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Oskarshamn site investigation

Difference flow logging of boreholes KLX26A and KLX26B

Subarea Laxemar

Jari Pöllänen, PRG-Tec Oy

March 2007

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Keywords: Laxemar, Hydrogeology, Hydraulic tests, Difference flow measurements, Flow logging, Pumping test, Transmissivity.

Abstract

Difference flow logging is a swift method for the determination of the transmissivity and the hydraulic head in borehole sections and fractures/fracture zones in core drilled boreholes. This report presents the main principles of the methods as well as the results of the measurements carried out in boreholes KLX26A and KLX26B at Oskarshamn, Sweden, February 2007, using Posiva flow log. Posiva Flow Log is a multipurpose measurement instrument developed by PRG-Tec Oy for the use of Posiva Oy. The primary aim of the measurements was to determine the position and flow rate of flow yielding fractures in the boreholes.

The flow measurements were done only during pumped conditions using a 1 m long test section. In these selective measurements the boreholes were pumped and measurement tool was moved in 0.1 m steps.

Length of borehole KLX26A is c. 101 m and respectively KLX26B is c. 50 m. No length calibrations were made since there are no length marks milled into the borehole walls.

A high-resolution absolute pressure sensor was used to measure the total pressure along the boreholes. These measurements were carried out together with the flow measurements.

The recovery of the groundwater level in the boreholes was measured after the pumping was stopped. Recovery measurement was performed only in borehole KLX26B.

Sammanfattning

Differensflödesloggning är en snabb metod för bestämning av transmissivitet och hydraulisk tryckhöjd i borrhålssektioner och sprickor/sprickzoner i kärnborrhål. Denna rapport presenterar huvudprinciperna för metoden och resultat av mätningar utförda i borrhål KLX26A och KLX26B i Oskarshamn, Sverige, i februari 2007 med Posiva flödesloggningsmetod. Det primära syftet med mätningarna var att bestämma läget och flödet för vattenförande sprickor i borrhålen KLX26A och KLX26B.

Flödesmätningarna upprepades bara med en 1 m lång testsektion som förflyttades successivt med 0,1 m under pumpade förhållanden.

Borrhål KLX26A är ca 101 m lång och KLX26B är ca 50 m. Ingen längdkalibrering har gjorts eftersom ingen spårfräsning var gjord i borrhålsväggen.

En högupplösande absoluttryckgivare användes för att mäta det absoluta totala trycket längs borrhålet. Dessa mätningar utfördes tillsammans med flödesmätningarna.

Återhämtningen av grundvattennivån mättes efter att pumpningen i hålen KLX26B avslutades.

Contents

1 Introduction

This document reports the results acquired by flow logging the boreholes KLX26A and KLX26B at Oskarshamn, Sweden. The work was carried out in accordance with activity plan AP PS 400-06-105. The controlling documents for performing according to this activity plan are listed in Table 1-1. The list of the controlling documents excludes the assignment-specific quality plans. Both the activity plan and the method descriptions are SKB's internal controlling documents.

The difference flow logging in the core drilled borehole KLX26A at Oskarshamn was conducted between February 16 and 18, 2007. KLX26A is 101.14 m long and its inclination is 60° from the horizontal plane. The first 2.64 m of the borehole was cased using a steel tube. The inner diameter of the cased section was 77 mm. The other properties of the borehole are given in Table 1-2. The length values given above are values on the axis parallel to the borehole. We call this the borehole length axis.

Borehole KLX26B was measured between February 19 and 20. Borehole KLX26B has a similar structure to that of borehole KLX26A. Its properties are also given in Table 1-2.

The locations of KLX26A and KLX26B in the subarea of Laxemar in Oskarshamn are illustrated in Figure 1-1.

The field work and the subsequent data interpretation were conducted by PRG-Tec Oy as Posiva Oy's subcontractor. The Posiva Flow Log/Difference Flow method has previously been employed in Posiva's site characterisation programme in Finland as well as at the Äspö Hard Rock Laboratory at Simpevarp, Sweden.

Table 1-1. SKB's internal controlling documents for the activities concerning this report.

Activity plan	Number	Version
Difference flow logging in boreholes KLX26A and KLX26B	AP PS 400-06-105	1.0
Method descriptions	**Number**	**Version**
Method description for difference flow logging	SKB MD 322.010e	2.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Instruction for length calibration in investigation of core boreholes	SKB MD 620.010e	2.0
Instruction for analysis of injection and single-hole pumping tests	SKB MD 320.004e	1.0

Table 1-2. Borehole construction.

Borehole	Length	Inclination	Core drilled interval (diameter 96 mm)	Core drilled interval (diameter 76 mm)	Cased interval (diameter 77 mm)	Z-coordinate of the top of the casing (elevation) [m.a.s.l.]
KLX26A	101.14 m	60.45°	0.30 m–2.64 m	2.64 m–101.14 m	0.00 m–2.64 m	15.63 m
KLX26B	50.37 m	60.01°	0.30 m–2.31 m	2.31 m–50.37 m	0.00 m–2.31 m	15.82 m

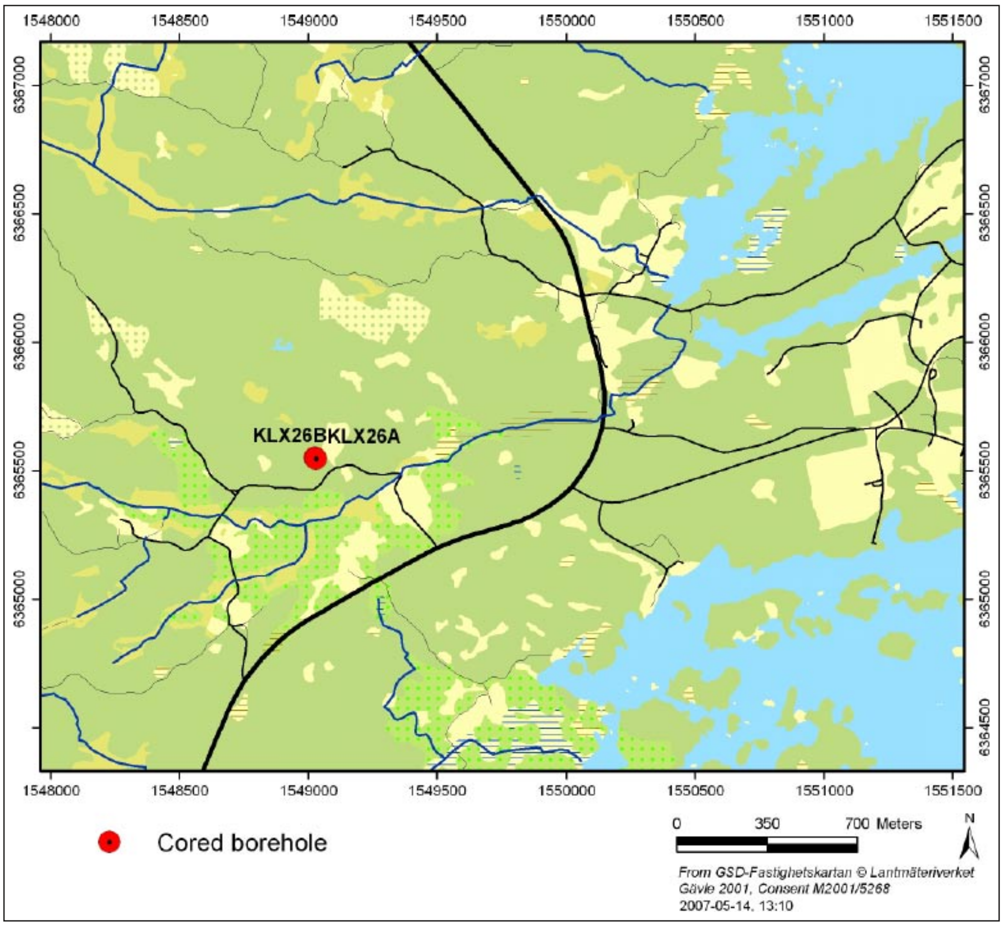

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Figure 1-1. *Site map showing the locations of boreholes KLX26A and KLX26B situated in the subarea of Laxemar.*

2 Objective and scope

The main objective of the difference flow logging in KLX26A and KLX26B was to identify water-conductive sections/fractures. Secondly, the measurements aim at a hydrogeological characterisation. Based on the results of these investigations, a more detailed characterisation of flow anomalies along the boreholes, e.g. an estimate of the conductive fracture frequency (CFF), may be obtained.

Besides difference flow logging, the measuring programme for boreholes KLX26A and KLX26B also included supporting measurements, performed in order to gain a better understanding of the overall hydrogeological conditions. The data gathered in these measurements consisted of the single-point resistance of the borehole wall. Furthermore, the recovery of the groundwater level after pumping was registered in borehole KLX26B and interpreted hydraulically.

A high-resolution absolute pressure sensor was used to measure the total pressure along the boreholes. These measurements were carried out together with the flow measurements. The results are used in the calculation of the hydraulic heads along the boreholes.

3 Principles of measurement and interpretation

3.1 Measurements

Unlike traditional types of borehole flowmeters, the Difference flowmeter measures the flow rate into or out of limited sections of the borehole instead of measuring the total cumulative flow rate along the borehole. The advantage of measuring the flow rate in isolated sections is a better detection of the incremental changes of flow along the borehole, which are generally very small and can easily be missed using traditional types of flowmeters.

Rubber disks at both ends of the downhole tool are used to isolate the flow rate in the test section from the flow rate in the rest of the borehole, see Figure 3-1. The flow inside the test section goes through its own tube and passes through the area where the flow sensors are located. The flow along the borehole outside the isolated test section passes through the test section by means of a bypass pipe and is discharged at the upper end of the downhole tool. This entire structure is called the flow guide.

The Difference flowmeter can be used in two modes, in a sequential mode and an overlapping mode. In the sequential mode, the measurement increment is as long as the section length. It is used for determining the transmissivity and the hydraulic head /Öhberg, Rouhiainen 2000/. In the overlapping mode, the measurement increment is shorter than the section length. It is mostly used to determine the location of hydraulically conductive fractures and classify them with regards to their flow rates.

The Difference flowmeter measures the flow rate into or out of the test section by means of thermistors, which track both the dilution (cooling) of a thermal pulse and the transfer of a thermal pulse with moving water. In the sequential mode, both methods are used, whereas in the overlapping mode, only the thermal dilution method is used because it is faster than thermal pulse method.

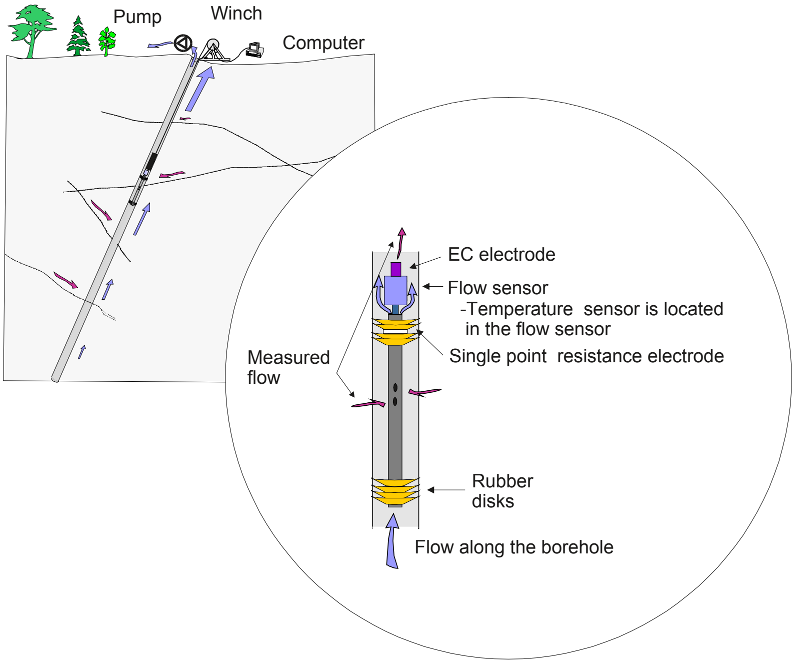

Figure 3-1. *Schematic of the downhole equipment used in the Difference flowmeter.*

Besides incremental changes of flow, the downhole tool of the Difference flowmeter can also be used to measure:

- The electric conductivity (EC) of the borehole water and fracture-specific water. The electrode for the EC measurements is located on the top of the flow sensor, Figure 3-1.
- The single-point resistance (SPR) of the borehole wall (grounding resistance). The electrode of the single-point resistance tool is located in between the uppermost rubber disks, see Figure 3-1. This method is used for high-resolution depth/length determination of fractures and geological structures.
- The diameter of the borehole (caliper). The caliper tool, combined with SPR, is used for the detection of the depth/length marks milled into the borehole wall. This enables an accurate depth/length calibration of the flow measurements.
- The prevailing water pressure profile in the borehole. The pressure sensor is located inside the electronics tube and connected through a tube to the borehole water, Figure 3-2.
- Temperature of the borehole water. The temperature sensor is placed in the flow sensor, Figure 3-1.

Only the overlapping mode during pumped conditions using a 1 m long test section was used in KLX26A and KLX26B. During the overlapping mode all of the additional measurements mentioned above expect caliper, EC and temperature of water were made.

The principles of difference flow measurements are described in Figures 3-3 and 3-4. The flow sensor consists of three thermistors, see Figure 3-3a. The central thermistor, A, is used both as a heating element and for the registration of temperature changes, Figures 3-3b and c. The side thermistors, B1 and B2, serve to detect the moving thermal pulse, Figure 3-3d, caused by the constant power heating in A, Figure 3-3b.

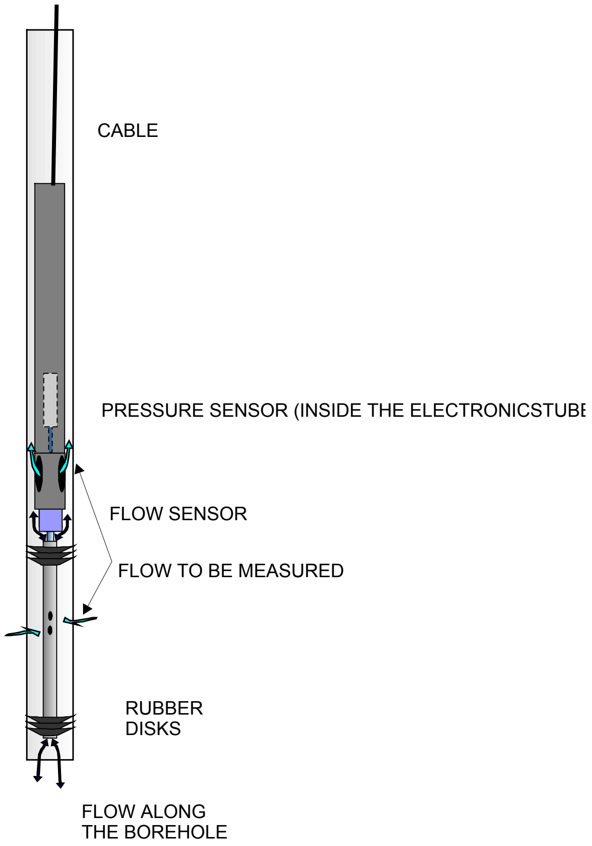

Figure 3-2. The absolute pressure sensor is located inside the electronics tube and connected through a tube to the borehole water.

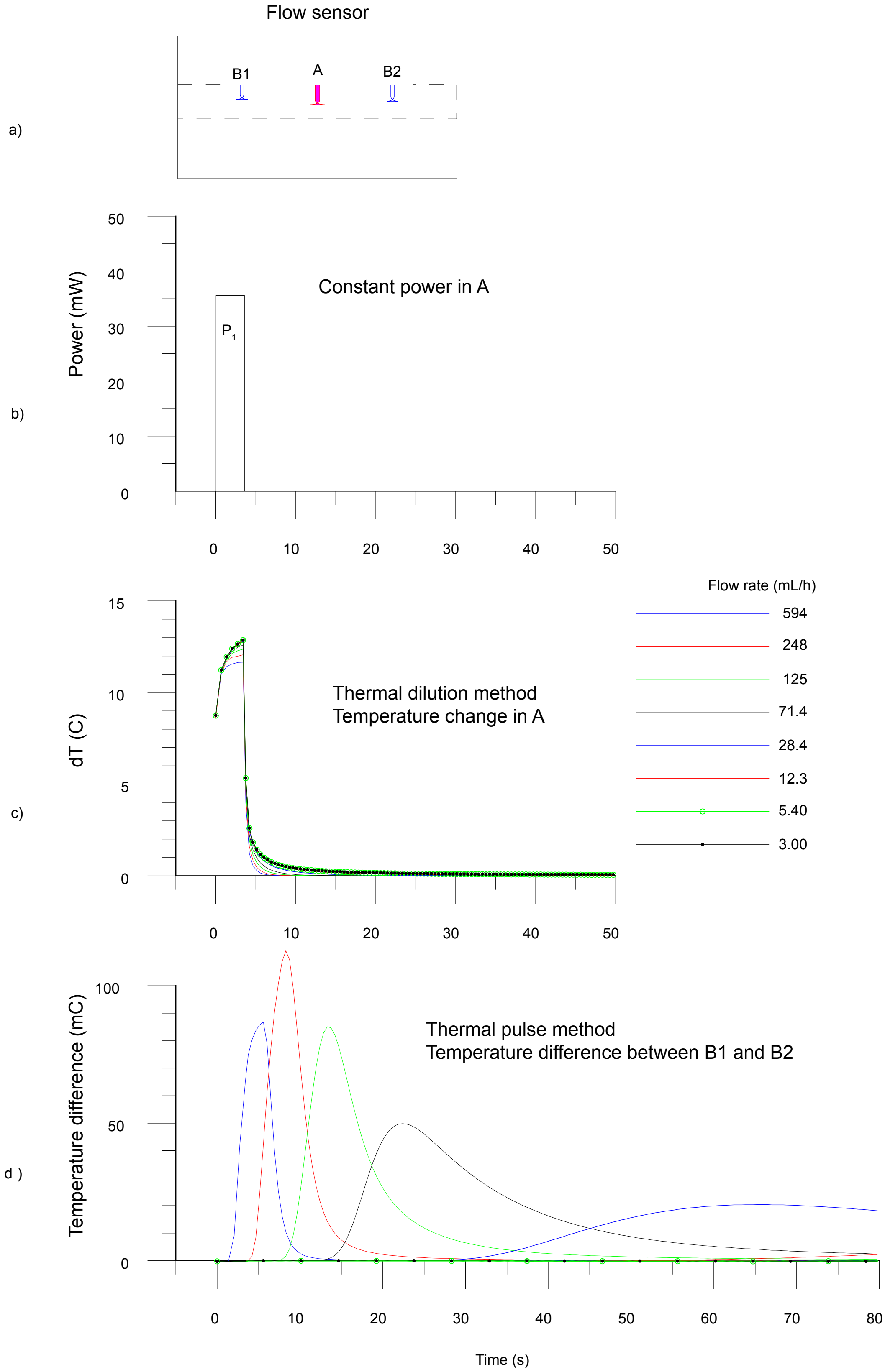

Figure 3-3. *Flow measurement, flow rate < 600 mL/h.*

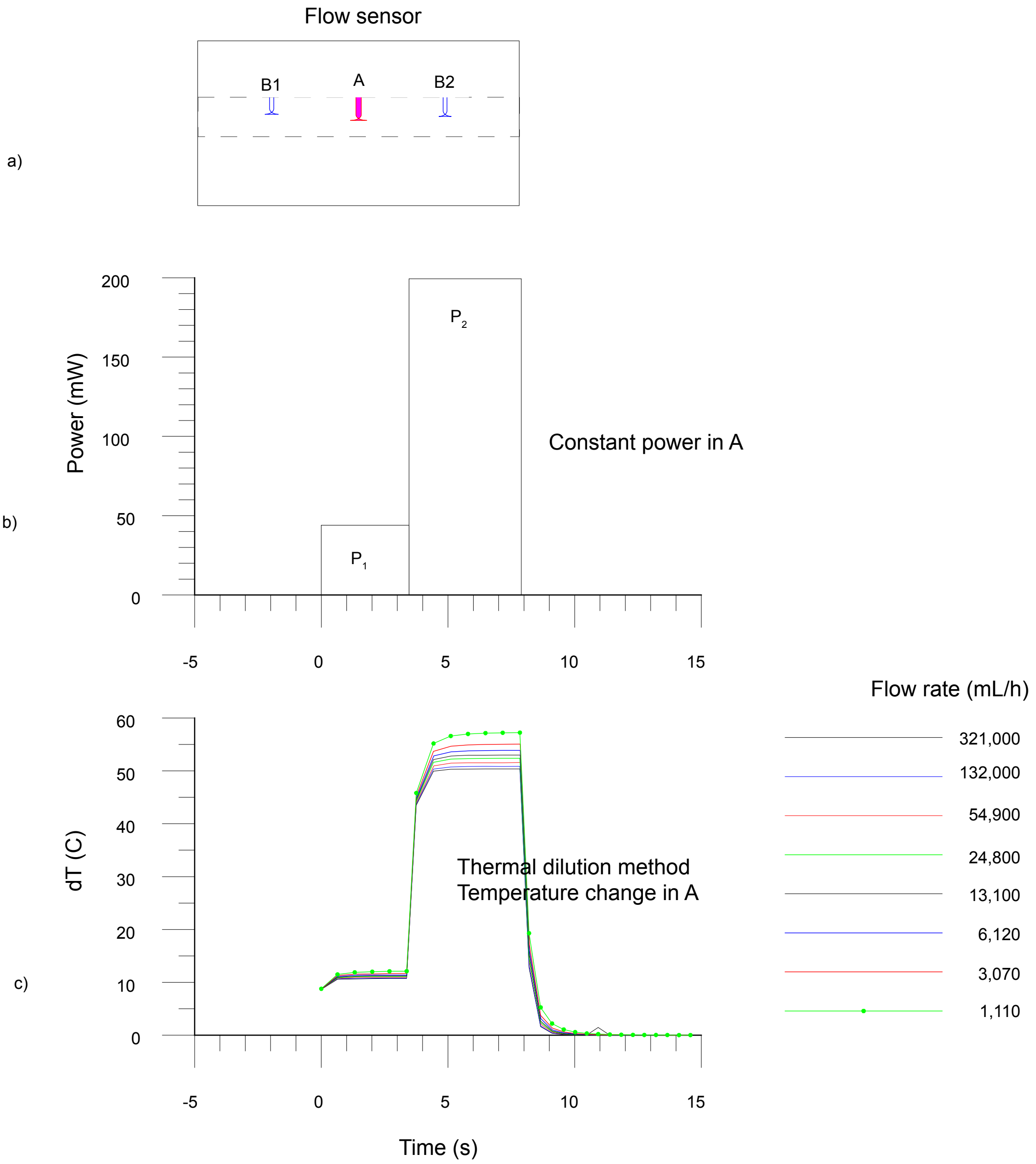

Figure 3-4. *Flow measurement, flow rate > 600 mL/h.*

Flow rate is measured during the constant power (P_1) heating (Figure 3-3b). If the flow rate exceeds 600 mL/h, the constant power heating is increased (to P_2), Figure 3-4b, and the thermal dilution method is applied.

If the flow rate during the constant power heating (Figure 3-3b) falls below 600 mL/h, the measurement continues by monitoring transient thermal dilution (Figure 3-3c) and thermal pulse response (Figure 3-3d). When applying the thermal pulse method, thermal dilution is also measured. The same heat pulse is used for both methods.

The flow is measured when the tool is at rest. After the tool is transferred to a new position, there is a waiting time (the duration of which can be adjusted according to the prevailing circumstances) before the heat pulse (Figure 3-3b) is applied. The waiting time after the constant power thermal pulse can also be adjusted, but is normally 10 s for thermal dilution and 300 s for the thermal pulse method. The measurement range of each method is given in Table 3-1.

Table 3-1. Ranges of flow measurement.

Method	Range of measurement (mL/h)
Thermal dilution P1	30–6,000
Thermal dilution P2	600–300,000
Thermal pulse	6–600

The lower end limits of the thermal dilution and the thermal pulse methods in Table 3-1 are theoretical lowest measurable values. Depending on the borehole conditions these limits may not always prevail. Examples of disturbing conditions are suspended drilling debris in the borehole water, gas bubbles in the water and high flow rates (above about 30 L/min) along the borehole. If the disturbing conditions are significant, a practical measurement limit is calculated for each set of data.

3.2 Interpretation

The interpretation of data is based on Thiem's or Dupuit's formula that describes a steady state and two dimensional radial flow into the borehole /Marsily 1986/:

$$h_s - h = Q/(T \cdot a) \qquad (3\text{-}1)$$

where

h is the hydraulic head in the vicinity of the borehole and h_S at the radius of influence (R),

Q is the flow rate into the borehole,

T is the transmissivity of the test section,

a is a constant depending on the assumed flow geometry.

For cylindrical flow, the constant a is:

$$a = 2 \cdot \pi / \ln(R/r_0) \qquad (3\text{-}2)$$

where

r_0 is the radius of the well and

R is the radius of influence, i.e. the zone inside which the effect of the pumping is felt.

If flow rate measurements are carried out using two levels of hydraulic heads in the borehole, i.e. natural or pump-induced hydraulic heads, then the undisturbed (natural) hydraulic head and transmissivity of the tested borehole sections can be calculated. Two equations can be written directly from equation 3-1:

$$Q_{s0} = T_s \cdot a \cdot (h_s - h_0) \qquad (3\text{-}3)$$

$$Q_{s1} = T_s \cdot a \cdot (h_s - h_1) \qquad (3\text{-}4)$$

where

h_0 and h_1 are the hydraulic heads in the borehole at the test level,

Q_{s0} and Q_{s1} are the measured flow rates in the test section,

T_s is the transmissivity of the test section and

h_s is the undisturbed hydraulic head of the tested zone far from the borehole.

Since, in general, very little is known about the flow geometry, cylindrical flow without any skin zones is assumed. Cylindrical flow geometry is also justified because the borehole is at a constant head and there are no strong pressure gradients along the borehole, except at its ends.

The radial distance R to the undisturbed hydraulic head h_S is not known and must be assumed. Here a value of 500 is selected for the quotient R/r_0.

The hydraulic head and the test section transmissivity can be deduced from the two measurements:

$h_s = (h_0 - b \cdot h_1)/(1-b)$ (3-5)

$T_s = (1/a)\ (Q_{s0} - Q_{s1})/(h_1 - h_0)$ (3-6)

where

$b = Q_{s0}/Q_{s1}$

Transmissivity (T_f) and the hydraulic head (h_f) of individual fractures can be calculated provided that the flow rates of individual fractures are known. Similar assumptions as above have to be used (a steady state cylindrical flow regime without skin zones).

$h_f = (h_0 - b \cdot h_1)/(1-b)$ (3-7)

$T_f = (1/a)\ (Q_{f0} - Q_{f1})/(h_1 - h_0)$ (3-8)

where

Q_{f0} and Q_{f1} are the flow rates at a fracture and

h_f and T_f are the hydraulic head (far away from borehole) and the transmissivity of a fracture, respectively.

Since the actual flow geometry and the skin effects are unknown, transmissivity values should be considered only as an indication of the orders of magnitude. As the calculated hydraulic heads do not depend on geometrical properties but only on the ratio of the flows measured at different heads in the borehole, they should be less sensitive to unknown fracture geometries. A discussion of potential uncertainties in the calculation of transmissivity and the hydraulic head is provided in /Ludvigson et al. 2002/.

Transmissivity of the entire borehole can be evaluated in several ways using the data of the pumping phase and of the recovery phase. For the pumping phase the assumptions above (cylindrical and steady state flow) lead to Dupuits formula /Marsily 1986/:

$$T = \frac{Q}{s2\pi} \ln\left(\frac{R}{r_0}\right), \qquad (3\text{-}9)$$

where

s is drawdown and

Q is the pumping rate at the end of the pumping phase.

In the Moye /Moye 1967/ formula it is assumed that the steady state flow is cylindrical near the borehole (to distance r = L/2, where L is the section under test) and spherical further away:

$$T = \frac{Q}{s2\pi} \cdot \left[1 + \ln\left(\frac{L}{2r_0}\right)\right], \qquad (3\text{-}10)$$

where L is length of test section (m), in this case the water filled, uncased part of the borehole.

4 Equipment specifications

The Posiva Flow Log/Difference flowmeter monitors the flow of groundwater into or out from a borehole by means of a flow guide (which uses rubber disks to isolate the flow). The flow guide thereby defines the test section to be measured without altering the hydraulic head. Groundwater flowing into or out from the test section is guided to the flow sensor. The flow is measured using the thermal pulse and/or thermal dilution methods. Measured values are transferred into a computer in digital form.

Type of instrument:	Posiva Flow Log/Difference Flowmeter.
Borehole diameters:	56 mm, 66 mm and 76 mm.
Length of test section:	A variable length flow guide is used.
Method of flow measurement:	Thermal pulse and/or thermal dilution.
Range and accuracy of measurement:	Table 4-1.
Additional measurements:	Temperature, single-point resistance, Electric conductivity of water, Caliper, Water pressure.
Winch:	Mount Sopris Wna 10, 0.55 kW, 220V/50Hz. Steel wire cable 1,500 m, four conductors, Gerhard -Owen cable head.
Length determination:	Based on a marked cable and a digital length counter.
Logging computer:	PC, Windows XP.
Software:	In-house developed software using MS Visual Basic.
Total power consumption:	1.5–2.5 kW depending on the pumps.
Calibrated:	October 2006.
Calibration of cable length:	Using length marks in the borehole.

Range and accuracy of sensors is presented in Table 4-1.

Table 4-1. Range and accuracy of sensors.

Sensor	Range	Accuracy
Flow	6–300,000 mL/h	± 10% curr.value
Temperature (middle thermistor)	0–50°C	0.1°C
Temperature difference (between outer thermistors)	–2 – + 2°C	0.0001°C
Electric conductivity of water (EC)	0.02–11 S/m	± 5% curr.value
Single-point resistance	5–500,000 Ω	± 10% curr.value
Groundwater level sensor	0–0.1 MPa	± 1% full-scale
Absolute pressure sensor	0–20 MPa	± 0.01% full-scale

5 Performance

5.1 Execution of the field work

The commission was performed according to Activity Plan AP PS 400-06-105 (SKB internal controlling document) following the SKB Method Description 322.010, Version 2.0 (Method description for difference flow logging). Prior to the measurements, the downhole tools and the measurement cable were disinfected. Every clock was synchronized to the official Swedish time. The activity schedule of the borehole measurements is presented in Table 5-1. The items and activities in Table 5-1 are the same as in the Activity Plan. The boreholes were measured in the order KLX26A and KLX26B.

The boreholes were dummy logged (Item 8) before any other measurements in order to assure that the measurement tools do not get stuck in the borehole.

The pumping of borehole KLX26A was started on February 16. After a waiting time of c. 24 hours, overlapping flow logging (Item 9) with a 1 m section length and a 0.1 m step length was conducted. In KLX26B the pumping was started on February 19. The waiting time after which the measurements (Item 9) were started was c. 1 h.

After this, the pump was stopped. The recovery of the groundwater level was monitored in borehole KLX26B (Item 9 extra).

5.2 Nonconformities

The flow logging tool went down to 94.4 m in borehole KLX26A (Appendix KLX26A.1.5) and to 44 m in borehole KLX26B (Appendix KLX26B.1.3). The bottom of the borehole KLX26A is 101.14 m and KLX26B is 50.37. About 6 m of the holes at the bottom were not measured, because there are the weights and a centralizer at the bottom of the device below the reference point.

Due to request of SKB groundwater recovery after pumping period was measured in borehole KLX26B. Measured recovery period was about 2.5 hours.

Table 5-1. Flow logging and testing in KLX26A and KLX26B. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site (KLX26A).	Unpacking the trailer.	2007-02-15 2007-02-16
8	Dummy logging.	Borehole risk/stability assessment.	2007-02-16
9	Selective overlapping flow logging.	Section length L_w=1 m, Step length dL=0.1 m, at pumping.	2007-02-17- 2007-02-18
10 and 2	Demobilisation at KLX26A and mobilisation at KLX26B.	Packing the trailer. Moving to KLX26B. Unpacking the trailer.	2007-02-18- 2007-02-19
8	Dummy logging.	Borehole risk/stability assessment.	2007-02-19
9	Selective overlapping flow logging.	Section length L_w=1 m, Step length dL=0.1 m, at pumping.	2007-02-19- 2007-02-20
9 Extra	Recovery transient.	Measurement of water level and absolute pressure in the borehole after stopping of pumping. KLX26B.	2007-02-20
10	Demobilisation.	Packing the trailer.	2007-02-20

6 Results

6.1 Length calibration

Accurate length measurements are difficult to conduct in long boreholes, i.e. the accurate position of the measurement equipment is difficult to determine. The main cause of inaccuracy is the stretching of the logging cable. The stretching depends on the tension on the cable that in turn depends, among other things, on the inclination of the borehole and the friction of the borehole wall. The cable tension is higher when the borehole is measured upwards. The cables, especially new cables, may also stretch out permanently.

Length marks on the borehole wall can be used to minimise the length errors. The length marks can be detected with the SKB caliper tool. The length scale is initially corrected according to the length marks. Single-point resistance is recorded simultaneously with the caliper logging. All flow measurement sequences can then be length corrected by synchronising the SPR results (SPR is recorded during all measurements) with the original caliper/SPR measurement.

Boreholes KLX26A and B are relatively short. Cable stretching is not significant at those lengths and no length marks were made in the borehole wall. Thereby no length calibration was possible in the measurements in boreholes KLX26A and B.

Length errors in KLX26A and B are caused by the following reasons:

1. The point interval in flow measurements is 0.1 m in overlapping mode. This could cause an error of ± 0.05 m.
2. The length of the test section is not exact. The section length is specified as the distance between the nearest upper and lower rubber disks. Effectively, the section length can be larger. At the upper end of the test section there are four rubber disks. The distance between them is 5 cm. This may cause rounded flow anomalies: a flow may be detected already when a fracture is between the upper rubber disks. This phenomenon can only be seen in the short step length (0.1 m) measurements and it can cause an error of ± 0.05 m.
3. Stretching of the logging cable. This could cause an error of ± 0.3 m at the length of 100 m. The error is linear and approaches zero when moving closer to the ground level.

In the worst case, the errors from sources 1, 2 and 3 are summed up. Then the total estimated error for fracture locations at the length of c. 100 m would be ± 0.4 m.

Knowing the location accurately is important when different measurements are compared, for instance if flow logging and borehole TV are compared. In that case the situation may not be as severe as the worst case above, since some of the length errors are systematic and the error is nearly constant in fractures that are close to each other. However, the error from source 1 is random. The maximum relative error in cable stretching between different flow measurements was ± 0.1 m.

Fractures nearly parallel with the borehole may also be problematic. Fracture location may be difficult to define accurately in such cases.

The errors given above are estimations and are based on the experiences and observations from earlier measurements.

6.2 Pressure measurements

Absolute pressure was registered with the other measurements in Item 9. The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered separately, Appendices KLX26A.8.2 and KLX26B.8.2. The hydraulic head along the borehole is determined in the following way. First, the monitored air pressure at the site is subtracted from the measured absolute pressure by the pressure sensor. The hydraulic head (h) at a certain elevation (z) is then calculated according to the following expression /Freeze et al. 1979/:

$$h = (p_{abs} - p_b)/(\rho_{fw}\ g) + z \qquad (6\text{-}1)$$

where

h is the hydraulic head (metres above sea level) according to the RHB 70 reference system,

p_{abs} is absolute pressure (Pa),

p_b is barometric (air) pressure (Pa),

ρ_{fw} is unit density 1,000 kg/m^3

g is standard gravity 9.80665 m/s^2 and

z is the elevation of measurement (metres above sea level) according to the RHB 70 reference system.

A tool-specific offset of 2.46 kPa is subtracted from absolute pressure raw data.

Exact z-coordinates are important in head calculations, 10 cm error in z-coordinate means 10 cm error in the head.

The calculated head values are presented in a graph in Appendices KLX26A.8.1 and KLX26B.8.1.

6.3 Flow logging

6.3.1 General comments on results

The flow results are presented together with the single-point resistance results (right hand side), see Appendices KLX26A.1.1–KLX26A.1.5 and KLX26B.1.1–KLX26B.1.3. Single-point resistance is usually lower in value on a fracture where a flow is detected. There are also many other resistance anomalies from other fractures and geological features. The electrode of the single-point resistance tool is located in between the upper rubber disks. Thus, the locations of the resistance anomalies of leaky fractures coincide with the lower end of the flow anomalies in the data plot.

Detected fractures are shown in the middle of the appendices with their positions (borehole length). They are interpreted on the basis of the flow curves and therefore represent flowing fractures. A long line represents the location of a leaky fracture; short line denotes that the existence of a leaky fracture is uncertain. A short line is used if the flow rate is less than 30 mL/h or the flow anomalies are overlapping or unclear because of noise.

The tables in Appendices KLX26A.6 and KLX26B.6 were used to calculate conductive fracture frequency (CFF). The number of conductive fractures was counted on the 5 meter sections. The number of conductive fractures was sorted in six columns depending on their flow rate. The total conductive fracture frequency is presented graphically, see Appendix KLX26A.7 and KLX26B.7.

The basic data for KLX26A and KLX26B measurements is presented in Appendices KLX26A.3 and KLX26B.3. The explanations to the tables in Appendices KLX26A.3 and KLX26A.4 is presented in Appendix KLX26A.5. Respectively the explanations to the tables in Appendices KLX26B.3 and KLX26B.4 is presented in Appendix KLX26B.5.

6.3.2 Transmissivity of fractures

An attempt was made to evaluate the magnitude of fracture-specific flow rates. The results for a 1 m section length and 0.1 m length increments were used for this purpose. The first step in this procedure is to identify the locations of individual flowing fractures and then evaluate their flow rates.

In cases where the fracture distance is less than one meter, it may be difficult to evaluate the flow rate. There are such cases for instance in Appendix KLX26A.1.2. In these cases a stepwise increase or decrease in the flow data plot equals the flow rate of a specific fracture (filled triangles in the appendices).

The flow and pressure measurements were not done in un-pumped conditions. Due to this Q_{f0} is assumed to be zero. Transmissivity was calculated on the basis of drawdown and flow rate. This in general justified because flow rate during pumping is much higher than without pumping.

Some fracture-specific results were classified to be “uncertain”. The basis for this classification is either a minor flow rate (< 30 mL/h) or unclear fracture anomalies. Anomalies are considered unclear if the distance between them is less than one meter or their nature is unclear because of noise.

The total amount of detected flowing fractures in KLX26A was 25 and in KLX26B it was 17. All detected flows were directed towards the borehole. All detected fractures were used for transmissivity estimations.

The transmissivity of the fractures is plotted in Appendices KLX26A.2 and KLX26B.2. The results are presented in a tabulated form in Appendices KLX26A.4 and KLX26B.4.

6.3.3 Theoretical and practical limits of flow measurements

The theoretical minimum of the measurable flow rate in the overlapping method (thermal dilution method only) is about 30 mL/h. The thermal pulse method can also be used. Its theoretical lower limit is about 6 mL/h. In these boreholes the thermal pulse method was only used to detect the flow direction not the flow rate. The upper limit of the flow measurements is 300,000 mL/h. These limits are determined on the basis of flow calibration. It is assumed that a flow can be reliably detected between the upper and lower theoretical limits in favorable borehole conditions.

In practice, the minimum measurable flow rate may be much higher. Borehole conditions may be such that the base level of flow (noise level) is higher than assumed. The noise level can be evaluated on such intervals of the borehole where there are no flowing fractures or other structures. The noise level may vary along the borehole.

There are several known reasons for increased noise levels:

1) Rough borehole wall.

2) Solid particles in the water such as clay or drilling mud.

3) Gas bubbles in the water.

4) High flow rate along the borehole.

A rough borehole wall always causes a high noise level, not only in the flow results but also in the single-point resistance results. The flow curve and the SPR curves are typically spiky when the borehole wall is rough.

Drilling mud in the borehole water usually increases the noise level. Typically this kind of noise is seen both in un-pumped and pumped conditions.

Pumping causes the pressure drop in the borehole water and in the water in the fractures near the borehole. This may lead to the release of dissolved gas and increase the amount of gas bubbles in the water. Some fractures may produce more gas than others. Sometimes the noise level is larger just above certain fractures (when the borehole is measured upwards). The reason for this is assumed to be gas bubbles. The bubbles may cause a decrease of the average density of water and therefore also decrease the measured head in the borehole.

The effect of a high flow rate along the borehole can often be seen above high flowing fractures. Any minor leak at the lower rubber disks is directly measured as increased noise.

A high noise level in a flow masks the "real" flow if it is smaller than the noise. Real flows are totally invisible if they are about ten times smaller than the noise and they are registered correctly if they are about ten times larger than the noise. Based on experience, real flows between 1/10 times the noise level and 10 times the noise level are summed with the noise. Therefore the noise level could be subtracted from the measured flow to get the real flow. This correction has not been done so far because it is unclear whether it is applicable in each case.

The practical minimum of the measurable flow rate is evaluated and presented in Appendices KLX26A.1.1–KLX26A.1.5 and KLX26B.1.1–KLX26B.1.3 using a grey dashed line (Lower limit of flow rate). The practical minimum level of the measurable flow is always evaluated in pumped conditions since this measurement is the most important for transmissivity calculations. The limit is an approximation. It is evaluated to obtain a limit below which there may be fractures or structures that remain undetected.

The noise level in KLX26A and KLX26B was near 30 mL/h. It is possible to detect anomalies below the limit of the thermal dilution method (30 mL/h), but the noise line (grey dashed line) was never drawn below 30 mL/h, because the values of flow rate measured below 30 mL/h are uncertain.

In some boreholes the upper limit of the flow measurement (300,000 mL/h) may be exceeded. Such fractures or structures hardly remain undetected (as the fractures below the lower limit). High flowing fractures can be measured separately at a smaller drawdown. In KLX26A and KLX26B the flow values never exceeded the upper limit.

6.3.4 Transmissivity of the entire borehole

The pumping phase for the logging and its subsequent recovery is utilized to evaluate the transmissivity of the entire borehole. This is done with the two steady state methods described in Chapter 3.

KLX26A

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 1.05 L/min and s (drawdown) was 5.02 m. Transmissivity calculated with Dupuit's formula is $3.45 \cdot 10^{-6}$ m²/s.

In Moye's formula (equation 3-10) the length of the test section L is 98.50 m (101.14 m–2.64 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $4.53 \cdot 10^{-6}$ m²/s.

KLX26B

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 1.4 L/min and s (drawdown) was 5.02 m. Transmissivity calculated with Dupuit's formula is $4.60 \cdot 10^{-6}$ m²/s.

In Moye's formula (equation 3-10) the length of the test section L is 48.06 m (50.37 m–2.31 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $5.51 \cdot 10^{-6}$ m²/s.

Table 6-1. Transmissivities of the entire boreholes.

	KLX26A	KLX26B
Dupuit (m²/s)	$3.45 \cdot 10^{-6}$	$4.60 \cdot 10^{-6}$
Moye (m²/s)	$4.53 \cdot 10^{-6}$	$5.51 \cdot 10^{-6}$

6.4 Groundwater level and pumping rate

The groundwater level and the pumping rate are illustrated in Appendices KLX26A.8.2 and KLX26B.8.2 and the recovery plot is presented in KLX26B.8.3. The groundwater recovery measurement in borehole KLX26B was done with two sensors, the groundwater level sensor (pressure sensor) and the absolute pressure sensor located in the flowmeter tool.

Individual borehole information is presented in Table 6-2. In Table 6-2 Top of C means the top of the casing tube (reference level). The groundwater level sensor is a pressure transducer attached to the pumping equipment. The locations in Table 6-2 are given as meters above sea level (m.a.s.l.) according to RHB70.

Table 6-2. Pumping and recovery periods and measurement setups.

Borehole	Pumping period	Pump intake level (m.a.s.l.)	Groundwater level sensor location (m.a.s.l.)	Top of C (m.a.s.l.)	Approx. drawdown (m)	Recovery period
KLX26A	2007-02-16 – 2007-02-18	6.5	4.58	15.63	5.02	–
KLX26B	2007-02-19 – 2007-02-20	6.4	4.48	15.82	5.02	2007-02-20

7 Summary

In this study, the Posiva Flow Log/Difference Flow method has been used to determine the location and flow rate of flowing fractures or structures in boreholes KLX26A and KLX26B at Oskarshamn. Measurements were carried out only during pumping. A 1 m section length with 0.1 m length increments was used.

The water level in the borehole was monitored during pumping. The recovery of water level after the pump was turned off was also measured in borehole KLX26B. Transmissivity of fractures was calculated for both boreholes.

The total amount of detected flowing fractures in KLX26A was 25. The highest transmissivity ($4.7 \cdot 10^{-7}$ m^2/s) was detected in a fracture at the length of 37.4 m.

In KLX26B the total amount of detected fractures was 17. The highest transmissivity ($1.9 \cdot 10^{-6}$ m^2/s) was detected in a fracture at the length of 36.6 m.

References

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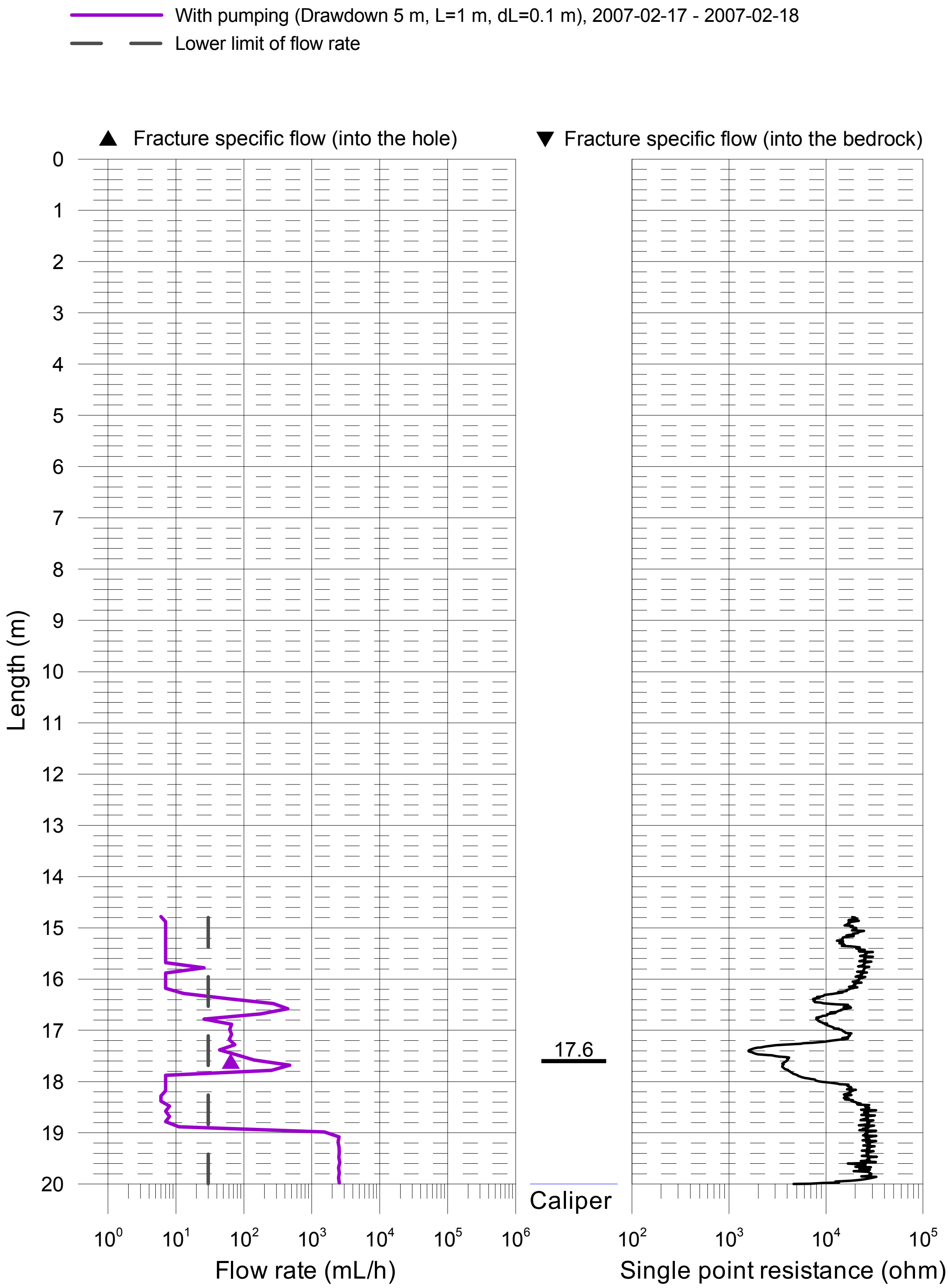
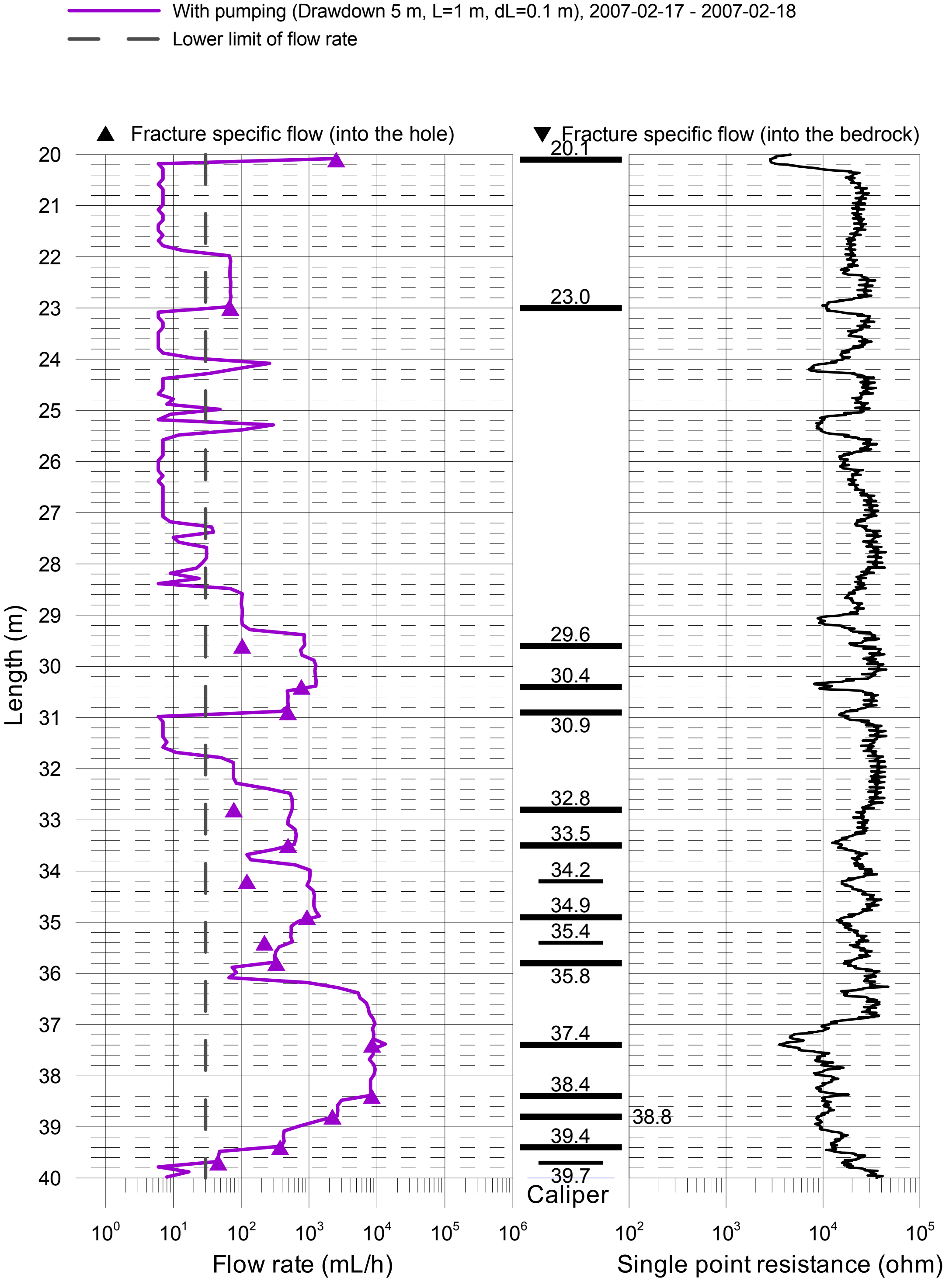
Appendix KLX26A

Appendices KLX26A.1.1–KLX26A.1.5	Flow rate and single-point resistance
Appendix KLX26A.2	Plotted transmissivity of detected fractures
Appendix KLX26A.3	Basic test data
Appendix KLX26A.4	Inferred flow anomalies from overlapping flow logging
Appendix KLX26A.5	Explanations for the tables in Appendices 3–4
Appendix KLX26A.6	Conductive fracture frequency
Appendix KLX26A.7	Plotted conductive fracture frequency
Appendix KLX26A.8.1	Head in the borehole during flow logging
Appendix KLX26A.8.2	Air pressure, water level in the borehole and pumping rate during flow logging

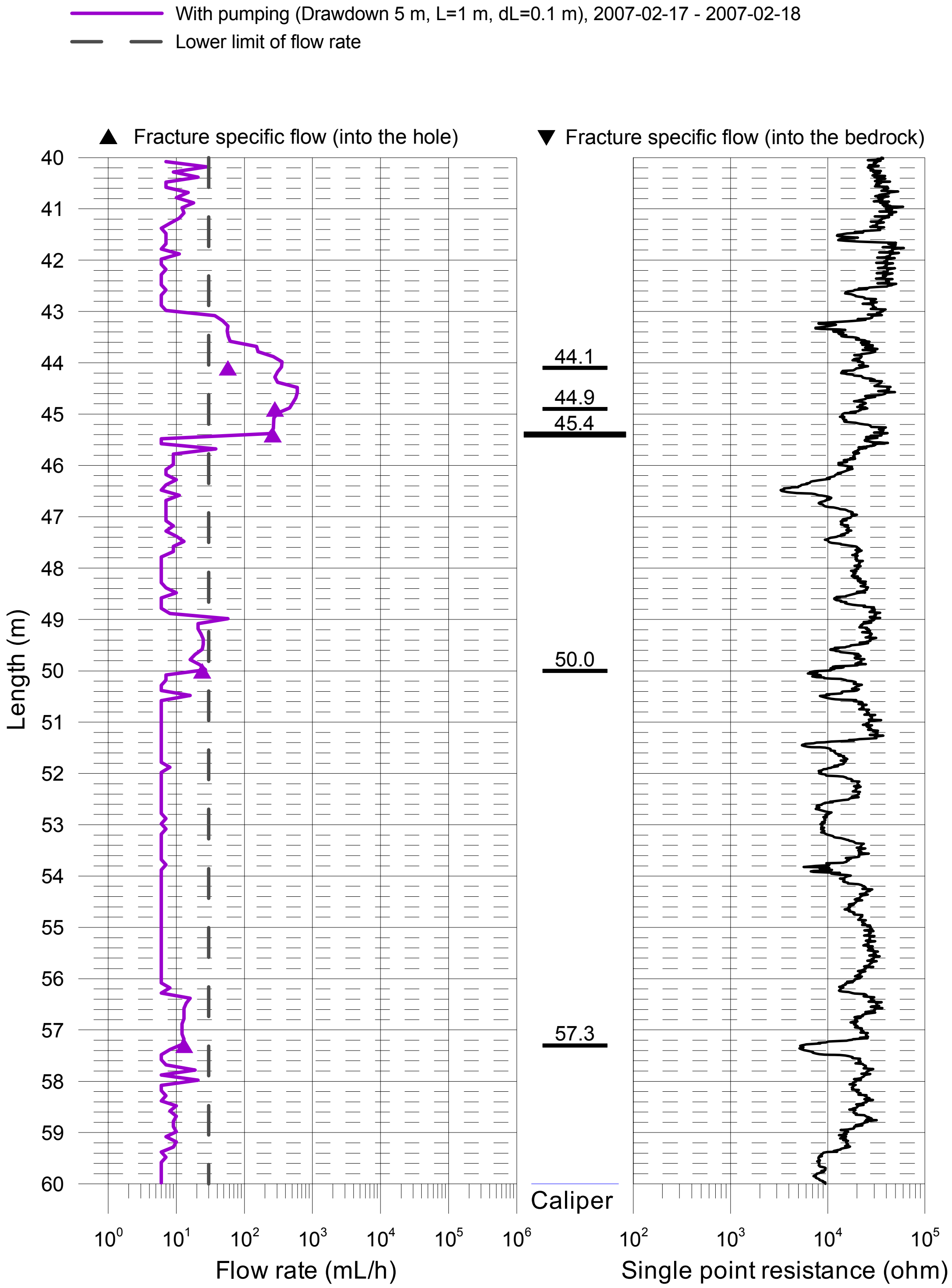
Laxemar, borehole KLX26A
Flow rate, caliper and single point resistance



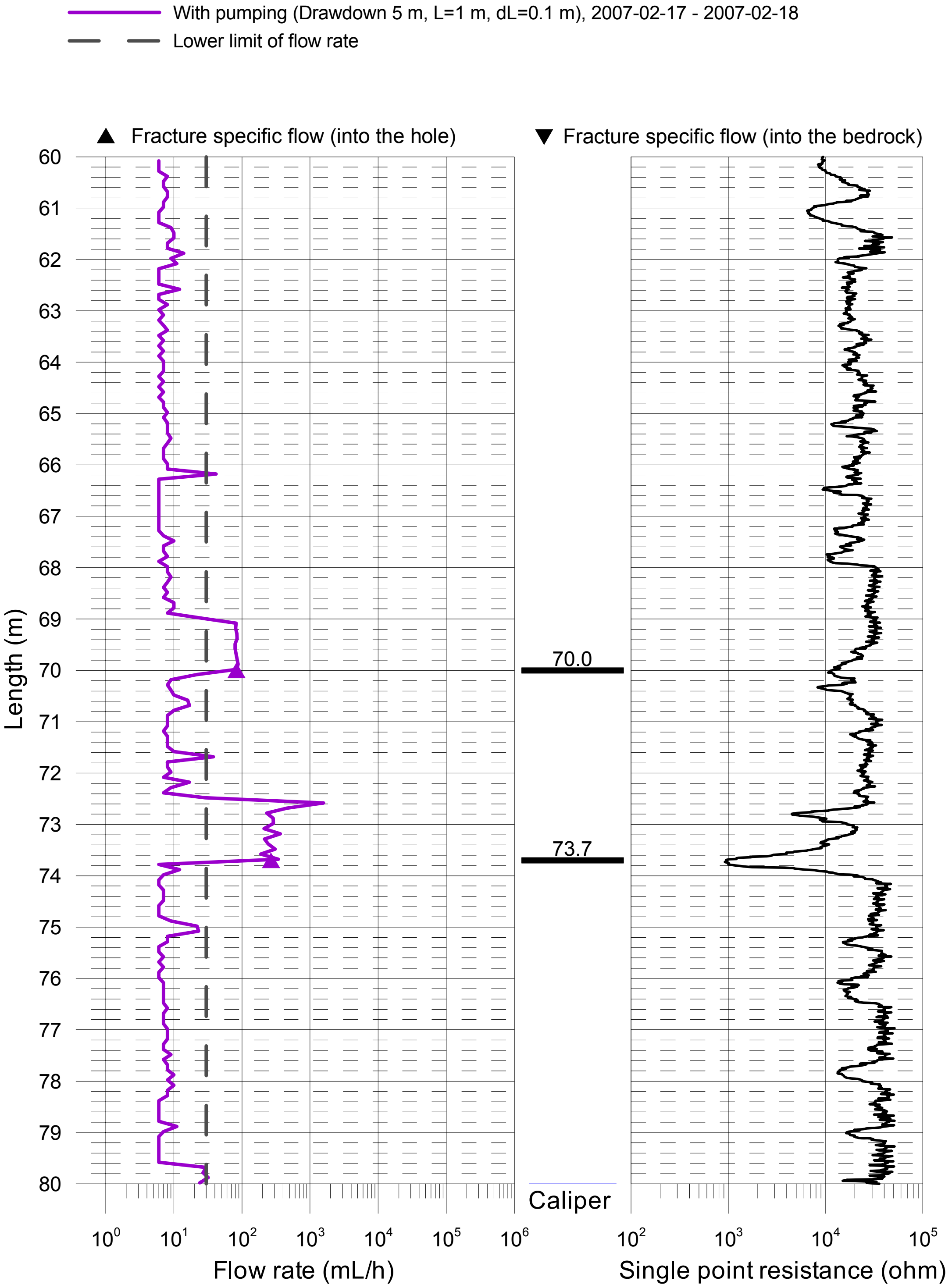
Laxemar, borehole KLX26A
Flow rate, caliper and single point resistance



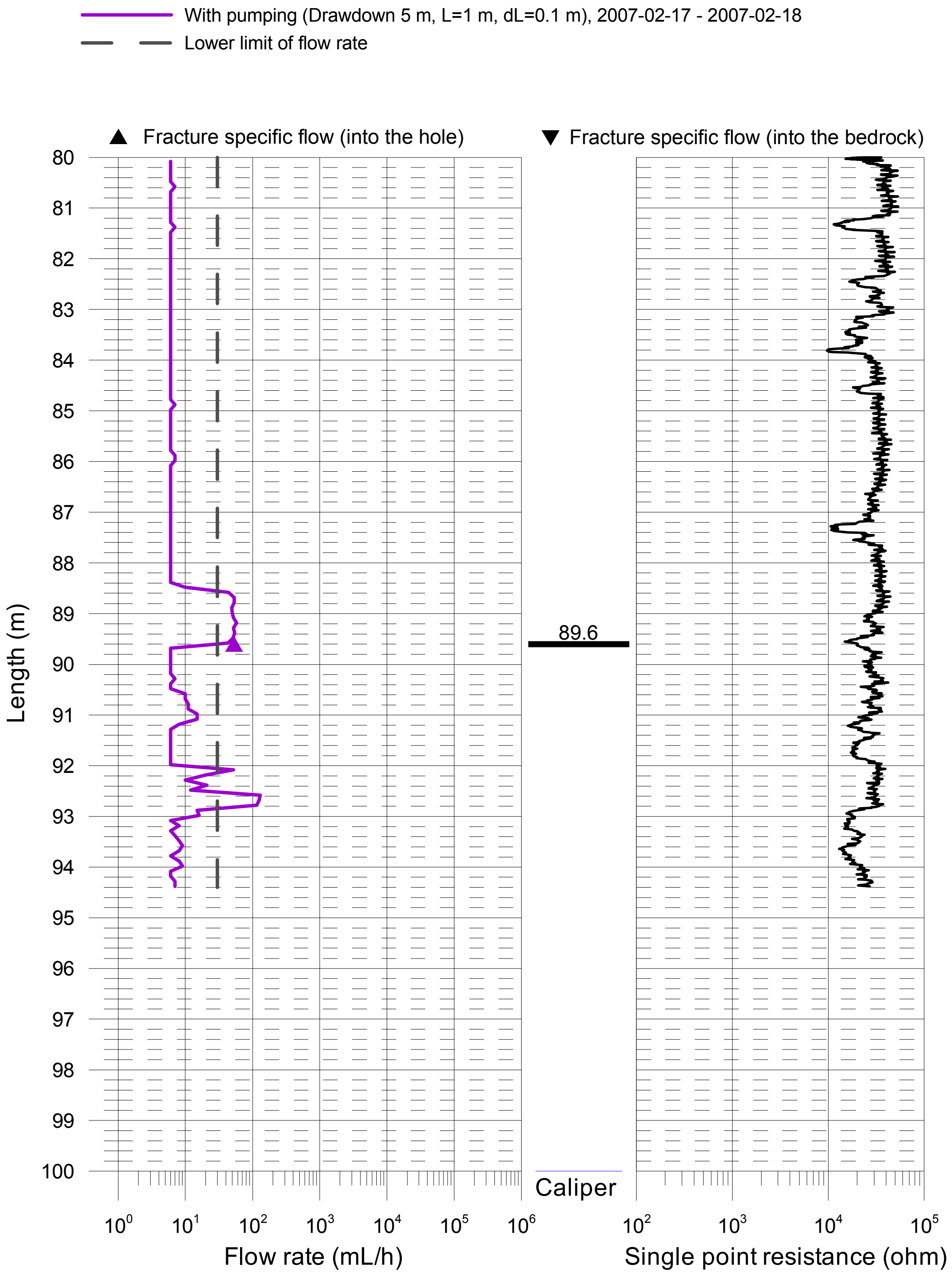
Laxemar, borehole KLX26A
Flow rate, caliper and single point resistance



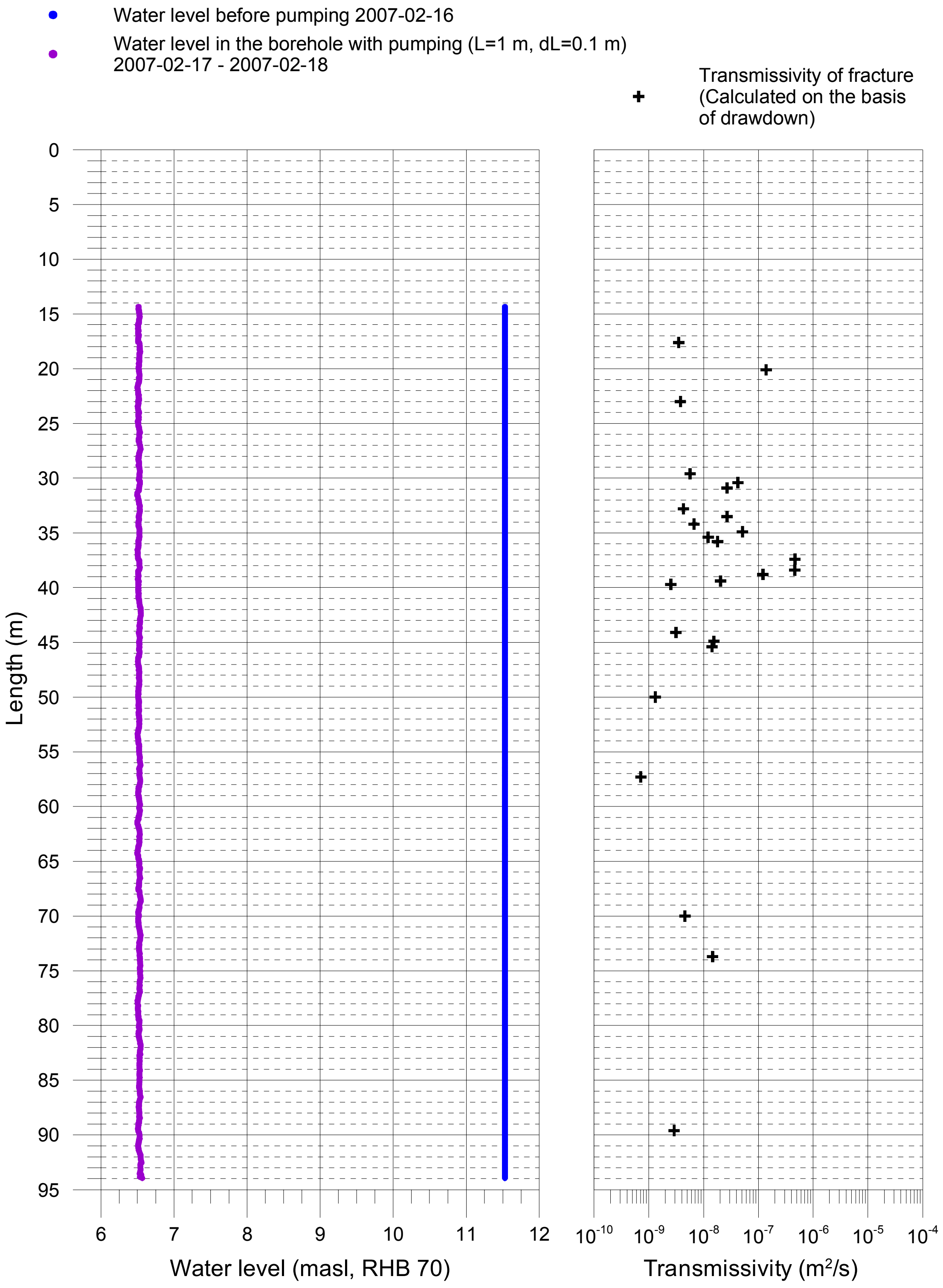
Laxemar, borehole KLX26A
Flow rate, caliper and single point resistance



Laxemar, borehole KLX26A
Flow rate, caliper and single point resistance



Laxemar, borehole KLX26A
Transmissivity of detected fractures



5. PFL – Difference flow logging – Basic test data.

Borehole ID	Logged interval Secup (m)	Seclow (m)	Test type (1–6)	Date of test, start YYYYMMDD	Time of test, start hh:mm	Date of flowl., start YYYYMMDD	Time of flowl., start hh:mm	Date of test, stop YYYYMMDD	Time of test, stop hh:mm	L_w (m)	dL (m)	Q_{p1} (m³/s)	Q_{p2} (m³/s)
KLX26A	2.64	101.14	5A	20070216	15:30	20070217	15:49	20070218	9:42	1	0.1	1.75E–05	–

5. PFL – Difference flow logging – Basic test data.

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (m.a.s.l.)	h_1 (m.a.s.l.)	h_2 (m.a.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m²/s)	Reference (–)	Comments (–)
151,920	–	0	–	11.53	6.51	–	–5.02	–	3.45E–06	–	–

PFL – Difference flow logging – Inferred flow anomalies from overlapping flow logging.

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 ** (m^3/s)	h_0 *** (m.a.s.l.)	Q_1 (m^3/s)	h_1 **** (m.a.s.l.)	T_D ***** (m^2/s)	h_i (m.a.s.l.)	Comments
KLX26A	17.6	1	0.1	–	11.53	1.78E–08	6.52	3.5E–09	–	*
KLX26A	20.1	1	0.1	–	11.53	6.97E–07	6.52	1.4E–07	–	
KLX26A	23.0	1	0.1	–	11.53	1.92E–08	6.51	3.8E–09	–	
KLX26A	29.6	1	0.1	–	11.53	2.86E–08	6.53	5.7E–09	–	
KLX26A	30.4	1	0.1	–	11.53	2.14E–07	6.53	4.2E–08	–	
KLX26A	30.9	1	0.1	–	11.53	1.35E–07	6.52	2.7E–08	–	
KLX26A	32.8	1	0.1	–	11.53	2.17E–08	6.53	4.3E–09	–	
KLX26A	33.5	1	0.1	–	11.53	1.36E–07	6.52	2.7E–08	–	
KLX26A	34.2	1	0.1	–	11.53	3.39E–08	6.51	6.7E–09	–	*
KLX26A	34.9	1	0.1	–	11.53	2.59E–07	6.53	5.1E–08	–	
KLX26A	35.4	1	0.1	–	11.53	6.11E–08	6.53	1.2E–08	–	*
KLX26A	35.8	1	0.1	–	11.53	9.11E–08	6.51	1.8E–08	–	
KLX26A	37.4	1	0.1	–	11.53	2.36E–06	6.51	4.7E–07	–	
KLX26A	38.4	1	0.1	–	11.53	2.33E–06	6.52	4.6E–07	–	
KLX26A	38.8	1	0.1	–	11.53	6.14E–07	6.51	1.2E–07	–	
KLX26A	39.4	1	0.1	–	11.53	1.03E–07	6.51	2.0E–08	–	
KLX26A	39.7	1	0.1	–	11.53	1.28E–08	6.51	2.5E–09	–	*
KLX26A	44.1	1	0.1	–	11.53	1.58E–08	6.52	3.1E–09	–	*
KLX26A	44.9	1	0.1	–	11.53	7.78E–08	6.52	1.5E–08	–	*
KLX26A	45.4	1	0.1	–	11.53	7.22E–08	6.53	1.4E–08	–	
KLX26A	50.0	1	0.1	–	11.53	6.67E–09	6.51	1.3E–09	–	*
KLX26A	57.3	1	0.1	–	11.53	3.61E–09	6.53	7.1E–10	–	*
KLX26A	70.0	1	0.1	–	11.53	2.31E–08	6.52	4.6E–09	–	
KLX26A	73.7	1	0.1	–	11.53	7.39E–08	6.53	1.5E–08	–	
KLX26A	89.6	1	0.1	–	11.53	1.47E–08	6.51	2.9E–09	–	

* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

** Not measured.

*** Water level in the borehole before pumping (Head was not measured).

**** Water level during Q_1.

***** Calculated on the basis of drawdown.

Explanations.

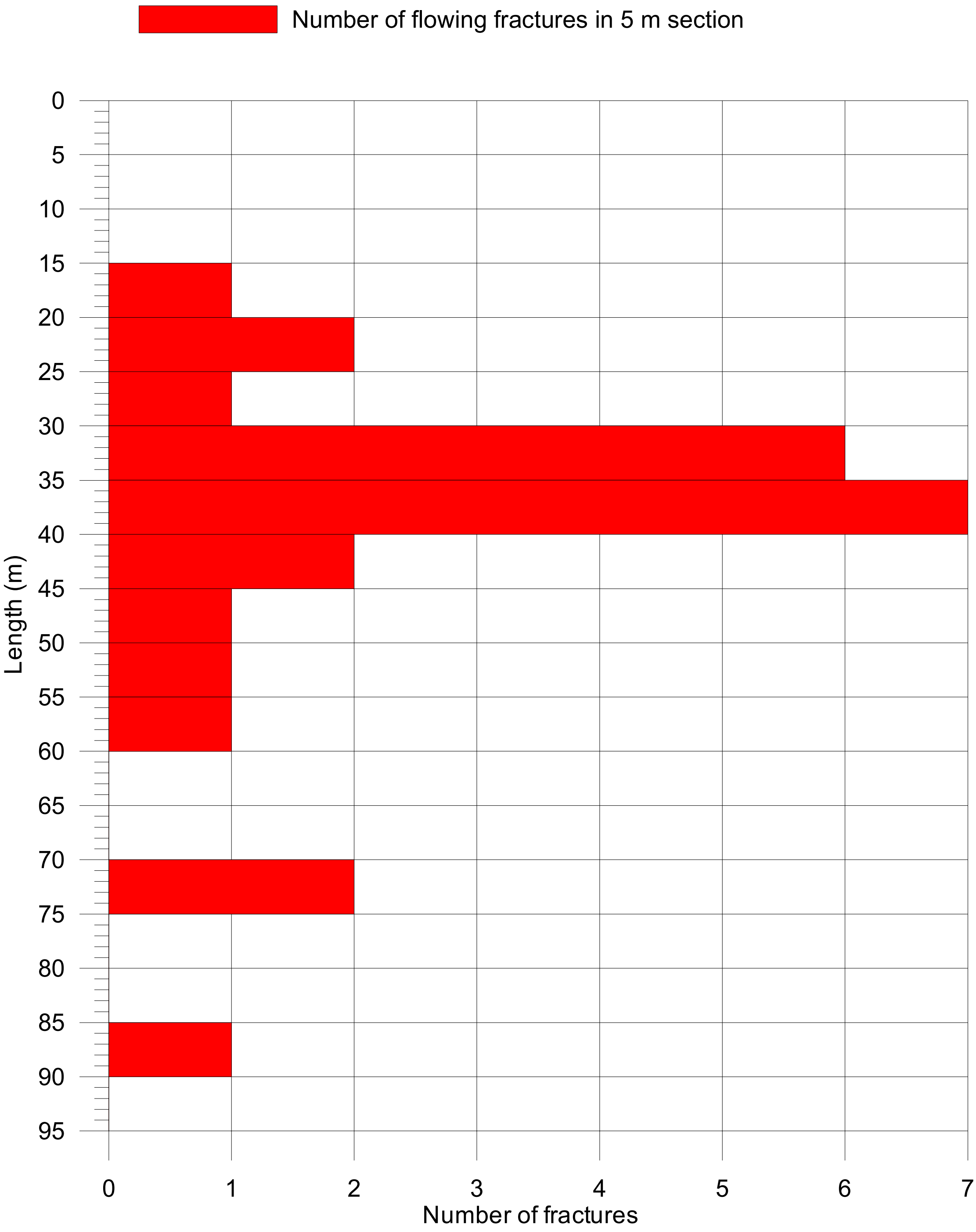
Header	Unit	Explanations
Borehole		ID for borehole
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L)
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L)
L	m	Corrected length along borehole based on SKB procedures for length correction
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
Test type (1–6)	(–)	1A: Pumping test – wire-line eq. 1B: Pumping test-submersible pump, 1C: Pumping test-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging – PFL-DIFF-Sequential, 5B: Difference flow logging – PFL-DIFF-Overlapping, 6: Flow logging-Impeller
Date of test, start	YY-MM-DD	Date for start of pumping
Time of test, start	hh:mm	Time for start of pumping
Date of flowl. start	YY-MM-DD	Date for start of the flow logging
Time of flowl. start	hh:mm	Time for start of the flow logging
Date of test, stop	YY-MM-DD	Date for stop of the test
Time of test, stop	hh:mm	Time for stop of the test
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_{p1}	m^3/s	Flow rate at surface by the end of the first pumping period of the flow logging
Q_{p2}	m^3/s	Flow rate at surface by the end of the second pumping period of the flow logging
t_{p1}	s	Duration of the first pumping period
t_{p2}	s	Duration of the second pumping period
t_{F1}	s	Duration of the first recovery period
t_{F2}	s	Duration of the second recovery period
h_0	m.a.s.l.	Initial hydraulic head before pumping. Elevation of water level in open borehole in the local co-ordinates system with z=0 m.
h_1	m.a.s.l.	Stabilised hydraulic head during the first pumping period. Elevation of water level in open borehole in the local co-ordinates system with z=0 m.
h_2	m.a.s.l.	Stabilised hydraulic head during the second pumping period. Elevation of water level in open borehole in the local co-ordinates system with z=0 m.
s_1	m	Drawdown of the water level in the borehole during first pumping period. Difference between the actual hydraulic head and the initial head ($s_1= h_1–h_0$)
s_2	m	Drawdown of the water level in the borehole during second pumping period. Difference between the actual hydraulic head and the initial head ($s_2=h_2–h_0$)
T	m^2/s	Transmissivity of the entire borehole
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with $h=h_0$ in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period
Q_2	m^3/s	Measured flow rate through the test section or flow anomaly during the second pumping period
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid before pumping
h_{1FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period
h_{2FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the second pumping period
EC_w	S/m	Measured electric conductivity of the borehole fluid in the test section during difference flow logging
Te_w	°C	Measured borehole fluid temperature in the test section during difference flow logging
EC_f	S/m	Measured fracture-specific electric conductivity of the fluid in flow anomaly during difference flow logging
Te_f	°C	Measured fracture-specific fluid temperature in flow anomaly during difference flow logging
T_D	m^2/s	Transmissivity of section or flow anomaly based on 2D model for evaluation of formation properties of the test section based on PFL-DIFF
T-measl$_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim
T-measl$_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim
T-measl$_U$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

Calculation of conductive fracture frequency.

Borehole ID	SecUp (m)	SecLow (m)	Number Of Fractures, Total	Number Of Fractures 10–100 (ml/h)	Number Of Fractures 100–1,000 (ml/h)	Number Of Fractures 1,000–10,000 (ml/h)	Number Of Fractures 10,000–100,000 (ml/h)	Number Of Fractures 100,000–1000,000 (ml/h)
KLX26A	15	20	1	1	0	0	0	0
KLX26A	20	25	2	1	0	1	0	0
KLX26A	25	30	1	0	1	0	0	0
KLX26A	30	35	6	1	5	0	0	0
KLX26A	35	40	7	1	3	3	0	0
KLX26A	40	45	2	1	1	0	0	0
KLX26A	45	50	1	0	1	0	0	0
KLX26A	50	55	1	1	0	0	0	0
KLX26A	55	60	1	1	0	0	0	0
KLX26A	60	65	0	0	0	0	0	0
KLX26A	65	70	0	0	0	0	0	0
KLX26A	70	75	2	1	1	0	0	0
KLX26A	75	80	0	0	0	0	0	0
KLX26A	80	85	0	0	0	0	0	0
KLX26A	85	90	1	1	0	0	0	0
KLX26A	90	95	0	0	0	0	0	0

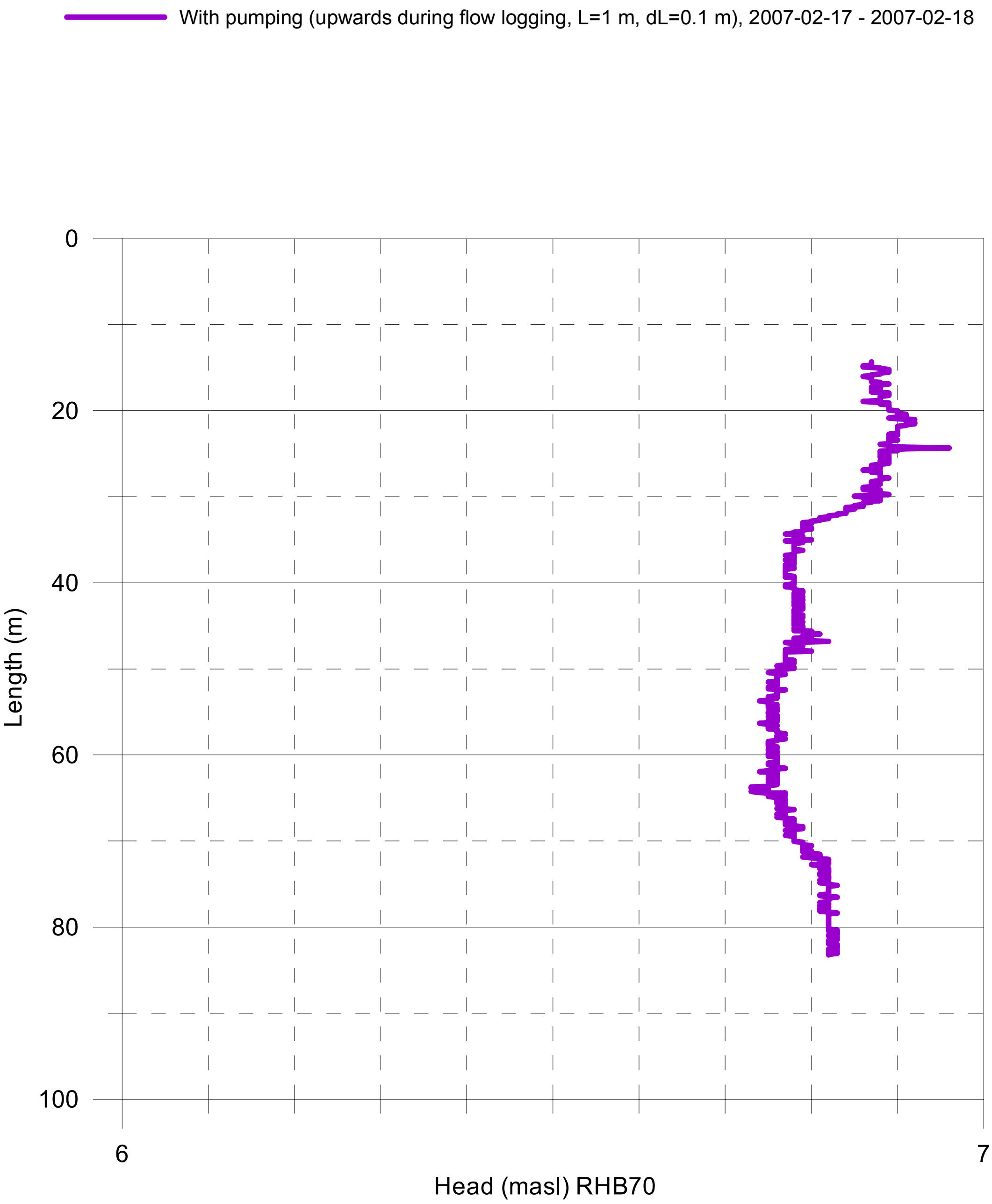
Appendix KLX26A.7

Laxemar, borehole KLX26A
Calculation of conductive fracture frequency

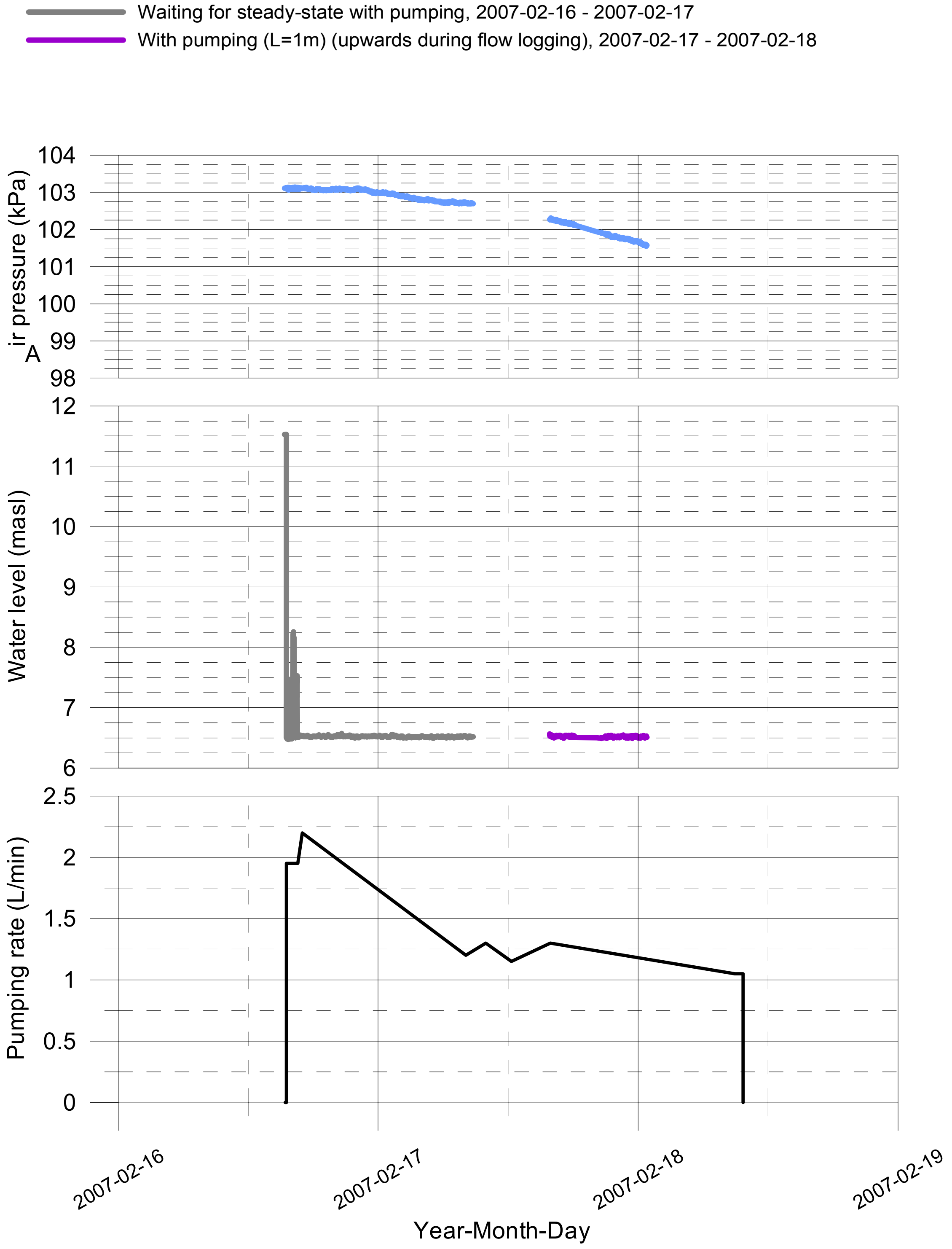


Laxemar, borehole KLX26A
Head in the borehole during flow logging

Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)



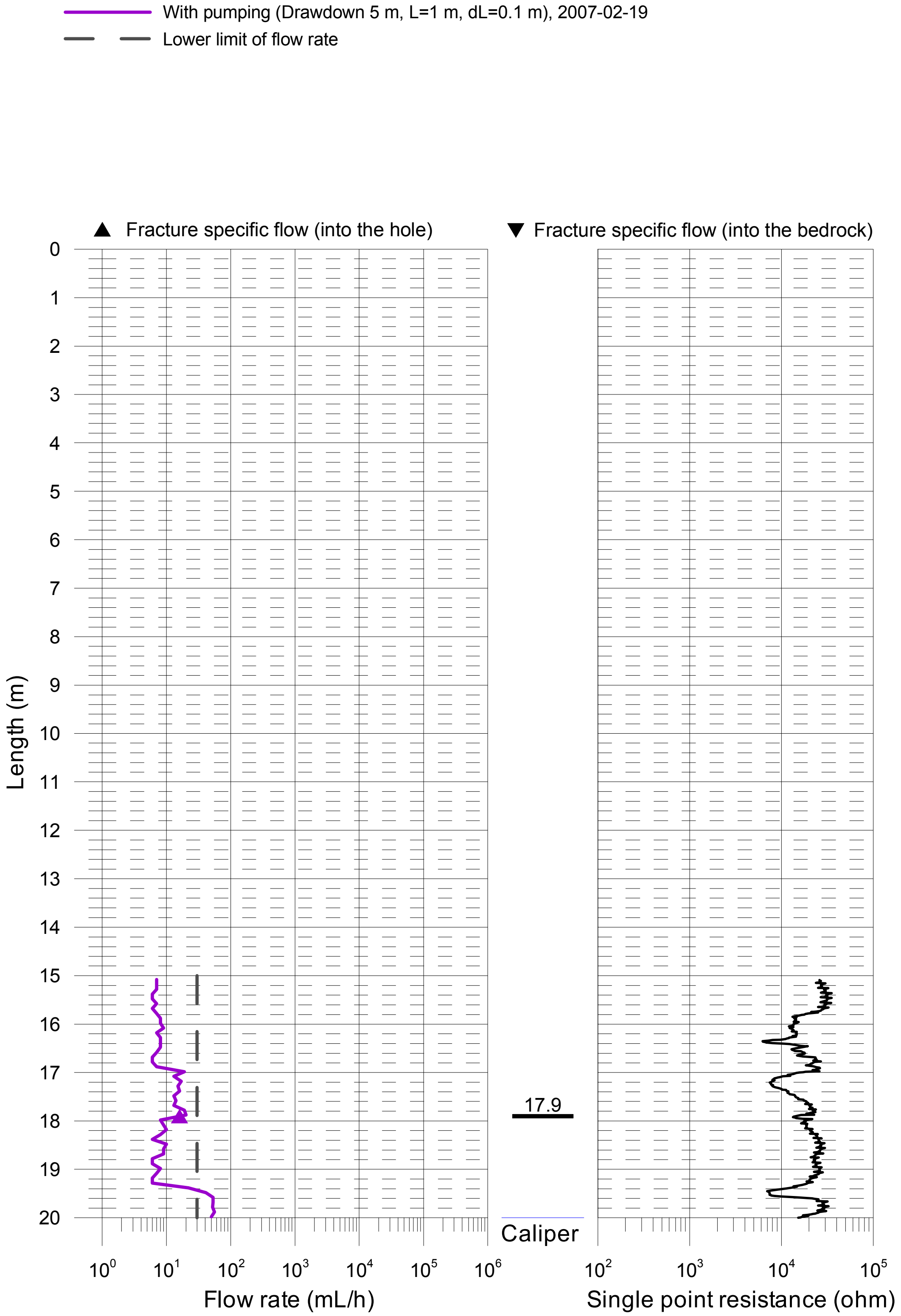
Laxemar, borehole KLX26A
Air pressure, water level in the borehole and pumping rate during flow logging



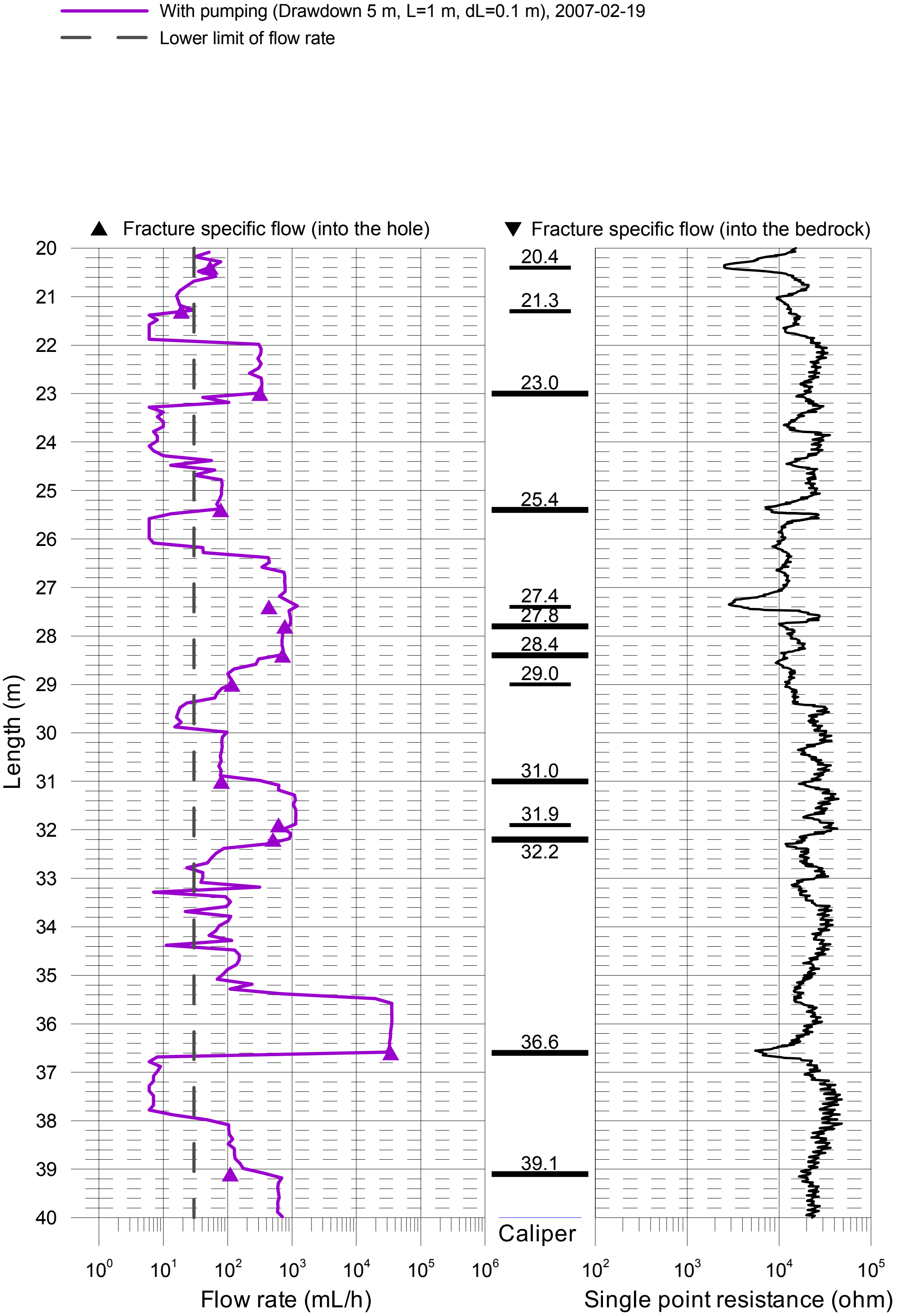
Appendix KLX26B

Appendices KLX26B.1.1–KLX26B.1.3	Flow rate and single-point resistance
Appendix KLX26B.2	Plotted transmissivity of detected fractures
Appendix KLX26B.3	Basic test data
Appendix KLX26B.4	Inferred flow anomalies from overlapping flow logging
Appendix KLX26B.5	Explanations for the tables in Appendices 3–4
Appendix KLX26B.6	Conductive fracture frequency
Appendix KLX26B.7	Plotted conductive fracture frequency
Appendix KLX26B.8.1	Head in the borehole during flow logging
Appendix KLX26B.8.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix KLX26B.8.3	Groundwater recovery after pumping

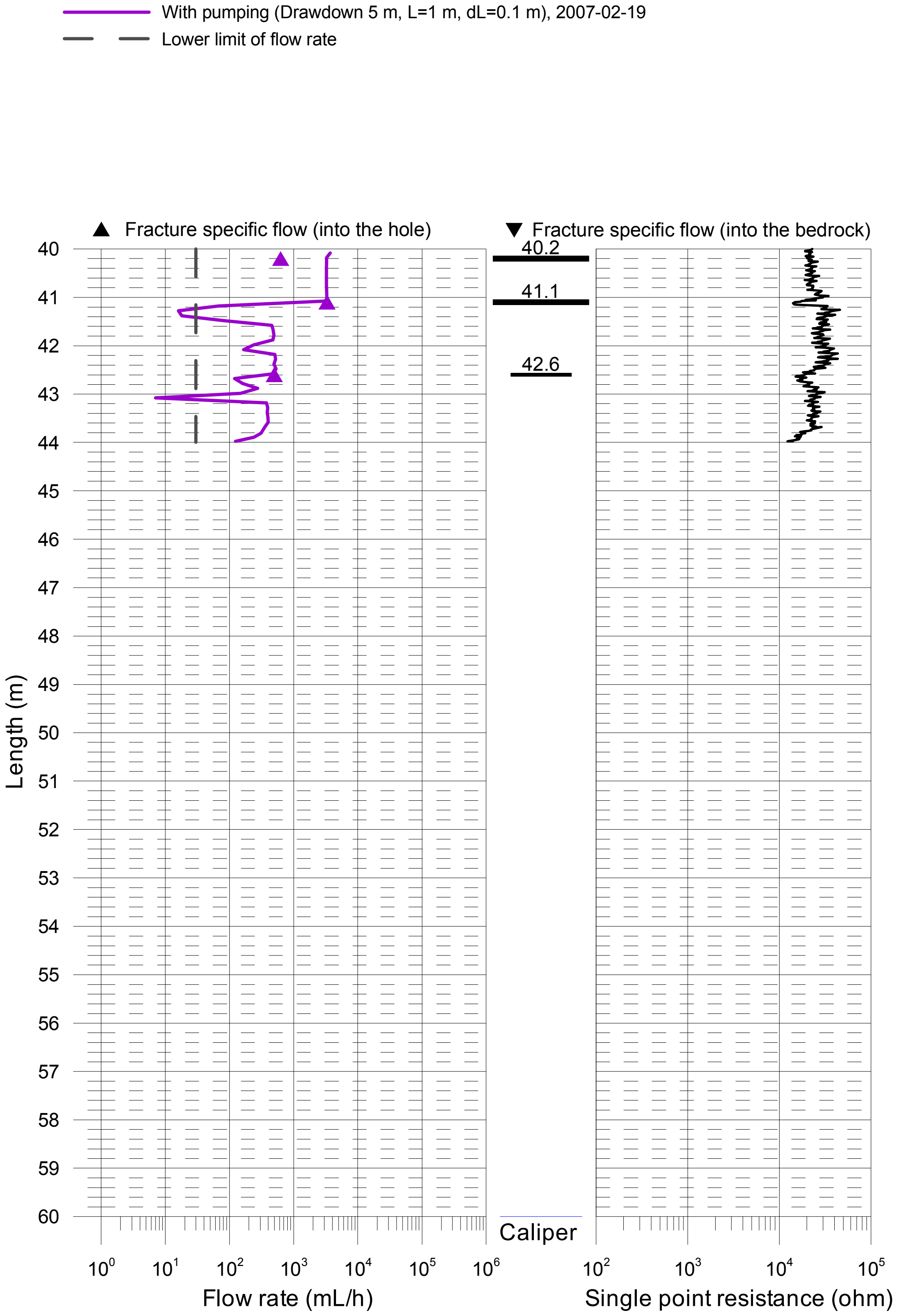
Laxemar, borehole KLX26B
Flow rate, caliper and single point resistance



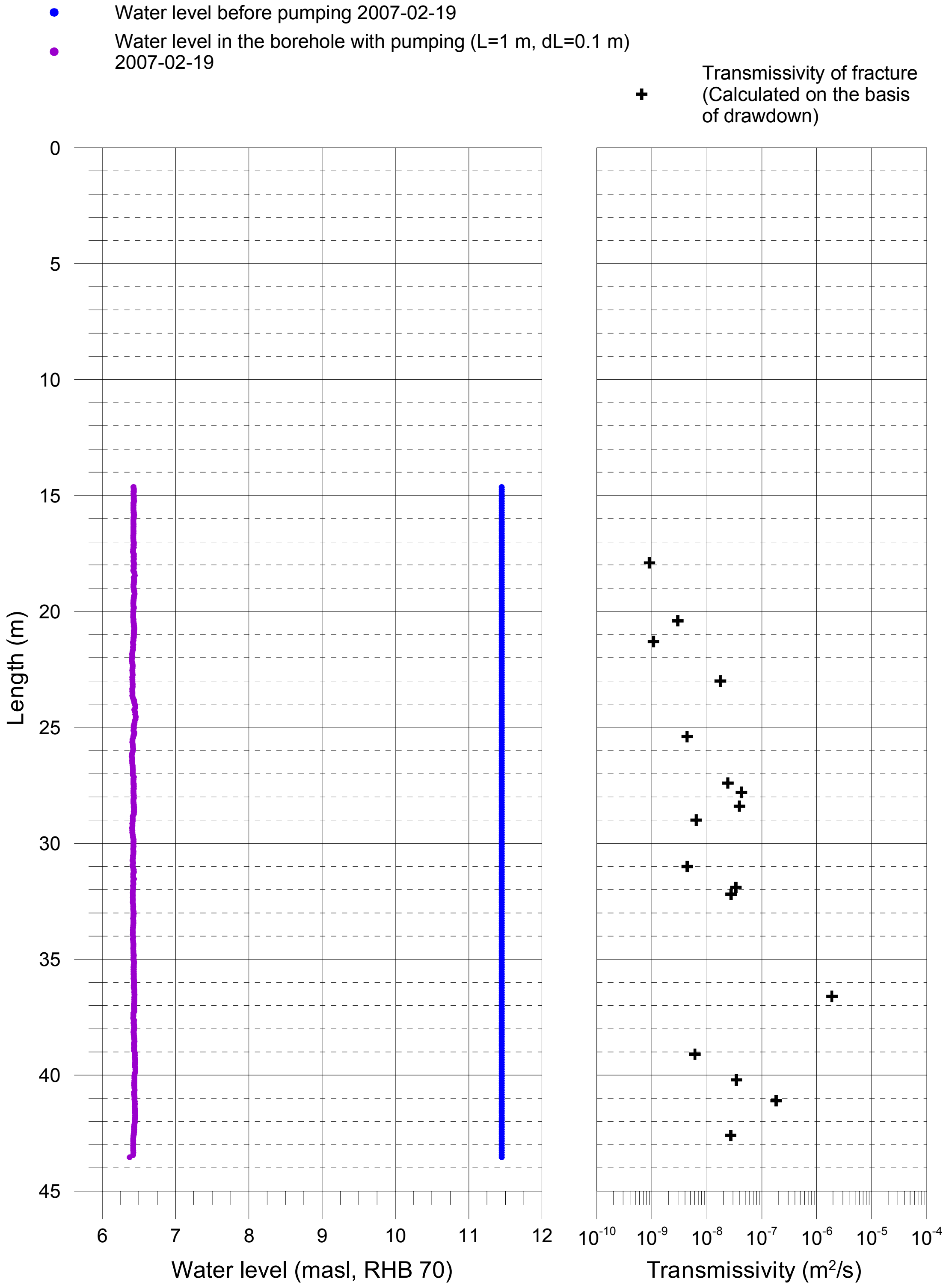
Laxemar, borehole KLX26B
Flow rate, caliper and single point resistance



Laxemar, borehole KLX26B
Flow rate, caliper and single point resistance



Laxemar, borehole KLX26B
Transmissivity of detected fractures



5. PFL – Difference flow logging – Basic test data.

Borehole ID	Logged interval Secup (m)	Seclow (m)	Test type (1–6)	Date of test, start YYYYMMDD	Time of test, start hh:mm	Date of flowl., start YYYYMMDD	Time of flowl., start hh:mm	Date of test, stop YYYYMMDD	Time of test, stop hh:mm	L_w (m)	dL (m)	Q_{p1} (m^3/s)	Q_{p2} (m^3/s)
KLX26B	2.31	50.37	5A	20070219	16:21	20070219	17:26	20070220	11:30	1	0.1	2.33E–05	–

5. PFL – Difference flow logging – Basic test data.

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (m.a.s.l.)	h_1 (m.a.s.l.)	h_2 (m.a.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
68,940	–	9,000	–	11.45	6.43	–	–5.02	–	4.6E–06	–	–

PFL – Difference flow logging – Inferred flow anomalies from overlapping flow logging.

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 ** (m^3/s)	h_0 *** (m.a.s.l.)	Q_1 (m^3/s)	h_1 **** (m.a.s.l.)	T_D***** (m^2/s)	h_i (m.a.s.l.)	Comments
KLX26B	17.9	1	0.1	–	11.45	4.44E–09	6.43	8.8E–10	–	*
KLX26B	20.4	1	0.1	–	11.45	1.47E–08	6.43	2.9E–09	–	*
KLX26B	21.3	1	0.1	–	11.45	5.28E–09	6.42	1.0E–09	–	*
KLX26B	23.0	1	0.1	–	11.45	8.72E–08	6.41	1.7E–08	–	
KLX26B	25.4	1	0.1	–	11.45	2.17E–08	6.42	4.3E–09	–	
KLX26B	27.4	1	0.1	–	11.45	1.21E–07	6.51	2.4E–08	–	*
KLX26B	27.8	1	0.1	–	11.45	2.14E–07	6.43	4.2E–08	–	
KLX26B	28.4	1	0.1	–	11.45	1.97E–07	6.43	3.9E–08	–	
KLX26B	29.0	1	0.1	–	11.45	3.22E–08	6.41	6.3E–09	–	*
KLX26B	31.0	1	0.1	–	11.45	2.22E–08	6.42	4.4E–09	–	
KLX26B	31.9	1	0.1	–	11.45	1.72E–07	6.42	3.4E–08	–	*
KLX26B	32.2	1	0.1	–	11.45	1.40E–07	6.42	2.8E–08	–	
KLX26B	36.6	1	0.1	–	11.45	9.53E–06	6.44	1.9E–06	–	
KLX26B	39.1	1	0.1	–	11.45	3.06E–08	6.45	6.0E–09	–	
KLX26B	40.2	1	0.1	–	11.45	1.74E–07	6.44	3.4E–08	–	
KLX26B	41.1	1	0.1	–	11.45	9.19E–07	6.44	1.8E–07	–	
KLX26B	42.6	1	0.1	–	11.45	1.38E–07	6.43	2.7E–08	–	*

* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

** Not measured.

*** Water level in the borehole before pumping (Head was not measured).

**** Water level during Q1.

***** Calculated on the basis of drawdown.

Explanations.

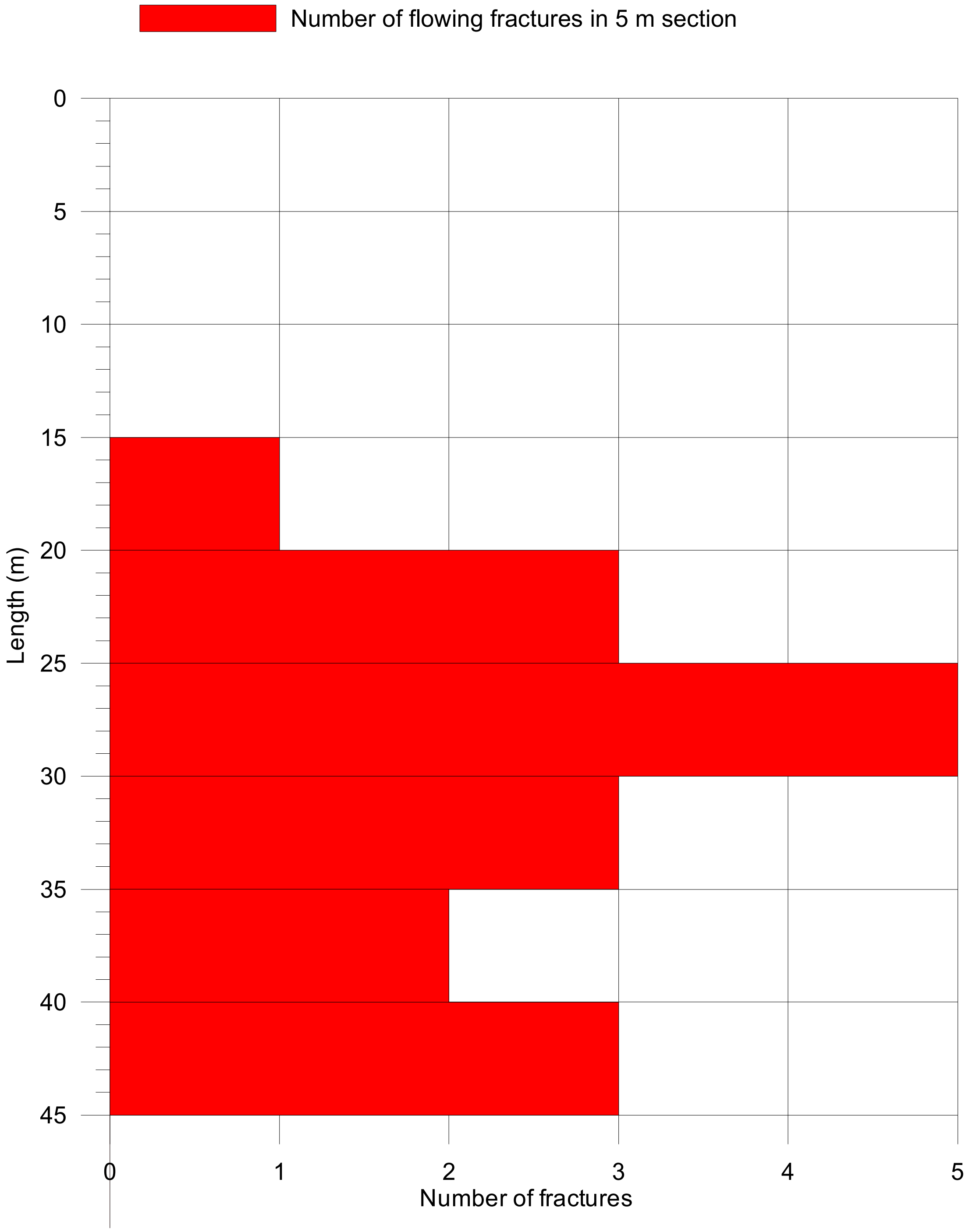
Header	Unit	Explanations
Borehole		ID for borehole
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L)
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L)
L	m	Corrected length along borehole based on SKB procedures for length correction
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
Test type (1–6)	(–)	1A: Pumping test – wire-line eq. 1B: Pumping test-submersible pump, 1C: Pumping test-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging – PFL-DIFF-Sequential, 5B: Difference flow logging – PFL-DIFF-Overlapping, 6: Flow logging-Impeller
Date of test, start	YY-MM-DD	Date for start of pumping
Time of test, start	hh:mm	Time for start of pumping
Date of flowl. start	YY-MM-DD	Date for start of the flow logging
Time of flowl. start	hh:mm	Time for start of the flow logging
Date of test, stop	YY-MM-DD	Date for stop of the test
Time of test, stop	hh:mm	Time for stop of the test
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_{p1}	m^3/s	Flow rate at surface by the end of the first pumping period of the flow logging
Q_{p2}	m^3/s	Flow rate at surface by the end of the second pumping period of the flow logging
t_{p1}	s	Duration of the first pumping period
t_{p2}	s	Duration of the second pumping period
t_{F1}	s	Duration of the first recovery period
t_{F2}	s	Duration of the second recovery period
h_0	m.a.s.l.	Initial hydraulic head before pumping. Elevation of water level in open borehole in the local co-ordinates system with z=0 m.
h_1	m.a.s.l.	Stabilised hydraulic head during the first pumping period. Elevation of water level in open borehole in the local co-ordinates system with z=0 m.
h_2	m.a.s.l.	Stabilised hydraulic head during the second pumping period. Elevation of water level in open borehole in the local co-ordinates system with z=0 m.
s_1	m	Drawdown of the water level in the borehole during first pumping period. Difference between the actual hydraulic head and the initial head ($s_1= h_1–h_0$)
s_2	m	Drawdown of the water level in the borehole during second pumping period. Difference between the actual hydraulic head and the initial head ($s_2=h_2–h_0$)
T	m^2/s	Transmissivity of the entire borehole
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with $h=h_0$ in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period
Q_2	m^3/s	Measured flow rate through the test section or flow anomaly during the second pumping period
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid before pumping
h_{1FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period
h_{2FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the second pumping period
EC_w	S/m	Measured electric conductivity of the borehole fluid in the test section during difference flow logging
Te_w	°C	Measured borehole fluid temperature in the test section during difference flow logging
EC_f	S/m	Measured fracture-specific electric conductivity of the fluid in flow anomaly during difference flow logging
Te_f	°C	Measured fracture-specific fluid temperature in flow anomaly during difference flow logging
T_D	m^2/s	Transmissivity of section or flow anomaly based on 2D model for evaluation of formation properties of the test section based on PFL-DIFF
T-measl$_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated $T_{D.}$ If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim
T-measl$_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated $T_{D.}$ If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim
T-measl$_U$	m^2/s	Estimated upper measurement limit for evaluated $T_{D.}$ If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

Calculation of conductive fracture frequency.

Borehole ID	SecUp (m)	SecLow (m)	Number Of Fractures, Total	Number Of Fractures 10–100 (ml/h)	Number Of Fractures 100–1,000 (ml/h)	Number Of Fractures 1,000–10,000 (ml/h)	Number Of Fractures 10,000–100,000 (ml/h)	Number Of Fractures 100,000–1000,000 (ml/h)
KLX26B	15	20	1	1	0	0	0	0
KLX26B	20	25	3	2	1	0	0	0
KLX26B	25	30	5	1	4	0	0	0
KLX26B	30	35	3	1	2	0	0	0
KLX26B	35	40	2	0	1	0	1	0
KLX26B	40	45	3	0	2	1	0	0

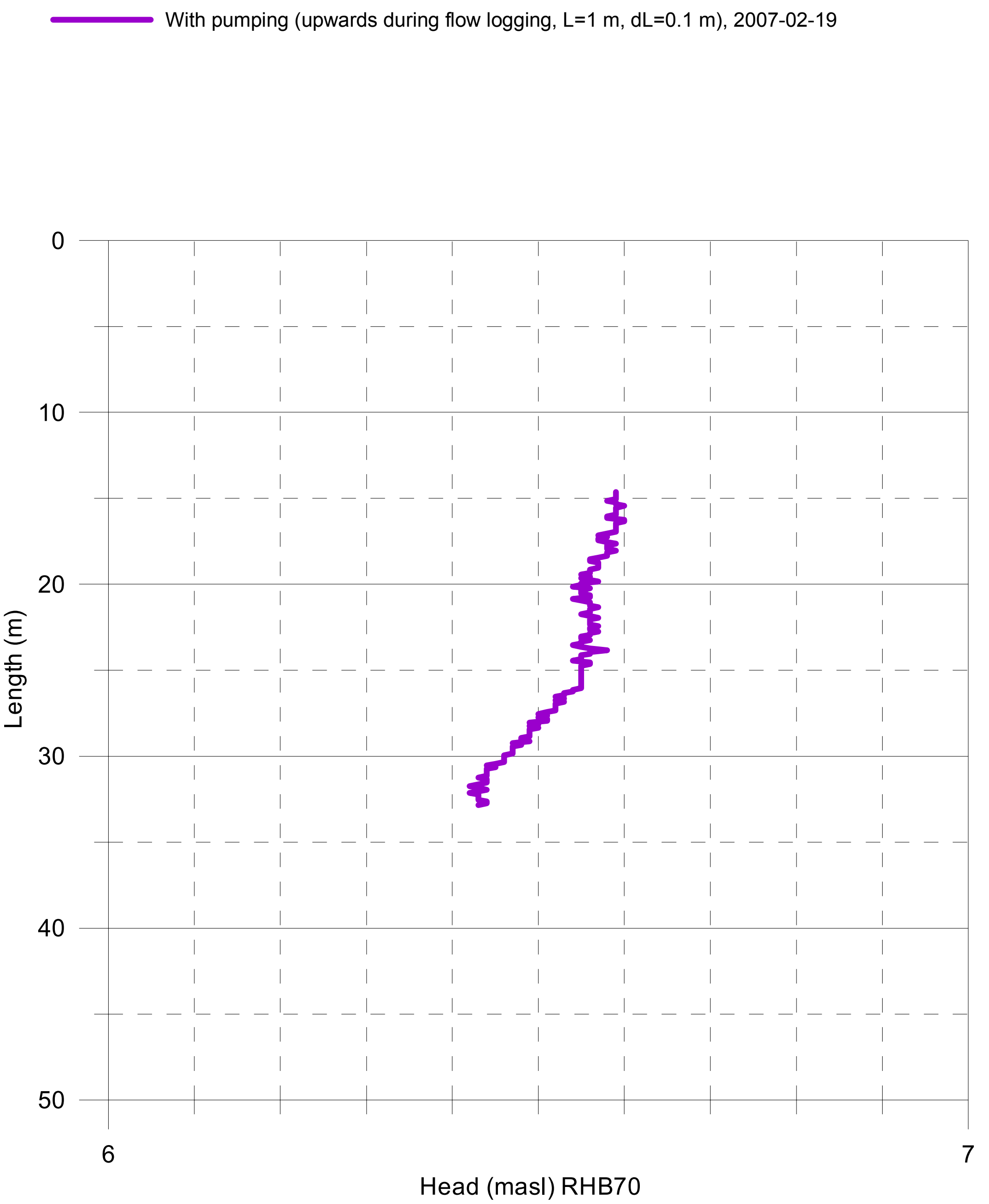
Appendix KLX26B.7

Laxemar, borehole KLX26B
Calculation of conductive fracture frequency

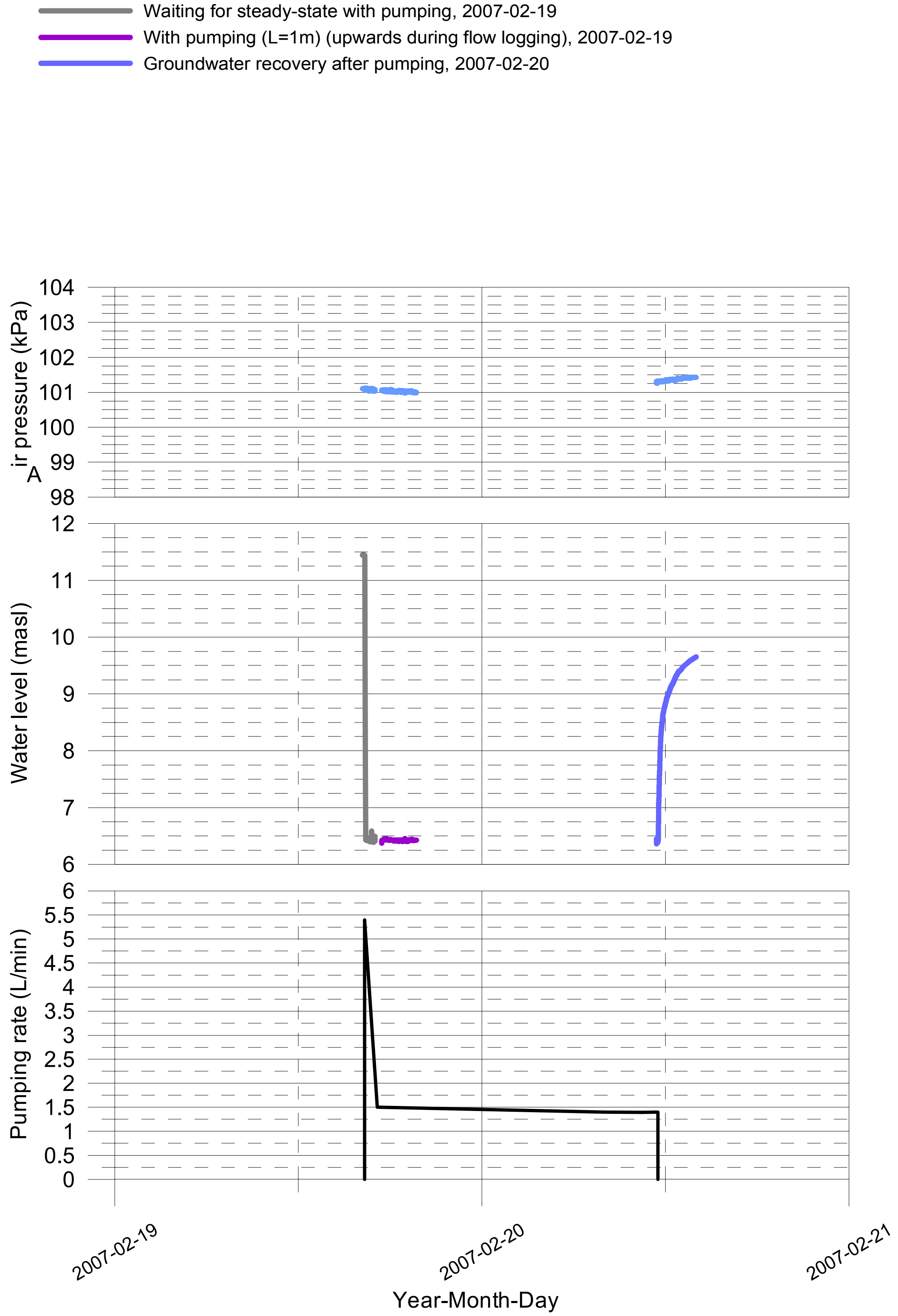


Laxemar, borehole KLX26B
Head in the borehole during flow logging

Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)



Laxemar, borehole KLX26B
Air pressure, water level in the borehole and pumping rate during flow logging



Laxemar, borehole KLX26B
Groundwater recovery after pumping

Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)