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Forsmark site investigation

Sampling and analyses of groundwater from percussion drilled boreholes

Results from the boreholes HFM36, HFM37, and HFM38

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April 2007

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Keywords: Forsmark, Percussion borehole, Groundwater, Chemical analyses, Isotope determination, Water sampling, AP PF 400-06-086.

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Abstract

Percussion boreholes are drilled as monitoring wells or as flushing water supply wells for core drilling. Further, percussion boreholes are drilled for general geological characterisation or in order to investigate specific geological features (e.g. lineaments) down to about 200 m depth in the bedrock.

Groundwater samples were collected in connection with hydraulic pumping tests in the percussion drilled boreholes HFM36, HFM37 and HFM38. The analytical protocol included major constituents and isotope options (δD , $\delta^{18}\text{O}$, $^{10}\text{B}/^{11}\text{B}$ and Tritium) according to SKB class 3. The main objective was to gain hydrogeochemical data to approximately 200 m depth from the three listed boreholes. Water samples were collected at three occasions during the pumping period. Borehole HFM36 shows increasing chloride concentrations during the pumping period, whereas the other boreholes demonstrate either stable or somewhat varying chloride concentrations.

The obtained analytical results seem to be of good quality and the relative charge balance error does not exceed 5% in any of the samples.

Sammanfattning

Hammarborrhål borrar dels för att övervaka grundvattennivåförändringar, dels för att utgöra spolvattenbrunnar vid kärnbrinning. Vidare används hammarborrhål för allmän geologisk karakterisering och för att undersöka specifika geologiska företeelser (t ex lineament) ner till cirka 200 m djup i berggrunden.

Grundvattenprov har tagits ut under hydrauliska pumptester från hammarborrhålen HFM36, HFM37 och HFM38. Analysomfattningen inkluderade huvudkomponenter och isotoptillvalen δD , $\delta^{18}O$, $^{10}B/^{11}B$ och tritium enligt SKB klass 3. Syftet med aktiviteten var att erhålla hydrogeokemiska data ner till cirka 200 m djup från de tre borrhålen. Vattenprover togs vid tre tidpunkter under pumpningen. Hammarborrhålet HFM36 visar ökande kloridkoncentrationer under pumpperioden medan i övriga undersökta borrhål uppmättes stabila eller något varierande kloridhalter.

Erhållna analysresultat verkar vara av god kvalitet och det relativa felet i jonbalansen överstiger inte 5 % för något av proven.

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1 Introduction

This document reports the performance and the results of the activity “Sampling of percussion boreholes after drilling”, which is one of the activities performed within the site investigation at Forsmark /1/. The work was carried out in accordance with the activity plan AP PF 400-06-086. In Table 1-1 controlling documents for conducting this activity are listed. Both activity plans and method descriptions are SKB’s internal controlling documents. The report presents hydro-geochemical data from the percussion boreholes HFM36, HFM37 and HFM38. The length of the boreholes varies between 153 m and 201 m /2, 3/.

The locations of the percussion boreholes are shown in Figure 1-1.

Samplings of the boreholes were accomplished in connection with pumping tests and flow logging carried out within the programme for hydrogeological investigations /4/.

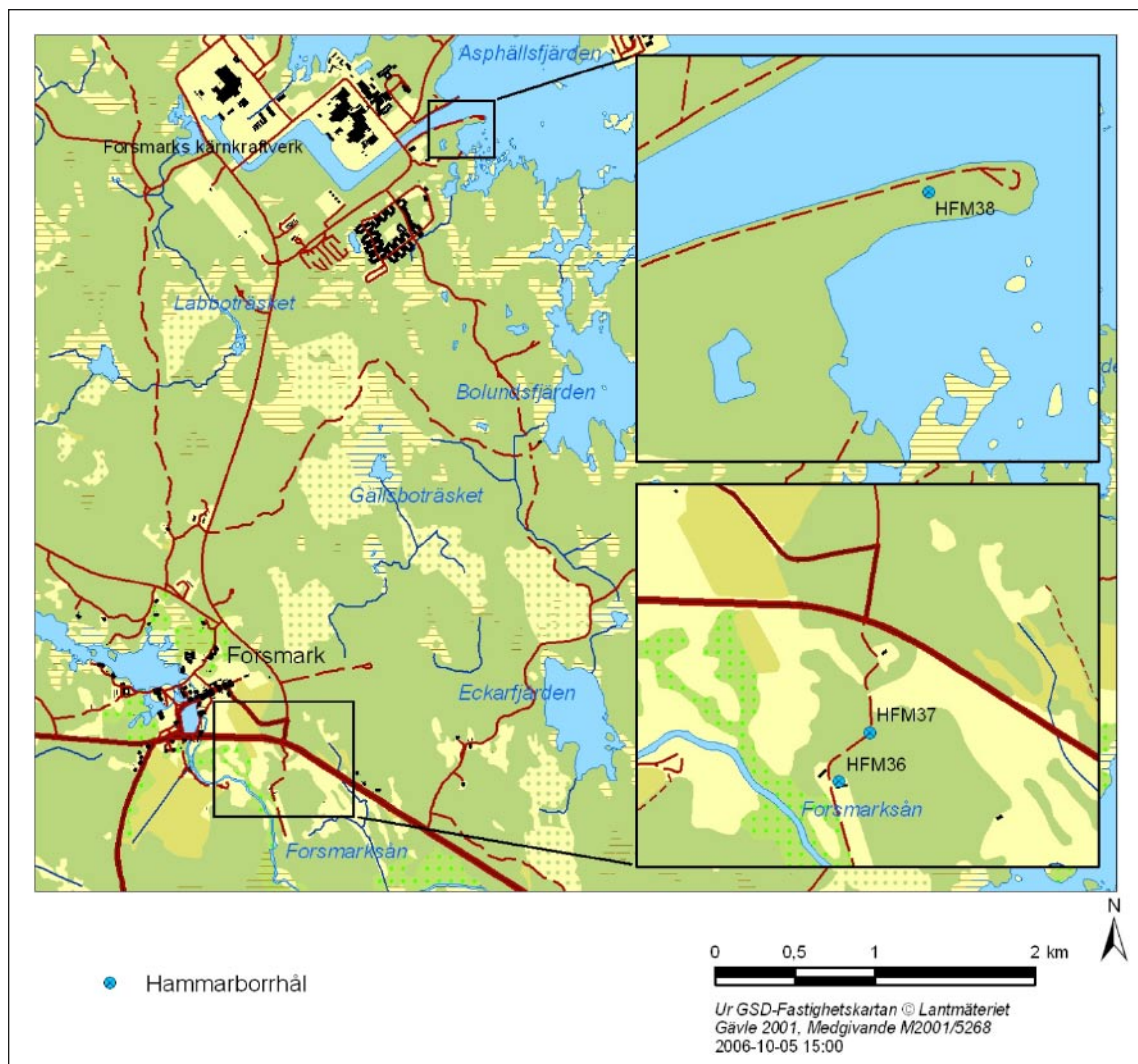


Figure 1-1. Locations of the investigated boreholes within the Forsmark investigation area.

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

Activity plan	Number	Version
Hydrotester och vattenprovtagning i hammarborrhålen HFM36, HFM37 och HFM38.	AP PF 400-06-086	1.0
Method description	Number	Version
Enkel vattenprovtagning i hammarborrhål och kärnborrhål.	SKB MD 423.002	2.0

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the activity plan number (AP PF 400-06-086). Only data in databases are accepted for further interpretation and modelling. The data presented in this report are regarded as copies of the original data. Data in the databases may be revised, if needed. Such revisions will not necessarily result in a revision of the P-report, although the normal procedure is that major data revisions entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se.

2 Objective and scope

Sampling and analysis of groundwater from the percussion boreholes were mainly performed in order to:

- Gain data on the chemical composition of so called “first strike” groundwater, i.e. groundwater sampled before the impact of short circuiting between fractures of different hydro-geochemical character has become significant.
- Contribute to area coverage of the hydrochemical data from the shallow part of the bedrock.
- Determine the suitability of some of the percussion boreholes to serve as supply wells for the flushing water needed for drilling the cored part of telescopic boreholes. Core drilling of a 1,000 m long borehole consumes approximately 1,000 m³ water. Core drilled boreholes of SKB chemical-type are of special importance and the total organic content in the flushing water must be low (< 5 mg/L) in order to avoid disturbing the microbiological conditions in the borehole.

Sampling and analysis are performed according to the SKB class 3 procedure. The analyses of the last collected sample from each borehole also include isotope options.

3 Background

The percussion boreholes HFM36 and HFM37 were both drilled at drill site 12 (DS12). HFM36 was drilled in order to serve as supply well of flushing water for the core drilling of KFM12A while the drilling of HFM37 aimed to characterize the Forsmark Zone in superficial sections and to provide observation hole during the drilling of KFM12A.

HFM38 were drilled close to the cooling water channel north of DS8 to, if possible, reveal sections of the “porous granite”, which had been encountered for instance in the core borehole KFM08C.

General information concerning the boreholes is presented in Table 3-1.

Table 3-1. Borehole information for HFM36, HFM37 and HFM38 (from Sicada).

Idcode	Date of completion	Bearing (degrees)	Inclination (degrees)	Northing (m)	Easting (m)	Elevation (m.a.s.l.)	Length (m)
HFM36	2006-09-04	256.6	-58.9	6,696,504	1,630,082	8.4	152.6
HFM37	2006-08-16	41.4	-59.2	6,696,502	1,630,137	11.4	191.8
HFM38	2006-06-22	93.6	-54.5	6,700,701	1,631,302	2.2	200.8

4 Equipment

The sampling in the percussion boreholes was performed in connection with hydraulic tests with the HTHB (Swedish abbreviation for Hydraulic Test System for Percussion Boreholes) and is described in the user's manual of the measurement system, SKB's internal controlling document SKB MD 326.001 (Mätssystembeskrivning för hydrotestutrustning för hammarborrhål – HTHB). The equipment allows pumping from packed off sections in boreholes of diameter 165 mm and 140 mm (\pm a few millimetres) using a single- or double packer system. The in-hole equipment includes a packer system, a measurement tube, an enclosed pump, and a combined pressure sensor and data logger. An overview of the HTHB equipment is given in Figure 4-1 and Figure 4-2 below.

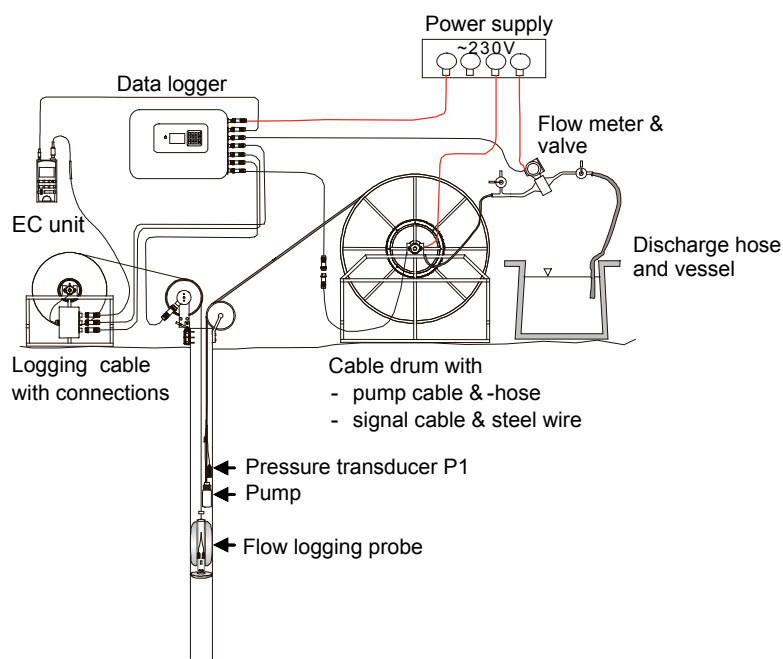


Figure 4-1. Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB. (From SKB MD 326.001, SKB's internal document).

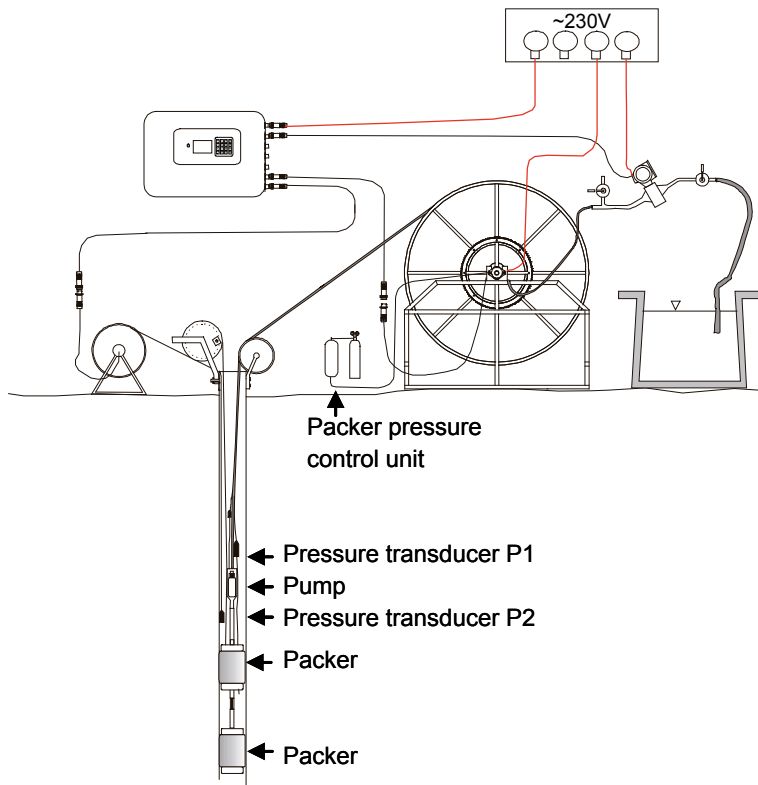


Figure 4-2. Schematic test set-up for a pumping test in an isolated borehole section with HTHB. (From SKB MD 326.001, SKB's internal document).

5 Execution

5.1 Sampling

Sampling of the percussion boreholes was carried out according to activity plan AP PF 400-06-086 following the method described in SKB MD 423.002 (Mätssystembeskrivning för hydrotest-utrustning för hammarborrhål – HTHB), both SKB's internal controlling documents.

Generally, the pumping proceeded during 10 hours, and samples were collected three times during the pumping period. Table 5-1 presents general sampling information from the pumping tests.

Sampling and analyses were performed according to SKB class 3 and isotope options were included for the last sample collected from each borehole. Total organic carbon (TOC) was mainly determined in order to investigate the suitability of the boreholes as sources for flushing water.

5.2 Sample treatment and chemical analyses

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

5.3 Data handling

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

Several components are determined by more than one method and/or laboratory. Moreover, duplicate analyses by an independent laboratory are performed as a standard procedure on each fifth or tenth collected sample.

All analytical results are stored in the Sicada database. The applied hierarchy path "Hydro-chemistry/Hydrochemical investigation/Analyses/Water in the database" contains two types of tables, raw data tables and primary data tables (final data tables).

Table 5-1. Pumping information and collected samples.

Borehole	Pumped section (m)	Date and time of pump start	Date and time of pump stop	Date and time of sampling	Pumped volume (m ³)	Sample no.
HFM36	12.1–152.6	061123 08:12	061123 18:13	061123 09:09	2.3	12548
				061123 12:54	11.2	12549
				061123 18:08	23.6	12550
HFM37	9.1–191.8	061121 08:51	061121 18:57	061121 09:50	0.4	12545
				061121 13:55	1.8	12546
				061121 18:47	3.2	12547
HFM38	9.1–200.8	061114 09:05	061114 19:31	061114 10:43	4.6	12533
				061114 14:35	18.5	12534
				061114 19:25	35.7	12535

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

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

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

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

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 5-1.

5.4 Nonconformities

No nonconformities have been reported from the activity.

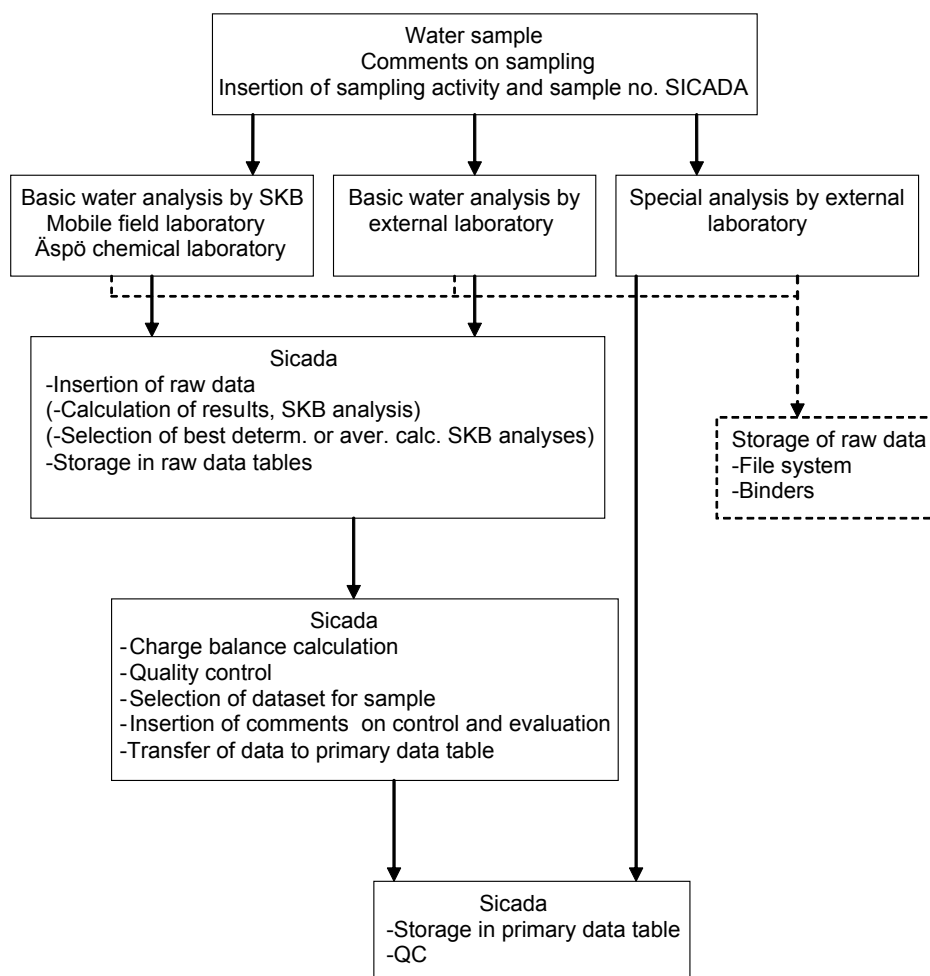


Figure 5-1. Overview of data management for hydrogeochemical data.

6 Results

6.1 Basic water analyses

The basic water analyses include the major components Na, K, Ca, Mg, S, SO_4^{2-} , Cl^- , Si and HCO_3^- as well as the minor constituents Li, Br, F and TOC (Total Organic Carbon). Furthermore, measurements of pH and electric conductivity are included. The basic water analysis data and relative charge balance errors are compiled in Appendix 2, Table A2-1.

Samples were collected three times in each borehole; 1) when borehole water reaches the surface, 2) in the middle and 3) in the end of the pumping period. Chloride concentrations from all boreholes and all samples are compared in Figures 6-1 and 6-2. Borehole HFM36, shows a minor increase in the chloride concentration during the pumping period, whereas the other boreholes display stable or somewhat varying concentrations almost within the analytical uncertainty.

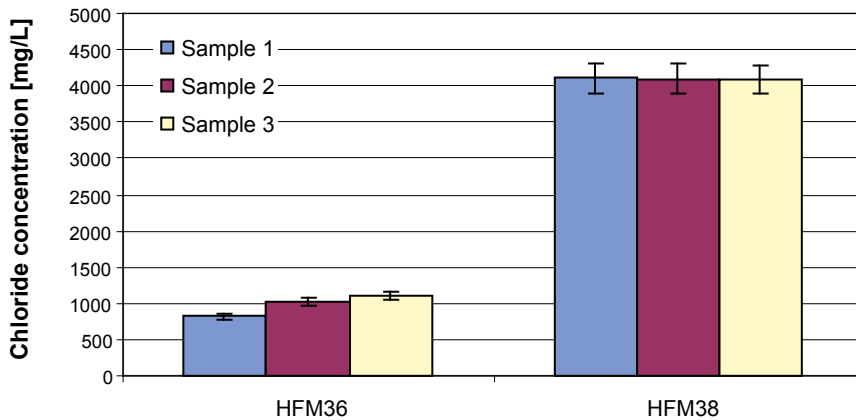


Figure 6-1. Chloride concentration series for boreholes HFM36 and HFM38.

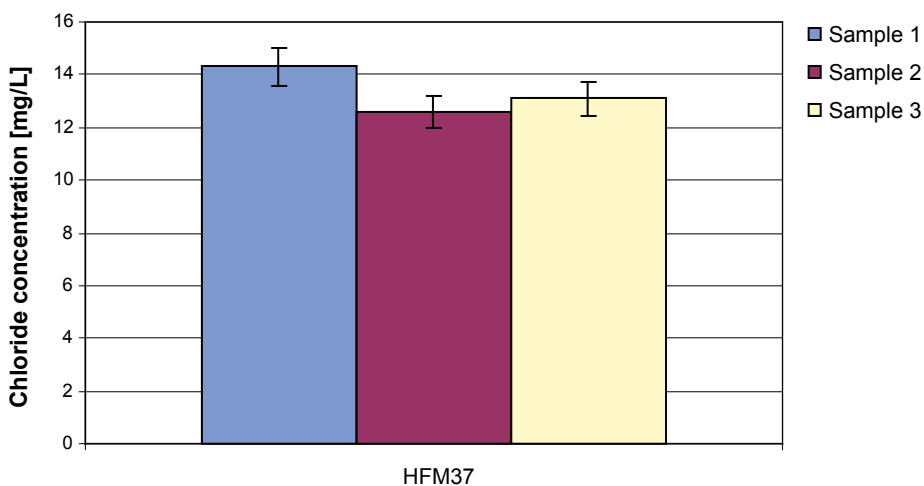


Figure 6-2. Chloride concentration series for borehole HFM37.

The charge balance errors give an indication of the quality and uncertainty of the analyses of major components. The errors do not exceed $\pm 5\%$ in any case.

The chloride concentrations are plotted versus the corresponding electrical conductivities in Figure 6-3. The plot provides a rough check that the values are reasonable.

Sulphate analysed by IC is plotted versus sulphate recalculated from total sulphur analysed by ICP technique in Figure 6-4. As shown, within the analytical error all sulphur is present as sulphate with some reservation for the samples with the highest concentrations. The results from ICP measurements are considered more reliable, by experience, since the variation in a time series often is smaller.

6.2 Isotope analysis

The isotope determinations include the stable isotopes δD , $\delta^{18}O$ and $^{10}B/^{11}B$ as well as the radioactive isotope 3H (Tritium). The isotope data are compiled in Appendix 2, Table A2-2.

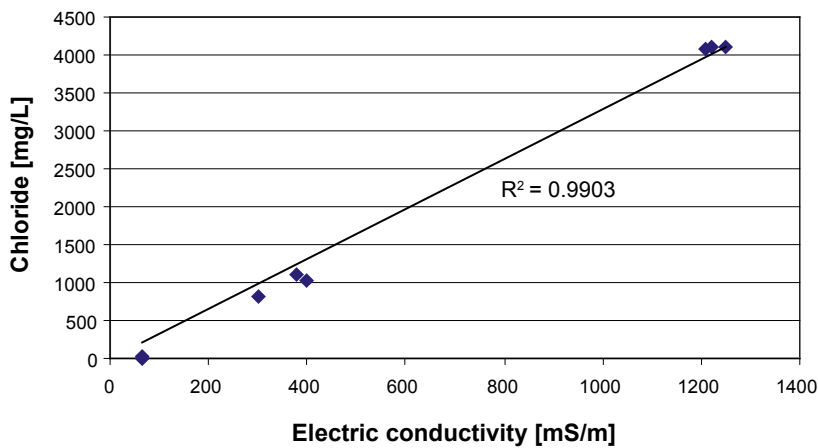


Figure 6-3. Electrical conductivity versus chloride concentration in boreholes HFM36, HFM37 and HFM38.

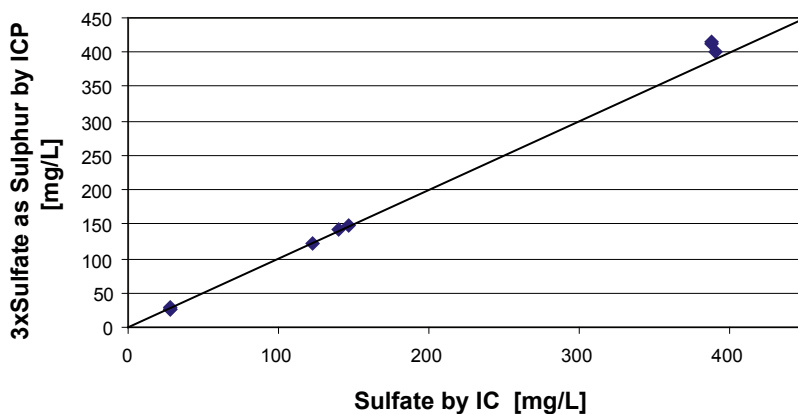


Figure 6-4. Sulphate (SO_4 by IC) versus sulphate calculated from total sulphur ($3 \times SO_4 - S$ by ICP) in boreholes HFM36, HFM37 and HFM38.

7 Summary and discussions

The sampling of groundwater from percussion drilled boreholes HFM36, HFM37 and HFM38 have been conducted in connection with hydraulic pumping tests performed in the boreholes during November 2006. The experimental results can be summarized as follows:

- The chloride concentration in borehole HFM36 shows a slight increase during the pumping period. The other boreholes demonstrate somewhat varying or stable chloride concentrations.
- It is recommended that the last sample in each series should be considered as the most representative for the groundwater in each borehole.
- The quality of the analytical data appears to be good. The relative charge balance error is below 5% for all collected samples and the checks by plotting show no obvious outliers.

References

- /1/ **SKB, 2001.** Site investigations. Investigation methods and general execution programme. SKB R-01-29. Svensk Kärnbränslehantering AB.
- /2/ **Claesson L-Å, Nilsson G, 2007.** Forsmark site investigation. Drilling of flushing water well, HFM36, and groundwater monitoring well in solid bedrock, HFM37, and ground water monitoring well in soil, SFM0109. SKB P-07-43, Svensk Kärnbränslehantering AB.
- /3/ **Claesson L-Å, Nilsson G, 2006.** Forsmark site investigation. Drilling of percussion boreholes HFM25–HFM27, HFM29–HFM32 and HFM38 for investigation of different lineaments and to be used as monitoring wells. SKB P-06-166, Svensk Kärnbränslehantering AB.
- /4/ **Walger E, Jönsson J, Ludvigson J-E, 2007.** Forsmark site investigation. Pumping tests and flow logging. Boreholes HFM36, HFM37 and HFM38. SKB P-07-22, Svensk Kärnbränslehantering AB.

Sampling and analytical methods

Table A1-1. Sample handling routines and analytical methods.

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

Component group	Component/element	Sample container (material)	Volume (mL)	Filtering	Preparation/Conservation*	Analysis method	Analysis within – or delivery time to lab.
Total organic Carbon	TOC	Plastic	250 25	No	Frozen, transported in isolated bag	UV oxidation, IR Carbon analysator Shimadzu TOC5000	Short transportation time
Environmental isotopes	$\delta^{2}\text{H}$, $\delta^{18}\text{O}$	Plastic	100	No	– –	MS	Not critical (month)
Tritium	^3H (enhanced.)	Plastic (dry bottle)	500	No	–	LSC	
Chlorine-37	^{37}Cl	Plastic	100	No	–	ICP MS	Not critical (month)
Carbon isotopes	^{13}C , pmC	Plastic (HDPE)	100×2	No	–	(A)MS	A few days
Sulphur isotopes	^{34}S	Plastic	500–1,000	No	–	Combustion, ICP MS	No limit
Strontium isotopes	$^{87}\text{Sr}/^{86}\text{Sr}$	Plastic	100	No	–	TIMS	Days or Week
Uranium and Thorium isotopes	^{234}U , ^{235}U , ^{238}U , ^{232}Th , ^{230}Th ,	Plastic	50 1,000	No	–	Chemical separat. Alfa/gamma spectrometry	No limit
Boron isotopes	$^{10}\text{B}/^{11}\text{B}$	Plastic	100	Yes	Yes (1 mL HNO_3)	ICP – MS	No limit
Radon and Radium isotopes	^{222}Rn , ^{226}Ra	Plastic	500–1,000	No	No	LSS	Immediate transport
Dissolved gas (content and composition)	Ar, N_2 , CO_2 , O_2 , CH_4 , H_2 , CO , C_2H_2 , C_2H_4 , C_2H_6 , C_3H_8	Cylinder of stainless steel	200	No	No	GC	Immediate transport
Colloids	Filter series	Polycarbonate filter	0.4, 0.2 and 0.05 μm	–	Ar atmosphere	ICP-AES ICP-MS	Immediate transport
Fractionation; Humic and fulvic acids, inorganic constituents	<1000 D >1000 D but <5000 D >5000 D	Fractions are collected in plastic bottles	250	–	N_2 atmosphere	UV oxidation, IR (DOC)	Immediate transport
Archive samples with acid	–	Plast (washed in acid)	100×2 **	Yes	Yes (1 mL HNO_3)	–	Storage in freeze container
Archive samples without acid	–	Plastic	250×2 **	Yes	No	–	Storage in freeze container
Carbon isotopes in humic and fulvic acids	^{13}C , ^{14}C (pmc)	DEAE cellulose (anion exchanger)	–	–	–	(A)MS	A few days
Nutrient salt + silicate	NO_2 , NO_3 , NO_2+NO_3 , NH_4 , PO_4 , SiO_4	Sample tubes, plastic	25×2 250	No	No, frozen immediately***	Spectrophotometry	Short transportation time

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

* Suprapur acid is used for conservation of samples.

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

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

Abbreviations and definitions:

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

Table A1-2. Reporting limits and measurement uncertainties.

Component	Method	Reporting limits or range	Unit	Measurement uncertainty ²	"Total" uncertainty ³
HCO ₃	Alkalinity titration	1	mg/L	4%	< 10%
Cl ⁻	Mohr-titration	> 70	mg/L	5%	< 10%
Cl ⁻	IC	1–100		6%	10%
SO ₄	IC	1	mg/L	10%	15%
Br ⁻	IC	0.2	mg/L	9%	20%
Br ⁻	ICP	0.001		15%	
F ⁻	IC	0.1	mg/L	10%	20%
F ⁻	Potentiometric	–		–	
I ⁻	ICP	0.001	mg/L	15%	20%
Na	ICP	0.1	mg/L	4%	10%
K	ICP	0.4	mg/L	6%	15%
Ca	ICP	0.1	mg/L	4%	10%
Mg	ICP	0.09	mg/L	4%	10%
S(tot)	ICP	0.160	mg/L	21%	15%
Si(tot)	ICP	0.03	mg/L	4%	15%
Sr	ICP	0.002	mg/L	4%	15%
Li	ICP	0.2 ¹ 2	mg/L	10%	20%
Fe	ICP	0.4 ¹ 4	mg/L	6%	10%
Mn	ICP	0.03 ¹ 0.1	µg/L	8%	10%
Fe(II), Fe(tot)	Spectrophotometry	0.02 (DL=0.005 mg/L)	mg/L	15% (> 30 µg/L)	20%
HS ⁻	Spectrophotometry	SKB 0.03 (DL=0.02)	mg/L	10%	30%
NO ₂ as N	Spectrophotometry	0.1	µg/L	2%	20%
NO ₃ as N	Spectrophotometry	0.2	µg/L	5%	20%
NO ₂ +NO ₃ as N	Spectrophotometry	0.2	µg/L	0.2 (0.2–20 µg/L) 2% (> 20 µg/L)	20%
NH ₄ as N	Spectrophotometry	0.8 50 (SKB)	µg/L	0.8 (0.8–20 µg/L) 5% (> 20 µg/L) 20%	20%
PO ₄ as P	Spectrophotometry	0.7	µg/L	0.7 (0.7–20 µg/L) 3% (> 20 µg/L)	20%
SiO ₄	Spectrophotometry	1	µg/L	3% (> 200 µg/L)	–
O ₂	Iodometric titration	0.2–20	mg/L	5%	–
Chlorophyll a, c pheopigment ⁴	See Table A1-2	0.5	µg/L	5%	–
PON ⁴	See Table A1-2	0.5	µg/L	5%	–
POP ⁴	See Table A1-2	0.1	µg/L	5%	–
POC ⁴	See Table A1-2	1	µg/L	4%	–
Tot-N ⁴	See Table A1-2	10	µg/L	4%	–
Tot-P ⁴	See Table A1-2	0.5	µg/L	6%	–
Al, Zn	ICP	0.2	µg/L	12%	20% ⁵
Ba, Cr, Mo, Pb	ICP	0.01	µg/L	7–10%	20% ⁵
Cd, Hg	ICP	0.002	µg/L	9 resp 5%	20% ⁵
Co, V	ICP	0.005	µg/L	8 resp 5%	20% ⁵
Cu	ICP	0.1	µg/L	8%	20% ⁵
Ni	ICP	0.05	µg/L	8%	20% ⁵
P	ICP	1	µg/L	6%	10%
As	ICP	0.01	µg/L	20%	Correct order of size (low conc.)

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

- Reporting limits at salinity ≤ 0.4‰ (520 mS/m) and ≤ 3.5‰ (3,810 mS/m) respectively.
- Measurement uncertainty reported by consulted laboratory, generally 95% confidence interval.
- Estimated total uncertainty by experience (includes effects of sampling and sample handling).
- Determined only in surface waters and near surface groundwater.
- Per mille deviation¹³ from SMOW (Standard Mean Oceanic Water).
- TU=Tritium Units, where one TU corresponds to a Tritium/hydrogen ratio of 10⁻¹⁸ (1 Bq/L Tritium = 8.45 TU).
- Per mille deviation¹³ from SMOC (Standard Mean Oceanic Chloride).
- Per mille deviation¹³ from PDB (the standard PeeDee Belemnite).
- The following relation is valid between pmC (percent modern carbon) and Carbon-14 age:

$$\text{pmC} = 100 \times e^{((1.950-y-1.03t)/8.274)}$$
where y = the year of the C-14 measurement and t = C-14 age.
- Per mille deviation¹³ from CDT (the standard Canyon Diablo Troilite).
- Isotope ratio without unit.
- The following expressions are applicable to convert activity to concentration, for uranium-238 and thorium-232: 1 ppm U = 12.4 Bq ppm Th = 3.93 Bq/kg²³²Th.
- Isotopes are often reported as per mill deviation from a standard. The deviation is calculated as:

$$\delta\text{‰} = 1,000 \times (K_{\text{sample}} - K_{\text{standard}}) / K_{\text{standard}}$$
where K= the isotope ratio and ‰ =²H, ¹⁸O, ³⁷Cl, ¹³C or ³⁴S etc.

Compilation of water analysis data

Table A2-1. Water Composition.

Idcode	Secup m	Seclow m	Sample no.	Sampling date and time	RCB %	Na mg/L	K mg/L	Ca mg/L	Mg mg/L	HCO ₃ ⁻ mg/L	Cl ⁻ mg/L	SO ₄ ²⁻ mg/L	SO ₄ _S mg/L	Br mg/l	F ⁻ mg/L	Si mg/L	Li mg/L	Sr mg/L	pH	TOC mg/L	EiCond mS/m
HFM36	0	152.55	12548	2006-11-23 09:09	-2.1	318	4.63	266	31.2	336	816	122	40.5	3.4	0.59	7.73	0.016	2.97	7.45	2.7	300
HFM36	0	152.55	12549	2006-11-23 12:54	-1.1	396	4.63	314	38.2	301	1,030	140	47.4	4.13	0.67	7.88	0.019	4.05	7.54	2.4	400
HFM36	0	152.55	12550	2006-11-23 18:08	-0.1	430	4.88	343	40.5	303	1,110	146	49	5.96	0.81	7.98	0.018	4.54	7.55	2.6	380
HFM37	0	191.75	12545	2006-11-21 09:50	-2	107	5.27	26.7	6.6	360	14.3	28.1	9.36	< 0.2	1.02	7.69	< 0.004	0.22	7.85	3.1	63.7
HFM37	0	191.75	12546	2006-11-21 13:55	-2.9	107	5.03	24.6	6.1	362	12.6	28.2	9.1	< 0.2	1.06	7.55	< 0.004	0.21	7.87	2.9	63.4
HFM37	0	191.75	12547	2006-11-21 18:47	-2.7	108	5.11	25.9	6.4	368	13.1	27.9	9.08	0.07	1.03	7.54	< 0.004	0.22	7.82	2.9	64.1
HFM38	0	200.75	12533	2006-11-14 10:43	-1.6	1,780	52.2	589	186	163	4,110	387	138	15.3	1.01	6.26	0.052	3.30	7.29	2.5	1,250
HFM38	0	200.75	12534	2006-11-14 14:35	-3.3	1,710	51.4	568	180	163	4,100	390	134	15.2	1.06	6.19	0.050	3.24	7.27	2.6	1,220
HFM38	0	200.75	12535	2006-11-14 19:25	-3.4	1,720	50.6	560	176	167	4,090	387	137	14.2	1.04	6.33	0.049	3.16	7.26	2.6	1,210

Compilation April 2007

< "value" = below reporting limit

RCB % = Rel. charge balance error %

SICADA: water_composition

Table A2-2. Isotopes I (H-, O- and B-isotopes).

Idcode	Secup m	Seclow m	Sample no	Sampling date	δ ² H dev SMOW	³ H TU	δ ¹⁸ O dev SMOW	¹⁰ B/ ¹¹ B no unit
HFM36	0	152.55	12550	2006-11-23	-88.5	2.3	-12.4	0.2394
HFM37	0	191.75	12547	2006-11-21	-83.7	8.1	-12.3	0.2398
HFM38	0	200.75	12535	2006-11-14	-69.1	1.9	-9.1	0.2353

Compilation April 2007

SICADA: isotopes_1