P-07-17

Oskarshamn site investigation

Difference flow logging of boreholes KLX28A and KLX29A

Subarea Laxemar

Jari Pöllänen, PRG-Tec Oy

January 2007

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

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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 KLX28A and KLX29A at Oskarshamn, Sweden, November 2006, 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 first flow logging measurements were done with a 5 m test section by moving the measurement tool in 0.5 m steps. This method was used to flow log the entire measurable part of the boreholes during natural (un-pumped) as well as pumped conditions. The flow measurements were repeated at the location of detected flow anomalies 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 KLX28A is c. 80 m. Length calibration was made based on length marks milled into the borehole wall at accurately determined positions along the borehole. The length marks were detected by caliper and single-point resistance measurements using sensors connected to the flow logging tool.

Borehole KLX29A is relatively short, c. 60 m. No length calibration was made since there are no length marks milled into the borehole wall.

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.

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 KLX28A och KLX29A i Oskarshamn, Sverige, i november 2006 med Posiva flödesloggningsmetod. Det primära syftet med mätningarna var att bestämma läget och flödet för vattenförande sprickor i borrhålen KLX28A och KLX29A.

Flödet till eller från en 5 m lång testsektion (som förflyttades successivt med 0,5 m) mättes i borrhålen KLX28A och KLX29A under såväl naturliga (icke-pumpade) som pumpade förhållanden. Flödesmätningarna upprepades vid lägena för de detekterade flödesanomalierna med en 1 m lång testsektion som förflyttades successivt med 0,1 m.

Borrhål KLX28A är cirka 80 m lång. Längdkalibrering gjordes baserad på längdmärkena som frästs in i borrhålsväggen vid noggrant bestämda positioner längs borrhålet. Längdmärkena detekterades med caliper-mätningar och med punktresistansmätningar med hjälp av sensorer anslutna på flödesloggningssonden.

Borrhål KLX29A är relativt kort, cirka 60 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 avslutades.

Contents

1 Introduction

This document reports the results acquired by flow logging the boreholes KLX28A and KLX29A at Oskarshamn, Sweden. The work was carried out in accordance with activity plan AP PS 400-06-106. 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 KLX28A at Oskarshamn was conducted between November 23 and 27, 2006. KLX28A is 80.23 m long and its inclination is 60° from the horizontal plane. The first 5.10 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 KLX29A was measured between November 27 and 29. Borehole KLX29A has a similar structure to that of borehole KLX28A. Its properties are also given in Table 1-2.

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

Activity plan	**Number**	**Version**
Difference flow logging in boreholes KLX28A and KLX29A	AP PS 400-06-106	1.0
Method descriptions	**Number**	**Version**
Method description for difference flow logging	SKB MD 322.010e	1.0
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 puming 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.]
KLX28A	80.23 m	60°	2.85 m–5.10 m	5.10 m–80.23 m	0.00 m–5.10 m	10.05 m
KLX29A	60.25 m	60°	0.30 m–2.35 m	2.35 m–60.25 m	0.00 m–2.35 m	13.63 m

The locations of KLX28A and KLX29A 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.

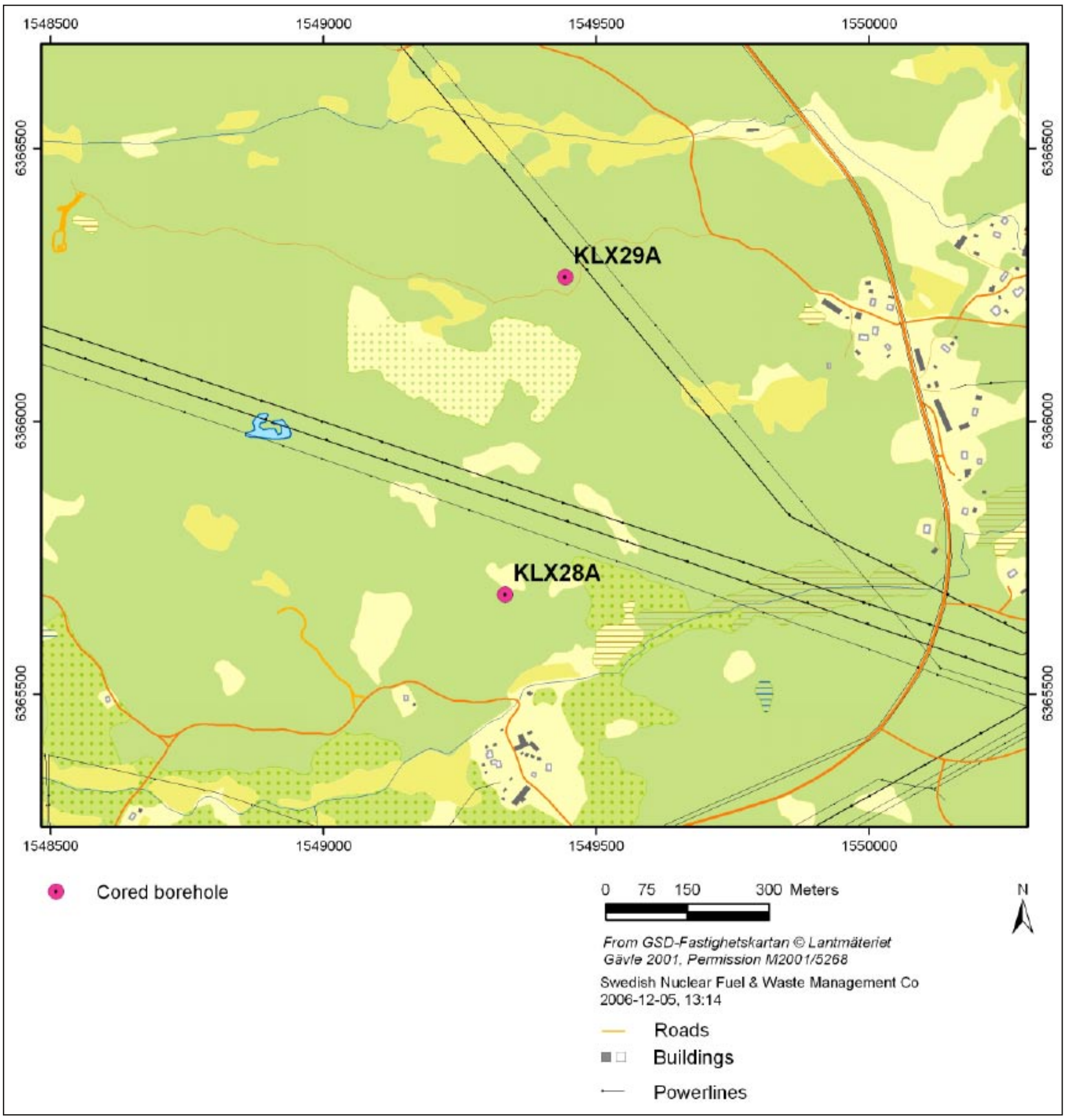

Figure 1-1. *Site map showing the locations of boreholes KLX28A and KLX29A situated in the subarea of Laxemar.*

2 Objective and scope

The main objective of the difference flow logging in KLX28A and KLX29A was to identify water-conductive sections/fractures. Secondly, the measurements aim at a hydrogeological characterisation, including the prevailing water flow balance in the boreholes. 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 KLX28A and KLX29A also included supporting measurements, performed in order to gain a better understanding of the overall hydrogeochemical 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 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 and 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.

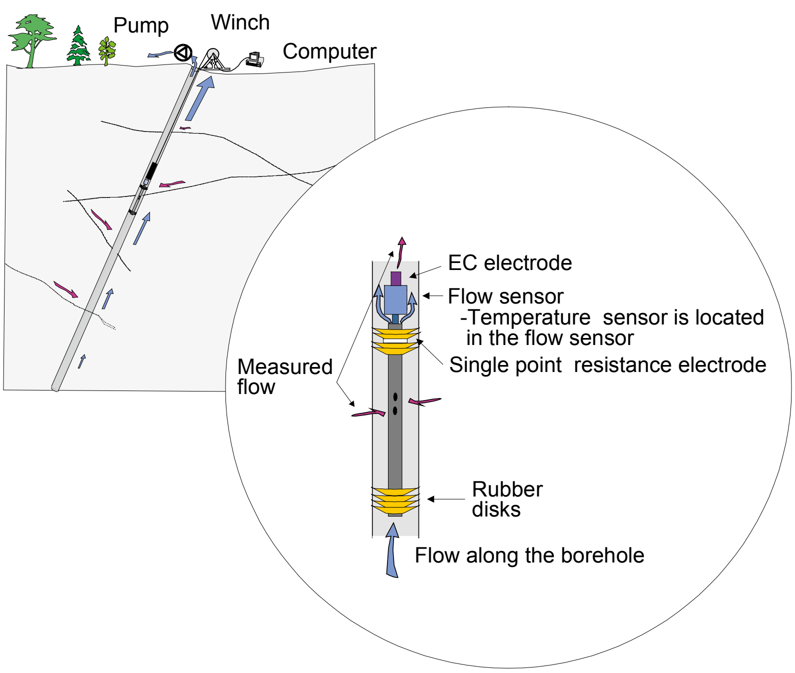

Figure 3-1. *Schematic of the downhole equipment used in the Difference flowmeter.*

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.

All of the above measurements except EC and caliper measurements were conducted in KLX29A. In KLX28A all of the above measurements except EC measurements were conducted.

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.

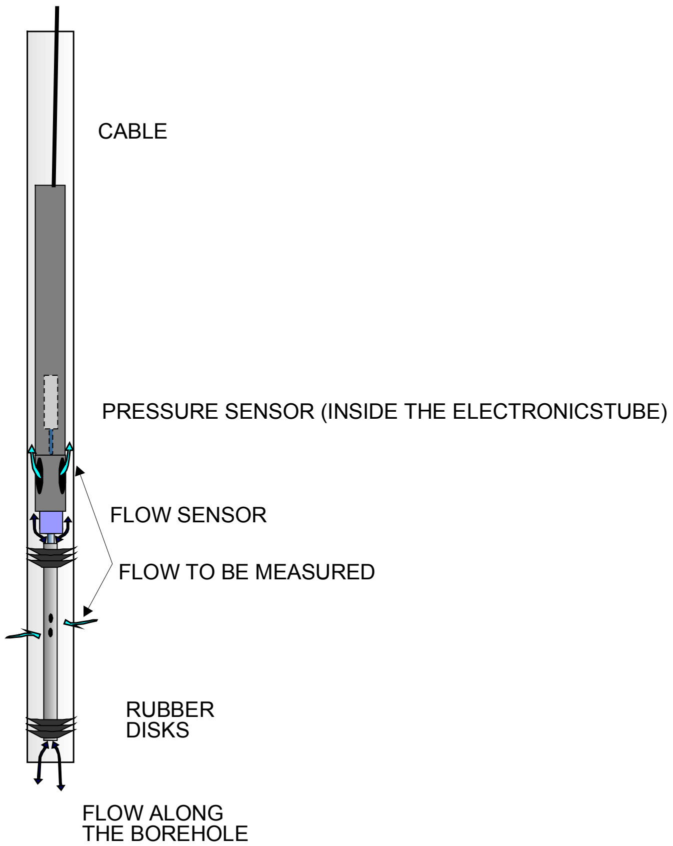

Figure 3-2. *The absolute pressure sensor is located inside the electronics tube and connected through a tube to the borehole water.*

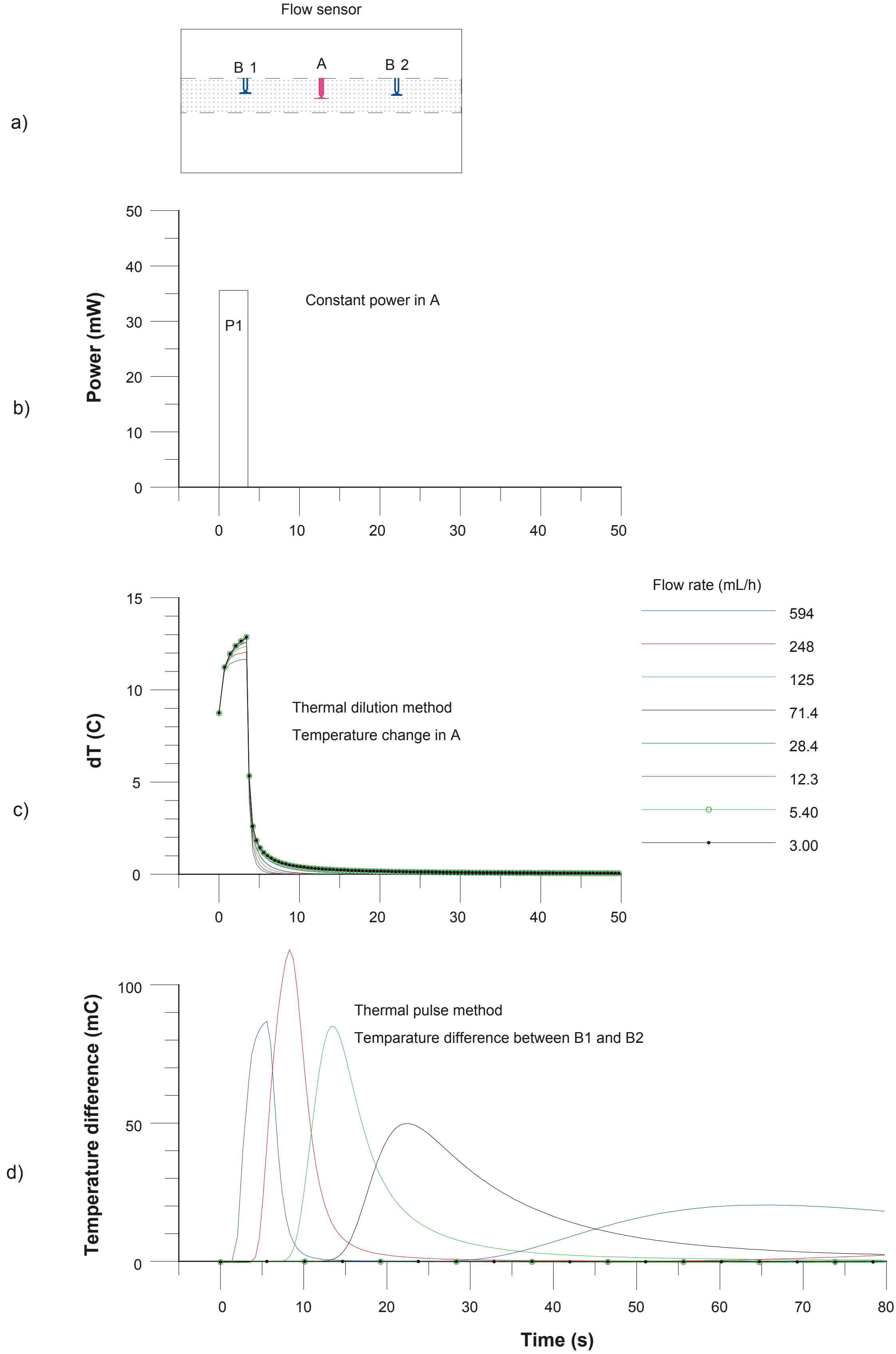

Figure 3-3. *Flow measurement, flow rate < 600 mL/h.*

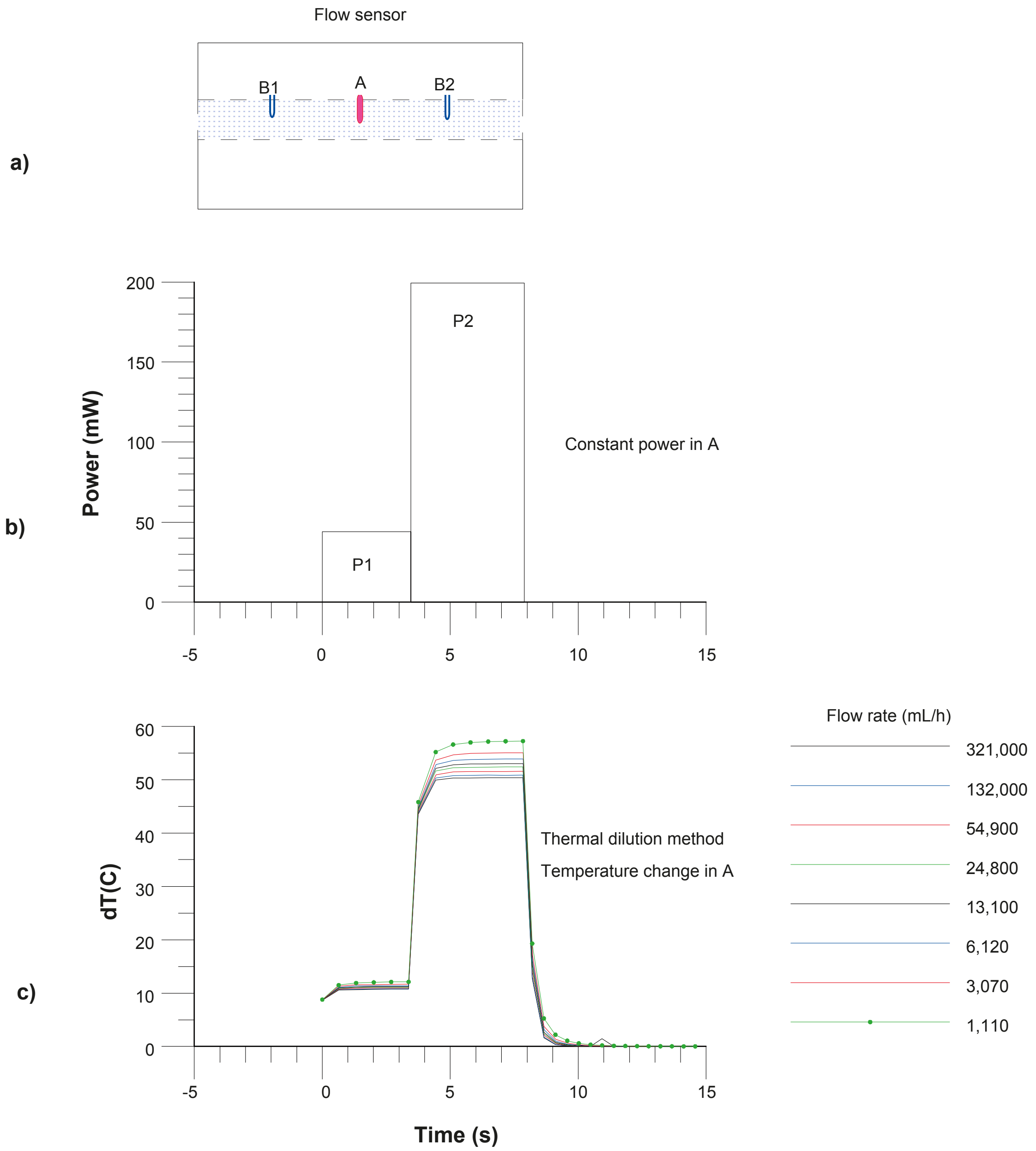

***Figure 3-4.** Flow measurement, flow rate > 600 mL/h.*

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 hs 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/:

$$T = \frac{Q}{s 2\pi} \ln\left(\frac{R}{r_0}\right) \qquad 3\text{-}9$$

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:

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

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 400-06-106 (SKB internal controlling document) following the SKB Method Description 322.010, Version 1.0 (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 KLX28A and KLX29A.

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.

Logging cables, wires, and pipe strings are exposed to stretching when lowered into a vertical or sub-vertical borehole. This will introduce a certain error in defining the position of a test tool connected to the end of a logging cable. Normally, the length calibration of logging tools is made by using the known positions of the length marks milled in the borehole wall. Boreholes KLX28A and KLX29A are however relatively short, and only one length mark was drilled on the borehole KLX28A wall. KLX29A had no length marks, and no length calibration was possible in that borehole.

Table 5-1. Flow logging and testing in KLX28A and KLX29A. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer. KLX28A	2006-11-23
8	Dummy logging	Borehole stability/risk evaluation. KLX28A	2006-11-23
9	Length calibration of the downhole tool	SKB Caliper and SPR logging. Logging without the lower rubber discs, no pumping. KLX28A	2006-11-23
10	Combined Overlapping/ Sequential flow logging	Section length Lw=5 m, Step length dL=0.5 m. No pumping. KLX28A	2006-11-24
11	Overlapping flow logging	Section length L_w=5 m, Step length dL=0.5 m at pumping (includes 1 day waiting after beginning of pumping). KLX28A	2006-11-25
12	Overlapping flow logging	Section length L_w=1 m, Step length dL=0.1 m, at pumping. KLX28A	2006-11-25
13	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping. KLX28A	2006-11-26 2006-11-27
14, 2	Demobilisation at KLX28A and mobilisation at KLX29A	Packing the trailer. Moving to KLX29A. Unpacking the trailer.	2006-11-27
8	Dummy logging	Borehole stability/risk evaluation. KLX29A	2006-11-27
10	Combined Overlapping/ Sequential flow logging	Section length L_w=5 m, Step length dL=0.5 m. No pumping. KLX29A	2006-11-27
11	Overlapping flow logging	Section length L_w=5 m, Step length dL=0.5 m at pumping (includes 1 day waiting after beginning of pumping). KLX29A	2006-11-28
12	Overlapping flow logging	Section length L_w=1 m, Step length dL=0.1 m, at pumping. KLX29A	2006-11-28
13	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping. KLX29A	2006-11-28 2006-11-29
14	Demobilisation	Packing the trailer.	2006-11-29

The combined overlapping/sequential flow logging (Item 10) was carried out in the boreholes with a 5 m section length and in 0.5 m length increments (step length). The measurements were performed during natural (un-pumped) conditions. Every tenth flow measurement (sequential mode) had a longer measurement time than normally in the overlapping mode. This was done in order to ensure the direction of the flow (into the borehole or out of it).

The pumping of borehole KLX28A was started on November 24. After a waiting time of c. 17.5 hours, overlapping flow logging (Item 11) was conducted using the same section and step lengths as before. In KLX29A the pumping was started on November 27. The waiting time after which the measurements (Item 11) were started was c. 16 h.

The overlapping flow logging was then continued by re-measuring previously detected flow anomalies with a 1 m section length and a 0.1 m step length (Item 12). After this, the pump was stopped and the recovery of the groundwater level was monitored (Item 13).

5.2 Nonconformities

The borehole elevation data used in the analysis was calculated by hand based on the borehole starting point inclination, since elevation data was not available from the borehole (see Section 6.2).

A pressure transducer was not used in the other borehole while the other borehole was flow logged. The transducer was not used, because SKB requested so.

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. Borehole KLX29A is relatively short, c. 60 m. Cable stretching is not significant at that length and no length marks were drilled in the borehole wall. Thereby no length calibration was applied in the measurements in borehole KLX29A.

Length errors in KLX29A are caused by the following reasons:

1. The point interval in flow measurements is 0.1 m in the 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 ± 0.2 m at the length of 150 m. The error is linear and approaches zero when moving closer to the ground level.

One length mark was drilled on the borehole KLX28A wall at the depth of 50 m. The procedure of the length correction was the following:

- The caliper/SPR-measurements (Item 9) were initially length corrected in relation to the known length marks, Appendix KLX28A.1.8, black curve. Corrections between the length marks were obtained by linear interpolation.
- The SPR curve of Item 9 was then compared with the SPR curves of Items 10, 11, and 12 to obtain relative length errors of these measurement sequences.
- All SPR curves could then be synchronized, as can be seen in Appendices KLX28A.1.2–KLX28A.1.7.

The results of the caliper and single-point resistance measurements from all measurements in the entire borehole are presented in Appendix KLX28A.1.1. The four SPR-curves are plotted together with the caliper-data. These measurements correspond to Items 9, 10, 11, 12 in Table 5-1.

The caliper has been adjusted and specified to change its output from a high voltage value to a low voltage value between borehole diameters 77 mm–78 mm.

Zoomed results of the caliper and SPR data are presented in Appendices KLX28A.1.2–KLX28A.1.7. There is only one length mark in the borehole KLX28A at the depth of 50 m. This mark was detected by the caliper tool and in the single-point resistance measurements.

The magnitude of the length correction along the borehole is presented in Appendix KLX28A.1.8. The negative values of the error represent the situation where the logging cable has been extended, i.e. the cable is longer than the nominal length marked on it.

6.2 Pressure measurements

Absolute pressure was registered with the other measurements in Items 10-13. The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered separately, Appendices KLX28A.12.2 and KLX29A.11.2. 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 and Cherry. 1979/:

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

where

h is the hydraulic head (meters 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 (meters 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 KLX28A.12.1 and KLX29A.11.1. In KLX28A the head values seem to decrease when going deeper into the borehole. One possible explanation for this could be that only the inclination of the starting point of these boreholes was given. There was no accurate elevation information for the entire lengths of the boreholes available.

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 KLX28A.2.1–KLX28A.2.4 and KLX29A.1.1–KLX29A.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.

The flow logging was first performed with a 5 m section length and with 0.5 m length increments, see Appendices KLX28A.2.1–KLX28A.2.4 and KLX29A.1.1–KLX29A.1.3. The method (overlapping flow logging) gives the length and the thickness of conductive zones with a length resolution of 0.5 m. To obtain quick results, only the thermal dilution method is used for flow determination.

Under natural conditions, the flow direction may be into the borehole or out from it. For small flow rates (< 100 mL/h) the flow direction can not be seen in the normal overlapping mode (thermal dilution method). Therefore the waiting time was longer for the thermal pulse method to determine the flow direction at every 5 m interval. The thermal pulse method was only used to detect the flow direction and not the flow rate, which would take a longer time to measure. The longer flow direction measurement has only been done in un-pumped conditions.

The test section length determines the width of a flow anomaly of a single fracture in the plots. If the distance between flow yielding fractures is less than the section length, the anomalies will overlap, resulting in a stepwise flow data plot. Overlapping flow logging was therefore repeated in the vicinity of identified flow anomalies using a 1 m long test section and 0.1 m length increments, see Appendices KLX28A.2.1–KLX28A.2.4 and KLX29A.1.1–KLX29A.1.3 (violet curve).

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 KLX28A.9 and KLX29A.8 were used to calculate conductive fracture frequency (CFF). The number of conductive fractures was counted on the same 5 m sections as in Appendices KLX28A.6 and KLX29A.5. 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 KLX28A.10 and KLX29A.9.

The basic data for KLX28A measurements is presented in Appendix KLX28A.5 and the explanations to the tables in Appendices KLX28A.5–KLX28A.7 in Appendix KLX28A.8. Respectively the basic data for KLX29A measurements is presented in Appendix KLX28A.4 and the explanations to the tables in Appendices KLX28A.4–KLX28A.6 in Appendix KLX28A.7.

6.3.2 Transmissivity and hydraulic head of borehole sections

KLX28A was logged between 22.00 m and 72.04 m with a 5 m section length and with 0.5 m length increments. In KLX29A the interval was 19.42 m–54.42 m. In addition to this, the depth interval 16.97 m–21.97 m in borehole KLX28A and the depth interval 9.42 m–19.42 m were measured during natural conditions. All the flow logging results presented in this report are derived from measurements with the thermal dilution method.

The results of the measurements with a 5 m section length are presented in tables, see Appendices KLX28A.6 and KLX29A.5. Only the results with 5 m length increments are used. All borehole sections are shown in Appendices KLX28A.2.1–KLX28A.2.4 and KLX29A.1.1–KLX29A.1.3. Secup and Seclow in Appendices KLX28A.6 and KLX29A.5 are the distance along the borehole from the reference level (top of the casing tube) to the upper end of the test section and to the lower end of the test section, respectively. The Secup and Seclow values for the two sequences (measurements at un-pumped and pumped conditions) are not exactly identical, due to a minor difference in the cable stretching. The difference between these two sequences was small. Secup and seclow given in Appendices KLX28A.6 and KLX29A.5 are calculated as the average of these two values.

Pressure was measured and calculated as described in Section 6.2. h_{0FW} and h_{1FW} in Appendices KLX28A.6 and KLX29A.5 represent heads determined without and with pumping, respectively. The head in the borehole and calculated heads of borehole sections are given on the RHB 70 scale.

The flow results in Appendices KLX28A.6 and KLX29A.5 (Q_0 and Q_1), representing the flow rates derived from measurements during un-pumped and pumped conditions, are presented side by side to make comparison easier. Flow rates are positive if the flow direction is from the bedrock into the borehole and vice versa.

In KLX28A – with the borehole at rest – nine sections were detected as flow yielding, six of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 10 detected flows were directed towards the borehole.

In KLX29A flows were detected in nine sections and all of these flows were negative. During pumping, all seven detected section flows were positive.

The flow data is presented as a plot, see Appendices KLX28A.3.1 and KLX29A.2.1. The left hand side of each diagram represents flow from the borehole into the bedrock for the respective test sections, whereas the right hand side represents the opposite. If the measured flow was zero, it is not visible in the logarithmic scale of the appendices.

The lower and upper measurement limits of the flow are also presented in the plots (Appendices KLX28A.3.1 and KLX29A.2.1) and in the tables (Appendices KLX28A.6 and KLX29A.5). There are theoretical and practical lower limits of flow, see Section 6.3.4.

The hydraulic head and transmissivity (T_D) of borehole sections can be calculated from the flow data using the method described in Chapter 3. The hydraulic head of sections is presented in the plots if none of the two flow values at the same length is equal to zero. Transmissivity is presented if none or just one of the flows is equal to zero, see Appendices KLX28A.3.2 and KLX29A.2.2. The measurement limits of transmissivity are also shown in Appendices KLX28A.3.2 and KLX29A.2.2 and in Appendices KLX28A.6 and KLX29A.5. All the measurement limit values of transmissivity are based on the actual pressure difference in the borehole (h_{0FW} and h_{1FW} in Appendices KLX28A.6 and KLX29A.5).

The sum of detected flows in KLX28A without pumping (Q_0) was $3.67 \cdot 10^{-8}$ m^3/s (132 mL/h). This sum should normally be zero if all the flows in the borehole are correctly measured, the borehole is not pumped, the water level is constant, the salinity distribution in the borehole is stabilized and the fractures are at steady state pressure. In this case the sum is close to zero.

In KLX29A the sum was $-3.73 \cdot 10^{-5}$ m^3/s (–134,439 mL/h). The sum is not close to zero. A fracture with a positive flow rate was detected above 9.42 m, but a complete section flow could not be determined, because it was not possible to measure the borehole high enough. It is also possible that there were flows below the lowest measured section.

6.3.3 Transmissivity and hydraulic head 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 KLX28A.2.2. 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).

Since the 1 m section was not used in un-pumped conditions, the results for the 5 m section were used. The fracture locations are important when evaluating the flow rate in un-pumped conditions. The fracture locations are known on the basis of the 1 m section measurements. It is not a problem to evaluate the flow rate in un-pumped conditions when the distance between flowing fractures is more than 5 m. The evaluation may be problematic when the distance between fractures is less than 5 m. In this case an increase or decrease of a flow anomaly at the fracture location determines the flow rate. However, this evaluation is used conservatively, it is only used in the clearest of cases and no flow value is usually evaluated in un-pumped conditions at densely fractured parts of bedrock. If the flow for a specific fracture can not be determined conclusively, the flow rate is marked with "–" and value 0 is used in the transmissivity calculation, see Appendices KLX28A.7 and KLX29A.6. The flow direction is evaluated as well. The results of the evaluation are plotted in Appendices KLX28A.2.1–KLX28A.2.4 and KLX29A.1.1–KLX29A.1.3, blue filled triangle.

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 KLX28A was 46, but only two could be defined without pumping. These two fractures could be used for head estimation and all 46 were used for transmissivity estimations.

In KLX29A 28 fractures were detected (and 26 of them were used for transmissivity estimations), but only five were detected without pumping. Three of these five were used for head estimations.

The transmissivity and hydraulic head of the fractures are plotted in Appendices KLX28A.4 and KLX29A.3. The results are presented in a tabulated form in Appendices KLX28A.7 and KLX29A.6.

Fracture-specific transmissivities were compared with the transmissivities of borehole sections in Appendices KLX28A.11 and KLX29A.10. All fracture-specific transmissivities within each 5 m interval were first summed together to make them comparable with the measurements with a 5 m section length. The results are, in most cases, consistent between the two types of measurements. In this case, the measurements were quite close to each other and the flow rate and transmissivity are generally nearly equal, i.e. the decrease of flow as a function of pumping time is not always clearly visible.

6.3.4 Theoretical and practical limits of flow measurements and transmissivity

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 KLX28A.2.1–KLX28A.2.4 and KLX29A.1.1–KLX29A.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 KLX28A and KLX29A 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 KLX28A and KLX29A the flow values never exceeded the upper limit.

The practical minimum of measurable flow rate is also presented in Appendices KLX28A.6 and KLX29A.5 (Q-lower limit P). It is taken from the plotted curve in Appendices KLX28A.2 and KLX29A.1 (Lower limit of flow rate). The practical minimum of measurable transmissivity can be evaluated using Q-lower limit and the actual head difference at each measurement location, see Appendices KLX28A.6 and KLX29A.5 (T_D-measl$_{LP}$). The theoretical minimum measurable transmissivity (T_D-measl$_{LT}$) is evaluated using a Q value of 30 mL/h (minimum theoretical flow rate with the thermal dilution method). The upper measurement limit of transmissivity can be evaluated using the maximum flow rate (300,000 mL/h) at the actual head difference as above, see KLX28A.6 and KLX29A.5 (T_D-measl$_U$).

All three flow limits are also plotted with measured flow rates, see Appendices KLX28A.3.1 and KLX29A.2.1. Theoretical minimum and maximum values are 30 mL/h and 300,000 mL/h, respectively.

The three transmissivity limits are also presented graphically, see Appendices KLX28A.3.2 and KLX29A.2.2.

Similar flow and transmissivity limits are not given for the fracture-specific results, Appendices KLX28A.4, KLX29A.3, KLX28A.7 and KLX29A.6. Approximately the same limits would also be valid for these results. The limits for fracture-specific results are more difficult to define. For instance, it may be difficult to see a small flow rate near (< 1 m) a high flowing fracture. The situation is similar for the upper flow limit. If there are several high flowing fractures less than one meter apart from each other, the upper flow limit depends on the sum of flows which must be below 300,000 mL/h.

6.3.5 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.

KLX28A

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 10.00 m. Transmissivity calculated with Dupuit's formula is $2.31 \cdot 10^{-6}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 75.13 m (80.23 m–5.10 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $2.93 \cdot 10^{-6}$ m^2/s.

KLX29A

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 9.4 L/min and s (drawdown) was 5.12 m. Transmissivity calculated with Dupuit's formula is $3.03 \cdot 10^{-5}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 57.9 m (60.25 m–2.35 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $3.72 \cdot 10^{-5}$ m^2/s.

6.4 Groundwater level and pumping rate

The groundwater level and the pumping rate are illustrated in Appendices KLX28A 12.2 and KLX29A.11.2 and the recovery plots are presented in Appendices KLX28A 12.3 and KLX29A.11.3. The groundwater recovery measurement in each borehole was done with two sensors, the groundwater level sensor (pressure sensor) and the absolute pressure sensor located in the flowmeter tool. Water level and head during pumping periods was not constant all the time. A diesel generator was used for generation of electricity instead of supply current. It has possibly caused some problem for pumping.

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 6-1. Transmissivities of the entire boreholes.

	KLX28A	KLX29A
Dupuit (m^2/s)	$2.31 \cdot 10^{-6}$	$3.03 \cdot 10^{-5}$
Moye (m^2/s)	$2.93 \cdot 10^{-6}$	$3.72 \cdot 10^{-5}$

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
KLX28A	2006-11-24–2006-11-26	–1.6	–3.49	10.05	10.00	2006-11-26–2006-11-27
KLX29A	2006-11-27–2006-11-28	4.24	2.35	13.63	5.12	2006-11-28–2006-11-29

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 KLX28A and KLX29A at Oskarshamn. Measurements were carried out both when the borehole was at rest and during pumping. A 5 m section length with 0.5 m length increments was used initially. The detected flow anomalies were re-measured with a 1 m section length using a 0.1 m measurement interval.

The water level in the borehole during pumping and its recovery after the pump was turned off were also measured.

Transmissivity and hydraulic head were calculated for borehole sections and fractures.

The total amount of detected flowing fractures in KLX28A was 46. The highest transmissivity ($4.7 \cdot 10^{-7}$ m^2/s) was detected in a fracture at the length of 28.0 m.

In KLX29A the total amount of detected fractures was 28. The highest transmissivity ($1.5 \cdot 10^{-6}$ m^2/s) was detected in a fracture at the length of 18.3 m.

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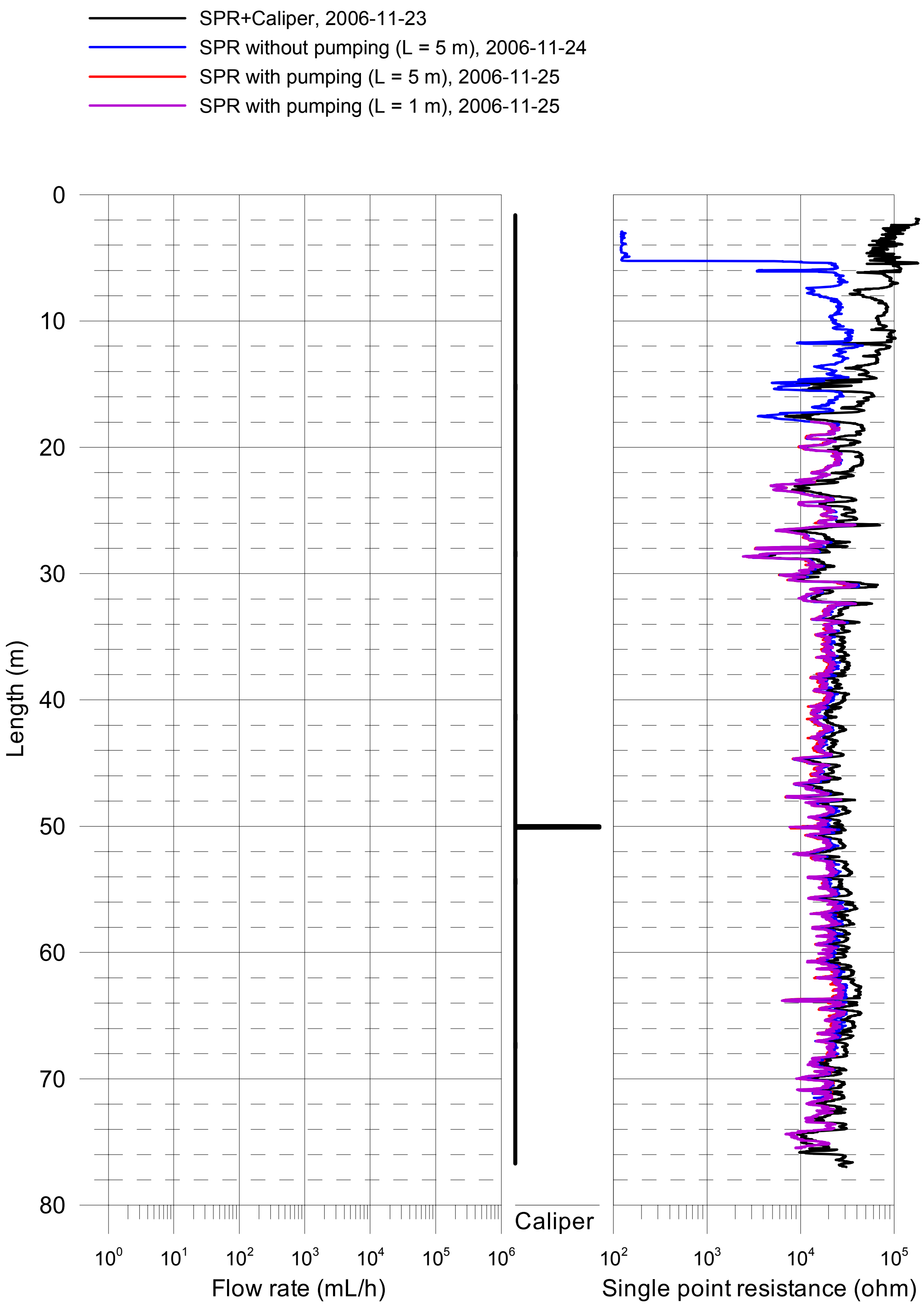
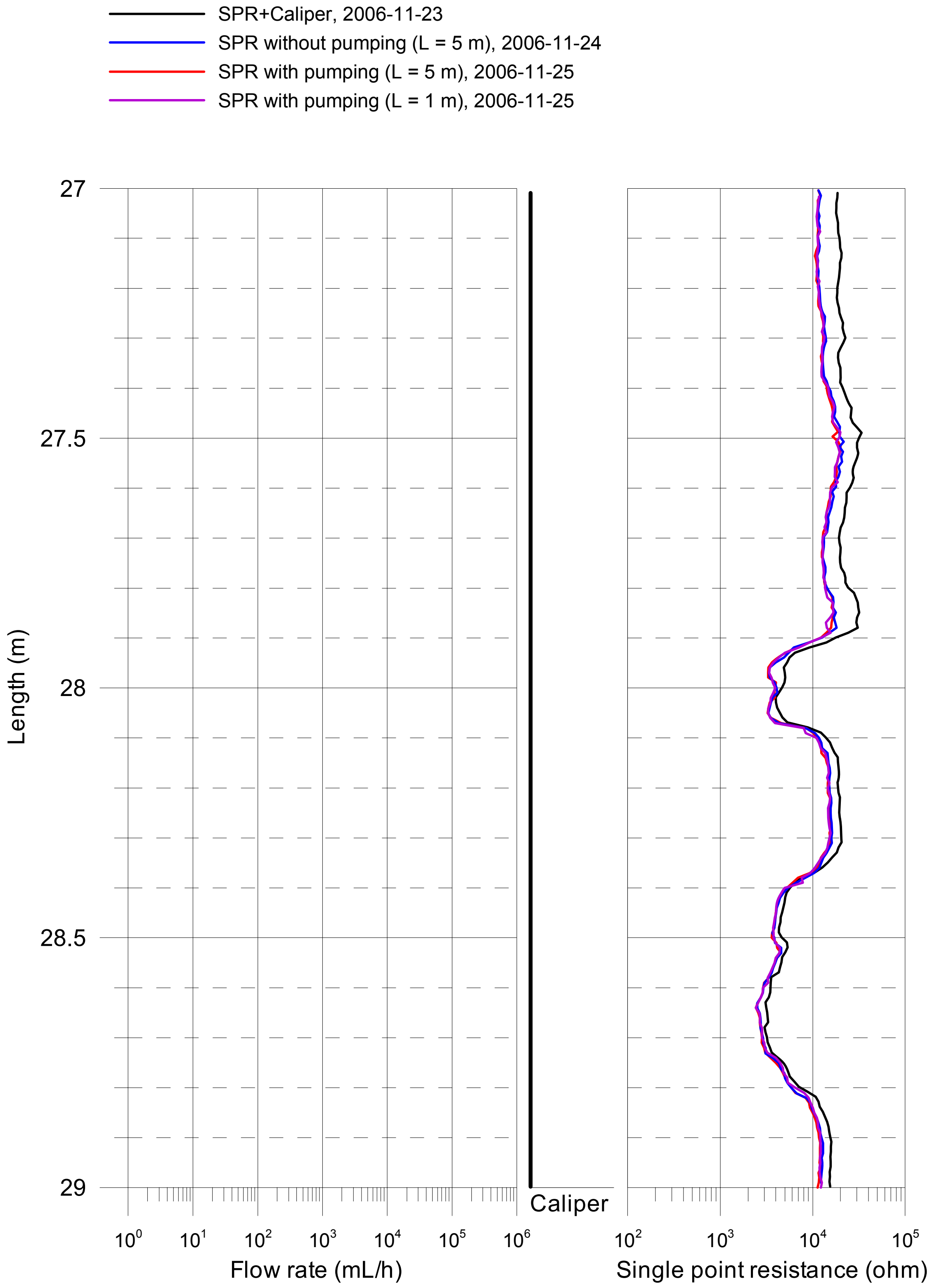
Appendices, KLX28A

Appendices	KLX28A.1.1–KLX28A.1.7	SPR and Caliper results after length correction
Appendix	KLX28A.1.8	Length correction
Appendices	KLX28A.2.1–KLX28A.2.4	Flow rate and single point resistance
Appendix	KLX28A.3.1	Plotted flow rates of 5 m sections
Appendix	KLX28A.3.2	Plotted transmissivity and head of 5 m sections
Appendix	KLX28A.4	Plotted transmissivity and head of detected fractures
Appendix	KLX28A.5	Basic test data
Appendix	KLX28A.6	Results of sequential flow logging
Appendix	KLX28A.7	Inferred flow anomalies from overlapping flow logging
Appendix	KLX28A.8	Explanations for the tables in Appendices 6–8
Appendix	KLX28A.9	Conductive fracture frequency
Appendix	KLX28A.10	Plotted conductive fracture frequency
Appendix	KLX28A.11	Comparison between section transmissivity and fracture transmissivity
Appendix	KLX28A.12.1	Head in the borehole during flow logging
Appendix	KLX28A.12.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	KLX28A.12.3	Groundwater recovery after pumping

Laxemar, borehole KLX28A
SPR and Caliper results after length correction



Laxemar, borehole KLX28A
SPR and Caliper results after length correction



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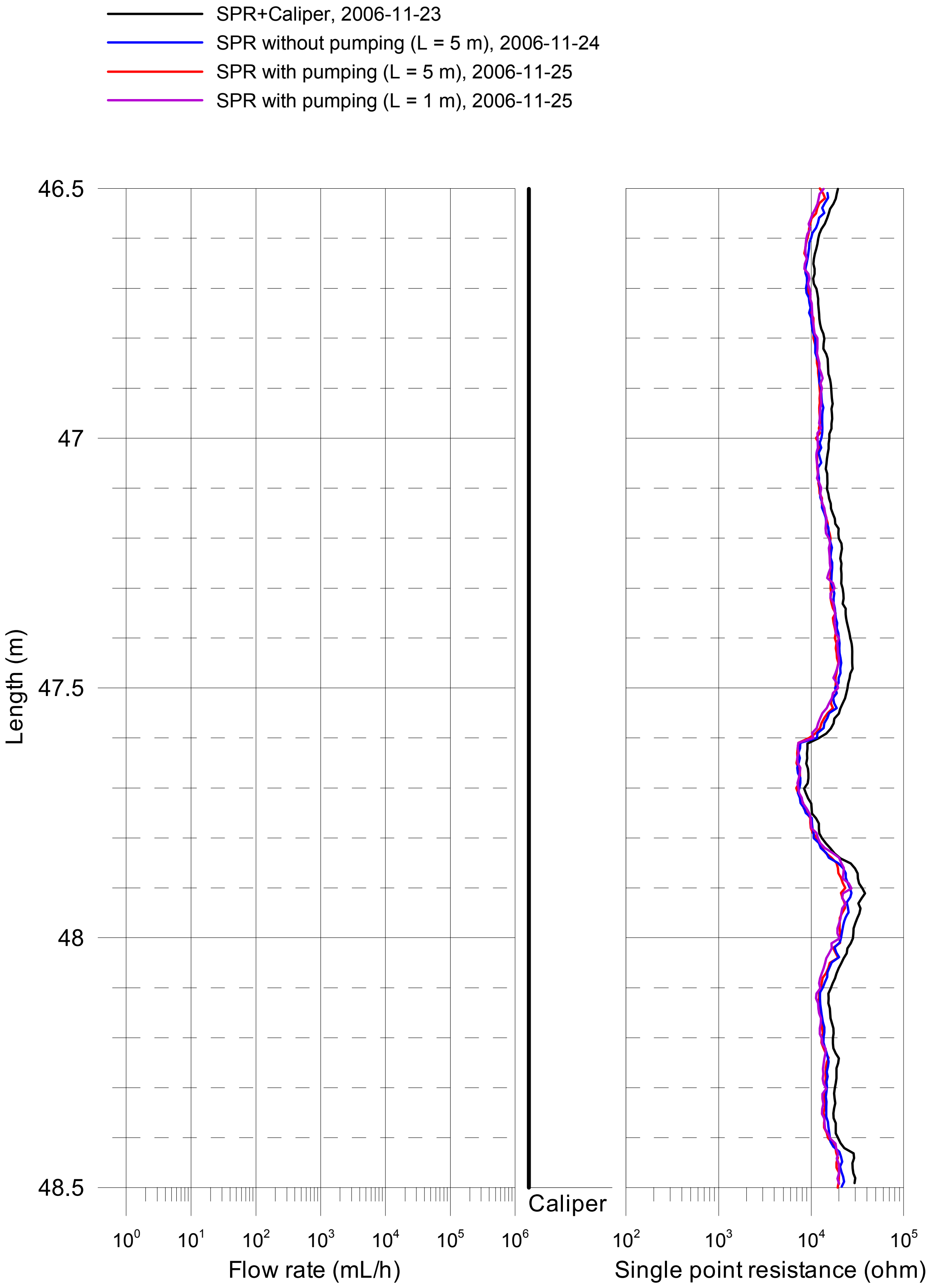
SPR and Caliper results after length correction



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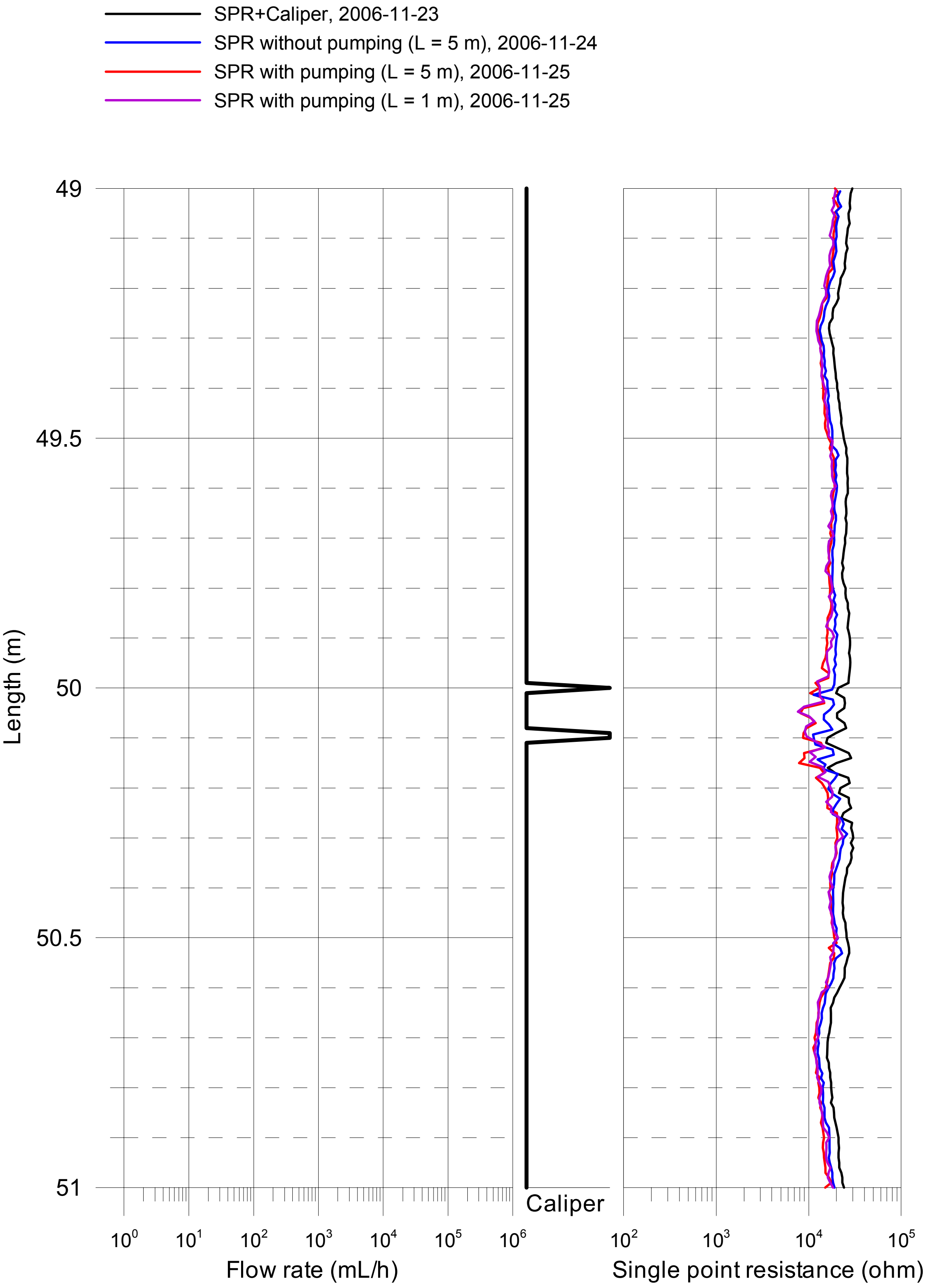
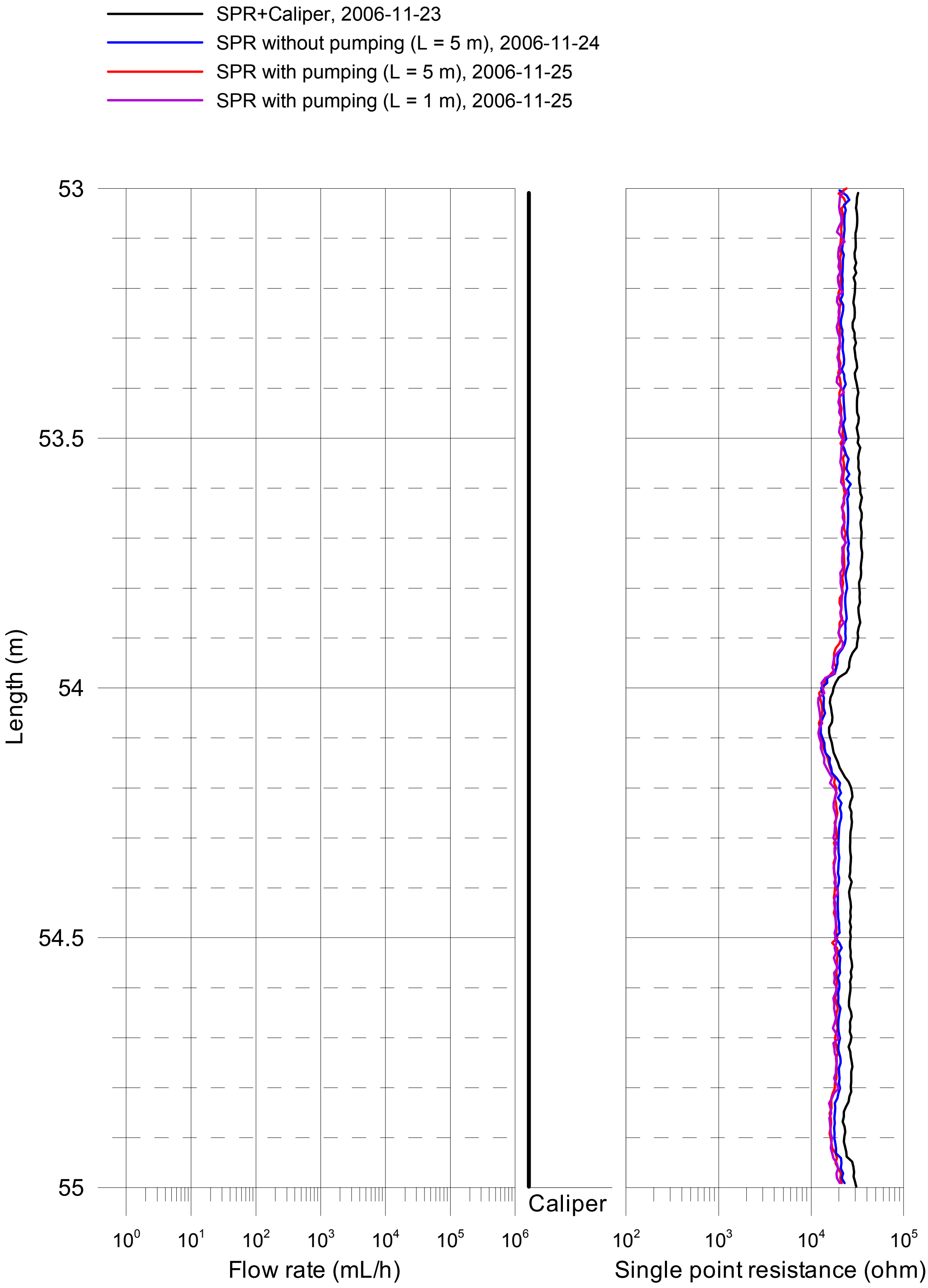
SPR and Caliper results after length correction



Laxemar, borehole KLX28A
SPR and Caliper results after length correction



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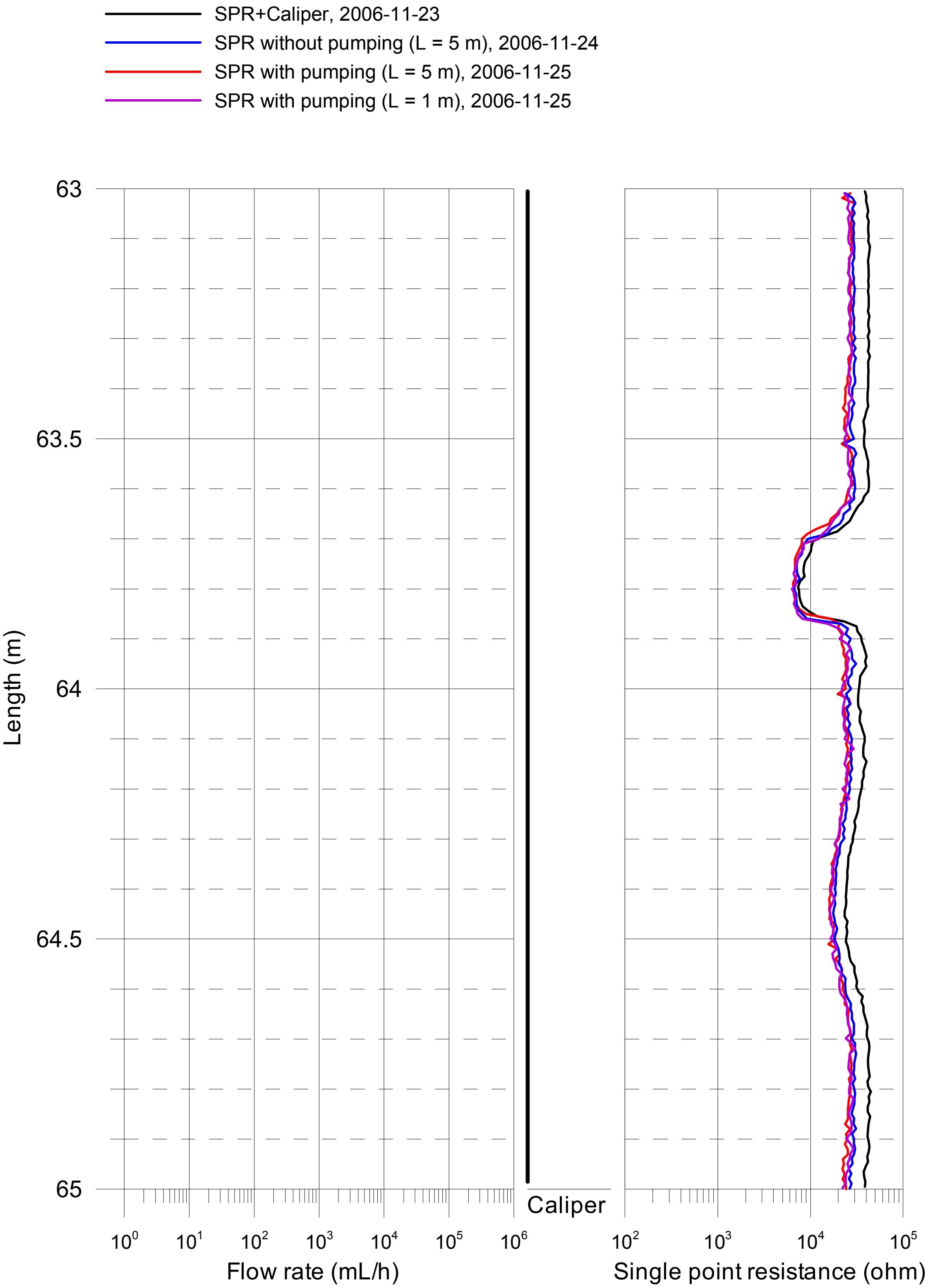
SPR and Caliper results after length correction



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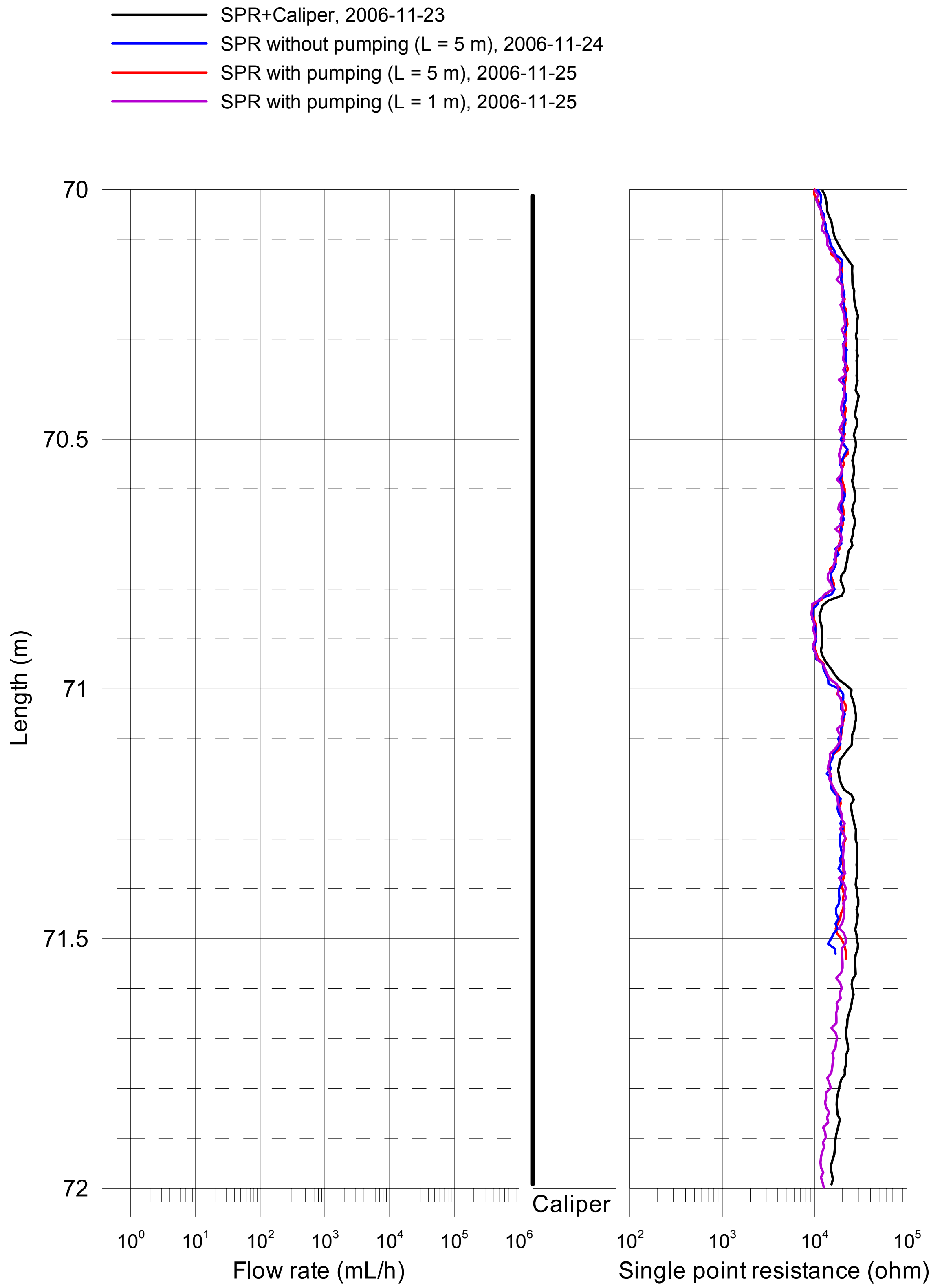
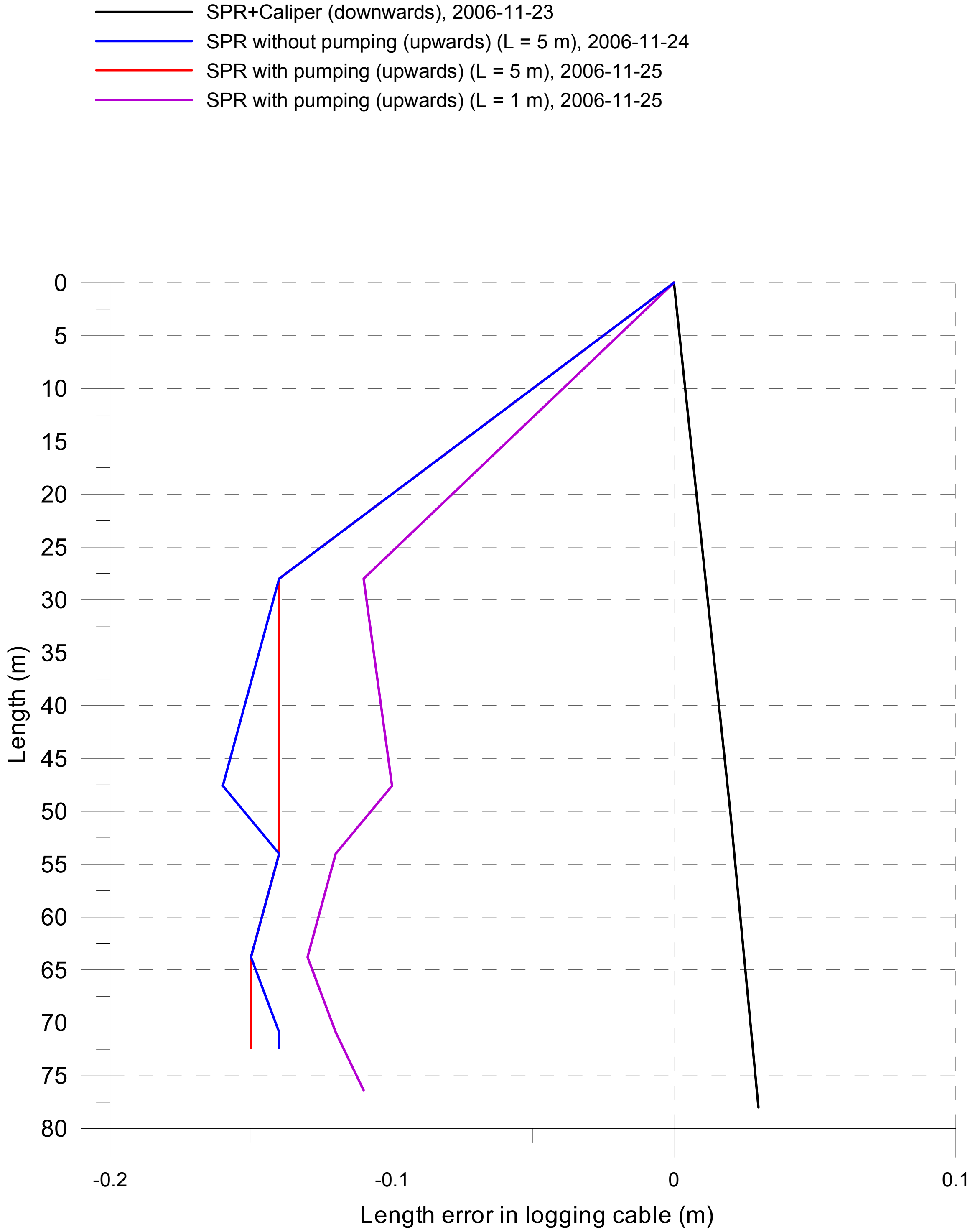
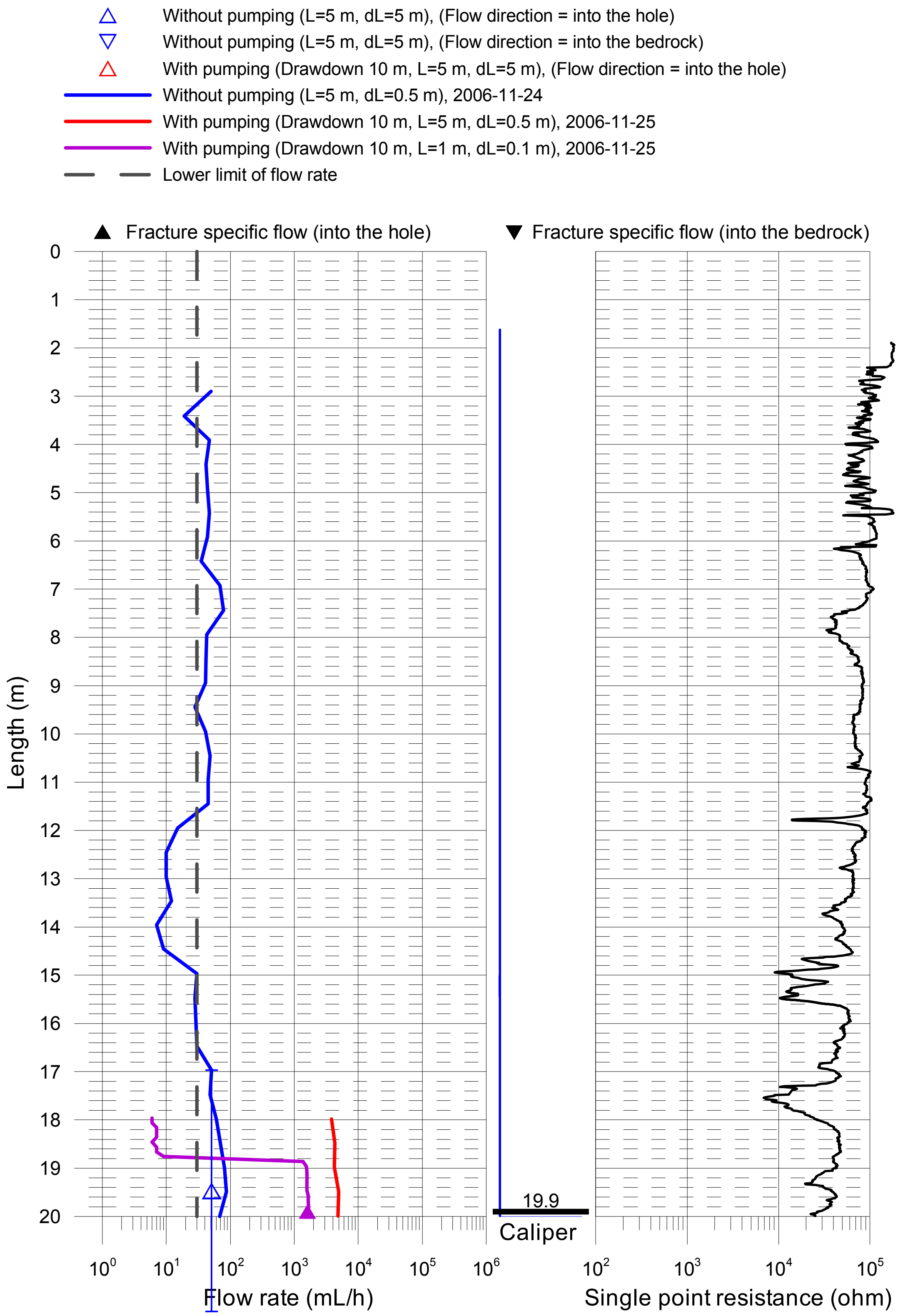
SPR and Caliper results after length correction

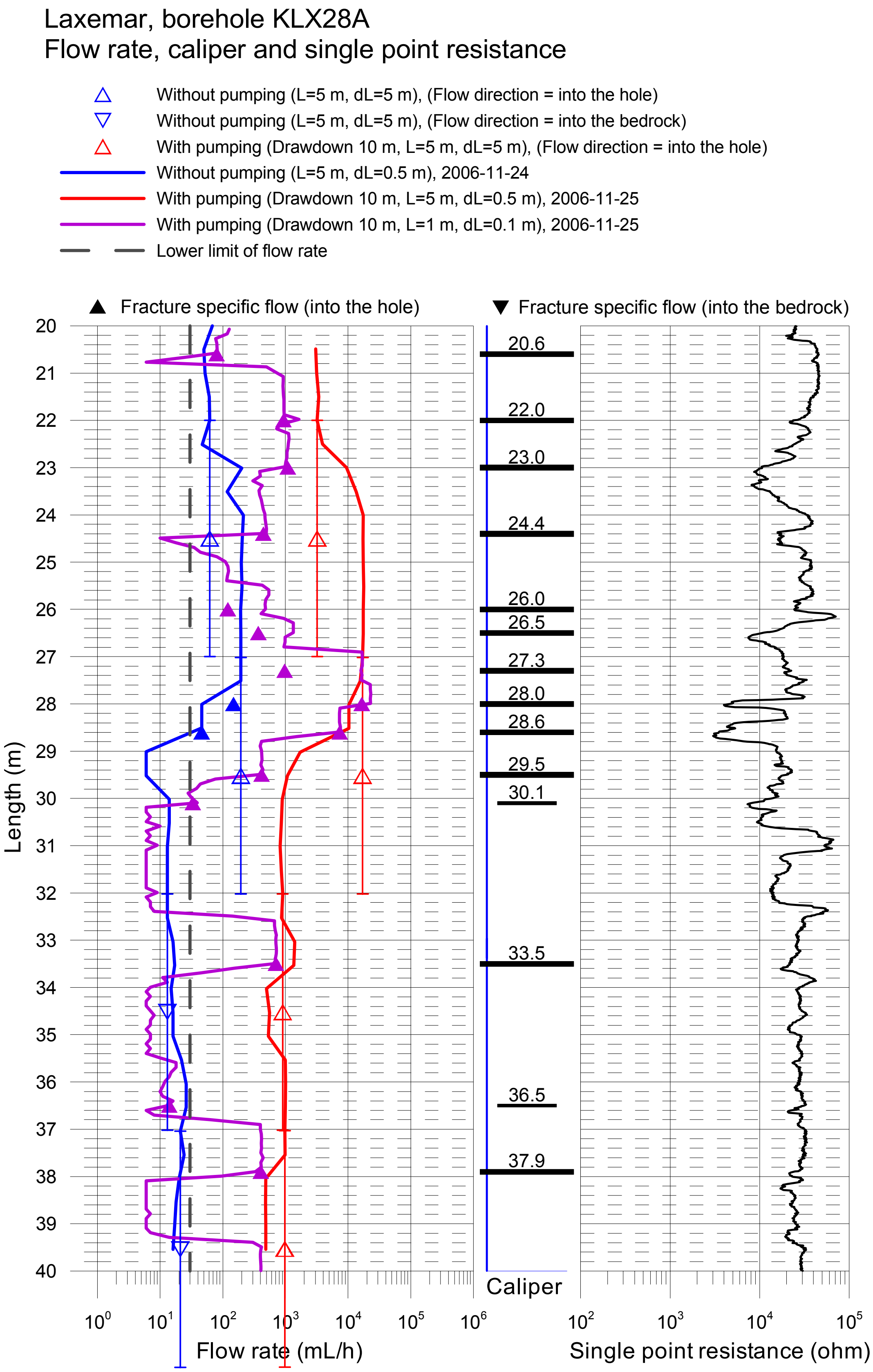


Laxemar, borehole KLX28A
Length correction

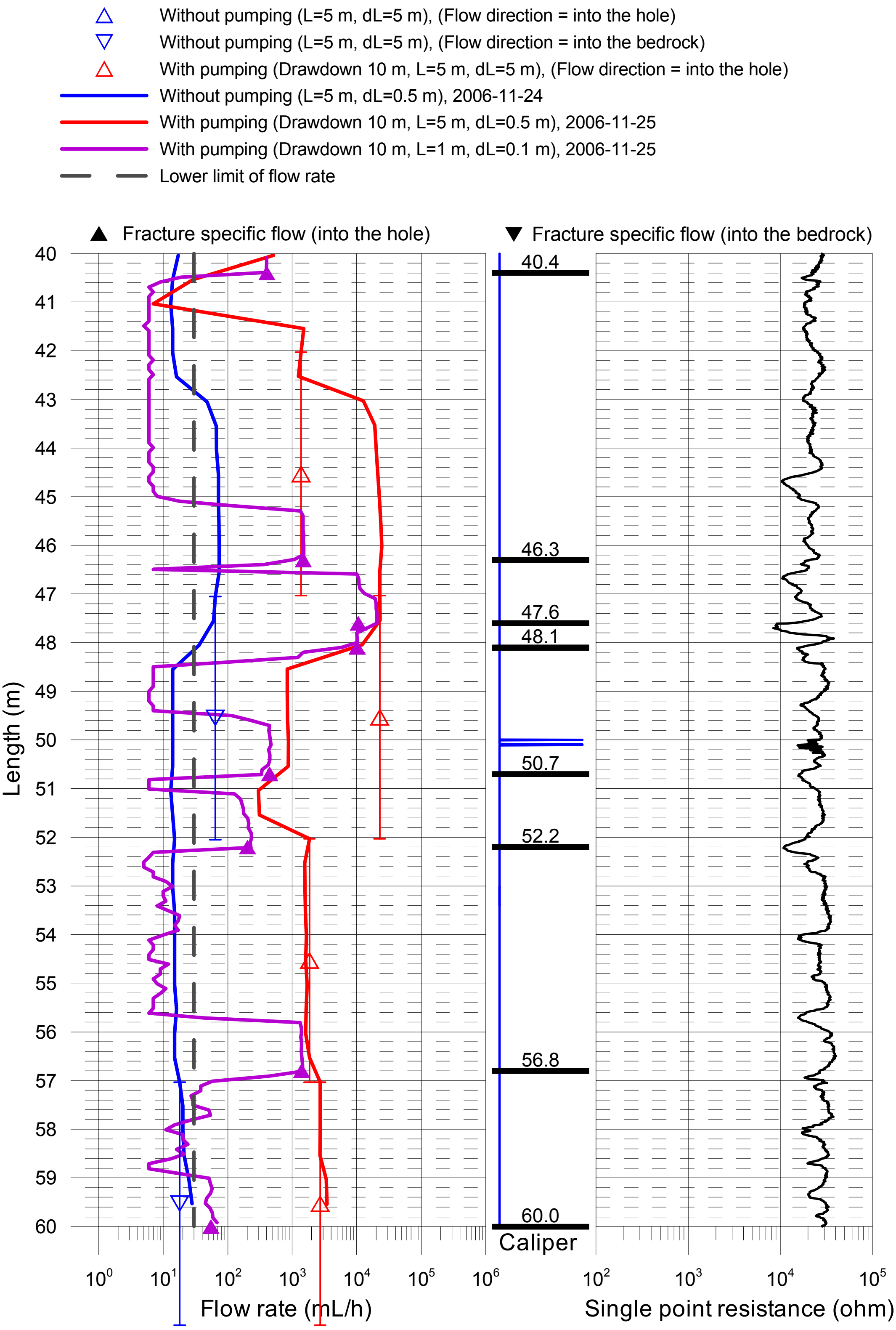


Laxemar, borehole KLX28A
Flow rate, caliper and single point resistance



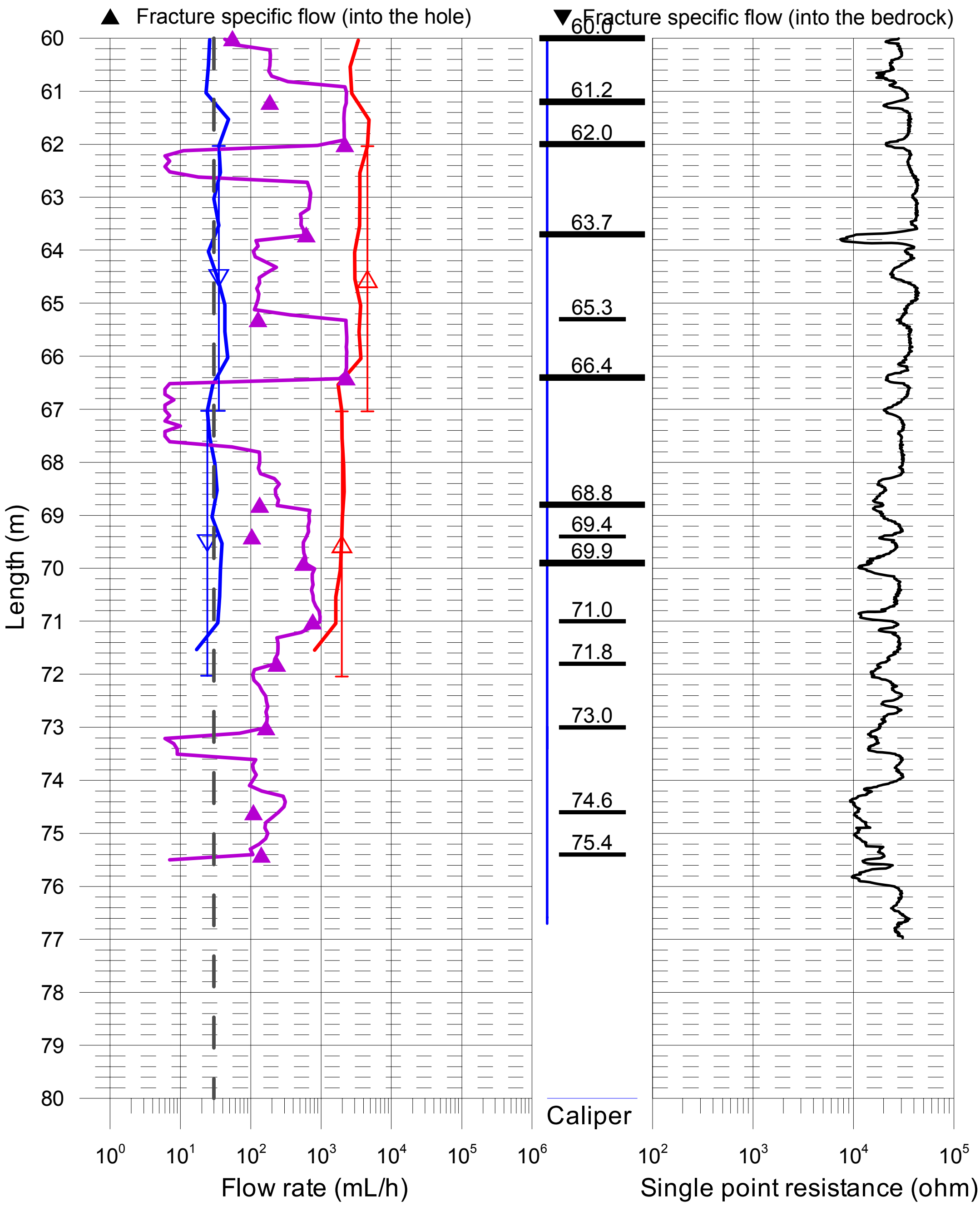

Laxemar, borehole KLX28A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (Drawdown 10 m, L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2006-11-24
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2006-11-25
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2006-11-25
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
20.6
22.0
23.0
24.4
26.0
26.5
27.3
28.0
28.6
29.5
30.1
33.5
36.5
37.9
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

Laxemar, borehole KLX28A
Flow rate, caliper and single point resistance

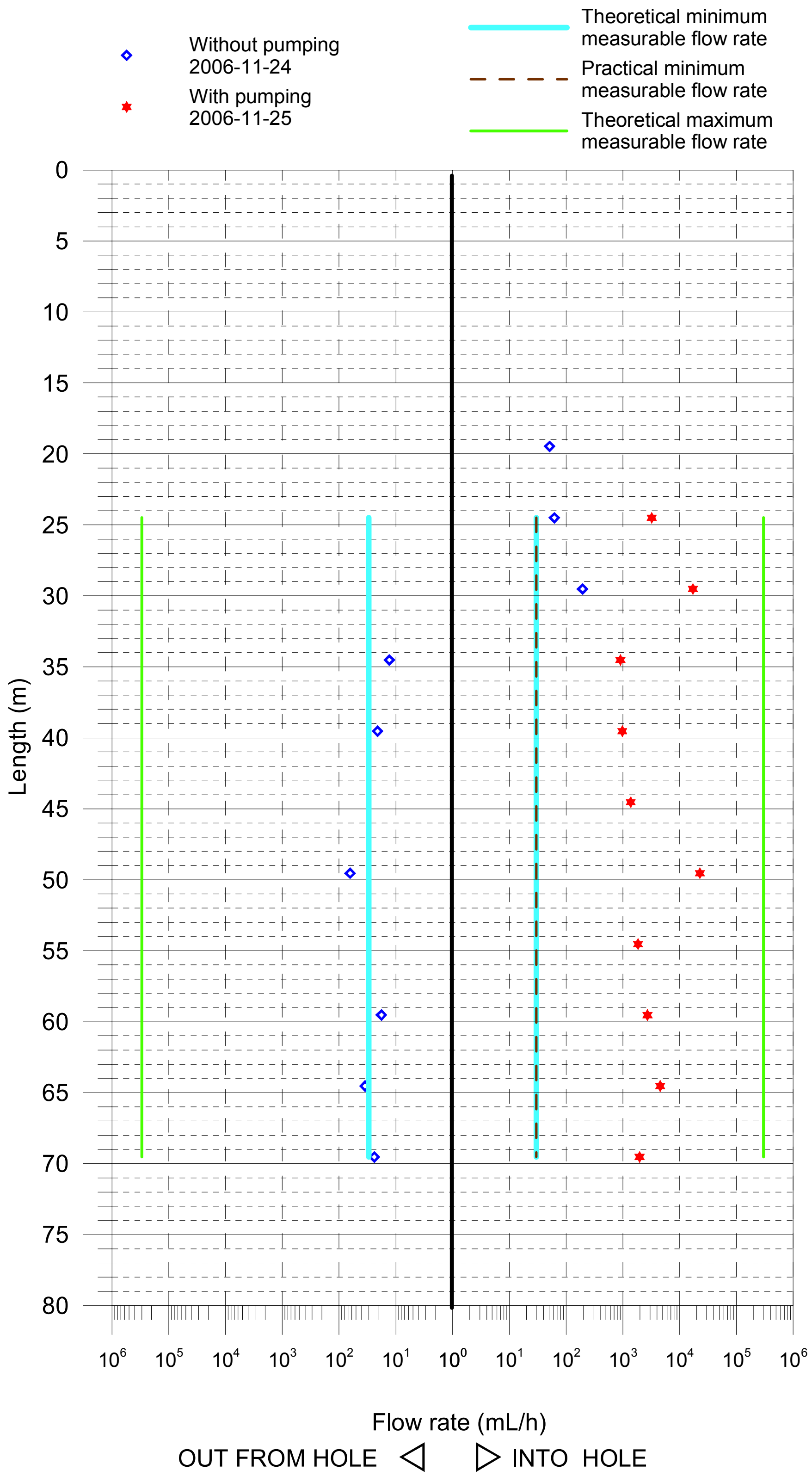


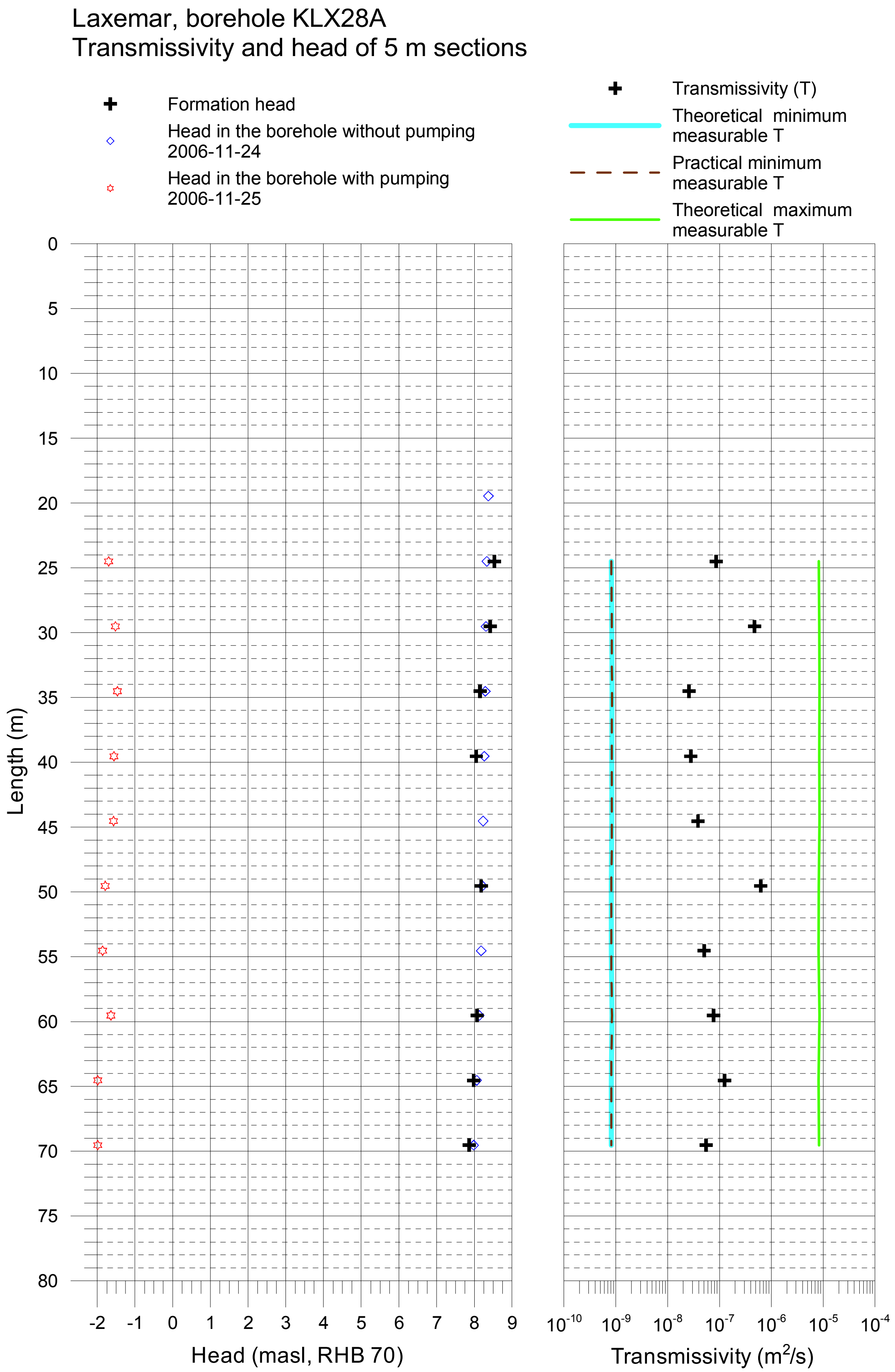
Laxemar, borehole KLX28A
Flow rate, caliper and single point resistance

- △ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- ▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
- △ With pumping (Drawdown 10 m, L=5 m, dL=5 m), (Flow direction = into the hole)
- Without pumping (L=5 m, dL=0.5 m), 2006-11-24
- With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2006-11-25
- With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2006-11-25
- Lower limit of flow rate

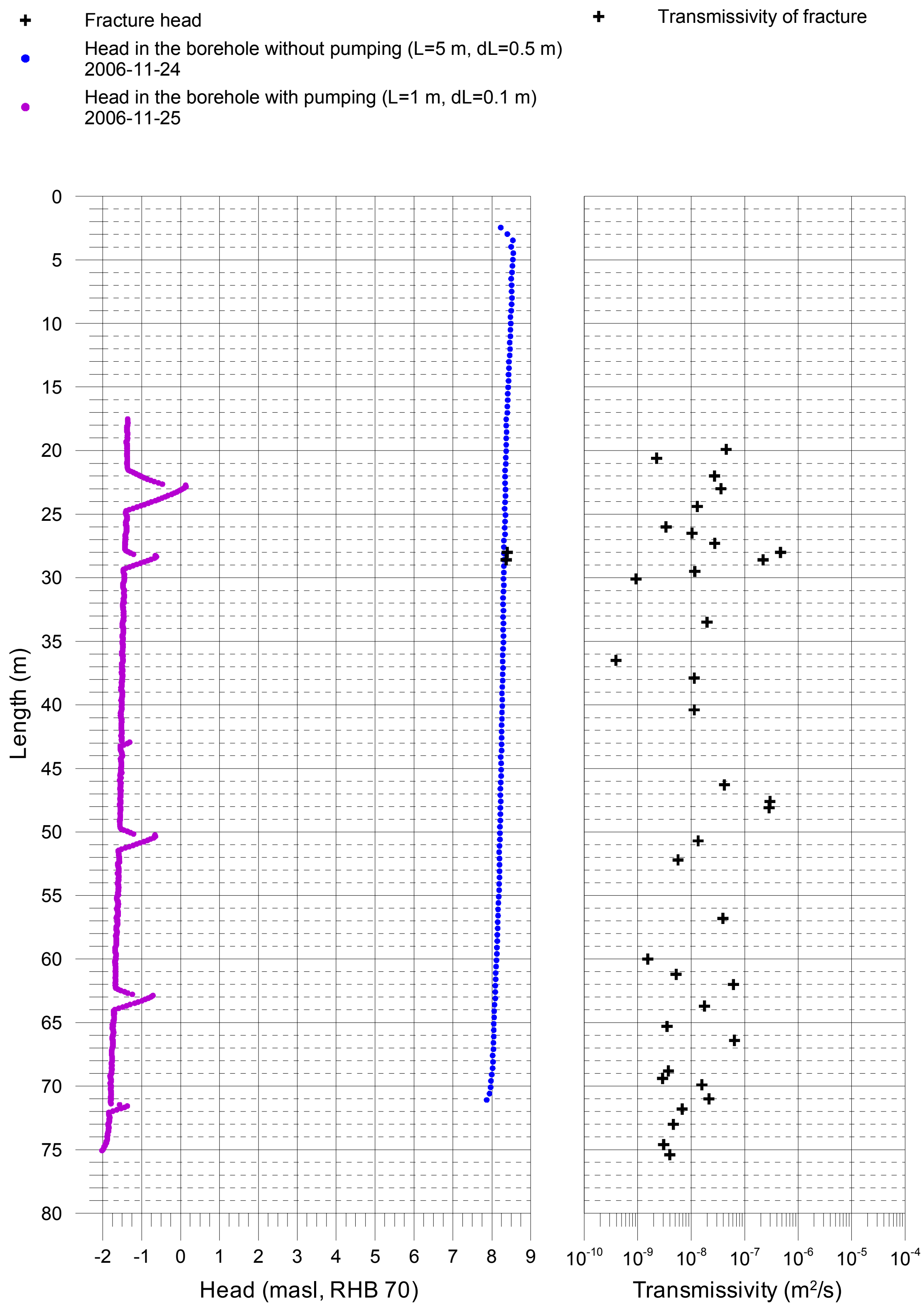


Laxemar, borehole KLX28A
Flow rates of 5 m sections




Laxemar, borehole KLX28A
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-11-24
Head in the borehole with pumping 2006-11-25
Transmissivity (T)
Theoretical minimum measurable T
Practical minimum measurable T
Theoretical maximum measurable T
Length (m)
Head (masl, RHB 70)
Transmissivity (m2/s)

Laxemar, borehole KLX28A
Transmissivity and head 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)
KLX28A	5.1	80.23	5A	20061124	15:46	20061125	9:19	20061126	8:11	5	0.5	2.33E–05	–

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 (–)
200100		88620		8.45	–1.55		–10.00	–	2.31E–06	–	–

Differnece flow logging – Sequential flow logging

Borehole ID	Secup L (m)	Seclow L (m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D- measl$_{LP}$ (m^2/s)	T_D- measl$_U$ (m^2/s)	Comments
KLX28A	16.97	21.97	5	1.42E–08	8.37	–	–	–	–	–	–	–	–	
KLX28A	22.00	27.00	5	1.72E–08	8.33	8.94E–07	–1.70	8.7E–08	8.5	30	8.2E–10	8.2E–10	8.2E–06	
KLX28A	27.02	32.02	5	5.39E–08	8.31	4.75E–06	–1.52	4.7E–07	8.4	30	8.4E–10	8.4E–10	8.4E–06	
KLX28A	32.02	37.02	5	–3.61E–09	8.29	2.51E–07	–1.47	2.6E–08	8.2	30	8.5E–10	8.5E–10	8.5E–06	
KLX28A	37.04	42.04	5	–5.83E–09	8.26	2.72E–07	–1.56	2.8E–08	8.1	30	8.4E–10	8.4E–10	8.4E–06	
KLX28A	42.04	47.04	5	–	8.23	3.81E–07	–1.57	3.8E–08	–	30	8.4E–10	8.4E–10	8.4E–06	
KLX28A	47.04	52.04	5	–1.78E–08	8.21	6.31E–06	–1.79	6.3E–07	8.2	30	8.2E–10	8.2E–10	8.2E–06	
KLX28A	52.04	57.04	5	–	8.18	5.14E–07	–1.86	5.1E–08	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX28A	57.03	62.03	5	–5.00E–09	8.13	7.53E–07	–1.64	7.7E–08	8.1	30	8.4E–10	8.4E–10	8.4E–06	
KLX28A	62.04	67.04	5	–9.72E–09	8.06	1.26E–06	–1.99	1.3E–07	8.0	30	8.2E–10	8.2E–10	8.2E–06	
KLX28A	67.04	72.04	5	–6.67E–09	7.98	5.47E–07	–1.99	5.5E–08	7.9	30	8.3E–10	8.3E–10	8.3E–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_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KLX28A	19.9	1	0.1	–	8.37	4.44E–07	–1.37	4.5E–08	–	
KLX28A	20.6	1	0.1	–	8.36	2.22E–08	–1.37	2.3E–09	–	
KLX28A	22.0	1	0.1	–	8.34	2.59E–07	–1.03	2.7E–08	–	
KLX28A	23.0	1	0.1	–	8.35	3.03E–07	0.06	3.6E–08	–	
KLX28A	24.4	1	0.1	–	8.33	1.24E–07	–1.07	1.3E–08	–	
KLX28A	26.0	1	0.1	–	8.33	3.33E–08	–1.39	3.4E–09	–	
KLX28A	26.5	1	0.1	–	8.34	1.03E–07	–1.40	1.0E–08	–	
KLX28A	27.3	1	0.1	–	8.31	2.70E–07	–1.43	2.7E–08	–	
KLX28A	28.0	1	0.1	4.11E–08	8.31	4.61E–06	–1.33	4.7E–07	8.4	
KLX28A	28.6	1	0.1	1.28E–08	8.31	2.04E–06	–0.79	2.2E–07	8.4	
KLX28A	29.5	1	0.1	–	8.31	1.16E–07	–1.47	1.2E–08	–	
KLX28A	30.1	1	0.1	–	8.30	9.17E–09	–1.44	9.3E–10	–	*
KLX28A	33.5	1	0.1	–	8.30	1.96E–07	–1.49	2.0E–08	–	
KLX28A	36.5	1	0.1	–	8.28	3.89E–09	–1.48	3.9E–10	–	*
KLX28A	37.9	1	0.1	–	8.28	1.13E–07	–1.50	1.1E–08	–	
KLX28A	40.4	1	0.1	–	8.26	1.13E–07	–1.51	1.1E–08	–	
KLX28A	46.3	1	0.1	–	8.23	4.14E–07	–1.54	4.2E–08	–	
KLX28A	47.6	1	0.1	–	8.23	2.94E–06	–1.54	3.0E–07	–	
KLX28A	48.1	1	0.1	–	8.22	2.83E–06	–1.54	2.9E–07	–	
KLX28A	50.7	1	0.1	–	8.21	1.24E–07	–0.89	1.4E–08	–	
KLX28A	52.2	1	0.1	–	8.20	5.61E–08	–1.58	5.7E–09	–	
KLX28A	56.8	1	0.1	–	8.16	3.89E–07	–1.64	3.9E–08	–	
KLX28A	60.0	1	0.1	–	8.12	1.53E–08	–1.66	1.6E–09	–	
KLX28A	61.2	1	0.1	–	8.10	5.17E–08	–1.67	5.2E–09	–	
KLX28A	62.0	1	0.1	–	8.09	6.08E–07	–1.67	6.2E–08	–	
KLX28A	63.7	1	0.1	–	8.07	1.71E–07	–1.41	1.8E–08	–	
KLX28A	65.3	1	0.1	–	8.05	3.50E–08	–1.73	3.5E–09	–	*
KLX28A	66.4	1	0.1	–	8.04	6.36E–07	–1.74	6.4E–08	–	
KLX28A	68.8	1	0.1	–	8.01	3.72E–08	–1.77	3.8E–09	–	
KLX28A	69.4	1	0.1	–	7.99	2.89E–08	–1.80	2.9E–09	–	*
KLX28A	69.9	1	0.1	–	7.97	1.56E–07	–1.80	1.6E–08	–	
KLX28A	71.0	1	0.1	–	7.88	2.11E–07	–1.79	2.2E–08	–	*
KLX28A	71.8	1	0.1	–	7.88	6.47E–08	–1.57	6.8E–09	–	*
KLX28A	73.0	1	0.1	–	7.88	4.58E–08	–1.86	4.7E–09	–	*
KLX28A	74.6	1	0.1	–	7.88	3.03E–08	–1.93	3.1E–09	–	*
KLX28A	75.4	1	0.1	–	7.88	3.94E–08	–1.93	4.0E–09	–	*

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

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.	Stabilized hydraulic head during the first pumping period. Elevation of water level in open borehole in the local co-ordinates system with z = 0 m.

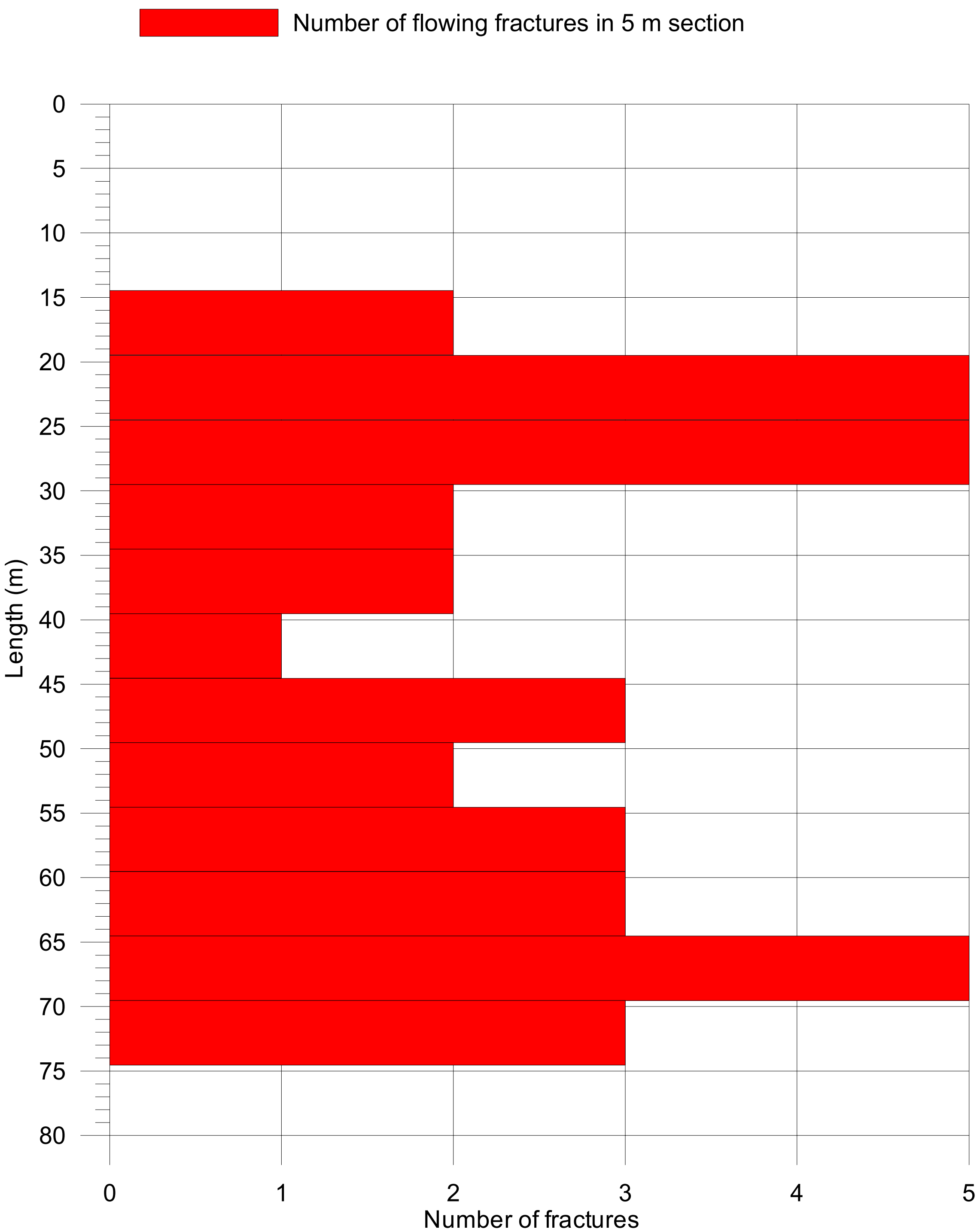
Explanations

Header	Unit	Explanations
h_2	m.a.s.l.	Stabilized 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 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 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 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).

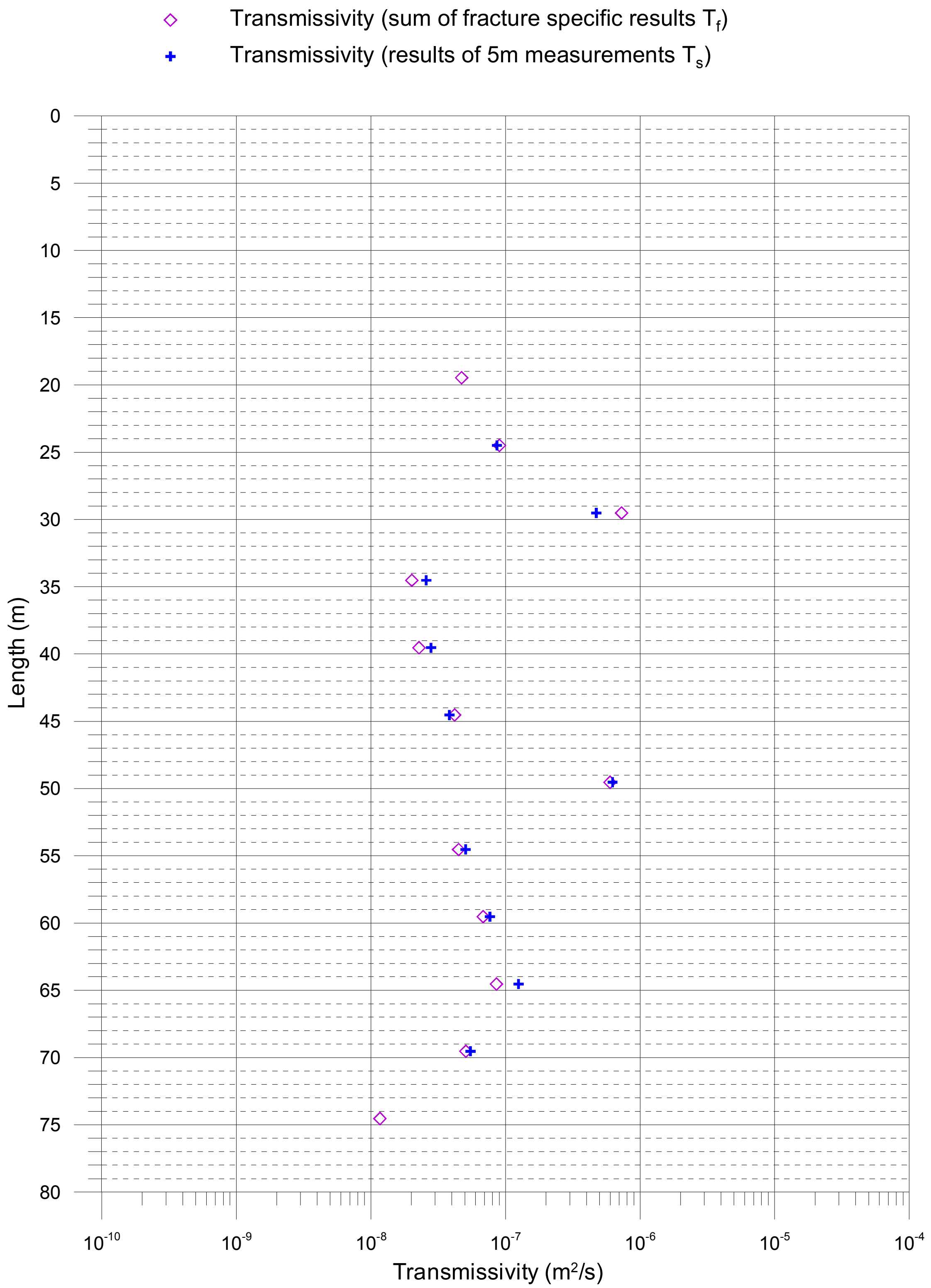
Calculation of conductive fracture frequency

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 100,000–1,000,000 (ml/h)
KLX28A	16.97	21.97	2	1	0	1	0	0
KLX28A	22.00	27.00	5	0	4	1	0	0
KLX28A	27.02	32.02	5	1	2	1	1	0
KLX28A	32.02	37.02	2	1	1	0	0	0
KLX28A	37.04	42.04	2	0	2	0	0	0
KLX28A	42.04	47.04	1	0	0	1	0	0
KLX28A	47.04	52.04	3	0	1	0	2	0
KLX28A	52.04	57.04	2	0	1	1	0	0
KLX28A	57.03	62.03	3	1	1	1	0	0
KLX28A	62.04	67.04	3	0	2	1	0	0
KLX28A	67.04	72.04	5	0	5	0	0	0
KLX28A	72.04	77.04	3	0	3	0	0	0

Laxemar, borehole KLX28A
Calculation of conductive fracture frequency

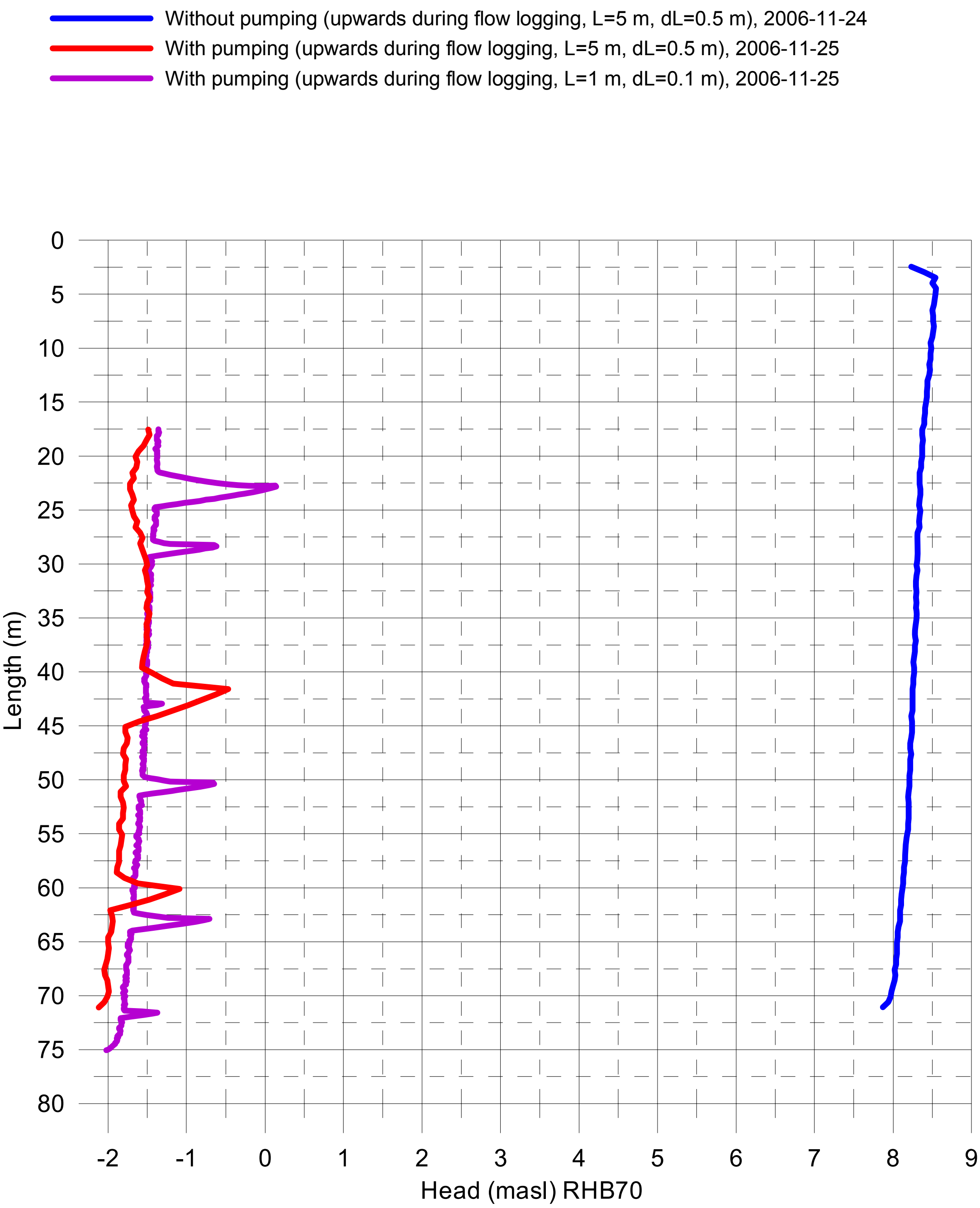


Laxemar, borehole KLX28A
Comparison between section transmissivity and fracture transmissivity

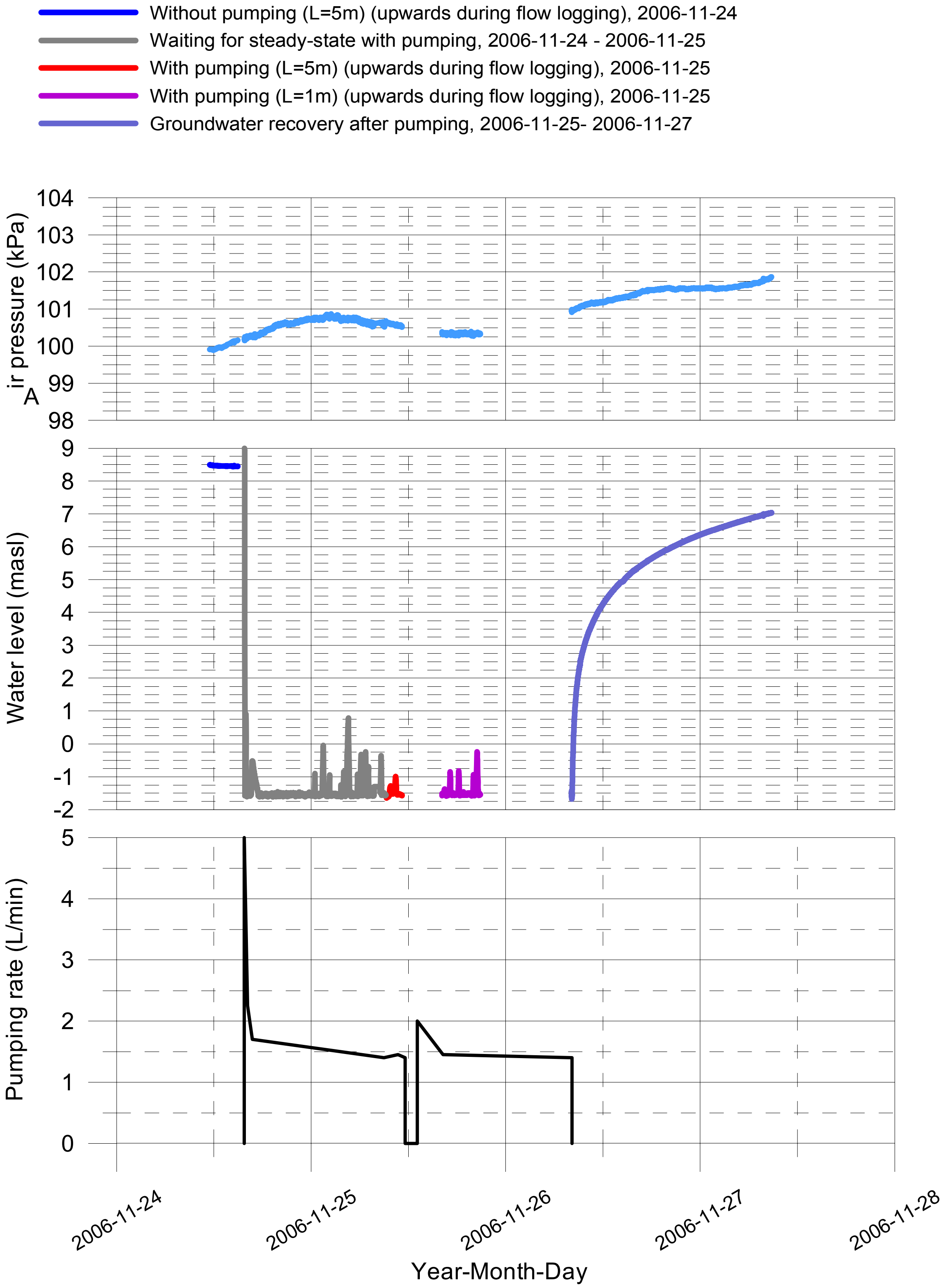


Laxemar, borehole KLX28A
Head in the borehole during flow logging

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)

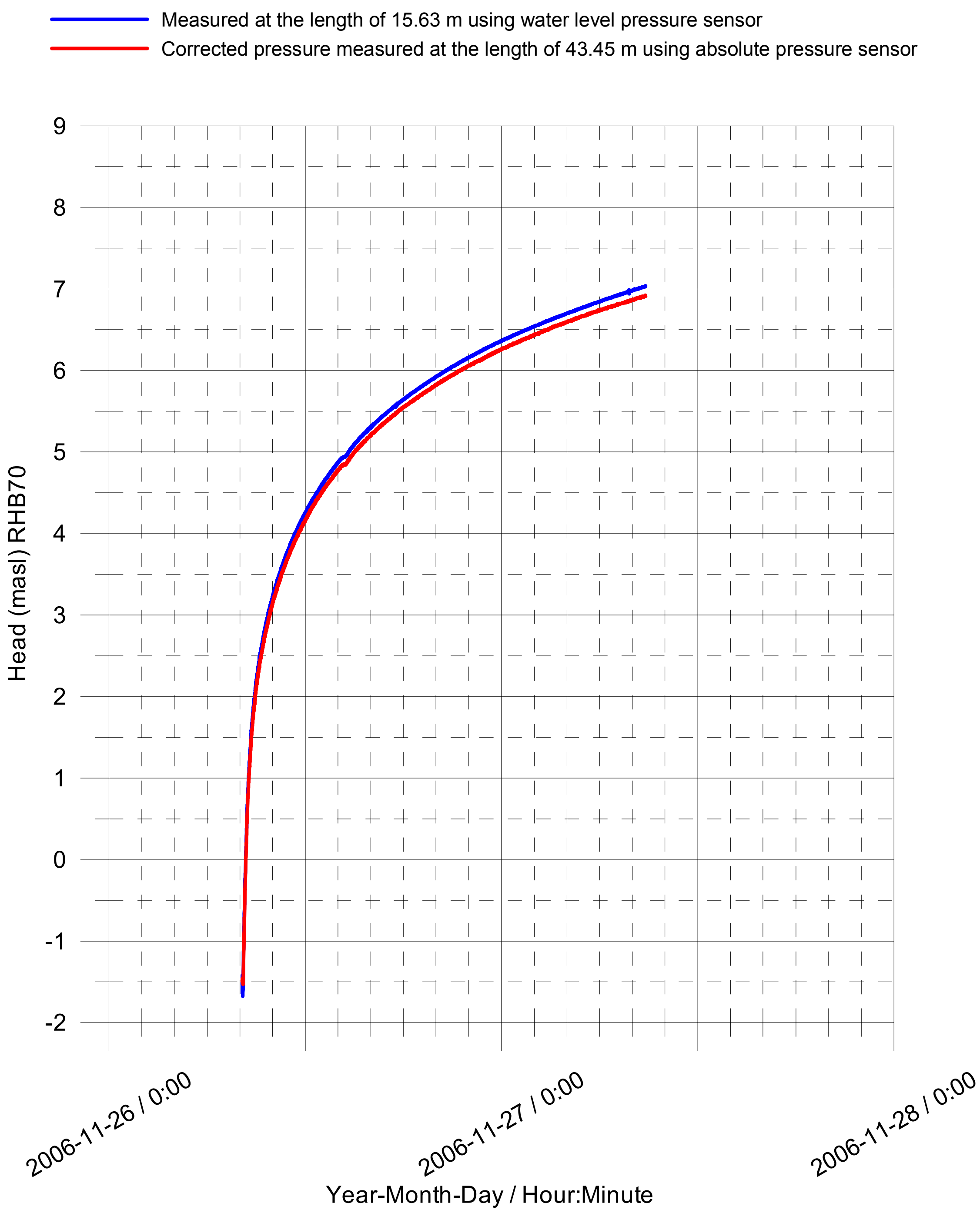


Laxemar, borehole KLX28A
Air pressure, water level in the borehole and pumping rate during flow logging



Laxemar, borehole KLX28A
Groundwater recovery after pumping

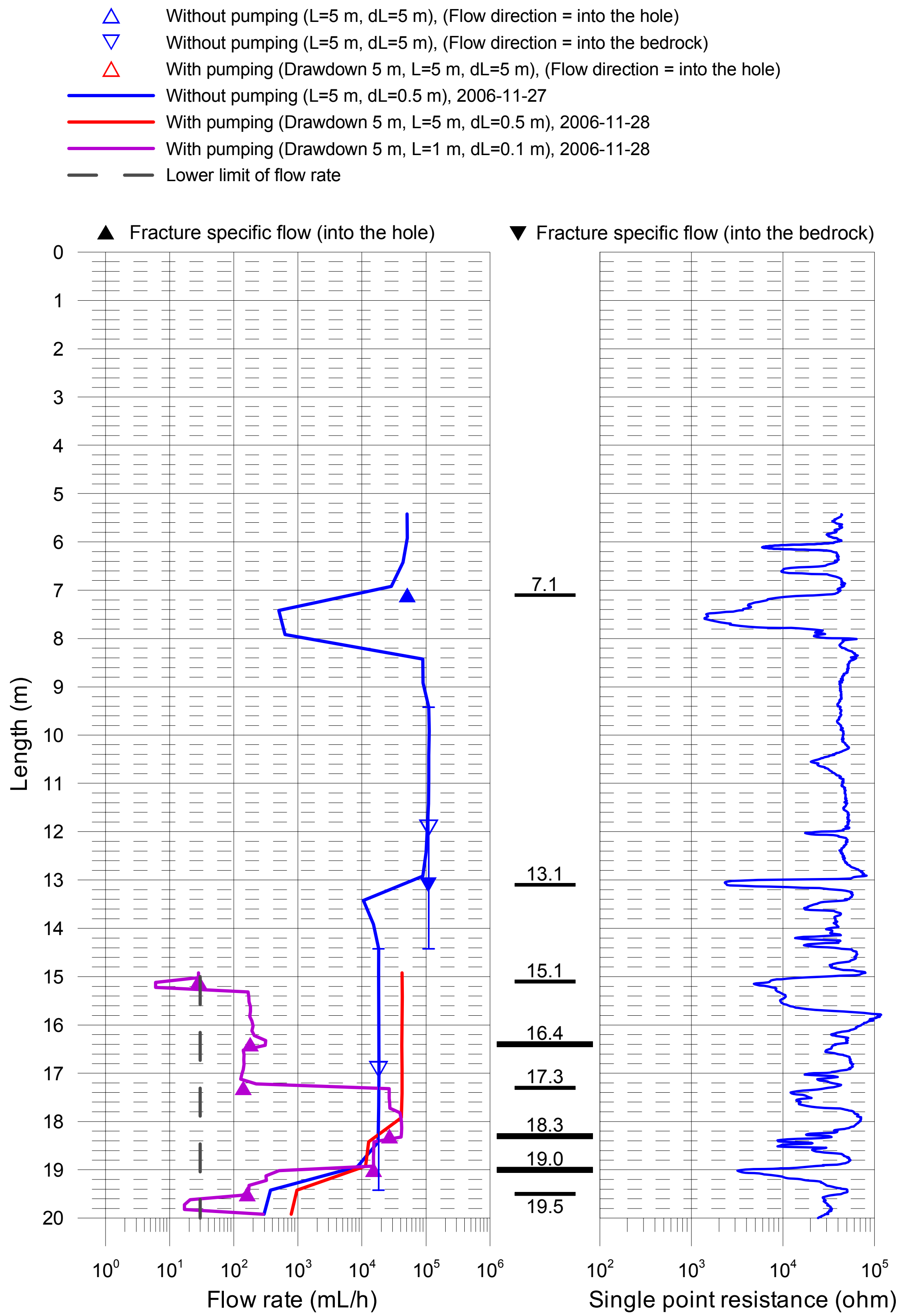
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)



Appendices, KLX29A

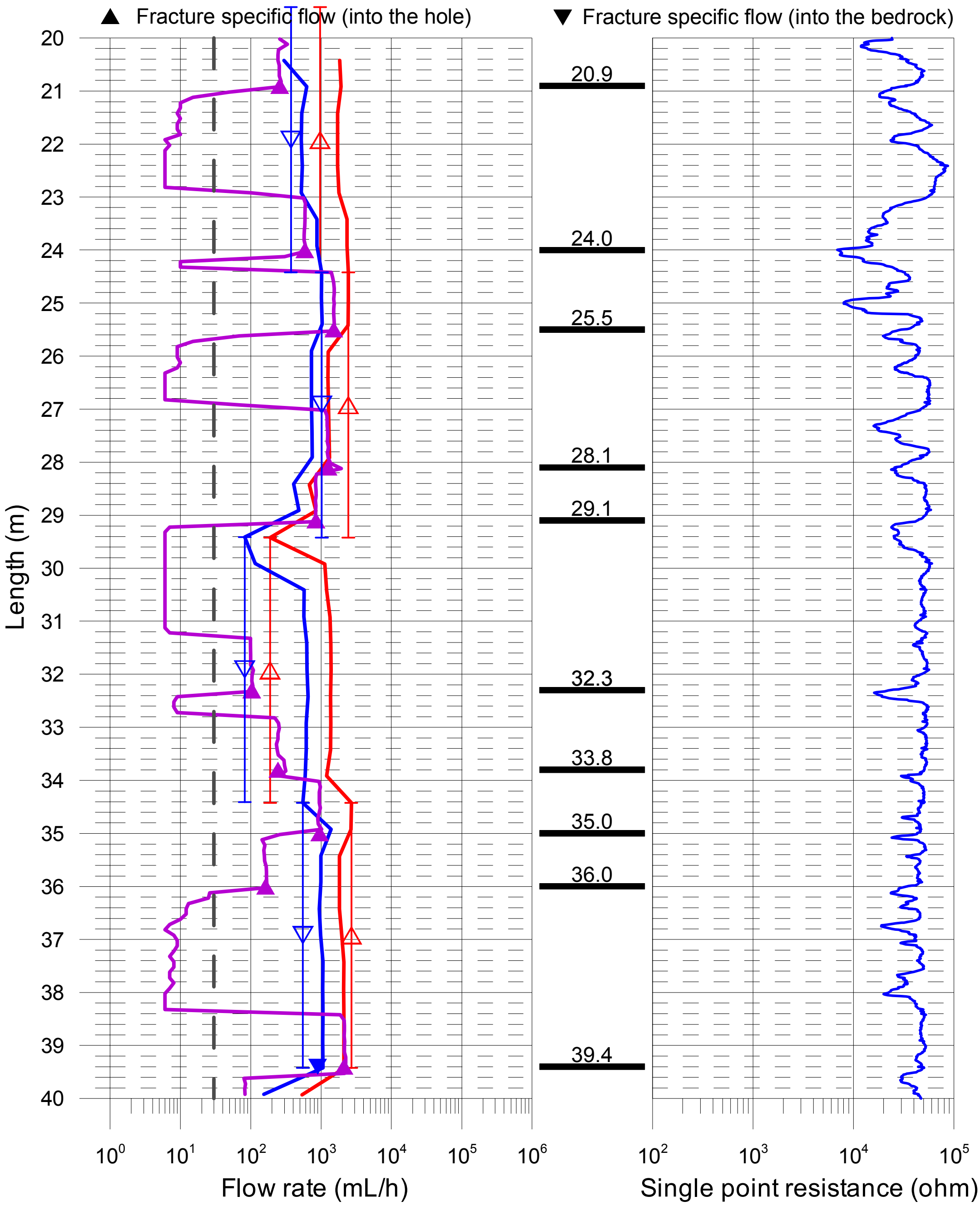
Appendices	KLX29A.1.1–KLX29A.1.3	Flow rate and single point resistance
Appendix	KLX29A.2.1	Plotted flow rates of 5 m sections
Appendix	KLX29A.2.2	Plotted transmissivity and head of 5 m sections
Appendix	KLX29A.3	Plotted transmissivity and head of detected fractures
Appendix	KLX29A.4	Basic test data
Appendix	KLX29A.5	Results of sequential flow logging
Appendix	KLX29A.6	Inferred flow anomalies from overlapping flow logging
Appendix	KLX29A.7	Explanations for the tables in Appendices 5–7
Appendix	KLX29A.8	Conductive fracture frequency
Appendix	KLX29A.9	Plotted conductive fracture frequency
Appendix	KLX29A.10	Comparison between section transmissivity and fracture transmissivity
Appendix	KLX29A.11.1	Head in the borehole during flow logging
Appendix	KLX29A.11.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	KLX29A.11.3	Groundwater recovery after pumping

Laxemar, borehole KLX29A
Flow rate, caliper and single point resistance

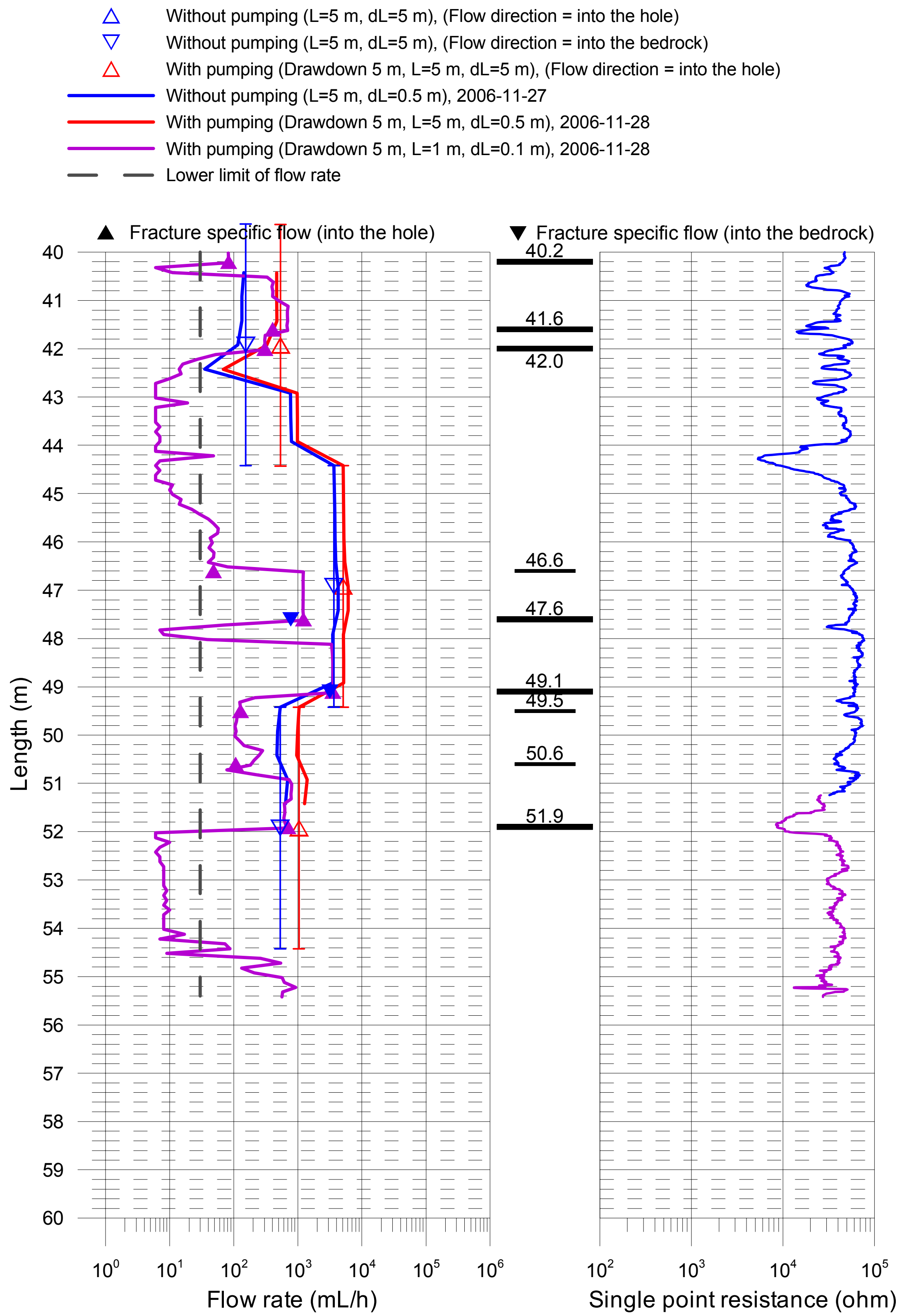


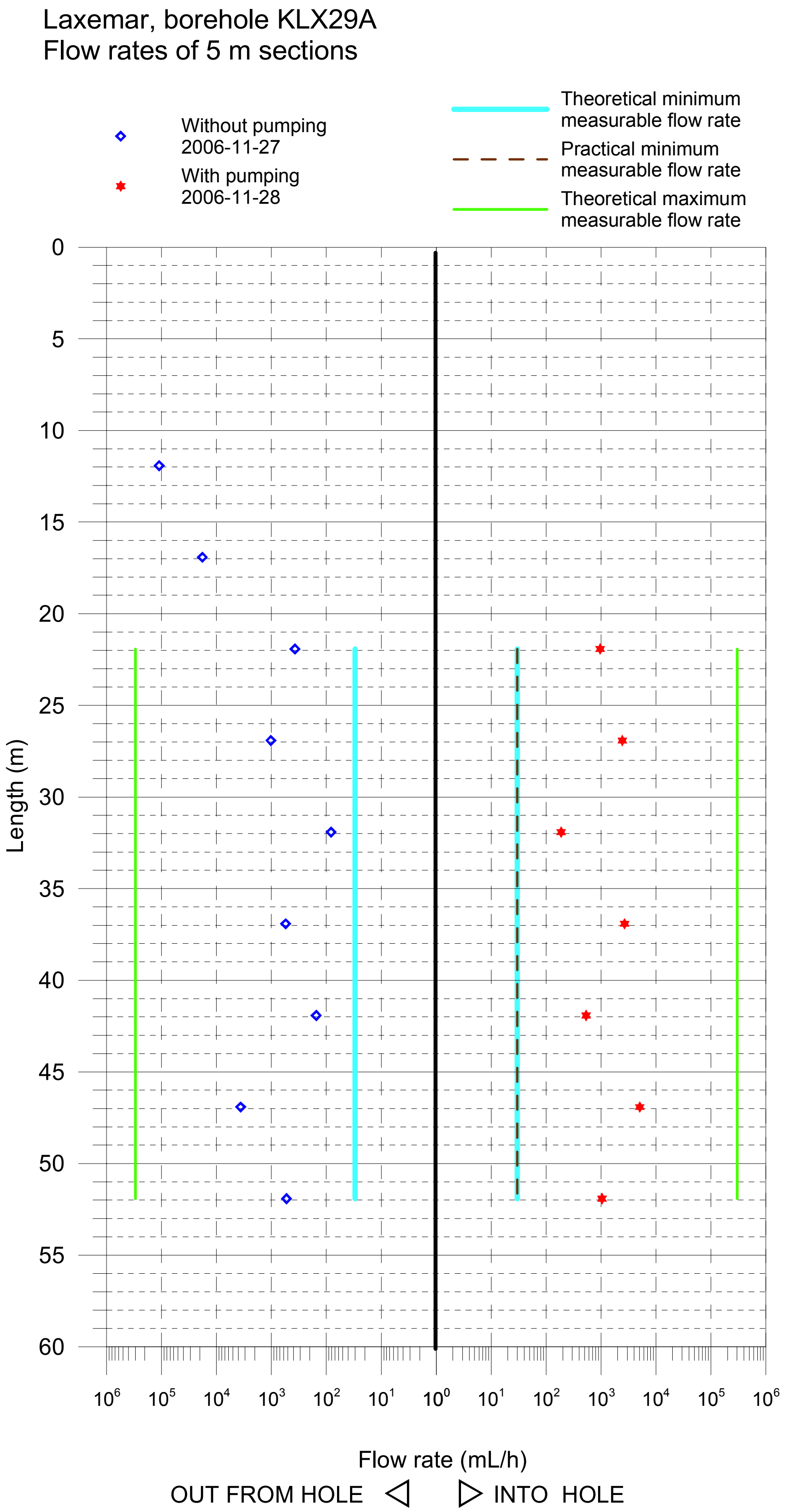
Laxemar, borehole KLX29A
Flow rate, caliper and single point resistance

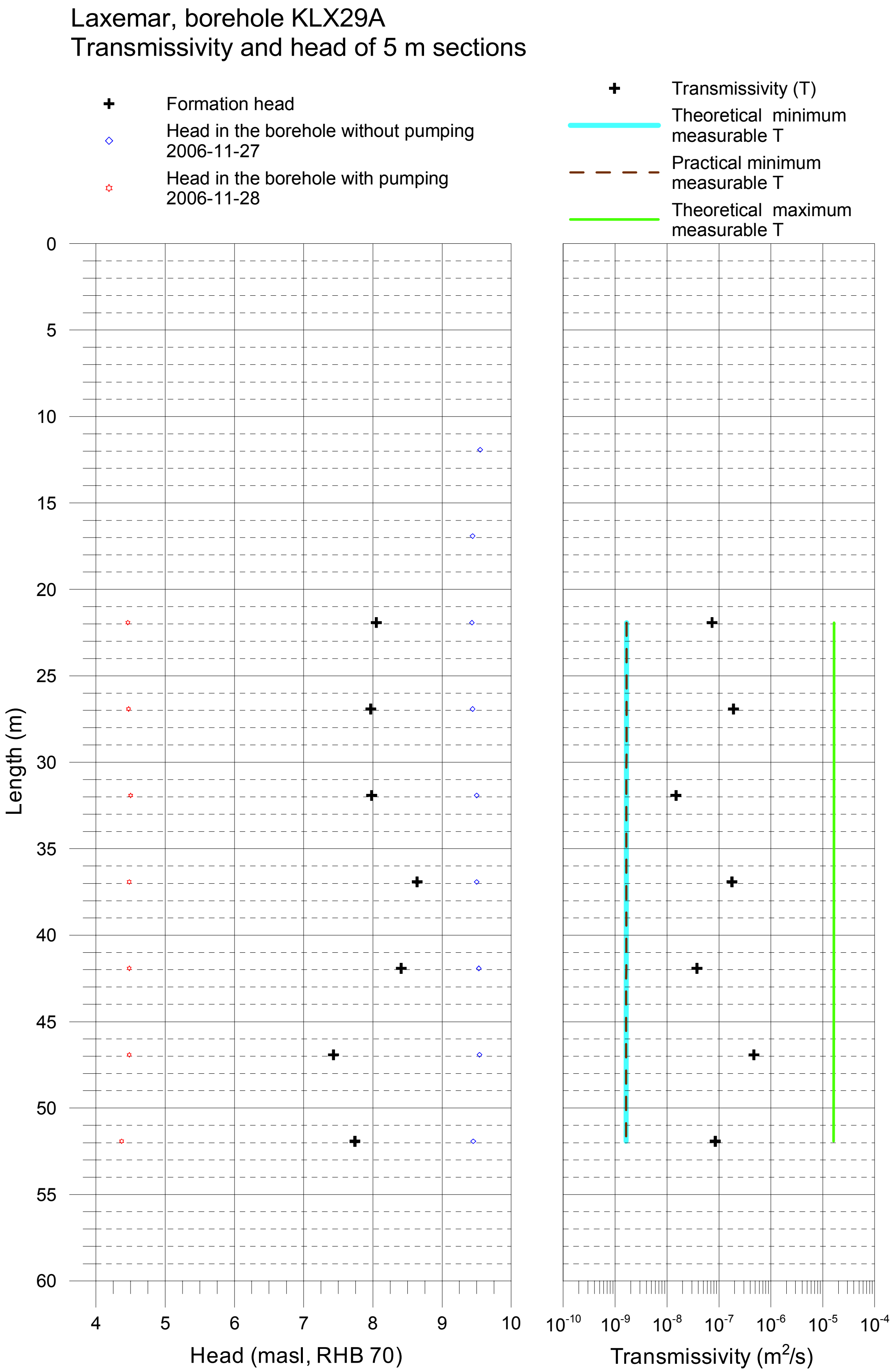
△ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
△ With pumping (Drawdown 5 m, L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2006-11-27
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2006-11-28
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2006-11-28
Lower limit of flow rate



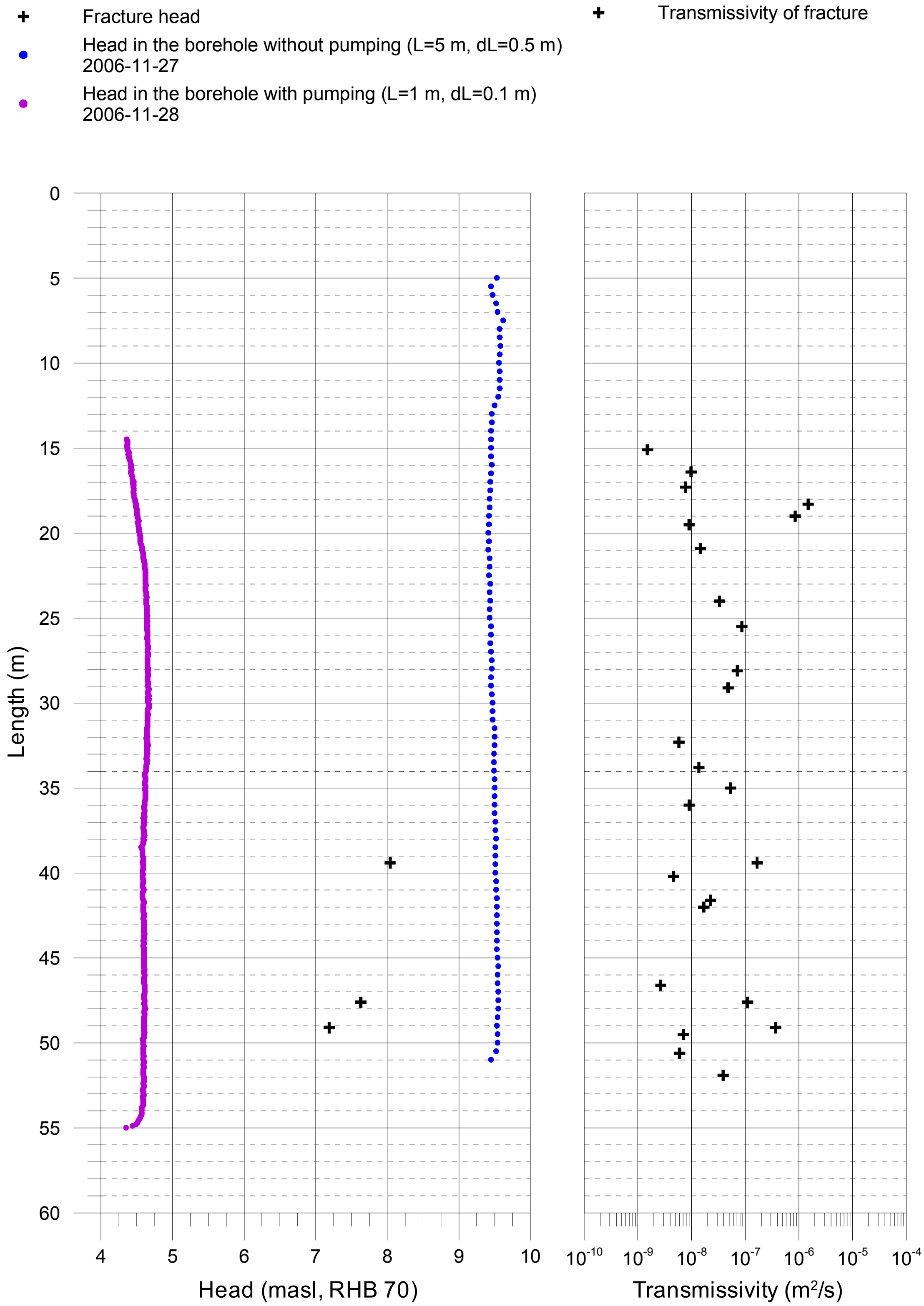
Laxemar, borehole KLX29A
Flow rate, caliper and single point resistance




Laxemar, borehole KLX29A
Flow rates of 5 m sections
Without pumping
2006-11-27
With pumping
2006-11-28
Theoretical minimum
measurable flow rate
Practical minimum
measurable flow rate
Theoretical maximum
measurable flow rate
Length (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
10^6 10^5 10^4 10^3 10^2 10^1 10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
OUT FROM HOLE
INTO HOLE


Laxemar, borehole KLX29A
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-11-27
Head in the borehole with pumping 2006-11-28
Transmissivity (T)
Theoretical minimum measurable T
Practical minimum measurable T
Theoretical maximum measurable T
Length (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
4
5
6
7
8
9
10
Head (masl, RHB 70)
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Transmissivity (m^2/s)

Laxemar, borehole KLX29A
Transmissivity and head 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)
KLX29A	2.35	60.25	5A	20061127	16:18	20061128	8:11	20061128	15:36	5	0.5	1.57E–04	–

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 (–)
88920		110400		9.38	4.26		–5.12	–	3.03E–05	–	–

Difference flow logging – Sequential flow logging

Borehole ID	Secup L (m)	Seclow L (m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D- measl$_{LP}$ (m^2/s)	T_D- measl$_U$ (m^2/s)	Comments
KLX29A	9.42	14.42	5	–3.06E–05	9.55	–	–	–	–	–	–	–	–	
KLX29A	14.42	19.42	5	–5.03E–06	9.44	–	–	–	–	–	–	–	–	
KLX29A	19.42	24.42	5	–1.03E–07	9.43	2.68E–07	4.46	7.4E–08	8.1	30	1.7E–09	1.7E–09	1.7E–05	
KLX29A	24.42	29.42	5	–2.83E–07	9.44	6.75E–07	4.47	1.9E–07	8.0	30	1.7E–09	1.7E–09	1.7E–05	
KLX29A	29.42	34.42	5	–2.28E–08	9.50	5.22E–08	4.50	1.5E–08	8.0	30	1.6E–09	1.6E–09	1.6E–05	
KLX29A	34.42	39.42	5	–1.53E–07	9.50	7.44E–07	4.48	1.8E–07	8.6	30	1.6E–09	1.6E–09	1.6E–05	
KLX29A	39.43	44.43	5	–4.25E–08	9.53	1.49E–07	4.48	3.7E–08	8.4	30	1.6E–09	1.6E–09	1.6E–05	
KLX29A	44.42	49.42	5	–1.01E–06	9.54	1.41E–06	4.48	4.7E–07	7.4	30	1.6E–09	1.6E–09	1.6E–05	
KLX29A	49.42	54.42	5	–1.47E–07	9.45	2.89E–07	4.37	8.5E–08	7.7	30	1.6E–09	1.6E–09	1.6E–05	

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_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KLX29A	7.1	1	0.1	1.41E-05	9.56	–	–	–	–	*
KLX29A	13.1	1	0.1	–3.00E–05	9.46	–	–	–	–	*
KLX29A	15.1	1	0.1	–	9.45	7.78E–09	4.37	1.5E–09	–	*
KLX29A	16.4	1	0.1	–	9.45	5.03E–08	4.42	9.9E–09	–	
KLX29A	17.3	1	0.1	–	9.44	3.92E–08	4.45	7.8E–09	–	*
KLX29A	18.3	1	0.1	–	9.43	7.47E–06	4.49	1.5E–06	–	
KLX29A	19.0	1	0.1	–	9.42	4.22E–06	4.51	8.5E–07	–	
KLX29A	19.5	1	0.1	–	9.42	4.47E–08	4.52	9.0E–09	–	*
KLX29A	20.9	1	0.1	–	9.41	7.17E–08	4.58	1.5E–08	–	
KLX29A	24.0	1	0.1	–	9.44	1.62E–07	4.63	3.3E–08	–	
KLX29A	25.5	1	0.1	–	9.45	4.19E–07	4.65	8.6E–08	–	
KLX29A	28.1	1	0.1	–	9.46	3.47E–07	4.66	7.2E–08	–	
KLX29A	29.1	1	0.1	–	9.45	2.34E–07	4.66	4.8E–08	–	
KLX29A	32.3	1	0.1	–	9.50	2.86E–08	4.65	5.8E–09	–	
KLX29A	32.3	1	0.1	–	9.50	2.86E–08	4.65	5.8E–09	–	
KLX29A	33.8	1	0.1	–	9.49	6.75E–08	4.63	1.4E–08	–	
KLX29A	35.0	1	0.1	–	9.50	2.64E–07	4.62	5.4E–08	–	
KLX29A	36.0	1	0.1	–	9.50	4.47E–08	4.61	9.1E–09	–	
KLX29A	39.4	1	0.1	–2.49E–07	9.51	5.86E–07	4.59	1.7E–07	8.0	
KLX29A	40.2	1	0.1	–	9.51	2.31E–08	4.58	4.6E–09	–	
KLX29A	41.6	1	0.1	–	9.53	1.12E–07	4.59	2.3E–08	–	
KLX29A	42.0	1	0.1	–	9.53	8.44E–08	4.59	1.7E–08	–	
KLX29A	46.6	1	0.1	–	9.54	1.33E–08	4.61	2.7E–09	–	*
KLX29A	47.6	1	0.1	–2.16E–07	9.55	3.39E–07	4.61	1.1E–07	7.6	
KLX29A	49.1	1	0.1	–8.78E–07	9.53	9.72E–07	4.60	3.7E–07	7.2	
KLX29A	49.5	1	0.1	–	9.54	3.53E–08	4.60	7.1E–09	–	*
KLX29A	50.6	1	0.1	–	9.50	2.97E–08	4.59	6.0E–09	–	*
KLX29A	51.9	1	0.1	–	9.53	1.93E–07	4.59	3.9E–08	–	

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

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.	Stabilized hydraulic head during the first pumping period. Elevation of water level in open borehole in the local co-ordinates system with z = 0 m.

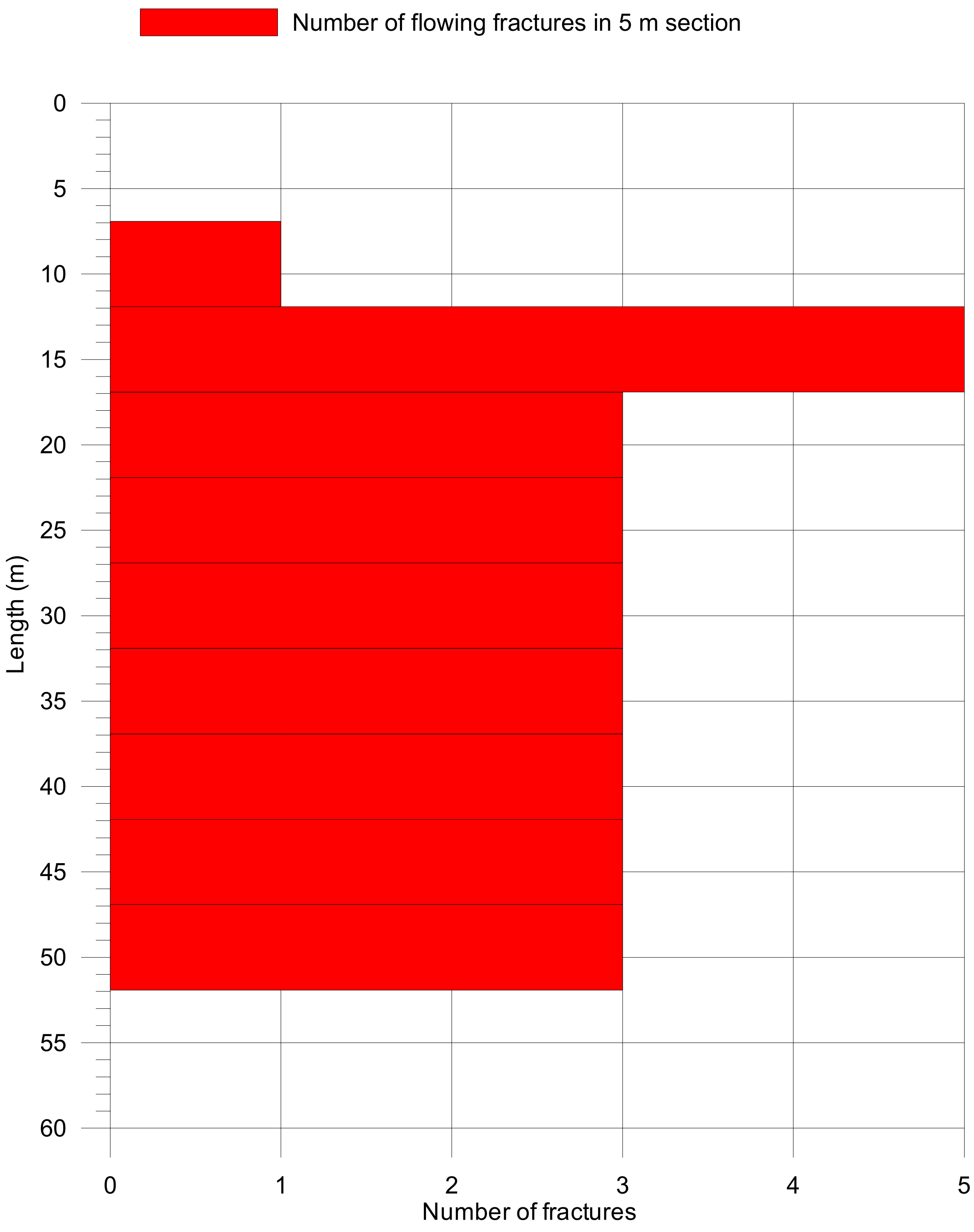
Explanations

Header	Unit	Explanations
h_2	m.a.s.l.	Stabilized 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 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 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 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	ºC	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	ºC	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).

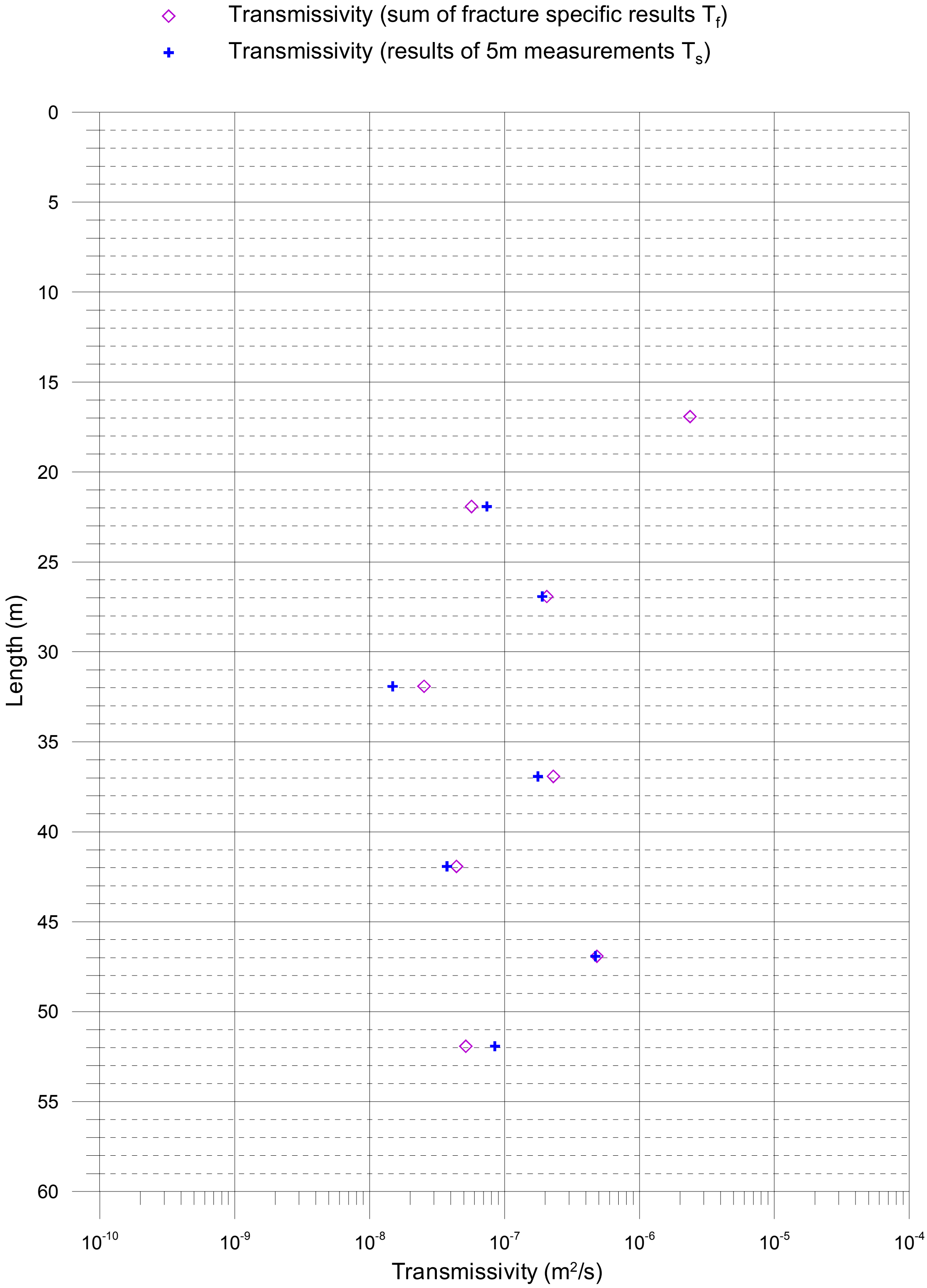
Calculation of conductive fracture frequency

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 100,000–1,000,000 (ml/h)
KLX29A	9.42	14.42	1	0	0	0	0	0
KLX29A	14.42	19.42	5	1	2	0	2	0
KLX29A	19.42	24.42	3	0	3	0	0	0
KLX29A	24.42	29.42	3	0	1	2	0	0
KLX29A	29.42	34.42	3	0	3	0	0	0
KLX29A	34.42	39.42	3	0	2	1	0	0
KLX29A	39.43	44.43	3	1	2	0	0	0
KLX29A	44.42	49.42	3	1	0	2	0	0
KLX29A	49.42	54.42	3	0	3	0	0	0

Laxemar, borehole KLX29A
Calculation of conductive fracture frequency

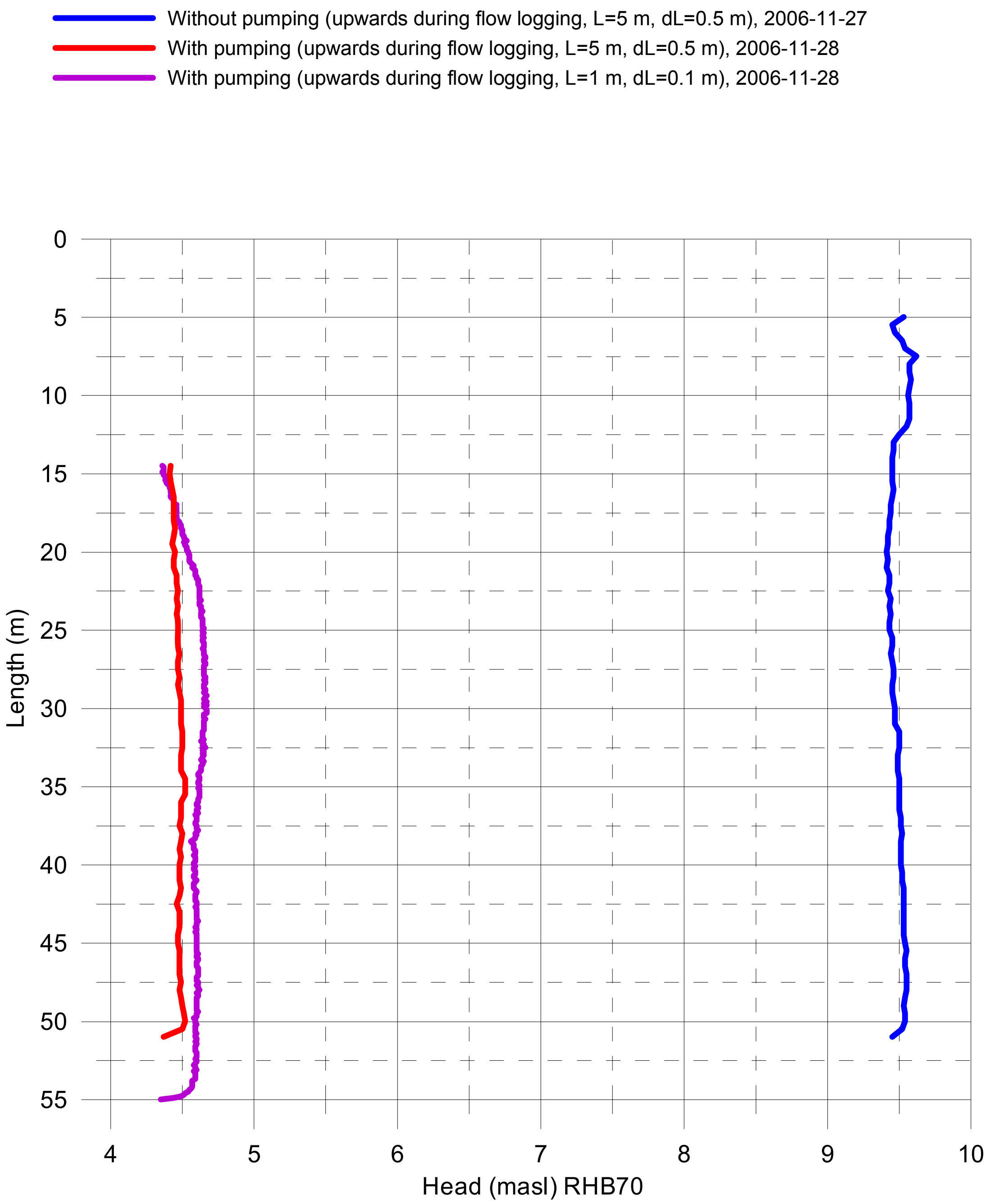


Laxemar, borehole KLX29A
Comparison between section transmissivity and fracture transmissivity

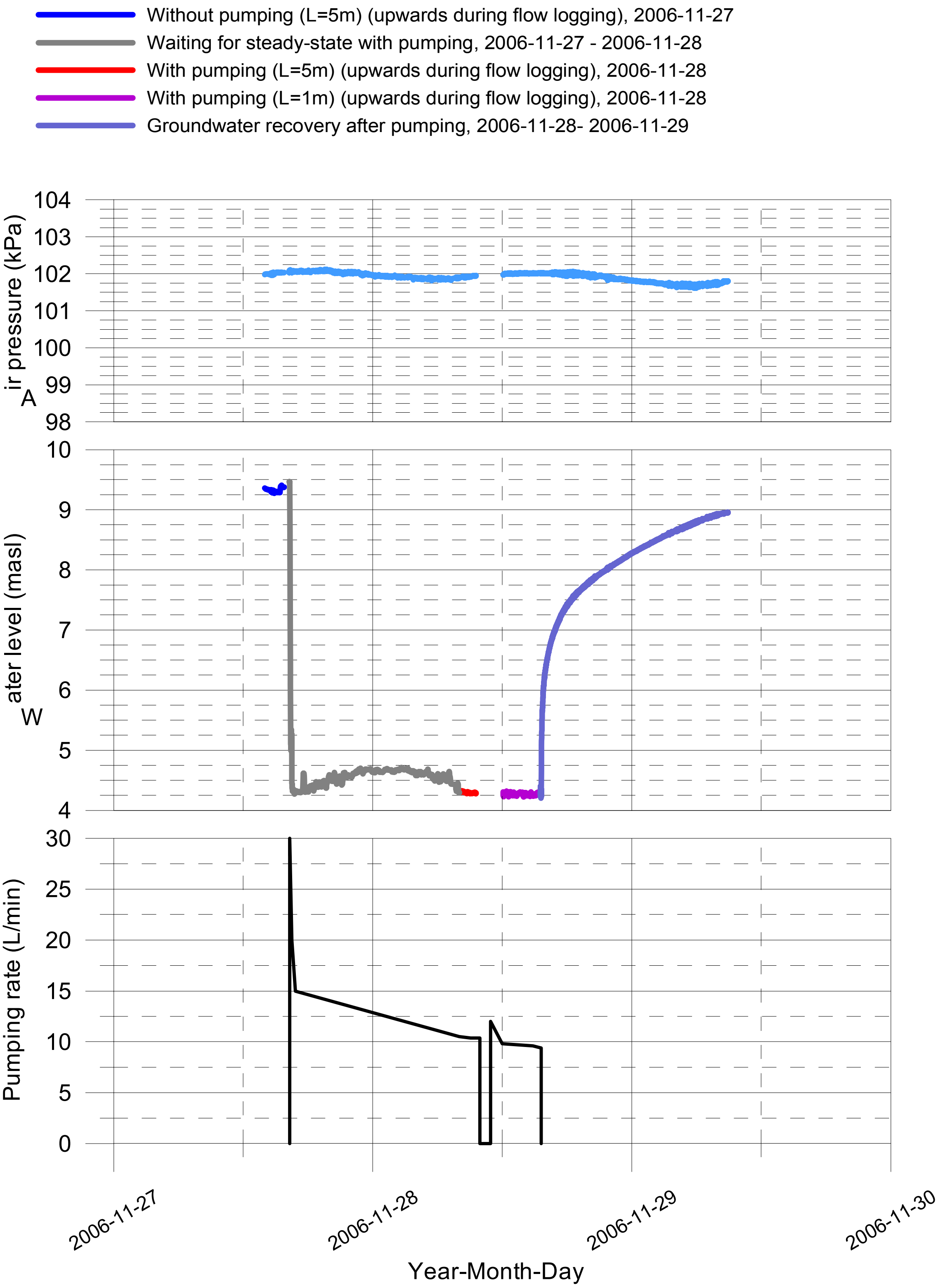


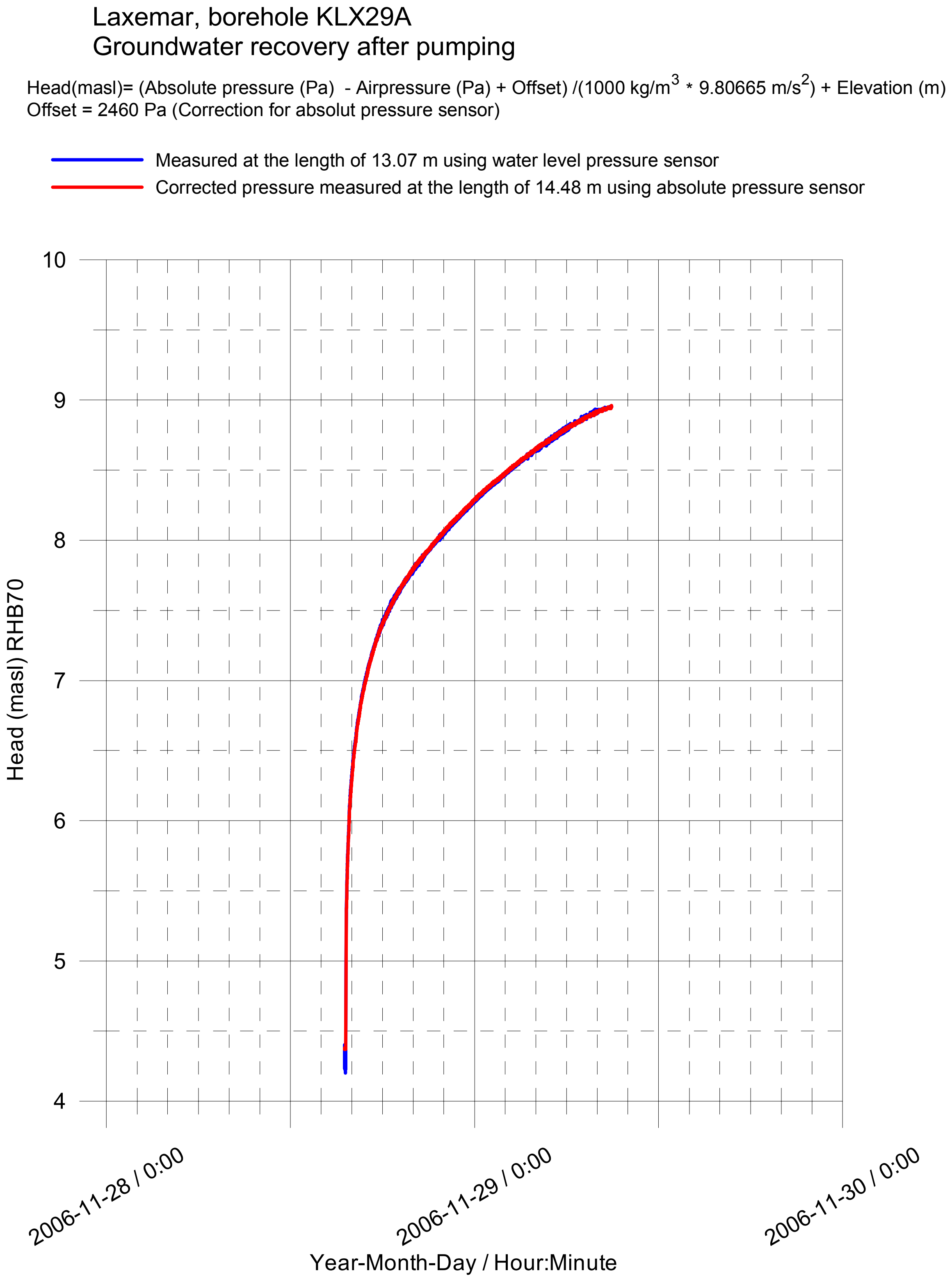
Laxemar, borehole KLX29A
Head in the borehole during flow logging

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 KLX29A
Air pressure, water level in the borehole and pumping rate during flow logging




Laxemar, borehole KLX29A
Groundwater recovery after pumping
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)
Measured at the length of 13.07 m using water level pressure sensor
Corrected pressure measured at the length of 14.48 m using absolute pressure sensor
Head (masl) RHB70
10
9
8
7
6
5
4
2006-11-28 / 0:00
2006-11-29 / 0:00
2006-11-30 / 0:00
Year-Month-Day / Hour:Minute