P-04-245

Forsmark site investigation

Drilling of two flushing water wells, HFM21 and HFM22, one groundwater monitoring well in solid bedrock, HFM20, and one groundwater monitoring well in soil, SFM0076

Lars-Åke Claesson, Mirab Mineral Resurser AB

Göran Nilsson, GNC AB

September 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-04-245

Forsmark site investigation

Drilling of two flushing water wells, HFM21 and HFM22, one groundwater monitoring well in solid bedrock, HFM20, and one groundwater monitoring well in soil, SFM0076

Lars-Åke Claesson, Mirab Mineral Resurser AB
Göran Nilsson, GNC AB

September 2004

Keywords: AP PF 400-04-54, Percussion drilling, Monitoring well, Soil, Campus, DS7, DS8.

Abstract

The main purpose of drilling the percussion boreholes HFM21 and HFM22 was to achieve flushing water for the core drillings at drill sites DS7 respectively DS8. A secondary objective was to investigate the geological and hydraulic character of the penetrated rock volumes with special emphasis on characterization of two N-S trending lineaments, which may possibly represent deformation zones at depth. Furthermore, the borehole was also intended to investigate the possible occurrence of shallow, flat-lying, water-bearing structures, which had earlier been observed at several drill sites at Forsmark.

Due to that high water inflows and a favourable water quality were achieved, the boreholes HFM21 and HFM22 later served as flushing water wells for the deep core drilling at DS7 and DS8 respectively. After completed drilling, the boreholes will be incorporated in the long-term groundwater monitoring programme.

The primary objective of drilling HFM20, which like the above mentioned boreholes is percussion drilled in solid bedrock, was to enable field checks of possible hydraulic connections in the shallow part of the bedrock (0 to c 300 m) in the north-western part of the investigation area. This can be achieved by monitoring groundwater levels during drilling at drill sites DS7 and DS8 and by performance of more controlled hydraulic interference tests between HFM20 and the boreholes drilled at DS7 and DS8 after drilling. Besides, the borehole offers an opportunity for geologic characterization as well as provides a new observation point for long-term monitoring

Borehole HFM20, which was drilled during the period May18th to June 1st, 2004, is 301.00 m long, inclined 85 degrees from the horizontal plane and has a diameter of c140 mm. A fracture at 23 m yielded 200 L/min at the drawdown achieved during drilling.

Borehole HFM21, drilled during June 2nd to 7th, 2004, and borehole HFM22, drilled between September 7th and 13th, 2004, are 202.00 m respectively 222.00 m long, are inclined 58 respectively 59 degrees from the horizontal plane and were both drilled with the diameter c140 mm. In HFM21 a fracture at 27 m yielded 30 L/min and another fracture at 162 m 60 L/min. Borehole HFM22 is characterized by a fracture zone at 62 m with an initial groundwater discharge of 10 L/min. During continued drilling, this zone was reactivated and a final outflow from the borehole of 200 L/min was measured at the maximum possible drawdown accomplished during percussion drilling.

Also a percussion drilled borehole in soil, SFM0076, was drilled at DS7 for monitoring the groundwater level and for groundwater sampling. The borehole, which was drilled on June 16th, 2004, is vertical and 2.70 m deep.

Sammanfattning

Huvudsyftet med hammarborrhålen HFM21 och HFM22 var att uppbringa spolvatten i tillräcklig mängd av god kvalitet till kärnborrningen på borrplatserna, BP7 respektive BP8 (DS7 och DS8 på engelska). Dessutom var avsikten att karaktärisera de genomborrade bergvolymerna i geologiskt och hydrauliskt avseende, med speciell inriktning på att undersöka två N-S-ligt strykande lineament, vilka skulle kunna representera deformationszoner. Slutligen var också avsikten med borrhålen att undersöka den eventuella förekomsten av ytliga, flackt stupande och hydrauliskt högkonduktiva strukturer av den typ som tidigare påträffats vid flera av borrplatserna i Forsmark.

Eftersom både HFM21 och HFM22 visade sig ha hög vattenkapacitet och gynnsam vattenkvalitet, valdes dessa borrhål senare till spolvattenbrunnar för borrningen av de djupa kärnborrhålen på borrplatserna BP7 respektive BP8. Efter avslutad borrning kommer de två hammarborrhålen att inkorporeras i programmet för hydraulisk och hydrokemisk långtidsmonitering. Borrhålet utnyttjas också för geologisk karaktärisering av det genomborrade partiet samt kommer i ett senare skede att ingå i moniteringsprogrammet för grundvattenobservationer.

Det primära syftet med HFM20, som liksom ovannämnda borrhål är en bergbrunn, var att kontrollera utsträckningen och karaktären av eventuella subhorisontella hydrauliska strukturer i berggrundens övre partier (ner till maximalt ca 300 m) i denna del av undersökningsområdet. Detta kan göras dels genom monitering av grundvattennivåer under borrning vid borrplatserna BP7 och BP8, dels genom att efter avslutad borrning utföra mer kontrollerade interferenstester mellan HFM20 och borrhålen vid BP7 och BP8. Borrhål HFM20 ger även möjligheter till geologisk karaktärisering av genomborrad bergvolym och planeras att senare ingå i programmet för långtidsmonitering av grundvattennivåer och grundvattenkemi.

HFM20, som borrades under perioden 18:e maj till 1:a juni 2004, är 301,00 m långt och ansatt ca 85 ° mot horisontalplanet. Diametern är ca 140 mm. En vattenförande spricka vid 23 m gav 200 L/min vid den avsänkning som rådde under hammarborrningen.

Borrhål HFM21, som borrades under perioden 2:a till 7:e juni, 2004, är 202,00 m långt och ansattes ca 58 ° mot horisontalplanet. Diametern är ca 140 mm. En vattenförande spricka vid 27 m gav 30 L/min och en annan spricka vid 162 m gav 60 L/min. Borrhål HFM22, borrades under perioden 7:e till 13:e september, 2004, är 222,00 m långt och ansattes ca 59 ° mot horisontalplanet. Diametern är ca 140 mm. En sprickzon vid 62 m gav initialt ett flöde om ca10 L/min. Under borrning och blåsning ökade sedan flödet till 200 L/min vid den maximala avsänkning som kunde åstadkommas vid hammarborrningen.

Även ett jordborrhål, SFM0076, borrades på borrplats BP7 för monitering av grundvattennivån i jordlagren och för grundvattenprovtagning. Hålet borrades den 16:e juni 2004, är vertikalt och 2,70 m djupt.

Contents

1 Introduction

SKB performs site investigations to locate a deep repository for high level radioactive waste /1/. The investigations are performed in two Swedish municipalities: Östhammar and Oskarshamn. The investigation area in Östhammar is situated close to the nuclear power plant at Forsmark /2/, see Figure 1-1.

Drilling is one important activity performed within the scope of the site investigations rendering geoscientific characterization of the bedrock down to and beyond repository depth possible. Three main types of boreholes are produced: core drilled boreholes, percussion drilled boreholes in bedrock, and boreholes drilled through unconsolidated soil. The initial phase of the investigations includes drilling of three, c 1,000 m deep boreholes within the candidate area, at drill sites DS1, DS2 and DS3, see Figure 1-1. These boreholes were succeeded by a fourth 1,000 m borehole, starting at drill site DS4 outside the candidate area, and a fifth borehole at DS5 in the north-central part of the candidate area. Both are inclined boreholes. A sixth 1,000 m borehole, KFM06A, has recently been finished at drill site DS6, and one 1,000 m-borehole is planned to be drilled on each of drill sites DS7 and DS8 and drilling has just recently been started. The location of all eight drill sites are presented in Figure 1-1.

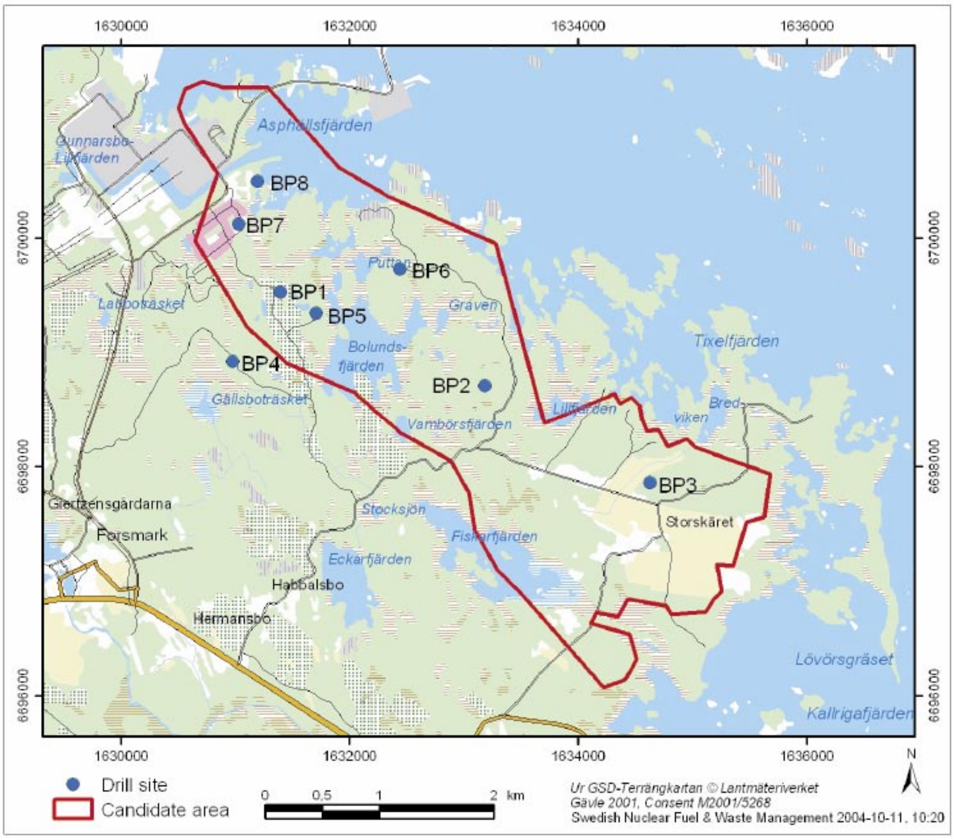


Figure 1-1. *The investigation area at Forsmark including the candidate area selected for more detailed investigations. Drill sites DS1–8 are marked with blue dots.*

Besides the core drilled boreholes, percussion drilled boreholes in bedrock, and boreholes drilled through unconsolidated soil are performed at most drill sites. This document reports the results gained by percussion drilling of HFM20, HFM21 and HFM22 as well as of SFM0076. Performance of and results from the drilling operations as well as from investigations made during and immediately after drilling are presented.

The percussion borehole in bedrock HFM20 was drilled about 300 m WNW of drill site DS7, whereas one percussion borehole in bedrock, HFM21, as well as one borehole through unconsolidated soil, SFM0076, were drilled at drill site DS7. Finally, the percussion borehole in bedrock HFM22 was drilled at drill site DS8. Figure 1-1 above displays the locations of the drill sites, whereas Figure 1-2 is a detailed map illustrating the positions of the respective percussion drilled boreholes presented in this report. Besides the positions of the collarings, the projections of those boreholes that are inclined (all except SFM0076) on the horizontal plane at the ground level (top of casing) are shown.

Drilling of HFM20, HFM21, HFM22 and SFM0076 is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance with activity plan AP PF 400-04-54. Controlling documents for performing this activity are listed in Table 1-1. Both the activity plan and method descriptions, which are SKB's internal controlling documents, refer to method instructions and to measurement systems descriptions not included in the table below.

Figure 1-2. *Borehole locations at and nearby drill sites DS7 (HFM21 and SFM0076) and DS8 (HFM22). Borehole HFM20 is situated about 300 m WNW of drill site DS7. The projections of inclined boreholes (all but SFM0076) on the horizontal plane at approximately the ground level (top of casing) are shown.*

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

Activity plan	Number	Version
Hammarborrning av borrhål HFM20–HFM22 samt jordborrhål SFM0076	AP PF 400-04-54	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hammarborrning	SKB MD 610.003	2.0
Metodbeskrivning för undersökning av borrkax vid hammarborrning.	SKB MD 142.001	1.0
Metodbeskrivning för genomförande av hydrauliska enhålspumptester.	SKB MD 321.003	1.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål.	SKB MD 224.001	1.0
Metodbeskrivning för jordborrning	SKB MD 630.003	1.0

The drilling operations were performed during the periods May 18th to June 7th, 2004, and Sept 7th to Sept 13th, 2004, by Sven Andersson in Uppsala AB, with support from SKB-personnel regarding measurements and tests during drilling. A Comacchio 1500 S percussion drilling machine operated by a two-man drill crew was engaged for the commission.

References to Field Note numbers in the SKB database SICADA are given in Table 1-2.

Table 1-2. Data references.

Subactivity	Database	Identity number
Borrning, provtagning och mätning av HFM20	SICADA	Field note 323
Borrning, provtagning och mätning av HFM21	SICADA	Field note 324
Borrning, utsättning mm SFM0076	SICADA	Field note 373
Borrning, utsättning mm HFM22	SICADA	Field note 375

2 Objective and scope

When drilling many of the deep cored boreholes at the SKB site investigations, a so called telescopic drilling technique is applied. This implies that the upper 100 m of the borehole are percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section 100–1,000 m is core drilled with a diameter of approximately 76–77 mm. Core drilling consumes relatively large amounts of flushing water, which is conducted through the drill string and drill bit for the double purpose of cooling the drill bit and for transportation of drill cuttings from the borehole bottom to the ground surface. The quality demands of the flushing water are high at the SKB site investigations. Groundwater from a water well drilled in the bedrock close to the cored borehole being drilled is preferred. The percussion boreholes HFM21 and HFM22 were drilled with the primary aim of serving as flushing water wells when drilling the telescopic boreholes KFM07A and KFM08A at drill sites DS7 respectively DS8.

During drilling, an air-lift pump is installed in the upper, large-diameter part of the telescopic borehole in order to enhance the recovery of flushing water and drill cuttings. During the entire core drilling period (comprising about three months when drilling a 1,000 m borehole) the air-lift pumping and, to a lesser extent, the injection of flushing water, affects the groundwater levels and, possibly, the groundwater-chemical composition near the deep borehole. To enable observation of groundwater level fluctuations in the bedrock and soil aquifers due to the deep drilling operations, monitoring wells are normally drilled prior to commencement of telescopic boreholes. These wells may also be used for groundwater sampling.

Boreholes HFM20 and SFM0076 were drilled in order to monitor the impact of drilling at drill sites DS7 and DS8. Borehole HFM20 will also be used for performance of more controlled hydraulic interference tests between HFM20 and the boreholes drilled at DS7 and DS8 after drilling in order to investigate the extent and character of possible hydraulic connections in the shallow part of the bedrock (0 to c 300 m) in the north-western part of the investigation area.

After completed drilling, the majority of the boreholes drilled at the site investigation are incorporated in a long-term groundwater level and hydrochemical monitoring programme. All boreholes presented in this report are planned to be included in this category.

Besides serving as flushing water wells and/or monitoring wells, all percussion drilled boreholes are used for lithological, structural and hydraulic characterization of the penetrated soil and rock volumes. These multiple objectives apply also for the boreholes described in this report. Regarding HFM21 and HFM22, a specific objective was to study two N-S trending lineaments, which may possibly represent deformation zones at depth.

All three boreholes HFM20–22 are of so called SKB chemical type, implying that they are prioritized for hydrogeochemical and bacteriological investigations. A practical consequence of this is that all DTH (Down The Hole)- equipment used during and/or after drilling must undergo severe cleaning procedures, see Section 4.1.

The soil borehole SFM0076 was drilled primarily for environmental control (of groundwater levels in the soil layer and of groundwater quality) during the drilling activities at DS7.

One criterion for detailed siting of the monitoring wells HFM20–22 and SFM0076 was to locate them within the expected radius of influence of groundwater-level drawdown due to air-lift pumping during drilling of KFM07A and KFM08A.

Monitoring during the percussion and core drilling of KFM07A and KFM08A is primarily part of the environmental control programme for these drilling operations. Data acquired later, during long-term monitoring of undisturbed conditions, will be part of the characterization of the groundwater conditions of the soil layer and the shallow part of the bedrock.

3 Equipment

Drilling was carried out with a Comacchio 1500 S percussion drilling machine (Figure 3-1) supplied with various accessory equipment. In this chapter short descriptions are given of the drilling equipment, the technique and equipment for gap injection of the borehole casing and of the instrumentation used for deviation measurements performed after completion of drilling. Also the equipment used for measurements and sampling during drilling is briefly described.

Figure 3-1. *The Comacchio 1500 S percussion drilling machine in action on borehole HFM21 at DS7.*

3.1 Drilling equipment

The drilling machine is equipped with separate engines for transportation and power supplies. Water and drill cuttings were discharged from the borehole by an Atlas-Copco XRVS 466 Md 27 bars diesel compressor. The DTH drill hammer was of type Secoroc 8", operated by a Driconeq 76 mm pipe string. All DTH-equipment was cleaned with a Kärcher HDS 1195 high-capacity steam cleaner.

3.2 Gap injection technique and equipment

In order to prevent surface water and shallow groundwater to infiltrate into deeper parts of the borehole, the normal procedure is to grout the gap between the borehole wall and the casing pipe with cement. The cement application may be performed by different technical approaches and with different equipment. Two variants are illustrated in Figure 3-2.

In all boreholes discussed in this report, grouting was performed by applying the borehole packer technique.

3.3 Equipment for deviation measurements

Deviation measurements in HFM20, HFM21 and HFM22 were performed with a Reflex EZ-shot (magnetic) equipment. Azimuth and dip were measured every third metre. The coordinates for the collaring point and the measured values from the EZ-shot instrument were used for calculating the coordinates for each of the measured points along the borehole.

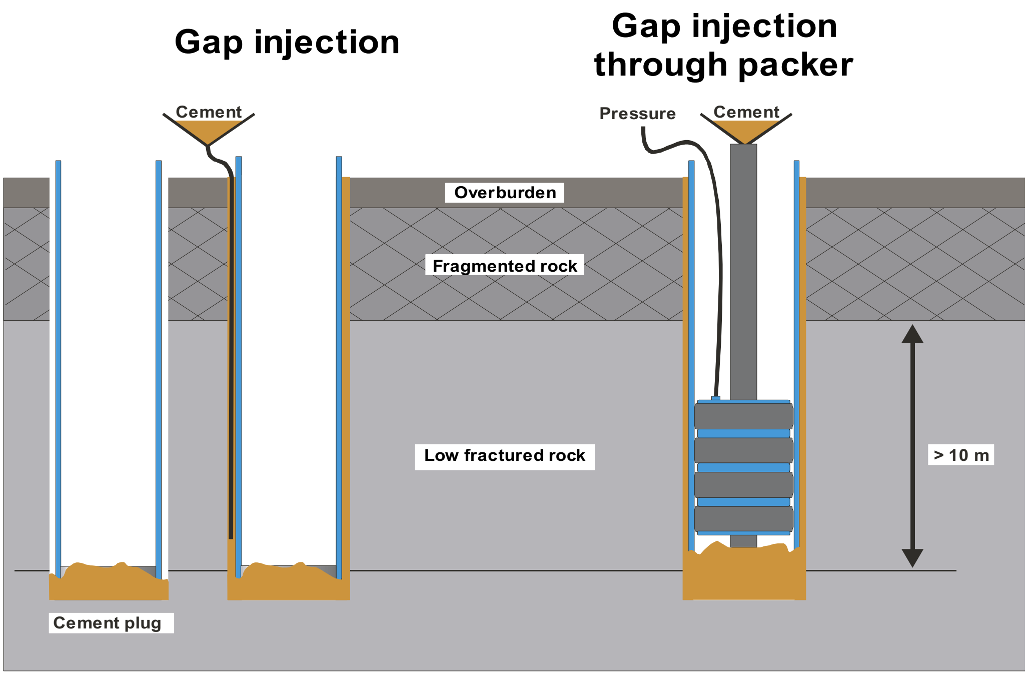


Figure 3-2. Gap injection technique. In order to grout the gap between the borehole wall and the casing pipe, different techniques may be applied. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer.

3.4 Equipment for measurements and sampling during drilling

The drilling machine was equipped with a new computerized logger system, D-MON (Figure 3-3), manufactured by ENVI Ltd, for measurements while drilling (MWD). The system measures the following parameters:

- Borehole length (m).
- Time (hh, mm, ss).
- Penetration presented in the units (m/min) and (sec/20 cm).
- Feed force (kN).
- Torque (MPa).
- Compressor air pressure (MPa).
- Discharged flow from the borehole (L/min).

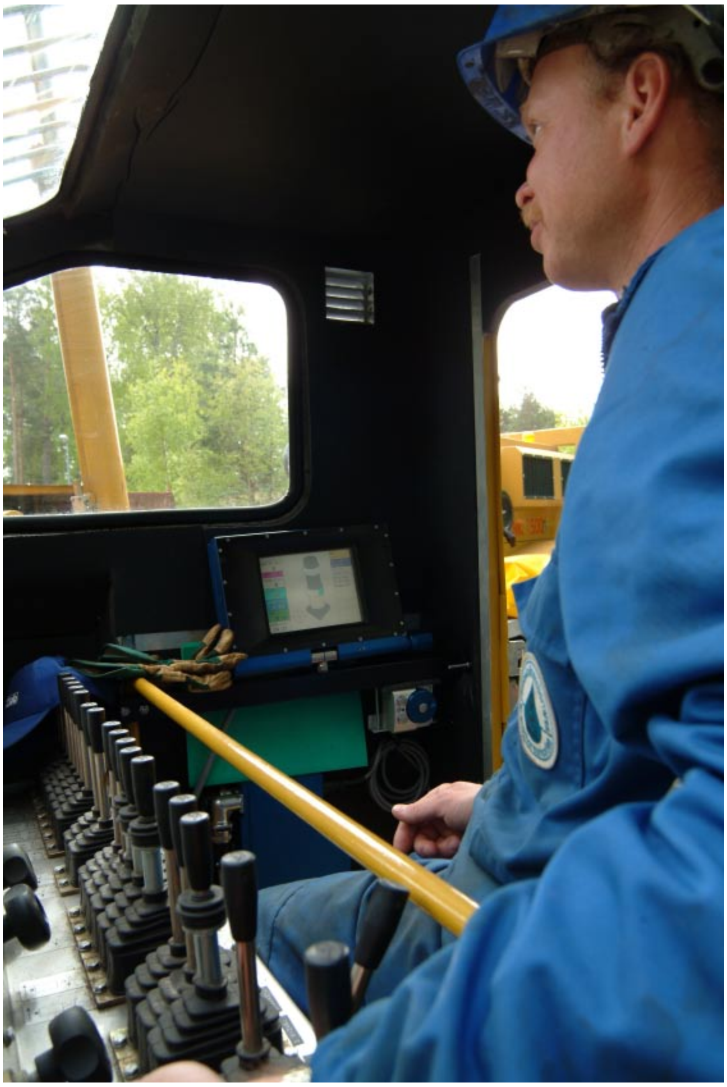


Figure 3-3. *A D-MON logger system for measurements while drilling is mounted close to the control panel within the pilot house of the drilling machine.*

To be able to make some controls of the results obtained by the computerized MWD system, flow measurements during drilling were conducted using measuring vessels of different sizes and a stop watch. Manual measurements of drilling penetration rate were accomplished with a carpenter´s rule and a stop watch (Figure 3-4). A field measuring devise, Kemotron 802, was used for measurements of electrical conductivity of the groundwater.

Since the MWD-system was new and not sufficiently tested during hard field conditions, only results from the manually aquired data are presented in this report. After evaluation of the MWD results, i.a. by comparing with manual data, and of the system function, a decision will be made whether to include the system in the standard routines for parameter measurements or not.

A common phenomenon within the Forsmark candidate area is the occurrence of sub-horizontal or gently dipping, highly water conductive single fractures or fracture zones in the shallow upper part of the bedrock. As the percussion drilled boreholes normally penetrate these zones, usually very high groundwater inflows are received. The large water yield in combination with the groundwater flow being highly volant due to in-mixing of high pressure compressor air when discharging from the borehole, makes sampling and measurements of groundwater and drill cuttings suspended in the water difficult. Therefore, a new container with a specially designed cyclone was developed to be in use during the sampling of soil, drill cuttings and groundwater and was tested during drilling of HFM20–22 (Figure 3-5).

Figure 3-4. *Manual measurements of drilling penetration rate were performed with a carpenter´s rule and a stop watch in order to check the results provided by the automatic MWD-system.*

Figure 3-5. *To improve flow measurements and simplify sampling of soil, drill cuttings and groundwater, a new container with a specially designed cyclone was used during drilling of HFM20–22.*

4 Execution

4.1 General

The Method Description for Percussion Drilling, SKB MD 610.003, Version 2.0 includes the following items:

- preparations,
- mobilization, including lining up the machine and measuring the position,
- drilling, measurements, and sampling during drilling,
- finishing off work,
- deviation measurements,
- data handling,
- environmental control.

The performance according to the above items is presented in Sections 4.2–4.7. Section 4.8, finally, describes nonconformities to plan.

4.2 Preparations

The preparation stage included the Contractor's service and function control of his equipment. The machinery was obliged to be supplied with fuel, oil and grease exclusively of the types stated in SKB MD 600.006, Version 1.0 (Method Instruction for Chemical Products and Materials). Finally, part of the equipment was cleaned in accordance with SKB MD 600.004, Version 1.0 (Method Instruction for Cleaning Borehole Equipment and certain Ground-based Equipment) at level two, used for SKB boreholes of chemical type (the remaining part of the equipment was cleaned on-site). The Method Instructions are SKB internal controlling documents.

For the borehole in soil, SFM0076, the well screen and riser pipes of HDPE-material (High Density PolyEthylene) were delivered in tight-fitting packages. Before delivery to the drill site, the pipes etc had been treated by acid leaching, followed by washing with deionized water, see procedure in /3/, Section 4.1. At the drill site, the screen and pipes were further prepared by steam-cleaning.

4.3 Mobilization

Mobilization onto and at the site started with transport of drilling and accessory equipment to the drill site. The mobilization also comprised preparation of the drill site, on-site cleaning of all DTH-equipment at level two according to SKB MD 600.004, lining up the machine and final function control.

4.4 Execution of field work for HFM20–22

4.4.1 Drilling through the overburden

For drilling through the overburden and nine metres into solid bedrock, so called TUBEX technique (an ODEX-variant) was applied (Figure 4-1). TUBEX is a system for simultaneous drilling and casing driving. The method is based on a pilot bit and an eccentric reamer, which produces a borehole slightly larger than the external diameter of the casing. This enables the casing tube to follow the drill bit down the hole. In the Ejector-TUBEX system (like in the Ejector-NO-X-system) the design of the discharge channels for the flushing medium, in this case compressed air, is such that the oxygen and oil contamination of the penetrated soil layers is reduced, compared to conventional systems.

4.4.2 Gap injection

When the casing string had been firmly installed in boreholes HFM20–22, the narrow gap between the borehole wall and the outer wall of the casing was grouted with a cement/ water-mixture according to the borehole packer technique illustrated in Figure 3-2.

4.4.3 Percussion drilling in solid rock

After the casing was set, drilling could continue and was now performed to the full borehole length according to conventional percussion drilling technique. Before start of drilling, the diameter of the drill bit was measured.

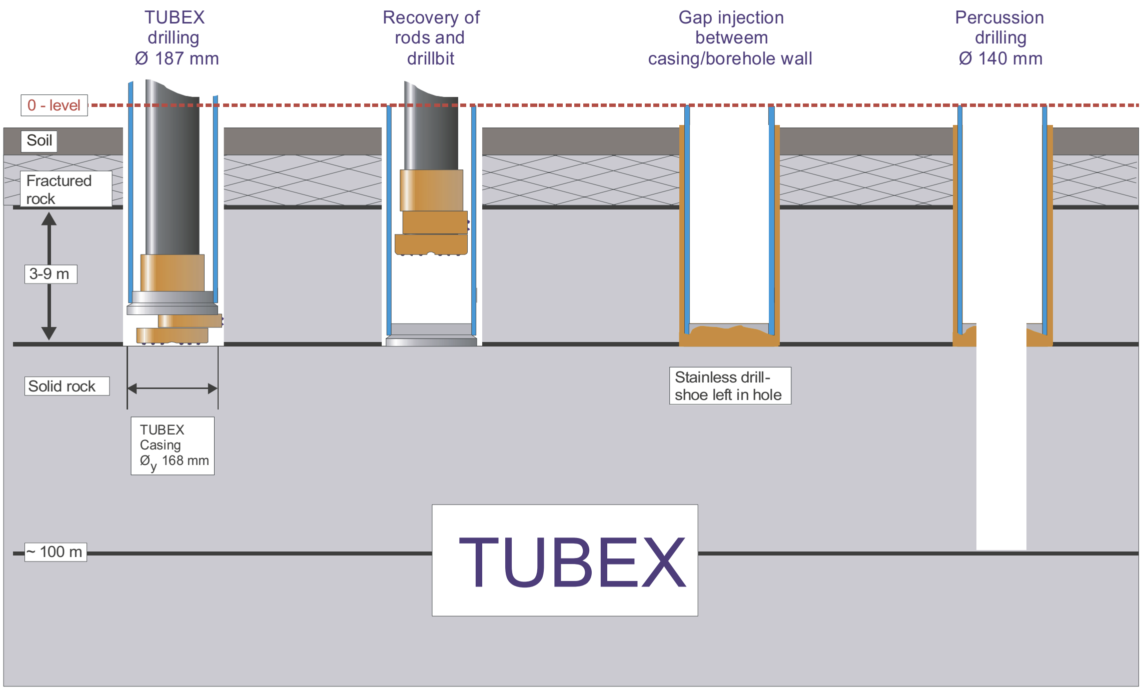


Figure 4-1. The different steps included in the performance of the percussion drilled boreholes HFM20–22.

4.4.4 Sampling and measurements during drilling

During drilling, a sampling and measurement programme was performed, which included:

- Collecting one soil sample per metre drilling length. Analysis and results from HFM20 and HFM21 are reported in /4/ and from HFM22 it will be reported later on.
- Collecting one sample per 3 m drilling length of drill cuttings from the bedrock (Figure 4-2). Each sample consists of three individual samples collected at every metre borehole length, stored in a plastic box marked with a sample number. As far as possible, mixing of the three individual samples was avoided. A first description of the material was made on-site, including the mineral content and rock structure, which provided a preliminary classification of the rock type. These samples will later be examined more thoroughly and interpreted together with a BIPS-log (so called Boremap-mapping) /5/.

Figure 4-2. *Samples of soil and drill cuttings were collected in plastic boxes and groundwater in small bottles.*

- Measurements of the penetration rate (one measurement per 20 cm drilling length). The time needed for the drill bit to sink 20 cm was recorded manually in a paper record. As mentioned in Section 3.4, the results from the MWD-system are regarded merely as test results for evaluation of the function and reliability of the MWD system, and are not presented in this report, nor exported to SICADA.
- Performing one observation of groundwater flow (if any) and water colour per 20 cm drilling length and a measurement of the flow rate at each major flow change observed. The measured values were noted in a paper record. Regarding the MWD flow rate parameter, see the previous item.
- Measurements of the electrical conductivity (EC) of the groundwater (if any) at every 3 m drilling length (noted in a paper record).
- Deviation measurements after completion of drilling.

The results from the third and fourth items were used as supporting data for the Boremap-mapping mentioned above. The fifth item gave on-site information about hydraulic and hydrogeochemical characteristics of the penetrated aquifer.

4.4.5 Finishing off work

Finishing off work included rinsing of the borehole from drill cuttings by a "blow out" with the compressor at maximum capacity during 30 minutes. The recovery of the groundwater table after rinsing was recorded, enabling a preliminary evaluation of hydraulic parameters. The drill pipes were then retrieved from the hole, and the diameter of the drill bit was measured. A deviation survey of the borehole completed the measurement programme during and immediately after drilling. The borehole was secured by a stainless steel lockable cap, mounted on the casing. Finally, the equipment was removed, the site cleaned and a joint inspection made by representatives from SKB and the Contractor, to ensure that the site had been satisfactorily restored.

4.5 Performance of soil borehole SFM0076

4.5.1 Drilling and sampling during drilling

Drilling through the overburden was performed using a variant of the TUBEX-system, called Ejector-TUBEX, see Section 4.4.1. During drilling, a temporary steel casing with the dimension 193.7 mm external and 165 mm internal diameter was simultaneously driven through the soil. When solid rock was indicated, drilling was continued almost one metre further, to ensure that the bedrock surface had been reached and not only compact till or a large boulder.

During drilling, a sampling and measurement programme was carried out, which included:

- One soil sample per metre. Analysis and results will be reported later on.
- One sample of drill cuttings from the bedrock. Rock samples collected during drilling of monitoring wells in soil will be examined more thoroughly and interpreted together with drill cuttings from the bedrock sampled during drilling of HFM20–22) /5/.

- One observation of groundwater flow (if any) and water colour per 20 cm and a measurement of the flow rate at each major flow change observed. Regarding the MWD flow rate parameter, see Section 4.4.4.
- Measurement of the electrical conductivity (EC) of the sampled groundwater (if any) at each 3 m.

The results from the last two items, preserved as field records, were used exclusively for the on-site decision of the design of the well screen and filter installation in the borehole.

4.5.2 Installation of well screen and screen filter

At completion of drilling, the temporary casing was driven approximately one metre into the bedrock. The results observed during drilling regarding soil depth and type, groundwater inflow etc were analysed on-site, and a decision was made about the design of the borehole installation. The well screen and screen filter were then assembled and the assembling documented. The installation was performed according to the design illustrated in Chapter 5.

The first part of the installation was to fill up a suitable amount of filter sand in the borehole, in order to cover the bedrock. The screen, connected to the riser pipes, was then descended in the borehole all the way down to the sand bed, where it was centralized in the borehole. During simultaneous lifting of the steel casing, the space between the plastic pipe and the inner casing wall was filled up with filter sand. In order to prevent surface water to infiltrate along the borehole, a bentonite sealing was installed at an appropriate level in the borehole. In the actual monitoring well, dry bentonite pellets were used. However, also a bentonite slurry may be suitable for this purpose.

4.5.3 Finishing off work

After installation of the screen, sand filter and sealing, the temporary casing was retrieved and the monitoring well secured with a stainless steel protective casing, which was driven a short distance into the ground around the upper part of the HDPE riser pipe. The casing was then moulded firmly to the ground. Supplied with a lockable stainless steel cover, this construction offers an effective protection against damage of the monitoring well.

Finally, the drilling machine was removed, the site cleaned, and a joint inspection of the drill site made by SKB and the Contractor.

4.6 Data handling/post processing

Minutes with the following headlines: Activities, Cleaning of equipment, Drilling, Borehole, Percussion drilling penetration rate, Deliverance of field material and Discrepancy report were collected by the Activity Leader, who made a control of the information, and had it stored in the SKB database SICADA.

4.7 Environmental control

A programme according to SKB´s routine for environmental control was complied with throughout the activity. A checklist was filled in and signed by the Activity Leader and was finally filed in the SKB archive.

4.8 Nonconformities

The activity was performed according the Activity Plan without nonconformities.

5 Results

All data were stored in the SICADA database for Forsmark under field note nos 323 (HFM20), 324 (HFM21), 373 (SFM0076), respectively 375 (HFM22).

Below, a summary of the data acquired is presented.

5.1 Design of the percussion drilled boreholes

5.1.1 Percussion drilled boreholes HFM20, HFM21 and HFM22

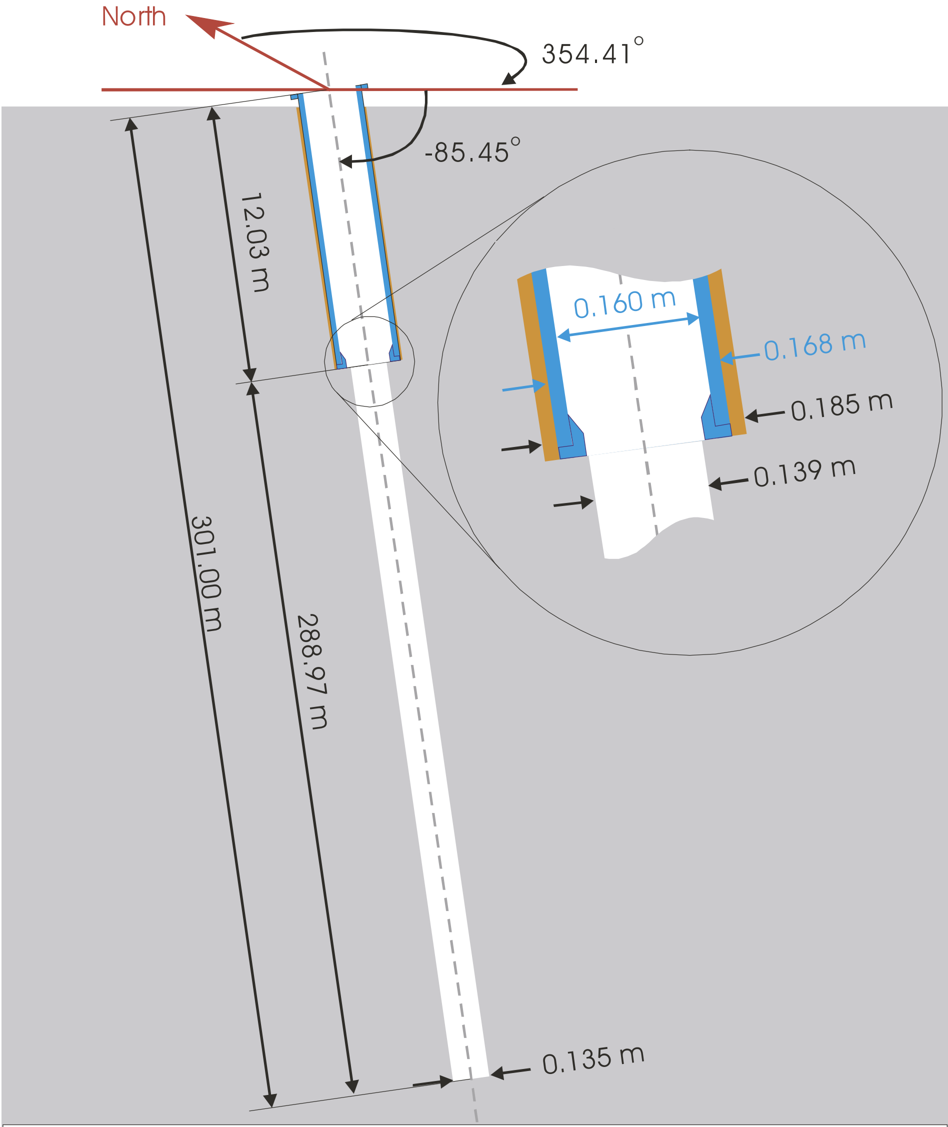
Administrative, geometric, and technical data for the percussion drilled boreholes HFM20–22 are presented in Table 5-1. The technical design of each borehole is illustrated in Figures 5-1, 5-2 and 5-3.

Table 5-1. Administrative, geometric and technical data for boreholes HFM20–22.

Parameter	HFM20	HFM21	HFM22
Drilling period	From 2004-05-18 to 2004-06-01	From 2004-06-02 to 2004-06-07	From 2004-09-06 to 2004-09-13
Borehole inclination (collaring point)	–85.45° (– = downwards)	–58.48° (– = downwards)	–58.85° (– = downwards)
Borehole bearing	354.41°	88.81°	90.08°
Borehole length	301.00 m	202.00 m	222.00 m
Borehole diameter	From 0.00 m to 12.03 m: 0.185 m	From 0.00 m to 12.03 m: 0.185 m	From 0.00 m to 12.03 m: 0.180 m
	From 12.03 m to 112.70 m: 0.139 m	From 12.03 m to 148.00 m: 0.139 m	From 12.03 m to 222.00 m: 0.136 m
	From 112.70 m to 250.00 m: 0.138 m	From 148.00 m to 202.00 m: 0.137 m	
	From 250.00 m to 301.00 m: 0.135 m		
Casing length	12.03 m	12.03 m	12.03 m
Casing diameter	$Ø_o/Ø_i$ = 168 mm/160 mm to 11.94 m	$Ø_o/Ø_i$ = 168 mm/160 mm to 11.94 m	$Ø_o/Ø_i$ = 168 mm/160 mm to 11.94 m
	$Ø_o/Ø_i$ = 168 mm/147 mm between 11.94 and 12.03 m	$Ø_o/Ø_i$ = 168 mm/147 mm between 11.94 and 12.03 m	$Ø_o/Ø_i$ = 168 mm/147 mm between 11.94 and 12.03 m
Drill bit diameter	Start of drilling: 0.139 m End of drilling: 0.135 m	Start of drilling: 0.139 m End of drilling: 0.137 m	Start of drilling: 0.140 m End of drilling: 0.136 m
Collaring point coordinates (system RT90 2.5 gon V/ RHB70)	Northing: 6700187.50 m Easting: 1630776.68 m Elevation: 2.97 m a s l	Northing: 6700125.57 m Easting: 1631074.05 m Elevation: 3.98 m a s l	Northing: 6700456.18 m Easting: 1631217.64 m Elevation: 1.54 m a s l

Technical data

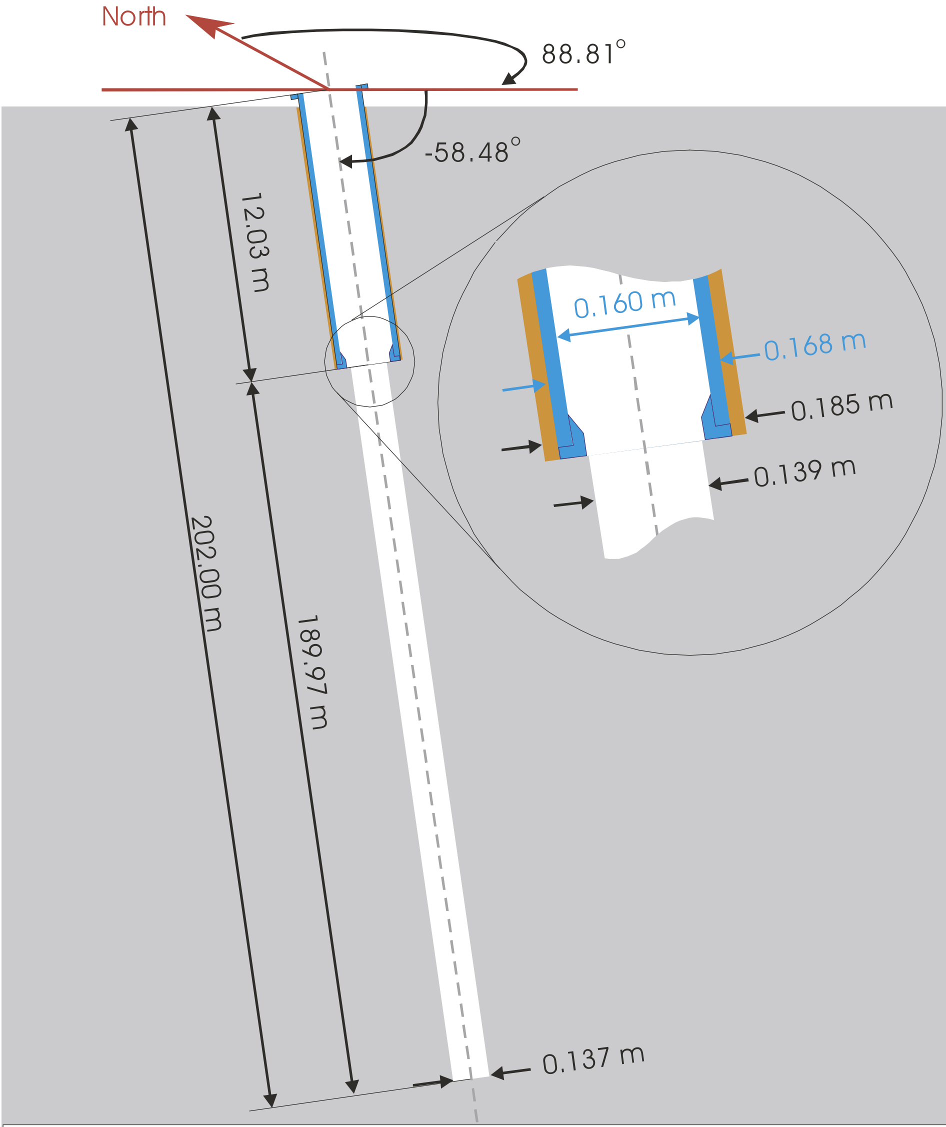
Borehole HFM20



Drilling reference point	
Northing:	6700187,50 (m), RT90 2,5 gon V 0:-15
Easting:	1630776,68 (m), RT90 2,5 gon V 0:-15
Elevation:	2,97 (m.a.s.l.), RHB 70
Drilling period	
Drilling start date:	2004-05-18
Drilling stop date:	2004-06-01

Figure 5-1. *Technical data for borehole HFM20.*

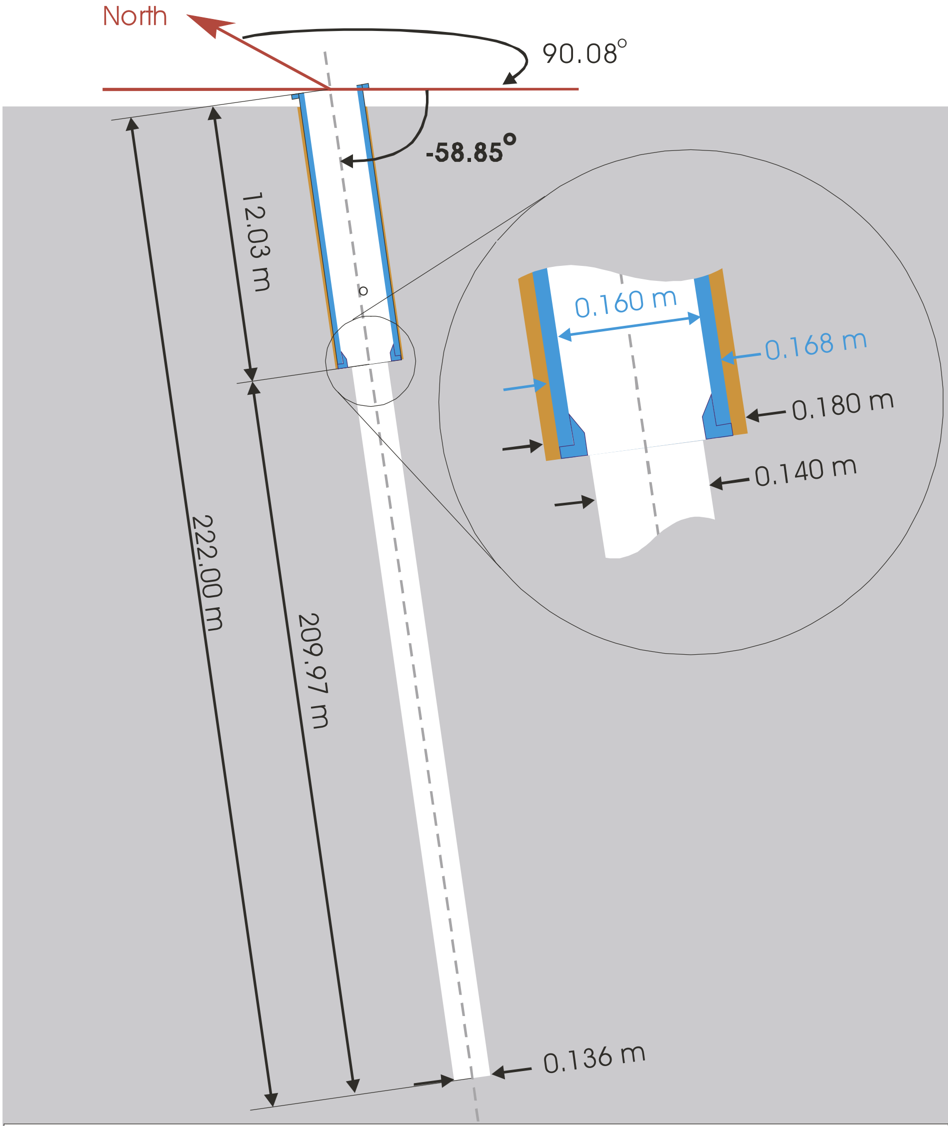
Technical data
Borehole HFM21



Drilling reference point		
Northing:	6700125,57	(m), RT90 2,5 gon V 0:-15
Easting:	1631074,05	(m), RT90 2,5 gon V 0:-15
Elevation:	3,98	(m.a.s.l.), RHB 70
Drilling period		
Drilling start date:	2004-06-02	
Drilling stop date:	2004-06-07	

Figure 5-2. *Technical data for borehole HFM21.*

Technical data
Borehole HFM22



Drilling reference point		
Northing:	6700456,18	(m)RT90 2,5 gon V 0:-15
Easting:	1631217,64	(m)RT90 2,5 gon V 0:-15
Elevation:	1,54	(m.a.s.l.), RHB 70
Drilling period		
Drilling start date:	2004-09-06	
Drilling stop date:	2004-09-13	

Figure 5-3. *Technical data for borehole HFM22.*

5.1.2 Soil borehole SFM0076

The design of the groundwater monitoring well SFM0076 is illustrated in Figure 5-4. Table 5-3 displays the geometric characteristics of the well.

Table 5-3. Geometric data for groundwater monitoring well SFM0076.

Drillhole ID	Inclina-tion	Northing	Easting	Elevation m a s l (top of HDPE-pipe)	Total depth from ground level (m)	Screen length (m)	Screen pipe length including a well screen (m)	Screen pipe diameter ($Ø_o/Ø_i$, mm)
SFM0076	90°	6700111.91	1631085.08	3.82	2.70	1.00	3.16	90/72

5.2 Consumables in HFM20, HFM21 and HFM22

The amount of oil products consumed in each borehole during drilling, and grout used for gap injection of the respective casings is reported in Tables 5-4 and 5-5. The cement was of a low alkalic type, consisting of microsilica (920-D) and white cement (Aalborg Portland CEM I, 52.5N).

Regarding contamination risks, albeit some amounts of hammer oil and compressor oil reach the borehole, they are, on the other hand, continuously retrieved due to the permanent air flushing during drilling. After completion of drilling, only minor residues of the products remain in the borehole.

Table 5-4. Oil consumption.

Borehole ID	Hammer oil Preem Hydra 46
HFM20	8 L
HFM21	4 L
HFM22	15 L

Table 5-5. Consumption of cement grout.

Borehole ID	Casing length	Cement volume (Aalborg Portland Cement/microsilica)	Grouting method
HFM20	12.03 m	80 L/72 kg	Packer technique
HFM21	12.03m	80 L/72kg	Packer technique
HFM22	12.03m	80 L/72 kg	Packer technique

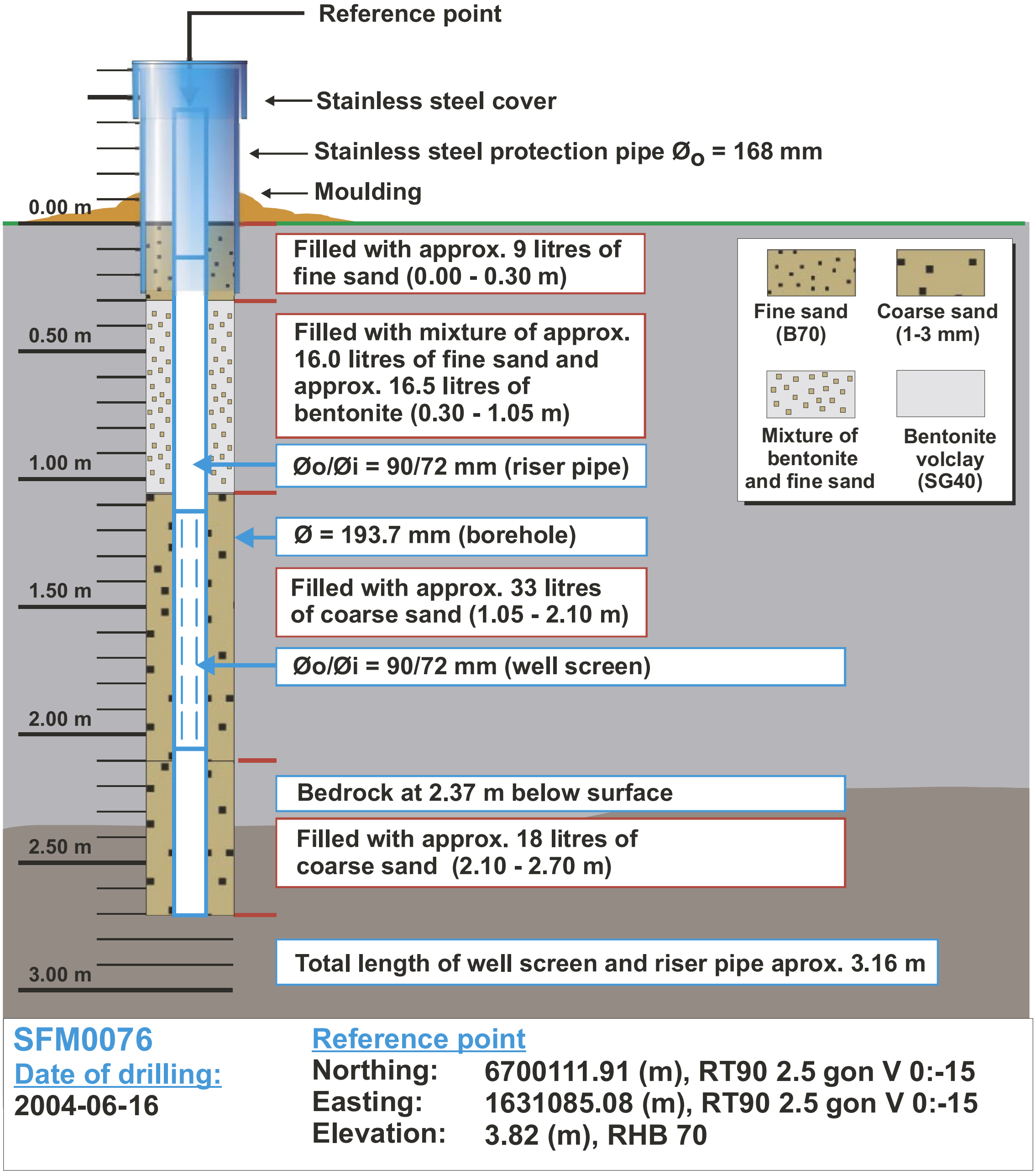


Figure 5-4. *The groundwater monitoring well installation in borehole SFM0076.*

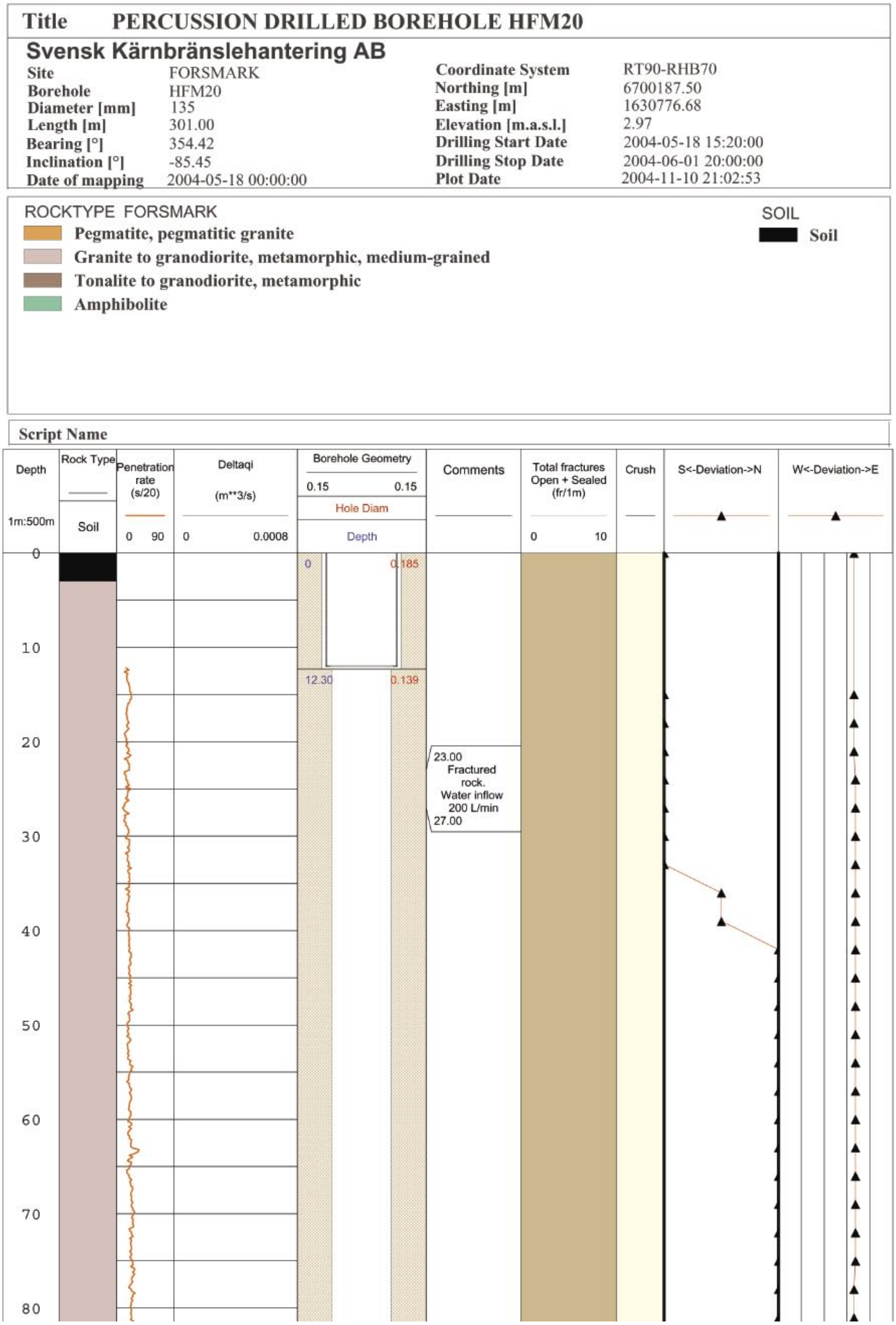
5.3 Well Cad presentations

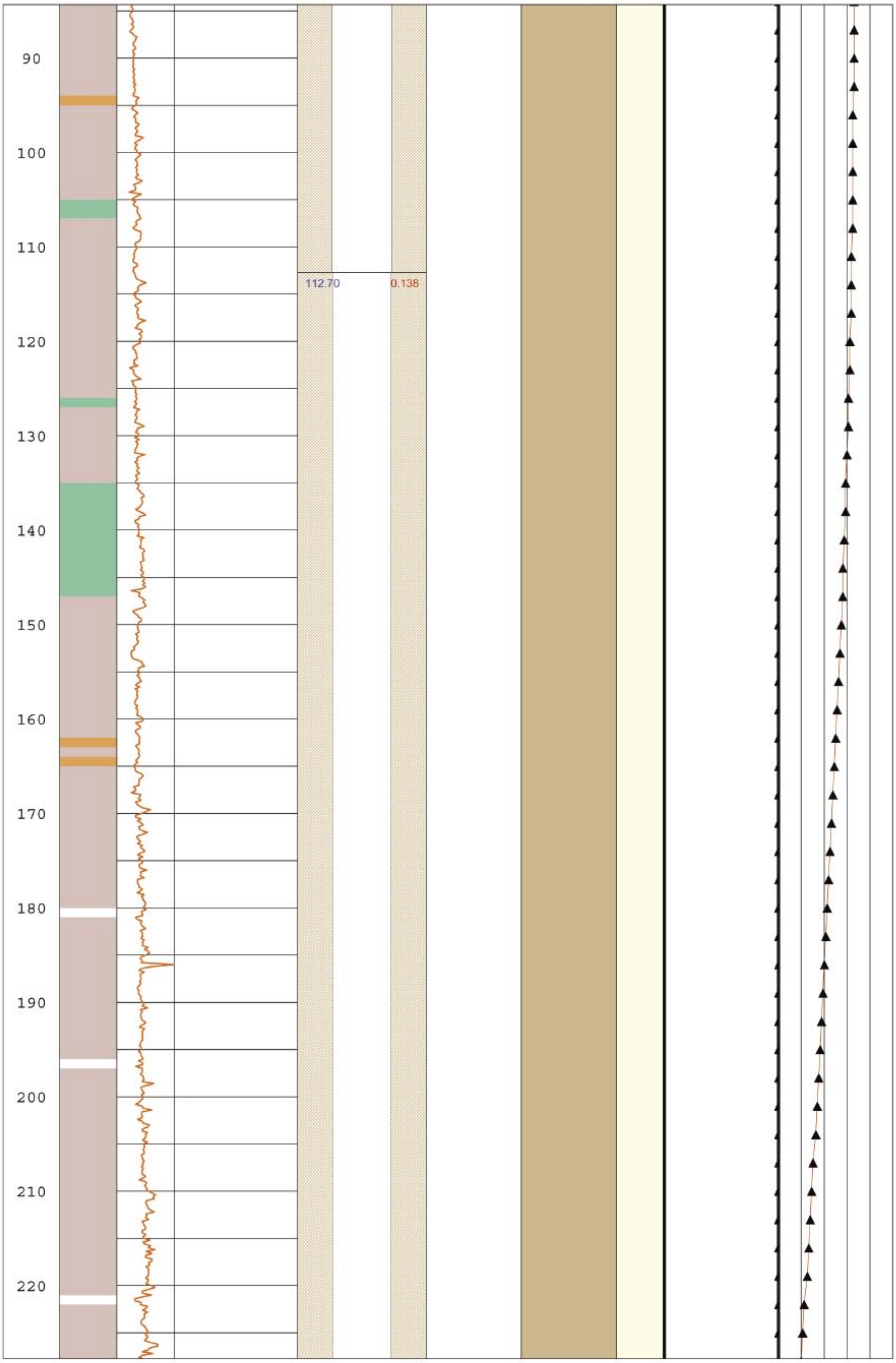
Technical as well as geoscientific results achieved during drilling are presented in the so called Well Cad plots in Figures 5-5, 5-6 and 5-7.

The deviation measurements made in boreholes HFM20, HFM21 and HFM22 (Figures 5-5, 5-6 and 5-7) indicate a moderate deviation of HFM20 but considerably large deviations of HFM21 and HFM22.

The deviation of HFM20 can more or less be described as a corkscrew shape around an imagined straight line. The end (bottom) point of HFM20 deviates approximately 0.5 m downwards and 23 m to the south compared to an imagined straight line following the dip and strike of the borehole collaring point (inclination –85.45° and bearing 354.41°).

The corresponding values for borehole HFM21 are 15 m upwards and 48 m to the right, compared to a straight line with the inclination –58.48° and bearing 88.81°. Finally, borehole HFM22 deviates approximately 33 m upwards and 52 m to the right compared to a straight line with the dip and strike –58.85° respectively bearing 90.08°.




90
100
110
120
130
140
150
160
170
180
190
200
210
220
112.70
0.138

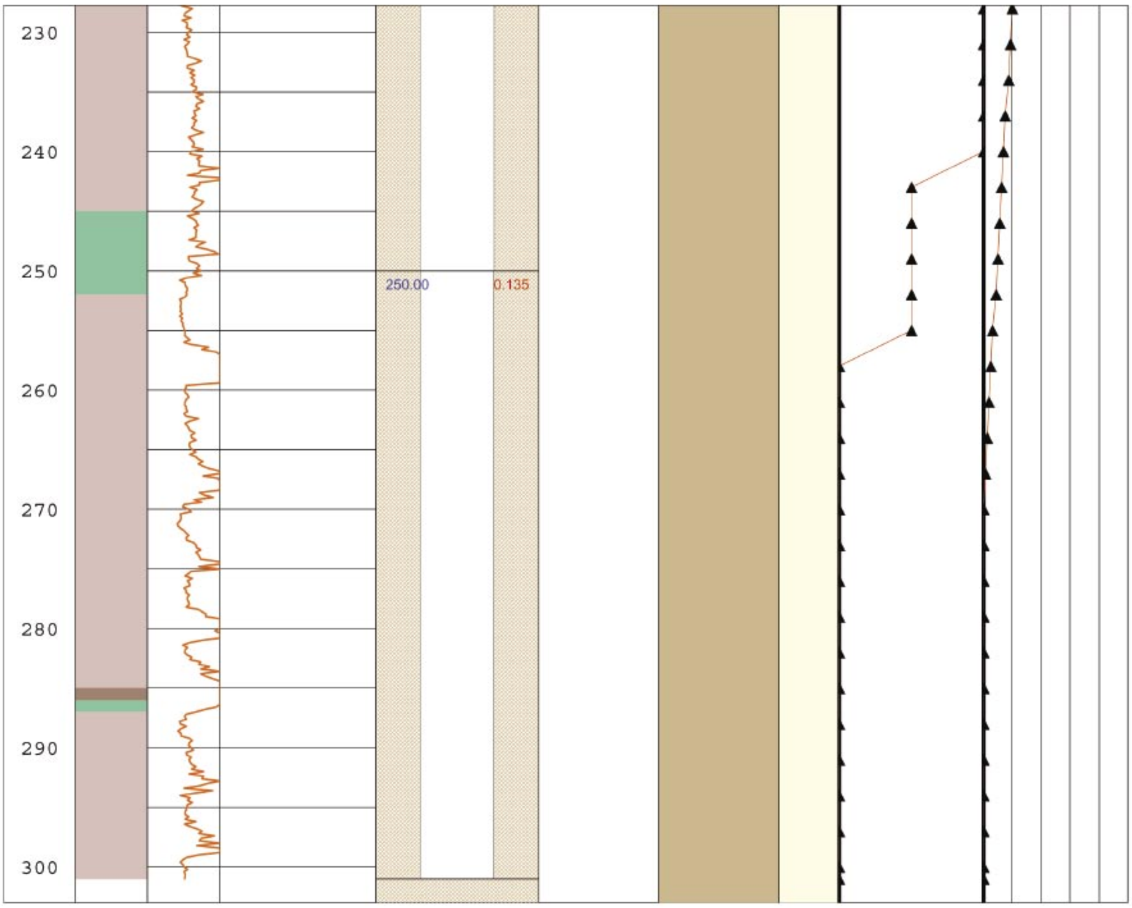


Figure 5-5. *Results achieved from drilling of borehole HFM20.*

Title **PERCUSSION DRILLED BOREHOLE HFM21**

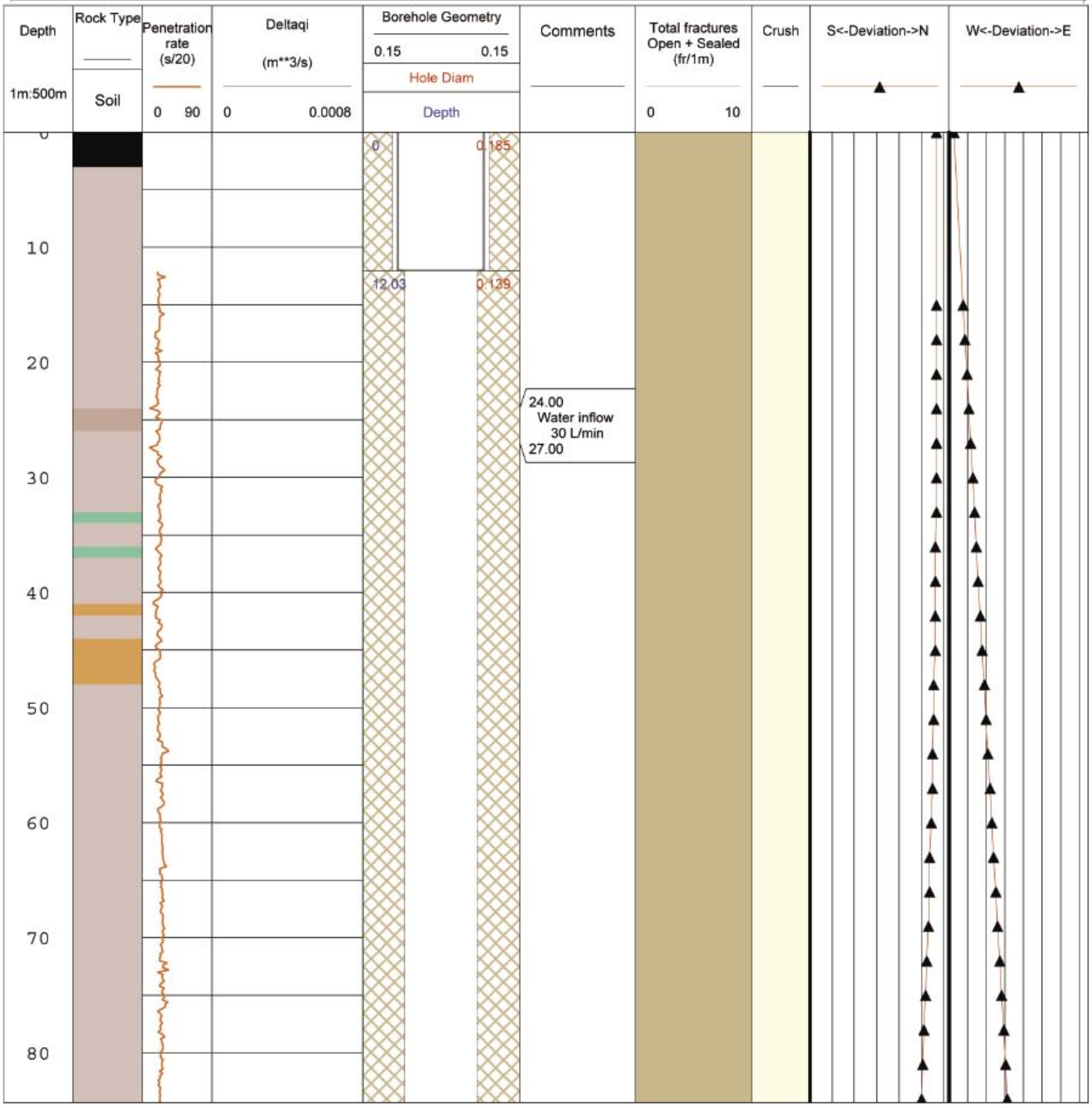
Svensk Kärnbränslehantering AB

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM21	**Northing [m]**	6700125.57
Diameter [mm]	137	**Easting [m]**	1631074.05
Length [m]	202.00	**Elevation [m.a.s.l.]**	3.98
Bearing [°]	88.81	**Drilling Start Date**	2004-06-02 09:00:00
Inclination [°]	-58.48	**Drilling Stop Date**	2004-06-07 11:40:00
Date of mapping	2004-06-02 00:00:00	**Plot Date**	2004-11-08 21:02:47

ROCKTYPE FORSMARK
- **Pegmatite, pegmatitic granite**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Granodiorite, metamorphic**
- **Amphibolite**

SOIL
- **Soil**

Script Name



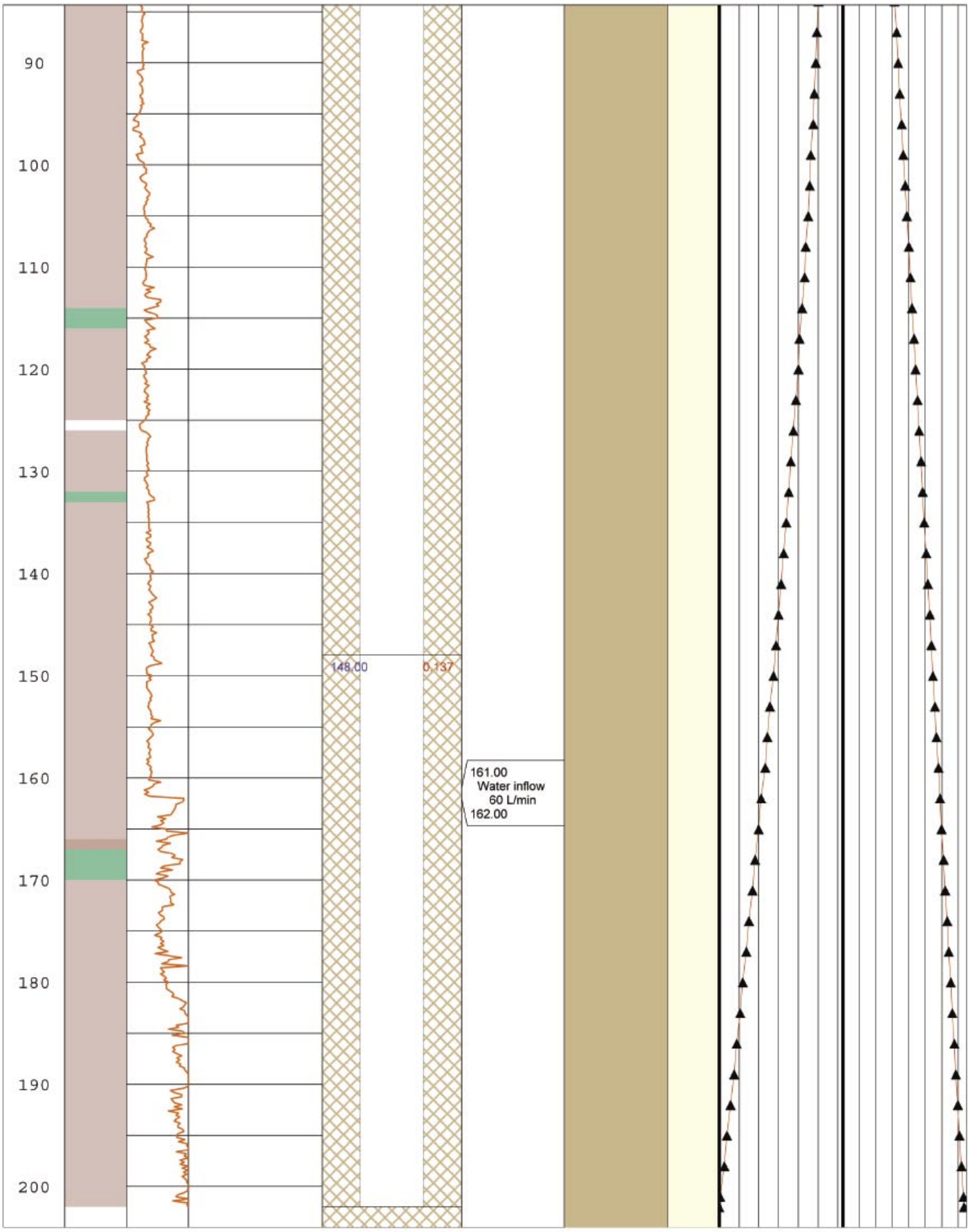


Figure 5-6. *Results achieved from drilling of borehole HFM21.*

Title	PERCUSSION DRILLED BOREHOLE HFM22

Svensk Kärnbränslehantering AB

Site	FORSMARK	**Coordinate System**	RT90-RHB70
Borehole	HFM22	**Northing [m]**	6700456.18
Diameter [mm]	136	**Easting [m]**	1631217.64
Length [m]	222.000	**Elevation [m.a.s.l.]**	1.54
Bearing [°]	90.08	**Drilling Start Date**	2004-09-06 12:00:00
Inclination [°]	-58.85	**Drilling Stop Date**	2004-09-13 10:17:00
Date of mapping	2004-09-07 00:00:00	**Plot Date**	2004-11-08 21:02:47

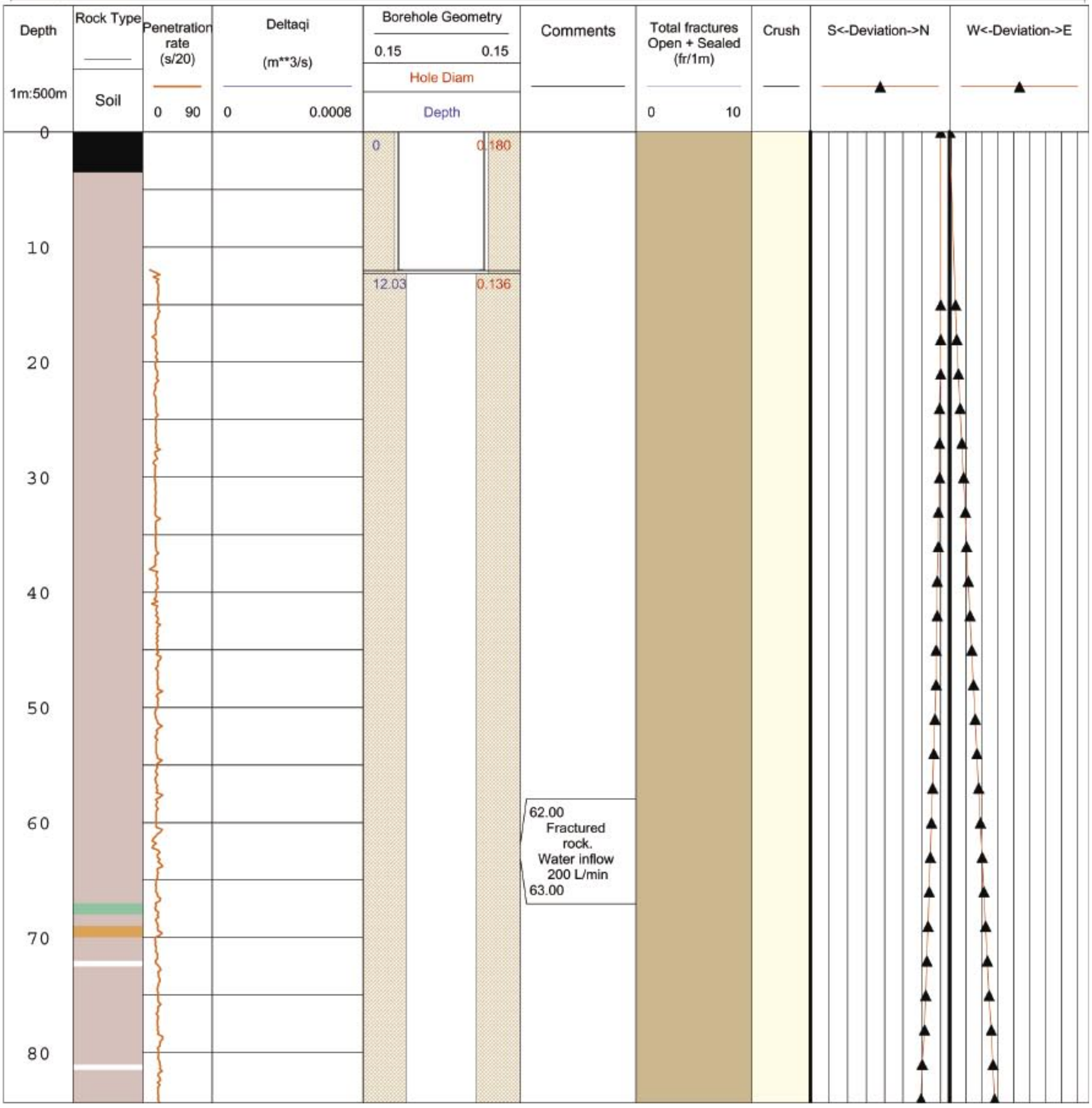
ROCKTYPE FORSMARK

- **Pegmatite, pegmatitic granite**
- **Granite to granodiorite, metamorphic, medium-grained**
- **Amphibolite**

SOIL

- **Soil**

Script Name



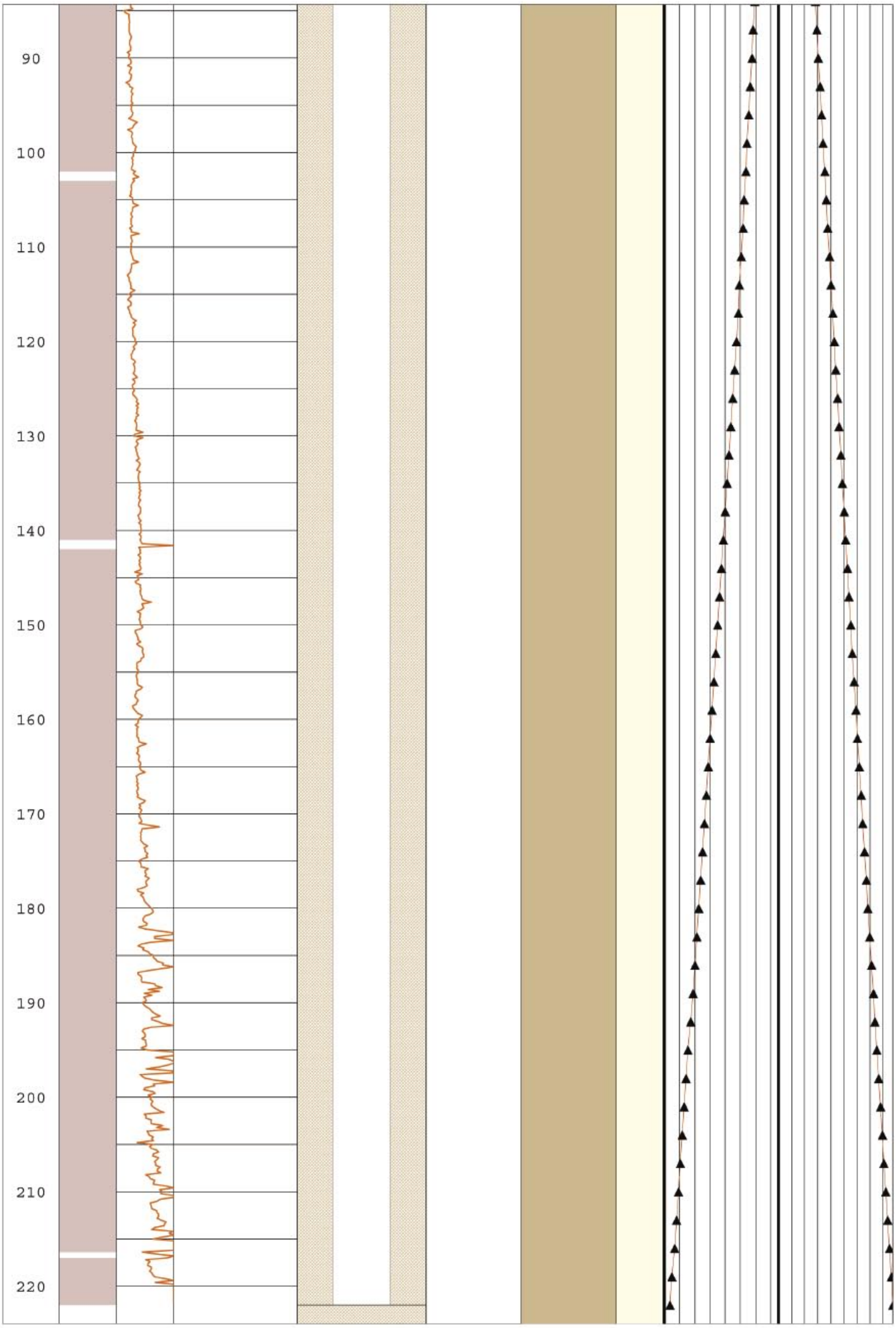


***Figure 5-7.** Results achieved from drilling of borehole HFM22.*

5.4 Hydrogeology

5.4.1 Observations during drilling

In borehole HFM20 (Figure 5-8), the first water yield (140 L/min) at 23 m borehole length corresponded to an EC-value of 70 mS/m, which remained constant down to 100 m, although there was a stepwisely increased inflow to 100 m. From that depth, the accumulated water inflow was quite constant at c 200 L/min until the end of drilling. During drilling stops at 118 m, 197 m and 250 m, groundwater recharged into the borehole and flushed out at drilling re-start the morning after, which reflects the stepwise changes of the EC-value from c 180 m and downwards. The results indicate shallow groundwater conditions (large water yield and moderate salinity).

Electrical conductivity together with accumulated groundwater inflow versus drilling length in HFM21 is presented in Figure 5-9. The first inflow encountered (25 L/min) was observed at 27 m and displayed an EC-value of 360 mS/m, indicating shallow groundwater. When the EC-value had increased to 750 mS/m at 150 m, the accumulated inflow was 30 L/min. The major inflow of 60 L/min was observed at 162 m and showed an EC-value of 1,300–1,400 mS/m. The results indicate semi-deep groundwater conditions from 162 m to the full borehole length (a relatively large water yield and increased salinity).

No measurable inflow of groundwater was observed in the upper part of borehole HFM22 (Figure 5-10), although the drilling debris was clammy with damp. When reaching the water-yielding fracture at 62 m, the first EC-value encountered was 1,200 mS/m. Even if the water inflow seems characterized by a stepwise increase, it is not in full accordance with the diagram of the EC-measurements. Anyway, the EC-values indicate semi-deep water conditions. During drilling stops at 141 m and 218 m, groundwater recharged into the borehole and flushed out at drilling re-start the morning after, entailing that the inflow at 141 m instantaneously increased to 180 L/min, whereas the EC-value remained constant at 1,100 mS/m. Finally, when flushing the borehole at 222 m an inflow of 200 L/min was measured.

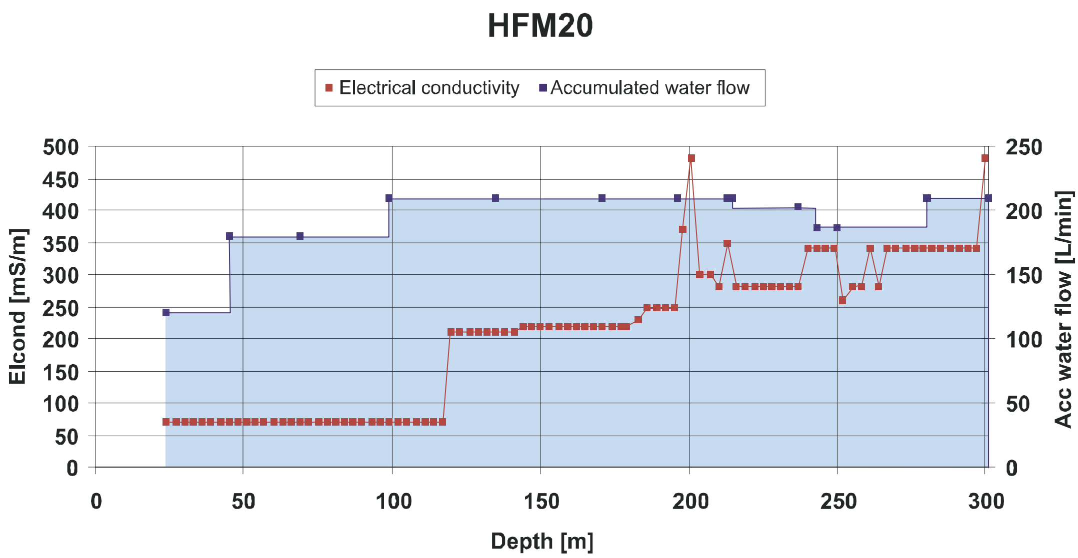


Figure 5-8. *Electrical conductivity and accumulated groundwater inflow versus drilling length in HFM20.*

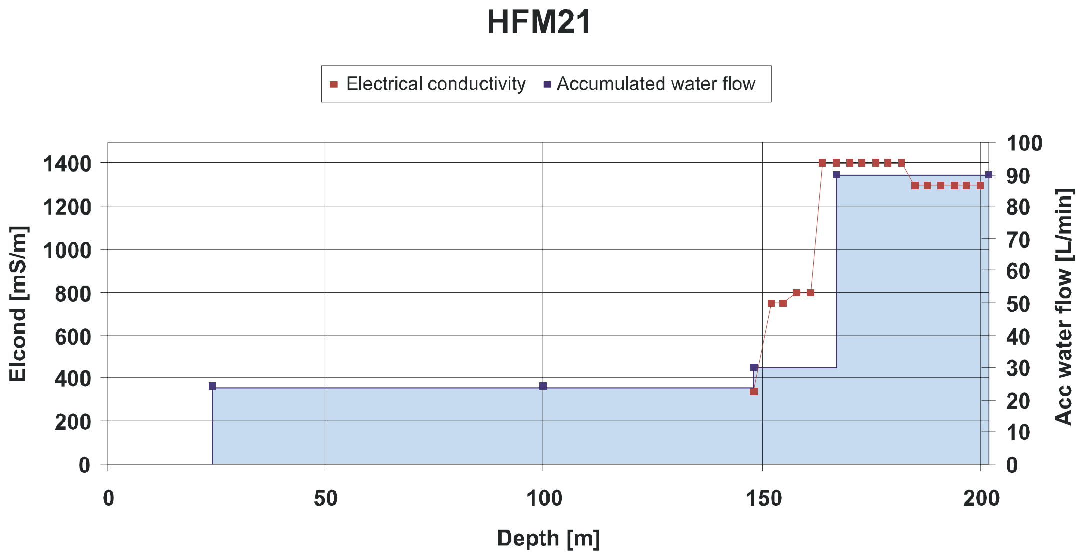


Figure 5-9. Electrical conductivity and accumulated groundwater inflow versus drilling length in HFM21.

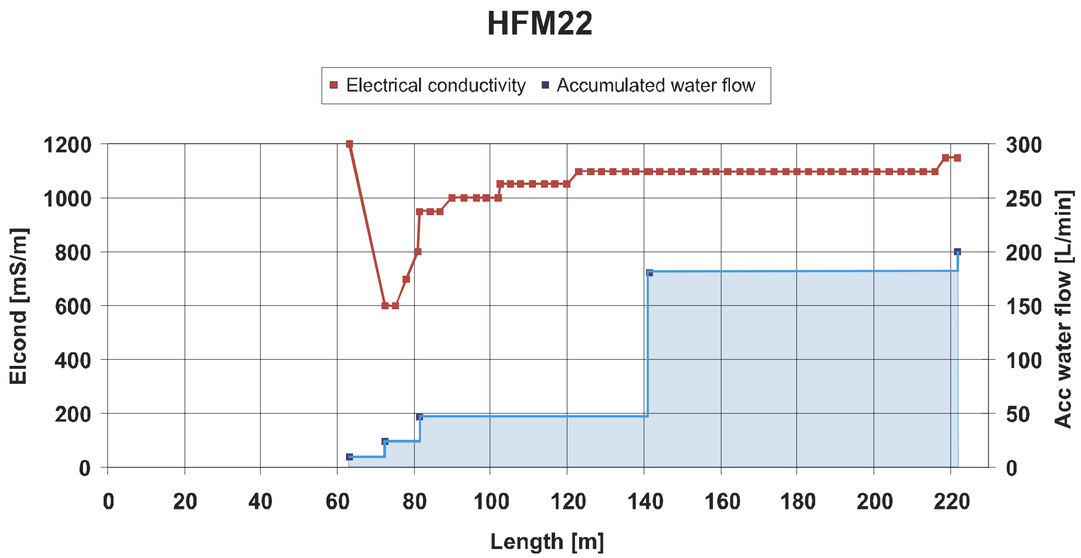


Figure 5-10. Electrical conductivity and water flow versus length in HFM22.

5.4.2 Hydraulic responses

During percussion drilling and reaming of the upper 100 m of the telescopic borehole KFM08A at DS8, significant hydraulic responses were observed in HFM22, see Figure 5-11. As the distance between KFM08A and HFM22 is about 80 m (see Figure 1-2), the quick responses indicate that the two boreholes penetrate the same highly water conductive and probably gently dipping fracture zone.

During percussion drilling and reaming of the upper 100 m of the telescopic borehole KFM07A at DS7, groundwater pressure measurements in two sections in HFM21 were performed as well as in (the entire) borehole HFM20, see Figure 5-12. Hydraulic responses are observed in all sections in the two boreholes. The marked response in the upper section of HFM21 is probably connected to an observed inflow in KFM07A at 57 m borehole length. Although the distance between KFM07A and HFM20 is about 300 m, the hydraulic response in the latter borehole is rapid and the magnitude is very significant.

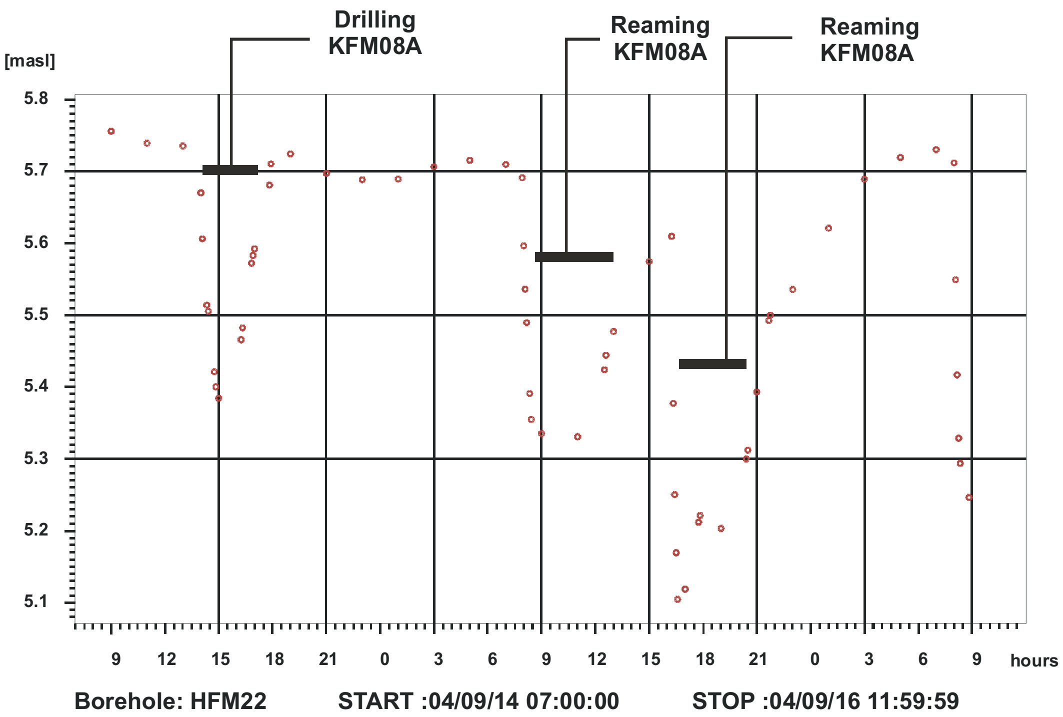


Figure 5-11. *Hydraulic responses in HFM22 when drilling and reaming KFM08A.*

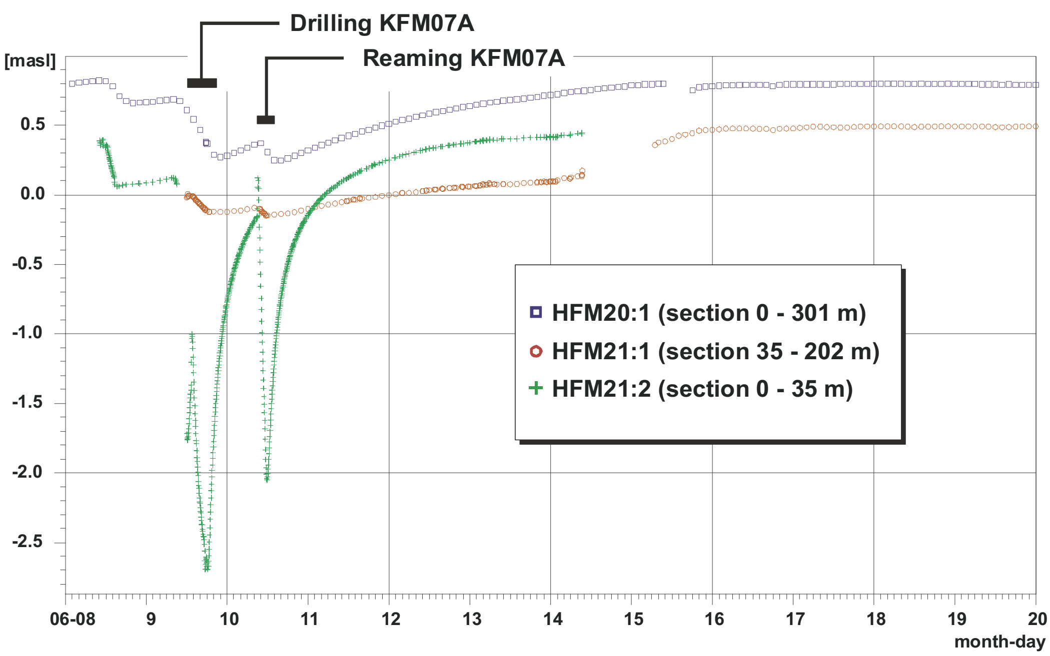


Figure 5-12. *Hydraulic responses in HFM20 and in two sections in HFM21 when drilling and reaming the percussion drilled part of KFM07A.*

References

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

/2/ **SKB, 2002.** Execution programme for the initial site investigations at Forsmark. SKB P-02-03. Svensk Kärnbränslehantering AB.

/3/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of groundwater monitoring wells SFM0001–SFM0003 in soil at drilling site DS1. SKB P-03-13. Svensk Kärnbränslehantering AB.

/4/ **Hedenström A, 2004.** Forsmark site investigation. Stratigraphical and analytical data of Quaternary deposits. SKB P-04-148. Svensk Kärnbränslehantering AB.

/5/ **Petersson J, Wängnerud A, 2004.** Forsmark. Boremap mapping of percussion boreholes HFM20, HFM21 and HFM22. SKB P-report in progress. Svensk Kärnbränslehantering AB.