P-04-108

Forsmark site investigation

Hydrochemical characterisation in KFM03A

Results from six investigated borehole sections: 386.0–391.0 m, 448.0–453.0 m, 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m, 980.0–1001.2 m

Pia Wacker, Anette Bergelin, Cecilia Berg
ÅF Energi och Miljö AB / Geosigma AB

Ann-Chatrin Nilsson, Geosigma AB

May 2004

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel   08-459 84 00
       +46 8 459 84 00
Fax   08-661 57 19
       +46 8 661 57 19

ISSN 1651-4416
SKB P-04-108

Forsmark site investigation

Hydrochemical characterisation in KFM03A

Results from six investigated borehole sections:
386.0–391.0 m, 448.0–453.0 m,
448.5–455.6 m, 639.0–646.1 m,
939.5–946.6 m, 980.0–1001.2 m

Pia Wacker, Anette Bergelin, Cecilia Berg
ÅF Energi och Miljö AB / Geosigma AB

Ann-Chatrin Nilsson, Geosigma AB

May 2004

Keywords: Groundwater, Measurements on line, *in-situ* sampling, Measurements *in-situ,* Redox potential, Dissolved gas, Humic and fulvic acids, Colloids, Microbes, Chemical analyses, Isotope determinations, AP PF 400-03-63, Field note nos Forsmark 204, 237, 244 and 253.

Abstract

Chemical characterisation has been conducted in six sections, 386.0–391.0, 448.0–453.0, 448.5–455.6, 639.0–646.1, 939.5–946.6 and 980.0–1001.2 m of borehole KFM03A. The characterisation has been conducted using two slightly different investigation methods, *complete chemical characterisation and sampling during pumping test.*

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

Sampling during pumping tests in core drilled boreholes implies that the pumping is performed at a flow rate of several litres per minute and that the collected water samples represent a larger bedrock volume and/or a more dominating hydraulic structure than the samples that are collected during Complete chemical characterisation. The pumping/measurement period is shorter and fewer samples are collected than in the previous method.

The results obtained from the *complete chemical characterisation* of sections 448.5–455.6, 639.0–646.1, 939.5–946.6 and 980.0–1001.2 m include on-line measurements of redox potential, pH, dissolved oxygen, electric conductivity and water temperature in the borehole section as well as chemical analyses of major constituents, trace metals and isotopes. Furthermore, gas content and composition, inorganic colloids as well as humic and fulvic acids were investigated. The results from the pumping test method performed in the two other sections, 386.0–391.0, 448.0–453.0 m, do not include redox potential, gas content and composition, and inorganic colloids by filtration technique.

The water composition was stable during the entire pumping and sampling periods in all borehole sections except 939.5–946.6 m. In this section, a slight increase in the salinity was observed during the pumping period. The chloride concentrations were approx. 5400 mg/L (386.0–391.0, 448.0–453.0, 448.5–455.6, 639.0–646.1 m), 7600–8600 mg/L (939.5–946.6 m) and 10000 mg/L (980.0–1001.2 m). Stable redox potential measurements are reported for the three sections 448.5–455.6, 639.0–646.1 and 939.5–946.6 m. The redox electrodes stabilized at approximately –176, –196 and –245 mV respectively. The reducing conditions in the groundwater of these sections were also verified by the presence of ferrous iron Fe(+II) at relatively high concentrations. In section 980.0–1001.2 m, the redox electrodes did not reach stable and credible values within the measurement period. This is probably due to the very low iron concentration in the groundwater of this section and thereby a lack of a dominating redox pair. The content of inorganic colloids was very low or nonexistent and the organic constituents were present mainly as fulvic acids and possibly other low molecular weight organic acids (citric acid, oxalic acid, etc).

Sammanfattning

Kemisk karakterisering har utförts i de sex borrhålssektionerna 386.0–391.0, 448.0–453.0, 448.5–455.6, 639.0–646.1, 939.5–946.6 och 980.0–1001.2 m av borrhålet KFM03A. Karakteriseringen har gjorts med två något olika undersökningsmetoder, *fullständig kemikarakterisering och provtagning under pumptester.*

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

Provtagning under pumptester i kärnborrhål innebär att pumpningen utförs med ett flöde på flera liter per minut och att de uttagna vattenproven representerar en större bergvolym och/eller en mer dominerande hydraulisk struktur än proven som tas ut vid Fullständig kemikarakterisering. Pump/mätperioden är kortare och färre prov tas ut än i ovanstående metod.

Resultaten som erhölls från den fullständiga kemikarakteriseringen av sektionerna 448.5–455.6, 639.0–646.1, 939.5–946.6 och 980.0–1001.2 m omfattar mätningar on-line av redoxpotential, pH, löst syre, elektrisk konduktivitet och vattentemperatur i borrhålssektionen liksom kemiska analyser av huvudkomponenter, spårelement och isotoper. Vidare undersöktes gasmängd och sammansättning, oorganiska kolloider samt humus- och fulvosyror i grundvattnet. Resultaten från pumptestmetoden som utförts i de andra två sektionerna, 386.0–391.0, 448.0–453.0 m, skiljer sig från ovanstående genom att de inte inkluderar inte redoxpotential, gasmängd och sammansättning samt oorganiska kolloider genom filtrering av *in-situ* prov.

Vattensammansättningen var stabil under hela pump- och provtagningsperioderna i samtliga borrhålssektioner utom 939.5–946.6 m. I denna sektion noterades en något ökande salinitet under pumpperioden. Kloridkoncentrationerna uppgick till ca 5400 mg/L (386.0–391.0, 448.0–453.0, 448.5–455.6, 639.0–646.1 m), 7600–8600 mg/L (939.5–946.6 m) och 10 000 mg/L (980.0–1001.2 m). Stabila redoxpotentialmätningar rapporteras för de tre sektionerna 448.5–455.6, 639.0–646.1 och 939.5–946.6 m. Redoxelektroderna stabiliserade sig vid ca –176, –196 respektive –245 mV. De reducerande förhållandena i grundvattnet i dessa sektioner verifieras också av närvaron av tvåvärt järn i relativt höga koncentrationer. I sektionen 980.0–1001.2 m nådde däremot inte redoxelektroderna stabila och trovärdiga värden under mätperioden. Detta beror förmodligen på de mycket låga järnkoncentrationerna i grundvattnet i denna sektion och därmed avsaknad av ett dominerande redoxpar. Förekomsten av oorganiska kolloider befanns vara mycket låg eller obefintlig och de organiska komponenterna förelåg huvudsakligen som fulvosyror eller andra lågmolekylära organiska syror (citronsyra, oxalsyra).

Contents

1 Introduction 7

2 Objectives and scope 9

3 Background 11
3.1 Flushing water history 11
3.2 Previous events and activities in the borehole 13
3.3 Choice of borehole sections 14

4 Equipment 17
4.1 The Pipe String System (PSS) 17
  4.1.1 Measurement container 17
  4.1.2 Downhole equipment 18
4.2 The mobile field laboratory (MFL) 19
4.3 Colloid filtering equipment 21
4.4 Equipment for enrichment of humic and fulvic acids 22
4.5 Equipment for fractionation of humic and fulvic acids 24

5 Performance 25
5.1 General 25
5.2 Overview of field work procedure 26
5.3 Performance in section 386.0–391.0 m (PSS3) 28
5.4 Performance in section 448.0–453.0 m (PSS3) 29
5.5 Performance in section 448.5–455.6 m (MFL) 30
5.6 Performance in section 639.0–646.1 m (MFL) 31
5.7 Performance in section 939.5–946.6 m (MFL) 32
5.8 Performance in section 980.0–1001.2 m (MFL) 33
5.9 Water sampling, sample treatment and analyses 34
5.10 Collection of *in-situ* water samples 35
5.11 Colloid filtration 35
5.12 Enrichment of humic and fulvic acids 36
5.13 Fractionation of humic and fulvic acids 37

6 Nonconformities 39

7 Data handling and interpretation 41
7.1 Chemmac measurement data 41
  7.1.1 Data file types and calculation software 41
  7.1.2 Calculations and evaluation of pH and redox potential 42
7.2 Water analysis data 43
7.3 Data from special sampling methods 45
  7.4.1 Colloid filtration 45
  7.3.2 Dissolved gases 45
  7.3.3 Enrichment of humic and fulvic acids 45
  7.3.4 Fractionation of humic and fulvic acids 45

8 Results 47
8.1 Chemmac measurements 47
8.2 Water analyses 48
  8.2.1 Basic water analyses 48
  8.2.2 Trace elements (rare earth metals and others) 55
  8.2.3 Stable and radioactive isotopes 55
8.3 Dissolved gas 57
8.4 Inorganic colloids 59
  8.4.1 Inorganic colloids – colloid filtration 59
  8.4.2 Inorganic colloids – fractionation 64
8.5 Humic and fulvic acids 66

9 Summary and discussion 67

10 References 69

Appendix 1 Design of cored borehole KFM03A 71
Appendix 2 Results of difference flow logging in KFM03A 73
Appendix 3 Measurement information, KFM03A 81
Appendix 4 Flow and pressure measurements in KFM03A 89
Appendix 5 Chemmac measurements (pH and electric conductivity) and water temperature in the borehole measured with the PSS equipment, section 386.0–391.0 m 93
Appendix 6 Chemmac measurements (pH and dissolved oxygen) and water temperature in the borehole measured with the PSS equipment, section 448.0–453.0 m 95
Appendix 7 Chemmac measurements (Eh, pH, electric conductivity, dissolved oxygen and temperature) section 448.5–455.6 m 97
Appendix 8 Chemmac measurements (Eh, pH, electric conductivity, dissolved oxygen and temperature) section 639.0–646.1 m 101
Appendix 9 Chemmac measurements (Eh, pH, electric conductivity, dissolved oxygen and temperature) section 939.5–946.6 m 105
Appendix 10 Chemmac measurements (Eh, pH, electric conductivity, dissolved oxygen and temperature) section 980.0–1001.2 m 109
Appendix 11 Sampling and analysis methods 113
  Table A11-1. Sample handling routines and analyses methods 113
  Table A11-2. Reporting limits and measurement uncertainties 116
  Table A11-3. Participant laboratories 118
Appendix 12 Compilation of water analysis data 119
  Table A12-1. Water composition 119
  Table A12-2. Isotopes I (H-, O-, B-, CI- and C-isotopes) 121
  Table A12-3. Trace elements 122
  Table A12-4. Isotopes II (U-, Th-, Ra- and Rn-isotopes) 124
  Table A12-5. Dissolved gases 125

1 Introduction

This document reports the performance and results from the two methods: ”Complete chemical characterisation” and “Sampling during pumping tests in core drilled boreholes” in the cored borehole KFM03A within the site investigation at Forsmark /1/. The work was conducted according to the activity plan AP PF 400-03-65 (SKB internal controlling document). The report presents hydrochemical data from the following six borehole sections:

- 386.0–391.0 m (Sampling and analyses during pumping tests in core drilled boreholes, modified method, conducted by Geosigma AB)
- 448.0–453.0 m (Sampling and analyses during pumping tests in core drilled boreholes, modified method, conducted by Geosigma AB)
- 448.5–455.6 m (Complete chemical characterisation, conducted by ÅF Energi och Miljö AB)
- 639.0–646.1 m (Complete chemical characterisation, conducted by ÅF Energi och Miljö AB)
- 939.5–946.6 m (Complete chemical characterisation, conducted by ÅF Energi och Miljö AB)
- 980.0–1001.2 m (Complete chemical characterisation, conducted by ÅF Energi och Miljö AB)

The field work was carried out during the period September 2003–April 2004. Sampling for microbe studies, based on activity plan AP PF 400-03-09 (SKB internal controlling document), was also performed within the present activity (in sections 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m). The microbe investigations are reported in /2/.

Borehole KFM03A is the third deep (1001.2 m) telescopic borehole drilled at Forsmark /3/. The borehole is located at the DS3 drilling site, shown in Figure 1-1. A detailed view of the DS3 drilling site showing the locations of borehole KFM03A, the percussion boreholes and the shallow monitoring wells is presented in Figure 1-2. The borehole section between 0–100 m is percussion drilled and the first 12 m are cased with a stainless steel casing with an inner diameter of 200 mm. The 100–1001.2 m interval is core drilled with a diameter of 77 mm. Initially, the first 100 m of the borehole did not yield much water and, therefore, a casing length of only 12 m was used instead of the usual 100 m. However, during drilling of a short (101.5 m) cored borehole, KFM03B, 12 m west of KFM03A, water bearing fractures were identified at 60–65 m depth. The technical design of KFM03A is presented in Appendix 1.

The borehole is of the so-called SKB chemical-type, see method descriptions MD 620.003 (Method description for drilling cored boreholes) and MD 610.003 (Method description for percussion drilling). An SKB chemical-type borehole requires that cleaning procedures are carried out on all downhole equipment to be used in the borehole, both during and after drilling, according to level 2 in the cleaning instructions in MD 600.004 (Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning). The mentioned method descriptions and instructions are SKB internal controlling documents.

2 Objectives and scope

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

"Sampling during pumping tests in core drilled boreholes" is primarily performed as a complementary study in order to increase the volume of hydrochemical data. The method is often used in borehole sections with a large yield of water. The water samples collected during pumping tests often represent a larger bedrock volume and/or a more dominating hydraulic structure than the samples that are collected during "Complete chemical characterisation". The method is based on sampling during pumping performed using equipment for hydraulic tests (PSS). The use of this method/equipment in two sections of KFM03A, instead of "Complete chemical characterisation", allowed investigations in boreholes KFM02A and KFM03A to be conducted at the same time.

The difference between the two methods regarding sampling and measurement activities is shown in table 2-1 below.

Table 2-1. List of sampling and measurement activities included in the two investigation methods.

Sampling or measurement activity	"Complete chemical characterisation"	"Sampling during pumping tests in core drilled boreholes"
Water sampling series including class 4 and class 5 samples.	Yes	Yes
Surface Chemmac measurement.	Yes	Yes (redox potential measurements are difficult due to heavy pumping through a pipe string and are seldom successful)
Borehole Chemmac measurement.	Yes	No
Collection of *in-situ* samples for gas, colloids and microbes.	Yes	No
Fractionation of humic and fulvic acids as well as inorganic species.	Yes	Yes
Enrichment of organic acids, determ of ∂^{13}C and pmC (percent modern carbon).	Yes	Yes

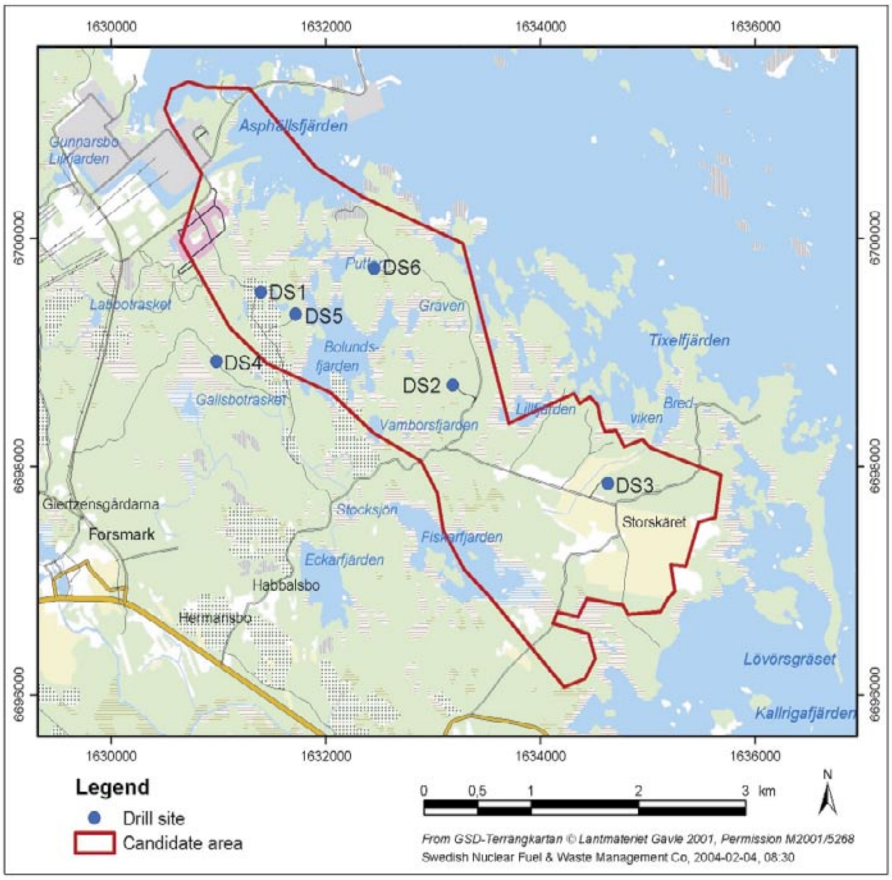


Figure 1-1. The investigation area at Forsmark (approximately the area inside the black square) including the candidate area selected for more detailed investigations. The six drilling sites for deep boreholes, DS1-6 are marked with blue circles. Borehole KFM03A is situated at DS3 drilling site.

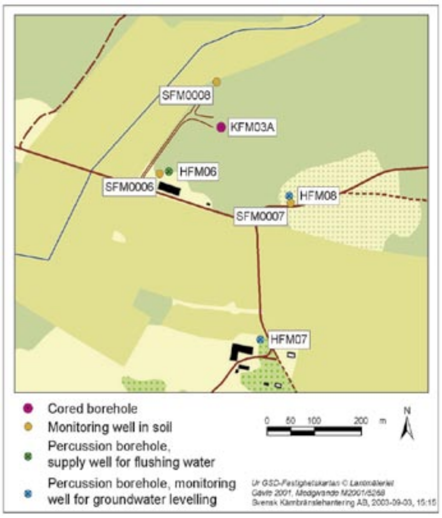


Figure 1-2. Location of the cored borehole KFM03A, the percussion boreholes and the monitoring wells at DS3 drilling site.

3 Background

3.1 Flushing water history

The percussion drilled borehole HFM06 /4/ served as a source for the flushing water used to drill borehole KFM03A. The chemical composition of the flushing water was checked before and during use. The analytical data from the supply well HFM06 are reported in /3, 5/. The core drilling of the 1000 m long borehole consumed 725 m^3 of flushing water and the volume of return water pumped from the borehole during drilling was 2806 m^3. The nominal concentration of the dye Uranine, added as a tracer to label the flushing water, was 0.2 mg/L. The Uranine concentration in the flushing water was checked regularly during the drilling and a total of 64 samples were analysed. The average Uranine concentration in the sample series was 0.147 ± 0.070 mg/L. The Uranine concentrations in the sample series of flushing water as well as return water are presented in Figure 3-1. Furthermore, the amount of Uranine added to the borehole via the flushing water and the estimated amount recovered in the return water is given in Table 3-1.

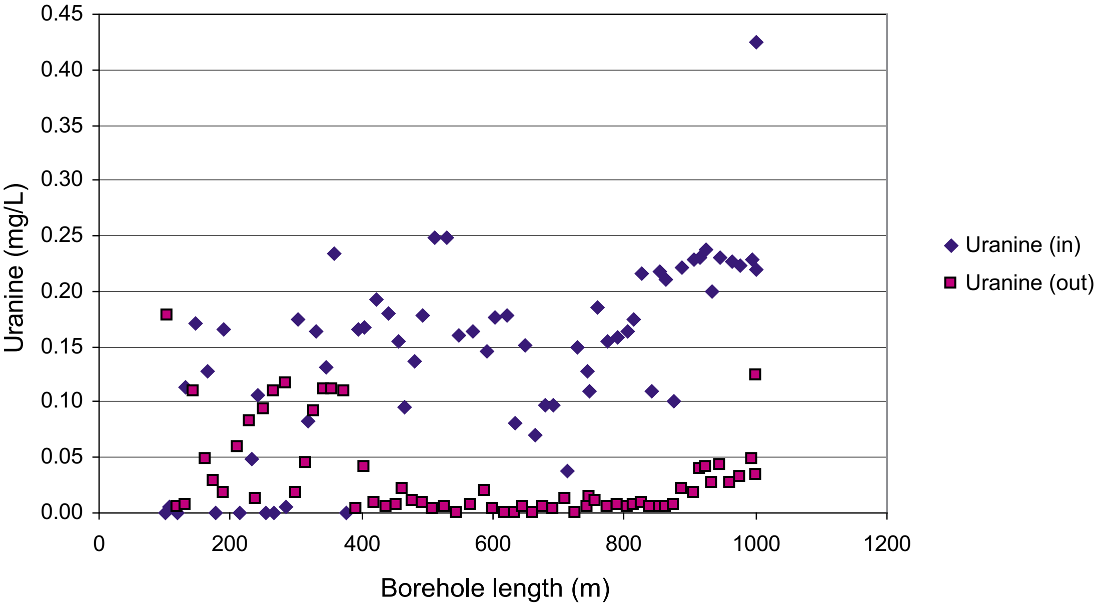


Figure 3-1. *Uranine concentrations in the flushing water and in the return water versus borehole length. The addition of Uranine was done using automatic dosing equipment which is controlled by a flow meter. After a relatively long period of problems, due to insufficient cleaning of the dosing system after terminating drilling of borehole KFM02A, the concentration of Uranine added to the flushing water was relatively constant at approximately 0.23 mg/L at the end of the drilling period.*

Table 3-1. Amount of Uranine added in KFM03A via the flushing water during core drilling and amount recovered from the contemporary mammoth pumping.

	Uranine (g)
Amount of Uranine added to the borehole via the flushing water according to the log book.	139
Amount of Uranine added to the borehole via the flushing water as calculated from average Uranine concentration and total volume of flushing water.	106
Amount of Uranine recovered in the return water as estimated from average Uranine concentration and total volume of return water.	91.1

The Uranine budget in Table 3-1 suggests that at least 106 m^3 of flushing water was lost to the borehole and the adjacent host bedrock. However, the disagreement between the calculated amount of Uranine and the added amount according to the log book demonstrates the large uncertainty in estimations using average Uranine concentrations obtained from too few samples.

As borehole KFM03A is of SKB chemical-type, the following special precautions were taken in order to minimize contamination via the flushing water:

- The supply well was also of SKB chemical-type.
- The concentration of Uranine should preferably be below 5 mg/L. Borehole HFM06 was selected as flushing water supply well with the dominant water bearing fractures situated at about 40–70 m depth and the concentration of total organic carbon (TOC) was in the range 5.1–5.8 mg/L.
- The dosing equipment for Uranine that was introduced during the drilling of KFM02A was used also in KFM03A. In this way the storage tank for flushing water after the UV-system could be omitted.

Analysis of microbe content in the flushing water was not performed during the drilling of KFM03A.

3.2 Previous events and activities in the borehole

KFM03A is an SKB chemical-type core borehole intended for complete hydrochemical characterisation. Only investigations that are necessary in order to select suitable borehole sections are carried out in the borehole prior to the chemistry campaign. The more equipment that is used in the borehole, the greater is the risk of contamination and effects on the *in-situ* microbiological conditions. The activities/investigations performed in KFM03A prior to the chemistry campaign are listed in Table 3-2 below.

Table 3-2. Activities performed in borehole KFM03A prior to, or related to the hydrochemical characterisation.

Activities performed	Date of completion	Length or section (m)	Comment
Percussion drilling	2003-03-24	0–100.34	–
Casing installed	2003-03-25	0–12	No initial hydraulic test was performed in the percussion drilled part of the borehole (0–100 m). The reason was that only a minor water yield could be recognized. As this part of the borehole was considered tight/dry, a shorter casing than usual was installed and the gap was grouted.
BIPS logging	2003-03-26	0–100	–
Core drilling	2003-06-23	100.34–1001.19	HFM06 was the source of flushing water for drilling the cored part of KFM03A. HFM06 is an SKB chemical-type borehole /3, 4, 5/.
Water sampling, Wireline sond	2003-05-06 2003-05-12	345.45–393.65 at 450 m	SKB no 4768 (9.5% flushing water) Sampling test conducted, no sample.
Flushing water treatment	–	–	The automatic dosing of Uranine that was introduced in KFM02A, was used also during the drilling of KFM03A. In this way no storage tank was needed after the UV-system /3/.
Mammoth pumping	2003-06-23 to 06-25	0–1001.19	Several starts and stops, total volume 250 m^3.
Hydrochemical logging	2003-06-30	994	High flushing water content in the central part of the borehole. The flow yielding fractures at depth were indicated by the decreased flushing water content at the bottom of the borehole /6/.
BIPS-logging	2003-08-03	101–999.5	Drilling debris in the water, no logging between 450.8–850 m.
Difference flow logging	2003-08-26	101–1001.19	–
BIPS-logging	2003-09-01	101–997.1	/7/
Geophysical logging	2003-10-13	101 – 981.7	/7/
Hydrogeochemical characterisation including sampling for microbe investigation in sections 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m	2004-04-27	–	Presented in this report.
Microbe investigation	–	–	/2/
Hydraulic evaluation of pumping activities	–	–	The electric conductivity values obtained at the flow logging occasion were consistently about 1000 mS/m higher than the corresponding values from the chemical investigation. This fact caused a special evaluation to be conducted /8/.

3.3 Choice of borehole sections

Borehole KFM03A is the first, of the boreholes drilled so far, to have water yielding fractures at great depth. Five water bearing fractures/fracture zones that were possible to investigate, are well spread along the borehole and were identified using the difference flow logging, see Appendix 2 and the list in Table 3-3.

Table 3-3. Significant water yielding fractures/fracture zones identified from difference flow logging of KFM03A. Listed flow rates were obtained from pumping one metre sections at a drawdown of approximately 10 m. All the listed fractures/fracture zones were selected and investigated.

Borehole length (m)	Approximate flow rate (L/h)
387.5–388.5	200 L/h, several fractures with a smaller water yield (10 L/h) are located between 357–385 m.
449.5–451	100
642–644	40
942–944	8
984–995	5 L/h, mainly two water yielding fractures

Sections 386.0–391.0 m and 448.0–453.0 m were selected in order to investigate the most dominant water inflows into the borehole. Pumping/sampling using the hydraulic test equipment as an alternative to the ordinary mobile chemical laboratory was preferred as the water yields were large, allowing high pumping flow rates. Furthermore, the mobile chemical laboratory was not available at the time (it was used for investigations in borehole KFM02A). The calculated hydraulic transmissivity (T) for the two borehole sections are given in Table 3-4. The range $T > 10^{-6}$ m^2/s is optimal for the PSS equipment. The flow logging diagrams covering the sections are given in Appendix 2.

Sections 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m were considered important to investigate in order to obtain chemical information at depth and therefore selected for complete hydrochemical characterisation using the mobile field laboratory. The fractures/zones are narrow and discrete and a section length of 7 m could be used in all cases except 980.0–1001.2 m. Here it was suitable to place a single packer at 980.0 m and let the bottom of the borehole constitute the lower section limit. The calculated hydraulic transmissivity (T) for the three borehole sections are given in Table 3-4. The range $T=10^{-8}$ to $T=10^{-6}$ m^2/s is optimal for the Mobile Field Laboratorium (MFL) equipment. The flow logging diagrams covering the sections are given in Appendix 2.

During the investigation in section 448.0–453.0 m, it appeared that the water yield was not as large as shown by the preceding difference flow logging. As a consequence, the pumping flow rate obtained was too low for the pump and water had to be re-circulated, resulting in sub-optimal water sampling conditions. Furthermore, since the remaining flushing water content was too high (approx 5%) in the last sample from KFM02A (i.e. section 509.0–516.1 m: repository depth), there was a desire to investigate one more section in detail at repository depth. Therefore, repeated investigations were performed in the fracture at 450 m, now included within section 448.5–455.6 m. The calculated hydraulic transmissivity (T) for the borehole section is presented in Table 3-4. The flow logging diagram covering the section is given in Appendix 2.

Table 3-4. Calculated hydraulic transmissivity (T) for the selected borehole sections.

Section (m)	T (m^2/s) /8/	Comment
386.0–391.0 obtained	2×10^{-4}	A transmissivity value between 2×10^{-4} and 3×10^{-4} m^2/s was later from the pumping/measurements with PSS3.
448.0–453.0	7×10^{-6}	A transmissivity value between 1×10^{-6} and 2×10^{-6} m^2/s was obtained later from the pumping/measurements with PSS3. The reason for the disagreement is not understood so far.
448.5–455.6	7×10^{-6}	The fracture at 451.3 m is dominating.
639.0–646.1	2.5×10^{-6}	
939.5–946.6	3.3×10^{-7}	
980.0–1001.2	3.1×10^{-7}	

4 Equipment

4.1 The Pipe String System (PSS)

The SKB Pipe String System (PSS) consists of a measurement container and downhole equipment. The system is normally used for hydraulic pumping tests but in this case it was used for pumping and chemical sampling. The equipment is described in SKB MD 345.100–124 (Pipe String System, SKB internal controlling document). The PSS unit was combined with a separate chemistry unit for computer work and Chemmac measurements (MYC). This unit is described in SKB MD 434.007 (Mätsystembeskrivning för mobil ytChemmac, SKB internal controlling document) and SKB MD 433.018 (Mätsystembeskrivning för dataapplikation, SKB internal controlling document). The Chemmac measurement system in the MYC unit includes communication systems, measurement application and a flow-through cell with electrodes and sensors at the ground surface. The PSS3 equipment is designed for flow rates between 5 and 30–40 L/min. In order to pump at lower flow rates down to 1 L/min, it is necessary to re-circulate pumped water to the pump.

The units used in borehole KFM03A consisted of the hydrotest unit PSS3 and the MYC3 unit for computer work and surface Chemmac measurements. The laboratory unit L3 was used for analytical work. However, since the laboratory unit was not placed at the drilling site it was not directly connected to the outlet of the pumped water during pumping of sections 386.0–391.0 m and 448.0–453.0 m.

4.1.1 Measurement container

The PSS is primarily designed for pumping and injection tests in packed off borehole sections. All equipment needed to perform the tests is located in a steel container placed on pallets in order to ensure a suitable working level in relation to the borehole casing. The container is divided into a computer room and a workshop compartment, see Figure 4-1.

The hoisting rig is hydraulically operated and is a chain-feed type. The jaws holding the pipe string are opened hydraulically and closed mechanically by springs. The rig is equipped with a load transmitter, maximized at 22 kN, and a limiting value for the load may be adjusted.

Packers and test valve are operated hydraulically by water-filled pressure vessels. Expansion and release of packers, as well as opening and closing of the test valve, is done by magnetic valves controlled by the software in the data acquisition system.

The PSS3-unit is also supplied with a system for water injection tests.

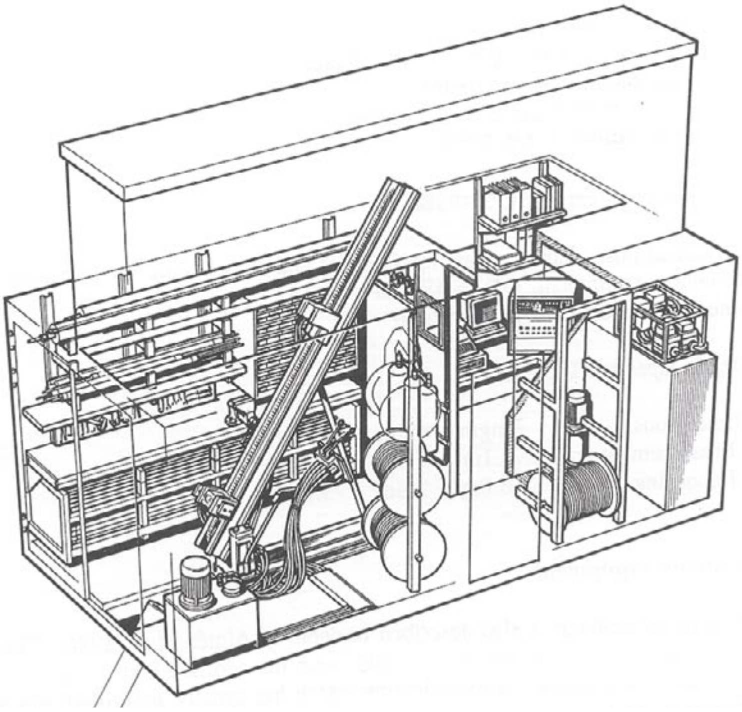


Figure 4-1. Outline of the PSS3 container with equipment.

4.1.2 Downhole equipment

A schematic drawing of the downhole equipment is shown in Figure 4-2. The pipe string consists of 3 m lengths of aluminium pipes with an inner diameter of 21 mm connected by stainless steel taps sealed with double o-rings. The test section is constructed from 5 m pipe lengths and can be adjusted to investigate 5, 20 or 100 m borehole sections; this conforms to available lengths of electric cable. The pressure is measured above (P_a), within (P) and below the test section (P_b), which is isolated by two packers. The groundwater temperature in the test section is also measured. The hydraulic connection between the pipe string and the test section can be closed or opened by a test valve operated by the measurement system.

At the lower end of the borehole equipment, a level indicator (caliper type) gives a signal when the borehole reference length marks, which are milled into the borehole wall at regular intervals, are passed.

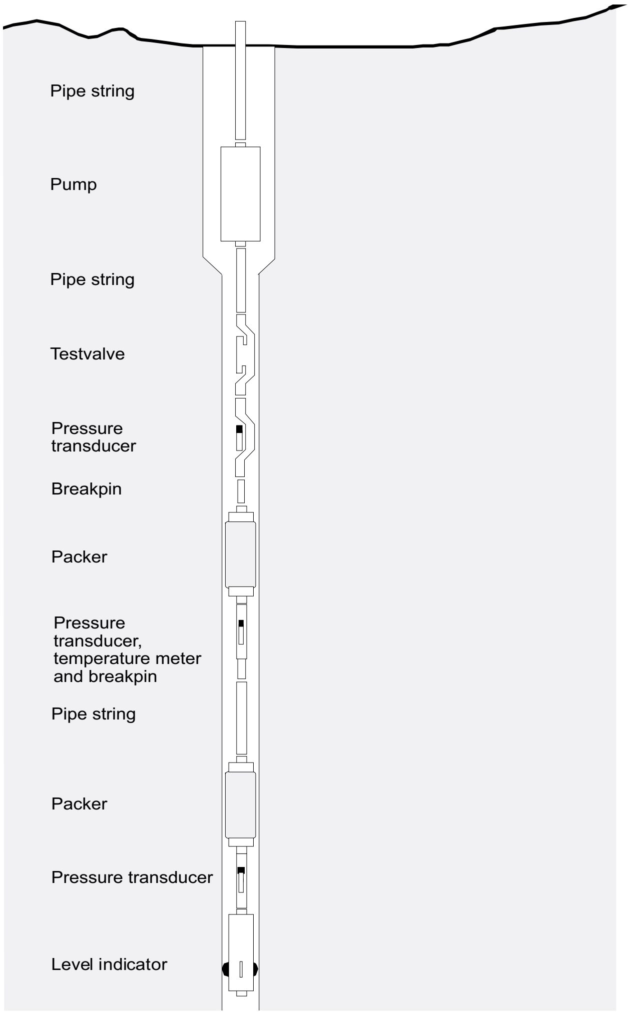


Figure 4-2. *Schematic drawing of the downhole equipment comprising the PSS3 system.*

4.2 The mobile field laboratory (MFL)

The mobile field laboratories used by SKB for water sampling and downhole measurements consist of a laboratory unit, a hose unit with downhole equipment and a Chemmac measurement system; the system is presented schematically in Figure 4-3. It is also possible to include a separate unit for computer work (MYC). The different parts of the system are described in the SKB internal controlling documents SKB MD 434.004, 434.005, 434.006, 434.007 and SKB MD 433.018 (Mätsystembeskrivningar för mobil kemienhet allmän del, slangvagn, borrhålsutrustning, mobil ytChemmac och dataapplikation).

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

The downhole equipment consists of inflatable packers, pump, borehole Chemmac and the *in-situ* sampling unit (PVP), allowing measurement (borehole Chemmac) and sampling *in-situ* in the borehole section (PVP sampling unit). The four sample portions collected with the PVP sampling unit maintain the pressure from the borehole section when lifted to the surface. The portions are used for colloid filtration, gas analyses and microbe investigations.

The mobile units used in borehole KFM03A consisted of the hose unit S3, the laboratory unit L3 and the MYC 3 unit for computer work. However, the laboratory unit was not placed at the drilling site and thus not directly connected to the outlet of the pumped water during the pumping of section 639.0–646.1m. The equipment used for colloid filtration, enrichment of humic and fulvic acids and fractionation of humic and fulvic acids are described below.

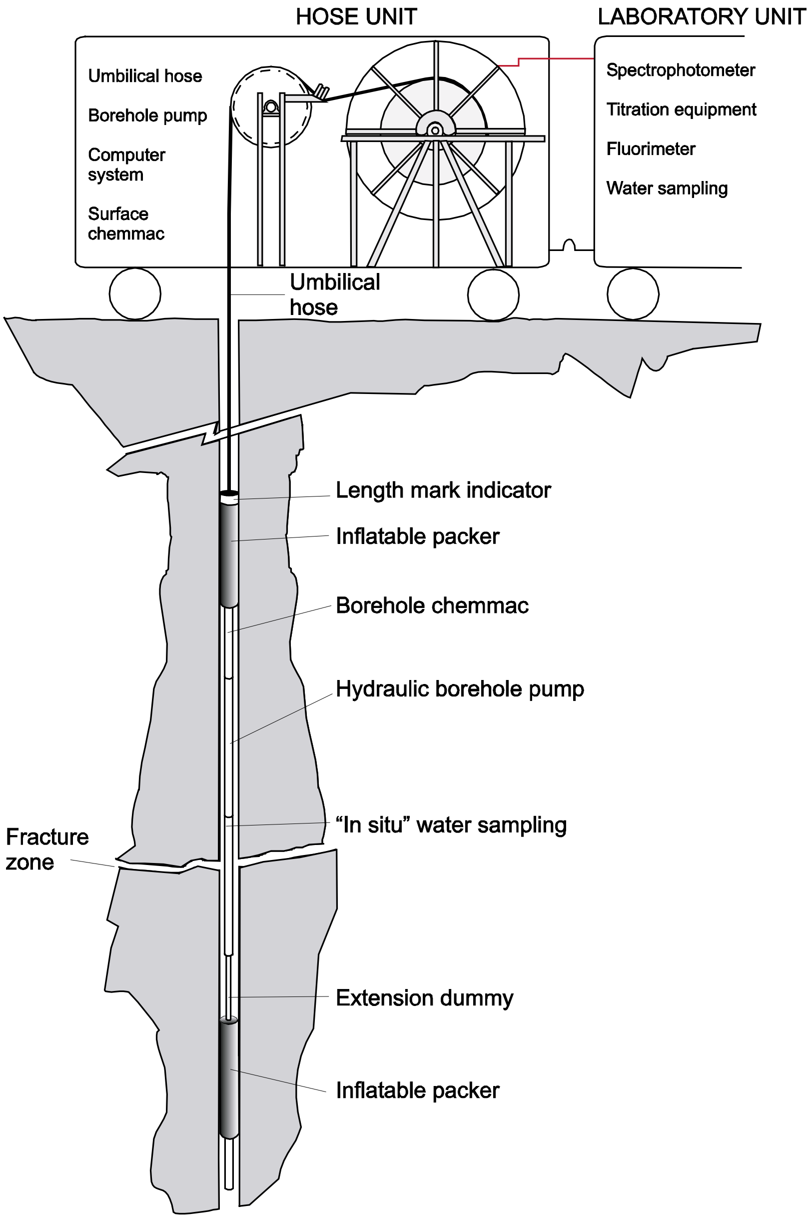


***Figure 4-3.** The mobile chemistry laboratory including laboratory unit, hose unit and downhole equipment. The configuration of the downhole units in the borehole can be varied depending on desired section length. However, the in-situ water sampler must always be positioned first in the sample water path.*

Some crucial differences between the PSS and the MFL equipment exist which require clarification;

- The sample water channel/tube of the umbilical hose in the hose unit of the mobile field laboratory has an inner diameter of 4 mm. The pipe string in the PSS3 equipment is 21 mm.
- The pipe string is made of aluminium, while the sample water channel/tubing is made of polyamide.
- The maximum flow rate possible with the hose unit pump is in the range of 200–250 mL/min, while the pipe string system has a maximum flow rate of 30–40 L/min (only about 200 mL/min is led through the surface Chemmac).
- At low flow rates it is necessary to re-circulate the pumped water to the PSS pump.

4.3 Colloid filtering equipment

The colloid filtering system is still at the development stage. The equipment is adapted to the sample containers (PVB) from the PVP water sampling unit. The colloid filtering equipment consists of holders for two PVB-containers, a separated tube and valve system for water and gas, a filter holder package for five filters, and a collecting container. The pore sizes of the five connected filters are 0.4, 0.4, 0.2, 0.05 and 0.05 µm. The equipment is described in SKB MD 431.045 (Mätsystembeskrivning för kolloidfiltreringssystem, handhavandedel (SKB internal controlling document to be published)). Figure 4-4 shows the equipment set up.

The major equipment features are:

- Filtering is performed in a closed system under an argon atmosphere, thus avoiding the risk of iron precipitation due to contact between the groundwater sample and air.
- Filtering is performed at a pressure similar to that of the groundwater in the borehole section. The system is adjusted to create a pressure difference between the inlet of the filter package and the outlet side. The pressure difference drives the sample water through the filters.
- The design of the sample containers, and the mounting with the outlet at the top, prevents migration of larger particles which may clog the filters. Furthermore, clogging is prevented by the first two filters with pore sizes 0.4 µm which are mounted parallel to each other.

Disadvantages/drawbacks, which may cause modifications of the equipment later on, are:

- The sample volume is limited to a maximum of 2×190 mL.
- The PVB sample containers are made of stainless steel which may contaminate the samples. If the method proves to be successful, an improvement could be to use Teflon coating on the insides of the cylindrical containers.

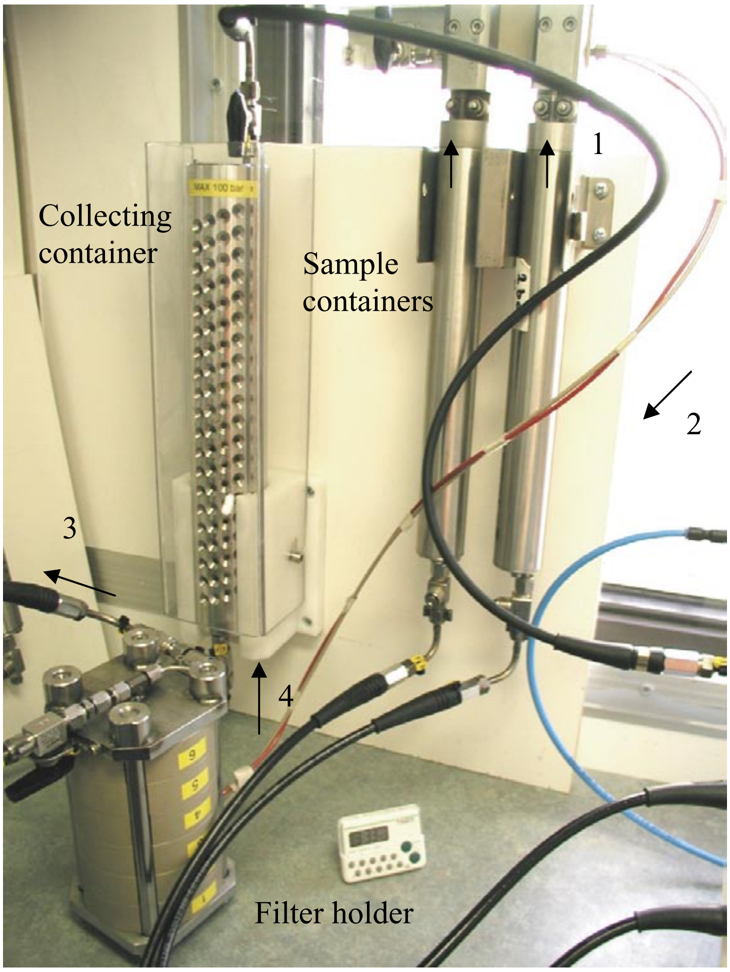


Figure 4-4. *The colloid filtering equipment including the sample containers, the filter holder package and the collecting container. The black arrows, 1 to 4, show the flow direction of the sample water through the system.*

4.4 Equipment for enrichment of humic and fulvic acids

Enrichment of humic and fulvic acids is conducted in order to collect enough material to determine $\partial^{13}C$ and pmC (percent modern carbon) on organic constituents in the groundwater. The equipment for enrichment includes a porous column filled with an anion exchanger (DEAE-cellulose) and a textile filter with a well-defined pore size. The textile filter is placed inside the column in order to prevent the ion exchange resin from diffusing through the column. The equipment and performance is described in SKB MD 431.044 (Mätsystembeskrivning för uppkoncentrering av humus- och fulvosyror, SKB internal controlling document). Figure 4-5 shows the equipment setup. Since the ion exchange resin in the column creates a counter-pressure, which disturbs the water flow through the surface Chemmac, a pump was used in sections 448.5–455.6 m, 639.0–646.1 m and 980.0–1001.2 m for pumping a portion of the outlet water through the column (approximately 2.4 L/hour).

Figure 4-5. *The ion exchange column mounted to the outlet of pumped groundwater from the borehole section.*

4.5 Equipment for fractionation of humic and fulvic acids

The equipment consists of membrane filters with a defined cut-off (pore size), a membrane pump, flexible tubing and vessels. Generally, one water sample from each section is filtered through two filters with different pore sizes (1000 D and 5000 D, D=Dalton, 1D=1 g/mol). The equipment and performance are described in SKB MD 431.043 (Mätsystembeskrivning för fraktionering av humus- och fulvosyror, SKB internal controlling document). Figure 4-6 shows the equipment setup.

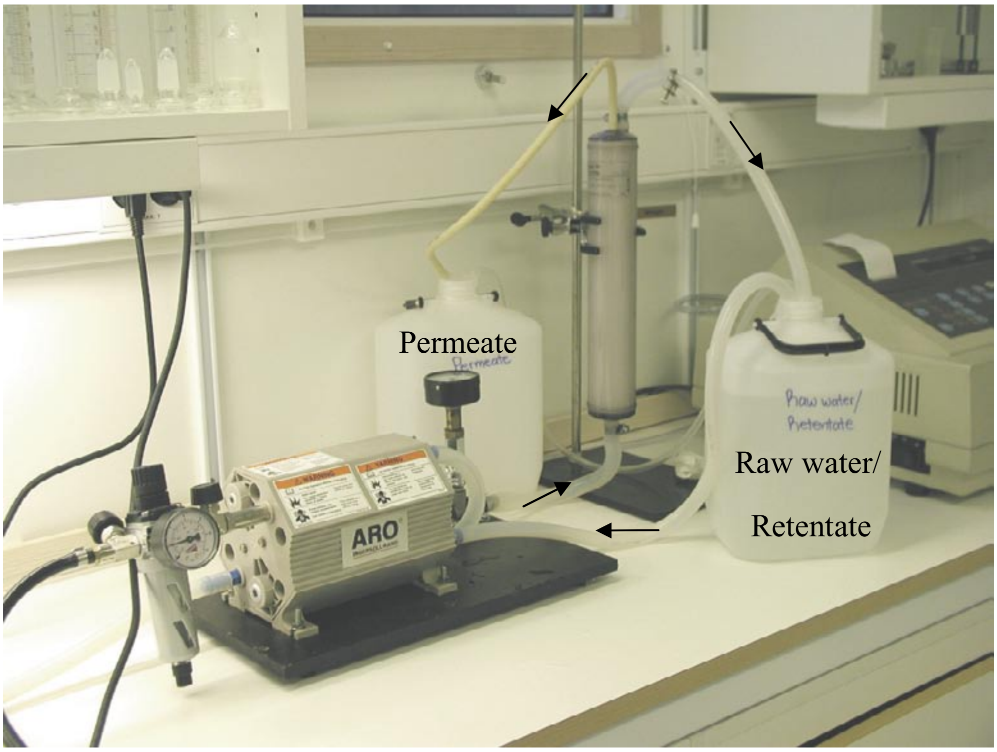


Figure 4-6. *Equipment for fractionation of humic and fulvic acids.*

5 Performance

5.1 General

Chemical characterisation of the six sections in borehole KFM03A was performed according to activity plan AP PF 400-03-63 (SKB internal controlling document) following the methods described in SKB MD 430.017 and SKB 430.018 (Metodbeskrivning för fullständig kemikarakterisering med mobilt fältlaboratorium and Metodbeskrivning för provtagning under pumptester i kärnborrhål, SKB internal controlling documents). The investigations in sections 386.0–391.0 m and 448.0–453.0 m were mainly based on the method outlined in SKB MD 430.018 (sampling during pumping tests in cored boreholes). As no actual pumping tests were performed, there was no need to follow standard pumping test procedures. Consequently, the pumping time could be prolonged and the sampling extended compared to the method description.

An overview of the investigation sequence is given in Table 5-1.

Table 5-1. Investigation sequence in KFM03A.

Start date/ Stop date	Investigation	Section (m)	Comment
2003-09-11/ 2003-10-09	Sampling during pumping tests, PSS3	386.0–391.0	Pumped volume = 944.5 m^3
2003-10-09/ 2003-10-27	Sampling during pumping tests, PSS3	448.0–453.0	Pumped volume = 42.4 m^3
2003-11-14/ 2003-12-09	Complete chemical characterisation	980.0–1001.2	Section between upper packer and bottom of the borehole. High flushing water content. Slow decrease. Pumped volume = 3.1 m^3
2004-01-14/ 2004-01-14	Geophysical logging (radar)	102–810	Interruption of chemical investigation.
2004-01-28/ 2004-02-24	Complete chemical characterisation	639.0–646.1	Pumped volume = 7.2 m^3
2004-02-25/ 2004-03-29	Complete chemical characterisation	939.5–946.6	Pumped volume = 6.2 m^3
2004-03-31/ 2004-04-27	Complete chemical characterisation	448.5–455.6	Pumped volume = 6.6 m^3

5.2 Overview of field work procedure

A short chronological summary of the different steps that constitute chemical characterisation of groundwater in a borehole section is given below. The procedure for the method *Sampling during pumping tests is basically the same as for Complete chemical characterisation,* except that no downhole measurements or *in-situ* sampling can be conducted. The parts of text below given in italic are valid for the complete chemical characterisation of the sections 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m but not for the pumping/measurements in sections 386.0–391.0 m and 448.0–453.0.

The preparations conducted before lowering of the downhole equipment include:

- *Cleaning of the inside of the sample water channel in the umbilical hose. (Before lowering to section* 639.0–646.1 m, *the hose was cleaned using 0.5 M HNO_3, followed by rinsing to neutral pH by de-ionised de-oxygenated water. For the other three sections, only de-ionised deoxygenated water was used both for cleaning and for rinsing.) Finally, the sample water channel is filled with de-ionised and de-oxygenised water prior to the lowering.*
- *Cleaning and preparation of the four sample containers (PVB) belonging to the in-situ water sampling unit (PVP). The containers are cleaned using 70% denatured ethanol. One of the containers is used for microbe sampling and sterile conditions are desirable. The containers are purged with nitrogen gas and a small nitrogen gas pressure is maintained in the containers. The magnitude of the pressure depends on the depth of the section to be sampled.*
- *Calibration of pH and redox electrodes in the borehole Chemmac.*

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

- The outside of the umbilical hose/pipe string is cleaned with 70% denatured ethanol (SKB MD 600.004).
- *Calibration of the umbilical hose length is conducted at least once for each borehole. For this, a length mark detector unit (caliper) is mounted together with the regular downhole equipment, see Figure 4-2. The length mark detector indicates length calibration marks milled into the borehole wall with a distance of (normally) 50 m /3/. At each indication, a reading is made of the corresponding length mark on the umbilical hose.* The length calibration for the pipes in the PSS equipment is made at each section. At the lower end of the borehole equipment, the same calliper type of level indicator transmits a signal when a reference depth mark is passed. The correct distance to each length mark is obtained from the SICADA database.

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

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

- Careful attention is paid in order to ensure that the packed off section is well isolated from the rest of the borehole. A significant drawdown in the section during pumping is one indication that the section is isolated. Leakage would cause pumping of water from the borehole column above and/or below the packers and not only from the fracture zone of interest. However, the drawdown in the borehole section must not be too large since the greater the drawdown, the larger the bedrock volume affected by the pumping and the risk of mixing with water from other fracture systems increases. The pumping flow rate is adjusted depending on the flow yield from the fracture or fracture zone (to between 50 and 300 mL/min using MFL, or as high as possible using PSS) and maintained more or less constant during the pumping and measurement period.

- Water samples are collected regularly once or twice a week during the pumping period. Changes in water composition are monitored by conductivity measurements and by immediate analyses at the site.

- Enrichment of humic and fulvic acids is conducted for as long time as possible in each section. The time needed depends on the carbon concentration in the water and the flow rate through the ion-exchanger. Generally, a period of at least two weeks is needed to collect the amount of carbon required to determine $\partial^{13}C$ and pmC.

- Fractionation of humic and fulvic acids, as well as inorganic species to determine the size distribution, is performed at the end of the pumping period.

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

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

- *Collection of in-situ samples prior to lifting the equipment. The valves to the PVB sampling containers in the borehole section are opened from the surface in order to rinse the system and fill the containers. After a few hours, the valves are closed and the water sample portions for analyses of colloids, dissolved gases and microbes are contained.*

- Following stopping of the borehole pump and deflation of the packers, the equipment is lifted and the different downhole units are de-assembled.

- Calibration of the electrodes in *the borehole Chemmac* and surface Chemmac. The final calibration for a section can be used as the initial calibration for the next section.

5.3 Performance in section 386.0–391.0 m (PSS3)

The pumping/measurement and water sampling in section 386.0–391.0 m were performed using the PSS3 unit in combination with the MYC3 unit.

Due to a pump failure the pumping/measurement period was divided in two phases. The flow rate at the start of the first phase was about 30 L/min. Thereafter, the flow rate decreased to about 19 L/min at the end of the first pumping phase. During the second pumping phase the flow rate decreased from 30 L/min to about 28.5 L/min. The pumping was performed at a relative constant drawdown of 1.5 m. Diagrams showing flow rate and pressures during the pumping/measurement period are given in Appendix 4, Figures A4-1 and A4-2. The total pumped volume discharged from the section was 944.5 m^3.

The events during the investigation are listed in Table 5-2.

Table 5-2. Events during the pumping/measurement period in section 386.0–391.0 m.

Date	Events *Improvement/deviation*	SKB sample no
030911	Preparation of section (386.0–391.0 m).	
	Start of pumping with PSS3.	
	Calibration of surface Chemmac.	
030916	Change from ball valve to needle valve.	
	Start of Chemmac measurements.	
	Water sampling: SKB class 4.	4983
030917	Adjustment of flow (to a higher flow).	
030918	Repair of loose plug in surface Chemmac.	
030919	Humic and fulvic acids; enrichment start.	
030923	Water sampling: SKB class 4.	8008
030924	*Restart of PSS3 due to pump failure.*	
031002	Water sampling: SKB class 4.	8011
	Humic and fulvic acids; fractionation 1 kD.	8012
	Ventilation of flow paths in order to try to bring about an improvement of the redox measurements.	
031003	Humic and fulvic acids; fractionation 5 kD.	8012
031006	Water sampling: SKB class 5.	8012
031007	Humic and fulvic acids; enrichment stop and eluation.	8012
	End of Chemmac measurements.	
	Lifting. Calibration of surface Chemmac.	

5.4 Performance in section 448.0–453.0 m (PSS3)

The pumping/measurements and water sampling in section 448.0–453.0 m were performed using the PSS3 unit in combination with the MYC3 unit.

Due to an electrical power failure, the pumping/measurement period was divided in two parts. Before the power failure the flow rate was about 2.0 L/min and after about 2.4 L/min. The pumping was performed at a constant drawdown of about 30 m. Diagrams showing the flow rate and pressures during the pumping/measurement period are given in Appendix 4, Figures A4-3 and A4-4. The total pumped volume from the section was 42.4 m^3.

The events during the investigation are listed in Table 5-3.

Table 5-3. Events during the pumping/measurement period in section 448.0–453.0 m.

Date	Events *Improvement/deviation*	SKB sample no
031007	Calibration of surface Chemmac.	
031009	Preparation of section (448.0–453.0).	
	Start of pumping with PSS3.	
	Start of Chemmac measurements.	
031010	Humic and fulvic acids; enrichment start.	
031017	Water sampling: SKB class 4.	8015
031021	Humic and fulvic acids; fractionation 5 kD.	8017
031022	*Failure in the electrical power supply to drilling site 3.*	
	Restart of PSS3.	
	Humic and fulvic acids; enrichment stop.	
031023	Humic and fulvic acids; enrichment eluation.	8017
031024	Humic and fulvic acids; fractionation 1 kD.	8017
	Water sampling: SKB class 5.	8017
	During water sampling it was observed that the Chemmac application had not been restarted after t he power failure.	
031027	End of Chemmac measurements.	
	Lifting.	
	Calibration of surface Chemmac.	

5.5 Performance in section 448.5–455.6 m (MFL)

The investigations in section 448.5–455.6 m were performed using the mobile field laboratory units. The configuration of the downhole equipment in the borehole was, from the top: umbilical hose, borehole Chemmac, upper packer, borehole pump, *in-situ* water sampler (PVP) and lower packer, see Appendix 3. The pressures above and within the section were measured by the borehole Chemmac unit and the PVP water sampling unit, respectively.

The pumping was performed at a flow rate of about 230 mL/min. A diagram showing the pressures within and above the borehole section and the flow rate during the pumping/measurement period is presented in Appendix 4, Figure A4-5. The total pumped volume from the section was 6.6 m^3.

The events during the investigation are listed in Table 5-4.

Table 5-4. Events during the pumping/measurement period in section 448.5–455.6 m.

Date	Events *Improvement/deviation*	SKB sample no
040330	Calibration of borehole Chemmac.	
040331	Lowering of downhole equipment (448.50–455.62 m).	
	Start of Chemmac measurements.	
	Calibration of surface Chemmac.	
040401	Lifting. No contact with electrodes.	
	Lowering of downhole equipment (448.50–455.62 m).	
040402	Lifting.	
	No flow, problem with borehole pump. Cleaning of non-return valve (backventil). The loss of flow was caused by drilling debris in the check valve. The downhole equipment was lifted to the surface and the check valve was rinsed from drilling debris.	
	Lowering of downhole equipment (448.50–455.62 m).	
040405	Sample water is not led through the surface Chemmac due to drilling debris present in the water.	
040407	Sample water is re-connected to the surface Chemmac.	
040413	Humic and fulvic acids; enrichment start.	
040415	Problem with the connection to the borehole Chemmac.	
	Water sampling: SKB class 5.	8282
040419	Disconnection of electrical supply to the umbilical hose.	
040421	No contact with the measurement system. The measurement system is restarted.	
040422	Loss of flow observed, flow was lost at about 16:00 on the 21st according to the measurement application. Preparation for lifting the downhole equipment.	
	Broken spring in borehole pump. Replacement of spring.	
	Repeated contact problems with the downhole equipment and high power consumption. After lifting the equipment, the cable between the hose and multi coupling is re-soldered.	
040423	Humic and fulvic acids; enrichment stop.	
040426	Humic and fulvic acids; fractionation 5 kD.	8284
040427	Water sampling: SKB class 5.	8284
	Humic and fulvic acids; fractionation 1 kD.	8284
	PVP-sampler: opening of valve at 14:39.	

040428	PVP-sampler: closure of valve at 05:16.	
	<u>End of Chemmac measurements.</u>	
	<u>Lifting.</u>	
	When lifting the equipment the borehole-cone follows. While removing the cone a tear was made in the umbilical hose.	
	Sampling of microbes and dissolved gases.	
	Sampling of colloids.	
	During colloid filtration there was a small leakage of water and gas from PVB 013 and no water reached the collection container. The filtration was stopped and the equipment was cleaned. At the second attempt to filtrate the colloids, only PVB 205 was used and a sample could be collected. The remaining water in PVB 205 contained many small particles.	
	Colloid filtration.	8284
	Calibration of borehole Chemmac.	
	Calibration of surface Chemmac.	
040429	Humic and fulvic acids; enrichment eluation.	8284
	*A *.MI file with comments is missing (KFM03A0419448K.MI). See deviation report.*	

5.6 Performance in section 639.0–646.1 m (MFL)

The investigations in section 639.0–646.1 m were performed using the mobile field laboratory units. The configuration of the downhole equipment in the borehole was, from the top: umbilical hose, borehole Chemmac, upper packer, borehole pump, *in-situ* water sampler (PVP) and lower packer, see Appendix 3. The pressures above and within the section were measured by the borehole Chemmac unit and the PVP water sampling unit, respectively.

The pumping was performed at a flow rate of about 200 mL/min. A diagram showing the pressures within and above the borehole section and the flow rate during the pumping/measurement period is presented in Appendix 4, Figure A4-6. The total pumped volume from the section was 7.2 m^3.

The events during the investigation are listed in Table 5-5.

Table 5-5. Events during the pumping/measurement period in section 639.0–646.1 m.

Date	**Events** ***Improvement/deviation***	**SKB sample no**
040127	Calibration of borehole Chemmac.	
040128	<u>Lowering of downhole equipment (639.00–646.12 m).</u>	
	<u>Start of Chemmac measurements.</u>	
040203	Calibration of surface Chemmac.	
040204	Water sampling: SKB class 2.	8158
	Restart of measurement application.	
040206	Water sampling: SKB class 4.	8265
040211	Water sampling: SKB class 5.	8268
040213	Water sampling: SKB class 4.	8270
040217	Humic and fulvic acids; enrichment start.	
040219	Humic and fulvic acids; fractionation 1 kD.	8273

040220	Humic and fulvic acids; fractionation 5 kD.	8273
	Water sampling: SKB class 5.	8271
040223	Water sampling: SKB class 5.	8273
	PVP-sampler: opening of valve at 12:04.	
040224	PVP-sampler: closure of valve at 07:01.	
	Humic and fulvic acids; enrichment stop and eluation.	8273
	End of Chemmac measurements.	
	Lifting.	
	Sampling of microbes and dissolved gases.	
	Sampling of colloids.	
	Colloid filtration.	8273
	Water at the gas side of the PVB containers, 022 and 023, was observed during colloid filtration.	
	Non-borehole water did probably intrude into the column for enrichment of humic and fulvic acids, placed inside the hose unit. The sample was, however, sent for analysis.	
	Calibration of borehole Chemmac.	
040225	Calibration of surface Chemmac.	

5.7 Performance in section 939.5–946.6 m (MFL)

The investigations in section 939.5–946.6 m were performed using the mobile field laboratory units. The configuration of the downhole equipment in the borehole was, from the top: umbilical hose, borehole Chemmac, upper packer, borehole pump, *in-situ* water sampler (PVP) and lower packer, see Appendix 3. The pressures above and within the section were measured by the borehole Chemmac unit and the PVP water sampling unit, respectively.

The pumping was performed at a flow rate of about 200 mL/min. A diagram showing the pressures within and above the borehole section and the flow rate during the pumping/measurement period is presented in Appendix 4, Figures A4-7. The total pumped volume from the section was 6.2 m^3.

The events during the investigation are listed in Table 5-6.

Table 5-6. Events during the pumping/measurement period in section 939.5–946.6 m.

Date	Events *Improvement/deviation*	SKB sample no
040224	Calibration of borehole Chemmac.	
040225	Lowering of downhole equipment (939.50–946.62 m).	
	Start of Chemmac measurements.	
040226	Calibration of surface Chemmac.	
	Water sampling: SKB class 2.	8274
040303	Problem with the flow. Filling of water into the borehole pump seems to resolve the problem.	
	Water sampling: SKB class 4.	8275
040305	Water sampling: SKB class 5.	8276
040308	Water sampling: SKB class 4.	8277
040311	Water sampling: SKB class 5.	8278

040315	Water sampling: SKB class 4.	8279
040319	No flow, problem with borehole pump.	
040322	*Lifting. Leak detection. Defect spring and O-rings in borehole pump.*	
040323	Lowering of downhole equipment (939.50–946.62 m).	
	Calibration of borehole Chemmac.	
	Calibration of surface Chemmac.	
040326	Water sampling: SKB class 4.	8280
040329	Water sampling: SKB class 5, all options.	8281
	PVP-sampler: opening of valve at 15:18.	
040330	PVP-sampler: closure of valve at 06:00.	
	End of Chemmac measurements.	
	Lifting.	
	Sampling of microbes and dissolved gases.	
	Sampling of colloids.	
	Colloid filtration.	8281
	Calibration of borehole Chemmac.	
	Calibration of surface Chemmac.	

5.8 Performance in section 980.0–1001.2 m (MFL)

The investigations in section 980.0–1001.2 m were performed using the mobile field laboratory units. The configuration of the downhole equipment in the borehole was, from the top: umbilical hose, borehole Chemmac, upper packer, borehole pump and *in-situ* water sampler (PVP), see Appendix 3. The bottom of the borehole constituted the lower section limit. The pressures above and within the section were measured by the borehole Chemmac unit and the PVP water sampling unit, respectively.

The pumping was performed at an irregular flow rate varying from about 30 mL/min to 160 mL/min. A diagram showing the pressures within and above the borehole section and the flow rate during the pumping/measurement period is presented in Appendix 4, Figure A4-8. The total pumped volume from the section was 3.1 m^3. The events during the investigation are listed in Table 5-7.

Table 5-7. Events during the pumping/measurement period in section 980.0–1001.2 m.

Date	Events *Improvement/deviation*	SKB sample no
031027	Calibration of surface Chemmac.	
031029	Calibration of borehole Chemmac.	
031030	Lowering of downhole equipment (980.00–1001.19 m).	
031104	Lifting, due to broken check valve.	
	Lowering.	
031106	Water sampling: SKB class 4.	8096
031111	Water sampling: SKB class 4.	8098
031114	Start of Chemmac measurements.	
031118	*Loss of flow, borehole pump stopped. Broken circuit breaker to the hydraulic pump caused the loss of flow.*	
031119	Restart of borehole pump.	

031120	*The platinum electrode in the surface Chemmac was damaged. It was ejected due to pressure increase in the measurement cell. The Pt-electrode was replaced with a plug and the measurement continued.*	
	Calibration of surface Chemmac.	
031120	Water sampling: SKB class 4.	8101
031121	Humic and fulvic acids; enrichment start.	
031124	Water sampling: SKB class 5.	8103
031126	Water sampling: SKB class 4.	8104
031126	Humic and fulvic acids; fractionation 5 kD.	8152
031127	Humic and fulvic acids; fractionation 1 kD.	8152
031201	Water sampling: SKB class 5.	8105
031203	Water sampling: SKB class 4.	8151
031208	Water sampling: SKB class 5.	8152
031208	Humic and fulvic acids; enrichment stop.	
	PVP-sampler; opening of valve at 14:33.	
031209	PVP-sampler; closure of valve at 07:07.	8152
	End of Chemmac measurements. Lifting.	
	Sampling of microbes and dissolved gases.	
	Sampling of colloids.	
	Colloid filtration.	8152
	Humic and fulvic acids; enrichment eluation.	8152
	Calibration of borehole Chemmac.	
031210	Calibration of surface Chemmac.	

5.9 Water sampling, sample treatment and analyses

The pumped water from the borehole section is led into the laboratory unit where sampling and sample filtration is carried out. When the laboratory unit is not available at the drilling site, as was the case for sections 386.0–391.0 m, 448.0–453.0 m and 639.0–646.1 m, the pumped borehole water is instead led into the MYC-unit. In either case, filtration of sample portions is performed on-line by connecting the filter holders directly to the water outlet. A water sample is defined as water collected during one day and consists of several sample portions, labelled with the same sample number.

An overview of sample treatment and analysis methods is given in Appendix 11. The routines are applicable independently of sampling method or type of sampling object.

5.10 Collection of *in-situ* water samples

The *in-situ* water sampling was conducted successfully in four sections: 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m.

The PVB-containers were checked before use. The checking procedure includes de-assembling of the container, thorough cleaning, re-assembling and measurement of piston friction.

The purpose of each sample portion is given in Table 5-8.

Table 5-8. Collection and purpose of *in-situ* water sample portions.

Sample portion no	Section 980.0–1001.2 m 2003-12-09	Section 639.0–646.1 m 2004-02-24	Section 939.5–946.6 m 2004-03-30	Section 448.5–455.6 m 2004-04-28
1	Dissolved gas	Dissolved gas	Dissolved gas	Dissolved gas
2	Microbes	Microbes	Microbes	Microbes
3	Colloid filtration	Colloid filtration	Colloid filtration	Colloid filtration
4	Colloid filtration	Colloid filtration	Colloid filtration	–

– = one of two PVB-containers was excluded from the colloid filtration due to leakage.

The two PVB-containers for colloid filtration were filtered the same day. The PVB-containers for dissolved gases and microbes were packed together with ice packs in insulated bags and sent by express delivery service immediately after sampling. The microbe sample arrived at the laboratory in Gothenburg before three o'clock the same day and the gas sample arrived at the laboratory in Finland the following morning.

5.11 Colloid filtration

Colloid filtration was performed in sections 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m respectively. The method for sampling of colloids in groundwater entails filtering the groundwater through a series of connected filters in a closed system under an argon atmosphere. The pressure in the system is maintained at the same level as the pressure in the sampled borehole section. The intention is that colloids should be collected on the different filters (descending pore sizes) according to their sizes. Two of the four sample portions collected *in-situ* in each borehole section are used for colloid filtration. Data on performance of the filtration runs are given in Table 5-9.

A leak test of the system at 10 bars was also done prior to the sampling in order to eliminate the risk of leakage. If no leakage was detected, the system was dried and assembled.

Table 5-9. Colloid filtration, data on performance.

Section/date	Entering pressure [bar]	Max. differential pressure over filter package [bar]	Temp [°C]	Filtering time [min]	Filtered volume [ml]	Comments
448.5–455.6 m /20040330	~47	8.8 (the diff. pressure was increased from about 3 bars during filtration in order to get the water through the filters)	~13	29	153.5	Leakage test prior to filtration. No leakage was noticed. Broken filter: the last 0,05 µm.
639.0–646.1 m /20040224	~66	7.9 (the diff. pressure was increased from about 3 bars during filtration in order to get the water through the filters)	~2	48	155.6	Leakage test prior to filtration. No leakage was noticed. Broken filters: 0,2 µm and the final 0,05 µm.
939.5–946.6 m /20040330	~96	3.9	~18	39	280	Leakage test prior to filtration. No leakage was noticed. Broken filters: 0,2 µm and the final 0,05 µm.
980.0–1001.2 m /20031209	~100	3.4	~15	75	315.5	Leakage test prior to filtration. No leakage was noticed. Broken filters: 0,2 µm and both 0,5 µm.

Each filtration results in five filter samples (two 0.4 µm, one 0.2 µm and two 0.05 µm filter pore sizes) and two water samples (water in and water out). All samples were sent for ICP analyses (major constituents and common trace metals).

5.12 Enrichment of humic and fulvic acids

Enrichment of humic and fulvic acids was conducted in order to collect enough material to determine ∂^{13}C and pmC in organic constituents in the groundwater. The enrichment method entails collection of organic acids on an ion exchanger, eluation of the resin and evaporation of the resulting solution. The method is described in SKB MD 431.044 (Mätsystembeskrivning för uppkoncentrering av humus- och fulvosyror). The dry residue is used for isotope determination; a minimum amount of 10 mg organic carbon is needed. In addition to organic material, the residue also contains sodium hydroxide from the eluation. The sample is acidified at the analytical laboratory prior to analysis in order to prevent the formation of carbon dioxide.

Table 5-10 summarises the time that the water was allowed to flow trough the ion exchanger and the estimated volume of water passing through each section. Due to the high content of remaining flushing water in section 939.5–946.6 m, no enrichment took place. Theoretically, assuming a 50% capacity of the ion exchange resin, the resin would adsorb 100 mg carbon (10 mg is needed for the isotope analysis).

Table 5-10. Estimations of time and volume of water passing through the ion exchanger in each investigated section.

Borehole section [m]	Duration of enrichment [days]	Volume through ion exchanger [L]
386.0–391.0	15	1000*
448.0–453.0	11	1700*
448.5–455.6	8	397
639.0–646.1	6	382
939.5–946.6**	–	–
980.0–1001.2	16	890

*Probably much less, especially in section 448.0–453.0 m due to counter pressure and leakage.

**Not performed due to high content of remaining flushing water.

5.13 Fractionation of humic and fulvic acids

Humic and fulvic acids were fractionated with respect to molecular weight using ultrafiltration technique. The method is described in SKB MD 431.043 (Mätsystembeskrivning för fraktionering av humus- och fulvosyror, SKB internal controlling document).

Sampled water from each investigated section, except from the section at 939.5–946.6 m, was first filtered through a 0.45 µm filter and then through membrane filters with cut-off sizes of 1000 D and 5000 D, respectively. The initial water volume, prior to filtration, was approximately 5 litres. The final retentate and permeate volumes following the filtration runs were approximately 1 and 4 litres, respectively, which gave an enrichment factor of five in the retentate.

Water samples were collected from the retentate and the permeate as well as from the untreated groundwater. Each sample was analysed for dissolved organic carbon (DOC), major constituents and common trace metals. The analyses of metal ions are conducted in order to detect any precipitation of metals that could possibly lead to co-precipitation of the humic and fulvic acids. Furthermore, the analyses of metal ions should indicate if metals such as Al, Si, Mn and Fe exist as colloidal species.

6 Nonconformities

The hydrochemical characterisation of the six investigated sections in KFM03A has been conducted according to the SKB internal controlling documents AP PF 400-03-63, SKB MD 430.017 and 430.018. Some equipment malfunctions (listed in Tables 5-2 to 5-7) have occurred during the pumping/measurement periods. Furthermore, the surface Chemmac redox measurements in sections 386.0–391.0 m and 448.0–453.0 m were considered erroneous and are therefore not reported. This was expected, since earlier experience from the pre-investigations at Äspö /9/ also showed difficulties in measuring redox parameters when sample water is pumped at a high flow rate through a pipe string. Due to equipment malfunction, dissolved oxygen was not measured in section 386.0–391.0. Electric conductivity in section 448.0–453.0 m was not measured due to a defective conductivity meter.

Problems with broken filters and contamination occurred in the colloid filtering experiments. Furthermore, one of two PVB-containers from section 448.5–455.6 m for colloid filtration was excluded due to leakage.

The calculation/estimation of the flushing water content in each sample is rather uncertain, since the Uranine concentration in the flushing water, added to the borehole during drilling, varied considerably from time to time.

The allowed upper limit for flushing water content (1%) was exceeded in sections 639.0–646.1 m (4%), 939.5–946.6 m (9%) and 980.0–1001.2 m (4%); this is not reported in deviation reports. The enrichment and fractionation activities of humic and fulvic acids were excluded in section 939.5–946.6 m due to the high flushing water content.

7 Data handling and interpretation

7.1 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).

7.1.1 Data file types and calculation software

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

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

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

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

7.1.2 Calculations and evaluation of pH and redox potential

The redox potential is measured by three electrodes at the surface and three in the borehole section. In addition, pH is measured by two electrodes at the surface and two in the borehole section. In sections 386.0–391.0 m and 448.0–453.0 m, only the surface electrodes were used. The registrations by the redox and the pH electrodes are logged each hour during a measurement period of approximately three weeks and a calibration is performed before and after the measurement period. The treatment of the raw data includes the following steps:

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

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

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

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

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

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

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

7.2 Water analysis data

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

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 equation (1). Relative errors within ± 5% are considered acceptable (in surface waters ± 10%).

$$\text{Relative error}\,(\%) = 100 \times \frac{\sum cations\,(equivalents) - \sum anions(equivalents)}{\sum cations\,(equivalents) + \sum anions(equivalents)} \tag{1}$$

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

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

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

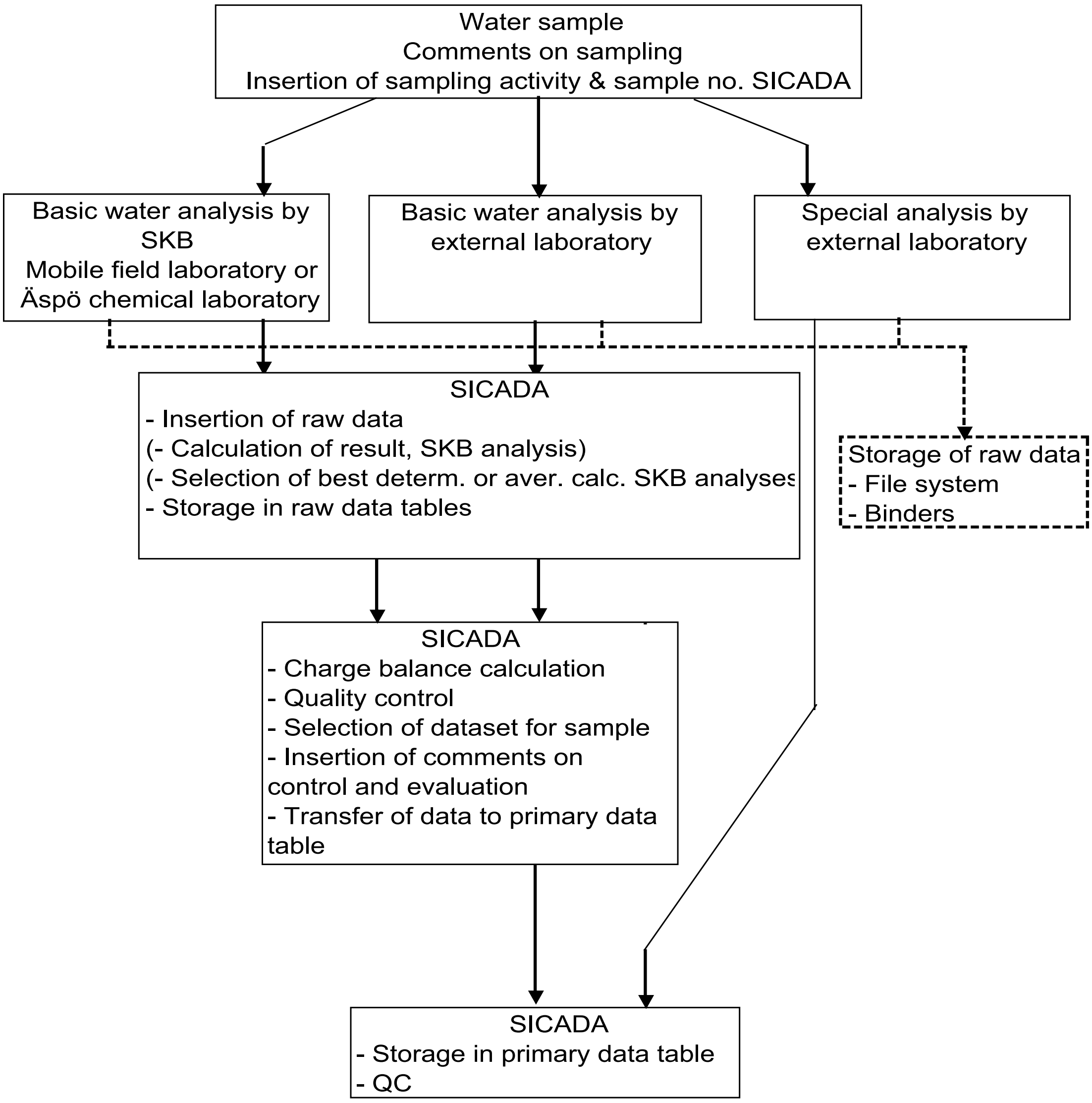


Figure 7-1. *Overview of data management for hydrogeochemical data.*

7.3 Data from special sampling methods

Special sampling methods include collection of *in-situ* samples (colloid filtration and dissolved gases), enrichment and fractionation of humic and fulvic acids.

Separate sampling activities, methods and sample numbers are defined for data on dissolved gases, colloids, fractions of humic and fulvic acids and ∂^{13}C and pmC determined on organic constituents. All analytical data are subjected to quality control and stored in the SICADA database.

7.4.1 Colloid filtration

The concentration of the colloid portion caught on each filter is calculated with the assumption that the water volume coming out in the collecting container is equal to the volume going into the system. This is not quite true as up to ten millilitres will be left in cavities in the filter holder package, in the tubing and in valves. A small volume of about 0.01 to 0.06 mL is left in each filter after the filtration and its content of the different elements is included in the analysis. The measurement uncertainty of each colloid concentration is calculated according to equation (2).

$$U = \sqrt{\left(\frac{1}{V^2} \cdot (\Delta m)^2 + \frac{m^2}{V^4} (\Delta V)^2 \right)} \qquad (2)$$

where U = measurement uncertainty [µg/L]
V = water volume through the system [L]
ΔV = estimated volume error, 0.010 L
m = amount on filter [µg]
Δm = measurement uncertainty of the filter analysis, 20% [µg].

The calculated results from the colloid filtration, filters, are stored in SICADA. The water samples (in and outgoing water) are inserted directly in SICADA without recalculation.

7.3.2 Dissolved gases

Results from gas analyses are stored in a primary data table in SICADA without post processing or interpretations.

7.3.3 Enrichment of humic and fulvic acids

The pmC and δ^{13}C values for enriched organic acids are stored in SICADA without post processing or interpretations.

7.3.4 Fractionation of humic and fulvic acids

The concentrations of organic and inorganic constituents in the retentate and permeate are re-calculated to concentrations of each fraction of carbon and metal ions with molecular weight lower or higher than the cut-off size of the filter. This is done using mass balance equations as described in SKB MD 431.043, (Mätsystembeskrivning för fraktionering av humus- och fulvosyror). Comparison of the four concentration values from the two filters results in values for three fractions i.e. < 1000 D, 1000 – 5000 D and > 5000 D.

8 Results

8.1 Chemmac measurements

Sections 386.0–391.0 m and 448.0–453.0 m were investigated using the PSS3 equipment combined with the surface Chemmac in the MYC3 unit. It is usually difficult to measure reliable redox potentials using pipe string systems and heavy pumping, and this case is no exception. Consequently, the redox potential values are therefore rejected. In addition, dissolved oxygen was not measured in section 386.0–391.0 m due to equipment malfunctions. Further, the electric conductivity measurement failed in section 448.0–453.0 m due to a defective conductivity meter. The measurement sequences of pH, electric conductivity (386.0–391.0 m), dissolved oxygen (448.0–453.0 m) and water temperature are plotted versus time in Appendices 5 and 6.

Sections 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m were investigated using the complete chemical characterisation method (MFL). The Chemmac measurements were successful except for the redox and pH measurements in section 980.0–1001.2 m. The reason why the redox electrodes did not reach stable and agreeing values is probably the very low iron concentration in this section and thereby the lack of a dominating redox pair. The behaviour of the pH electrodes is, on the other hand, more difficult to explain. Except for section 448.5–455.6 m, the data sequences measured by the downhole electrodes were calculated using calibration constants corrected for linear drift. Furthermore, the two pH measurement sequences of this section differ before the interruption. The values measured by the PHIB electrode are selected as the measurement level agrees with the level of both electrodes after the break. The measurement sequences of Eh, pH, electric conductivity, dissolved oxygen and water temperature values are plotted versus time in Appendices 7 to 10.

The measurement data sequences were evaluated in order to obtain one representative value of Eh, pH, electric conductivity and dissolved oxygen for the borehole section as described in Section 7.1. Data were selected from a part of the measurement sequences where the electrodes show stabile values (marked with an arrow in the diagrams). The evaluated results from the measurements in the six investigated sections are given in Table 8-1.

Table 8-1. Evaluated results from the Chemmac measurements in KFM03A.

Borehole section [m]	Electric conductivity* [mS/m]	pH (surface chemmac)**	pH (borehole chemmac)**	Eh (borehole and surface chemmac)** [mV]	Dissolved oxygen*** [mg/L]
386.0–391.0	1637 ± 20	7.42 ± 0.12	–	–	–
448.0–453.0	–	7.58 ± 0.12	–	–	0.00 ± 0.01
448.5–455.6	1571 ± 20	7.27 ± 0.42	7.29 ± 0.14	–176 ± 10B	0.00 ± 0.01
639.0–646.1	1529 ± 20	7.48 ± 0.32	7.38 ± 0.12	–196 ± 12	0.00 ± 0.01
939.5–946.6	2205 ± 20	7.53 ± 0.12	7.32 ± 0.15	–245 ± 12	0.00 ± 0.01
980.0–1001.2	2547 ± 20	7.97 ± 0.46	rejected	rejected	0.00 ± 0.01

*The electric conductivity is measured between 0–10 000 mS/m with a resolution of 1% of the measurement interval.

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

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

B = only values from borehole Chemmac have been used in the calculation.

8.2 Water analyses

8.2.1 Basic water analyses

The basic water analyses include the major constituents Na, K, Ca, Mg, S, SO_4^{2-}, Cl^-, Si and HCO_3^- as well as the minor constituents Fe, Li, Mn, DOC, Br, F, HS^- and NH_4^+. Furthermore, batch measurements of pH and electric conductivity are included. Another important parameter is the flushing water content in each sample. The basic water analysis data and relative charge balance errors are compiled in Appendix 12, Table A12-1. Existing batch measurement values of pH and/or electric conductivity are compared to the corresponding on-line Chemmac measurement values in Appendices 5 to 10.

The charge balance errors give an indication of the quality and uncertainty of the analyses of major constituents. The errors do not exceed ± 5% in any case. Furthermore, the last sample in each section was also analysed by an independent laboratory. A comparison between results from different laboratories and methods shows that the agreement is acceptable in most cases. Generally, the difference in concentrations between laboratories/methods for each analysed constituent is less than 10%.

The flushing water contents in the sample series collected from the borehole sections are presented in Figure 8-1a to 8-1c. The flushing water content should not exceed 1% in order for a sample to be considered representative for the groundwater of the sampled fracture zone. This condition was met for samples collected in section 386.0–391.0 m, 448.0–453.0 m and 448.5–455.6 m. However, in sections 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m, the flushing water content was 4%, 9% and 4%, respectively, in the final water sample. The flushing water content in the samples is calculated using the nominal Uranine concentration (0.2 mg/L) in the flushing water which implies that it is underestimated rather than overestimated.

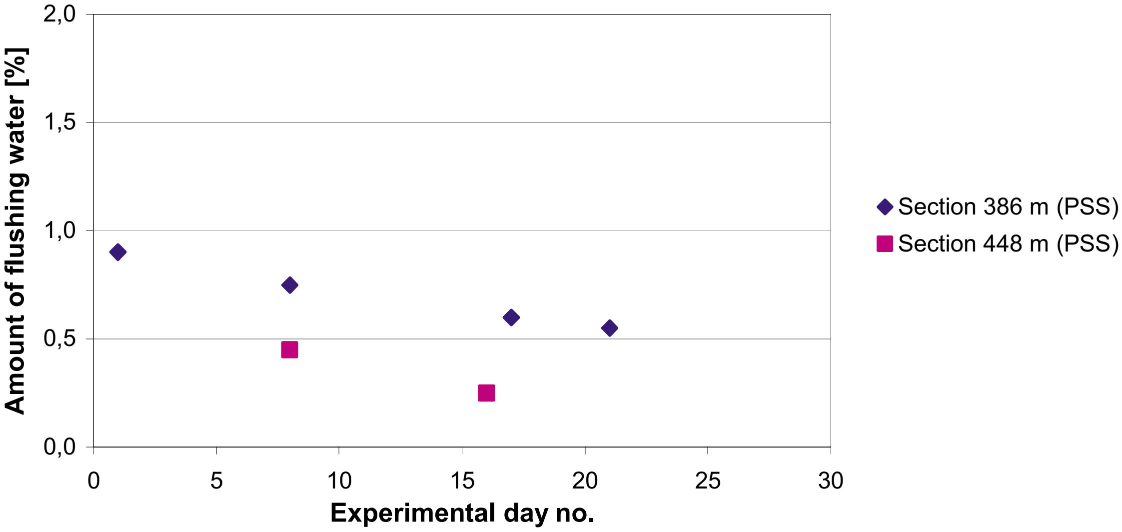


***Figure 8-1a.** Flushing water content versus experimental day number, sections 386–391 m and 448–453 m.*

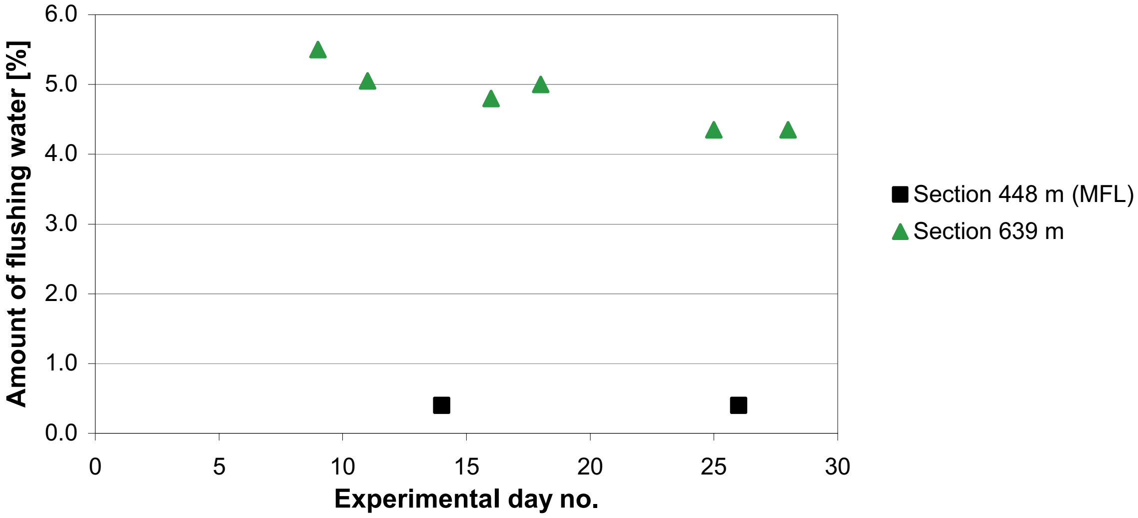


Figure 8-1b. *Flushing water content versus experimental day number, sections 448.5–455.6 m and 639.0–646.1 m.*

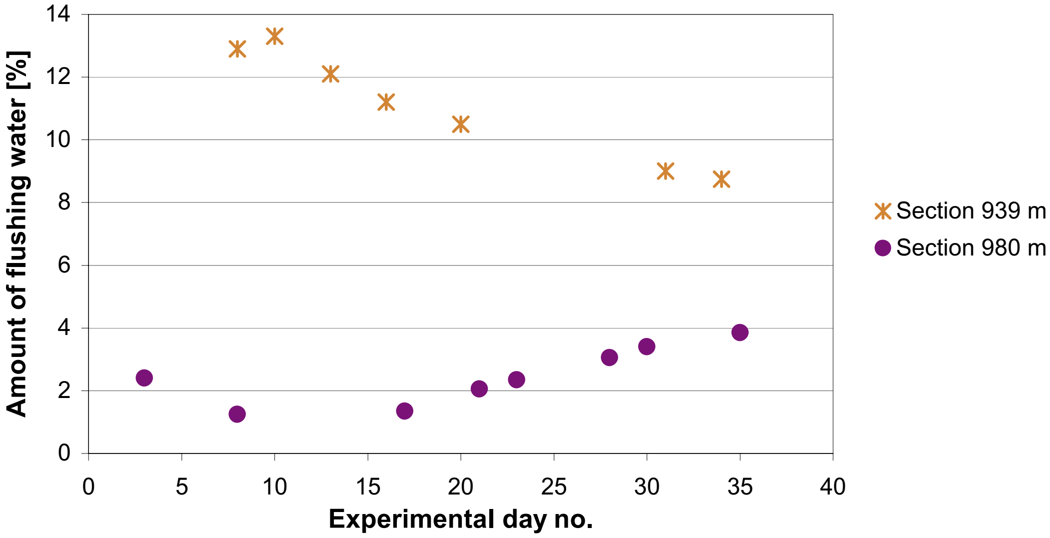


Figure 8-1c. *Flushing water content versus experimental day number, sections 939.5–946.6 m and 980.0–1001.2 m.*

The concentration levels of sodium, calcium and chloride are presented in Figures 8-2 to 8-7. The concentrations of all major constituents remained practically constant during the pumping and sampling periods except for in section 939.5–946.6 m, where a slightly increasing concentration trend was observed.

The iron concentrations determined by ICP-AES (total Fe) and by spectrophotometry (Fe(+II) and Fe-tot) are compared in Figures 8-8 to 8-13. Some analyses for sections 386.0–391.0 m and 448.0–453.0 m show low Fe(+II) concentrations compared to total iron concentrations. It is unlikely that the difference constitutes the Fe(+III) concentration in a groundwater representative of the borehole section therefore, these deviating Fe(+II) data will be omitted in SICADA. The discrepancy may be caused by:

- Oxidation of Fe(+II) prior to the analyses due to time delay between sampling and reagent addition. According to the field laboratory staff, this was not the case.
- Contamination by rust or Fe(+III) precipitate from equipment prior to sampling.
- Intrusion of air somewhere in the water sampling line and oxidation of Fe(+II). This is the most likely explanation although the oxygen measurements show zero concentration (448.0–453.0 m).

The total iron concentrations determined by ICP agree reasonably well with the results obtained by spectrophotometry. However, in a few cases the ICP results are somewhat lower. Any colloidal iron present in a sample would give the opposite effect, as the spectrophotometric method excludes (or only partly includes) colloids, while the ICP technique makes no distinction between different iron-containing species.

Sulphate analysed by ion chromatography (IC) is compared to sulphate determined as total sulphur by ICP-AES in Figures 8-14 to 8-19. As shown, there is a satisfactory agreement. The results from the ICP measurements are considered more reliable, by experience, since the variation between the samples in a time series is often smaller. The sulphate concentration remains constant during the investigation time except in section 939.5–946.6 m where the concentrations are decreasing.

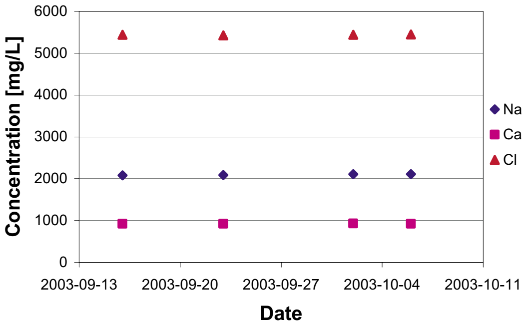


Figure 8-2. *Sodium, calcium and chloride concentration trends from sample series at 386.0–391.0 m.*

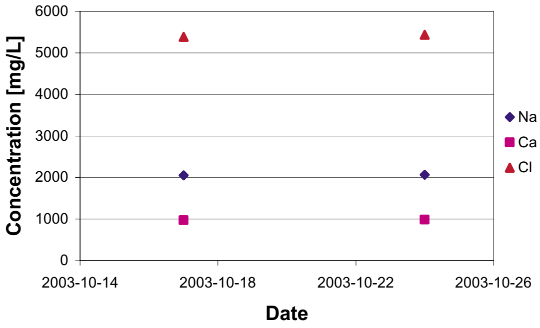


Figure 8-3. *Sodium, calcium and chloride concentration trends from sample series at 448.0–453.0 m.*

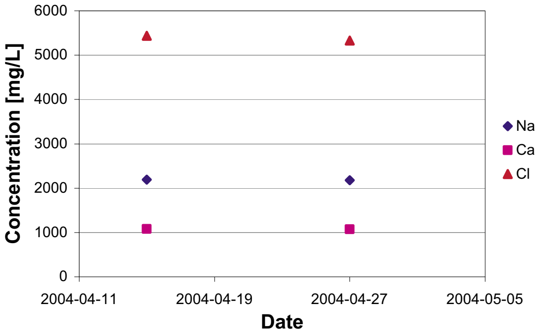


Figure 8-4. *Sodium, calcium and chloride concentration trends from sample series at 448.5–455.6 m.*

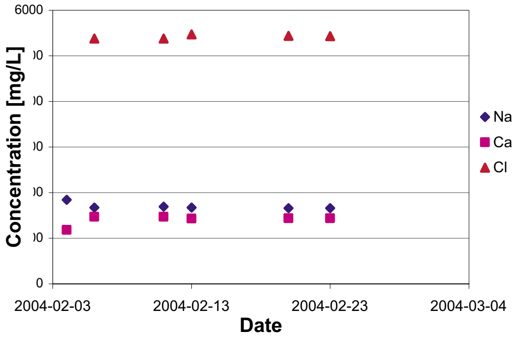


Figure 8-5. *Sodium, calcium and chloride concentration trends from sample series at 639.0–646.1 m.*

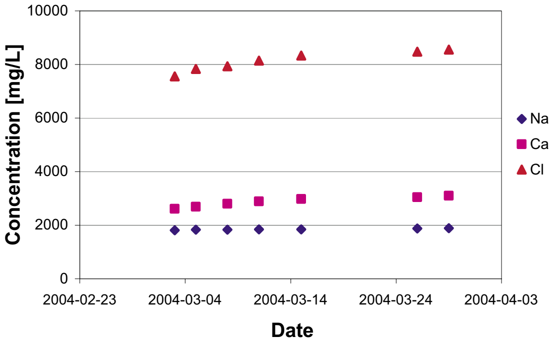


Figure 8-6. *Sodium, calcium and chlorid concentration trends from sample series at 939.5–946.6 m.*

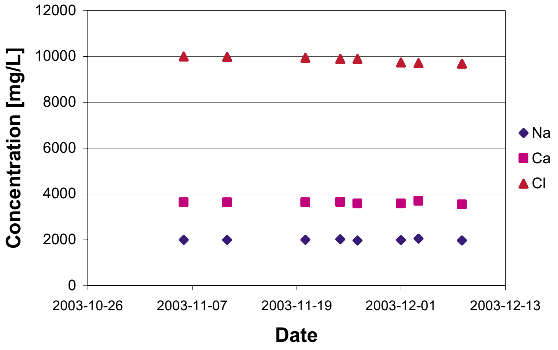


Figure 8-7. *Sodium, calcium and chloride concentration trends from sample series at 980.0–1001.2 m.*

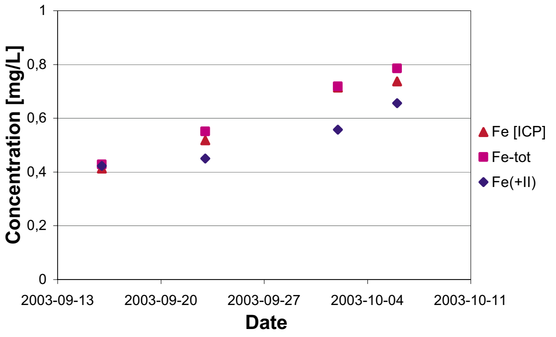


Figure 8-8. *Comparison of iron concentrations obtained by ICP-AES and spectrophotometry from borehole section 386.0–391.0 m.*

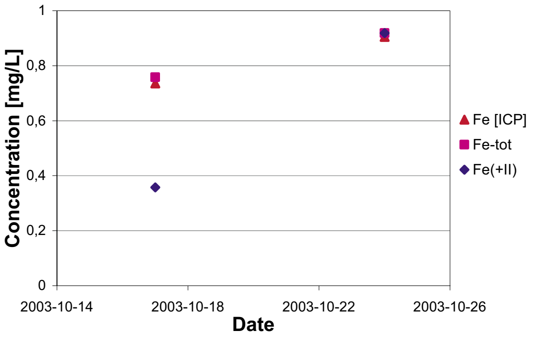


Figure 8-9. *Comparison of iron concentrations obtained by ICP-AES and spectrophotometry from borehole section 448.0–453.0 m.*

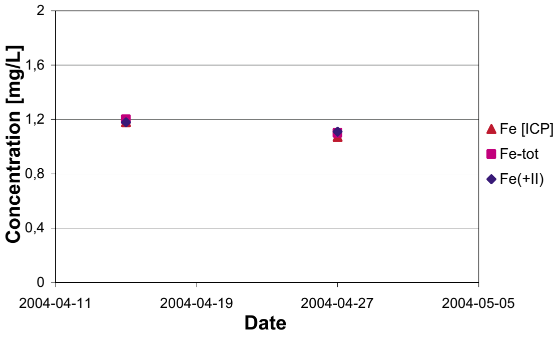


Figure 8-10. *Comparison of iron concentrations obtained by ICP-AES and spectrophotometry from borehole section 448.5–455.6 m.*

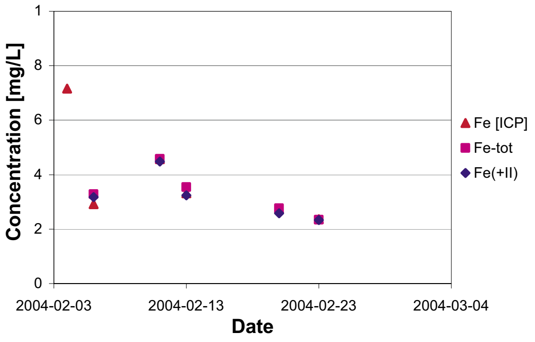


Figure 8-11. *Comparison of iron concentrations obtained by ICP-AES and spectrophotometry from borehole section 639.0–646.1 m.*

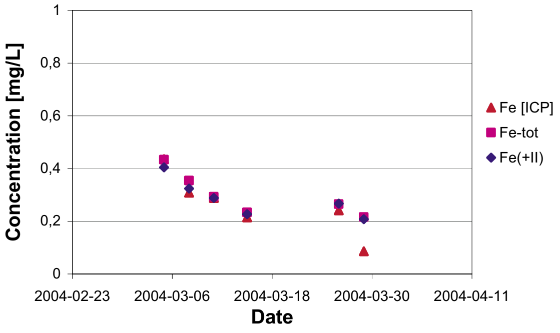


Figure 8-12. *Comparison of iron concentrations obtained by ICP-AES and spectrophotometry from borehole section 939.5–946.6 m.*

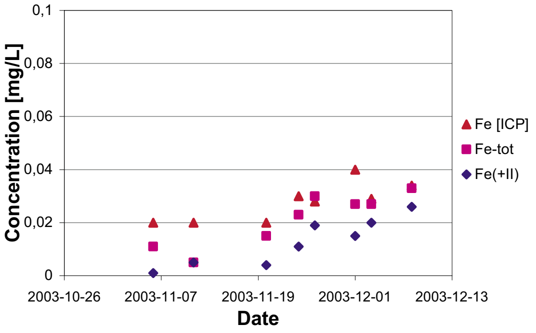


Figure 8-13. *Comparison of iron concentrations obtained by ICP-AES and spectrophotometry from borehole section 980.0–1001.2 m.*

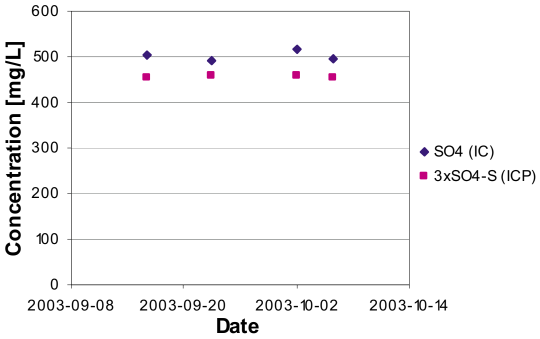


Figure 8-14. *Sulphate (SO_4 by IC) to total sulphate calculated from total sulphur ($3\times SO_4$-S by ICP) versus date. Samples collected in section 386.0–391.0 m.*

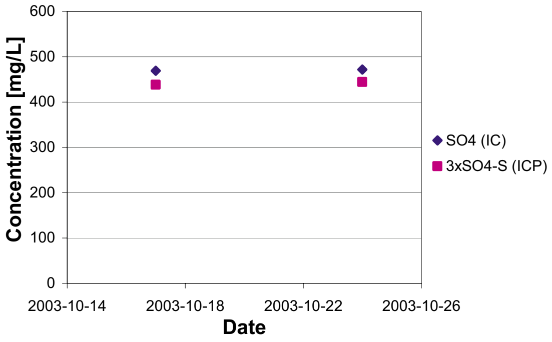


Figure 8-15. *Sulphate (SO_4 by IC) to total sulphate calculated from total sulphur ($3\times SO_4$-S by ICP) versus date. Samples collected in section 448.0–453.0 m.*

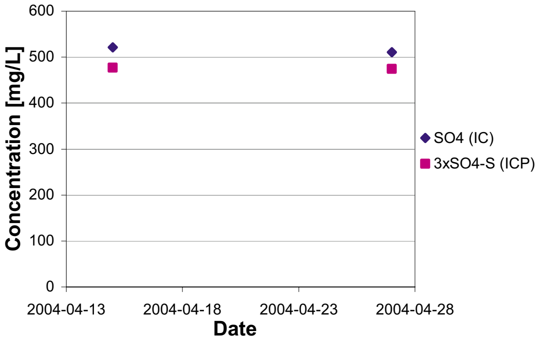


Figure 8-16. *Sulphate (SO_4 by IC) to total sulphate calculated from total sulphur ($3\times SO_4$-S by ICP) versus date. Samples collected in section 448.5–455.6 m.*

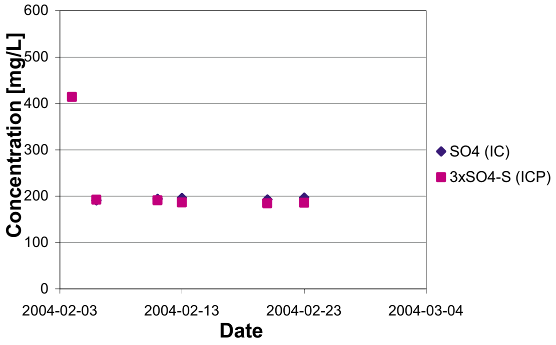


Figure 8-17. *Sulphate (SO_4 by IC) to total sulphate calculated from total sulphur ($3\times SO_4$-S by ICP) versus date. Samples collected in section 639.0–646.1 m.*

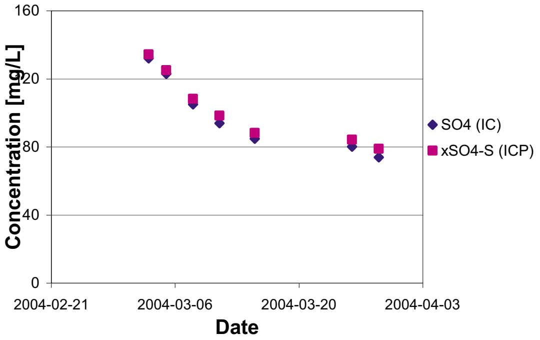


Figure 8-18. *Sulphate (SO_4 by IC) to total sulphate calculated from total sulphur ($3\times SO_4$-S by ICP) versus date. Samples collected in section 939.5–946.6 m.*

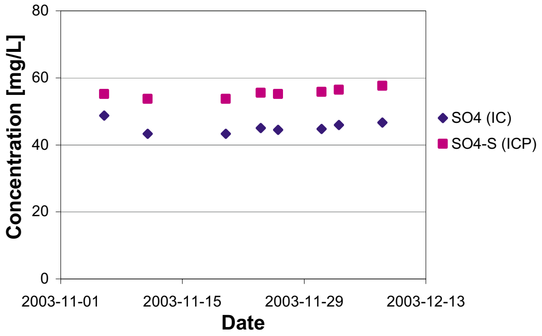


Figure 8-19. *Sulphate (SO_4 by IC) to total sulphate calculated from total sulphur ($3\times SO_4$-S by ICP) versus date. Samples collected in section 980.0–1001.2 m.*

The DOC results from the borehole sections are plotted versus experimental day in Figure 8-20. DOC analyses in saline waters are, by experience, considered less reliable than in fresh waters. However, in this case the concentrations appear to be quite consistent, except for section 639.0–646.1 m. Some DOC results were not available at the printing date and will be included in a later version of this report.

The chloride concentrations are plotted versus the corresponding electric conductivity values in Figure 8-21. The plot gives a rough check of the data. As shown, the data from the borehole sections agree well with the regression line obtained by earlier data from the Äspö Hard Rock Laboratory.

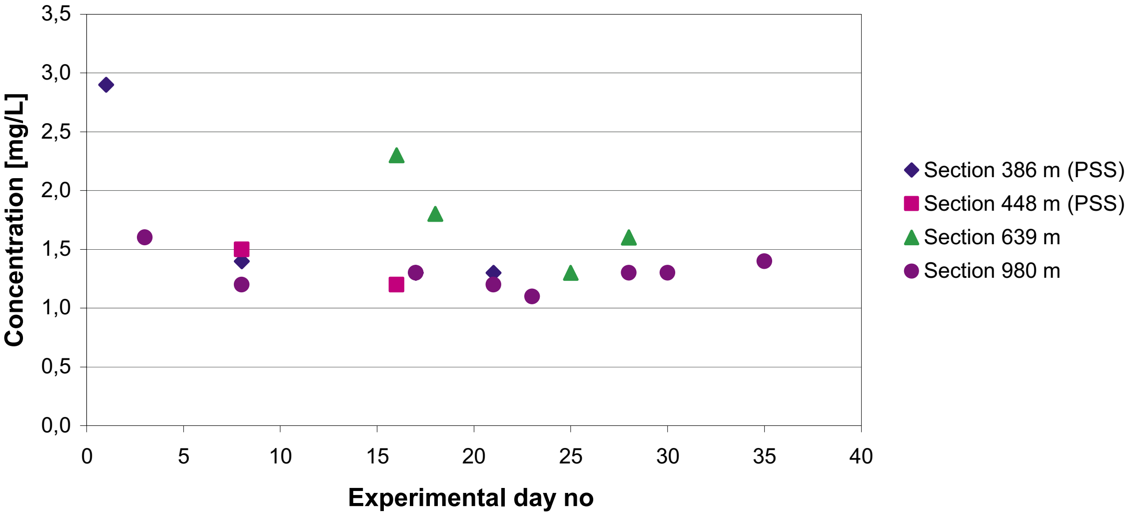


Figure 8-20. *DOC concentrations versus experimental day number.*

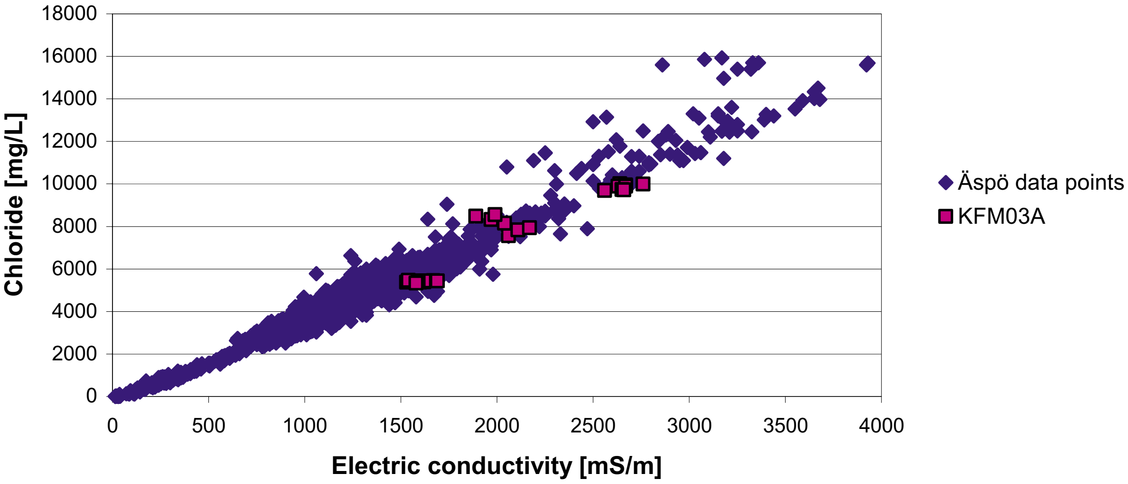


Figure 8-21. *Chloride concentration versus electric conductivity. Data from earlier investigations at the Äspö Hard Rock Laboratory are used to show the linear relationship. Data from KFM03A do not deviate significantly from the regression line.*

8.2.2 Trace elements (rare earth metals and others)

The analyses of trace and rare earth metals include U, Th, Sc, Rb, Y, Zr, In, Sb, Cs, La, Hf, Tl, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu. Commonly occurring metals, such as Cu, Zn, Pb and Mo, are not included in the analysis programme due to contamination considerations. The trace element data are compiled in Appendix 12, Table A12-3.

8.2.3 Stable and radioactive isotopes

The isotope determinations include the stable isotopes δD, $\delta^{18}O$, $^{10}B/^{11}B$, $\delta^{34}S$, $\delta^{13}C$ and $^{87}Sr/^{86}Sr$ as well as the radioactive isotopes Tr (TU), ^{14}C (pmC), ^{238}U, ^{235}U, ^{234}U, ^{232}Th, ^{230}Th, ^{226}Ra and ^{222}Rn. The isotope data are compiled in Appendix 12, Table A12-2 and Table A12-4. Some of the isotope results were not available at the printing date and will be included in a later version of this report.

The tritium and $\delta^{18}O$ results from section 386.0–391.0 m, 448.0–453.0 m, 639.5–646.6 m and 980.0–1001.2 m are presented in Figure 8-22 to 8-25. The tritium content was below the detection limit (0.8 Tritium Units) in most samples. The $\delta^{18}O$ ratios remained stable during the sampling periods.

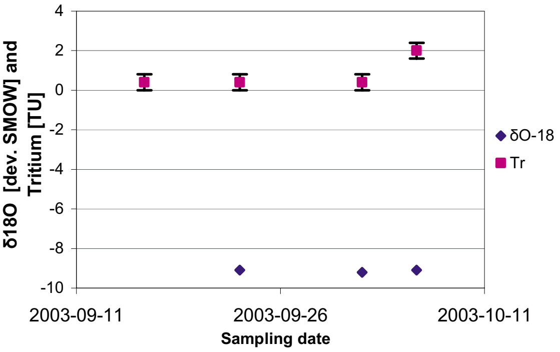


Figure 8-22. *Tritium and $\delta^{18}O$ data from samples collected in section 386.0–391.0 m.*

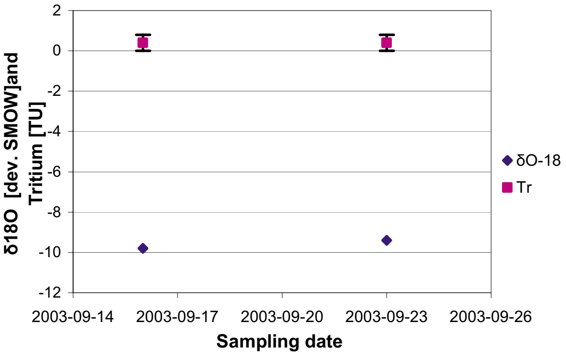


Figure 8-23. *Tritium and $\delta^{18}O$ data from samples collected in section 448.0–453.0 m.*

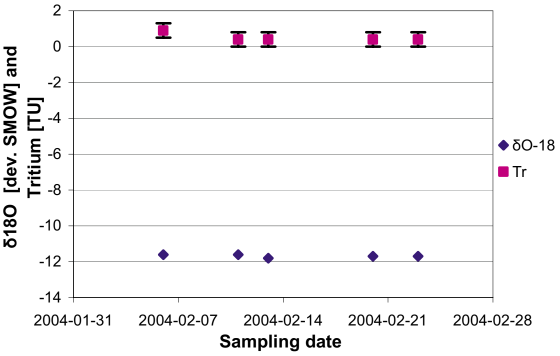


Figure 8-24. *Tritium and $\delta^{18}O$ data from samples collected in section 639.0–646.1 m.*

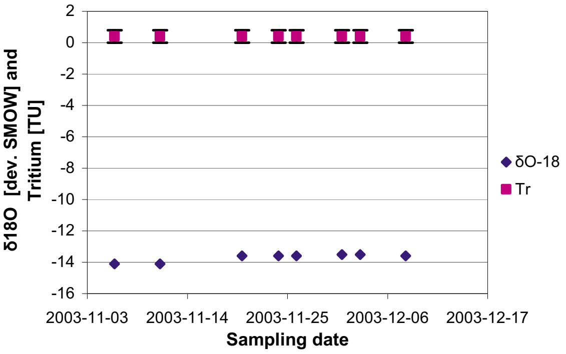


Figure 8-25. *Tritium and $\delta^{18}O$ data from samples collected in section 980.0–1001.2 m.*

The carbon isotopes ($\delta^{13}C$ and pmC) were determined both in inorganic carbon (hydrogen carbonate) and in organic constituents. The results are compared in Table 8-2 below. Enrichment of organic carbon was necessary in order to collect enough organic material.

Table 8-2. Inorganic and organic $\delta^{13}C$ and pmC.

Borehole section (m)	Inorg. $\delta^{13}C$ (dev PDB)	Org. $\delta^{13}C$ (dev PDB)	Inorg. pmC	Org. pmC
386.0–391.0	–7.5	–26.8	17.6	70.6
448.0–453.0	–7.6	–27.7	15.7	55.5
448.5–455.6	A	A	A	A
639.0–646.1	A	–26.7	A	***
939.5–946.6	A	**	A	**
980.0–1001.2	A	*	A	*

*Not enough carbon in sample to perform determinations at the laboratory.

**Enrichment/sampling not performed due to high remaining amount of flushing water.

***Inexplicable value (511.6) obtained from laboratory.

A = Analytical results yet to be reported.

The pmC values obtained from the organic carbon are approximately 3 to 4 times higher than the corresponding values for inorganic carbon. This discrepancy is typical and is explained by the different origin of the carbon and by substitution reactions that occur between dissolved carbonates in the water and carbonate minerals, which alter the isotope signature of the inorganic carbon in the water.

A comparison between re-calculated uranium and thorium isotope determinations and ICP-analyses are given in Table 8-3. The isotopes uranium-238 and thorium-232 are converted to element concentrations using the expressions given in Appendix 11. Generally, agreement within the same order of magnitude is considered satisfactory.

Table 8-3. Comparison of isotope determinations (^{238}U and ^{232}Th) and ICP-analyses of uranium and thorium.

Borehole section [m]	Sample no	Date	U [µg/L]	U* [µg/L]	Th [µg/L]	Th** [µg/L]
386.0–391.0	8012	2003-10-06	3.49	< 4	< 0.2	< 12.7
448.0–453.0	8017	2003-10-24	2.21	A	< 0.2	A
448.5–455.6	8282	2004-04-15	A	_	A	_
448.5–455.6	8284	2004-04-27	A	3.3	A	A
639.0–646.1	8268	2004-02-11	58.5	_	< 0.2	_
639.0–646.1	8271	2004-02-20	49	_	< 0.2	_
639.0–646.1	8273	2004-02-23	46.1	A	< 0.2	A
939.5–946.6	8276	2004-03-05	1.45	_	< 0.4	_
939.5–946.6	8278	2004-03-11	0.99	_	< 0.4	_
939.5–946.6	8281	2004-03-29	0.70	0.2	< 0.4	A
980.0–1001.2	8103	2003-11-24	0.27	0.2	< 0.2	_
980.0–1001.2	8105	2003-12-01	0.18	25.8	< 0.2	_
980.0–1001.2	8152	2003-12-08	0.45	0.8	< 0.2	A

* recalculated from ^{238}U [mBq/L].

** recalculated from ^{232}Th [mBq/L].

"–" not performed.

A= analytical result yet to be reported.

8.3 Dissolved gas

Sampling for gas analyses was performed in sections 448.5–455.6, 639.0–646.1, 939.5–946.6 and 980.0–1001.2 m. The analyses of dissolved gases include argon (Ar), helium (He), nitrogen (N_2), carbon dioxide (CO_2), methane (CH_4), oxygen (O_2), hydrogen (H_2), carbon monoxide (CO), ethane (C_2H_6), ethene (C_2H_4), ethyne (C_2H_2), propane (C_3H_8) and propene (C_3H_6). The gas data are compiled in Appendix 12, Table A12-5.

The total gas content in the groundwater of each borehole section is given in Table 8-4. The oxygen content was above zero in all samples, see Table 8-4, indicating air leakage into the purging system at the consulted laboratory. The results can be corrected by removing the air effect (nitrogen, oxygen and argon) assuming that the oxygen content is zero.

Table 8-4. Total content of dissolved gas.

	Section 448.5–455.6 m	Section 639.0–646.1 m	Section 939.5–946.6 m	Section 980.0–1001.2 m
Total gas content [mL/L]	80.2	89.0	124.5	127.5
Oxygen content [mL/L]	0.07	0.03	0.12	0.04

The gas compositions of the four different borehole sections are compared in Figures 8-26 and 8-27.

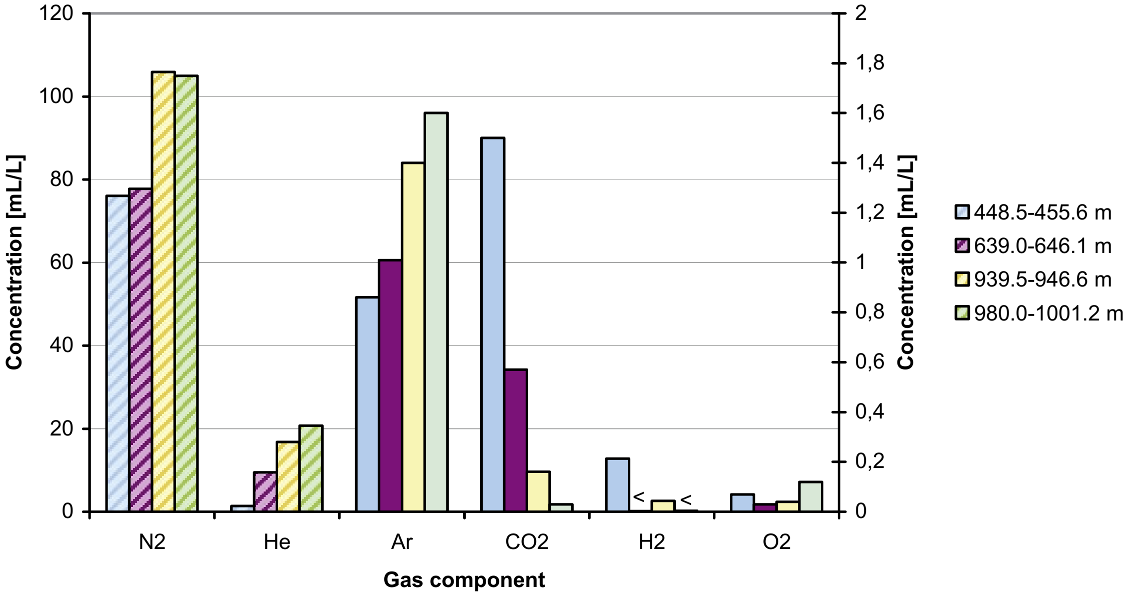


Figure 8-26. *Gas components of high concentrations (N_2, He, Ar, CO_2, H_2 and O_2) in samples collected in KFM03A using the in-situ sampling equipment. Striped and not striped bars refer to the scales on left and right axis, respectively.*

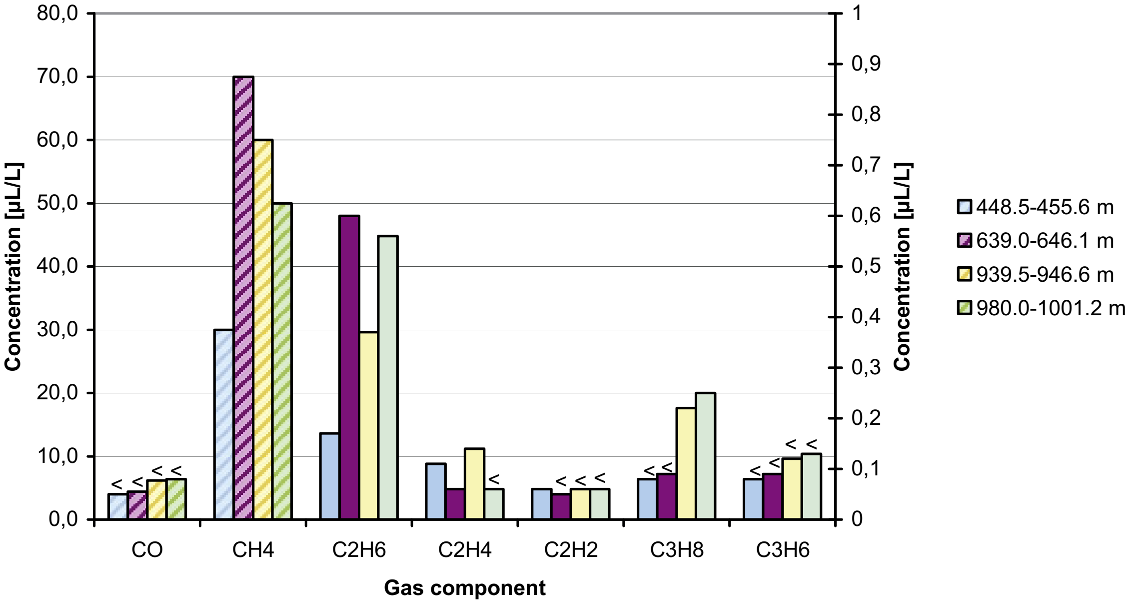


Figure 8-27. *Gas components of low concentrations (CO, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8 and C_3H_6) in samples collected in KFM03A using the in-situ sampling equipment. Striped and not striped bars refer to the scales on left and right axis, respectively.*

8.4 Inorganic colloids

The presence of inorganic colloids was investigated by two different methods. One method was colloid filtration through a series of connected filters of different pore sizes. A second method was fractionation/ultra filtration using cylindrical membrane filters with a cut-off of 1000 D and 5000 D, respectively. The results of the two methods are difficult to compare quantitatively, but a qualitative agreement is identified.

8.4.1 Inorganic colloids – colloid filtration

The colloid filtering system is still at the development stage. The results from the colloid filtration method conducted in sections 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m are presented in Figures 8-28 to 8-43, respectively. The method is described in a final method evaluation report /10/.

The results in the diagrams are presented as contents (µg) of aluminium, iron, silicon and manganese entering the filter package, incorporated on each filter and present in the collecting container. The total amount is calculated assuming that the water volume coming out in the collecting container is equal to the volume going into the system. This is not quite the case as up to ten millilitres will be left in cavities in the filter holder package, in the tubing and in valves. A small volume of about 0.01 to 0.06 mL is left in each filter after the filtration and this is included in the analysis.

Two main problems which make the interpretation/evaluation of the results from the filtering experiments in KFM03A more difficult are; 1) several filters were broken during the filtrations, 2) increased concentration levels in samples from remaining water in the *in-situ* sample container, probably due to contamination.

A better control of the pressure differences between different positions in the filtering line or a more gentle pressure regulation and slower filtration might possibly prevent broken filters and improve the filtering performance. However, it can be noted that the amount of the different elements are not significantly different on broken filters compared to intact filters. Results obtained from broken filters are given within brackets in the diagrams, Figures 8-28 to 8-43.

The input sample is collected after the filtration from the small residual volume in the PVB-container. As the concentrations of the output sample agree well with the ordinary class 4 and class 5 samples collected from pumped water, it can be concluded that the “input sample” is severely contaminated. It is possible that the contamination is due to that the PVB-container contains particles from the borehole (material from wear and tear of drilling equipment and/or drilling debris). These particles follow the water when poured from the PVB-container to the sample bottle but not when the water is driven/pushed by gas pressure through the filter package. Another explanation is that the sample water, when poured from the PVB-container, contacts dirty surfaces inside the outlet. It is necessary to solve this contamination problem in order to obtain accurate mass balances and overall data reliability.

The concentrations of aluminium, iron, silica and manganese in filter sample blanks, taken directly from their boxes without any preparation, were insignificant.

Furthermore, the results show that calcite did not precipitate to any significant extent during the colloid filtrations.

Results of colloid filtering experiment, using water sample from section 448.5-455.6 metres

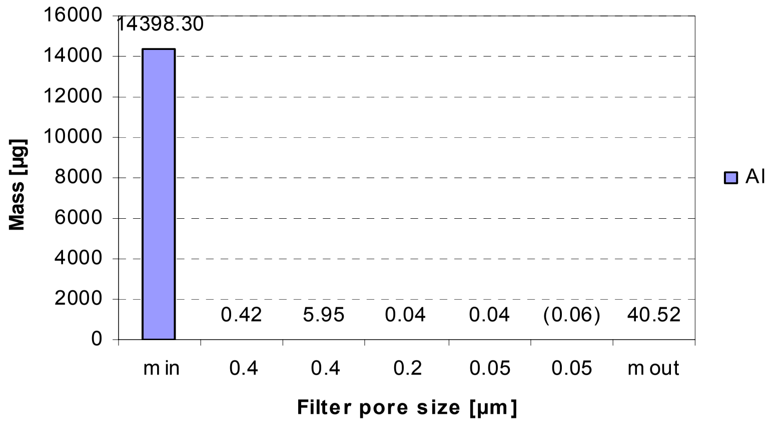


Figure 8-28. *Amount of aluminium entering the filter system (m in), in the filters and in the collecting container (m out).*

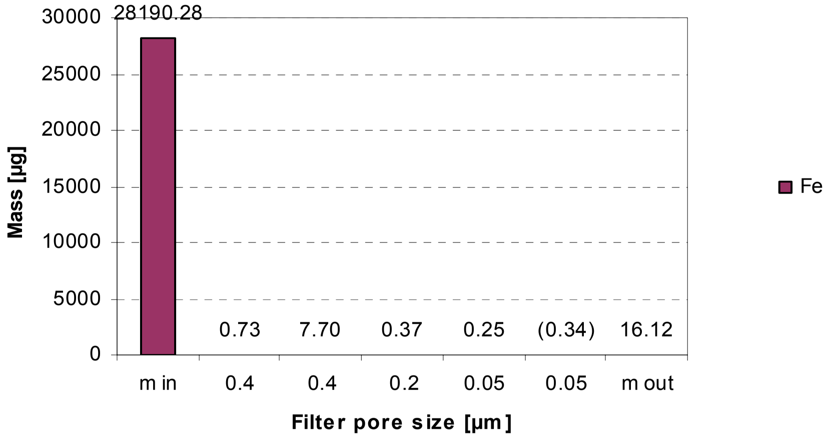


Figure 8-29. *Amount of iron entering the filter system (m in), in the filters and in the collecting container (m out).*

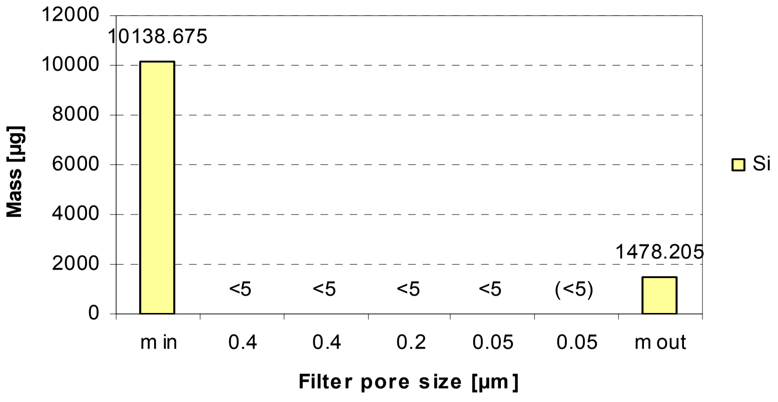


Figure 8-30. *Amount of silicon entering the filter system (m in), in the filters and in the collecting container (m out).*

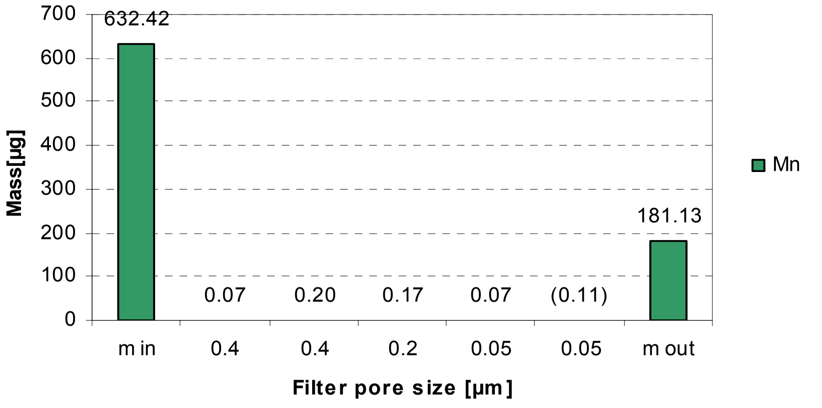


Figure 8-31. *Amount of manganese entering the filter system (m in), in the filters and in the collecting container (m out).*

Results of colloid filtering experiment, using water sample from section 639.0-646.1 meters

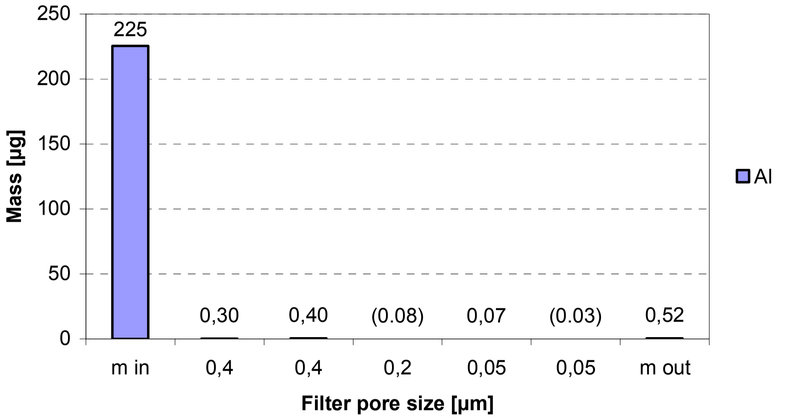


Figure 8-32. *Amount of aluminium entering the filter system (m in), in the filters and in the collecting container (m out).*

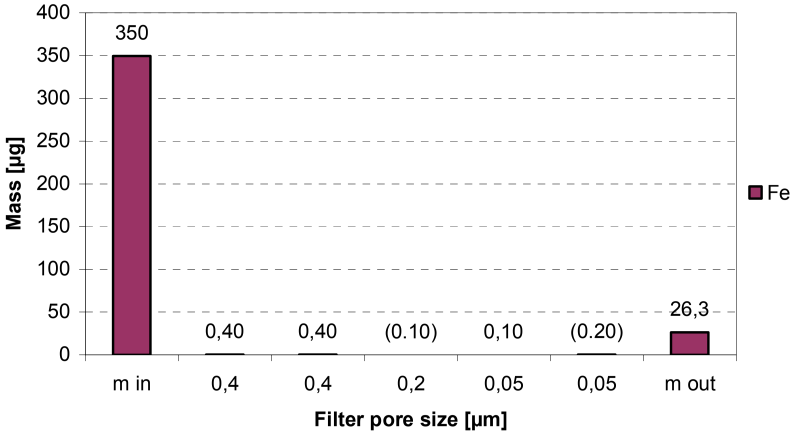


Figure 8-33. *Amount of iron entering the filter system (m in), in the filters and in the collecting container (m out).*

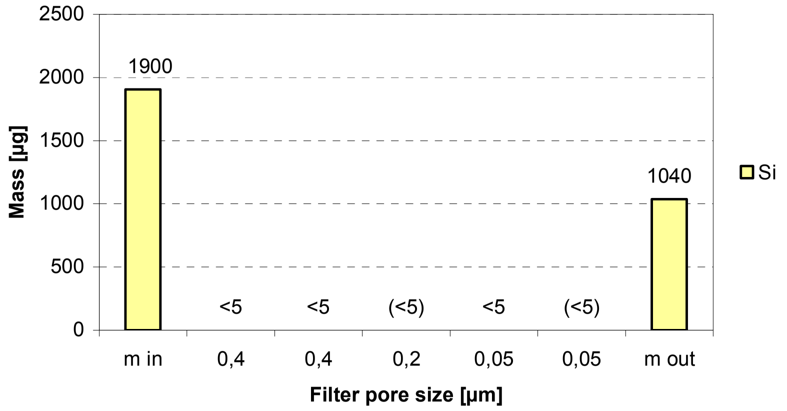


Figure 8-34. *Amount of silicon entering the filter system (m in), in the filters and in the collecting container (m out).*

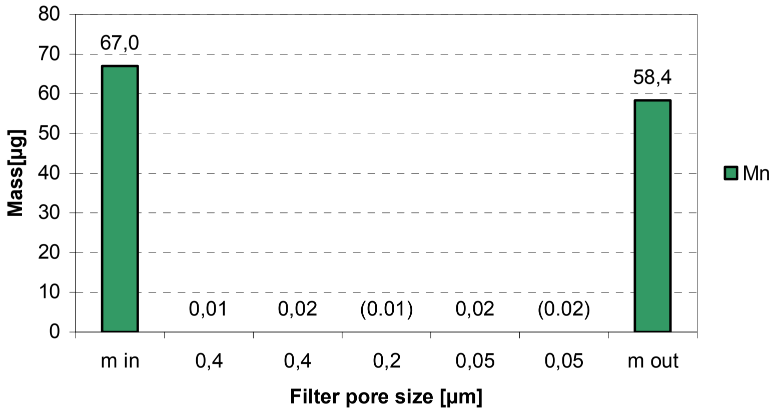


Figure 8-35. *Amount of manganese entering the filter system (m in), in the filters and in the collecting container (m out).*

Results of colloid filtering experiment, using water sample from section 939.5-946.6 metres

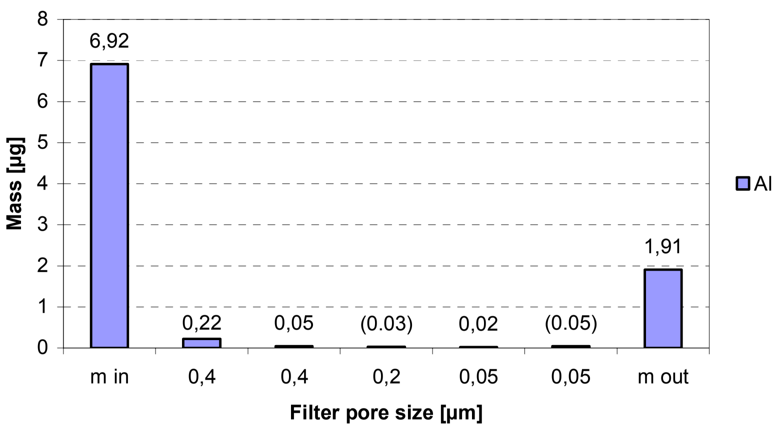


Figure 8-36. *Amount of aluminium entering the filter system (m in), in the filters and in the collecting container (m out).*

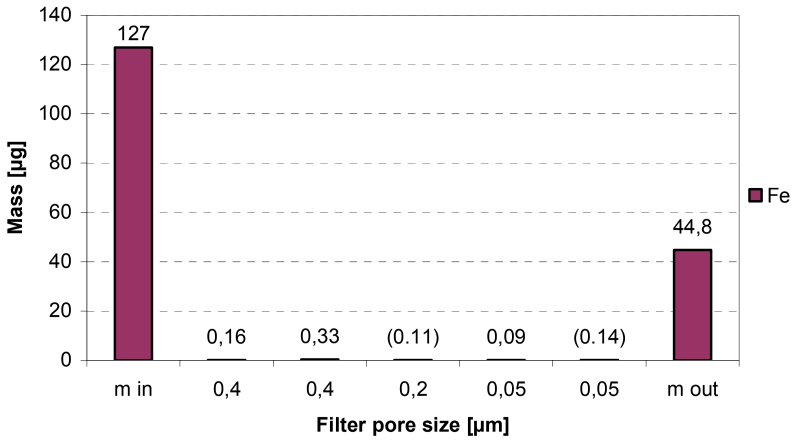


Figure 8-37. *Amount of iron entering the filter system (m in), in the filters and in the collecting container (m out).*

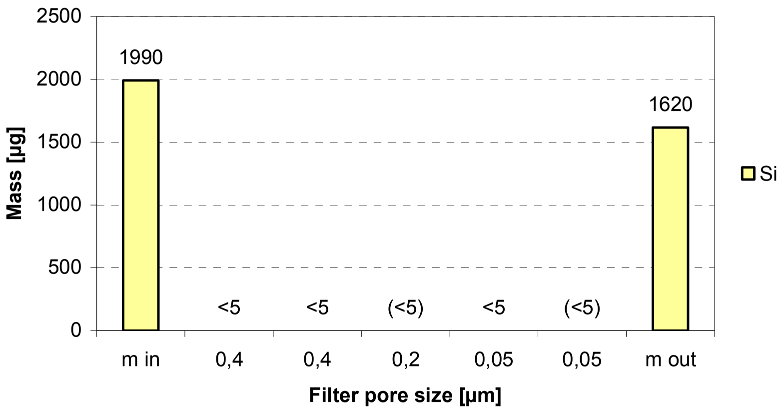


Figure 8-38. *Amount of silicon entering the filter system (m in), in the filters and in the collecting container (m out).*

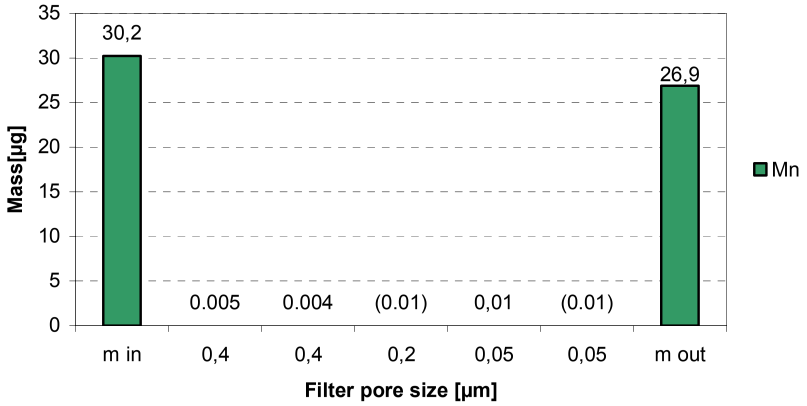


Figure 8-39. *Amount of manganese entering the filter system (m in), in the filters and in the collecting container (m out).*

Results of colloid filtering experiment, using water sample from section 980.0-1001.2 metres

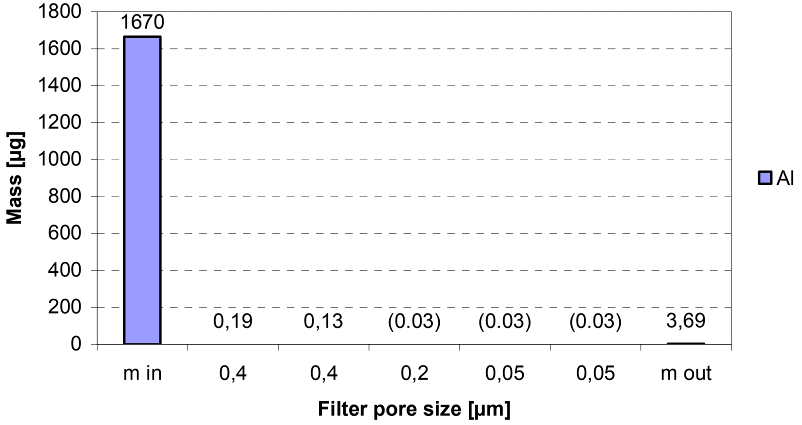


Figure 8-40. *Amount of aluminium entering the filter system (m in), in the filters and in the collecting container (m out).*

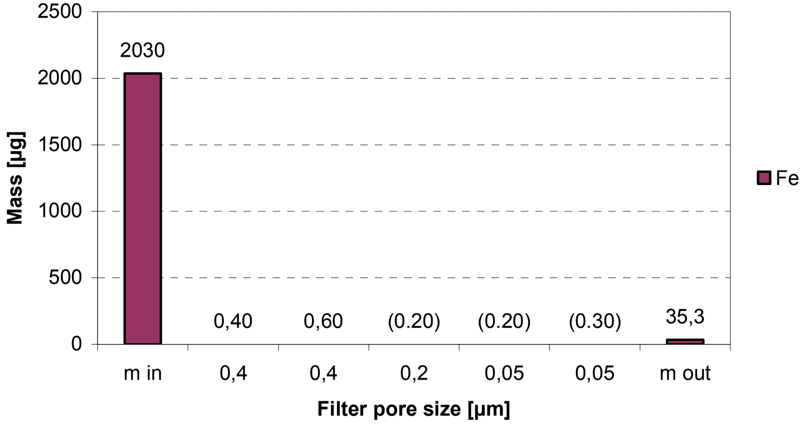


Figure 8-41. *Amount of iron entering the filter system (m in), in the filters and in the collecting container (m out).*

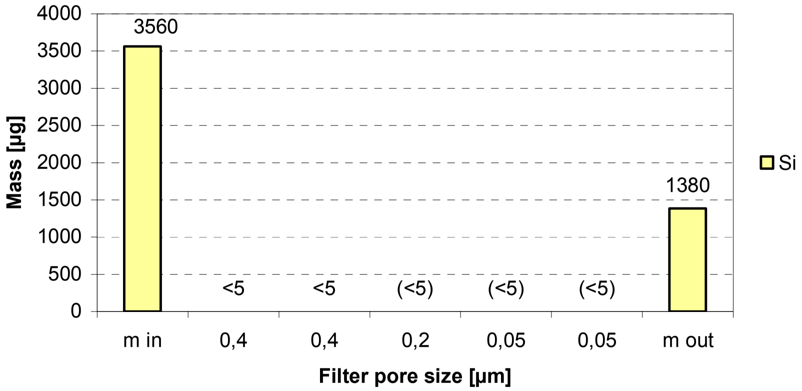


Figure 8-42. *Amount of silicon entering the filter system (m in), in the filters and in the collecting container (m out).*

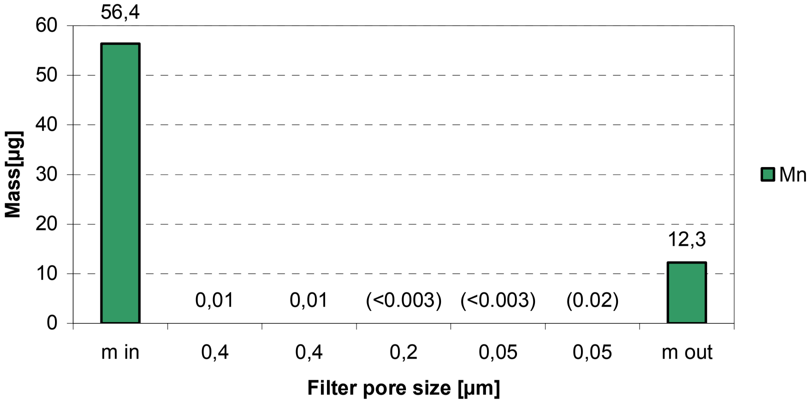


Figure 8-43. *Amount of manganese entering the filter system (m in), in the filters and in the collecting container (m out).*

8.4.2 Inorganic colloids – fractionation

Besides the DOC analyses, the samples from fractionation experiments were analysed by ICP-AES. The determined elements were; Ca, Fe, K, Mg, Na, S, Si, Al, Ba, Cd, Co, Cr, Cu, Hg, Li, Mn, Mo, Ni, P, Pb, Sr, V and Zn. Only iron, silicon, aluminium, calcium and manganese were considered important as colloid species.

The results presented in Tables 8-5 to 8-9 were calculated using mass balance equations (SKB MD 431.043). As shown, Fe, Si, Al and Mn exist as species (associated or non-associated with humic and fulvic acids) with a molecular weight less than 1000 g/mol. Such species are too small to be referred to as colloids. Iron and aluminium were partly precipitated during the fractionation, since oxygen is present in the filtering system (pump, filter, hose etc). Although unlikely, the presence of iron and aluminium containing species of a larger fraction cannot be completely excluded in the cases where adsorption occures.

The filters were carefully washed before use and samples of de-ionised water (after passing through the washed filters) were analysed as sample blanks. The concentrations of iron, silicon and manganese were insignificant but aluminium was found in the sample blanks for all sections except section 386.0–391.0 m. The aluminium concentrations in the groundwater of sections 448.0–453.0, 639.0–646.1 and 980.0–1001.2 m were below detection limit.

Unfortunately, the aluminium concentration of the deionised water used for section 448.5–455.6 m was at a detectable level (12.2 µg/L) Furthermore, the concentration in the untreated groundwater varied between the two fractionation runs (1000 D and 5000 D). The results from all sections show that calcite was not precipitated to any significant extent during the filtrations.

Table 8-5. Inorganic fractions (1000 D and 5000 D filters) in section 386.0–391.0 m.

Fraction	Fe [mg/L]	Si [mg/L]	Al [µg/L]	Mn [mg/L]
< 1000 D	0.94 ± 0.09	5.86 ± 0.9	8.4 ± 1.7	1.07 ± 0.11
< 5000 D	0.56 ± 0.06	5.47 ± 0.8	6.3 ± 1.3	0.99 ± 0.10
> 1000 D but < 5000 D	–	–	–	–
> 5000 D	–	–	–	–
Adsorption 1000 D	–	–	2.2 ± 1.8	–
Adsorption 5000 D	0.14 ± 0.09	–	–	–

– = Not found.

Table 8-6. Inorganic fractions (1000 D and 5000 D filters) in section 448.0–453.0 m.

Fraction	Fe [mg/L]	Si [mg/L]	Mn [mg/L]
< 1000 D	0.74 ± 0.07	8.2 ± 1.2	1.14 ± 0.11
< 5000 D	0.64 ± 0.06	8.1 ± 1.2	1.13 ± 0.11
> 1000 D but < 5000 D	–	–	–
> 5000 D	–	–	–
Adsorption 1000 D	0.14 ± 0.12	–	–
Adsorption 5000 D	0.17 ± 0.11	–	–

– = Not found.

Table 8-7. Inorganic fractions (1000 D and 5000 D filters) in section 448.5–455.6 m.

Fraction	Fe [mg/L]	Si [mg/L]	Mn [mg/L]
< 1000 D	0.74 ± 0.07	9.2 ± 1.4	1.15 ± 0.12
< 5000 D	0.87 ± 0.09	9.2 ± 1.4	1.13 ± 0.11
> 1000 D but < 5000 D	–	–	–
> 5000 D	–	–	–
Adsorption 1000 D	0.29 ± 0.13	–	–
Adsorption 5000 D	0.11 ± 0.14	–	–

– = Not found.

Table 8-8. Inorganic fractions (1000 D and 5000 D filters) in section 639.0–646.1 m.

Fraction	Fe [mg/L]	Si [mg/L]	Mn [mg/L]
< 1000 D	0.17 ± 0.02	5.8 ± 0.9	0.30 ± 0.03
< 5000 D	0.15 ± 0.02	5.8 ± 0.9	0.30 ± 0.03
> 1000 D but < 5000 D	–	–	–
> 5000 D	–	–	–
Adsorption 1000 D	–	–	–
Adsorption 5000 D	0.06 ± 0.03	–	–

– = Not found.

Table 8-9. Inorganic fractions (1000 D and 5000 D filters) in section 980.0–1001.2 m.

Fraction	Fe [mg/L]	Si [mg/L]	Mn [mg/L]
< 1000 D	0.01 ± 0.001	3.9 ± 0.6	0.97 ± 0.12
< 5000 D	0.03 ± 0.003	3.9 ± 0.6	1.06 ± 0.12
> 1000 D but < 5000 D	–	–	–
> 5000 D	–	–	–
Adsorption 1000 D	0.01 ± 0.004	–	–
Adsorption 5000 D	–	–	–

– = Not found.

8.5 Humic and fulvic acids

The results from fractionation of organic acids in sections 386.0–391.0 m, 448.0–453.0 m, 448.5–455.6 m, 639.0–646.1 m and 980.0–1001.2 m are summarized in Table 8-10. Fractionation was excluded in section 939.5–946.6 m due to a high content of flushing water. As shown, the water in the sections contains organic acids with a molecular weight less than 1000 D. This means that the organic constituents are present as low molecular weight fulvic acids and possibly other low molecular weight organic acids such as citric acid and oxalic acid.

Table 8-10. Summary of fractionation results.

Section Fraction	386.0–391.0 m DOC [mg/L]	448.0–453.0 m DOC [mg/L]	448.5–455.6 m DOC [mg/L]	639.0–646.1 m DOC [mg/L]	980.0–1001.2 m DOC [mg/L]
< 1000 D	1.2 ± 0.1	1.1 ± 0.1	A	1.2 ± 0.1	1.4 ± 0.2
> 1000 D but < 5000 D	–	–	A	–	–
> 5000 D	–	–	A	–	–

– = Not found.

A = analytical results yet to be reported.

The results from the 1000 D filter and 5000 D filter were consistent.

9 Summary and discussion

The complete chemical characterisation (MFL) and the pumping/sampling using hydraulic test equipment (PSS3) in KFM03A were, on the whole, performed successfully. Due to equipment malfunctions, measurement data of dissolved oxygen and electric conductivity are missing from sections 386.0–391.0 m (O_2) and 448.0–453.0 m (EC).

Downhole logging of the electric conductivity (EC) in discrete fractures was performed in connection with the difference flow logging prior to the chemical investigation of the borehole. These results were consistently higher (approx differences = 1000 mS/m) than the results presented in this report. Therefore, the chemical characterisation reported here was followed by repeated EC logging. This showed that the EC logging results and the Chemmac EC measurements agreed as well as could be expected. No malfunctions of the EC-logging equipment at the first occasion was evident. The now prevailing explanation is that the salinity gradient of the groundwater was lifted, due to the heavy pumping during the drilling (a so called up-coning effect), at the first EC-logging occasion just after drilling. A hydraulic evaluation of pumping activities in KFM03A and their effect indicated the presence of a more saline water system just below 1000 m depth /8/. This suggestion is supported by the slight salinity increase during the pumping period in section 939.5–946.6 m. However, no increase was observed during the pumping of section 980.0–1001.2 m. This may be due to pumping at lower flow rate or the absence of a connection between this fracture zone and the suggested deeper saline water system.

The main conclusions from the experimental results are:

- It is usually difficult to measure reliable redox potentials using pipe string systems and heavy pumping. This was also the case in sections 386.0–391.0 m and 448.0–453.0 m where the PSS3 equipment was used. These redox measurement data were rejected.
- The redox potential measurements by the downhole Chemmac and the surface Chemmac in sections 639.0–646.1 m and 939.5–946.6 m appear to be of good quality. The six electrodes (gold, glassy carbon and platinum) reached stable and agreeing values in both cases (–196 mV and –245 mV respectively). In section 448.5–455.6 m the downhole electrodes stabilized at –176 mV, while the electrodes in the surface Chemmac were unstable and showed conflicting values. Possible reasons for this may bee air intrusion or gas bubbles on electrode surfaces. The redox measurements in section 980.0–1001.2 m did not show stable or consistent values within the measurement period. The measurement behaviour is probably due to the very low iron concentration in this section and thereby the lack of a dominating redox pair. Furthermore, the pH measurement is also unreliable in this section which, however, is more difficult to explain.
- An upper limit for the allowed flushing water content in a representative water sample is set to 1%. This condition was met in sections 386.0–391.0 m, 448.0–453.0 m and 448.5–455.6 m but not in sections 639.0–646.1 m (4 %), 939.5–946.6 m (9 %) and 980.0–1001.2 m (4%).
- The salinity was stable during the pumping and sampling periods, except for section 939.5–946.6 m, were a slightly increasing concentration trend was recognized. A stable salinity indicates that there was no contribution of water from more distant fracture systems with a different water composition.

- Some iron analyses from sections 386.0–391.0 m and 448.0–453.0 m showed low Fe(+II) concentrations compared to total iron concentrations. It is not likely that these differences represent the Fe(+III) concentration of the groundwater. It seems as if the disparity appears only when the PSS-equipment is used. The reason could be that very small amounts of air enter somewhere in the water sampling line and cause oxidation of Fe(+II) prior to, or at, the time of sampling.

- The results from the colloid filtering experiment are less useful due to the many broken filters and inconsistent mass balances. However, the fractionation results for the inorganic constituents appear to be quite consistent. From the fractionation results it can be concluded that the content of inorganic colloidal components in the groundwater in sections 448.5–455.6 m, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m is very low or non-existent.

- The organic constituents in the groundwater are present as fulvic acids and possibly other low molecular weight organic acids such as citric acid and oxalic acid.

10 References

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

/2/ **Pedersen K, Kalmus A, 2004.** Forsmark site investigation. Total numbers and metabolic diversity of microorganisms in borehole KFM03A. Results from three investigated sections, 639.0–646.1 m, 939.5–946.6 m and 980.0–1001.2 m in KFM03A. SKB P-04-89. Svensk Kärnbränslehantering AB.

/3/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of the telescopic borehole KFM03A and the core drilled borehole KFM03B at drilling site DS3. SKB P-03-59 (in progress). Svensk Kärnbränslehantering AB.

/4/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of a flushing water well, HFM06, and the two groundwater monitoring wells, HFM07 and HFM08, at drilling site DS3. SKB P-03-58. Svensk Kärnbränslehantering AB.

/5/ **Nilsson A-C, 2003.** Forsmark site investigation. Sampling and analyses of groundwater in percussion drilled boreholes at drillsite DS3. Results from the percussion boreholes HFM06, and HFM08. SKB P-03-49. Svensk Kärnbränslehantering AB.

/6/ **Berg C, Nilsson A-C, 2003.** Forsmark site investigation. Hydrochemical logging in KFM03A. SKB P-03-95**.** Svensk Kärnbränslehantering AB.

/7/ **Aaltonen Jaana, Gustafsson Christer, 2004.** Forsmark site investigation. RAMAC and BIPS logging in boreholes KFM02A and KFM03A. SKB P-04-40. Svensk Kärnbränslehantering AB.

/8/ **Ludvigson J-E, Jönsson S, Levén J, 2004.** Forsmark site investigation. Hydraulic evaluation of pumping activities prior to hydro-chemical sampling in borehole KFM03A – Comparison with results from difference flow logging. SKB P-04-xx. Svensk Kärnbränslehantering AB. (in progress).

/9/ **Smellie J, Laaksoharju M, 1992.** The Äspö hard rock laboratory: Final evaluation of the hydrogeochemical pre-investigations in relation to existing geologic and hydraulic conditions. SKB TR 92-31. Svensk Kärnbränslehantering AB.

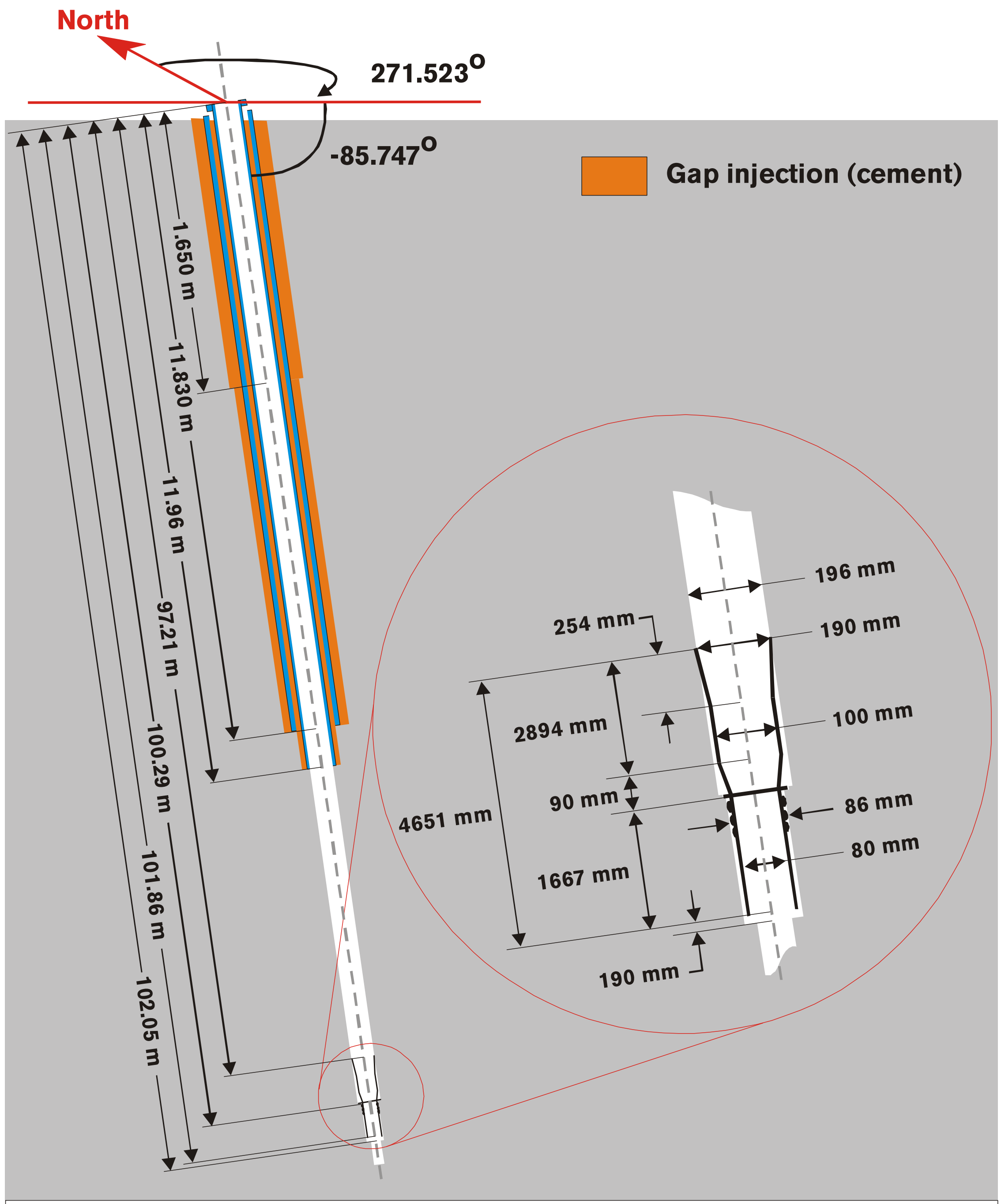
/10/ **Wacker P, Nilsson A-C, 2004.** Evaluation of a colloid sampling method (in progress).

Appendix 1

Design of cored borehole KFM03A

Technical data

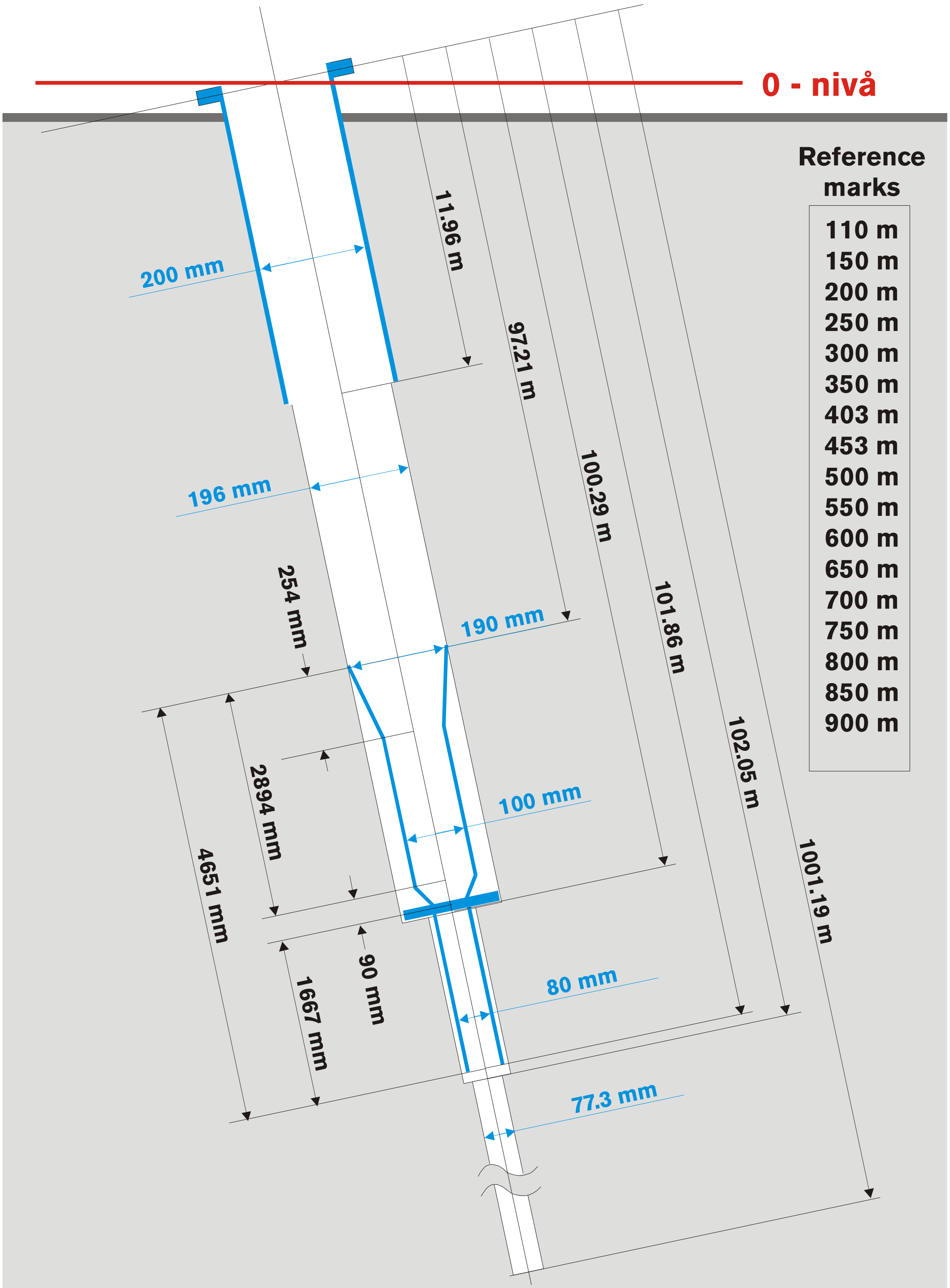
Borehole KFM03A



Drilling reference point

Northing:	**6697852.096 (m), RT90 2,5 gon V 0:-15**
Easting:	**1634630.737 (m), RT90 2,5 gon V 0:-15**
Elevation:	**8.285 (m), RHB 70**
Borehole length:	**1001,19 m**

KFM03A



Drilling period
Drilling start date: 2002-04-16
Drilling stop date: 2003-06-23

Drilling reference point
Northing: 6697852.096 (m), RT90 2,5 gon V 0:-15
Easting: 1634630.737 (m), RT90 2,5 gon V 0:-15
Elevation: 8.285 (m), RHB 70

Appendix 2

Results of difference flow logging in KFM03A

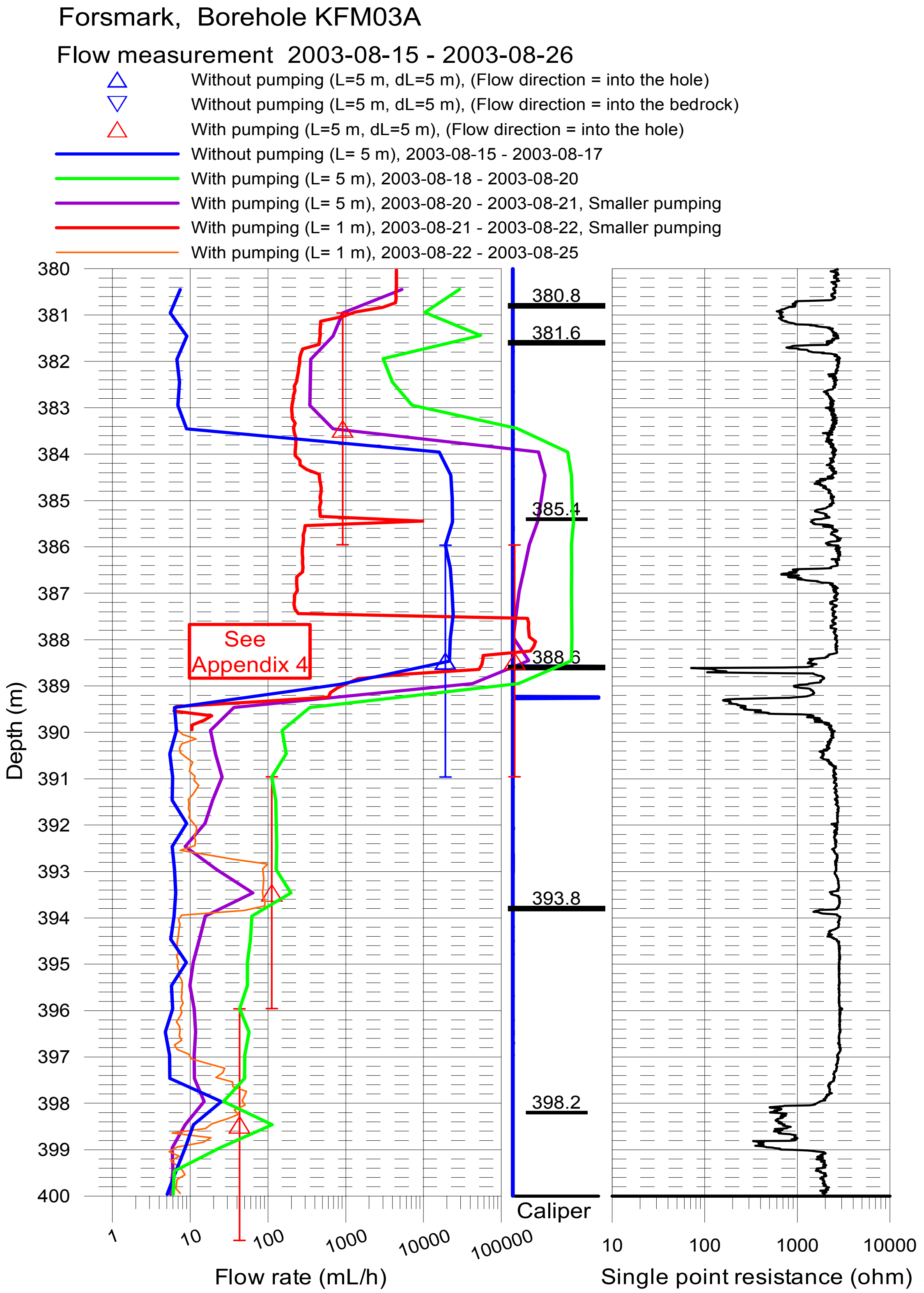


Figure A2-1. Borehole KFM03A: Differential flow measurements from 380-400 m including the water bearing fracture zone at 388 m, August 2003.

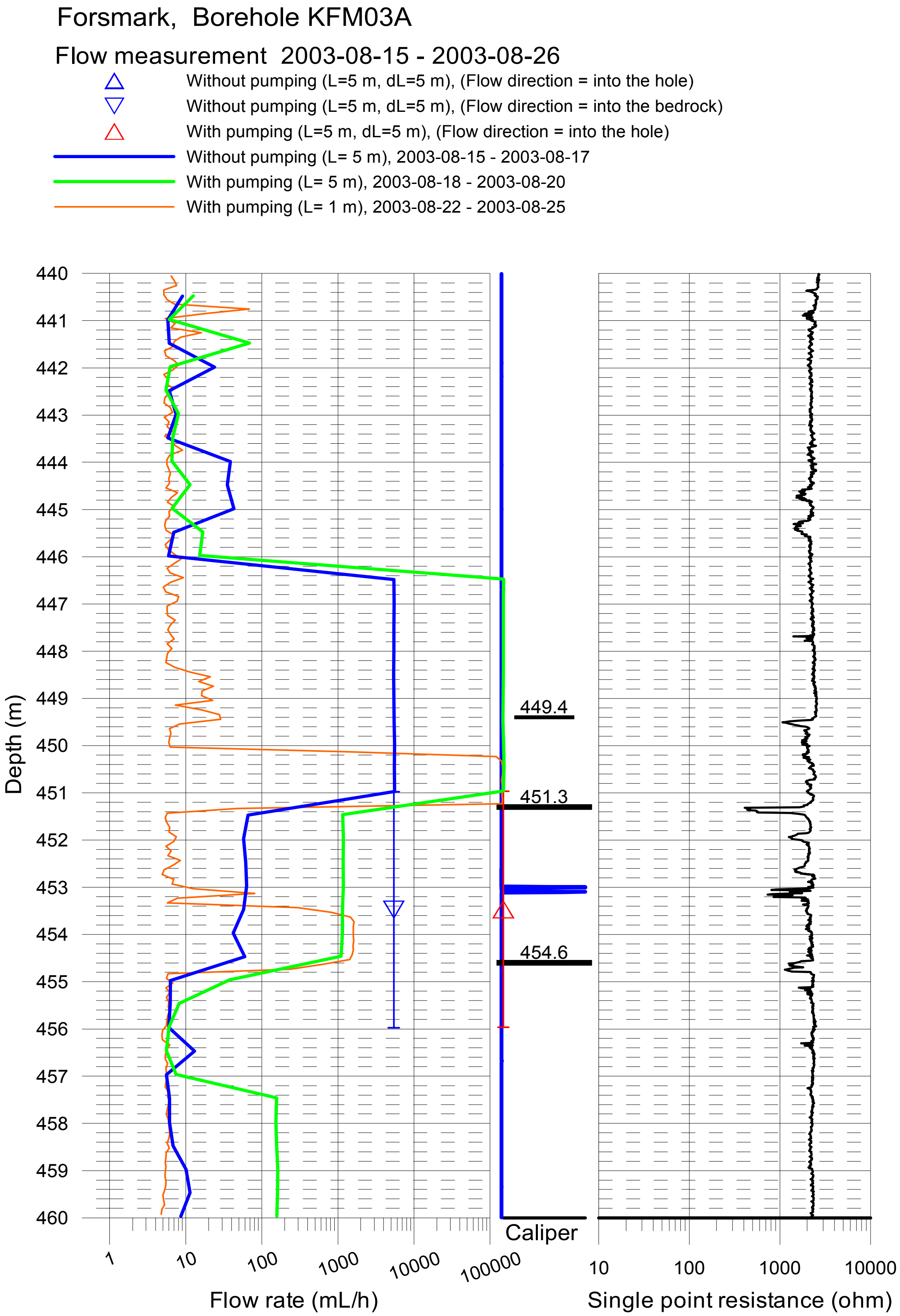


Figure A2-2. *Borehole KFM03A: Differential flow measurements from 440-460 m including the water bearing fracture zone at 451 m, August 2003.*

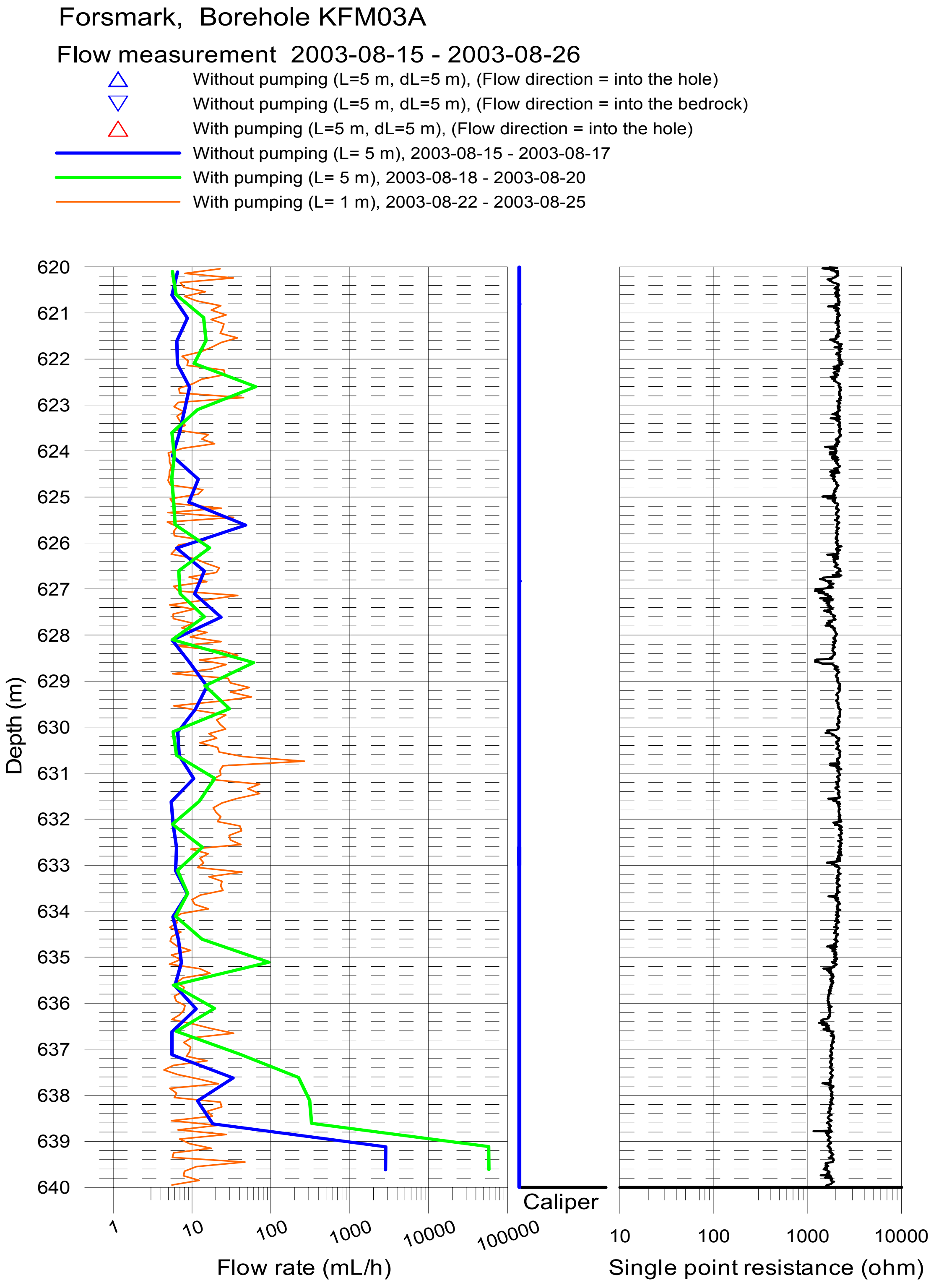


***Figure A2-3.** Borehole KFM03A: Differential flow measurements from 620-640 m including the water bearing fracture zone at 640 m, August 2003.*

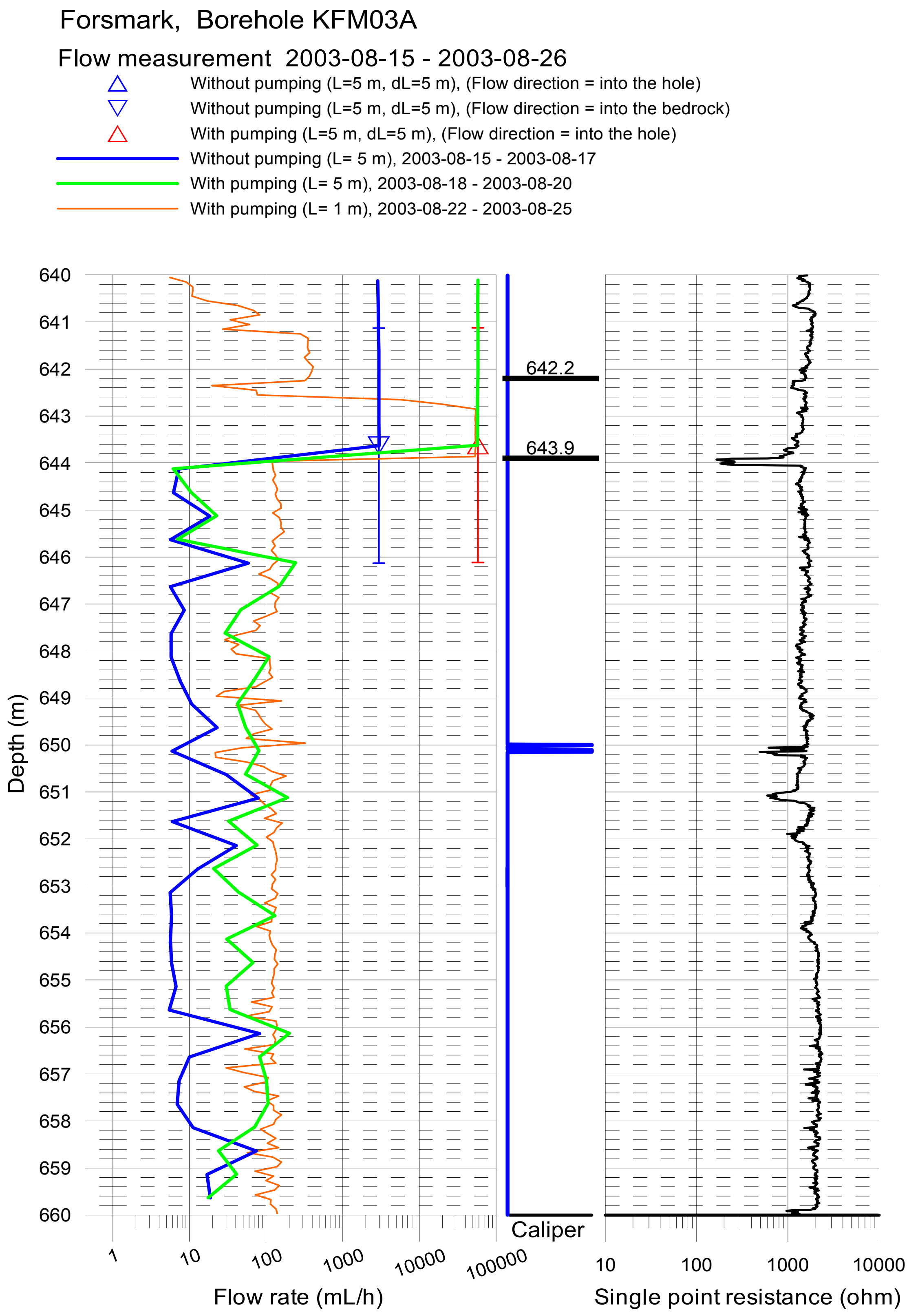


Figure A2-4. *Borehole KFM03A: Differential flow measurements from 640-660 m including the water bearing fracture zone at 643 m, August 2003.*

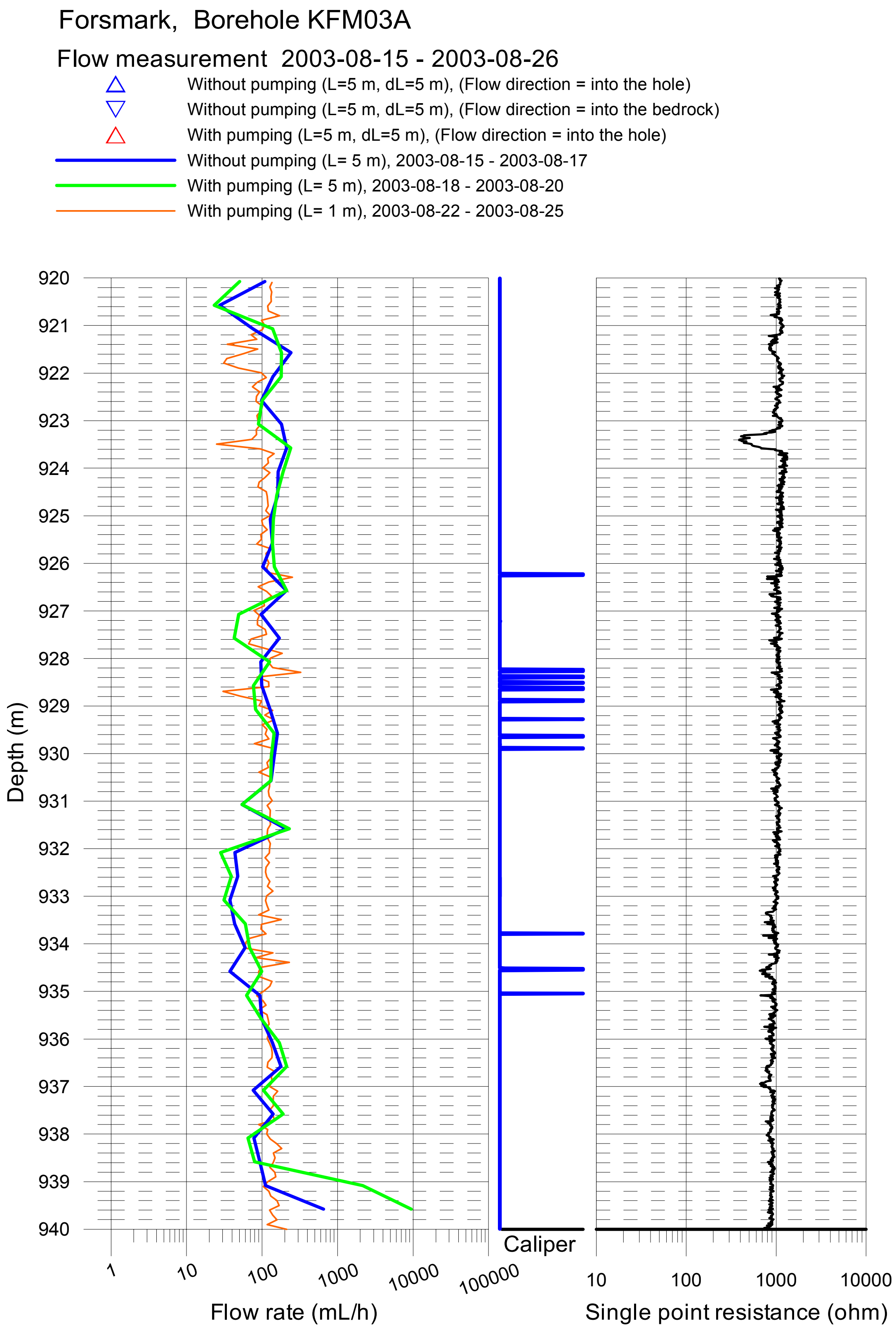


Figure A2-5. *Borehole KFM03A: Differential flow measurements from 920-940 m including the water bearing fracture zone at 940 m, August 2003.*

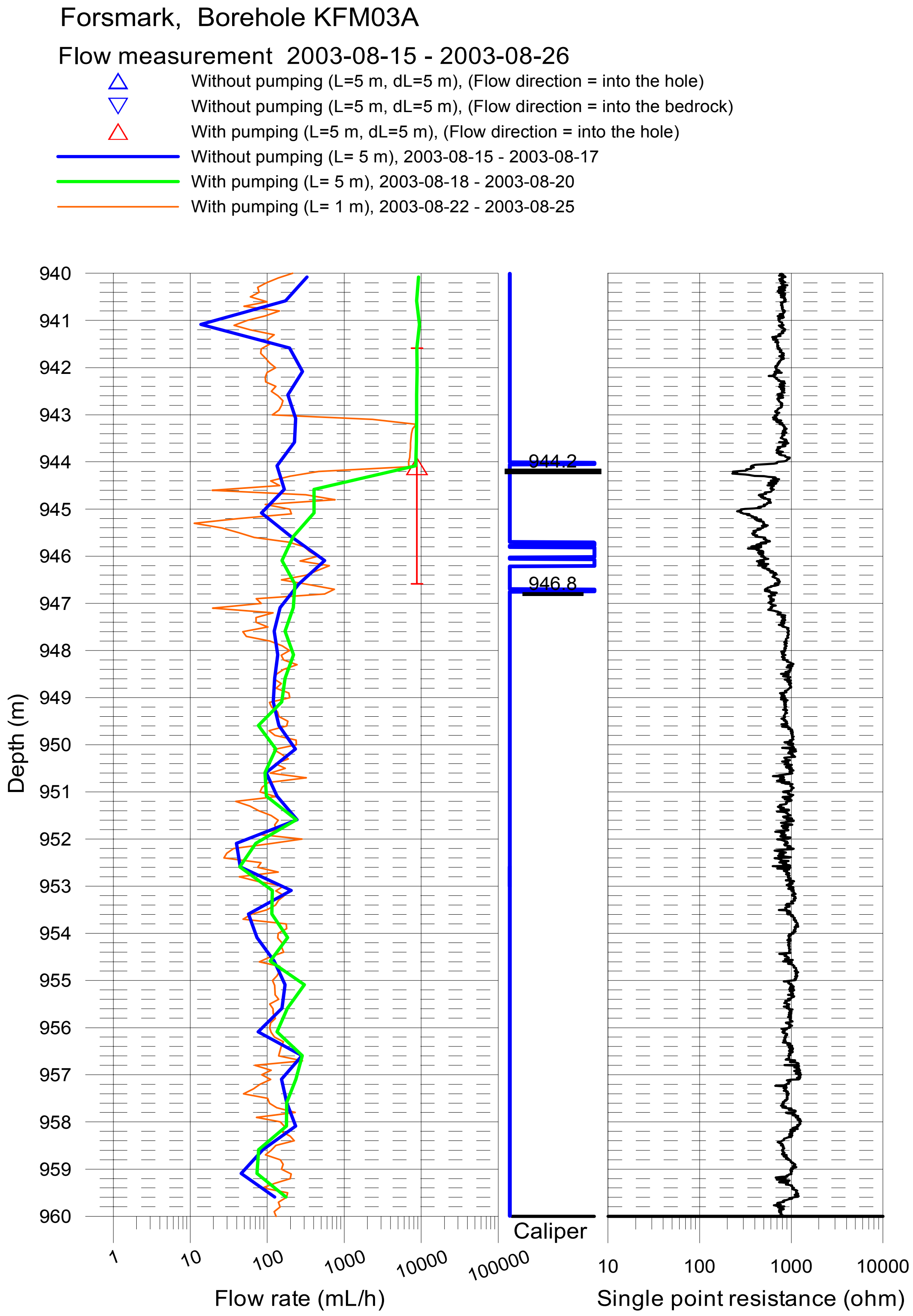


Figure A2-6. *Borehole KFM03A: Differential flow measurements from 940-960 m including the water bearing fracture zone at 944 m, August 2003.*

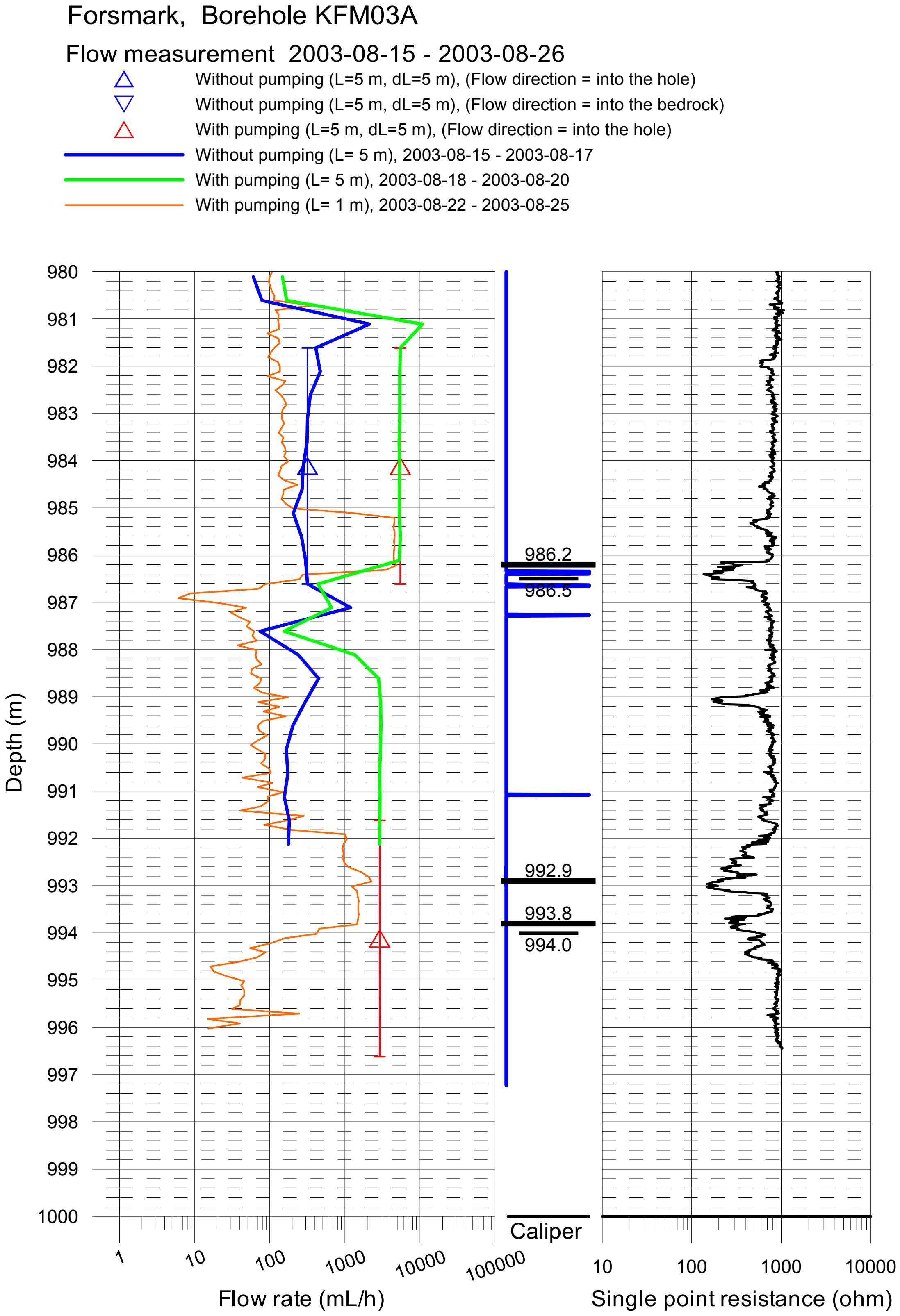
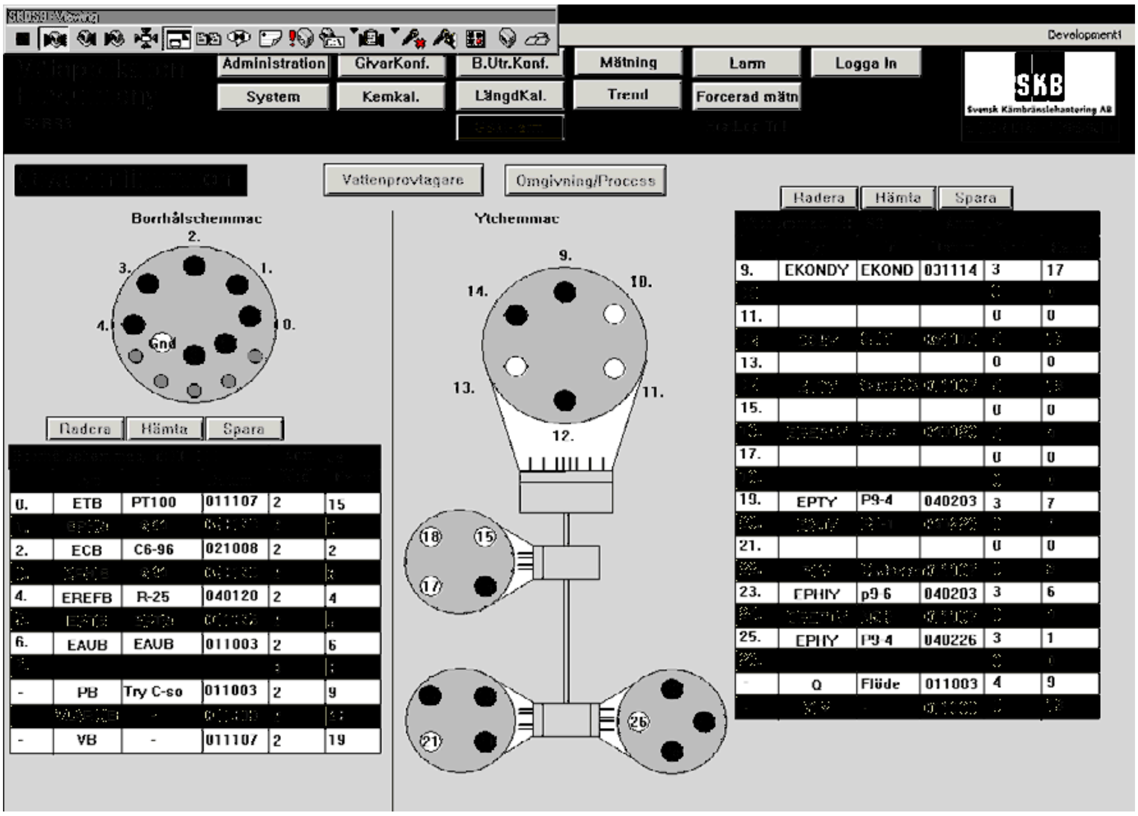


Figure A2-7. *Borehole KFM03A: Differential flow measurements from 980-1000 m including the water bearing fracture zone at 986 m, August 2003.*

Appendix 3

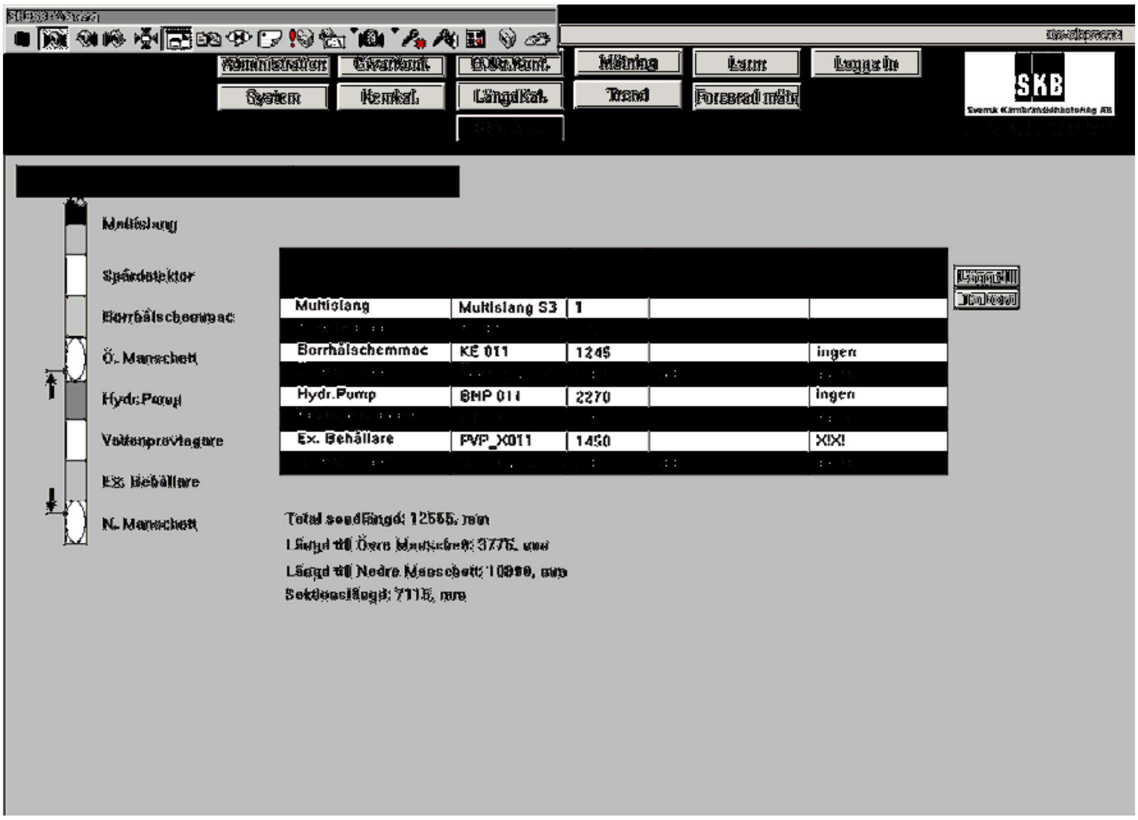
Measurement information, KFM03A



0.	ETB	PT100	011107	2	15
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2.	ECB	C6-96	021008	2	2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4.	EREFB	R-25	040120	2	4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6.	EAUB	EAUB	011003	2	6
[illegible]				[illegible]	[illegible]
-	PB	Try C-so	011003	2	9
	[illegible]	-	[illegible]	[illegible]	[illegible]
-	VB	-	011107	2	19

9.	EKONDY	EKOND	031114	3	17
[illegible]				[illegible]	[illegible]
11.				0	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13.				0	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15.				0	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17.				0	0
[illegible]				[illegible]	[illegible]
19.	EPTY	P9-4	040203	3	7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21.				0	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23.	EPHIY	p9-6	040203	3	6
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25.	EPHY	P9-4	040226	3	1
[illegible]				[illegible]	[illegible]
-	Q	Flöde	011003	4	9
-	[illegible]	-	[illegible]	[illegible]	[illegible]

Figure A3-1. *Electrode configuration, section 448.5-455.6 m*



Multislang	Multislang S3	1		
[illegible]	[illegible]	[illegible]		
Borrhålschemmac	KE 011	1245		ingen
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hydr.Pump	BHP 011	2270		ingen
[illegible]	[illegible]	[illegible]		[illegible]
Ex. Behållare	PVP_X011	1450		X!X!
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Total sondlängd: 12555, mm
Längd till Övre Manschett: 3775, mm
Längd till Nedre Manschett: 10890, mm
Sektionslängd: 7115, mm

Figure A3-2. *Configuration of downhole equipment, section 448.5-455.6 m*

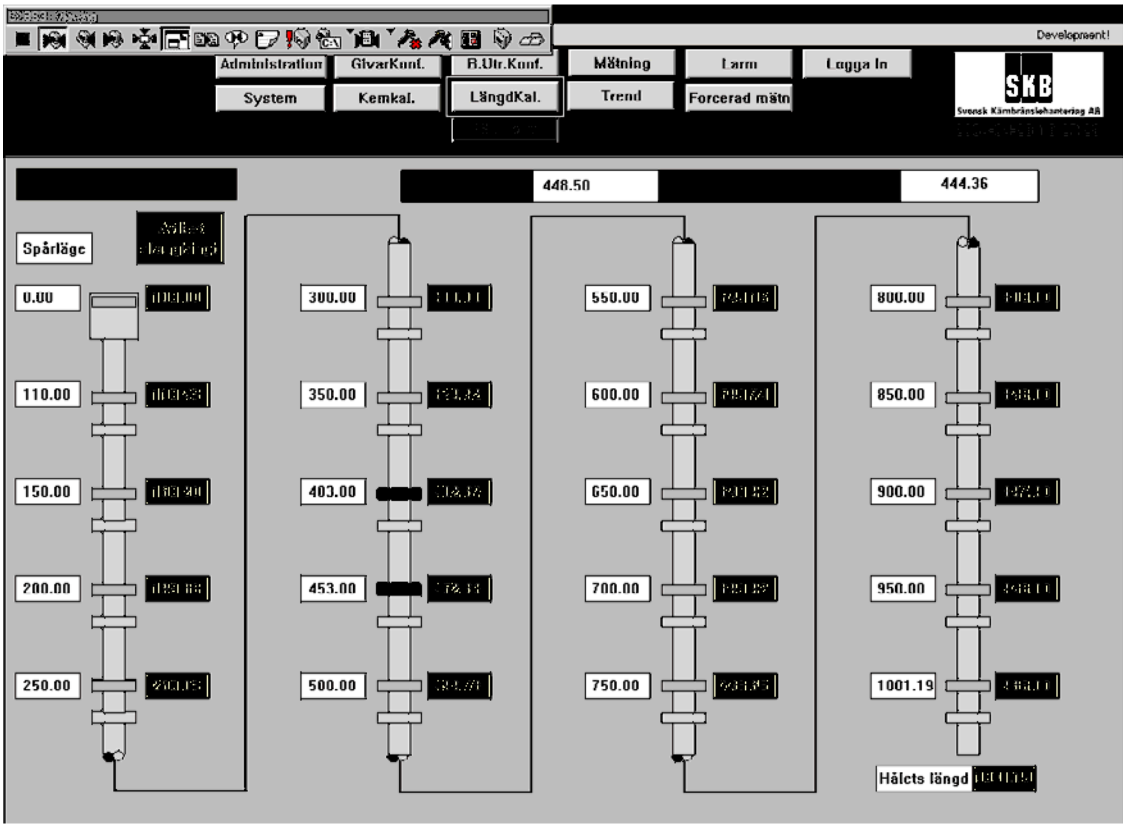
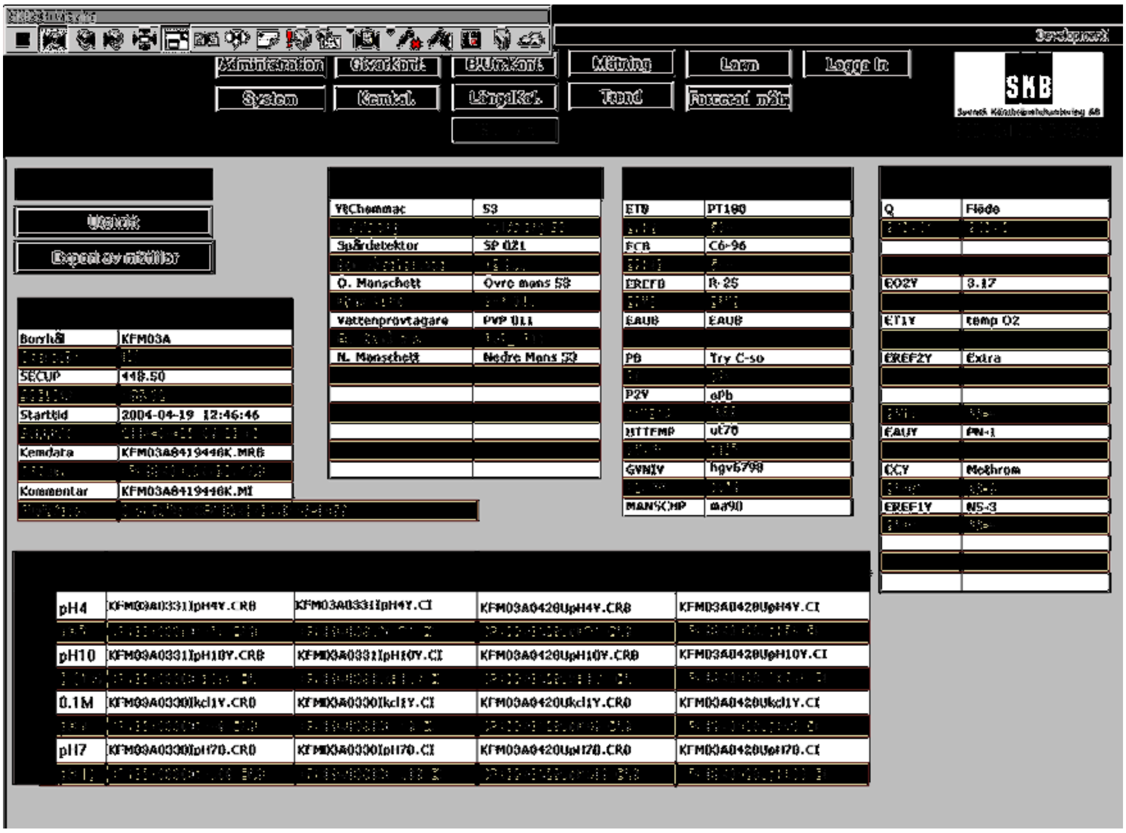


Figure A3-3. *Length calibration, section 448.5-455.6 m*



Borrhål	KFM03A
[illegible]	[illegible]
SECUP	448.50
[illegible]	[illegible]
Starttid	2004-04-19 12:46:46
[illegible]	[illegible]
Kemdata	KFM03A8419446K.MRB
[illegible]	[illegible]
Kommentar	KFM03A8419446K.MI
[illegible]	[illegible]

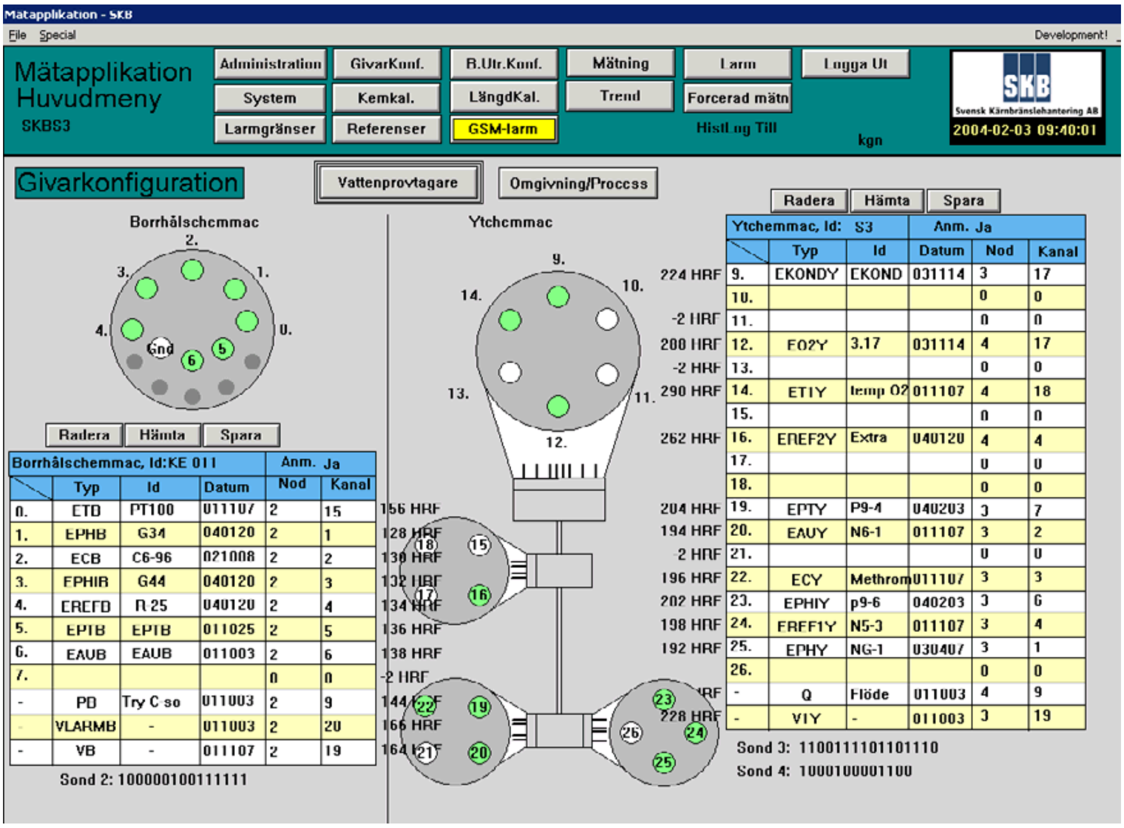
YtChemmac	S3
[illegible]	[illegible]
Spårdetektor	SP 021
[illegible]	[illegible]
O. Manschett	Övre mans S3
[illegible]	[illegible]
Vattenprovtagare	PVP 011
[illegible]	[illegible]
N. Manschett	Nedre Mans S3

ETB	PT100
[illegible]	[illegible]
FCB	C6-96
[illegible]	[illegible]
EREFB	R-25
[illegible]	[illegible]
EAUB	EAUB
PB	Try C-so
[illegible]	[illegible]
P2Y	oPb
[illegible]	[illegible]
UTTEMP	ut70
[illegible]	[illegible]
GVNIV	hgv6798
[illegible]	[illegible]
MANSCHP	ma90

Q	Flöde
[illegible]	[illegible]
EO2Y	3.17
ET1Y	temp O2
EREF2Y	Extra
[illegible]	[illegible]
EAUY	PN-1
CCY	Methrom
[illegible]	[illegible]
EREF1Y	N5-3
[illegible]	[illegible]

pH4	KFM03A0331IpH4Y.CRB	KFM03A0331IpH4Y.CI	KFM03A0420UpH4Y.CRB	KFM03A0420UpH4Y.CI
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
pH10	KFM03A0331IpH10Y.CRB	KFM03A0331IpH10Y.CI	KFM03A0420UpH10Y.CRB	KFM03A0420UpH10Y.CI
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
0.1M	KFM03A0330Ikcl1Y.CRB	KFM03A0330Ikcl1Y.CI	KFM03A0420Ukcl1Y.CRB	KFM03A0420Ukcl1Y.CI
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
pH7	KFM03A0330IpH70.CRB	KFM03A0330IpH70.CI	KFM03A0420UpH70.CRB	KFM03A0420UpH70.CI
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure A3-4. *Administration (040428), section 448.5-455.6 m*



Borrhålschemmac, Id:KE 011				Anm. Ja	
	Typ	Id	Datum	Nod	Kanal
0.	ETD	PT100	011107	2	15
1.	EPHB	G34	040120	2	1
2.	ECB	C6-96	021008	2	2
3.	EPHIB	G44	040120	2	3
4.	EREFB	R-25	040120	2	4
5.	EPTB	EPTB	011025	2	5
6.	EAUB	EAUB	011003	2	6
7.				0	0
-	PD	Try C-so	011003	2	9
-	VLARMB	-	011003	2	20
-	VB	-	011107	2	19

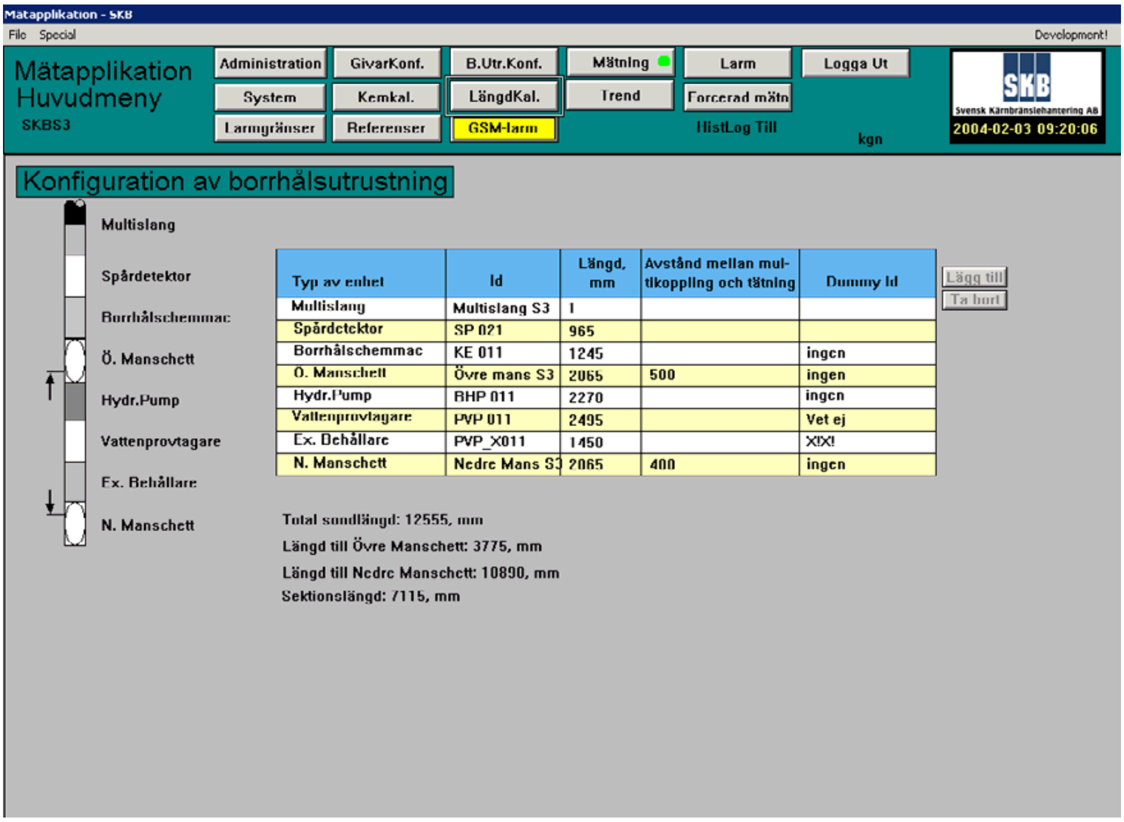
Sond 2: 100000100111111

Ytchemmac, Id: S3			Anm. Ja		
	Typ	Id	Datum	Nod	Kanal
9.	EKONDY	EKOND	031114	3	17
10.				0	0
11.				0	0
12.	EO2Y	3.17	031114	4	17
13.				0	0
14.	ETIY	Temp O2	011107	4	18
15.				0	0
16.	EREF2Y	Extra	040120	4	4
17.				0	0
18.				0	0
19.	EPTY	P9-4	040203	3	7
20.	EAUY	N6-1	011107	3	2
21.				0	0
22.	ECY	Methrom	011107	3	3
23.	EPHIY	p9-6	040203	3	6
24.	EREF1Y	N5-3	011107	3	4
25.	EPHY	N6-1	030407	3	1
26.				0	0
-	Q	Flöde	011003	4	9
-	VIY	-	011003	3	19

Sond 3: 1100111101101110

Sond 4: 1000100001100

Figure A3-5. Electrode configuration, section 639.0-646.1 m.



Typ av enhet	Id	Längd, mm	Avstånd mellan multikoppling och tätning	Dummy Id
Multislang	Multislang S3	1		
Spårdetektor	SP 021	965		
Borrhålschemmac	KE 011	1245		ingen
Ö. Manschett	Övre mans S3	2065	500	ingen
Hydr.Pump	BHP 011	2270		ingen
Vattenprovtagare	PVP 011	2495		Vet ej
Ex. Behållare	PVP_X011	1450		X!X!
N. Manschett	Nedre Mans S3	2065	400	ingen

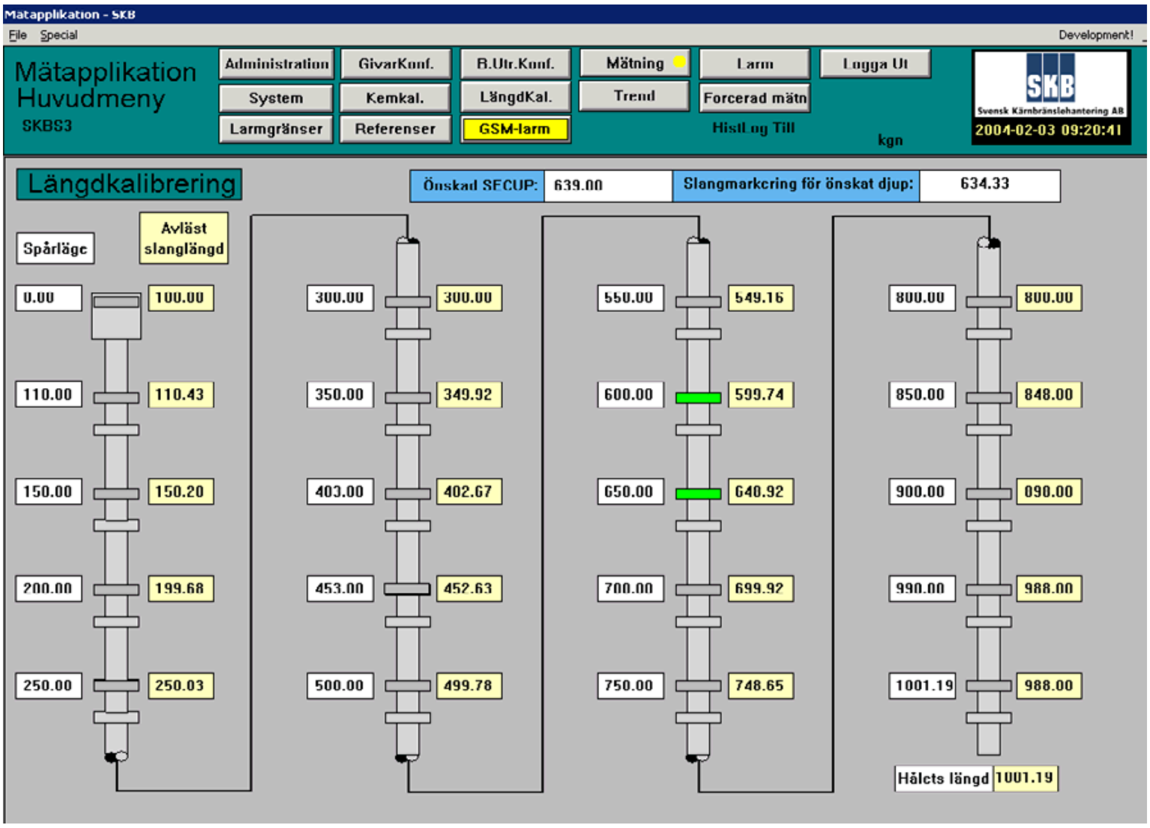
Total sondlängd: 12555, mm

Längd till Övre Manschett: 3775, mm

Längd till Nedre Manschett: 10890, mm

Sektionslängd: 7115, mm

Figure A3-6. Configuration of downhole equipment, section 639.0-646.1 m.



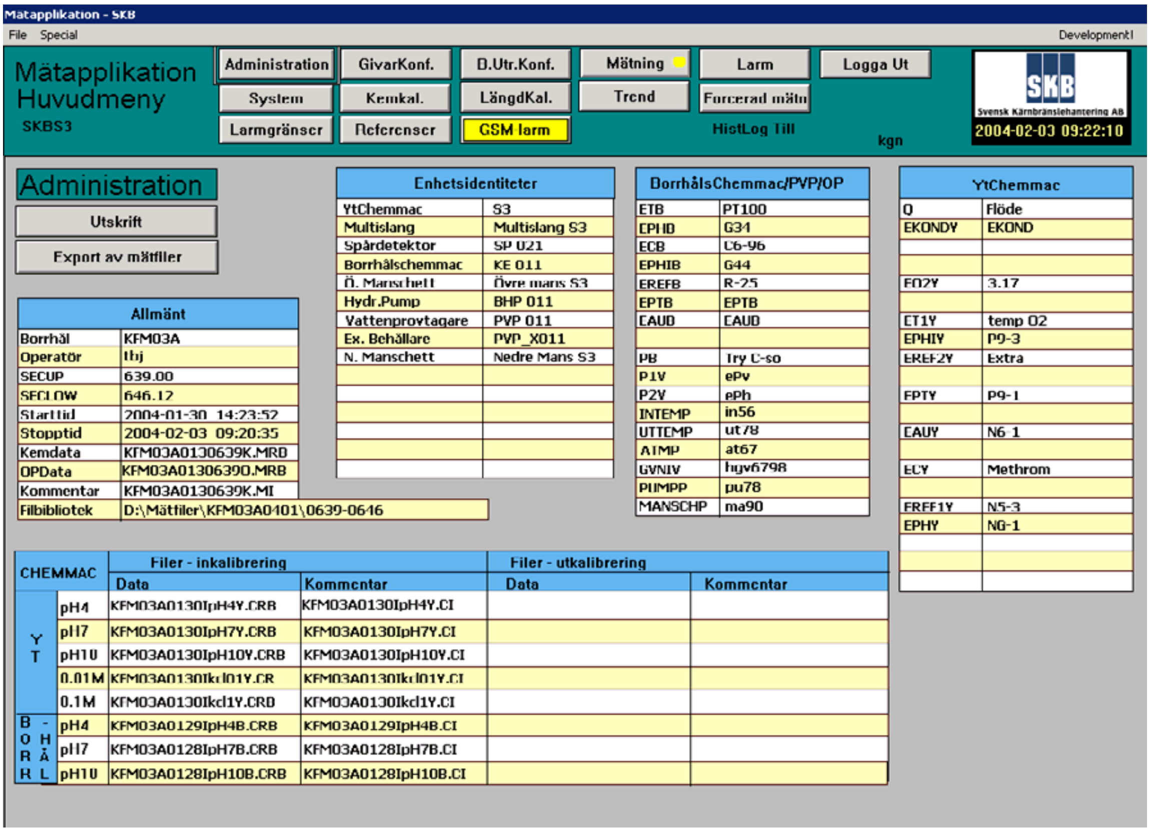
Önskad SECUP: 639.00

Slangmarkering för önskat djup: 634.33

Spårläge	Avläst slanglängd
0.00	100.00
110.00	110.43
150.00	150.20
200.00	199.68
250.00	250.03
300.00	300.00
350.00	349.92
403.00	402.67
453.00	452.63
500.00	499.78
550.00	549.16
600.00	599.74
650.00	640.92
700.00	699.92
750.00	748.65
800.00	800.00
850.00	848.00
900.00	090.00
990.00	988.00
1001.19	988.00

Hålets längd 1001.19

***Figure A3-7.** Length calibration, section 639.0-646.1 m.*



Allmänt	
Borrhål	KFM03A
Operatör	thj
SECUP	639.00
SECLOW	646.12
Starttid	2004-01-30 14:23:52
Stopptid	2004-02-03 09:20:35
Kemdata	KFM03A0130639K.MRD
OPData	KFM03A01306390.MRB
Kommentar	KFM03A0130639K.MI
Filbibliotek	D:\Mättfiler\KFM03A0401\0639-0646

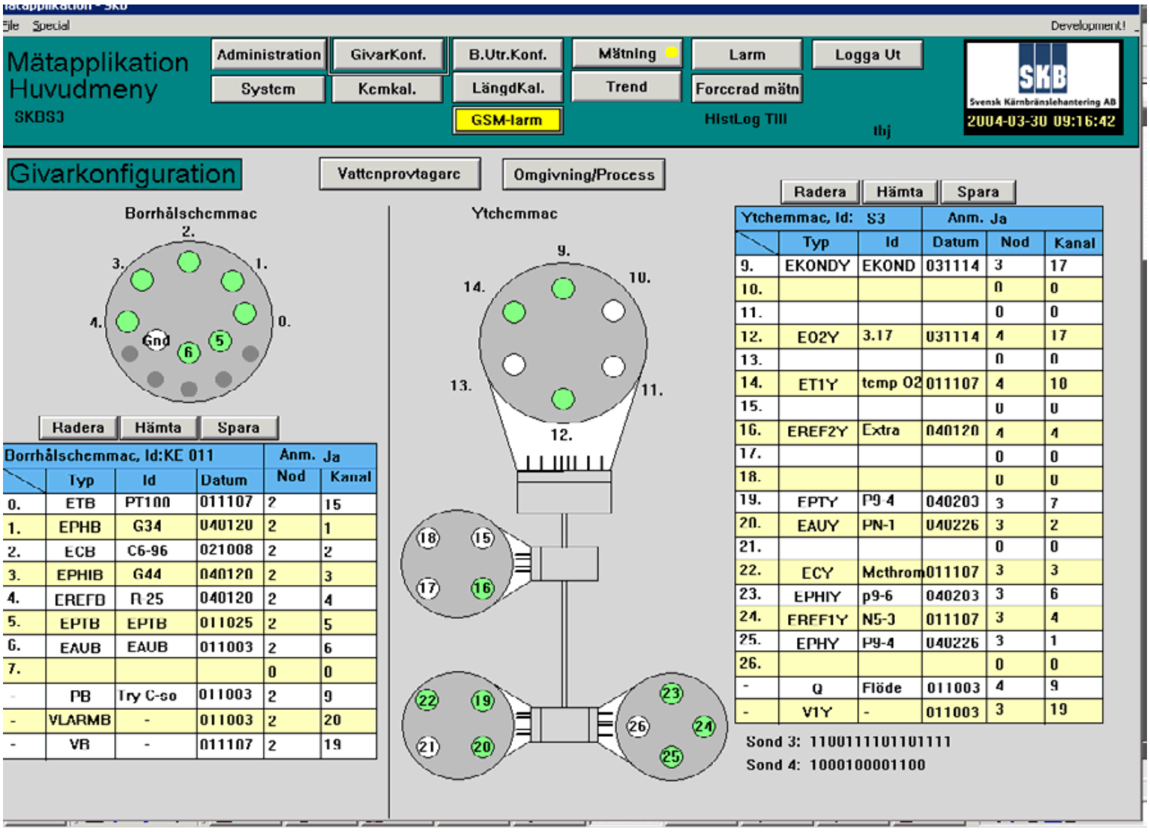
Enhetsidentiteter	
YtChemmac	S3
Multislang	Multislang S3
Spårdetektor	SP 021
Borrhålschemmac	KE 011
Ö. Manschett	Övre mans S3
Hydr.Pump	BHP 011
Vattenprovtagare	PVP 011
Ex. Behållare	PVP_X011
N. Manschett	Nedre Mans S3

BorrhålsChemmac/PVP/OP	
ETB	PT100
EPHB	G34
ECB	C6-96
EPHIB	G44
EREFB	R-25
EPTB	EPTB
EAUB	EAUB
PB	Try C-so
P1V	ePv
P2V	ePh
INTEMP	in56
UTTEMP	ut78
ATMP	at67
GVNIV	hgv6798
PUMPP	pu78
MANSCHP	ma90

YtChemmac	
Q	Flöde
EKONDY	EKOND
EO2Y	3.17
ET1Y	temp O2
EPHIY	P9-3
EREF2Y	Extra
EPTY	P9-1
EAUY	N6-1
ECY	Methrom
EREF1Y	N5-3
EPHY	NG-1

CHEMMAC		Filer - inkalibrering		Filer - utkalibrering	
		Data	Kommentar	Data	Kommentar
YT	pH4	KFM03A0130IpH4Y.CRB	KFM03A0130IpH4Y.CI		
	pH7	KFM03A0130IpH7Y.CRB	KFM03A0130IpH7Y.CI		
	pH10	KFM03A0130IpH10Y.CRB	KFM03A0130IpH10Y.CI		
	0.01M	KFM03A0130Ikcl01Y.CR	KFM03A0130Ikcl01Y.CI		
	0.1M	KFM03A0130Ikcl1Y.CRB	KFM03A0130Ikcl1Y.CI		
BORR-HÅL	pH4	KFM03A0129IpH4B.CRB	KFM03A0129IpH4B.CI		
	pH7	KFM03A0128IpH7B.CRB	KFM03A0128IpH7B.CI		
	pH10	KFM03A0128IpH10B.CRB	KFM03A0128IpH10B.CI		

Figure A3-8. *Administration (040203), section 639.0-646.1 m.*

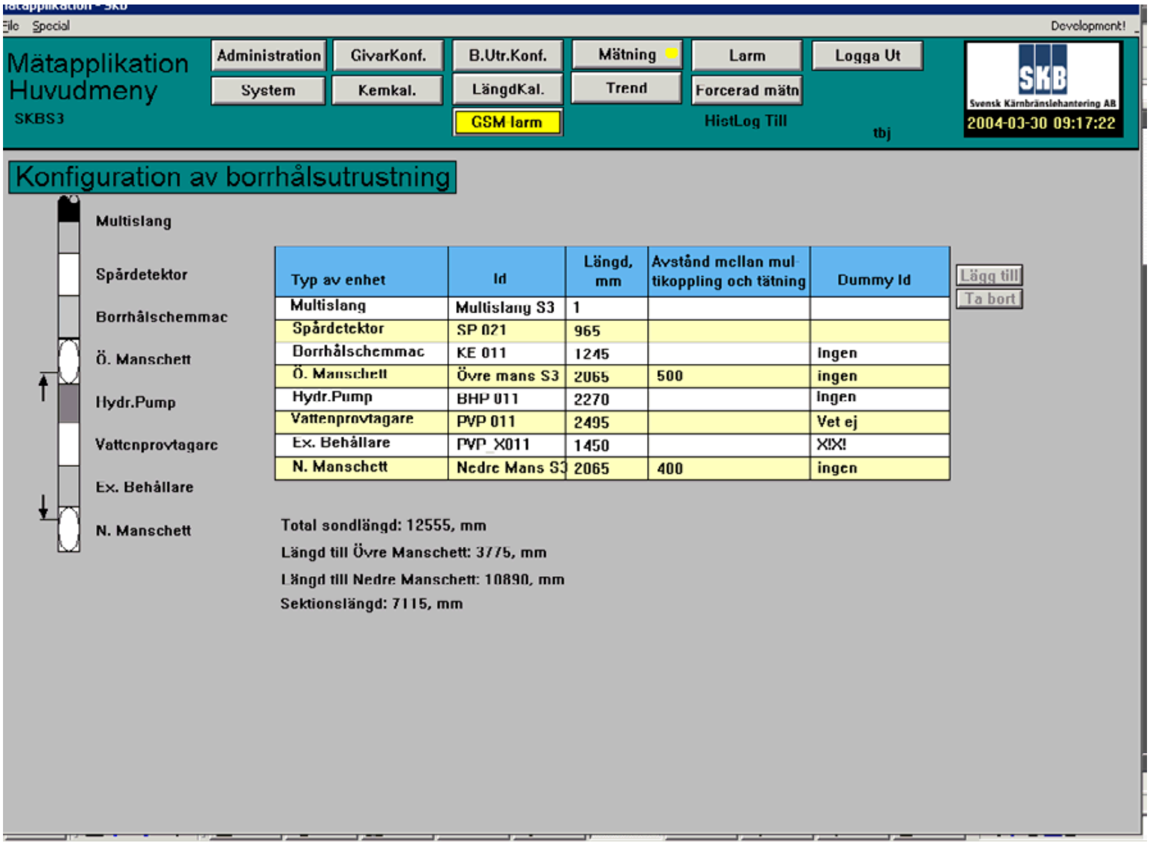


Borrhålschemmac, Id:KE 011				Anm. Ja	
	Typ	Id	Datum	Nod	Kanal
0.	ETB	PT100	011107	2	15
1.	EPHB	G34	040120	2	1
2.	ECB	C6-96	021008	2	2
3.	EPHIB	G44	040120	2	3
4.	EREFD	R-25	040120	2	4
5.	EPTB	EPTB	011025	2	5
6.	EAUB	EAUB	011003	2	6
7.				0	0
-	PB	Try C-so	011003	2	9
-	VLARMB	-	011003	2	20
-	VB	-	011107	2	19

Ytchemmac, Id: S3			Anm. Ja		
	Typ	Id	Datum	Nod	Kanal
9.	EKONDY	EKOND	031114	3	17
10.				0	0
11.				0	0
12.	EO2Y	3.17	031114	4	17
13.				0	0
14.	ET1Y	temp 02	011107	4	10
15.				0	0
16.	EREF2Y	Extra	040120	4	4
17.				0	0
18.				0	0
19.	EPTY	P9-4	040203	3	7
20.	EAUY	PN-1	040226	3	2
21.				0	0
22.	ECY	Methrom	011107	3	3
23.	EPHIY	p9-6	040203	3	6
24.	EREF1Y	N5-3	011107	3	4
25.	EPHY	P9-4	040226	3	1
26.				0	0
-	Q	Flöde	011003	4	9
-	V1Y	-	011003	3	19

Sond 3: 1100111101101111
Sond 4: 1000100001100

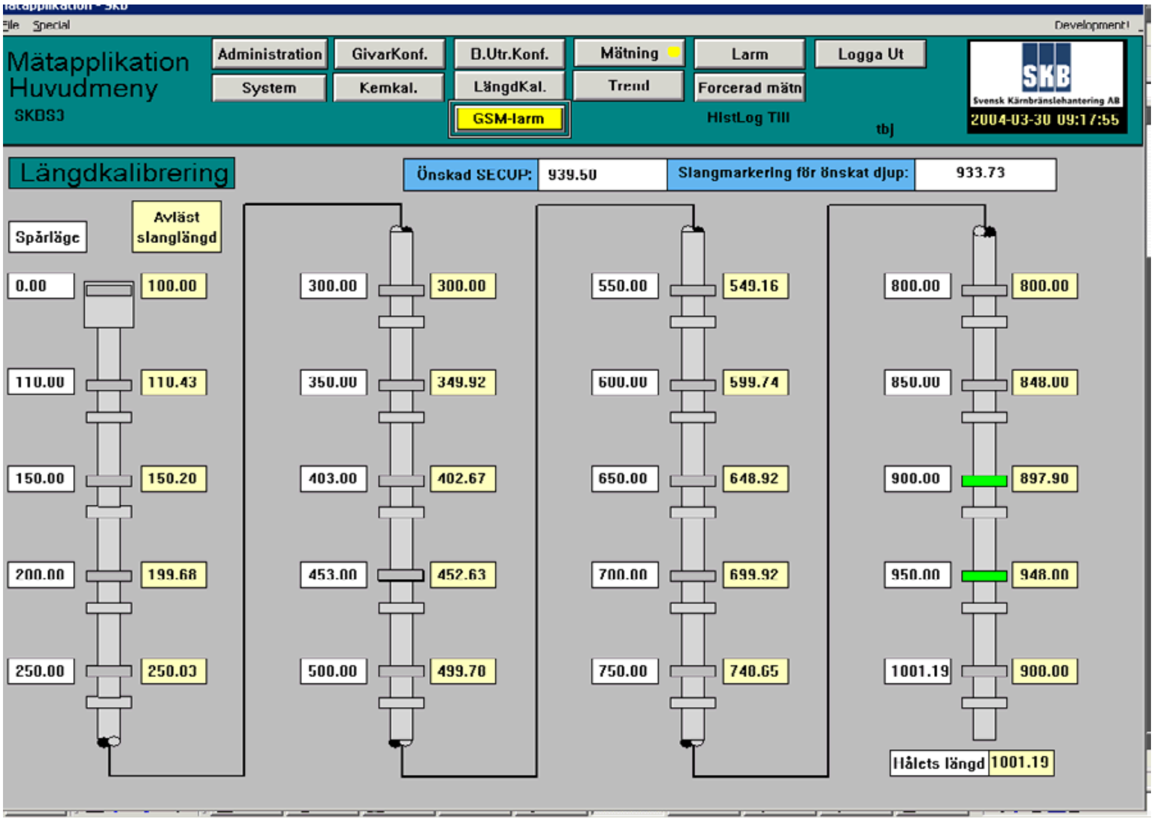
Figure A3-9. *Electrode configuration, section 939.5-946.6 m.*



Typ av enhet	Id	Längd, mm	Avstånd mellan multikoppling och tätning	Dummy Id
Multislang	Multislang S3	1		
Spårdetektor	SP 021	965		
Borrhålschemmac	KE 011	1245		Ingen
Ö. Manschett	Övre mans S3	2065	500	ingen
Hydr.Pump	BHP 011	2270		Ingen
Vattenprovtagare	PVP 011	2495		Vet ej
Ex. Behållare	PVP_X011	1450		X!X!
N. Manschett	Nedre Mans S3	2065	400	ingen

Total sondlängd: 12555, mm
Längd till Övre Manschett: 3775, mm
Längd till Nedre Manschett: 10890, mm
Sektionslängd: 7115, mm

Figure A3-10. *Configuration of downhole equipment, section 939.5-946.6 m.*



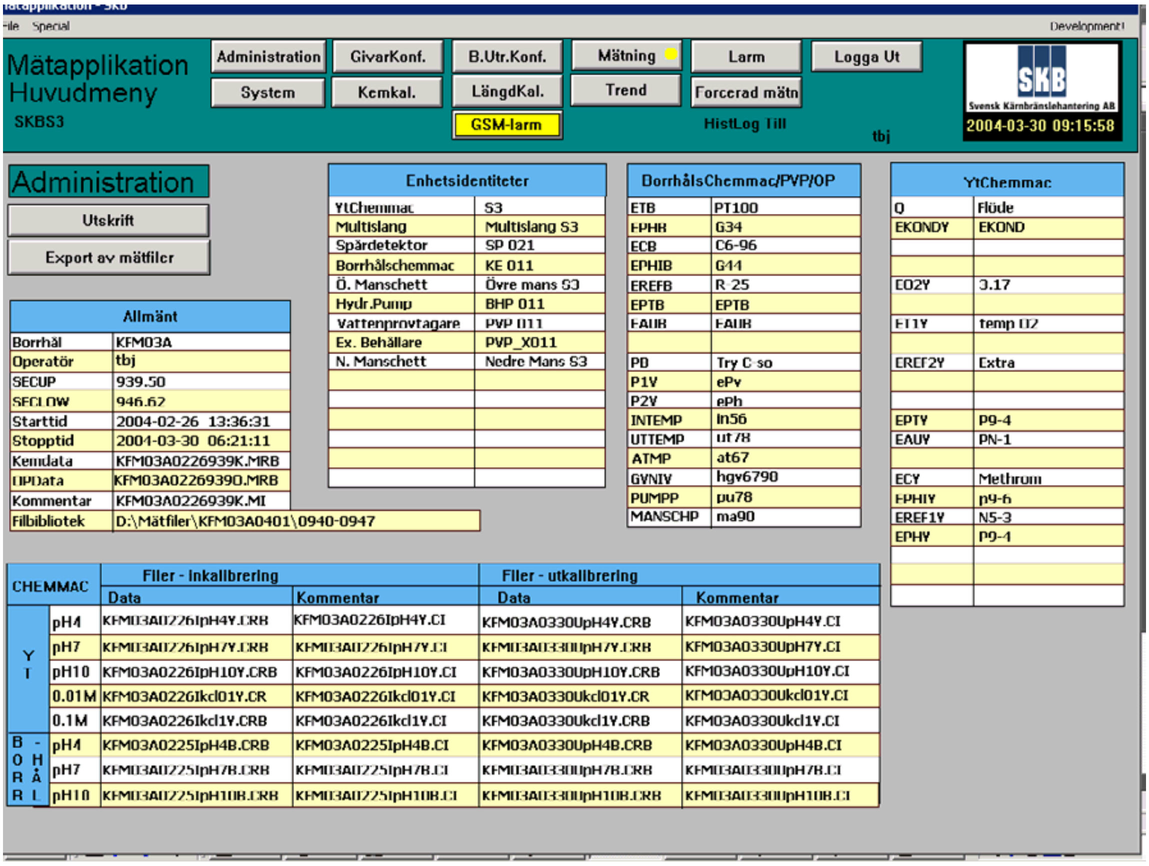
Önskad SECUP: 939.50

Slangmarkering för önskat djup: 933.73

Spårläge	Avläst slanglängd
0.00	100.00
110.00	110.43
150.00	150.20
200.00	199.68
250.00	250.03
300.00	300.00
350.00	349.92
403.00	402.67
453.00	452.63
500.00	499.70
550.00	549.16
600.00	599.74
650.00	648.92
700.00	699.92
750.00	740.65
800.00	800.00
850.00	848.00
900.00	897.90
950.00	948.00
1001.19	900.00

Hålets längd 1001.19

Figure A3-11. *Length calibration, section 939.5-946.6 m.*



Allmänt	
Borrhål	KFM03A
Operatör	tbj
SECUP	939.50
SECLOW	946.62
Starttid	2004-02-26 13:36:31
Stopptid	2004-03-30 06:21:11
Kemdata	KFM03A0226939K.MRB
UPData	KFM03A02269390.MRB
Kommentar	KFM03A0226939K.MI
Filbibliotek	D:\Mätfiler\KFM03A0401\0940-0947

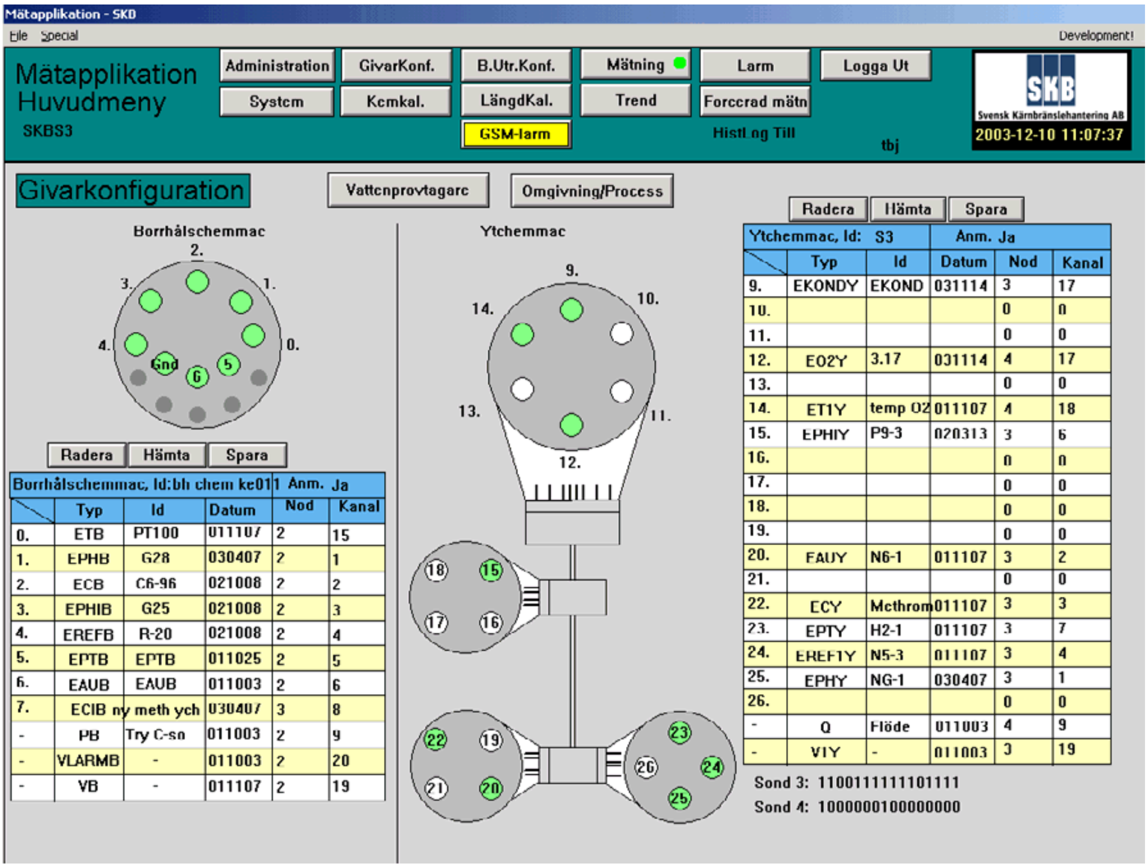
Enhetsidentiteter	
YtChemmac	S3
Multislang	Multislang S3
Spårdetektor	SP 021
Borrhålschemmac	KE 011
Ö. Manschett	Övre mans S3
Hydr.Pump	BHP 011
Vattenprovtagare	PVP 011
Ex. Behållare	PVP_X011
N. Manschett	Nedre Mans S3

BorrhålsChemmac/PVP/OP	
ETB	PT100
EPHB	G34
ECB	C6-96
EPHIB	G44
EREFB	R-25
EPTB	EPTB
EAUB	EAUB
PD	Try C-so
P1V	ePv
P2V	ePh
INTEMP	In56
UTTEMP	ut78
ATMP	at67
GVNIV	hgv6790
PUMPP	pu78
MANSCHP	ma90

YtChemmac	
Q	Flöde
EKONDY	EKOND
EO2Y	3.17
ET1Y	temp O2
EREF2Y	Extra
EPTY	P9-4
EAUY	PN-1
ECY	Methrom
EPHIY	p9-6
EREF1Y	N5-3
EPHY	P9-4

CHEMMAC		Filer - Inkalibrering		Filer - utkalibrering	
		Data	Kommentar	Data	Kommentar
YT	pH4	KFM03A0226IpH4Y.CRB	KFM03A0226IpH4Y.CI	KFM03A0330UpH4Y.CRB	KFM03A0330UpH4Y.CI
	pH7	KFM03A0226IpH7Y.CRB	KFM03A0226IpH7Y.CI	KFM03A0330UpH7Y.CRB	KFM03A0330UpH7Y.CI
	pH10	KFM03A0226IpH10Y.CRB	KFM03A0226IpH10Y.CI	KFM03A0330UpH10Y.CRB	KFM03A0330UpH10Y.CI
	0.01M	KFM03A0226Ikcl01Y.CR	KFM03A0226Ikcl01Y.CI	KFM03A0330Ukcl01Y.CR	KFM03A0330Ukcl01Y.CI
	0.1M	KFM03A0226Ikcl1Y.CRB	KFM03A0226Ikcl1Y.CI	KFM03A0330Ukcl1Y.CRB	KFM03A0330Ukcl1Y.CI
BORR - HÅL	pH4	KFM03A0225IpH4B.CRB	KFM03A0225IpH4B.CI	KFM03A0330UpH4B.CRB	KFM03A0330UpH4B.CI
	pH7	KFM03A0225IpH7B.CRB	KFM03A0225IpH7B.CI	KFM03A0330UpH7B.CRB	KFM03A0330UpH7B.CI
	pH10	KFM03A0225IpH10B.CRB	KFM03A0225IpH10B.CI	KFM03A0330UpH10B.CRB	KFM03A0330UpH10B.CI

Figure A3-12. *Administration (040330), section 939.5-946.6 m.*

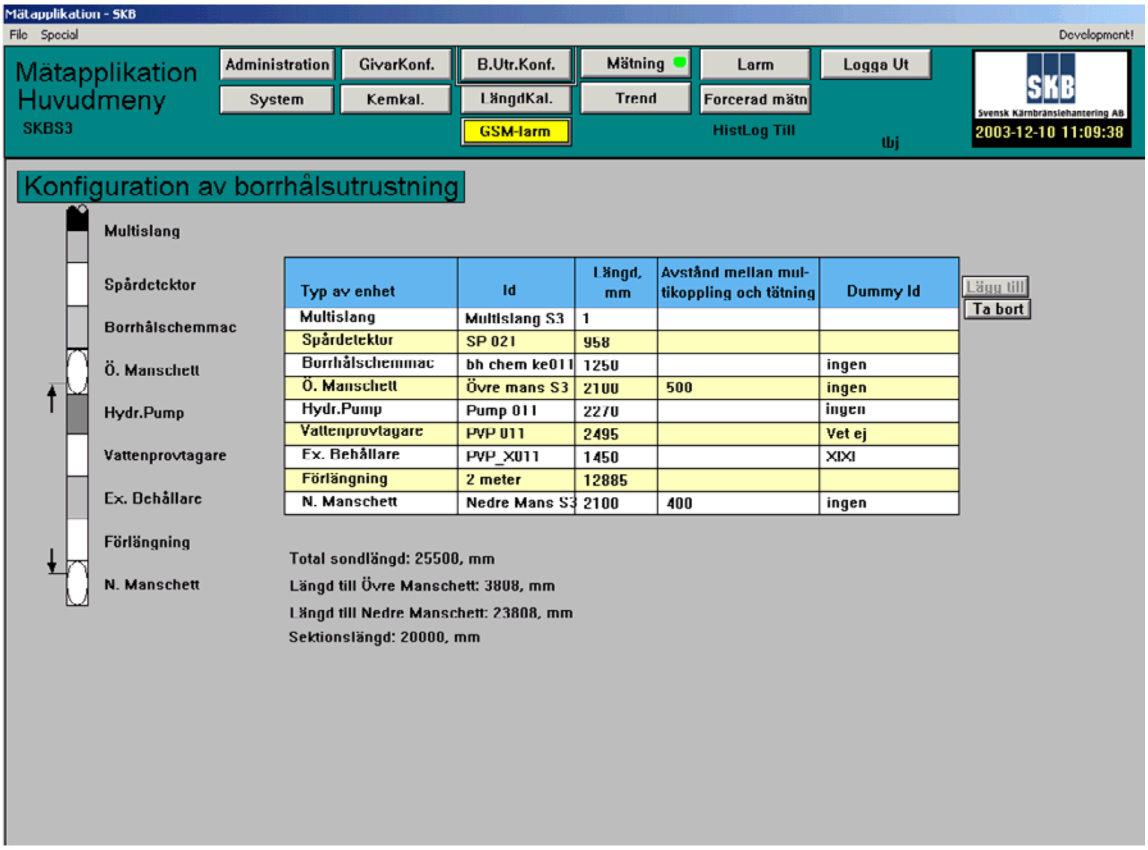


Borrhålschemmac, Id:bh chem ke011				Anm. Ja	
	Typ	Id	Datum	Nod	Kanal
0.	ETB	PT100	011107	2	15
1.	EPHB	G28	030407	2	1
2.	ECB	C6-96	021008	2	2
3.	EPHIB	G25	021008	2	3
4.	EREFB	R-20	021008	2	4
5.	EPTB	EPTB	011025	2	5
6.	EAUB	EAUB	011003	2	6
7.	ECIB	ny meth ych	030407	3	8
-	PB	Try C-so	011003	2	9
-	VLARMB	-	011003	2	20
-	VB	-	011107	2	19

Ytchemmac, Id: S3			Anm. Ja		
	Typ	Id	Datum	Nod	Kanal
9.	EKONDY	EKOND	031114	3	17
10.				0	0
11.				0	0
12.	EO2Y	3.17	031114	4	17
13.				0	0
14.	ET1Y	temp O2	011107	4	18
15.	EPHIY	P9-3	020313	3	6
16.				0	0
17.				0	0
18.				0	0
19.				0	0
20.	EAUY	N6-1	011107	3	2
21.				0	0
22.	ECY	Methrom	011107	3	3
23.	EPTY	H2-1	011107	3	7
24.	EREF1Y	N5-3	011107	3	4
25.	EPHY	NG-1	030407	3	1
26.				0	0
-	Q	Flöde	011003	4	9
-	V1Y	-	011003	3	19

Sond 3: 1100111111101111
Sond 4: 1000000100000000

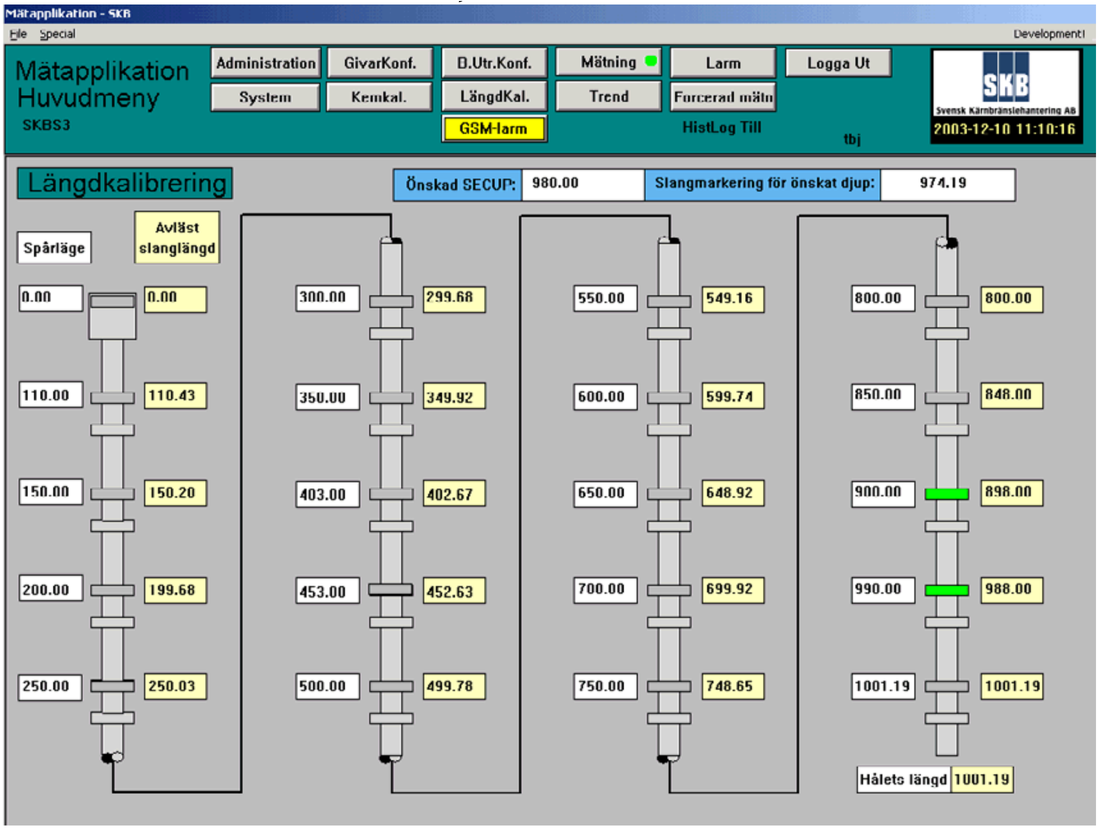
Figure A3-13. *Electrode configuration, section 980.0-1001.2 m.*



Typ av enhet	Id	Längd, mm	Avstånd mellan multikoppling och tätning	Dummy Id
Multislang	Multislang S3	1		
Spårdetektor	SP 021	958		
Borrhålschemmac	bh chem ke011	1250		ingen
Ö. Manschett	Övre mans S3	2100	500	ingen
Hydr.Pump	Pump 011	2270		ingen
Vattenprovtagare	PVP 011	2495		Vet ej
Ex. Behållare	PVP_X011	1450		XIXI
Förlängning	2 meter	12885		
N. Manschett	Nedre Mans S3	2100	400	ingen

Total sondlängd: 25500, mm
Längd till Övre Manschett: 3808, mm
Längd till Nedre Manschett: 23808, mm
Sektionslängd: 20000, mm

Figure A3-14. *Configuration of downhole equipment, section 980.0-1001.2 m.*



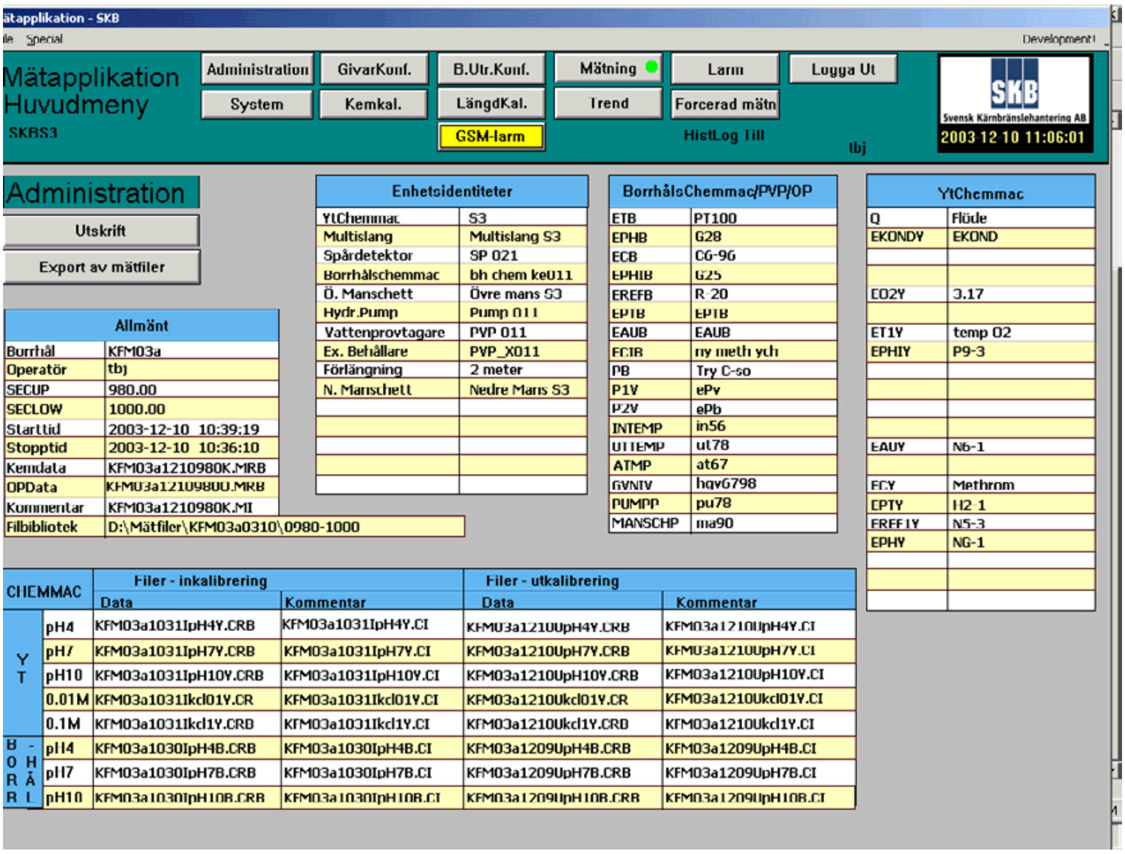
Önskad SECUP: 980.00

Slangmarkering för önskat djup: 974.19

Spårläge	Avläst slanglängd
0.00	0.00
110.00	110.43
150.00	150.20
200.00	199.68
250.00	250.03
300.00	299.68
350.00	349.92
403.00	402.67
453.00	452.63
500.00	499.78
550.00	549.16
600.00	599.74
650.00	648.92
700.00	699.92
750.00	748.65
800.00	800.00
850.00	848.00
900.00	898.00
990.00	988.00
1001.19	1001.19

Hålets längd 1001.19

Figure A3-15. *Length calibration, section 980.0-1001.2 m.*



Allmänt	
Borrhål	KFM03a
Operatör	tbj
SECUP	980.00
SECLOW	1000.00
Starttid	2003-12-10 10:39:19
Stopptid	2003-12-10 10:36:10
Kemdata	KFM03a1210980K.MRB
OPData	KFM03a1210980O.MRB
Kommentar	KFM03a1210980K.MI
Filbibliotek	D:\Mätfiler\KFM03a0310\0980-1000

Enhetsidentiteter	
YtChemmac	S3
Multislang	Multislang S3
Spårdetektor	SP 021
Borrhålschemmac	bh chem ke011
Ö. Manschett	Övre mans S3
Hydr.Pump	Pump 011
Vattenprovtagare	PVP 011
Ex. Behållare	PVP_X011
Förlängning	2 meter
N. Manschett	Nedre Mans S3

BorrhålsChemmac/PVP/OP	
ETB	PT100
EPHB	G28
ECB	C6-96
EPHIB	G25
EREFB	R-20
EPTB	EPTB
EAUB	EAUB
ECIB	ny meth ych
PB	Try C-so
P1V	ePv
P2V	ePb
INTEMP	in56
UTTEMP	ut78
ATMP	at67
GVNIV	hqv6798
PUMPP	pu78
MANSCHP	ma90

YtChemmac	
Q	Flöde
EKONDY	EKOND
EO2Y	3.17
ET1Y	temp O2
EPHIY	P9-3
EAUY	N6-1
ECY	Methrom
EPTY	H2-1
EREF1Y	N5-3
EPHY	NG-1

CHEMMAC		Filer - inkalibrering		Filer - utkalibrering	
		Data	Kommentar	Data	Kommentar
YT	pH4	KFM03a1031IpH4Y.CRB	KFM03a1031IpH4Y.CI	KFM03a1210UpH4Y.CRB	KFM03a1210UpH4Y.CI
	pH7	KFM03a1031IpH7Y.CRB	KFM03a1031IpH7Y.CI	KFM03a1210UpH7Y.CRB	KFM03a1210UpH7Y.CI
	pH10	KFM03a1031IpH10Y.CRB	KFM03a1031IpH10Y.CI	KFM03a1210UpH10Y.CRB	KFM03a1210UpH10Y.CI
	0.01M	KFM03a1031Ikcl01Y.CR	KFM03a1031Ikcl01Y.CI	KFM03a1210Ukcl01Y.CR	KFM03a1210Ukcl01Y.CI
	0.1M	KFM03a1031Ikcl1Y.CRB	KFM03a1031Ikcl1Y.CI	KFM03a1210Ukcl1Y.CRB	KFM03a1210Ukcl1Y.CI
BORR-HÅL	pH4	KFM03a1030IpH4B.CRB	KFM03a1030IpH4B.CI	KFM03a1209UpH4B.CRB	KFM03a1209UpH4B.CI
	pH7	KFM03a1030IpH7B.CRB	KFM03a1030IpH7B.CI	KFM03a1209UpH7B.CRB	KFM03a1209UpH7B.CI
	pH10	KFM03a1030IpH10B.CRB	KFM03a1030IpH10B.CI	KFM03a1209UpH10B.CRB	KFM03a1209UpH10B.CI

Figure A3-16. *Administration (031210), section 980.0-1001.2 m.*

Flow and pressure measurements in KFM03A

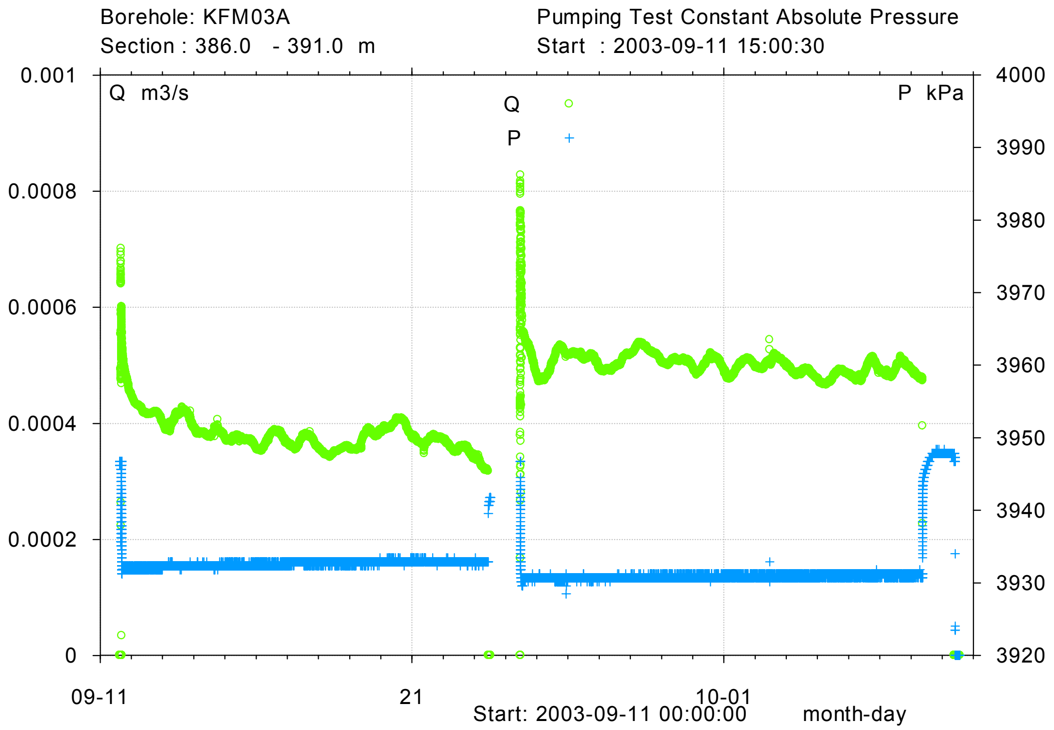


Figure A4-1. *Pressure (P) and flow rate (Q) measurements from within borehole section 386.0-391.0 m. The variations in flow rate are due to the automatic control system which is set to maintain a constant pressure in the section. When the pressure is altered, the system will change the flow rate to maintain the pressure at a constant level.*

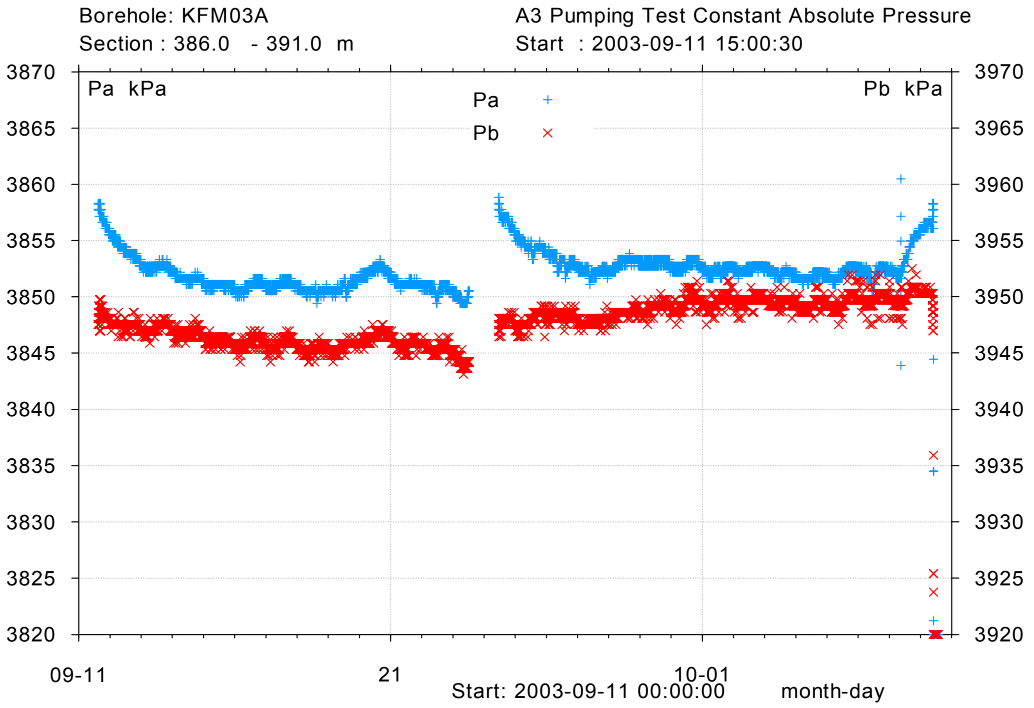


Figure A4-2. *Pressure measurements from above (Pa) and below (Pb) borehole section.386.0-391.0 m.*

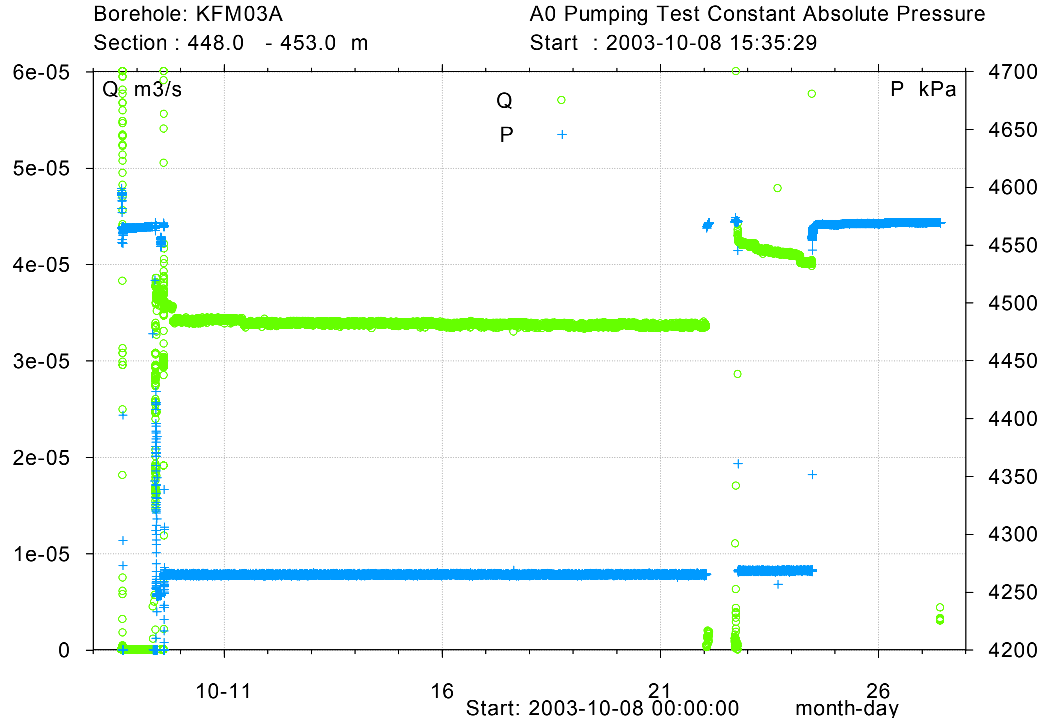


Figure A4-3. *Pressure (P) and flow rate (Q) measurements from within borehole section 448.0-453.0 m.*

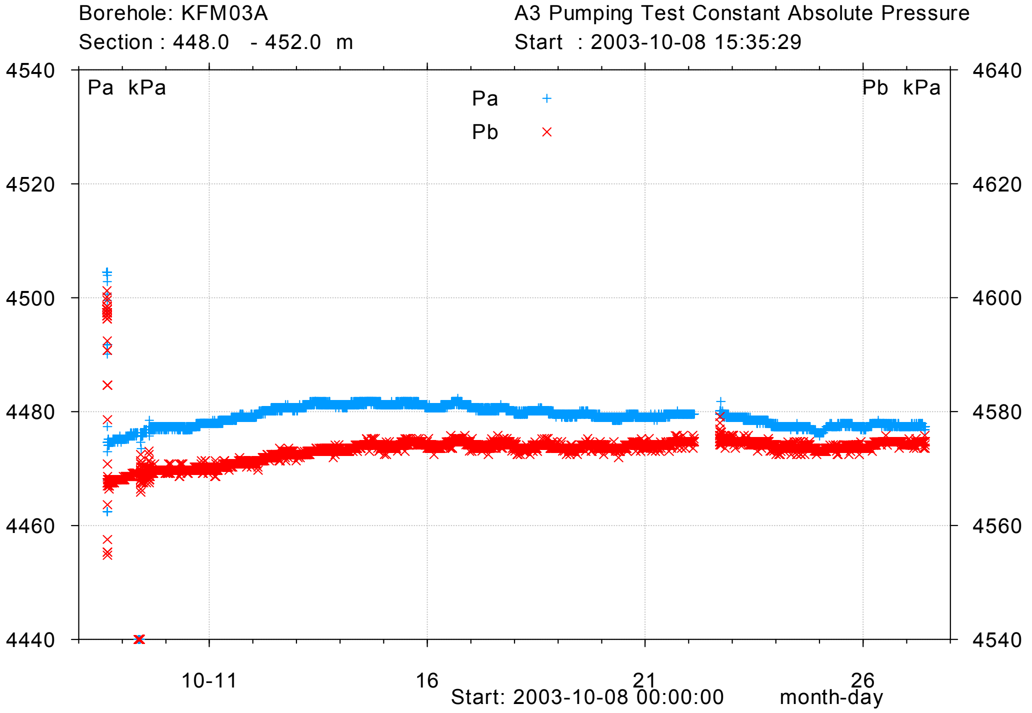


Figure A4-4. *Pressure measurements from above (Pa) and below (Pb) borehole section 448.0-453.0 m.*

Figure A4-5. *Pressure (P1V, P2V and PB) and flow rate (Q) measurements from borehole section 448.5-455.6 m. The P1V and P2V pressure sensors are placed in the in-situ sampling unit and measure the pressure in the section. PB is the sensor in the borehole chemmac and measures the pressure above the section.*

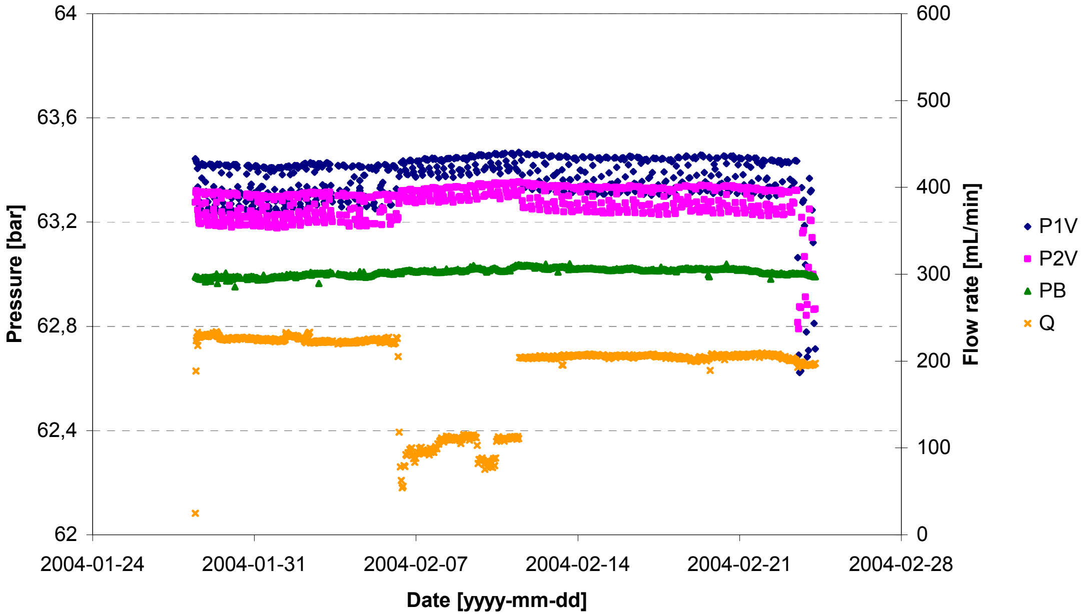


Figure A4-6. *Pressure (P1V, P2V and PB) and flow rate (Q) measurements from borehole section 639.0-646.1 m. P1V and P2V are pressure sensors placed in the in-situ sampling unit and measure the pressure in the section. PB is the sensor in the borehole chemmac and measures the pressure above the section.*

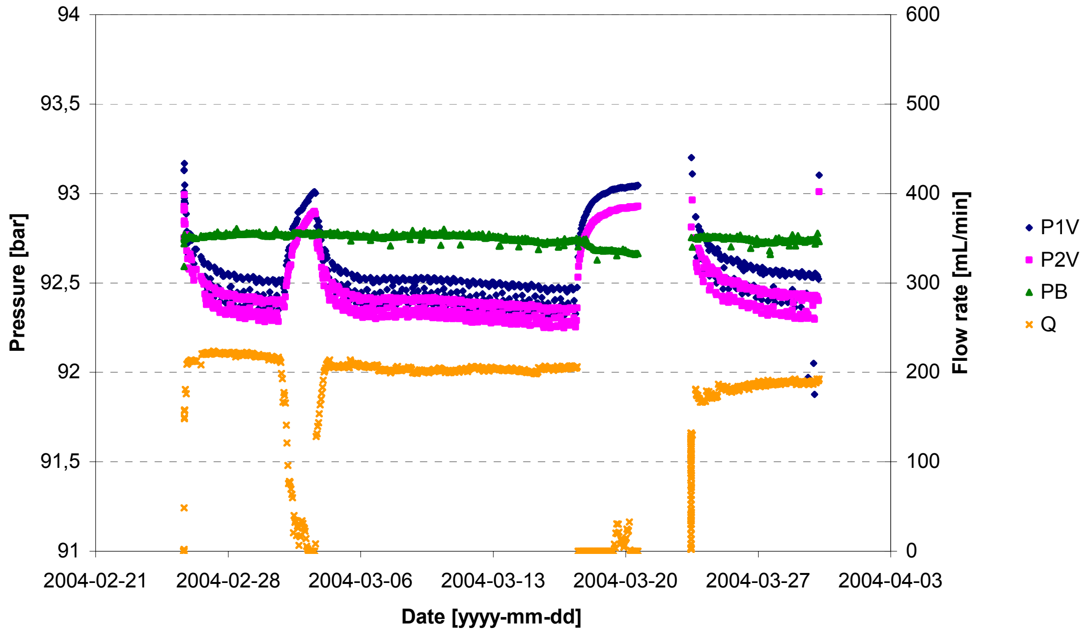


Figure A4-7. *Pressure (P1V, P2V and PB) and flow rate (Q) measurements from borehole section 939.5-946.6 m. P1V and P2V are pressure sensors placed in the in-situ sampling unit and measure the pressure in the section. PB is the sensor in the borehole chemmac and measures the pressure above the section.*

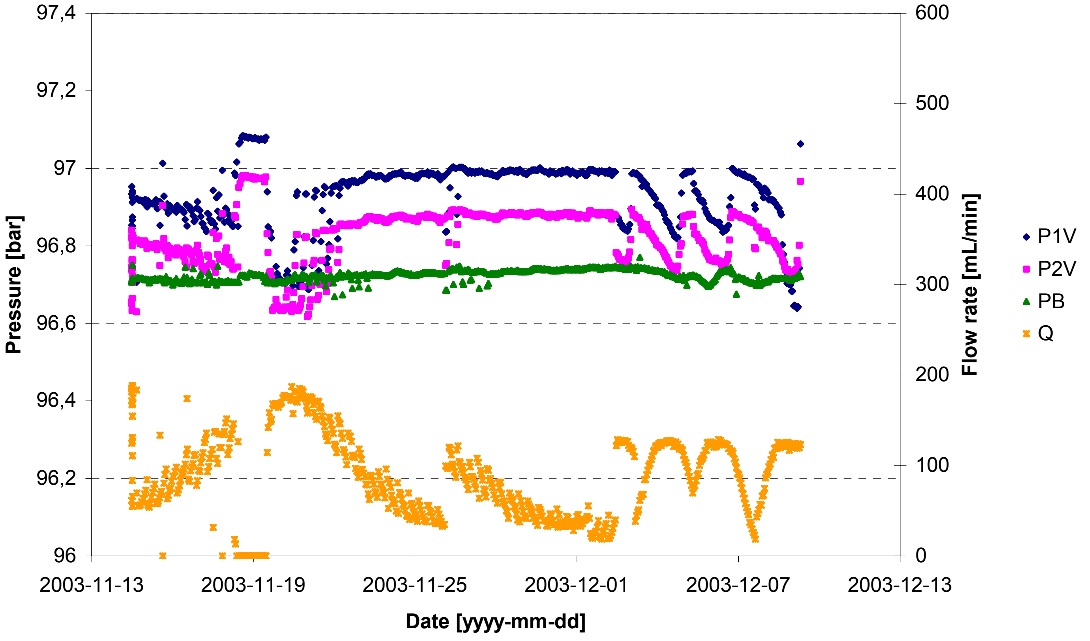


Figure A4-8. *Pressure (P1V, P2V and PB) and flow rate (Q) measurements from the borehole section 980.0-1001.2 m. P1V and P2V are pressure sensors placed in the in-situ sampling unit and measure the pressure in the section. PB is the sensor in the borehole chemmac and measures the pressure above the section.*

4(4)

Chemmac measurements in KFM03A, section 386.0–391.0 m

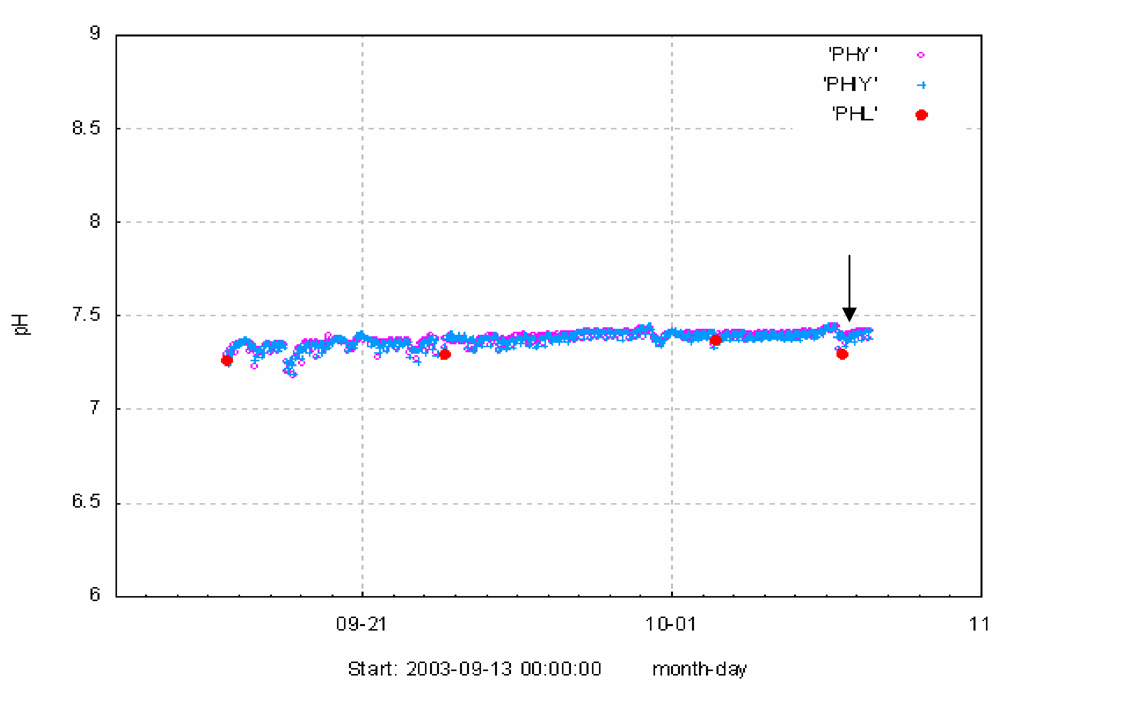


Figure A5-1. *Measurements of pH by two glass electrodes at the surface (PHY and PHIY). The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the chosen representative pH values for the borehole section.*

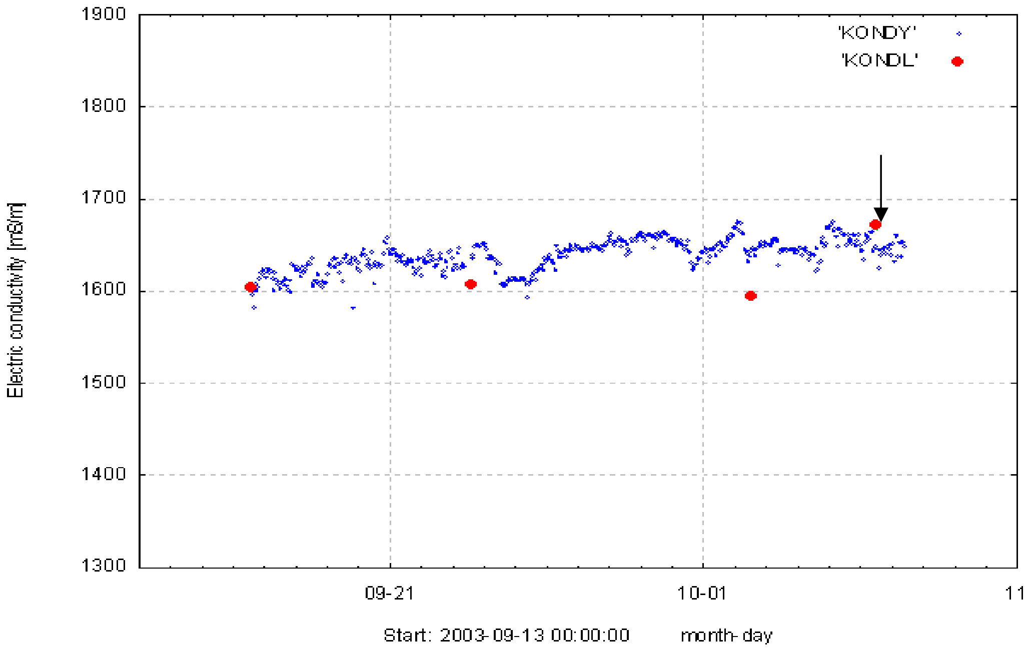


Figure A5-2. *Electric conductivity measurements in the surface measurement cell (KONDY). The electric conductivity measured in each collected sample (KONDL) is given for comparison. The arrow shows the chosen representative electric conductivity value for the borehole section.*

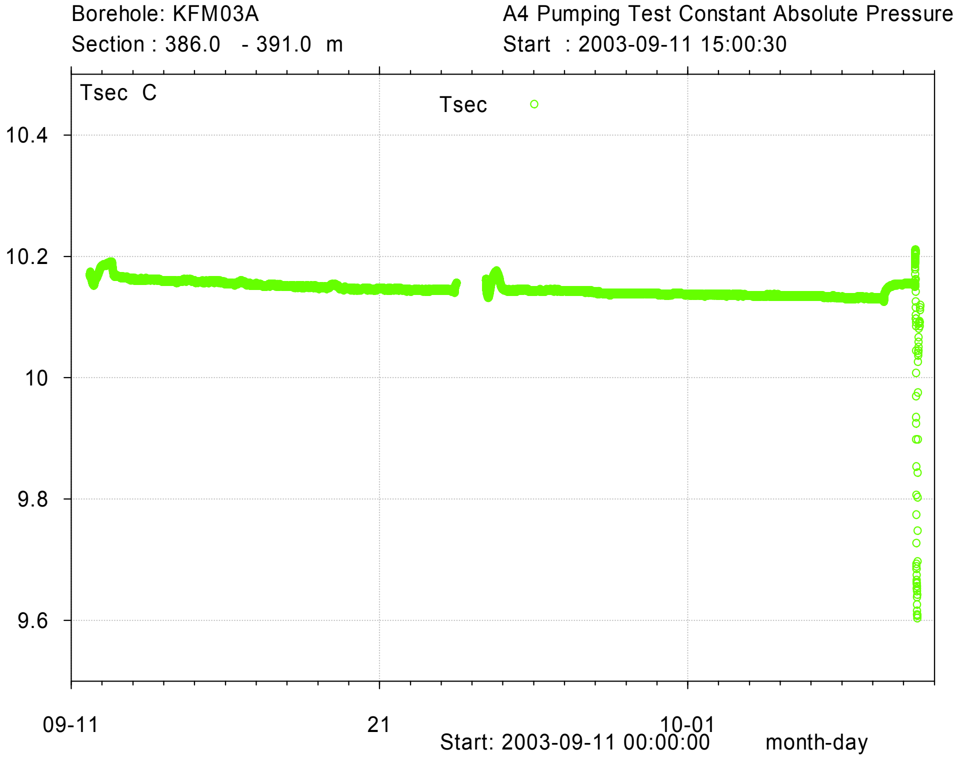


Figure A5-3. *Temperature within the borehole section, measured with the PSS3 equipment.*

Appendix 6

Chemmac measurements in KFM03A, section 448.0–453.0 m

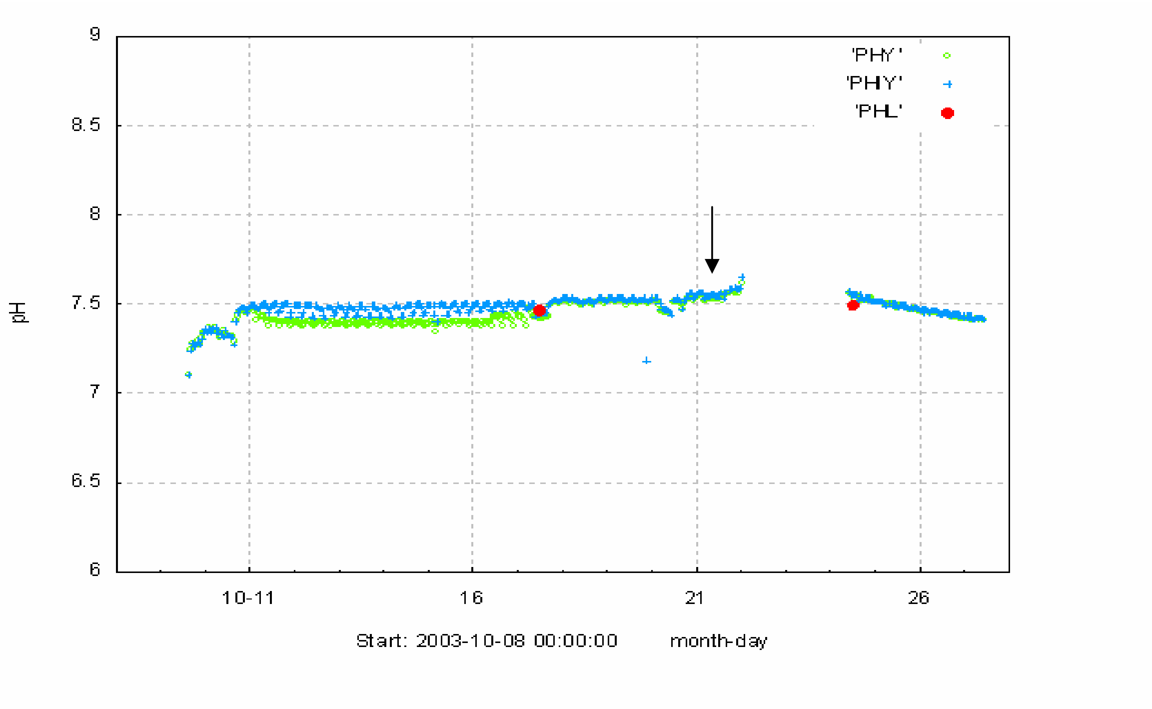


***Figure A6-1.** Measurements of pH by two glass electrodes at the surface (PHY and PHIY). The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the chosen representative pH values for the borehole section.*

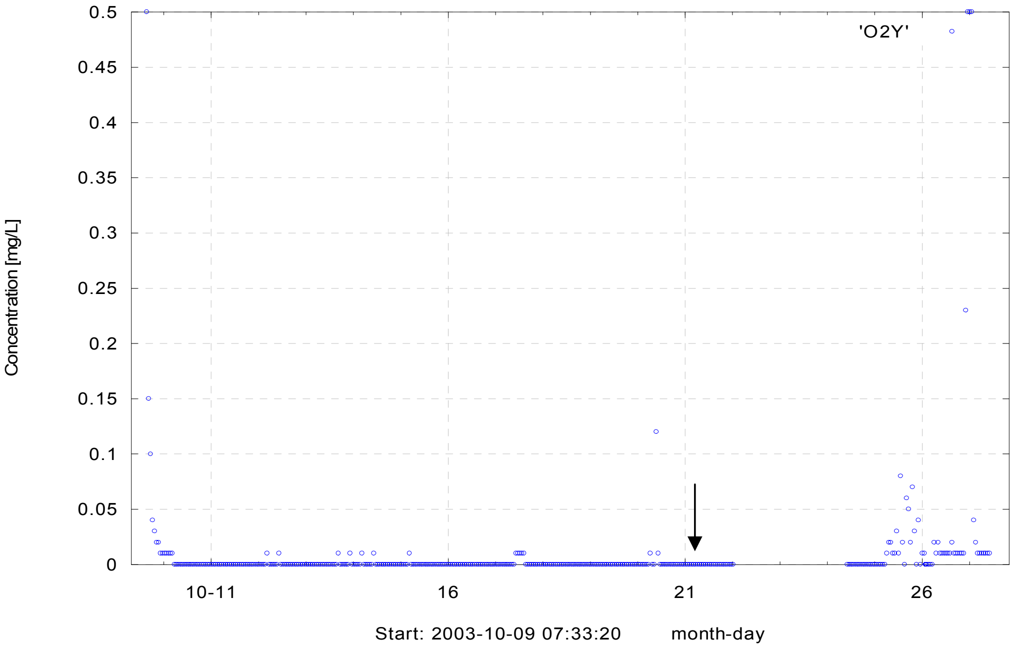


***Figure A6-2.** Dissolved oxygen measurements (O2Y) in the surface measurement cell. The arrow shows the chosen representative value for dissolved oxygen in the borehole section.*

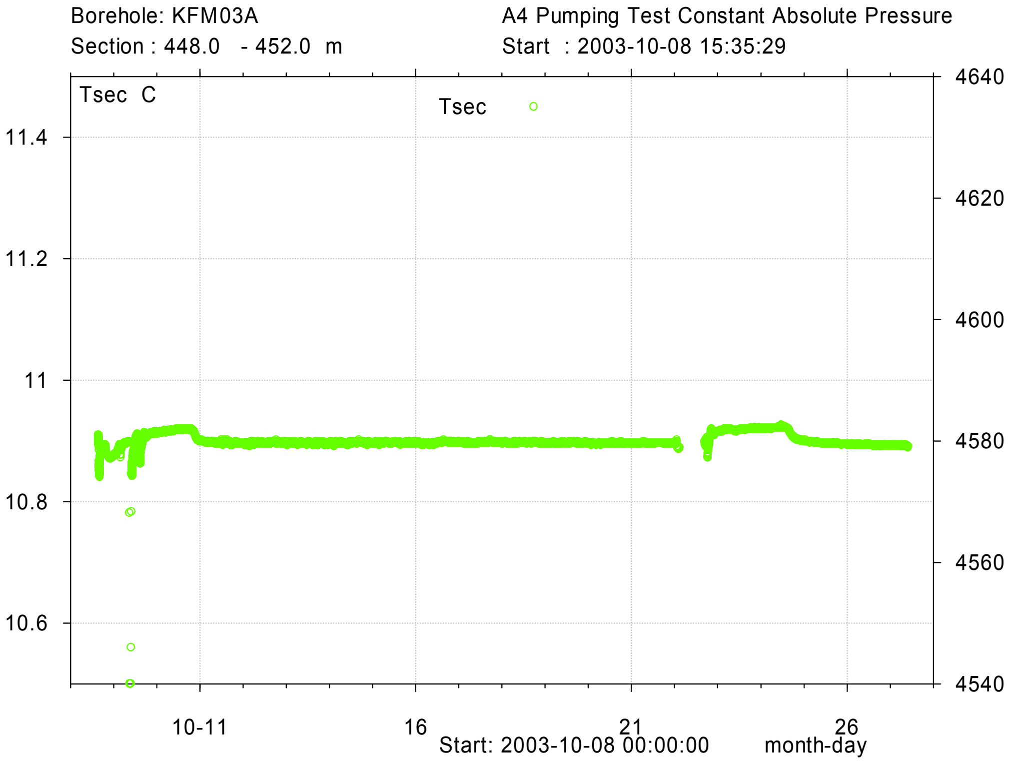


Figure A6-3. *Temperature within the borehole section, measured with the PSS3 equipment.*

Appendix 7

Chemmac measurements in KFM03A, section 448.5–455.6 m

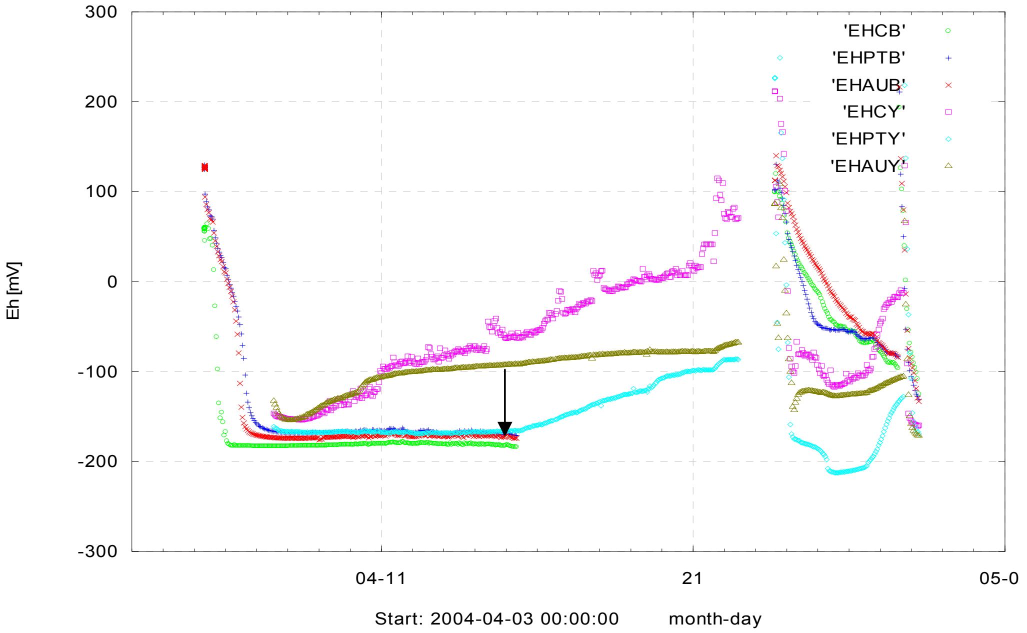


Figure A7-1. *Redox potential measurements (Eh) by platinum, gold and glassy carbon electrodes in the borehole section (EHPTB, EHAUB and EHCB) and at the surface (EHPTY, EHAUY and EHCY). The arrow shows the chosen representative Eh values for the borehole section.*

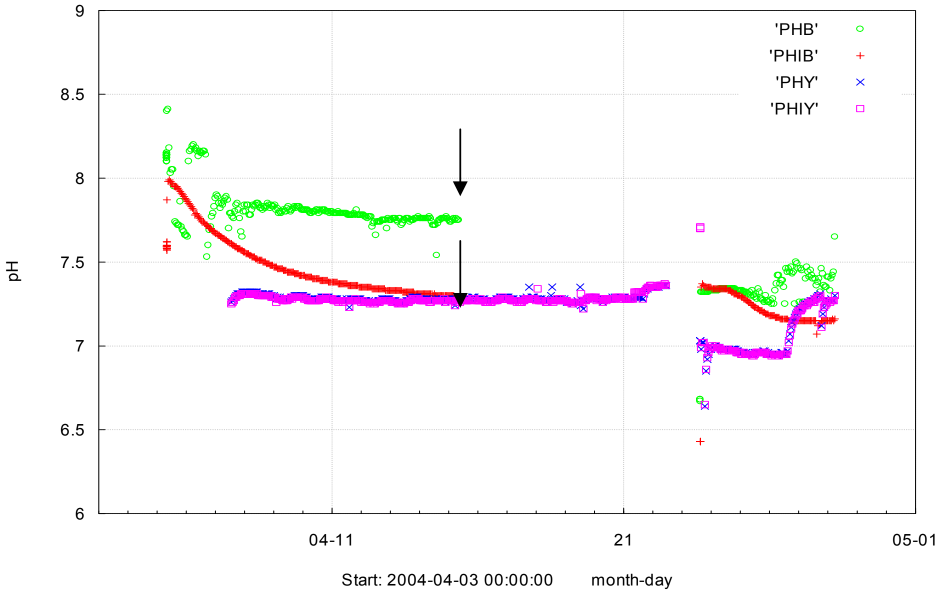


Figure A7-2. *Measurements of pH by two glass electrodes in the borehole section (PHB and PHIB) and two glass electrodes at the surface (PHY and PHIY). The arrow shows the chosen representative pH values for the borehole section.*

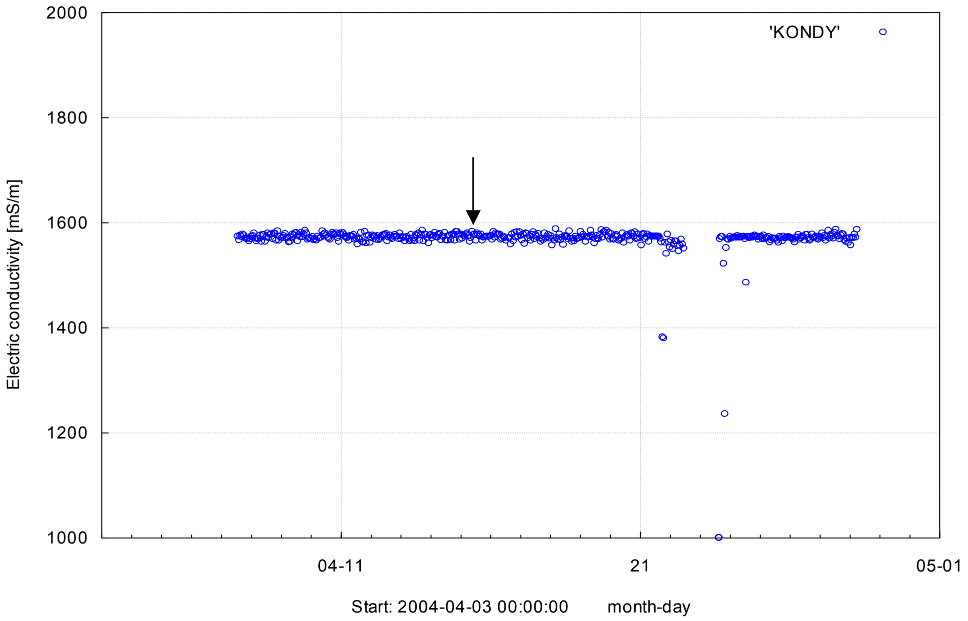


Figure A7-3. *Electric conductivity measurements in the surface measurement cell (KONDY). The arrow shows the chosen representative electric conductivity value for the borehole section.*

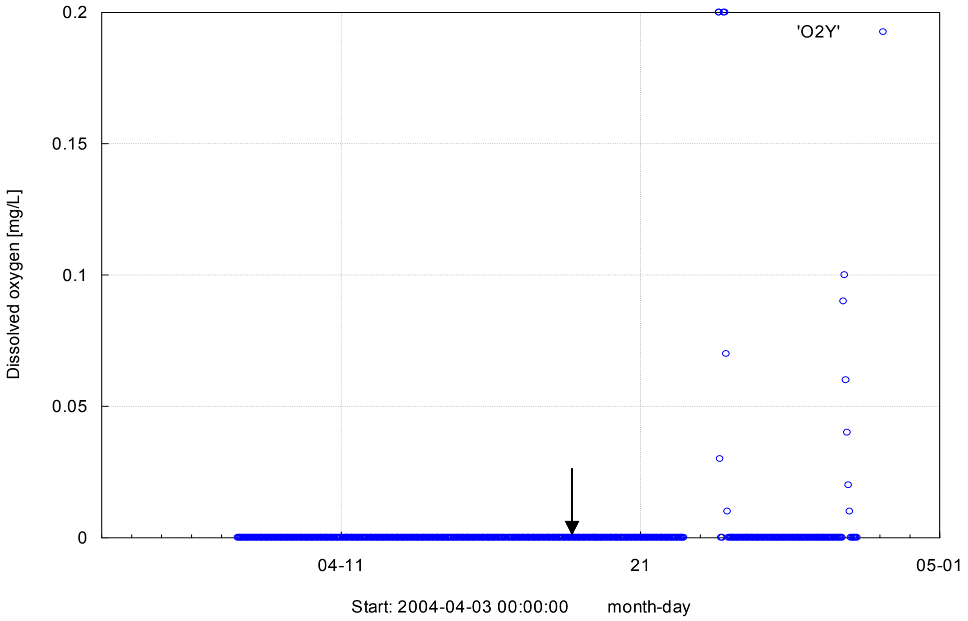


Figure A7-4. *Dissolved oxygen measurements (O2Y) in the surface measurement cell. The arrow shows the chosen representative value for dissolved oxygen in the borehole section.*

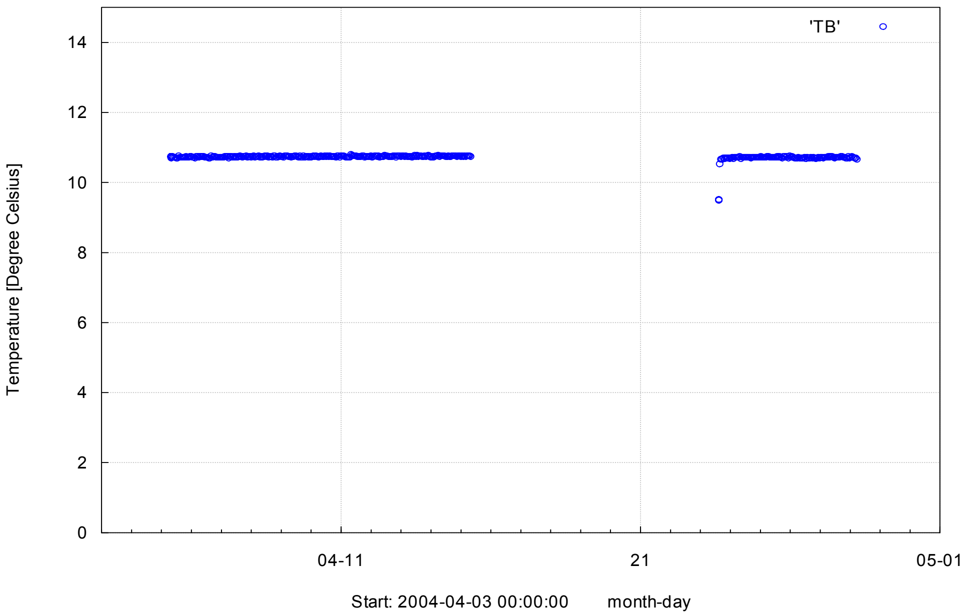


Figure A7-5. *Temperature of the groundwater in the borehole section (TB).*

Appendix 8

Chemmac measurements in KFM03A, section 639.0–646.1 m

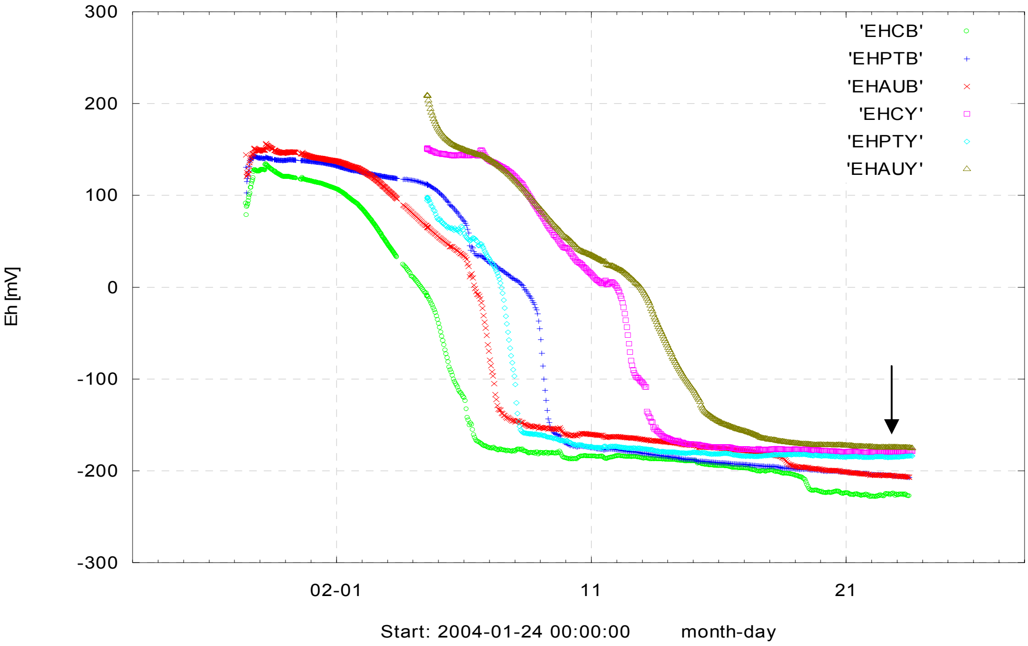


Figure A8-1. *Redox potental measurements (Eh) by platinum, gold and glassy carbon electrodes in the borehole section (EHPTB, EHAUB and EHCB) and at the surface (EHPTY, EHAUY and EHCY). The arrow shows the chosen representative Eh values for the borehole section.*

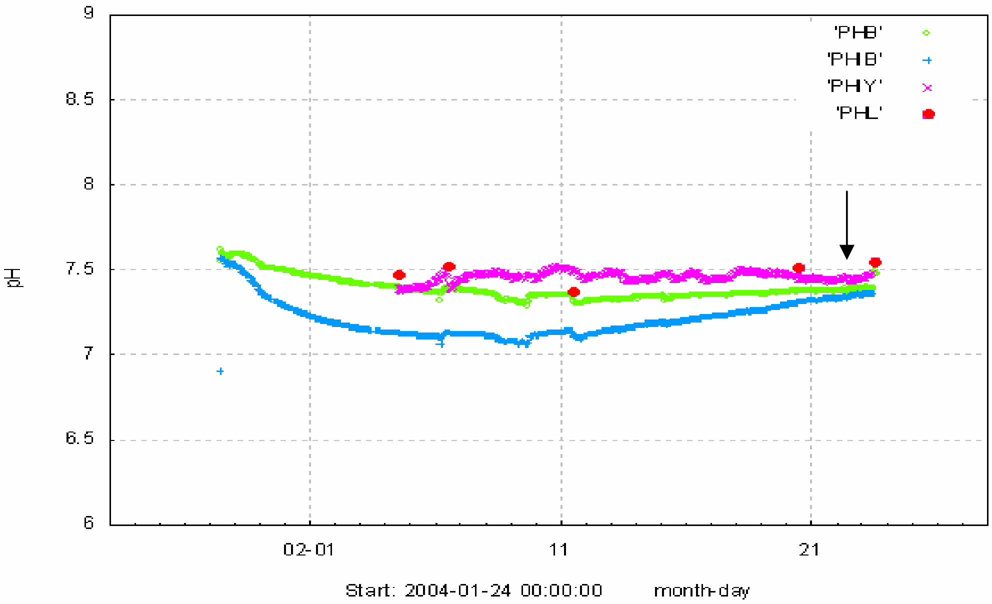


Figure A8-2. *Measurements of pH by two glass electrodes in the borehole section (PHB and PHIB) and one glass electrode at the surface (PHIY). The respons from PHY was not stable and was therefore rejected. The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the chosen representative pH values for the borehole section.*

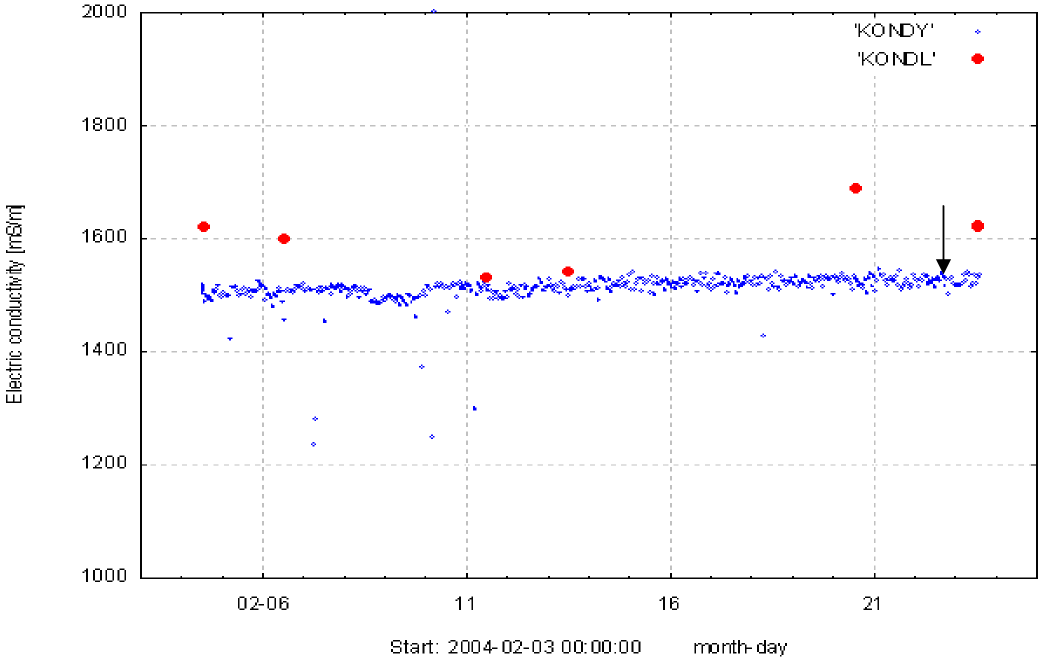


Figure A8-3. *Electric conductivity measurements in the surface measurement cell (KONDY) . The laboratory conductivity in each collected sample (KONDL) is given for comparison. The arrow shows the chosen representative electric conductivity value for the borehole section.*

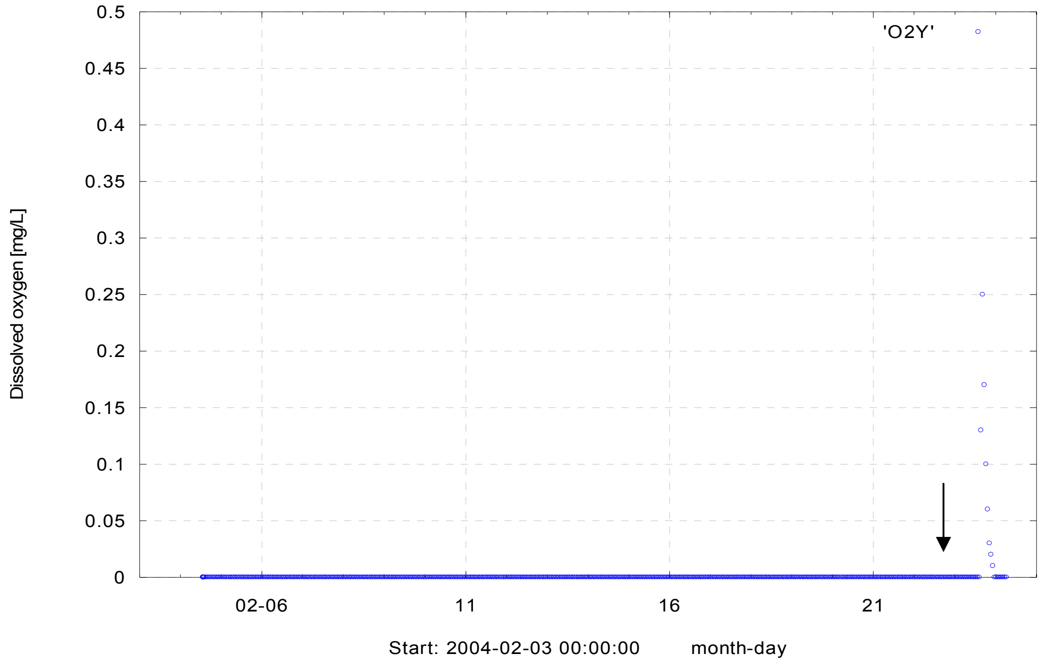


Figure A8-4. *Dissolved oxygen measurements (O2Y) in the surface measurement cell. The arrow shows the chosen representative value for dissolved oxygen in the borehole section.*

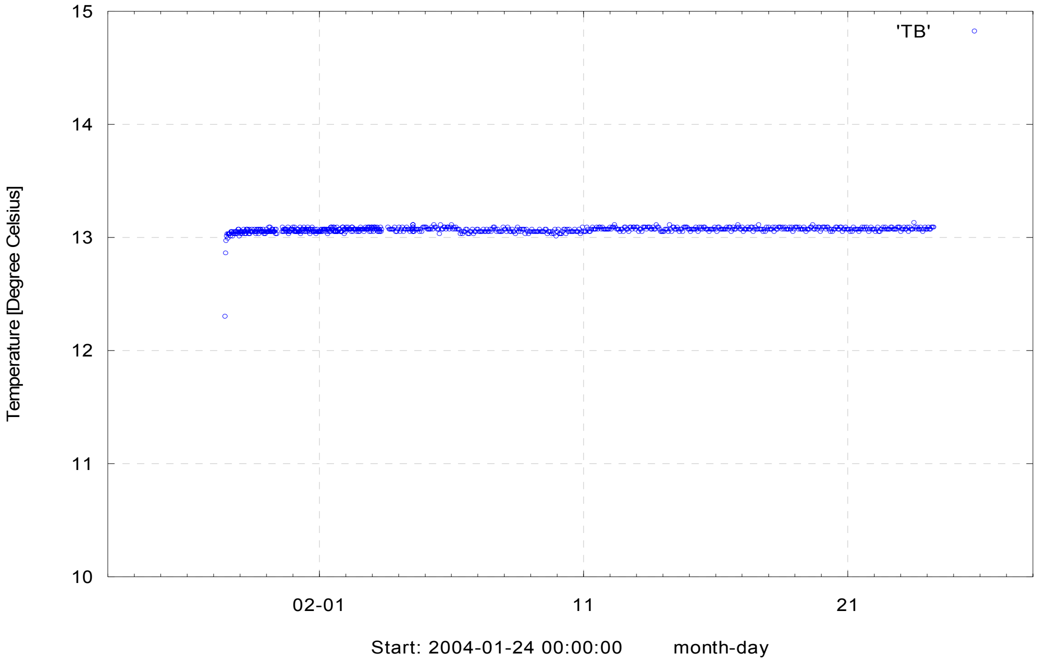


Figure A8-5. *Temperature of the groundwater in the borehole section (TB).*

Appendix 9

Chemmac measurements in KFM03A, section 939.5–946.6 m

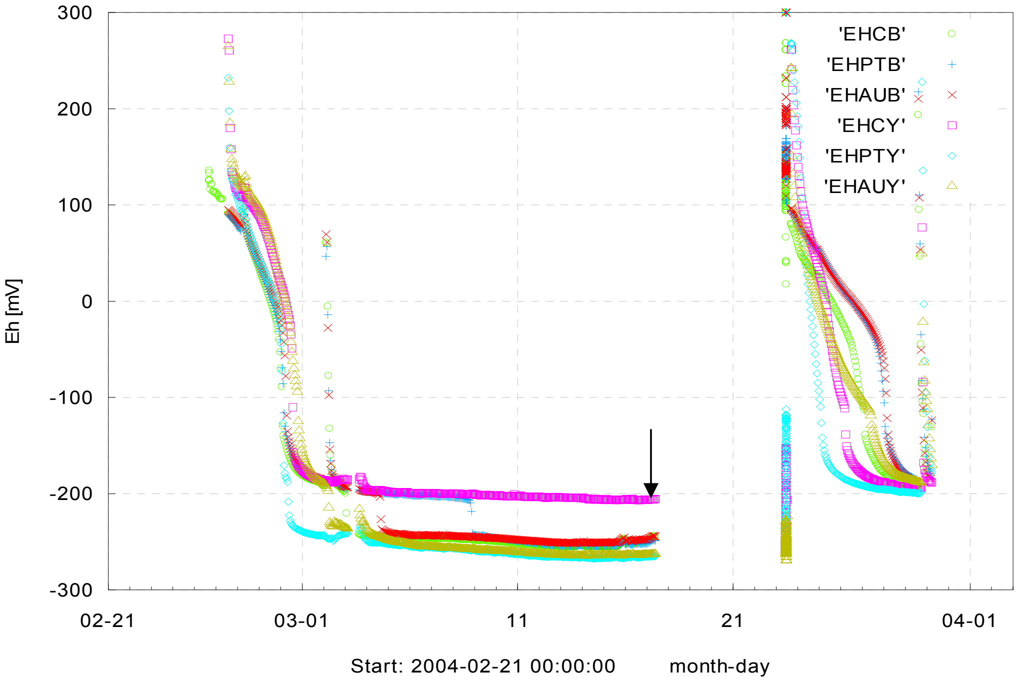


Figure A9-1. *Redox potental measurements (Eh) by platinum, gold and glassy carbon electrodes in the borehole section (EHPTB, EHAUB and EHCB) and at the surface (EHPTY, EHAUY and EHCY). The arrow shows the chosen representative Eh values for the borehole section.*

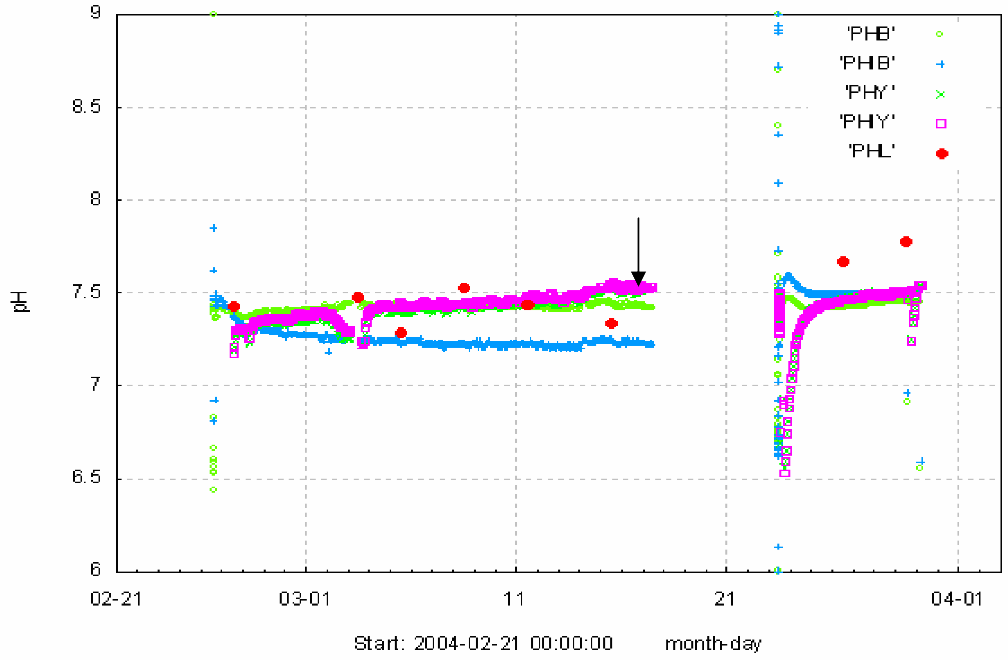


Figure A9-2. *Measurements of pH by two glass electrodes in the borehole section (PHB and PHIB) and one glass electrode at the surface (PHIY). The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the chosen representative pH values for the borehele section.*

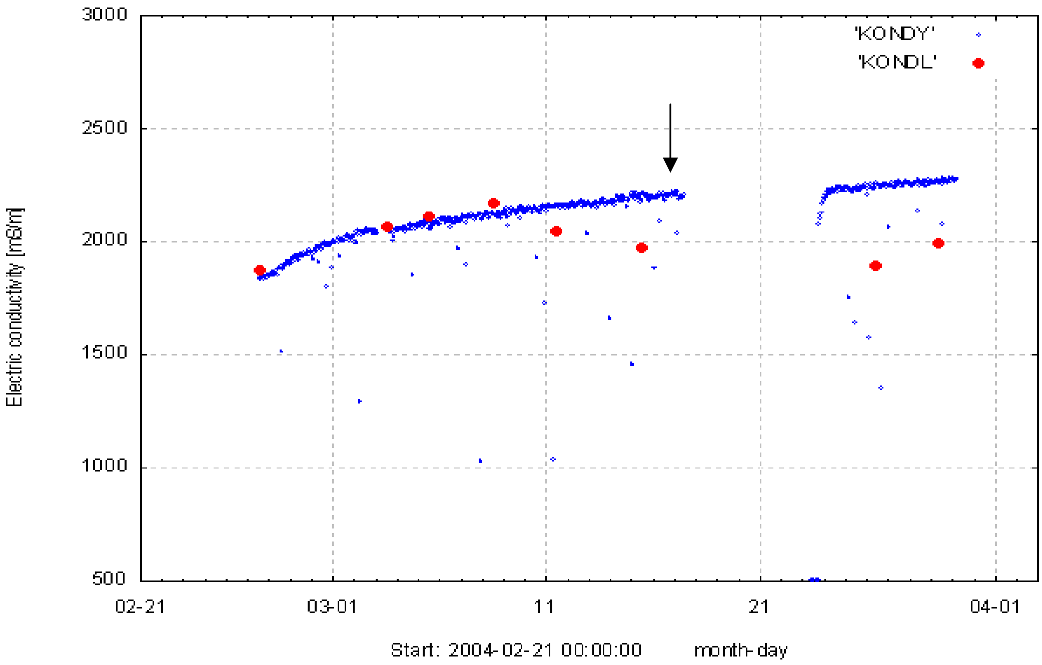


Figure A9-3. *Electric conductivity measurements in the surface measurement cell (KONDY) . The laboratory conductivity in each collected sample (KONDL) is given for comparison. The arrow shows the chosen representative electric conductivity value for the borehole section.*

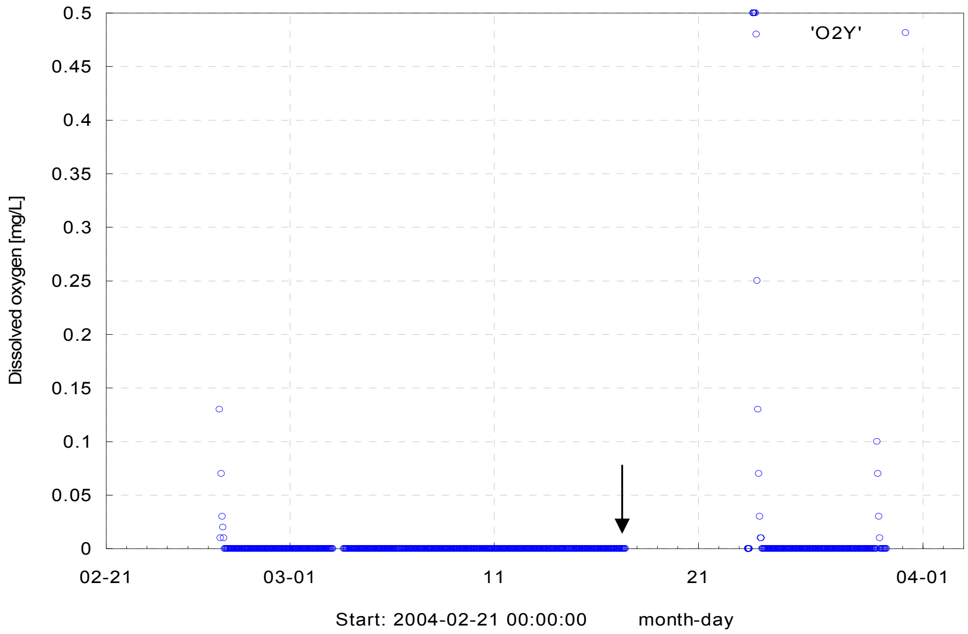


Figure A9-4. *Dissolved oxygen measurements (O2Y) in the surface measurement cell. The arrow shows the chosen representative value for dissolved oxygen in the borehole section.*

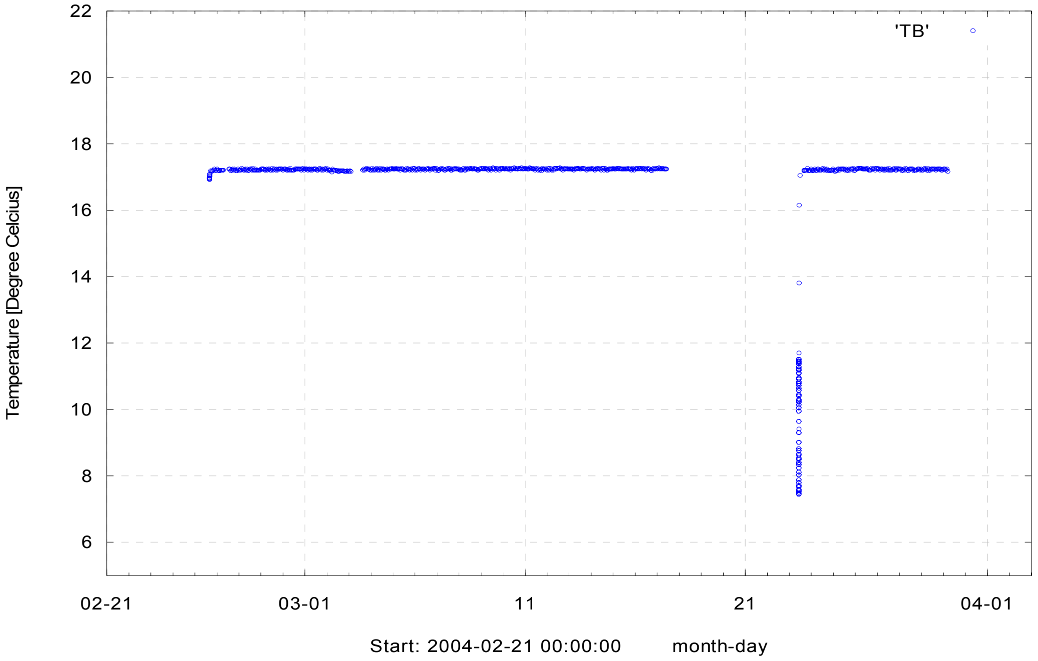


Figure A9-5. *Temperature of the groundwater in the borehole section (TB).*

Appendix 10

Chemmac measurements in KFM03A, section 980.0–1001.2 m

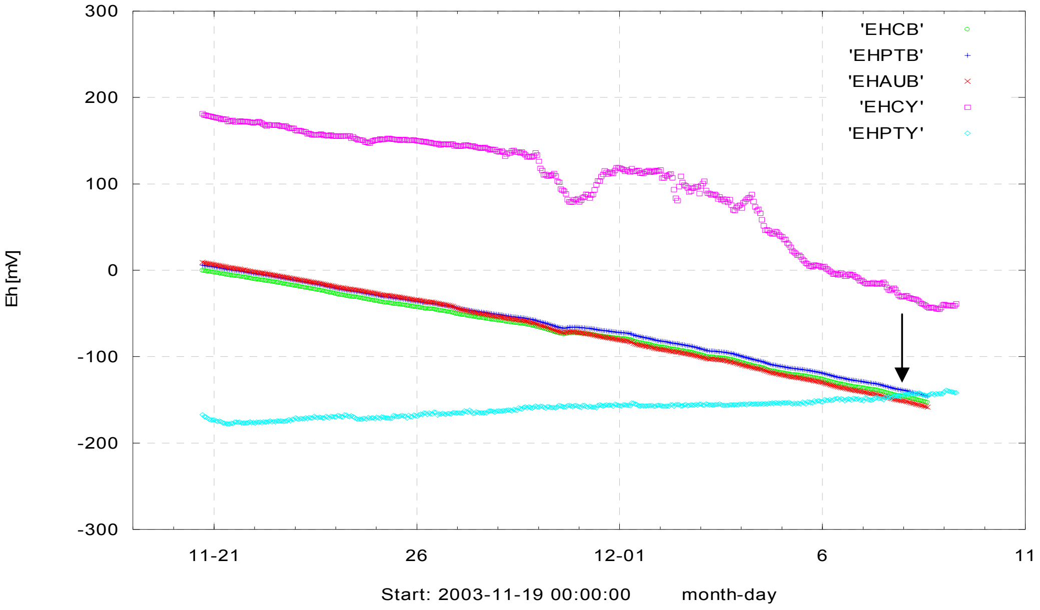


Figure A10-1. Redox potental measurements (Eh) by platinum, gold and glassy carbon electrodes in the borehole section (EHPTB, EHAUB and EHCB) and at the surface (EHPTY and EHCY). EHAUY was omitted due to non-stable results. The arrow shows the chosen representative Eh values for the borehole section.

Figure A10-2. Measurements of pH by two glass electrodes in the borehole section (PHB and PHIB) and one glass electrodes at the surface (PHY). The results from PHIY was not stable and was therefore omitted. The laboratory pH in each collected sample (PHL) is given for comparison. The arrow shows the chosen representative pH values for the borehole section.

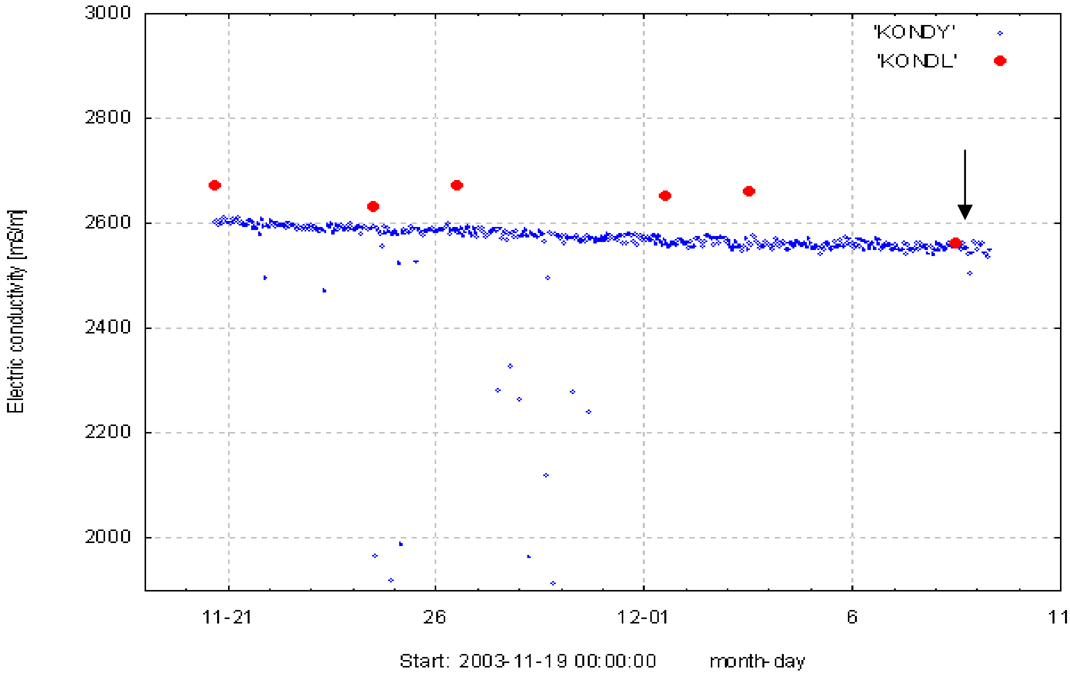


***Figure A10-3.** Electric conductivity measurements in the surface measurement cell (KONDY). The electric conductivity measured in each collected sample (KONDL) is given for comparison. The arrow shows the chosen representative electric conductivity value for the borehole section.*

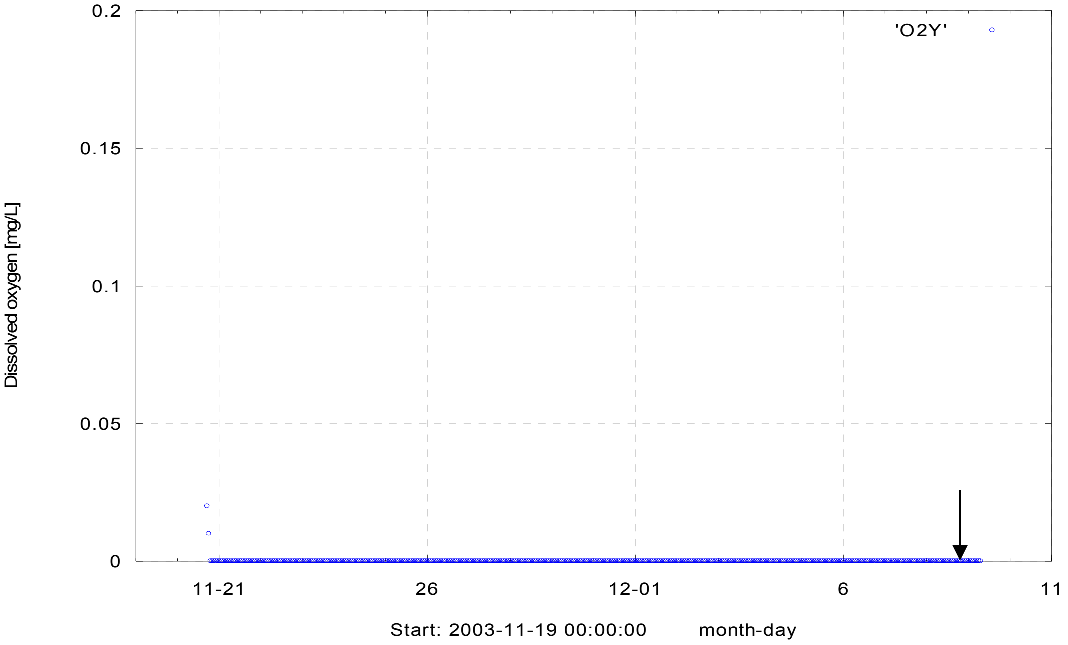


***Figure A10-4.** Dissolved oxygen measurements (O2Y) in the surface measurement cell. The arrow shows the chosen representative value for dissolved oxygen in the borehole section.*

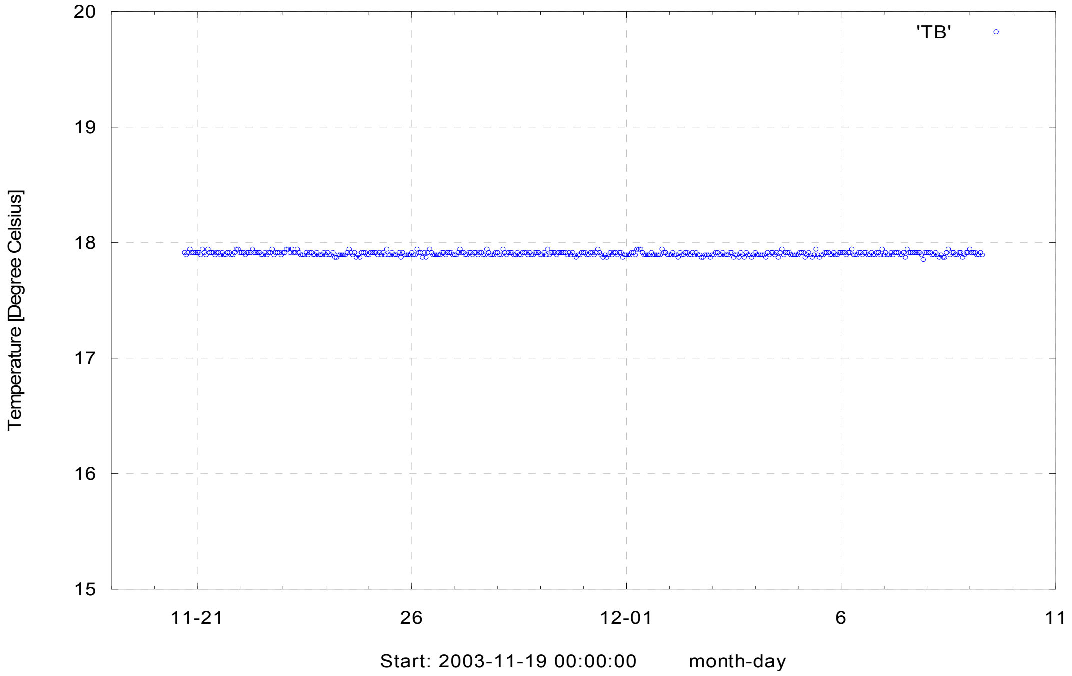


Figure A10-5. *Temperature of the groundwater in the borehole section (TB).*

Appendix 11

Sampling and analysis methods

Table A11-1. Sample handling routines and analyses methods

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ Conservation*	Analysis method	Laboratory***	Analysis within - or delivery time to lab.
Anions 1.	HCO_3 pH(lab) cond (lab)	Plastic	250	Yes (not in the field)	No	Titration Pot. meas, Cond. meas	Mobile field lab. AnalyCen	The same day – maximum 24 hours
Anions 2	Cl, SO_4, Br^-, F^-, I^-	Plastic	100	Yes (not in the field)	No	Titration (Cl^-) IC (Cl^-, SO4, Br^-, F^-) ISE (F^-)	Äspö:s chemistry lab. AnalyCen	Not critical (month)
	Br, I	Plastic	100	Yes (not in the field)	No	ICP MS	Paavo Ristola OY Analytica AB,	Not critical (month)
Cations, Si and S according to SKB class 3	Na, K, Ca, Mg, S(tot), Si(tot), Li, Sr	Plastic (at low conc. acid washed bottles)	100	Yes (not in the field)	Yes (not in the field, 1 mL HNO_3)	ICP-AES ICP-MS	Analytica AB, AnalyCen	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	Analytica AB, AnalyCen	Not critical (month)
Fe(II), Fe(tot)	Fe(II), Fe(tot)	Plastic (Acid washed)	500	Yes	Yes (5 mL HCl))	Spectrophotometry Ferrozine method	Mobile field lab.	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	AnalyCen Äspö:s chemistry lab.	Immediately or if conserved, a few days
Nutrient salts	NO_2, NO_3+NO_2, NH_4, PO_4	Plastic	250	No	No	Spectrophotometry	Äspö:s chemistry lab. AnalyCen	Maximum 24 hours
Environmental metals	Al, As, Ba, B, Cd, Co, Cr, Cu, Hg, Mo, Ni, P, Pb, V, Zn	Plastic	100	Yes	Yes (1 mL HNO_3)	ICP-AES ICP-MS	Analytica AB, AnalyCen	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	100	Yes	Yes (1 mL HNO_3)	ICP-AES ICP-MS	SGAB Analytica, AnalyCen	Not critical (month)

Component group	**Component/ element**	**Sample container (material)**	**Volume (mL)**	**Filtering**	**Preparation/ Conservation***	**Analysis method**	**Laboratory*****	**Analysis within - or delivery time to lab.**
Dissolved organic Carbon, dissolved inorganic Carbon	DOC, DIC	Plastic	250 25	Yes	Frozen, transported in isolated bag	UV oxidation, IR Carbon analysator Shimadzu TOC5000	Paavo Ristola OY Dept. of System ecology, SU	Short transportation time
Total organic Carbon	TOC	Plastic	250 25	No	Frozen, transported in isolated bag	UV oxidation, IR Carbon analysator Shimadzu TOC5000	Paavo Ristola OY Dept. of System ecology, SU	Short transportation time
Environmental isotopes	∂^{2}H, ∂^{18}O	Plastic	100	No	- -	MS	IFE	Not critical (month)
Tritium, Chlorine-37	^{3}H (enhanced.) ∂^{37}Cl	Plastic (dry bottle) Plastic	500 100	No No	- -	LSC ICP MS	Univ. of Waterloo	Not critical (month)
Carbon isotopes	∂^{13}C, pmC (^{14}C)	Glass (brown)	100×2	No	-	(A)MS	Univ. of Waterloo	A few days
Sulphur isotopes	∂^{34}S	Plastic	500 –1000	Yes	-	Combustion, ICP MS	IFE	No limit
Strontium-isotopes	^{87}Sr/^{86}Sr	Plastic	100	Yes	-	TIMS	IFE	Days or Week
Uranium and Thorium isotopes	^{234}U, ^{235}U, ^{238}U, ^{232} Th, ^{230}Th,	Plastic	50	No	-	Chemical separat. Alfa/gamma spectrometry	IFE SUERC	No limit
Boron isotopes	^{10}B/^{11}B	Plastic	100	Yes	Yes (1 mL HNO_3)	ICP – MS	Analytica AB	No limit
Radon and Radium isotopes	^{222}Rn, ^{226}Ra	Plastic	500	No	No	EDA, RD-200	IFE SUERC	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	Paavo Ristola OY	Immediate transport
Colloids	Filter series and fractionation (see below)	Polycarbonate filter	0.45, 0.2 and 0.05 µm	-	N_2 atmosphere	ICP-AES ICP-MS	Analytica AB	Immediate transport
Humic and fulvic acids	Fractionation	Fractions are collected in plastic bottles	250	-	N_2 atmosphere	UV oxidation, IR (DOC)	Paavo Ristola OY	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

Component group	Component/ element	Sample container (material)	Volume (mL)	Filtering	Preparation/ Conservation*	Analysis method	Laboratory***	Analysis within - or delivery time to lab.
Carbon isotopes in humic and fulvic acids	$\partial^{13}C$, pmC (^{14}C)	DEAE cellulose (anion exchanger)	-	-	-	(A)MS	The Ångström laboratory, Uppsala	A few days

* Suprapur acid is used for conservation of samples.

** Minimum number, the number of archive samples can vary depending on how many similar samples that are collected at the same occasion.

*** Full name and address is given in Table A2-3.

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
LSC	Liquid Scintillation Counting
(A)MS	(Accelerator) Mass Spectrometry
GC	Gas Chromatography

Table A11-2. Reporting limits and measurement uncertainties

Component	Method	Detection limit	Reporting limit or range	Unit	Measurement uncertainty[2]	”Total” uncertainty[3]
HCO_3	Alkalinity titration	0.2	1	mg/L	4 %	<10 %
Cl^- Cl^-	Mohr titration IC	5 0.2	70 0.5	mg/L	5 % 6 %	<10 % 10 %
SO_4	IC	0.2	0.5	mg/L	6 %	15 %
Br^- Br^-	IC ICP	0.2 -	0.7 0.001 – 0.010[1]	mg/L	9 % 15 %	20 %
F^- F^-	IC Potentiometry	0.2 -	0.6 -	mg/L	10 % -	20 % -
I^-	ICP	-	0.001 – 0.010[1]	mg/L	15 %	20 %
Na	ICP	-	0.1	mg/L	4 %	10 %
K	ICP	-	0.4	mg/L	6 %	15 %
Ca	ICP	-	0.1	mg/L	4 %	10 %
Mg	ICP	-	0.09	mg/L	4 %	10 %
S(tot)	ICP	-	0.160	mg/L	10 %	15 %
Si(tot)	ICP	-	0.03	mg/L	4 %	15 %
Sr	ICP	-	0.002	mg/L	4 %	15 %
Li	ICP	-	0.2 - 2[1]	µg/L	10 %	20 %
Fe	ICP	-	0.4-4[1]	µg/L	6 %	10 %
Mn	ICP	-	0.03-0.1[1]	µg/L	8 %	10 %
Fe (II), Fe(tot)	Spectrophotometry	5	20	µg/L	15 % (>30 µg/L)	20 %
S^{2-}	Spectrophotometry	0.02	0.03	mg/L	10 %	-
DOC	See tab. 1	-	0.5	mg/L	8 %	30 %
TOC	See tab. 1	-	0.5	mg/L	10 %	30 %
δ^2H	MS	-	2	‰ SMOW[4]	1.0 ‰	-
$\delta^{18}O$	MS	-	0.1	‰ SMOW[4]	0.2 ‰	-
^3H	LSC	-	0.8 or 0.1	TU[5]	0.8 or 0.1 TU	-

Component	Method	Detection limit	Reporting limit or range	Unit	Measurement uncertainties [2]	”Total” uncertainties [3]
δ^{37}Cl	ICP MS	-	0.2 ‰ (20 mg/L)	‰ SMOC[6]	-	-
δ^{13}C	A (MS)	-	>20 mg Carbon	‰ PDB[7]	-	-
pmC (^{14}C)	A (MS)	-	>20 mg Carbon	pmC[8]	-	-
δ^{34} S	ICP MS	-	0.2 ‰	‰ CDT[9]	0.2 ‰	-
^{87}Sr/^{86}Sr	MS	-	-	No unit (ratio) [10]	0.000020	-
^{10}B/^{11}B	ICP MS	-	-	No unit (ratio) [10]	0,0020	-
^{234}U, ^{235}U, ^{238}U, ^{232}Th, ^{230}Th	Alfa spectr.	-	0.05 (0.0005[13])	Bq/L[12]	0.05 Bq/L	Right order of magnitude
^{222}Rn, ^{226}Rn	LSC	-	0.1 (0.0005[13])	Bq/L	0.05 Bq/L	

1. Reporting limits at salinity ≤ 0.4 % (520 mS/m) and ≤ 3.5 % (3810 mS/m) respectively.
2. Measurement uncertainty reported by consulted laboratory, generally 95 % confidence interval.
3. Estimated total uncertainty by experience (includes effects of sampling and sample handling).
4. Per mille deviation[11] from SMOW (Standard Mean Oceanic Water).
5. TU=Tritium Units, where one TU corresponds to a Tritium/hydrogen ratio of 10^{-18} (1 Bq/L Tritium = 8.45 TU).
6. Per mille deviation[11] from SMOC (Standard Mean Oceanic Chloride).
7. Per mille deviation[11] from PDB (the standard PeeDee Belemnite).
8. The following relation is valid between pmC (percent modern carbon) and Carbon-14 age: $pmC = 100 \times e^{((1950-y-1.03t)/8274)}$
   where y = the year of the C-14 measurement and t = C-14 age
9. Per mille deviation[12] from CDT (the standard Canyon Diablo Troilite).
10. Isotope ratio without unit.
11. Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as:
    $\delta^{y}I = 1000\times(K_{sample}-K_{standard})/K_{standard}$, where K= the isotope ratio and $^{y}I = {}^{2}H$, ^{18}O, ^{37}Cl, ^{13}C or ^{34}S etc.
12. The following expressions are applicable to convert activity to concentration, for uranium-238 and thorium-232:
    1 ppm U = 12.4 Bq/kg^{238}U
    1 ppm Th = 3.93 Bq/kg^{232}Th
13. The consulted laboratory is changed recently and the new laboratory reports lower detection limits.

Table A11-3. Participant laboratories

Äspö water chemical laboratory (SKB) Mobile field laboratory, Forsmark (SKB)
Inainööritoimisto Paavo Ristola Oy Teollisuus-ja Voimalaitoskemia Rajantorpantie 8, C-talo 01600 Vantaa FINLAND
Dept. of System ecology Stockholm University 10691 Stockholm
Analytica AB Aurorum 10 977 75 Luleå (Nytorpsvägen 16 Box 511 183 25 Täby)
Environmental Isotope Laboratory Dep. Of earth sciences University of Waterloo Waterloo, Ontario N2L 3G1 CANADA
Institutt for energiteknik (IFE) Insituttveien 18 P.O Box 40 2027 Kjeller NORGE
AnalyCen Nordic AB Box 905 531 19 Lidköping
The Ångström laboratory Box 534 Se-751 21 Uppsala
Scottish Universities Environmental Research Centre (SUERC) Rankin Avenue, Scottish Enterprise Technology Park, East Kilbride, G75 0QF, Scotland, UK.

Compilation of water analysis data

Table A12-1. Water composition

Compilation June 2004

Idcode	Secup m	Seclow m	Sample no.	Sampling date	Charge Bal %	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO_3^- mg/L	Cl^- mg/L	SO_4^{2-} mg/L	SO_4-S mg/L	Br mg/l	F^- mg/L	Si mg/L	Fe mg/L	Fe-tot mg/L	FeII mg/L	Mn mg/L	Li mg/L
KFM03A	386,0	391,0	4983	2003-09-16	-3,2	2080	47,5	926	221	99	5440	502	152	23,0	0,93	6,2	0,413	0,428	0,423	1,14	0,050
KFM03A	386,0	391,0	8008	2003-09-23	-2,9	2090	47,5	926	222	100	5420	493	153	22,2	0,85	6,3	0,518	0,551	0,450	1,14	0,050
KFM03A	386,0	391,0	8011	2003-10-02	-2,6	2110	47,6	927	224	99	5440	515	153	23,3	0,88	6,4	0,714	0,718	x	1,14	0,050
KFM03A	386,0	391,0	8012	2003-10-06	-2,8	2110	47,6	925	223	101	5450	495	152	22,8	0,88	6,4	0,737	0,785	0,656	1,13	0,050
KFM03A	448,0	453,0	8015	2003-10-17	-3,0	2050	25,8	973	199	90	5380	469	146	23,9	0,89	6,4	0,736	0,758	x	1,14	0,048
KFM03A	448,0	453,0	8017	2003-10-24	-2,8	2070	26,8	985	202	91	5430	472	148	24,7	<0.2	8,5	0,905	0,919	0,919	1,17	0,049
KFM03A	448,50	455,62	8282	2004-04-15	0,3	2190	28,1	1080	216	92	5440	521	159	20,5	1,70	10,0	1,18	1,20	1,18	1,12	0,056
KFM03A	448,50	455,62	8284	2004-04-27	1,0	2180	27,5	1070	216	93	5330	511	158	20,9	1,60	9,9	1,07	1,10	1,11	1,25	0,050
KFM03A	639,00	646,12	8158	2004-02-04		1840	21,6	1180	199	25	-	-	138	-	-	7,7	0,716	-	-	1,85	0,052
KFM03A	639,00	646,12	8265	2004-02-06	-2,3	1670	15,0	1470	55,2	25	5380	191	64,0	39,4	<0.2	6,2	0,292	0,328	0,317	0,34	0,030
KFM03A	639,00	646,12	8268	2004-02-11	-2,0	1690	15,2	1470	55,6	25	5380	194	63,6	38,7	<0.2	6,3	0,457	0,458	0,448	0,34	0,033
KFM03A	639,00	646,12	8270	2004-02-13	-3,7	1670	14,8	1430	54,4	24	5470	196	62,0	36,8	<0.2	6,3	0,332	0,354	0,324	0,33	0,026
KFM03A	639,00	646,12	8271	2004-02-20	-3,5	1660	14,5	1440	53,1	22	5440	193	61,5	38,4	<0.2	6,3	0,273	0,276	0,258	0,32	0,031
KFM03A	639,00	646,12	8273	2004-02-23	-3,4	1660	14,3	1440	52,7	22	5430	197	61,9	38,2	<0.2	6,2	0,237	0,234	0,233	0,32	0,028
KFM03A	939,50	946,62	8274	2004-02-26		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
KFM03A	939,50	946,62	8275	2004-03-03	-1,6	1810	12,1	2610	37,3	19	7560	132	44,8	71,8	-	6,5	1,26	2,61	2,63	0,21	0,026
KFM03A	939,50	946,62	8276	2004-03-05	-2,1	1830	12,1	2690	33,3	15	7830	123	41,7	63,5	-	6,3	0,436	0,433	0,404	0,20	0,025
KFM03A	939,50	946,62	8277	2004-03-08	-1,6	1830	11,0	2800	27,0	13	7930	105	36,1	79,9	-	6,1	0,308	0,354	0,324	0,15	0,023
KFM03A	939,50	946,62	8278	2004-03-11	-1,7	1850	11,0	2890	23,4	11	8150	93,9	32,8	68,1	-	5,9	0,288	0,293	0,288	0,15	0,023
KFM03A	939,50	946,62	8279	2004-03-15	-1,9	1850	10,2	2980	20,3	11	8330	84,8	29,4	85,6	-	5,8	0,215	0,233	0,227	0,11	0,022
KFM03A	939,50	946,62	8280	2004-03-26	-1,8	1880	10,4	3040	20,1	10	8480	80,1	28,1	87,5	-	5,9	0,241	0,265	0,267	0,11	0,022
KFM03A	939,50	946,62	8281	2004-03-29	-1,6	1890	10,4	3100	17,6	9	8560	73,9	26,3	72,3	-	5,8	0,086	0,216	0,208	0,11	0,022
KFM03A	980,00	1001,19	8096	2003-11-06	-0,3	2000	7,9	3630	9,4	7	10000	48,7	18,4	100	<0.2	4,9	<0.02	0,011	0,001	0,04	0,024
KFM03A	980,00	1001,19	8098	2003-11-11	-3,1	2000	7,2	3640	8,3	6	9990	43,3	17,9	99,7	<0.2	4,7	<0.02	0,005	<0.005	0,03	0,025
KFM03A	980,00	1001,19	8101	2003-11-20	-2,9	2000	7,0	3640	8,0	6	9950	43,3	17,9	103	<0.2	4,6	<0.02	0,015	0,004	0,03	0,023
KFM03A	980,00	1001,19	8103	2003-11-24	-2,3	2020	7,0	3650	8,2	9	9890	45,0	18,5	101	<0.2	4,7	0,030	0,023	0,011	0,03	0,024
KFM03A	980,00	1001,19	8104	2003-11-26	-3,3	1980	7,0	3580	8,0	7	9890	44,5	18,4	101	<0.2	4,7	0,028	0,030	0,019	0,03	0,024
KFM03A	980,00	1001,19	8105	2003-12-01	-2,4	1990	6,9	3590	8,0	7	9740	44,8	18,6	99,1	<0.2	4,7	0,040	0,027	0,015	0,03	0,023
KFM03A	980,00	1001,19	8151	2003-12-03	-0,8	2050	6,9	3700	8,0	6	9720	45,9	18,8	95,9	<0.2	4,7	0,029	0,027	0,020	0,03	0,023
KFM03A	980,00	1001,19	8152	2003-12-08	-2,6	1980	6,9	3550	8,1	6	9690	46,7	19,2	97,5	<0.2	4,8	0,034	0,033	0,026	0,01	0,024

- = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< "value" = result less than detection limit
ChargeBal % = Rel. charge balance error %
SICADA: water_composition,

Compilation June 2004

Idcode	Secup m	Seclow m	Sample no.	Sr mg/L	I^- mg/L	pH	DOC mg/L	TOC mg/L	HS^- mg/L	Drill_water %	ElCond mS/m	NH_4N mg/L
KFM03A	386,0	391,0	4983	8,31	-	7,27	2,9	-	-	0,9	1600	2,36
KFM03A	386,0	391,0	8008	8,34	-	7,29	1,4	-	<0.03	0,8	1610	2,32
KFM03A	386,0	391,0	8011	8,36	-	7,37	1,3	-	<0.03	0,6	1590	2,43
KFM03A	386,0	391,0	8012	8,31	-	7,30	1,3	1,3	-	0,6	1670	2,34
KFM03A	448,0	453,0	8015	10,1	-	7,46	1,5	-	<0.03	0,5	1620	1,33
KFM03A	448,0	453,0	8017	10,1	A	7,49	1,2	1,0	<0.03	0,3	1600	2,33
KFM03A	448,50	455,62	8282	10,6	0,041	7,41	A	-	0,03	0,4	1590	1,32
KFM03A	448,50	455,62	8284	10,5	0,041	7,42	A	-	0,05	0,4	1580	1,38
KFM03A	639,00	646,12	8158	11,2	-	7,47	-	-	-	5,5	1620	-
KFM03A	639,00	646,12	8265	16,6	-	7,52	A	-	<0.03	5,1	1600	0,164
KFM03A	639,00	646,12	8268	16,7	-	7,37	2,3	-	<0.03	4,8	1530	0,181
KFM03A	639,00	646,12	8270	16,7	-	7,45	1,8	-	<0.03	5,0	1540	0,177
KFM03A	639,00	646,12	8271	16,6	-	7,51	1,3	-	<0.03	4,4	1690	0,163
KFM03A	639,00	646,12	8273	16,7	-	7,55	1,6	-	-	4,4	1620	0,159
KFM03A	939,50	946,62	8274	-	-	7,43	-	-	-	-	1870	-
KFM03A	939,50	946,62	8275	26,7	-	7,48	A	-	0,16	12,9	2060	0,187
KFM03A	939,50	946,62	8276	27,8	0,215	7,28	A	-	0,06	13,3	2110	0,087
KFM03A	939,50	946,62	8277	28,9	-	7,53	A	-	0,07	12,1	2170	0,151
KFM03A	939,50	946,62	8278	30,1	0,243	7,43	A	-	0,03	11,2	2040	0,143
KFM03A	939,50	946,62	8279	30,6	-	7,33	A	-	0,03	10,5	1970	0,118
KFM03A	939,50	946,62	8280	31,4	-	7,67	A	-	0,05	9,0	1890	0,163
KFM03A	939,50	946,62	8281	32,2	0,241	7,78	A	-	0,06	8,8	1990	0,154
KFM03A	980,00	1001,19	8096	42,4	-	7,89	1,6	-	0,09	2,4	2640	0,037
KFM03A	980,00	1001,19	8098	42,2	-	8,13	1,2	-	0,07	1,3	2760	0,032
KFM03A	980,00	1001,19	8101	41,9	-	8,17	1,3	-	0,04	1,4	2670	0,029
KFM03A	980,00	1001,19	8103	42,7	-	8,23	1,2	-	0,02	2,1	2630	0,039
KFM03A	980,00	1001,19	8104	41,5	-	8,27	1,1	-	0,01	2,4	2670	0,037
KFM03A	980,00	1001,19	8105	41,8	-	8,27	1,3	-	0,04	3,1	2650	0,033
KFM03A	980,00	1001,19	8151	43,0	-	8,21	1,3	-	0,06	3,4	2660	0,046
KFM03A	980,00	1001,19	8152	41,6	-	8,26	1,4	-	0,03	3,9	2560	x

- = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< "value" = result less than detection limit
ChargeBal % = Rel. charge balance error %
SICADA: water_composition,

Table A12-2. Isotopes I (H-, O-, B-, Cl- and C-isotopes)

Compilation June 2004

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	AGE_BP years	$\delta^{37}Cl$ dev SMOC
KFM03A	386,0	391,0	4983	2003-09-16	-	<0.8	-	0,2370	-	-	-	-	-	-
KFM03A	386,0	391,0	8008	2003-09-23	-69,5	<0.8	-9,1	0,2360	-	-	-	-	-	-
KFM03A	386,0	391,0	8011	2003-10-02	-69,1	<0.8	-9,2	0,2362	-	-	-	-	-	-
KFM03A	386,0	391,0	8012	2003-10-06	-69,4	2,0	-9,1	0,2363	25,0	-7,5	0,71828	17,6	13925	A
KFM03A	448,0	453,0	8015	2003-10-17	-70,5	<0.8	-9,8	0,2361	-	-	-	-	-	-
KFM03A	448,0	453,0	8017	2003-10-24	-70,4	<0.8	-9,4	0,2365	25,4	-7,6	0,717339	15,7	14800	A
KFM03A	448,50	455,62	8282	2004-04-15	A	A	A	A	A	-	A	-	-	-
KFM03A	448,50	455,62	8284	2004-04-27	A	A	A	A	A	A	A	A	A	A
KFM03A	639,00	646,12	8265	2004-02-06	-83,4	0,9	-11,6	A	-	-	-	-	-	-
KFM03A	639,00	646,12	8268	2004-02-11	-84,4	<0.8	-11,6	A	26,4	-	0,71748	-	-	-
KFM03A	639,00	646,12	8270	2004-02-13	-84,3	<0.8	-11,8	A	-	-	-	-	-	-
KFM03A	639,00	646,12	8271	2004-02-20	-85,5	<0.8	-11,7	0,2421	A	-	A	-	-	-
KFM03A	639,00	646,12	8273	2004-02-23	-84,3	<0.8	-11,7	0,2404	A	A	A	A	A	A
KFM03A	939,50	946,62	8275	2004-03-03	A	A	A	0,2364	-	-	-	-	-	-
KFM03A	939,50	946,62	8276	2004-03-05	A	A	A	0,2361	A	-	A	-	-	-
KFM03A	939,50	946,62	8277	2004-03-08	A	A	A	0,2364	-	-	-	-	-	-
KFM03A	939,50	946,62	8278	2004-03-11	A	A	A	0,2364	A	-	A	-	-	-
KFM03A	939,50	946,62	8279	2004-03-15	A	A	A	0,2364	-	-	-	-	-	-
KFM03A	939,50	946,62	8280	2004-03-26	A	A	A	0,2364	-	-	-	-	-	-
KFM03A	939,50	946,62	8281	2004-03-29	A	A	A	0,2364	A	A	A	A	A	A
KFM03A	980,00	1001,19	8096	2003-11-06	-97,0	<0.8	-14,1	0,2393	-	-	-	-	-	-
KFM03A	980,00	1001,19	8098	2003-11-11	-95,8	<0.8	-14,1	0,2391	-	-	-	-	-	-
KFM03A	980,00	1001,19	8101	2003-11-20	-98,4	<0.8	-13,6	0,239	-	-	-	-	-	-
KFM03A	980,00	1001,19	8103	2003-11-24	-99,9	<0.8	-13,6	0,2390	28,9	-	0,717779	-	-	-
KFM03A	980,00	1001,19	8104	2003-11-26	-99,1	<0.8	-13,6	0,2391	-	-	-	-	-	-
KFM03A	980,00	1001,19	8105	2003-12-01	-98,6	<0.8	-13,5	0,2385	28,9	-	0,717769	-	-	-
KFM03A	980,00	1001,19	8151	2003-12-03	-97,4	<0.8	-13,5	0,2385	-	-	-	-	-	-
KFM03A	980,00	1001,19	8152	2003-12-08	-98,5	<0.8	-13,6	0,2393	29,6	A	0,717768	A	A	A

- = Not analysed
A = results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< "value" = result less than detection limit
SICADA: h_o_isotopes, b_s_cl_sr_isotopes, c_s_isotopes

Table A12-3. Trace elements

Compilation June 2004

Idcode	Secup m	Seclow m	Sample no.	Sampling date	U ug/L	Th ug/L	Sc ug/L	Rb ug/L	Y ug/L	Zr ug/L	Sb ug/L	Cs ug/L	La ug/L	Hf ug/L	Tl ug/L	Ce ug/L	Pr ug/L	Nd ug/L	Sm ug/L	Eu ug/L
KFM03A	386,0	391,0	8012	2003-10-06	3,49	<0.2	<0.5	64,5	2,39	<0.3	<0.1	1,55	0,183	<0.05	<0.3	0,161	<0.05	0,081	<0.05	<0.05
KFM03A	448,0	453,0	8017	2003-10-24	2,21	<0.2	<0.5	79,5	2,66	<0.3	<0.1	1,78	0,367	<0.05	<0.3	0,406	<0.05	0,223	0,053	<0.05
KFM03A	448,50	455,62	8282	2004-04-15	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
KFM03A	448,50	455,62	8284	2004-04-27	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
KFM03A	639,00	646,12	8268	2004-02-11	58,5	<0.2	<0.5	41,2	0,18	1,82	1,31	0,85	<0.05	<0.05	<0.3	<0.05	<0.05	<0.05	<0.05	<0.05
KFM03A	639,00	646,12	8271	2004-02-20	49,0	<0.2	<0.5	40,0	0,29	<0.3	0,175	0,74	0,063	<0.05	<0.3	<0.05	<0.05	<0.05	<0.05	<0.05
KFM03A	639,00	646,12	8273	2004-02-23	46,1	<0.2	<0.5	38,3	0,32	<0.3	0,399	0,74	0,073	<0.05	<0.3	<0.05	<0.05	<0.05	<0.05	<0.05
KFM03A	939,50	946,62	8276	2004-03-05	1,45	<0.4	<0.8	44,1	0,25	<0.2	0,884	0,86	0,627	<0.04	<0.2	0,151	<0.04	<0.04	<0.04	<0.04
KFM03A	939,50	946,62	8278	2004-03-11	0,991	<0.4	<0.8	41,7	0,28	<0.2	0,532	0,84	0,757	<0.04	<0.2	0,270	<0.04	0,059	<0.04	<0.04
KFM03A	939,50	946,62	8281	2004-03-29	0,699	<0.4	<0.8	43,2	0,25	<0.2	0,601	1,01	0,563	<0.04	<0.2	0,224	<0.04	0,055	<0.04	<0.04
KFM03A	980,00	1001,19	8103	2003-11-24	0,273	<0.2	<0.5	34,2	0,46	0,81	0,339	0,67	<0.05	<0.05	<0.3	<0.05	<0.05	<0.05	<0.05	0,0501
KFM03A	980,00	1001,19	8105	2003-12-01	0,183	<0.2	<0.5	34,0	0,45	0,62	0,362	0,69	<0.05	<0.05	<0.3	<0.05	<0.05	<0.05	<0.05	<0.05
KFM03A	980,00	1001,19	8152	2003-12-08	0,445	<0.2	<0.5	35,4	0,58	1,44	0,480	0,74	<0.05	<0.05	<0.3	<0.05	<0.05	<0.05	<0.05	0,0597

- = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< "value" = result less than detection limit
SICADA: trace_elements

Compilation June 2004

Idcode	Secup m	Seclow m	Sample no.	Gd ug/L	Tb ug/L	Dy ug/L	Ho ug/L	Er ug/L	Tm ug/L	Yb ug/L	Lu ug/L
KFM03A	386,0	391,0	8012	<0.05	<0.05	0,069	<0.05	0,069	<0.05	<0.05	<0.05
KFM03A	448,0	453,0	8017	0,101	<0.05	0,113	<0.05	0,086	<0.05	0,0554	<0.05
KFM03A	448,50	455,62	8282	A	A	A	A	A	A	A	A
KFM03A	448,50	455,62	8284	A	A	A	A	A	A	A	A
KFM03A	639,00	646,12	8268	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
KFM03A	639,00	646,12	8271	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
KFM03A	639,00	646,12	8273	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
KFM03A	939,50	946,62	8276	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
KFM03A	939,50	946,62	8278	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
KFM03A	939,50	946,62	8281	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
KFM03A	980,00	1001,19	8103	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0,080	<0.05
KFM03A	980,00	1001,19	8105	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0,090	<0.05
KFM03A	980,00	1001,19	8152	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0,070	<0.05

- = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< "value" = result less than detection limit
SICADA: trace_elements

Table A12-4. Isotopes II (U-, Th-, Ra- and Rn-isotopes)

Compilation June 2004

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
KFM03A	386,0	391,0	8012	2003-10-06	< 50	< 50	< 50	< 50	< 50	1,20	138
KFM03A	448,0	453,0	8017	2003-10-24	A	A	A	A	A	1,40	169
KFM03A	448,50	455,62	8284	2004-04-27	40,4	A	105	A	A	0,90	123
KFM03A	639,00	646,12	8273	2004-02-23	A	A	A	A	A	13,5	157
KFM03A	939,50	946,62	8281	2004-03-29	2,4	A	5,88	A	0,25	A	A
KFM03A	980,00	1001,19	8104	2003-11-26	2,6	-	5,6	-	-	-	-
KFM03A	980,00	1001,19	8105	2003-12-01	320	-	1330	-	34,7	-	-
KFM03A	980,00	1001,19	8152	2003-12-08	10	A	24,3	A	< 0,5	A	A

- = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< "value" = result less than detection limit
SICADA: u_th_isotope_t, ra_rn_isotope_t

Table A12-5. Dissolved gases

Compilation June 2004

Idcode	Secup m	Seclow m	Sample no.	Sampling date	Ar mL/L	He mL/L	N_2 mL/L	CO_2 mL/L	CH_4 mL/L	O_2 mL/L	H_2 µL/L	CO µL/L	C_2H_6 µL/L	C_2H_4 µL/L	C_2H_2 µL/L	C_3H_8 µL/L	C_3H_6 µL/L	DISS_GAS mL/L H_2O
KFM03A	448,50	455,62	8282	2004-04-15	0,86	1,4	76,1	1,5	0,03	0,07	213	<4.0	0,17	0,11	0,06	<0.08	<0.08	80,2
KFM03A	639,00	646,12	8273	2004-02-23	1,01	9,5	77,8	0,57	0,07	0,03	<2.7	<4.4	0,60	0,06	<0.05	<0.09	<0.09	88,9
KFM03A	939,50	946,62	8281	2004-03-29	1,40	16,8	105,9	0,16	0,06	0,12	44	<6.2	0,37	0,14	<0.06	0,22	<0.12	124,5
KFM03A	980,00	1001,19	8152	2003-12-08	1,60	20,7	105	0,03	0,05	0,04	<3.8	<6.4	0,56	<0.06	<0.06	0,25	<0.13	127,5

- = Not analysed
A = Results will be reported later
x = No result due to sampling problems
xx = No result due to analytical problems
< "value" = result below detection limit
SICADA: Dissolved_gases