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Site investigation SFR

Drilling of groundwater monitoring well HFR106

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Abstract

A borehole drilled in solid rock, HFR106, was drilled from “Kobben”, a small islet located 225 m SE of the pier at the Forsmark harbour, using percussion drilling technique. Borehole HFR106 was drilled with two purposes, firstly to investigate the possible existence of near sub-horizontal fracture zones and secondly, to be used as a monitoring well, enabling long-term study of groundwater levels and groundwater-chemical composition.

Borehole HFR106 was drilled during the period June 24th to July 2nd 2009. The borehole is 190.40 m long, inclined 60.87° to the horizontal plane and is drilled with a diameter of approximately 141 mm (in the upper part). The first groundwater inflow of 14 L/min was encountered at c. 43 m length, but at the final drilling length the accumulated ground water inflow had increased to 162 L/min.

Sammanfattning

Ett hammarborrhål har borrats på ”Kobben” som ligger 225 m SE om piren från Asphällskulten vid Forsmarks hamn. Borrhål HFR106 utfördes med två syften, dels för att undersöka den eventuella förekomsten av flacka sprickzoner, dels för att användas som observationsbrunn för monitering av grundvattennivån vid såväl ostörda som störda (t ex vid pumptester) förhållanden och för grundvattenkemisk provtagning.

HFR106 borrades under perioden 24 juni till den 2 juli 2009. Borrhålet är 190,40 m långt och är ansatt med 60,87° graders lutning mot horisontalplanet samt är borrat med startdiametern 141 mm. Under borrningen noterades ett första inflöde om 14 l/min vid 43 m borrlängd. Flödet ökade gradvis och vid fullt borrlängd ger borrhålet 162 L/min.

Contents

1 Introduction

The Swedish Nuclear Fuel and Waste Management Co (SKB) is since the mid 80-ies running the underground final repository for low- and medium level radioactive operational waste (SFR) at Forsmark within the Östhammar municipality, see Figure 1-1. Since April 2008, SKB conducts bedrock investigations for a future extension of the repository. The extension project, in Swedish termed “Projekt SFR-utbyggnad” (Project SFR Extension), is organized into a number of sub-projects, of which geoscientific investigations are included in one sub-project, “Projekt SFR-utbyggnad – Undersökningar” (Project SFR Extension – Investigations).

The geoscientific investigations for the planned extension of SFR are performed in compliance with an investigation programme /1/. Experience and data from the construction of the existing SFR facility in the 1980-ies served as important input for the programme. Further, the recently completed comprehensive site investigations for a final repository for spent nuclear high-level waste at Forsmark (controlled by a general investigation programme /2/), provided a vast amount of data about the sub-surface realm down to about 1,000 m in the immediate vicinity of, and even overlapping, the SFR-area. Data and experiences also from these investigations have strongly influenced the elaboration of investigation strategies for the current SFR-investigation programme.

Figure 1-1. General overview over Forsmark and the SFR site investigation area.

For direct sub-surface investigations, drilling is an inevitable activity. Providing investigation boreholes is especially vital in the SFR-project, because the major part of the rock volume to be investigated is covered by the Baltic Sea, thereby rendering ground geophysical measurements and other surface-based investigations more difficult than at land. Two main types of boreholes will be produced within the scope of the site investigations, core drilled- and percussion drilled boreholes, respectively. For the initial phase of the investigations five percussion-drilled and five core-drilled boreholes from the ground surface and one core-drilled borehole drilled underground from the SFR facility have been suggested /1/. However, recent assessments of the investigation results obtained so far indicate that two of percussion boreholes, HFR103 and HFR104, may not be to be drilled in order to obtain the objectives of the site investigation.

This document reports data and results gained by drilling percussion borehole HFR106 from a small islet, "Kobben", located c. 225 m SE from the pier at the Forsmark harbour, which according to current planning is the final investigation borehole drilled within Project SFR Extension – Investigations. The activity was carried out in accordance with Activity Plan AP SFR-09-015. The controlling documents for performing this activity are listed in Table 1-1. Both activity plan and method descriptions are SKB's internal controlling documents.

New drill sites for five cored boreholes were built on the pier at Asphällskulten during the spring 2008, see Figure 1-2. In addition, an old borehole drilled 1985, KFR27, was rediscovered, in spite of a one metre thick concealing layer of gravel. A minor drill site was prepared also around this borehole, which was restored, prolonged and used for measurements within the scope of Project SFR Extension.

Züblin (Sven Andersson in Uppsala AB) was contracted for the drilling commission. Support was provided from SKB-personnel regarding measurements and sampling during drilling.

Drilling and measurements while drilling of HFR106 were carried out during the period June 24^{th} to July 2^{nd} 2009.

Original data from the reported activity are stored in the primary database Sicada. Data are traceable in Sicada by the Activity Plan number (AP SFR-09-015). 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 revisions also entail a revision of the P-report. Minor revisions are normally presented as supplements, available at www.skb.se

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

Activity plan	**Number**	**Version**
Hammarborrning av borrhål HFR106	AP SFR-09-015	1.0
Method descriptions	**Number**	**Version**
Metodinstruktion för utsättning och ansättning av hammar- och kärnborrhål	SKB MD 600.002	1.0
Metodbeskrivning för hammarborrning	SKB MD 610.003	4.0
Metodinstruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Metodinstruktion för användning av kemiska produkter och material vid borrning och undersökningar	SKB MD 600.006	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	2.0

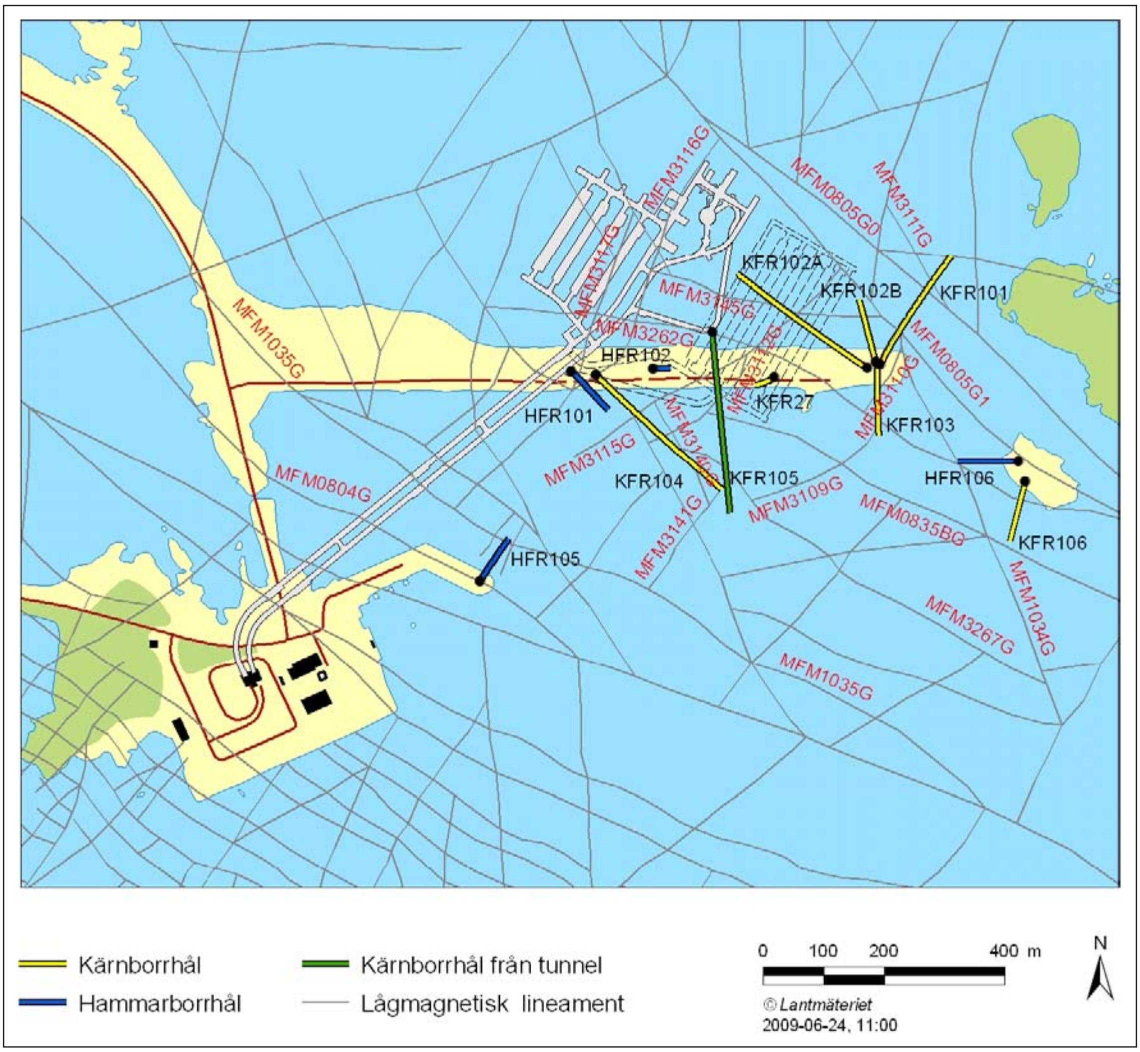


Figure 1-2. *Overview over the SFR site investigation area with existing and planned boreholes and the candidate area for the SFR extension marked with dashed lines.*

2 Objective and scope

Percussion borehole HFR106 was drilled with multiple aims, firstly intended to explore possible sub-horizontal fracture zones in the upper bedrock and, secondly, was also aimed to be used as monitoring well, enabling long-term study of groundwater levels and groundwater-chemical composition.

Borehole HFR106 is of so called SKB chemical type, implying that it is prioritized for hydrogeochemical and bacteriological investigations. The practical consequence of this is that all DTH (Down The Hole) equipment used during and/or after drilling must undergo several cleaning procedures, see Section 4.1.

After completion of drilling and borehole investigations, the borehole discussed in this report will be used for long-term groundwater level monitoring and groundwater sampling. Data gained during monitoring of the undisturbed groundwater level in HFR106 is part of the characterization of the groundwater conditions of the shallow part of the bedrock. Monitoring during the percussion- and, later, core drilling operations at the islet "Kobben", i.e. at stressed conditions, is primarily part of the environmental control program for the drilling operations. However, also these data may be used for basic hydraulic characterization.

3 Equipment

In this chapter short descriptions are given of the drilling system and the technique and equipment for gap injection of the borehole casing. Besides, the instrumentation used for deviation measurements performed after completion of drilling as well as the equipment applied for measurements and sampling during drilling are briefly described.

3.1 Drilling system

A Nemek 407 RE drilling machine was employed for the commission of drilling the borehole HFR106, see Figure 3-1. This type of machine is equipped with separate engines for transportation and power supplies. Water and drill cuttings were discharged from the borehole by means of an Atlas-Copco XRVS 455 Md 27 bars diesel compressor. The air-operated DTH drilling hammer was of type Secoroc 5”, operated in the borehole by a Driconeq 76 mm pipe string.

All DTH (Down The Hole)-components were 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 equipments. Two variants of gap injection with cement are illustrated in Figure 3-2. In HFR106 only the borehole packer technique was applied.

3.3 Equipment for deviation measurements

After completion of drilling, a deviation measurement was carried out with a FLEXIT Smart Tool System, which is based on magnetic accelerometer technique. Azimuth and dip are measured at every third metre. The coordinates of the centre of the collaring and the measured values are used for calculating the coordinates of the position of the borehole at every measurement point.

Figure 3-1. *The Nemek 407 RE percussion drilling machine employed for drilling the percussion borehole HFR106. As the borehole is of chemical type, all DTH-equipment was cleaned on-site with hot water.*

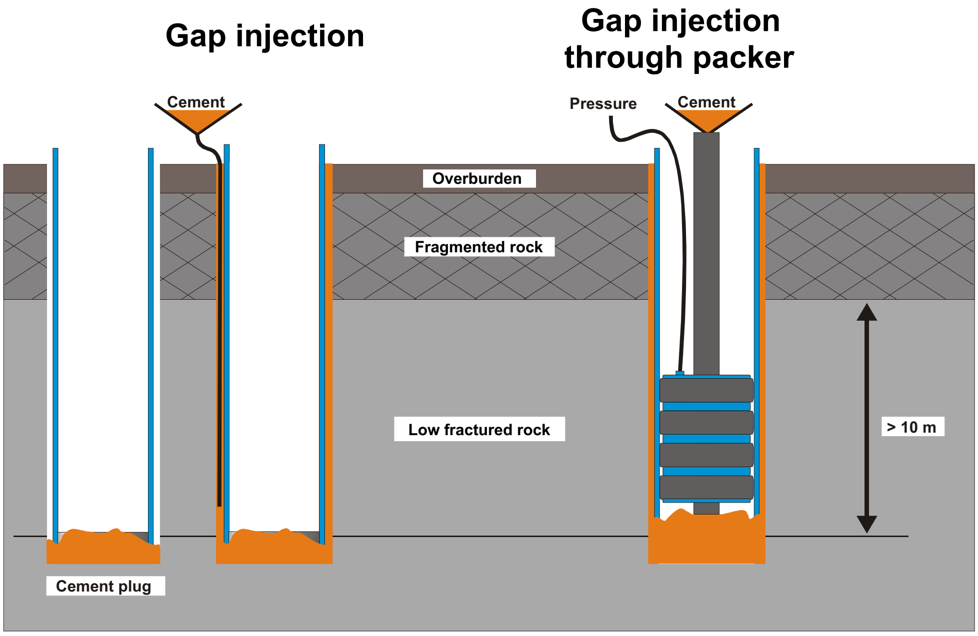


Figure 3-2. Examples of gap injection technique. In order to grout the gap between the borehole wall and the casing, different systems may be used. To the left, filling up a cement-water mixture with a flexible hose is shown. To the right, injection is performed through a borehole packer.

3.4 Equipment for measurements and sampling during drilling

A number of measurements were performed while drilling each of the three boreholes, see Figure 3-3. Flow measurements during drilling were conducted using measuring vessels of different sizes and a stop watch. Drilling penetration rate was measured 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. The electrical conductivity of the groundwater was measured by a Yokogawa Mod SE72 field measuring devise. This instrument was calibrated before use according to standards.

Figure 3-3. To the left, drilling penetration rate is manually measured with a stop watch, and to the right drill cuttings are sampled in a bucket of stain-less steel before placed in labeled pots.

4 Execution

4.1 General

Drilling of borehole HFR106 followed SKB MD 610.003, (Latest version of "Method Description for Percussion Drilling"), including 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.

4.2 Preparations

The preparations 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 ("Method Instruction for Chemical Products and Materials"). Finally, the down-hole part of the equipment was cleaned in accordance with SKB MD 600.004 ("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). SKB MD 600.004 and SKB MD 600.006 are both SKB internal controlling documents, see Table 1-1.

4.3 Drilling and measurements during drilling of borehole HFR106

A TUBEX- system (an ODEX-variant) was applied for drilling c. 9 metres into solid bedrock (Figure 4-1).

4.3.1 Drilling through the overburden

TUBEX is a system for simultaneous drilling and casing driving. The method is based on a system with a pilot bit and an eccentric reamer, which produces a borehole slightly larger than the external diameter of the casing tube. This enables the casing tube 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.

4.3.2 Gap injection

The special technique applied in this activity for grouting the casings in boreholes HFR106, was described in Section 3.2.

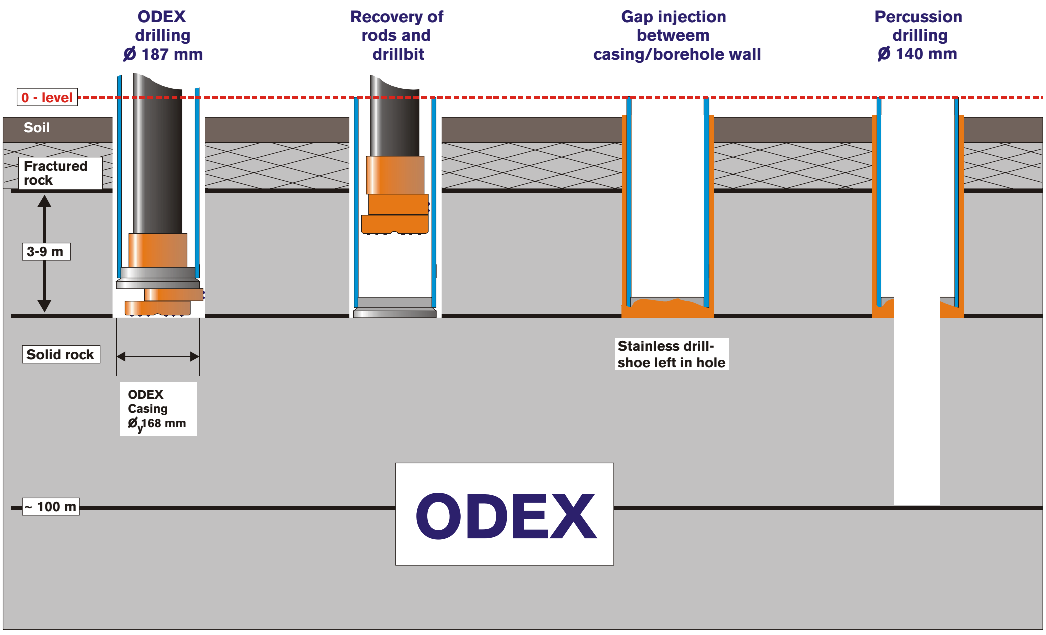


Figure 4-1. The different steps included in the performance of the percussion drilled borehole HFR106.

4.3.3 Percussion drilling in solid rock

After the casing was set, 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. 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 at SFR, and when drilling long boreholes the drill bit has to be grinded at least once before completion of the borehole.

4.3.4 Sampling and measurements during drilling

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

- Collecting one soil sample per metre drilling length. Analysis and results will be reported separately.
- Collecting one sample per 3 metres drilling length of drill cuttings from the bedrock. Each major sample consists of three individual minor samples collected at every metre borehole length, stored in one 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 later examined more thoroughly and interpreted together with a BIPS-log (so called Boremap mapping). The results will be reported elsewhere.
- 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 discharged groundwater flow rate (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 every 3 metres drilling length (noted in a paper record).

The results from the second and third items were used as supporting data for the Boremap mapping mentioned above. The last two items gave on-site information about hydraulic and hydrogeochemical characteristics of the penetrated aquifer at the drill site.

4.4 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 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 flange, which finishes off 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 Deviation measurements

A short time after completed drilling, deviation measurements were carried out with the FLEXIT Smart Tool System. The deviation measurements were carried out at every 3 m, both downwards and upwards. The quality control program of deviation measurements is mostly concentrated to the handling of the instrument as well as to routines applied for the performance. However, it is normally not possible to "calibrate" the deviation measurement instrument, as no boreholes with access to both the borehole collar and the borehole end are available. As a compensating measure, deviation measurements should always be performed at least twice. Two FLEXIT-loggings were made in HFR106, downwards and upwards to 189 m, respectively. The degree of repeatability serves as a quality measure. In the calculation of the final borehole deviation file, which will be "in use" displayed in Sicada (i.e. the exclusive deviation file permitted for data analyses), results from all deviation surveys are included (if not discarded for measurement technical or other quality reasons), see Section 5.5.

Results from the deviation measurements are stored in SKB's database Sicada but are also presented in Section 5.4.

4.6 Data handling

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 where they are traceable by the Activity Plan number.

4.7 Environmental control

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

4.8 Nonconformities

No deviations from the Activity Plan occurred.

5 Results

Prior to drilling of HFR106, the basic drilling programme within Project SFR-Extension had successfully been executed with six cored and three percussion drilled boreholes from the ground surface as well as one cored borehole drilled from the SFR underground facilities.

When the preliminary results were summarized, the geological model indicated a possible, however not verified, near-horizontal fracture zone striking NW-SE that, if existing, could penetrate the preliminary SFR extension layout, see Figure 1-2. At least one cored borehole would be preferable to verify or dismiss this potential zone. As most of the area, the Forsmark harbour area, suitable for drilling boreholes with a potential to penetrate this zone is covered by the sea, off-shore drilling initially seemed to be inevitable. However, a pre-study was initiated aiming at assessing all available possibilities regarding drilling technique (primarily off-shore technique) as well as costs and time consumption for different alternatives regarding drilling in the Forsmark harbour area. Primarily, one inclined cored borehole of 300–400 m length and one inclined percussion borehole of about 200 m length were considered in the pre-study. The result from the study focused on three different alternatives;

- Extension of the existing pier.
- Drilling from an offshore platform.
- Drilling from the islet "Kobben".

The first alternative includes construction of a 300 m long pier perpendicular to the existing pier. That would provide a drill site placed on ground surface, meaning that drilling and measuring activities could follow the standard investigation programme. By using material from the existing pier it could be constructed in six weeks. On the other hand, a facility like this would have to undergo an environmental impact assessment, that probably could demand several years to be approved, and therefore this alternative was excluded.

The second alternative involved drilling from an off-shore located platform. The alternative was judged practicable but cost expensive. Drilling and measurement progress depends on the weather conditions. Furthermore, the borehole will have to be plugged before liquidation of the platform, entailing that a long-time monitoring programme must be left out, implying less data input to the models.

Finally, the third alternative, drilling from a small islet, "Kobben", 225 m SE of the pier at Asphällskulten, involves a flat-bottomed barge for transportation of drilling and measuring equipments. Transportation and establishment of equipment cause increased costs, but on the other hand drilling, measurements and monitoring activities can be performed according to the standard programme for on-land boreholes. Also the environmental demands can be fulfilled by following the standard routines with an announcement to the local government and a building licence from the local community that could be received in not more than about two months.

When the modelling group confirmed that drilling of two boreholes from the islet could cover the lack of data in the Forsmark harbour area and provide sufficient information to be used for different model purposes, the project management decided to choose the third alternative and to conclude the drilling program with these boreholes. Below, a summary of the site preparation and data acquired during drilling of and measurements in the first borehole drilled on "Kobben", the percussion borehole HFR106, is presented.

5.1 Preparation of the drill site

In early May 2009, when the location and orientation of the cored borehole KFR106 and the percussion borehole HFR106 were settled, the practical preparations continued with building of a temporary slope at the end of the pier at Asphällskulten, see Figure 5-2. The end of the pier offers a lot of space and could be used as a temporary storage for the equipments before they were shipped to the islet "Kobben".

Figure 5-1. *Overview of the surroundings at the Forsmark harbour area and SFR. The new drill sites for percussion borehole HFR106 and the cored borehole KFR106 are located on the islet "Kobben".*

Figure 5-2. *At the end of the pier at Asphällskulten a temporary slope was built in order to easily load or un-load the barge.*

In mid June 2009, a flat-bottomed barge was contracted for three weeks, and started to carry gravel and a bucket loader from the pier to the islet for building a temporary slope on the northern part of the islet. Gravel was also used to level the rock surface on vital parts for smoother transportation on the rocky islet, see Figure 5-3.

Figure 5-3. *Also at the islet "Kobben" a temporary slope was built of gravel carried from the pier with the barge. A bucket loader is stationed on the islet in order to load and un-load the barge.*

After these introductory measures, the percussion rig with appurtenant equipment was established onto the islet, see Figure 5-4. At the same time as pre-drilling of KFR106 and percussion drilling of HFR106 was performed, most of the core drilling equipment planned to be used for drilling of KFR106 as well as measurement equipment for investigation of the two boreholes were carried to the islet. As the SFR-Extension project is the only currently on-going field project, most of the SKB owned measurement instruments are presently available, e.g. the BIPS/radar- and HTHB-instruments (the latter used for flow measurement in percussion boreholes). Also these instruments were stationed at the islet, giving more flexibility in time to execute the measurements, see Figure 5-5.

Figure 5-4. *The percussion drilling rig arrives to the islet. The air-compressor was left on the pier and supports the rig through a hose floating on the water.*

***Figure 5-5.** Two drilling rigs including all measurement equipment were successfully transported to the islet. To minimize the number of establishments of the flat-bottomed barge, also measurement instruments as BIPS/ radar, flow logging and air-flushing equipment were shipped to the islet during the first three weeks.*

Finally, when drilling of borehole HFR106 was completed at 190.40 m length, the barge could re-establish the percussion rig to the pier. A flat-bottomed barge is sensitive for strong wind and despite a couple of days standstill the work followed the time schedule. Therefore, in early July the main part of the field crew could leave for a well-deserved summer vacation.

For the daily transports of SKB staff and the drill crew, an all-around boat supplied with an outboard engine was used, that easily could find lee on either side of the island, depending on current weather conditions.

5.2 Overview of the drilling of HFR106

Figure 5-6 illustrates the logistics during drilling of HFR106 and the separate sub-activities versus time, such as drilling, casing driving, grouting, and measurements while drilling. The horizontal axis represents real time and the vertical is the length of the borehole during the activity.

5.3 Geometrical design of the percussion drilled borehole

Administrative, geometric, and technical data for HFR106 is presented in Table 5-1. The technical design of the borehole is illustrated in Figure 5-7.

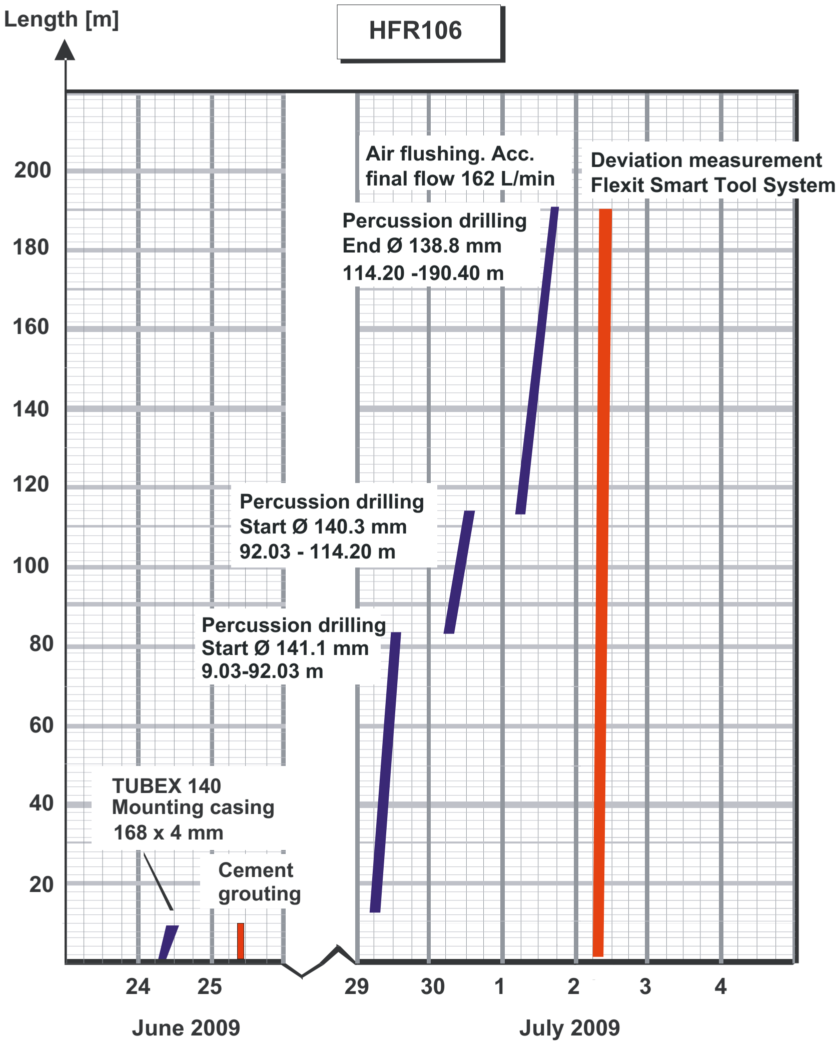
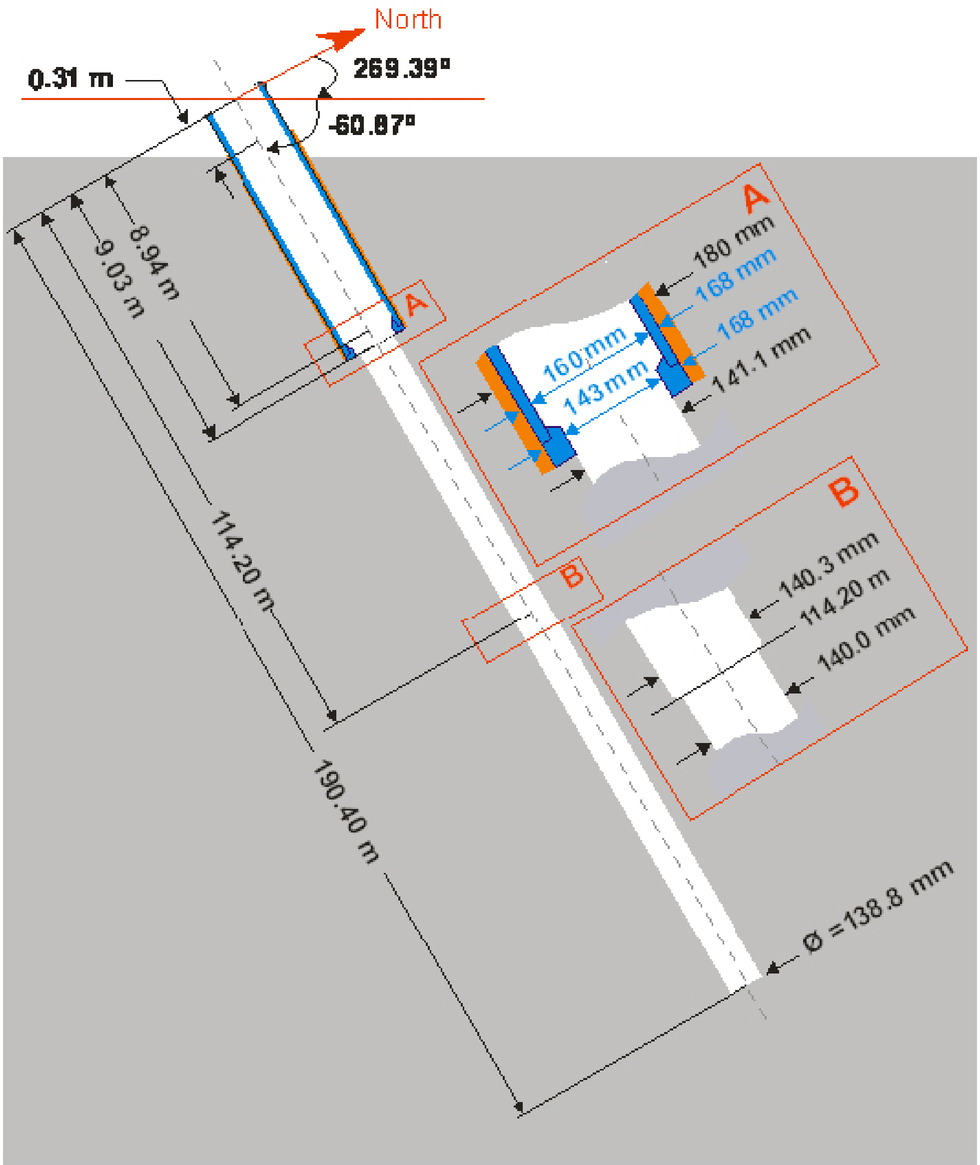


Figure 5-6. Overview of the drilling progress for percussion borehole HFR106.

Table 5-1. Administrative, geometric and technical data for borehole HFR106.

Parameter	HFR106
Drilling period	From 2009-06-24 to 2009-07-02
Borehole inclination (collaring)	–60.87° (– = downwards)
Borehole bearing	269.39°
Borehole length	190.40 m
Borehole diameter	From 0.00 m to 9.03 m: 0.180 m From 9.03 m to 114.20 m: decreasing from 0.1411 m to 0.1403 m From 114.20 m to 190.40 m: decreasing from 0.1403 m to 0.1388 m
Casing length	9.03 m
Casing diameter	$Ø_o/Ø_i$ = 168 mm/160 mm
Drill bit diameter	Start of drilling: 0.1411 m End of drilling: 0.1388 m
Collaring coordinates (system RT90 2.5 gon V/RHB70)	Northing: 6701574.11 m Easting: 1633579.85 m Elevation: 1.27 m RBH70

Technical data
Borehole HFR106



Drilling reference point
Northing: 6701574.11 (m), RT90 2,5 gon V 0:-15
Easting: 1633579.85 (m), RT90 2,5 gon V 0:-15
Elevation: 1.27 (m), RHB 70

Drilling period
Drilling start date: 2009-06-24
Drilling stop date: 2009-07-02

rev 2010-01-08

Figure 5-7. *Technical data of borehole HFR106.*

5.4 Consumables used in HFR106

The amount of oil products consumed during drilling of borehole HFR106, and grout used for gap injection of the casing is reported in Table 5-2. The cement was a mixed type of Standard Cement and Calcium Chloride in proportions according to Table 5-3.

Table 5-2. Oil consumption during drilling.

Borehole ID	Hammer oil (preem Hydra 40)	Compressed oil (Schuman 40)
HFR106	10 L	Not detectable consumption

Table 5-3. Consumption of cement for grouting.

Borehole ID	Casing length [m]	Cement weight (Standard cement/Calcium chloride)	Grouting method (See under 3.2 for method description)
HFR106	0.31–9.03	50 kg/1 kg	Borehole packer

5.5 Deviation measurements

The principal method applied for deviation measurements in percussion drilled boreholes is based on magnetic accelerometer technique. For borehole HFR106, the FLEXIT Smart tool system was used.

To ensure high quality measurements with the Flexit tool, the disturbances (variations) of the global magnetic field must be small during the period of measurements. Regular registrations of the global magnetic field are made at a number of measurement stations all over the world. For magnetic field values that apply for Forsmark with surroundings, a measurement station in Sodankylä, Finland, provides one-minute magnetic field values that are available on the Internet at www.intermagnet.org and gives sufficient information. The magnetic field variations during the two Flexit surveys in HFR106 on July 2nd 2009 are shown in Figure 5-8 and display only minor disturbances.

The principles of the equipment for and performance of deviation measurements were explained in Sections 3.3 and 4.5, respectively. In the following a description of the construction of deviation data for the percussion drilled borehole HFR106 is given.

The deviation data used for construction of the final deviation file are the two FLEXIT-loggings to 189 m borehole length, see Table 5-4. With the FLEXIT Smart Tool System, the deviation measurements were carried out every 3 m both downwards and upwards. The used activity marked "CF" also includes comments as well as a file describing the measures that have been applied during the measurements and data treatment.

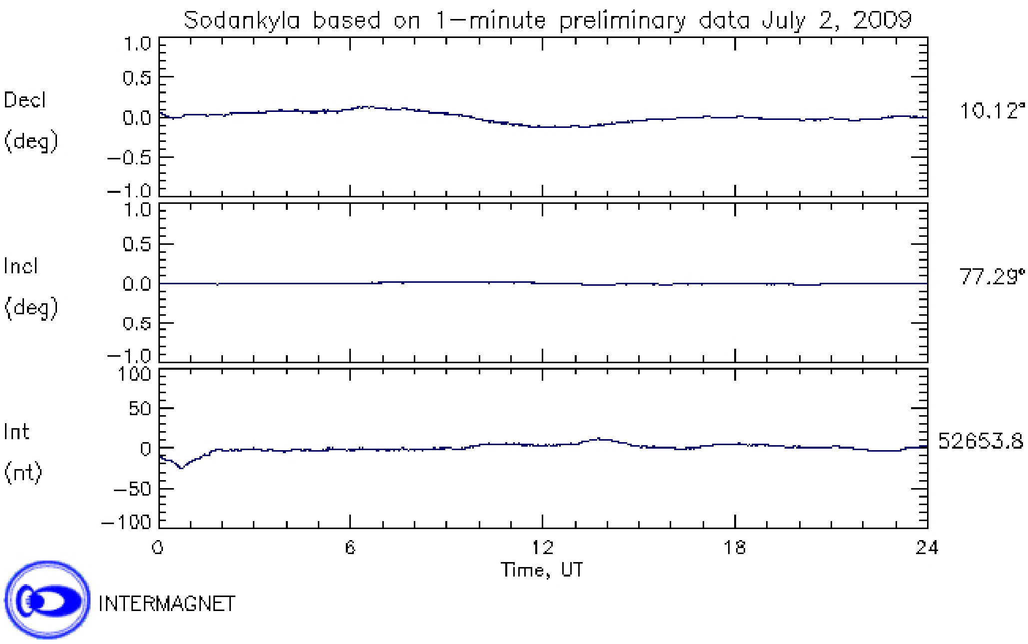


Figure 5-8. Magnetic field variation during FLEXIT surveys performed on July 2nd 2009 in HFR106.

Table 5-4. Activity data for all deviation measurements approved for HFR106 (from Sicada). Two magnetic measurements in the borehole were used for calculation of the final borehole deviation file, as well as for calculation of the deviation uncertainty.

Activity ID	Activity Type Code	Activity	Start date	Idcode	Secup (m)	Seclow (m)	Flags
13228442	EG157	Magnetic – accelerometer measurement	2009-07-02 14:18	HFR106	3.00	189.00	CF
13228443	EG157	Magnetic – accelerometer measurement	2009-07-02 15:15	HFR106	3.00	189.00	CF
13228448	EG154	Borehole deviation multiple measurements	2009-07-03 13:00	HFR106	3.00	189.00	ICF

The two magnetic accelerometer surveys in the borehole have followed the recommended quality routines according to SKB MD 224.001, Version 2.0 (see Table 1-1). This file is termed EG154 (Borehole deviation multiple measurements). See illustration of the construction principle in Figure 5-9.

The EG154-activity specifies the sections of the deviation measurements used in the resulting calculation presented in Table 5-5. The different lengths of the upper sections between the bearing and the inclination are chosen due to that the magnetic accelerometer measurement (bearing) is influenced by the 9 m steel casing which is not the case for the inclinometer measurements (inclination).

Table 5-5. Contents of the EG154 file (multiple borehole deviation intervals).

Activity ID	Deviation Angle Type	Approved Secup [m]	Approved Seclow [m]
13228442	Bearing	12.00	189.00
13228442	Inclination	3.00	189.00
13228443	Bearing	12.00	189.00
13228443	Inclination	3.00	189.00

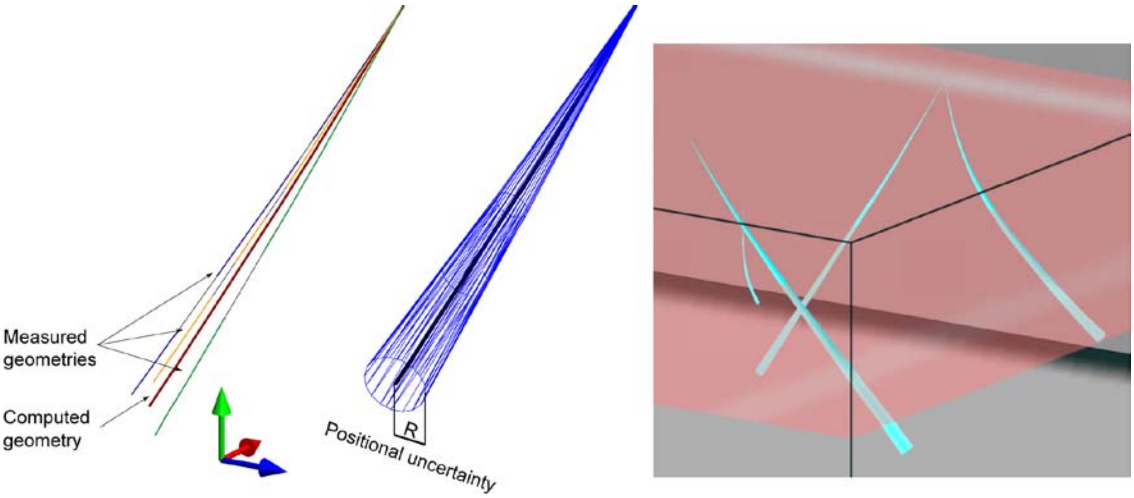


Figure 5-9. The figure to the left is an illustration of the principles for calculating the borehole geometry from several deviation measurements. The two other figures illustrate one of the uncertainty measures used for deviation measurements. In the middle figure, "R" denotes "Radial uncertainty", representing a function, which is monotonously increasing versus borehole length in relation to the borehole axis, defining the shape of a cone surrounding the borehole axis and corresponding to the parameter in the column furthest to the right in Tables 5-6 and 5-7. The figure to the right is a block diagram imaging four fictitious boreholes deviating in different ways and with radius uncertainty illustrated as blue cones (modified after Figures 4-1, 5-1 and 5-3 in Munier and Stigsson /3/).

A subset of the resulting deviation files and the estimated radius uncertainty is presented in Tables 5-6 and 5-7. Figure 5-9 illustrates the principles behind computing the borehole deviation, i.e. the borehole geometry, from several measurements, and also displays the concept of radial uncertainty.

The calculated deviation (EG154-file) in borehole HFR106 indicates that the borehole deviates upwards and to the right with an absolute deviation of 23 m compared to an imagined straight line following the dip and strike of the borehole start point.

The "absolute deviation" is here defined as the shortest distance in space between a point in the borehole at a certain borehole length and the imaginary position of that point if the borehole had followed a straight line with the same inclination and bearing as of the borehole collaring.

Table 5-6. Deviation data from HFR106 for approximately every 21 m borehole length calculated from EG154. Coordinate system RT90 2.5 gon V 0:-15/RHB 70.

Borehole	Length [m]	Northing [m]	Easting [m]	Elevation [m]	Inclination* [degrees]	Bearing [degrees]
HFR106	0.00	6701574.11	1633579.85	1.27	–59.78	269.39
HFR106	21.00	6701574.02	1633568.94	–16.67	–57.73	269.64
HFR106	42.00	6701573.86	1633557.49	–34.27	–56.06	270.86
HFR106	63.00	6701574.23	1633545.50	–51.50	–54.52	271.66
HFR106	84.00	6701574.64	1633533.14	–68.48	–53.41	272.35
HFR106	105.00	6701575.27	1633520.41	–85.17	–51.82	273.05
HFR106	126.00	6701576.03	1633507.40	–101.64	–52.01	274.25
HFR106	147.00	6701577.09	1633494.63	–118.27	–52.81	275.28
HFR106	171.00	6701578.44	1633480.35	–137.51	–53.24	275.67
HFR106	189.00	6701579.50	1633469.67	–151.97	–53.59	276.09
HFR106	190.40	6701579.59	1633468.85	–153.09	–53.59	276.09

* The starting values of inclination and bearing in EG154 are calculated and could therefore show a discrepancy against the values seen in Borehole direction surveying (EG151).

Table 5-7. Uncertainty data for the deviation measurements in HFR106 for approximately every 21 m borehole length calculated from EG154. Coordinate system RT90 2.5 gon V 0:-15/RHB 70.

Borehole	Northing [m]	Easting [m]	Elevation [m RHB70]	Inclination uncertainty	Bearing uncertainty	Radius uncertainty
HFR106	6701574.11	1633579.85	1.27	0.065	0.450	0.00
HFR106	6701574.02	1633568.94	–16.67	0.065	0.450	0.09
HFR106	6701573.86	1633557.49	–34.27	0.065	0.450	0.18
HFR106	6701574.23	1633545.50	–51.50	0.065	0.450	0.27
HFR106	6701574.64	1633533.14	–68.48	0.065	0.450	0.37
HFR106	6701575.27	1633520.41	–85.17	0.065	0.450	0.47
HFR106	6701576.03	1633507.40	–101.64	0.065	0.450	0.57
HFR106	6701577.09	1633494.63	–118.27	0.065	0.450	0.67
HFR106	6701578.44	1633480.35	–137.51	0.065	0.450	0.78
HFR106	6701579.50	1633469.67	–151.97	0.065	0.450	0.87
HFR106	6701579.59	1633468.85	–153.09	0.065	0.450	0.87

5.6 Hydrogeolgy

5.6.1 Observations during drilling

During drilling and sampling in borehole HFR106, the first water inflow of 14 L/min was encountered at c. 43 m drilling length. The electrical conductivity of the groundwater (EC-value) rises immediately to 800 mS/m (see Figure 5-10). When drilling continued, the accumulated groundwater inflow successively increased to c. 120 L/min, while the EC-value is stable at 850 mS/m. However, when the inflow increased to 162 L/min at 181 m drilling length the EC-value also increased rapidly to 950 mS/m, indicating more saline water inflow at depth.

Figure 5-11 provides an impression of the environmental and technical conditions during drilling of HFR106.

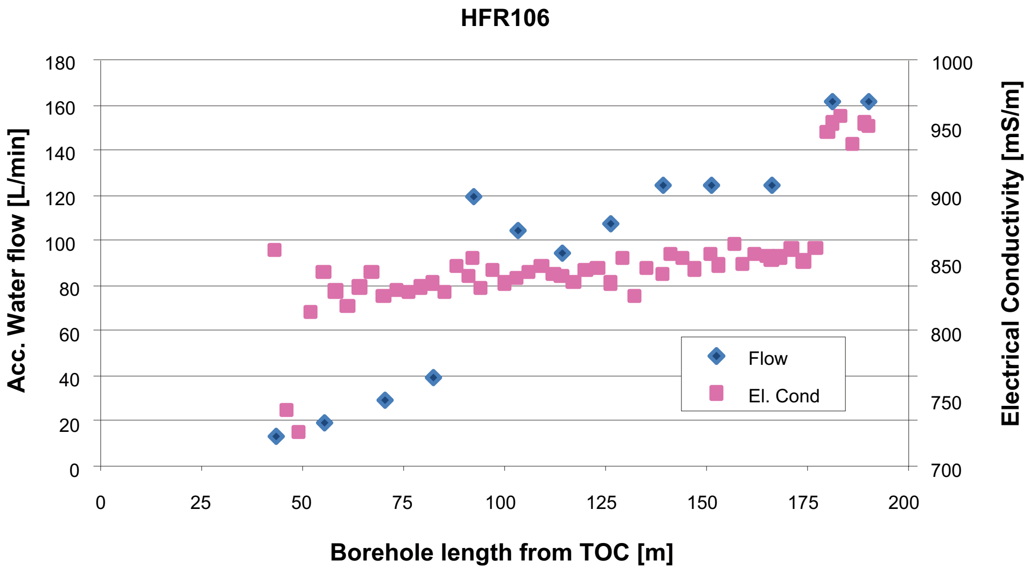


Figure 5-10. *Electrical conductivity and accumulated groundwater flow rate versus drilling length in HFR106.*

Figure 5-11. *An overview of the percussion drilling of HFR106. The accumulated groundwater inflow is constantly flushed from the borehole to a container during drilling. After sampling and sedimentation in the container the water is led to the sea.*

6 References

/1/ **SKB, 2008.** Geovetenskapligt undersökningsprogram för utbyggnad av SFR (Investigation programme for the extension of SFR). SKB R-08-67, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2008.** Site investigations. Investigation methods and general execution programme. SKB TR-01-29, Svensk Kärnbränslehantering AB.

/3/ **Munier R, Stigsson M, 2007.** Implementation of uncertainties in borehole geometries and geological orientation data in Sicada. SKB R-07-19, Svensk Kärnbränslehantering AB.

Well Cad presentation of percussion drilled borehole HFR106

Title PERCUSSION DRILLED BOREHOLE HFR106

Svensk Kärnbränslehantering AB

Site	FORSMARK - SFR	Coordinate System	RT90-RHB70
Borehole	HFR106	Northing [m]	6701574.11
Diameter [mm]	139	Easting [m]	1633579.85
Length [m]	190.40	Elevation [m]	1.27
Azimuth [°]	269.39	Drilling Start Date	2009-06-24
Inclination [°]	-59.77	Drilling Stop Date	2009-07-02
		Plot Date	2010-01-07

ROCK TYPE

- Granite, fine- to medium-grained
- Pegmatite, pegmatitic granite
- Granite to granodiorite, metamorphic, medium-grained
- Felsic to intermediate volcanic rock, metamorphic

Note 1. Difference between the azimuth value at each 3 m length and the azimuth value of the borehole collar.
Note 2. Difference between the inclination value at each 3 m length and the inclination value of the borehole collar.
Note 3. The uncertainty of the borehole location, which defines the shape of a cone surrounding the borehole.