P-04-76

Forsmark site investigation

Drilling of a flushing water well, HFM10, a groundwater monitoring well in solid bedrock, HFM09, and a groundwater monitoring well in soil, SFM0057, at drilling site DS4

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February 2004

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Keywords: AP PF 400-03-52, Percussion drilling, Flushing water well, Monitoring well, Soil, Solid bedrock, DS4.

Summary

Two percussion boreholes, HFM09–10, and one soil borehole, SFM0057, were drilled at drilling site DS4. The primary aim of the former was to penetrate structures that, at least in one of the boreholes, could yield enough water of good quality as to provide flushing water for the deep drilling at drilling site DS4. A secondary aim was that the boreholes could be used for monitoring of groundwater levels during pumped as well as during undisturbed conditions.

In HFM10, an inflow of 600 L/min was obtained from section 114–116 m. The TOC-value (Total Organic Content) proved to be as low as 2.7 mg/L, and hence the well was judged as an excellent flushing water well. Albeit yielding 300 L/min at 27 m, a too high TOC-value entailed that HFM09 was rejected as a flushing water well. The objectives of borehole SFM0057 are monitoring of the groundwater level in the soil layer and water sampling.

Borehole HFM09, which was drilled during the period June 18th to 30th, 2003, is 50.25 m long, inclined 69 degrees to the horizontal plane and has a diameter of c 140 mm. Borehole HFM10 was drilled between August 11th and 20th, 2003. It is 150.00 m long, inclined 69 degrees to the horizontal plane and has a diameter of c 140 mm. Finally, the soil borehole SFM0057, drilled on September 4th, 2003, is vertical and 4.00 m deep.

Although evident proofs are not available, a water-bearing fracture zone supposed to be penetrated by both HFM09 and HFM10 may also be intersected by the deep boreholes KFM04A and KFM04B at drilling site DS4. If the water-bearing structures encountered in these four boreholes are one and the same, this zone has a north-easterly strike and a flat dip towards south-east.

Sammanfattning

Två hammarborrhål i berg, HFM09–10, och ett jordborrhål, SFM0057, borrades vid borrplats BP4 (benämns DS4 i engelsk text). Ett huvudsyfte med de bergborrade brunnarna var att nå strukturer som ger tillräckligt med vatten av god kvalité, så att åtminstone en av brunnarna skulle kunna leverera spolvatten till kärnborrningen på borrplats BP4. Ett annat syfte var att borrhålen skulle kunna användas som moniteringsbrunnar för registrering av grundvattennivå under pumpning eller vid ostörda förhållanden.

I HFM10 uppmättes ett inflöde av 600 L/min från sektion 114–116 m. Vattnets TOC-värde (totala organiska halt) var så lågt som 2,7 mg/L, varför HFM10 bedömdes som en utmärkt spolvattenbrunn. Borrhål HFM09 gav visserligen ett inflöde på 300 L/min vid ca 27 m, men vattnet hade ett alltför högt TOC-värde för att vara lämpligt för spolvattenändamål. Jordborrhålet SFM0057 är avsett för monitering av grundvattennivån i jordlagret och för vattenprovtagning.

Borrhål HFM09, som borrades under perioden 18:e till 30:e juni 2003, är 50,25 m långt, ansattes 69° mot horisontalplanet och har diametern ca 140 mm. HFM10 borrades mellan 11:e och 20:e augusti 2003, är 150,00 m långt och ansattes likaledes 69° mot horisontal-planet och har liksom HFM09 diametern ca 140 mm. Jordborrhålet SFM0057, slutligen, som borrades den 9:e september 2003, är vertikalt och 4,00 m djupt.

Även om säkra bevis saknas, kan en vattenförande zon, som genomkorsats av både HFM09 och HFM10, vara densamma som påträffats i djupborrhålen KFM04A och KFM04B på borrplats BP4. Om detta är fallet, har denna zon nordostlig strykning och flack stupning mot sydost.

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 /2/ is situated close to the nuclear power plant at Forsmark, see Figure 1-1.

Drilling is one important activity within the scope of the site investigations. Three main types of boreholes are produced: core drilled boreholes, percussion drilled boreholes in solid rock, and boreholes drilled through unconsolidated soil. The initial phase of the investigations included drilling of three, c 1000 m deep boreholes inside the candidate area at drilling sites DS1, DS2 and DS3, see Figure 1-1. Also a fourth, c 1000 m long borehole with its collaring point at drilling site DS4, outside the candidate area, has now been drilled, see Figure 1-1. This borehole, KFM04A, is inclined 60° to the horizontal plane, and strikes N45°E, i.e. towards the candidate area, which it penetrates at c 480 m drilling length, see Figure 1-2.

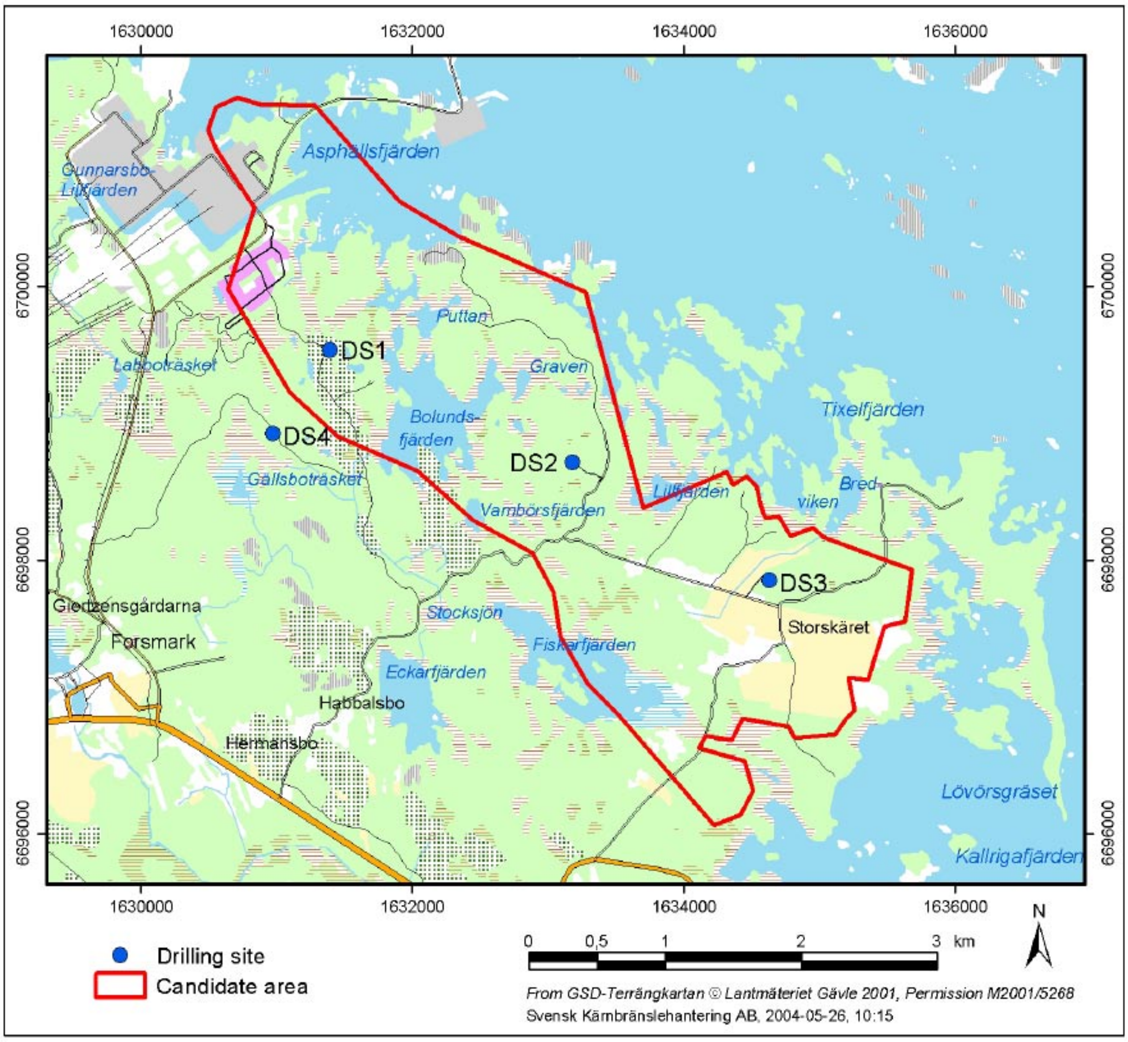


Figure 1-1. The investigation area at Forsmark including the candidate area selected for more detailed investigations. Drilling sites DS1-4 are marked with blue dots.

The results from drilling of KFM04A will be presented in /3/. Borehole KFM04A is telescopic drilled, i.e. the upper section 0–100 m is performed with a larger diameter than the remaining part of the borehole. Section 0–100 m of a second telescopic borehole at drilling site DS4, KFM04B, has been drilled as well, see Figure 1-2. Also KFM04B is inclined 60° but in the opposite direction compared to KFM04A.

Also percussion drilled boreholes in solid bedrock and in soil have been produced at each of the drilling sites depicted in Figure 1-1. At drilling site DS4, two percussion boreholes in solid bedrock, HFM09 and HFM10, with the depths 50.25 m respectively 150.00 m, and one borehole through the soil layer, SFM0057, have been drilled, see Figure 1-2.

In the present report, performance of and results from drilling HFM09 and HFM10 and SFM0057 at drilling site DS4 are presented. The report also scopes investigations made during and immediately after the drilling operations.

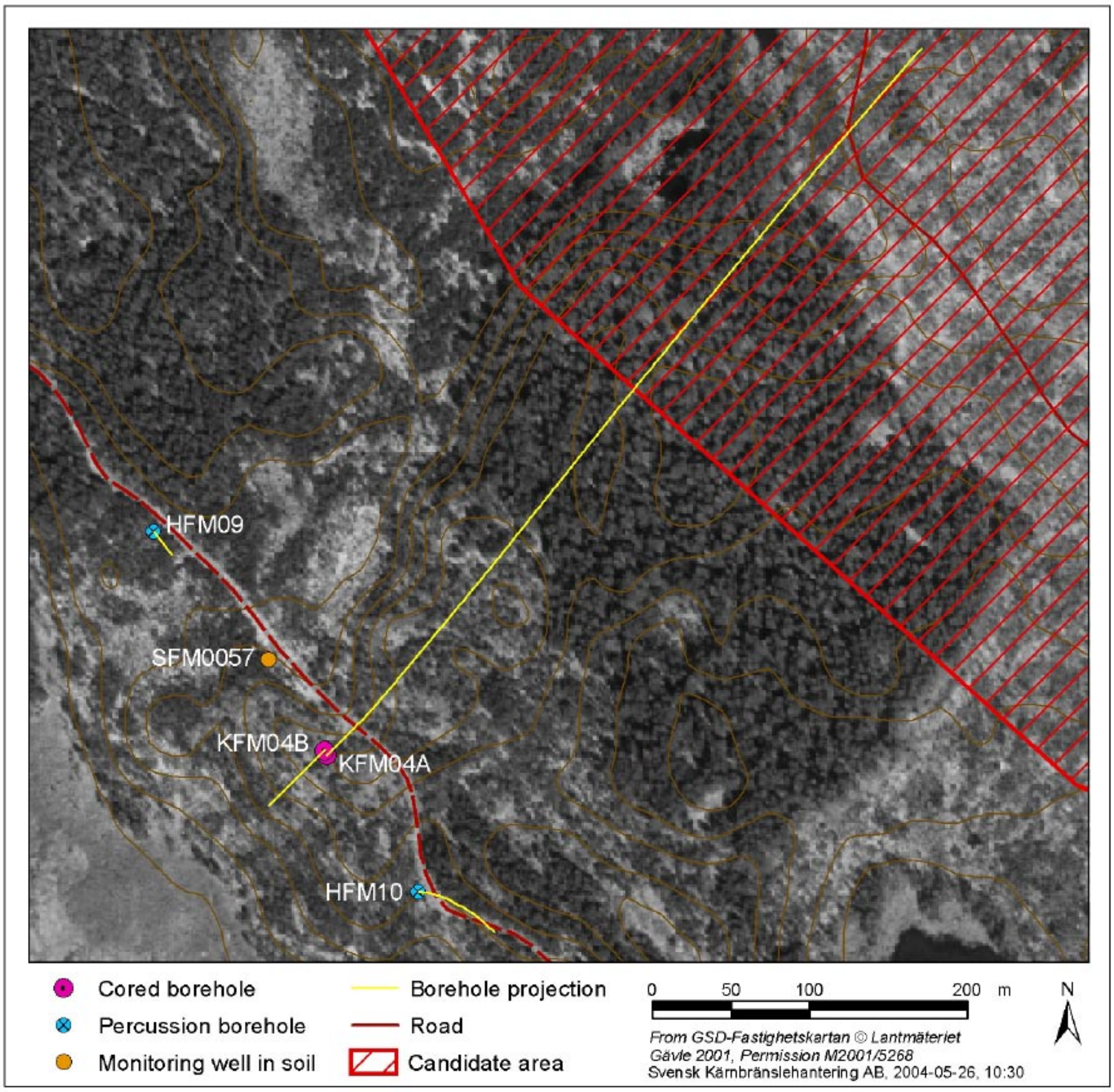


Figure 1-2. *Borehole locations at drilling site DS4. The projections of inclined boreholes on the horizontal plane at the ground level (top of casing) are shown. Besides the flushing water well HFM10 and the monitoring well in solid rock, HFM09, the drilling site also incorporates one monitoring well in soil, SFM0057.*

Borehole HFM10, which was drilled during the period August 11th to August 20th, 2003, was primarily produced for supply of the flushing water needed for drilling the deep cored borehole KFM04A (and later KFM04B), whereas boreholes HFM09, drilled between June 18th and June 30th, 2003, and SFM0057, drilled on Sept 4th, 2003, were produced to serve as monitoring wells, enabling long-term study of groundwater levels and groundwater-chemical composition.

Sven Andersson in Uppsala AB, furnishing a Nemek 407 RE percussion drilling machine operated by a one-man drill crew, was contracted for the commission. Assistance was provided from SKB-personnel regarding measurements and tests during drilling.

Drilling and measurements during and immediately after drilling were performed according to Activity Plan AP PF 400-03-52 (SKB internal controlling document). The Activity Plan refers to SKB MD 610.003, Version 1.0 (Method Description for Percussion Drilling) and SKB MD 630.003, Version 1.0 (Method Description for Soil Drilling), both SKB internal controlling documents.

2 Objective and scope

Drilling of a 1000 m deep cored borehole according to SKB procedures is associated with extensive operations regarding e.g. water handling. A so called telescopic drilling technique is applied, which involves that the upper 100 m of the borehole is percussion drilled with a large diameter (≥ 200 mm), whereas the borehole section 100–1000 m is core drilled with a diameter of approximately 76–77 mm.

Core drilling demands injection of relatively large amounts of flushing water through the drilling pipe string and drill bit for cooling the latter and for transportation of drill cuttings from the borehole bottom to the ground surface. At the SKB site investigations, an air-lift pump is installed in the upper, large-diameter part of the telescopic drilled borehole in order to enhance the recovery of flushing water and drill cuttings. During the entire drilling period (comprising about three months when drilling a 1000 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 in the near-surrounding of the deep borehole. To enable observation of groundwater level fluctuations and changes due to the deep drilling, monitoring wells have to be drilled.

Borehole HFM10 was drilled with the primary aim to, at a convenient distance (c 110 m) from the core drilled borehole KFM04A, account for the supply of relatively large amounts of clean flushing water, whereas the boreholes HFM09 and SFM0057 were drilled to serve primarily as monitoring wells. However, with more favourable groundwater chemical quality (mainly regarding organic content), borehole HFM09 might as well have been selected as a flushing water well. Another purpose with the monitoring well HFM09 was to investigate a week conductor /4/ and a coincident lineament striking NNE between boreholes HFM09 and SFM0057 (Figure 2-1).

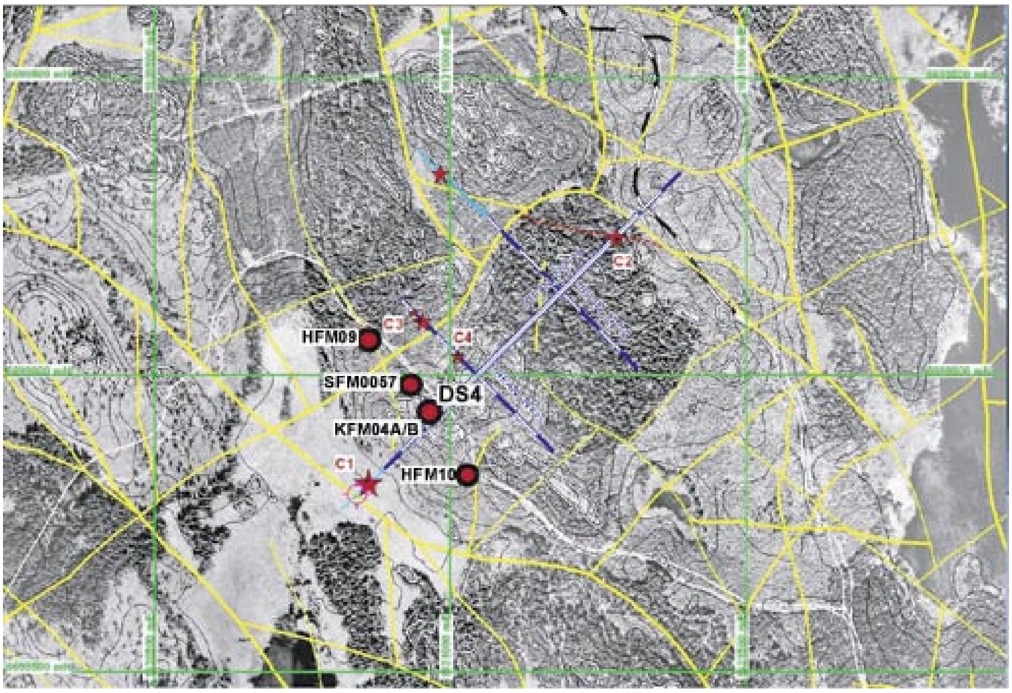


Figure 2-1. *Lineaments (yellow), geophysical survey lines (blue), EM conductors (red stars) and boreholes (red dots) at drilling site DS4. Tommy Karlberg after Pitkänen and Isaksson /4/.*

Boreholes HFM09–10 are of so called SKB chemical type. This implies that the boreholes are prioritized for hydro-geochemical investigations (also including examination of micro-organisms, primarily bacteria, occurring in the groundwater). The 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 strategy for siting the monitoring wells HFM09 and SFM0057 was to set them within the expected radius of influence of groundwater-level drawdown due to air-lift pumping during drilling. With consideration to that, they were located 180 m respectively 75 m from borehole KFM04A.

Groundwater level and hydrogeochemical data gained during monitoring of undisturbed hydraulic conditions (i.e. prior to or after deep drilling operations at the site) will be part of the characterization of the groundwater conditions of the shallow part of the bedrock.

Monitoring in the near-sited boreholes during the percussion and core drilling operations in KFM04A (and later KFM04B) is primarily part of the environmental control program. However, also these data may be used for basic characterization purposes. After completion of drilling and borehole investigations at DS4, boreholes HFM09, HFM10 and SFM0057 will be used for long-term groundwater level monitoring and groundwater sampling.

3 Equipment

Drilling of the percussion boreholes in solid bedrock and the soil borehole at drilling site DS4 was performed with a Nemek 407 RE DTH 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.

3.1 Drilling equipment

The drilling machine was equipped with separate engines for transportation and power supplies. For discharge of water and drill cuttings from the borehole, a 27 bars diesel air-compressor, type Atlas-Copco XRVS 455 Md, was used. The DTH drillhammer was of type Secoroc 5", operated by a Driconeq 76 mm pipe string.

Cleaning of all DTH-equipment was performed with a high-capacity steam cleaner of type Kärcher HDS 1195.

Figure 3-1. *The Nemek 407 percussion drilling machine employed for drilling three boreholes at drilling site DS4. Water and drilling debris is discharged to a container.*

3.2 Gap injection technique and equipment

A temporary steel casing with the external diameter 219 mm was driven through the soil layer and further through fractured rock and a certain distance into solid rock, see detailed description in Section 4.3. The gap between the borehole wall and the casing was grouted with cement in order to prevent surface water and shallow groundwater to infiltrate into deeper parts of the borehole. The cement application may be performed using different technical approaches and equipment. Two variants are illustrated in Figure 3-2. In boreholes HFM09 and HFM10 only the borehole packer technique was applied.

3.3 Equipment for deviation measurements

Deviation measurements in HFM09 and HFM10 were performed using a Reflex EZ-shot (magnetic) equipment. Azimuth and dip were measured every third metre. The coordinates for the starting point and the measured values were used for calculating the coordinates for every measured point.

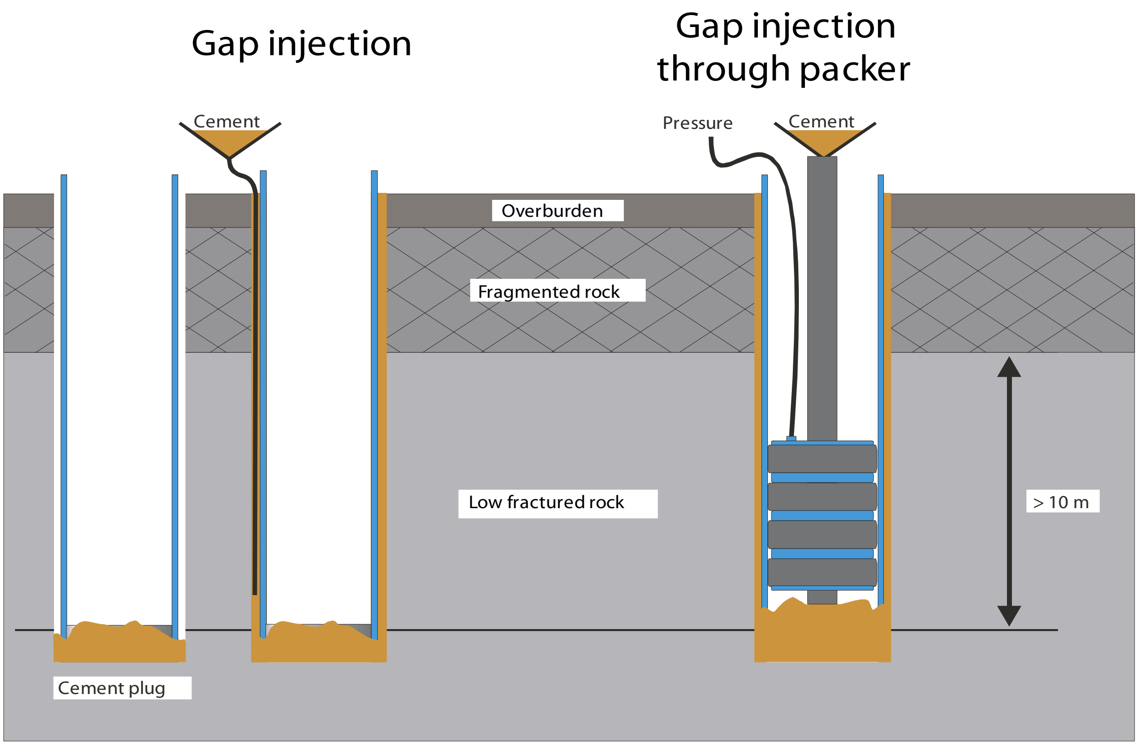


Figure 3-2. Gap injection technique. In order to grout the gap between the borehole wall and the casing, two different systems may be used. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer.

3.4 Equipment for measurements and sampling during drilling

Flow measurements during drilling were performed using measuring vessels of different sizes and a stop watch. Measurements of the drilling penetration rate were accomplished with a carpenter's rule and a stop watch.

Samples of soil and drill cuttings were collected in sampling pots and groundwater in small bottles. A field measuring devise, Kemotron 802, was used for measurements of electrical conductivity of the groundwater.

4 Execution

The performance of the boreholes in bedrock, HFM09 and HFM10, followed SKB MD 610.003, Version 1.0 (Method Description for Percussion Drilling), while the execution of the soil borehole SFM0057 followed SKB MD 630.003, Version 1.0 (Method Description for Soil Drilling). Both descriptions included 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.

4.1 Preparations

The preparation stage included the Contractor's service and function control of his equipment. The machinery was obliged to be supplied with fuel and lubricants, (oil and grease) exclusively of the types stated in SKB MD 600.006, Version 1.0 (Method Instruction for Chemical Products and Materials). Finally, 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. SKB MD 600.006 and SKB 600.004 are both SKB internal controlling documents.

For the borehole in soil, SFM0057, well screen and riser pipes of HDPE-material (High Density PolyEthylene) were delivered in tight-fitting packages. Before delivery to the drilling site, the pipes with accessories had been treated by acid leaching followed by rinsing with deionized water, see procedure in /5/, Section 4.1. At the drilling site, the screen and pipes were further prepared by steam-cleaning.

4.2 Mobilization

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

4.3 Drilling, measurements, sampling during drilling and finishing-off work – boreholes HFM09 and HFM10

4.3.1 Drilling through the overburden

In normal Swedish terrain, the rock surface is often covered with a more or less thick stratum of unconsolidated rock material, e.g. till. The procedure of drilling a percussion borehole is in this case divided into two drilling sequences: 1) drilling through the overburden and 2) drilling in fragmented and/or solid rock. The bedrock where boreholes HFM09 and HFM10 were sited is till covered, and hence drilling was performed according to these two sequences. Figure 4-1 schematically illustrates the different steps carried out.

Drilling through the overburden may be accomplished by using different technical approaches. In the present commission, so called Ejector NO-X technique was applied. The prefix "ejector" indicates that the discharge channels for the flushing medium, which in this case was compressed air, are constructed in such a way that the exposure of the penetrated soil layers to compressed air during drilling is reduced, compared to conventional systems. This has the advantage that contamination with oxygen and compressor oil, which is part of compressed air (although compressor oil at a very low content), is limited.

The NO-X system represents a method for concentric drilling and casing driving through the overburden (Figure 4-1). A circular pilot bit, attached to a DTH-hammer shank, and with large internal flushing holes and external flushing grooves, is connected to a symmetrical ring bit (reamer) with an internal bayonet coupling. The pilot bit and the ring bit are both rotating clockwise, thereby drilling a borehole with a diameter large enough to let the casing easily slip down into the reamed borehole. The ring bit is rotating freely against the casing shoe, which is welded to the lower end of the casing. The casing is non-rotating during drilling.

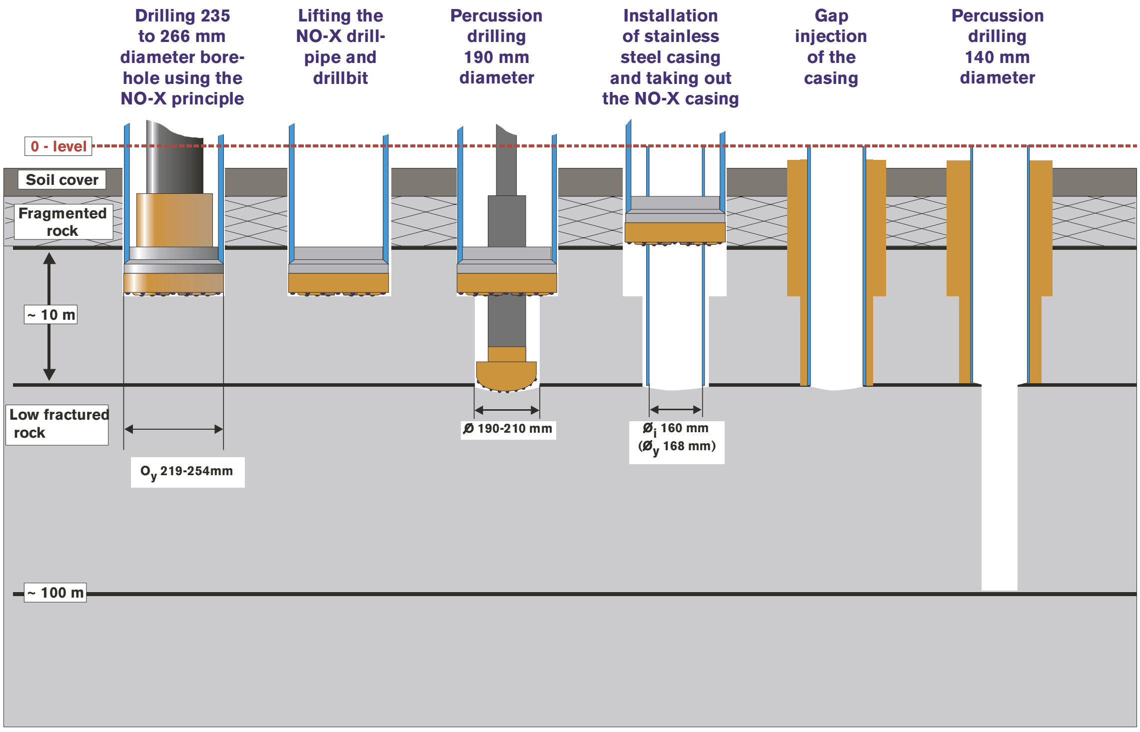


Figure 4-1. The different steps included in the performance of the percussion drilled boreholes HFM09–10.

Drilling through the overburden of boreholes HFM09–10 basically followed the principles for the Ejector-NO-X system. However, the method was to some extent applied in a non-conventional manner. During drilling of a borehole with the diameter 235 mm, a temporary steel casing with an outer diameter of 219 mm was driven through the till overburden and through fragmented rock a short distance into fresh, low-fractured rock, see Figure 4-1. The drilling pipes with the drill hammer and pilot bit were then retrieved from the borehole. A percussion drill bit was lowered into the borehole inside the temporary casing, and a borehole with a diameter of 190 mm was drilled to 17.02 m in HFM09 respectively 11.80 m in HFM10 into high-quality, low-fractured rock.

Again the drilling pipes, drill hammer and drill bit were retrieved, whereupon a stainless steel casing with the external/internal diameter 168/160 mm was brought down into the borehole in 3 m-lengths, which were successively welded together.

4.3.2 Gap injection

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

4.3.3 Percussion drilling in hard rock

After stiffening of the grout, drilling could continue and was now performed to the full borehole length with conventional percussion drilling technique. Before start of drilling, the diameter of the drill bit was measured. In this last drilling step, the initial borehole diameter (approximately the same as the drill bit diameter) is normally 140 mm, see Figure 4-1. However, a diameter decrease of about 1 mm/100 m drilling length is to be expected when drilling in the rock types prevailing in the Forsmark area. For boreholes deeper then 100 m, the drill bit normally has to be grinded.

4.3.4 Sampling and measurements during drilling

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

- Collecting of one soil sample per metre drilling length. Analysis and results are reported in /6/.
- Collecting of 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 gave a preliminary classification of the rock type. These samples were examined and interpreted together with a BIPS-log (so called Boremap-mapping) and reported in /7/.
- 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.
- 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.
- Measurements of the electrical conductivity of the groundwater (if any) at each 3 m drilling length (noted in a paper record).

The results from the third and fourth items were used as supporting data for the Boremap-mapping mentioned above. The last item gave information used on-site about hydraulic and hydro-geochemical characteristics of the penetrated aquifers at the respective drilling sites.

4.3.5 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. By measuring the flow rate of the discharged groundwater, a rough estimate of the water yielding capacity of the borehole at maximum drawdown was achieved. The drilling string was then pulled, and the diameter of the drill bit was measured as well as the deviation of the borehole.

Recovered drill cuttings and groundwater when drilling in solid bedrock were for environmental reasons not allowed to spread out on the ground surface, and were therefore conducted to and collected in a steel container. After completion of drilling, the container was removed from the site and emptied at an approved deposit.

Figure 4-2. *Sampling of one sample per 3 m drilling length of drill cuttings from the bedrock.*

Finally, the borehole was secured by a stainless steel lockable cap, mounted on the casing flange. 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.

4.4 Drilling, measurements, sampling during drilling, installations and finishing-off work – borehole SFM0057

4.4.1 Drilling, measurements and sampling during drilling

Drilling through the overburden was performed using a variant of the Tubex system, called Ejector-Tubex. Tubex is a system for simultaneous drilling and casing driving. The method is based on a pilot bit and an eccentric reamer, which together produce a borehole slightly larger than the external diameter of the casing tube. This enables the casing to follow the drill bit down the hole. In the Ejector-Tubex 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 (cf Section 4.3.1). During drilling, a temporary steel casing with the dimension 168.3 mm external and 160.0 mm internal diameter was simultaneously driven through the soil. When solid rock was indicated, drilling was continued approximately a couple of decimetres 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 accomplished. The programme included:

- One soil sample per metre. Analysis and results are reported in /6/.
- One sample of drill cuttings from the bedrock. Rock samples collected during drilling of monitoring wells in soil will be analysed and the results reported within the scope of Activity Plan AP PF 400-03-74 (SKB internal controlling document).
- 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.
- Measurement of the electrical conductivity 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 each borehole.

4.4.2 Installation of well screen and screen filter

At completion of drilling, the temporary casing was driven approximately 2–3 dm 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 installed, see Figure 4-3, and the design of the installation was documented, see Figure 5-3.

The first part of the installation was to fill up a suitable amount of filter sand into the borehole, in order to cover the bedrock. The screen, connected to the riser pipes, was then installed, lowered all the way down to the sand bed, and centralized in the hole.

Figure 4-3. Installation of the HDPE well screen, riser pipes, sand filter and bentonite sealings in a groundwater monitoring well inside a temporary steel casing. The snap-shot illustrates when the bentonite is filled between the riser pipe and the temporary steel casing.

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 bentonite slurry may be suitable for this purpose.

4.4.3 Finishing off work

After installation of the screen, sand filter and sealing, the temporary casing was removed 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 firmly moulded 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 drilling site made by SKB and the Contractor.

4.5 Data handling

Minutes for the following items: 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 /8/.

4.6 Environmental control

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

4.7 Nonconformities

According to the Activity Plan AP PF 400-03-52, a second percussion drilled borehole, SFM0058, in soil was supposed to be drilled at drilling site DS4. However, because an already existing soil borehole, SFM0013, is situated relatively close to the drilling site, it was assessed that this borehole, together with SFM0057, would fulfil the needs for the environmental controlling programme. Borehole SFM0058 was therefore excluded from the drilling programme at DS4. However, the borehole number has later been assigned a soil borehole at drilling site DS5 with Activity Plan AP PF 400-03-68 as the SKB internal controlling document.

The planned drilling depth of HFM09 was maximum c 200 m. Drilling was however stopped already at 50.25 m, because an enough water yielding capacity for the supposed flushing water supply was indicated at 27 m. However, a too high content of organic substances entailed that the borehole was rejected as a flushing water well.

5 Results

All data were stored in the SICADA database for Forsmark. Field note numbers are Forsmark 147 (HFM09), 177 (HFM10) and 197 (SFM0057) /8/.

Below, a summary of the data acquired is presented.

5.1 Design of the percussion drilled boreholes

5.1.1 Boreholes HFM09 and HFM10

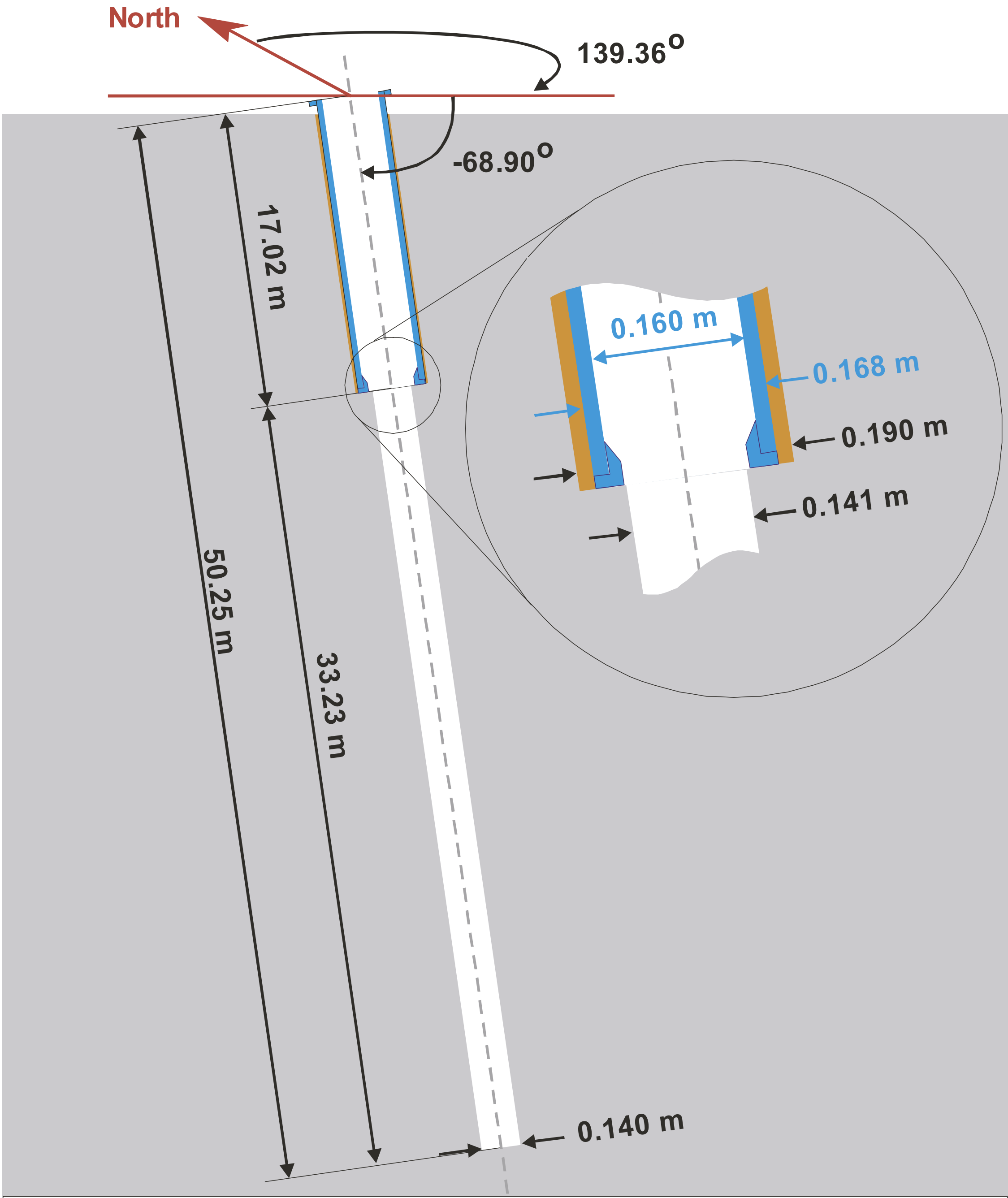
Administrative, geometric and technical data for the percussion drilled boreholes HFM09–10 are presented in Table 5-1. The technical design of each borehole is illustrated in drawings in Figures 5-1 and 5-2.

Table 5-1. Administrative, geometric and technical data for boreholes HFM09–10.

Parameter	HFM09	HFM10
Drilling period	From 2003-06-18 to 2003-06-30	From 2003-08-11 to 2003-08-20
Borehole inclination (starting point)	–68.90° (– = downwards)	–68.70° (– = downwards)
Borehole bearing	139.36°	92.93°
Borehole length	50.25 m	150.00 m
Borehole diameter	From 0.00 m to 5.30 m: 0.235 m From 5.30 m to 17.02 m: 0.190 m From 17.02 m to 50.25 m: decreasing from 0.141 m to 0.140 m	From 0.00 m to 4.50 m: 0.235 m From 4.50 m to 11.80 m: 0.190 m From 11.80 m to 150.00 m: decreasing from 0.140 m to 0.139 m
Casing length	17.02 m	11.80 m
Casing diameter	Øo/Øi = 168 mm/160 mm to 17.02 m Øo/Øi = 168 mm/146 mm between 17.00 and 17.02 m	Øo/Øi = 168 mm/160 mm to 11.80 m Øo/Øi = 168 mm/146 mm between 11.78 and 11.80 m
Drill bit diameter	Start of drilling: 0.141 m End of drilling: 0.140 m	Start of drilling: 0.140 m End of drilling: 0.139 m
Starting point coordinates (system RT90 2.5 gon V /RHB70)	Northing: 6699064.65 m Easting: 1630869.12 m Elevation: 5.15 m.a.s.l.	Northing: 6698834.79 m Easting: 1631037.19 m Elevation: 4.99 m.a.s.l.

Technical data

Borehole HFM09



Drilling reference point

Northing:	6699064.65	(m), RT90 2,5 gon V 0:-15
Easting:	1630869.12	(m), RT90 2,5 gon V 0:-15
Elevation:	5.15	(m.a.s.l.), RHB 70

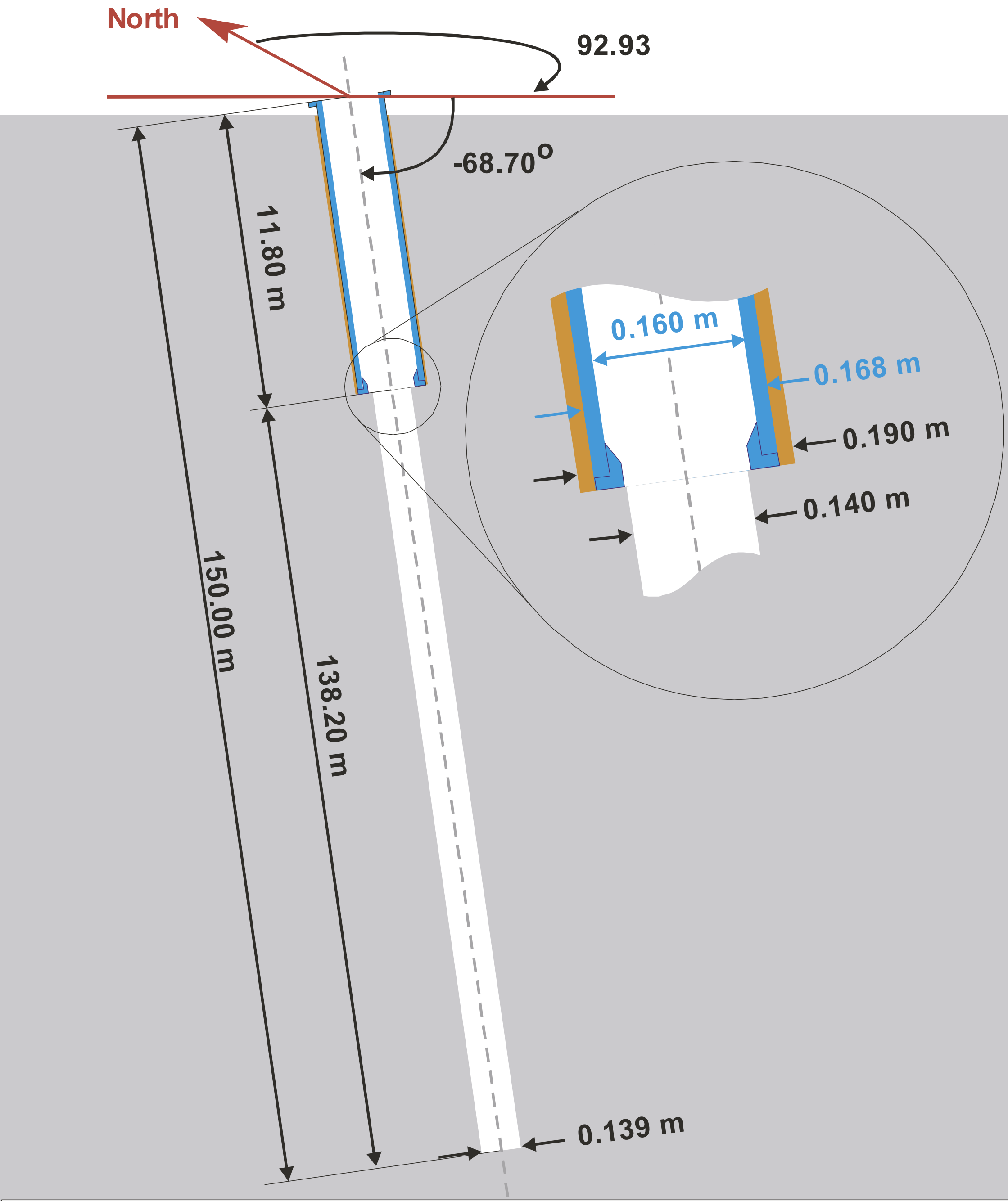
Drilling period

Drilling start date:	2003-06-18
Drilling stop date:	2003-06-30

Figure 5-1. *Technical data for borehole HFM09.*

Technical data

Borehole HFM10



Drilling reference point		
Northing:	**6698834.79**	**(m), RT90 2,5 gon V 0:-15**
Easting:	**1631037.19**	**(m), RT90 2,5 gon V 0:-15**
Elevation:	**4.99**	**(m.a.s.l.), RHB70**
Drilling period		
Drilling start date:	**2003-08-11**	
Drilling stop date:	**2003-08-20**	

***Figure 5-2**. Technical data for borehole HMF10.*

5.1.2 Borehole SFM0057

The design of the groundwater monitoring well SFM0057 is illustrated in Figure 5-3. Table 5-2 displays the geometric characteristics of the well.

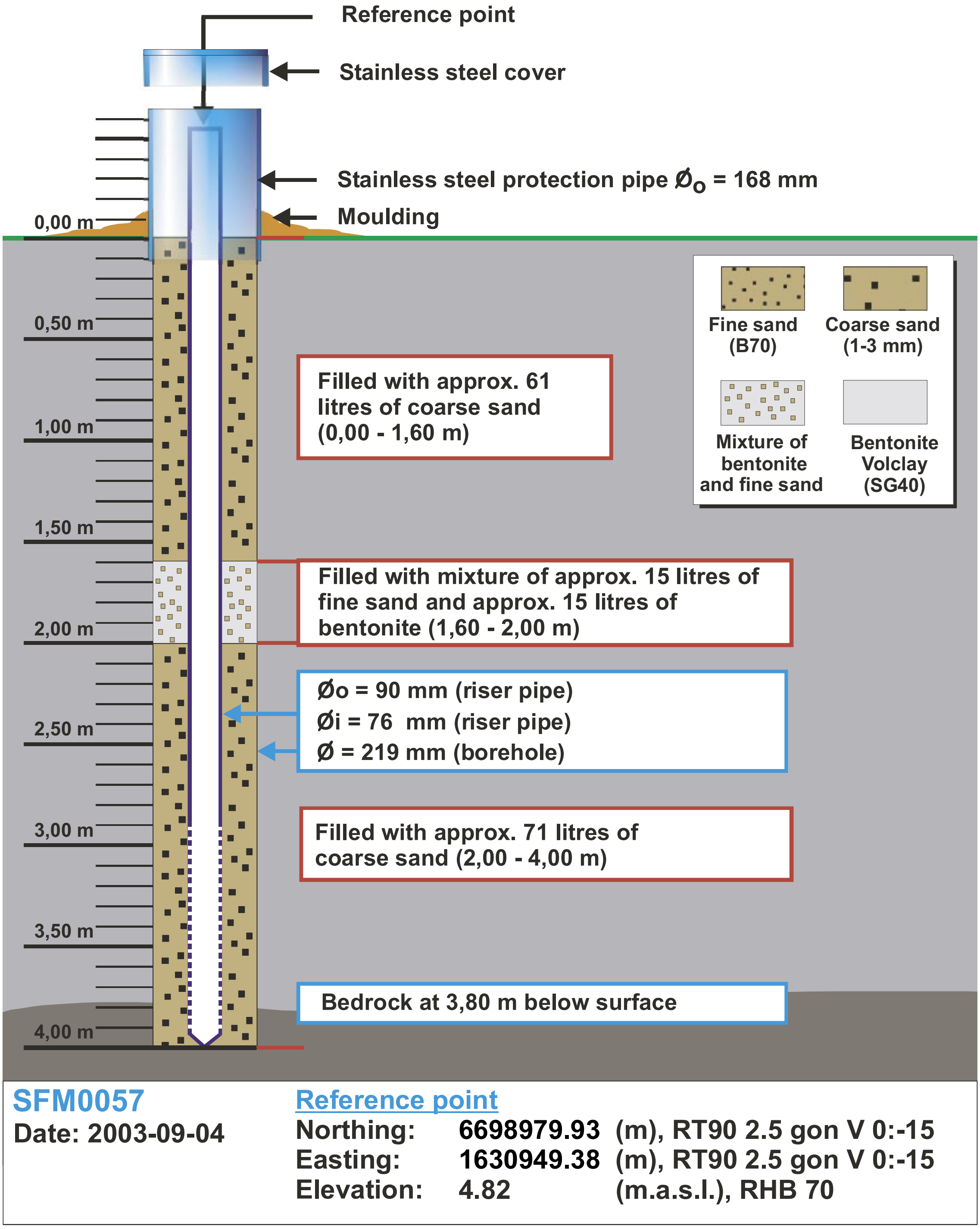


Figure 5-3. The groundwater monitoring well installation in borehole SFM0057.

Table 5-2. Geometric data for groundwater monitoring well SFM0057.

Drillhole ID	Incli-nation	Northing	Easting	Elevation m.a.s.l. (top of HDPE-pipe)	Total depth from ground level (m)	Screen length (m)	Screen pipe length (m)	Screen pipe diameter (Øo/Øi, mm)
SFM0057	90°	6698979.93	1630949.38	4.82	4.00	1.10	4.55	90/76

5.2 Consumables in HFM09 and HFM10

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 5-3 and 5-4. Cement of a new type was introduced for all grouting at drilling site DS4. The cement is of low alkalic type consisting of microsilica (920-D) and white cement (Aalborg Portland CEM I, 52.5N). This type was selected due to lower pH than conventional cement types and therefore, when mixed with groundwater, supposed to be less aggressive to underground technical installations. Regarding hammer oil and compressor oil, these products are indeed entering the borehole but are, on the other hand, continuously retrieved from the borehole due to the permanent air flushing during drilling. After completion of drilling, only minor remainders of the products are left in the borehole.

Table 5-3. Oil consumption.

Borehole ID	Hammer oil Preem Hydra 46	Compressor oil Schuman 46
HFM09	2 L	Not detected
HFM10	5 L	Not detected

Table 5-4. Consumption of cement grout.

Borehole ID	Casing length	Cement volume (Aalborg Portland cement/microsilica)	Grouting method
HFM09	17.02 m	125/55 kg	Packer technique
HFM10	11.80 m	100/44 kg	Packer technique

5.3 Well Cad presentations

Technical as well as geoscientific results achieved during drilling are also presented in Figures 5-4 and 5-5.

The deviation measurements made in boreholes HFM09 and HFM10 (Figure 5-4 and 5-5) indicate that the deviation is rather limited. The end (bottom point) of HFM09 deviates approximately 0.2 m upwards and 0.7 m to the left compared to an imagined straight line following the dip and strike of the borehole start point (inclination –68.90° and bearing 139.36°). The corresponding values for borehole HFM10 are 2.1 m upwards and 1.6 m to the left, compared to a straight line with the inclination –68.70° and bearing 92.93°.

Especially notable results are associated with a written comment in the Well Cad diagram. In borehole HFM09 (Figure 5-4), a section between 11–28 m consists of highly fractured rock. At 27 m depth, a water inflow of 300 L/min was recorded. Initially, the borehole was intended as a well for the supply of flushing water to KFM04A, and therefore the casing was extended more then usual to avoid high values of total organic content (TOC). However, this measure proved to be insufficient.

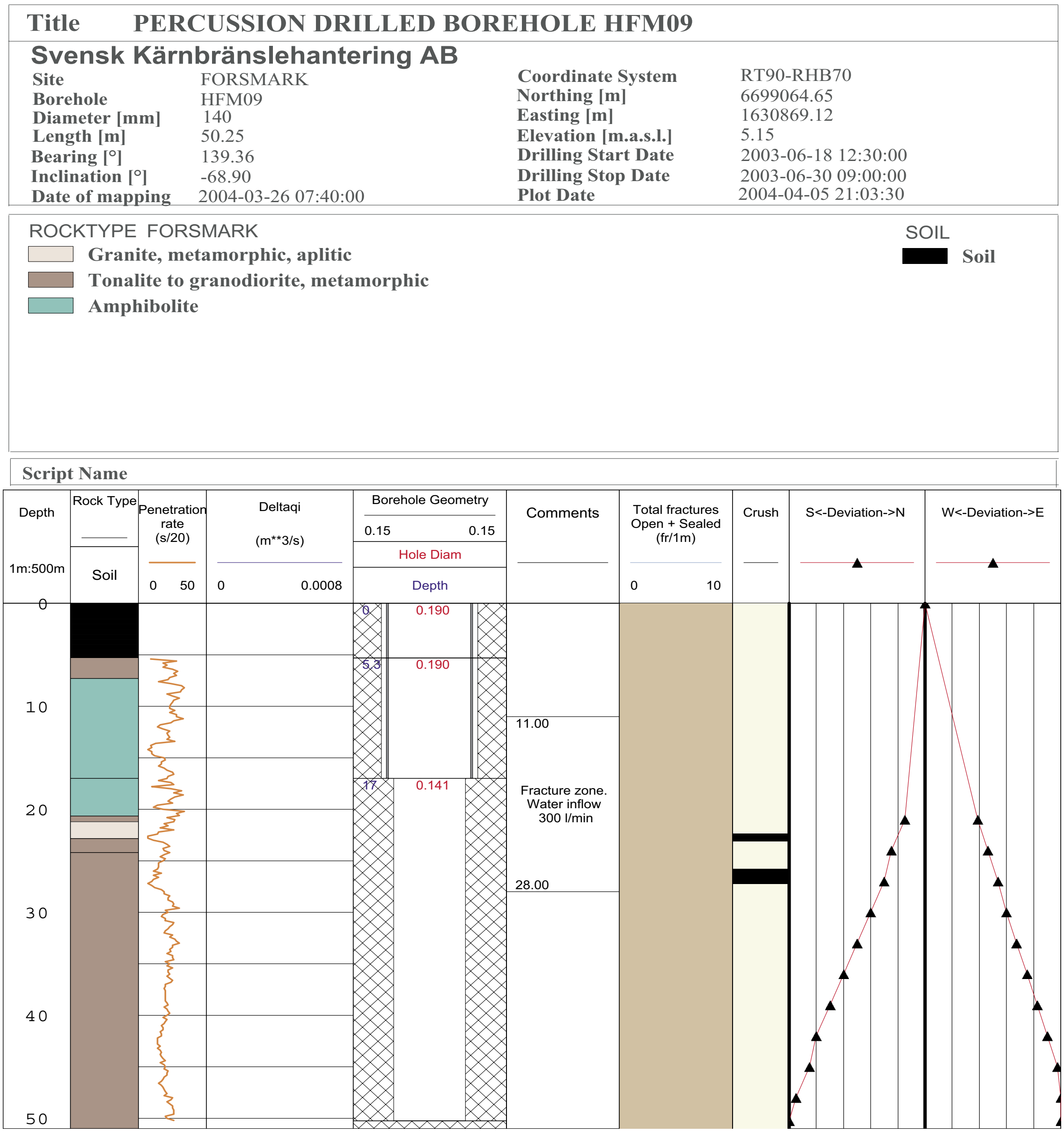
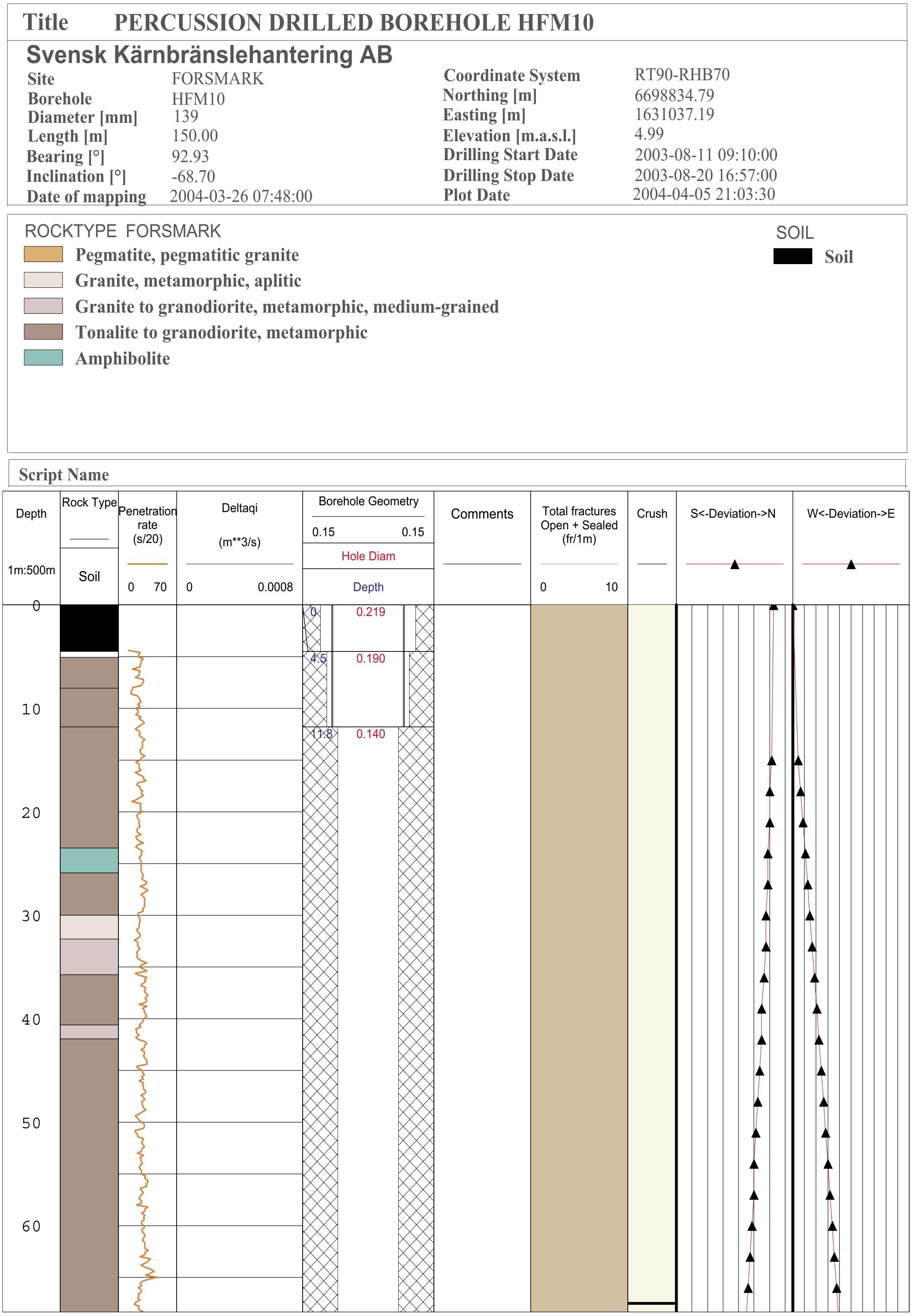


Figure 5-4. Results achieved during drilling of borehole HMF09 supplemented with results from Boremap mapping of the borehole /7/.

In borehole HFM10 (Figure 5-5), a section between 114–116 m indicates a significant decrease in penetration rate, and a water inflow of 600 L/min was measured. This high inflow and the low TOC-value (2.7 mg/L) were acceptable to allow HFM10 to be used for the flushing water supply for drilling the cored boreholes at drilling site DS4.



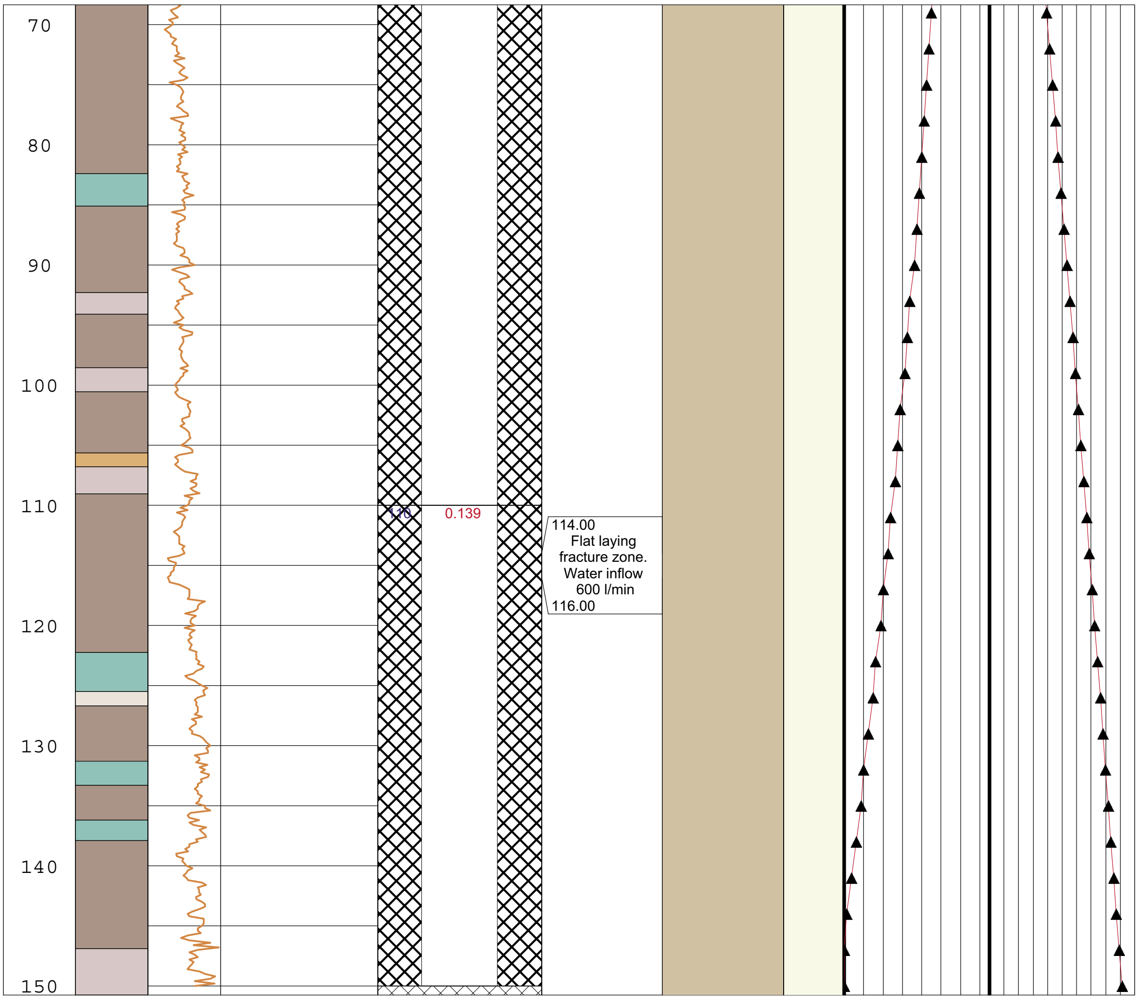


Figure 5-5. *Results achieved during drilling of borehole HMF10 supplemented with results from Boremap mapping of the borehole /7/.*

5.4 Hydrogeologi

5.4.1 Observations during drilling

In the short borehole HFM09, only two measurements of electrical conductivity and groundwater flow rate were made during drilling (Figure 5-6). The accumulated flow rate from all fractures down to c 27 m is 300 L/m, and the electrical conductivity is 105 mS/m, indicating fresh, i.e. non-saline water. No measurable increase of the flow rate was observed during the remaining drilling to 50.25 m, although the electric conductivity showed a minor increase, to 120 mS/m at the final drilling depth.

Measurements during drilling of HFM10 show an inflow at 114–116 m (Figure 5-7). When continued drilling, the accumulated flow rate increases to c 600 L/m. The electrical conductivity displays a small decrease versus depth, which confirms that only the fracture zone at 114–116 m yields water and that the drawdown during drilling entails more shallow groundwater to reach the borehole, probably due to a laterally enlarged cone of depression versus time. This water has an electrical conductivity of c1500 mS/m which corresponds to a salinity of c 5000 mg/L.

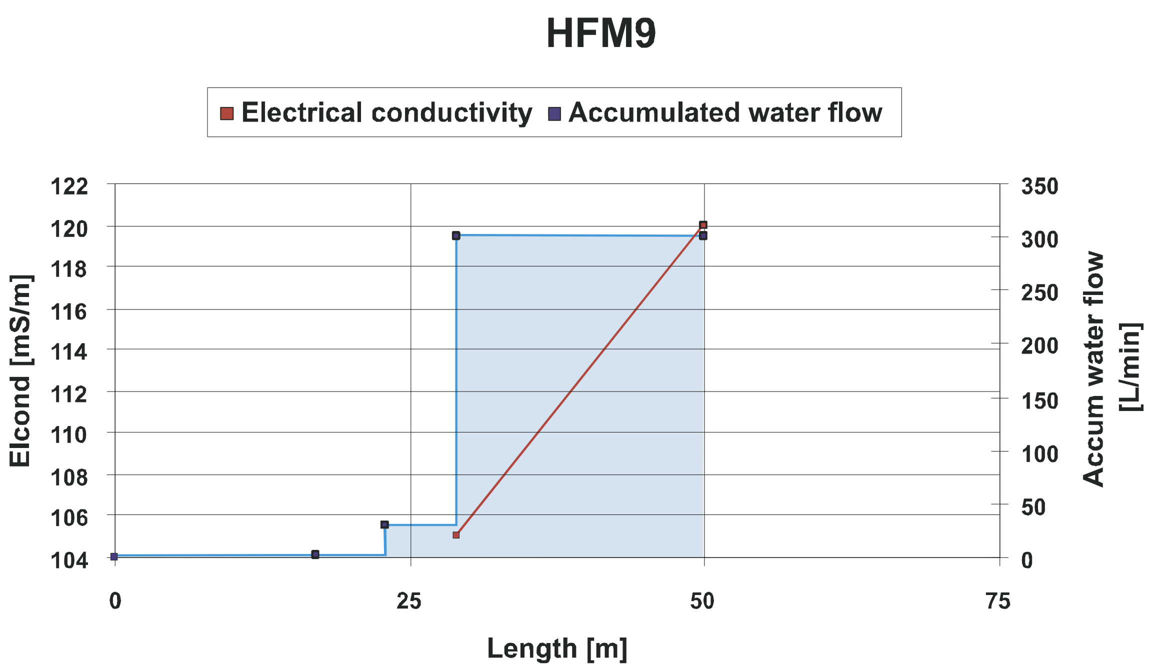


Figure 5-6. Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM09.

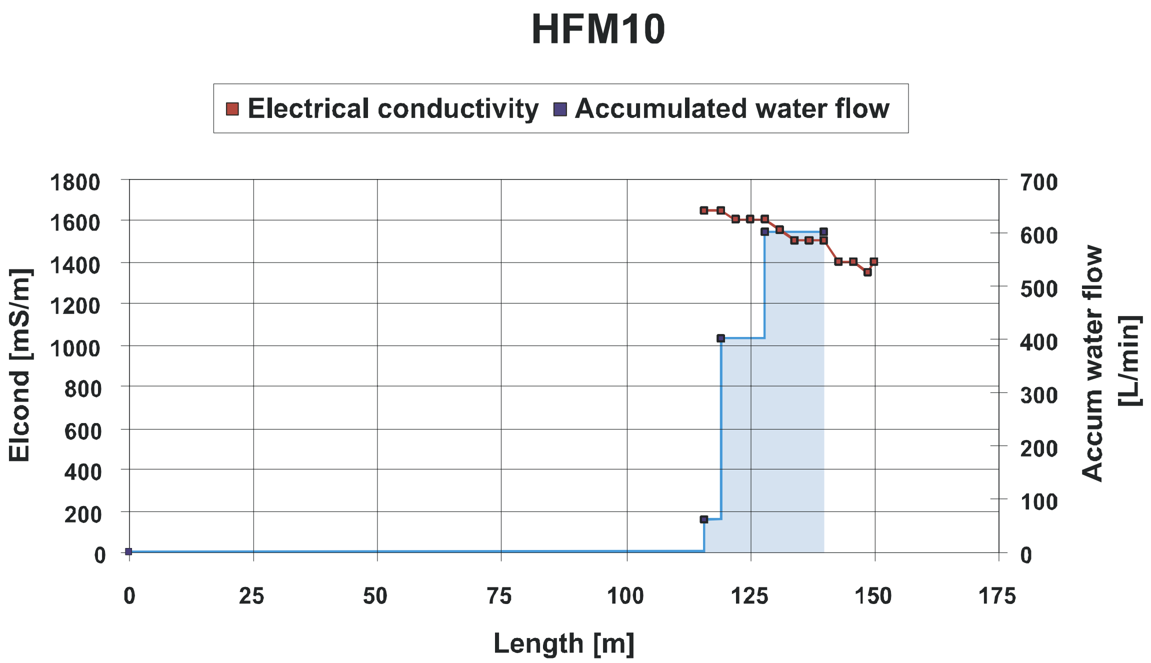


Figure 5-7. Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFM10.

5.4.2 Hydraulic responses

A tentative, simplified and schematic interpretation of the structural and hydraulic conditions of the shallow part of the bedrock at drilling site DS4 is presented in Figure 5-8. Although evident proofs are not available, the water-bearing fracture zone supposed to be penetrated by both HFM09 and HFM10 may also be intersected by boreholes KFM04A and KFM04B. The distance between HFM09 and HFM10 is about 280 m. Boreholes KFM04A and B are situated in between, c 180 m from HFM09 and 100 m from HFM10. If the water-bearing zones penetrated by those boreholes are one and the same, this zone has a north-easterly strike and a flat dip towards south-east.

Regarding HFM09, another interpretation may be, that the water yielding zone at 27 m represents the lineament/conductor striking NNE between HFM09 and SFM0057. In this case, the conductor would have a dip of approximately 70° towards WNW.

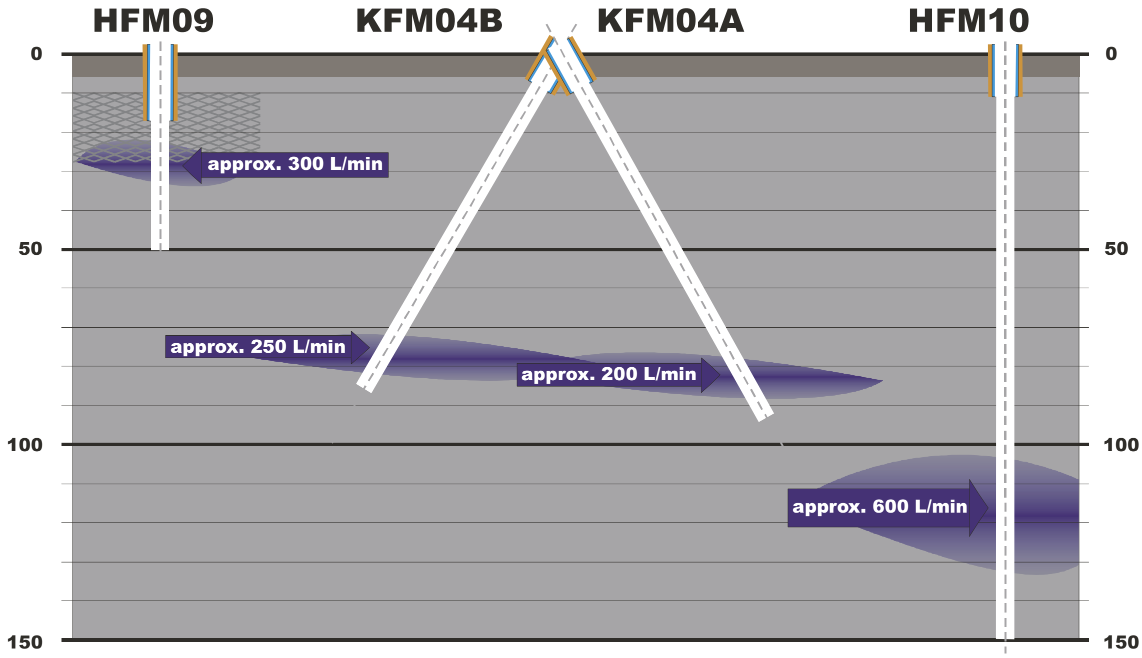


Figure 5-8. *Tentative, simplified interpretation of the structural and hydraulic conditions in the shallow part of the bedrock at drilling site DS4.*

6 References

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

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/8/ **SICADA.** Field note numbers are Forsmark 147, 177 and 197.