P-10-02

Site investigation SFR

Hydrochemical characterisation of groundwater in borehole KFR105

Results from five investigated borehole sections

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March 2010

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Abstract

This report summarises results from chemical characterisation of groundwater in the core-drilled borehole KFR105. The most extensive hydrochemical sampling within the SFR investigations is performed in this borehole. Five sealed-off borehole sections were investigated. Samples for chemical analyses (major constituents, trace metals and isotopes) were collected in all five sections. On-line measurements of pH, electrical conductivity (EC), redox potential (Eh), dissolved oxygen and water temperature were conducted in two of the sections, see below. Furthermore, sampling for gas analyses and microbe studies were performed in the two latter sections.

Section (m borehole length)	Section elevation (m.b.s.l.)	Investigations
4.0–119.0	107.5–127.1	Groundwater sample series.
120.0–137.0	127.2–130.0	Groundwater sample series, gases, microbes and on-line measurements.
138.0–169.0	130.2–135.2	Groundwater sample series.
170.0–264.0	135.4–150.3	Groundwater sample series.
265.0–306.8	150.4–156.6	Groundwater sample series, gases, microbes and on-line measurements.

The investigation yielded groundwater chemistry data in accordance with SKB chemistry class 3, 4 and 5 including gas and microbe data as well as data measurement files with on-line parameters.

The water composition was stable during the sampling periods in all borehole sections. The chloride concentrations amounted to between 3,240 and 3,820 mg/L, while the flushing water contents were very low with a maximum value of 0.3%. The measured redox potentials (Eh) reached fairly stable values in both sections, but stayed in the positive range. This is probably due to intrusion of oxygen from air. Therefore, the redox potential measurements have been repeated in one of the sections (256.0 to 306.8 m) during January–February 2010, using a different type of equipment. The measured Eh-values from this period also reached fairly stable values, negative with an average value of –190 ± 15 mV. The low oxygen-18 values obtained in groundwater from borehole section 265.0 to 306.8 m indicate a significant contribution of glacial meltwater. The groundwaters at 120.0 to 137.0 m, 138.0 to 169.0 m and 170.0 to 264.0 m borehole length, on the other hand, show a clearly marine oxygen-18 signature with relatively high values. The oxygen-18 values from section 4.0 to 119.0 m are again somewhat lower.

The microbe contents in these SFR groundwaters were found unusually low compared to the observations from the previous site investigations in Forsmark and Laxemar (PLU). The reason for this is unknown but it cannot be excluded that the consistently low numbers of bacteria is an artifact. This, since microbes are easily affected by unfavorable sampling conditions.

Sammanfattning

Rapporten sammanfattar resultat från kemisk karakterisering av grundvatten i kärnborrhålet KFR105. Den mest omfattande hydrokemiska provtagningen inom undersökningarna för projektet SFR utbyggnad gjordes i detta borrhål. Fem avgränsade borrhålssektioner undersöktes. Grundvattenprov för kemiska analyser (huvudkomponenter, spårmetaller och isotoper) togs ut från samtliga fem borrhålssektioner. On-line mätningar av pH, elektrisk konduktivitet (EC), redoxpotential (Eh), löst syre och vattentemperatur utfördes i två av sektionerna, se nedan. Vidare togs prov för gasanalyser och mikrobstudier i de två nämnda sektionerna.

Sektion (m borrhålslängd)	Sektion elevation (m.b.s.l.)	Undersökningar
4,0–119,0	107,5–127,1	Grundvatten provserier.
120,0–137,0	127,2–130,0	Grundvatten provserier, gaser, mikrober och on-line mätningar.
138,0–169,0	130,2–135,2	Grundvatten provserier.
170,0–264,0	135,4–150,3	Grundvatten provserier.
265,0–306,8	150,4–156,6	Grundvatten provserier, gaser, mikrober och on-line mätningar.

Undersökningarna resulterade i grundvattenkemiska data enligt SKB kemiklasser 3, 4 och 5 inkluderande gas- och mikrobdata samt mätfiler med data för on-line parametrar.

Vattensammansättningen var stabil under provtagningsperioderna i samtliga borrhålssektioner. Kloridkoncentrationerna uppgick till mellan 3 240 och 3 820 mg/L, medan spolvatteninnehållet var mycket lågt med ett maxvärde på 0,3%. Redoxpotentialmätningarna (Eh) nådde ganska stabila värden i båda sektionerna men förblev i det positiva området. Detta beror förmodligen på inträngande luftsyre. Därför har redoxpotentialmätningarna upprepats i en av sektionerna (256,0 till 306,8 m) under januari–februari 2010, med en annan typ av utrustning. De uppmätta Eh-värdena under denna period nådde även här ganska stabila värden, negativa med ett medelvärde på –190 ± 15 mV. De låga syre-18 värden som erhölls i grundvattnet från borrhålssektionen 265,0 till 306,8 m indikerar ett signifikant bidrag av glacialt smältvatten. Grundvattenproven från 120,0 till 137,0 m, 138,0 till 169,0 m och 170,0 till 264,0 m borrhålslängd visar, å andra sidan, en tydlig marin syre-18 signatur med relativt höga värden. Syre-18 värdena från sektionen 4,0 till 119,0 m är åter igen en aning lägre.

Mikrobhalterna i dessa grundvatten från SFR visade sig vara ovanligt låga jämfört med observationerna under de föregående platsundersökningarna i Forsmark och Laxemar (PLU). Orsaken till detta är okänd men det kan inte uteslutas att det genomgående låga antalet bakterier är en artefakt. Detta, eftersom mikrober lätt kan påverkas av ogynnsamma provtagningsförhållanden.

Contents

1 Introduction

SKB is conducting investigations prior to a future enlargement of the SFR repository for low- and medium-level nuclear waste, situated close to the Forsmark nuclear plant in the Östhammar community. The investigations are performed in the planned area for the enlargement and are made according to the established geoscientific investigation program /1/.

This document reports the results obtained from the Hydrogeochemical characterisation of groundwater in borehole KFR105, which is one of the activities performed within the site investigation at SFR. The work was carried out in accordance with activity plan AP SFR-09-022. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Original data from the reported activity are stored in the primary database Sicada and traceable in Sicada by the activity plan number (AP SFR-09-022). Only data in databases are accepted for further interpretation and modeling. The data presented in this report are regarded as copies of the original data. Data in the database may be revised, if needed. However, such revision of the database will not necessarily result in a revision of this report although the normal procedure is that major data revisions entail a reversion of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

The field work was performed during July and August 2009 and consisted of water sampling from five different borehole sections together with on-line measurements (Chemmac measurements) of pH, redox potential (Eh), electrical conductivity, dissolved oxygen and temperature in two of the sections. Water samples intended for analyses with respect to dissolved gas and microbes were also collected from the same two sections. The sampling procedure and analyses of microbe samples are reported in Appendix 1.

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

Activity plan	**Number**	**Version**
Hydrokemisk karakterisering av grundvatten i borrhål KFR105	AP SFR-09-022	1.0
Redoxmätningar i KFR105	AP SFR-09-031*	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för vattenprovtagning och analys i instrumenterade borrhål (under framtagning)	SKB MD 425.001	In prep.
Mätsystembeskrivning – Handhavandedel; System för hydrologisk och meterologisk datainsamling. Vattenprovtagning och utspädningsmätning i observationshål.	SKB MD 368.010	1.0
Metodbeskrivning för fullständig kemikarakterisering med mobilt fältlaboratorium	SKB MD 430.017	2.0
Mobila kemienheter	SKB MD 434.007	1.0
Chemmac mätsystem	SKB MD 434.007	1.0
Dataapplikation till Chemmac mätsystem	SKB MD 433.018	1.0
Provtagning och analys- kemilaboratorium	SKB 452.001-019	–

* Results from this activity are presented in Appendix 10.

Borehole KFR105 was drilled towards south from the lower construction tunnel in SFR with an almost horizontal inclination. The borehole is approximately 307 m long. Prior to the hydrochemical investigations the borehole was instrumented with packers in order to isolate five sections. Technical description and design of the borehole is presented in Appendix 2. The drilling of the borehole was completed on June 2nd, 2009.

The site investigation area in Forsmark with borehole locations is shown in Figure 1-1.

The investigated sections together with transmissivity values are listed in Table 1-2.

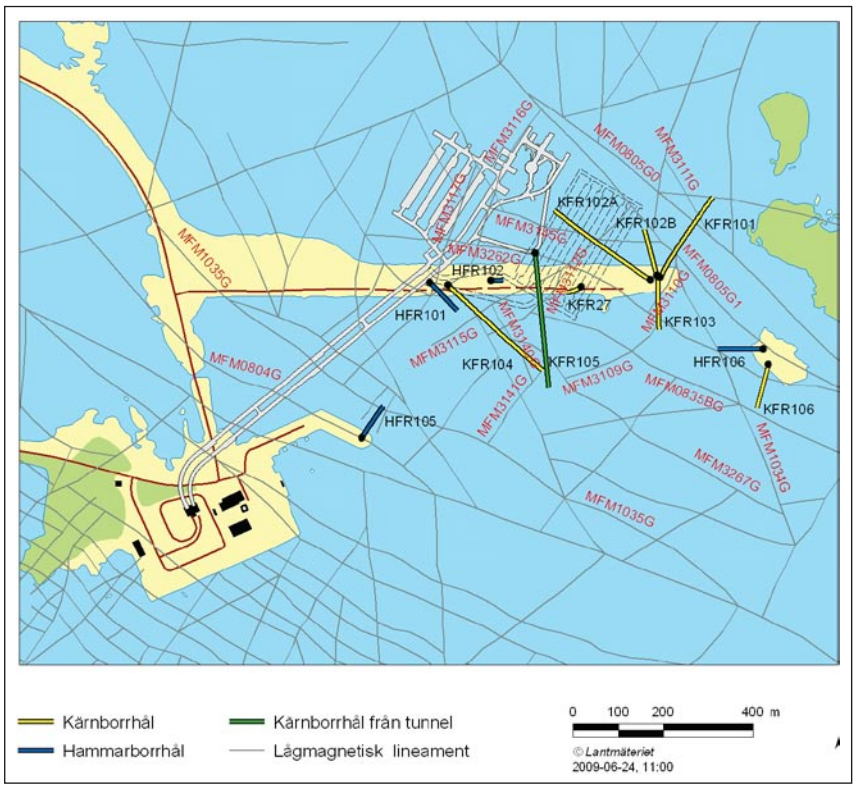


Figure 1-1. *SFR site with borehole locations. Borehole KFR105 is marked with green colour.*

Table 1-2. Investigated sections in KFR105 (borehole length and meters below sea level).

Section	Borehole length (m)	m.b.s.l.	T (m²/s) *
KFR105:5	4.0–119.0	107.5–127.1	2.10E-07
KFR105:4	120.0–137.0	127.2–130.0	7.45E-07
KFR105:3	138.0–169.0	130.2–135.2	1.13E-07
KFR105:2	170.0–264.0	135.4–150.3	3.53E-07
KFR105:1	256.0–306.8	150.4–156.6	6.06E-08

*Differential flow logging (PFL) overlapping mode, from Sicada.

2 Objective and scope

KFR105 was drilled from the lower construction tunnel in SFR in order to investigate conditions below repository depth and to detect possible gently dipping zones. It is the only borehole planned to be drilled from below the surface. Since the risk of contaminating tunnel boreholes with flushing water is much smaller than for boreholes drilled from the surface, this borehole is particularly suitable for hydrochemical investigations. The most extensive hydrochemical sampling within the SFR investigations (documented in this P-report) was therefore performed in this borehole.

The analytical protocol includes sampling and analyses according to SKB chemistry class 3, 4 and 5 and was performed in all five borehole sections (4.0 to 119.0 m, 120.0 to 137.0 m, 138.0 to 169.0 m, 170.0 to 264.0 m and 256.0 to 306.8 m borehole length). The analyses of the water samples include major constituents, minor constituents, trace elements and stable as well as radioactive isotopes.

The on-line measurements include pH, electrical conductivity (Eh) and dissolved oxygen and were performed in two of the borehole sections; 1 and 4. Furthermore, special sampling was also carried out for analysis of dissolved gas and microbes in the same borehole sections. For borehole lengths, see Table 1-2. These two sections for more extensive investigations were selected in order to get the maximum distance between the sampling locations and at the same time avoid the section close to the tunnel which probably is more disturbed from the tunnel than the others.

3 Background

3.1 Flushing water history

The lower drainage basin was used to supply flushing water for the drilling of borehole KFR105. The chemical composition of the flushing water was analysed regularly during the drilling, see Appendix 3. The drilling of the 306.81 m long borehole consumed 264.7 m^3 of flushing water and the volume of return water flowing from the borehole during drilling was 553.6 m^3.

Automatic dosing equipment for injection of uranine was installed in the flushing water supply line to the drilling head. The uranine concentration in the flushing water and return water was checked regularly and a total of 73 samples of each sample type were analysed. The uranine concentrations in the flushing water and in the return water are presented in Figure 3-1. An uranine budget, comparing 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. According to the uranine budget, no flushing water should be left in the borehole. This is also confirmed by the uranine concentrations in the groundwater samples presented in Appendix 3.

3.2 Previous events and activities in the borehole

Only those borehole activities that are necessary in order to select borehole sections are carried out prior to the hydrochemical characterization. The more downhole equipment used in the borehole, the greater is the risk of contamination. The activities/investigations performed in KFR105 prior to the chemistry campaign are listed in Table 3-2.

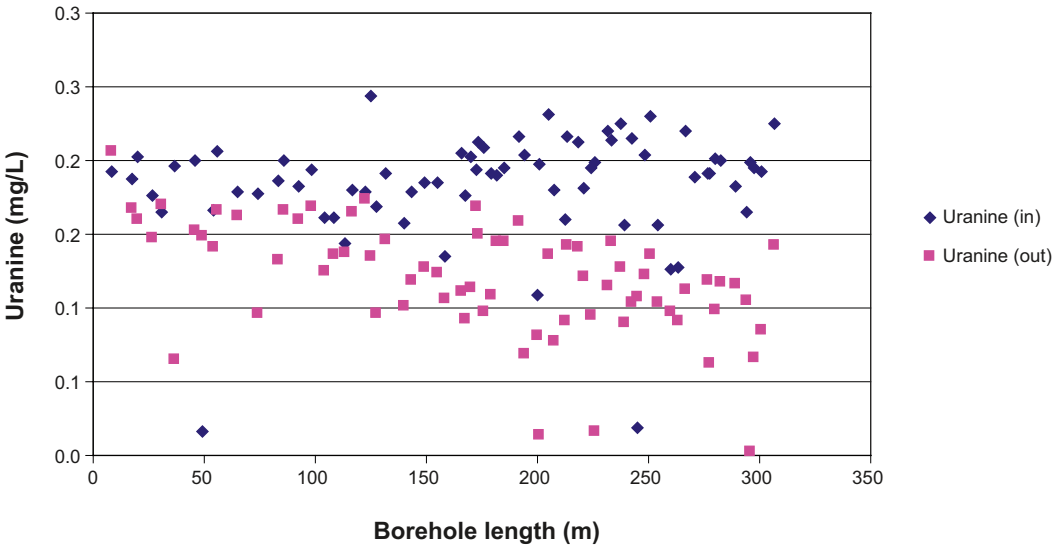


Figure 3-1. *Uranine concentrations in the flushing water and in the recovered water versus borehole length.*

Table 3-1. Amount of uranine added to KFR105 via the flushing water during core drilling and the amount recovered from return flow of mixed flushing water and formation water.

Uranine	(g)
Added, according to the log book.	57
Added, estimated from the average uranine concentration in the flushing water and the total volume of flushing water.	49
Recovered, estimated from the average uranine concentration in the return water and the total volume of returned water.	66

Table 3-2. Activities performed in KFR105 prior to the hydrochemical characterisation.

Activities performed*	Date of completion*	Borehole length (m)*
Core drilling	2009-06-02	0.00–306.81
Geophysical logging	2009-06-03	2.74–305.24
BIPS logging	2009-06-16	4.00–300.00
Radar logging	2009-06-17	0.00–292.00
Flow logging (PFL)	2009-06-30	1.39–305.97
Packer installation	2009-07-07	3.00–265.00

* From Sicada.

4 Equipment

4.1 General

The sampled borehole KFR105 contains five borehole sections sealed off by inflated packers. The instrumentation in a core-drilled borehole is illustrated in Figure 4-1.

As mentioned earlier, the borehole is drilled from the tunnel. Hence, no pumping is required since the pressure in the rock is higher than at the tunnel wall and water can be discharged by opening a valve on the tubing connected to the sampled sections.

4.2 The mobile field laboratory

The mobile field laboratories used by SKB for water sampling and down-hole measurements consist of several units. The system is described in the SKB internal controlling documents SKB MD 434.004, 434.007 and SKB MD 433.018 (Mätsystembeskrivningar för mobil kemienhet allmän del, mobil ytChemmac och dataapplikation). Since no down-hole equipment is needed in tunnel borehole cases, only the computer unit MYC 4 including the surface Chemmac measurement system and the laboratory unit L3 were employed for measurements, sampling and analytical work. The laboratory unit L3 was located close to the Forsmark core-mapping facility and not at the drill site in the construction tunnel.

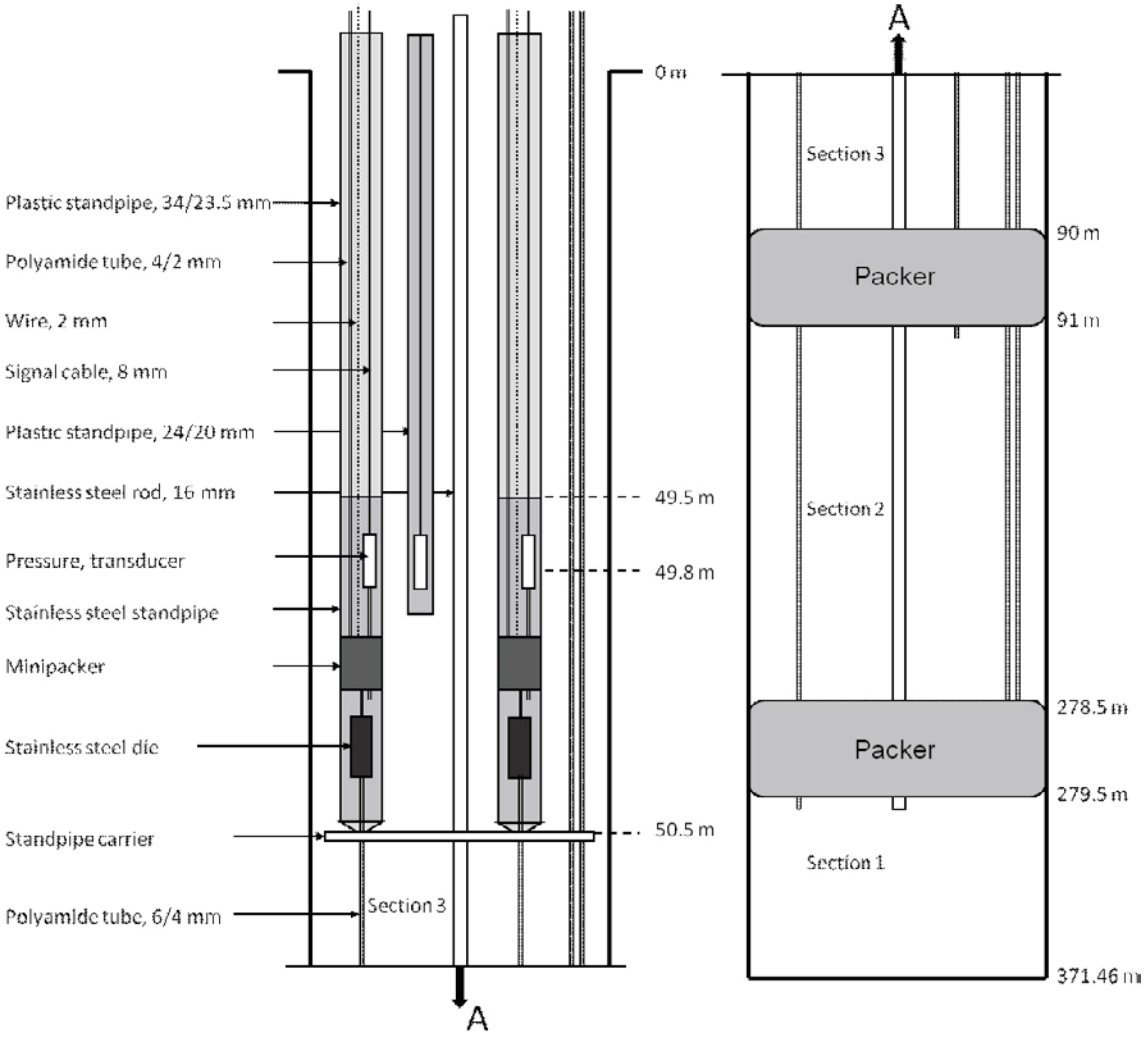


Figure 4-1. *Schematic outline of the instrumentation in a core-drilled borehole.*

The surface Chemmac, see Figure 4-2, includes the probe for oxygen measurements, the conductivity cell and the temperature sensor. Furthermore, two glass electrodes, three redox electrodes (glassy carbon, platinum, gold) and a reference electrode of type Ag/AgCl are used for pH and redox potential measurements, respectively. The flow rate is also measured by the surface Chemmac.

The equipment used during the measurement period in January–February 2010 is shown in Appendix 10.

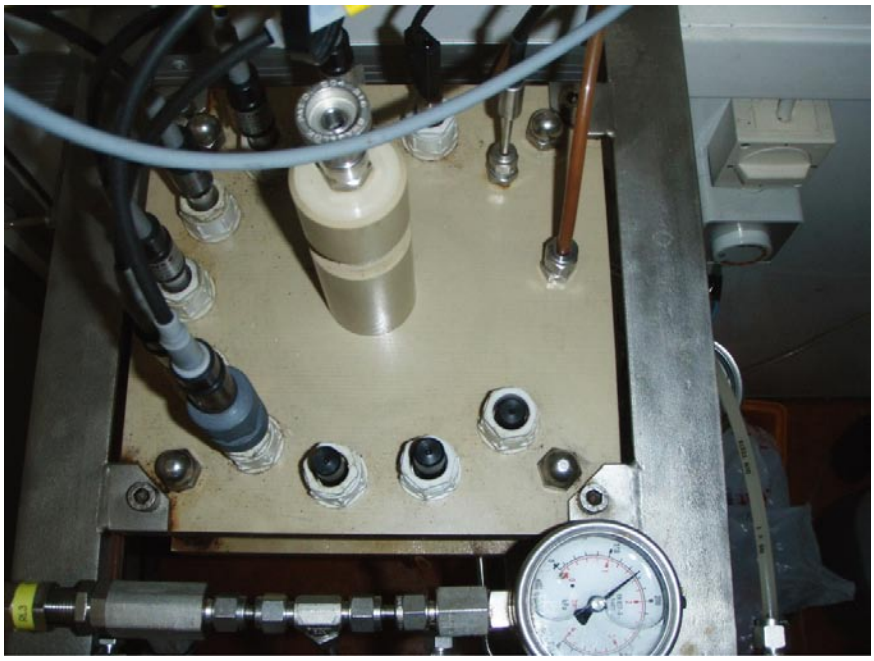


Figure 4-2. *The surface Chemmac.*

5 Execution

5.1 General

The work included water sampling from five borehole sections in borehole KFR105. In addition, on-line measurements of pH and electrical conductivity (Chemmac measurements) were performed in two of the sections. The work was carried out according to the method descriptions presented in Table 1-1.

5.2 Hydrochemical characterisation

5.2.1 Overwiew of the field work procedure

The borehole is located in a tunnel below the surface and there is no need to pump water since the pressure in the borehole is higher than in the tunnel. The water flows automatically when the valve on the tubing connected to the various borehole sections is opened. Events during the sampling periods, including flow rate adjustments, are shown in Tables 5–1 to 5–5. After the valve was opened, one tube volume of water was removed before the first sample was taken. The volumes discharged from each section prior to sampling are given in Appendix 4.

Chemmac measurements were performed in borehole sections 120.0 to 137.0 m and 256.0 to 306.8 m borehole length, respectively. In section 120.0 to 137.0 m, four water samples were collected during the measurement period and an additional sample the day after completed measurements. The flow rate tended to decrease during the flow period. Hence, a few flow rate adjustments were made. In borehole section 256.0 to 306.8 m, five water samples were collected during the measurement period and an additional sample was collected two weeks after the termination of the measurements. No flow rate adjustments were made. The flow rate was kept in the range of 100–200 mL/min during the measurement periods, see Appendix 5.

The discharged water was lead into the surface Chemmac located in the computer unit (MYC4). Calibration of the pH and redox electrodes as well as the electrical conductivity and oxygen sensors in the surface Chemmac was conducted when the water from the borehole section reached the MYC-unit and again at the end of the Chemmac measurements. The measurement period was restricted to about two weeks per section. During this time, water samples were collected regularly 3–4 times a week.

In the three sections where only water sampling was performed, the valve was opened and water was allowed to flow continuously during the whole sampling period. Four samples in each section were collected over a period of about one week.

The pressure responses in all five sections during the investigations are shown in Appendix 6. In most cases, the flow rate adjustments are also reflected by pressure changes. The pressure responses (Appendix 6, Figures A6-1 to A6-3) clearly shows that sections 2, 3 and 4 are well connected, whereas sections 1 and 5 seem to be better isolated. The short-circuiting between sections 2, 3 and 4 may affect the chemical composition of the samples from these sections.

The events from the sampling period in January–February 2010 are presented in Appendix 10.

Table 5-1. Events during the sampling period in section 5 (4.00–119.00 m).

Date	Event	Sample no.	Discharged volume (m^3)	Flow rate (mL/min)
090814 08:28	Valve opening			
090814	Water sampling SKB class 5	16371		190
090817	Flow rate adjustment			From 105 to 200
090817	Water sampling SKB class 5	16372		200
090819	Water sampling SKB class 4	16373		170
090821	Water sampling SKB class 5+	16374		160
090821 09:40	Valve closing			
			1.85	**105–200**

Table 5-2. Events during the sampling/measurement period in section 4 (120.00–137.00 m).

Date	Event	Sample no.	Discharged volume (m^3)	Flow rate (mL/min)
090728	Calibration of surface Chemmac, MYC4			
090728 13:41	Valve opening			
090728	Start of Chemmac measurements			
090728	Flow rate adjustments			200
090728	Water sampling SKB class 5 (reduced)	16361		198
090731	Flow rate adjustments			From 120 to 140
090731	Water sampling SKB class 5 (reduced)	16362		118
090731	Flow rate adjustments			From 120 to 135
090803	Water sampling SKB class 4	16363		120
090806	Power failure			
090807	Water sampling SKB class 5+	16364		116
090810	Stop of Chemmac measurements			
090810	Calibration of surface Chemmac, MYC4			
090811	Water sampling SKB class 3	16366		
	Sampling of gas and microbes			
090811 13:55	Valve closing			
			2.27	**110–150**

Table 5-3. Events during the sampling period in section 3 (138.00–169.00 m).

Date	Event	Sample no.	Discharged volume (m^3)	Flow rate (mL/min)
090814 08:28	Valve opening			
090814	Water sampling SKB class 5 (reduced)	16367		180
090817	Flow rate adjustment			From 150 to 180
090817	Water sampling SKB class 5 (reduced)	16368		
090819	Water sampling SKB class 4	16369		180
090821	Water sampling SKB class 5+	16370		155
090821 09:55	Valve closing			
			1.91	**150–180**

Table 5-4. Events during the sampling period in section 2 (170.00–264.00 m).

Date	Event	Sample no.	Discharged volume (m^3)	Flow rate (mL/min)
090727 12:51	Valve opening			
090727	Water sampling SKB class 5 (reduced)	16357		200
090731	Water sampling SKB class 5 (reduced)	16358		
090803	Flow rate adjustment			From 120 to 200
090803	Water sampling SKB class 4	16359		
090807	Water sampling SKB class 5+	16360		
090807 10:18	Valve closing			
			2.98	**170–200**

Table 5-5. Events during the sampling/measurement period in section 1 (265.00–306.80 m).

Date	Event	Sample no.	Discharged volume (m^3)	Flow rate (mL/min)
090713–14	Calibration of surface Chemmac, MYC4			
090714 11:08	Valve opening			
090714	Start of Chemmac measurements			
090714	Water sampling SKB class 5 (reduced)	16333		116
090717	Water sampling SKB class 5 (reduced)	16334		92
090720	Water sampling SKB class 4	16335		84
090723	Water sampling SKB class 4	16336		80
090727	Water sampling SKB class 5+	16337		75
090727	Stop of Chemmac measurements			
090728 13:41	Valve closing			
090728	Calibration of surface Chemmac, MYC4			
090811	Water sampling SKB class 3 Sampling of gas and microbes	16365		
			1.73	**75–100**

5.2.2 Water sampling, sample treatment and analyses

The water from the borehole section is led into the MYC unit where the surface Chemmac is located. Sampling and sample filtration is carried out outside the MYC unit. Filtration of sample portions is performed on-line by connecting the filter holders directly to the water outlet (See Figure 5-1). A water sample is defined as groundwater collected during one day and consists of several sample portions, labelled with the same sample number. Some sample portions are analysed immediately (pH, electrical conductivity, uranine, chloride, alkalinity, ammonium, ferrous and total iron) while others are sent to laboratories or stored in a refrigerator or freezer to be analysed later on.

Sample portions intended for analysis of major constituents, iron (by spectrophotometry), DOC and nutrient salts were filtered. Disposable 0.4 µm membrane filters were fitted directly to the 6/8 mm polyamide-tube leading the discharged water from the borehole section. During the entire sampling procedure, laboratory gloves were used to minimise the risk of contamination. Sampling was performed according to SKB class 3, 4 and 5, of which class 5 is the most extensive one. The first two class 5 samples in each section included options of sulphide, trace metals, tritium, deuterium and oxygen-18.

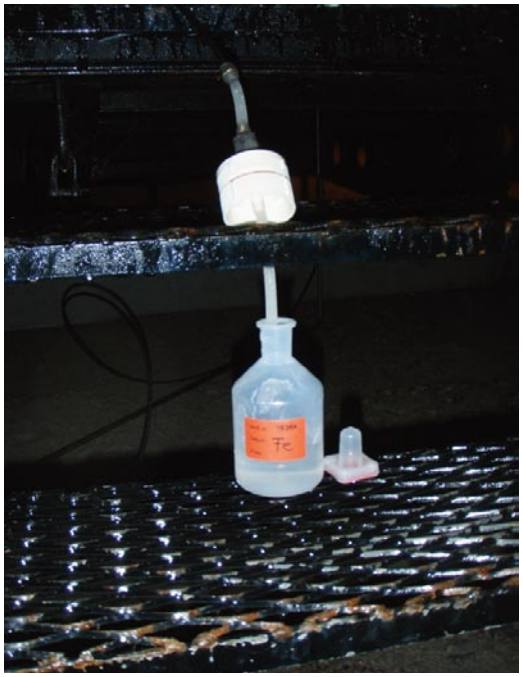


Figure 5-1. *Water sampling. The photograph shows the water outlet, the filter holder for on-line filtering and a sample bottle.*

In class 5+ all options are included. An overview of sample treatment and analysis methods is given Appendix 7. The routines are applicable independently of sampling method or type of sampling object.

5.2.3 Stability of groundwater composition over time

The electrical conductivity (EC) in several specific fractures was measured previously during differential flow logging (PFL). In Figure 5-2, these results are compared with batch measurements conducted in the laboratory in groundwater samples from this investigation. Generally, the EC-values from the differential flow logging are higher than in the water samples (Figure 5-2), but the agreement is fairly good considering the different hydraulic circumstances under which the measurements and the water sampling is performed. Unlike the logged EC, the samples represent several flow anomalies along the sampled section which is one explanation to varying and disagreeing values. A considerably higher flow rate is used during the differential flow logging and another explanation to differences may, at least partly, be the fact that differential flow logging involves discharge of larger water volumes and thereby affects water from a larger rock volume than water discharged for chemical sampling.

The measurement accuracy of the measurement sensor used in the differential flow logging equipment is ± 5%. The volumes discharged before each sampling occasion is presented in Appendix 4.

The stable laboratory results of EC indicate that the length of the flow period has been sufficient to obtain water representative for ambient conditions in the sampled borehole section and this is also supported by the fact that the previously logged values agree fairly well.

5.3 Nonconformities

Measurement data from borehole section 120.0 to 137.0 m borehole length was lost during the period 2009-08-06 16:25 until 2009-08-07 08:35 because of power failiure when a fuse was blown.

Nonconformities during the measurement period in January–February 2010 in KFR105 are presented in Appendix 10.

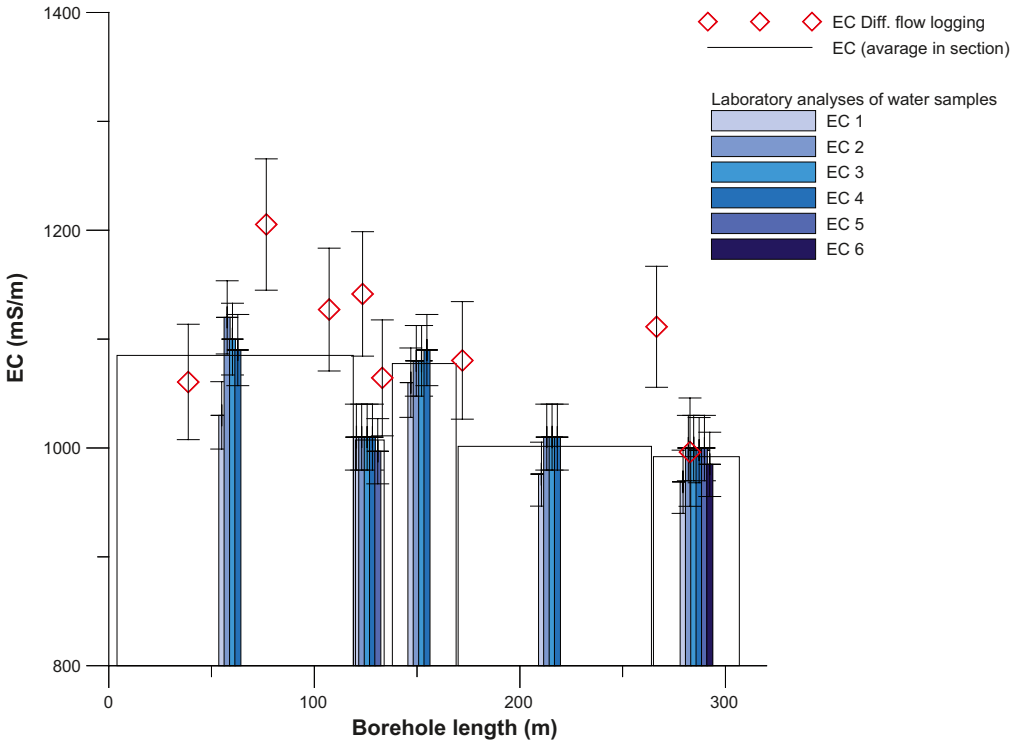


Figure 5-2. *Electrical conductivity (EC) in KFR105. The section limits are shown by the un-filled bars and the height represents the average EC (laboratory measurements) in the section. Individual measurements (laboratory analyses) are shown with different shades of blue at mid-section length. As a comparison, the EC values in different flow anomalies measured during differential flow logging are displayed as red diamonds.*

6 Data handling and interpretation

6.1 Chemmac measurement data

The processing of Chemmac data are described in SKB MD 434.007-02 (Mätsystembeskrivning för Chemmac mätsystem, SKB internal controlling document, in progress).

6.1.1 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.
- Raw data files containing the logged measurement sequences (*K.MRB) and corresponding comments (*.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 atmospheric pressure and outdoor temperature.

The original raw data files listed above are stored in the Sicada file archive. Furthermore, the files are re-calculated and evaluated to obtain values of pH and redox potential and to correct the electrical conductivity values using the 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 field work and the calculation/evaluation. The comments in the file are imported as activity comments in Sicada.

6.1.2 Calculation and evaluation of redox potential and pH

The registrations from the redox and the pH electrodes are logged each hour during a measurement period of approximately two 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 redox electrodes and two 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 results 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 selected 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 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 largest 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 for the redox potential and the pH, respectively. Data from 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. 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.
- Number of electrodes showing reasonable agreement. Data from obviously erroneous electrodes are excluded from the calculation.

6.2 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.

Some 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. These data sets are compiled in a primary data table named “water composition”. The evaluation is based on:

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

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

- 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 the results which are considered most reliable. An overview of the data management is given in Figure 6-1.

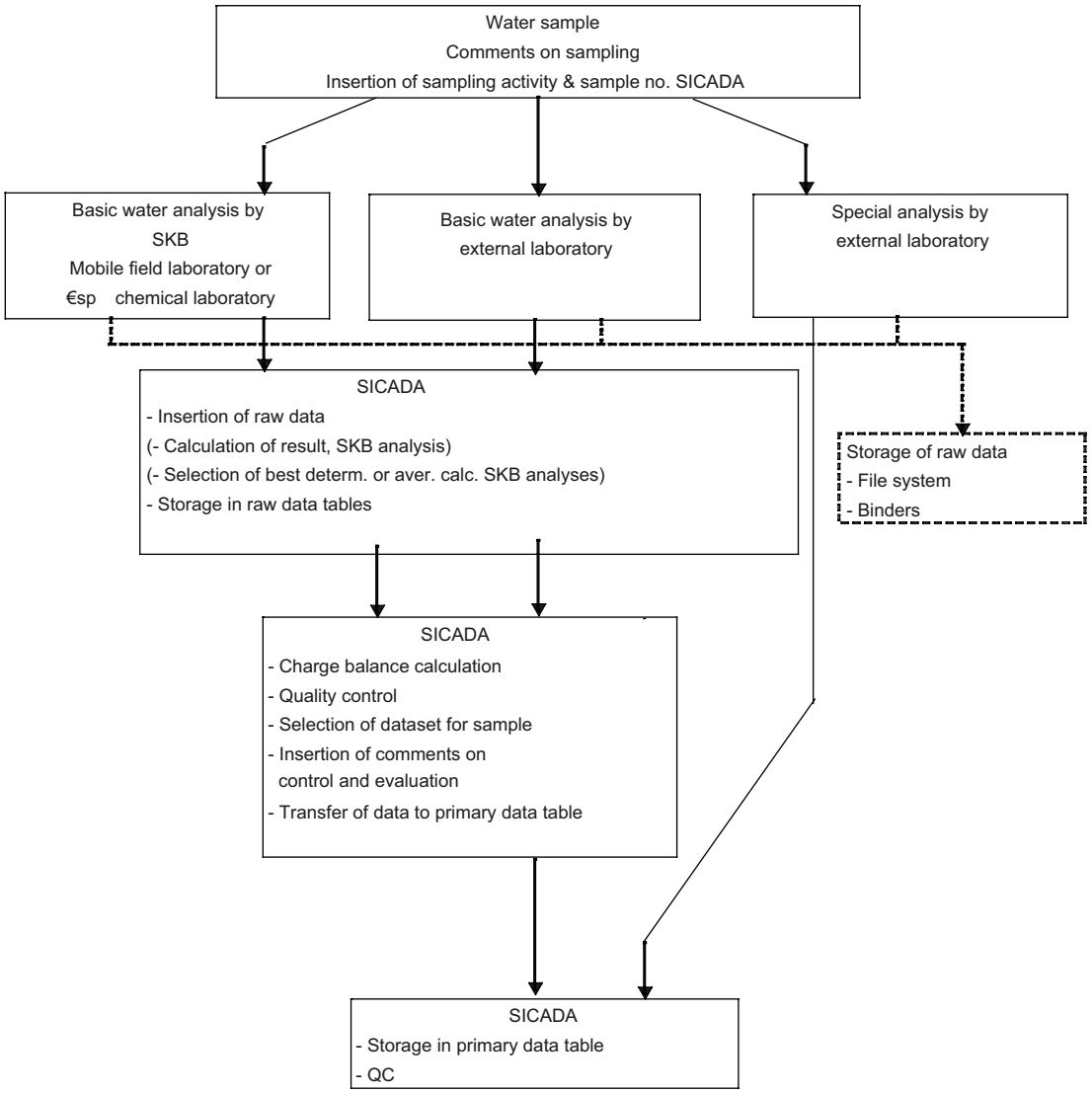


Figure 6-1. *Overview of data management for hydrogeochemical data.*

7 Results

7.1 Chemmac measurements

The data sequences of pH, Eh, electrical conductivity, oxygen and temperature values from the Chemmac measurements in borehole section 120.0 to137.0 m are plotted versus time in Appendix 8 and from section 265.0 to 306.8 m in Appendix 9. Measurement data from the period 2009-08-06 16:25 until 2009-08-07 08:35 in borehole section 120.0 to 137.0 was lost because of power failiure. Chemmac measurements in borehole section 265.0 to 306.8 m from the measurement period in January–February 2010 are plotted versus time in Appendix 10.

The measured time series were evaluated in order to obtain representative values of pH, Eh, electrical conductivity and dissolved oxygen for the borehole sections as described in Section 6.1. 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. The evaluated results from the measurements in the investigated sections are given in Table 7-1.

The redox potentials of the electrodes in borehole and surface Chemmac were quite stable and consistent, but it is likely that the positive redox potentials are artefacts caused by intruding oxygen. Therefore, the obtained Eh values were not considered as representative for the two borehole sections. At the end of the measurement period, the measured Eh values were 43 mV and 52 mV in sections 120.0 to 137.0 and 265.0 to 306.8 m, respectively. The pH electrodes were consistent and stable. The redox measurements have been repeated in one of the sections (256.0 to 306.8 m) during January–February 2010, using a different type of equipment and these measurements showed negative Eh-values, see Appendix 10.

There is a difference between pH measured during the first Chemmac measurement (in July 2009) and the re-measurement (during January-February 2010). The results from the Chemmac measurement are regarded as representative, since all calibration constants showed consistent values during calibration (initial as well as final), for both electrodes. Hence, the chosen constant was calculated as the average value of the six calibration constants for each electrode.

The difference between initial calibration and final calibration was larger (>20 mV) fort the re-measurement . Hence linear correction was necessary for one of the glass electrodes. The calibration measurements for the other electrode diverged more than was acceptable and the calibration constant at pH 7 had to be used for the calculation of pH. Furthermore, the measurement sequence in the groundwater showed more scattering this second time.

Table 7-1. Evaluated results from the Chemmac measurements in KFR105.

Borehole section [m]	Electrical conductivity* [mS/m]	pH (surface Chemmac)**	Eh*** [mV]	Dissolved oxygen**** [mg/L]
120.0–137.0	980 ± 30	7.5 ± 0.1	–	0.00 ± 0.01
265.0–306.8	990 ± 30	7.7 ± 0.2	–	0.00 ± 0.01

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

** Evaluated result and measurement uncertainty calculated as described in Section 5.1.

*** A representative Eh value was not chosen since the recorded redox potentials were considered unreliable due to possible intrusion of oxygen from air.

**** Measurement interval 0–15 mg/L, resolution and measurement uncertainty ± 0.01 mg/L.

7.2 Groundwater analyses

7.2.1 Basic analyses

The basic 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, Br^-, F^-, I^-, HS^- and NH_4^+. Samples collected according to SKB chemistry class 5 also include P, NO_2^-, NO_3^-, TOC and DOC. Furthermore, batch measurements of pH (lab-pH) and electrical conductivity (lab-EC) are included. Another important parameter is the flushing water content in each sample. The flushing water contents in KFR105 were low and did not exceed 1% in any of the samples. The highest flushing water content was 0.3% in section 4.0 to 119.0 m but in this low range the uncertainty is large and variations between 0% and 0.5% are of little consequence. Existing lab-pH and lab-EC values are compared with the corresponding on-line Chemmac measurement values in Appendices 8 and 9.

The charge balance errors provide an indication of the quality and uncertainty of the analyses of major constituents. The errors did not exceed the acceptable limit of ± 5% for any of the samples. The basic water analysis data and relative charge balance errors are compiled in Appendix 3, Table A3-1.

The diagram in Figure 7-1 shows chloride concentrations versus EC values from previous investigations in Forsmark as well as results from borehole KFR105. The data from KFR105 follow the trend line, which indicates that the EC and chloride data sets are consistent.

The concentrations of chloride, calcium and sodium are presented in Figures 7-2 to 7-6. The concentrations of the major constituents remained quite constant during the whole sampling period.

The iron concentrations are compared in Figures 7-7 to 7-11. The determinations by ICP-AES, total Fe, and spectrophotometry, Fe(II) and Fe-tot, agree well. The concentrations are more or less stable by the end of the sampling periods.

Sulphate analysed by ion chromatography (IC) is compared with sulphate determined as total sulphur by ICP-AES in Figures 7-12 to 7-16. The agreement between the two analytical methods (IC and ICP-AES) is fairly good, however, sulphate concentrations by IC are consistently lower. The discrepancies are within the size of the analytical error.

The chemical analyses from the sampling period in January–February 2010 are presented in Appendix 10.

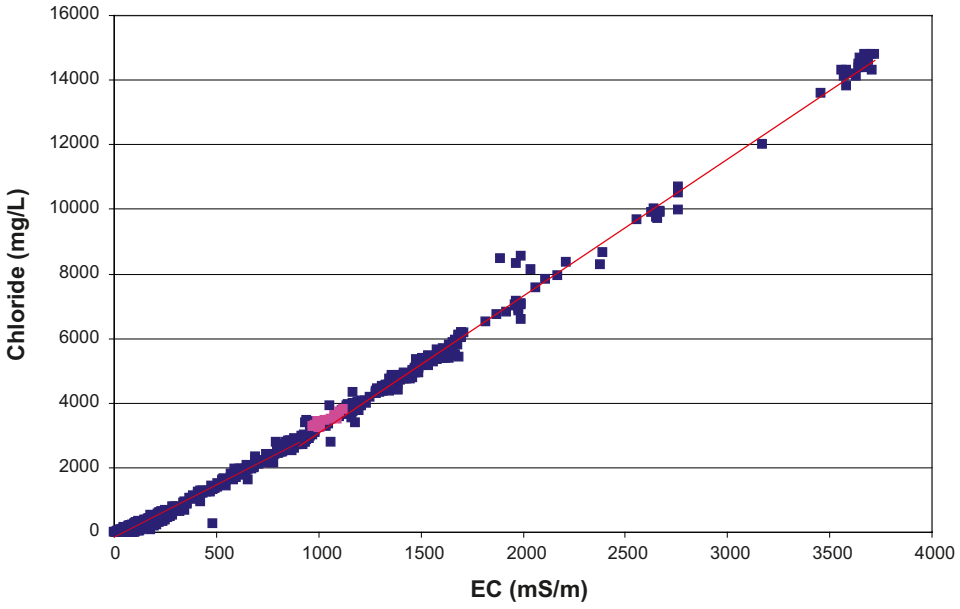


Figure 7-1. *Chloride concentration versus electrical conductivity. Data from previous investigations at Forsmark are used to show the linear trend. Data from KFR105 are shown in pink.*

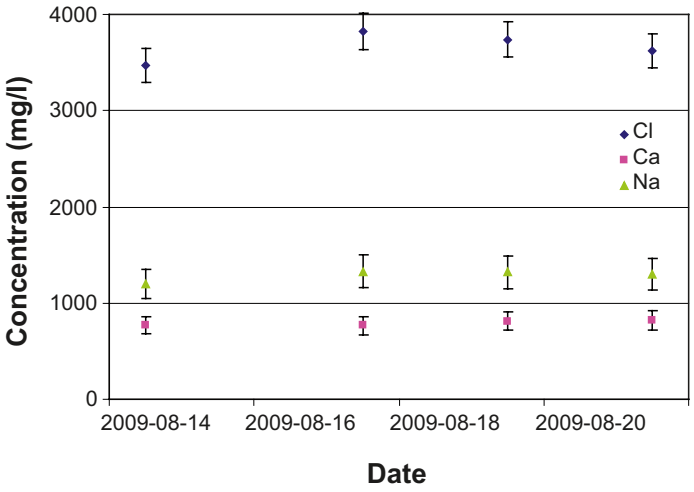


Figure 7-2. *Chloride, calcium and sodium concentrations in the groundwater sample from KFR105, section 4.0–119.0 m.*

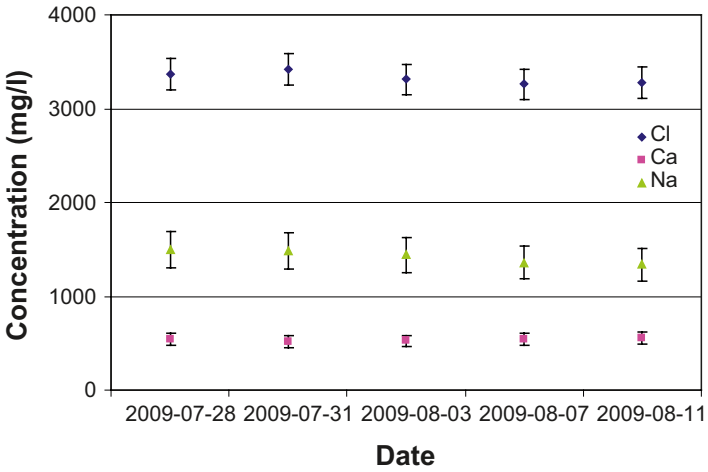


Figure 7-3. *Chloride, calcium and sodium concentrations in the groundwater sample from KFR105, section 120.0–137.0 m.*

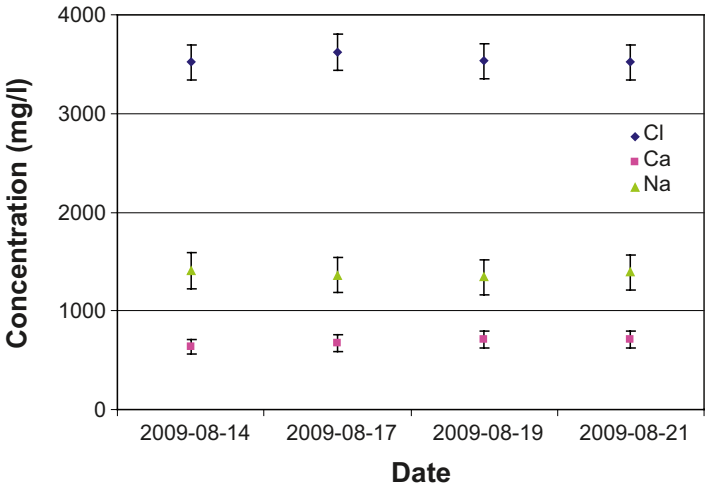


Figure 7-4. *Chloride, calcium and sodium concentrations in the groundwater sample from KFR105, section 138.0–169.0 m.*

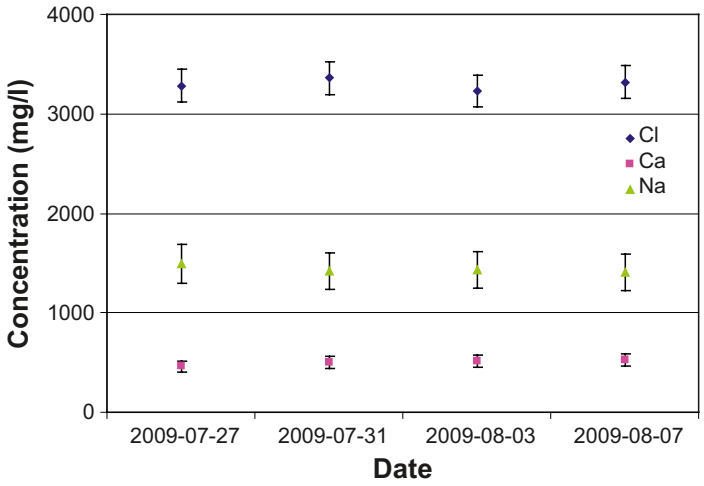


Figure 7-5. *Chloride, calcium and sodium concentrations in the groundwater sample from KFR105, section 170.0–264.0 m.*

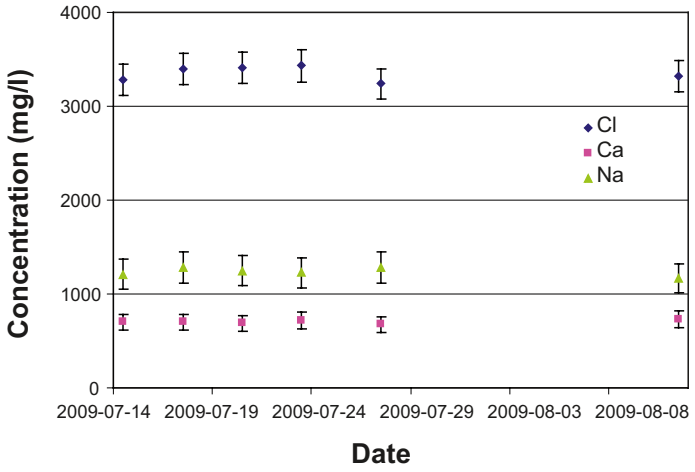


Figure 7-6. *Chloride, calcium and sodium concentrations in the groundwater sample from KFR105, section 265.0–306.8 m.*

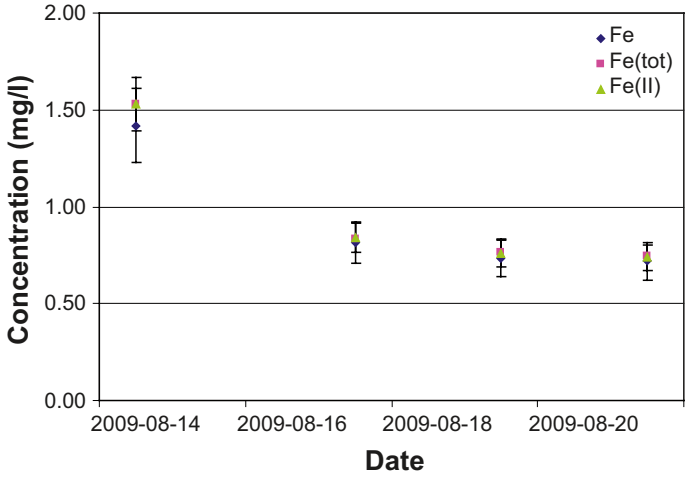


Figure 7-7. *Comparisons of iron concentrations obtained by ICP-AES and by spectrophotometry, KFR105, section 4.0–119.0 m.*

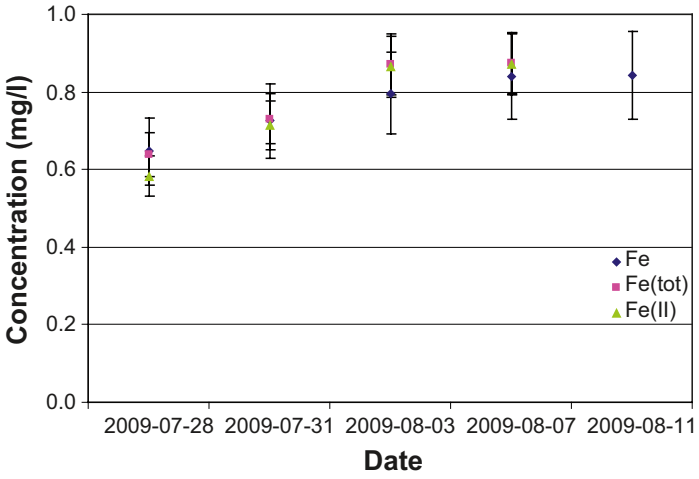


Figure 7-8. *Comparisons of iron concentrations obtained by ICP-AES and by spectrophotometry KFR105, section 120.0–137.0 m.*

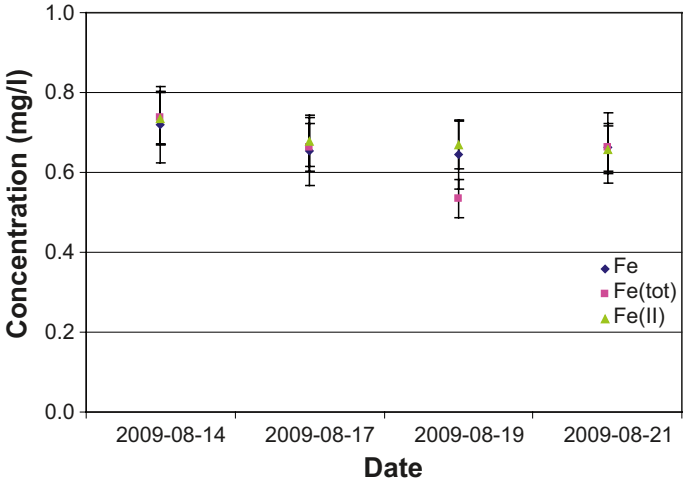


Figure 7-9. *Comparisons of iron concentrations obtained by ICP-AES and by spectrophotometry, KFR105, section 138.0–169.0 m.*

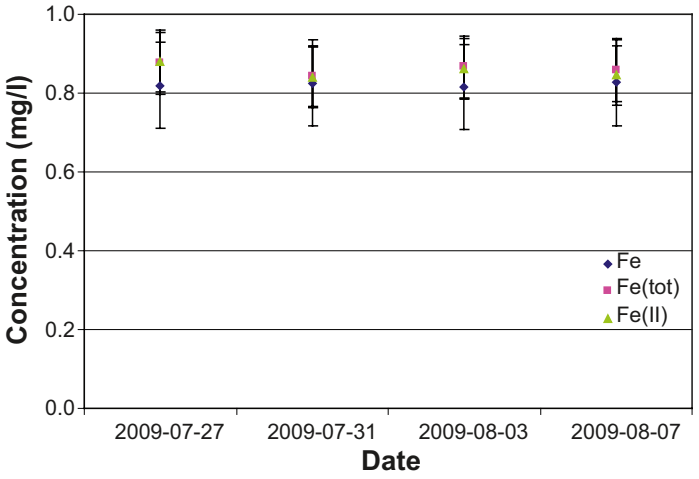


Figure 7-10. *Comparisons of iron concentrations obtained by ICP-AES and by spectrophotometry, KFR105, 170.0–264.0 m.*

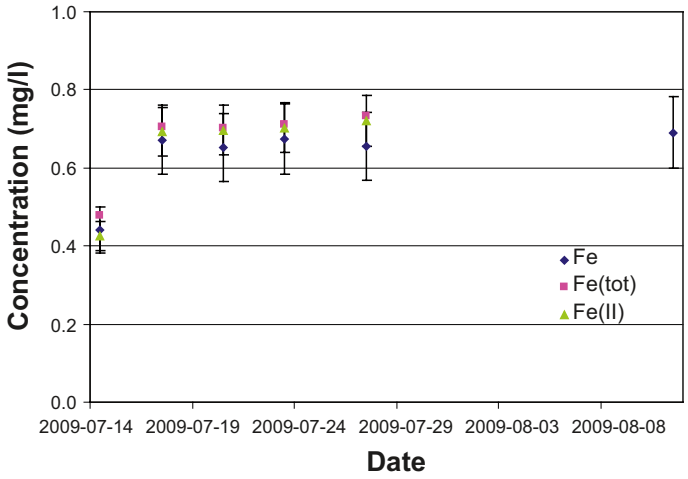


Figure 7-11. *Comparisons of iron concentrations obtained by ICP-AES and by spectrophotometry, KFR105, section 265.0–306.8 m.*

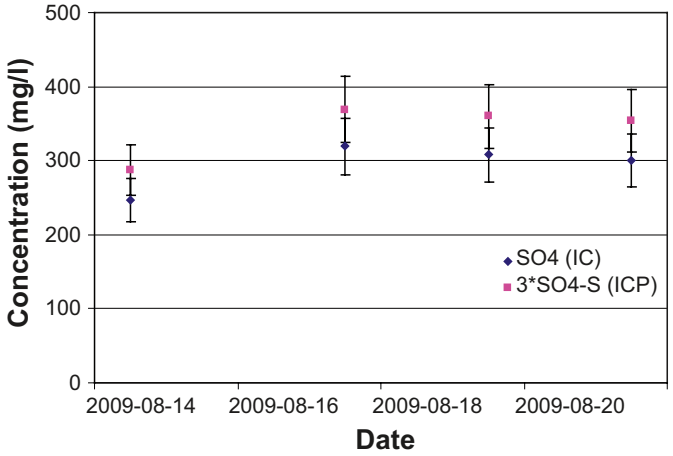


Figure 7-12. *Sulphate (SO4 by IC) compared to total sulphate calculated from total sulphur (3×SO_4–S by ICP) versus date, KFR105, section 4.0–119.0 m.*

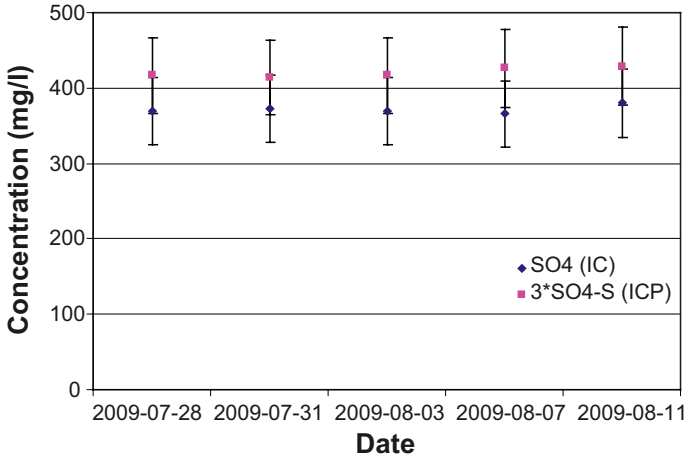


Figure 7-13. *Sulphate (SO4 by IC) compared to total sulphate calculated from total sulphur (3×SO_4–S by ICP) versus date, KFR105, section 120.0–137.0 m.*

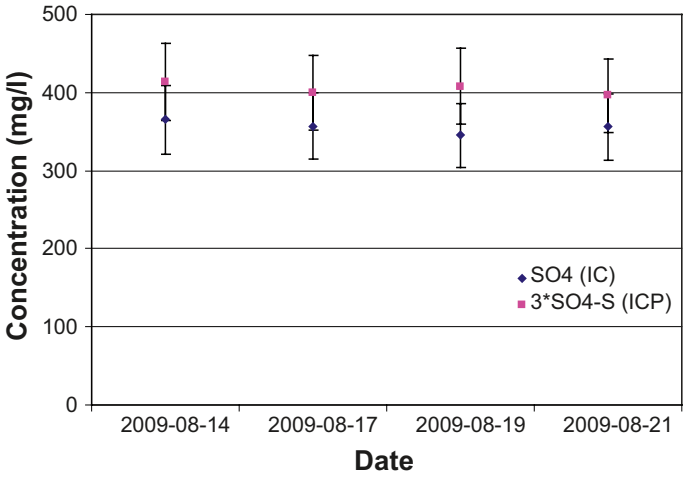


Figure 7-14. *Sulphate (SO4 by IC) compared to total sulphate calculated from total sulphur (3×SO_4–S by ICP) versus date, KFR105, section 138.0–169.0 m.*

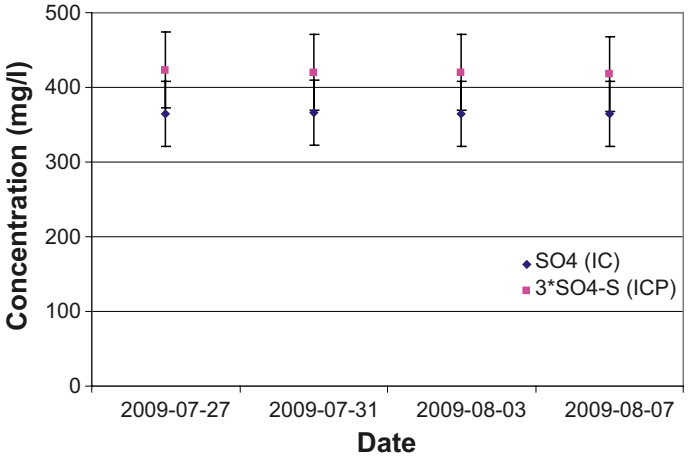


Figure 7-15. *Sulphate (SO4 by IC) compared to total sulphate calculated from total sulphur (3×SO_4–S by ICP) versus date, KFR105, section 170.0–264.0 m.*

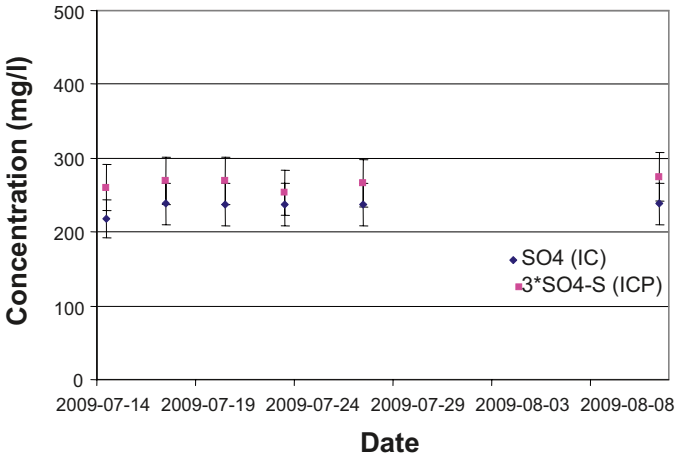


Figure 7-16. *Sulphate (SO4 by IC) compared to total sulphate calculated from total sulphur (3×SO_4–S by ICP) versus date, KFR105, section 265.0–306.8 m.*

7.2.2 Trace elements (rare earth metals and others)

The analyses of trace elements include Cr, Cu, Co, Ni, Mo, Pb, Zn, Sb, Al, U, Th, B, As, Sc, Cd, Hg, V, Rb, Y, Zr, In, Cs, Ba, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb as well as Lu and are compiled in Appendix 3, Table A3-2. Due to low natural concentrations and frequent use in various pieces of equipment, the risk of contamination is high for common metals like Cr, Cu, Co, Ni, Mo, Zn and Al.

7.2.3 Stable and radioactive isotopes

The isotope determinations include the stable isotopes δ^2H, $\delta^{18}O$, $^{10}B/^{11}B$, $\delta^{34}S$, $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ as well as the radioactive isotopes ^3H (TU), ^{14}C (pmC), ^{238}U, ^{234}U, ^{230}Th, ^{226}Ra and ^{222}Rn. Available isotope data are compiled in Appendix 3, Tables A3-3 and A3-4.

The ^3H and $\delta^{18}O$ results from KFR105 are presented in Figure 7-17.

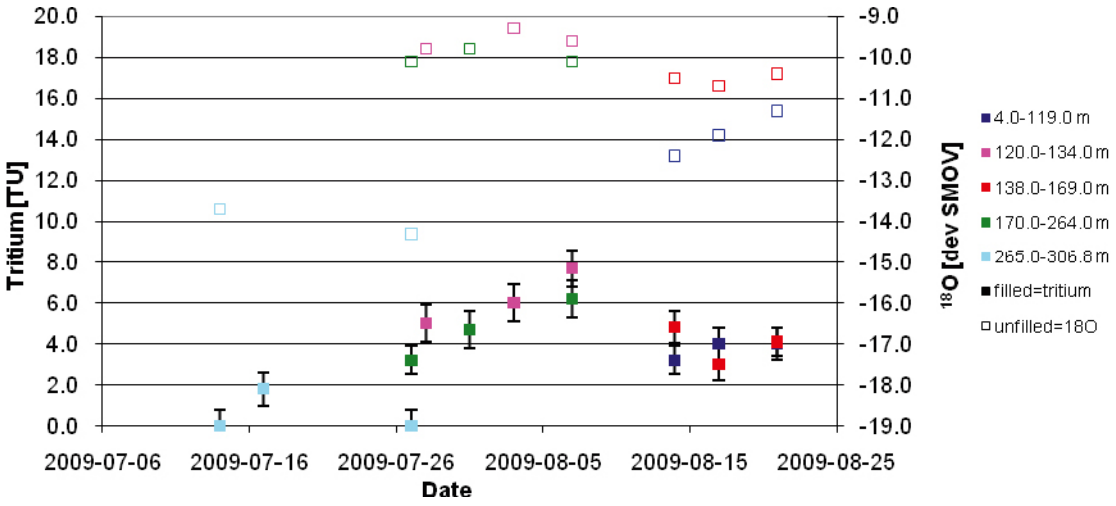


Figure 7-17. *$\delta^{18}O$ and ^3H data versus sampling date in KFR105.*

8 Summary and discussions

The hydrogeochemical investigation in KFR105 in July–August 2009 included collection of four samples from each of the borehole sections 4.0 to 119.0 m, 138.0 to 169.0 m and 170.0 to 264.0 m borehole length, five samples from section 120.0 to 137.0 m and six samples from section 265.0 to 306.8 m borehole length. Some observations regarding the performance and the results are listed below:

- The collected samples from all borehole sections showed very low flushing water contents (between 0 and 0.3%). Furthermore, the water compositions were stable within each time series.
- The pressure responses indicate that there is short-circuiting between sections 2, 3 and 4. This may affect the composition of the samples from these sections.
- The possible connection between section 2, 3 and 4 is supported by the water chemistry data. The concentrations of the major constituents as well as the composition of the isotopes deuterium and oxygen-18 are very similar in these three sections and they are significantly different from section 1 and section 5.
- The low oxygen-18 values obtained in groundwater from borehole section 265.0 to 306.8 m indicates a significant contribution of glacial meltwater. The groundwaters at 120.0 to 137.0 m, 138.0 to 169.0 m and 170.0 to 264.0 m borehole length, on the other hand, show a clearly marine oxygen-18 signature with relatively high values while the oxygen-18 signature in section 4.0 to 119.0 m borehole length is again somewhat lower but still far from the signature in the inner bottom section of the borehole.
- The uranium concentrations are relatively high (c. 20–40 µg/L).
- All of the samples show low sulphide concentrations. From previous investigations /2/ it has been suggested that the sulphide concentration (microbial production) could be affected by pumping. Various activities during and after the drilling and prior to the installation of packers, have resulted in a total discharge of 761 m^3 of water from the borehole. It cannot be excluded that low concentrations is an artifact caused by discharge during recent drilling and investigation activities.
- Comparison between EC measurements in specific fractures during differential flow logging and results from the groundwater samples in this report indicate that the length of the sampling flow period has been sufficient to obtain samples representative of formation water. This is also supported by the fact that the chemical composition is relatively stable within each sample series.
- The redox measurements during January–February 2010, using special equipment, show negative Eh values of –190 ± 15 mV.

References

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

/1/ **SKB, 2008.** Geovetenskapligt undersökningsprogram för utbyggnad av SFR. SKB R-08-67, Svensk Kärnbränslehantering AB.

/2/ **Smellie J, Tullborg E-L, Nilsson A-C, Sandström B, Waber N, Gimeno M, Gascoyne M, 2008.** Explorative analysis of major components and isotopes. SDM Site Forsmark. SKB R-08-84, Svensk Kärnbränslehantering AB.

Appendix 1

Site investigation SFR

Microorganisms in groundwater from borehole KFR105 – numbers, viability, and metabolic diversity

Results from two sections 120–137 m and 265–306 m in KFR105

Karsten Pedersen
Microbial Analytics Sweden AB

January 2010

A1.1 Introduction

This document reports the performance and results of microbe investigations in borehole KFR105 as part of the site investigation programme in SFR Forsmark. Microbiological data from the following borehole sections are presented:

- KFR105 120–137 m, the sampling date was 2009-08-11.
- KFR105 265–306 m, the sampling date was 2009-08-11.

The sampling was carried out as a part of the complete chemical characterization in KFR105, according to the activity plan AP SFR-09-022 (SKB internal control document; see Table A1-1). The sampling process and the borehole sampling equipment are described elsewhere (SKB MD 425.001). Subsequent laboratory work was performed over the 12 weeks after the sample had reached the laboratory.

Original data from the reported activity are stored in the primary database Sicada. Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

A1.2 Objective and scope

A1.2.1 Objectives

The microbial communities occurring in granitic rock from the surface to a depth of at most 1,700 m have been studied for two decades /1/. It has been found that the total numbers of microbial cells in granitic groundwater range from 10^6 mL^{-1} in shallow waters to 10^4 mL^{-1} at greater depths, down to approximately 1,000 m. These results have been used to formulate a conceptual model of microbiologically catalysed biogeochemical reactions in granitic groundwater in the Fennoscandian shield. Finnish investigations of shallow groundwater in Olkiluoto showed large numbers of all types of organisms

Table A1-1. Control documents for performance of the activity.

Activity plan	Number	Version
Fullständig kemikaraktärisering i KFR105	AP SFR-09-022	1.0
Metodbeskrivning för hydrogeokemisk provtagning i borrhål med fasta manschettinstallationer	SKB MD 425.001	1.0

in the upper 20 m, but deeper, the microbial diversity and biomass had a "deep" characteristics. The investigated borehole KFR105 is below 20 m and is, therefore, expected to have deep microbial characteristics.

- The first objective here was to enumerate all physiological groups of microorganisms that, through their growth and metabolising activities, may influence groundwater geochemistry.
- The second objective of this investigation was to quantify microbial biomass in groundwater from the analysed boreholes.
- The third objective was to enumerate different phylogenetic groups of microorganisms by extraction of their DNA and real time quantitative polymerase chain reaction methodology.

A1.2.2 Scope

The microbiological analysis programme reported here was carried out according to protocols developed in previous investigations of Forsmark and Laxemar groundwater /2/. These protocols cover the determination of the total number of cells in groundwater (TNC), number of cultivable, heterotrophic aerobic bacteria (CHAB), concentration of adenosine-tri-phosphate (ATP), and a statistical cultivation method for estimating the most probable number (MPN) of cultivable metabolic groups of microorganisms. They were nitrate, manganese, iron, and sulphate reducing bacteria, autotrophic and heterotrophic acetogens, and autotrophic and heterotrophic methanogens. In addition, new nucleic acid methods, developed and tested on deep groundwater samples from Finland, Japan, Belgium and Sweden during 2008–2009 were applied that analyse for phylogenetic groups of microorganisms. The use of these nucleic acid methods are still awaiting publication; it is demonstrated that they reflect biodiversity and biomass in an excellent way.

A1.3 Equipment and methods

A1.3.1 Cultivation of microorganisms and biomass determination

Sampling the KFR105 groundwater

The sampled borehole sections stood open before and during sampling. The sampling vessels were as follows: sealable, sterilized anaerobic glass tubes (no. 2048-00150; Bellco Glass), sealed with butyl rubber stoppers (no. 2048-117800; Bellco Glass) and sealed with aluminium crimp seals (no. 2048-11020, Bellco Glass), were filled with approximately 10 mL of sampled groundwater for analysis of the most probable number (MPN) of cultivable microorganisms. At each sampling point, two sterile, 15-mL polypropylene tubes (Sarstedt, Landskrona, Sweden) were filled with groundwater. One sample was subsequently analysed for the total number of cells (TNC) and ATP.

Equipment for most probable number determination

Preparing anaerobic media required an anaerobic box and a gas bench for mixing and delivering gas mixtures and gases for growth, as described in detail elsewhere /2/. Typically, preparing one sample for delivery require the equivalent of approximately two weeks of full-time laboratory work. Diluting and inoculating samples for the analysis of metabolic groups follow a well-defined procedure, depicted in Figure A1-1. One set of 30–45 tubes was used for each analysis, and incubation was done at approximately 17°C. Finally, each tube was analysed for the consumption of the electron donor or the presence of metabolic products typical of the following cultivated metabolic groups: nitrate reducing bacteria (NRB) – consumption of nitrate, manganese reducing bacteria (MRB) – manganese(II), iron reducing bacteria (IRB) – ferrous iron, sulphate reducing bacteria (SRB) – sulphide, autotrophic and heterotrophic acetogens AA, HA) – acetate, and autotrophic and heterotrophic methanogens (AM, HM) – methane.

Method for total number enumeration

The total number of cells (TNC) was determined using an acridine orange direct count procedure. All solutions used were filtered through sterilised 32 mm diameter, 0.2 µm pore size Filtropur S syringe filters (Sartorius, GTF, Göteborg, Sweden). Prior to filtration, stainless steel analytical filter holders, 13 mm (no. XX3001240; Millipore, Solna, Sweden), were rinsed with sterile filtered, analytical grade water (AGW) (Millipore Elix 3, Millipore, Solna, Sweden). Samples of 1 mL were suction

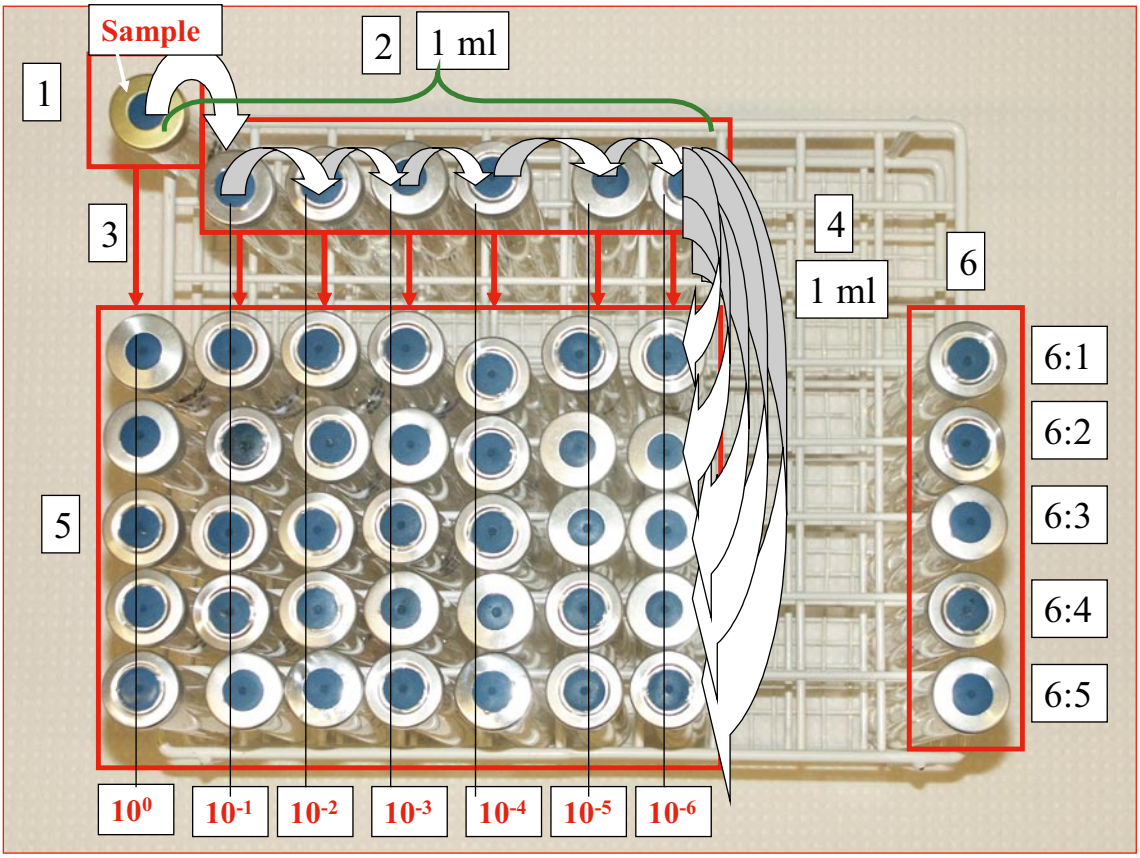


Figure A1-1. *The procedure for most probable number determination. The tube containing the sample is used as the inoculation source (1). Serial dilution is performed first (2); thereafter, subsamples are transferred (3–4) to the growth tubes (5) and control tubes (6).*

filtered (−20 kPa) onto 0.22 µm pore size Sudan black-stained polycarbonate isopore filters, 13 mm in diameter (Millipore, Solna, Sweden). The filtered cells were stained for 5 minutes with 200 µL of an acridine orange (AO) solution (SigmaAldrich, Stockholm, Sweden). The AO solution was prepared by dissolving 10 mg of AO in 100 mL of a 6.6 mM sodium potassium phosphate buffer (pH 6.7). The filters were mounted between microscope slides and cover slips using fluorescence free immersion oil (Olympus). The number of cells was counted under blue light (390–490 nm), using a band-pass filter for orange light (530 nm), in an epifluorescence microscope (Nikon DIPHOT 300, Tekno-Optik, Göteborg, Sweden). Between 400 and 600 cells, or a minimum of 30 microscopic fields (1 field = 0.01 mm^2), were counted on each filter.

Method for cultivation of aerobic, heterotrophic bacteria

Petri dishes containing agar with nutrients were prepared for determining the CHAB. This agar contained 0.5 g L^{-1} of pepton (Merck, VWR, Stockholm, Sweden), 0.5 g L^{-1} of yeast extract (Merck), 0.25 g L^{-1} of sodium acetate, 0.25 g L^{-1} of soluble starch (Merck), 0.1 g L^{-1} of K_2HPO_4, 0.2 g L^{-1} of $CaCl_2$ (Merck), 10 g L^{-1} of NaCl (Merck), 1 mL L^{-1} of trace element solution /3/, and 15 g L^{-1} of agar (Merck). The medium was sterilised in 1-L batches by autoclaving at 121°C for 20 minutes; after this they were cooled to approximately 60°C in a water bath, and finally distributed in 20-mL portions in 9-cm-diameter plastic Petri dishes (GTF, Göteborg, Sweden). Ten times dilution series of culture samples were made in AGW with 0.9 g L^{-1} of NaCl; 0.1 mL portions of each dilution were spread with a sterile glass rod on the plates in triplicate. The plates were incubated for between 5 hours and 7 days at 20°C, after which the number of colony forming units (CFU) was counted. Plates with between 10 and 300 colonies were counted.

Method for ATP determination

The ATP Biomass Kit HS (no. 266-311; BioThema AB, Handen, Sweden) was used to determine total ATP in living cells. Sterile, PCR Clean epTIPS with filters (Eppendorf, GTF, Göteborg, Sweden) were used in transferring all solutions and samples to prevent ATP contamination of pipettes and solutions. Light may cause the delayed fluorescence of materials and solutions, so all procedures described below were performed in a dark room and all plastic materials, solutions and pipettes were stored in the dark. A new 4.0-mL, 12-mm diameter polypropylene tube (no. 68.752; Sarstedt AB, Landskrona, Sweden) was filled with 400 µL of the ATP kit reagent HS (BioThema, Handen, Sweden) and inserted into an FB12 tube luminometer (Sirius Berthold, Pforzheim, Germany). The quick measurement FB12/Sirius software, version 1.4 (Berthold Detection Systems, Pforzheim, Germany) was used to calculate light emission as relative light units per second (RLU s^{-1}). Light emission was measured for three 5-seconds intervals with a 5-seconds delay before each interval, and the average of the three readings was registered as a measurement. The background light emission (I_{bkg}) from the HS reactant and the tube was monitored and allowed to decrease to below 50 RLU s^{-1} prior to registration of a measurement. ATP was extracted from 100 µL aliquots of sample within 1 hour of collection by mixing for 5 seconds with 100 µL of B/S extractant from the ATP kit in a separate 4.0 mL polypropylene tube. Immediately after mixing, 100 µL of the obtained ATP extract mixture was added to the HS reactant tube in the FB12 tube luminometer, and the sample light emission (I_{smp}) was measured. Subsequently, a volume of 10 µL of an internal ATP standard was added to the reactant tube, and the standard light emission (I_{std}) was measured. The concentration of the ATP standard was 10^{-7} M; samples with ATP concentrations close to or higher than that of the ATP standard were diluted with B/S extractant to a concentration of approximately 1/10 that of the ATP standard. Mixtures of HS reactant and B/S extractant were measured at regular intervals to control for possible ATP contamination. Values of 1,600 ± 500 amol ATP mL^{-1} (n = 10) were obtained using clean solutions, while solutions displaying values above 1,600 amol ATP mL^{-1} were disposed off. The ATP concentration of the analysed samples was calculated as follows:

$$\text{amol ATP mL}^{-1} = (I_{smp} - I_{bkg}) / ((I_{smp+std} - I_{bkg}) - (I_{smp} - I_{bkg})) \times 10^6 / \text{sample volume} \quad (1)$$

where I represents the light intensity measured as relative light units, s^{-1}, smp represents sample, bkg represents the background value of the HS reagent, and std represents the standard (all referring to a 10^{-7} M ATP standard). The ATP measurements were performed nine times each for the samples from the different depths; the mean reading for the nine samples was calculated and reported along with the standard deviation (SD).

Method for most probable number analysis

Media for the MPN determination of microorganisms in groundwater were formulated based on chemical data from the site. This allowed, for optimal microbial cultivation, the creation of artificial media /3/ with that very closely resembled *in situ* groundwater in terms of chemistry. Media for the metabolic groups of NRB, IRB, MRB, SRB, AA, HA, AM, HM were prepared anaerobically in 27 mL anaerobic tubes (no. 2048-00150; Bellco Glass Inc., Vineland, NJ, USA) fitted with butyl rubber stoppers and sealed with aluminium crimps (nos. 2048-117800 and 2048-11020, respectively; Bellco Glass Inc.), as described elsewhere /2/. All culture tubes were flushed with 80/20% N_2/CO_2 gas and then filled with 9 mL of their respective media. Inoculations for NRB, IRB, MRB, SRB, AA, HA, AM and HM were performed in the laboratory within 6 hours of sample collection from all boreholes. After inoculation, the headspace of only the AA and AM tubes was supplied with H_2 to an overpressure of 2 bars. All MPN tubes were incubated in the dark at 17°C for 8−13 weeks. Confirmation of growth in the MPN tubes after incubation was done by detecting either metabolic products or electron acceptor consumption. The MPN method produced results according to a scheme with tubes that score positive or negative for growth when analysed as described below. Combinations of three dilutions (15 tubes) were used to calculate the most probable numbers of all microbial groups, as described elsewhere /2/.

Nitrate consumed by nitrate reducing bacteria

A chromotropic method (0.2–30 mg L^{-1} NO_3^- – N) was used, according to HACH DR/2500, method 10,020 for water and wastewater.

Ferrous iron from iron reducing bacteria

A phenanthroline method (0.02–3 mg L^{-1} Fe^{2+}) was used, according to HACH DR/2500, method 8,146 for water, wastewater and seawater.

Manganese(II) from manganese reducing bacteria

A periodate oxidation method (0.2–20 mg L^{-1} Mn^{2+}) was used, according to HACH DR/2500, method 8,034 for soluble manganese in water and wastewater.

Sulphide from sulphate reducing bacteria

Sulphide was measured as copper sulphide, using a spectrophotometer, and compared with a standard curve /3/. The main reagent comprised 1.25 g of $CuSO_4 \cdot 5H_2O$ and 4.14 mL of concentrated HCl dissolved in (AGW) to 1,000 mL. The detection limit was 0.01 mg L^{-1}.

Acetate from acetogens

A model 10-148-261-035 kit (Boehringer Mannheim/R-Biopharm Enzyme BioAnalyis, Food diagnosticsm Göteborg, Sweden) and UV methods were used for the determination of acetate; the detection limit of this method was approximately 0.15 mg L^{-1}.

Methane from methanogens

A Varian 3,400 gas chromatograph (Varian, Palo Alto, CA, USA) with a 2 m stainless steel HayeSep A column (VICI AG, Schenkon, Switzerland) attached to a flame ionisation detector (FID) was used to determine the methane produced by methanogens; the detection limit was 0.2 ppm.

Tests for stability and reproducibility of the methods

The methods used for MPN determination have been under development and subject to testing since 1997 /4, 5/. Quality control procedures have continuously been applied to the analyses of MPN, and also to the investigations reported here. The decontamination procedures and the reproducibility of the analysis methods used here have previously been tested, and detailed results have been presented /2/. The main conclusions regarding the stability and reproducibility of the methods are given below.

Reproducibility of the analytical procedures

The reproducibility of the analytical procedures has been extensively tested, and the main finding was that the methods are extremely reproducible from sample to sample /2/. Repeating the sampling and analytical procedures for a specific borehole level gave two datasets that were very nearly identical, and the MPN analyses never differed from one tube to another. Reproducibility over time was demonstrated to be good as well. Two boreholes were each analysed twice at approximately a 3.5-month interval; the two boreholes displayed very different signatures, but the results were reproduced very well within each borehole.

In conclusion, the analytical procedures reported here are reliable, reproducible, and distinguish between different boreholes and borehole sections. The obtained results can be regarded as providing borehole and section specific signatures that give the required information as to what microbial processes were dominant at the time of sampling.

A1.3.2 Nucleic acid analysis

Sampling

At each sampling point, two sterile, 15-mL polypropylene tubes (Sarstedt, Landskrona, Sweden) were filled with 10 mL groundwater. The sample was mixed with 20 mL of RNA Later solution (no. AM7021; Ambion, Stockholm, Sweden) in a 50 mL sterile plastic 50 ml tubes. The samples were stored and transported at +4 º C to the laboratory for analysis.

DNA extraction

Each sample/RNA Later mix was centrifuged at 8,000 rpm (5,800 g), for 15 min in a Heraus Multifuge 3SRplus centrifuge (Thermo Fischer Scientific, Waltham, MA, USA). The supernatant was discarded, and the DNA was extracted from the pellet using the DNeasy Blood&Tissue DNA extraction kit (no. 69504; QIAGEN, Solna, Sweden) according to the manufacturer's protocol for Gram positive bacteria. The DNA extraction was stored at –20°C.

Real-time quantitative PCR

Each sample was analysed using real-time quantitative PCR to estimate the total biomass of *Bacteria, Archaea* and *Eukarya* (using 16/18S rRNA genes) and the numbers of SRB using adenosine-5'-phosphosulphate reductase alpha subunit *(apsA)* gene, acetogens using the formyltetrahydrofolate synthetase *(fthfs)* gene, nitrate reducing bacteria using the nitrate reductase (NarG1/2) genes, siderophore producing bacteria using the pyoverdin synthethase gene *(psvA)*, Anaerobic methane oxidizing bacteria using the ANME-1/2a/2b genes, and methanotrophs and methylotrophs using the methanol dehydrogenase gene *(mxaF)* and particulate methane monooxygenase subunit A *(pmoA)*.

DNA was serially diluted six times in ¼ increments, 16 ng per reaction being the most concentrated standard sample. The Q-PCR reactions were run in duplicate. The PCR mixture contained 1.0 µL of the primer (10 pmol μl^{-1}), 16 ng of DNA, 12.5 µL Stratagene Brilliant SYBR II Q-PCR Mastermix 2X (AH Diagnostics AB, Skärholmen, Sweden) and sterile water to a final reaction volume of 25 µL. Amplification was carried out on a Stratagene Mx35005P Q-PCR thermal cycler (AH Diagnostics AB). The primers were temperature optimized and the products with the standard samples were checked on agarose gels to verify the size of the fragments. The dissociation curves (melting curves) were also checked to evaluate the specificity of the primers. *Desulfovibrio aespoeensis* was used as standard for all functional genes except for *Pseudomonas fluorescence* that was used as standard for *NarG* and *psvA* and *Methanobacterium subterreaneum* for *mxaF*. *Desulfovibrio aespoeensis, Methanobacterium subterreaneum* and *Saccharomyces cerevisiae* were used as standards for of *Bacteria* 16S rRNA gene, *Archaea* 16S rRNA gene and *Eukarya* 18S rRNA gene, respectively.

A1.4 Performance

The microbial characterisations were performed according to the methods described in Chapter 3 (with references).

A1.4.1 Sample transport

Samples were rapidly transported from the tunnel site where the borehole KFR105 was sampled to the mobile field laboratory at the entrance of SFR by car, reaching the laboratory within one hour of the day of sampling.

A1.4.2 Preparation of media

The media were prepared less than three weeks before each sampling date. The media incorporated a redox indicator that turned pink if the redox potential went above –40 mV (relative to an H_2 electrode). Tubes in which this happened were not used or analysed, guaranteeing anoxic cultivation conditions. Controls were used for the media and the inoculation procedure.

A1.4.3 Start of analyses

All cultivation and ATP analyses started on the day of sampling. ATP was measured on the sample day in the field laboratory and the results were obtained directly. The samples for determination of the total number of cells were preserved and counted in the following weeks. The CHAB analysis started on the sample day in the field laboratory, and the plates were counted after approximately 5−7 days. The MPN analyses were inoculated according to specific instructions and cultivated for up to 12 weeks. The DNA analyses started in the laboratory of Microbial Analytics AB in Mölnlycke in the following weeks.

A1.4.4 End of analyses

After the specific growth periods required for them, various analyses were started to measure the number of positive and negative MPN tubes in terms of growth. To be regarded as positive, the value of a reading had to be at least twice that of a sterile filtered control, a control with medium only, or adjacent, negative MPN tubes /2/. DNA analyses were executed during September and October 2009.

A1.5 Data handling

A1.5.1 Analyses and interpretation

The total numbers of microorganisms were counted on one filtration filters from three sample tubes. Each filter was regarded as one independent observation. The mean of three filters from three tubes was calculated and reported, along with the standard deviation (SD) and number of observations (n).

Petri dishes containing agar with nutrients were prepared for determining the number of CHAB. The plates were incubated for between 5 and 7 days at 20°C, after which the number of colony forming units (CFU) was counted. Plates with between 10 and 300 colonies were counted and the average was reported, along with the standard deviation (SD) and number of observations (n).

The ATP Biomass Kit HS (no. 266-311; BioThema AB, Handen, Sweden) was used to determine total ATP in living cells. The ATP measurements were performed three times for each sample from the different depths; the mean of the nine samples was calculated and reported, along with the standard deviation (SD).

The MPN method produced results according to a scheme in which tubes scored positive or negative for growth when analysed. Combinations of three dilutions (15 tubes) were used to calculate the most probable number for each microbial group, as described elsewhere /2/.

Two independent samples were analysed with Q-PCR and the average numbers are given in the results. The output from the Q-PCR was recalculated to show numbers equivalent to copies of the used standard microorganisms.

A1.6 Results

The detailed results are given in the Appendix.

A1.6.1 Total number of microorganisms and ATP concentration

The AODC indicated the TNC in the sample (Table A1-2). The number found in the sample from KFR105 was low in comparison to other analysed groundwater from the site investigation area of Forsmark /6, 7 /. The ATP concentration correlated well with the TNC and was also the lowest obtained value of the samples analysed from the Forsmark area.

The TNC number, by definition includes active, inactive, and sometimes even dead cells. An inactive microbe can still appear in the TNC analysis, even if it has been inactive for a long time. Because of the uncertainty of the TNC count and to obtain an indication of the activity and viability of the detected microbes, the measurement of ATP was applied. The measurement of ATP reflects the living bio volume because all living cells contain a relatively constant concentration of ATP. A detailed analysis of the relationship between the TNC and ATP of microbes has previously been performed /8/. Pure culture experiments have demonstrated that cell volume is nested in metabolic activity, which is reflected by the amount of ATP cell^{-1}. A high amount of ATP cell^{-1} should indicate high activity and large cells. Inspection of the ratio of ATP to TNC in over 100 samples from deep groundwater, plotted versus TNC, revealed that there was a large range of values, for the total dataset, distributed over the averages. The results strongly suggest that ATP/TNC ratios indicate the metabolic state and viability of a groundwater population. The average of all ATP/TNC ratios in deep groundwater was determined to be 0.43 /8/. An ATP/TNC ratio above this average indicates populations that were more active than were those with ratios below the average. The groundwater sample from KFR105 265–306 m had an ATP/TNC ratio (Figure A1-3) which was above the average found in Fennoscandian groundwater while KFR105 120–137 m was much lower. This suggests more active microbial populations in the inner analysed section. However, all numbers were close to the detection limit, which introduces a significant uncertainty here, small

variations will have a large influence on all ratios in Figure A1-3). The percent of TNC cultured with MPN again suggests that the microbial populations analysed KFR105 265–306 m were more active than in KFR105 120–137 m groundwater. The percentage of TNC cultivated with CHAB was also highest in KFR105 265–306 m. It seems as if the microbial population in KFR105 was a bit more diversified and active than in KFR105 120–137 m as judged from the cultivation data. However, as all cultivable numbers (TNC, CHAB) and biomass (ATP) and nucleic acids (Figure A1-4) were very low, close to the detection limits, conclusions based on the quotients are dubious in this case. The numbers suggest that the analysed groundwaters were almost totally devoid of microbial activity, and the MPN analyses support this conclusion. It may be that most of the microorganisms in these groundwater systems were attached as biofilms. New data from analysis of drill core fracture surfaces in the Äspö hard rock laboratory tunnel show that biofilms develop on fracture surfaces with flowing groundwater (Jägevall and Pedersen, manuscript in preparation).

A1.6.2 Numbers of cultivable microorganisms

The CHAB determination was lower than found in any sample /6, 7/ previously in groundwater from the Forsmark site investigations (Figure A1-2). The analysis of CHAB was done under aerobic conditions in opposite to all other cultivation methods that were performed under anaerobic conditions. Many bacteria are known to be facultative anaerobes. These can switch from an aerobic respiration with oxygen to anaerobic respiration with nitrate and commonly also with ferric iron and manganese(IV) as alternative electron acceptors. Microorganisms in groundwater must be adapted to anoxic conditions, but if oxygen appear for some reason, it is advantageous for the microbe to switch to oxygen respiration. Indigenous groundwater microorganisms should consequently be detectable both as CHAB and NRB, while contaminants from the surface should have a smaller tendency to do so. Very low CHAB and NRB numbers found here, suggest that there was no drill water contamination.

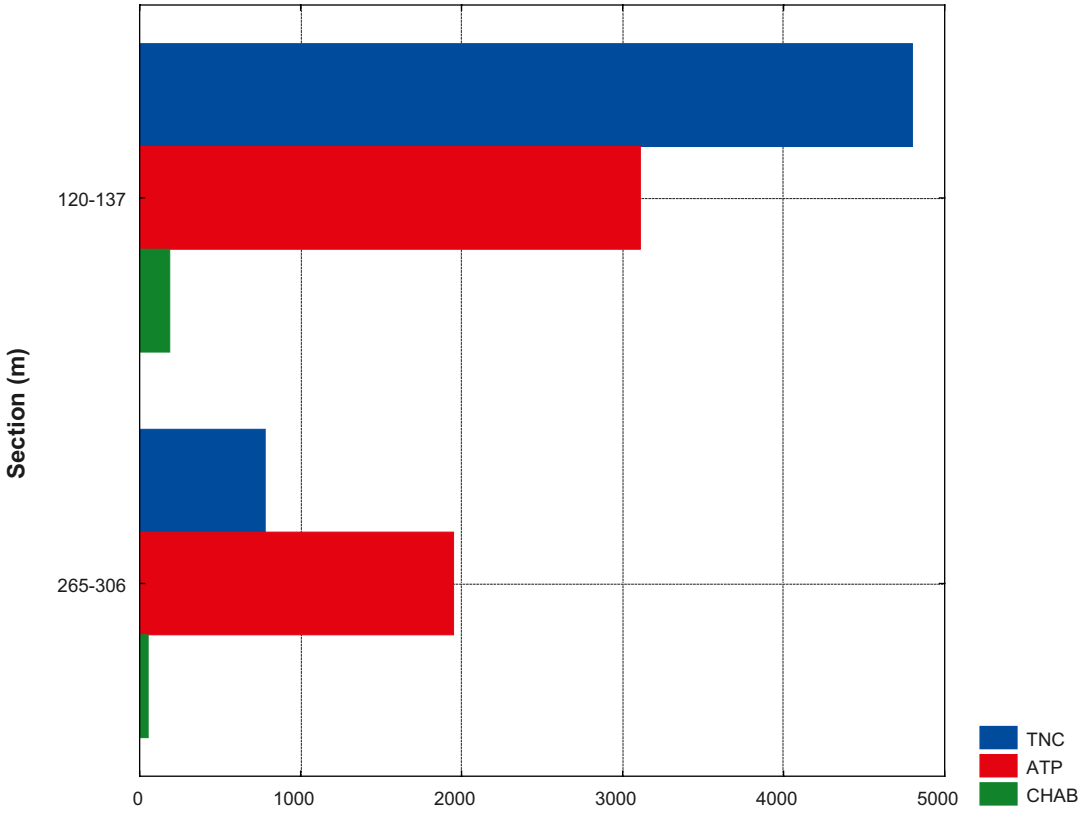


Figure A1-2. *The numbers of cultivable heterotrophic, aerobic bacteria (CHAB, cells mL^{-1}), the ATP concentrations (amol mL^{-1}) and the total numbers of cells (TNC, cells mL^{-1}) in the analysed groundwater samples from boreholes KFR105 (Tables A1-2 and A1-3).*

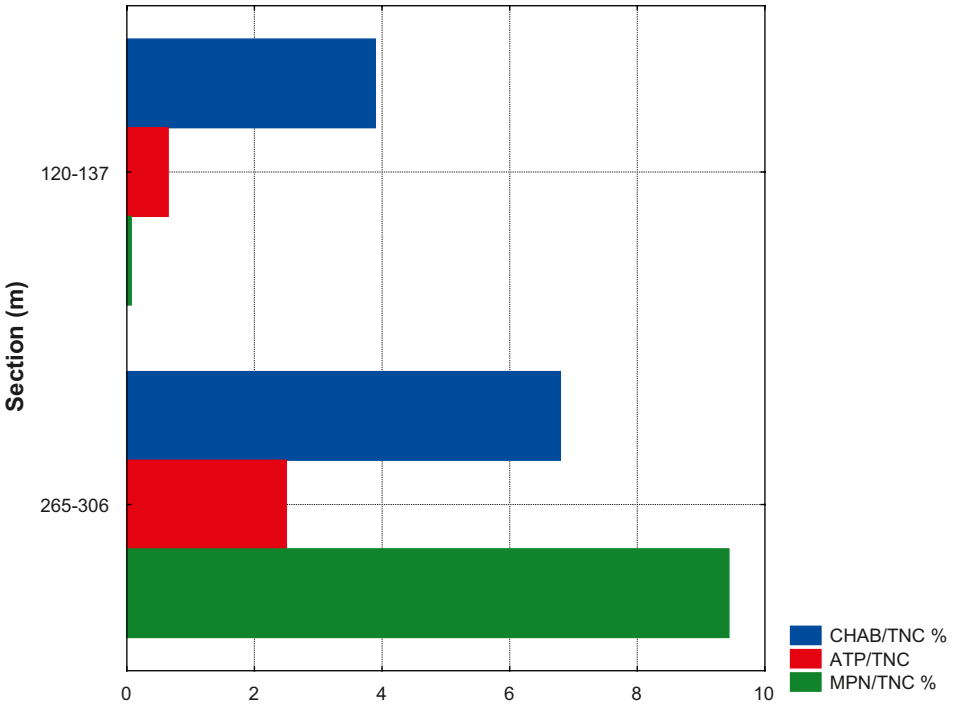


Figure A1-3. *A compilation of the ratios of ATP to the total number of cells (TNC) (amol cell^{-1}) and the percentages of the TNC that could be cultured using the most probable number (MPN) and the cultivable heterotrophic aerobic bacteria (CHAB) methods (Table A1-4).*

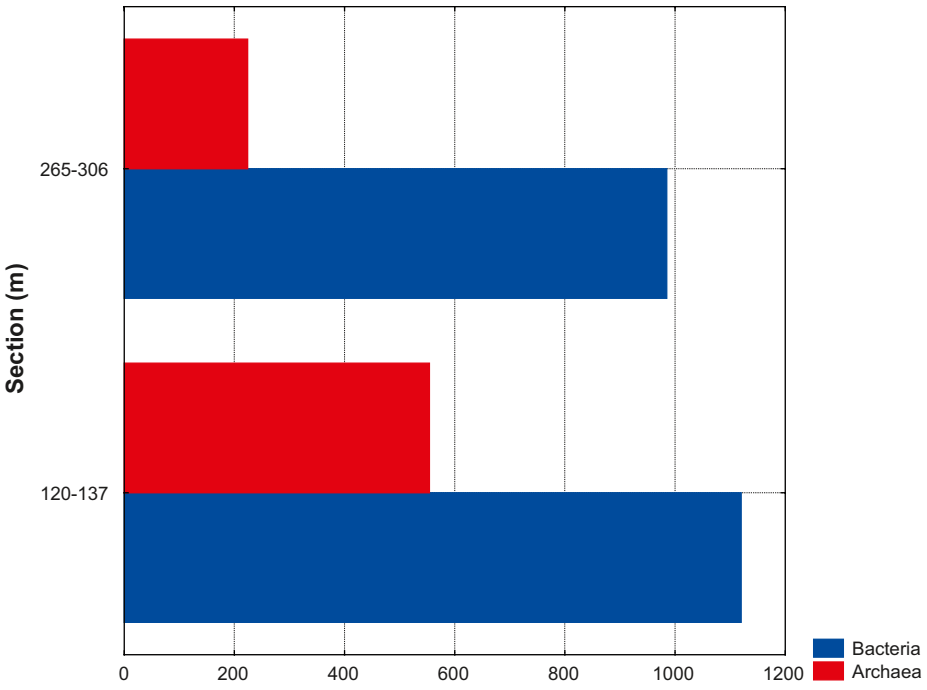


Figure A1-4. *The numbers of Bacteria and Archaea (copies mL^{-1}) in the groundwater samples from boreholes KFR105 analysed with Q-PCR (Tables A1-5 and A1-6).*

Each MPN analysis (Figure A1-5) with positive results is briefly commented on below. Detailed examination and modelling of the relationships between the MPN data and depth, hydrology, geology, and geochemistry will be performed as part of the site descriptive modelling.

Nitrate reducing bacteria

Next to oxygen, nitrate is the most favourable electron acceptor for bacteria. Facultative anaerobic bacteria can generally switch from oxygen to nitrogen when oxygen disappears. NRB can thus survive in deep anaerobic groundwater. There were very few NRA in the outer section of KFR105, and somewhat more in the inner section, but both numbers were very low compared to what has been observed elsewhere in the area /6, 7/.

Iron and manganese reducing bacteria

Iron and manganese reducing bacteria have generally been observed in larger numbers at shallower than at deeper depths, at which SRB tend to increase in number. The data obtained from Forsmark generally indicate low numbers of IRB and MRB /6, 7/. Groundwater from KFR105, together with the previously analysed borehole showed among the lowest values found in the Forsmark site investigations of IRB, and MRB was below detection in both samples.

Sulphate reducing bacteria

The number of SRB in KFR105 was below detection.

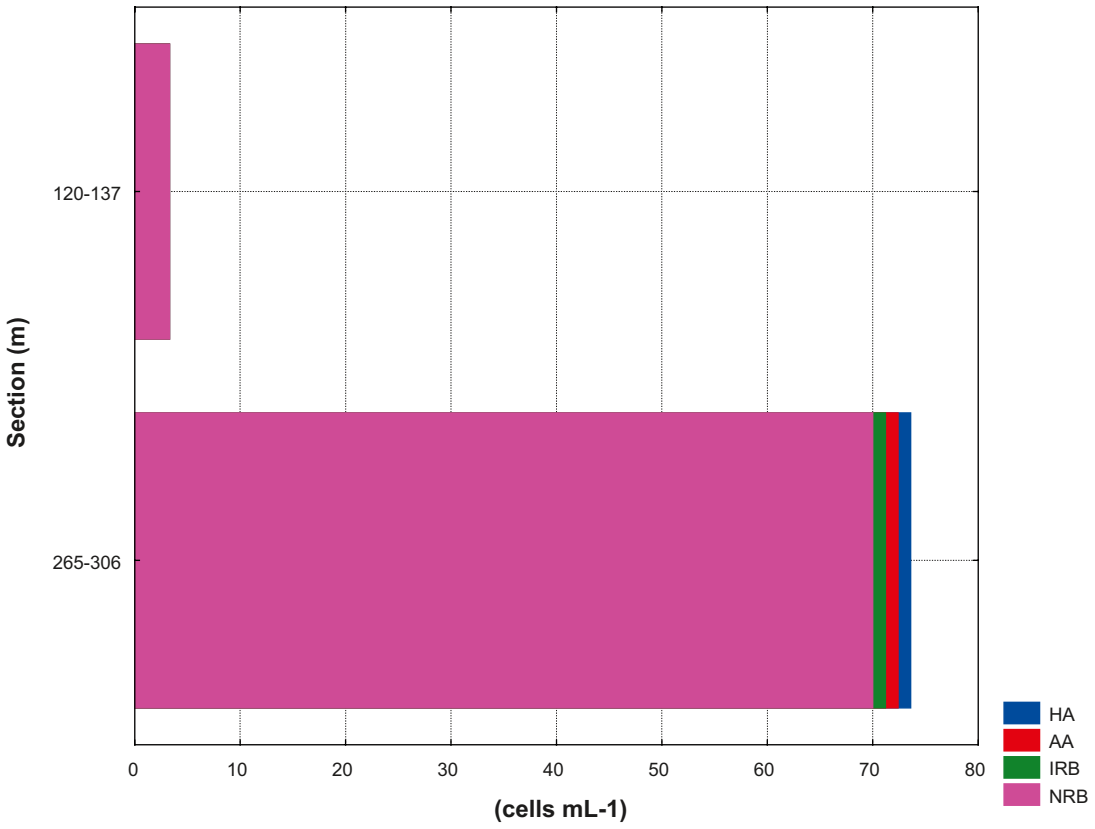


Figure A1-5. *Sum of most probable numbers (MPN) of identified physiological groups in groundwater samples from KFR105. Abbreviations: HA (heterotrophic acetogens, AA (autotrophic acetogens), IRB (iron-reducing bacteria), NRB (nitrate-reducing bacteria).*

Acetogens

Acetogens produce acetate from one carbon organic compounds or from hydrogen and carbon dioxide. They were detected in groundwater from all boreholes and sections, with just a few exceptions, during the site investigations in Forsmark /6, 7/ and also in Oskarshamn site investigations, in the Äspö Hard Rock Laboratory and in shallow and deep groundwater from Olkiluoto. It is thus a very versatile and common group present in the groundwater investigated here in numbers that were among the lowest for the microbes detected in groundwater.

Methanogens

Methanogens produce methane from small organic compounds (one carbon) and acetate or from hydrogen and carbon dioxide. They were commonly present above the detection limit during the various site investigations. Heterotrophic methanogens have been found in relatively high numbers in Forsmark, while autotrophic methanogens have been more sparsely observed /6, 7/. This finding was not upheld in the samples investigated here where both the AM and the HM analyse returned on the detection limit data (0.2 cells mL^{-1}) (Table A1-7, A1-8).

As all numbers (TNC, ATP, CHAB, MPN, Nucleic acids) were very low, close to the detection limits, conclusions based on the results about presence and activity are difficult to make in this case. The numbers suggest that the analysed borehole was almost totally devoid of microbes and microbial activity, and the MPN and nuleic acids analyses support this conclusion. The results then reflect a very unusual groundwater situation with respect to microbiology that has not previously been found during the site investigations. Alternatively, there was some kind of disturbance of the sampling procedure that reduced the numbers of microorganisms significantly. It is, based on the results presented here, not possible to judge which of these two suggested cases is the correct assumption.

A1.7 Conclusions

- As all numbers (TNC, ATP, CHAB, MPN, Nucleic acids) were very low, close to the detection limits, conclusions based on the results about presence and activity are difficult to make in this case. The numbers suggest that the analysed borehole was almost totally devoid of microbes and microbial activity, and the MPN analyses support this conclusion. The results then reflect a very unusual groundwater that has not been found previously during the site investigations in Forsmark and Laxemark (PLU). Alternatively, there was some kind of disturbance of the sampling procedure that reduced the numbers of microorganisms significantly.
- It may be possible that most of the microorganisms in these groundwater systems were attached as biofilms. New data from analysis of drill core fracture surfaces in the Äspö hard rock laboratory tunnel show that biofilms develop on fracture surfaces with flowing groundwater; then, they do not show up in groundwater. New analytical procedures are now at hand to analyse the biology of fracture surfaces directly upon drilling.

A1.8 References

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

/1/ **Pedersen K, 2001.** Diversity and activity of microorganisms in deep igneous rock aquifers of the Fennoscandian Shield. In: Subsurface microbiology and biogeochemistry. Edited by Fredrickson JK, Fletcher M. Wiley-Liss, New York. pp 97–139.

/2/ **Hallbeck L, Pedersen K, 2008.** Characterization of microbial processes in deep aquifers of the Fennoscandian Shield. Appl. Geochem. 23:1796–819.

/3/ **Widdel F, Bak F, 1992.** Gram-negative mesophilic sulfate-reducing bacteria. In: The prokaryotes, vol. 4, 2nd ed. Edited by Balows A, Trüper HG, Dworkin M, Harder W, Schleifer K-H. Springer-Verlag, New York. pp 3352–3378.

/4/ **Haveman SH, Pedersen K, Routsalainen P, 1999.** Distribution and metabolic diversity of microorganisms in deep igneous rock aquifers of Finland. Geomicrobiol J 16, 277–294.

/5/ **Haveman SA, Pedersen K, 2002.** Distribution of cultivable anaerobic microorganisms in Fennoscandian Shield groundwater. FEMS Microbiol Ecol 39, 129–137.

/6/ **Pedersen K, 2007.** Forsmark site investigation. Numbers and metabolic diversity of microorganisms in boreholes KFM01D and KFM08A. Results from section 683.5–690.6 m in KFM08A and sections 428.5−435.6 and 568.0−575.0 m in KFMA01D. SKB P-07-53, Svensk Kärnbränslehantering AB.

/7/ **Pedersen K, 2007.** Microorganisms in groundwater from boreholes KFM10A, KFM11A and KFM08D – numbers, viability, and metabolic diversity Results from five sections 298.0–305.1 m and 478.0–487.5 m in KFM10A, 447.5–454.6 m in KFM11A, and 669.7–676.8 m and 828.4–835.5 m in KFM08D. SKB P-07-198, Svensk Kärnbränslehantering AB.

/8/ **Eydal HSC, Pedersen P, 2007.** Use of an ATP assay to determine viable microbial biomass in Fennoscandian Shield groundwater from depths of 3–1,000 m. J. Microbiol Meth 70, 363–73.

A1.9 Appendix – Data

Table A1-2. Total number of cells and concentration of ATP in groundwater from the analysed sections of KFR105.

Borehole (section m)	Total counts (cells mL^{-1})			ATP (amol mL^{-1})		
	TNC	Standard deviation	Number of observations	ATP	Standard deviation	Number of observations
KFR105 (120–137 m)	4,800	1,500	3	3,110	930	9
KFR105 (265–305 m)	780	120	3	1,950	340	9

Table A1-3. Number of cultivable, heterotrophic aerobic bacteria (CHAB) in groundwater from the analysed sections of KFR105.

Borehole (section m)	CHAB	Standard deviation	Number of observations
KFR105 (120–137 m)	187	23	3
KFR105 (265–305 m)	53	6	3

Table A1-4. Ratios of the cells cultured using MPN (Tables A1-7, A1-8), CHAB (Table A1-3) and ATP (Table A1-2) versus total number of cells (TNC) (Table A1-2) in groundwater of KFR105.

Borehole (section, m)	% cultured		Ratio
	MPN/TNC	CHAB/TNC	ATP/TNC
KFR105 (120–137 m)	3.9	0.6	0.07
KFR105 (265–305 m)	6.8	2.5	9.44

Table A1-5. Number of copies mL^{-1} of phylogenetic groups of microorganisms in groundwater of KFR105, section 120–137.

Analysis	Sample 1	Sample 2	Average	Standard deviation
16S rRNA gene *Bacteria* (copies ml^{-1})	1,060	1,180	1,120	87.7
16S rRNA gene *Archaea* (copies ml^{-1})	525	583	554	40,9
18S rRNA gene *Eukarya* (copies ml^{-1})	21,700	31,500	26,600	69,400
apsA DNA (copies ml^{-1})	<100	<100	<100	–
fthfs DNA (copies ml^{-1})	<100	<100	<100	–
pmoA DNA (copies ml^{-1})	<100	<100	<100	–
narG1 DNA (copies ml^{-1})	<100	<100	<100	–
pvsA DNA (copies ml^{-1})	<100	<100	<100	–
ANME-1 DNA (copies ml^{-1})	<1,000	<1,000	<1,000	–
ANME-2a DNA (copies ml^{-1})	<1,000	<1,000	<1,000	–
ANME-2c DNA (copies ml^{-1})	<1,000	<1,000	<1,000	–
mxaF DNA (copies ml^{-1})	<100	<100	<100	–
narG2 DNA (copies ml^{-1})	<100	<100	<100	–

Table A1-6. Number of copies mL^{-1}of phylogenetic groups of microorganisms in groundwater of KFR105, section 265–306.

Analysis	Sample 1	Sample 2	Average	Standard deviation
16S rRNA gene *Bacteria* (copies ml^{-1})	1,370	600	985	545
16S rRNA gene *Archaea* (copies ml^{-1})	302	147	224	110
18S rRNA gene *Eukarya* (copies ml^{-1})	26,700	22,100	24,400	32,200
apsA DNA (copies ml^{-1})	<100	<100	<100	–
fthfs DNA (copies ml^{-1})	<100	<100	<100	–
pmoA DNA (copies ml^{-1})	<100	<100	<100	–
narG1 DNA (copies ml^{-1})	<100	<100	<100	–
pvsA DNA (copies ml^{-1})	<100	<100	<100	–
ANME-1 DNA (copies ml^{-1})	<1,000	<1,000	<1,000	–
ANME-2a DNA (copies ml^{-1})	<1,000	<1,000	<1,000	–
ANME-2c DNA (copies ml^{-1})	<1,000	<1,000	<1,000	–
mxaF DNA (copies ml^{-1})	<100	<100	<100	–
narG2 DNA (copies ml^{-1})	<100	<100	<100	–

Table A1-7. Most probable number (MPN) of cultivable metabolic groups of microorganisms in groundwater of KFR105, section 120–137.

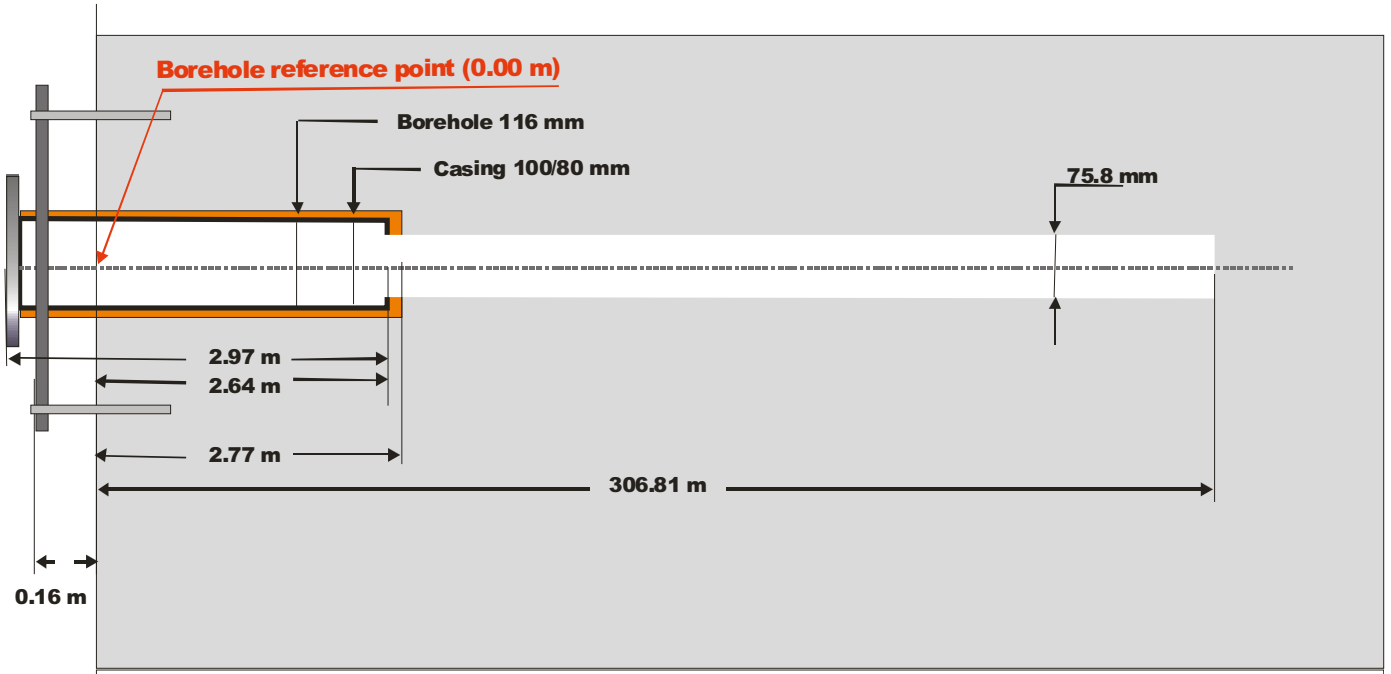
Metabolic groups	Cells mL^{-1}	
	MPN	Lower–upper 95% confidence limits
Nitrate-reducing bacteria	3.3	1.5–7.7
Iron-reducing bacteria	≤ 0.2	–
Manganese-reducing bacteria	≤ 0.2	–
Sulphate-reducing bacteria	≤ 0.2	–
Autotrophic acetogens	≤ 0.2	–
Heterotrophic acetogens	≤ 0.2	–
Autotrophic methanogens	≤ 0.2	–
Heterotrophic methanogens	≤ 0.2	–

Table A1-8. Most probable number (MPN) of cultivable metabolic groups of microorganisms in groundwater of KFR105, section 265–306.

Metabolic groups	Cells mL^{-1}	
	MPN	Lower–upper 95% confidence limits
Nitrate-reducing bacteria	70	30–210
Iron-reducing bacteria	0.2	0.1–1.1
Manganese-reducing bacteria	≤ 0.2	–
Sulphate-reducing bacteria	≤ 0,2	–
Autotrophic acetogens	0.7	0.2–2.1
Heterotrophic acetogens	0.4	0.1–1.7
Autotrophic methanogens	≤ 0.2	–
Heterotrophic methanogens	≤ 0.2	–

Design of cored borehole KFR105

Technical data
Borehole KFR105



Drilling reference point		**Core drilling period**	**Reference marks (m)**
Northing:	6701789.85 (m), RT90 2,5 gon V 0:-15	Drilling start date: 2009-04-21	50
Easting:	1633072.96 (m), RT90 2,5 gon V 0:-15	Drilling stop date: 2009-06-02	99
Elevation:	-106.82 (m), RHB 70		153
Orientation			203
Bearing (degrees):	174.48°		262
Inclination (degrees):	-10.12°		
Borehole			
Length:	306.81 m		

Rev. 2009-07-02

Appendix 3

Table A3-1. 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	Fe(II) mg/L	Mn mg/L	Li mg/L	Sr mg/L
KFR105	4.00	119.00	16371	2009-08-14	–3.16	1,200	5.78	770	97.0	90.1	3,470	247	95.8	14.1	1.09	5.45	1.42	1.53	1.53	0.561	0.0567	12.1
KFR105	4.00	119.00	16372	2009-08-17	–4.88	1,330	6.43	765	119	93.8	3,820	319	123	14.3	1.07	6.31	0.816	0.836	0.840	0.554	0.0581	11.5
KFR105	4.00	119.00	16373	2009-08-19	–3.14	1,320	6.23	812	114	92.6	3,740	308	120	14.6	1.13	6.00	0.735	0.768	0.759	0.534	0.0573	10.5
KFR105	4.00	119.00	16374	2009-08-21	–1.89	1,300	6.30	817	114	92.6	3,620	300	118	17.6	1.12	6.09	0.719	0.748	0.738	0.536	0.0576	11.0
KFR105	120.00	134.00	16361	2009-07-28	–1.71	1,500	7.85	544	117	124	3,370	369	139	13.3	1.26	6.84	0.647	0.639	0.583	0.843	0.0505	7.20
KFR105	120.00	134.00	16362	2009-07-31	–3.46	1,480	7.97	520	115	126	3,420	373	138	13.6	1.24	6.87	0.725	0.731	0.714	0.810	0.0484	7.22
KFR105	120.00	134.00	16363	2009-08-03	–2.76	1,440	7.85	524	116	126	3,310	370	139	13.8	1.28	6.88	0.797	0.871	0.865	0.786	0.0485	7.23
KFR105	120.00	134.00	16364	2009-08-07	–3.63	1,360	7.88	537	115	126	3,260	366	142	12.6	1.26	6.95	0.841	0.873	0.872	0.793	0.0512	6.79
KFR105	120.00	134.00	16366	2009-08-11	–3.98	1,340	7.73	553	116	126	3,280	380	143	11.1	1.70	6.97	0.843	–	–	0.796	0.0504	6.71
KFR105	138.00	169.00	16367	2009-08-14	–3.34	1,410	6.88	635	115	114	3,520	365	138	13.8	1.18	6.41	0.719	0.738	0.734	0.704	0.0552	8.55
KFR105	138.00	169.00	16368	2009-08-17	–4.45	1,360	6.59	673	117	105	3,620	357	133	14.2	1.19	6.52	0.655	0.664	0.677	0.683	0.0586	9.25
KFR105	138.00	169.00	16369	2009-08-19	–2.99	1,340	6.45	707	118	107	3,530	345	136	16.1	1.16	6.26	0.645	0.534	0.669	0.669	0.0555	8.84
KFR105	138.00	169.00	16370	2009-08-21	–1.41	1,390	7.46	714	121	107	3,520	356	132	14.8	1.16	6.17	0.662	0.664	0.657	0.718	0.0531	8.83
KFR105	170.00	264.00	16357	2009-07-27	–3.29	1,490	7.57	459	109	130	3,280	365	141	12.4	1.33	6.45	0.819	0.876	0.881	0.930	0.0486	6.02
KFR105	170.00	264.00	16358	2009-07-31	–4.62	1,420	7.12	502	112	124	3,360	366	140	12.5	1.31	6.64	0.826	0.843	0.840	0.866	0.0494	6.94
KFR105	170.00	264.00	16359	2009-08-03	–2.22	1,430	7.41	515	114	124	3,230	364	140	13.6	1.32	6.64	0.815	0.867	0.861	0.866	0.0521	7.18
KFR105	170.00	264.00	16360	2009-08-07	–3.69	1,410	7.22	523	113	123	3,320	364	139	12.0	1.30	6.48	0.827	0.857	0.845	0.854	0.0531	6.74
KFR105	265.00	306.81	16333	2009-07-14	–1.87	1,210	6.54	700	94.8	81.6	3,280	218	86.8	14.6	1.22	5.81	0.440	0.477	0.425	1.52	0.0618	11.7
KFR105	265.00	306.81	16334	2009-07-17	–2.06	1,280	6.42	700	95.8	84.6	3,400	238	89.9	14.9	1.27	5.87	0.672	0.706	0.692	1.53	0.0657	11.4
KFR105	265.00	306.81	16335	2009-07-20	–3.09	1,250	6.53	690	96.1	84.2	3,410	237	89.7	15.3	1.21	5.86	0.652	0.702	0.697	1.44	0.0639	11.7
KFR105	265.00	306.81	16336	2009-07-23	–2.63	1,230	7.17	717	104	85.1	3,430	237	84.2	15.2	1.25	5.66	0.675	0.710	0.703	1.49	0.0631	10.8
KFR105	265.00	306.81	16337	2009-07-27	–0.39	1,280	6.66	675	96.3	84.5	3,240	237	88.5	15.6	1.27	5.84	0.656	0.733	0.720	1.45	0.0649	11.9
KFR105	265.00	306.81	16365	2009-08-11	–2.76	1,170	6.21	727	96.1	83.8	3,320	238	91.6	12.1	1.23	5.98	0.690	–	–	1.45	0.0634	11.1
PFR000122	–	–	16270	2009-04-28	–0.51	1,430	34.3	354	140	125	2,910	365	144	9.92	1.08	5.55	0.019	–	–	0.078	0.0405	4.23
PFR000122	–	–	16271	2009-05-12	–1.15	1,420	33.4	356	140	128	2,940	361	143	9.67	1.05	5.49	–	–	–	–	0.0403	4.30
PFR000122	–	–	16272	2009-05-20	–1.77	1,400	32.8	365	140	127	2,960	356	146	9.64	1.06	5.57	–	–	–	–	0.0394	4.43

Table A3-1. Water composition forts.

Idcode	Secup m	Seclow m	Sample no.	I^- mg/L	pH	pH_F	Temp_F °C	DOC mg/L	TOC mg/L	HS^- mg/L	Drill water %	EC mS/m	EC_F mS/m	NH_4^-N mg/L	NO_2^-N mg/L	NO_3^-N mg/L	$NO_2^-N+NO_3^-N$ mg/L	PO_4^-P mg/L	PO_4^-P [1] mg/L	P mg/L
KFR105	4.00	119.00	16371	0.0493	7.62			1.4	1.5	0.008	0.3	1,030		0.0084	0.0002	<0.0003	0.0004	<0.0005	<0.0005	<0.005
KFR105	4.00	119.00	16372	0.0473	7.63			1.1	1.0	0.007	0.1	1,120		0.0170	<0.0002	<0.0003	<0.0003	<0.0005	<0.0005	<0.005
KFR105	4.00	119.00	16373	0.0475	7.58			1.1	1.2	0.007	0.2	1,100		0.0125	–	–	–	<0.0005	<0.0005	<0.005
KFR105	4.00	119.00	16374	0.0570	7.63			1.1	1.1	<0.006	0.1	1,090		0.0211	<0.0002	<0.0003	0.0003	<0.0005	<0.0005	<0.005
KFR105	120.00	134.00	16361	0.0395	7.49			3.8	3.6	<0.006	<0.1	1,010		0.0433	0.0009	0.0026	0.0035	<0.0005	0.0007	<0.005
KFR105	120.00	134.00	16362	0.0389	7.51			1.8	1.9	0.008	<0.1	1,010		0.0624	0.0006	<0.0003	0.0006	<0.0005	<0.0005	<0.005
KFR105	120.00	134.00	16363	0.0377	7.53			1.7	1.8	<0.006	<0.1	1,010		0.0670	–	–	0.0015	<0.0005	0.0005	–
KFR105	120.00	134.00	16364	0.0450	7.48	7,50	11.5	1.7	1.7	<0.01	<0.1	1,010	980	0.0685	0.0003	<0.0003	0.0004	<0.0005	0.0005	–
KFR105	120.00	134.00	16366	–	7.54			–	–	–	<0.1	997		–	–	–	–	–	–	–
KFR105	138.00	169.00	16367	0.0384	7.61			1.7	1.6	<0.006	0.1	1,060		0.0386	0.0002	<0.0003	0.0003	<0.0005	<0.0005	<0.005
KFR105	138.00	169.00	16368	0.0545	7.59			1.2	1.4	0.009	0.1	1,080		0.0286	<0.0002	<0.0003	<0.0003	<0.0005	<0.0005	<0.005
KFR105	138.00	169.00	16369	0.0449	7.57			1.4	1.4	0.008	<0.1	1,080		0.0333	–	–	–	<0.0005	<0.0005	–
KFR105	138.00	169.00	16370	0.0517	7.63			1.3	1.4	<0.006	<0.1	1,090		0.0279	<0.0002	<0.0003	<0.0003	<0.0005	<0.0005	<0.005
KFR105	170.00	264.00	16357	0.0288	7.61			2.1	2.1	<0.006	<0.1	976		0.0658	0.0002	0.0007	0.0009	<0.0005	<0.0005	<0.005
KFR105	170.00	264.00	16358	0.0315	7.56			1.6	1.7	0.007	<0.1	1,010		0.1730	0.0002	0.0021	0.0022	<0.0005	<0.0005	<0.005
KFR105	170.00	264.00	16359	0.0343	7.55			1.6	1.7	0.007	<0.1	1,010		0.0484	–	–	0.0004	<0.0005	<0.0005	–
KFR105	170.00	264.00	16360	0.0434	7.55			1.6	1.6	<0.01	<0.1	1,010		0.0491	<0.0002	0.0025	0.0026	<0.0005	<0.0005	<0.005
KFR105	265.00	306.81	16333	0.0516	7.54			3.6	3.6	0.007	<0.1	969		0.0210	0.0006	0.0106	0.0112	<0.0005	0.0007	<0.005
KFR105	265.00	306.81	16334	0.0558	7.57			<1	<1	0.006	<0.1	1,000		0.0170	0.0003	0.0033	0.0035	<0.0005	<0.0005	<0.005
KFR105	265.00	306.81	16335	0.0601	7.57			<1	<1	<0.006	<0.1	1,000		0.0173	–	–	0.0019	<0.0005	<0.0005	–
KFR105	265.00	306.81	16336	0.0513	7.56			<1	<1	<0.006	<0.1	998		0.0155	–	–	0.0025	<0.0005	<0.0005	–
KFR105	265.00	306.81	16337	0.0589	7.54	7.7	11.3	<1	<1	<0.006	<0.1	1,000	990	0.0194	<0.0002	0.0007	0.0008	<0.0005	<0.0005	<0.005
KFR105	265.00	306.81	16365	–	7.57			–	–	–	<0.1	985		–	–	–	–	–	–	–
PFR000122	–	–	16270	–	7.98			–	2.0	–	–	926		0.0100	–	–	–	–	–	0.006
PFR000122	–	–	16271	–	7.95			–	2.0	–	–	930		0.0140	–	–	–	–	–	<0.005
PFR000122	–	–	16272	–	7.96			–	1.9	–	–	935		0.0140	–	–	–	–	–	<0.005

Table A3-2. Trace elements.

Idcode	Secup m	Seclow m	Sample no.	Sampling date	U mg/L	Th mg/L	As mg/L	B mg/L	Sc mg/L	Cd mg/L	Hg mg/L	V mg/L	Rb mg/L	Y mg/L	In mg/L	Zr mg/L	Cs mg/L	Ba mg/L	La mg/L	Hf mg/L	Tl mg/L
KFR105	4.00	119.00	16371	2009-08-14	6.14	<0.2	<0.5	875	<0.4	<0.02	<0.002	0.196	11.7	1.88	<0.2	<0.1	0.314	105	0.060	<0.02	<0.05
KFR105	4.00	119.00	16372	2009-08-17	23.3	<0.2	<0.5	868	<0.4	<0.02	<0.002	0.216	12.3	4.45	<0.2	0.618	0.238	77.8	0.173	<0.02	<0.05
KFR105	4.00	119.00	16374	2009-08-21	26.9	<0.2	<0.5	870	<0.4	<0.02	<0.002	<0.03	12.0	4.84	<0.2	0.124	0.285	82.1	0.165	<0.02	<0.05
KFR105	120.00	134.00	16361	2009-07-28	38.6	<0.2	<0.5	751	<0.4	0.246	<0.002	0.049	13.9	3.42	<0.2	<0.1	0.322	41.8	0.087	<0.02	<0.05
KFR105	120.00	134.00	16362	2009-07-31	43.9	<0.2	<0.5	728	<0.4	<0.02	<0.002	0.036	13.6	7.24	<0.2	<0.1	0.323	37.2	0.224	<0.02	<0.05
KFR105	120.00	134.00	16364	2009-08-07	39.4	<0.2	<0.5	738	<0.4	<0.02	<0.002	0.074	14.8	8.61	<0.2	<0.1	0.408	35.6	0.326	<0.02	<0.05
KFR105	138.00	169.00	16367	2009-08-14	23.3	<0.2	<0.5	841	<0.4	<0.02	<0.002	0.141	13.9	3.08	<0.2	<0.1	0.352	46.6	0.0913	<0.02	<0.05
KFR105	138.00	169.00	16368	2009-08-17	28.4	<0.2	<0.5	832	<0.4	<0.02	<0.002	<0.03	14.2	6.26	<0.2	<0.1	0.365	44.7	0.290	<0.02	<0.05
KFR105	138.00	169.00	16370	2009-08-21	28.8	<0.2	<0.5	845	<0.4	<0.02	<0.002	<0.03	14.5	6.45	<0.2	0.236	0.359	45.4	0.295	<0.02	<0.05
KFR105	170.00	264.00	16357	2009-07-27	40.9	<0.2	<0.5	802	<0.4	0.151	<0.002	0.053	13.6	4.66	<0.2	<0.1	0.333	33.2	0.0865	<0.02	<0.05
KFR105	170.00	264.00	16358	2009-07-31	34.3	<0.2	<0.5	824	<0.4	<0.02	<0.002	0.066	13.4	6.09	<0.2	<0.1	0.331	38.2	0.164	<0.02	<0.05
KFR105	170.00	264.00	16360	2009-08-07	32.6	<0.2	<0.5	819	<0.4	<0.02	<0.002	0.109	14.2	6.73	<0.2	<0.1	0.389	36.7	0.201	<0.02	<0.05
KFR105	265.00	306.81	16333	2009-07-14	39.0	<0.2	<0.5	968	<0.4	<0.02	<0.002	<0.03	11.2	2.81	<0.2	<0.1	0.286	205	0.197	<0.02	<0.05
KFR105	265.00	306.81	16334	2009-07-17	32.4	<0.2	<0.5	959	<0.4	<0.02	<0.002	<0.3	11.0	4.35	<0.2	<0.1	0.295	166	0.174	<0.02	<0.05
PFR000122	–	–	16270	2009-04-28	24.9	<0.2	1.32	645	<0.4	<0.02	<0.002	0.090	18.8	0.312	<0.2	<0.1	0.492	40.1	<0.02	<0.02	<0.05
PFR000122	–	–	16271	2009-05-12	25.6	<0.2	1.70	641	0.605	0.0456	<0.002	0.113	19.9	0.368	<0.2	<0.1	0.478	41.8	<0.02	<0.02	<0.05
PFR000122	–	–	16272	2009-05-20	25.8	<0.2	1.56	651	<0.4	<0.02	<0.002	0.107	19.9	0.288	<0.2	<0.1	0.495	41.9	<0.02	<0.02	<0.05

< ”value” = below detection limit value

Sicada: trace_elements

Table A3-2. Trace elements forts.

Idcode	Secup m	Seclow m	Sample no.	Ce mg/L	Pr mg/L	Nd mg/L	Sm mg/L	Eu mg/L	Gd mg/L	Tb mg/L	Dy mg/L	Ho mg/L	Er mg/L	Tm mg/L	Yb mg/L	Lu mg/L	Cr mg/L
KFR105	4.00	119.00	16371	0.092	<0.02	0.0863	0.0293	<0.02	0.0723	<0.02	0.0878	0.0256	0.0939	<0.02	0.0841	0.0263	0.101
KFR105	4.00	119.00	16372	0.243	0.0366	0.230	0.0641	0.0220	0.160	0.0283	0.229	0.0644	0.232	0.0281	0.199	0.0375	0.0975
KFR105	4.00	119.00	16374	0.272	0.0406	0.245	0.0874	<0.02	0.188	0.0316	0.238	0.0671	0.246	0.0306	0.197	0.0353	0.272
KFR105	120.00	134.00	16361	0.150	0.0226	0.117	0.0397	<0.02	0.0960	<0.02	0.119	0.0421	0.142	<0.02	0.132	0.0246	0.138
KFR105	120.00	134.00	16362	0.432	0.0632	0.364	0.117	0.0214	0.290	0.0419	0.355	0.111	0.399	0.0477	0.308	0.0542	<0.04
KFR105	120.00	134.00	16364	0.635	0.0885	0.589	0.143	0.0346	0.429	0.0682	0.540	0.155	0.518	0.0696	0.438	0.0797	0.163
KFR105	138.00	169.00	16367	0.139	0.0229	0.112	0.0508	<0.02	0.106	<0.02	0.140	0.0455	0.172	0.0219	0.152	0.0360	<0.04
KFR105	138.00	169.00	16368	0.482	0.0639	0.418	0.112	0.0230	0.295	0.0410	0.325	0.101	0.367	0.0478	0.294	0.0582	0.0974
KFR105	138.00	169.00	16370	0.500	0.0773	0.417	0.115	<0.02	0.287	0.0422	0.339	0.108	0.361	0.0455	0.283	0.0497	0.273
KFR105	170.00	264.00	16357	0.141	0.0218	0.140	0.0494	<0.02	0.136	0.0203	0.183	0.0649	0.221	0.0270	0.168	0.0299	0.0631
KFR105	170.00	264.00	16358	0.291	0.0458	0.266	0.0962	<0.02	0.266	0.0363	0.319	0.0968	0.338	0.0403	0.264	0.0447	<0.04
KFR105	170.00	264.00	16360	0.384	0.0597	0.337	0.110	0.0319	0.319	0.0473	0.394	0.115	0.430	0.0515	0.333	0.0595	0.202
KFR105	265.00	306.81	16333	0.133	<0.02	0.0868	0.026	<0.02	0.083	<0.02	0.104	0.0334	0.115	<0.02	0.0928	<0.02	0.0439
KFR105	265.00	306.81	16334	0.291	0.0352	0.202	0.066	<0.02	0.155	0.0246	0.200	0.0558	0.204	0.0228	0.168	0.0276	0.0681
PFR000122	–	–	16270	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.0424
PFR000122	–	–	16271	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.0236	<0.02	<0.04
PFR000122	–	–	16272	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.362

< ”value” = below detection limit value

Sicada: trace_elements

Table A3-2. Trace elements forts.

Idcode	Secup m	Seclow m	Sample no.	Cu mg/L	Co mg/L	Ni mg/L	Mo mg/L	Pb mg/L	Zn mg/L	Sb mg/L	Al mg/L
KFR105	4.00	119.00	16371	<0.2	0.509	10.4	6.89	<0.1	15.5	0.149	7.53
KFR105	4.00	119.00	16372	<0.2	0.0365	0.774	3.53	<0.1	6.74	<0.1	3.29
KFR105	4.00	119.00	16374	0.228	0.0351	0.906	3.86	<0.1	11.7	<0.1	15.6
KFR105	120.00	134.00	16361	0.857	0.348	34.1	8.15	<0.1	14.8	0.122	28.1
KFR105	120.00	134.00	16362	<0.2	<0.02	0.317	4.53	<0.1	<0.8	<0.1	15.8
KFR105	120.00	134.00	16364	<0.2	<0.02	<0.2	4.17	<0.1	1.06	<0.1	30.8
KFR105	138.00	169.00	16367	<0.2	0.393	16.1	5.72	<0.1	13.3	<0.1	3.87
KFR105	138.00	169.00	16368	<0.2	<0.02	0.288	3.68	<0.1	2.73	<0.1	6.03
KFR105	138.00	169.00	16370	<0.2	0.0382	1.41	3.48	<0.1	1.59	<0.1	25.4
KFR105	170.00	264.00	16357	<0.2	0.195	20.4	4.40	<0.1	10.4	<0.1	3.44
KFR105	170.00	264.00	16358	<0.2	0.0228	0.864	3.76	<0.1	5.11	<0.1	2.77
KFR105	170.00	264.00	16360	<0.2	0.0212	0.320	3.70	<0.1	2.87	<0.1	2.59
KFR105	265.00	306.81	16333	2.42	0.0889	3.92	3.06	0.482	26.4	<0.1	16.4
KFR105	265.00	306.81	16334	<0.2	0.0242	0.568	2.25	<0.1	8.81	<0.1	27.7
PFR000122	–	–	16270	0.991	<0.02	0.489	4.16	<0.1	14.7	<0.1	2.63
PFR000122	–	–	16271	1.30	<0.02	0.800	5.95	<0.1	11.3	<0.1	12.2
PFR000122	–	–	16272	1.49	<0.02	1.02	5.39	<0.1	13.7	<0.1	12.5

< ”value” = below detection limit value

Sicada: trace_elements

Table A3-3. Isotopes I (H-, O- B-, S- Cl- and C-isotopes).

Idcode	Secup m	Seclow m	Sample no	Sampling date	$\delta^{2}H$ dev SMOW	^{3}H TU	$\delta^{18}O$ dev SMOW	$^{10}B/^{11}B$ no unit	$\delta^{34}S$ dev CDT	$\delta^{13}C$ dev PDB	$^{87}Sr/^{86}Sr$ no unit	^{14}C pmC	$\delta^{37}Cl$ dev SMOC
KFR105	4.00	119.00	16371	2009-08-14	–94.9	3.2	–12.4	0.2372	23.4	–	0.716325	–	–
KFR105	4.00	119.00	16372	2009-08-17	–88.2	4.0	–11.9	0.2365	23.7	–	0.716450	–	–
KFR106	4.00	119.00	16373	2009-08-19	–	–	–	0.2365	–	–	–	–	–
KFR105	4.00	119.00	16374	2009-08-21	–88.2	4.0	–11.3	0.2358	23.5	–9.71	0.716436	A	A
KFR105	120.00	134.00	16361	2009-07-28	–73.2	5.0	–9.8	0.2373	23.3	–	0.716846	–	–
KFR106	120.00	134.00	16362	2009-07-31	–75.0	6.0	–9.3	0.2373	23.2	–	0.716963	–	–
KFR105	120.00	134.00	16363	2009-08-03	–75.0	6.0	–9.3	0.2373	23.2	–	0.716963	–	
KFR105	120.00	134.00	16364	2009-08-07	–73.3	7.7	–9.6	0.2356	22.4	–7.16	0.716970	A	A
KFR105	138.00	169.00	16367	2009-08-14	–79.6	4.8	–10.5	0.2357	23.0	–	0.716571	–	–
KFR105	138.00	169.00	16368	2009-08-17	–80.5	3.0	–10.7	0.2368	23.4	–	0.716534	–	–
KFR105	138.00	169.00	16370	2009-08-21	–81.8	4.1	–10.4	0.2363	23.3	–8.11	0.716552	A	A
KFR105	170.00	264.00	16357	2009-07-27	–76.1	3.2	–10.1	0.2377	23.1	–	0.716953	–	–
KFR105	170.00	264.00	16358	2009-07-31	–73.7	4.7	–9.8	0.2367	23.4	–	0.716849	–	–
KFR105	170.00	264.00	16360	2009-08-07	–75.1	6.2	–10.1	0.2354	22.0	–7.41	0.716864	A	A
KFR105	265.00	306.81	16333	2009-07-14	–109.0	<0.8	–13.7	0.2361	24.1	–	0.716396	–	–
KFR105	265.00	306.81	16334	2009-07-17	–106.6	1.8	–13.4	0.2365	24.3	–	0.716413	–	–
KFR105	265.00	306.81	16337	2009-07-27	–103.6	<0.8	–14.3	0.2365	24.4	–10.33	0.716448	A	A
PFR000122	–	–	16270	2009-04-28	–65.9	11.2	–9.0	0.2387	–	–4.38	–	–	–
PFR000122	–	–	16271	2009-05-12	–65.7	9.3	–9.2	0.2370	–	–4.32	–	–	–
PFR000122	–	–	16272	2009-05-20	–66.2	9.9	–9.2	0.2366	–	–4.27	–	–	–

– = Not analysed.

< ”value” = below detection limit value.

A = Results will be reported later.

Sicada: isotopes_1_t.

Table A3-4. Isotopes II (U-, Th, Ra- and Rn-isotopes).

Idcode	Secup m	Seclow m	Sample no.	Sampling date	^{238}U mBq/L	^{235}U mBq/L	^{234}U mBq/L	^{232}Th mBq/L	^{230}Th mBq/L	^{226}Ra Bq/L	^{222}Rn Bq/L At time of analysis	^{222}Rn Bq/L At time of collection
KFR105	4.00	119.00	16374	2009-08-21	358	12	1,902	0.25	0.74	2.84	2,365	4,443
KFR105	120.00	134.00	16364	2009-08-07	488	18	2,333	0.18	0.49	1.10	1,190	2,887
KFR105	138.00	169.00	16370	2009-08-21	372	14	1,664	0.23	0.35	1.34	1,112	4,298
KFR105	170.00	264.00	16360	2009-08-07	406	16	1,722	0.34	0.90	0.947	763	1,781
KFR105	265.00	306.81	16337	2009-07-27	433	17	2,012	0.38	0.50	6.01	2,106	3,559

Appendix 4

Sampling information

Idcode:section	Tube volume [dm³]	Section volume [dm³]	Total volume [dm³]	Pumping time	Flow rate [mL/min]	Pumped volume [dm³]	Sampling date	Sample no.	Pressure responses in other sections of the borehole
KFR105A:1	22.4	170.2	192.6	3 h 29 min	116	25.2 [1)]	2009-07-14	16333	No
"	"	"	"	65 h 45 min	92	411 [1)]	2009-07-17	16334	No
"	"	"	"	72 h 8 min	84	805 [1)]	2009-07-20	16335	No
"	"	"	"	74 h 9 min	80	1185 [1)]	2009-07-23	16336	No
"	"	"	"	93 h 39 min	75	1618 [1)]	2009-07-27	16337	No
"	"	"	"			3)	2009-08-11	16365	No
KFR105A:2	13.7	384.6	398.3	1 h 24 min	200	16.8 [2)]	2009-07-27	16357	Yes, in section 3 and 4
"	"	"	"	90 h 0 min	175	945 [2)]	2009-07-31	16358	Yes, in section 3 and 4
"	"	"	"	72 h 30 min	200	870 [2)]	2009-08-03	16359	Yes, in section 3 and 4
"	"	"	"	95 h 40 min	200	1148 [2)]	2009-08-07	16360	Yes, in section 3 and 4
KFR105A:3	11.2	119.0	130.2	0 h 57 min	200	11.4 [2)]	2009-08-14	16367	Yes, in section 2 and 4
"	"	"	"	71 h 40 min	175	752 [2)]	2009-08-17	16368	Yes, in section 2 and 4
"	"	"	"	49 h 15 min	200	591 [2)]	2009-08-19	16369	Yes, in section 2 and 4
"	"	"	"	46 h 22 min	200	556 [2)]	2009-08-21	16370	Yes, in section 2 and 4
KFR105A:4	11.0	64.6	75.6	0 h 49 min	198	5.3 [1)]	2009-07-28	16361	Yes, in section 2 and 3
"	"	"	"	65 h 47 min	118	527 [1)]	2009-07-31	16362	Yes, in section 2 and 3
"	"	"	"	72 h 13 min	120	1107 [1)]	2009-08-03	16363	Yes, in section 2 and 3
"	"	"	"	96 h 0 min	116	1777 [1)]	2009-08-07	16364	Yes, in section 2 and 3
"	"	"	"	96 h 25 min	116	2266 [1)]	2009-08-11	16366	Yes, in section 2 and 3
KFR105A:5	0.6	419.5	420.1	0 h 7 min	190	1.33 [2)]	2009-08-14	16371	No
"	"	"	"	72 h 0 min	200	864 [2)]	2009-08-17	16372	No
"	"	"	"	50 h 2 min	170	510 [2)]	2009-08-19	16373	No
"	"	"	"	46 h 3 min	170	470 [2)]	2009-08-21	16374	No

Flow rate during Chemmac measurements KFR105

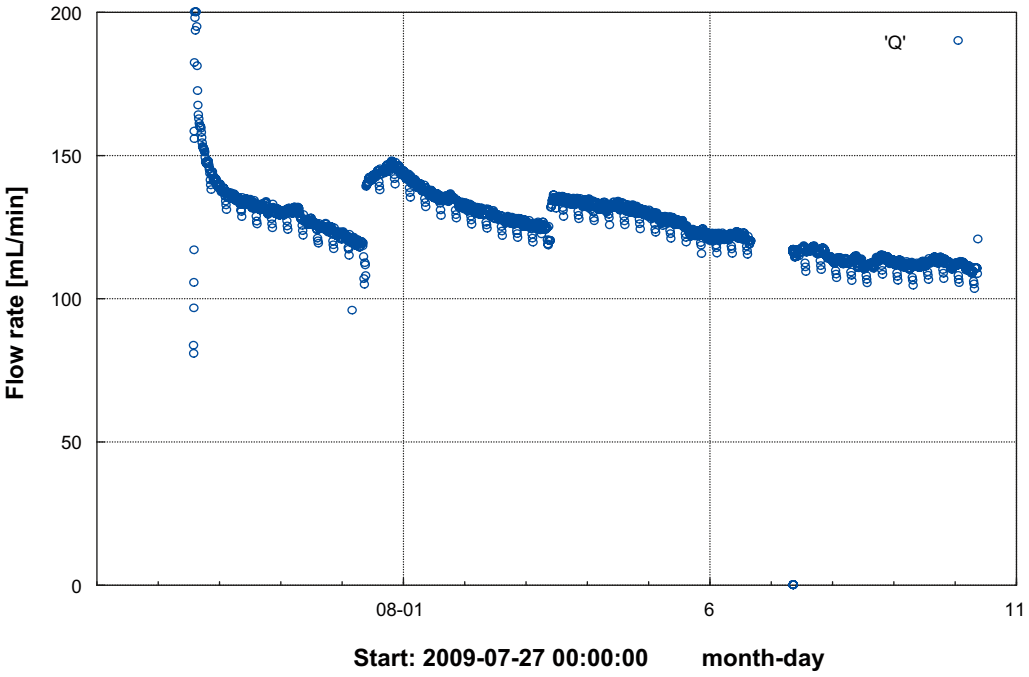


Figure A5-1. *Flow rate (Q), section 120.0–137.0 m.*

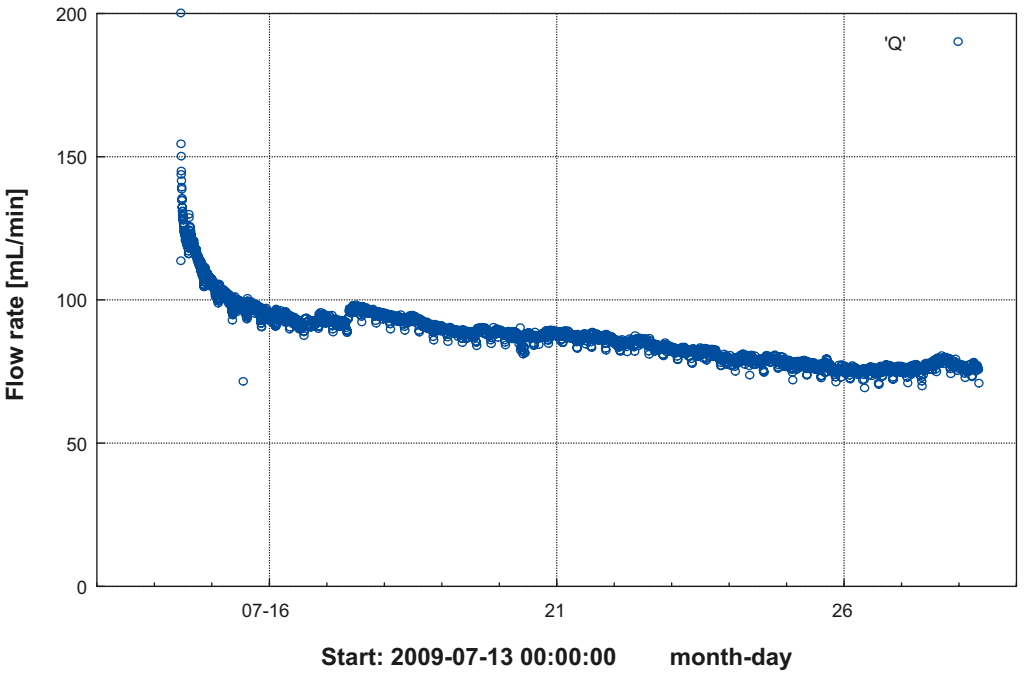


Figure A5-2. *Flow rate (Q), section 265.0–306.8 m.*

Appendix 6

Pressure registrations during measurements and samling HMS system

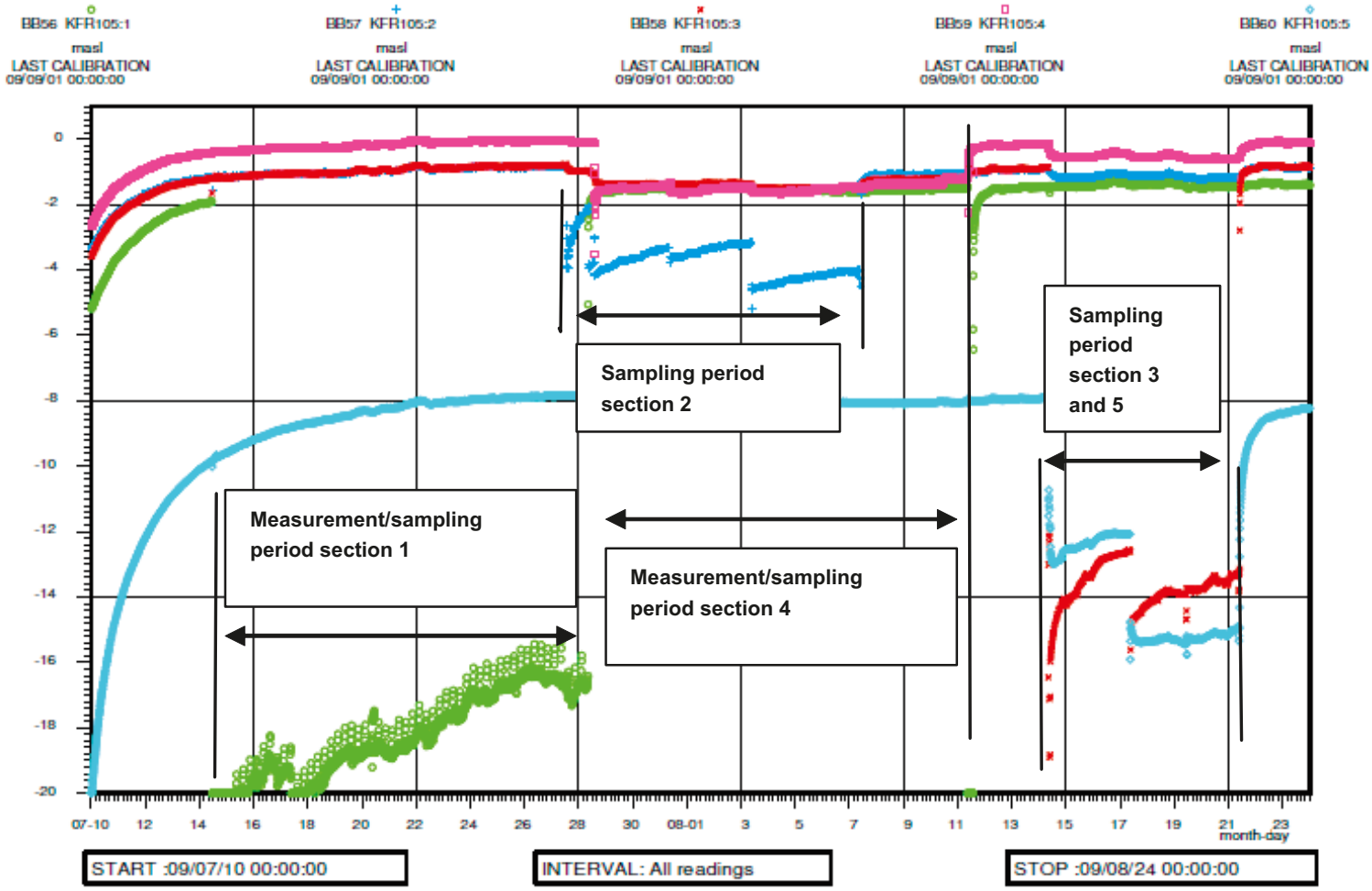


Figure A6-1. *Pressure registration in KFR105 during the hydrochemical investigation (July to August 2009). The figure shows the pressure registration in all five sections in KFR105, section 265.0–306.8 m (green circle), section 170.0–264.0 m (blue plus), section 138.0–169.0 m (red cross), 120.0–137.0 m (pink square), and section 4.0–119.0 m (turquoise diamond).*

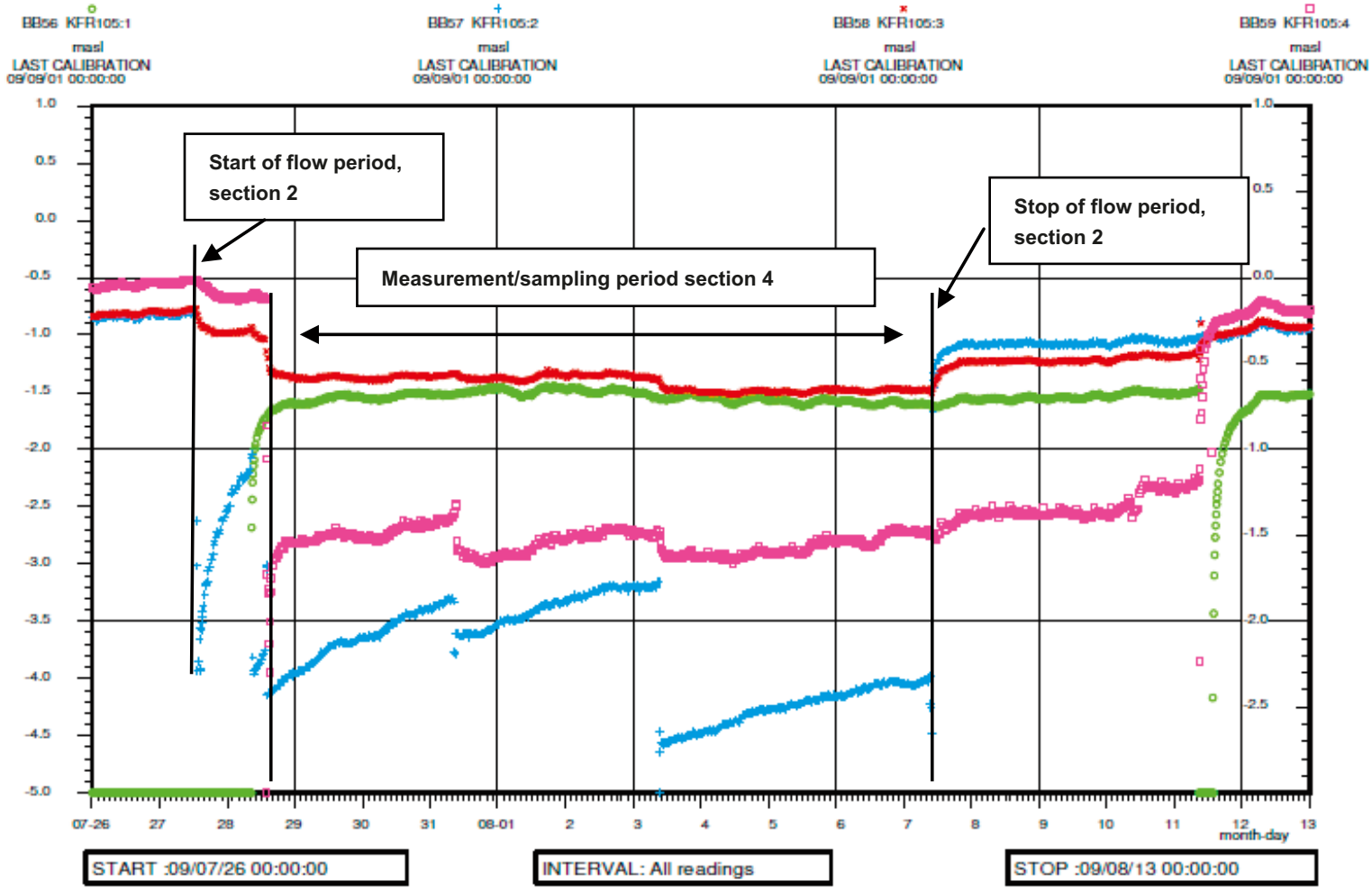


Figure A6-2. *Detail of Figure A6-1; pressure registration during measurement and sampling in section 2, 3 and 4 in KFR105. Pressure registrations in four of the five sections in KFR105, section 265.0–306.8 m (green circle), section 170.0–264.0 m (blue plus), section 138.0–169.0 m (red cross) and 120.0–137.0 m (pink square) are displayed. Note that the pressure for section 4 is plotted at the right axis. The figure indicates pressure responses between section 2, 3 and 4.*

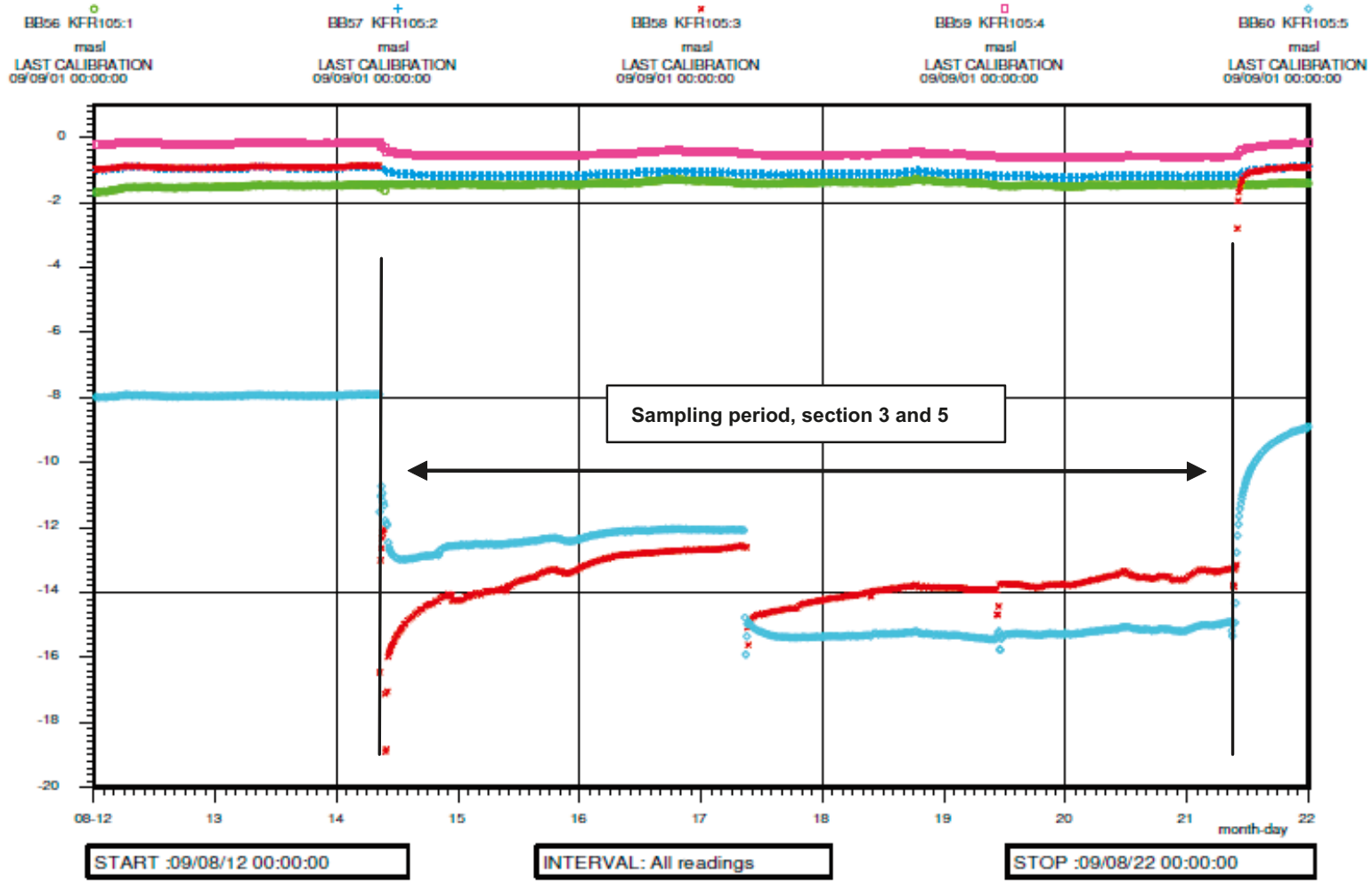


Figure A6-3. *Detail of Figure A6-1; pressure registrations during the sampling in section 3 and 5 in KFR105. Pressure registration in all five sections in KFR105, section 265.0–306.8 m (green circle), section 170.0–264.0 m (blue plus), section 138.0–169.0 m (red cross), 120.0–137.0 m (pink square), and section 4.0–119.0 m (turquoise diamond) are displayed . The figure indicates responses in section 2 and Appendix 7.*

Appendix 7

Sampling and analytical methods

Table A7-1. 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 (at the laboratory)	No	Titration Pot. meas, Cond. meas	The same day – maximum 24 hours
Anions 2	Cl, SO_4, Br^-, F^-, I^-	Plastic	100	Yes (at the laboratory)	No	Titration (Cl^-) IC (Cl^-, SO_4, Br^-, F^-) ISE (F^-)	Not critical (month)
	Br, I	Plastic	100	Yes (at the laboratory)	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 (at the laboratory)	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 (1mL 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 1M 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
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	^2H, ^{18}O	Plastic	100	No	– –	MS	Not critical (month)
Tritium, Chlorine-37	^3H (enhanced.)	Plastic (dry bottle)	500	No	–	LSC	Not critical (month)
	Chlorine-37	Plastic	100	No	–	MS	
Carbon isotopes	^{13}C, ^{14}C	Glass (brown)	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

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ Conservation*	Analysis method	Analysis within – or delivery time to lab.
Uranium and Thorium isotopes	^{234}U, ^{235}U, ^{238}U, ^{232}Th, ^{230}Th,	Plastic	50	Nej	–	Alfa spectros-copy	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	No	No	LSS	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 and fractionation (see below)	Polycar-bonate filter	0.45, 0.2 and 0.05 µm	–	N_2 atmosphere	ICP-AES ICP-MS	Immediate transport
Humic and fulvic acids	Fractionation	Fractions are collected in plastic bottles	250	–	N_2 atmosphere	UV oxida-tion, 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 cel-lulose (anion exchanger)	–	–	–	(A)MS	A few days
Nutrient salt + silicate	NO_2, NO_3, NO_2+NO_3, NH_4, PO_4, SiO_4	Sample tubes, plastic	25×2	Yes (in the field)	No, frozen immediately***	Spectropho-tometry	Short transpor-tation time
Total concentra-tions of Nitrogen and Phosphorous	N-tot, P-tot	Plastic	100	No	No, frozen immediately***	Spectropho-tometry	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	Spectropho-tometry Fluorometry	Short transportation time
Oxygen	Dissolved O_2	Winkler, glass	2×ca 120	No	Mn (II) reagent Iodide reagent	Spectro-photometry 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
LSS	Liquid Scintillation Spectroscopy

Table A7-2. Reporting limits and measurement uncertainties, updated 2008.

Component	Method[1]	Reporting limits (RL), detection limits (DL) or range[2]	Unit	Measurement uncertainty[3]
pH	Potentiometric	3–10	pH unit	± 0.1
EC	Electrical conductivity meas.	1–150 150–10,000	mS/m	5% 3%
HCO_3	Alkalinity titration	1	mg/L	4%
Cl^-	Mohr- titration	≥ 70	mg/L	5%
Cl^-	IC	0.5–70		8%
SO_4	IC	0.5	mg/L	12%
Br^-	IC	DL 0.2, RL 0.5	mg/L	15%
Br	ICP SFMS	0.001, 0.004, 0.010[4]	mg/L	25%[5]
F^-	IC	DL 0.2, RL 0.5	mg/L	13%
F^-	Potentiometric	DL 0.1, RL 0.2		12%
I^-	ICP SFMS	0.001, 0.004, 0.010[4]	mg/L	25%[5]
Na	ICP AES	0.1	mg/L	13%
K	ICP AES	0.4	mg/L	12%
Ca	ICP AES	0.1	mg/L	12%
Mg	ICP AES	0.09	mg/L	12%
S(tot)	ICP AES	0.16	mg/L	12%
Si(tot)	ICP AES	0.03	mg/L	14%
Sr	ICP AES	0.002	mg/L	12%
Li	ICP AES	0.004	mg/L	12.2%
Fe	ICP AES	0.02	mg/L	13.3%[6]
Fe	ICP SFMS	0.0004, 0.002, 0.004[4]	mg/L	20%[6]
Mn	ICP AES	0.003	mg/L	12.1%[5]
Mn	ICP SFMS	0.00003, 0.00004, 0.0001[4]	mg/L	53%[6]
Fe(II), Fe(tot)	Spectrophotometry	DL 0.006, RL 0.02	mg/L	0.005 (0.02–0.05 mg/L) 9% (0.05–1 mg/L) 7% (1–3 mg/L)
HS^-	Spectrophotometry, SKB	SKB DL 0.006, RL 0.02	mg/L	25%
HS^-	Spectrophotometry, external laboratory	0.01	mg/L	0.02 (0.01–0.2 mg/L) 12% (>0.2 mg/L)
NO_2 as N	Spectrophotometry	0.1	µg/L	2%
NO_3 as N	Spectrophotometry	0.2	µg/L	5%
NO_2+NO_3 as N	Spectrophotometry	0.2	µg/L	0.2 (0.2–20 µg/L) 2% (> 20 µg/L)
NH_4 as N	Spectrophotometry, SKB	11	µg/L	30% (11–20 µg/L) 25% (20–50 µg/L) 12% (50–1,200 µg/L)
NH_4 as N	Spectrophotometry external laboratory	0.8	µg/L	0.8 (0.8–20 µg/L) 5% (> 20 µg/L)
PO_4 as P	Spectrophotometry	0.7	µg/L	0.7 (0.7–20 µg/L) 3% (> 20 µg/L)
SiO_4	Spectrophotometry	1	µg/L	2.5% (>100 µg/L)
O_2	Iodometric titration	0.2–20	mg/L	5%
Chlorophyll a, c pheopigment[7]	/1/	0.5	µg/L	5%
PON[7]	/1/	0.5	µg/L	5%
POP[7]	/1/	0.1	µg/L	5%
POC[7]	/1/	1	µg/L	4%
Tot-N[7]	/1/	10	µg/L	4%
Tot-P[7]	/1/	0.5	µg/L	6%
Al,	ICP SFMS	0.2, 0.3, 0.7[4]	µg/L	17.6%[6]
Zn	ICP SFMS	0.2, 0.8, 2[4]	µg/L	15.5, 17.7, 25.5%[6]
Ba, Cr, Mo,	ICP SFMS	0.01, 0.04, 0.1[4]	µg/L	Ba 15%[4], Cr 22%[5] Mo 39%[6]
Pb	ICP SFMS	0.01, 0.1, 0.3[4]	µg/L	15%[6]
Cd	ICP SFMS	0.002, 0.02, 0.5[4]	µg/L	15.5%[6]
Hg	ICP AFS	0.002	µg/L	10.7%[6]
Co	ICP SFMS	0.005, 0.02, 0.05[4]	µg/L	25.9%[6]
V	ICP SFMS	0.005, 0.03, 0.05[4]	µg/L	18.1%[6]
Cu	ICP SFMS	0.1, 0.2, 0.5[4]	µg/L	14.4%[6]
Ni	ICP SFMS	0.05, 0.2, 0.5[4]	µg/L	15.8%[6]
P	ICP SFMS	1, 5, 40[4]	µg/L	16.3%[6]
As	ICP SFMS	0.01 (520 mS/m)	µg/L	59.2%[6]

Component	Method[1]	Reporting limits (RL), detection limits (DL) or range[2]	Unit	Measurement uncertainty[3]
La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu	ICP SFMS	0.005, 0.02, 0.05[4]	µg/L	20%, 20%, 25%[6]
Sc, In, Th	ICP SFMS	0.05, 0.2, 0.5[4]	µg/L	25%[6]
Rb, Zr, Sb, Cs	ICP SFMS	0.025, 0.1, 0.25[4]	µg/L	15%, 20%, 20%[5] 25%[6]
Tl	ICP SFMS	0.025, 0.1, 0.25[4]	µg/L	14.3%[5 and 6]
Y, Hf	ICP SFMS	0.005, 0.02, 0.05[4]	µg/L	15%, 20%, 20%[5] 25%[6]
U	ICP SFMS	0.001, 0.005, 0.01[4]	µg/L	13.5%, 14.3%, 15.9%[5] 19.1%, 17.9%, 20.9%[6]
DOC	UV oxidation, IR Carbon analysator	0.5	mg/L	8%
TOC	UV oxidation, IR Carbon analysator	0.5	mg/L	10%
$\delta^{2}H$	MS	2	‰ SMOW[8]	0.9 (one standard deviation)
$\delta^{18}O$	MS	0.1	‰ SMOW[8]	0.1 (one standard dev.)
^{3}H	LSC	0.8	TU[9]	0.8
$\delta^{37}Cl$	A (MS)	0.2	‰ SMOC[10]	0.2[17]
$\delta^{13}C$	A (MS)	–	‰ PDB[11]	0.3[17]
^{14}C pmc	A (MS)	–	PMC[12]	0.4[17]
$\delta^{34}S$	MS	0.2	‰ CDT[13]	0.4 (one standard dev.)
$^{87}Sr/^{86}Sr$	TIMS	–	No unit (ratio)[14]	0.00002
$^{10}B/^{11}B$	ICP SFMS	–	No unit (ratio)[14]	–
^{234}U, ^{235}U, ^{238}U, ^{232}Th, ^{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, 1,440 mS/m and 3,810 mS/m respectively.
5. Measurement uncertainty at concentrations 100×RL.
6. Measurement uncertainty at concentrations 10×RL.
7. Determined only in surface waters. PON, POP and POC refers to Particulate Organic Nitrogen, Phosphorous and Carbon, respectively.
8. Per mille deviation[16] from SMOW (Standard Mean Oceanic Water).
9. TU = Tritium Units, where one TU corresponds to a tritium/hydrogen ratio of 10^{-18} (1 Bq/L Tritium = 8.45 TU).
10. Per mille deviation[16] from SMOC (Standard Mean Oceanic Chloride).
11. Per mille deviation[16] from PDB (the standard PeeDee Belemnite).
12. The following relation is valid between pmC (percent modern carbon) and Carbon-14 age: $pmC = 100 \times e^{((1,950-y-1.03t)/8,274)}$.
    where y = the year of the C-14 measurement and t = C-14 age.
13. Per mille deviation[16] from CDT (the standard Canyon Diablo Troilite).
14. Isotope ratio without unit.
15. The following expressions are applicable to convert activity to concentration, for uranium-238 and thorium-232: 1 ppm U = 12.4 Bq/kg^{238}U, 1 ppm Th = 3.93 Bq/kg^{232}Th.
16. Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as: $\delta^{y}I = 1,000\times(K_{sample}-K_{standard})/K_{standard}$, where K = the isotope ratio and $^{y}I = {}^{2}H$, ^{18}O, ^{37}Cl, ^{13}C or ^{34}S etc.
17. SKB estimation from duplicate analyses by the contracted laboratory.

Appendix 8

Chemmac measurements in KFR105, section 120.0–137.0 m

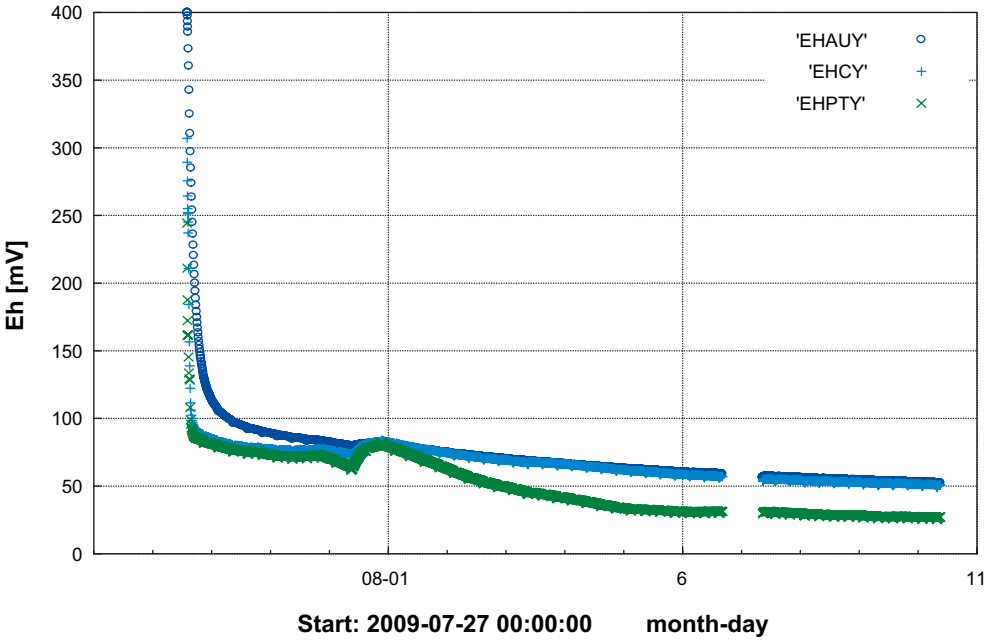


Figure A8-1. *Redox potential measurements (Eh) by gold, glassy carbon and platinum electrodes (EHAUY, EHCY and EHPTY). No representative Eh value was selected for the borehole section due to suspected intrusion of oxygen from air.*

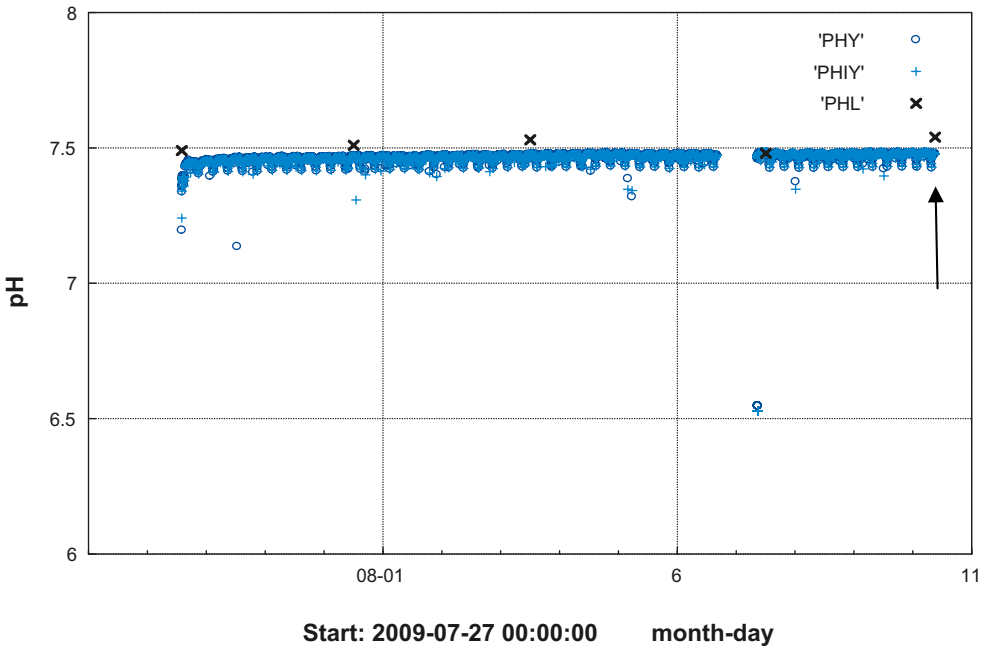


Figure A8-2. *Measurements of pH by two glass electrodes (PHY and PHIY). The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the selected representative pH value for the borehole section.*

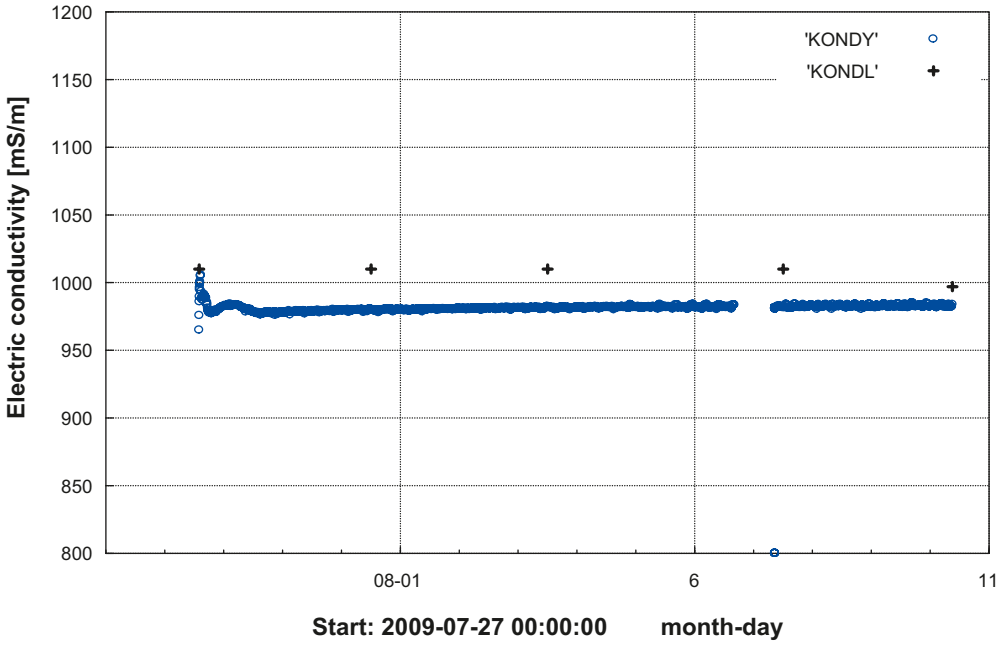


Figure A8-3. *Electrical conductivity measurements (KONDY). Corresponding laboratory values (KONDL) are given for comparison. The arrow shows the selected representative electrical conductivity value for the borehole section.*

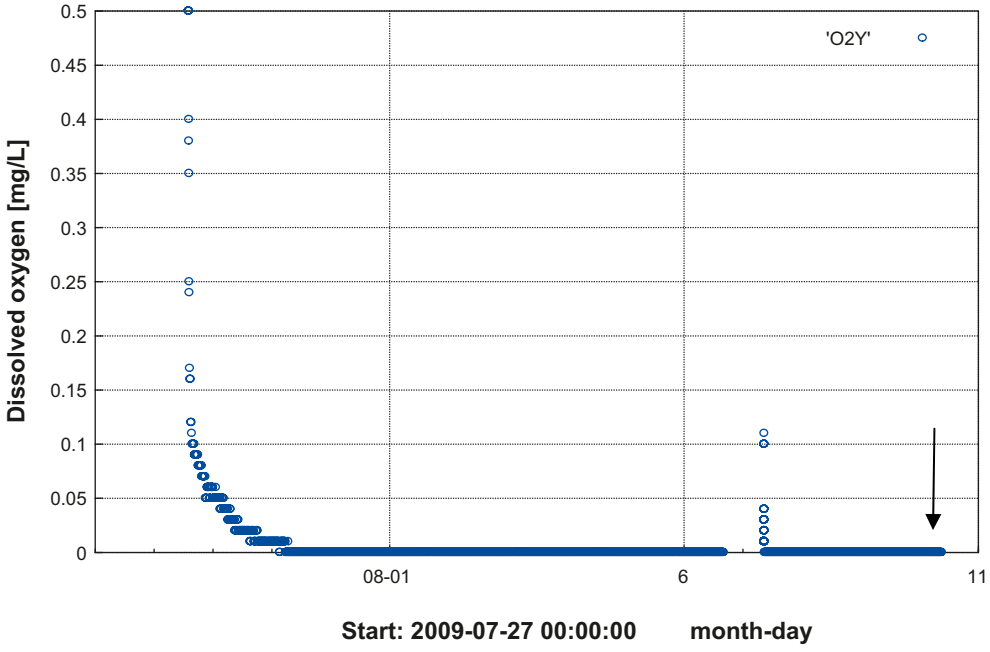


Figure A8-4. *Dissolved oxygen measurements (O2Y). The arrow shows the selected representative oxygen value for the borehole section.*

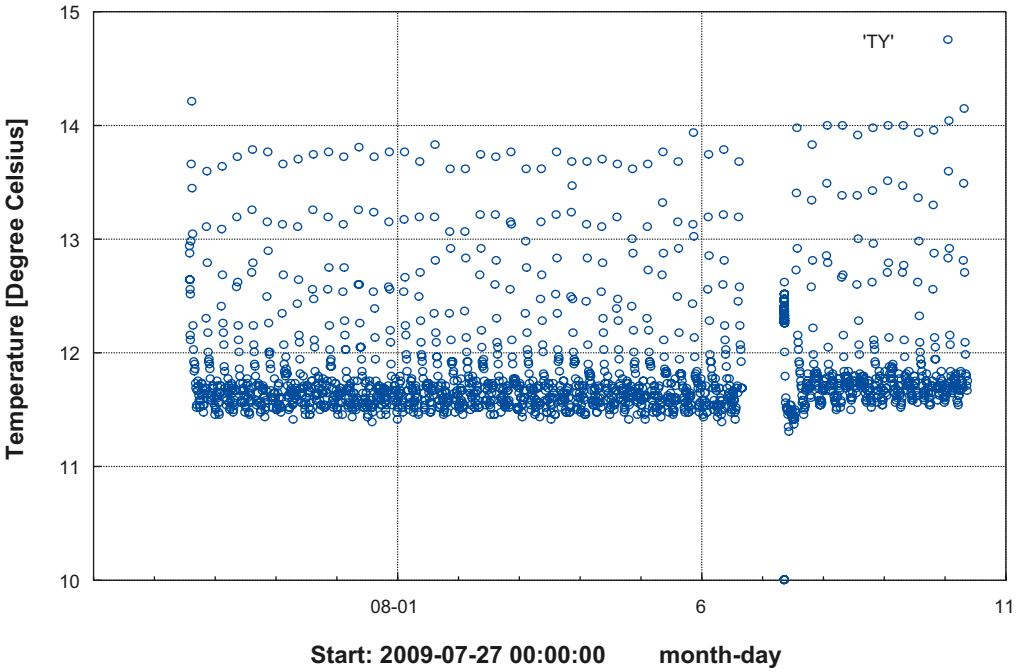


Figure A8-5. *Water temperature in the measurement cell (TY).*

Appendix 9

Chemmac measurements in KFR105, section 265.0–306.8 m

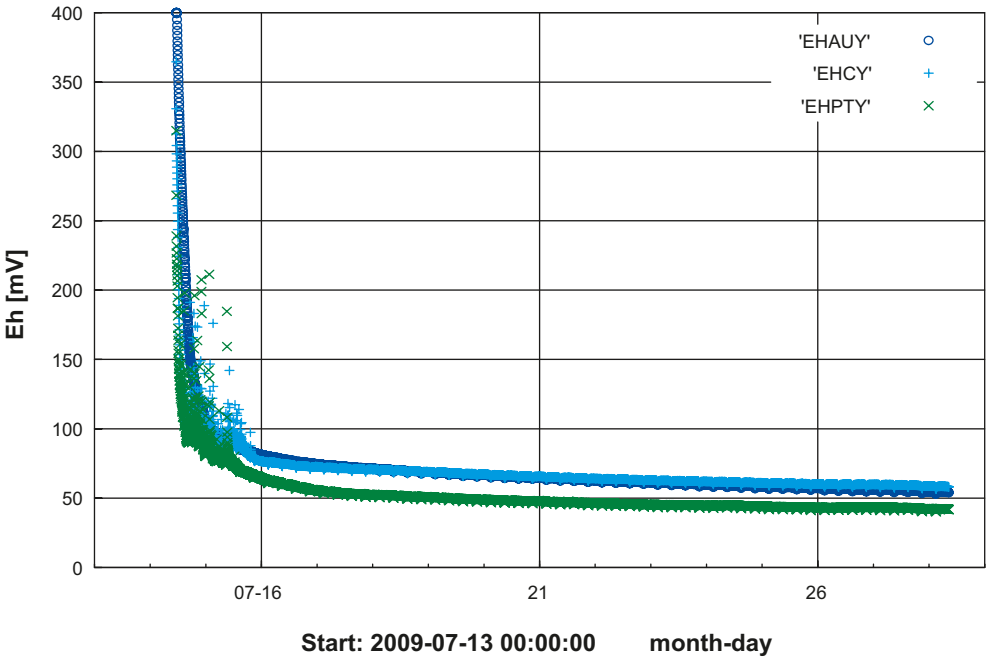


Figure A9-1. *Redox potential measurements (Eh) by gold, glassy carbon and platinum electrodes (EHAUY, EHCY and EHPTY). No representative Eh value was selected for the borehole section due to suspected intrusion of oxygen from air.*

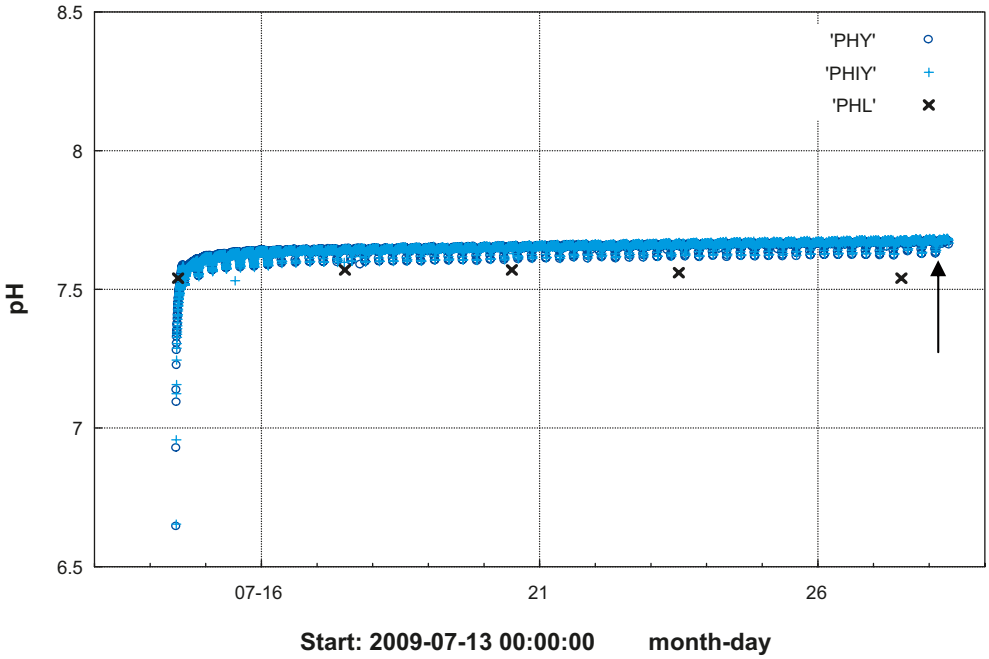


Figure A9-2. *Measurements of pH by two glass electrodes (PHY and PHIY). The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the selected representative pH value for the borehole section.*

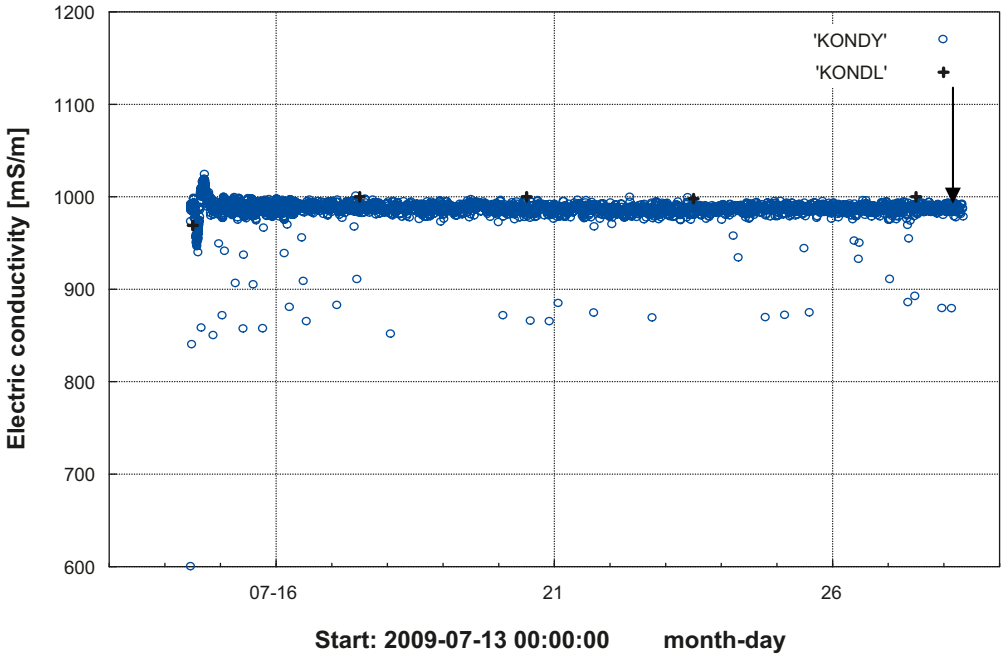


Figure A9-3. *Electrical conductivity measurements (KONDY). Corresponding laboratory values (KONDL) are given for comparison. The arrow shows the selected representative electrical conductivity value for the borehole section.*

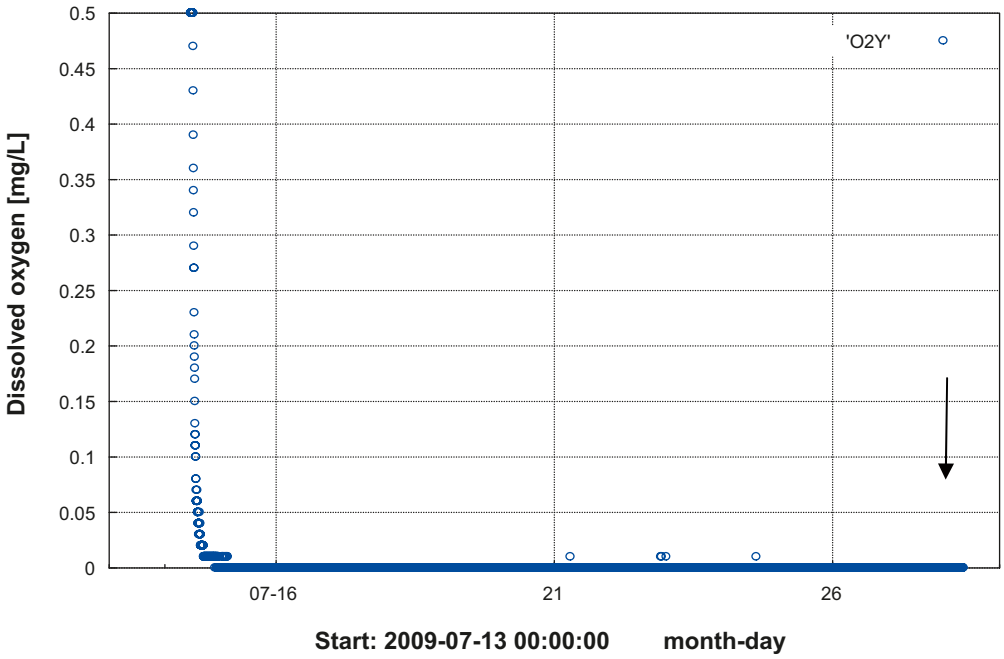


Figure A9-4. *Dissolved oxygen measurements (O2Y) in the surface measurement cell. The arrow shows the chosen representative oxygen value for the borehole section.*

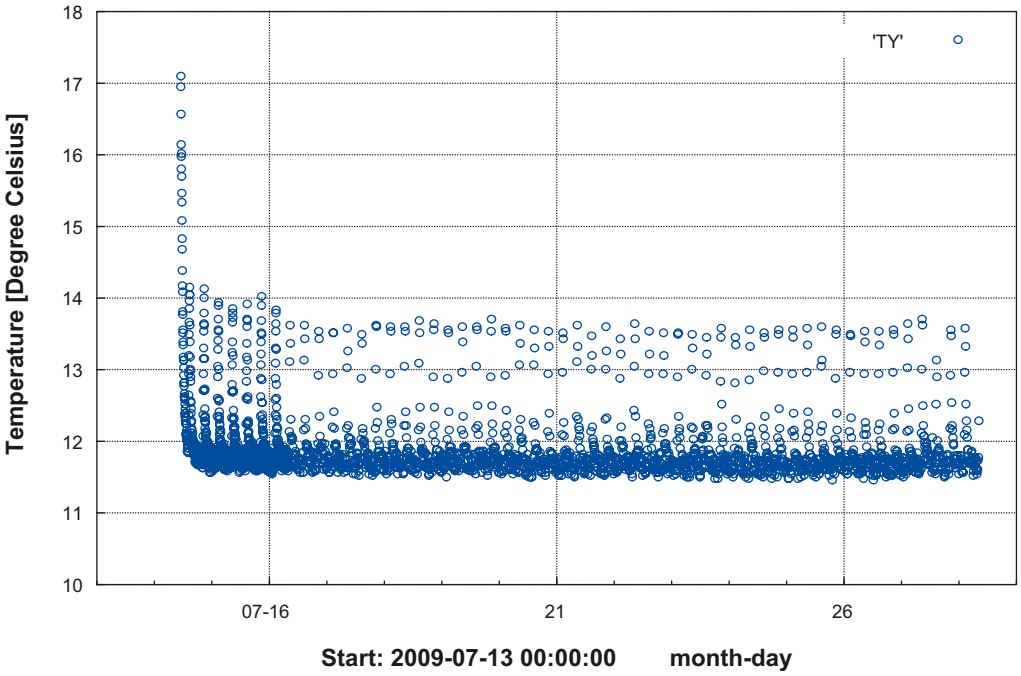


Figure A9-5. *Water temperature in the measurement cell (TY).*

Appendix 10

Results from measurements in KFR105 during January–February 2010

A10.1 Equipment

A10.1.1 The measurement chamber and electrodes

Figure A10-1 shows an outline of the measurement chamber containing two glass electrodes, a gold electrode (Au), a platinum electrode (Pt), a glossy-carbon electrode (C) and a reference electrode (Ag, AgCl). The glass- and reference electrodes are specially designed for measurements at high pressure. Figure A10-2 shows a photo of the measurement chamber.

The equipment was connected to the line for pressure measurements (made of polyamide PA11 instead of the teflonized tubes intended for water sampling). The reason for the change was to reduce the amount of junctions as they increase the risk of oxygen leakage. In addition, the leakage in a ball valve in the line for water sampling was visible and thus considered as a great risk.

A10.1.2 The measurement system and software

The measurement system consists of a voltmeter, amplifier and software designed by Research Electronics AB. The software is a simple data logging function, where the electrode potentials are given in milliVolts (mV).

The original raw data files obtained from this measurement system are not of the same type as the ones obtained from Chemmac measurements. The files were adapted (some nomenclature was changed and some help files were added) in order to be compatible with the calculation software (Hilda) normally used for the calculations of Chemmac measurement data.

Calculation of calibration constants and recalculation of the measurement data were made according to the method described in Section 6.1.1 and 6.1.2 in the main report.

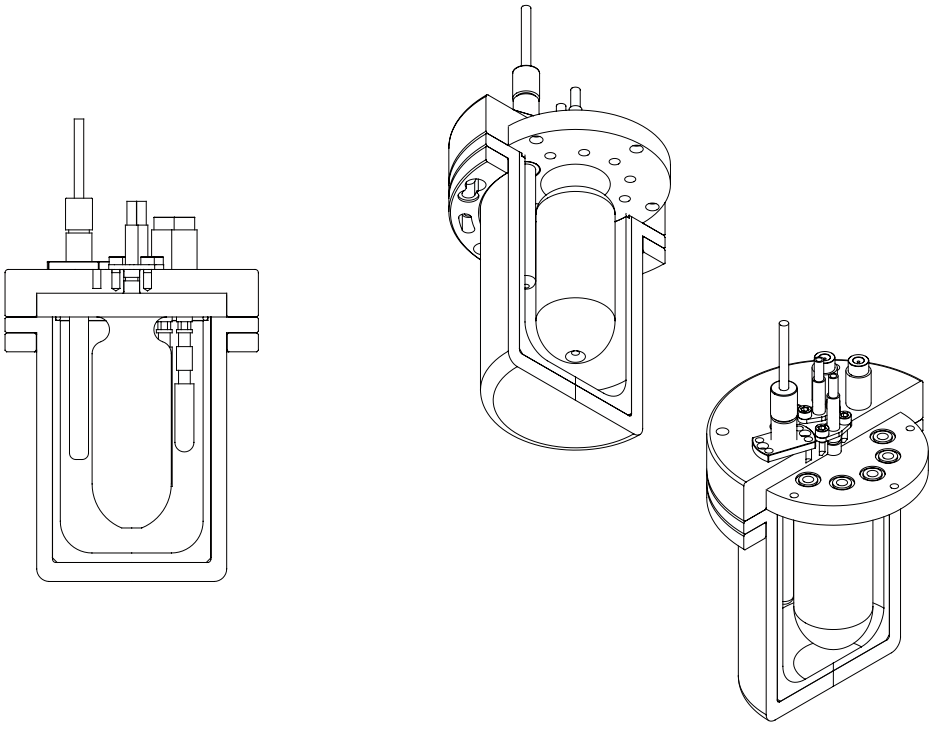


Figure A10-1. *Outline of the measurement chamber with electrodes.*

Figure A10-2. *The measurement chamber.*

A10.2 Execution

A10.2.1 Execution of field work

The technique used is briefly described below in connection to the results presented. For detailed descriptions the reader is referred to the method descriptions, Table 1-1 in the main report.

The field work consisted of on-line measurements of pH and redox potential as well as water sampling. The events during the measurement period together with sample numbers and flow rate are listed in Table A10-1.

A10.2.2 Nonconformities

- A power failure caused lack of measurement data during the period 2010-01-26 15:42 until 2010-02-01 09:35.
- Problems with the computer unit caused lack of measurement data during the period 2010-02-01 15:59 until 2010-02-04 10:53.
- No reasonable values of Eh were obtained from the platinum electrode due to malfunction.
- The measurement period was extended by two weeks and the last water sample was not taken the same day as the measurements were finished but four days earlier. However, the electrodes were stable already at that time so the water sample can be considered as representative for the section and the redox conditions.

Table A10-1. Events during the measurement/sampling period in section 1 (256.0–306.8 m).

Date	Event	Sample no.	Discharged volume (m^3)	Flow rate (mL/min)
100113 14:08	Valve opening			90
100114 09:00	Valve closing			
100114 09:05	Valve opening			84
100118	Water sampling SKB class 3	16646	0.59	82
100125	Water sampling SKB class 3	16649	1.40	78
100215	Water sampling SKB class 3	16651	3.76	78
100219 12:50	Valve closing			
			4.11	**82–90**

A10.3 Chemical data

No significant changes compared with the results from July–August 2009 was observed.

A10.4 On-line measurements in KFR105, section 265.0–306.8 m

The measured Eh-values, shown in Figure A10-3, from the glassy carbon- and gold electrodes reached fairly stable values. Although not quite consistent they were negative with an average value of –190 ± 15 mV. The Eh-values from the platinum electrode showed erroneous values and are therefore not presented in Figure A10-3.

Table A10-2. Water composition, compilation April 2010.

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
KFR105	265.00	306.81	16646	2010-01-18	–1.51	1,240	6.23	746	97.0	82.9
KFR105	265.00	306.81	16649	2010-01-25	–1.09	1,240	6.55	740	96.8	82.7
KFR105	265.00	306.81	16651	2010-02-15	–1.00	1,220	6.38	766	104	81.1

Idcode	Secup m	Seclow m	Sample no.	Sampling date	Cl^- mg/L	SO_4^{2-} mg/L	SO_4–S mg/L	Br^- mg/L	F^- mg/L	Si mg/L
KFR105	265.00	306.81	16646	2010-01-18	3,380	237	92.3	12.5	1.30	5.58
KFR105	265.00	306.81	16649	2010-01-25	3,340	234	91.7	12.0	1.37	5.63
KFR105	265.00	306.81	16651	2010-02-15	3,360	229	97.9	11.9	1.25	5.98

Idcode	Secup m	Seclow m	Sample no.	Sampling date	Fe mg/L	Mn mg/L	Li mg/L	Sr mg/L	pH	DOC mg/L
KFR105	265.00	306.81	16646	2010-01-18	0.705	1.49	0.0641	11.9	7.55	0.9
KFR105	265.00	306.81	16649	2010-01-25	0.704	1.49	0.0620	11.8	7.59	0.8
KFR105	265.00	306.81	16651	2010-02-15	0.757	1.53	0.0647	11.7	7.59	0.7

Idcode	Secup m	Seclow m	Sample no.	Sampling date	TOC mg/L	HS^- mg/L	Drill water %	EC mS/m
KFR105	265.00	306.81	16646	2010-01-18	0.7	<0.006	<0.1	1,010
KFR105	265.00	306.81	16649	2010-01-25	0.7	<0.006	<0.1	1,010
KFR105	265.00	306.81	16651	2010-02-15	0.8	0.010	<0.1	1,020

< “value” = below detection limit value.

RCB = Rel. charge balance error %.

EC = Electrical Conductivity.

Sicada: water_composition_t.

Table A10-3. Trace elements, compilation March 2010.

Idcode	Secup m	Seclow m	Sample no.	Sampling date	U µg/L	Th µg/L
KFR105	265.00	306.81	16646	2010-01-18	29.9	<0.2
KFR105	265.00	306.81	16649	2010-01-25	31.1	<0.2
KFR105	265.00	306.81	16651	2010-02-15	31.5	0.540

< "value" = below detection limit value.
Sicada: trace_elements.

Table A10-4. Isotopes (H and O-isotopes), compilation March 2010.

Idcode	Secup m	Seclow m	Sample no.	Sampling date	$\delta^{2}H$ dev SMOV	^{3}H TU	$\delta^{18}O$ dev SMOW
KFR105	265.00	306.81	16651	2010-02-15	–102.6	1.3	–13.9

Sicada: isotopes_1_t.

The two pH-electrodes show consistent and stable values (7.4±0.2 at the end of the period (Figure A10-4). The values measured on-line are however lower than the corresponding laboratory measurements. The results also differ from the previously performed Chemmac measurements (7.7±0.2), and as the calibration constants are less consistent, the Chemmac measurements are considered more reliable.

The water temperature is shown in Figure A10-5.

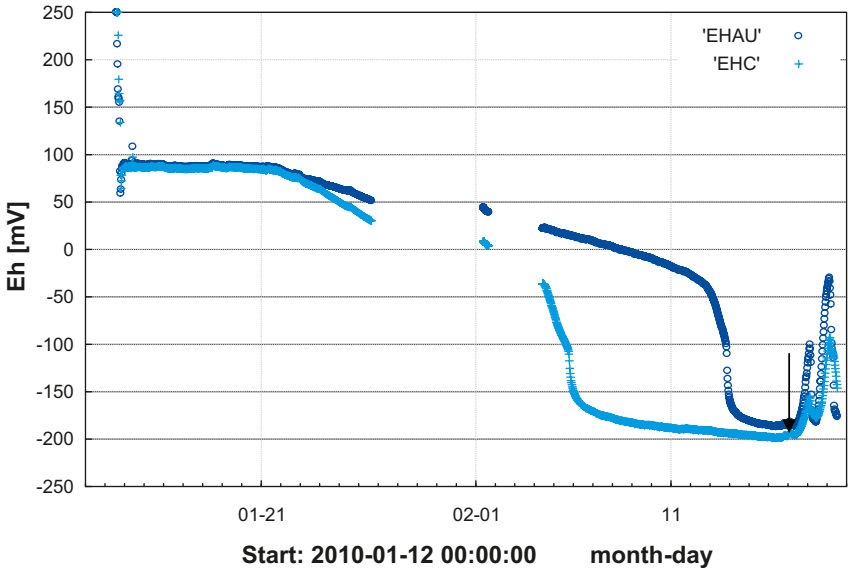


Figure A10-3. *Redox potential measurements (Eh) by gold and glassy carbon electrodes (EHAU and EHC). The arrow shows the selected representative Eh value for the borehole section.*

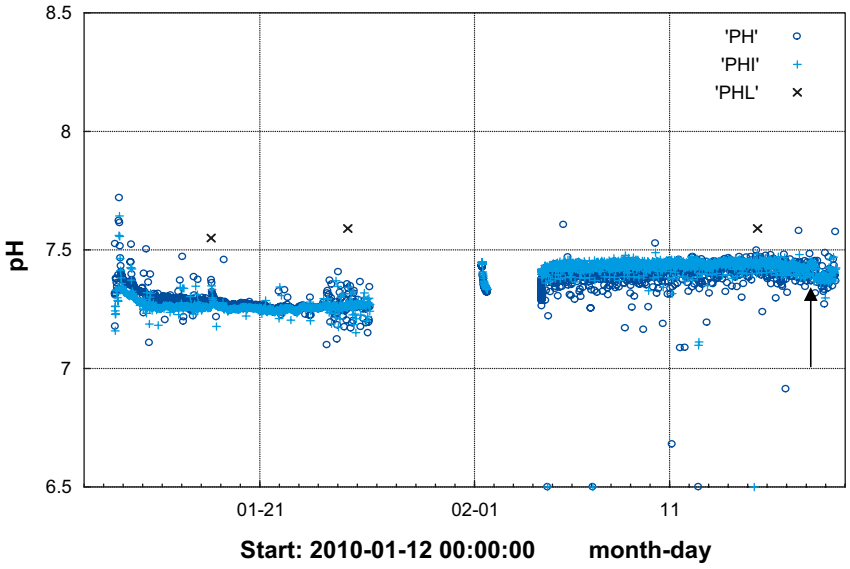


Figure A10-4. *Measurements of pH by two glass electrodes (PH and PHI). The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the selected representative pH value for the borehole section.*

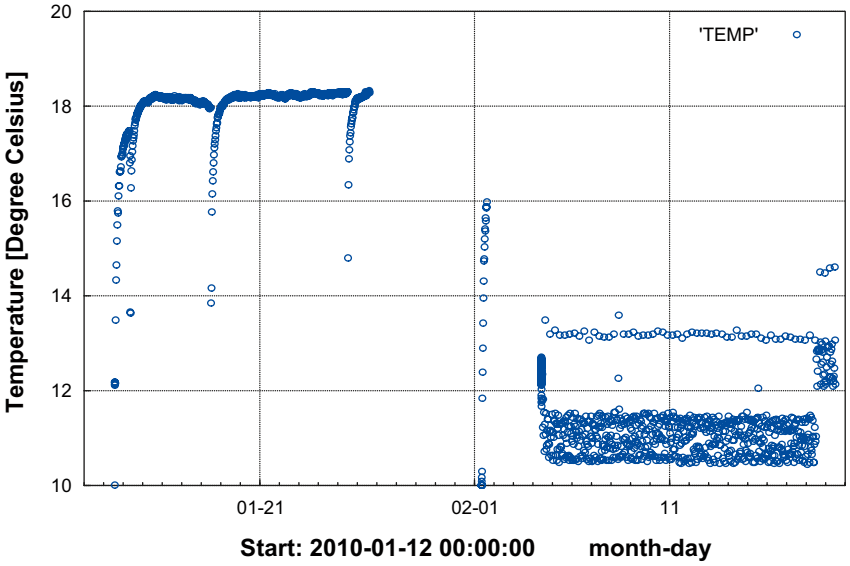


Figure A10-5. *Water temperature in the measurement cell (TEMP).*