electrodes as well as the electrical conductivity and oxygen sensors in the surface Chemmac is conducted when the pumped water from the borehole section has reached the surface.

- Careful attention is paid in order to ensure that the packed-off section is well isolated from the rest of the borehole. A significant drawdown in the section during pumping is one indication that the section is properly sealed off. Leakage would cause pumping of water from the borehole column above and/or below the packers and not only from the fracture zone of interest. However, the drawdown in the borehole section must not be too large, because the greater the drawdown, the larger the bedrock volume affected by the pumping, and the risk of mixing with groundwater from other shallower and/or deeper fracture systems increases. The pumping flow rate is adjusted depending on the flow yield from the fracture or fracture zone (to between 50 and 200 mL/min) and maintained more or less constant during the pumping and measurement period.

- Water samples are collected regularly once or twice a week during the pumping period. Changes in water composition are monitored by conductivity measurements and by immediate analyses (pH, Uranine, chloride, alkalinity, ferrous and total iron, and ammonium) at the site.

- A decision when to terminate the sampling work in the section is made during a suitable stage of the pumping and measurement period. The investigation might be prolonged if the concentration of flushing water exceeds 1% or if the redox potential measurements have not reached stable values. A final SKB Class 5 sample including options is collected the day before termination.

Completion of the investigation in the section and lifting of the downhole equipment entails:

- Collection of in situ samples prior to lifting the equipment. The valves to the PVB sampling containers in the borehole section are opened from the surface in order to rinse the system and fill the containers. After some hours the valves are closed and the water sample portions for analyses of colloids, dissolved gases and microbes are secured.
- Following stopping of the borehole pump and deflation of the packers, the equipment is lifted and the different downhole units are dismantled.
- Calibration of the electrodes in the downhole Chemmac and surface Chemmac.

5.2 Performance in section 785.1–792.2 m

The chemical characterisation in section 785.1–792.2 m was performed using the following configuration of the downhole equipment in the borehole. From the top: umbilical hose, length mark detector, borehole Chemmac, upper packer, borehole pump, in situ water sampler (PVP), and lower packer, see Appendix 3. The pressures above and within the section were measured by the borehole Chemmac unit and the PVP water sampling unit, respectively.

The pumping flow rate was about 115–140 mL/min. The drawdown varied, and was approximately 20–40 m during the measurement period. The total pumped volume at the end of the measurement period was 1.6 m^3. Diagrams showing the pressures above and within the borehole section and the flow rate during the pumping/measurement period are presented in Appendix 3. The events during the investigation are listed in Table 5-1.

Table 5-1. Events during the chemical characterisation pumping/measurement period in section 785.1–792.2 m.

Date	Event	Sample no.
060410	Calibration of borehole Chemmac.	
060411	Lowering of downhole equipment S3 (785.10–792.24 m).	
060412	Calibration of surface Chemmac.	
	Start of Chemmac measurements.	
060418	Water sampling: SKB class 2.	12239
060420	Water sampling: SKB class 5.	12241
060421	Loss of contact with borehole equipment. Borehole pump stopped, Rasing equipment and removing the length mark indicator.	
060421	Lowering equipment.	
060424	Water sampling: SKB class 4.	12242
060425	No logging of data by the measurement application. Restart.	
	Restart after power failure.	
060426	No logging of data by the measurement application. Restart.	
	No flow. Borehole pump stopped. Filling of water to the hydraulic pump tank.	
060427	Water sampling: SKB class 5.	12243
060502	Water sampling: SKB class 4.	12244
060504	Leakage of water because of a broken swivel connection. Raising equipment.	
060505	Calibration of surface and borehole Chemmac.	

5.3 Water sampling, sample treatment and analyses

The pumped water from the borehole section is led from the hose unit into a container furnished with a sink and a tank for collecting the outlet water. Filtration of sample portions is performed on-line by connecting the filter holders directly to the water outlet. A water sample is defined as groundwater collected during one day and consists of several sample portions, labelled with the same sample number.

An overview of sample treatment and analysis methods is given in Appendix 6. The routines are applicable independently of sampling method or type of sampling object.

6 Nonconformities

The hydrochemical characterisation in KFM09A has been conducted according to the SKB internal controlling documents AP PF 400-05-026 and SKB MD 430.017 with the following deviations and remarks:

- During the period April 21 to April 25, the Chemmac measurements were not recorded due to malfunction of the measurement device.
- The allowed upper limit for flushing water content, 1%, was slightly exceeded.
- The SLT did not function at the time of sampling in KFM09A, see Appendix 2.
- Only one of the planned sections was investigated because of leakage due to a broken swivel connection.

Due to the broken swivel connection, the following activities were excluded:

- Inorganic colloid filtration.
- Enrichment and fractionation of humic and fulvic acids.
- The in situ sampling (four sample containers; PVB).
- Sampling of a last SKB chemistry class 5 water sample, taken just before raising the equipment.

7 Data handling and interpretation

7.1 Chemmac measurement data

The processing of Chemmac data is described in SKB MD 434.007, version 2.0 (Mätsystembeskrivning för Chemmac mätsystem, SKB internal controlling document, in progress).

7.1.1 Data file types and calculation software

The on-line measurements in a borehole section produce the following types of raw data files:

- Calibration files from calibration measurements (*.CRB) and corresponding comment files (*.CI). The files are used for calculation of calibration constants (pH and Eh) and the calibration factor (electrical conductivity). For surface Chemmac ten *.CRB and ten *.CI files are produced, and for borehole Chemmac six *.CRB and six *.CI files.
- Raw data file containing the logged measurements from the borehole section and the surface (*K.MRB) as well as a corresponding comment file (*.MI). The logged voltage values need to be converted to pH and Eh values (also in mV) using the calibration constants obtained from calibration.
- Measurement file including equipment and environment parameters (*O.MRB), such as power consumption in the downhole Chemmac unit and temperature inside the hose unit.

The original raw data files listed above are stored in the SICADA file archive. Furthermore, the files are re-calculated and evaluated to obtain pH and redox potential values and to correct the electrical conductivity values using the specially designed calculation software (Hilda). The resulting files containing calculated and evaluated values as well as comments on the performance are:

- A file **constants.mio* containing all the calculated calibration constants (one constant for each electrode in each buffer solution). The file is stored in the SICADA file archive and is useful in order to follow the development of single electrodes.
- A file **measurements.mio* containing the calculated and evaluated measurement values (pH, redox potential, electrical conductivity and water temperature). The data from the file are exported to the data tables "redox" and "ph_cond" in SICADA. As the file also contains some measured parameters that are not included in the tables mentioned above (e.g. pressure registrations), the complete file is also stored in the SICADA file archive.
- A file **comments.mio* containing comments on the fieldwork and the calculation/evaluation. The comments in the file are imported as activity comments in SICADA.

7.1.2 Calculations and evaluation of redox potential and pH

The redox potential is measured by three electrodes at the surface and three in the borehole section. In addition, pH is measured by two electrodes at the surface and two downhole in the borehole section. The registrations by the redox and the pH electrodes are logged each hour during a measurement period of approximately three weeks and a calibration is performed before and after the measurement period. The treatment of the raw data includes the following steps:

- Calculation and choice of calibration constants.
- Calculation of one pH and one redox potential sequence for each electrode (i.e. three or six redox electrodes and two or four pH electrodes).
- Determination of representative pH and redox potential values as well as estimated measurement uncertainties for the investigated borehole section.

One calibration constant is selected for each electrode using one of the following alternatives:

- Case 1: Calculation of the average calibration constant value and the standard deviation. The initial and the final calibration measurements result in four constants for each redox electrode (in pH 4 and pH 7 buffer solutions) and six constants for each pH electrode (in pH 4, 7 and 10 buffer solutions).
- Case 2: The calibration constant obtained from the initial calibration measurement at pH 7 is selected since it is closest to the pH of the borehole water. This alternative is chosen if the calibration constants obtained in the different buffers show a large variation in value (generally a difference larger than 20 mV between the highest and the lowest value). The standard deviation is calculated in the same way as in Case 1.
- Case 3: If the final calibration constants turn out to be very different (more than 20 mV) from the initial constants, a linear drift correction is needed. The reason for this is most often a drift in the reference electrode. The values and standard deviations are calculated for the initial and the final calibration constants separately and a linear correction is made between the selected initial and the selected final constant. The higher of the two standard deviation values is used in the estimation of the total measurement uncertainty.

The values in the measurement raw data file are converted to pH and Eh measurement sequences for each pH and redox electrode using the calibration constant selected as stated above.

The next step is to choose a logging occasion in a stable part of the measurement period and select a representative result for each electrode. The average values are calculated for each electrode group in order to obtain one representative value of redox potential, pH (borehole Chemmac) and pH (surface Chemmac), respectively. Obviously erroneous electrodes are omitted. The corresponding total measurement uncertainties are estimated using the standard deviations of the calibration constants and the standard deviations of the Eh and the pH values obtained by the different sets of electrodes. It is useful to evaluate pH at the surface and pH in the borehole section separately, since pH in the pumped water might differ from the pH measured in the borehole section. This is due to changing gas pressure conditions and their effects on the carbonate system.

Factors considered when evaluating the measurement uncertainties in pH and redox potential (Eh) values are:

- Difference in calibration constants for each electrode and calibration/buffer solution.
- Drift in calibration constants between the initial and the final calibration.
- Stability in voltage value during the final part of the on-line measurement. A successful measurement shows no tendency of a slope.
- Agreement between the different pH and redox electrodes on the surface and in the downhole Chemmac.
- Number of electrodes showing reasonable agreement. Obviously erroneous electrodes are excluded from the calculation.

7.2 Water analysis data

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

Several components are determined by more than one method and/or laboratory. Moreover, duplicate analyses by an independent laboratory are performed as a standard procedure on each fifth or tenth collected sample. All analytical results are stored in the SICADA database. The applied hierarchy path “Hydrochemistry/Hydrochemical investigation/Analyses/Water in the database” contains two types of tables, raw data tables and primary data tables (final data tables).

Data on **basic water analyses** are inserted into the raw data tables for further evaluation. The evaluation results in a final reduced data set for each sample which are compiled in a primary data table named “water composition”. The evaluation is based on:

- Comparison of the results from different laboratories and/or methods. The analyses are repeated if a large disparity is noted (generally more than 10%).
- Calculation of charge balance errors according to the equation below. Relative errors within ± 5% are considered acceptable (in surface waters ± 10%).

$$\text{Relative error } (\%) = 100 \times \frac{\sum cations(equivalents) - \sum anions(equivalents)}{\sum cations(equivalents) + \sum anions(equivalents)}$$

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

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

An overview of the data management is given in Figure 7-1.

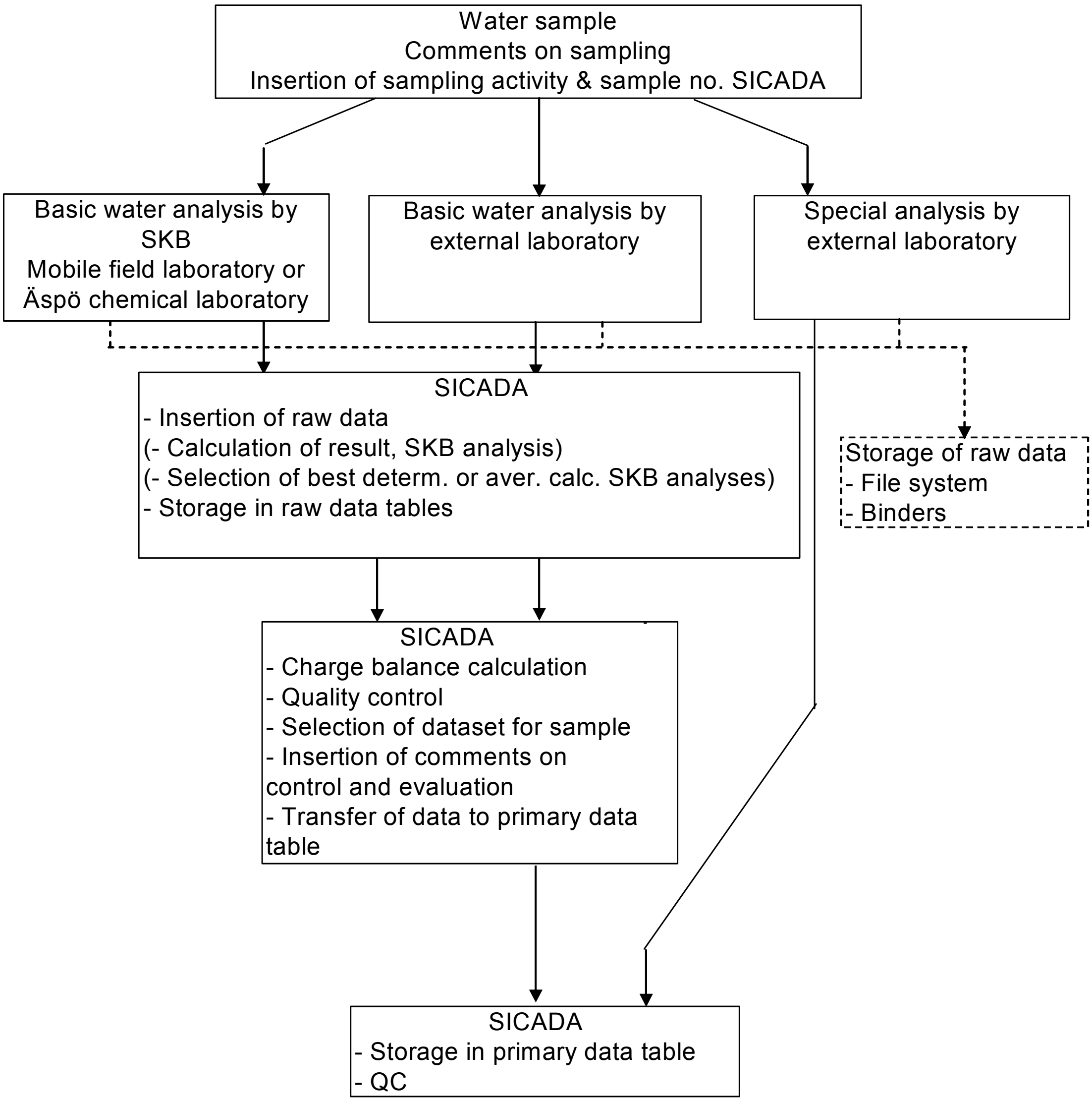


Figure 7-1. *Overview of data management for hydrogeochemical data.*

8 Results

8.1 Chemmac measurements

The data sequences of flow and pressure measurements in section 785.1–792.2 m are plotted versus time in Appendix 4. Eh, pH, electrical conductivity, oxygen and temperature values from the Chemmac measurements are plotted versus time in Appendix 5.

The redox measurements in this section did not stabilise and the readings from the different electrodes diverge. However, the platinum electrode in the surface Chemmac, with a negative redox value, was considered the most reliable one, since even the slightest leakage of oxygen might disturb the measurements and give positive redox values. However, the choice of redox value is based on only one electrode and it is associated with a high uncertainty. The carbon electrode in the surface Chemmac showed a noisy and disturbed behaviour and these measurements were therefore rejected.

The two pH-electrodes at the ground surface agreed completely at the end of the measurement period but varied periodically in a regular way (day/night). This variation is caused by temperature variations in the hose unit. Of the two borehole pH-electrodes, only the one showing small variations in time was used in the calculations. By the second half of the measurement period, the content of oxygen was below detection level.

The measured time series of data were evaluated in order to obtain one representative value of Eh, pH, electrical conductivity and dissolved oxygen for the borehole section as described in Section 7.1. Data were selected from the last part of the measured time series sequences (where the electrodes show stable values), marked with an arrow in the diagrams in Appendix 5. The evaluated results from the measurements in the investigated section are given in Table 8-1.

8.2 Water analyses

8.2.1 Basic water analyses

The basic water analyses include the major constituents Na, K, Ca, Mg, S, Sr, SO_4^{2-}, Cl^-, Si and HCO_3^- as well as the minor constituents Fe, Li, Mn, DOC, Br, F, I, HS^- and NH_4^+. Furthermore, batch measurements of pH (lab-pH) and electrical conductivity (lab-EC) are included. Another important parameter is the drill water content in each sample. The basic water analysis data and relative charge balance errors are compiled in Appendix 7, Table A7-1. Existing lab-pH and lab-Eh values are compared with the corresponding on-line Chemmac measurement values in Appendix 5.

Table 8-1. Evaluated results from the Chemmac measurement in KFM09A.

Borehole section [m]	EC* [mS/m]	pH (surface Chemmac)**	pH (borehole Chemmac)**	Eh (platinum electrode in borehole Chemmac)** [mV]	Dissolved oxygen*** [mg/L]
785.2–792.2	3,610 ± 110	8.2 ± 0.2	8.1 ± 0.8	(–229 ± 11)	0.00 ± 0.01

* The electrical conductivity is measured between 0–10,000 mS/m with a measurement uncertainty of 3%.

** Evaluated result and measurement uncertainty calculated as described in Section 7.1.

*** Measurement interval 0–15 mg/L, resolution 0.01 mg/L.

The charge balance errors give an indication of the quality and uncertainty of the analyses of major constituents. The errors do not exceed ± 5% in any case. No last SKB class 5 sample from this section was collected, and consequently no sample was analysed by a second laboratory in this investigation.

The concentration levels of chloride, calcium and sodium are presented in Figure 8-1. The concentrations of all major constituents remained practically constant during the entire pumping and sampling period.

The iron concentrations determined by ICP-AES (total Fe) and by spectrophotometry (Fe(II) and Fe-tot) are compared in Figure 8-2. The total iron concentrations determined by ICP agree reasonably well with the results obtained by spectrophotometry.

Sulphate analysed by ion chromatography (IC) is compared with sulphate determined as total sulphur by ICP-AES in Figure 8-3. As shown, about 80% of the sulphur is present as sulphate and the remaining sulphur is present as other species or the discrepancy is due to analytical error. The results from the ICP measurements are considered more reliable, by experience, since the variation in a time series often is smaller. The sulphate concentration remains constant during the sampling period.

8.2.2 Trace elements (rare earth metals and others)

The analyses of trace and rare earth metals include Al, B, Ba, U, Th, Sc, Rb, Y, Zr, In, Sb, Cs, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. The risk of contamination is large for aluminium, but the aluminium concentration is still reported due to its importance for the modelling work. The trace element data are compiled in Appendix 7, Table A7-3.

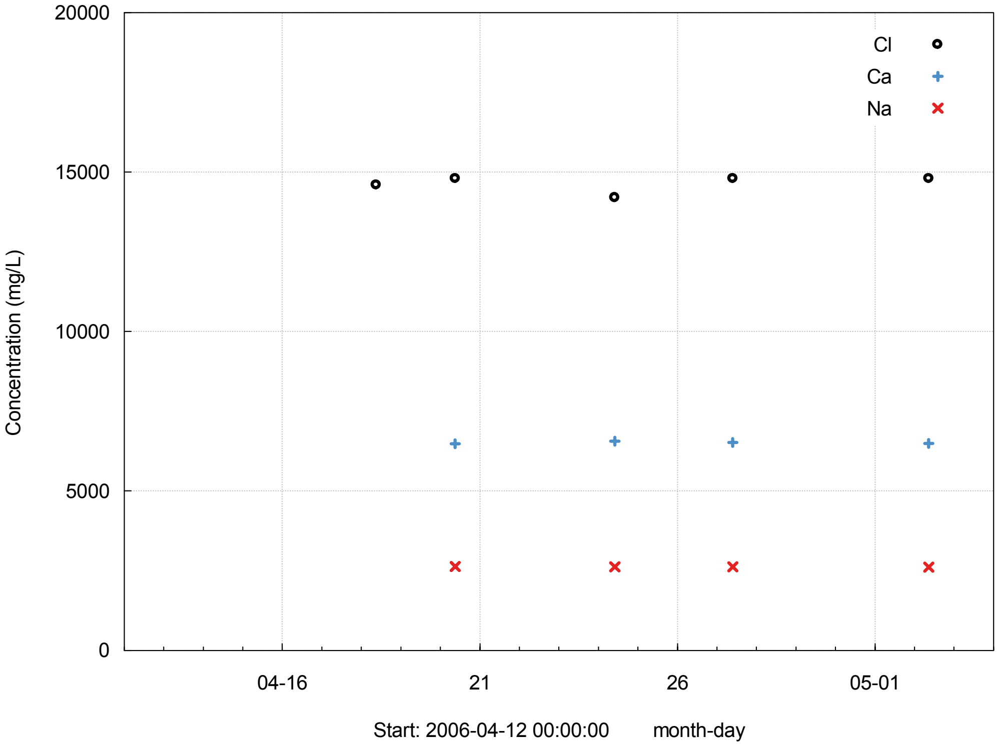


Figure 8-1. *Chloride, calcium and sodium concentration from the sample series at 785.1–792.2 m.*

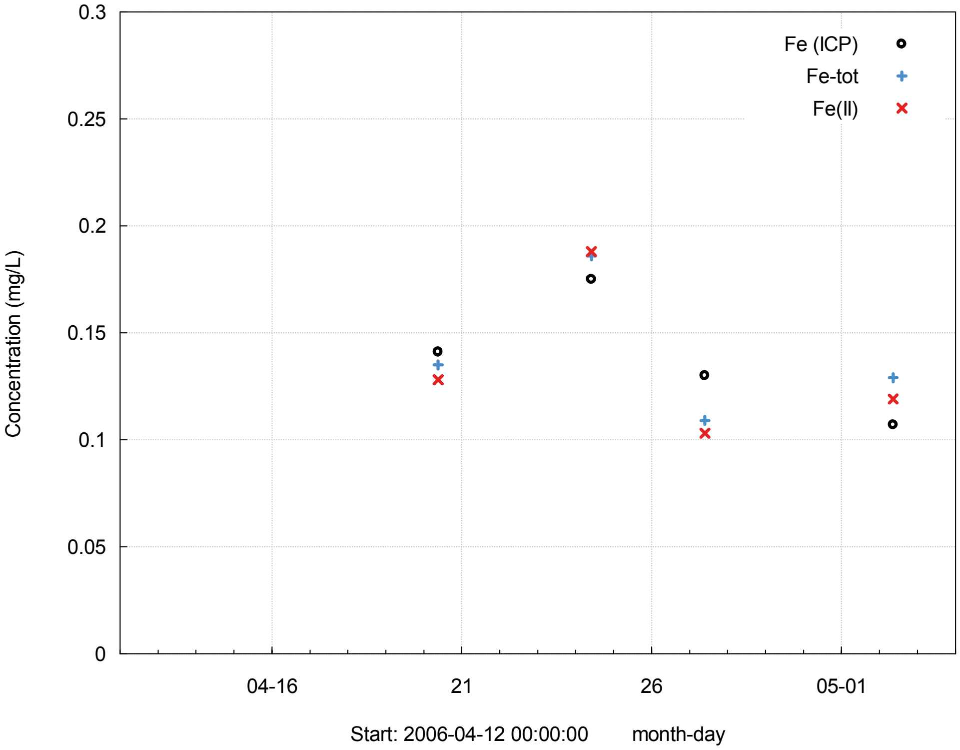


Figure 8-2. *Comparison of iron concentrations obtained by ICP-AES and by spectrophotometry, borehole section 785.1–792.2 m.*

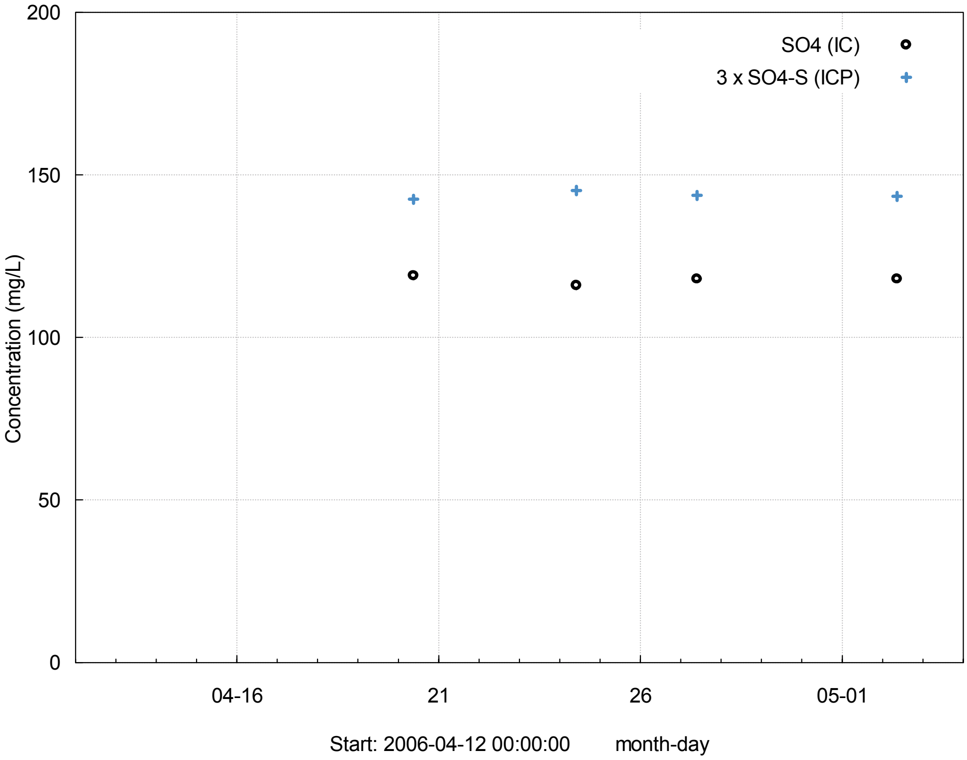


Figure 8-3. *Sulphate (SO_4^{2-} by IC) to total sulphate calculated from total sulphur (3×SO_4–S by ICP) versus date, borehole section 785.1–792.2 m.*

8.2.3 Stable and radioactive isotopes

The isotope determinations include the stable isotopes δD, δ^{18}O, ^{10}B/^{11}B, δ^{34}S, δ^{13}C, ^{37}Cl and ^{87}Sr/^{86}Sr as well as the radioactive isotopes Tr (TU), ^{14}C (pmC), ^{238}U, ^{235}U, ^{234}U, ^{232}Th, ^{230}Th, ^{226}Ra and ^{222}Rn. Available isotope data at the time of reporting are compiled in Appendix 7, Table A7-2.

The tritium and δ^{18}O results for section 785.1–792.2 m are presented in Figure 8-4. The tritium content was below the detection limit (0.8 Tritium Units) in all samples. The sample series showed more or less constant δ^{18}O values.

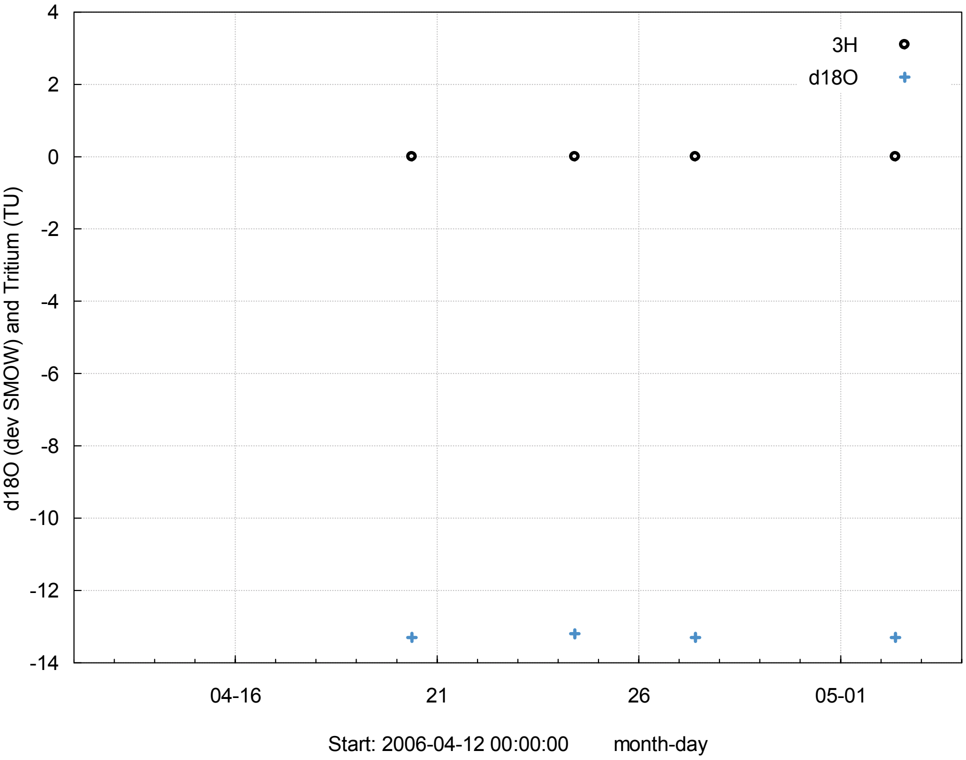


Figure 8-4. *Tritium and δ^{18}O (‰ SMOW) data versus sampling date, section 785.1–792.2 m.*

9 Summary and discussion

The investigation period in the only section sampled in borehole KFM09A was interrupted due to malfunction of the measurement device. Furthermore, the downhole equipment was raised before completion of the sampling programme due to a broken swivel-connection. The somewhat incomplete data obtained in this investigation are, however, important as they add information on spatial distribution of deeper saline groundwaters. Figure 9-1 presents the chloride concentration for the single data point from KFM09A together with corresponding chloride concentrations versus depths from other boreholes at Forsmark.

The main conclusions from the experimental results are:

- The six redox electrodes disagree considerably and only the surface ground platinum electrode reached a plausible Eh-value. Therefore the reported Eh (–229 mV) for this groundwater should be considered highly uncertain.
- The flushing water content was relatively low (about 2–3%), and almost reached the desired value 1% which is the upper limit allowed in a representative water sample.
- The quality of the water analyses is generally high, based on comparison between results from different methods and acceptable charge balance errors. The relative errors are all within ± 5%.
- The major constituents show stable concentrations during the pumping/sampling period which indicates that no mixing occurred with water from other fracture systems with different water compositions.
- The uranium concentration in the groundwater from KFM09A at 785.1–792.2 m was low (0.05–0.1 µg/L) compared to a previous result (85.9 µg/L) obtained from hydrochemical logging /5/ close to the bottom of the borehole. These different conditions might suggest that the high uranium concentrations observed in some boreholes are due to some drilling artefact.

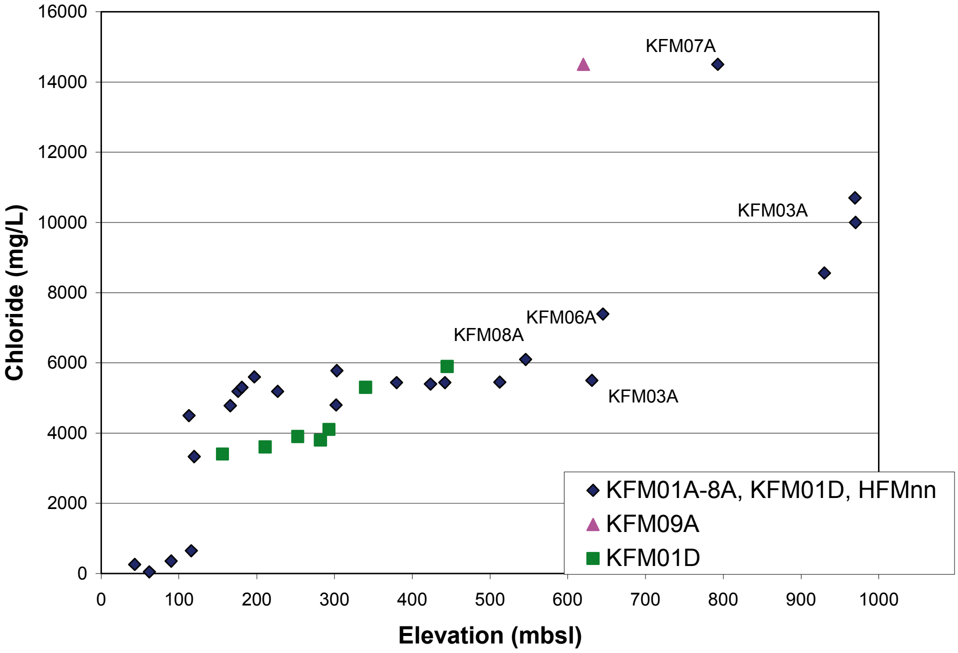


Figure 9-1. *Chloride concentrations versus depth (m) at the Forsmark site. The data point from KFM09A is plotted in pink colour. The diagram also presents data that will be included in a subsequent report.*

10 References

/1/ **SKB, 2001.** Site investigations. Investigation methods and general execution programme. SKB R-01-29, Svensk Kärnbränslehantering AB.

/2/ **Claesson L-Å, Nilsson G, 2006.** Forsmark site investigation. Drilling of the cored boreholes KFM09A and KFM09B at drilling site DS9. SKB P-06-NN, Svensk Kärnbränslehantering AB. In progress.

/3/ **SKB, 2005.** Forsmark site investigation. Programme for further investigations of geosphere and biosphere. SKB R-05-14, Svensk Kärnbränslehantering AB.

/4/ **Nielsen U T, Ringgaard J, Vangkilde-Pedersen T, 2006.** Forsmark site investigation. Geophysical borehole logging in boreholes KFM09A, KFM07B, HFM25, HFM27 and HFM28. SKB P-06-22. Svensk Kärnbränslehantering AB.

/5/ **Nilsson K, 2006.** Forsmark site investigation. Hydrochemical logging in KFM09A. SKB P-06-95**,** Svensk Kärnbränslehantering AB.

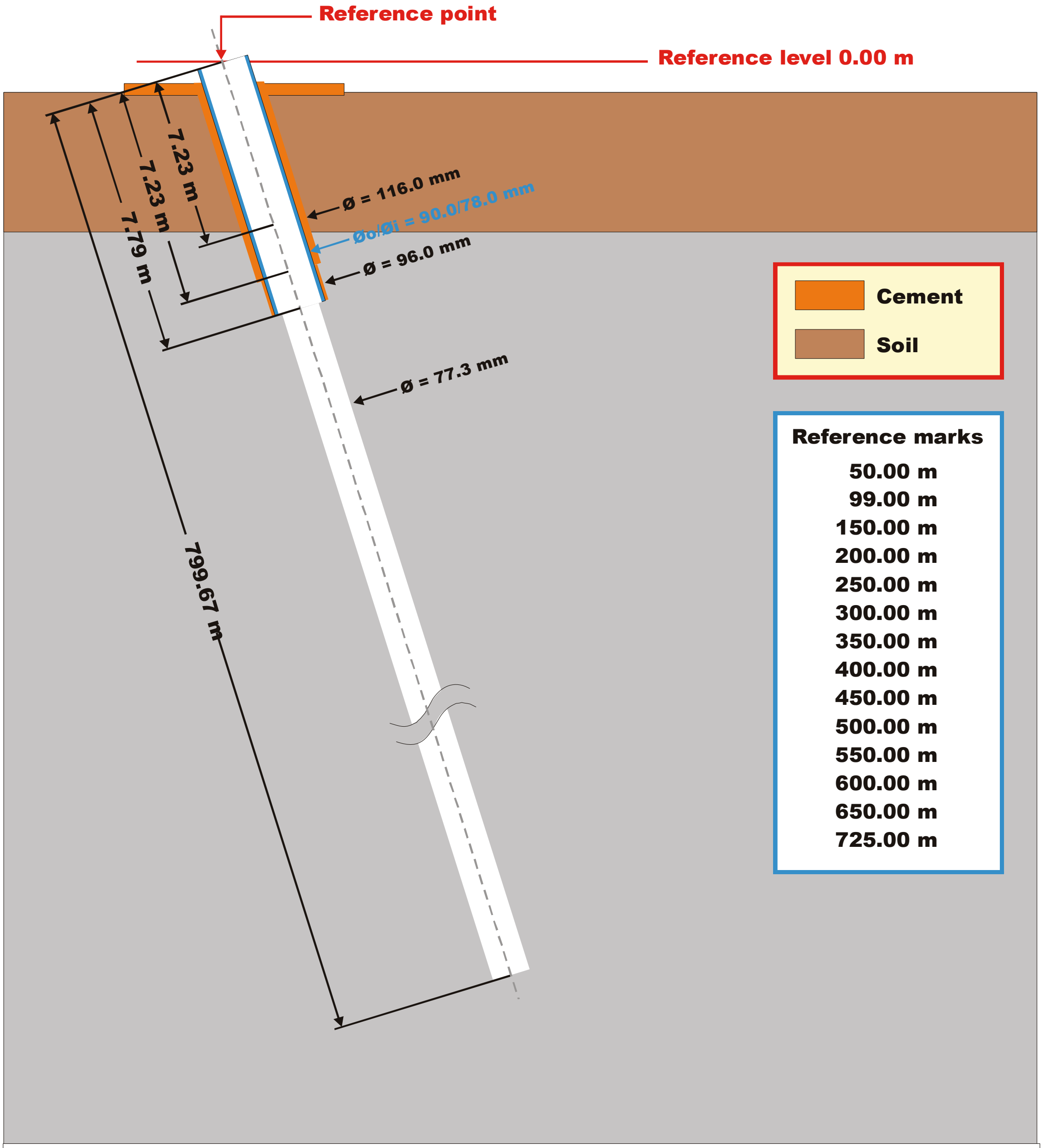
/6/ **Gustafsson J, Gustafsson C, 2006.** Forsmark site investigation. RAMAC and BIPS logging in boreholes KFM07B, KFM09A, HFM25 and HFM28. SKB P-06-44, Svensk Kärnbränslehantering AB.

/7/ **Lindquist A, Ludvigson J-E, Harrström J, Svensson T, 2006.** Forsmark site investigation. Single-hole injection tests in borehole KFM09A. SKB P-06-52, Svensk Kärnbränslehantering AB.

Design of cored borehole KFM09A

Technical data

Borehole KFM09A



Drilling reference point

Northing: 6700115.04 (m), RT90 2,5 gon V 0:-15
Easting: 1630647.50 (m), RT90 2,5 gon V 0:-15
Elevation: 4.29 (m), RHB 70

Orientation

Bearing: 200.08°
Inclination: -59.46°

Drilling period

Drilling start date: 2005-09-05
Drilling stop date: 2005-10-27

2005-11-09 rev 2

Appendix 2

Sampling equipment for Low hydraulic Transmissivity fractures (SLT), KFM09A

Test of equipment for water sampling in KFM09A

Jan Sundberg, Geosigma AB

September 2006

A short summary

During May 2006, a test was performed of the prototype equipment developed by Geosigma AB for water sampling in low-transmissive zones. When performing the tests on the first day, we could establish the following:

- A stopper was mounted in the lower part of the in situ water sampler sampler (PVP), channel 3. This stopper was removed since the channel is supposed to be used for packer inflation.
- At the blow test of the water tank before lowering the equipment, we discovered that an intake at channel 7 (in the PVP) must be plugged (1/8”) in order to make the sampling work as intended. Channel 7 in the PVP was therefore plugged.

When all the tests at the ground surface seemed to be satisfactory, lowering of the equipment was started. When in place at the chosen section, the packers were inflated and the section was blown. After the blowing, the pressure in the section was to be lowered to two bars below the surrounding pressure, but it turned out to be difficult to lower the pressure. The section was quickly refilled with water. The equipment was raised, and the conclusion was that the cause of the problems was litter in the non-return valve where the blowing of the section takes place.

The non-return valves and the vent coupling to the water tank were dismounted and brought to the Geosigma workshop in Uppsala. Another type of non-return valve, not so sensitive to fouling, was ordered. The decision was also made that filters should be installed before all of the non-return valves, in order to minimize the risk of leakage. New vent couplings with new non-return valves and filters (60 µm + 40 µm) were mounted, (Figure A2-1) followed by another attempt of water sampling. The second attempt was stopped when a leakage on the hose unit swivel connection was discovered on channel 7. The swivel connection was dismounted and taken to the workshop for repair.

After repairing the swivel connection (it was teflonised and new O-rings were mounted) and re-assembling it, a third attempt was made. The lowering of equipment, blowing of the section and lowering of the pressure with two bars went well. While filling the water tank, the appearance of the pressure graph was not as expected (Figure A2-2), and after some time the communication with the measuring nodes in the probe was lost. Later, it was established that the problems were caused by a leakage in the cable head in the multi-tube. The leakage had probably caused creeping currents resulting in the unexpected measurement test results, and subsequent communication failure. No more tests could be performed in KFM09A. The cable head on the multi-tube needs to be re-cast.

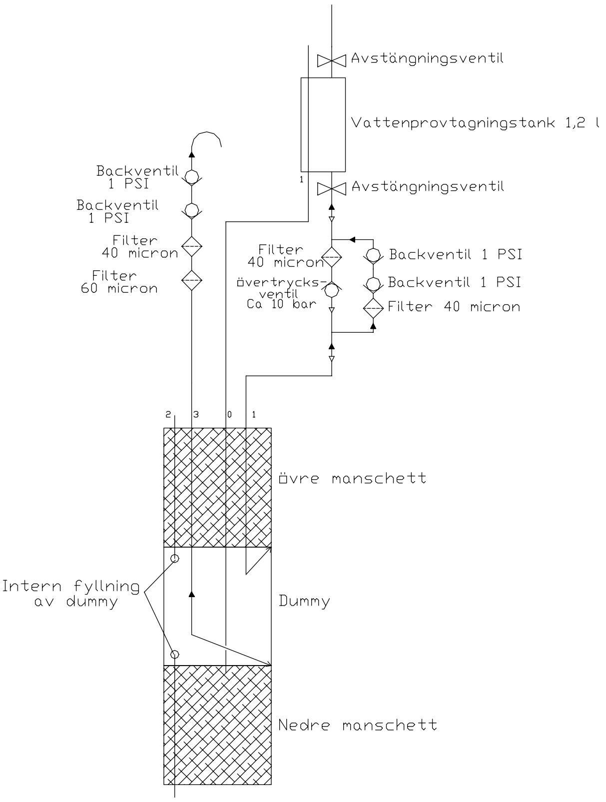


Figure A2-1. New non-return valves and filters connected between the upper packer and the sample tank.

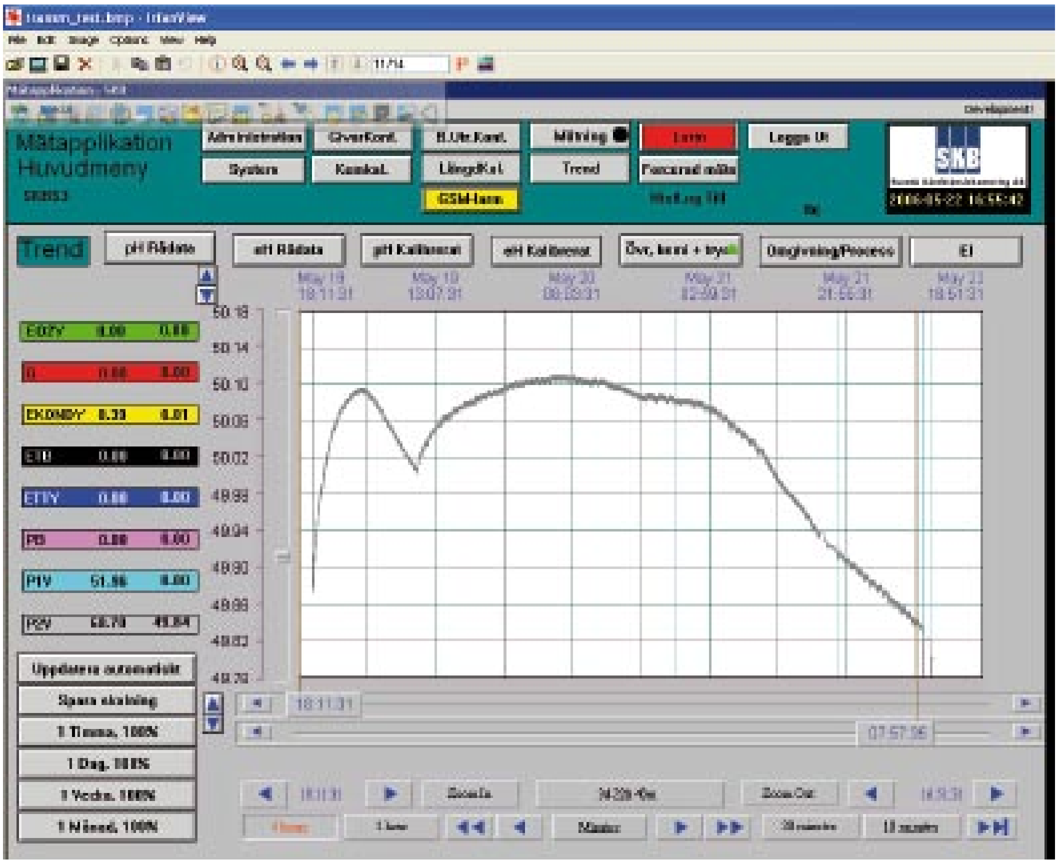
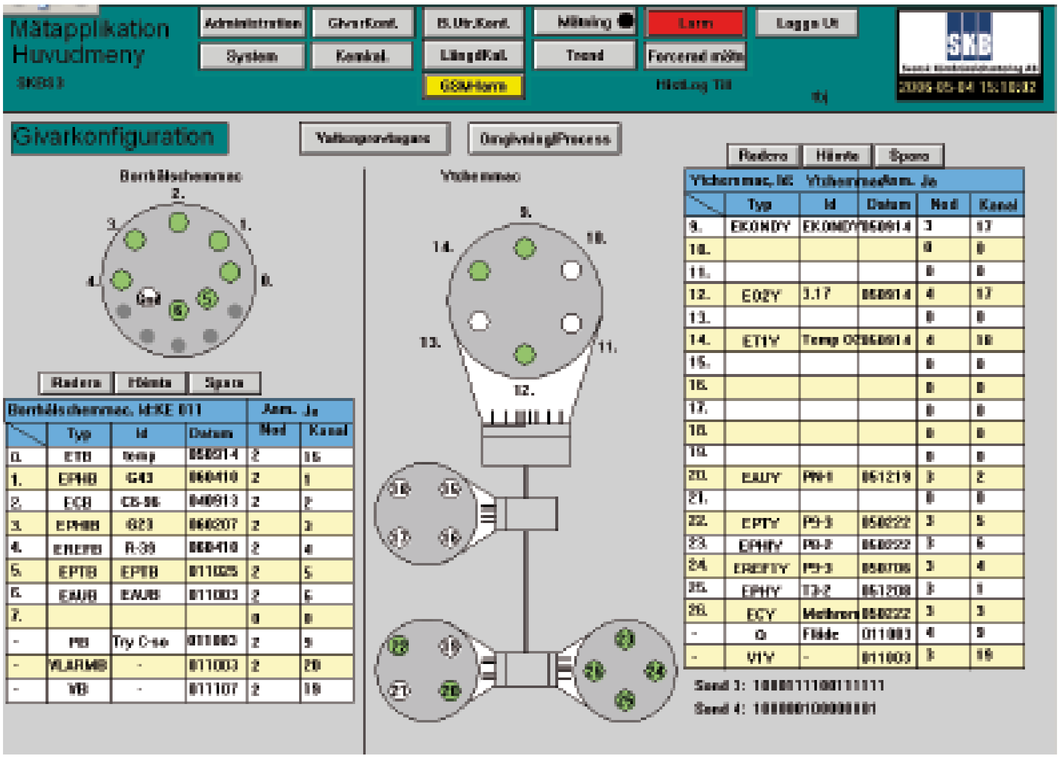


Figure A2-2. Pressure graph for channel 7 at the third attempt.

Measurement information, KFM09A



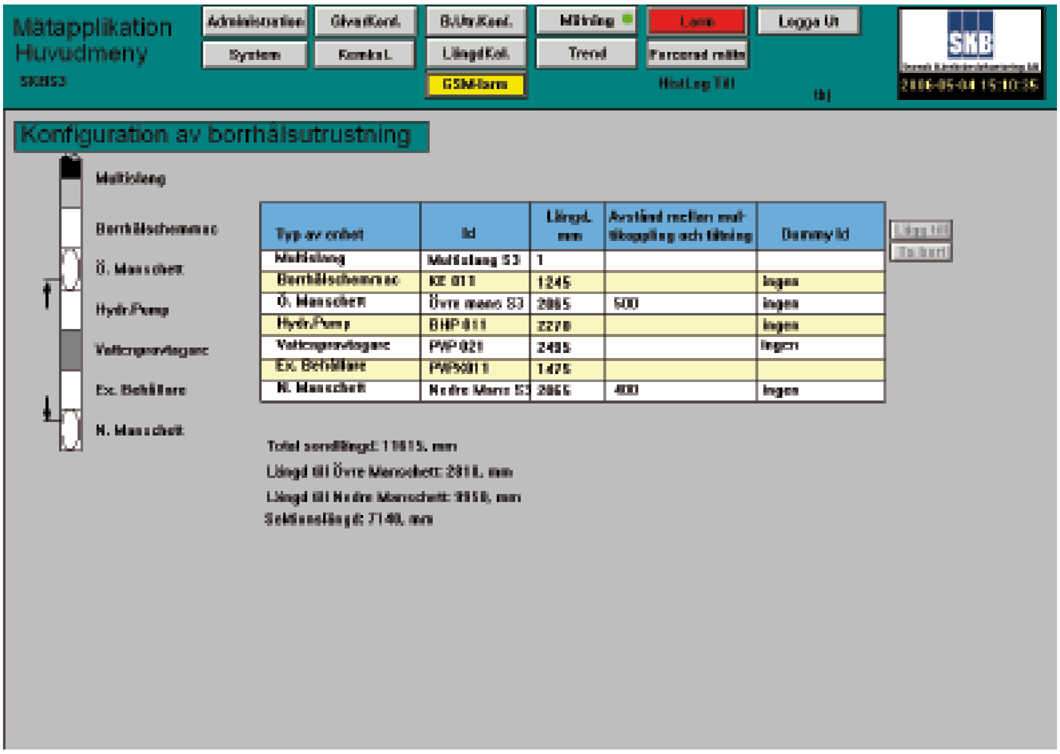
Borrhålsbehmnac, Id:KE 011				Anm. Ja	
	Typ	Id	Datum	Nod	Kanal
0.	ETB	temp	050914	2	16
1.	EPHB	G43	060410	2	1
2.	ECB	CB-96	040913	2	2
3.	EPHBB	623	060207	2	3
4.	EREFB	R-38	060410	2	4
5.	EPTB	EPTB	011025	2	5
6.	EAUB	EAUB	011003	2	6
7.				0	0
-	PB	Try C-so	011003	2	9
-	VLARMB	-	011003	2	20
-	VB	-	011107	2	19

Ytbemnac, Id:	Ytbemnac Anm. Ja				
	Typ	Id	Datum	Nod	Kanal
9.	EKONDY	EKONDY	050914	3	17
10.				0	0
11.				0	0
12.	EO2Y	3.17	050914	4	17
13.				0	0
14.	ETIY	Temp O2	050914	4	16
15.				0	0
16.				0	0
17.				0	0
18.				0	0
19.				0	0
20.	EAUY	PN-1	051219	3	2
21.				0	0
22.	EPTY	P9-3	050222	3	5
23.	EPHY	P8-2	050222	3	6
24.	EREFTY	P9-3	050708	3	4
25.	EPHY	T3-2	051208	3	1
26.	ECY	Methrom	050222	3	3
-	Q	Flöde	011003	4	9
-	VIY	-	011003	3	19

Sond 3: 1000011100111111

Sond 4: 1000000100000001

Figure A3-1. *Electrode configuration, section 785.10–792.24 m.*



Typ av enhet	Id	Längd, mm	Avstånd mellan mät-tillkoppling och tätning	Dummy Id
Multislang	Multislang 53	1		
Borrhålsbehmnac	KE 011	1245		Ingen
Ö. Manschett	Övre mans 53	2065	500	Ingen
Hydr.Pump	BHP 011	2270		Ingen
Vattenprovtagare	PVP 021	2495		Ingen
Ex. Behållare	PWS011	1475		
N. Manschett	Nedre Mans 53	2065	400	Ingen

Total sondlängd: 11615, mm

Längd till Övre Manschett: 2816, mm

Längd till Nedre Manschett: 9958, mm

Sektionslängd: 7140, mm

Figure A3-2. *Configuration of downhole equipment, section 785.10–792.24 m.*

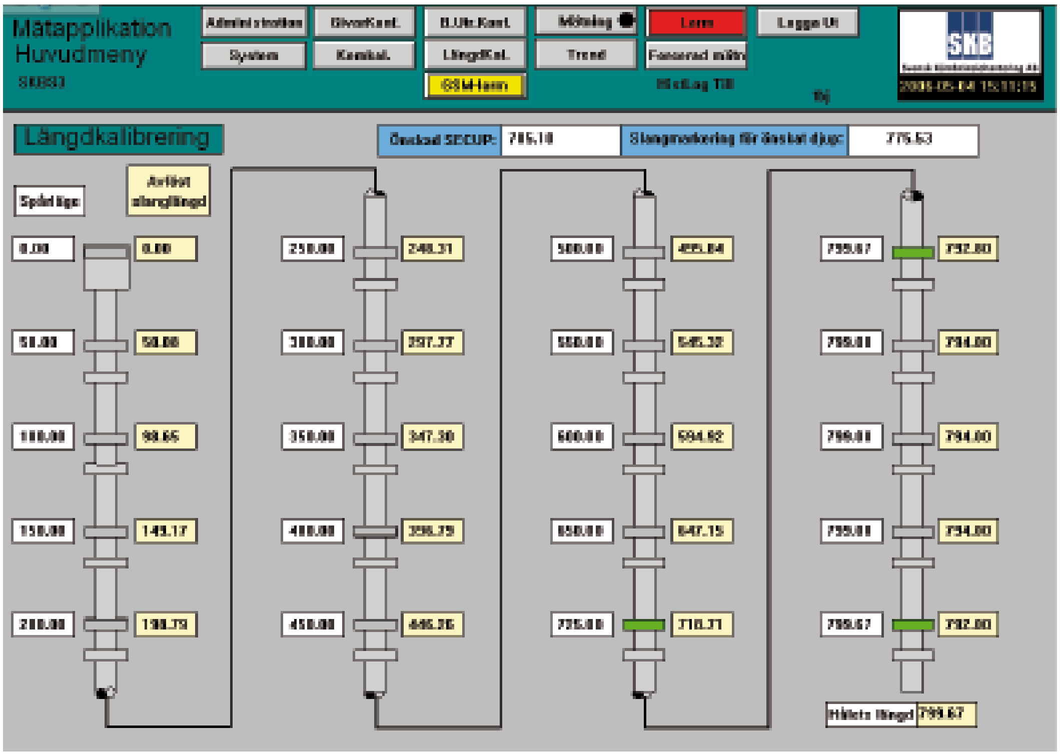


Figure A3-3. *Length calibration, section 785.10–792.24 m.*

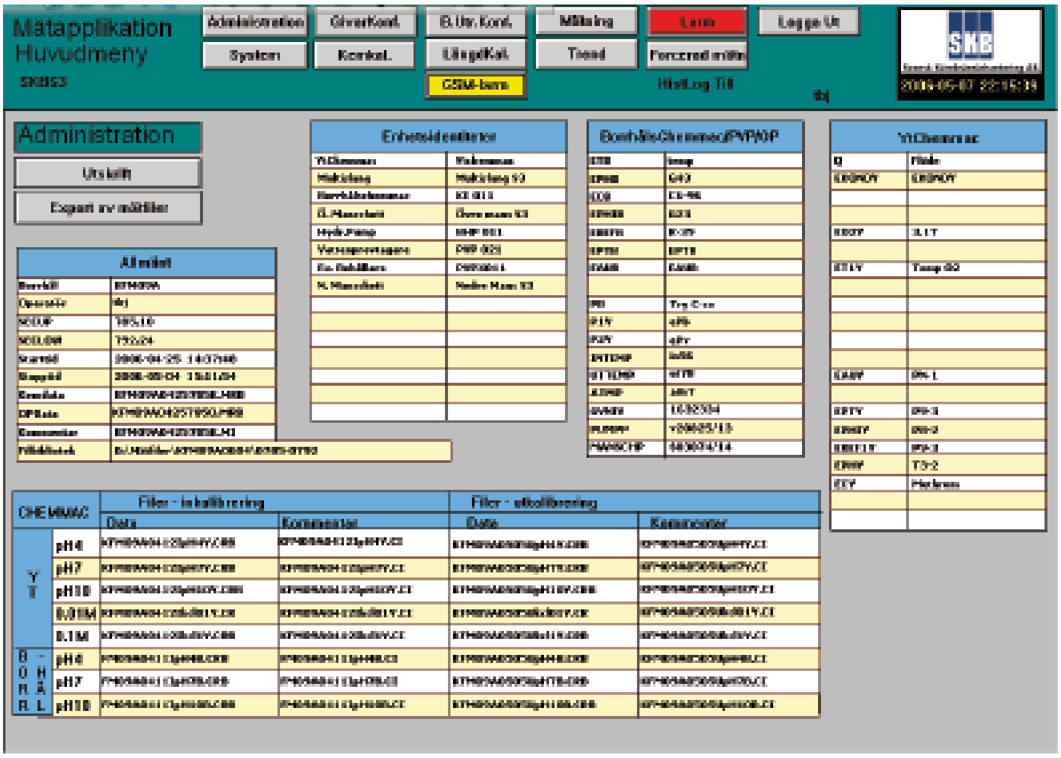


Figure A3-4. *Administration, section 785.10–792.24 m.*

Flow and pressure measurements, KFM09A

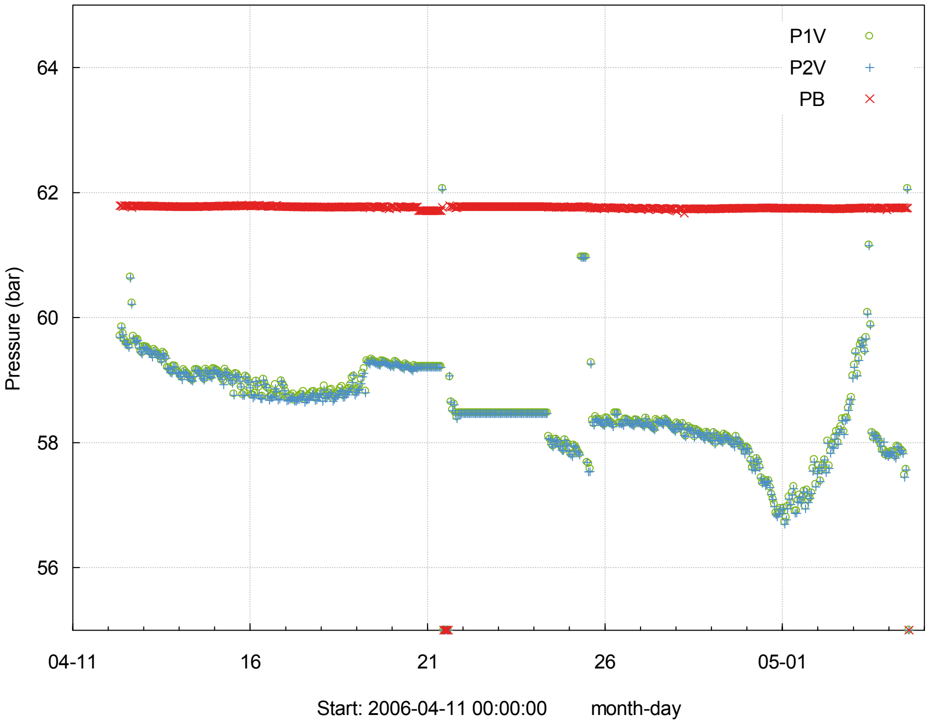


Figure A4-1. *Pressure measurements (P1V, P2V and PB), section 785.1–792.2 m. The sensors P1V and P2V measure the pressure within the section and are both placed in the within situ sampling unit. The sensor PB, placed in the borehole Chemmac, measures the pressure above the section.*

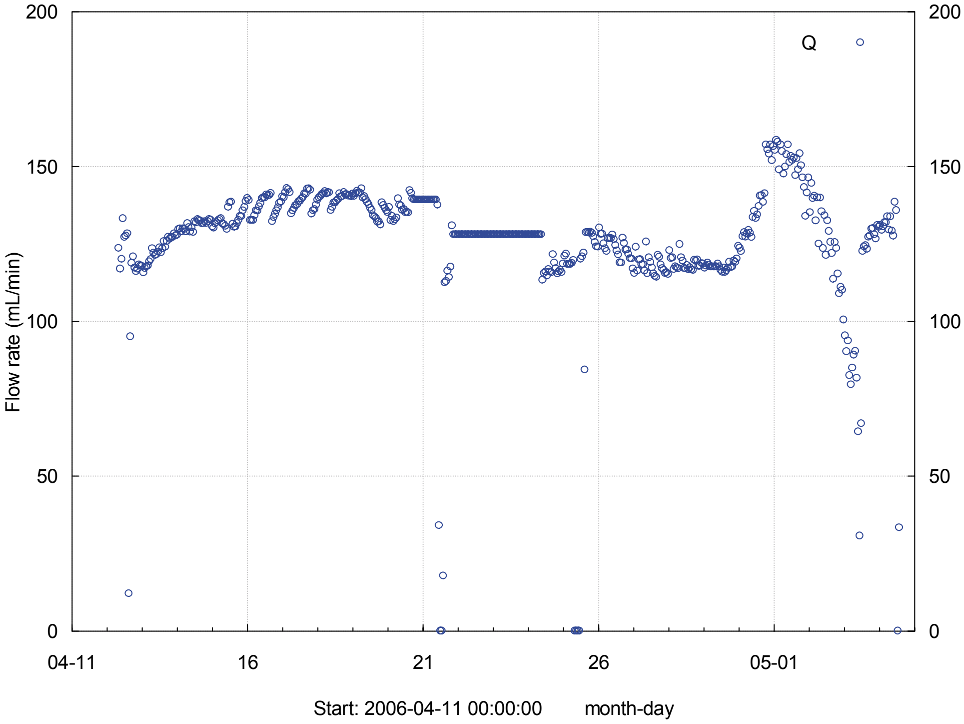


Figure A4-2. *Pumping flow rate (Q), section 785.1–792.2 m.*

Chemmac measurements in KFM09A, section 785.1–792.2 m

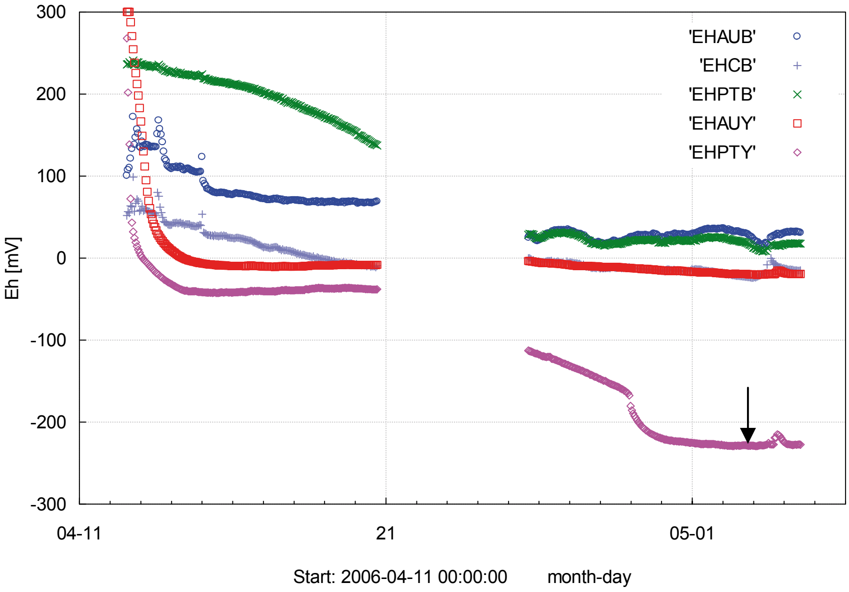


Figure A5-1. *Redox potential measurements (Eh) by gold, glassy carbon and platinum electrodes in the borehole section (EHAUB, EHCB and EHPTB) and at the surface (EHAUY and EHPTY). The results from the surface glassy carbon electrode were omitted because of noisy values. The arrows show the chosen representative Eh- values for the borehole section.*

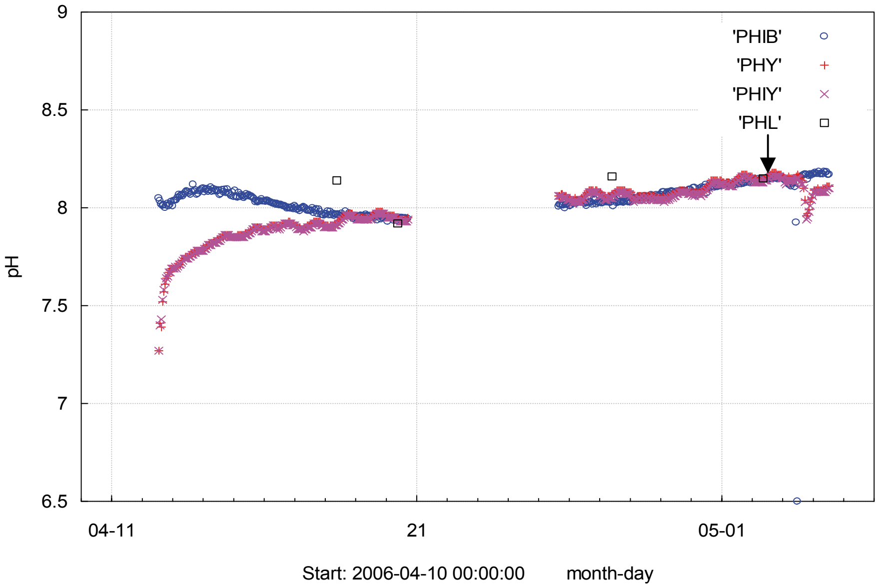


Figure A5-2. *Measurements of pH by one glass electrode in the borehole section (PH1B) and two glass electrodes at the surface (PHY and PHIY). The results from one glass electrode in the borehole section were omitted because of unstable values in the latter part of the investigation. The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the chosen representative pH values for the borehole section.*

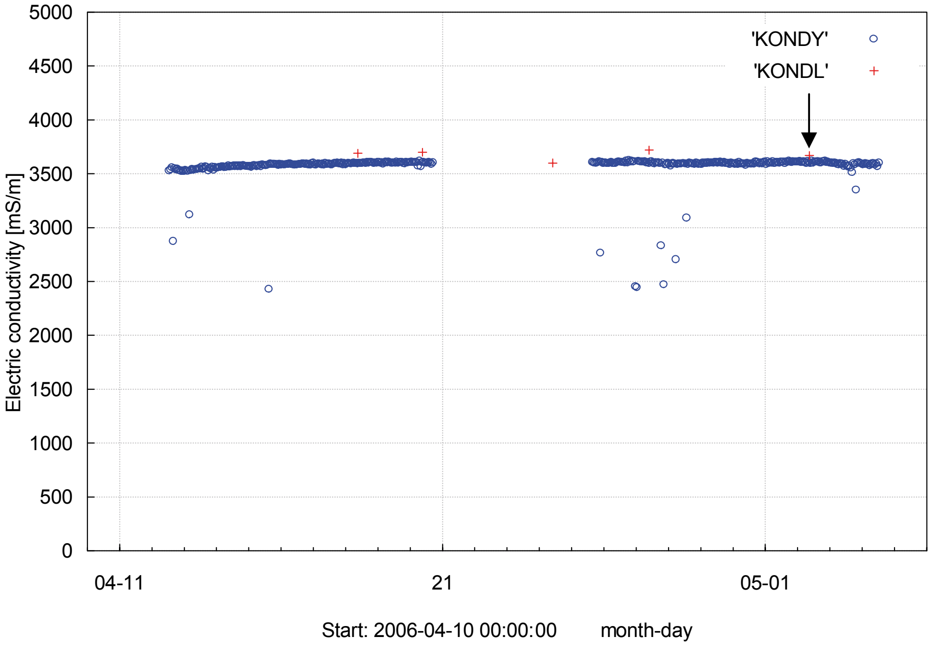


Figure A5-3. *Electrical conductivity measurement in the surface measurement cell (KONDY). The laboratory conductivity in each collected sample (KONDL) is given for comparison. The arrow shows the chosen representative electric conductivity value for the borehole section.*

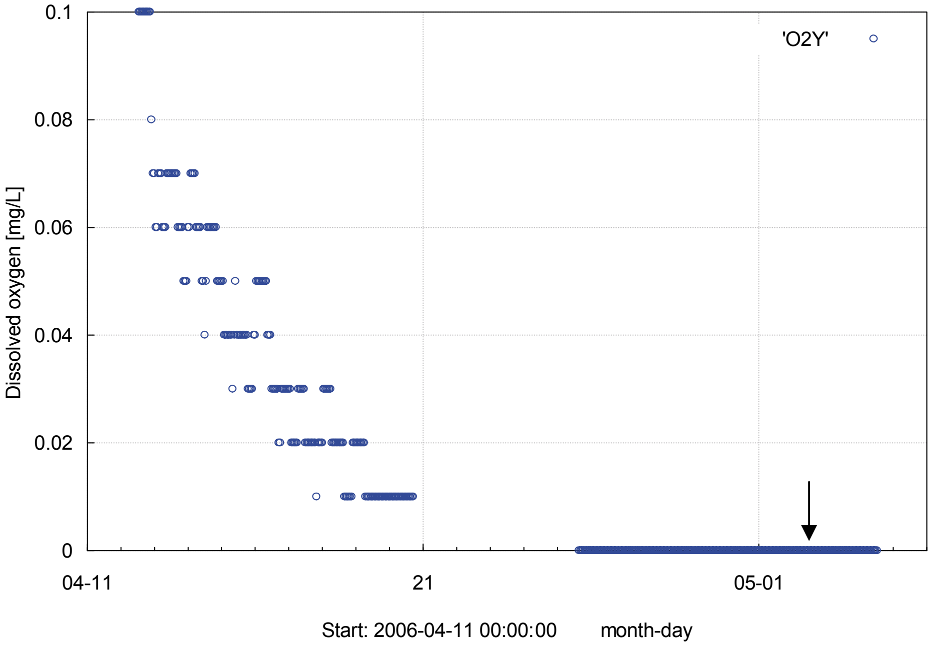


Figure A5-4. *Dissolved oxygen measurement (O2Y) in the surface measurement cell. The arrow shows the chosen representative value for dissolved oxygen in the borehole section.*

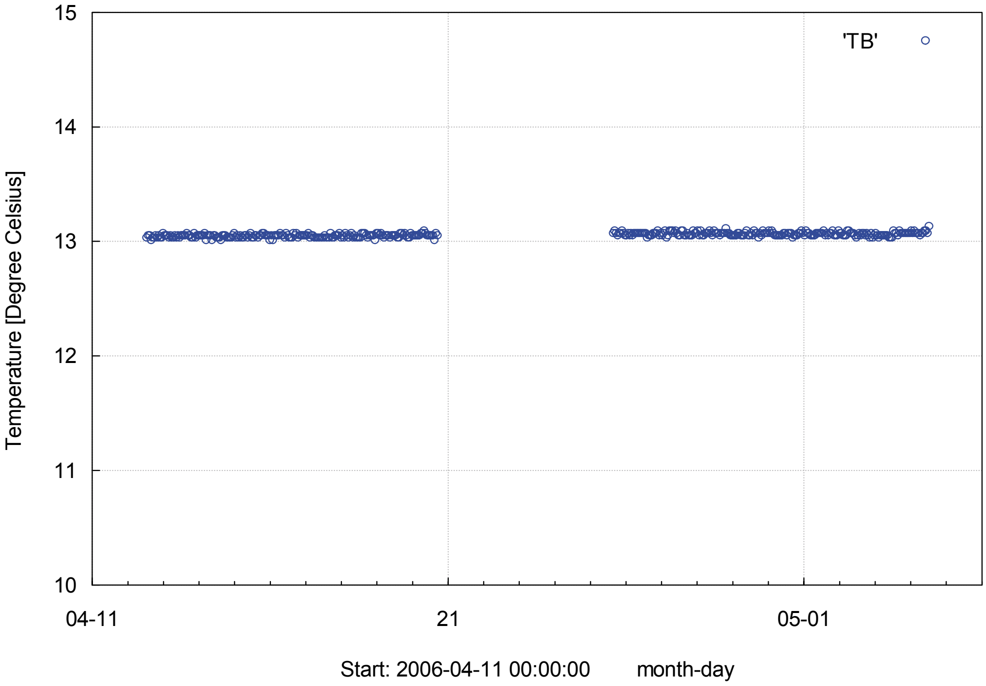


Figure A5-5. *Temperature of the groundwater in the borehole section (TB).*

Appendix 6

Sampling and analytical methods

Table A6-1. Sample handling routines and analytical methods.

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ conservation*	Analysis method	Analysis within – or delivery time to lab.
Anions 1	HCO_3 pH(lab) cond (lab)	Plastic	250	Yes (not in the field)	No	Titration Pot. meas, Cond. meas	The same day – maximum 24 hours
Anions 2	Cl, SO_4, Br^-, F^-, I^-	Plastic	100	Yes (not in the field)	No	Titration (Cl^-) IC (Cl^-, SO4, Br^-, F^-) ISE (F^-)	Not critical (month)
	Br, I	Plastic	100	Yes (not in the field)	No	ICP MS	Not critical (month)
Cations, Si and S according to SKB class 3	Na, K, Ca, Mg, S(tot), Si(tot), Li, Sr	Plastic (at low conc. acid washed bottles)	100	Yes (not in the field)	Yes (not in the field, 1 mL HNO_3)	ICP-AES ICP-MS	Not critical (month)
Cations, Si and S according to SKB class 4 and 5	Na, K, Ca, Mg, S(tot), Si(tot), Fe, Mn, Li, Sr	Plastic (Acid washed)	100	Yes (immediately in the field)	Yes (1 mL HNO_3)	ICP-AES ICP-MS	Not critical (month)
Fe(II), Fe(tot)	Fe(II), Fe(tot)	Plastic (Acid washed)	500	Yes	Yes (5 mL HCl))	Spectrophotometry Ferrozine method	As soon as possible the same day
Hydrogen sulphide	HS-	Glass (Winkler)	About 120×2	No	Ev 1 mL 1 M NaOH+ 1 mL 1 M ZnAc	Spectrophotometry	Immediately or if conserved, a few days
Environmental metals	Al, As, Ba, B, Cd, Co, Cr, Cu, Hg, Mo, Ni, P, Pb, V, Zn	Plastic (Acid washed)	100	Yes	Yes (1 mL HNO_3)	ICP-AES ICP-MS	Not critical (month)
Lantanoids, U, Th and so on.	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	Plastic (Acid washed)	100	Yes	Yes (1 mL HNO_3)	ICP-AES ICP-MS	Not critical (month)
Dissolved organic Carbon, dissolved inorganic Carbon	DOC, DIC	Plastic	250 25	Yes	Frozen, transported in isolated bag	UV oxidation, IR Carbon analysator Shimadzu TOC5000	Short transportation time

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ conservation*	Analysis method	Analysis within – or delivery time to lab.
Total organic Carbon	TOC	Plastic	250 25	No	Frozen, transported in isolated bag	UV oxidation, IR Carbon analysator Shimadzu TOC5000	Short transportation time
Environmental isotopes	^{2}H, ^{18}O	Plastic	100	No	– –	MS	Not critical (month)
Tritium	^{3}H (enhanced.)	Plastic (dry bottle)	500	No	–	LSC	
Chlorine-37	Chlorine-37	Plastic	100	No	–	ICP MS	Not critical (month)
Carbon isotopes	^{13}C, ^{14}C	Plastic (HDPE)	100×2	No	–	(A)MS	A few days
Sulphur isotopes	^{34}S	Plastic	500–1,000	Yes	–	Combustion, MS	No limit
Strontium-isotopes	^{87}Sr/^{86}Sr	Plastic	100	Yes	–	TIMS	Days or Week
Uranium and Thorium isotopes	^{234}U, ^{235}U, ^{238}U, ^{232}Th, ^{230}Th,	Plastic	50 1,000	Nej	–	Chemical separat. Alfa/ gamma spectrometry	No limit
Boron isotopes	^{10}B	Plastic	100	Yes	Yes (1 mL HNO_3)	ICP – MS	No limit
Radon and Radium isotopes	^{222}Rn, ^{226}Ra	Plastic	500–1,000	No	No	EDA, RD-200	Immediate transport
Dissolved gas (content and composition)	Ar, N_2, CO_2, O_2, CH_4, H_2, CO, C_2H_2, C_2H_4, C_2H_6, C_3H_8	Cylinder of stainless steel	200	No	No	GC	Immediate transport
Colloids	Filter series	Polycarbonate filter	0.4, 0.2 and 0.05 µm	–	Ar atmosphere	ICP-AES ICP-MS	Immediate transport
Fractionation; Humic and fulvic acids, inorganic constituents	<1,000 D >1,000 D but <5,000 D >5,000 D	Fractions are collected in plastic bottles	250	–	N_2 atmosphere	UV oxidation, IR (DOC)	Immediate transport
Archive samples with acid	–	Plast (washed in acid)	100×2 **	Yes	Yes (1 mL HNO_3)	–	Storage in freeze container
Archive samples without acid	–	Plastic	250×2 **	Yes	No	–	Storage in freeze container
Carbon isotopes in humic and fulvic acids	^{13}C, ^{14}C (pmc)	DEAE cellulose (anion exchanger)	–	–	–	(A)MS	A few days

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ conservation*	Analysis method	Analysis within – or delivery time to lab.
Nutrient salt + silicate	NO_2, NO_3, NO_2+NO_3, NH_4, PO_4, SiO_4	Sample tubes, plastic	25×2 250	Yes (in the field)	No, frozen immediately***	Spectrophotometry	Short transportation time
Total concentrations of Nitrogen and Phosphorous	N-tot, P-tot	Plastic	100	No	No, frozen immediately***	Spectrophotometry	Short transportation time
Particulate Carbon, Nitrogen and Phosphorous	POC, PON, POP	Plastic	1,000	Yes (within 4 h) prepared filters. Blank filters	Filtering, the filters are frozen immediately 2 filters/sample	Elementar-analysator (N, C) own method 990121 (P)	Short transportation time
Chlorophyll	Chlorophyll a, c and pheopigment	Plastic	1,000–2,000	Yes (within 4 h)	Filtering, the filters are frozen immediately	Spectrophotometry Fluorometry	Short transportation time
Oxygen	Dissolved O_2	Winkler, glass	2×ca 120	No	Mn (II) reagent Iodide reagent	Spectrophotometry SIS SS-EN 25813	Within 3 days
Archive samples for supplementary radio nuclides		Plastic	5,000	No	50 mL HNO_3	–	Storage in freeze container

* Suprapur acid is used for conservation of samples.

** Minimum number. The number of archive samples can vary depending on the number of similar samples collected at the same occasion.

*** The sample is transported in frozen condition to the laboratory. It is possible that the silicate concentration can change due to polymerisation for this reason.

Abbreviations and definitions:

IC	Ion chromatograph
ISE	Ion selective electrode
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectrometry
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
INAA	Instrumental Neutron Activation Analysis
MS	Mass Spectrometry
TIMS	Thermal Ionization Mass Spectrometer
LSC	Liquid Scintillation Counting
(A)MS	(Accelerator) Mass Spectrometry
GC	Gas Chromatography

Table A6-2. Reporting limits and measurement uncertainties.

Component	Method	Reporting limits or range	Unit	Measurement uncertainty [2]	"Total" uncertainty [3]
HCO_3	Alkalinity titration	1	mg/L	4%	<10%
Cl^-	Mohr- titration	> 70	mg/L	5%	<10%
Cl^-	IC	1–100		6%	10%
SO_4	IC	1	mg/L	10%	15%
Br^-	IC	0.2	mg/L	9%	20%
Br^-	ICP	0.001		15%	
F^-	IC	0.1	mg/L	10%	20%
F^-	Potentiometric	–		–	
I^-	ICP	0.001	mg/L	15%	20%
Na	ICP	0.1	mg/L	4%	10%
K	ICP	0.4	mg/L	6%	15%
Ca	ICP	0.1	mg/L	4%	10%
Mg	ICP	0.09	mg/L	4%	10%
S(tot)	ICP	0.160	mg/L	21%	15%
Si(tot)	ICP	0.03	mg/L	4%	15%
Sr	ICP	0.002	mg/L	4%	15%
Li	ICP	0.2[1] 2	mg/L	10%	20%
Fe	ICP	0.4[1] 4	mg/L	6%	10%
Mn	ICP	0.03[1] 0.1	µg/L	8%	10%
Fe(II), Fe(tot)	Spectrophotometry	0.02 (DL=0.005 mg/L)	mg/L	15% (>30 µg/L)	20%
HS^-	Spectrophotometry	SKB 0.03 (DL=0.02)	mg/L	10%	30%
NO_2 as N	Spectrophotometry	0.1	µg/L	2%	20%
NO_3 as N	Spectrophotometry	0.2	µg/L	5%	20%
NO_2+NO_3 as N	Spectrophotometry	0.2	µg/L	0.2 (0.2–20 µg/L) 2% (> 20 µg/L)	20%
NH_4 as N	Spectrophotometry	0.8	µg/L	0.8 (0.8–20 µg/L) 5% (> 20 µg/L)	20%
		50 (SKB)		20%	
PO_4 as P	Spectrophotometry	0.7	µg/L	0.7 (0.7–20 µg/L) 3% (> 20 µg/L)	20%
SiO_4	Spectrophotometry	1	µg/L	3% (>200 µg/L)	–
O_2	Jodometric titration	0.2–20	mg/L	5%	–
Chlorophyll a, c pheopigment[4]	See Table A1-2	0.5	µg/L	5%	–
PON[4]	See Table A1-2	0.5	µg/L	5%	–
POP[4]	See Table A1-2	0.1	µg/L	5%	–
POC[4]	See Table A1-2	1	µg/L	4%	–
Tot-N[4]	See Table A1-2	10	µg/L	4%	–
Tot-P[4]	See Table A1-2	0.5	µg/L	6%	–
Al, Zn	ICP	0.2	µg/L	12%	20%[5]
Ba, Cr, Mo, Pb	ICP	0.01	µg/L	7–10%	20%[5]
Cd, Hg	ICP	0.002	µg/L	9 resp 5%	20%[5]
Co, V	ICP	0.005	µg/L	8 resp 5%	20%[5]
Cu	ICP	0.1	µg/L	8%	20%[5]

Component	Method	Reporting limits or range		Unit	Measurement uncertainty ^{2}	“Total” uncertainty ^{3}
Ni	ICP	0.05		µg/L	8%	20%^{5}
P	ICP	1		µg/L	6%	10%
As	1CP	0.01		µg/L	20%	Correct order of size (low conc.)
La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb	ICP	0.0051	0.05	µg/L	10%	Correct order of size (low conc.)
Sc, In, Th	ICP	0.05^1	0.5	µg/L	10%	Correct order of size (low conc.)
Rb, Zr, Sb, Cs, Tl	ICP	0.025^1	0.25	µg/L	10%	Correct order of size (low conc.)
Y, Hf	ICP	0.005^1	0.05	µg/L	10%	Correct order of size (low conc.)
U	ICP	0.001^1	–	µg/L	12%	Correct order of size (low conc.)
DOC	See Table A1-1	0.5		mg/L	8%	30%
TOC	See Table A1-1	0.1		mg/L	10%	30%
δ^2H	MS	2		‰ SMOW^5	1‰	–
δ^{18}O	MS	0.1		‰ SMOW^5	0.2‰	–
^{3}H	LSC	0.8 eller 0.1		TU^6	0.8 eller 0.1	Correct order of size
^{37}Cl	ICP MS	0.2‰◦ (20 mg/L)		‰ SMOC^7	–	–
δ^{13}C	A (MS)	–		‰ PDB^8	–	–
^{14}C pmc	A (MS)	–		PMC^9	–	–
δ^{34} S	MS	0.2‰		‰ CDT^{10}	0.3‰	–
^{87}Sr/^{86}Sr	TIMS	–		No unit (ratio)^{11}	–	–
^{10}B/^{11}B	ICP MS	–		No unit (ratio)^{11}	–	–
234U, 235U, 238U, 232Th, 230Th	Alfa spectr.	0.0005		Bq/L13	5%	–
222Rn, 226Rn	LSC	0.03		Bq/L	5%	–

1. Reporting limits at salinity ≤ 0.4% (520 mS/m) and ≤ 3.5% (3,810 mS/m) respectively.
2. Measurement uncertainty reported by consulted laboratory, generally 95% confidence interval.
3. Estimated total uncertainty by experience (includes effects of sampling and sample handling).
4. Determined only in surface waters and near surface groundwater.
5. Per mille deviation[13] from SMOW (Standard Mean Oceanic Water).
6. TU=Tritium Units, where one TU corresponds to a Tritium/hydrogen ratio of 10^{-18} (1 Bq/L Tritium = 8.45 TU).
7. Per mille deviation[13] from SMOC (Standard Mean Oceanic Chloride).
8. Per mille deviation[13] from PDB (the standard PeeDee Belemnite).
9. The following relation is valid between pmC (percent modern carbon) and Carbon-14 age:
$\text{pmC} = 100\times e^{((1,950-y-1.03t)/8,274)}$
where y = the year of the C-14 measurement and t = C-14 age.
10. Per mille deviation[13] from CDT (the standard Canyon Diablo Troilite).
11. Isotope ratio without unit.
12. The following expressions are applicable to convert activity to concentration, for uranium-238 and thorium-232: 1 ppm U = 12.4 Bq/kg^{238}U
1 ppm Th = 3.93 Bq/kg^{232}Th
13. Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as:
$\delta^yI = 1,000\times(K_{sample}-K_{standard})/K_{standard}$, where K= the isotope ratio and $^yI = ^2$H, ^{18}O, ^{37}Cl, ^{13}C or ^{34}S etc.

Appendix 7

Compilation of water analysis data

Table A7-1. Water composition.

Idcode	Secup m	Seclow m	Sample no.	Sampling date	RCB (%)	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO_3^- mg/L	Cl^- mg/L	SO_4^{2-} mg/L	SO_4-S mg/L	Br mg/l	F^- mg/L	Si mg/L	Fe mg/L	Fe-tot mg/L	FeII mg/L	Mn mg/L
KFM09A	785.10	792.24	12239	2006/4/18		–	–	–	–	8.74	14,600	–	–	–	–	–	–	–	–	–
KFM09A	785.10	792.24	12241	2006/4/20	2.18	2,630	12.7	6,480	17.3	7.84	14,800	119	47.5	138	1.24	4.72	0.141	0.135	0.128	0.105
KFM09A	785.10	792.24	12242	2006/4/24	4.60	2,620	13.1	6,560	16.7	6.48	14,200	116	48.4	143	1.21	4.39	0.175	0.186	0.188	0.110
KFM09A	785.10	792.24	12243	2006/4/27	2.35	2,620	12.5	6,520	17.7	6.67	14,800	118	47.9	143	1.29	4.66	0.130	0.109	0.103	0.107
KFM09A	785.10	792.24	12244	2006/5/2	2.12	2,610	12.8	6,490	17.0	6.72	14,800	118	47.8	145	1.25	4.74	0.107	0.129	0.119	0.103

Idcode	Secup m	Seclow m	Sample no.	Sampling date	Li mg/L	Sr mg/L	I^- mg/L	pH	DOC mg/L	HS^- mg/L	Drill_water %	ElCond mS/m	NH_4N mg/L	NO_2N mg/L	NO_3N mg/L	NO_2NO_3 mg/L	PO_4P mg/L	P mg/L
KFM09A	785.10	792.24	12239	2006/4/18	–	–	–	8.14		–	2.72	3,690	–	–	–	–	–	–
KFM09A	785.10	792.24	12241	2006/4/20	0.058	72.6	0.492	7.92	<1.0	<0.002	2.33	3,700	0.0173	<0.0002	0.0005	0.0005	0.0012	<0.04
KFM09A	785.10	792.24	12242	2006/4/24	0.062	70.5	–	8.01	1.5	<0.002	1.94	3,600	0.0393	–	–	–	–	
KFM09A	785.10	792.24	12243	2006/4/27	0.074	73.7	0.525	8.16	1.3	0.004	1.83	3,720	0.0456	<0.0002	<0.0003	<0.0003	0.0025	<0.04
KFM09A	785.10	792.24	12244	2006/5/2	0.062	72.1	–	8.15	<1.0	0.002	1.56	3,670	0.0126	–	–	–	–	–

– = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< value = below reporting limit
RCB (%) = Rel. charge balance error %
SICADA: water_composition.

Table A7-2. Isotopes I (H-, O-, B-, S-, Cl- and C-isotopes).

Idcode	Secup m	Seclow m	Sample no	Sampling date	δ^{2}H ‰ SMOW	^{3}H TU	δ^{18}O ‰ SMOW	^{10}B/^{11}B no unit	δ^{34}S ‰ CDT	δ^{13}C ‰ PDB	^{87}Sr/^{86}Sr no unit	^{14}C pmC	δ^{37}Cl ‰ SMOC
KFM09A	785.10	792.24	12241	2006/4/20	–91.9	<0.8	–13.3	0.2384	27.1	–	0.717132	–	0.03
KFM09A	785.10	792.24	12242	2006/4/24	–91.6	<0.8	–13.2	–	–	–	–	–	–
KFM09A	785.10	792.24	12243	2006/4/27	–91.6	<0.8	–13.3	0.2382	27	–	0.717132	–	0.05
KFM09A	785.10	792.24	12244	2006/5/2	–91.9	<0.8	–13.3	–	–	–	–	–	–

– = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< value = below reporting limit
SICADA: Isotopes I.

Table A7-3. Trace elements.

Idcode	Secup m	Seclow m	Sample no.	Sampling date	Al ug/L	B ug/L	Ba ug/L	Cd ug/L	Cr ug/L	Cu ug/L	Co ug/L	Hg ug/L	Ni ug/L	Mo ug/L	Pb ug/L	V ug/L	Zn ug/L	U ug/L	Th ug/L	Sc ug/L	Rb ug/L	Y ug/L	Zr ug/L
KFM09A	785.10	792.24	12241	2006/4/20	8.31	744	422	<0.05	0.403	2	0.0952	<0.002	4.05	156	0.342	0.0984	11.3	0.105	<0.2	<0.5	39.2	0.313	<0.3
KFM09A	785.10	792.24	12243	2006/4/27	28	748	413	<0.05	3.51	1.14	0.174	<0.002	3.35	90.5	<0.3	0.125	5.63	0.0535	<0.2	0.517	35.2	0.342	<0.3

Idcode	Secup m	Seclow m	Sample no.	Sampling date	In ug/L	Sb ug/L	Cs ug/L	La ug/L	Hf ug/L	Tl ug/L	Ce ug/L	Pr ug/L	Nd ug/L	Sm ug/L	Eu ug/L	Gd ug/L	Tb ug/L	Dy ug/L	Ho ug/L	Er ug/L	Tm ug/L	Yb ug/L	Lu ug/L
KFM09A	785.10	792.24	12241	2006/4/20	<0.5	3.42	0.911	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
KFM09A	785.10	792.24	12243	2006/4/27	<0.5	2.15	0.763	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

– = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< value = below reporting limit
SICADA: trace_elements