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Oskarshamn site investigation

Drilling of boreholes KLX21A and KLX21B

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April 2008

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Data in SKB's database can be changed for different reasons. Minor changes in SKB's database will not necessarily result in a revised report. Data revisions may also be presented as supplements, available at www.skb.se.

Abstract

Boreholes KLX21A and KLX21B are located in the eastern parts of the Laxemar subarea. Drilling was made between August and November 2006 as a part of the site investigation for a possible repository for spent nuclear fuel in Oskarshamn municipality, Sweden. KLX21B was the twentieth deep cored borehole within the site investigation in Oskarshamn. Only the upper, percussion drilled part of borehole KLX21A was performed as it was decided against drilling the deeper cored section.

KLX21B was core drilled to a length of 858.78 metres with N-size (76 mm) equipment. The uppermost section, to the length of 99.41 metres, was constructed as a telescopic borehole with an inner nominal diameter of 200 mm.

KLX21A was percussion drilled to a length of 75.00 metres, with the initial purpose of constructing a telescopic section for future core drilling. No core drilling was however performed in KLX21A.

No water inflow could be measured in either KLX21A or KLX21B over the entire length of the telescopic section after percussion drilling of the pilot borehole (nominal diameter 165 mm).

Seven successful tests were completed with wireline equipment from fourteen attempts at various intervals. The resulting transmissivities (T_M) varied between 7.6×10^{-4} and 3.1×10^{-8} m^2/s. The most transmissive section was between 101 and 263 metres.

Continuous monitoring of drilling parameters and flushing water parameters with the drilling monitoring system was conducted throughout the core drilling phase in KLX21B.

Three water samples for chemical analysis were collected during the core drilling of KLX21B.

The air-lift pumping test in the telescopic section performed when borehole KLX21B was core drilled to its full length gave a transmissivity (T_M) of 5.5×10^{-4} m^2/s.

Lithologically the core is dominated Ävrö granite with intercalations of subordinate rock types. Below 770 metres the core is composed mainly of quartz monzodiorite.

Rock alteration is mostly weak. A section with significant red staining and elevated fracture frequency exists from 610 to 710 m. Sections with red staining are indicated as “oxidized” in Appendix 1.

The average fracture frequency over the core drilled section is 2.2 (fractures/metre) expressed as open fractures.

Sammanfattning

Borrhål KLX21A och KLX21B ligger i den östra delen av delområde Laxemar. Borrningen utfördes mellan augusti och november 2006 som ett led i platsundersökningen för ett möjligt djupförvar för använt kärnbränsle i Oskarshamns kommun. KLX21B var det tjugonde djupa kärnborrhålet inom platsundersökningen i Oskarshamn. Endast den övre, hammarborrade delen av KLX21A utfördes eftersom det beslutades att inte borra den djupare kärnborrade delen.

KLX21B kärnborrades med borrstorlek N (76 mm) till 858,88 meters borrad längd. Den övre delen av hålet, från markytan till 99,41 meter, utfördes som en teleskopdel med ca 200 mm inre diameter.

KLX21A hammarborrades till en längd av 75,00 meter, där det ursprungliga syftet var att bygga en grovdel inför kommande kärnborrning. Ingen kärnborrrning utfördes emellertid i KLX21A.

Inget vatteninflöde kunde mätas i varken KLX21A eller KLX21B över hela teleskopdelen vid hammarborrningen av pilotdelen (nominell diameter 165 mm).

Sju stycken lyckade pumptester slutfördes med wireline-baserad mätutrustning från fjorton försök på varierande nivåer. De uppmätta transmissiviteterna (T_M) varierade mellan $7{,}6\times10^{-4}$ och $3{,}1\times10^{-8}$ m^2/s. Den mest transmissiva sektionen var mellan 101 och 263 meter.

Kontinuerliga mätningar av borrningsparametrar och spolvattenparametrar via DMS (drilling monitoring system) gjordes under hela kärnborrningsfasen i KLX21B.

Tre vattenprover för kemisk analysering togs i samband med borrning i KLX21B.

Mammutpumpningen i teleskopdelen som gjordes när kärnborrningen i KLX21B utförts till full längd gav en transmissivitet (T_M) på $5{,}5\times10^{-4}$ m^2/s.

Litologiskt domineras kärnan av Ävrögranit med inslag av underordnade bergarter.
Under 770 meter består kärnan huvudsakligen av kvartsmonzodiorit.

Bergartsomvandling är oftast svag. Ett parti med betydande rödfärgning och förhöjd sprickfrekvens har karterats från 610 till 710 m. Sektioner med rödfärgning är angivna som ”oxiderade” i Bilaga 1.

Den genomsnittliga sprickfrekvensen i det kärnborrade partiet är 2,2 (sprickor/meter) uttryckt som öppna sprickor.

Contents

1 Introduction

SKB, the Swedish Nuclear Fuel and Waste Management Company, performs site investigations in order to evaluate the feasibility of locating a deep repository for spent nuclear fuel /1, 2/. The investigations are performed in two Swedish municipalities: Östhammar and Oskarshamn. Borehole KLX21B is located in the eastern part of the Laxemar subarea of the investigation area in Oskarshamn.

Drilling and investigations in boreholes are fundamental activities in order to facilitate characterisation of rock and groundwater properties at depth. KLX21B was the twentieth 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 KLX21A and KLX21B and all related on-site operations were performed according to specific Activity Plans, which in turn refer to a number of Method Descriptions, see Table 1-1.

The Activity Plans and Method Descriptions are SKB internal documents.

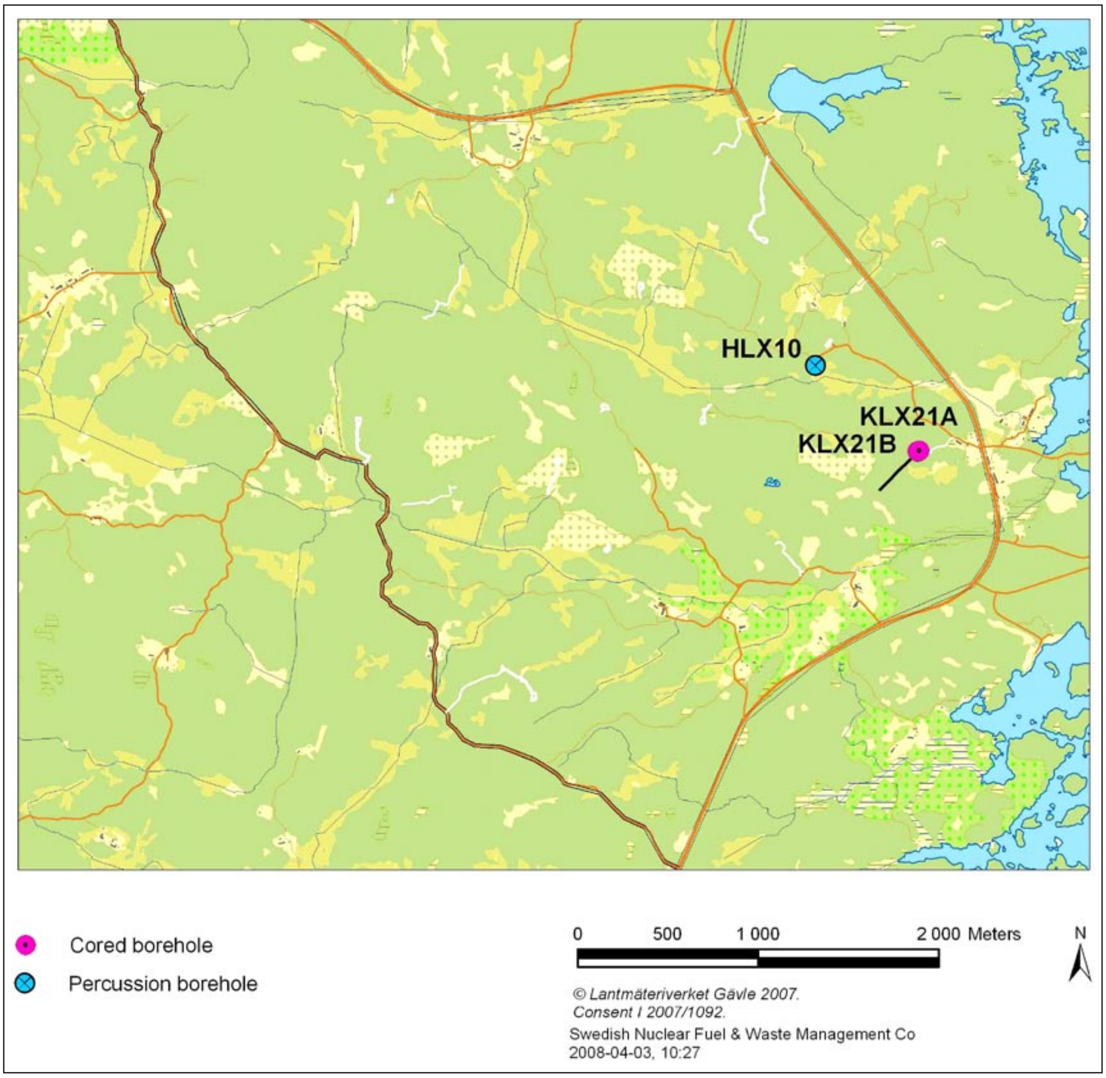


Figure 1-1. *Location of the boreholes KLX21A, KLX21B and the water source, percussion borehole HLX10 in the Laxemar subarea.*

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

Activity Plan	Number	Version
Kärnborrning KLX21A	AP PS 400-06-095	1.0*
Kärnborrning KLX21B	AP PS 400-06-108	1.0**
Method Descriptions	**Number**	**Version**
Metodbeskrivning för kärnborrning	SKB MD 620.003	2.0
Metodbeskrivning för hammarborrning	SKB MD 610.003	3.0
Metodbeskrivning för hydrauliska enhålstrester	SKB MD 321.003	1.0
Metodbeskrivning för registrering och provtagning av spolvatten-parametrar 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	2.0
Metodbeskrivning för jordborrning	SKB MD 630.003	1.0

* One amendment to the Activity Plan, KLX21A exists.

** One amendment to the Activity Plan, KLX21B exists.

2 Objective and scope

This report will describe the methods employed and the results achieved during the drilling of borehole KLX21A and KLX21B. A number of related activities, such as wireline hydraulic tests, water sampling and monitoring of drilling parameters that were performed in conjunction with deeper drilling in KLX21B will also be reported here.

The initial purpose for drilling the borehole KLX21A was to characterize and gain further geological information about deformation zone NE005 as well as to facilitate further investigation at depth in the eastern part of the Laxemar subarea. The initial decision to drill KLX21A is given in SKB id no 1058178, dated 2006-08-14. The decision NOT to drill KLX21A to the full length was taken on 2006-11-29, SKB id 1064533 after consultation with the modelling group within the site investigation.

The main reason for drilling the borehole KLX21B was to verify and characterize possible rock volumes for a deep repository as well as to gain geological information and facilitate further investigation at depth in the eastern part of the Laxemar subarea. The decision to drill KLX21B is given in SKB id no 1060438, dated 2006-09-19. A second decision to prolong KLX21B was taken on 2006-11 29, SKB id 1064540.

KLX21B was constructed as a "telescope hole", which means that the upper, normally, 100 metre section of the hole has a wider diameter than the deeper core drilled part of the hole.

Notifications in accordance with the Environmental Code and supplementary letters of information of the final coordinates and details regarding the return water handling were sent to the Regional Authorities as given in Table 2-1. Notification for KLX21B was not necessary since this hole was drilled from the drill site established for KLX21A.

Table 2-1. Notification and letters of information to the Regional Authorities.

	SKB id	Date
Notification KLX21A	1055239	2006-05-24
Supplementary information KLX21A	1056970	2006-06-30
Supplementary information KLX21B	1059936	2006-09-14

3 Overview of the drilling method

3.1 The SKB telescope drilling method

In brief, the telescope drilling method is based on the construction of a larger diameter hole (200 mm diameter) to a length of normally 100 metres followed by a N-size (76 mm diameter) cored section to full length. The larger diameter section can either be percussion drilled or reamed with a percussion bit after core drilling of a pilot hole.

The main purpose of the upper large diameter section is to improve the removal of water from the hole by air-lift pumping in order to minimize the intrusion of foreign substances (flushing water and cuttings) to the surrounding bedrock. It also enables the use of submersible pumps for tests and to facilitate the installation of multi-packer systems for ground water pressure recordings.

After drilling 0–100 m, equipment for air-lift pumping is installed in the borehole. The air-lift pumping will create a pressure drawdown and help remove water and cuttings while core drilling between 100 metres and full planned length, see Figure 3-1. The effect of drawdown is dependent on the depth and capacity of major groundwater conductors.

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 and a conical guide of stainless steel is installed between the telescope part and the deeper core drilled part, see Figure 3-2.

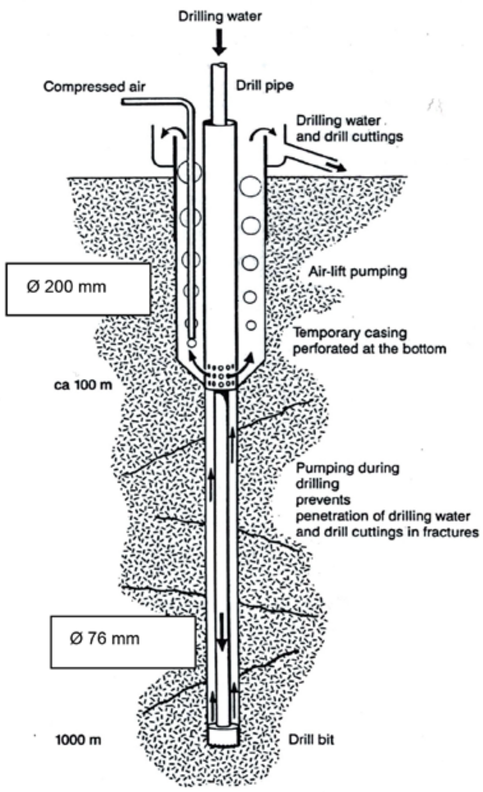


Figure 3-1. *A sketch of the telescopic drilling method with air-lift pumping for retrieval of drilling water and cuttings.*

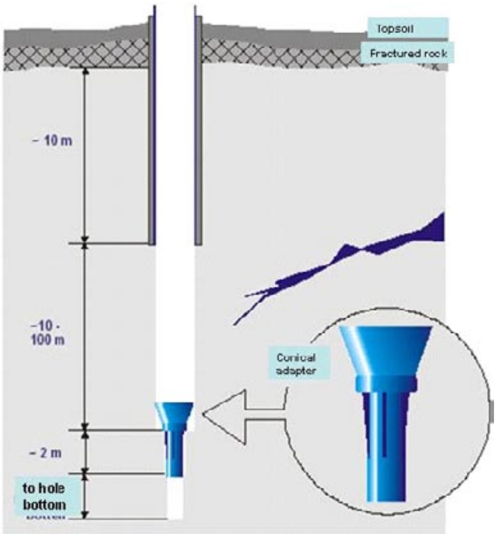


Figure 3-2. *Installation of the conical guide.*

3.1.1 The flushing water system

The handling of flushing water includes a source of water with a submersible pump, tanks and air-lift pumps for raising the water from the bottom of the telescope part to surface. The return water is led to settling containers before discharge, see Figure 3-3.

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 3-4.

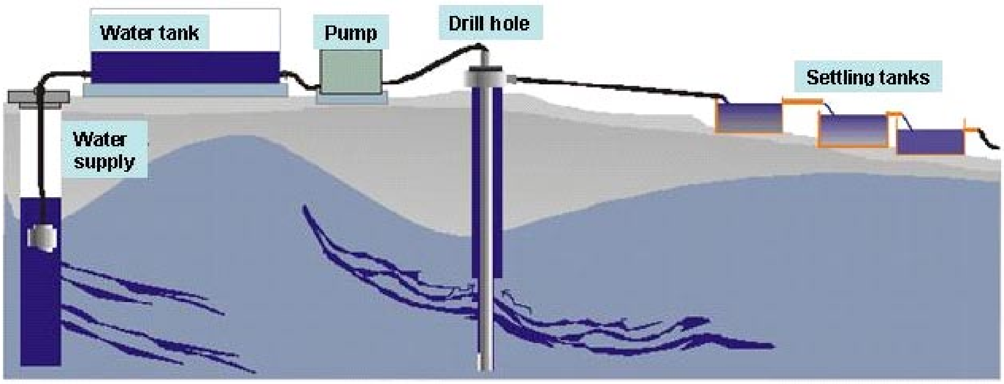


Figure 3-3. *The flushing water system from source to discharge point.*

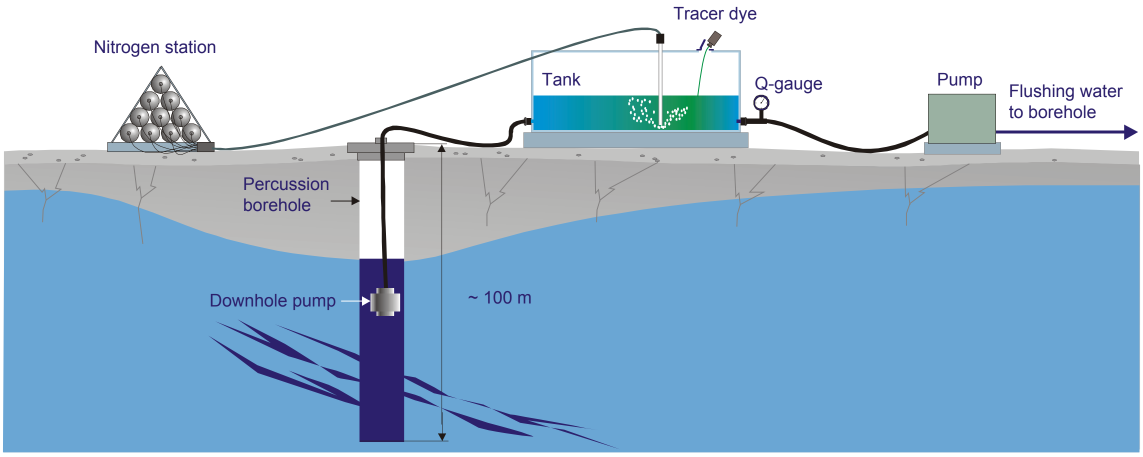


Figure 3-4. *Schematic drawing of the preparation of flushing water. Uranine is added to the water as a tracer dye and nitrogen is bubbled through the water to remove dissolved oxygen.*

3.2 Measurements and sampling during drilling

3.2.1 Percussion drilling

Drill cuttings were collected for every metre during the percussion drilling of both KLX21A and KLX21B. A preliminary geological logging of the cuttings was done on site. During the preliminary logging notes were made on the dominating lithology, size and shape of the cutting or any other noticeable geological feature. The magnetic susceptibility of the cuttings samples were measured with hand held equipment. Small cups of return water were taken systematically of the return water. The water colour and intensity were noted as indications on degree of rock oxidation and clay content. The return water flow (i.e. the amount of water driven up by compressed air) was measured when noticeable changes in flow occur. The drill penetration rate during percussion drilling was either logged automatically or manually.

3.2.2 Core drilling

The sampling and measurements during the core drilling phase of KLX21B consisted of:

- Wireline measurements.
- Air-lift pumping and recovery tests.
- Water sampling at the surface.
- The drilling monitoring system.

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 /4/ and are normally performed for every 100 metres 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 Measurement of absolute pressure were not done in KLX21B following an internal decision, (SKB id 1044856, SKB internal document).

Air-lift pumping with evaluation of drawdown

Air-lift pumping with evaluation of drawdown is done with 300 metres intervals, nominally at 400 metres 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 test cycle is started with air-lift pumping in the telescopic section.
- Drilling or other related activities such as rinsing of drill cuttings can occur prior to lifting the stem. This means that an inflow of water through the drill stem can occur during the initial stages of the test cycle.
- After the stem has been removed the 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 telescopic section 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 drilling monitoring system (DMS).

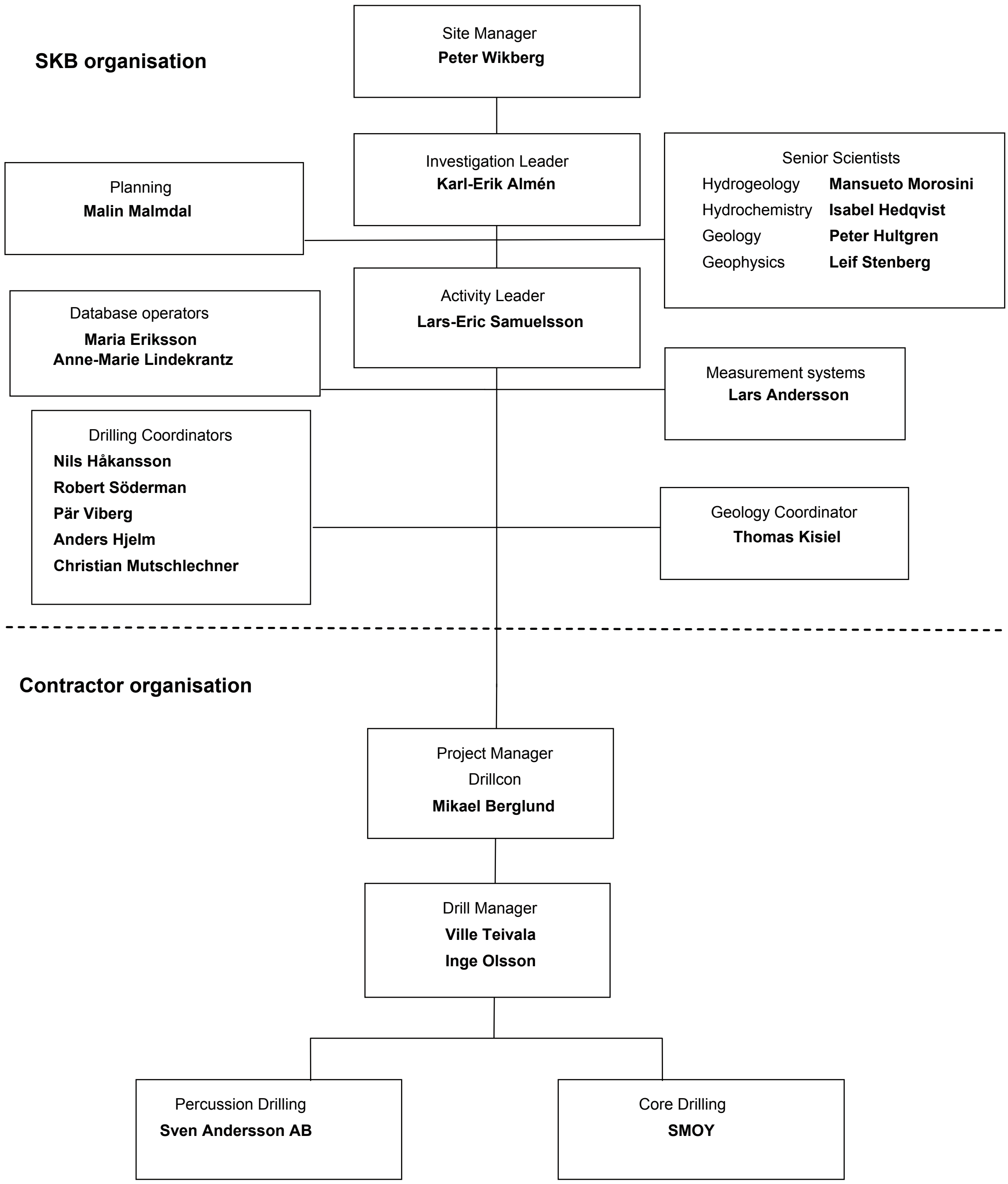
4 Contractors and equipment

4.1 Contractors

The main contractor for the drilling in both KLX21A and KLX21B was Drillcon Core AB, with subcontractor for core drilling Suomen Malmi OY (SMOY) and subcontractor for percussion drilling Sven Andersson AB.

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

Table 4-1. Drill activity organisation.



4.2 Percussion drilling equipment

The percussion drill rig used in KLX21A was a Enteco E14G. For KLX21B a Comacchio MC1500 drill rig was used. In both cases an Atlas Copco XRVS 455 Md air compressor was used. Overburden drilling was made with NO-X 280 mm equipment. The down-the-hole hammer was a Secoroc 165 mm (nominal diameter) for the pilot borehole and the drill rods were Driqoneq 114 mm. Reamings were done with Secoroc DTH-hammers for 200 or 250 mm diameter. The casings utilized were 208×4 mm (SS 2343, stainless) and 323×11 mm (non stainless). The casing dimensions are presented here as outer diameter × thickness in mm.

Figure 4-1. *The Comacchio MC1500 drill rig performing NO-X 280 drilling through the overburden at KLX21B.*

4.3 Core drilling equipment

Core drilling in KLX21B was made with a B20 APC Atlas Copco JKS Boyles 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 KLX21B. No core drilling was made in KLX21A.

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.

Figure 4-2. *The drill site while core drilling KLX21B.*

4.3.1 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 4-3.

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.

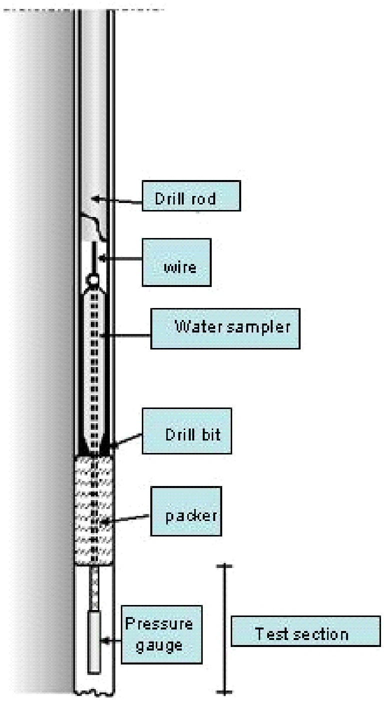


Figure 4-3. The wireline probe and its emplacement in the hole.

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 KLX21B.

4.3.2 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.

4.3.3 Deviation measurements

Two types of deviation measurements were made in KLX21B:

- Measurements to keep track on the borehole orientation were made with the magnetometer/accelerometer method Reflex EZ-AQ/EMS (or Easy-Shot), see also Table 5-3 and Section 5.4.3.
- 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.

A final measurement of borehole deviation was made with the Flexit method in KLX21A.

4.3.4 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.

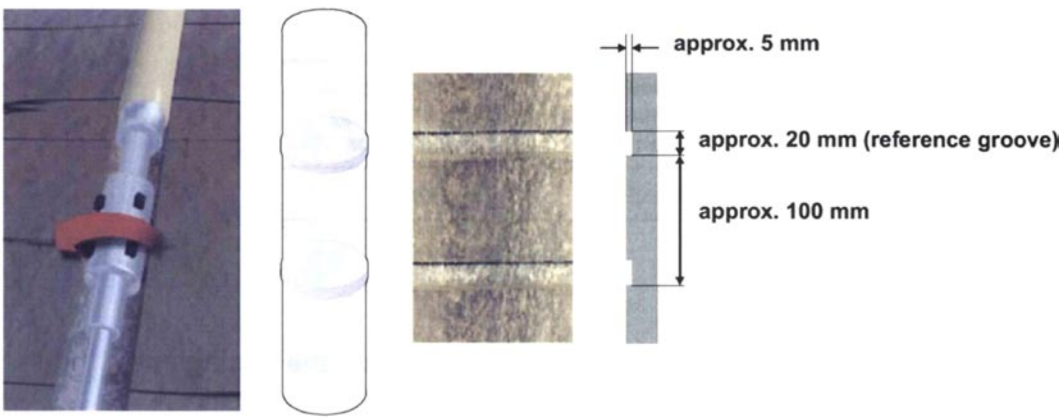


Figure 4-4. *The equipment for reaming of reference slots. To the left, the reaming tool with openings for the cutters is shown. The resulting reference slots are illustrated in the three pictures to the right.*

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 numbers, AP PS 400-06-095 for KLX21A and AP PS 400-06-108 for KLX21B.

5.1 Drilling summary for KLX21A and KLX21B

5.1.1 KLX21A

A technical summary of the drilling of KLX21A is given in Table 5-1. A graphical presentation of the borehole after completion is given in Figure 5-1.

Further description of the percussion drilling of the telescopic section in KLX21A and the measurements performed during this phase are given in Section 5.2.

A decision not to core drill in KLX21A was taken on November 29, 2006, SKB id 1064533.

5.1.2 KLX21B

A technical summary of the drilling of KLX21B is given in Table 5-2. A graphical presentation of the borehole after completion is given in Figure 5-2. A summary of drilling progress and borehole measurements is given in Table 5-3 and chronological summary is presented in Table 5-4.

Further description of the percussion drilling of the telescopic section in KLX21B and the measurements performed during this phase are given in Section 5.3.

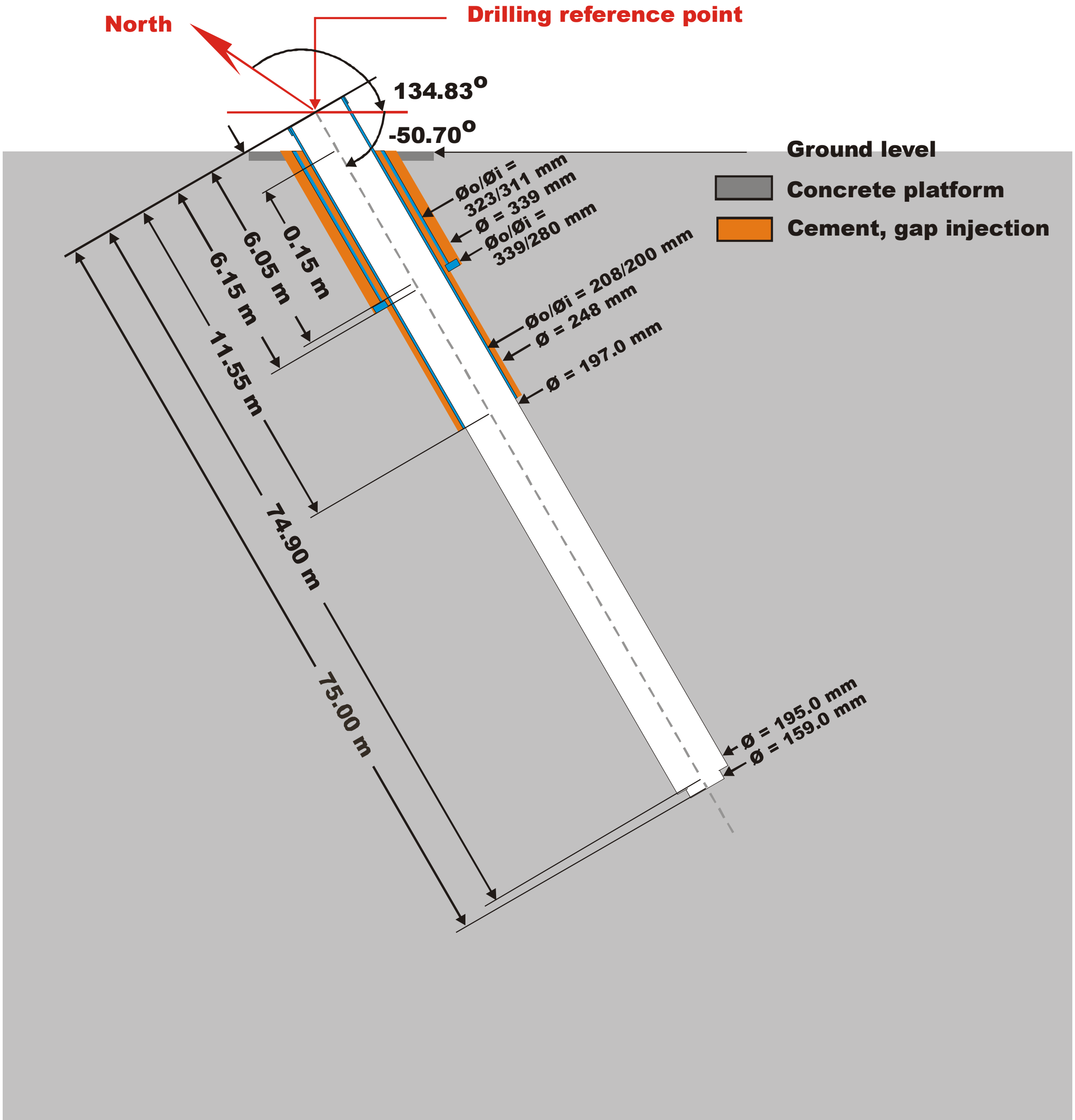
The core drilling in KLX21B between 99.41–858.78 metres is further described in Section 5.4. Results from hydrogeological and hydrogeochemical measurements during core drilling are presented in Section 5.5. Drilling progress over time is further reported in Section 5.6 "Drilling monitoring results".

Table 5-1. KLX21A Technical summary.

General	Technical
Name of hole: KLX21A	*Percussion drill rig* Enteco E14G
Location: Laxemar, Oskarshamn Municipality, Sweden	*Percussion hole length* 74.90 m (diam 195.0 mm) 75.00 m (diam 159.0 mm)
Contractor for drilling Drillcon AB	*Position KLX21A (RT90 RH70) at top of casing:* N 6366158.1 E 1549706.23 Z 10.69 (m.a.s.l.)
Subcontractor percussion drilling Sven Andersson AB	*Azimuth (0–360)/ Dip (0–90)* 134.83 / –50.70
Percussion drill start date August 21, 2006	*Position KLX21A (RT90 RH70) at 75.00 m length:* N 6366124.01 E 1549738.87 Z –47.54 (m.a.s.l.)
Completion date August 29, 2006	*Azimuth (0–360)/ Dip (0–90)* 134.09 / –50.95

Technical data

Borehole KLX21A



Drilling reference point

Northing: 6366158.1 (m), RT90 2,5 gon V 0:-15

Easting: 1549706.23 (m), RT90 2,5 gon V 0:-15

Elevation: 10.69 (m), RT90-RHB 70

Drilling period

Drilling start date: 2006-08-21

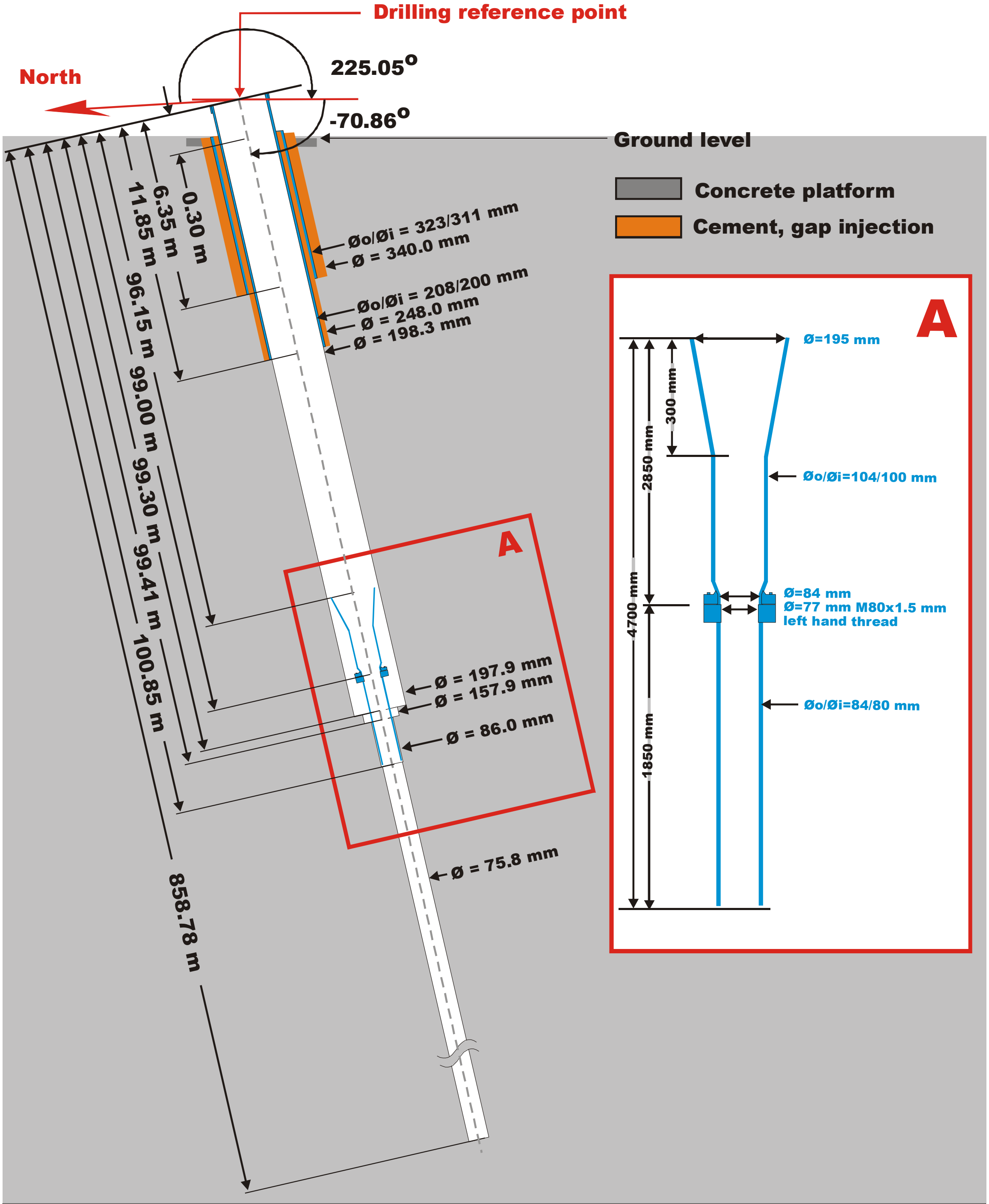
Drilling stop date: 2006-08-29

Ver 2007-06-01

Figure 5-1. *Technical data from KLX21A.*

Technical data

Borehole KLX21B



Drilling reference point

Northing: 6366164.00 (m), RT90 2,5 gon V 0:-15

Easting: 1549715.10 (m), RT90 2,5 gon V 0:-15

Elevation: 10.68 (m), RHB 70

Drilling period

Drilling start date: 2006-09-20

Drilling stop date: 2006-11-29

Ver 2007-04-12

Figure 5-2. *Technical data from KLX21B.*

Table 5-2. KLX21B Technical summary.

General	Technical
Name of hole: KLX21B	*Percussion drill rig* Comacchio MC1500
Location: Laxemar, Oskarshamn Municipality, Sweden	*Percussion hole length* 99.30 m (diam 197.9 mm) 99.41 m (diam 157.9 mm)
Contractor for drilling Drillcon AB	*Core drill rig* B20 APC Atlas Copco
Subcontractor percussion drilling Sven Andersson AB	*Core drill dimension* N-size (76 mm)
Percussion drill start date September 20, 2006	*Cored interval* 99.41–858.78 m
Completion date September 25, 2006	*Diamond bits used* 6
Subcontractor core drilling Suomen Malmi OY (SMOY)	*Average bit life* 127 metres
Core drill start date October 12, 2006	*Position KLX21B (RT90 RH70) at top of casing:* N 6366164.00 E 1549715.10 Z 10.68 (m.a.s.l.)
Completion date November 29, 2006	*Azimuth (0–360)/ Dip (0–90)* 225.05 / –70.86
	Position KLX21B (RT90 RH70) at 858.78 m length: N 6365944.24 E 1549493.71 Z –789.36 (m.a.s.l.)
	Azimuth (0–360)/ Dip (0–90) 222.97 / –67.94

Table 5-3. Summary of core drilling progress and borehole measurements in KLX21B.

bh metres	Drilled length, pumping tests and water sampling	Airlift pumping with evaluation of drawdown and/or recovery	Deviation measurement	Miscellaneous
	060919 – 060925 Percussion drilling of the telescopic section 0–99.40 m (pilot) Reaming Ø 197.9 mm 0–99.30 m Stainless casing 0–11.85 m.		060927 Collar survey Azimuth 225.05 Dip –70.86.	
100			060921 Easy-shot at 96 m Azimuth 225.8 Dip –69.6.	
200				
	061018 Pumping test 101.50–263.20 m. Water flow 11 L/min at approximately 14 m drawdown. Water sample taken.		061016 Easy-shot at 241 m Azimuth 227.3.7 Dip –68.9.	
300				
400	061022 Pumping test 262.00–371.18 m. Water flow 1 L/min at 22 m drawdown. No water sample.		061022 Easy-shot at 363 m Azimuth 225.4 Dip –68.5.	
	061028 Pumping test 368.91–448.87 m. Water flow 0.3 L/min at 22 m drawdown. No water sample.	061027 Airlift puming 11.85–442.68 m. No drillstem in borehole.		
500			061007 Easy-shot at 494 m Azimuth 15.0 Dip –58.2.	
	061104 Pumping test 446.91–544.83 m. Water flow 0.7 L/min at approximately 22 m drawdown. No water sample.			
600			061111 Easy-shot at 634 m Azimuth 224.2 Dip –68.4.	
700	061116 Pumping test 543.21–671.07 m. Water flow 9 L/min at approximately 10 m drawdown. Water sample taken.			
800	061122 Pumping test 668.94–773.338 m. Water flow 0.5 L/min at approximately 22 m drawdown. No water sample.			
	061129 Drilling stopped at 858.69 m. Pumping test 770.91–858.69 m. Water flow 0.1 L/min at approximately 27 m drawdown. No water sample.	061130 Airlift pumping 11.85–858.78 m. No drillstem in borehole.	061201 Final Maxibor at 855 m	061213 Nitrogen lifting for borehole rinsing 2 times. 34 cu m flushed out. 061214 Nitrogen lifting for borehole rinsing 3 times. 45 cu m flushed out.

Table 5-4. Chronological summary of main core drilling events in KLX21B.

Task Name	Start	Finish
First activity starts	**Wed 06-09-20**	**Thu 06-12-07**
Percussion drilling	Wed 06-09-20	Mon 06-09-25
Core drilling	Thu 06-10-12	Wed 06-11-29
Recovery test	Fri 06-10-27	Sat 06-10-28
Recovery test	Thu 06-11-30	Fri 06-12-01
Maxibor measurement	Fri 06-12-01	Fri 06-12-01
Maxibor measurement	Fri 06-12-01	Fri 06-12-01
Length calibration marks	Wed 06-12-06	Thu 06-12-07
Last activity ends	Sun 06-10-01	Fri 06-12-08

10-01

5.2 Drilling, measurements and results in the telescopic section KLX21A

Drilling, reaming and grouting (gap injection) were made from August 7 to 15, 2006.

5.2.1 Preparations

A cement pad for emplacement of drill rig, fuel container and compressor was built. A suitable area was cleared and levelled for establishing of a drill site. Cleaning of all DTH (down-the-hole) equipment was done with a high-capacity steam cleaner.

5.2.2 Drilling and casing installation KLX21A

The construction of the upper telescope section (0–75.00 metres) of KLX21A was made in steps as shown in Figure 5-3.

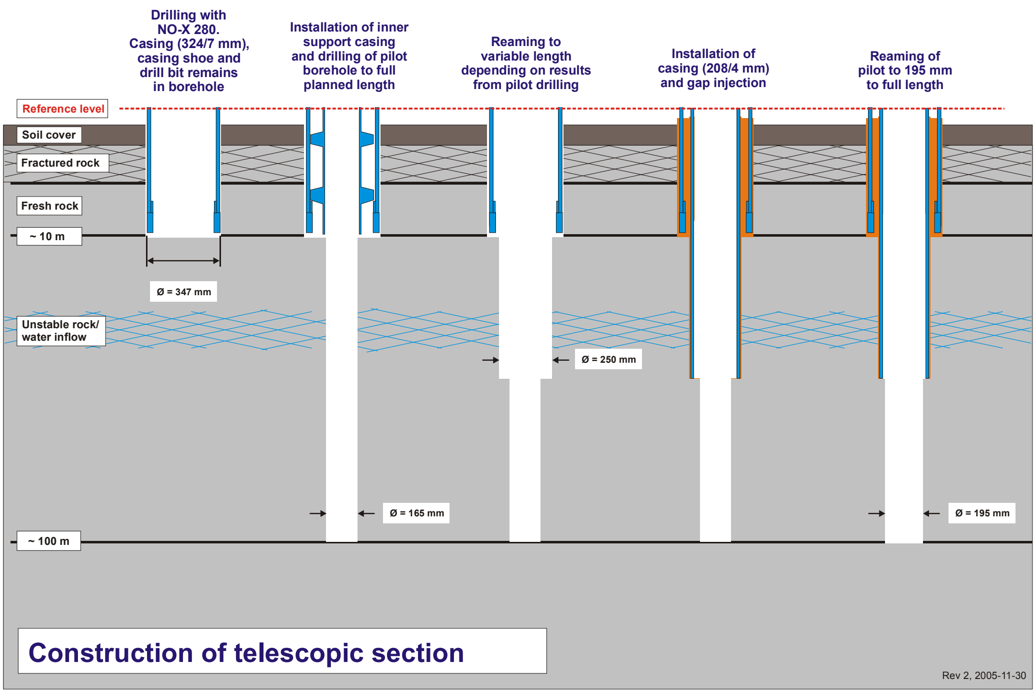


Figure 5-3. Construction of the telescopic section. The cement for casing grouting is introduced between the casing and the rock wall. The drill bit acts as a barrier so that cement does not enter the pilot hole.

Drilling was done by Sven Andersson AB and consisted of the following items:

- Drilling was made to 6.15 metres length with NO-X 280 mm equipment. This gave a hole diameter of 339 mm and left a casing (323/311 mm diameter) to a length of 6.15 m.
- Inner supportive casing for guidance for the drill string was mounted.
- A pilot percussion hole was drilled to a depth of 75.00 metres with 5″ DTH-hammer (nominal diameter 165 mm).
- Deviation measurement was done in the pilot borehole at 75 m length. No record of results could be found, see also Section 5.10 "Nonconformities".
- Reaming to diameter 248 mm was done to 11.55 m.
- Stainless casing of 208×4 mm was installed from 0 to 11.55 metres.
- Casing grouting (gap injection) with low alkali cement based concrete (360 kg or 400 litres) was made for both sets of casing. The outer casing was cut along the ground surface.
- After the concrete had hardened the borehole was rinsed and flushed to remove loose concrete and water. The tightness of the concrete seal (casing grouting) was tested by emplacing a packer below the casing and filling the steel casing with water.
- The borehole was subsequently reamed to a diameter of 197 mm to 74.90 m.

5.2.3 Measurements and sampling during drilling of the telescopic section KLX21A

Sampling and measurements done during drilling of the telescopic section included:

- The percussion drilling progress was monitored by a contracted geologist. Drill cuttings samples were collected every metre and a preliminary geological logging including measurement of magnetic susceptibility was made.
- Penetration rate (expressed as seconds per 20 cm) was recorded automatically and observation of changes in water flow was noted.

The preliminary geological results with penetration rate and magnetic susceptibility as measured on the cuttings are presented in Figure 5-4.

The depth to bedrock from top of casing (TOC) was 3.6 m. The depth of overburden (ground surface to rock) was 3.45 metres i.e. the drilling reference level (TOC) was located 15 cm above the concrete slab.

No water samples were collected in the telescopic section in KLX21A as no inflow of water could be noted during the drilling of the telescopic section. No hydrogeological tests were performed in KLX21A.

5.3 Drilling, measurements and results in the telescopic section KLX21B

Drilling, reaming and grouting (gap injection) were made from September 20 to 25, 2006.

5.3.1 Preparations

A cement pad for emplacement of drill rig, fuel container and compressor was built. A suitable area was cleared and levelled for establishing of a drill site. Cleaning of all DTH (down-the-hole) equipment was done with a high-capacity steam cleaner.

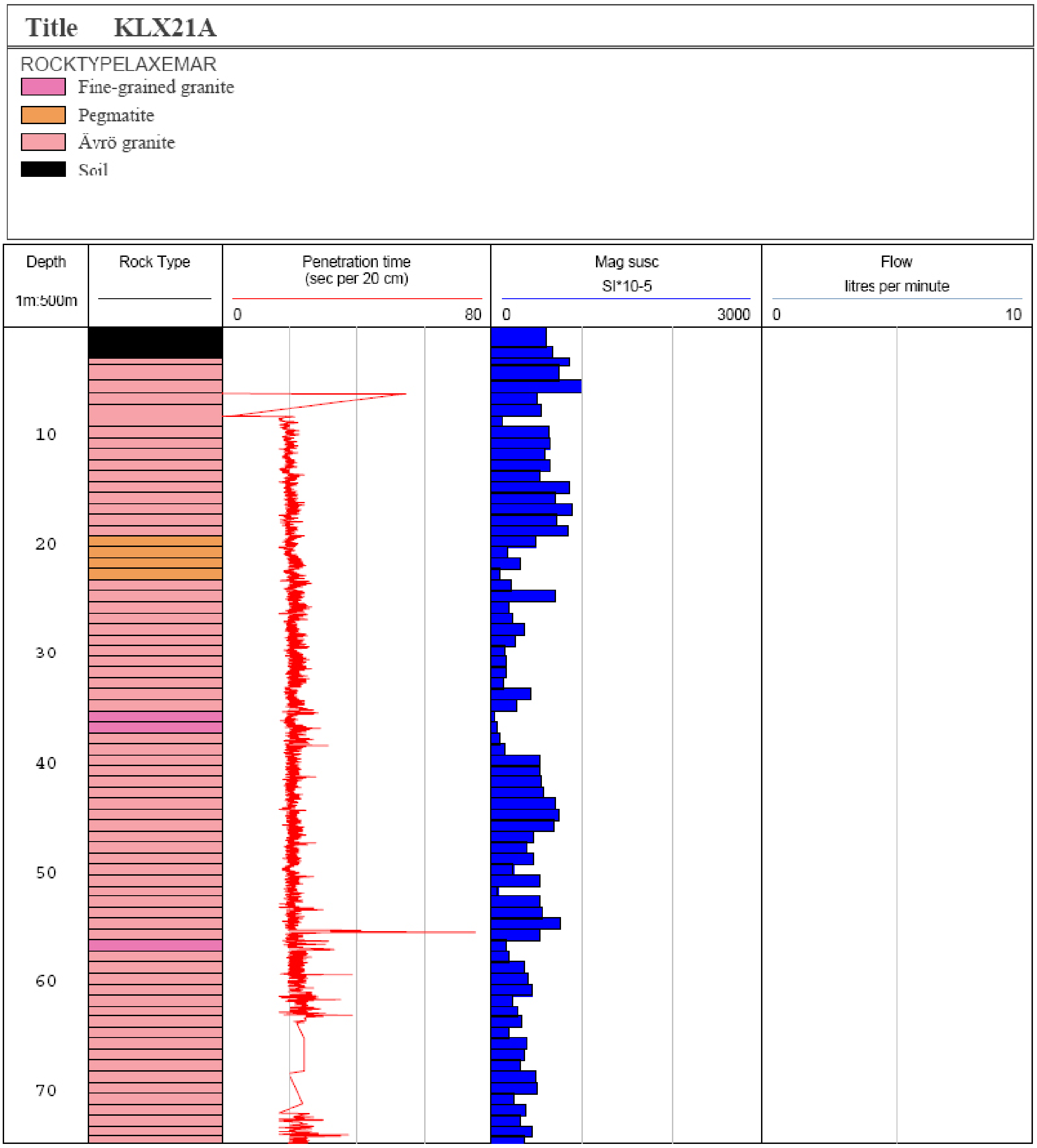


Figure 5-4. *Preliminary geological results based on logging of drill cuttings and penetration rate from percussion drilling of KLX21A.*

5.3.2 Drilling and casing installation KLX21B

The construction of the upper telescope section (0–99.41 metres) of KLX21B was made in steps as shown schematically in Figure 5-3 and described below:

Drilling was done by Sven Andersson AB and consisted of the following items:

- Drilling was made to 6.35 metres length with NO-X 280 mm equipment. This gave a hole diameter of 340 mm and left a casing (323/311 mm diameter) to a length of 6.35 m.
- Inner supportive casing for guidance for the drill string was mounted.
- A pilot percussion hole was drilled to a depth of 99.41 metres with 5″ DTH-hammer. The bottom diameter of the pilot borehole was 157.9 mm

- Deviation measurements with the Easy-Shot equipment was done in the pilot borehole to 96 m length.
- Reaming to diameter 248 mm was done to 11.85 m.
- Stainless casing of 208×4 mm was installed from 0 to 11.85 m.
- Casing grouting (gap injection) with low alkali cement based concrete (321 kg or 315 litres) was made for both sets of casing. The outer casing was cut along the ground surface.
- After the concrete had hardened the borehole was rinsed and flushed to remove loose concrete and water. The tightness of the concrete seal (casing grouting) was confirmed by emplacing a packer below the casing and filling the steel casing with water on September 25.
- The pilot borehole was reamed to 99.30 m. The starting diameter at drilled length 11.85 m was 198.3 m and the final diameter at 99.30 m was 197.9 mm.

5.3.3 Measurements and sampling during drilling of the telescopic section KLX21B

Sampling and measurements done during drilling of the telescopic section included:

- The percussion drilling progress was monitored by a contracted geologist. Drill cuttings samples were collected every metre and a preliminary geological logging including measurement of magnetic susceptibility was made.
- Penetration rate (expressed as seconds per 20 cm) was recorded automatically and observation of changes in water flow was noted.

The preliminary geological results with penetration rate and magnetic susceptibility as measured on the cuttings are presented in Figure 5-5.

The depth to bedrock from top of casing (TOC) was 3.3 m. The depth of overburden (ground surface to rock) was 3.0 metres i.e. the drilling reference level (TOC) was located 30 cm above the concrete slab.

No water samples were collected in the telescopic section in KLX21B as no inflow of water could be noted during the drilling of the telescopic section. No pumping test or other hydrogeological tests were performed in the percussion drilled part of KLX21B.

5.4 Core drilling KLX21B 99.41–858.78 m

Core drilling in KLX21B was conducted between October 10 and November 29, 2006.

The main work in KLX21B after drilling the telescopic section consisted of the following steps:

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

Measurements and results from wireline tests and drilling monitoring are given in Sections 5.5 and 5.6.

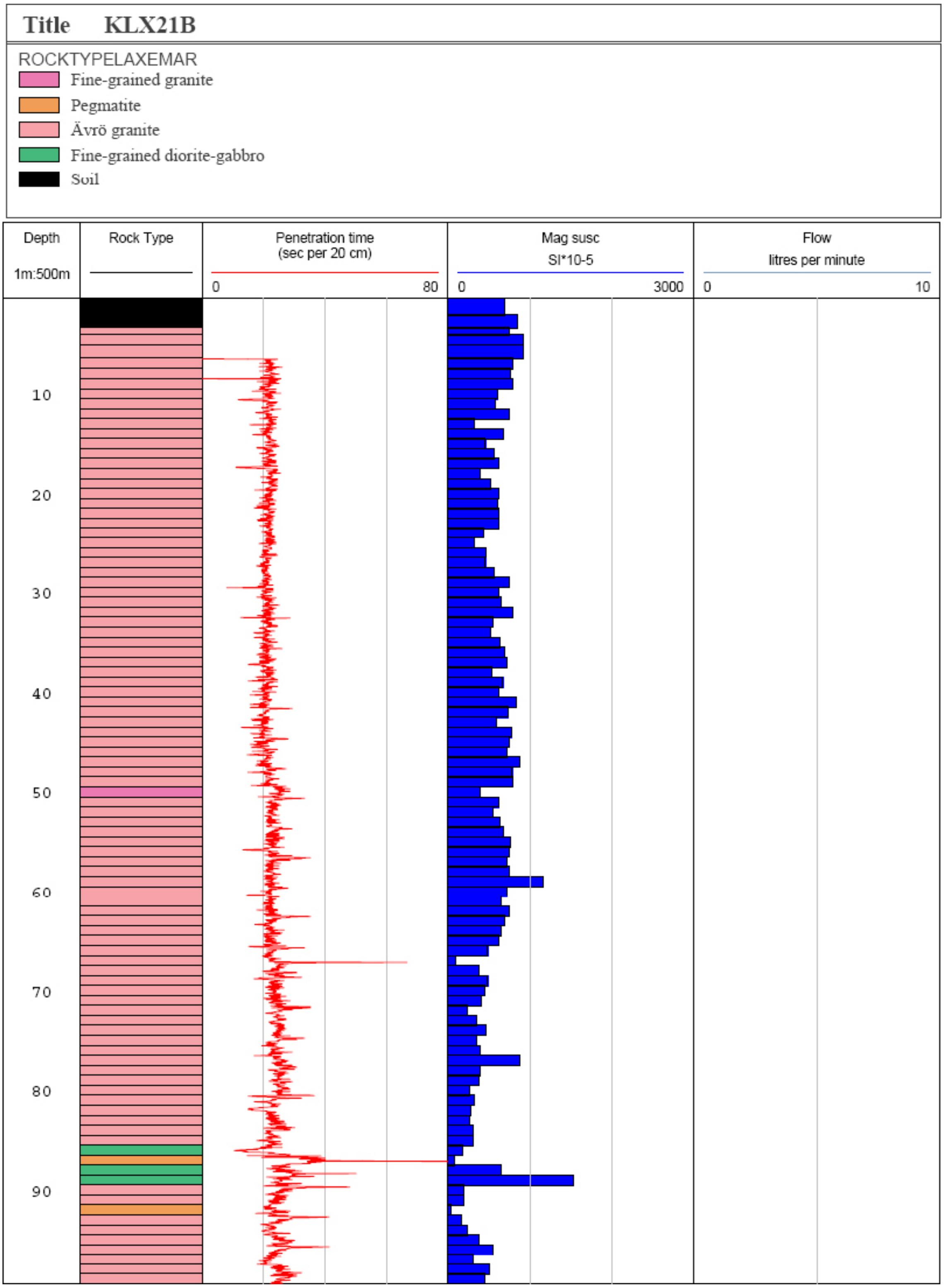


Figure 5-5. Preliminary geological results based on logging of drill cuttings and penetration rate from percussion drilling of KLX21B.

5.4.1 Preparations

The preparations for core drilling started on October 4, 2006 and consisted of mounting the drill rig, installation of air-lift pumping equipment and supportive casing for alignment of the core drill rods, see Figure 5-6.

The installation of supportive casing was done in steps:

- An outer casing with a diameter of 98/89 mm, fitted with fins to align with the diameter of the percussion drilled borehole was installed.
- Equipment for air-lift pumping was installed and a discharge header was fitted to collect the return water.
- Drilling was made between 99.41 and 100.00 m with T-86 equipment. An inner supportive casing with diameter 84/77 mm was installed to the borehole bottom.

The supportive casings have a perforated section below 90 metres length so that water from the borehole can be lead to the air-lift pumping system outside the supportive casings. A pressure meter for monitoring of the water level was emplaced at a length of 90 metres.

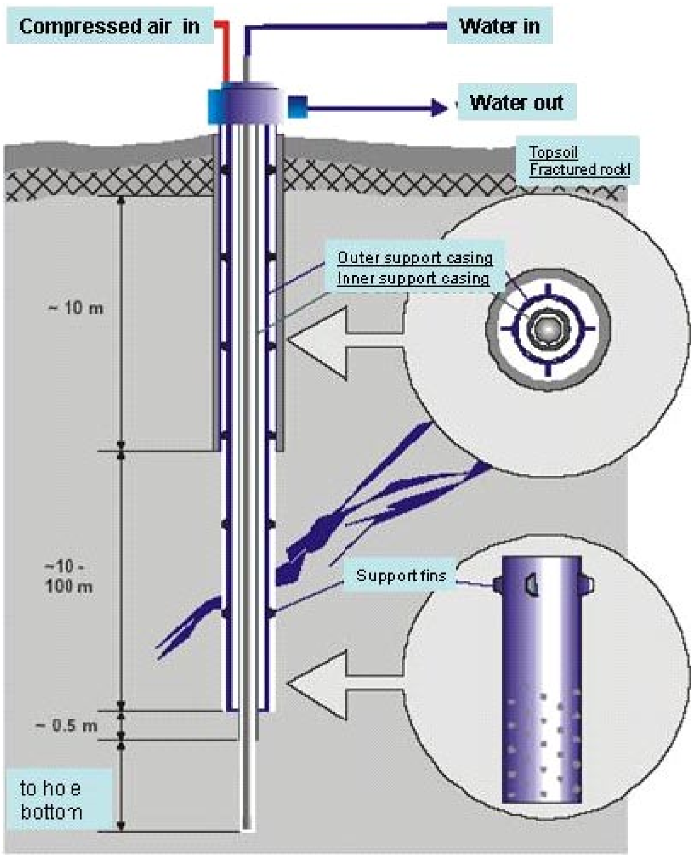


Figure 5-6. In the telescopic part of the drill hole a temporary installation is made with casing tubes for support and alignment and equipment for air-lift pumping. In the uppermost part the return water discharge header is mounted. The water discharge is led to the settling containers.

5.4.2 Flushing and return water handling

The flushing water source was percussion borehole HLX10. 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 KLX21B is shown in Figure 5-7.

The targeted content for uranine in the flushing water was 0.20 mg/L and the actual average uranine content was 0.210 mg/L, see also Figure 5-11 and Section 5.5.2.

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 5.9.

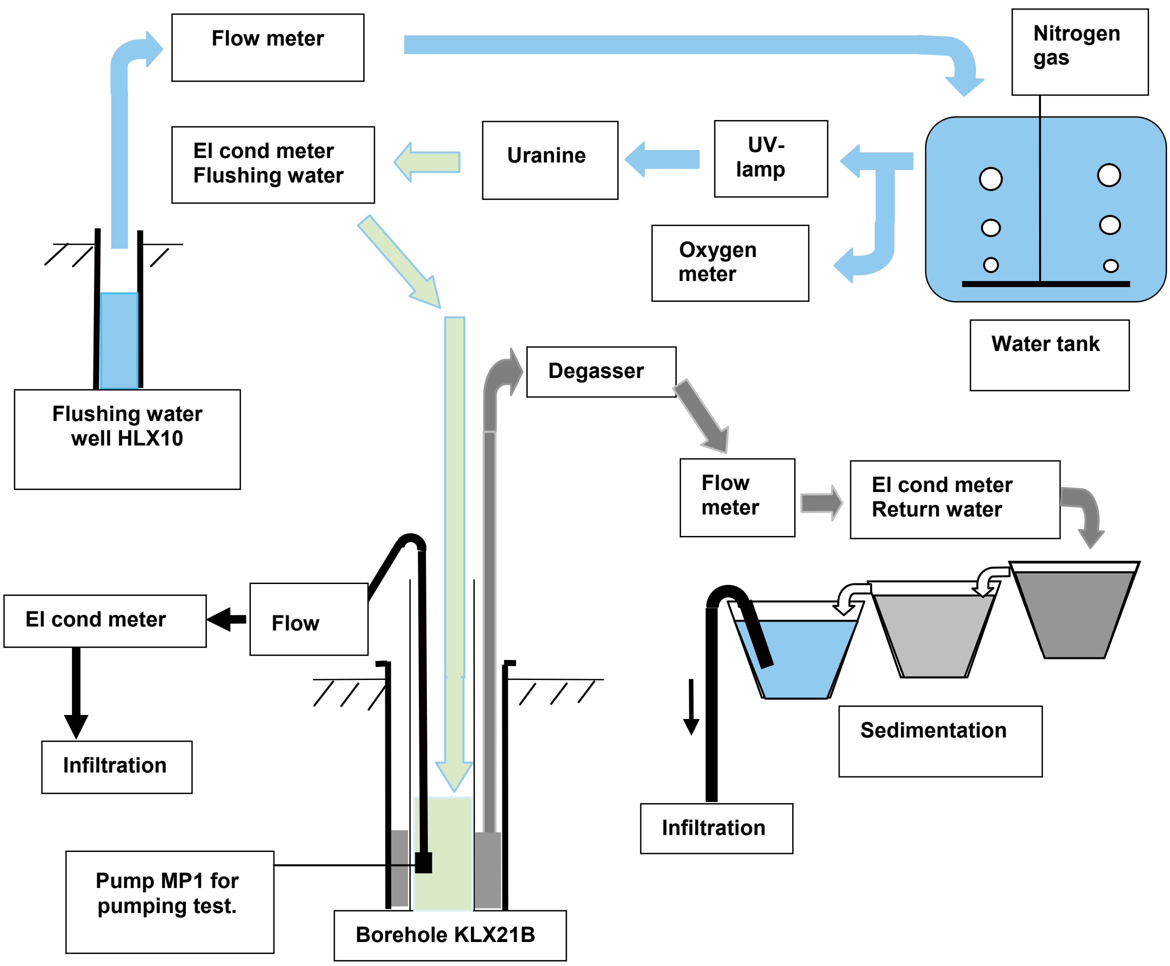


Figure 5-7. The flushing and return water handling and the emplacement of related monitoring equipment in KLX21B.

5.4.3 Drilling and deviation measurements KLX21B

Core drilling with T-86 equipment giving an 86 mm diameter hole was done from 99.41 to 100.85 m in KLX21B. The part from 100.00 to 100.85 m was first drilled with N-size and subsequently reamed to T-86 as part of the borehole completion, see Section 5.4.4.

Core drilling with N-size (76 mm) triple-tube, wireline equipment was conducted from 100.00 m to the final length of 858.78 m in KLX21B.

The core diameters and intervals for drilling dimensions are given in Table 5-5. Directional drilling, i.e. intentional change of direction or dip of the borehole was not made in KLX21B.

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 Easy-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 5-3.

A combination of the Maxibor and Flexit methods were used for the final calculation of the borehole deviation in KLX21B. The Maxibor measurement was done to 855 m as part of the drilling activity whereas the Flexit measurement was done to 852 m as part of a separate geophysical activity. The final deviation file in KLX21B is calculated based on the measurements given in Table 5-6 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 /3/.

Horizontal and vertical plots of the results of the calculated deviation covering the entire length of borehole KLX21B are given in Appendix 4.

One section with core loss was noted in KLX21B during the Boremap (geological) mapping between 592.67–592.90 m. The core loss was labelled as "missing core piece".

A total of six drill bits were used for KLX21B, see Figure 5-8.

Further results from drill monitoring i.e. drill penetration rate and various measurements are presented in Section 5.6 "Drilling monitoring results" and in Appendix 1.

Table 5-5. Core diameters, borehole diameters and drilling dimensions during core drilling in KLX21B.

Core diameter (mm)	Borehole diameter (mm)	Interval (m drilled length)	Drilling dimension	Comment
72.0	86	99.41–100.00	T-86	
50.2	86	100.00–100.85	N and T-86	Reamed to 86 mm diameter
50.2	76	100.85–858.78	N	

Table 5-6. Measurements used for borehole deviation calculation in KLX21B.

Deviation measurement method	Used for calculation of bearing/inclination	Interval From (m)	Interval To (m)	Measuring direction	Date	Sicada database activity ID
Flexit	BEARING	117	858.78	down/in	2007-01-04	13144889
Flexit	INCLINATION	3	858.78	down/in	2007-01-04	13144889
Flexit	BEARING	117	858.78	up/out	2007-01-04	13144890
Flexit	INCLINATION	3	858.78	up/out	2007-01-04	13144890
Maxibor	BEARING	3	858.78	down/in	2006-12-01	13138801
Maxibor	INCLINATION	3	858.78	down/in	2006-12-01	13138801
Maxibor	BEARING	3	858.78	up/out	2006-12-01	13138803
Maxibor	INCLINATION	3	858.78	up/out	2006-12-01	13138803

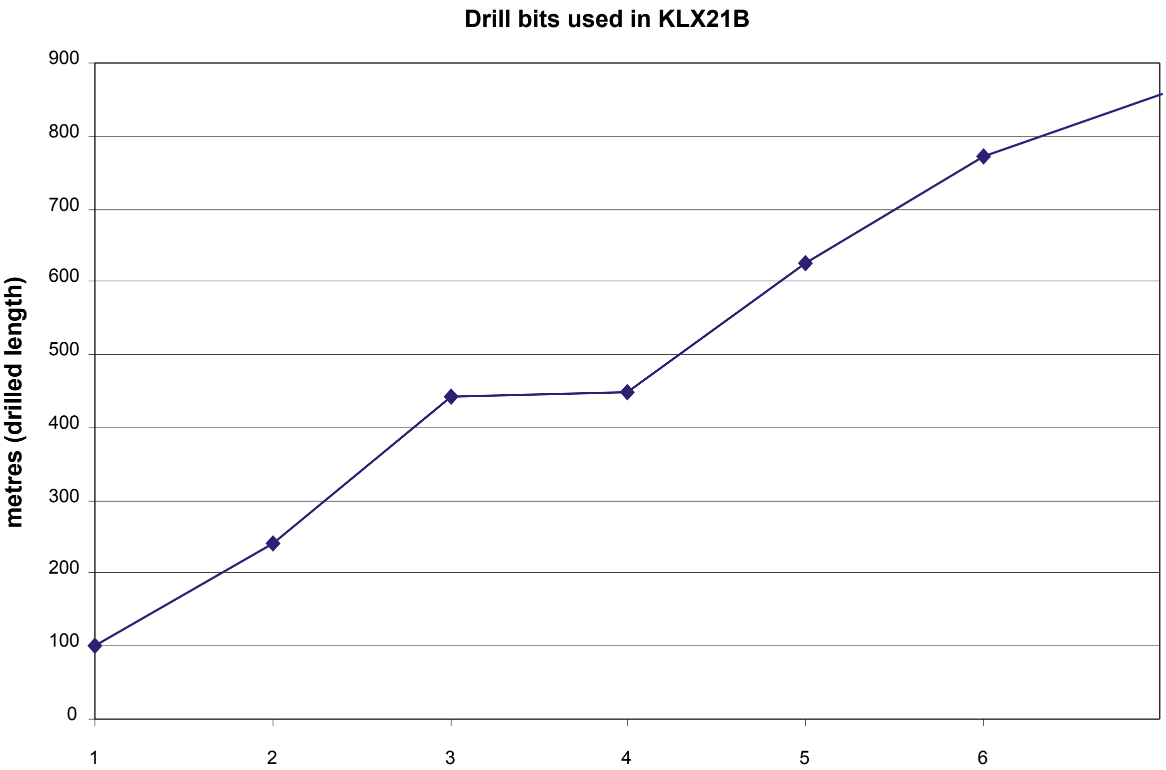


Figure 5-8. Drill bit changes during core drilling in KLX21B.

5.4.4 Borehole wall risk assessment, stabilisation and completion

Borehole wall risk assessment and stabilisation

A borehole wall assessment was approved on January 5, 2007, SKB id no 1066324, SKB internal document.

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

- Diamond drilling completed at 858.78 m on November 30, 2006.
- Flushing and brushing with high water pressure on the borehole wall was done along intervals as given in Table 5-7. The selection of the intervals to rinse was based on study of the drill core. The flush and brush tool is shown in Figure 5-9.
- 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/metre. The dimensions pf the dummy is 2.24 m length and 74.5 mm diameter.
- Downhole operations consisting of deviation measurements, milling of reference grooves and flushing of the borehole with nitrogen gas were made without stability problems.
- BIPS logging for final risk assessment was done to along the full drilled length. 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 to medium in the borehole.

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

From (bh length m)	To (bh length m)
102	106
108	110
143	144
151	153
155	157
292	294
322	323
338	389
397	398
449	451
452	456
475	478
604.5	608
618	620
624.5	628
640	658
672	674
685	689
690	707

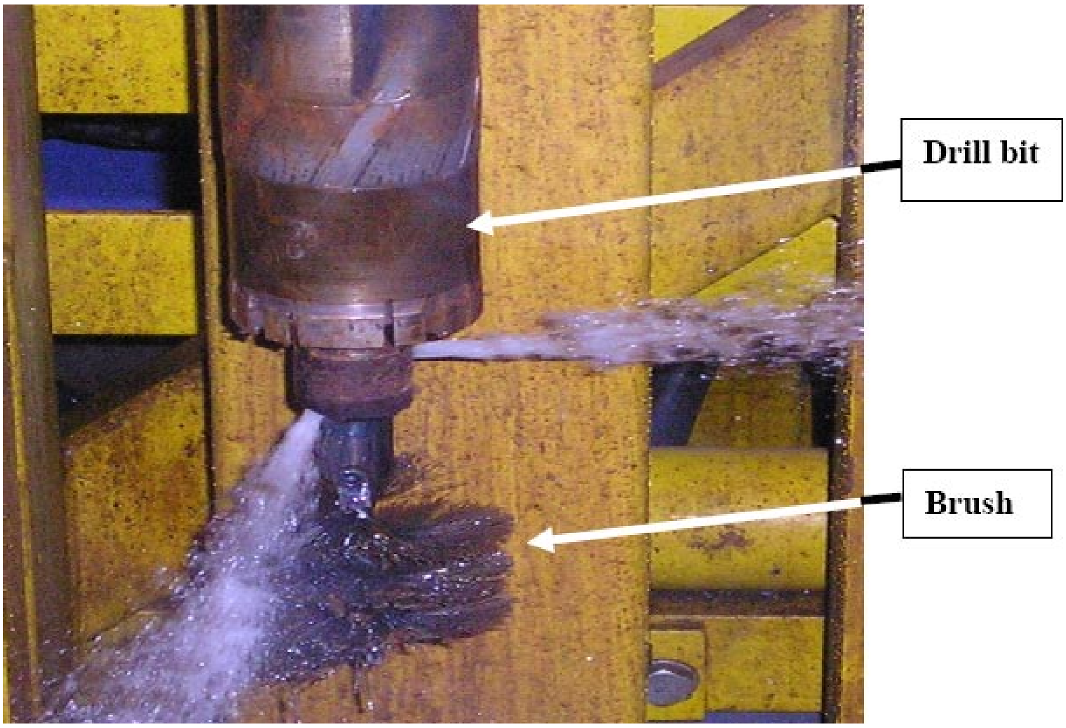


Figure 5-9. The water flushing and rotating steel brush tool. The tool is lowered into the drill stem and can be seen in place just below the drill bit. During operating the drill string is moved up and down to remove loose rock fragments from the borehole wall.

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 air lift pumping equipment and the inner supportive casing in the telescopic section were removed.

The borehole was reamed from 100.00 to 100.85 with T-86 equipment. A steel conical guide was installed in KLX21B between 96.15 m and 100.85 m. The conical guide tapers from an inner diameter of 195 mm to 77 mm.

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

Table 5-8. Depth reference slots (m) in KLX21B.

110.00	550.00
150.00	600.00
200.00	650.00
250.00	650.00
300.00	700.00
350.00	750.00
400.00	800.00
450.00	830.00
500.00	

Table 5-9. Nitrogen gas lifting in KLX21B. (time is in Swedish Normal Time i.e. GMT+1).

Date	Time	Interval (m)	Volume removed (m^3)
061213	14.00–14.35	11.85–858.78	17
061213	15.35–16.08	11.85–858.78	17
061214	07.15–08.01	11.85–858.78	15
061214	09.05–09.38	11.85–858.78	15
061214	10.20–11.00	11.85–858.78	15

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.

5.5 Hydrogeological and hydrochemical measurements and results in KLX21B 99.41–858.78 m.

The performed measurements in KLX21B, as already outlined in Tables 5-3 and 5-4, can be summarized as follows

Measurements and sampling with wireline equipment:

- Seven completely successful tests were conducted out of fourteen attempts at various intervals, see Section 5.5.1.
- Three water samples were taken, see Section 5.5.2.

Two air-lift pumping tests with evaluation of drawdown and/or recovery phase were made, for results see Section 5.5.3.

Hydraulic responses in near-by boreholes from drilling in KLX21B are commented in Section 5.5.4.

5.5.1 Hydrogeological results from wireline measurements

Results from the wire line tests in KLX21B are presented in Table 5-10 and Figure 5-10.

The pumping tests were evaluated with steady-state assumption in accordance with Moye /4/. 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.

A total of fourteen tests were performed in KLX21B, and seven achieved sufficiently stable conditions for calculating pseudo steady-state transmissivity and hydraulic conductivity. The reason behind the failed tests was mainly leakage between the pipe string and the borehole coupled with problems with the packer. The plots from the pumping tests are given in Appendix 5.

The start and stop times for the interval used for evaluation of the pumping tests are given in Table 5-11.

Table 5-10. Pumping tests with wireline probe in KLX21B.

Tested section [m]	Q/s [m²/s]	T_M [m²/s]	Comments
101.50–263.2	$6.2 \cdot 10^{-4}$	$7.6 \cdot 10^{-4}$	The drawdown in the pipe-string was 139 KPa, but only c. 2 KPa in the tested borehole interval, most likely due to friction losses caused by the wire line probe. Pi is probably too low. The flow rate was relatively constant during the pumping. The section pressure, however increased 2 KPa the same period.
262.00–371.18	$8.0 \cdot 10^{-7}$	$1.1 \cdot 10^{-6}$	The flow rate was somewhat decreasing during the pumping. The section pressure was kept on a constant level. Recovery = 88% of the drawdown.
368.91–448.87	$1.4 \cdot 10^{-7}$	$1.8 \cdot 10^{-7}$	Pseudo steady state conditions prevail during the pumping although the flow rate fluctuates around a constant level. Recovery = 80% of the drawdown.
446.91–544.83	$5.1 \cdot 10^{-7}$	$6.6 \cdot 10^{-7}$	The flow rate fluctuates around a constant level. The section pressure was fairly constant during the pumping. In the pipe string the water level was lowered below the pressure sensor. Recovery = 88% of the drawdown.
543.21–671.07	$2.6 \cdot 10^{-5}$	$3.4 \cdot 10^{-5}$	Both the flow rate and the section pressure were decreasing during the pumping. The recovery was 60% of the drawdown. Prior to the test a leakage from the drill pipes was measured. Starting c. 3 hours after pumping start the electric conductivity increased from 50 mS/m to 250 mS/m at pump stop.
668.94–773.98	$3.1 \cdot 10^{-7}$	$4.1 \cdot 10^{-7}$	Pseudo steady state conditions: only slowly declining flow and a constant section pressure during the pumping. Recovery = 91% of the drawdown.
770.91–858.78	$2.4 \cdot 10^{-8}$	$3.1 \cdot 10^{-8}$	The flow rate graph varies around a low level. The section pressure was constant during the pumping, but recovers only 32% after pump stop. Possibly the initial pressure pi was too high.

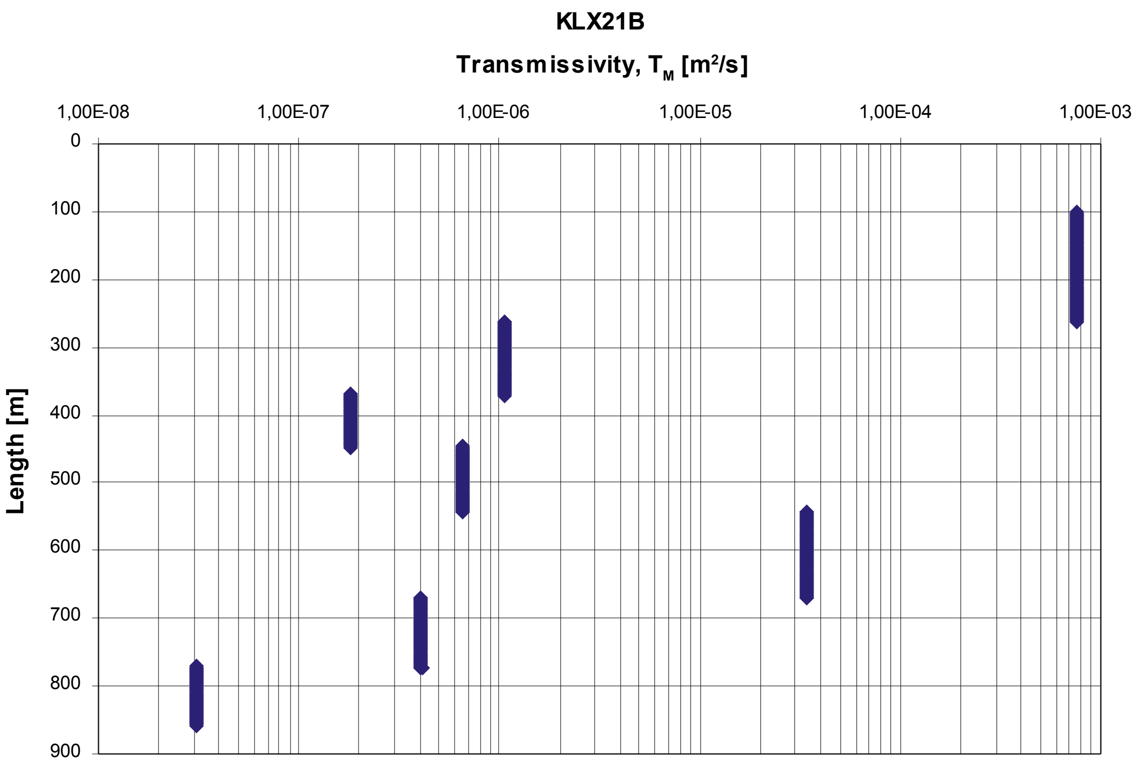


Figure 5-10. Transmissivity from wireline pumping tests in KLX21B versus borehole length.

Table 5-11. Evaluated test periods.

Tested section	Pumping start (YYYY-MM-DD HH:MM)	Pumping stop (YYYY-MM-DD HH:MM)
101.50–263.2	2006-10-18 18:28	2006-10-19 03:05
262.00–371.18	2006-10-22 15:46	2006-10-22 18:30
368.91–448.87	2006-10-28 16:23	2006-10-28 20:09
446.91–544.83	2006-11-04 17:28	2006-11-04 19:43
543.21–671.07	2006-11-15 16.10	2006-11-16 02.27
668.94–773.98	2006-11-22 16.54	2006-11-22 20.51
770.91–858.78	2006-11-29 16.35	2006-11-29 20.08

5.5.2 Hydrochemistry

Three water samples were collected in connection with core drilling in KLX21B. Times and lengths for the samples are given in Table 5-12.

Sampling and analysis were performed according to the SKB classes specified in Table 5-12. The samples were collected at the drill site as soon as possible after the sampling occasion and prepared and conserved at the Äspö laboratory. The samples were stored in refrigerator until the drilling of the borehole was completed.

The sample 11405 was discarded due to a probable leakage in the wireline probe during sampling. It was therefore decided not to analyse this sample further. Bottles for main components and isotopes are stored in freezer ($\delta^{13}C$, ^{14}C and ^{3}H in refrigerator).

The sample 11527 was only analysed for drill water percentage due to the high amount of drilling water in the sample.

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.

Archive samples have been collected for the samples 11405 and 11410. The samples are stored in a freezer at the Äspö laboratory.

Selected analytical results from KLX21B are given in Table 5-13. A complete record of analytical results is given in Appendix 2.

The percussion drilled borehole HLX10 was used as water source during the drilling of KLX21B. No water samples were collected from HLX10 in connection with the drilling of KLX21B. However, water samples have been collected from HLX10 at earlier occasions and results from those analyses are reported in conjunction with the drilling of borehole KLX12A /5/.

Table 5-12. Sample dates and length during core drilling in KLX21B.

Sample number	Borehole	Date	Test section, length (m)	SKB chemistry class
11405	KLX21B	2006-10-17	102.00–242.22	3 (main components and isotopes not included)
11410	KLX21B	2006-10-19	101.50–263.20	3 (isotope options included)
11527	KLX21B	2006-11-16	543.21–671.07	3 (only drill water percentage)

Table 5-13. Analytical results from water chemistry sampling.

Borehole	Sample no	Date	From m	To m	Drill water %	pH	Conductivity mS/m	Cl mg/l
KLX21B	11405	2006-10-17	102.00	242.22	0.97	8.50	62.2	28.4
KLX21B	11410	2006-10-19	101.50	263.20	28.70	8.46	64.5	32.9
KLX21B	11527	2006-11-16	543.21	671.07	68.30	–	–	–

Monitoring of uranine tracer content

From KLX21B, a total of 80 samples for uranine content and electrical conductivity in flushing and returning water were taken along the borehole. The results are shown graphically in Figure 5-11. All the samples were analysed at the Äspö laboratory.

The calculated average uranine content for the whole borehole is 0.210 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.

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

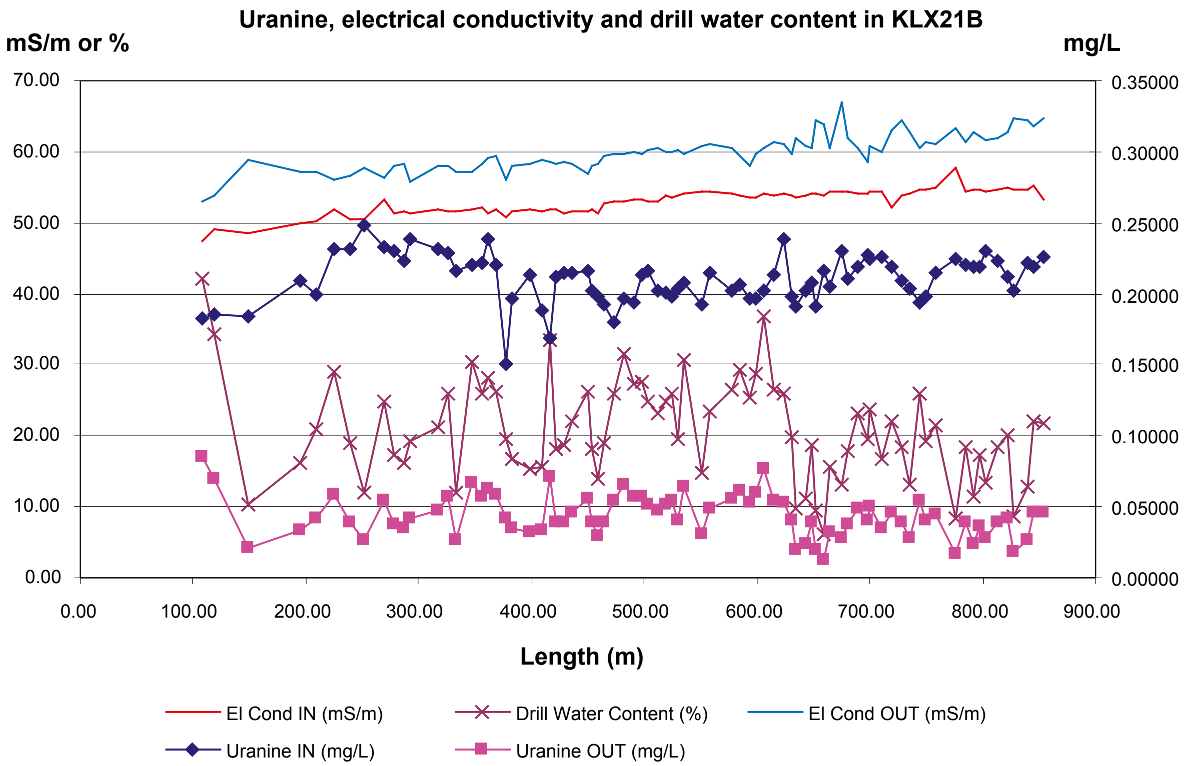


Figure 5-11. *The uranine concentration and electrical conductivity of the flushing water (IN) and the return water (OUT) in KLX21B. The drill water content in the return water is also shown.*

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

One airlift pumping test was conducted during drilling, and one additional test was conducted after the borehole was drilled to full depth. The execution of the tests varies in detail as drilling or other related activities such as cleaning and flushing of drill cuttings may occur prior to lifting the stem.

The steady state transmissivity, T_M, was calculated according to Moye /4/, as well as the specific capacity, *Q/s*. The results are shown in Table 5-14, and stored in the SICADA database as "recovery tests" (code HY050). 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 5-12 and 5-13.

Table 5-14. Results from airlift pumping in KLX21B.

Tested section [m]	Flow rate [L/min]	Drawdown [m]	Q/s [m²/s]	T_M [m²/s]	Comments
11.85–442.68	90	4.6	$3.2 \cdot 10^{-4}$	$5.0 \cdot 10^{-4}$	Pumping 06:11 to 13:00 (GMT+2) October 27, 2006
11.85–858.78	93	4.6	$3.3 \cdot 10^{-4}$	$5.5 \cdot 10^{-4}$	Pumping 08:50 to 16:01 (GMT+1) November 30, 2006

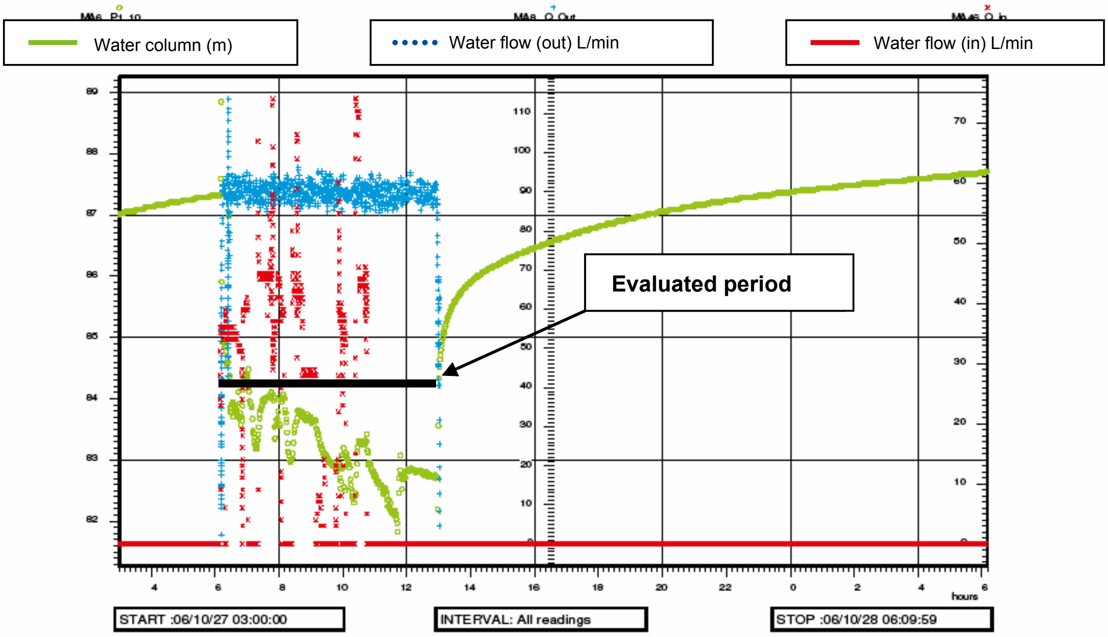


Figure 5-12. Airlift pumping in KLX21B 11.85–442.68 m. The green line represents the height of the water column in the borehole, the out flow is shown as the blue dotted line and the inflow rate as the red line. The times are shown with daylight saving time, GMT+2.

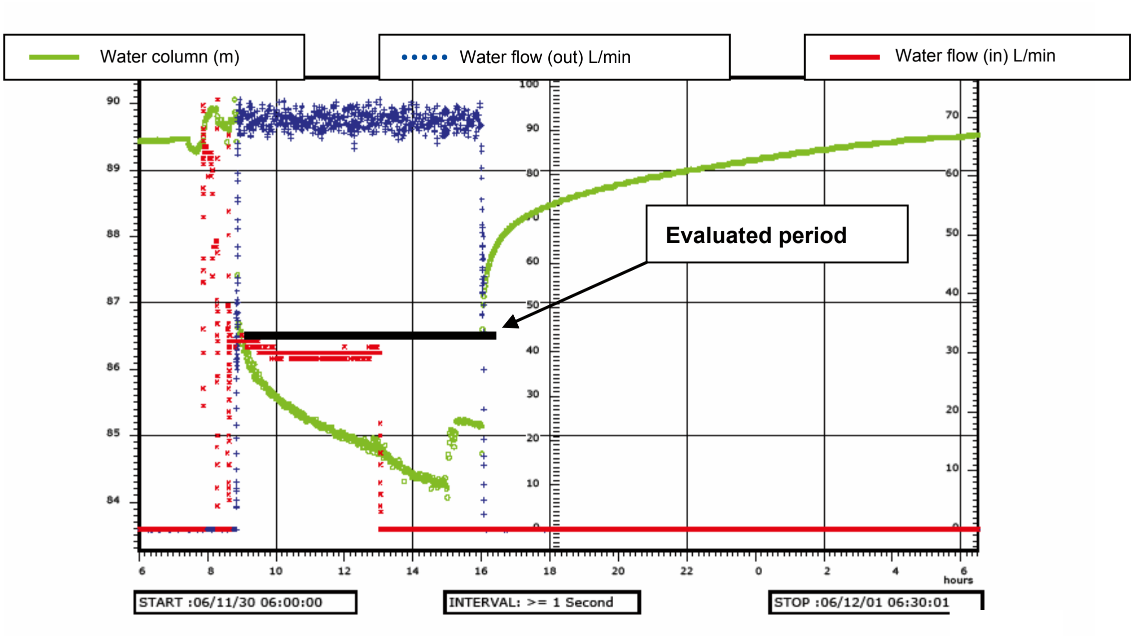


Figure 5-13. *Airlift pumping in KLX21B 11.85–858.78 m. The green line represents the height of the water column in the borehole, the out flow is shown as the blue dotted line and the inflow rate as the red line. The times are given in Swedish Normal Time, GMT+1.*

5.5.4 Hydraulic responses in near-by boreholes

Hydraulic responses from drilling activities in a borehole are created by the drawdown from air-lift pumping during core drilling and from flushing or rinsing the borehole with nitrogen gas (i.e. lifting the water with nitrogen gas). Percussion drilling of the telescopic section also constitutes an air-lift pumping from a hydrogeological point of view. All times in plots in this section (Section 5.5.4) are given in Swedish Normal Time (GMT+1).

No evaluation of the hydraulic responses from drilling of KLX21A has been made. The borehole was dry i.e. no inflow of water was noted during the percussion drilling. It is likely that there should be no observable hydraulic responses in the surrounding boreholes as there was none observed during the percussion drilling of KLX21B , see also comments under "Hydraulic responses in near-by boreholes from percussion drilling of the telescopic section in KLX21B" below.

The following account of hydraulic responses will be concerned with the drill period for KLX21B. Summary conclusions are given in the list below and in Table 5-15. The locations of the observation boreholes, flushing water supply well and KLX21B are shown in Figure 5-23. Further comment on the hydraulic responses are presented in text under subsections for "percussion drilling", "core drilling" and "nitrogen lifting" in conjunction with Figures 5-14 through 5-21. A list of section lengths in selected observation boreholes is given in Table 5-16.

- Clear hydraulic responses from drilling activities in KLX21B are only observed in HLX21, HLX22 and the deeper sections in KLX07A.
- It is possible that some hydraulic responses are obscured by the pumping in HLX10 that clearly influences the water table in some observation boreholes.
- The observed hydraulic responses all start to occur shortly after the core drilling commenced i.e. from about 100 m borehole length. During the progression of the core drilling down to full length no additional responses can be discerned due to drilling. This implies that the connectivity between the boreholes is dominated through the fracturing of the shallow rock, tentatively between 100 and 200 m.

Table 5-15. Summary of hydraulic responses from drilling and related activities in KLX21B.

Observation borehole and section	Activities in KLX21B Percussion drilling 0–99.4 m	Core drilling with air-lift pumping 99.4–858.78 m	Nitrogen lifting 11.85–858.78 m	Pumping in flushing water well HLX10
KLX21A	No	No data	No data	No data
HLX21:1	Not evaluated	yes	yes	No
HLX21:2	Not evaluated	yes	yes	No
HLX22:1	Not evaluated	yes	No data	No
HLX22:2	Not evaluated	yes	No data	No
HLX23:1	Not evaluated	?	?	yes
HLX23:2	Not evaluated	?	?	yes
HLX24:1	Not evaluated	?	?	yes
HLX24:2	Not evaluated	No	No	No
HLX16	Not evaluated	No	No	No
HLX17	Not evaluated	No	No	No
HLX18 both sections	Not evaluated	No	No	No
HLX19	Not evaluated	No	No	No
HLX33 both sections	Not evaluated	No	No	No
KLX02:1	Not evaluated	No	No	No
KLX02:2	Not evaluated	No	No	No
KLX02:3	Not evaluated	No	No	No
KLX02:4	Not evaluated	No	No	No
KLX02:5	Not evaluated	No	No	No
KLX02:6	Not evaluated	?	?	yes
KLX02:7	Not evaluated	?	?	yes
KLX02:8	Not evaluated	?	?	yes
KLX07A:1	Not evaluated	No	yes	No
KLX07A:2	Not evaluated	No	yes	No
KLX07A:3	Not evaluated	No	yes	No
KLX07A:4	Not evaluated	yes	yes	No
KLX07A:5	Not evaluated	?	?	?
KLX07A:6	Not evaluated	?	?	yes
KLX07A:7	Not evaluated	?	?	yes
KLX07A:8	Not evaluated	?	?	yes
KLX05:1	Not evaluated	No	No	No
KLX05:2	Not evaluated	No	No	No
KLX05:3	Not evaluated	No	No	No
KLX05:4	Not evaluated	No	No	No
KLX05:5	Not evaluated	?	No	No
KLX05:6	Not evaluated	?	No	No
KLX05:7	Not evaluated	?	No	No
KLX05:8	Not evaluated	?	No	No
KLX05:9	Not evaluated	?	No	No
KLX05:10	Not evaluated	?	No	No
KLX10 all sections	Not evaluated	No	No	No
KLX12A all sections	Not evaluated	No	No	No

Legend No = no response yes = strong response ? = weak or uncertain response

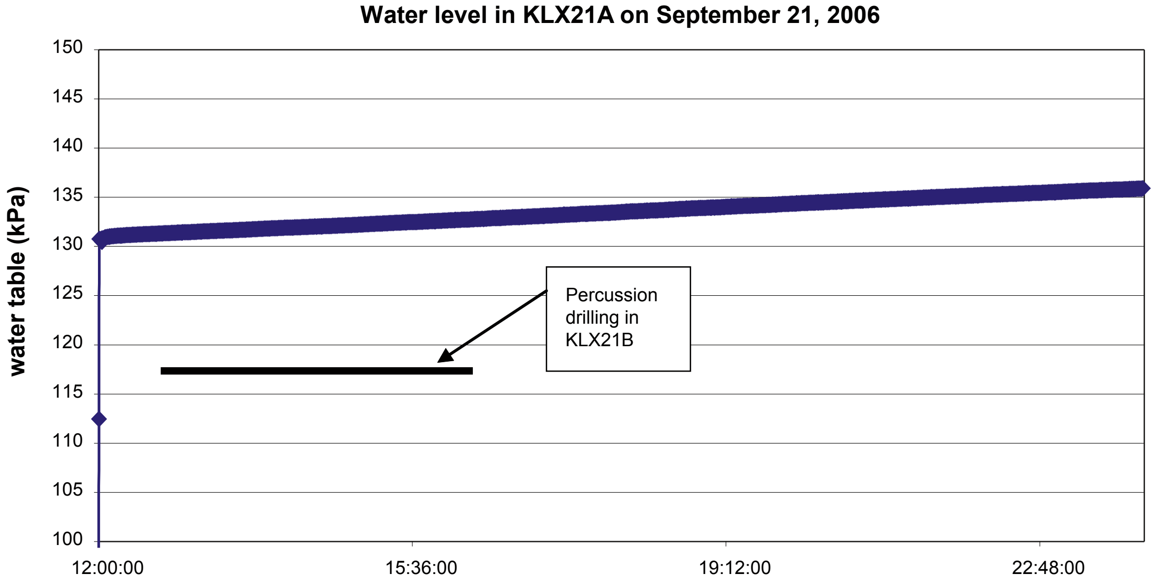


Figure 5-14. No hydraulic response could be seen in borehole KLX21A during percussion drilling in KLX21B.

Table 5-16. Section lengths in selected observation boreholes.

Borehole	Section	Start (m)	Stop (m)
KLX02	8	200.8	208
KLX02	7	209	347
KLX02	6	348	451
KLX02	5	452	494
KLX02	4	495	717
KLX02	3	718	1,144
KLX02	2	1,145	1,164
KLX02	1	1,165	1,700
KLX05	10	15	127
KLX05	9	128	219
KLX05	8	220	240
KLX05	7	241	255
KLX05	6	256	360
KLX05	5	361	500
KLX05	4	501	624
KLX05	3	625	633
KLX05	2	634	720
KLX05	1	721	1,000
KLX07A	8	11.8	103
KLX07A	7	104	203
KLX07A	6	204	332
KLX07A	5	333	456
KLX07A	4	457	611
KLX07A	3	612	752
KLX07A	2	753	780
KLX07A	1	781	844.73
HLX21	2	9.03	72
HLX21	1	73	150.3
HLX22	2	9.03	85
HLX22	1	86	163.2
HLX23	2	6.03	60
HLX23	1	61	160.2
HLX24	2	9.03	40
HLX24	1	41	175.2

Hydraulic responses in near-by boreholes from percussion drilling of the telescopic section in KLX21B

No hydraulic responses from percussion drilling in KLX21B could be seen in observation hole KLX21A, see Figure 5-14. No hydraulic response from the percussion drilling in KLX21B could be seen in any other of the investigated observation boreholes.

Hydraulic responses in near-by boreholes from core drilling activities (mainly air-lift pumping) in KLX21B

Figure 5-15 presents the groundwater level in boreholes HLX21 and HLX22 together with drilling parameters during the drilling in borehole KLX21B. There is no response in HLX21 or HLX22 from the pumping in the flushing water well HLX10 on October 11. Drilling in KLX21B commenced on October 12. From this date on there are clear responses from drilling in KLX21B in the observation boreholes HLX21 and HLX22. This indicates a clear hydraulic connection between HLX21 and HLX22 on one hand and KLX21B on the other.

Figure 5-16 presents the groundwater level in borehole KLX05, sections 1 to 5, together with drilling parameters during the drilling in borehole KLX21B. A gentle drawdown can be seen in KLX05 section 5 starting at the same time as drilling in KLX21B commences on October 12, 2006. This could be a hydraulic response. The lowermost sections 1 to 4 are not affected by the drilling in KLX21B. No effect from pumping in HLX10 can be seen in sections 1 to 5.

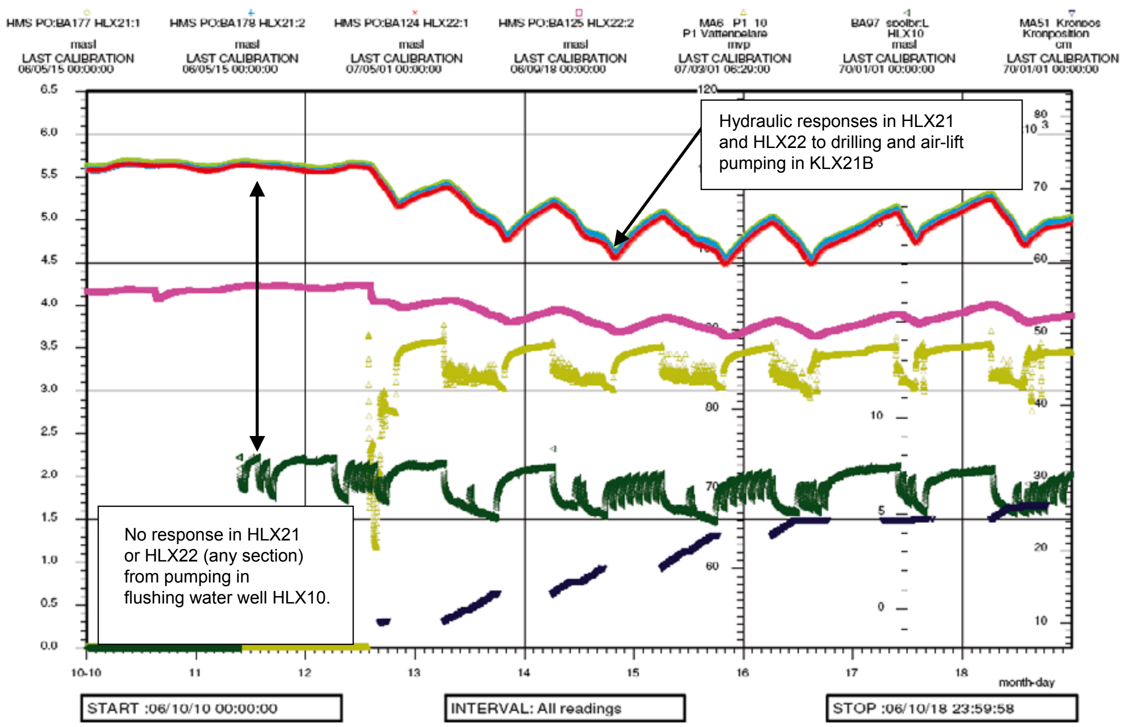


__Figure 5-15.__ Groundwater level in boreholes HLX21 and HLX22 together with drilling parameters (pressure in the drilling borehole, position of drill bit and water level in the flushing water well) during the drilling in borehole KLX21B. Detail 2006-10-10–2006-10-18. There is no response in HLX21 or HLX22 from the pumping in HLX10 done on October 11. Drilling in KLX21B commenced on October 12. From this date on there are clear responses from drilling in KLX21B in the observation boreholes HLX21 and HLX22.

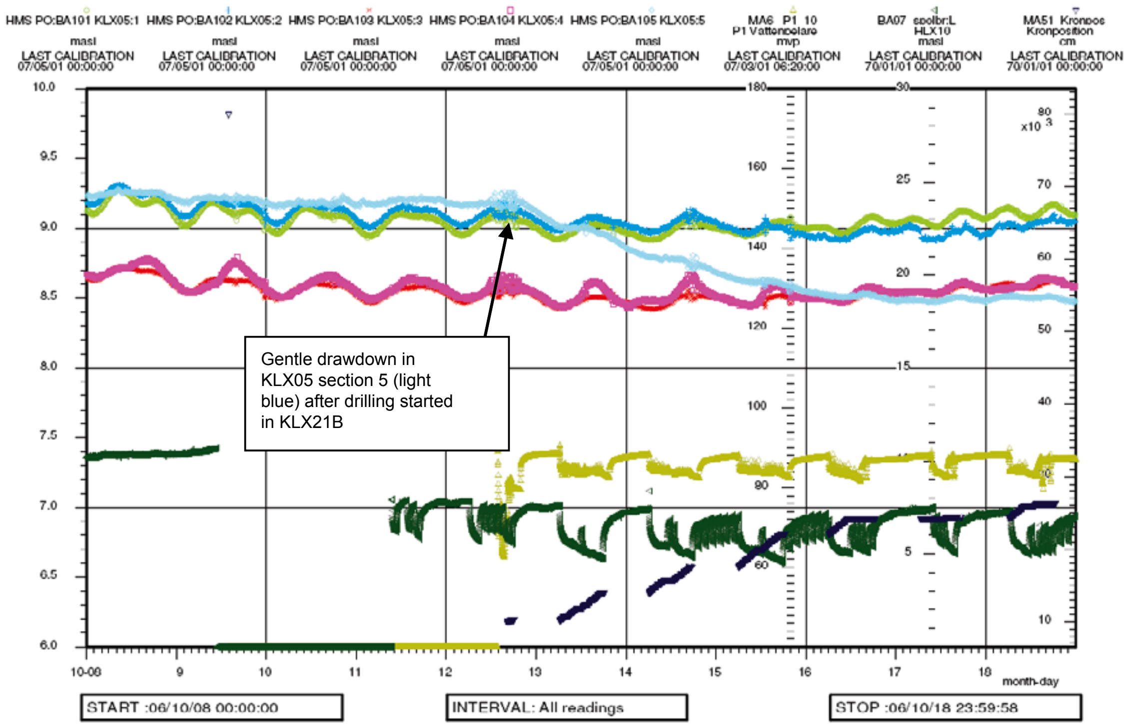


Figure 5-16. *Groundwater level in borehole KLX05, sections 1 to 5, together with drilling parameters (pressure in the drilling borehole, position of drill bit and water level in the flushing water well) during the drilling in borehole KLX21B. Detail 2006-10-08–2006-10-18. A gentle drawdown can be seen in KLX05:5 (light blue) starting at the same time as drilling in KLX21B commences, October 12, 2006.*

Figure 5-17 shows the groundwater level in borehole KLX05, upper sections 6 to 10, together with drilling parameters during drilling in borehole KLX21B. No response can be seen in the upper sections of KLX05 from pumping in the flushing water well HLX10. There is a very gently sloping drawdown and other minor variations in the water table that coincide with the start of drilling in KLX21B. The variations are nevertheless very subtle and any interpretation of hydraulic responses in KLX05, sections 6 to 10, from drilling in KLX21B is uncertain.

The groundwater level in borehole KLX07A, sections 1 though 4 i.e. below 457 m, together with drilling parameters during the drilling in borehole KLX21B is given in Figure 5-18. Section 4 in KLX07A responds to drilling and air-lift pumping in KLX21B but not to the pumping in the flushing water well HLX10. No responses can be seen in the lowermost sections, 1, 2 or 3.

Groundwater level in the upper sections, 5 to 8, in borehole KLX07A is presented together with drilling parameters for KLX21B in Figure 5-19. There is a clear response from pumping in the flushing water well HLX10 in the uppermost sections, especially sections 6 and 7, in KLX07A. After drilling and air-lifting had started in KLX21B there is a more accentuated drawdown in section 5 in KLX07A indicating a hydraulic connection between section KLX07A:5 and KLX21B.

Comments on hydraulic responses not shown graphically in this report:
No hydraulic response could be seen in the observation boreholes HLX16, HLX17, HLX18, HLX19, HLX33, KLX10 or KLX12A from drilling activities in borehole KLX21B.

Borehole HLX23 and the lower section in borehole HLX24 are weakly affected by pumping in the flushing water supply well, HLX10. Any response from drilling is thereby obscured. The upper section in HLX24 is unaffected both by pumping and drilling activities in KLX21B.

The lowermost sections 1 to 5, i.e. below 452 m, in observation borehole KLX02 are not affected by drilling activities. Responses from pumping in the flushing water well, HLX10, can be seen in the uppermost sections 6, 7 and 8 i.e. above 451 m. Any response from drilling in KLX21B is thereby obscured by pumping.

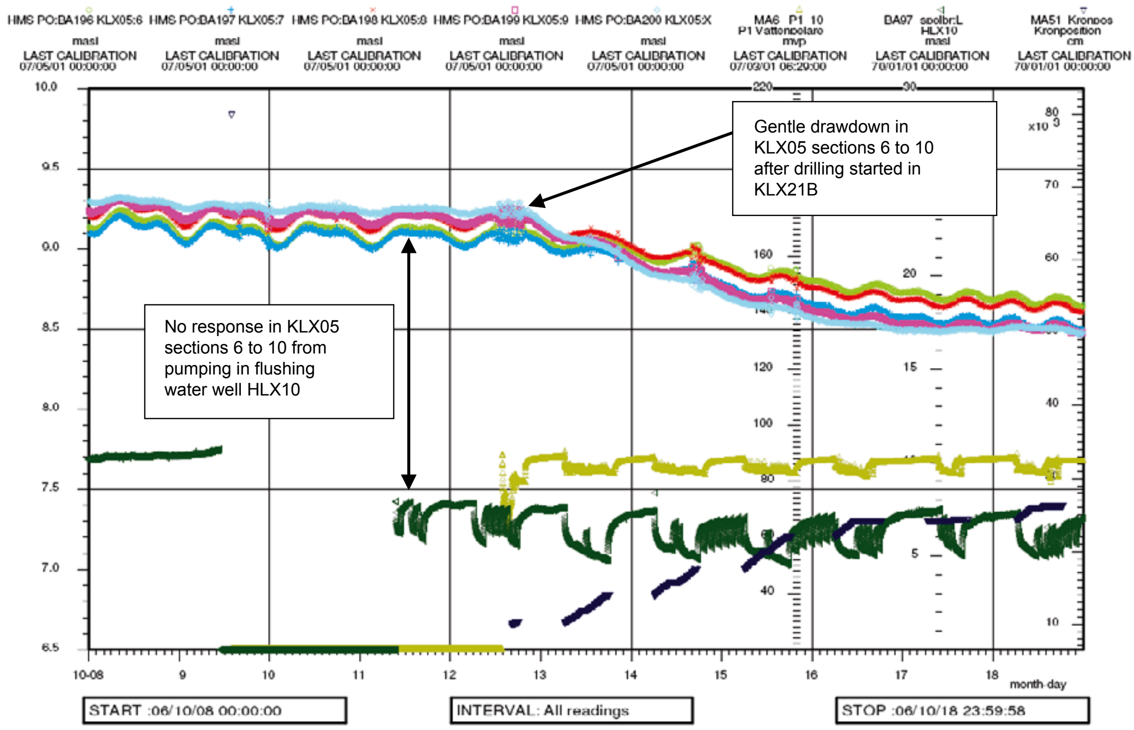


Figure 5-17. *Groundwater level in borehole KLX05, the upper sections 6 to 10, together with drilling parameters (pressure in the drilling borehole, position of drill bit and water level in the flushing water well) during drilling in borehole KLX21B. Detail 2006-10-08–2006-10-18. No response can be seen in the upper sections of KLX05 from pumping in the flushing water well HLX10. There is a very gently sloping drawdown and other minor variations in the water table that coincide with the start of drilling in KLX21B. The variations are nevertheless very subtle and any interpretation of hydraulic responses in KLX05, sections 6 to 10, from drilling in KLX21B is uncertain.*

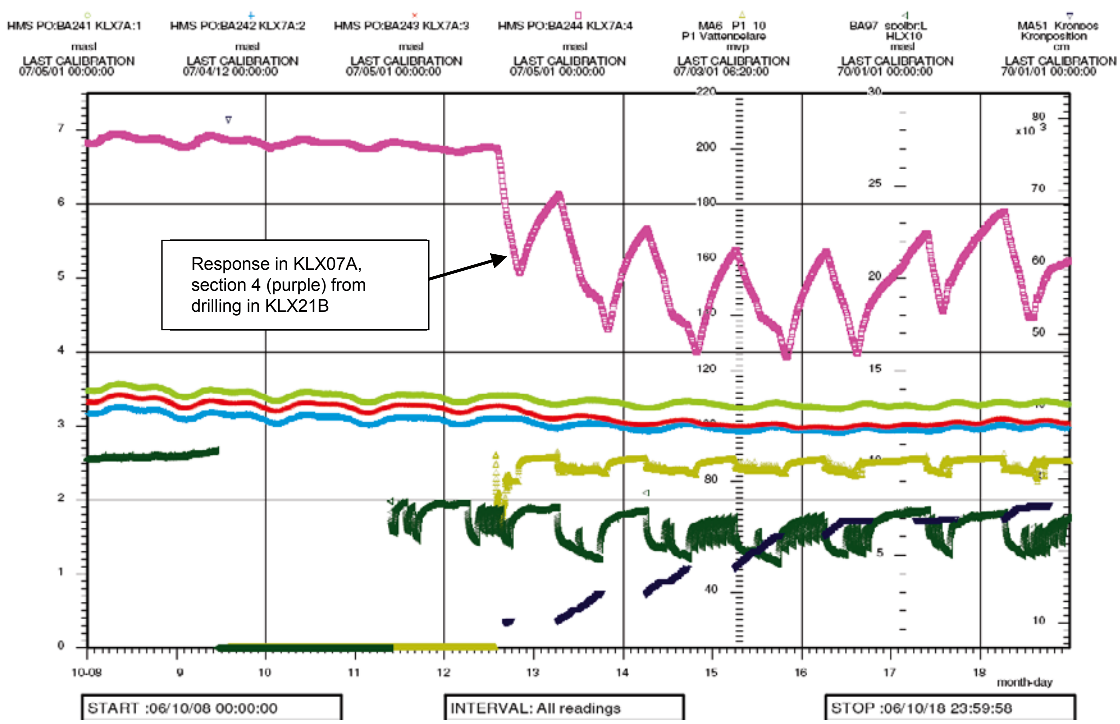


Figure 5-18. *Groundwater level in borehole KLX07A, sections 1–4, together with drilling parameters (pressure in the drilling borehole, position of drill bit and water level in the flushing water well) during the drilling in borehole KLX21B. Detail 2006-10-08–2006-10-18. Section 4 responds to drilling and air-lift pumping in KLX21B but not to the pumping in the flushing water well HLX10 on October 11. No responses can be seen in the lowermost sections.*

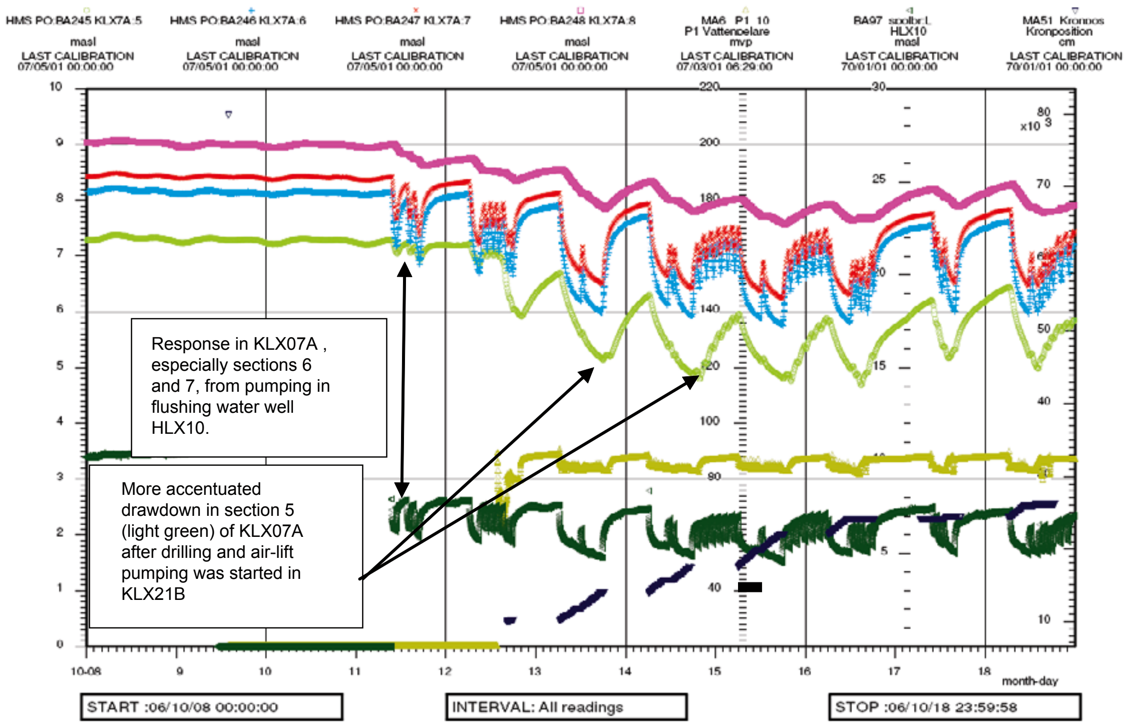


Figure 5-19. *Groundwater level in borehole KLX07A, sections 5–8, together with drilling parameters (pressure in the drilling borehole, position of drill bit and water level in the flushing water well) during the drilling in borehole KLX21B. Detail 2006-10-08–2006-10-18. There is a clear response from pumping in the flushing water well HLX10 in the upper sections, especially sections 6 and 7, in KLX07A. After drilling and air-lifting had started in KLX21B there is a more accentuated drawdown in section 5 in KLX07A indicating a hydraulic connection.*

Hydraulic responses in near-by boreholes from nitrogen gas flushing in KLX21B

Lifting with nitrogen gas covering the entire length of the borehole was done five times on December 13 and 14, twice on the 13th and three times on the 14th.

The groundwater level in observation boreholes HLX16, HLX17, HLX18, HLX19 and HLX21 during the nitrogen lifting in borehole KLX21B is given in Figure 5-20. A clear drawdown coinciding with the nitrogen lifting in KLX21B can be seen in observation borehole HLX21, both sections. No data was available for HLX22 during this time. The water levels in observation boreholes HLX16, HLX17, HLX18 and HLX19 are not affected by the nitrogen lifting.

The groundwater level in borehole KLX07A during the nitrogen lifting in borehole KLX21B is shown in Figure 5-21. It can be seen that sections 4 and 5 in KLX07A are heavily affected by nitrogen lifting and the lower sections in KLX07A, sections 1, 2 and 3 are weakly affected. The uppermost sections 6, 7 and 8 i.e. above 332 m, do not seem to be affected by nitrogen lifting as they are strongly influenced by pumping in HLX10.

A plot of the groundwater level of sections 1 to10 in borehole KLX05 during the nitrogen lifting in borehole KLX21B is given in Figure 5-22. The distinct drawdowns in section 4 that occur on the 12th and the 13th cannot be from nitrogen lifting. There is also a very weak drawdown on the 14th that does not fit the times for the nitrogen lifting in KLX21B well either. The drawdowns in sections 4 and the very erratic pattern in section 3 are interpreted as not being related to the nitrogen lifting in KLX21B.

The location of the observation boreholes, water supply well and KLX17A is given in Figure 5-23.

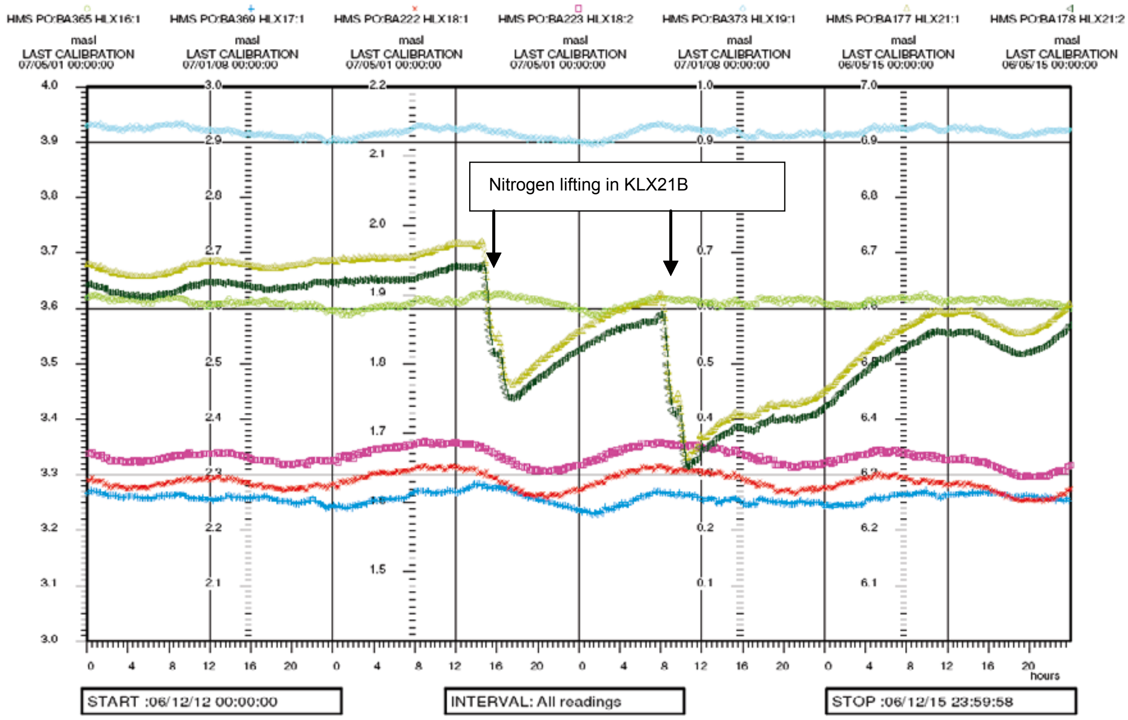


*Figure 5-20. Groundwater level in observation boreholes HLX16, HLX17, HLX18, HLX19 and HLX21 during the nitrogen lifting in borehole KLX21B, 2006-12-13 (14:00–14:35, 15:35–16:08) and 2006-12-14 (07:15–08:01, 09:05–09:38, 10:20–11:*00). *A clear drawdown coinciding with the nitrogen lifting in KLX21B can be seen in observation borehole HLX21. No data was available for HLX22 during this time. The water levels in observation boreholes HLX16, HLX17, HLX18 and HLX19 are not affected by the nitrogen lifting.*

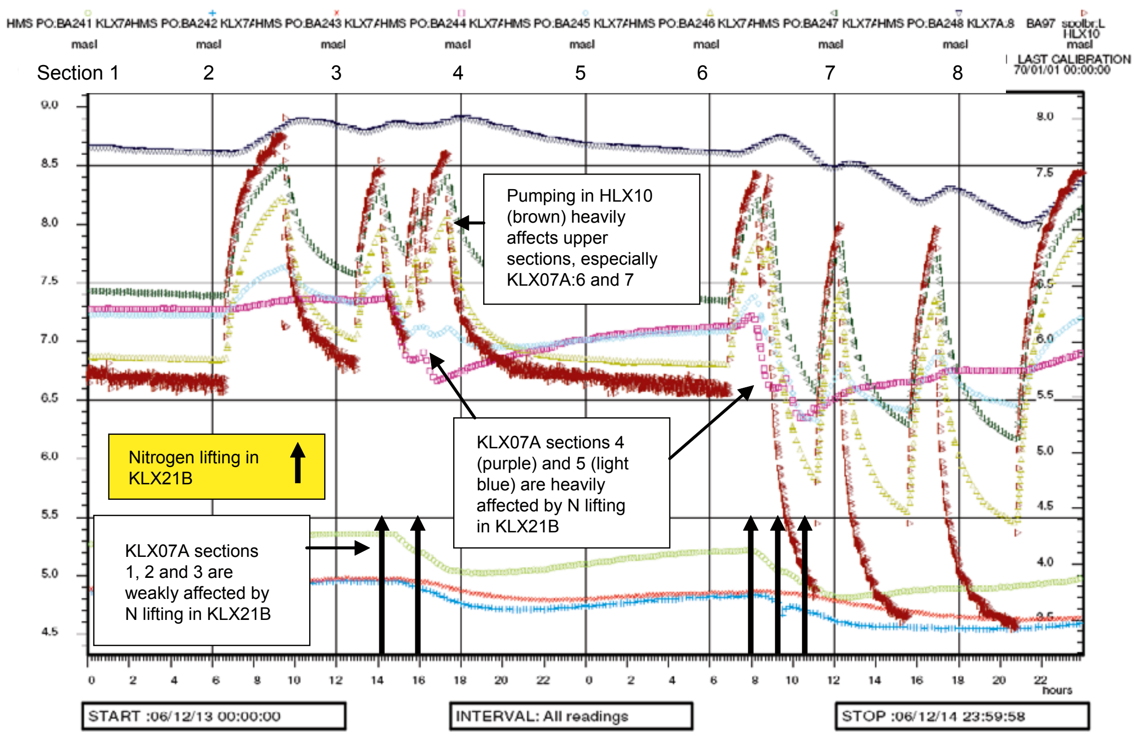


Figure 5-21. Groundwater level in borehole KLX07A, sections 1 to 8,during the nitrogen lifting in borehole KLX21B. The nitrogen lifting was made on 2006-12-13 (14:00–14:35, 15:35–16:08) and 2006-12-14 (07:15–08:01, 09:05–09:38, 10:20–11:00). Sections 4 and 5 are heavily affected by nitrogen lifting and the lower sections in KLX07A, sections 1, 2 and 3 are weakly affected. The uppermost sections do not seem to be affected by nitrogen lifting as they are strongly influenced by pumping in HLX10.

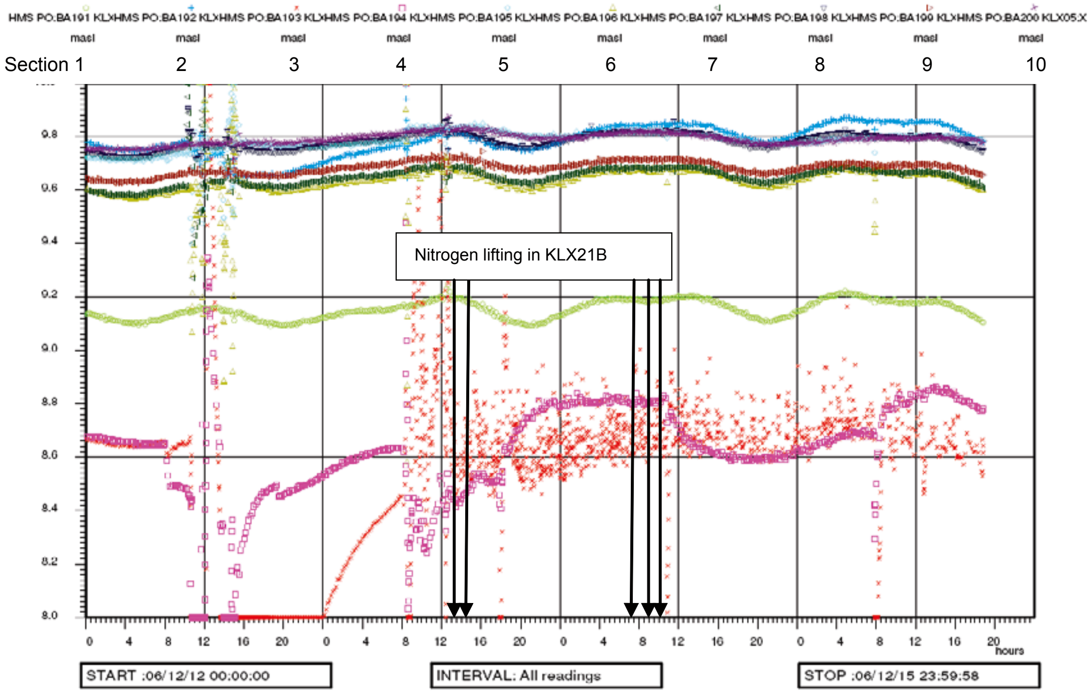


Figure 5-22. Groundwater level in borehole KLX05 during the nitrogen lifting in borehole KLX21B, 2006-12-13 (14:00–14:35, 15:35–16:08) and 2006-12-14 (07:15–08:01, 09:05–09:38, 10:20–11:00). The distinct drawdowns in section 4 occurs on the 12th and the 13th cannot be from nitrogen lifting. There is also a very weak drawdown on the 14th that does not fit the times for the nitrogen lifting in KLX21B well either. The drawdowns in sections 4 and the very erratic pattern in section 3 are interpreted as not being related to the nitrogen lifting in KLX21B.

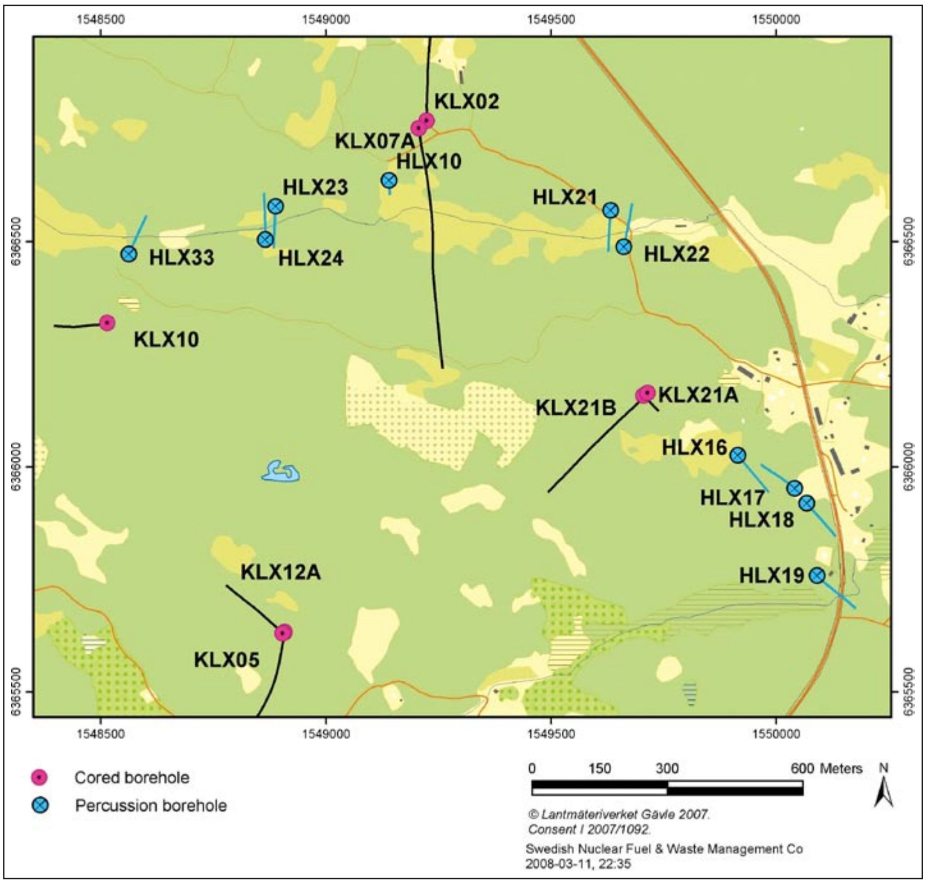


Figure 5-23. Map showing the location of borehole KLX21B and observation boreholes KLX02, KLX05, KLX07A, KLX10, KLX12A, KLX21A, HLX10, HLX16, HLX17, HLX18, HLX19, HLX21, HLX22, HLX23, HLX24 and HLX33.

5.6 Drilling monitoring results in KLX21B

This section presents the results from drill monitoring i.e. continuous data series of water parameters or technical drilling parameters. The two main drilling steps in KLX21B, the telescope section 0–99.41 metres and the core drilling section 99.41–858.78 metres are described in Sections 5.3 and 5.4 respectively.

5.6.1 Drill monitoring system – DMS

The DMS database contains substantial amounts of drilling monitoring data. A selection of results primarily from the monitoring of the flushing water parameters are presented in Figures 5-24 through 5-26 below.

Selected parameters from the drill rig (MWD parameters) are presented in Appendix 1. 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.

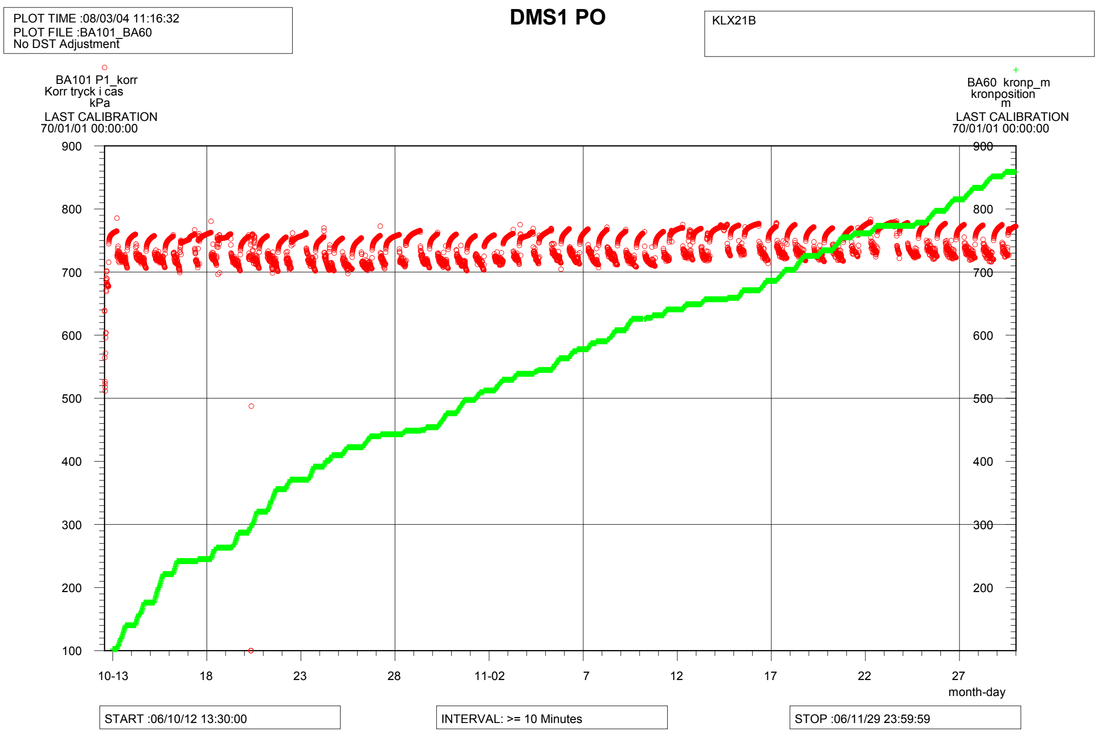


Figure 5-24. Drill bit position (green) and water level from air-lift pumping (red). The water level is expressed as the pressure in kPa of the water column overlying the pressure gauge i.e. the ambient air-pressure has been subtracted. The pressure gauge is emplaced at 90 metres borehole length.

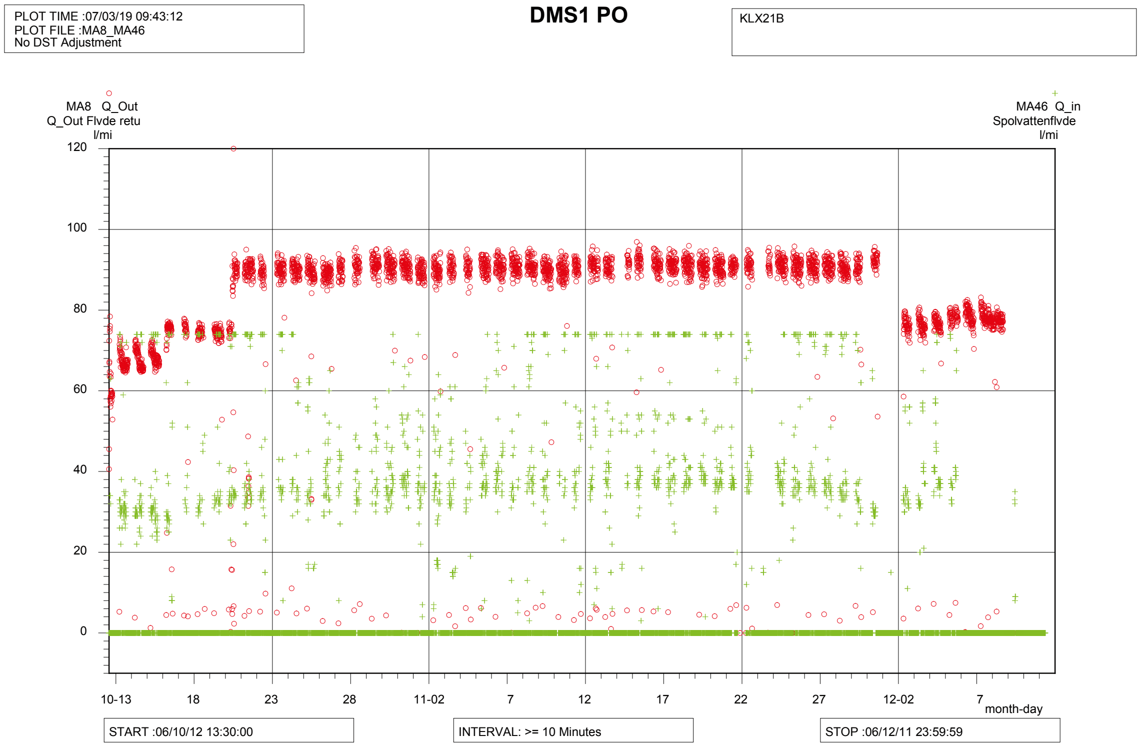


***Figure 5-25.** Flushing water flow (green) and return water flow (red) in litres per minute.*

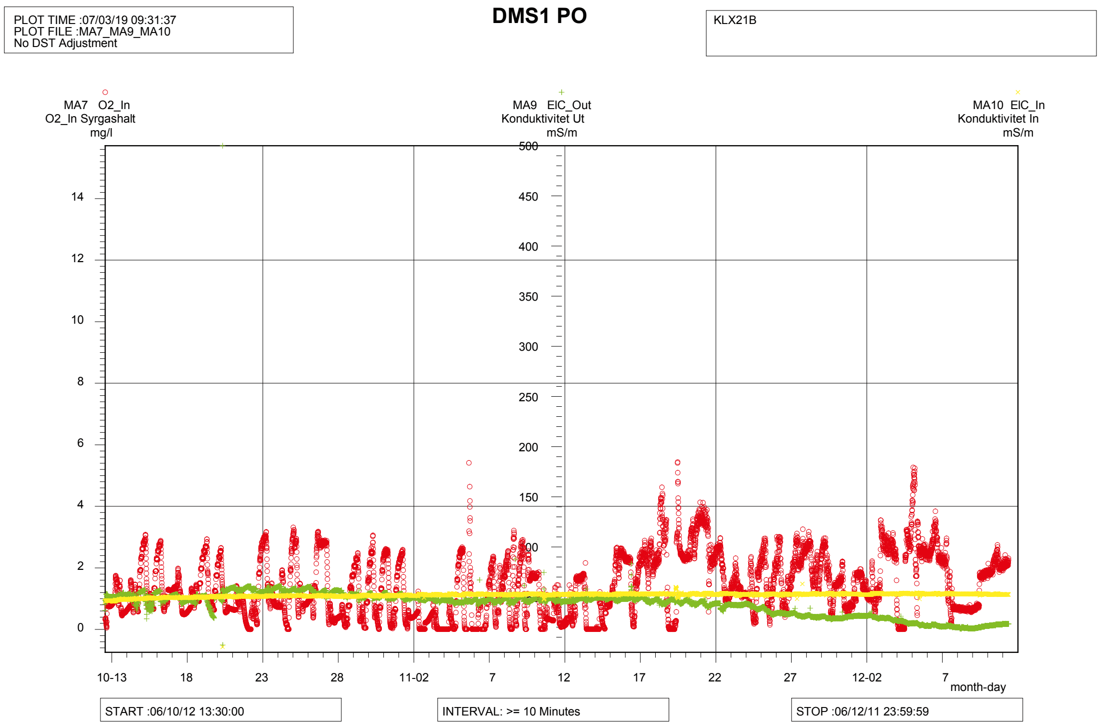


***Figure 5-26.** Conductivity of flushing water (yellow) and return water (green). The oxygen content in mg/L of the flushing water (red) is also shown. The oxygen content of the flushing water is typically below 4 mg/L. The conductivity of the return water (green) is low and stable at below 100 mS/m.*

In order to maintain reasonable size data files, a reduction in the number of points incorporated in the pictures has been done in Figures 5-24 through 5-26. Since DMS data are related to time (i.e. not strictly to borehole length) periods where drilling is not performed are also registered.

Figure 5-24 depicts the drill bit position (green) over time and the water level (red) in the telescope part of the drill hole. The water level, given as pressure of the overlying water column reflects the air-lift pumping activity in the hole.

Figure 5-25 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 ca 25–40 litres/minute corresponding to pumped flow during drilling.
- A flow of 60–75 litres/minute corresponding to the flow while pumping down the core barrel.
- No flow (zero litres/minute) when no drilling is performed.

Figure 5-26 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 4 mg/L, which is very low. The electrical conductivity of the return water is stable at less than 100 mS/m.

5.6.2 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 5-27.

The amount of flushing water consumed during drilling was 750 m^3, giving an average consumption of 1 m^3 per metre core drilled. The amount of effluent return water from drilling in KLX21B was measured by the DMS system to 3,300 m^3, giving an average of ca 4.3 m^3 per metre core drilled.

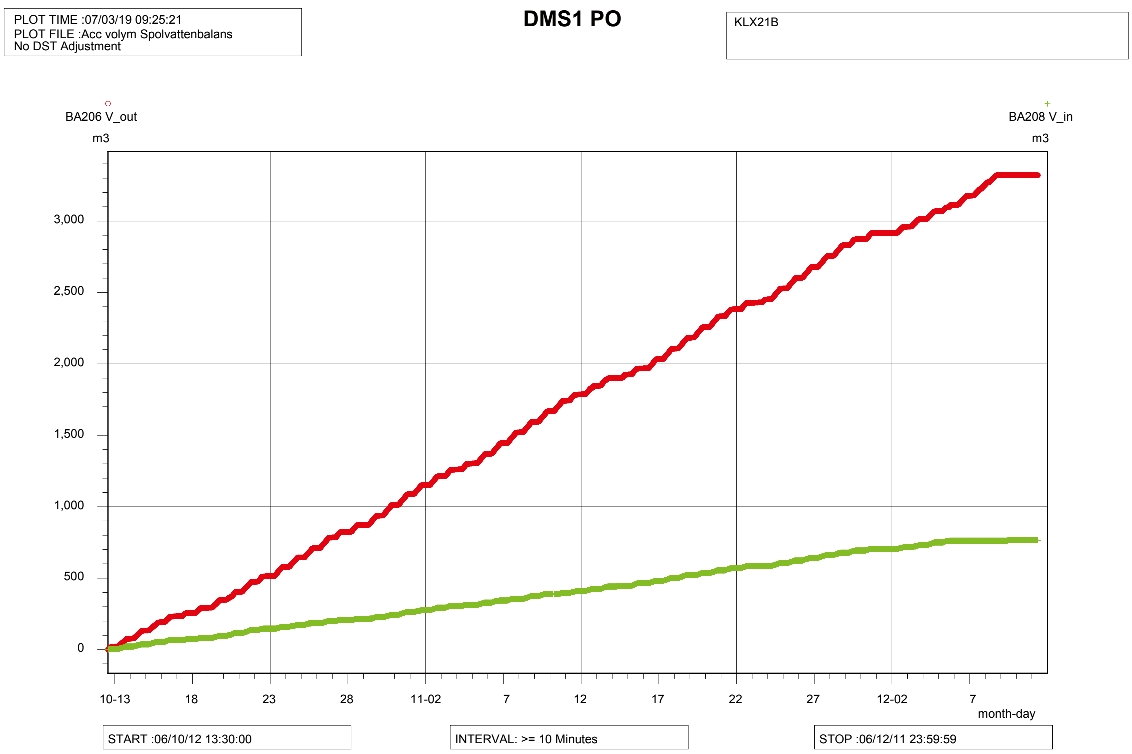


Figure 5-27. *The flushing water balance in KLX21B as recorded by the DMS system. The accumulated volume of the ingoing flushing water is shown in green and the outgoing return water is shown in red.*

Drill cutting balance

The weight of cuttings in the settling containers amounted to 1,248 kg. The theoretical amount that should be produced from drilling with 76 mm triple tubing, with core barrel N3/50, over a length of 760 metres is 5,125 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 5-17. The results show that most (92%) of the introduced amount of uranine was retrieved during drilling of KLX21B.

5.7 Geology KLX21B

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 /6/.

Lithologically the core is dominated Ävrö granite with intercalations of diorite/gabbro, fine-grained dioritoid, fine-grained granite and fine-grained diorite-gabbro. Below 770 metres the core is composed mainly of quartz monzodiorite with minor sections of Ävrö granite.

Rock alteration is mostly weak. A section with significant red staining and elevated fracture frequency exists from 610 to 710 m. Sections with red staining are indicated as “oxidized” in Appendix 1.

The average fracture frequency over the core drilled section is 2.2 (fractures/metre) 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).

Table 5-17. Balance calculation of uranine tracer in KLX21B.

Average uranine content IN (mg/L)	0.210
Flushing water volume IN (m^3)	750
Amount uranine introduced (g)	158
Average uranine content OUT (mg/L)	0.044
Return water volume OUT (m^3)	3,300
Amount uranine recovered (g)	145

5.8 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.

5.9 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 SSM000256 and SSM000257 is shown in Figure 5-28. 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.

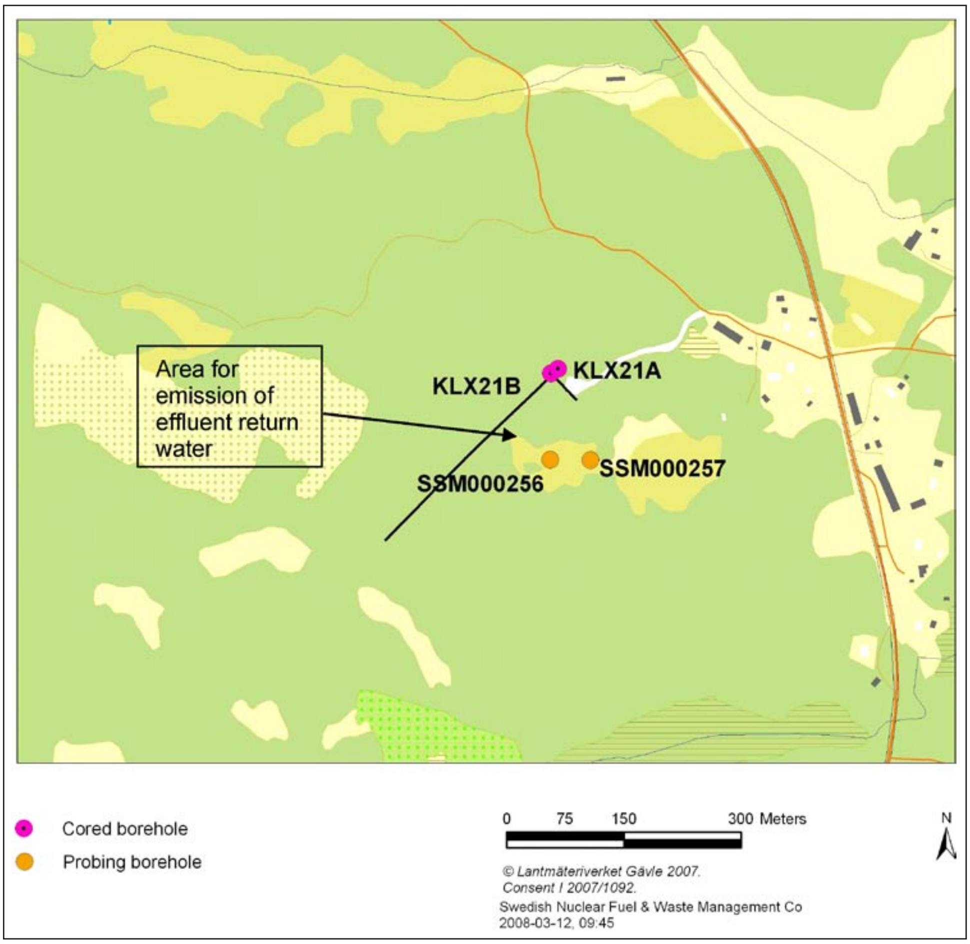


Figure 5-28. The location of the site for return water emission and the environmental monitoring wells SSM000256 and SSM000257 in relation to the core drill site for KLX21B.

Monitoring of effluent water

The electrical conductivity, as measured by the DMS system, of the return water from the core drilling of KLX21B 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 60 mS/m, see Figure 5-9.

The uranine content in the return water was well below 0.3 mg/L, see Figure 5-11.

The concentration of suspended material in the return water from drilling was not analyzed for borehole KLX21B 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 /7/ and 400 mg/L in KSH03 /8/. The amount of suspended material in the return water from core drilling in KLX21B 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 KLX21B. Changes in the handling of the return water could therefore only be initiated in the last planned borehole, KLX15A as a direct result of the sampling in KLX17A (SKB id 1091530, internal document).

Environmental monitoring wells and reference sampling

Two environmental monitoring wells, SSM000256 and SSM000257, were drilled as part of the core drilling activity for KLX21A. The main use of the environmental wells was however for the core drilling in KLX21B. The technical specifications are given in Appendix 6.

Reference samples of the surface soil and ground water, before drill start and establishment of the drill site were taken as given in Table 5-18.

Monitoring of soil ground water levels

A pressure logger (transducer) for measuring the ground water table was installed in SSM000256 and SSM000257 during the core drilling of KLX21B. The fluctuations of the water table in the two monitoring wells were almost identical. Plot from SSM000256 and SSM000257 are given in Figures 5-29 and 5-30. The pronounced and large increase in water level (c. 1.2 m) in both SSM000256 and SSM000257 could not be correlated to precipitation events. It does however coincide with the start of the core drilling and hence emission of return water from KLX21B. The location of the emission area for return water in relation to the environmental monitoring wells is shown in Figure 5-28.

Table 5-18. Reference samples for environmental monitoring.

Date	Sample no	Comment
2006-10-02	SKB PO 9014	Undisturbed soil sample at the drill site for KLX21A and KLX21B
2006-07-13	11220	Reference water sample in SSM000256
2006-07-13	11221	Reference water sample in SSM000257

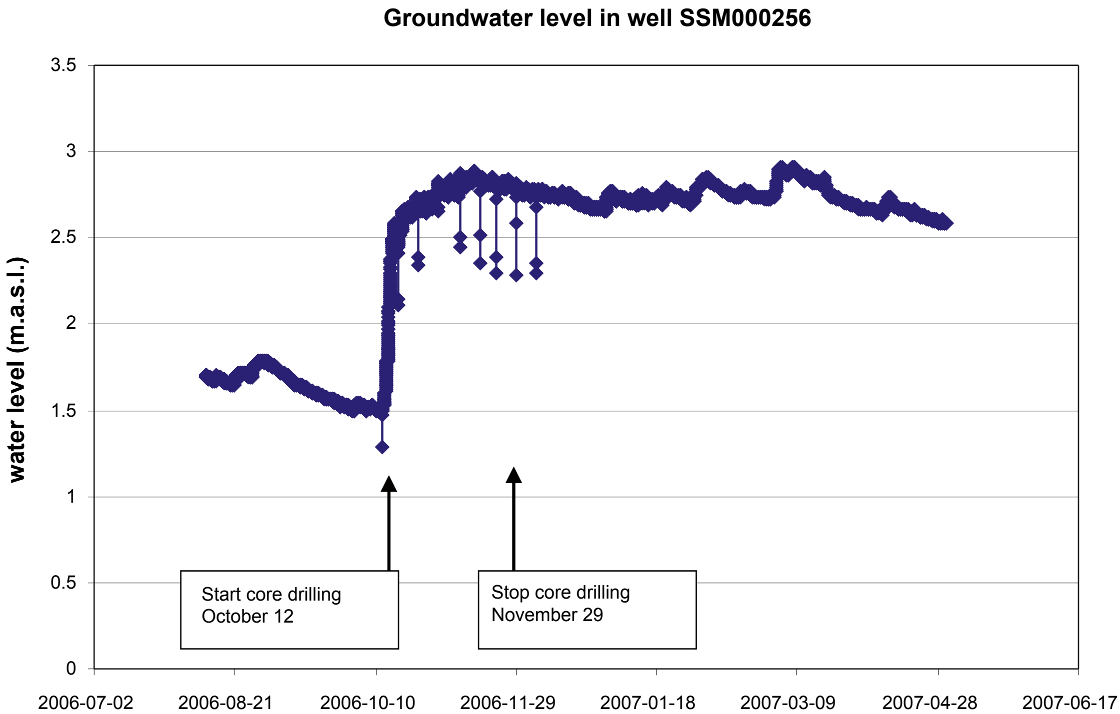


Figure 5-29. *The ground water level in well SSM000256. The momentary dips in water levels are related to water sampling.*

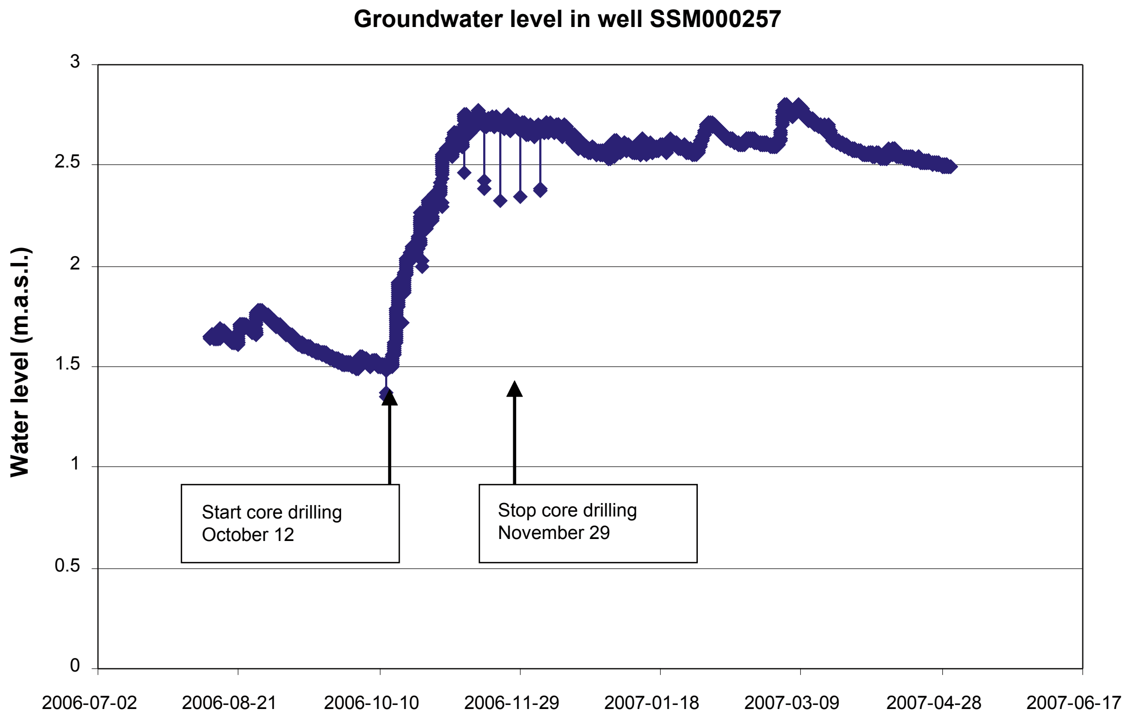


Figure 5-30. *The ground water level in well SSM000257. The momentary dips in water levels are related to water sampling.*

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, EC, and pH in the ground water in the environmental monitoring wells SSM000256 and SSM000257, see Figures 5-31 and 5-32. Both the pH and the EC in the monitoring wells drop significantly during the drilling period. This would imply an effect from the drilling on the shallow water chemistry in the monitoring wells. It is however hard to explain the lower EC in the monitoring wells during drilling since the pre-drilling EC of the soil water is similar to the EC of the emitted return water from drilling.

5.9.1 Consumption of oil and chemicals

The consumption of hammer oil (Hydra 46) is typically around 20 litres for the percussion drilling of a telescopic section, no exact record of the oil consummation was kept. No other significant amounts of oils or lubricants were consumed during the drilling.

The concrete consumption in KLX21A was 400 litres (360 kg). The consumption of concrete in KLX21B was 315 litres (321 kg). The concrete was based on white silica, low alkali cement.

5.10 Nonconformities

No formal nonconformities are noted for borehole KLX21A or KLX21B.

No record of the results from deviation measurements in the pilot borehole of KLX21A was kept.

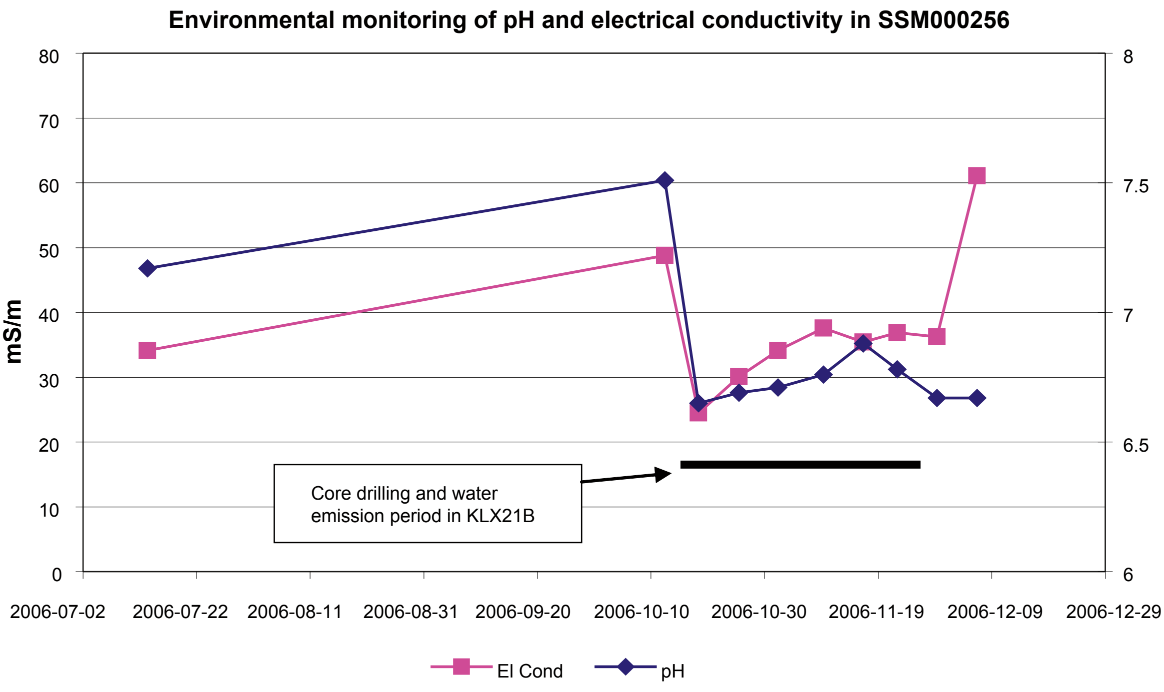


Figure 5-31. Electrical conductivity and pH in ground water samples from SSM000256. The sampling events are shown with blue and purple symbols.

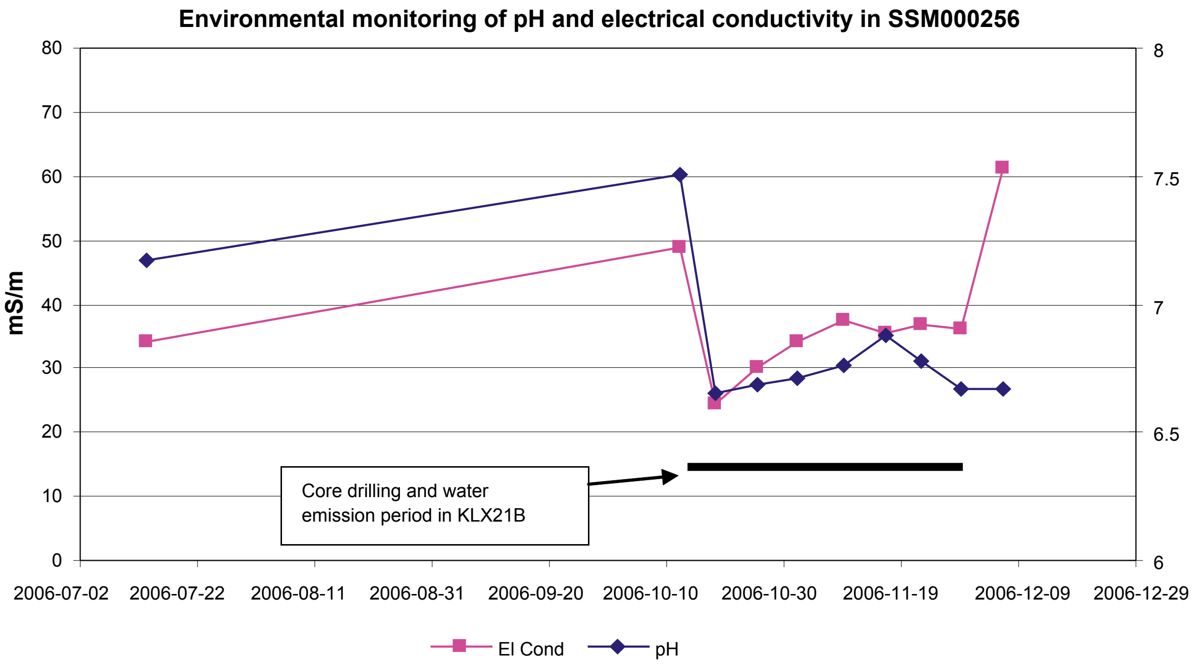


Figure 5-32. *Electrical conductivity and pH in ground water samples from SSM000257. The sampling events are shown with blue and purple symbols.*

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.

/3/ **Stenberg L, Håkanson N, 2007**. Revision of borehole deviation measurements in Oskarshamn, SKB P-07-55, Svensk Kärnbränslehantering AB.

/4/ **Moye D G, 1967.** Diamond drilling for foundation exploration, Civil Eng. Trans. Inst. Eng, Australia.

/5/ **Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2006.** Drilling of cored borehole KLX12A, SKB P-06-305, Svensk Kärnbränslehantering AB.

/6/ **Mattsson K-J, Dahlin P, Lundberg E, 2007.** Boremap mapping of telescopic drilled borehole KLX21B, SKB P-07-218, Svensk Kärnbränslehantering AB.

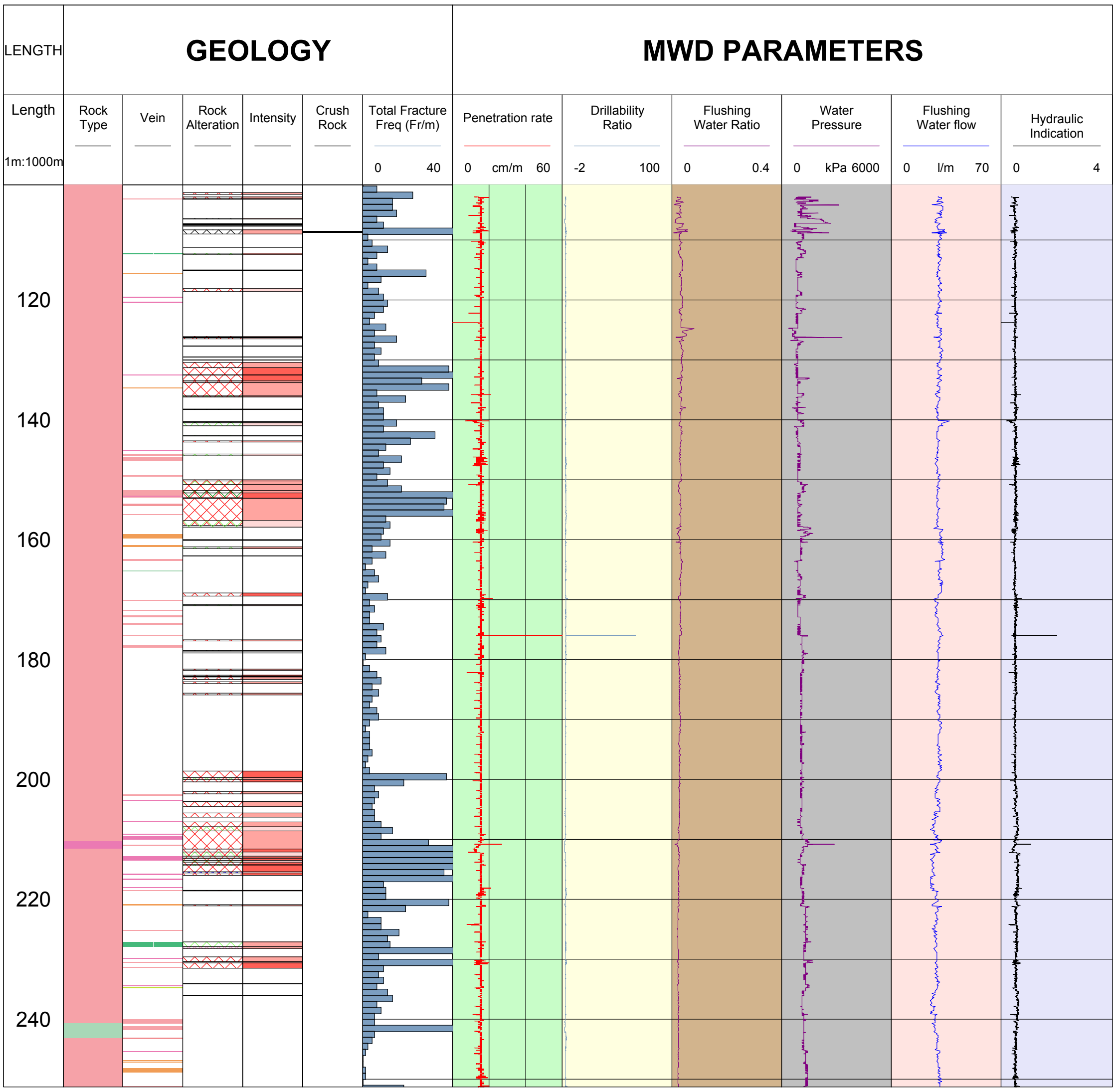
/7/ **Ask H, Morosini M, Tiberg L, 2007.** Drilling of cored borehole KLX17A, SKB P-07-221, Svensk Kärnbränslehantering AB.

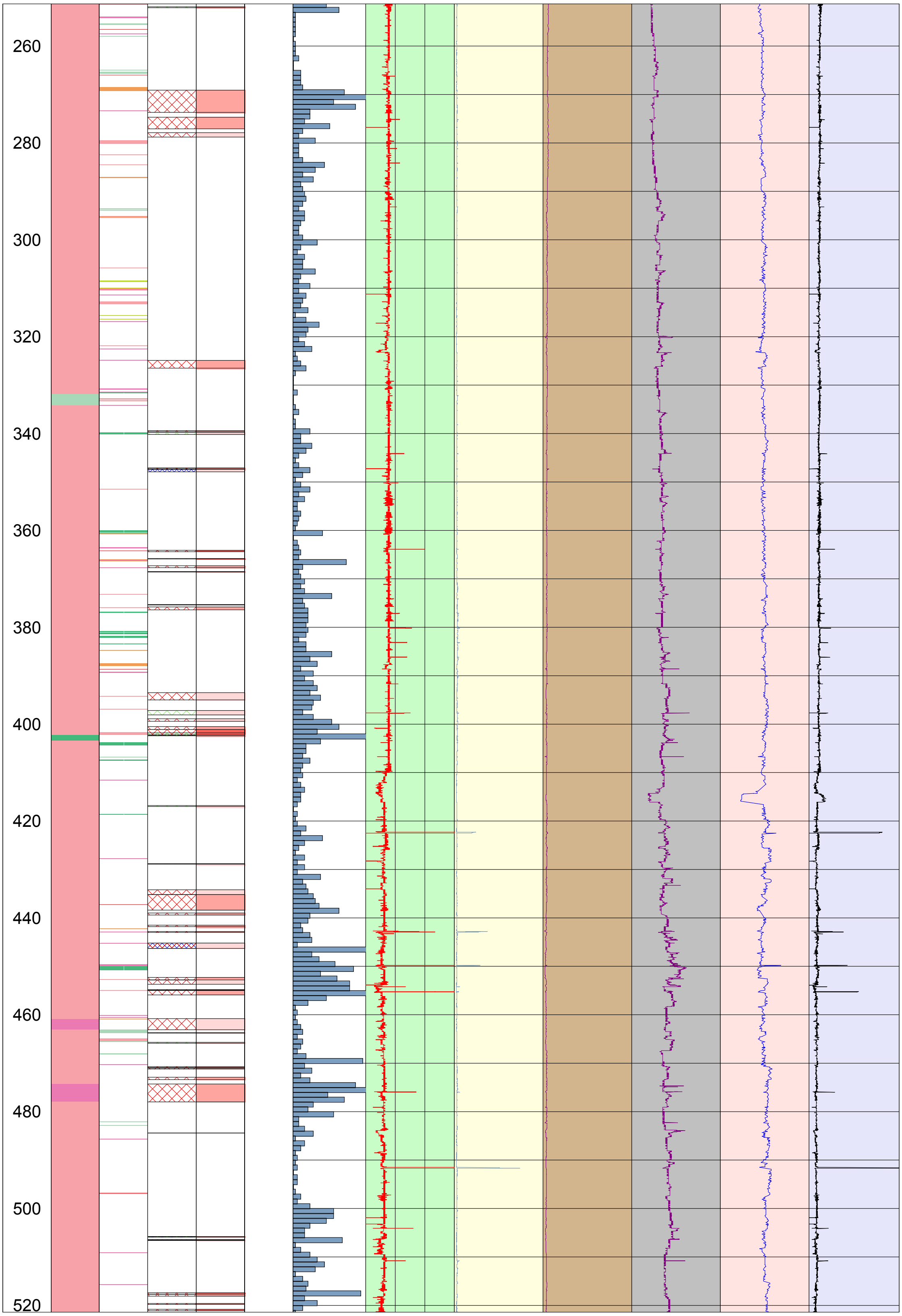
/8/ **Ask H, Morosini M, Samuelsson L-E, Ekström L, Håkanson N, 2004.** Drilling of cored borehole KSH03, SKB P-04-233, Svensk Kärnbränslehantering AB.

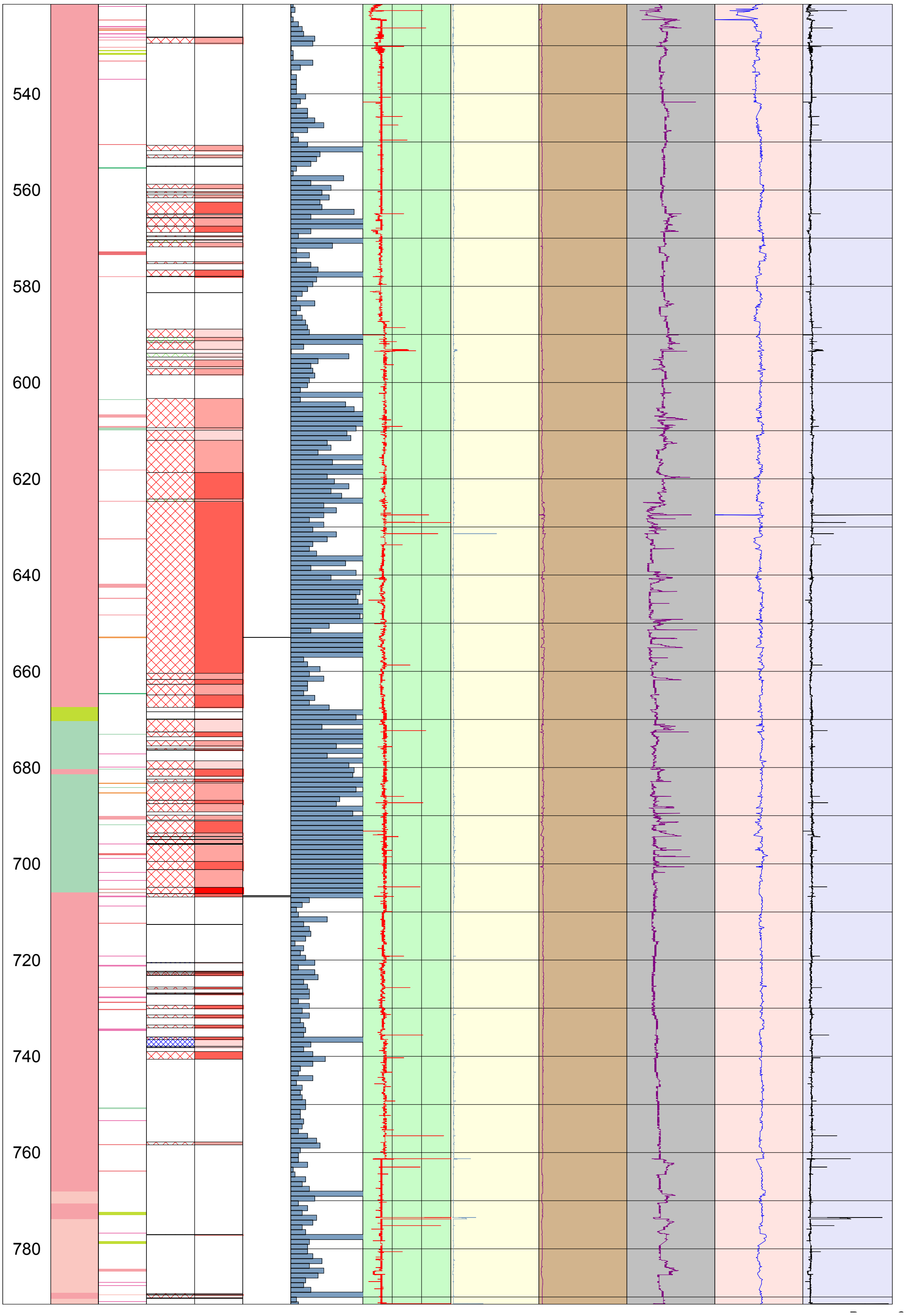
Geology and MWD parameters KLX21B

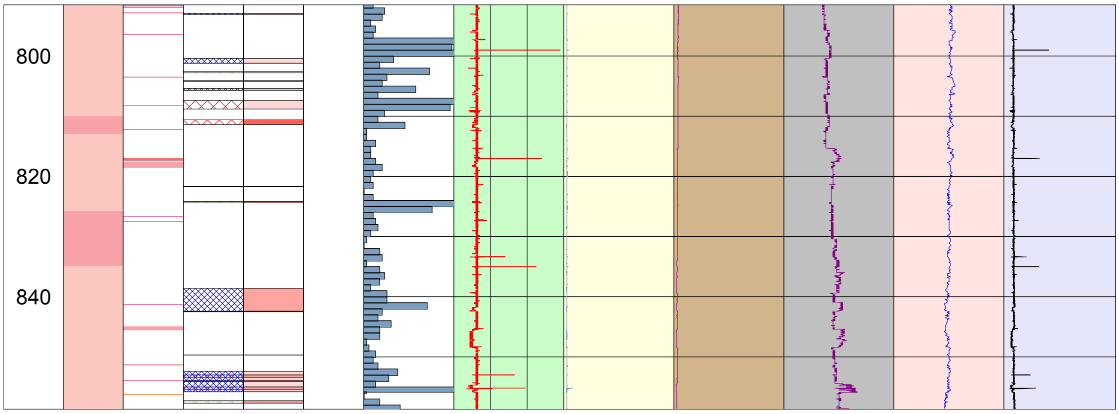
Title	GEOLOGY & MWD PARAMETERS KLX21B			Appendix 1
SKB	Site	LAXEMAR	Coordinate System	RT90-RHB70
	Borehole	KLX21B	Northing [m]	6366164.00
	Diameter [mm]	76	Easting [m]	1549715.10
	Length [m]	858.780	Elevation [m.a.s.l.]	10.68
	Bearing [°]	225.05	Drilling Start Date	2006-09-20 07:00:00
	Inclination [°]	-70.85	Drilling Stop Date	2006-11-29 10:30:00
	Date of mapping	2007-01-30 15:06:00	Plot Date	2008-02-06 22:03:22

ROCKTYPE LAXEMAR	ROCK ALTERATION	INTENSITY
Fine-grained granite	Oxidized	Faint
Ävrö granite	Chloritisized	Weak
Quartz monzodiorite	Epidotisized	Medium
Diorite / Gabbro	Silicification	Strong
Fine-grained dioritoid	Albitization	
Fine-grained diorite-gabbro	Saussuritization	




260
280
300
320
340
360
380
400
420
440
460
480
500
520


540
560
580
600
620
640
660
680
700
720
740
760
780


800
820
840

Appendix 2

Chemical results

Borehole	KLX21B	KLX21B	KLX21B
Date of measurement	2006-10-17	2006-10-19	2006-11-16
Upper section limit (m)	102.00	101.50	543.21
Lower section limit (m)	242.22	263.20	671.07
Sample_no	11405	11410	11527
Groundwater Chemistry Class	3	3	3
pH	8.50	8.46	x
Conductivity mS/m	62.2	64.5	x
Drill water %	0.97	28.70	68.30
Density g/ml	0.9976	0.9975	x
Charge balance %	x	–0.27	x
Na mg/l	x	122.0	x
K mg/l	x	8.31	x
Ca mg/l	x	10.4	x
Mg mg/l	x	5.3	x
HCO3 mg/l Alkalinity	238	235	x
Cl mg/l	28.4	32.9	x
SO4 mg/l	62.50	70.20	x
SO4_S mg/l Total Sulphur	x	23.70	x
Br mg/l	–0.200	–0.200	x
F mg/l	4.82	4.94	x
Si mg/l	x	22.3	x
Fe mg/l Total Iron	x	7.290	x
Mn mg/l	x	0.1790	x
Li mg/l	x	0.019	x
Sr mg/l	x	0.0223	x
TOC mg/l	x	x	x
PMC % Modern Carbon	x	50.70	x
C-13 dev PDB	x	–16.30	x
AGE_BP Groundwater age	x	5,400	x
AGE_BP_CORR	x	45	x
D dev SMOW	x	–79.9	x
Tr TU	x	3.70	x
O-18 dev SMOW	x	–10.90	x
B-10 B-10/B-11	x	0.2376	x
S-34 dev SMOW	x	18.3	x
Cl-37 dev SMOC	x	–0.11	x
Sr-87 Sr-87/Sr86	x	0.718416	x

x = not analysed.

Appendix 3

Chemistry – analytical method and quality

SKB Chemistry class 3 Analysis	Sample bottle	Preparation	SKB label	Laboratory
pH, conduktivity, alkalinity	250 ml		green	Äspö/field
Anions (F^-, Br^-, Cl^-, SO_4^{2-})	250 ml	Filtered in connection with analyse	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 plastic		green	Ångström
S-34	1,000 ml		green	IFE

Quality of the analyses

The charge balance errors (see Appendix 2) give an indication of the quality and uncertainty of the analyses of the major components. The relative charge balance error is calculated for the set of data from borehole KLX21B, i.e. sample 11410. The error does not exceed ± 5%.

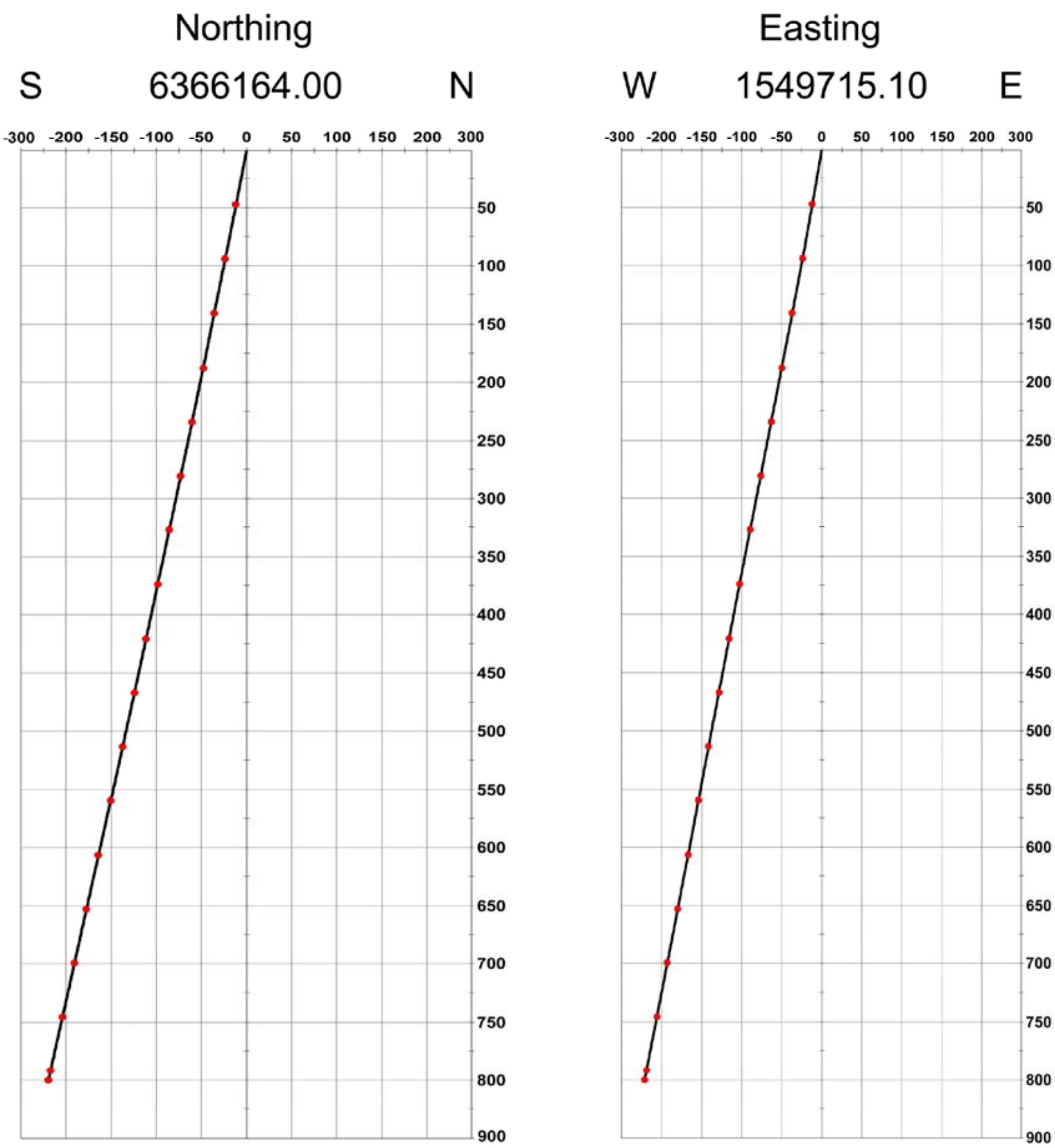
The following routines for quality control and data management are generally applied for hydrogeochemical analysis data, independent of sampling method or sampling object.

- 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 KLX21B.
- 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.

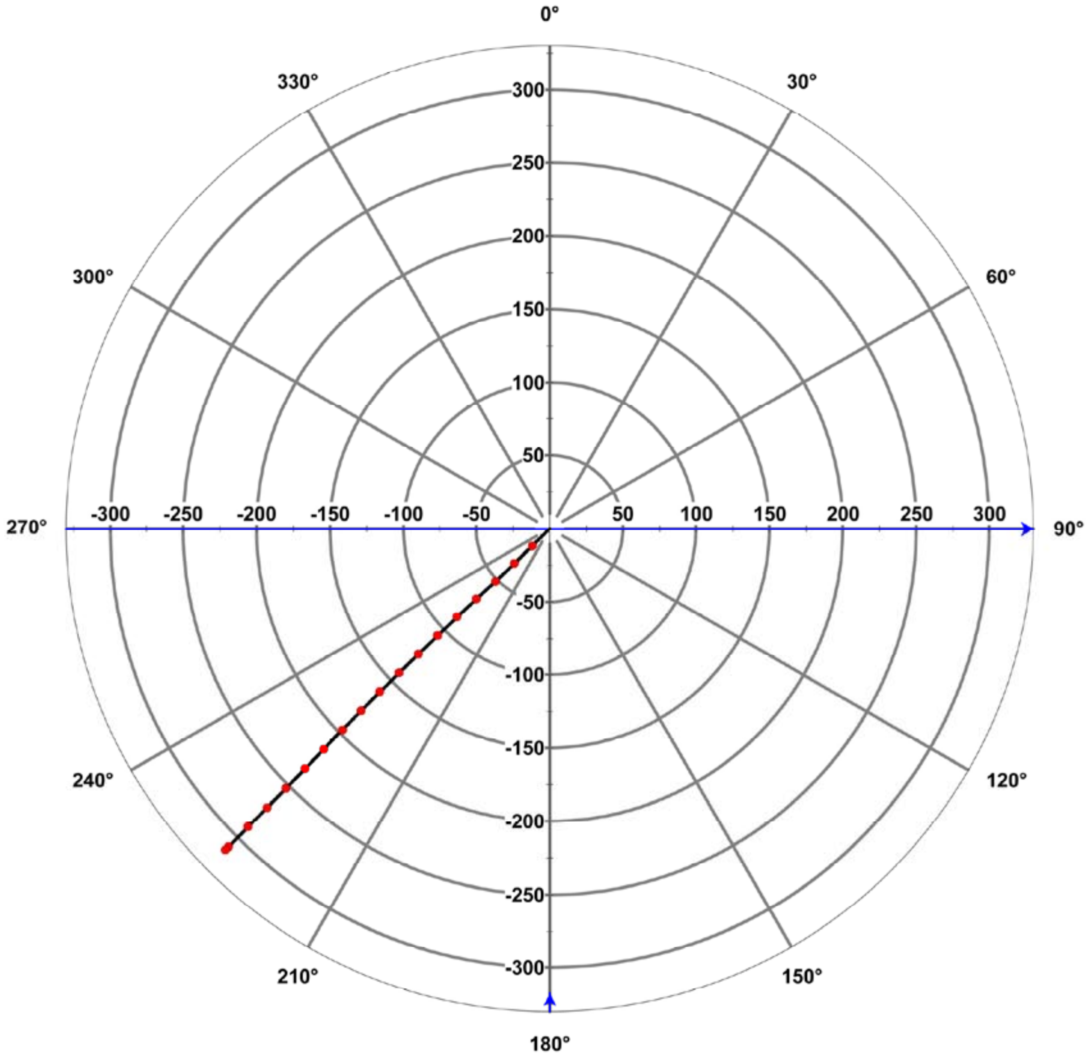
All results from "biochemical" components and special analyses of trace metals and isotopes are inserted directly into primary data tables. In those cases where the analyses are repeated or performed by more than one laboratory, a "best choice" notation will indicate those results which are considered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

Deviation measurements

Deviation measurement		Appendix: 4
	Site LAXEMAR Borehole KLX21B Vertical Section	



Site LAXEMAR
Borehole KLX21B
View from above

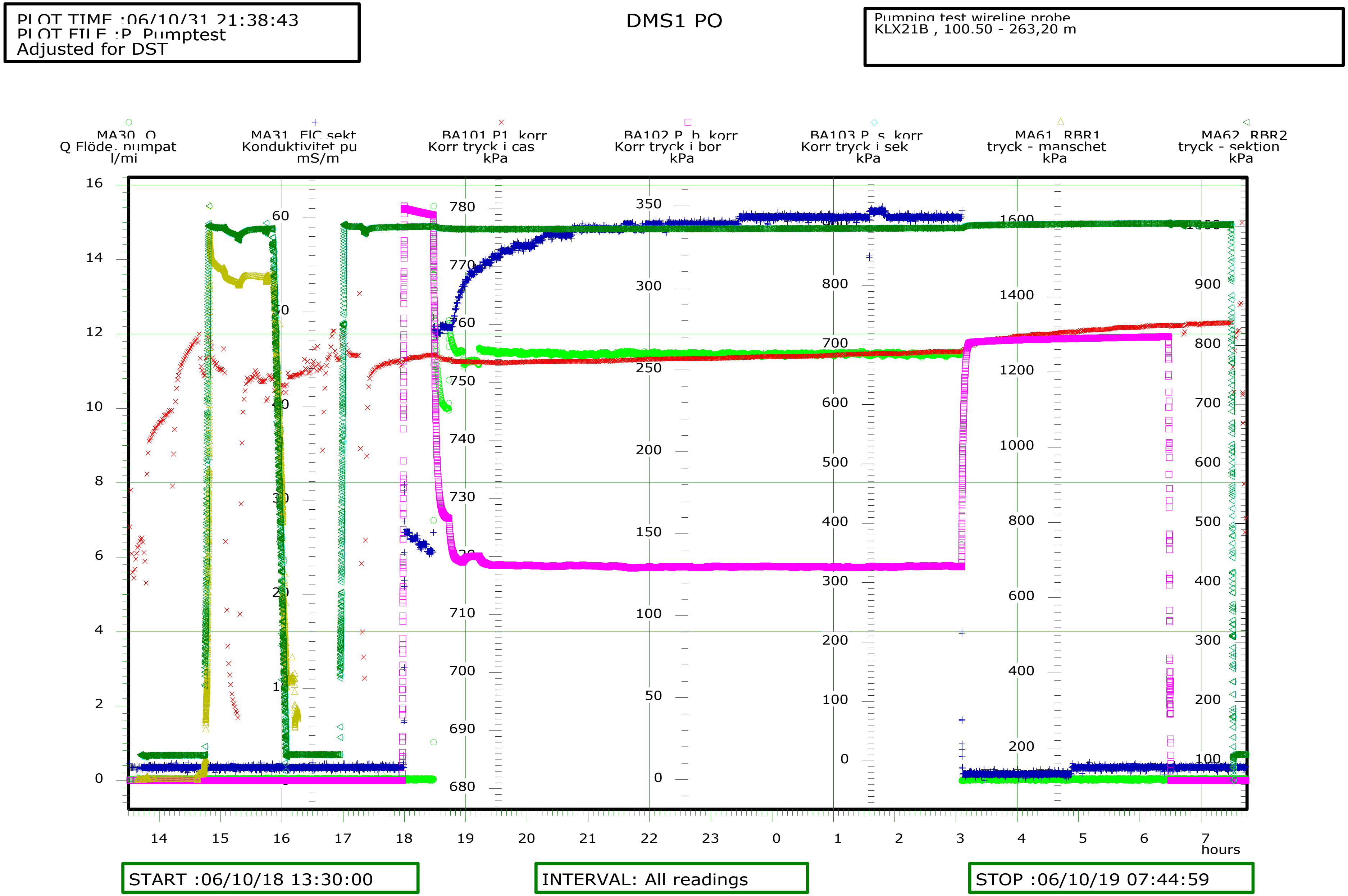


Appendix 5

Wireline pumping tests in KLX21B

Description of the parameters in the enclosed plots

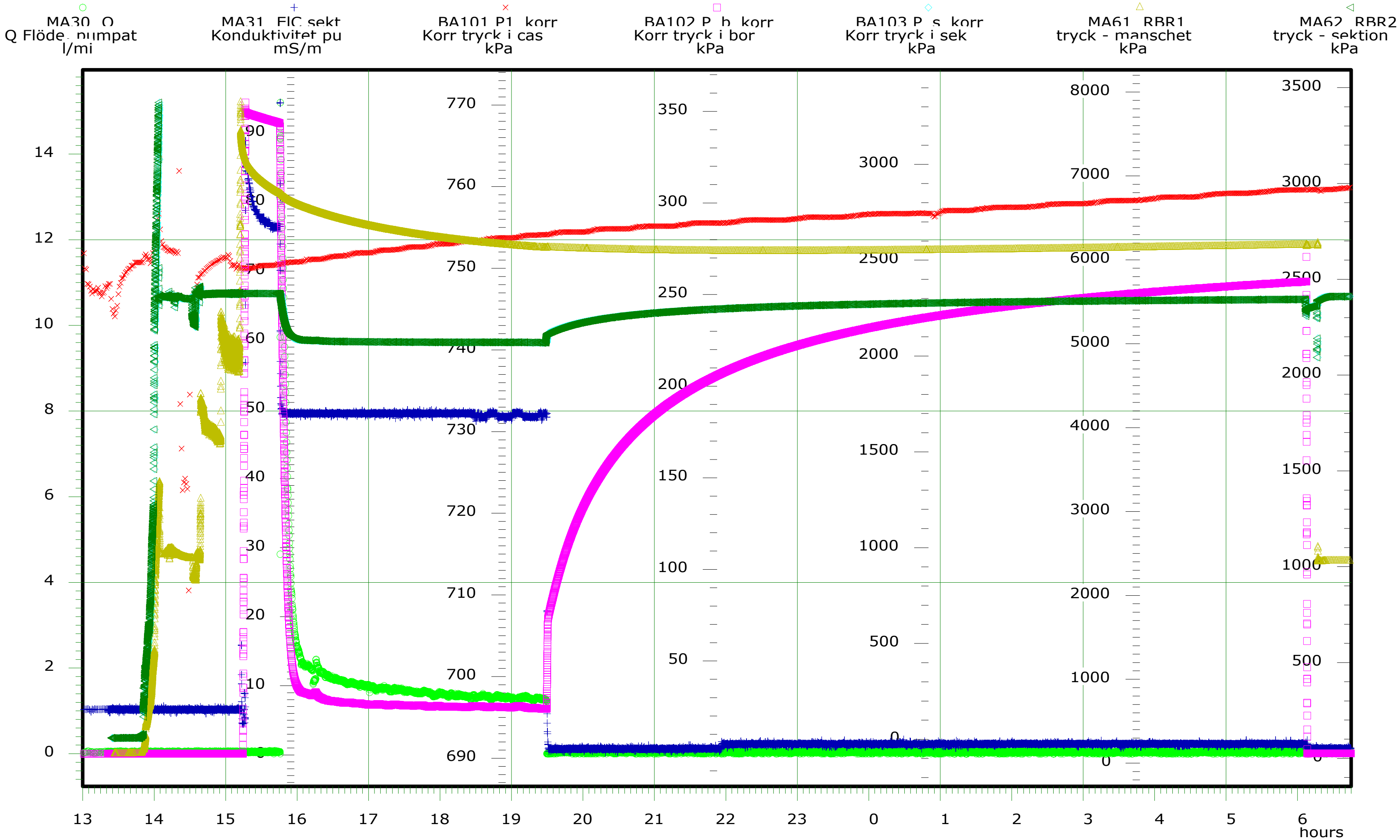
Channel	Parameter	Unit	Description
MA30	Water flow	Litre/minute	Flow of water pumped up from the borehole during the test.
MA31	Electrical conductivity	mS/m	Electrical conductivity in the pumped out water.
BA101	Pressure	kPa	Pressure of the water column in the telescopic section subtracted with the ambient air pressure.
BA102	Pressure	kPa	Pressure of the water column in the test section i.e. at depth in the borehole, subtracted with the ambient air pressure.
BA103	Pressure – section	kPa	Pressure of the water column in the test section i.e. at depth in the borehole, subtracted with the ambient air pressure.
MA61	Pressure – packer	kPa	Inflation pressure in packer.
MA62	Pressure – section	kPa	Pressure of the water column in the test section i.e. at depth in the borehole. Not corrected for ambient air pressure.


PLOT TIME :06/10/31 21:38:43
PLOT FILE :P_Pumptest
Adjusted for DST
DMS1 PO
Pumping test wireline probe
KLX21B , 100.50 - 263,20 m
MA30 Q
Q Flöde, pumpat
l/mi
MA31 EIC sekt
Konduktivitet pu
mS/m
BA101 P1 korr
Korr tryck i cas
kPa
BA102 P_b korr
Korr tryck i bor
kPa
BA103 P_s korr
Korr tryck i sek
kPa
MA61 RBR1
tryck - manschet
kPa
MA62 RBR2
tryck - sektion
kPa
hours
START :06/10/18 13:30:00
INTERVAL: All readings
STOP :06/10/19 07:44:59

PLOT TIME :06/11/01 12:27:35
PLOT FILE :P_Pumptest
Adjusted for DST

DMS1 PO

Pumping test wireline probe
KLX21B , 262.00 - 371,18 m



START :06/10/22 13:00:00

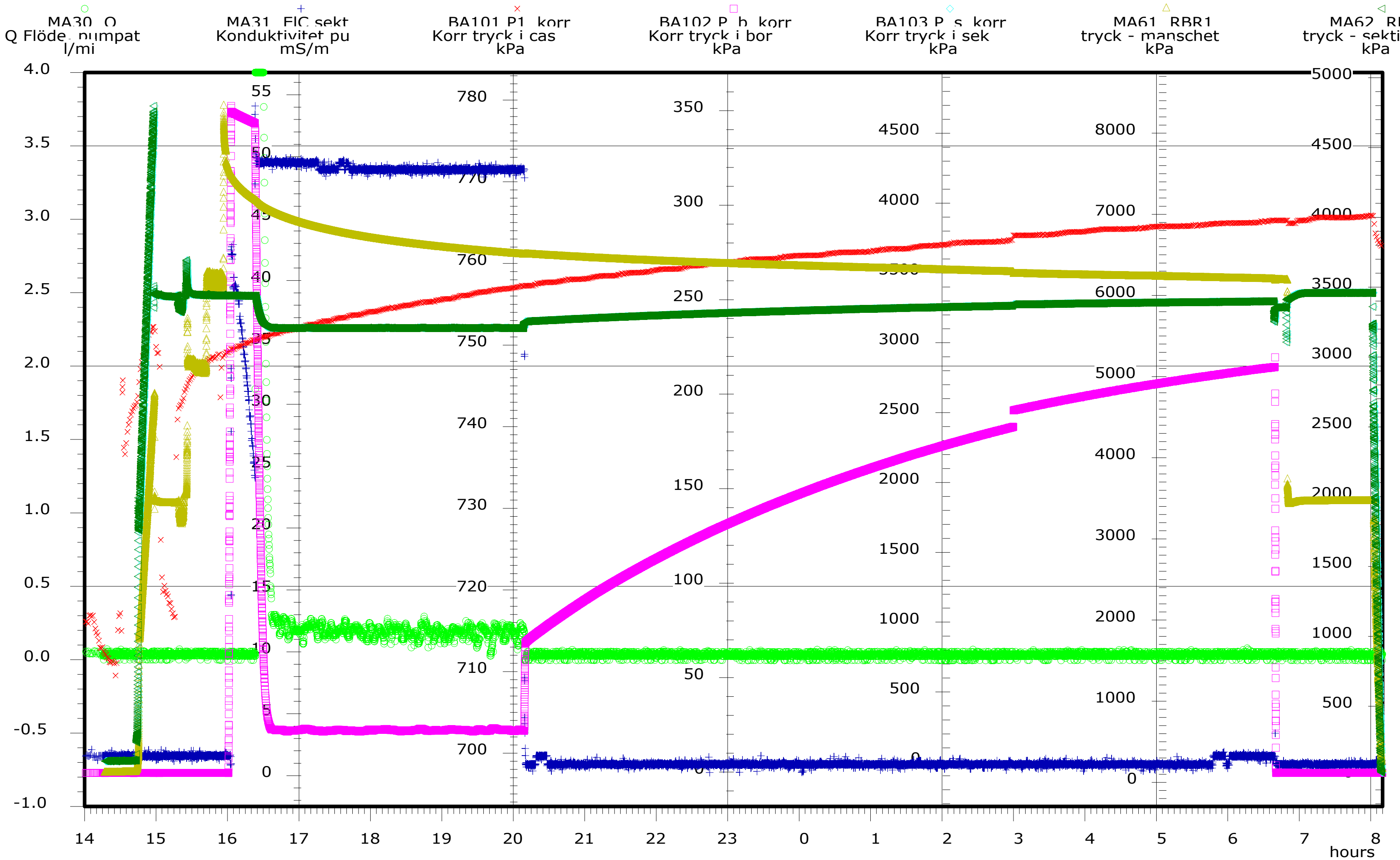
INTERVAL: All readings

STOP :06/10/23 06:44:59

PLOT TIME :06/11/01 13:56:04
PLOT FILE :P_Pumptest
Adjusted for DST

DMS1 PO

Pumping test wireline probe
KLX21B , 368.91 - 448,87 m



START :06/10/28 14:00:00

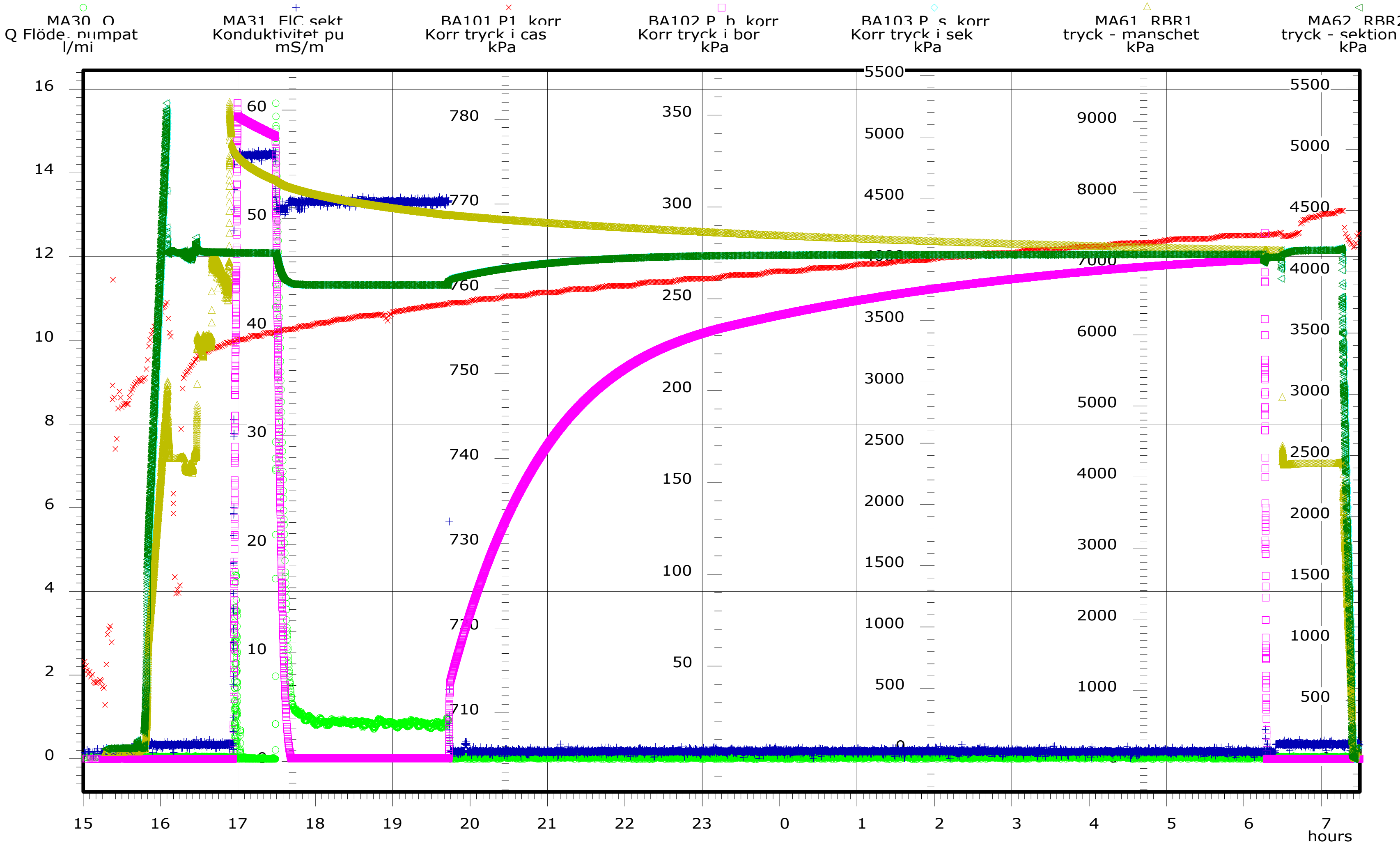
INTERVAL: All readings

STOP :06/10/29 08:09:59

PLOT TIME :06/11/09 20:40:42
PLOT FILE :P_Pumptest
Adjusted for DST

DMS1 PO

Pumping test wireline probe
KLX21B , 446.91 - 544.83 m



START :06/11/04 15:00:00

INTERVAL: All readings

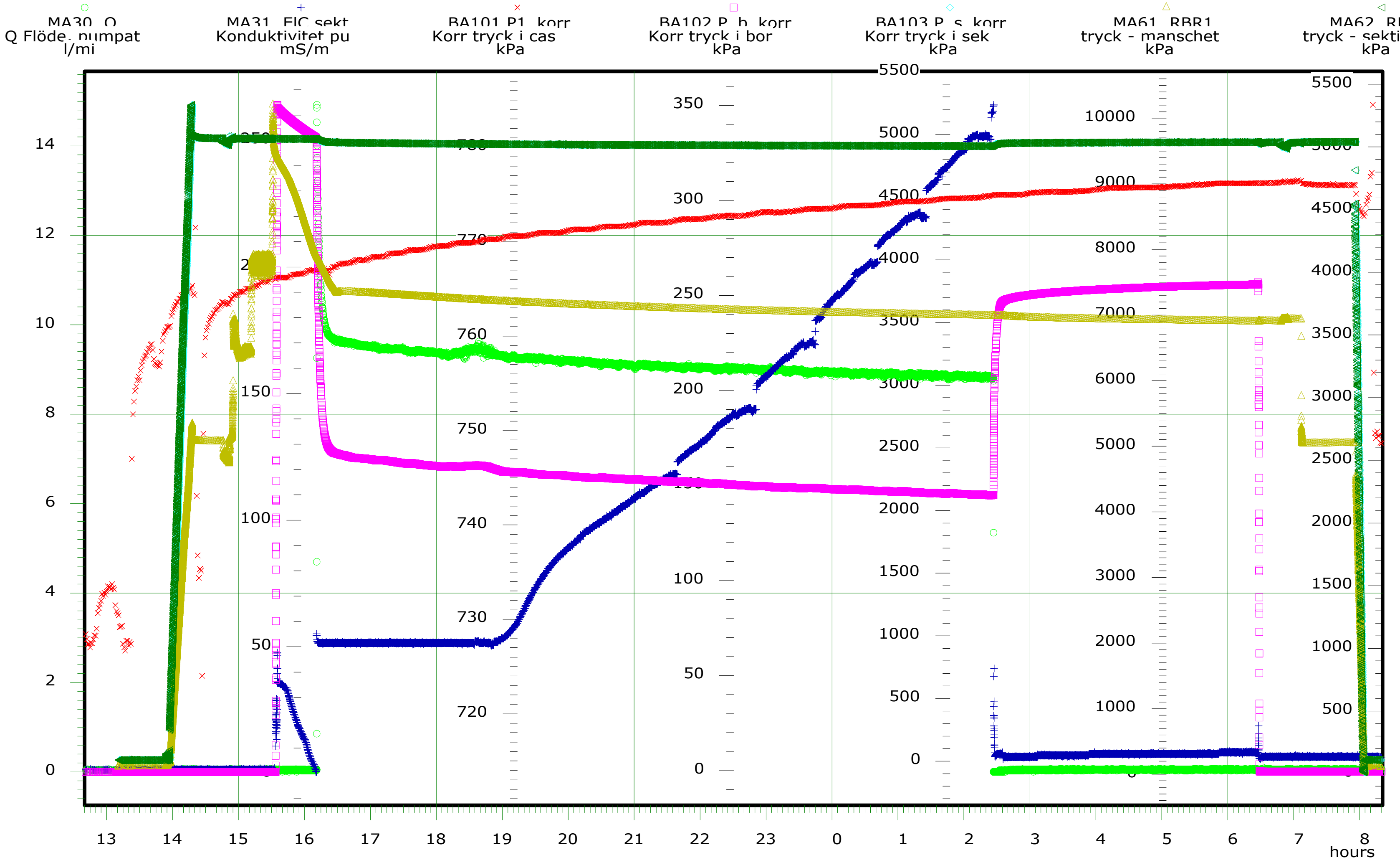
STOP :06/11/05 07:29:59

75

PLOT TIME :06/11/17 08:54:28
PLOT FILE :P_Pumptest
Adjusted for DST

DMS1 PO

Pumping test wireline probe
KLX21B , 543.21 - 671.07 m



START :06/11/15 12:40:00

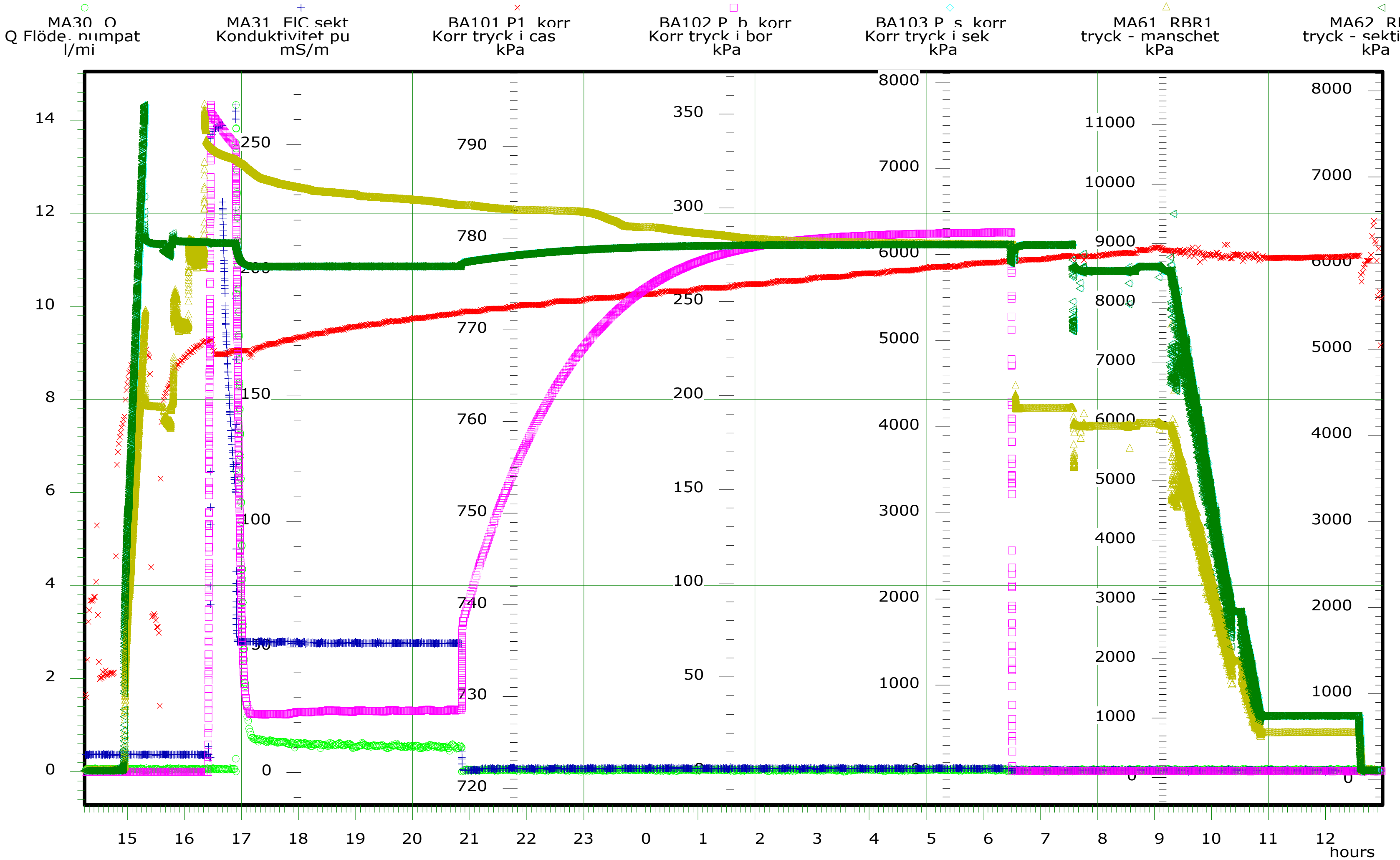
INTERVAL: All readings

STOP :06/11/16 08:20:55

PLOT TIME :06/11/24 11:11:54
PLOT FILE :P_Pumptest
Adjusted for DST

DMS1 PO

Pumping test wireline probe
KLX21B , 668.94 - 773.98 m



START :06/11/22 14:15:00

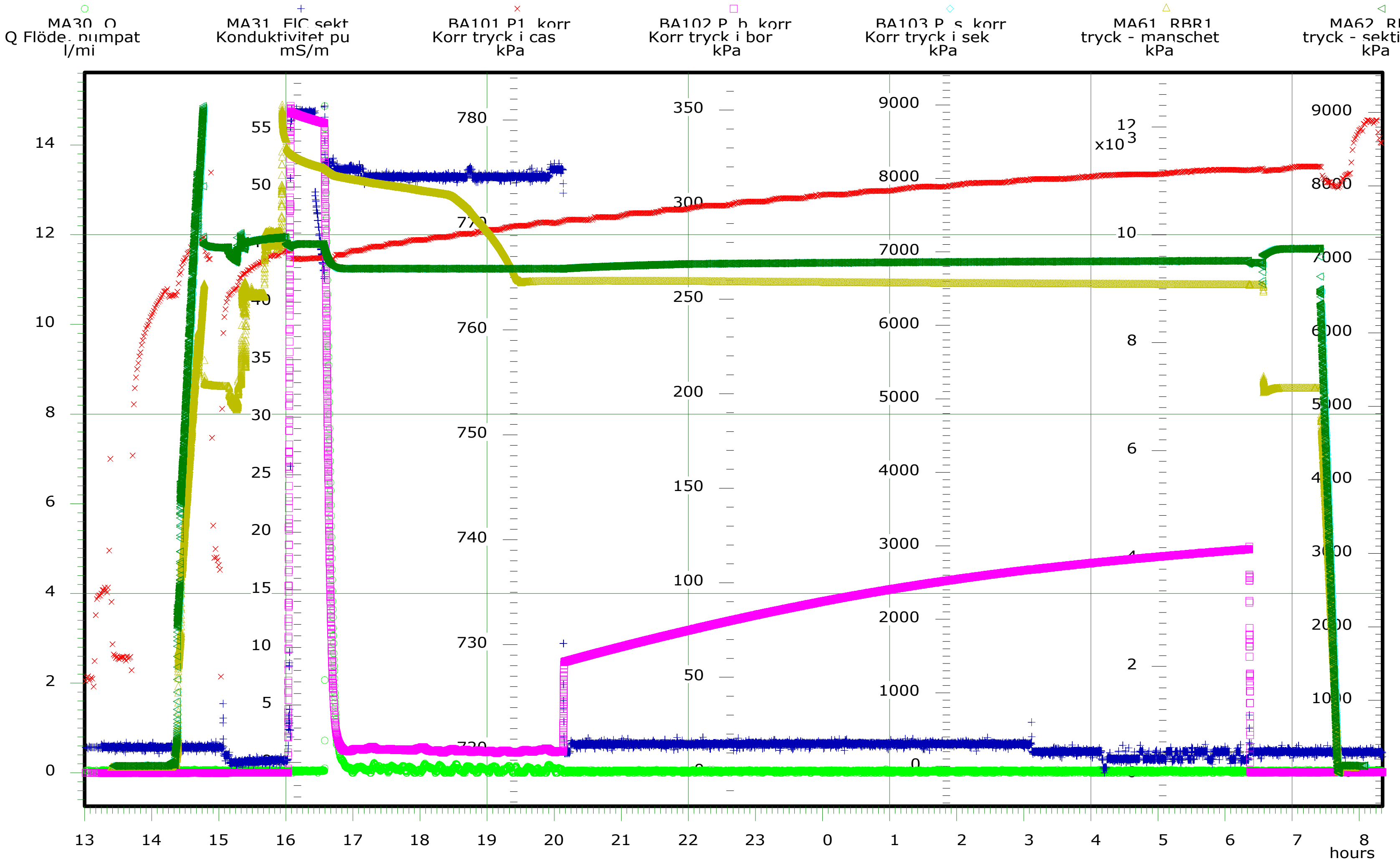
INTERVAL: All readings

STOP :06/11/23 12:59:59

PLOT TIME :06/12/01 13:45:16
PLOT FILE :P Pumptest
No DST Adjustment

DMS1 PO

Pumping test wireline probe
KLX21B, 770,91 - 858,69 m



START :06/11/29 13:00:00

INTERVAL: All readings

STOP :06/11/30 08:20:55

Appendix 6

Technical data from environmental monitoring wells SSM000256 and SSM000257

WSP

BOREHOLE SSM000256

Company rep.
Torbjörn Johansson

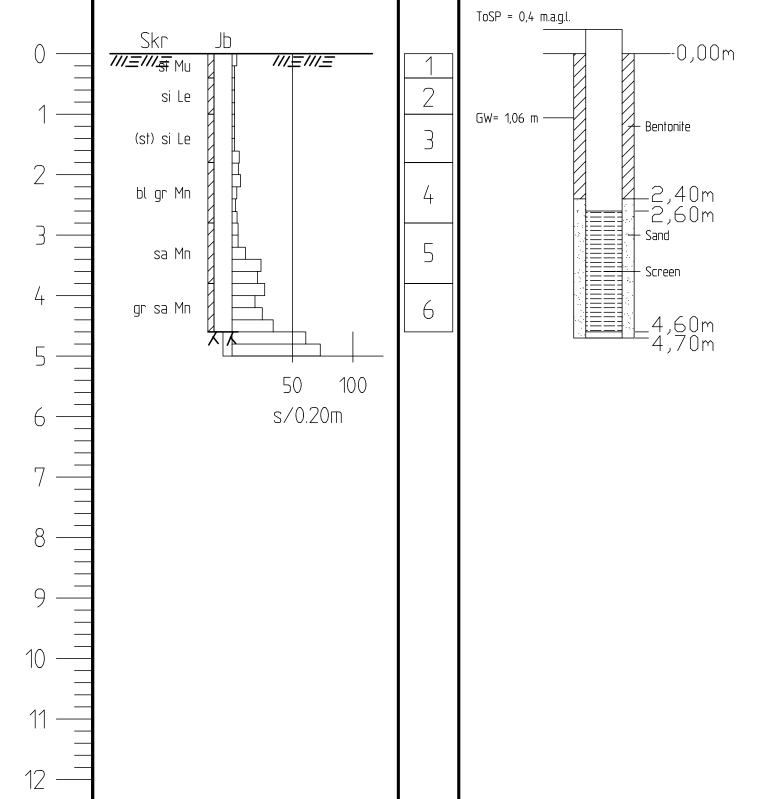
Client: Svensk Kärnbränslehantering AB

Northing :6366048,022
Easting :1549705,343

Coordinate system : RT90-RHB70

Top of stand pipe : 0,4 m.a.g.l.
Total pipe length : 5,10 m
Groundwater level : 1,06 m.b.g.l.
Date of completion : 2006-07-11

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information



Drilling method : NOEK
Borehole diameter : 120 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 3,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 3,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 2,40 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 2,30 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Φ44
Drill bit : Stift Φ54

GEOLOGICAL LOG
0-0,4m Silty topsoil
0,4-1,0m silty clay
1,0-1,8m somewhat cobble-bearing silty clay
1,8-2,8m boulder-bearing gravelly till
2,8-3,8m sandy till
3,8-4,6m gravelly sandy till
4,6m rock surface

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net

BOREHOLE SSM000257

Company rep.
Torbjörn Johansson

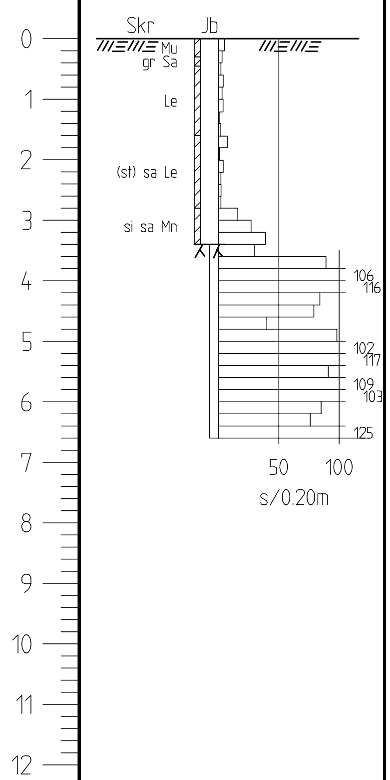
Client: Svensk Kärnbränslehantering AB

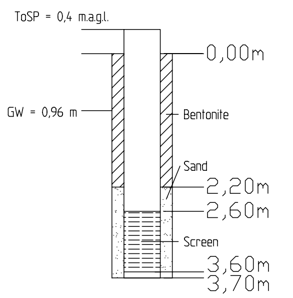
Northing :6366047,489
Easting :1549756,897

Coordinate system : RT90-RHB70

Top of stand pipe : 0,4 m.a.g.l.
Total pipe length : 4,10 m
Groundwater level : 0,96 m.b.g.l.
Date of completion : 2006-07-10

Depth (m)	Description	Samples	Groundwater monitoring well description	Borehole Construction Information





Drilling method : NOEK
Borehole diameter : 120 mm
sampling method : Auger

CASING
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 3,00 m

SCREEN
Material : PEH
Outer diameter : 63 mm
Inner diameter : 50 mm
Total length : 1,00 m
Slot : 0,3 mm

ANNULUS SEAL
Material : Bentonite clay
Total length : 2,20 m

SAND PACK
Grain size : 0,4-0,8 mm
Total length : 1,50 m

DRILLING EQUIPMENT
Drilling rig : GM 65 GTT
Drill hammer : Furukawa HB2G
Drill rod : Geostång Φ44
Drill bit : Stift Φ54

GEOLOGICAL LOG
0-0,3m Topsoil
0,3-0,45m gravelly sand
0,45-1,6m clay
1,6-2,8m somewhat cobble-bearing sandy clay
2,8-3,4m silty sandy till
3,4m rock surface

ToSP : Top of Stand Pipe
m.a.g.l. : meters above ground level
m.b.g.l. : meters below ground level

Nomenclature see SGF homepage:
www.sgf.net