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Drilling of cored borehole KLX16A

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Abstract

Borehole KLX16A is located in the Laxemar subarea. Drilling was made between November 2006 and January 2007 as a part of the site investigation for a possible repository for spent nuclear fuel in Oskarshamn municipality, Sweden. KLX16A was the twenty-first deep cored borehole within the site investigation in Oskarshamn.

KLX16A was core drilled to a length of 433.55 metres with N-size (76 mm) equipment.

One open hole pumping test and four successful wireline tests were made in KLX16A. The resulting transmissivities (T_M) varied between 8.5×10^{-5} and 6.0×10^{-8} m^2/s. The most transmissive section was between 109 and 203 metres.

Continuous monitoring of drilling parameters and flushing water parameters with the drilling monitoring system was conducted throughout the core drilling phase in KLX16A.

Four water samples for chemical analysis were collected during the core drilling of KLX16A.

The air-lift pumping test in the telescopic section performed when borehole KLX16A was core drilled to its full length gave a transmissivity (T_M) of 2.1×10^{-4} m^2/s.

Lithologically the core is dominated Quartz monzodiorite with intercalations of other rock types. The contact towards the Ävrö granite was not intercepted in the borehole.

Rock alteration is mostly weak and reasonably common in the interval 250 to 410 m.
The altered interval also coincides with elevated fracture frequency.

The average fracture frequency in KLX16A is 2.98 (fractures/metre) expressed as open fractures.

Sammanfattning

Borrhål KLX16A ligger inom delområde Laxemar. Borrningen utfördes mellan november 2006 och januari 2007 som ett led i platsundersökningen för ett möjligt djupförvar för använt kärnbränsle i Oskarshamns kommun. KLX16A var det tjugoförsta djupa kärnborrhålet inom platsundersökningen i Oskarshamn.

KLX16A kärnborrades med borrstorlek N (76 mm) till 433,55 meters borrad längd.

Ett pumptest i öppet borrhål samt fyra lyckade wireline tester gjordes i KLX16A. De uppmätta transmissiviteterna (T_M) varierade mellan $8{,}5 \times 10^{-5}$ och $6{,}0 \times 10^{-8}$ m^2/s. Den mest transmissiva sektionen var mellan 109 och 203 meter.

Kontinuerliga mätningar av borrningsparametrar och spolvattenparametrar via DMS (**d**rilling **m**onitoring **s**ystem) gjordes under hela kärnborrningsfasen i KLX16A.

Fyra vattenprover för kemisk analys togs i samband med borrning i KLX16A.

Mammutpumpningen (avsänkning med tryckluft eller ”air-lift pumping”) som gjordes när kärnborrningen i KLX16A utförts till full längd gav en transmissivitet (T_M) på $2{,}1 \times 10^{-4}$ m^2/s.

Litologiskt domineras kärnan av kvartsmonzodiorit med inslag av andra bergarter. Kontakten mot Ävrögranit påträffades inte i borrhålet.

Bergartsomvandling är oftast svag och ganska vanlig i intervallet 250 till 410 m. Det omvandlade intervallet sammanfaller med förhöjd sprickfrekvens.

Den genomsnittliga sprickfrekvensen i KLX16A är 2,98 (sprickor/meter) uttryckt som öppna sprickor.

Contents

1 Introduction

SKB, the Swedish Nuclear Fuel & Waste Management Company, performs site investigations in order to evaluate the feasibility of locating a deep repository for spent nuclear fuel /1 and 2/. The investigations are performed in two Swedish municipalities: Östhammar and Oskarshamn. Borehole KLX16A is located south of the Laxemar subarea of the investigation area in Oskarshamn, as defined by the programme for further investigations /2/. The decision to proceed with drilling and investigations in KLX16A was taken at a planning meeting that included representatives from the Site Investigation, Modelling Group, Design Group and Project Management (SUMP#9, doc id 1063268, 2006-11-08, SKB internal document).

Drilling and investigations in boreholes are fundamental activities in order to facilitate characterisation of rock and groundwater properties at depth. KLX16A was the twenty-first deep cored borehole within the Oskarshamn site investigation. The location of the core drilled borehole and the water source, HLX10 in the Laxemar subarea is shown in Figure 1-1.

The drilling of KLX16A and all related on-site operations were performed according to a specific activity plan, which in turn refers to a number of method descriptions, see Table 1-1.

The activity plans and method descriptions are SKB internal documents.

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

Activity plan	Number	Version
Kärnborrning KLX16A	AP PS 400-06-133	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning	SKB MD 620.003	2.0
Metodbeskrivning för hydrauliska enhålstrester	SKB MD 321.003	1.0
Metodbeskrivning för registrering och provtagning av spolvattenparametrar samt borrkax under kärnborrning	SKB MD 640.001	1.0
Metodbeskrivning för vattenprovtagning, pumptest och tryckmätning i samband med wireline-borrning	SKB MD 321.002	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Instruktion för användning av kemiska produkter och material vid borrning och undersökningar	SKB MD 600.006	1.0
Instruktion för borrplatsanläggning	SKB MD 600.005	1.0
Instruktion för spolvattenhantering	SKB MD 620.007	1.0
Instruktion för utsättning och ansättning av hammar och kärnborrhål	SKB MD 600.002	1.0
Instruktion för längdmarkering i kärnborrhål	SKB MD 620.009	2.0
Instruktion för hantering och provtagning av borrkärna	SKB MD 143.007	1.0
Metodbeskrivning för krökningsmätning av hammar- och kärnborrhål	SKB MD 224.001	1.0
Instruktion för miljökontroll av ytvatten, ytnära grundvatten och mark vid borrning och pumpning i berg	SKB MD 300.003	3.0
Metodbeskrivning för jordborrning	SKB MD 630.003	1.0

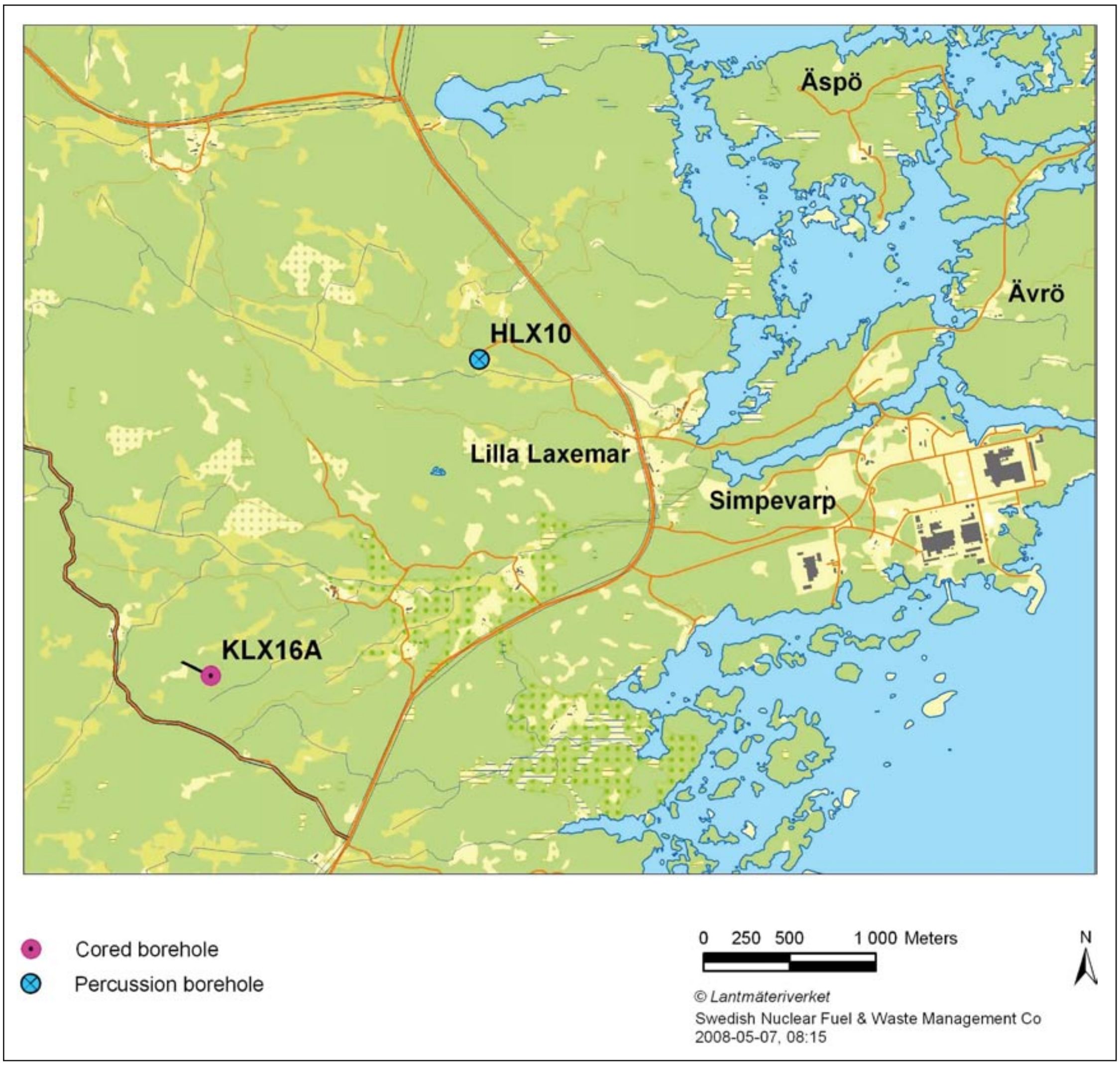


Figure 1-1. Location of borehole KLX16A and the water source, percussion borehole HLX10 in the Laxemar subarea.

2 Objective and scope

This report will describe the methods employed and the results achieved during the drilling of borehole KLX16A. A number of related activities, such as hydraulic tests, water sampling and monitoring of drilling parameters that were performed in conjunction with the core drilling in KLX16A will also be reported here.

The initial purpose for drilling the borehole KLX16A was to gain geometrical information about the lithological contact between the Quartz monzodiorite and Ävrö granite in the southern part of the Laxemar subarea. Additional objectives were to gather knowledge of the modelled deformation zone NE107 and the Quartz monzodiorite as a rock unit. The decision to drill KLX16A is given in SKB ID no 1064187, dated 2006-11-23.

A list of formal communications with authorities including the notification to the Regional Authorities (Länsstyrelsen) in accordance with the Environmental Code is given in Table 2-1.

Table 2-1. Formal communication with authorities for KLX16A.

	SKB ID	Date
Notification to Regional Authorities for KLX16A in accordance with the Environmental Code*	1060852	2006-09-29
Heritage assessment from the National Heritage Board (Riksantikvarieämbetet)	1062305	2006-10-23
Supplementary information to Regional Authorities	1064200	2006-10-25
Permit application according to the Cultural Heritage Act (Kulturminneslagen)	1063141	2006-11-02
Permission according to the Cultural Heritage Act (Kulturminneslagen)	1063444	2006-11-10

* NB The planned borehole name was different at the time of writing. The area is nevertheless the same.

3 Overview of the drilling method, measurements and water handling

Core drilling of KLX16A was done with normal wireline triple tube equipment, i.e. the SKB telescope type drilling method with air-lift pumping during core drilling was not used. After installation of casing through the overburden, core drilling was done with N-size (76 mm diameter) to full length.

During the core drilling phase several measurements and sampling exercises are performed through the drilling monitoring system (DMS), wireline tests for hydraulic purposes and sampling for water chemistry.

After the core drilling is completed to full length, depth reference slots are reamed in the borehole wall.

3.1 The flushing water system

The handling of flushing water includes a source of water with a submersible pump and tanks. The return water is led to settling containers before discharge, see Figure 3-1.

Nitrogen gas is bubbled through the drilling water to remove dissolved oxygen. This is done to avoid introduction of oxygen to the formation water and thereby disturbing the pristine chemical properties.

In order to monitor possible mixing of formation and drilling water, a tracer dye (uranine) is added to the drilling water to a fixed concentration, see Figure 3-2.

3.2 Measurements and sampling during drilling

The sampling and measurements during the core drilling phase of KLX16A consisted of:

- Wireline measurements.
- Hydraulic tests during air-lift pumping.
- Water sampling at the surface.
- The drilling monitoring system.

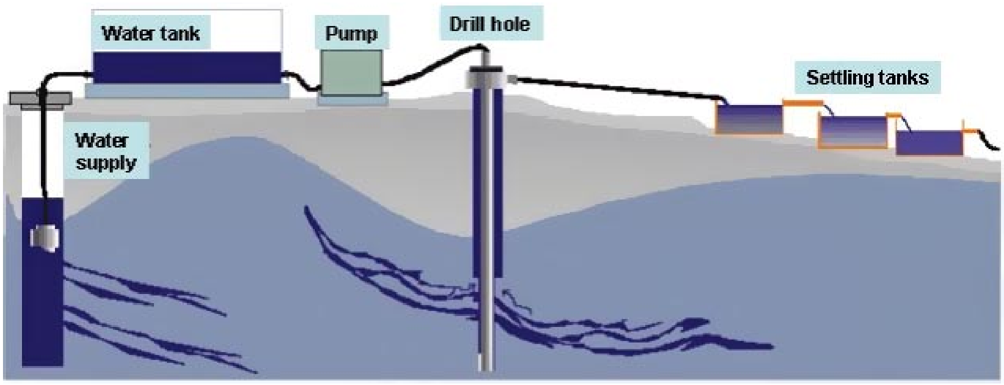


Figure 3-1. The flushing water system from source to discharge point.

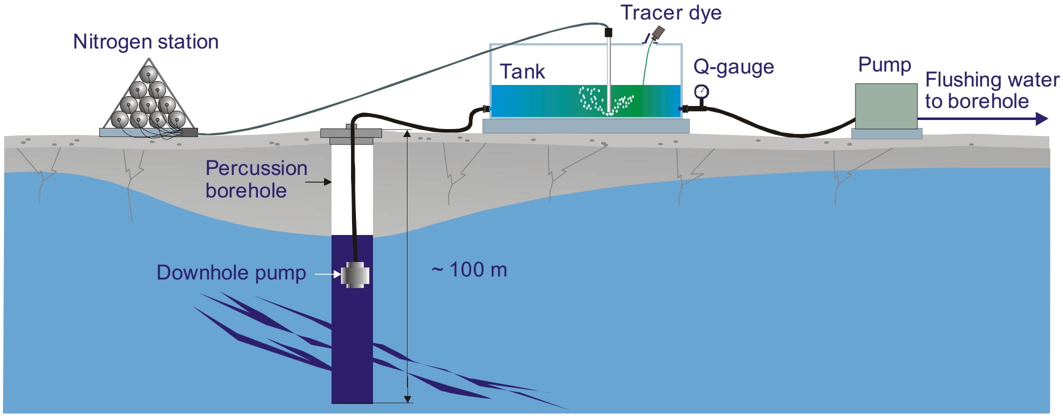


***Figure 3-2.** Schematic drawing of the preparation of flushing water. Uranine is added to the water as a tracer dye and nitrogen is bubbled through the water to remove dissolved oxygen.*

Wireline measurements and water sampling

The measurements and the sampling are made in the borehole with a wireline based equipment. Pumping tests are evaluated according to Moye /3/ and are normally performed for every 100 m of drilled length. Sampling of water for chemical analysis is done in conjunction with the pumping tests where feasible. The wireline tests are done in accordance with SKB Method Description MB 321.002, SKB internal document.

NB Measurementsof absolute pressure were not done in KLX16A.

Air-lift pumping with evaluation of drawdown and/or recovery

Air-lift pumping with evaluation of drawdown was normally done with 300 m intervals in the deeper boreholes of the site investigation, but in KLX16A it was done at 213 m and full drilled length. The actual levels are adapted to when changes of drill bit, or some other reason to raise the drill stem, occur. The test is normally based on the drawdown phase.

The normal procedure of air-lift pumping that is done in the telescopic section of a borehole had to be modified since KLX16A was drilled without a telescopic section. The method of drilling telescopic boreholes is described in several SKB drilling reports, see for instance the drilling of KLX05 or KLX12A /4 and 5/.

The method for air-lift pumping in KLX16A was as follows:

- The drill stem was removed and a temporary plastic inner tube was inserted to the bottom of the borehole. A pressure transducer for logging of the water level is lowered into the borehole.
- Compressed air was pumped into the tube thereby removing water from the borehole. The water flow is measured via the DMS system.
- Air-lift pumping continues between 30 minutes and two hours to achieve stable conditions.
- The air-lift pumping is stopped.
- The recovery of the water table in the borehole is monitored.

Water sampling at the surface

Water samples of flushing and return water, i.e. the water entering and returning from the borehole at the surface, are taken at 10 to 20 metre intervals of drilled length for analysis of drilling water content (percentage of water with uranine tracer content) and electrical conductivity.

Drilling monitoring system (DMS)

Drilling is monitored on-line by continuous registration of drill rig and flushing water parameters in accordance with the method description for registration and sampling of flushing water parameters during drilling (SKB MD 640.001) and the method description for quality assurance of DMS-data (SKB MD 640.008). The method descriptions are SKB internal documents. The data is compiled into a database called **d**rilling **m**onitoring **s**ystem (DMS).

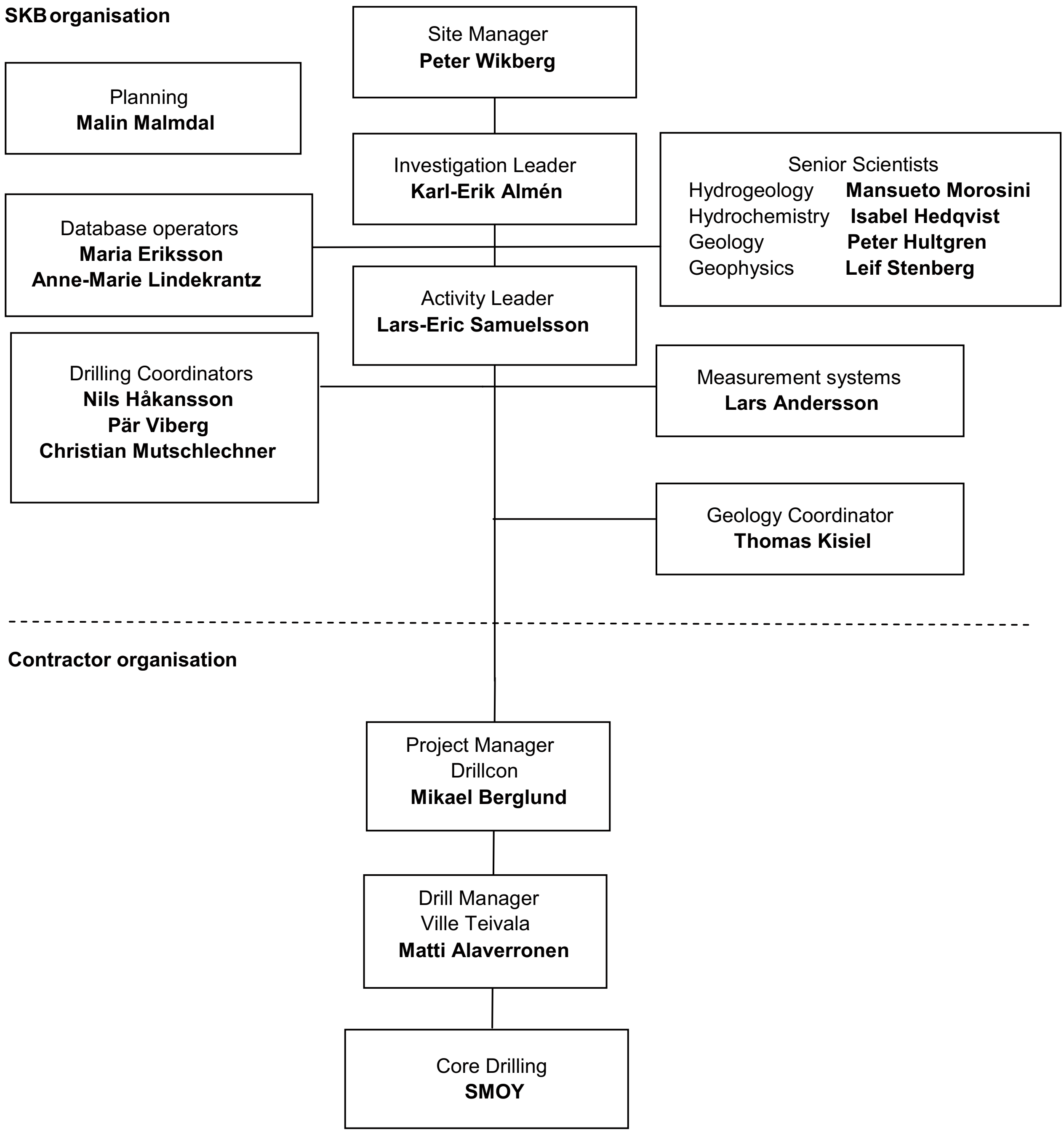
4 Contractors and equipment

4.1 Contractors

The main contractor for the drilling in both KLX16A was Drillcon Core AB, with subcontractor for core drilling Suomen Malmi OY (SMOY).

An overview of the organisation for the drilling activity is given in Table 4-1.

Table 4-1. Drill activity organisation.



4.2 Core drilling equipment

Core drilling in KLX16A was made with a Diamec U8 APC Atlas Copco Craelius fully hydraulic machine fitted with a modern and environmentally adapted diesel engine. The drilling was done with N-size, i.e. giving a borehole of 76 mm diameter. The core barrel was of the type AC Corac N3/50, a triple-tube wireline equipment which gives a core diameter of 50.2 mm. The rods were of type NT. Directional drilling was not made in KLX16A.

The drill rig was fitted with a diesel power generator of 175 kW which would give a capacity for drilling to a depth of ca 1,500 m with N-size drilling.

4.2.1 Measurements with wireline probe

The wireline probe has been developed by SKB. With this equipment water sampling, pump tests and measurements of absolute pressure in a borehole section can be made without having to lift the drill stem.

Measurements are made as specified in method description SKB MD 321.002, SKB internal document.

The principal components are:

- An inflatable packer.
- Pressure gauges for the test section and for the packer.
- A water sampler.
- A submersible pump (placed in the upper part of the drill stem).
- A flow meter (placed at the ground surface).

The probe is lowered through the drill stem into position at the drill bit. The test section is between the lower end of the packer and the bottom of the borehole, see Figure 4-1.

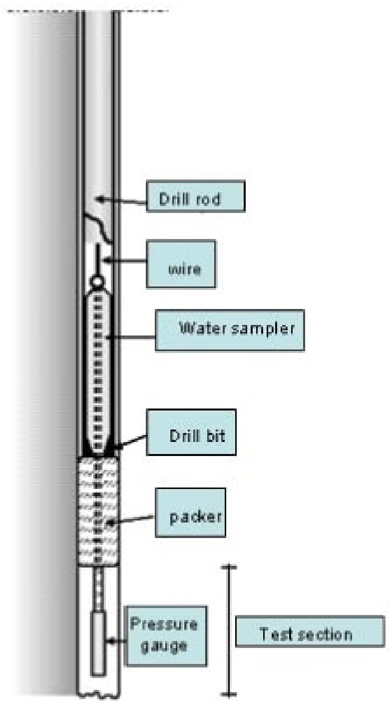


Figure 4-1. *The wireline probe and its emplacement in the hole.*

Before the pumping tests are made leakage tests of the drill string are done.

Hydraulic tests performed during drilling are generally affected to some degree by disturbances caused by the drilling operations. Transients from changes in pressure, temperature and salinity might affect the hydraulic response curves.

Pumping tests

The wireline probe is emplaced at the bottom of the drill stem. A submersible pump (Grundfoss MP1 or equivalent) is lowered into the upper part of the drill stem at a length of about 40 m. The test section is hydraulically connected to the drill stem by opening a valve at a predetermined pressure. This creates a passage between the test section and the water column in the drill stem. The packer remains expanded during the entire test. Water is pumped from the drill stem and the pressure in the test section and packer are recorded in a data logger. The pumped surface flow rate is recorded in a data logger on the ground surface. The pressure gauge (or pressure transducer) is situated 1.10 m below the lower end of the packer. The test consists of a pressure drawdown phase and a recovery phase. Typically the pumping time is three hours with a recovery phase of the same duration. However, the duration is sometimes adapted to the hydraulic situation of the tested section. The tests are normally carried out in sections of about 100 m length.

Water sampling

The equipment for water sampling is the same as for the pumping tests. The water volume in the section is removed at least three times by pumping water out of the drill stem. The water in the test section is then replaced by formation water and a sample is collected. The wireline probe, with the sampling unit containing a maximum volume of 5 litres, is subsequently brought to the surface.

Pumping tests and water sampling are normally performed as an integrated activity. The aim is to characterize the hydrochemistry as well as the hydrology in the bedrock when the conditions are least affected by hydraulic short circuiting in the borehole.

Absolute pressure measurement

No measurements of absolute pressure were done in KLX16A.

4.2.2 Drilling monitoring system

During the core drilling phase continuous monitoring was made of several measurement-while-drilling (MWD) parameters and flushing water parameters. The data is compiled into the DMS database. The procedure for data handling and quality assurance is given in method description SKB MD 640.008 (SKB internal document).

The drill rig (MWD) parameters include:

- Rotational pressure (bar).
- Bit force (kN).
- Flush water flow in (L/min).
- Water pressure at bit (kPa).
- Rotation (rpm).
- Penetration rate (cm/min).

The flushing water parameters include:

- Water level in the telescope part of the borehole (kPa).
- Oxygen level of flushing water (mg/L).
- Flow of flushing (ingoing) and return (outgoing) water (L/min).
- Electrical conductivity of flushing and return water (mS/m).
- Barometric pressure (kPa).

Data from on-line monitoring of flushing water parameters were stored on two different logging units (CR10 and CR23). A separate logging unit was used for the measurement-while-drilling (MWD) dataset. The data from the loggers was downloaded either continuously (CR10 and CR23) or by disk to the DMS database.

4.2.3 Deviation measurements

Two types of deviation measurements were made:

- Measurements to keep track on the borehole orientation were made with the magnetometer/accelerometer method Reflex EZ-AQ/EMS (or EZ-Shot), see also Table 5-2 and section 5.3.3.
- Final measurements, along the entire length of the borehole after the drilling was completed, were made with two methods, Flexit and Maxibor. The Maxibor (Reflex **MAXIBOR™**) is a non-magnetic, optical method. The Flexit instrument (Flexit SmartTool) is based on magnetometer/accelerometer measurements.

4.2.4 Equipment for reaming reference slots

In order to establish accurate and similar depth references for the various measurements that will be performed in the borehole, reference slots are reamed in the borehole wall.

The equipment has been developed by SKB and consists of a reaming tool that can be fitted to conventional drilling rods for 56 and 76 mm drilling equipment. The reaming tool is operated hydraulically from the surface, so that the cutters expand when the water pressure is increased.

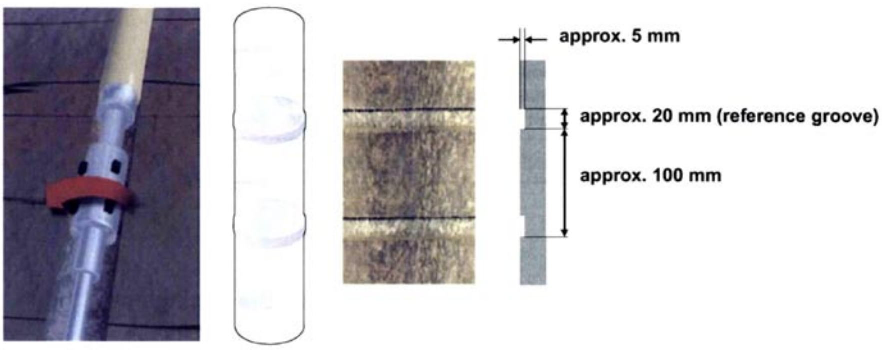


***Figure 4-2.** The equipment for reaming of reference slots. To the left, the reaming tool with openings for the cutters is shown. The resulting reference slots are illustrated in the three pictures to the right.*

5 Execution and results

The original data and results are stored in the Sicada database. Only the datasets in the database will be used for further interpretation and modelling. The data is traceable in Sicada by the Activity Plan number AP PS 400-06-133 for KLX16A.

5.1 Drilling summary

A technical summary of the drilling of KLX16A is given in Table 5-1. A graphical presentation of the borehole after completion is given in Figure 5-1. A summary of drilling progress and borehole measurements is given in Table 5-2 and chronological summary is presented in Table 5-3.

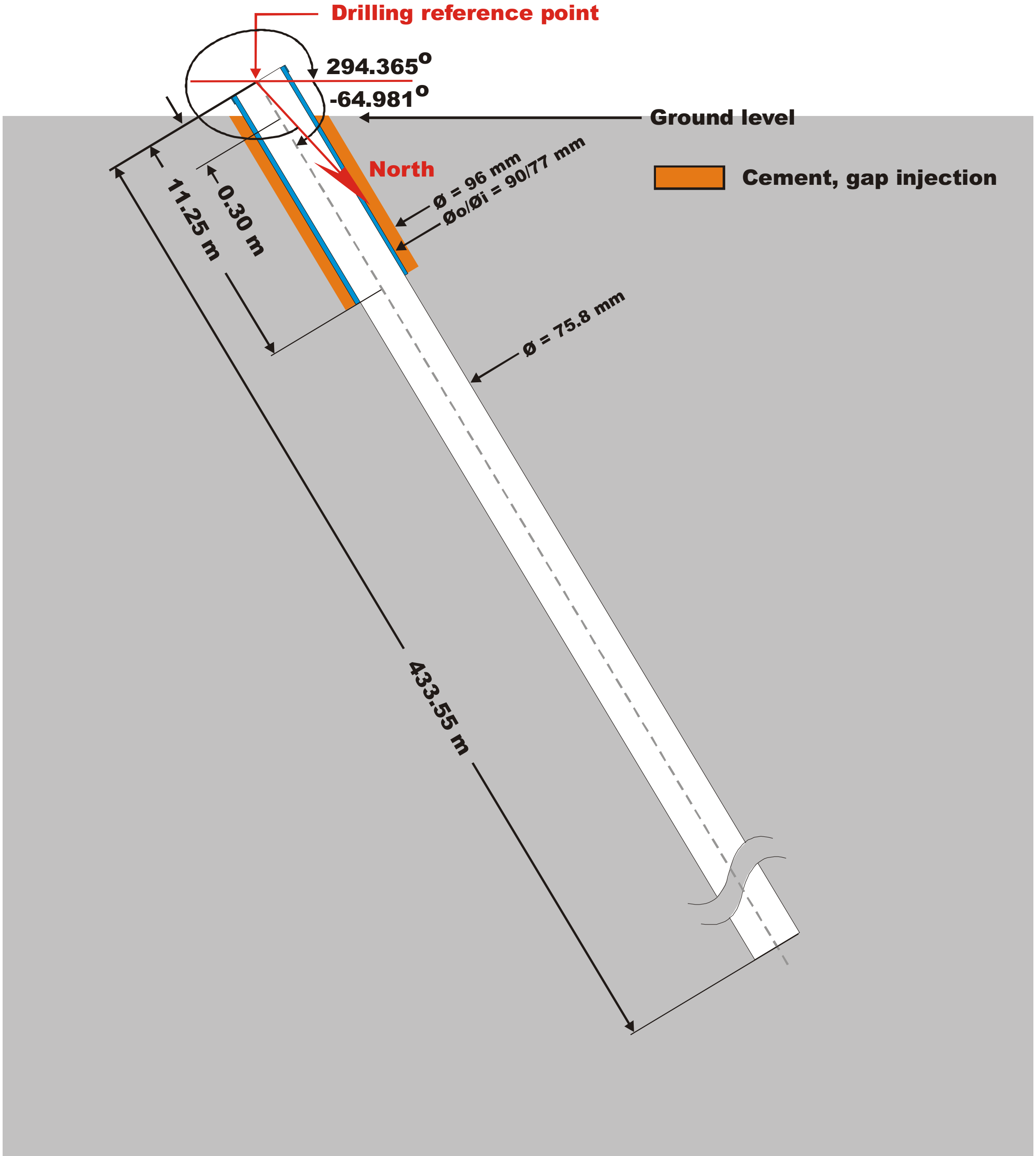
The core drilling in KLX16A is further described in section 5.2. Results from hydrogeological and hydrogeochemical measurements during core drilling are presented in section 5.3. Drilling progress over time is further reported in section 5.4 “Drilling monitoring results”.

Table 5-1. KLX16A Technical summary.

General	Technical
Name of hole: KLX16A	*Core drill rig:* Diamec U8 APC Atlas Copco
Location: Laxemar, Oskarshamn Municipality, Sweden	*Core drill dimension:* N-size (76 mm)
Contractor for drilling: Drillcon AB	*Overburden:* 0.3–0.93 (gravel fill)
Subcontractor core drilling: Suomen Malmi OY (SMOY)	*Cored interval:* 0.93–433.55 m
Core drill start date: November 28, 2006	*Diamond bits used:* 3
Completion date: January 9, 2007	*Average bit life:* 144 metres
	Position KLX16A (RT90 RH70) at top of casing:
	N 6364797.69 E 1547584.09 Z 18.85 (m.a.s.l.)
	Azimuth (0–360)/ Dip (0–90): 294.36/–64.98
	Position KLX16A (RT90 RH70) at 433.55 m length:
	N 6364880.17 E 1547414.29 Z –371.44 (m.a.s.l.)
	Azimuth (0–360)/Dip (0–90): 295.11/–63.22

Technical data

Borehole KLX16A



Drilling reference point

Northing: 6364797.693 (m), RT90 2,5 gon V 0:-15

Easting: 1547584.058 (m), RT90 2,5 gon V0:-15

Elevation: 18.853 (m), RHB 70

Drilling period

Drilling start date: 2006-11-28

Drilling stop date: 2007-01-09

Ver 2007-04-11

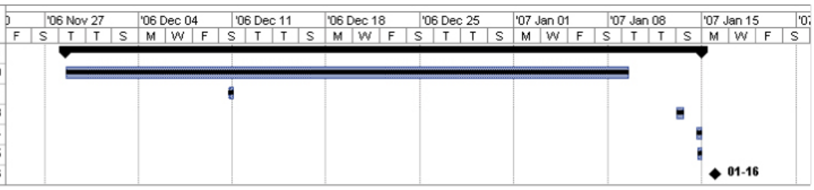
Figure 5-1. *Technical summary, KLX16A.*

Table 5-2. Summary of core drilling progress and borehole measurements in KLX16A.

bh metres	Drilled length, pumping tests and water sampling	Airlift pumping with evaluation of drawdown and/or recovery	Deviation measurement	Miscellaneous
			061117 Borehole collar survey Az 294.95 Dip -65.04	061129 Casing grouting 0-11.25 m. Test of grouting tightness 061201, the leakage was measured to 0.03 L/min.
100	061204 Pumping test without WL probe 11.25-109.20 m. Flow 11 L/min at 23 m drawdown. Water sample taken.		061202 at 55 m Az 293.6 Dip -65.0	
		061210 11.25-213.25 m airlift pumping. No drill stem in borehole		
200	061209 Pumping test 109.00-203.16 m. Flow 11 L/min at 9 m drawdown. Water sample taken.		061209 at 200 m Az 296.6 Dip -64.5	
300	061215 Pumping test 202.00-296.16 m. Flow 10.5 L/min at 10 m drawdown. Water sample taken		061218 at 316 m Az 296.1 Dip -64.2	
400	070106 Pumping test 296.00-400.78 m. Flow 3L/min at 19 m drawdown. No water sample	070114 11.25-433.55 m airlift pumping. No drill stem in borehole		070109 Drilling stopped at 433.55 m.
	070111 Pumping test 399.65-433.55 m. Flow 9.2 L/min at 16 m drawdown. No water sample		070113 Maxibor measurement to 429 m	070115-070116 Rinsing of borehole with airlift pumping in drill stem lowered to hole bottom. The removed volume of water amounted to 25 cu m. The electrical conductivity in the removed water was measured to < 50 mS/m.

Table 5-3. Chronological summary of main core drilling events in KLX16A.

ID	Task Name	Start	Finish
1	**First activity starts**	**Tue 06-11-28**	**Mon 07-01-15**
2	Core drilling	Tue 06-11-28	Tue 07-01-09
3	Recovery test	Sun 06-12-10	Mon 06-12-11
4	Maxibor measurement	Sat 07-01-13	Sat 07-01-13
5	Length calibration marks	Sun 07-01-14	Sun 07-01-14
6	Recovery test	Sun 07-01-14	Mon 07-01-15
7	Last activity ends	Tue 07-01-16	Tue 07-01-16



5.2 Core drilling in KLX16A

Core drilling in KLX16A was conducted between November 28, 2006 and January 9, 2007.

The main steps were:

- flushing and return water handling,
- core drilling and deviation measurements,
- borehole completion including risk assessment of the borehole wall stability.

Hydrogeological and hydrochemical measurements and results are given in section 5.3 and results from drill monitoring are given in section 5.4.

5.2.1 Flushing and return water handling

The flushing water source was percussion borehole HLX10, see also sections 5.3.2 and 5.4. The location of the water source, borehole HLX10 is shown in Figure 1-1.

Treatment of the flushing water before introduction into the boreholes consisted of stripping (removal) of oxygen with nitrogen gas and addition of the fluorescent tracer uranine. The water is also treated with ultraviolet light in order to reduce the microbial content. The flushing and return water handling and the emplacement of related monitoring equipment in KLX16A is shown in Figure 5-2.

The targeted content for uranine in the flushing water was 0.20 mg/L and the actual average uranine content was 0.217 mg/L, see also Figure 5-6 and section 5.3.2.

The return water from drilling was led to a series of sedimentation containers in order to collect cuttings before infiltration to the ground, see also section 5.7.

5.2.2 Drilling and deviation measurements KLX16A

Core drilling was started with N-size (76 mm) triple-tube, wireline equipment from surface. Loose overburden of gravel fill material was encountered from 0.3 to 0.93 m. Core drilling was initially made to a length 11.25 m. The hole was then reamed to 96 mm diameter. A stainless steel casing was emplaced and grouting of the annular space was done. The hole was rinsed from concrete and the water tightness of the casing grouting was tested and found to be sufficient. Core drilling with N-size was resumed and continued to the final length of 433.55 m in KLX16A.

The core diameters and intervals for drilling dimensions are given in Table 5-4. Directional drilling, i.e. intentional change of direction or dip of the borehole was not made in KLX16A.

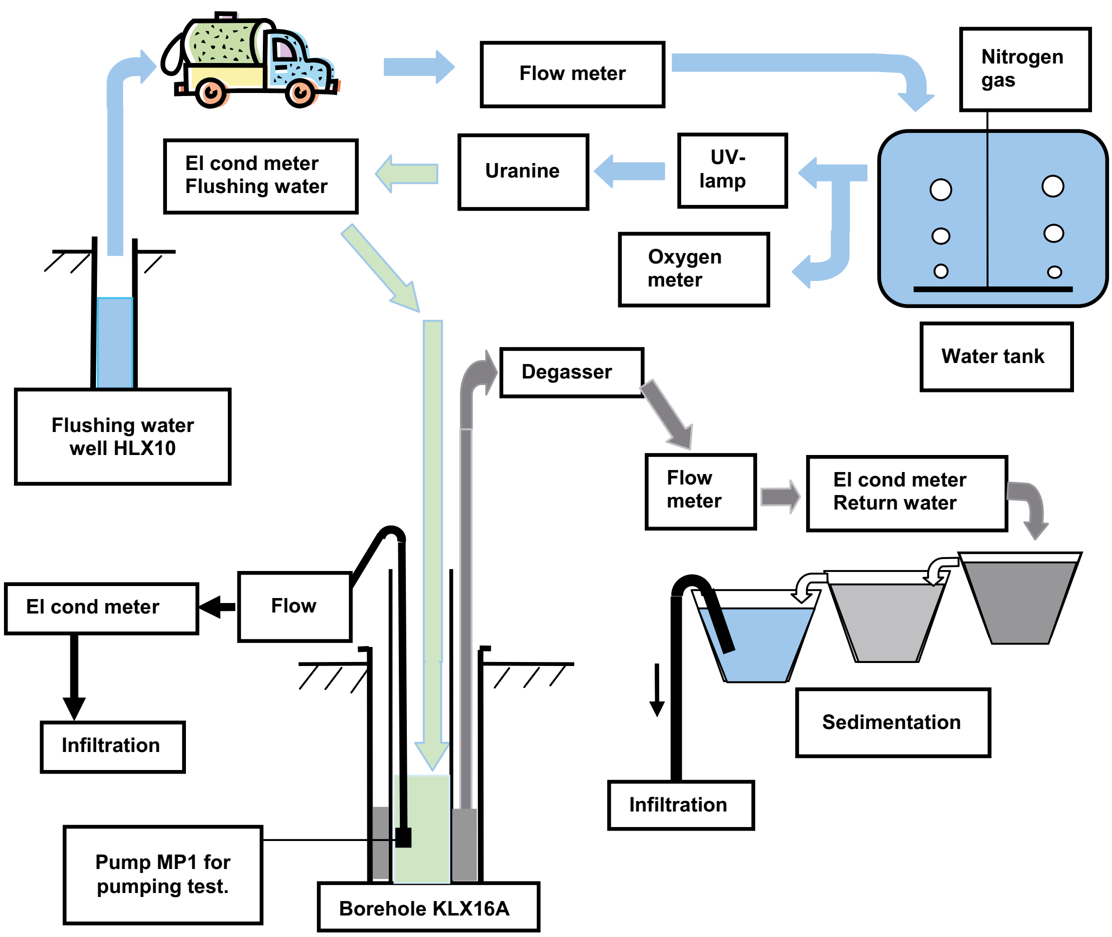


Figure 5-2. The flushing and return water handling and the emplacement of related monitoring equipment in KLX16A.

Measurements of borehole deviation are made for two purposes:

- Monitoring of drilling progress.
- Measurements at full drilled length for final calculation of borehole deviation.

The core drilling progress was followed by deviation measurements with the EZ-Shot method three times along the core drilled section of the borehole. The results from these measurements are not stored in the Sicada database but are given in a summary fashion in Table 5-2.

A combination of the Maxibor and Flexit methods were used for the final calculation of the borehole deviation in KLX16A. The Maxibor measurement was done to 429 m as part of the drilling activity whereas the Flexit measurement was done to 426 m as part of a separate geophysical activity (AP PS 400-07-004). The final deviation file in KLX16A is calculated based on the measurements given in Table 5-5 together with the surveyed bearing and inclination of the top-of-casing. The calculations are made according to routines specified in the Sicada database and general expert judgement. Further comment on the method for calculation of final borehole deviation is given in /6/.

Horizontal and vertical plots of the results of the calculated deviation covering the entire length of borehole KLX16A are given in Appendix 4. Information about which deviation measurements, or parts thereof, that are used for calculation of the borehole deviation are stored in the Sicada database under activity ID 13166848 (activity type code EG154).

Two sections with core losses were noted in KLX16A, see Table 5-6.

Three drill bits were used for KLX16A, see Figure 5-3.

Further results from drill monitoring i.e. drill penetration rate and various measurements will be presented in section 5.4 "Drilling monitoring results" and in Appendix 1.

Table 5-4. Core diameters, borehole diameters and drilling dimensions during core drilling in KLX16A.

Core diameter (mm)	Borehole diameter (mm)	Interval (m drilled length)	Drilling dimension	Comment
50.2		0.93–433.55	N	
	96	0.93–11.25	N and T-96	Reamed to 96 mm diameter
	76	11.25–433.55	N	

Table 5-5. Measurements used for borehole deviation calculation in KLX16A.

Deviation measurement method	Used for calculation of bearing/ inclination	Calculation interval From (m)	Calculation interval To (m)	Measuring direction	Date	Sicada database activity ID
Maxibor	BEARING	27	433.55	down/in	2007-01-13	13145711
Maxibor	INCLINATION	3	433.55	down/in	2007-01-13	13145711
Maxibor	BEARING	27	433.55	up/out	2007-01-13	13145708
Maxibor	INCLINATION	3	433.55	up/out	2007-01-13	13145708
Flexit	BEARING	27	433.55	down/in	2007-01-31	13147170
Flexit	INCLINATION	3	433.55	down/in	2007-01-31	13147170
Flexit	BEARING	27	433.55	up/out	2007-01-31	13147171
Flexit	INCLINATION	3	433.55	up/out	2007-01-31	13147171

Table 5-6. Core losses in KLX16A.

From (m)	To (m)	Core loss length (m)	Comment
87.81	87.93	0.12	Missing Core Piece
340.96	341.03	0.07	Missing Core Piece

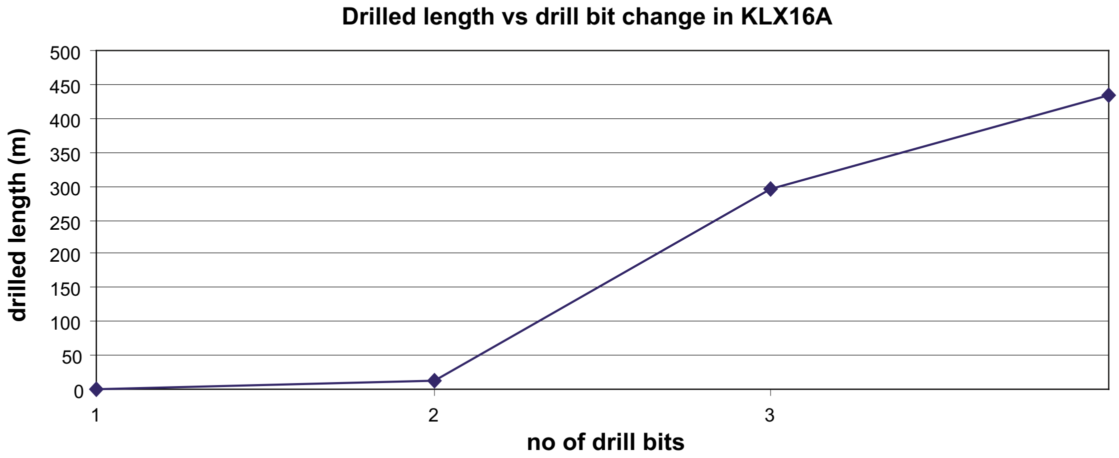


Figure 5-3. *Drill bit changes during core drilling in KLX16A.*

5.2.3 Borehole wall risk assessment, stabilisation and completion

Borehole wall risk assessment and stabilisation

The final borehole wall assessment was approved on February 8, 2007, SKB ID no 1068008, SKB internal document.

The main drilling events that have influence on the risk assessment are summarized as follows:

- Diamond drilling completed at 433.55 m on January 9, 2007.
- Flushing and brushing with high water pressure on the borehole wall was done along intervals as given in Table 5-6. The selection of the intervals to rinse was based on study of the drill core. The flush and brush tool is shown in Figure 5-4.
- Downhole operations consisting of deviation measurements, milling of reference grooves and flushing of the borehole with nitrogen gas were made without stability problems.
- The steel dummy was lowered without any problems along the entire length of the borehole. The probe is designed so that it will run smoothly along the borehole if the curvature does not exceed 0.1 degree/m. The dimensions of the dummy is 2.24 m length and 74.5 mm diameter.
- BIPS logging for final risk assessment was done to full drilled length. The BIPS instrument had a problem to pass through the fractured zone at 340.30–340.50 m. The BIPS logging was made as part of a separate geophysical activity i.e. strictly not part of the drilling activity.

The overall assessment was that the probability for rock fallout was low in the borehole, but that care must be taken while performing down-hole activities in the interval 340–341 m.

Table 5-7. Borehole sections that were mechanically rinsed by water flushing and rotating steel brush in KLX16A.

From (bh length m)	To (bh length m)
12	13
33.5	35
45	47
91	94
140	142
213	214
228	230
234	235
237.5	238.5
252	254
259.5	265
331	332
334	335
338	339
341.5	343
344	345
365	371
378.5	389

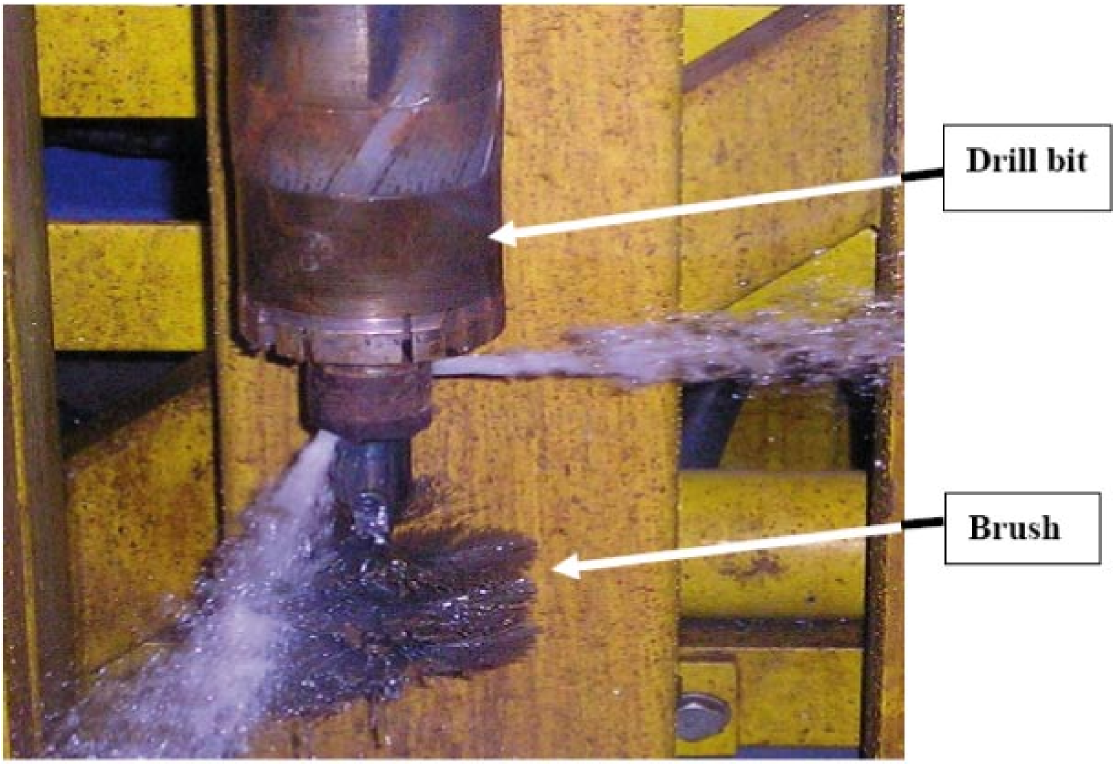


Figure 5-4. *The water flushing and rotating steel brush tool. The tool is lowered into the drill stem and can be seen in place just below the drill bit. During operating the drill string is moved up and down to remove loose rock fragments from the borehole wall.*

Borehole completion

Reaming of depth reference slots was done at the drilled lengths shown in Table 5-8. The depth reference slots are used for depth calibration of down-hole equipment for subsequent investigations in the hole. The presence of the depth reference slots have been confirmed by caliper log measurements.

The length of the holes was rinsed by flushing (lifting) with nitrogen gas ten times as given in Table 5-9.

The boreholes were secured by mounting of lockable steel caps fastened to the concrete pad. All equipment was removed, the site cleaned and inspected by representatives from SKB and the contractor to ensure that the site had been satisfactorily restored.

5.3 Hydrogeological and hydrochemical measurements and results

The performed measurements, as already outlined in Tables 5-2 and 5-3, can be summarized as follows.

Measurements and sampling consisted of:

- Five successful tests were conducted out of eight attempts at various intervals, see Section 5.3.1.
- Four water samples were taken, see Section 5.3.2.
- Two air-lift pumping tests with evaluation of drawdown and/or recovery phase were made, for results see Section 5.3.3.

Hydraulic responses in near-by boreholes from drilling in KLX16A are commented in Section 5.3.4.

Table 5-8. Depth reference slots (m) in KLX16A.

20.00	150.00	300.00
50.00	200.00	350.00
100.00	250.00	400.00

Table 5-9. Nitrogen gas lifting in KLX16A. (Swedish Normal Time i.e. GMT+1).

Date	Time	Interval (m)	Volume water removed (m^3)
2007-01-20	11.27–11.38	11.25–443.55	no record
2007-01-20	13.04–13.16	11.25–443.55	no record
2007-01-20	13.39–13.49	11.25–443.55	no record
2007-01-20	14.07–14.19	11.25–443.55	no record
2007-01-20	14.38–14.51	11.25–443.55	no record
2007-01-20	15.08–15.22	11.25–443.55	no record
2007-01-20	15.41–15.58	11.25–443.55	no record
2007-01-22	12.10–12.25	11.25–443.55	no record
2007-01-23	10.15–10.30	11.25–443.55	no record
2007-01-23	10.42–10.52	11.25–443.55	no record

5.3.1 Hydrogeological results from wireline measurements

A single-hole pumping test was performed in open borehole i.e. not with the wireline equipment in the uppermost part of KLX16A between 11.25 and 109.20 m. In all were seven wireline pumping tests performed in KLX16A and four of these achieved sufficiently stable conditions for calculating pseudo steady-state transmissivity and hydraulic conductivity. The reason behind the failed tests is mainly problems with the packer and a malfunctioning pump. Results from the pumping tests in KLX16A are presented in Table 5-10 and Figure 5-5. The plots from the pumping tests are given in Appendix 2.

Table 5-10. Pumping tests with in KLX16A.

Tested section [m]	Q/s [m²/s]	T_M [m²/s]	Comments
11.25–109.20	$8.0\ 10^{-6}$	$9.1\ 10^{-6}$	Open hole pumping test without wireline probe. The flow rate was increased 17 minutes after pump start. Thereafter both the pressure and the flow rate decreased. Pseudo steady state conditions prevailed during the last two hours of the flowing period.
109.00–203.16	$6.5\ 10^{-5}$	$8.5\ 10^{-5}$	Gently decreasing pressure and flow rate during the pumping. The recovery was 86% of the drawdown. A small leakage in the drill stem was detected.
202.00–296.16	$3.6\ 10^{-5}$	$4.6\ 10^{-5}$	A 46 minutes interruption with start c. two hours after pump start was caused by electric power failure. Despite the break. pseudo steady state condition could be identified most of the pumping period. The electrical conductivity (EC) rises from 50 to 150 mS/m. Recovery of the water table after pumping stopped amounted to 82% of the drawdown.
296.00–400.87	$2.6\ 10^{-6}$	$3.4\ 10^{-6}$	During the drawdown phase there were major problems with the pump and pseudo steady state conditions could be identified only during a short period. After the pump stop there were attempts to restart the pump.
399.65–433.55	$5.3\ 10^{-8}$	$6.0\ 10^{-8}$	The flow rate is difficult to estimate. It varied between 0 and 0.15 L/min. The pressure graph shows a drawdown of 245 kPa (too high?) and a recovery of 80 kPa.

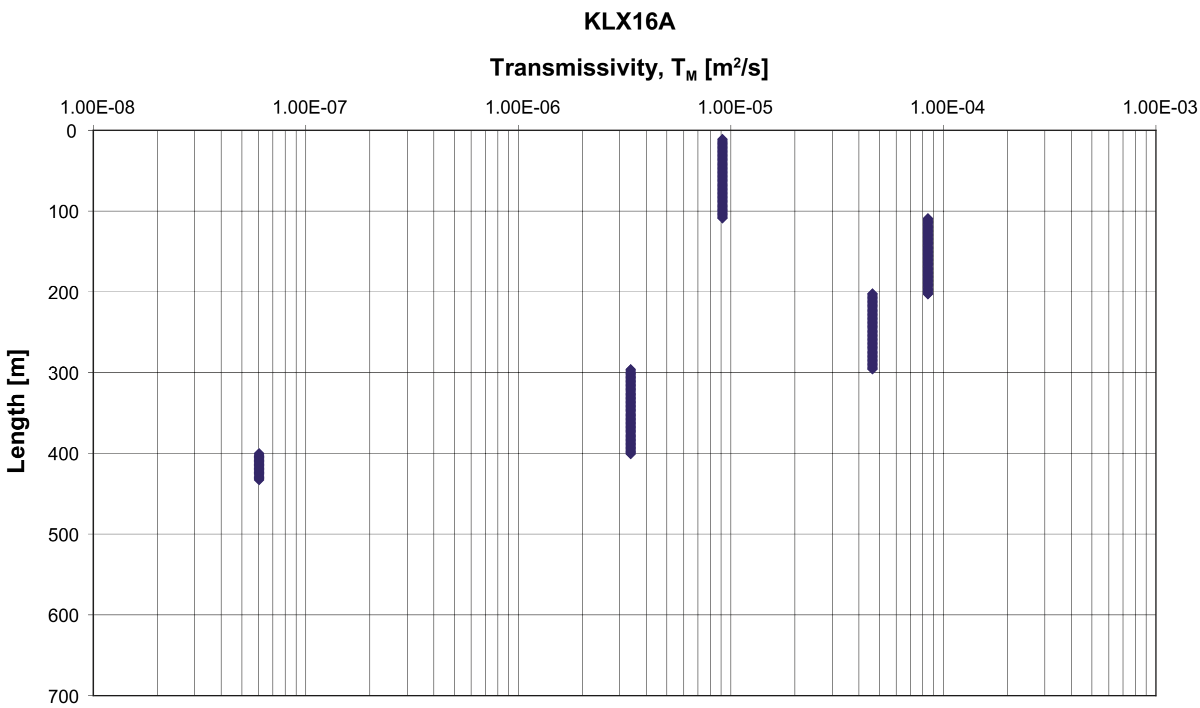


Figure 5-5. Transmissivity from wireline pumping tests in KLX16A versus borehole length.

The pumping tests were evaluated with steady-state assumption in accordance with Moye, 1967 /3/. The flow rate at the end of the drawdown phase was used for calculating the transmissivity (T_M) and the specific capacity (Q/s), where Q is the flow rate and s is the drawdown.

The start and stop times (Swedish Normal Time) for the intervals used for evaluation of the pumping tests are given in Table 5-11.

5.3.2 Hydrochemistry

Four water samples were collected in connection with core drilling in KLX16A. Time and lengths for the samples are given in Table 5-12 together with complete results.

The samples were collected at the drill site as soon as possible after the sampling occasion and analysed at the Äspö laboratory.

The samples were originally intended to be of so called SKB chemistry class 3 but since the drill water content in the samples was high (see Table 5-12) they were only analyzed for drill water content.

The drilling water content is a measure of the amount of uranine tracer in the return water. A low percentage of drilling water implies that the amount of pristine formation water is high in the sample i.e. low amount of the uranine-spiked flushing water.

The percussion drilled borehole HLX10 was used as water source during the drilling of KLX16A.

No water samples were collected from HLX10 in connection with the drilling of KLX16A. However, water samples have been collected from HLX10 at earlier occasions and results from those analyses are given in drilling reports for KLX05 and KLX12A /4 and 5/.

The original plan for water supply for KLX16A was to utilize the near-by percussion drilled borehole HLX42, see Figure 5-12 for location. The low quality of the water in HLX42 however prevented the use of this borehole as a water source /7/.

Monitoring of uranine tracer content

From KLX16A, a total of 61 samples for uranine content and electrical conductivity in flushing and returning water were taken along the borehole.

Table 5-11. Evaluated test periods for the wireline pumping tests.

Tested section	Start (YYYY-MM-DD HH:MM)	Stop (YYYY-MM-DD HH:MM)
109.00–203.16	2006-12-09 16:21	2006-12-10 03:04
202.00–296.16	2006-12-15 15:42	2006-12-16 02:44
296.00–400.87	2007-01-06 15:47	2007-01-06 16:07
399.65–433.55	2007-01-11 17:01	2007-01-11 19:54

Table 5-12. Sample dates, lengths and results during core drilling in KLX16A.

Borehole	Sample no	Date	From	To	SKB chemistry class	Drill water %
KLX16A	11575	2006-12-05	11.25	109.20	1 (only analysed for drill water content)	66.60
KLX16A	11582	2006-12-09	109.00	197.16	1 (only analysed for drill water content)	59.70
KLX16A	11583	2006-12-10	109.00	203.16	1 (only analysed for drill water content)	67.50
KLX16A	11593	2006-12-16	202.00	296.16	1 (only analysed for drill water content)	56.60

The results are shown graphically in Figure 5-6. All the samples were analysed at the Äspö laboratory.

The calculated average uranine content for the whole borehole is 0.217 mg/l. This value has also been used for further calculations of the drill water content in the samples collected after drilling. However, for the samples collected during drilling (i.e. the samples in this report), the drill water content for each sample is based on the average uranine content in the flushing water samples up to the time of sampling. Further comment on the drastic reduction of the uranine content in the return water after 140 m drilled length is given in section 5.4 "Drill Monitoring".

A further account on analytical method, chemistry class and quality is given in Appendix 3.

5.3.3 Results from air-lift pumping with evaluation of drawdown and/or recovery

One pumping test was conducted during drilling when almost half the borehole was completed. One additional test was conducted after the borehole was drilled to full depth. The execution of the tests varied in detail but a MP1 pump was lowered c. 40 m in the borehole. The pumping period lasted 30–50 minutes followed by a long recovery period of 13–17 hours.

The steady state transmissivity, T_M, was calculated according to Moye, 1967 /3/ as well as the specific capacity. Q/s . The results are shown in Table 5-13. The tested section is here defined as the section between the lower end of the grouted casing and the borehole bottom.

The plots from the drawdown and recovery tests are given in Figures 5-7 and 5-8.

Table 5-13. Results from pumping in KLX16A.

Tested section [m]	Flow rate [L/min]	Drawdown [m]	Q/s [m²/s]	T_M [m²/s]	Comments
11.25 – 213.25	29	23.6	$2.0 \cdot 10^{-4}$	$2.8 \cdot 10^{-4}$	The pumping rate was increased in 5 steps from c. 14 L/min to c. 29 L/min.
11.25 – 433.55	27.7	33	$1.4 \cdot 10^{-4}$	$2.1 \cdot 10^{-4}$	

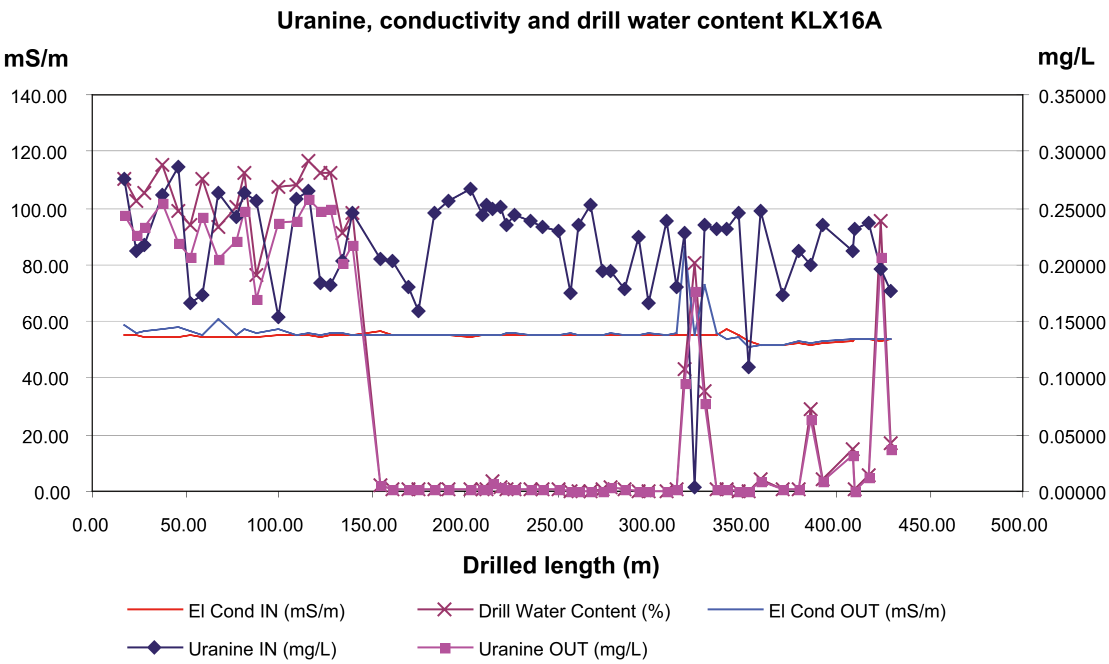


Figure 5-6. *The uranine concentration and electrical conductivity of the flushing water (IN) and the return water (OUT) in KLX16A. The drill water content in the return water is also shown. Note the drop in uranine content after 140 m drilled length.*

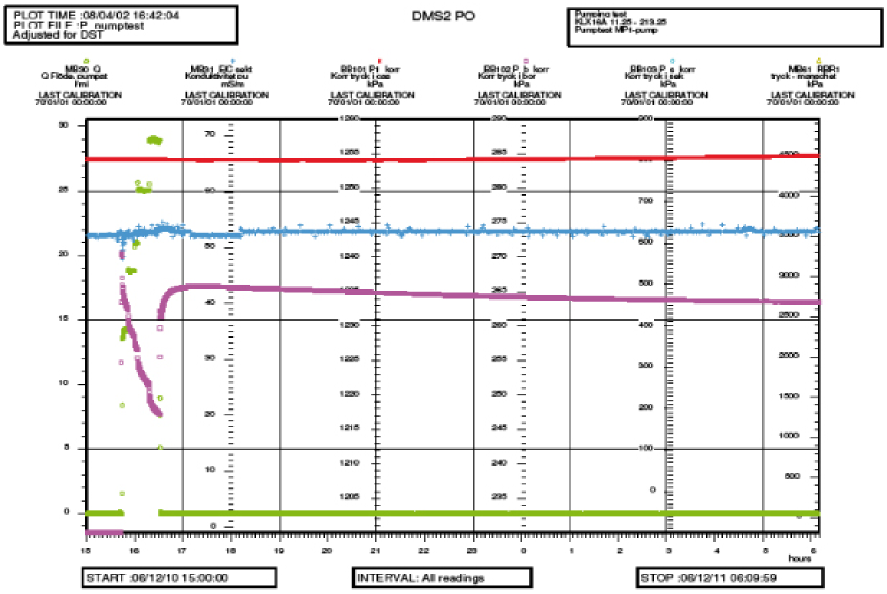


Figure 5-7. *Pumping in KLX16A 11.25–213.25 m.*

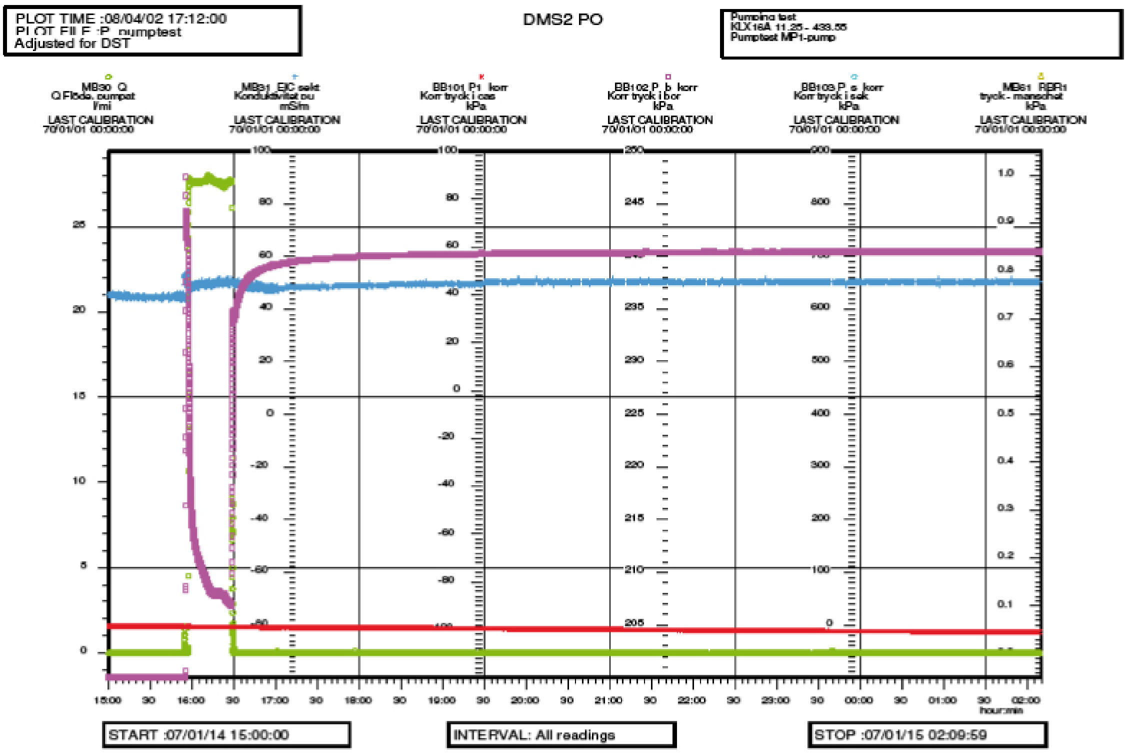


Figure 5-8. *Pumping in KLX16A 11.25–433.55 m.*

5.3.4 Hydraulic responses in near-by boreholes

Hydraulic responses from drilling activities in a borehole can be created by drawdown from percussion drilling, air-lift pumping during core drilling and from lifting with nitrogen gas. The amount of air-lift pumping was very limited in KLX16A and no percussion drilling was done. The study of hydraulic responses during drilling of KLX16A was therefore limited to the period of nitrogen lifting in KLX16A.

Summary conclusions are listed below. The locations of the observation boreholes, flushing water supply well and KLX16A are shown in Figure 5-12.

- A clear response from the nitrogen lifting in KLX16A could be seen in HLX42, see Figure 5-9. The lag time from the lifting in KLX16A to the response in HLX42 is typically 1–1.5 hours. There is however one exception on January 23 when the lag is over 6 hours. This could possibly be explained by wrong times listed for the last nitrogen lifting, see Figure 5-10.
- No response from nitrogen lifting in KLX16A could be seen in observation boreholes HLX15, HLX26, HLX38 or KLX03. An example from KLX03 is shown in Figure 5-11.
- The variations in the water table in observation borehole HLX27 do sometimes coincide reasonably close to the nitrogen lifting in KLX16A, see Figure 5-9. A careful examination shows however that the variations in the water table in HLX27 cannot be explained as responses from KLX16A. It is very likely that they originate from activities such as air-lift pumping and wireline pumping tests in KLX15A.

No data was available for KLX19A during the drilling in KLX16A. All times in plots in this section (section 5.4.4) are given in Swedish Normal Time (GMT+1).

The location of the observation boreholes and KLX16A is given in Figure 5-12.

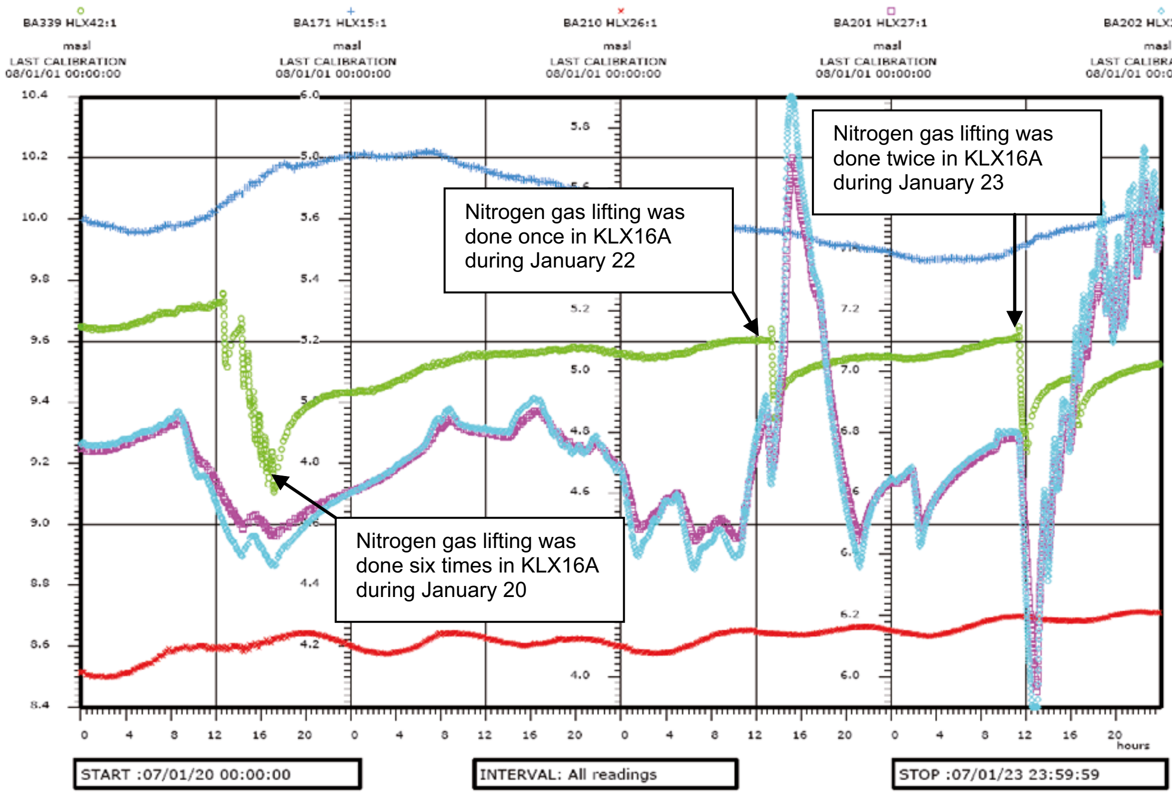


Figure 5-9. *Water levels in boreholes HLX15, HLX26, HLX27 and HLX42 during the nitrogen lifting in borehole KLX16A, 2007-01-20–2007-01-23.A clear response from nitrogen lifting in KLX16A can be seen in HLX42 (green). No response can be seen in HLX26 (red) or in HLX15 (dark blue). The variations in HLX27 (light blue and purple) do sometimes coincide with the nitrogen lifting in KLX16A or hydraulic responses in HLX42. There are however variations in the water table in HLX27 that are clearly not related to nitrogen lifting in KLX16A. The variations are very likely linked to air-lift pumping and wireline pumping tests in KLX15A.*

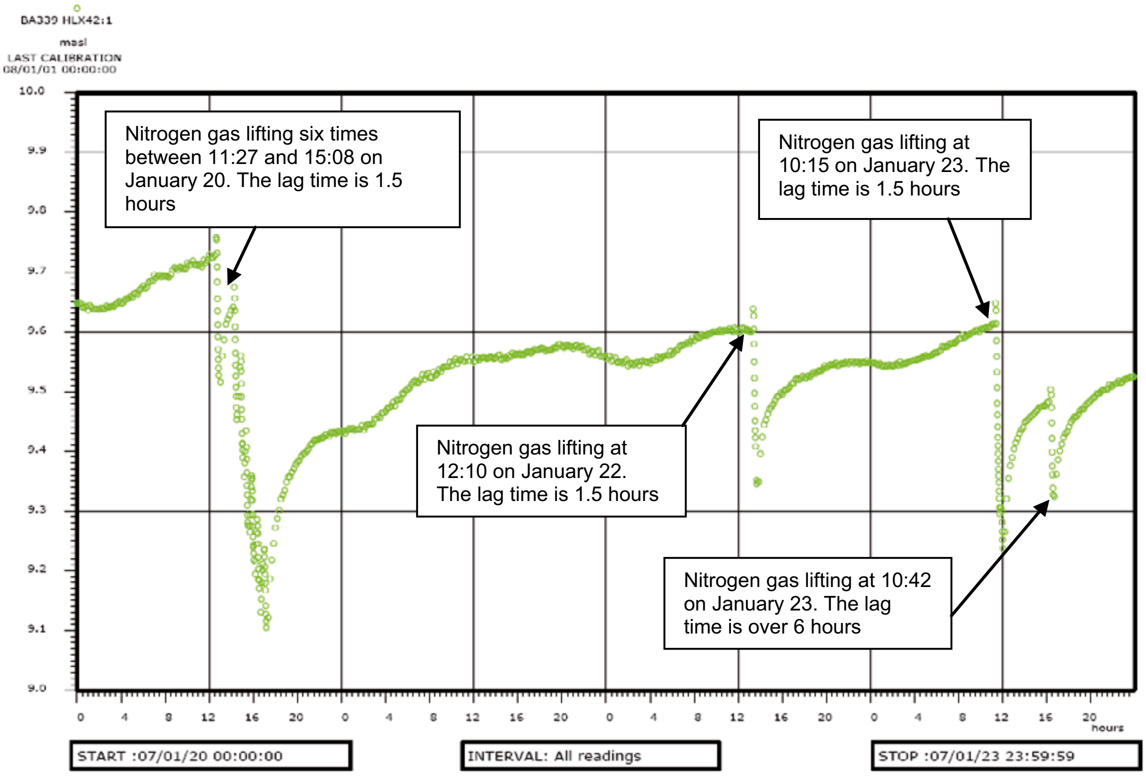


Figure 5-10. *Water level in borehole HLX42 during the nitrogen lifting in borehole KLX16A, 2007-01-20–2007-01-23. The lag time i.e. the time from when the nitrogen lifting took place until the drawdown occurs in HLX42 is typically around 1.5 hours in nitrogen lifting instances except the last one on January 23. The reason for this behaviour is not clear but could possibly be explained simply by the wrong time has been recorded for the nitrogen lifting.*

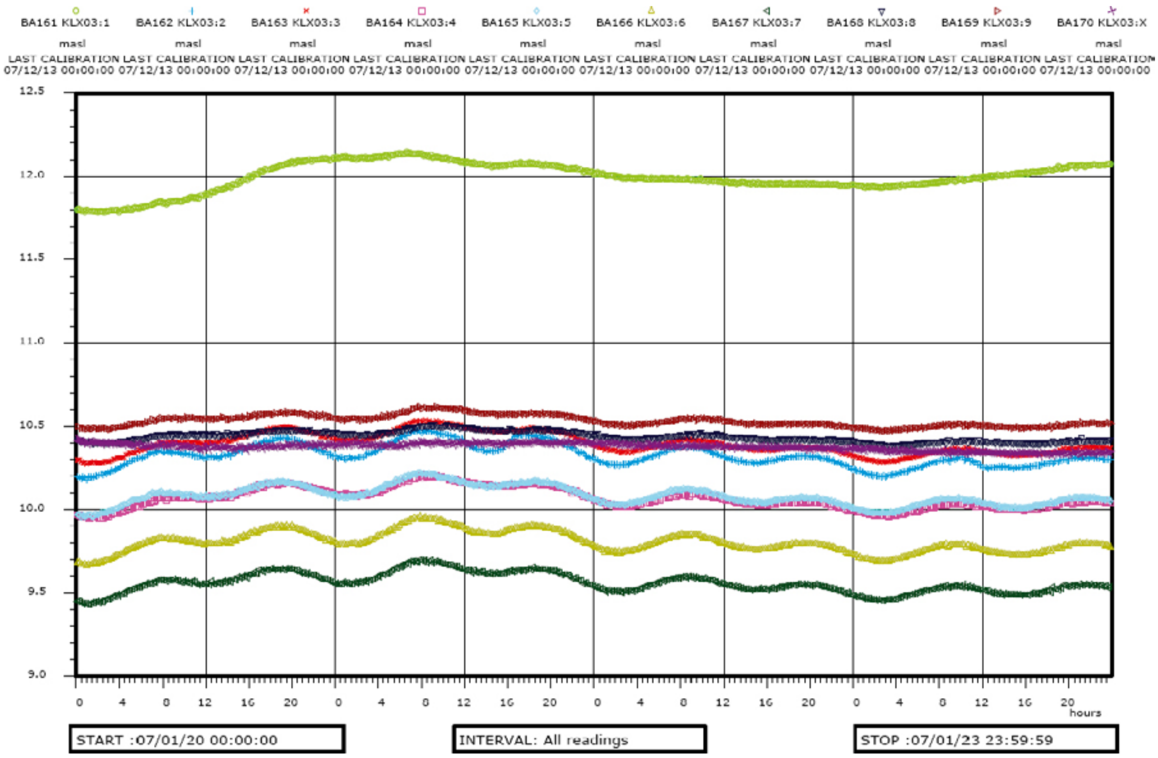


Figure 5-11. *Water levels in borehole KLX03 (sections 1 through 10) during the nitrogen lifting in borehole KLX16A, 2007-01-20–2007-01-23. No response can be seen in any section of KLX03 from the nitrogen lifting in KLX16A.*

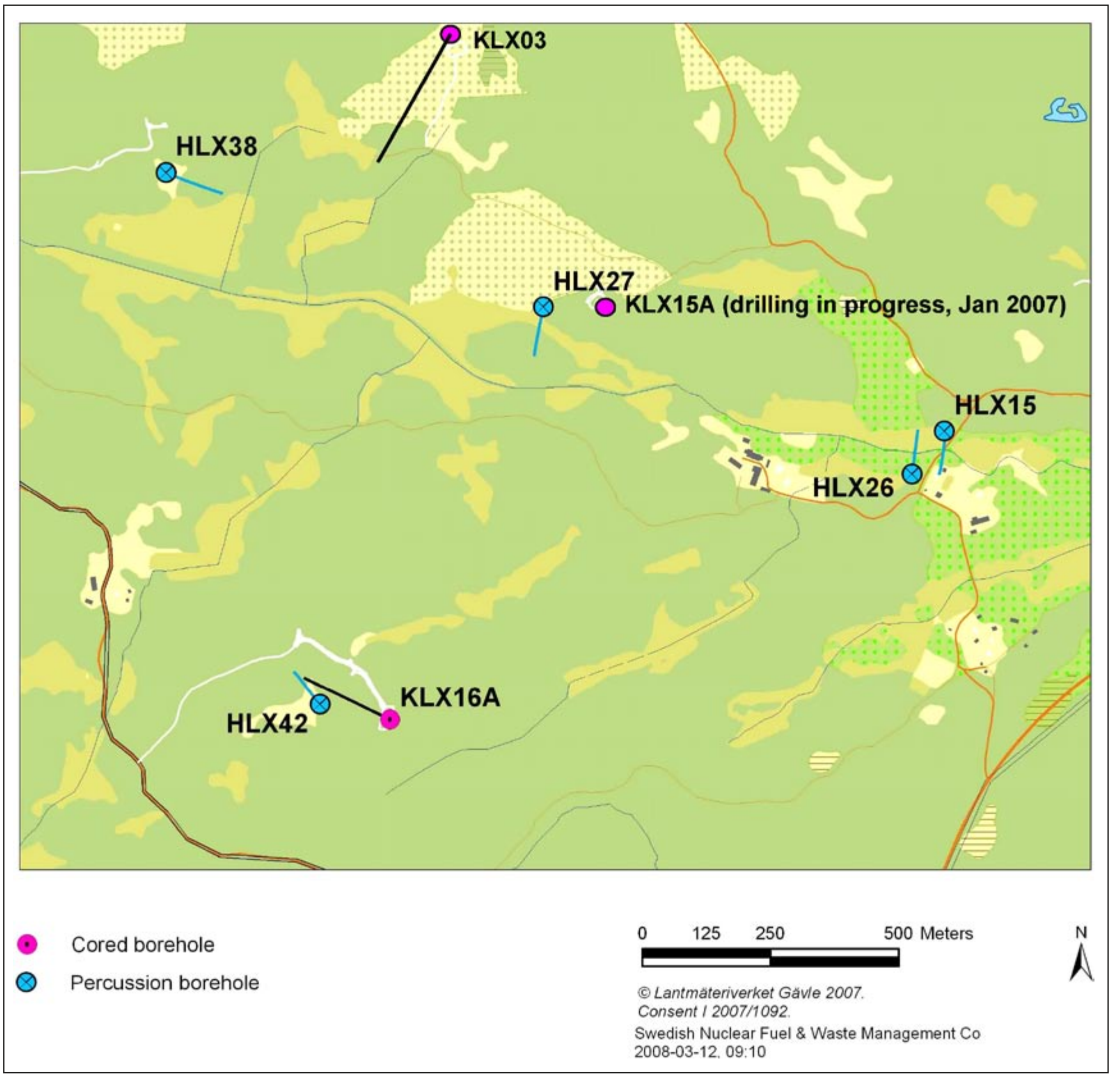


Figure 5-12. *Map showing the location of observation boreholes HLX15, HLX26, HLX27, HLX38, HLX42 and KLX03 together with borehole KLX16A and the then on-going drilling of KLX15A.*

5.4 Drill monitoring

This section presents the results from drill monitoring i.e. continuous data series of water parameters or technical drilling parameters. The reading are collected in a database called DMS. The DMS database contains substantial amounts of data and a selection of results primarily from the monitoring of the flushing water parameters are presented in Figures 5-13 through 5-15 below. Selected parameters from the drill rig (MWD parameters) are presented in Appendix 1. A notable feature in KLX16A is the distinct drop in uranine content that occurs after 140 m, see Figure 5-6. The MWD data in Appendix 1 show an increase in flushing water flow and decrease in water pressure coupled with reduced return water flow from 140 m. This is further supported by the flattening of the curve for return water after December 6, see Figure 5-16.

The MWD parameters require some explanation:

- Drillability ratio- this parameter is defined as penetration rate divided by feed force.
- Flushing water ratio- this is defined as flushing water flow divided by flushing water pressure.
- Water pressure (of the water entering the drill stem).
- Flushing water flow (flow of ingoing water).
- Penetration rate (rate of drill bit penetration as measured on the surface on the drill stem).
- Hydraulic indication- this parameter is defined as penetration rate divided by flushing water flow.

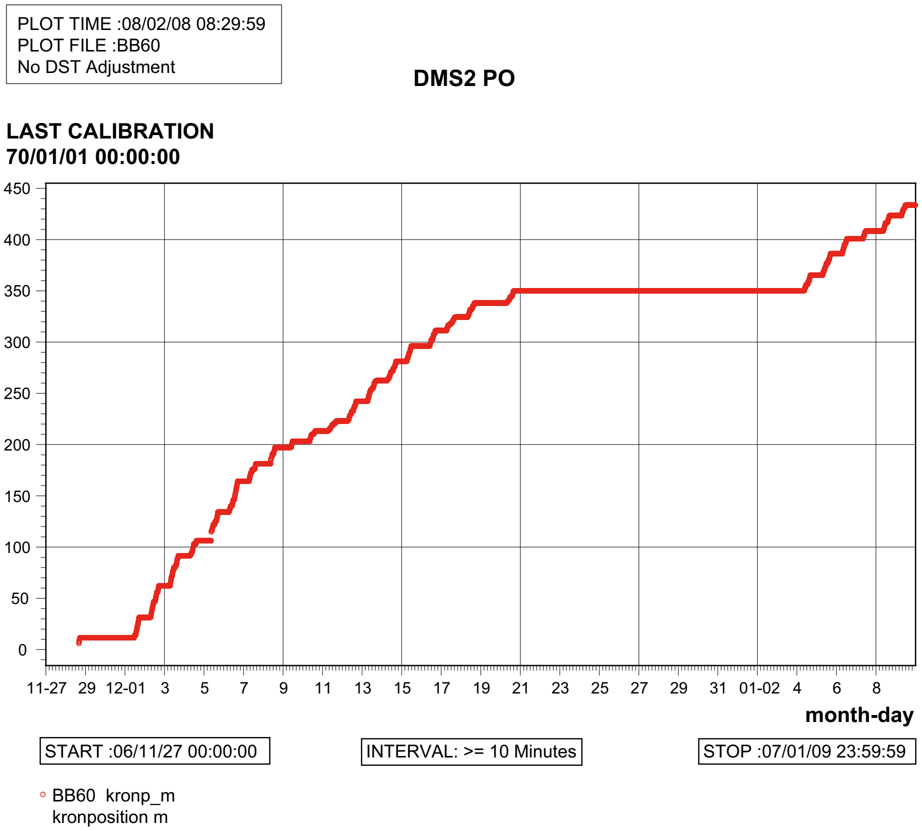


Figure 5-13. Drill bit position in KLX16A over time.

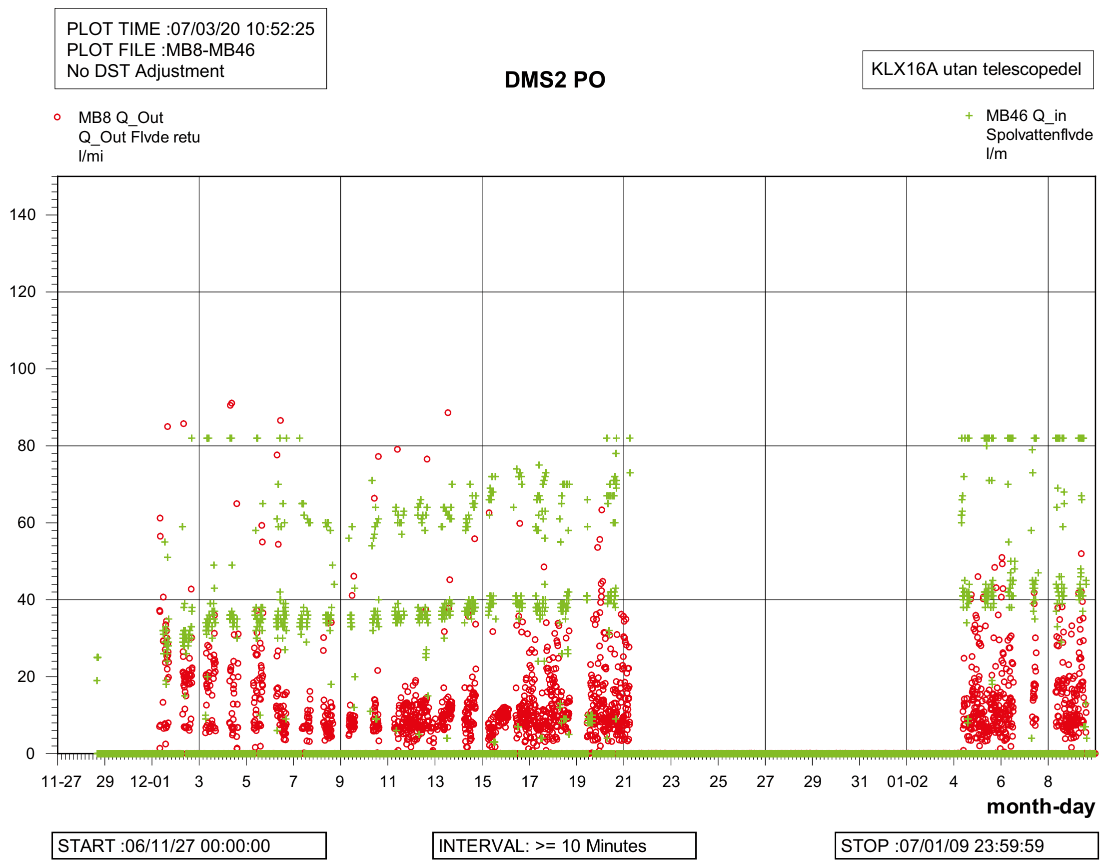


Figure 5-14. Flushing water flow (green) and return water flow (red) in litres per minute.

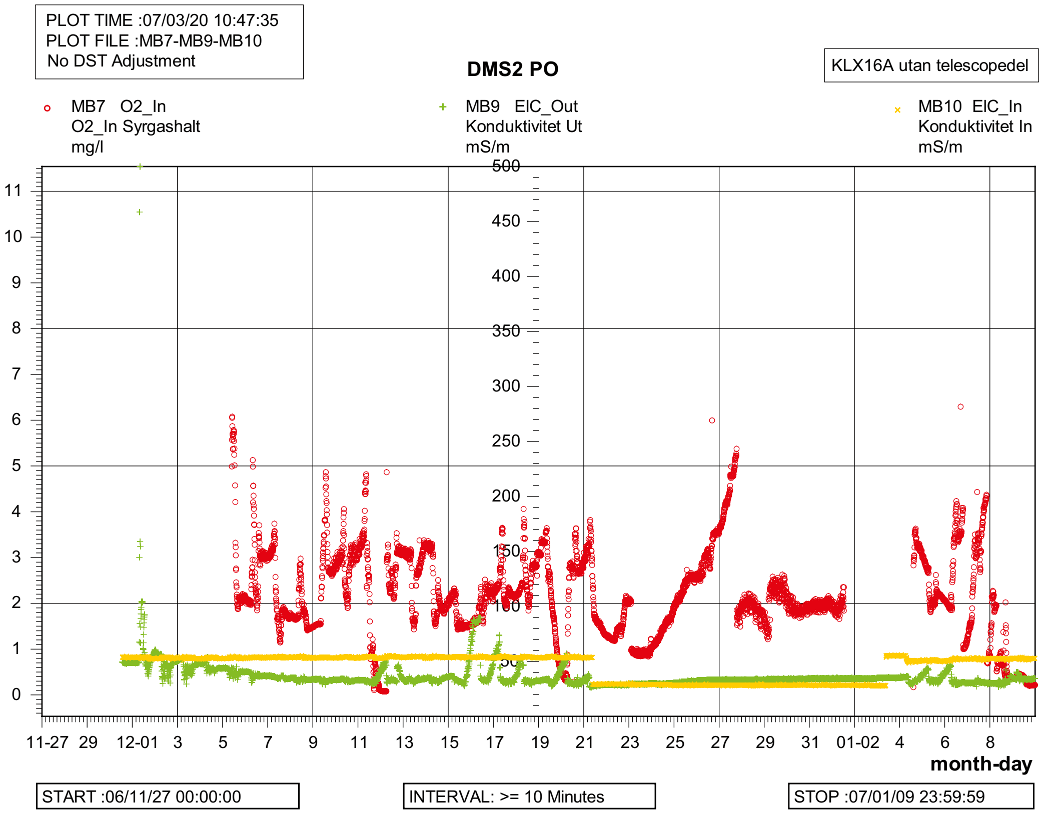


__Figure 5-15.__ Conductivity of flushing water (yellow) and return water (green). The oxygen content in mg/L of the flushing water (red) is also shown. The oxygen content of the flushing water is typically below 5 mg/L. The conductivity of the return water (green) is low and stable at around 50 mS/m. The Christmas break is reflected in the shift of conductivity from late December to early January.

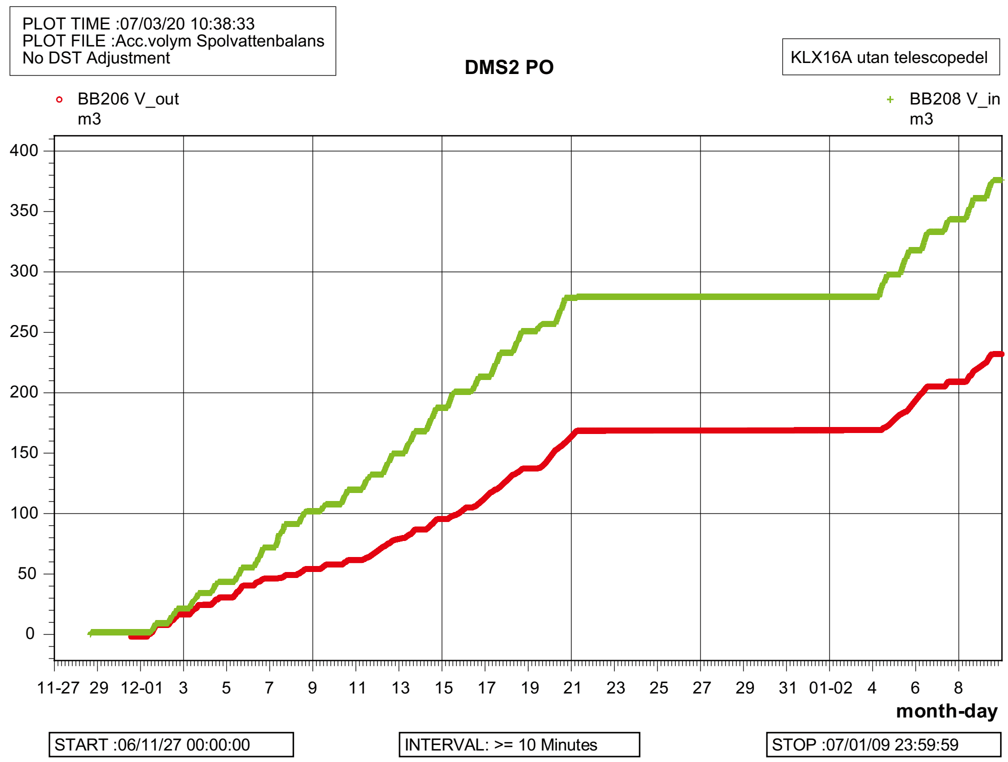


__Figure 5-16.__ The flushing water balance in KLX16A as recorded by the DMS system. The accumulated volume of the ingoing flushing water is shown in green and the outgoing return water is shown in red.

In order to maintain reasonable size data files, a reduction in the number of points incorporated in the pictures has been done in Figures 5-13 through 5-15. Since DMS data are related to time (i.e. not strictly to borehole length) periods where drilling is not performed are also registered.

Figure 5-13 depicts the drill bit position (green) over time.

Figure 5-14 shows the flushing water flow (green) entering the hole and the return water flow (red). The flushing water flows (green) show three distinct levels of flow:

- A flow of around 40 litres/minute corresponding to pumped flow during drilling.
- A flow of 60–80 litres/minute corresponding to the flow while pumping down the core barrel.
- No flow (zero litres/minute) when no drilling is performed.

Figure 5-15 shows the conductivity of the ingoing flushing water, conductivity of the return water and the oxygen content of the flushing water. The oxygen content of the flushing water was typically below 5 mg/L, which is very low. The electrical conductivity of the return water is stable around 50 mS/m.

5.4.1 Measurements of flushing water and drill cuttings

A calculation of accumulated amounts of water flowing in and out of the borehole based on water flow measurements from the DMS system (continuous readings) is given in Figure 5-16.

The amount of flushing water consumed during drilling was 430 m^3, giving an average consumption of 1 m^3 per metre core drilled. The amount of effluent return water from drilling in KLX16A was measured by the DMS system to 240 m^3, giving an average of ca 0.55 m^3 per metre core drilled. One reason for the relatively low amount of return water is that air-lift pumping was not performed during the drilling.

Drill cutting balance

The weight of cuttings in the settling containers amounted to 347 kg. The theoretical amount that should be produced from drilling with 76 mm triple tubing, with core barrel N3/50, over a length of 433 metres is 2,920 kg assuming a density of 2.7 kg/dm^3. The remainder of the cuttings should be transported as suspended material in the return water or remains in fractures in the bedrock formation.

The recovered drill cuttings were collected in steel containers. After completion of drilling, the containers were removed from the site and emptied at an approved site.

Uranine tracer balance

The amount of introduced and recovered uranine is presented in Table 5-14. The results show that only a fraction of the introduced amount of uranine was retrieved during drilling of KLX16A.

Table 5-14. Balance calculation of uranine tracer in KLX16A.

Average uranine content IN (mg/L)	0.217
Flushing water volume IN (m^3)	430
Amount uranine introduced (g)	93
Average uranine content OUT (mg/L)	0.080
Return water volume OUT (m^3)	240
Amount uranine recovered (g)	19

5.5 Geology

A preliminary geological mapping of the core is done as drilling progresses as part of the drilling activity. This mapping phase includes a first pass mapping of major geological features as well as RQD-logging and photodocumentation of the core.

A more detailed mapping with the Boremap method is made after measurements have been made in the borehole that can provide orientation of geological features. Boremap mapping and the related measurements are not part of the drilling activity. The results from the Boremap logging are included in this report as it represents a more complete geological record than the preliminary geological mapping.

The geological results based on the Boremap logging are shown in Appendix 1. It should be stressed that the geological description given in this report is a brief summary only. A more complete account is given in /8/.

Lithologically the core is dominated Quartz monzodiorite with intercalations of other rock types. The contact to the Ävrö granite was not intercepted in the borehole.

Rock alteration is mostly weak and reasonably common in the interval 250 to 410 m consisting of red staining and saussuritization (alteration of Ca-plagioclase to epidote). The altered interval also coincides with elevated fracture frequency. Sections with red staining are indicated as "oxidized" in Appendix 1. The average fracture frequency over the core drilled section is 2.98 (fractures/m) expressed as open fractures. NB The fracture frequency given in Appendix 1 shows the total fracture frequency (i.e. open fractures, sealed fractures, sealed network and fractures in crushed sections).

5.6 Data handling

Data collected by the drilling contractor and the SKB drill coordinators were reported in daily logs and other protocols and delivered to the Activity Leader. The information was entered to Sicada (SKB database) by database operators.

5.7 Environmental control

The SKB routine for environmental control (SDP-301, SKB internal document) was followed throughout the activity. A checklist was filled in and signed by the Activity Leader and filed in the SKB archive.

All waste generated during the establishment, drilling and completion phases have been removed and disposed of properly. Water effluent from drilling was allowed to infiltrate to the ground in accordance with an agreement with the environmental authorities. The location of the water emission area and the environmental monitoring wells SSM000269 and SSM000271 is shown in Figure 5-17. Precautionary guideline values for effluent return water emission to the ground were prescribed by the Regional Authorities for the following parameters:

- Salinity, 2,000 mg/l (monitored as electrical conductivity, with the limit 300 mS/m).
- Uranine content, 0.3 mg/l.
- Suspended material, 600 mg/l.

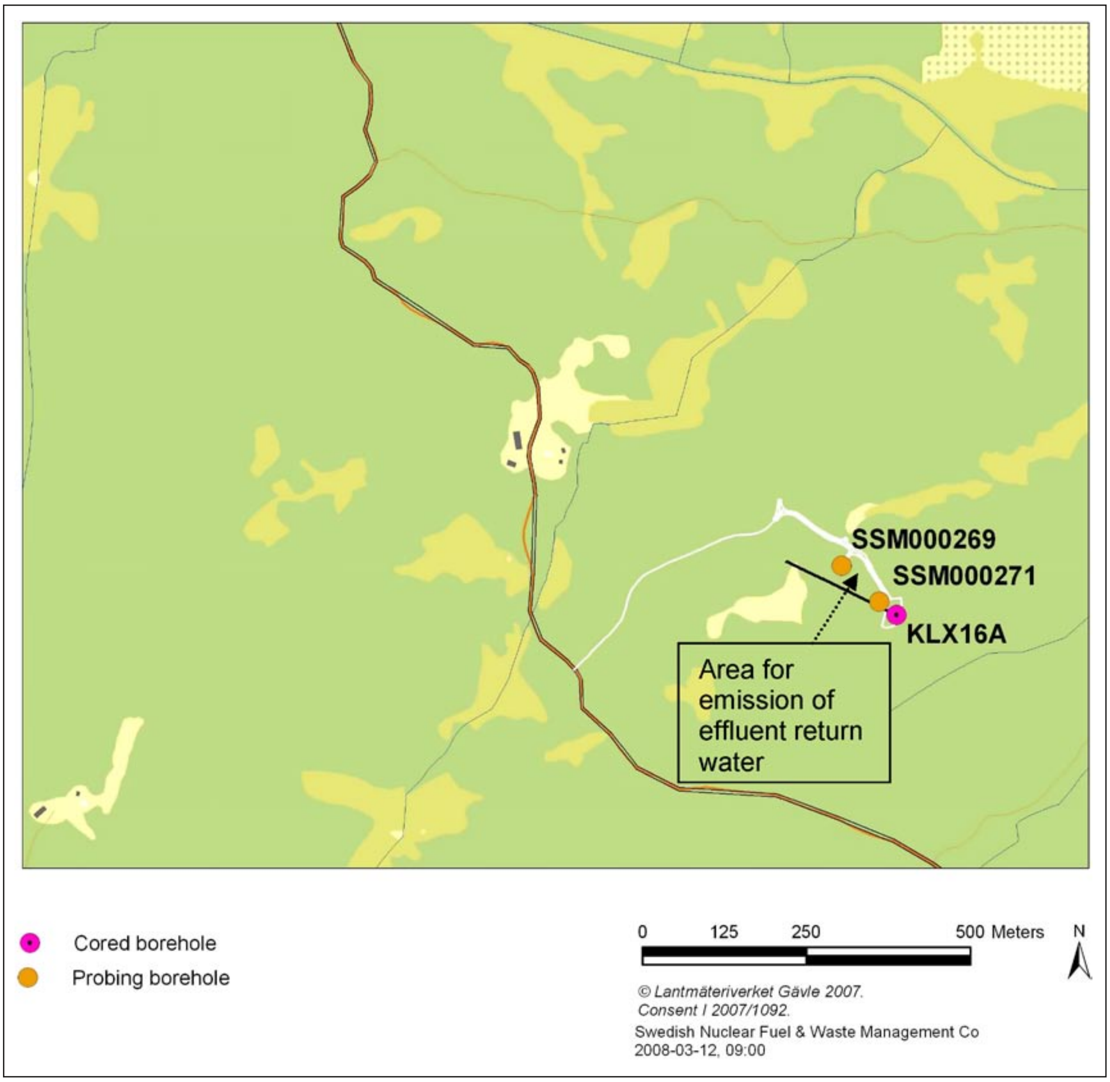


Figure 5-17. *The location of the site for return water emission and the environmental monitoring wells SSM000269 and SSM000271 in relation to the core drill site for KLX16A.*

Monitoring of effluent water

The electrical conductivity, as measured by the DMS system, of the return water from the core drilling of KLX16A was well below 100 mS/m throughout the core drilling phase. Samples of the return water that were analysed for electrical conductivity were also all around 50–60 mS/m, see Figure 5-6.

The uranine content in the return water was well below 0.3 mg/L, see Figure 5-6.

The concentration of suspended material in the return water from drilling was not analyzed for borehole KLX16A but has been analyzed from previous drillings. On average, the amount of suspended material from the sampling campaign in KLX17A was 1,200 mg/L /9/ and 400 mg/L in KSH03 /10/. The amount of suspended material in the return water from core drilling in KLX16A could exceed the stipulated guidelines for emission at 600 mg/L.

The analytical results from KLX17A were not available at the time of drilling in KLX16A. Changes in the handling of the return water were therefore not initiated in KLX16A.

Environmental monitoring wells and reference sampling

Two environmental monitoring wells, SSM000269 and SSM000271, were drilled as part of another soil drilling activity (AP PS 400-06-78). The technical specifications of the two monitoring wells are reported separately /11/.

Reference samples of the surface soil and ground water, before drill start and establishment of the drill site were taken as given in Table 5-15.

Monitoring of soil ground water levels

Logging of the water table was made in monitoring wells SSM000269 and SSM000271 during the core drilling in KLX16A. Plots of the logging results are given in Figures 5-18 and 5-19.

Table 5-15 Reference samples for environmental monitoring.

Date	Sample No	Comment
2006-11-08	SKB PO 9015	Undisturbed soil sample at the drill site for KLX16A.
2006-11-23	11555	Reference water sample in SSM000271.

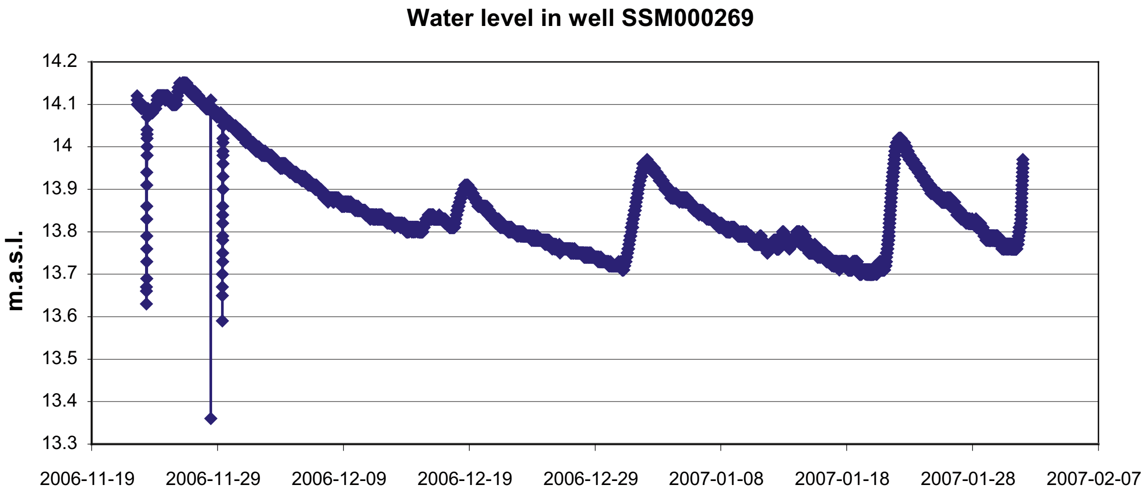


Figure 5-18. *The water table in SSM000269 (metres above sea level).*

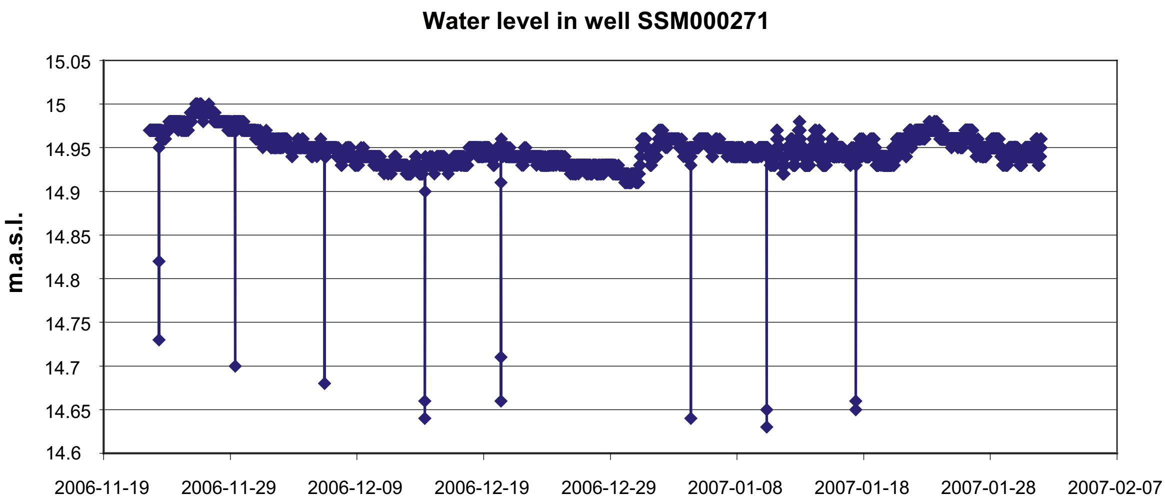


Figure 5-19. *The water table in SSM000271 (metres above sea level). The sharp dips in the water table are associated with water sampling events.*

Monitoring of electrical conductivity and pH in ground water samples

Water samples were collected with a one to two week interval for monitoring of the electrical conductivity and pH in the ground water in environmental monitoring well SSM000271, see Figure 5-20.

No significant influence can be seen on the shallow ground water in the monitoring well SSM000271 from the drilling activity in KLX16A.

5.7.1 Consumption of oil and chemicals

No significant amounts of oils or lubricants were consumed during the drilling.

The concrete consumption in KLX16A was 40 litres. The concrete was based on white silica, low alkali cement.

5.8 Nonconformities

No formal nonconformities are noted for borehole KLX16A.

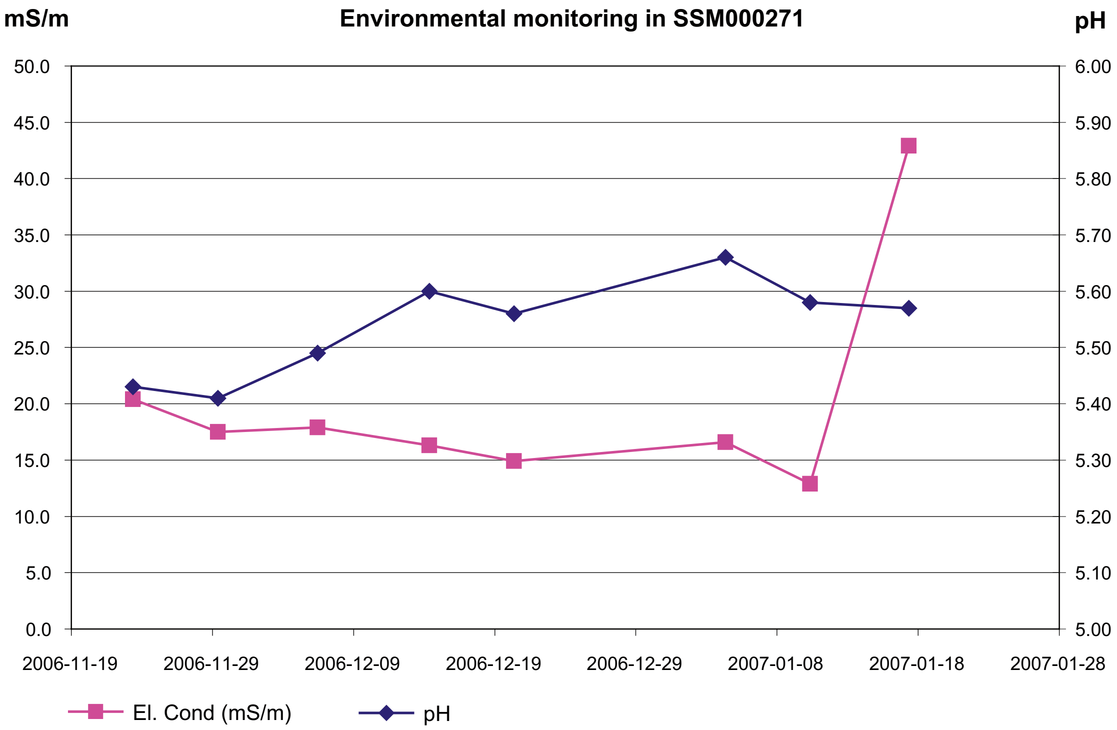


Figure 5-20. *Electrical conductivity and pH in ground water samples from SSM000271. The sampling events are shown with blue and purple symbols.*

6 References

/1/ **SKB, 2001.** Platsundersökningar, Undersökningsmetoder och generellt genomförande-program. SKB R-01-10, Svensk Kärnbränslehantering AB.

/2/ **SKB, 2005.** Platsundersökning Oskarshamn, Program för fortsatta undersökningar i mark, vatten och miljö inom delområde Laxemar. SKB R-05-37, Svensk Kärnbränslehantering AB.

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/4/ **Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2006.** Drilling of cored borehole KLX05. SKB P-05-233, Svensk Kärnbränslehantering AB.

/5/ **Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2007.** Drilling of cored borehole KLX12A. SKB P-06-305, Svensk Kärnbränslehantering AB.

/6/ **Stenberg L, Håkanson N, 2007.** Revision of borehole deviation measurements in Oskarshamn. SKB P-07-55, Svensk Kärnbränslehantering AB.

/7/ **Ask H, 2007.** Percussion drilling of boreholes HLX38, HLX39, HLX40, HLX41, HLX42 and HLX43 for lineament investigation. SKB P-06-291, Svensk Kärnbränslehantering AB.

/8/ **Mattsson K-J, Dahlin P, Lundberg E, 2007.** Boremap mapping of core drilled borehole KLX16A. SKB P-07-211, Svensk Kärnbränslehantering AB.

/9/ **Ask H, Morosini M, Tiberg L, 2007.** Drilling of cored borehole KLX17A. SKB P-07-221, Svensk Kärnbränslehantering AB.

/10/ **Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2004.** Drilling of cored borehole KSH03. SKB P-04-233, Svensk Kärnbränslehantering AB.

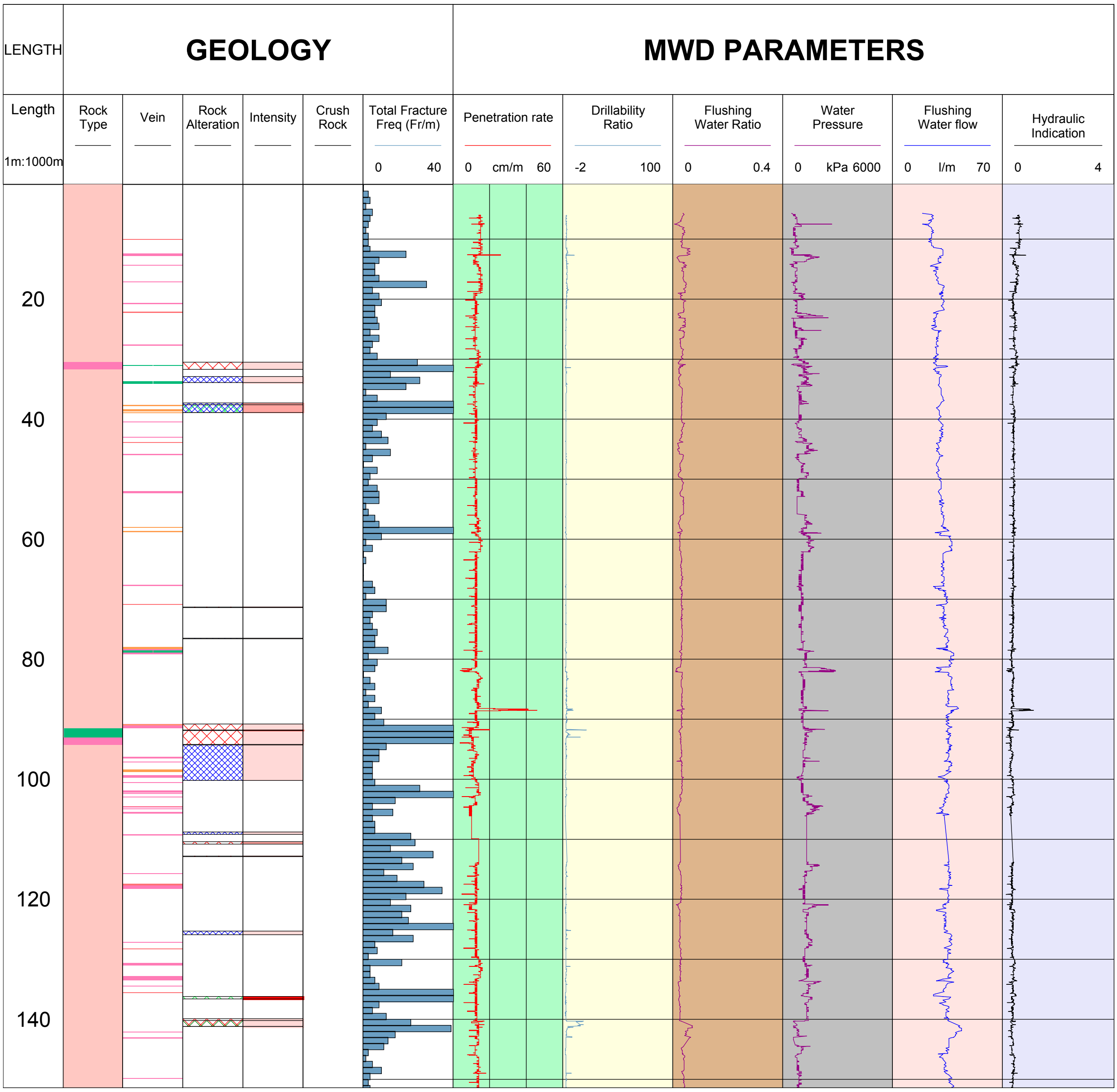
/11/ **Morosini M, Jenkins C, Simson S, Albrecht J, Zetterlund M, 2007.** Hydrogeological characterization of deepest valley soil aquifers and soil-rock transition zone at Laxemar, 2006. SKB P-07-91, Svensk Kärnbränslehantering AB.

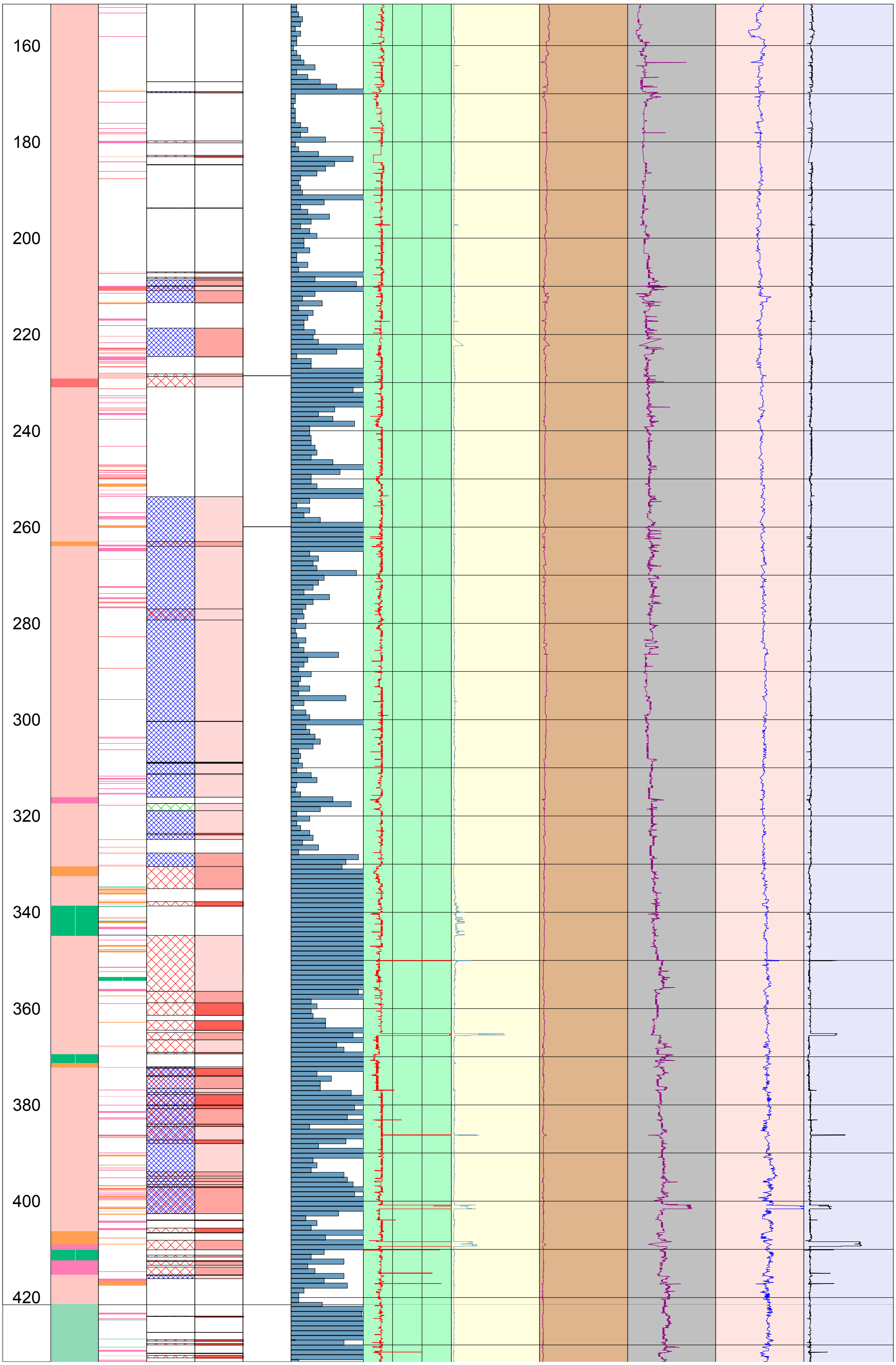
Appendix 1

Geology and MWD parameters KLX16A

Site	LAXEMAR	**Coordinate System**	RT90-RHB70
Borehole	KLX16A	**Northing [m]**	6364797.69
Diameter [mm]	76	**Easting [m]**	1547584.06
Length [m]	433.550	**Elevation [m.a.s.l.]**	18.85
Bearing [°]	294.37	**Drilling Start Date**	2006-11-28 13:00:00
Inclination [°]	-64.97	**Drilling Stop Date**	2007-01-09 13:00:00
Date of mapping	2007-03-01 09:13:00	**Plot Date**	2008-02-06 22:03:22

ROCKTYPE LAXEMAR	ROCK ALTERATION	INTENSITY
Fine-grained granite	Oxidized	No intensity
Pegmatite	Chloritisized	Faint
Granite	Epidotisized	Weak
Quartz monzodiorite	Silicification	Medium
Fine-grained dioritoid	Argillization	Strong
Fine-grained diorite-gabbro	Albitization	
	Saussuritization	




160
180
200
220
240
260
280
300
320
340
360
380
400
420

Appendix 2

Pumping tests

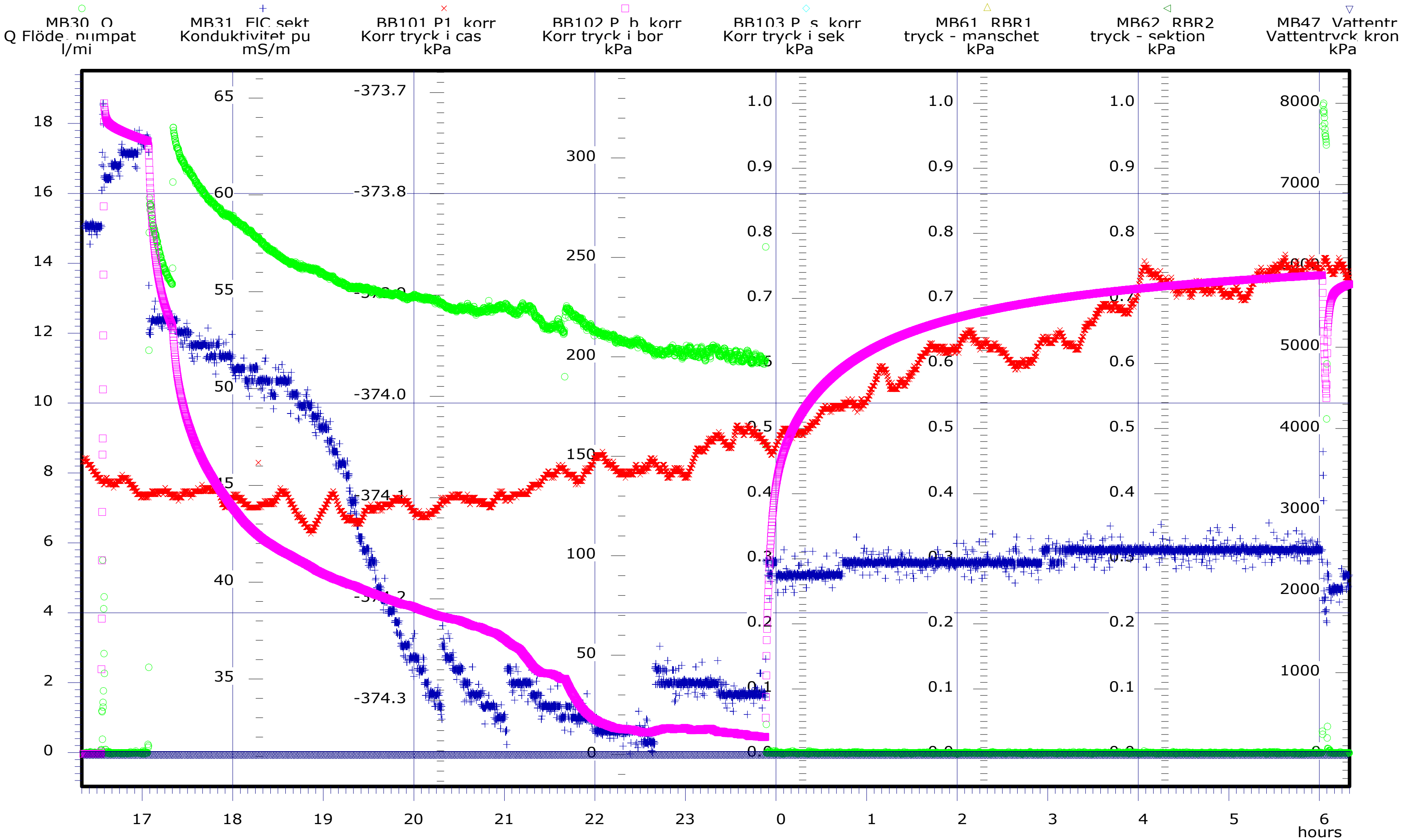
Description of the parameters in the enclosed plots

Channel	Parameter	Unit	Description
MB30	Water flow	Litre/minute	Flow of water pumped up from the borehole during the test.
MB31	Electrical conductivity	mS/m	Electrical conductivity in the pumped out water.
BB101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient air pressure.
BB102	Pressure	kPa	Pressure of the water column in the test section ie at depth in the borehole, subtracted with the ambient air pressure.
BB103	Pressure – section	kPa	Pressure of the water column in the test section ie at depth in the borehole, subtracted with the ambient air pressure.
MB61	Pressure – packer	kPa	Inflation pressure in packer.
MB62	Pressure – section	kPa	Pressure of the water column in the test section ie at depth in the borehole. Not corrected for ambient air pressure.
MB47	Water pressure	kPa	Water pressure on the drill bit.

PLOT TIME :06/12/05 10:18:29
PLOT FILE :P_pumptest
No DST Adjustment

DMS2 PO

Pumping test
KLX16A 11.25 - 109.20 m
No Wireline probe



START :06/12/04 16:20:00

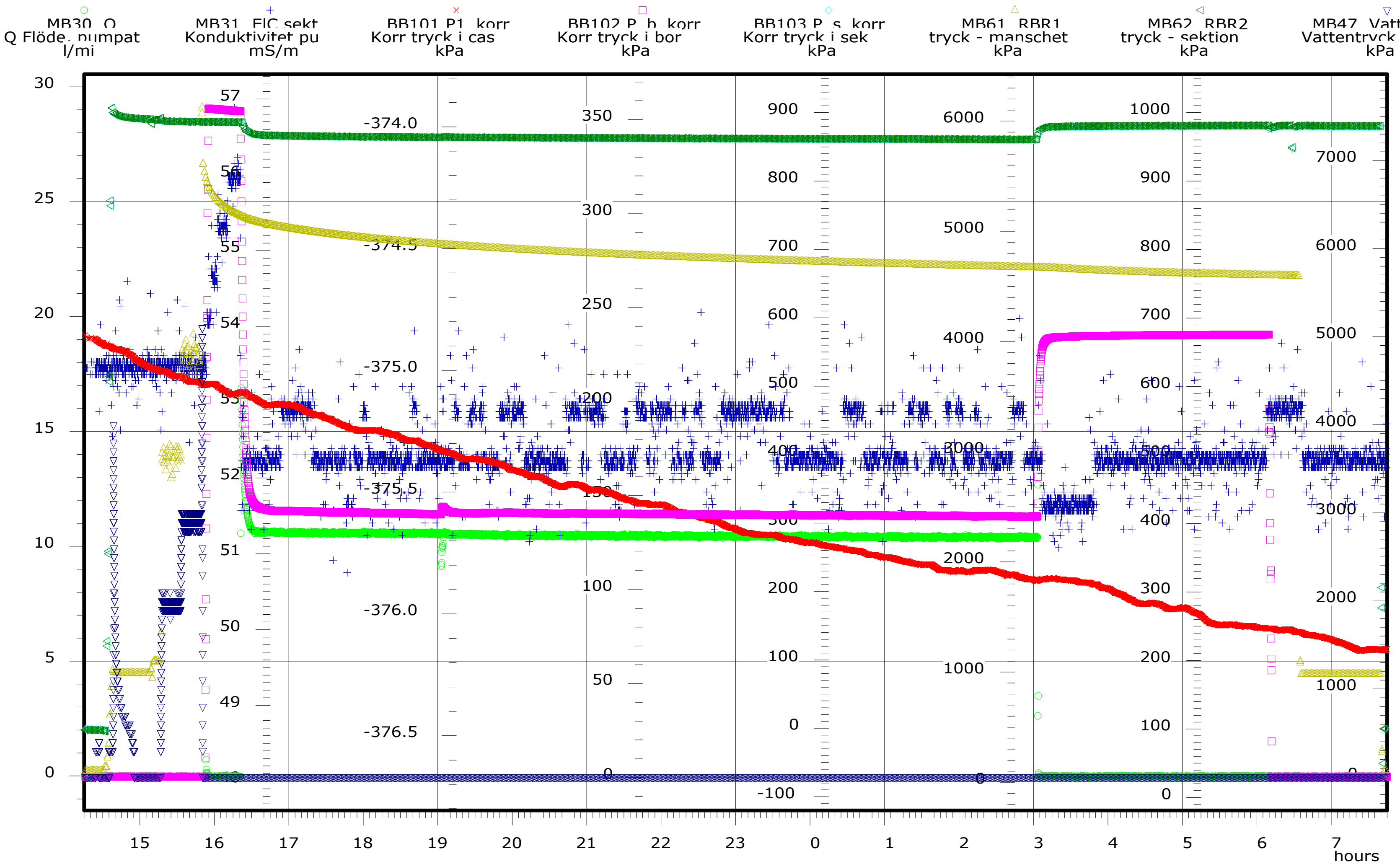
INTERVAL: All readings

STOP :06/12/05 06:19:59

PLOT TIME :06/12/12 12:34:56
PLOT FILE :P_pumptest
No DST Adjustment

DMS2 PO

Pumping test
KLX16A 109.00 - 203.16 m
Wireline probe test



START :06/12/09 14:15:00

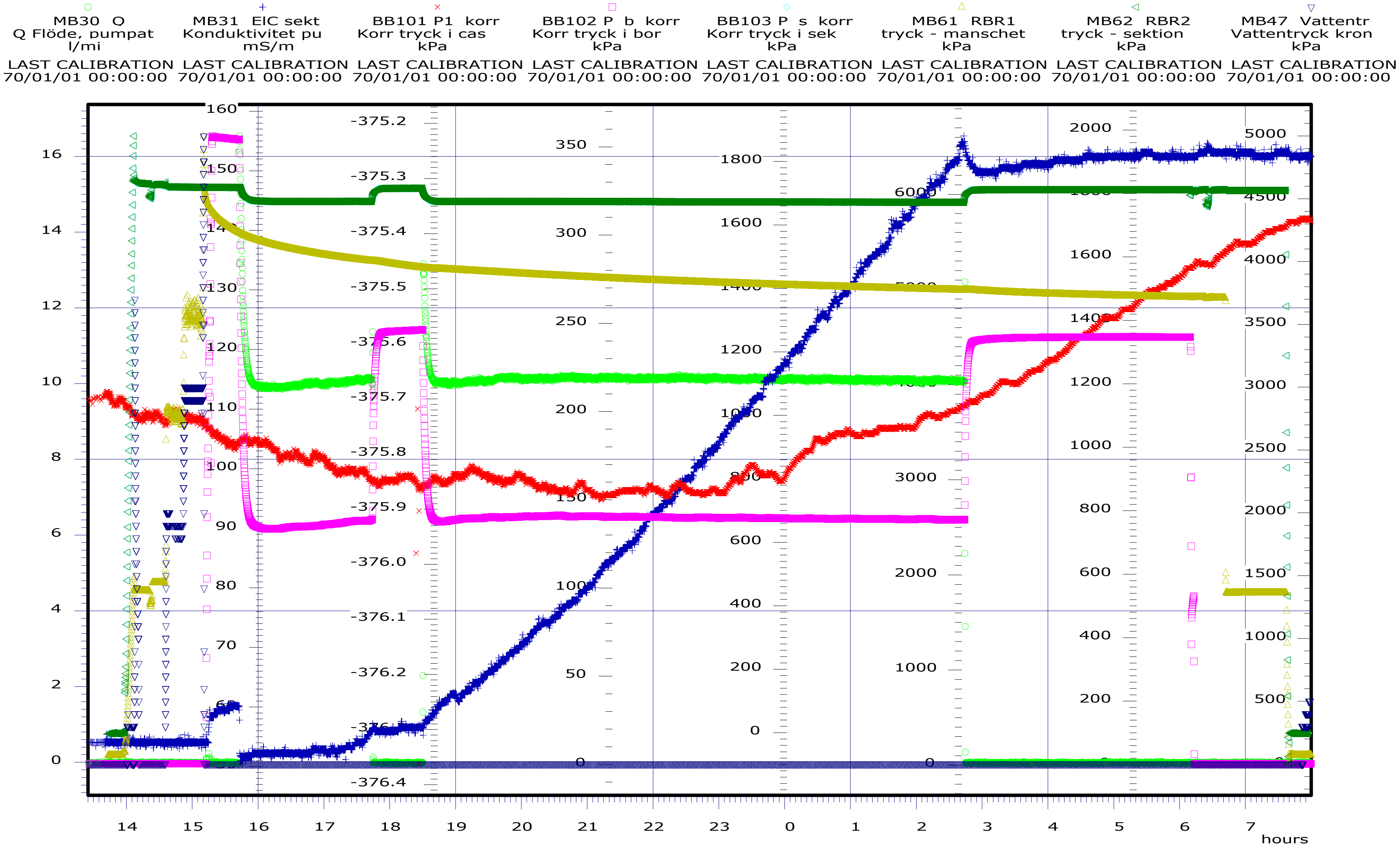
INTERVAL: All readings

STOP :06/12/10 07:44:59

PLOT TIME :06/12/21 11:27:04
PLOT FILE :P pumptest
No DST Adjustment

DMS2 PO

Pumping test
KLX16A 202.00 - 296.16 m
Wireline probe test



START :06/12/15 13:25:00

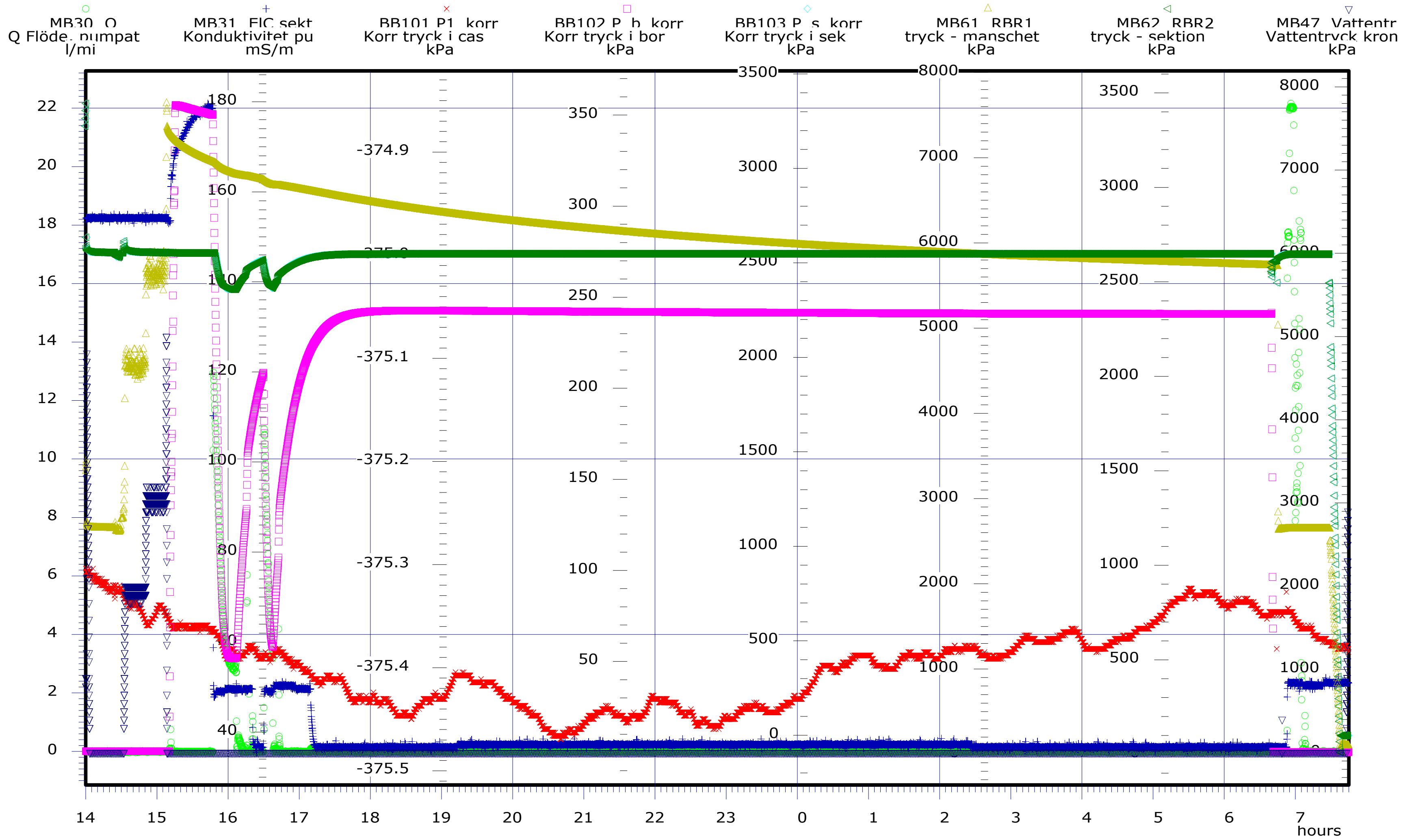
INTERVAL: All readings

STOP :06/12/16 07:59:59

PLOT TIME :07/01/08 09:46:37
PLOT FILE :P_pumptest
No DST Adjustment

DMS2 PO

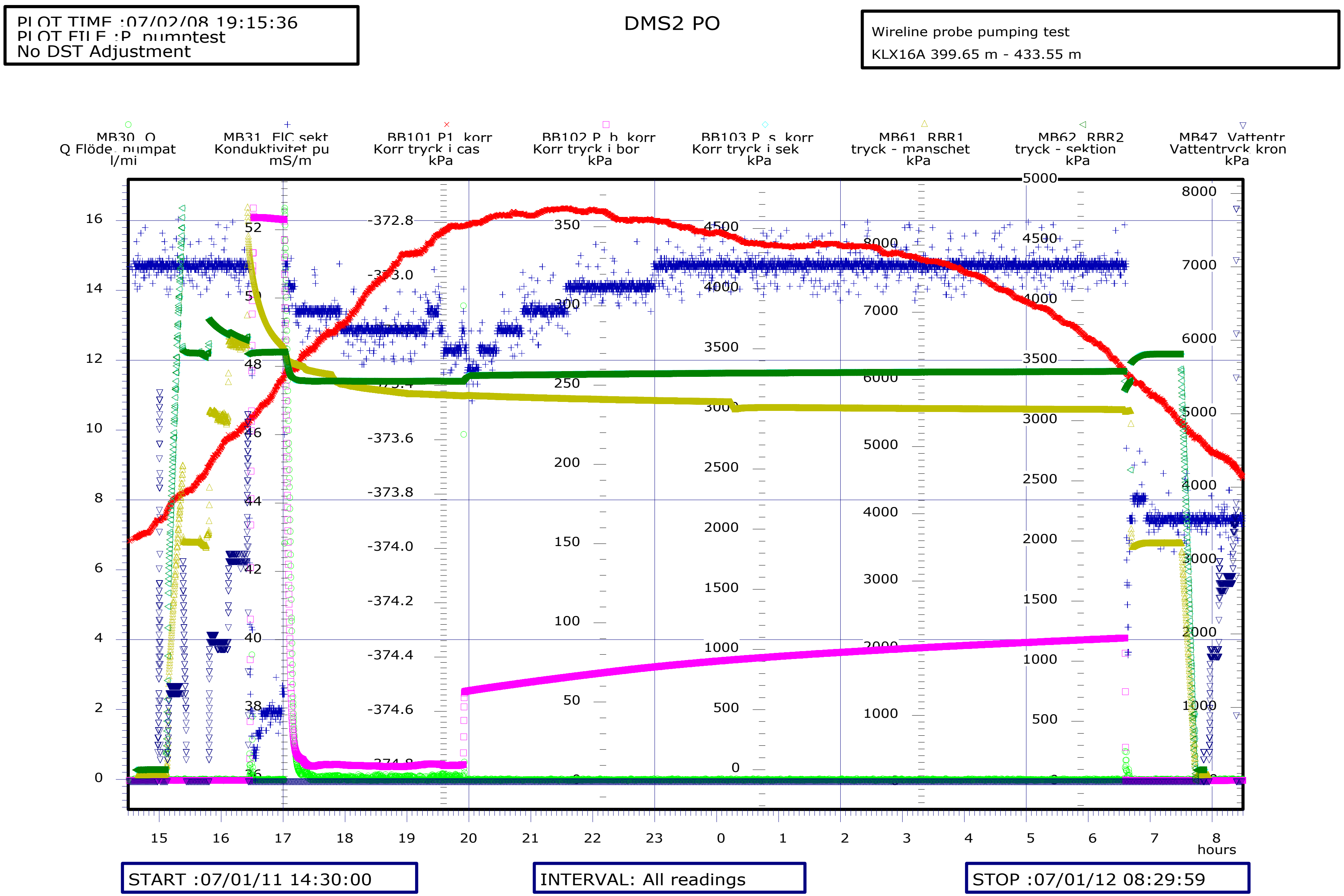
Pumping test
KLX16A 296.00 - 400.78 m
Wireline probe test



START :07/01/06 14:00:00

INTERVAL: All readings

STOP :07/01/07 07:44:59


PLOT TIME :07/02/08 19:15:36
PLOT FILE :P_pumptest
No DST Adjustment
DMS2 PO
Wireline probe pumping test
KLX16A 399.65 m - 433.55 m
MB30 Q
Q Flöde, pumpat
l/mi
MB31 EIC sekt
Konduktivitet pu
mS/m
BB101 P1 korr
Korr tryck i cas
kPa
BB102 P b korr
Korr tryck i bor
kPa
BB103 P s korr
Korr tryck i sek
kPa
MB61 RBR1
tryck - manschet
kPa
MB62 RBR2
tryck - sektion
kPa
MB47 Vattentr
Vattentryck kron
kPa
hours
START :07/01/11 14:30:00
INTERVAL: All readings
STOP :07/01/12 08:29:59

Appendix 3

Chemistry – analytical method and quality

SKB Chemistry class 3

Analysis	Sample bottle	Preparation	SKB label	Laboratory
pH, conductivity, alkalinity	250 ml		green	Äspö/field
Anions (F^-, Br^-, Cl^-, SO_4^{2-})	250 ml		green	Äspö/field
Uranine	100 ml brown glass		green	Äspö/field
Main components (except Fe, Mn)	Analytica's 100 ml acid washed	1 ml HNO_3 suprapur, filtering membrane filter	red	Analytica
Archive samples	2 ea 250 ml	Filtering Pallfilter	green	
Option				
Deuterium, O-18	100 ml square		green	IFE
Tritium	500 ml dried	Flooded at least once	green	Waterloo
Sr-87	100 ml square		green	IFE
Cl-37	500 ml		green	Waterloo
B-10	Same as for main components	1 ml HNO_3 suprapur, filtering membrane filter	red	Analytica
C-13, PMC	2 st 100 ml brown glass		green	Waterloo
S-34	1,000 ml		green	IFE

Quality of the analyses

The charge balance errors give an indication of the quality and uncertainty of the analyses of the major components. The relative charge balance errors are not calculated for the set of data from borehole KLX16A since the samples only are analysed for drill water content.

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

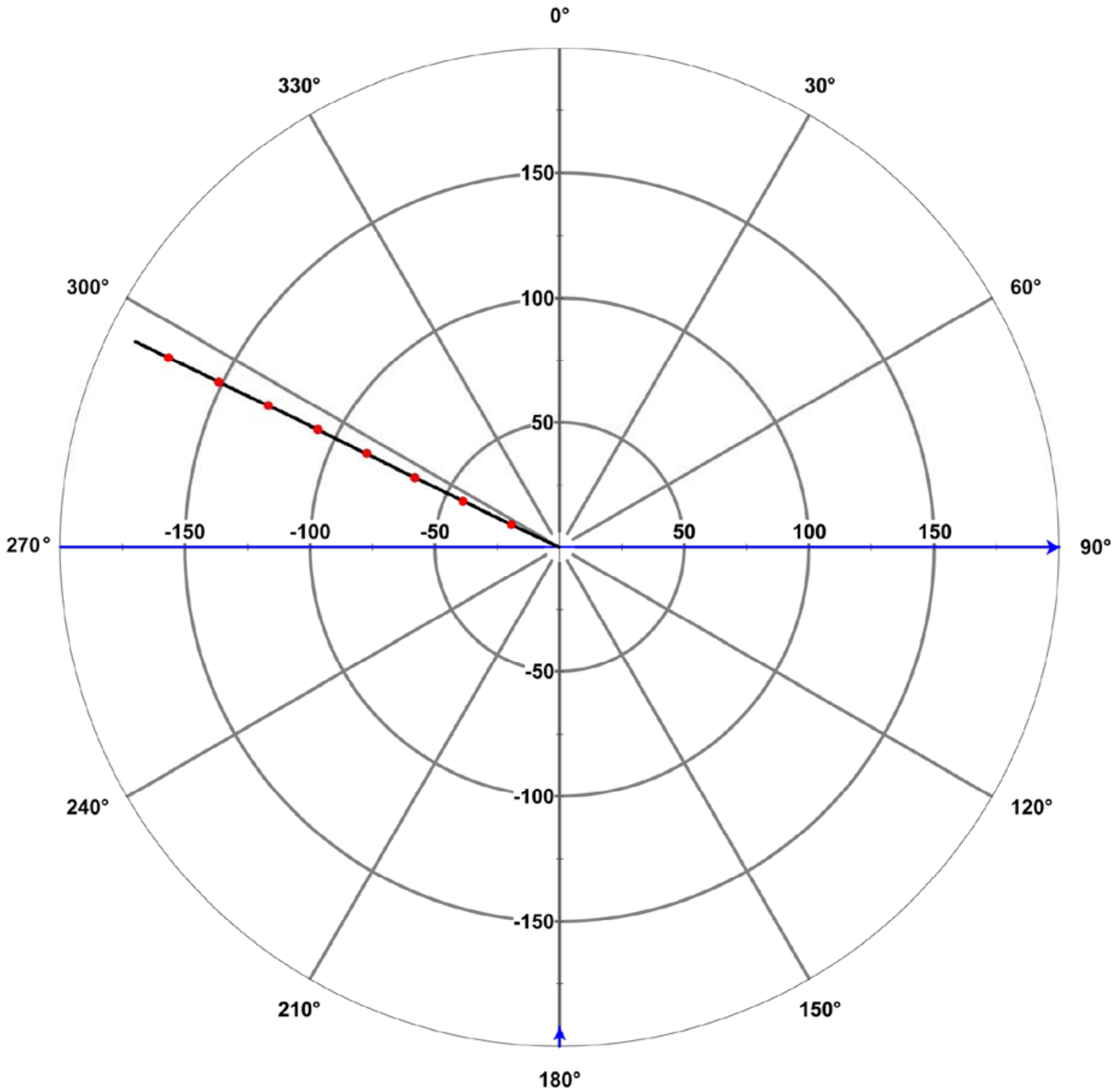
- Several components are determined by more than one method and/or laboratory. Control analyses by an independent laboratory are normally performed as a standard procedure on every five or ten collected samples. No control analyses were performed on the water samples from KLX16A.
- All analytical results were stored in the SICADA database. The chemistry part of the database contains two types of tables, raw data tables and primary data tables (final data tables).
- Data on basic water analyses are inserted into raw data tables for further evaluation. The evaluation results in a final reduced data set for each sample. These data sets are compiled in a primary data table named "water composition". The evaluation is based on:
  - Comparison of the results from different laboratories and/or methods. The analyses are repeated if a large disparity is noted (generally more than 10 %).
  - Calculation of charge balance errors. Relative errors within ± 5 % are considered acceptable. For surface waters errors of ± 10 %.
  - $\text{Rel. Error (\%)} = 100\times \frac{(\sum \text{cations(equivalents)} - \sum \text{anions(equivalents)})}{(\sum \text{cations(equivalents)} + \sum \text{anions(equivalents)})}$
  - General expert judgement of plausibility based on earlier results and experiences.

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

Appendix 4

Borehole deviation measurements

Site LAXEMAR
Borehole KLX16A
View from above



Site LAXEMAR
Borehole KLX16A
Vertical Section