P-06-229

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Subarea Laxemar

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PRG-Tec Oy

September 2006

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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 KLX09G, KLX10B and KLX10C at Oskarshamn, Sweden, July 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.

Boreholes KLX09G, KLX10B and KLX10C are relatively short, c 50 m–150 m. No length calibration was 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 electric conductivity (EC) and temperature of borehole water were also measured. The EC measurements were used to study the occurrence of saline water in the boreholes during natural as well as pumped conditions.

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 KLX09G, KLX10B och KLX10C i Oskarshamn, Sverige, i juli 2006 med Posiva flödesloggningsmetod. Det primära syftet med mätningarna var att bestämma läget och flödet för vattenförande sprickor i borrhålen KLX09G, KLX10B och KLX10C.

Flödet till eller från en 5 m lång testsektion (som förflyttades successivt med 0,5 m) mättes i borrhålen KLX09G, KLX10B och KLX10C under såväl naturliga (icke-pumpade) som pumpade förhållanden. Flödesmätningarna upprepades vid lägena för de detekterade flödes-anomalierna med en 1 m lång testsektion som förflyttades successivt med 0,1 m.

Borrhålen KLX09G, KLX10B och KLX10C är relativt korta, ca 50 m–150 m. Ingen längd-kalibrering 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.

Elektrisk konduktivitet och temperatur på borrhålsvattnet mättes också. EC-mätningarna användes för att studera förekomsten av saltvatten i borrhålet under såväl naturliga som pumpade förhållanden.

Återhämtningen av grundvattennivån mättes efter att pumpningen i hålen avslutades.

Contents

1 Introduction

This document reports the results acquired by flow logging the boreholes KLX09G, KLX10B and KLX10C at Oskarshamn, Sweden. The work was carried out in accordance with activity plan AP PS 400-06-084. 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 KLX09G at Oskarshamn was conducted between July 11 and 15, 2006. KLX09G is 100.10 m long and its inclination is 60.1° from the horizontal plane. The 0 m–9.30 m interval of the borehole was core drilled with a diameter of 96 mm and the 9.30 m–100.10 m was core drilled with a diameter of 76 mm. The first 9.30 m of the borehole was cased using a steel tube. The inner diameter of the cased section was 77 mm. The length values given above are values on the axis parallel to the borehole. We call this the borehole length axis.

Boreholes KLX10B and KLX10C have a similar structure to that of borehole KLX09G. The properties of all the boreholes are 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 KLX09G, KLX10B and KLX10C	AP PS 400-06-084	1.0
Method descriptions	**Number**	**Version**
Method description for difference flow logging	SKB MD 322.010	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Instruktion för längdkalibrering vid undersökningar i kärnborrhål	SKB MD 620.010	1.0
Instruktion för analys av injektions- och enhålspumptester	SKB MD 320.004	1.0

Table 1-2. Borehole construction.

Borehole	Length	Inclination[1)]	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.]
KLX09G	100.10 m	–60.1°	0.30 m–9.30 m	9.30 m–100.10 m	0.30 m–9.30 m	19.629 m
KLX10B	50.25 m	–59.7°	0.30 m–9.00 m	9.00 m–50.25 m	0.00 m–9.00 m	18.152 m
KLX10C	146.25 m	–60.2°	0.30 m–9.00 m	9.00 m–146.25 m	0.00 m–9.00 m	16.935 m

[1)] Inclination is defined as zero degrees when horizontal and negative when inclined downwards.

The locations of KLX09G, KLX10B, and KLX10C 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.

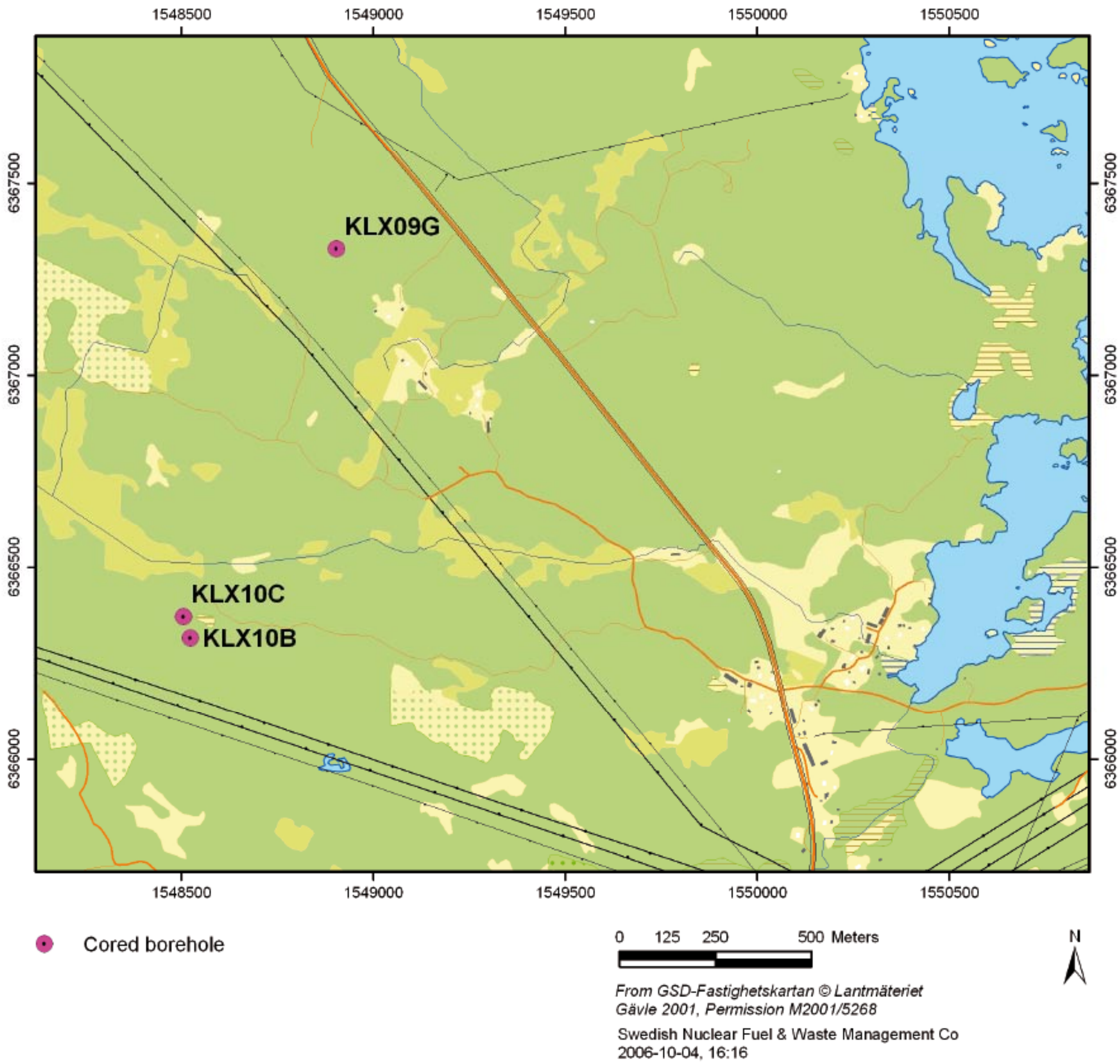

Figure 1-1. *Site map showing the locations of boreholes KLX09G, KLX10B and KLX10C situated in the subarea of Laxemar.*

2 Objective and scope

The main objective of the difference flow logging in KLX09G, KLX10B and KLX10C 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 KLX09G, KLX10B and KLX10C 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 and the electric conductivity of the borehole water. 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.

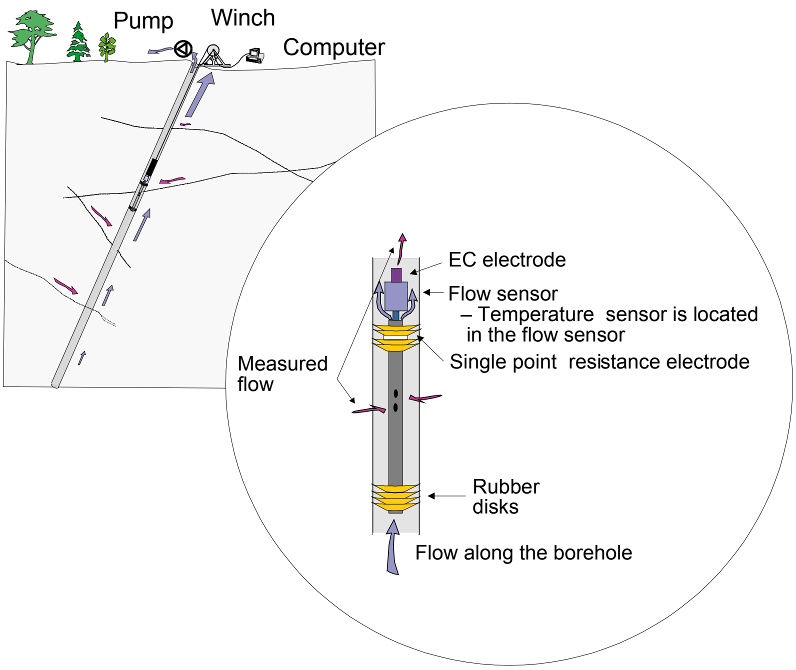

Figure 3-1. *Schematic of the downhole equipment used in the Difference flowmeter.*

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 fracture-specific EC and caliper measurements were conducted in KLX09G, KLX10B and KLX10C.

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

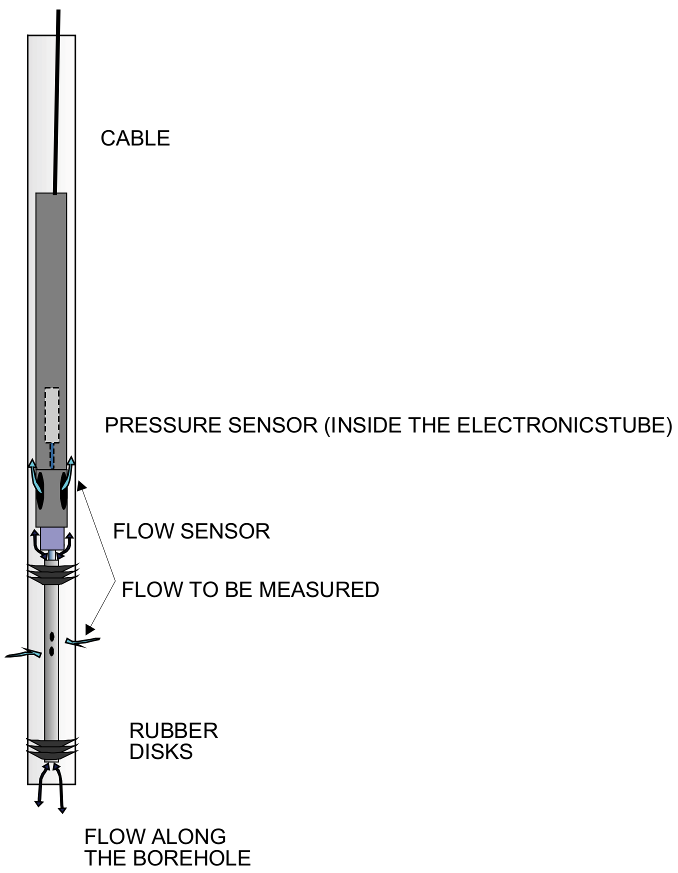

Figure 3-2. *The absolute pressure sensor is located inside the electronics tube and connected through a tube to the borehole water.*

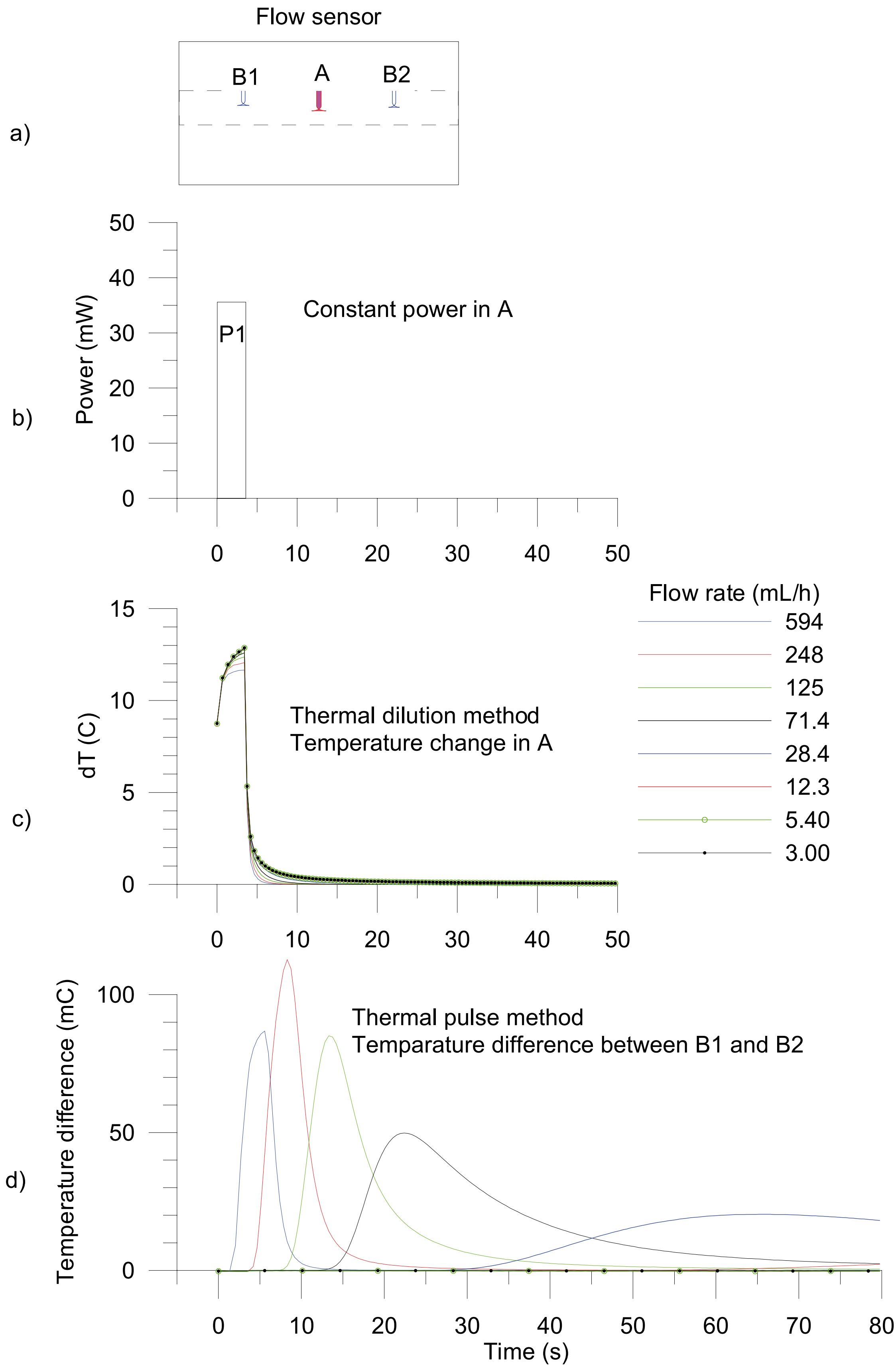

Figure 3-3. *Flow measurement, flow rate < 600 mL/h.*

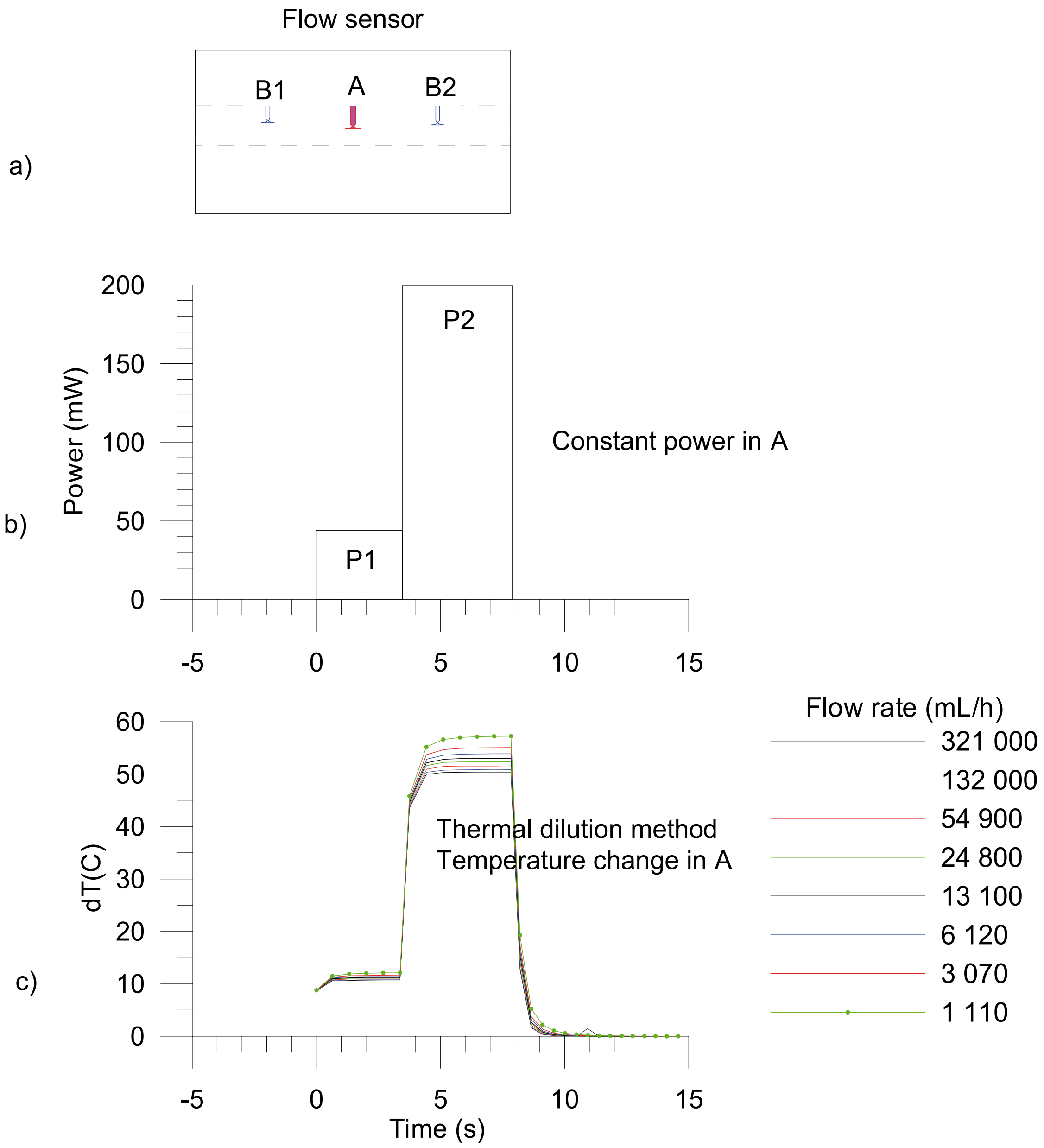

***Figure 3-4.** Flow measurement, flow rate > 600 mL/h.*

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

If the flow rate during the constant power heating (Figure 3-3 b) falls below 600 mL/h, the measurement continues by monitoring transient thermal dilution (Figure 3-3 c) and thermal pulse response (Figure 3-3 d). 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 3-3 b) 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/:

$h_s – h = Q/(T \cdot a)$ 3-1

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:

$a = 2 \cdot \pi / \ln(R/r_0)$ 3-2

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:

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

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

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:	April 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 400-06-084 (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 schedules of the borehole measurements are presented in Tables 5-1, 5-2 and 5-3. The items and activities in Tables 5-1, 5-2 and 5-3 are the same as in the Activity Plan. The boreholes were measured in the order KLX09G, KLX10B and KLX10C.

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. Borehole KLX09G, KLX10B and KLX10C are however relatively short, and no length marks were drilled on the borehole wall. Thereby no length calibration was possible in the measurements in boreholes KLX09G, KLX10B and KLX10C.

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 dummy logging was followed by measurements of the electric conductivity (EC) and temperature of the borehole water (Item 10) during natural (un-pumped) conditions.

The combined overlapping/sequential flow logging (Item 11) 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).

Table 5-1. Flow logging and testing in KLX09G. Activity schedule.

Item	Activity	Explanation	Date
8	Dummy logging	Borehole stability/risk evaluation.	2006-07-11
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber disks, no pumping.	2006-07-12
11	Combined overlapping/sequential flow logging	Section length L_w=5 m. Step length dL=0.5 m. No pumping.	2006-07-12
12	Overlapping flow logging	Section length L_w=5 m. Step length dL=0.5 m, pumping (includes 1 day waiting after the pumping was begun).	2006-07-13–2006-07-14
13	Selective overlapping flow logging	Section length L_w=1 m. Step length dL=0.1 m, pumping.	2006-07-14–2006-07-15
14	EC- and temp-logging of the borehole fluid	Logging without the lower rubber disks, pumping.	2006-07-15
15	Recovery transient	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued between 2006-07-15 and 2006-07-19 by SKB.	2006-07-15

Table 5-2. Flow logging and testing in KLX10B. Activity schedule. The extra measurements were performed to capture flows which were above measurement limit.

Item	Activity	Explanation	Date
8	Dummy logging	Borehole stability/risk evaluation.	2006-07-17
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber disks, no pumping.	2006-07-18
11	Combined overlapping/sequential flow logging	Section length L_w=5 m. Step length dL=0.5 m. No pumping.	2006-07-18
12	Overlapping flow logging	Section length L_w=5 m. Step length dL=0.5 m, pumping (includes 1 day waiting after the pumping was begun). Drawdown 10.0 m.	2006-07-19–2006-07-20
13	Selective overlapping flow logging	Section length L_w=1 m. Step length dL=0.1 m, pumping. Drawdown 10.0 m.	2006-07-20
14	EC- and temp-logging of the borehole fluid	Logging without the lower rubber disks, pumping.	2006-07-21
15	Recovery transient	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued between 2006-07-21 and 2006-07-22 by SKB.	2006-07-21
Extra 11	Combined overlapping/sequential flow logging	Section length L_w=1 m. Step length dL=0.1 m. No pumping.	2006-07-22
Extra 13_1	Selective overlapping flow logging	Section length L_w=1 m. Step length dL=0.1 m, pumping. Drawdown 3.0 m.	2006-07-22
Extra 13_2	Selective overlapping flow logging	Section length L_w=1 m. Step length dL=0.1 m, pumping. Drawdown 3.0 m. (Repeated because of disturbances in Extra 13_1.)	2006-07-23
Extra 15	Recovery transient	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued between 2006-07-23 and 2006-07-25 by SKB.	2006-07-23

Table 5-3. Flow logging and testing in KLX10C. Activity schedule.

Item	Activity	Explanation	Date
8	Dummy logging	Borehole stability/risk evaluation.	2006-07-23
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber disks, no pumping.	2006-07-24
11	Combined overlapping/sequential flow logging	Section length L_w=5 m. Step length dL=0.5 m. No pumping.	2006-07-24
12	Overlapping flow logging	Section length L_w=5 m. Step length dL=0.5 m, pumping (includes 1 day waiting after the pumping was begun). Drawdown 10.0 m.	2006-07-25–2006-07-26
13	Selective overlapping flow logging	Section length L_w=1 m. Step length dL=0.1 m, pumping. Drawdown 10.0 m.	2006-07-26–2006-07-27
14	EC- and temp- logging of the borehole fluid	Logging without the lower rubber disks, pumping.	2006-07-27
15	Recovery transient	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued between 2006-07-27 and 2006-07-30 by SKB.	2006-07-27

The pumping of borehole KLX09G was started on July 13. After a waiting time of c 23 hours, overlapping flow logging (Item 12) was conducted using the same section and step lengths as before. In KLX10B and KLX10C the pumping was started on July 19 and July 25, respectively. The waiting time after which the measurements (Item 12) were started was in both boreholes c 24 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 13).

The EC of borehole water (Item 14) was measured while the borehole was still pumped. After this, the pump was stopped and the recovery of the groundwater level was monitored (Item 15).

Borehole KLX10B required some extra measurements because some flow rates exceeded the measurement limit when the borehole was pumped. All the extra flow logging measurements were done with a 1 m section length. The measurement of Item Extra 11 was done in natural conditions and the measurements of Items Extra 13_1 and Extra 13_2 were done with a 3.0 m drawdown. There were some disturbances in the pumping in measurement Extra 13_1 and measurement Extra 13_2 was done to verify the results. The same disturbances occurred in measurement Extra 13_2 and only the results of Extra 13_1 are presented in this report. After the extra flow logging measurements the recovery transient was also measured again (Item Extra 15).

In addition to all these measurements the SKB pressure sensor was used in boreholes KLX10B and KLX10C to measure interference between these two holes. The sensor was always located in the hole that was not being measured (using the flow logging device) at that particular time. This measurement was not included in the Activity Plan. Its results are presented separately in Appendix SKB.1.

5.2 Nonconformities

There were no nonconformities during this activity.

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. Boreholes KLX09G, KLX10B and KLX10C are relatively short, c 50 m–150 m. Cable stretching is not significant at that length and no length marks were drilled in the borehole walls. Thereby no length calibration was applied in the measurements in boreholes KLX09G, KLX10B or KLX10C.

Length errors in KLX09G, KLX10B and KLX10C 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.

In the worst case, the errors from sources 1, 2 and 3 are summed. Then the total estimated error for fracture locations at the length of c 150 m would be ± 0.3 m.

Knowing the location accurately is important when different measurements are compared, for instance flow logging and borehole TV. 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 Electric conductivity and temperature of borehole water

The electric conductivity of the borehole water was initially measured when the boreholes were at rest, i.e. at natural, un-pumped conditions. The measurement was performed downwards and upwards, see Appendices 9G.2.1, 10B.2.1 and 10C.2.1.

The EC measurements were repeated during pumping, see Appendices 9G.2.1, 10B.2.1, 10C.2.1, green curves.

The temperature of the borehole water was measured simultaneously with the EC measurements. The EC values are temperature corrected to 25°C to make them more comparable with other EC measurements /Heikkonen et al. 2002/. The temperature results in Appendices 9G.2.2, 10B.2.2 and 10C.2.2 have the same length axis as the EC results in Appendices 9G.2.1, 10B.2.1 and 10C.2.1.

6.3 Pressure measurements

Absolute pressure was registered with the other measurements in Items 10–15 (and all the extra measurements in KLX10B). The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered separately, Appendices 9G.13.2, 10B.13.2, 10C.13.2. 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 (m.a.s.l.) 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 (m.a.s.l.) 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 9G.13.1, 10B.13.1, 10C.13.1. In KLX09G and KLX10C 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.

The results of the SKB's interference test between holes KLX10B and KLX10C are presented in Appendix SKB.1. In these measurements the SKB pressure sensor was always located in the hole that was not being measured with the flow logging device. This same sensor was also used in the recovery measurements in KLX10B and KLX10C.

6.4 Flow logging

6.4.1 General comments on results

The flow results are presented together with the single-point resistance results (right hand side), see Appendices 9G.3.1–9G.3.5, 10B.3.1–10B.3.3 and 10C.3.1–10C.3.7. 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. All the SPR plots for each borehole all presented in Appendices 9G.1, 10B.1 and 10C.1.

The flow logging was first performed with a 5 m section length and with 0.5 m length increments, see Appendices 9G.3.1–9G.3.5, 10B.3.1–10B.3.3 and 10C.3.1–10C.3.7. 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 metre 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 9G.3.1–9G.3.5, 10B.3.1–10B.3.3 and 10C.3.1–10C.3.7 (violet curve).

Some of the measured flow rates during pumping in KLX10B were larger than the measurement limit of the device and part of the borehole was re-measured without pumping and with a smaller drawdown (3 m) using 1 m section length. The results of these measurements are used in the Appendices where noted. The 5 m section flow can be calculated from the 1 m measurements by summing the 1 m flows on the interval in question. When the borehole was pumped (3 m drawdown) the pump was stopped for a short period of time. It is possible that the rubber disks of the device blocked a large positive flow into the borehole when the device was moved to a certain position. This would explain that the water level dropped just before the pump stopped (the pump stops if there's no water for it to pump). The pump started again automatically after a few moments.

In KLX10C the flow rate in the 1 m section measurement with pumping was larger than the flow rate in the 5 m section measurement with pumping at 62.4 m and 110.1 m. The measurements are separate and it is possible that, for example, drilling mud was cleared from the fractures between these measurements.

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 9G.10, 10B.10 and 10C.10 were used to calculate conductive fracture frequency (CFF). The number of conductive fractures was counted on the same 5 metre sections as in Appendices 9G.7, 10B.7 and 10C.7. 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 9G.11, 10B.11 and 10C.11.

6.4.2 Transmissivity and hydraulic head of borehole sections

KLX09G was logged between 22.58 m and 92.58 m with a 5 m section length and with 0.5 m length increments. In KLX10B the interval was 10.73 m–40.72 m and in KLX10C 9.75 m–139.75 m. 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 9G.7, 10B.7 and 10C.7. Only the results with 5 m length increments are used. All borehole sections are shown in Appendices 9G.3.1–9G.3.5, 10B.3.1–10B.3.3 and 10C.3.1–10C.3.7. Secup and Seclow in Appendices 9G.7, 10B.7 and 10C.7 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 9G.7, 10B.7 and 10C.7 are calculated as the average of these two values.

Pressure was measured and calculated as described in Chapter 6.3. h_{0FW} and h_{1FW} in Appendices 9G.7, 10B.7 and 10C.7 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 9G.7, 10B.7 and 10C.7 (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 KLX09G – with the borehole at rest – 12 sections were detected as flow yielding, four of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 13 detected flows were directed towards the borehole.

In KLX10B flows were detected in five sections and one of these flows was negative. During pumping, all five detected section flows were positive.

In KLX10C, which was the longest of the holes, nine sections were detected as flow yielding. Two of these section flows were negative. During pumping 14 flows were detected and they were all positive.

It is possible to detect the existence of flow anomalies below the measurement limit (30 mL/h = $8.33 \cdot 10^{-9}$ m³/s), even though the exact numerical values below the limit are uncertain. Some of the section flow rates in the natural conditions were below this limit (see Appendices 9G.7, 10B.7 and 10C.7).

The flow data is presented as a plot, see Appendices 9G.4.1, 10B.4.1 and 10C.4.1. 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 9G.4.1, 10B.4.1 and 10C.4.1) and in the tables (Appendices 9G.7, 10B.7 and 0C.7). There are theoretical and practical lower limits of flow, see Chapter 6.4.4.

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 9G.4.2, 10B.4.2 and 10C.4.2. The measurement limits of transmissivity are also shown in Appendices 9G.4.2, 10B.4.2 and 10C.4.2 and in Appendices 9G.7, 10B.7 and 10C.7. All the measurement limit values of transmissivity are based on the actual pressure difference in the borehole (h_{0FW} and h_{1FW} in Appendices 9G.7, 10B.7 and 10C.7).

The sum of detected flows in KLX09G without pumping (Q_0) was $-1.36 \cdot 10^{-8}$ m³/s (–49 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 KLX10B the sum of detected flows in natural conditions was $2.87 \cdot 10^{-7}$ m^3/s (1,033 mL/h). The sum is fairly close to zero.

In KLX10C the sum was $-2.76 \cdot 10^{-6}$ m^3/s (–9,931 mL/h). The sum is not close to zero. The borehole was not measured below c 140 m and it is possible that there were flows below 140 m. It is also possible that there is a flow between 9.00 m and 9.75 m, because no measurements were conducted in this interval.

6.4.3 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 metre, it may be difficult to evaluate the flow rate. There are such cases for instance in Appendix 9G.3.2. 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 instead (except in KLX10B, where the 1 m section measurements were used in the applicable interval). 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 9G.8, 10B.8 and 10C.8. The flow direction is evaluated as well. The results of the evaluation are plotted in Appendices 9G.3.1–9G.3.5, 10B.3.1–10B.3.3 and 10C.3.1–10C.3.7, 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 metre or their nature is unclear because of noise.

The total amount of detected flowing fractures in KLX09G was 42, but only 6 could be defined without pumping. These 6 fractures could be used for head estimation and all 42 were used for transmissivity estimations.

In KLX10B the total amount of detected fractures was 24 and 6 of them could be defined without pumping. 18 of the 24 were used for transmissivity estimations and all 6 were used for head estimation.

In KLX10C 25 fractures were detected (and used for transmissivity estimations), but only 5 of them were detected without pumping. These 5 were used for head estimations.

There are also additional fractures at 11.3 m, 13.3 m, 17.3 m and 19.0 m in KLX10C. The only measurements done in this section of the borehole were done in natural conditions (and therefore no transmissivity values could be estimated). The flows at these fractures were 6,400 mL/h at 11.3 m, 2,900 mL/h at 13.3 m, 650 mL/h at 17.3 m and 130 mL/h at 19.0 m.

The transmissivity and hydraulic head of the fractures are plotted in Appendices 9G.5, 10B.5 and 10C.5. The results are presented in a tabulated form in Appendices 9G.8, 10B.8 and 10C.8.

Fracture-specific transmissivities were compared with the transmissivities of borehole sections in Appendices 9G.12, 10B.12 and 10C.12. 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.

6.4.4 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 9G.3.1–9G.3.5, 10B.3.1–10B.3.3 and 10C.3.1–10C.3.7 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 KLX09G, KLX10B and KLX10C 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 KLX09G and KLX10C the flow values never exceeded the upper limit. In KLX10B the limit was exceeded and extra measurements with a smaller drawdown were conducted (Table 5-2).

The practical minimum of measurable flow rate is also presented in Appendices 9G.7, 10B.7 and 10C.7 (Q-lower limit P). It is taken from the plotted curve in Appendices 9G.3, 10B.3 and 10C.3 (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 9G.7, 10B.7 and 10C.7 (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 Appendices 9G.7, 10B.7 and 10C.7 (T_D-measl$_U$).

All three flow limits are also plotted with measured flow rates, see Appendices 9G.4.1, 10B.4.1 and 10C.4.1. 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 9G.4.2, 10B.4.2, 10C.4.2.

Similar flow and transmissivity limits are not given for the fracture-specific results, Appendices 9G.5, 10B.5, 10C.5, 9G.8, 10B.8 and 10C.8. 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 metre apart from each other, the upper flow limit depends on the sum of flows which must be below 300,000 mL/h.

6.4.5 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.

Table 6-1. Transmissivities of the entire boreholes.

	KLX09G	KLC10B	KLX10C
Dupuit (m^2/s)	$1.72 \cdot 10^{-05}$	$4.64 \cdot 10^{-05}$	$1.11 \cdot 10^{-05}$
Moye (m^2/s)	$2.23 \cdot 10^{-05}$	$5.45 \cdot 10^{-05}$	$1.52 \cdot 10^{-05}$

KLX09G

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 8.2 L/min and s (drawdown) was 7.87 m. Transmissivity calculated with Dupuit's formula is $1.72 \cdot 10^{-05}$ m²/s.

In Moye's formula (Equation 3-10) the length of the test section L is 90.80 m (100.10 m–9.30 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $2.23 \cdot 10^{-05}$ m²/s.

KLX10B

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 27.8 L/min and s (drawdown) was 9.88 m. Transmissivity calculated with Dupuit's formula is $4.64 \cdot 10^{-05}$ m²/s.

In Moye's formula (Equation 3-10) the length of the test section L is 41.25 m (52.25 m–9.00 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $5.45 \cdot 10^{-05}$ m²/s.

KLX10C

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 6.77 L/min and s (drawdown) was 10.01 m. Transmissivity calculated with Dupuit's formula is $1.11 \cdot 10^{-05}$ m²/s.

In Moye's formula (Equation 3-10) the length of the test section L is 137.25 m (146.25 m–9.00 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $1.52 \cdot 10^{-05}$ m²/s.

6.5 Groundwater level and pumping rate

The groundwater level and the pumping rate are illustrated in Appendices 9G.13.2, 10B.13.2 and 10C.13.2 and the recovery plots are presented in Appendices 9G.13.3, 10B.13.3, 10B.13.4 and 10C.13.3. 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. After the initial recovery phase of the recovery measurement was completed, the measurement was continued with a pressure sensor provided by SKB.

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 metres above sea level (m.a.s.l.) according to RHB70.

Because borehole KLX10B had to be re-measured with a smaller drawdown, two recovery curves were measured for it. These two different measurements are also visible in Table 6-2.

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

Bore-hole	Pumping period	Pump intake level (m.a.s.l.)	Groundwater level sensor location (m.a.s.l.)	Top of casing (m.a.s.l.)	Approx. drawdown (m)	Recovery period
9G	2006-07-13–2006-07-15	1.0	0.72	19.629	7.9	2006-07-15–2006-07-19
10B	2006-07-19–2006-07-21	1.4	–0.02	18.152	9.9	2006-07-21–2006-07-22
	2006-07-22–2006-07-23	8.1	6.56		3.0	2006-07-23–2006-07-25
10C	2006-07-25–2006-07-27	1.1	–0.43	16.935	10.0	2006-07-27–2006-07-30

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 KLX09G, KLX10B and KLX10C 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 distribution of saline water along the borehole was logged by electric conductivity and temperature measurements of the borehole water.

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 KLX09G was 42. The highest transmissivity ($9.8 \cdot 10^{-6}$ m^2/s) was detected in a fracture at the length of 43.5 m. High-transmissive fractures were also found at 41.7 m, 52.9 m and 61.1 m. The lowest identified flowing fracture was at the approximate length of 92.5 m.

In KLX10B the total amount of detected fractures was 24. The highest transmissivity ($1.9 \cdot 10^{-5}$ m^2/s) was detected in a fracture at the length of 27.4 m. Other high-transmissive fractures were found at 21.3 m, 29.7m and 32.7 m. The lowest identified flowing fracture in KLX10B was at 43.5 m.

The total amount of detected flowing fractures was 25 and the highest fracture transmissivity ($6.0 \cdot 10^{-6}$ m^2/s) was at 44.6 m. Other high-transmissive fractures were found at 45.5 m, 115.8 m and 123.2 m. The lowest identified flowing fracture was at 123.9 m.

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Appendices

Appendices KLX09G

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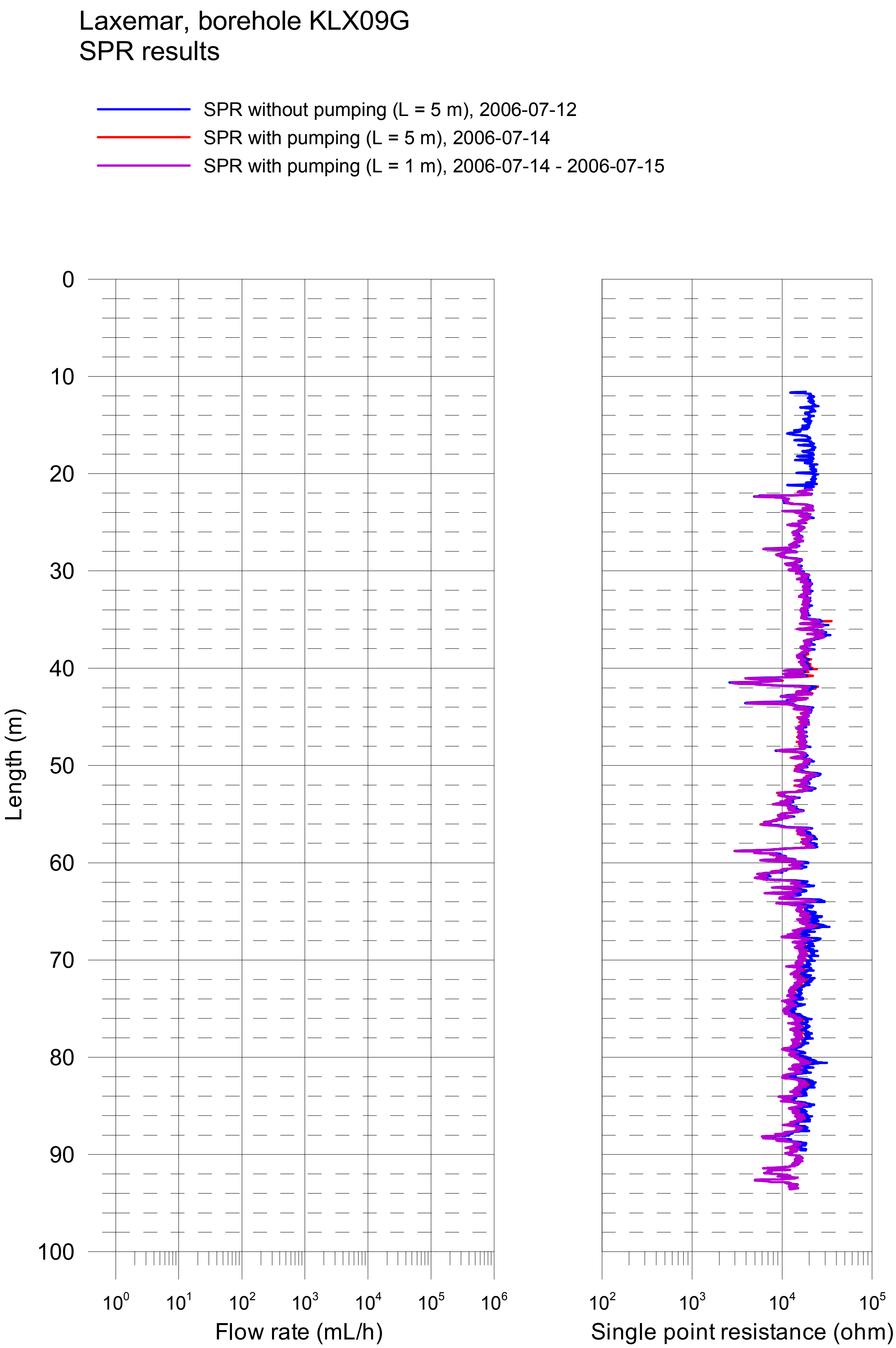
10B.13.1	Head in the borehole during flow logging
10B.13.2	Air pressure, water level in the borehole and pumping rate during flow logging
10B.13.3	Groundwater recovery after pumping
10B.13.4	Groundwater recovery after smaller pumping

Appendices KLX10C

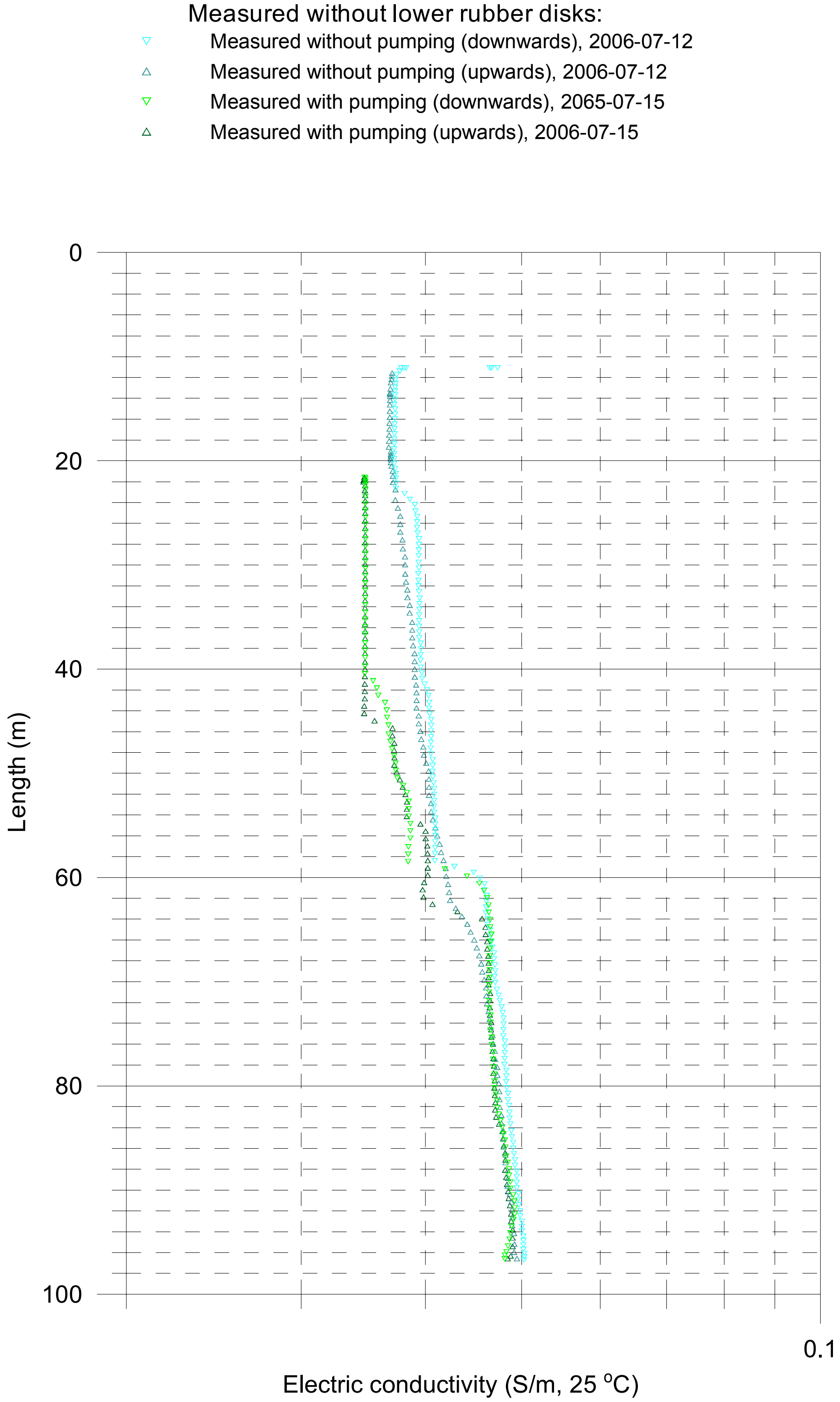
Appendix SKB (KLX10B-10C Interference)

PFL results

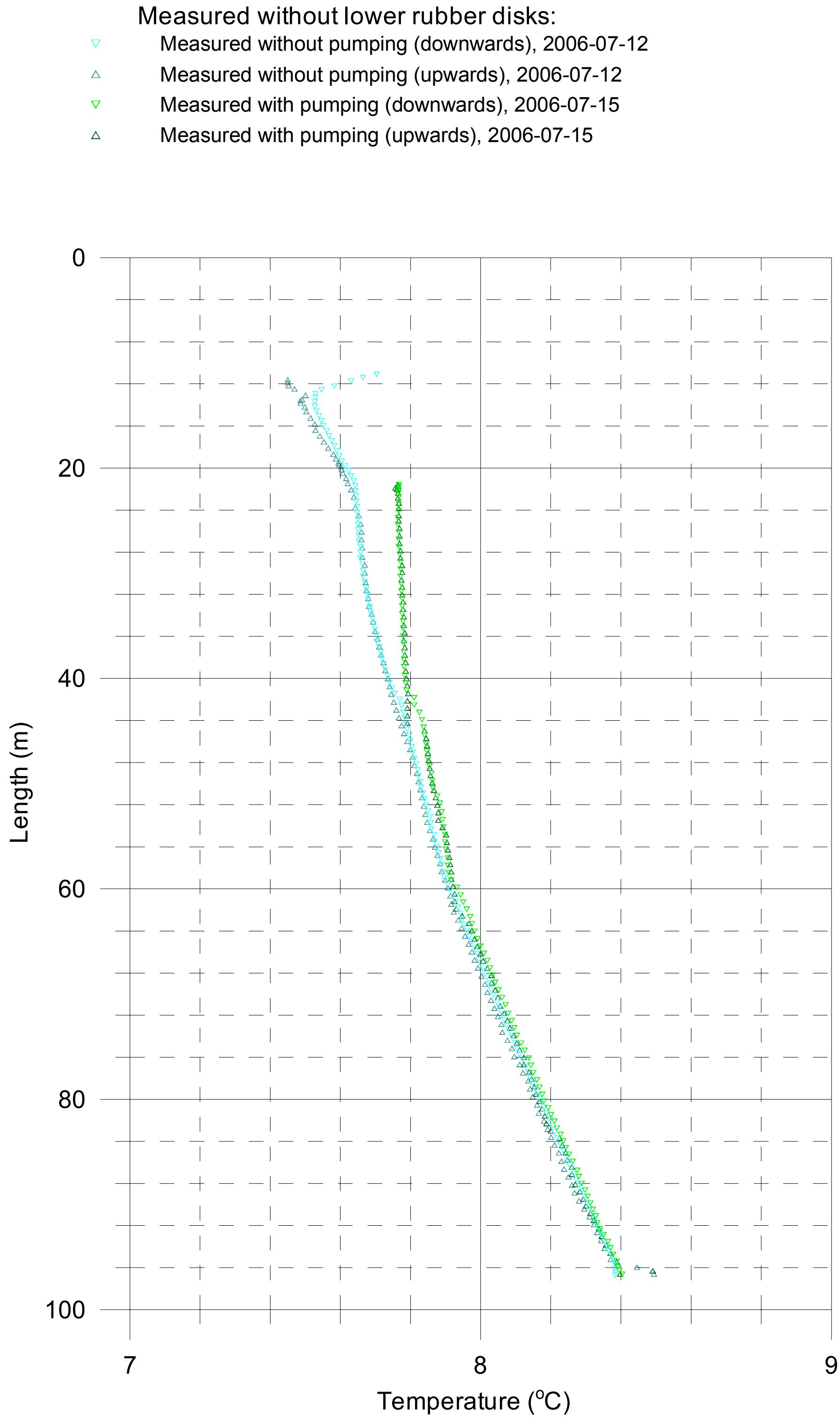
Appendix 9G.1



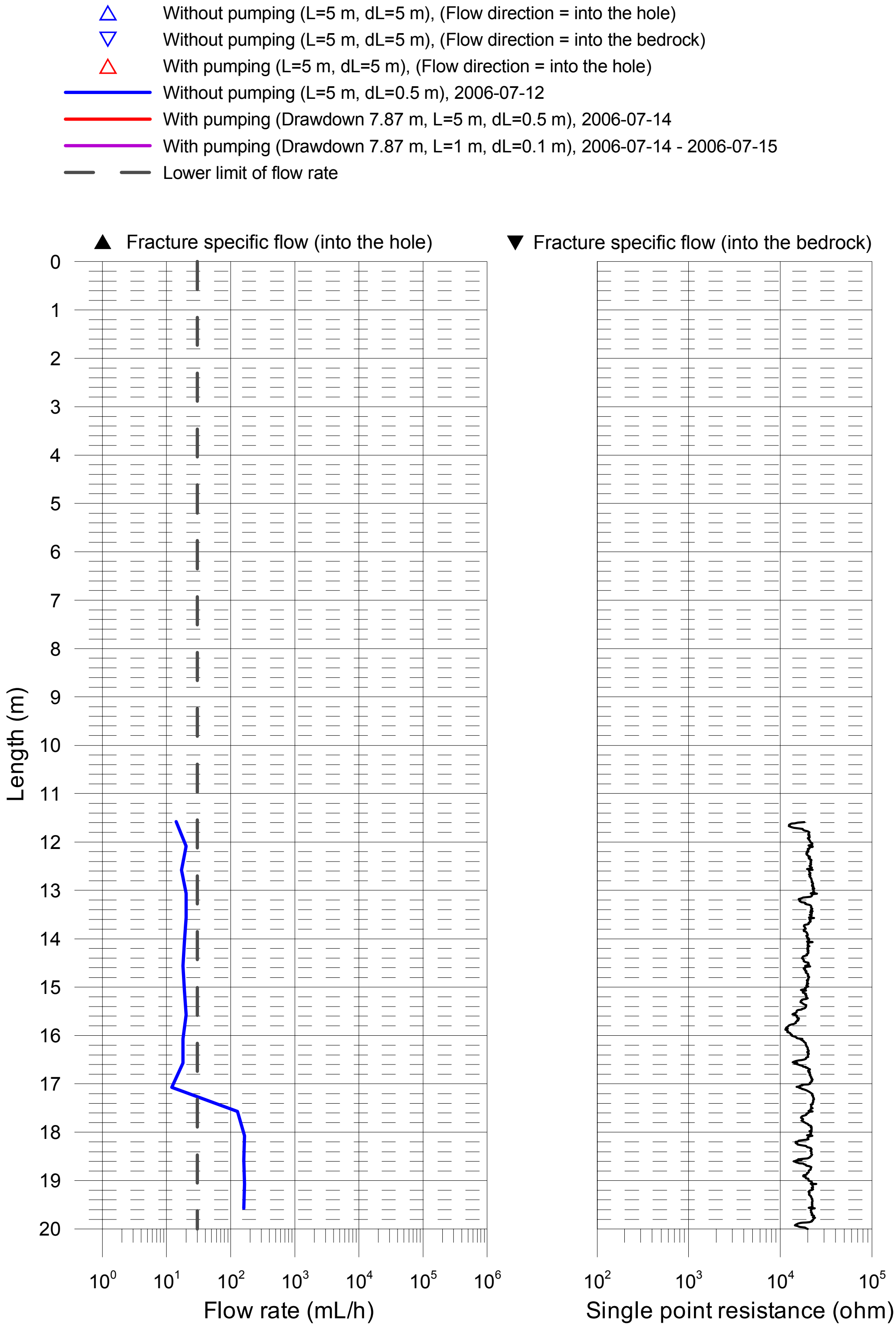
Laxemar, borehole KLX09G
Electric conductivity of borehole water



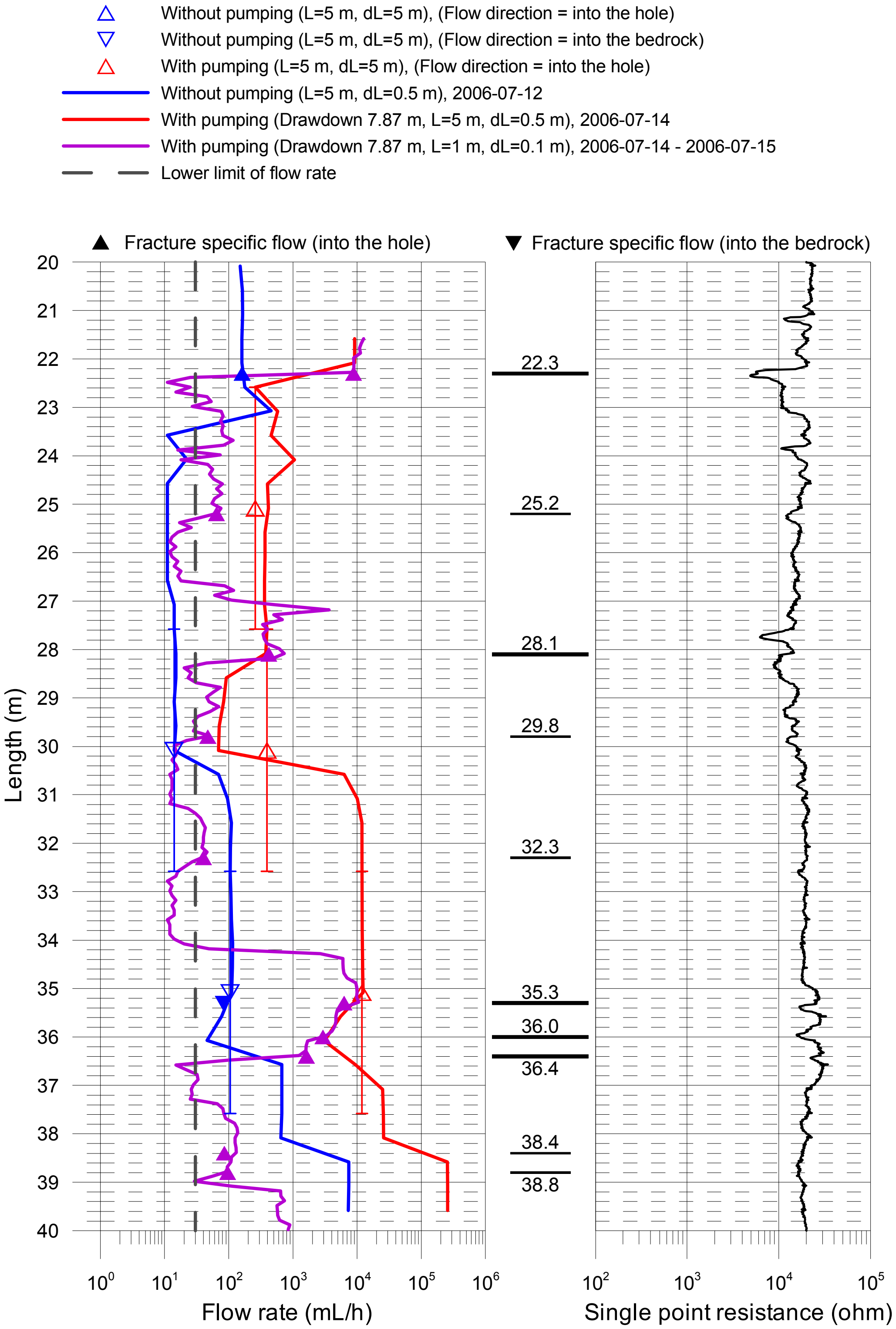
Laxemar, borehole KLX09G
Temperature of borehole water



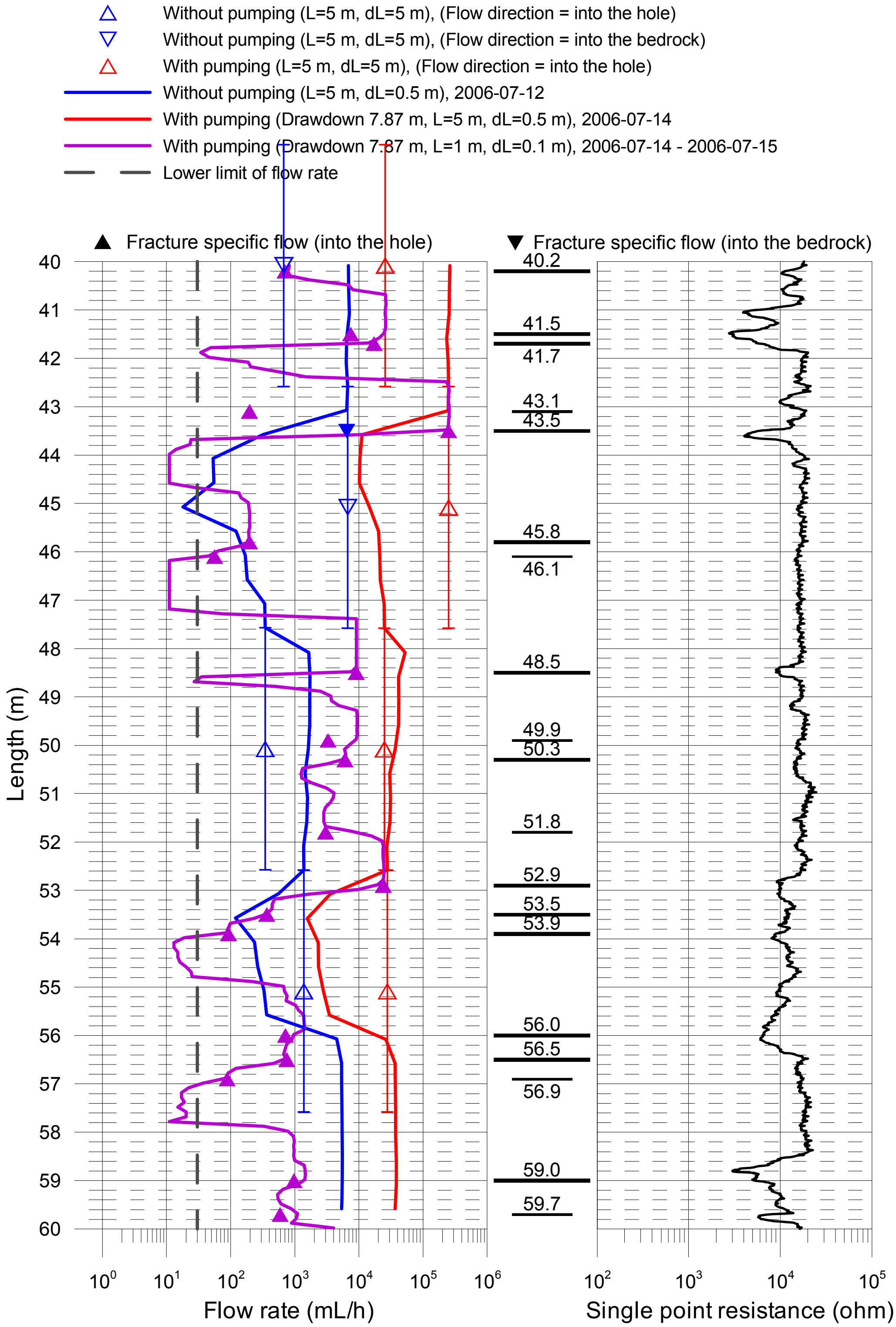
Laxemar, borehole KLX09G
Flow rate and single point resistance



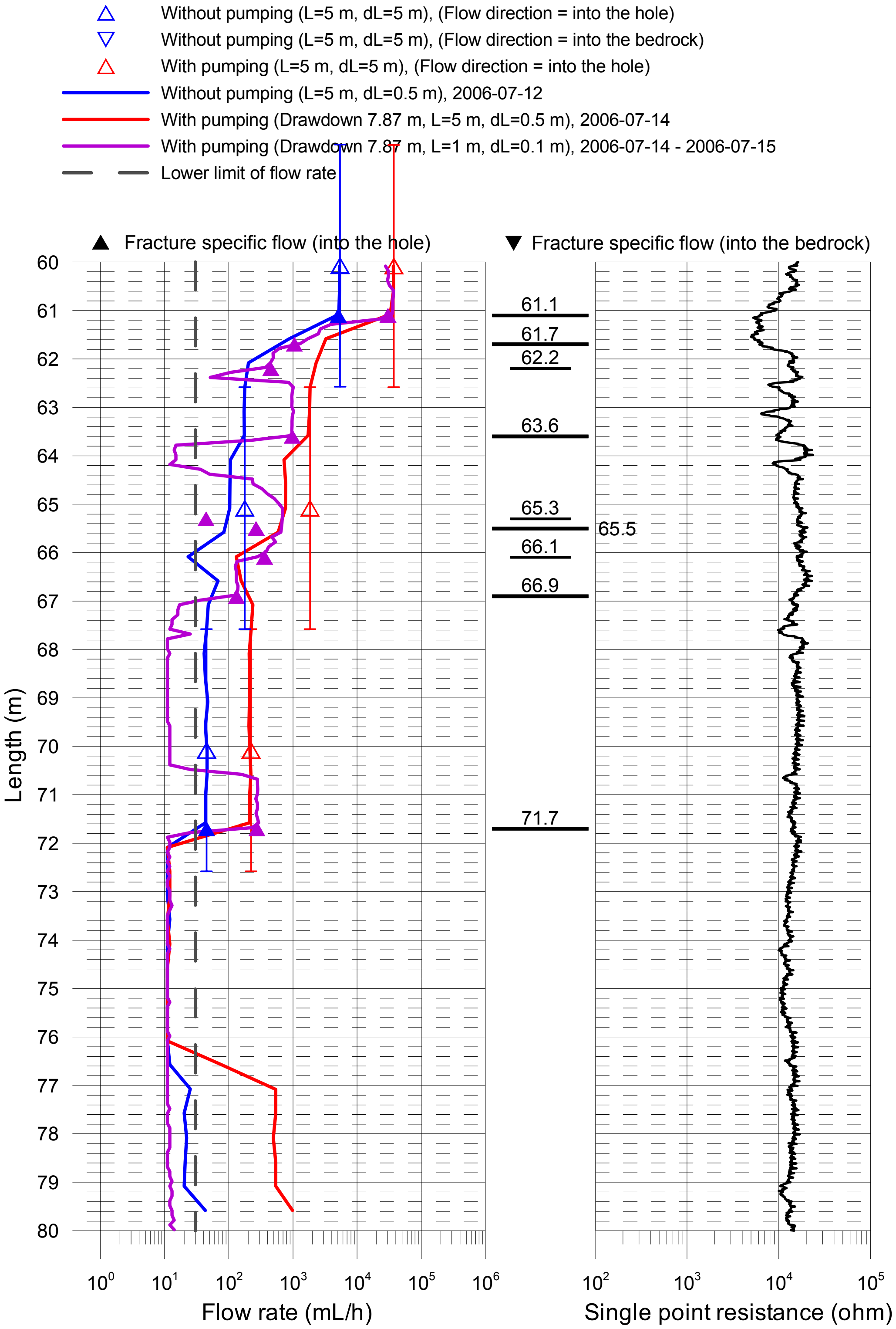
Laxemar, borehole KLX09G
Flow rate and single point resistance



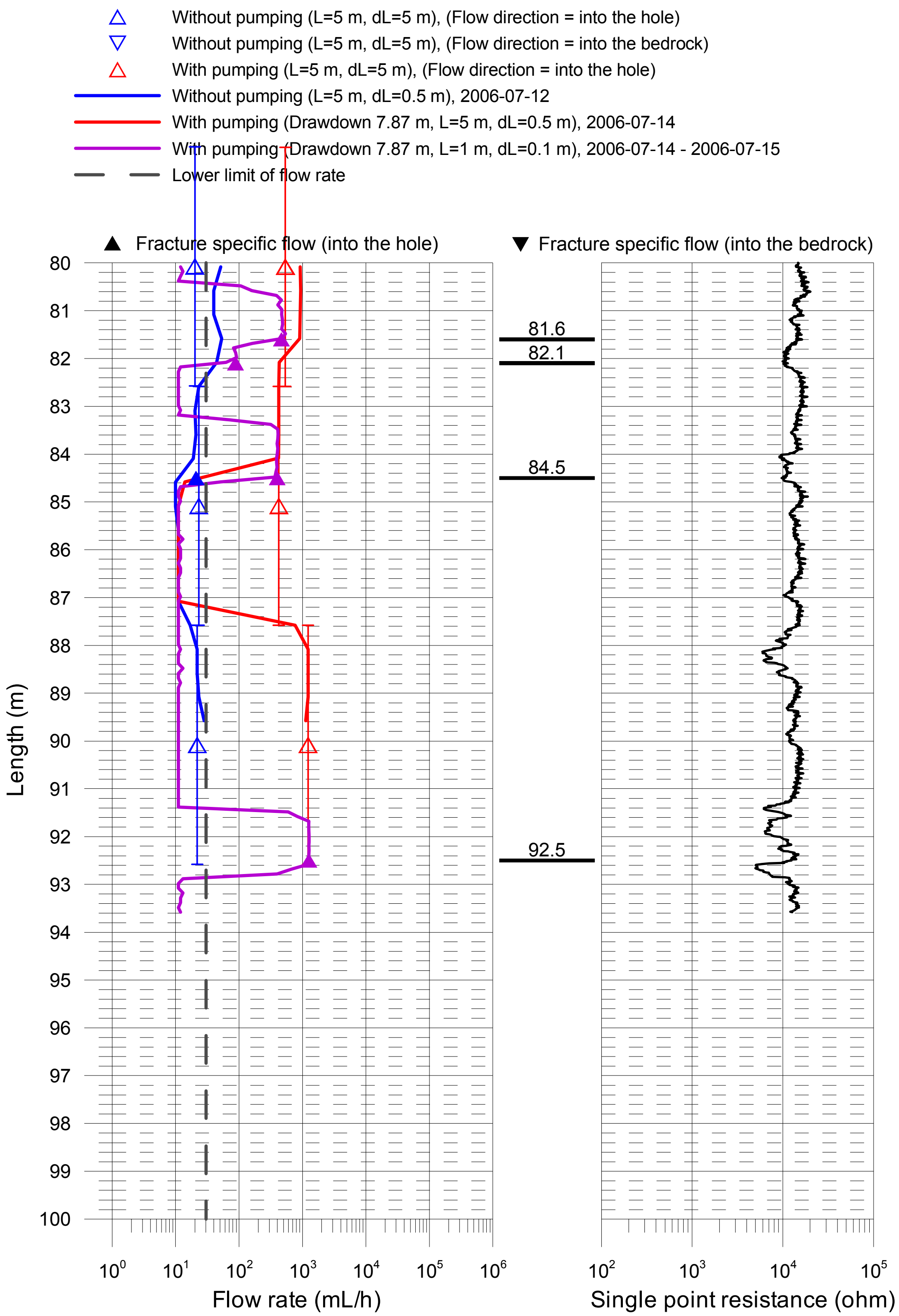
Laxemar, borehole KLX09G
Flow rate and single point resistance



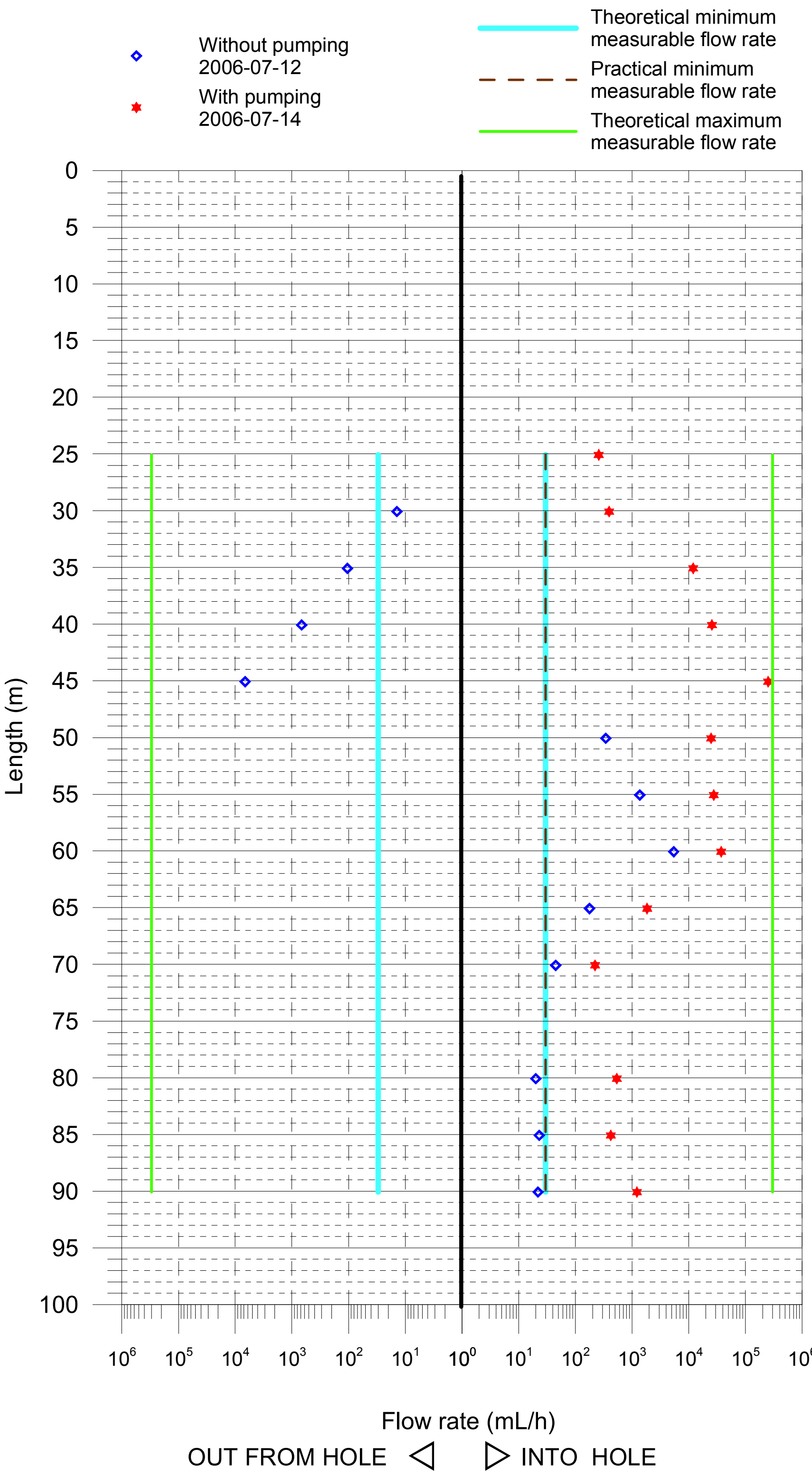
Laxemar, borehole KLX09G
Flow rate and single point resistance



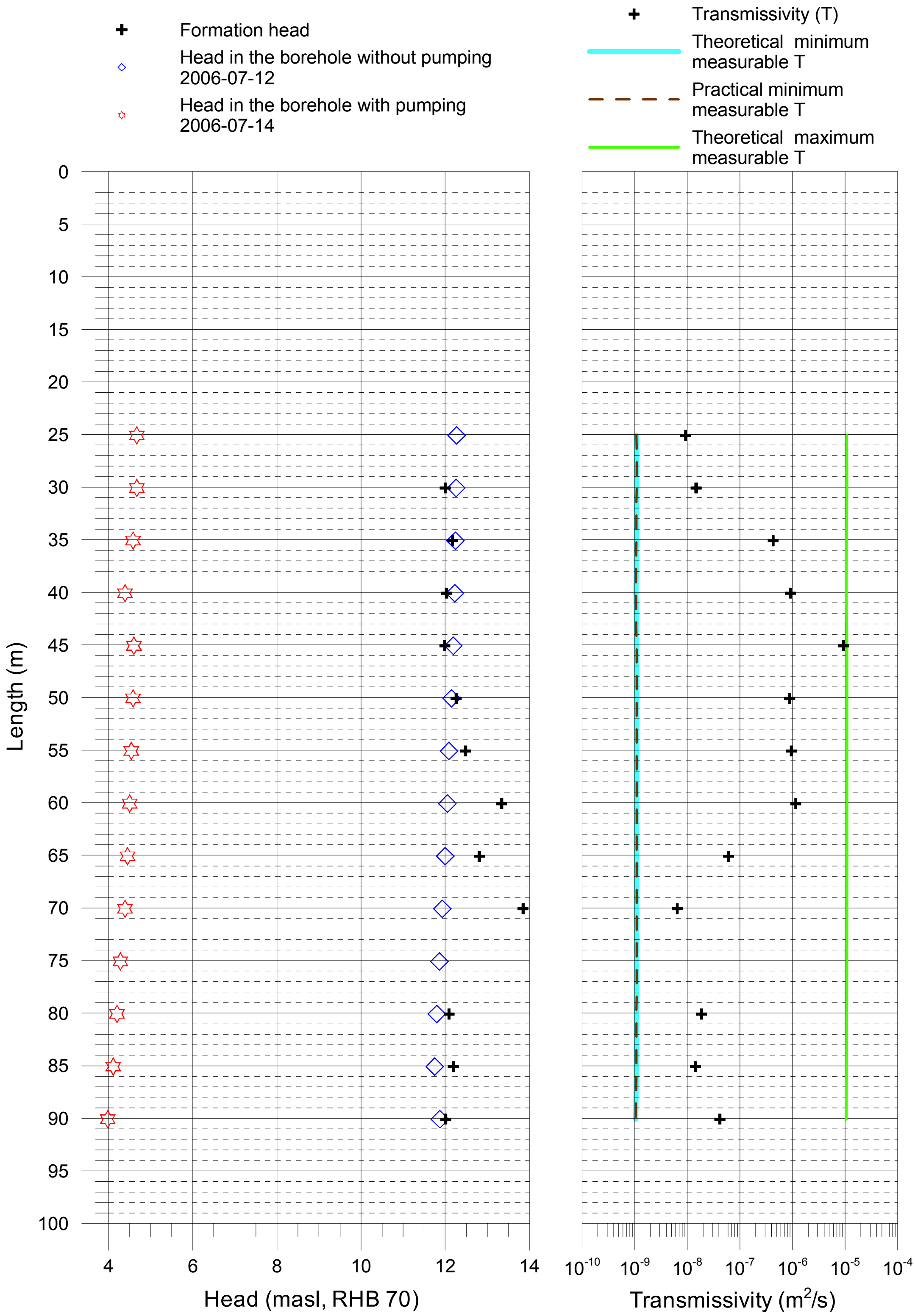
Laxemar, borehole KLX09G
Flow rate and single point resistance



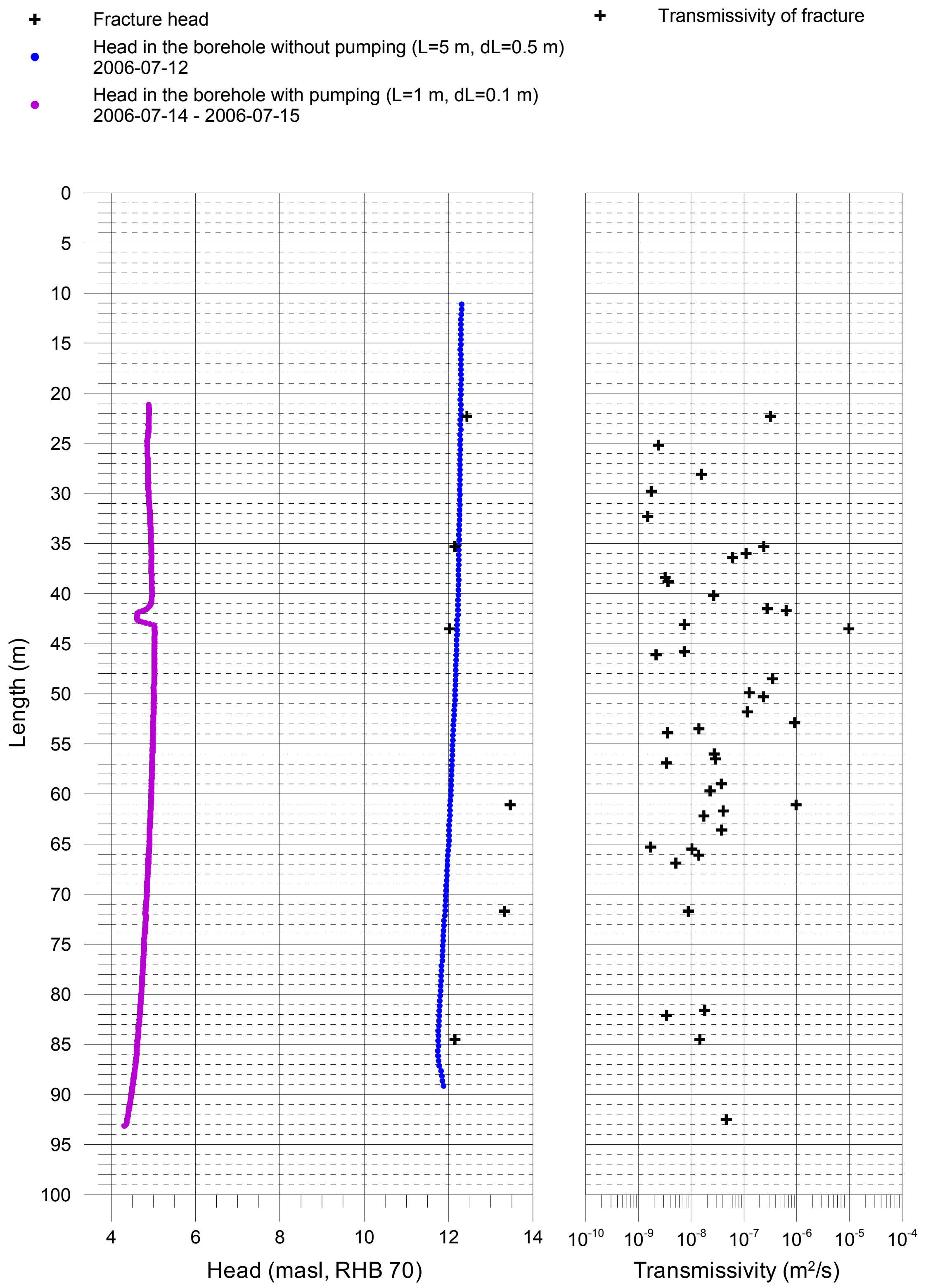
Laxemar, borehole KLX09G
Flow rates of 5 m sections



Laxemar, borehole KLX09G
Transmissivity and head of 5 m sections



Laxemar, borehole KLX09G
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)
KLX09G	9.3	100.1	5A	20060713	10:41	20060714	11:29	20060715	14:22	5	0.5	1.37E–04	–

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 (–)
186,060	–	358,620	–	12.72	4.85	–	–7.87	–	1.72E–05	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q0 (m^3/s)	h0FW (m.a.s.l.)	Q1 (m^3/s)	h1FW (m.a.s.l.)	TD (m^2/s)	hi (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measlLT (m^2/s)	TD-measlLP (m^2/s)	TD-measlU (m^2/s)	Comments
KLX09G	22.58	27.58	5	–	12.27	7.17E–08	4.67	9.3E–09	–	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	27.58	32.58	5	–3.89E–09	12.26	1.09E–07	4.67	1.5E–08	12.0	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	32.58	37.58	5	–2.92E–08	12.24	3.31E–06	4.58	4.3E–07	12.2	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	37.58	42.58	5	–1.87E–07	12.23	7.11E–06	4.39	9.2E–07	12.0	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	42.58	47.58	5	–1.86E–06	12.19	6.97E–05	4.60	9.3E–06	12.0	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	47.58	52.58	5	9.56E–08	12.15	6.86E–06	4.58	8.8E–07	12.3	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	52.58	57.58	5	3.81E–07	12.09	7.67E–06	4.54	9.5E–07	12.5	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	57.58	62.58	5	1.51E–06	12.05	1.03E–05	4.50	1.2E–06	13.3	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	62.58	67.58	5	4.94E–08	12.00	5.11E–07	4.45	6.0E–08	12.8	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	67.58	72.58	5	1.25E–08	11.93	6.17E–08	4.39	6.5E–09	13.9	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	72.58	77.58	5	–	11.86	–	4.28	–	–	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	77.58	82.58	5	5.56E–09	11.80	1.49E–07	4.20	1.9E–08	12.1	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	82.58	87.58	5	6.39E–09	11.75	1.17E–07	4.11	1.4E–08	12.2	30	1.1E–09	1.1E–09	1.1E–05	
KLX09G	87.58	92.58	5	6.11E–09	11.87	3.39E–07	3.98	4.2E–08	12.0	30	1.0E–09	1.0E–09	1.0E–05	

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

Borehole ID	Length to flow anom. L (m)	Lw (m)	dL (m)	Q0 (m³/s)	h0FW (m.a.s.l.)	Q1 (m³/s)	h1FW (m.a.s.l.)	TD (m²/s)	hi (m.a.s.l.)	Comments
KLX09G	22.3	1	0.1	4.47E–08	12.29	2.44E–06	4.89	3.2E–07	12.4	
KLX09G	25.2	1	0.1	–	12.27	1.78E–08	4.85	2.4E–09	–	*
KLX09G	28.1	1	0.1	–	12.27	1.17E–07	4.87	1.6E–08	–	
KLX09G	29.8	1	0.1	–	12.26	1.31E–08	4.89	1.8E–09	–	*
KLX09G	32.3	1	0.1	–	12.26	1.11E–08	4.92	1.5E–09	–	*
KLX09G	35.3	1	0.1	–2.28E–08	12.24	1.73E–06	4.95	2.4E–07	12.2	
KLX09G	36.0	1	0.1	–	12.24	8.11E–07	4.95	1.1E–07	–	
KLX09G	36.4	1	0.1	–	12.24	4.50E–07	4.96	6.1E–08	–	
KLX09G	38.4	1	0.1	–	12.24	2.36E–08	4.96	3.2E–09	–	*
KLX09G	38.8	1	0.1	–	12.24	2.67E–08	4.97	3.6E–09	–	*
KLX09G	40.2	1	0.1	–	12.23	1.95E–07	4.97	2.7E–08	–	
KLX09G	41.5	1	0.1	–	12.22	2.06E–06	4.85	2.8E–07	–	
KLX09G	41.7	1	0.1	–	12.22	4.78E–06	4.76	6.3E–07	–	
KLX09G	43.1	1	0.1	–	12.20	5.44E–08	4.97	7.5E–09	–	*
KLX09G	43.5	1	0.1	–1.79E–06	12.20	6.92E–05	5.02	9.8E–06	12.0	
KLX09G	45.8	1	0.1	–	12.19	5.42E–08	5.02	7.5E–09	–	
KLX09G	46.1	1	0.1	–	12.18	1.56E–08	5.02	2.2E–09	–	*
KLX09G	48.5	1	0.1	–	12.16	2.52E–06	5.02	3.5E–07	–	
KLX09G	49.9	1	0.1	–	12.15	9.11E–07	5.01	1.3E–07	–	*
KLX09G	50.3	1	0.1	–	12.15	1.68E–06	5.02	2.3E–07	–	
KLX09G	51.8	1	0.1	–	12.13	8.36E–07	5.01	1.2E–07	–	*
KLX09G	52.9	1	0.1	–	12.11	6.61E–06	4.99	9.2E–07	–	
KLX09G	53.5	1	0.1	–	12.11	1.01E–07	4.99	1.4E–08	–	
KLX09G	53.9	1	0.1	–	12.10	2.56E–08	4.99	3.6E–09	–	
KLX09G	56.0	1	0.1	–	12.09	1.97E–07	4.98	2.7E–08	–	
KLX09G	56.5	1	0.1	–	12.08	2.08E–07	4.98	2.9E–08	–	
KLX09G	56.9	1	0.1	–	12.08	2.44E–08	4.97	3.4E–09	–	*
KLX09G	59.0	1	0.1	–	12.06	2.69E–07	4.96	3.8E–08	–	
KLX09G	59.7	1	0.1	–	12.05	1.63E–07	4.95	2.3E–08	–	*
KLX09G	61.1	1	0.1	1.41E–06	12.03	8.42E–06	4.94	9.8E–07	13.5	
KLX09G	61.7	1	0.1	–	12.03	2.92E–07	4.93	4.1E–08	–	
KLX09G	62.2	1	0.1	–	12.03	1.25E–07	4.93	1.7E–08	–	*
KLX09G	63.6	1	0.1	–	12.01	2.71E–07	4.91	3.8E–08	–	
KLX09G	65.3	1	0.1	–	12.00	1.22E–08	4.90	1.7E–09	–	*
KLX09G	65.5	1	0.1	–	11.99	7.39E–08	4.90	1.0E–08	–	
KLX09G	66.1	1	0.1	–	11.98	9.97E–08	4.89	1.4E–08	–	*
KLX09G	66.9	1	0.1	–	11.97	3.67E–08	4.89	5.1E–09	–	
KLX09G	71.7	1	0.1	1.25E–08	11.92	7.61E–08	4.81	8.9E–09	13.3	
KLX09G	81.6	1	0.1	–	11.78	1.29E–07	4.69	1.8E–08	–	
KLX09G	82.1	1	0.1	–	11.78	2.44E–08	4.67	3.4E–09	–	
KLX09G	84.5	1	0.1	5.83E–09	11.75	1.10E–07	4.63	1.5E–08	12.2	
KLX09G	92.5	1	0.1	–	11.75	3.47E–07	4.37	4.7E–08	–	

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

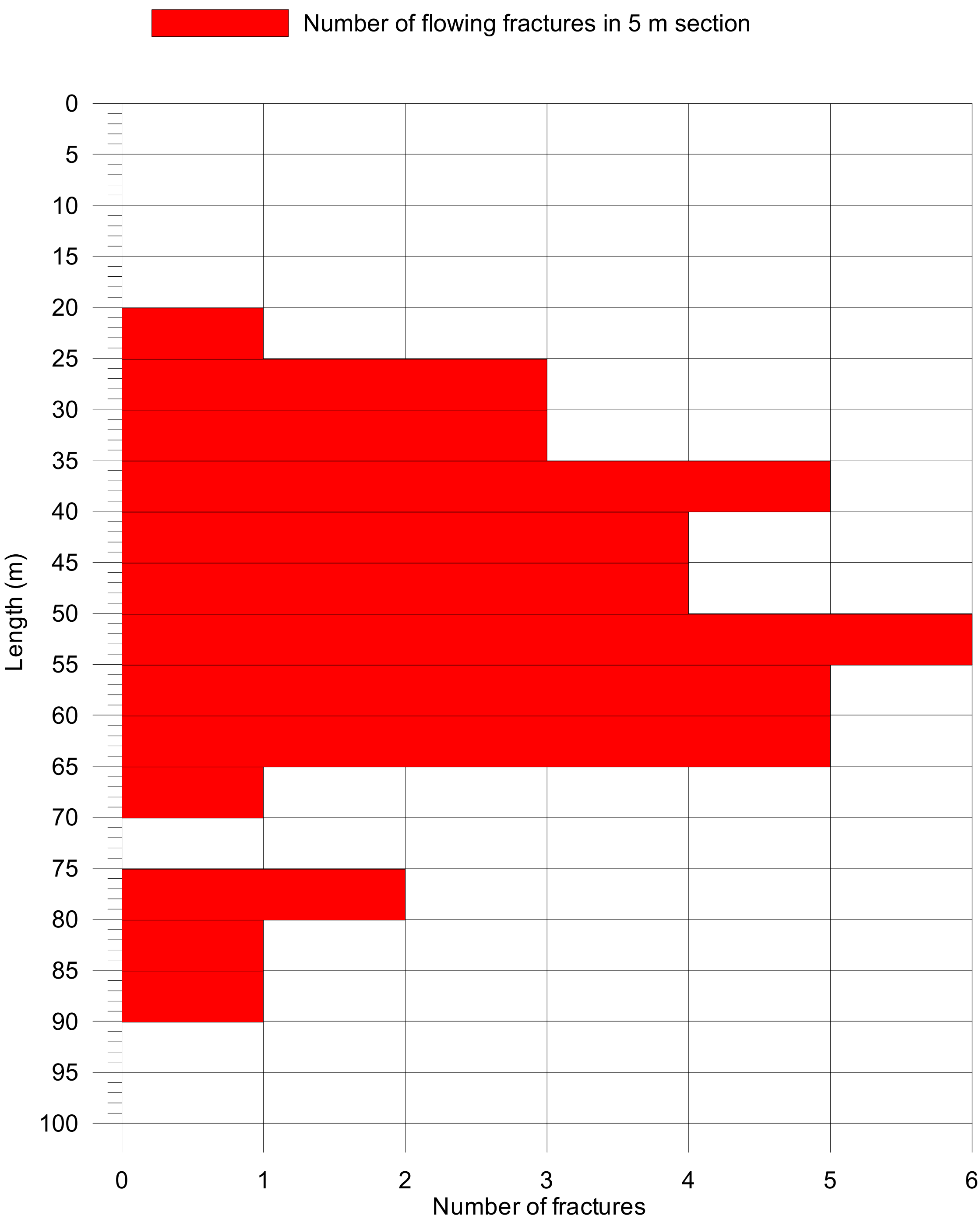
Explanations.

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.
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-$meas_{lLP}$	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-$meas_{lU}$	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)

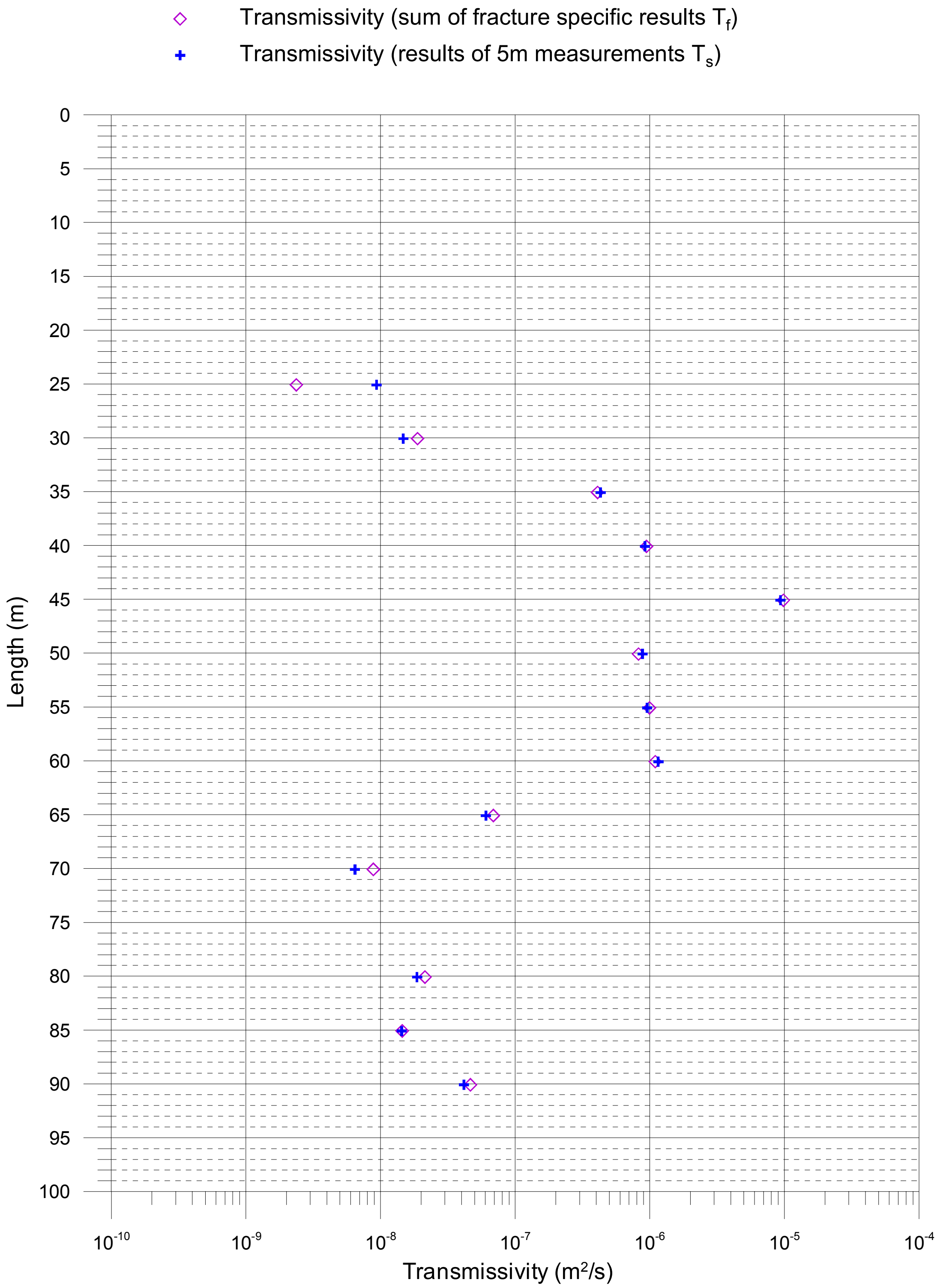
Calculation of conductive fracture frequency.

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)
KLX09G	22.58	27.58	1	1	0	0	0	0
KLX09G	27.58	32.58	3	2	1	0	0	0
KLX09G	32.58	37.58	3	0	0	3	0	0
KLX09G	37.58	42.58	5	2	1	1	1	0
KLX09G	42.58	47.58	4	1	2	0	0	1
KLX09G	47.58	52.58	4	0	0	4	0	0
KLX09G	52.58	57.58	6	2	3	0	1	0
KLX09G	57.58	62.58	5	0	3	1	1	0
KLX09G	62.58	67.58	5	1	4	0	0	0
KLX09G	67.58	72.58	1	0	1	0	0	0
KLX09G	72.58	77.58	0	0	0	0	0	0
KLX09G	77.58	82.58	2	1	1	0	0	0
KLX09G	82.58	87.58	1	0	1	0	0	0
KLX09G	87.58	92.58	1	0	0	1	0	0

Laxemar, borehole KLX09G
Calculation of conductive fracture frequency



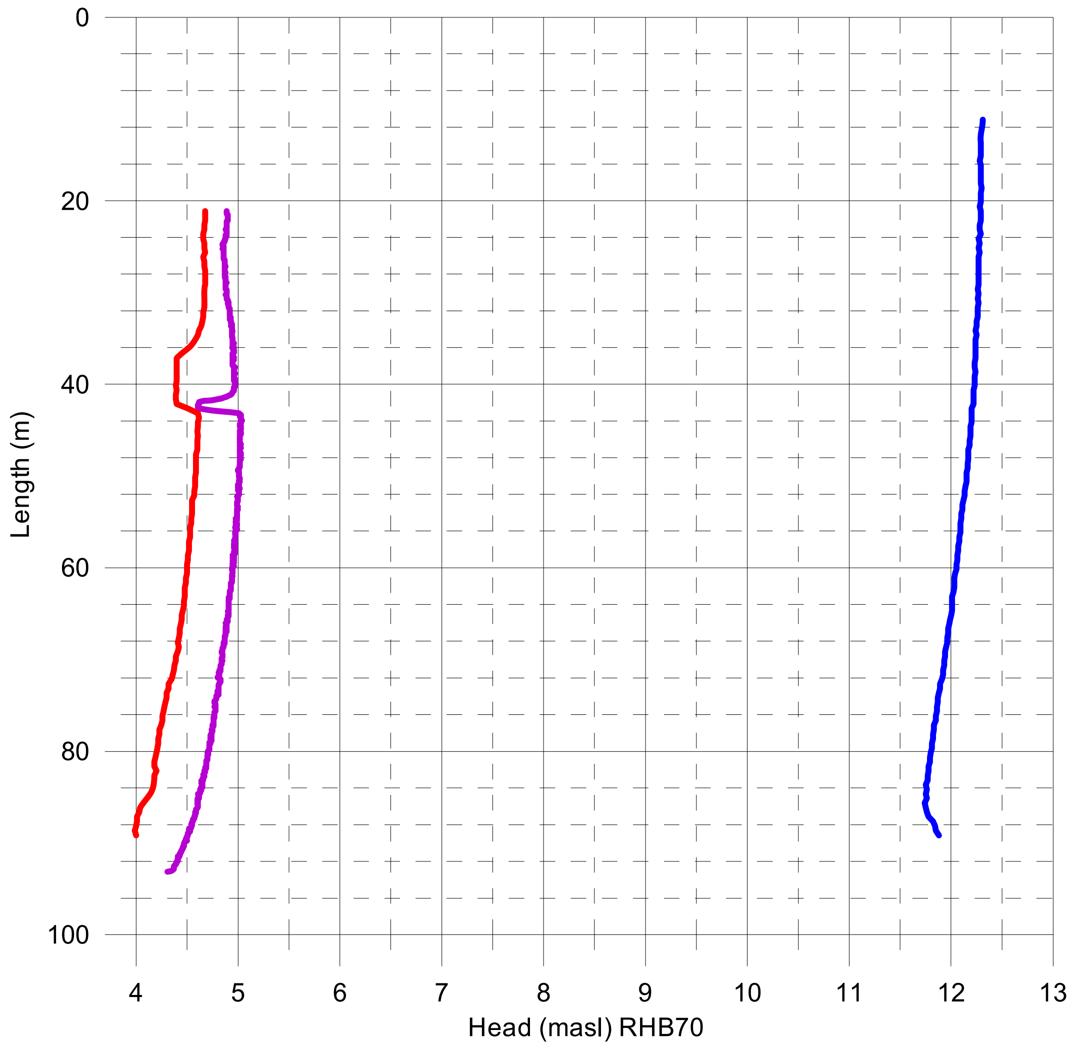
Laxemar, borehole KLX09G
Comparison between section transmissivity and fracture transmissivity



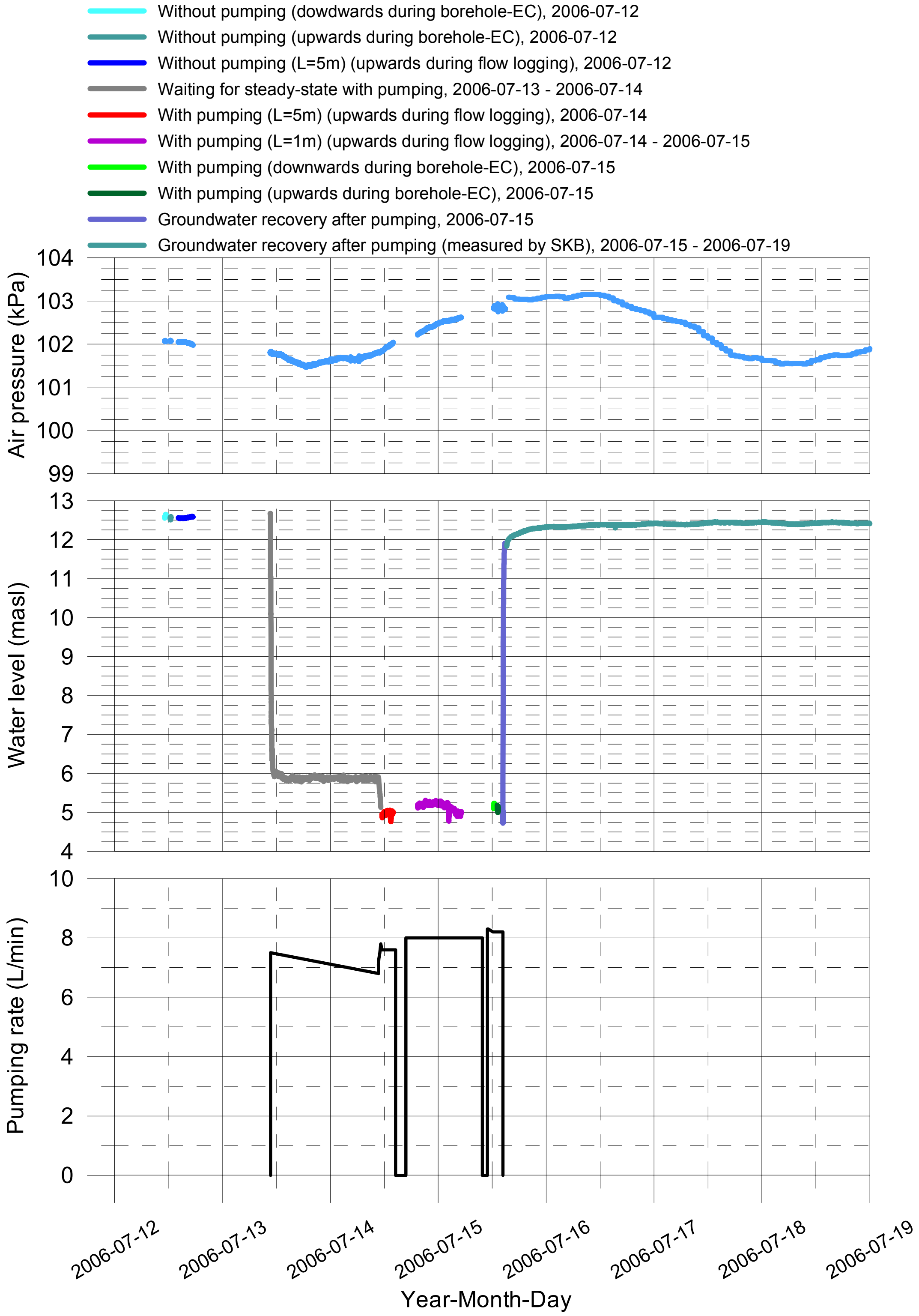
Laxemar, borehole KLX09G
Head in the borehole during flow logging

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)

- Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-07-12 - 2006-07-12
- With pumping (upwards during flow logging, Drawdown 7.87 m, L=5 m, dL=0.5 m), 2006-07-14 - 2006-07-14
- With pumping (upwards during flow logging Drawdown 7.87 m, L=1 m, dL=0.1 m), 2006-07-14 - 2006-07-15

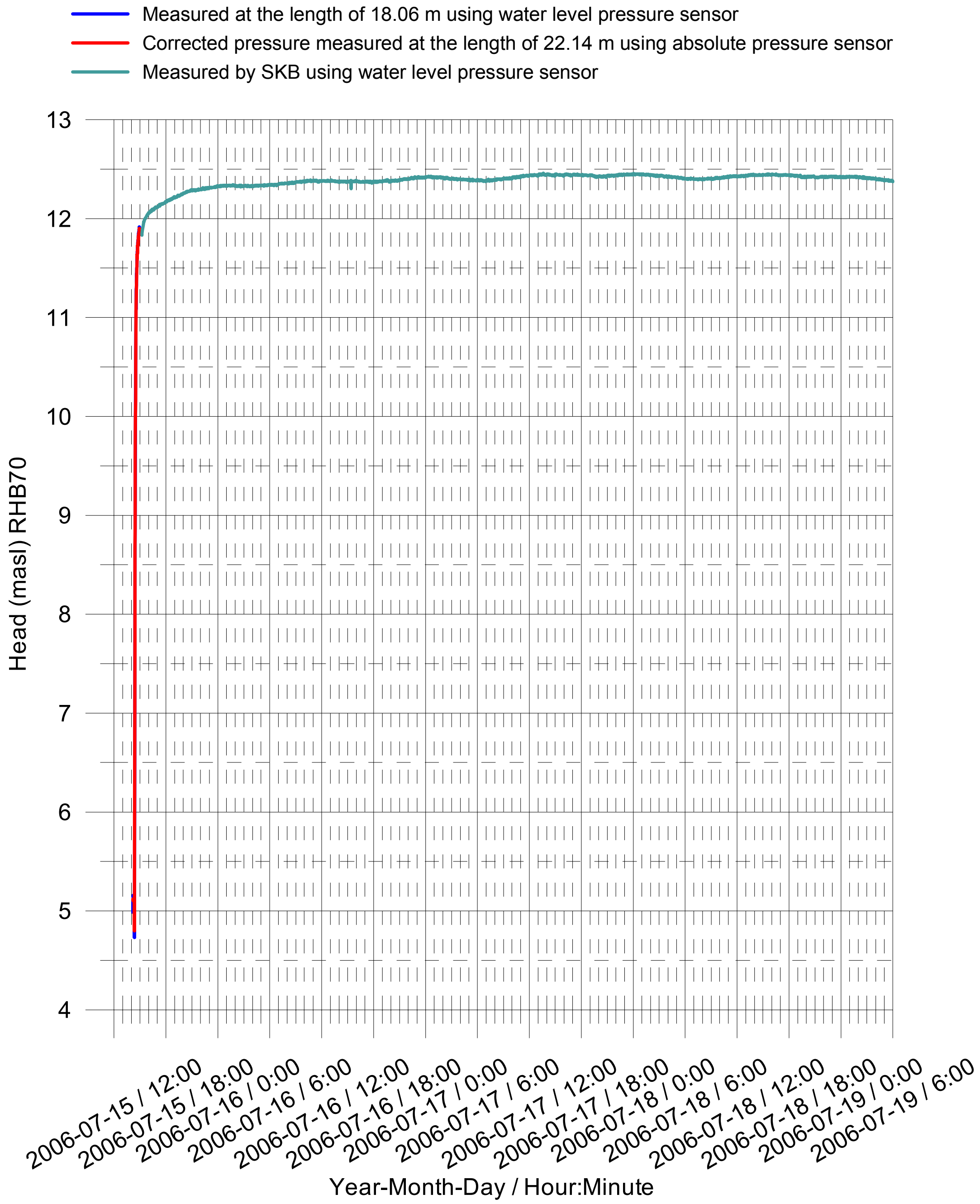


Laxemar, borehole KLX09G
Air pressure, water level in the borehole and pumping rate during flow logging



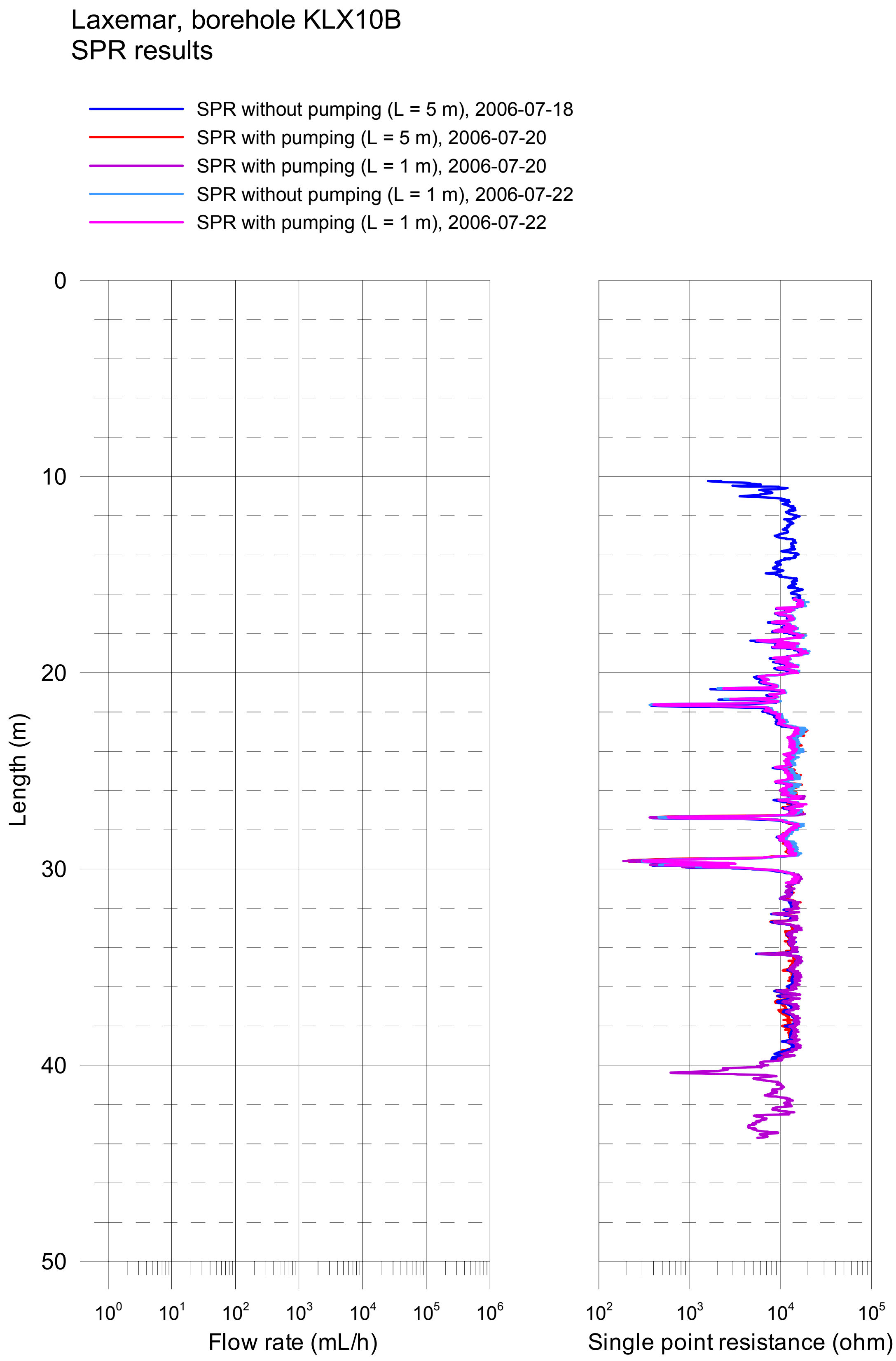
Laxemar, borehole KLX09G
Groundwater recovery after pumping

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)

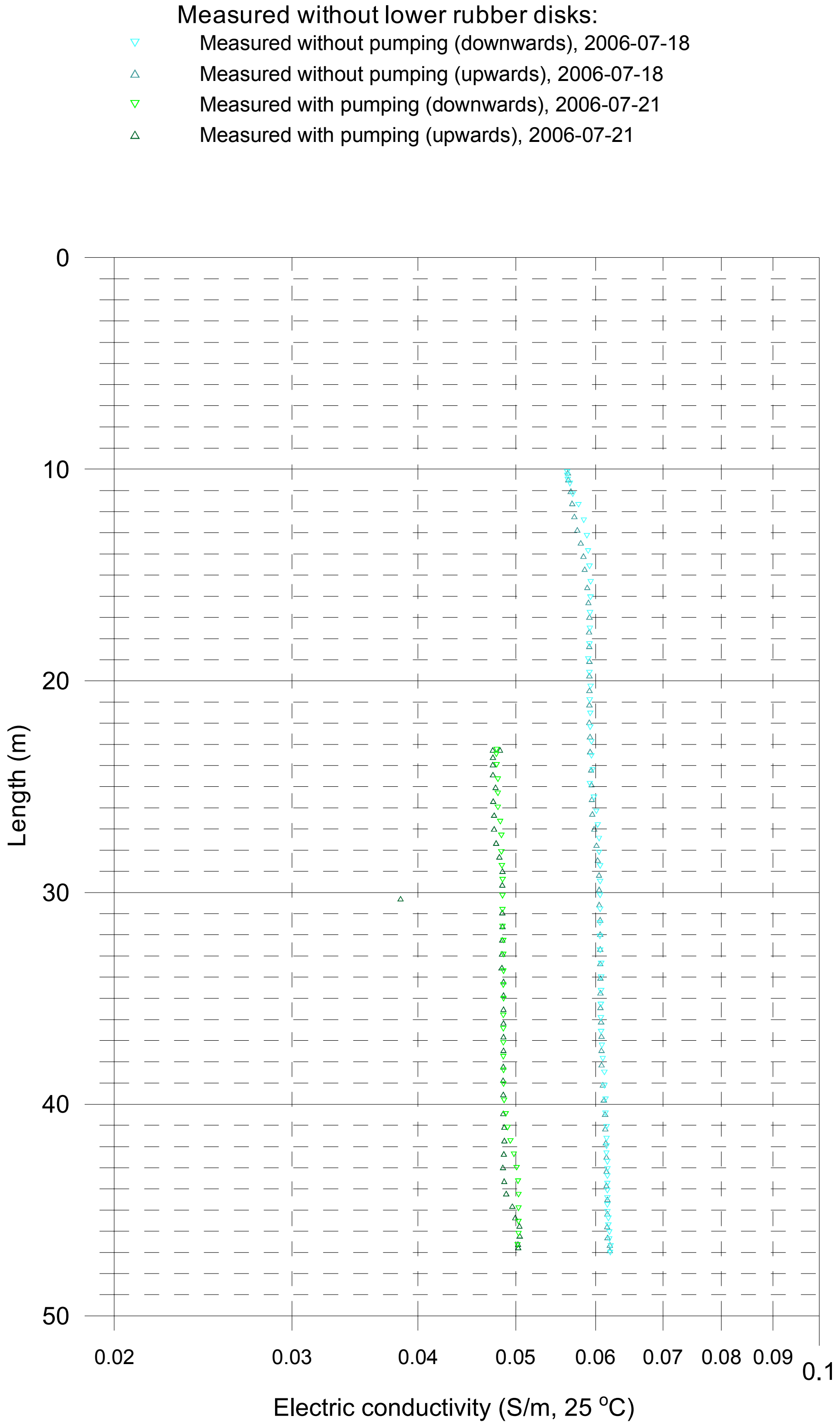


PFL results

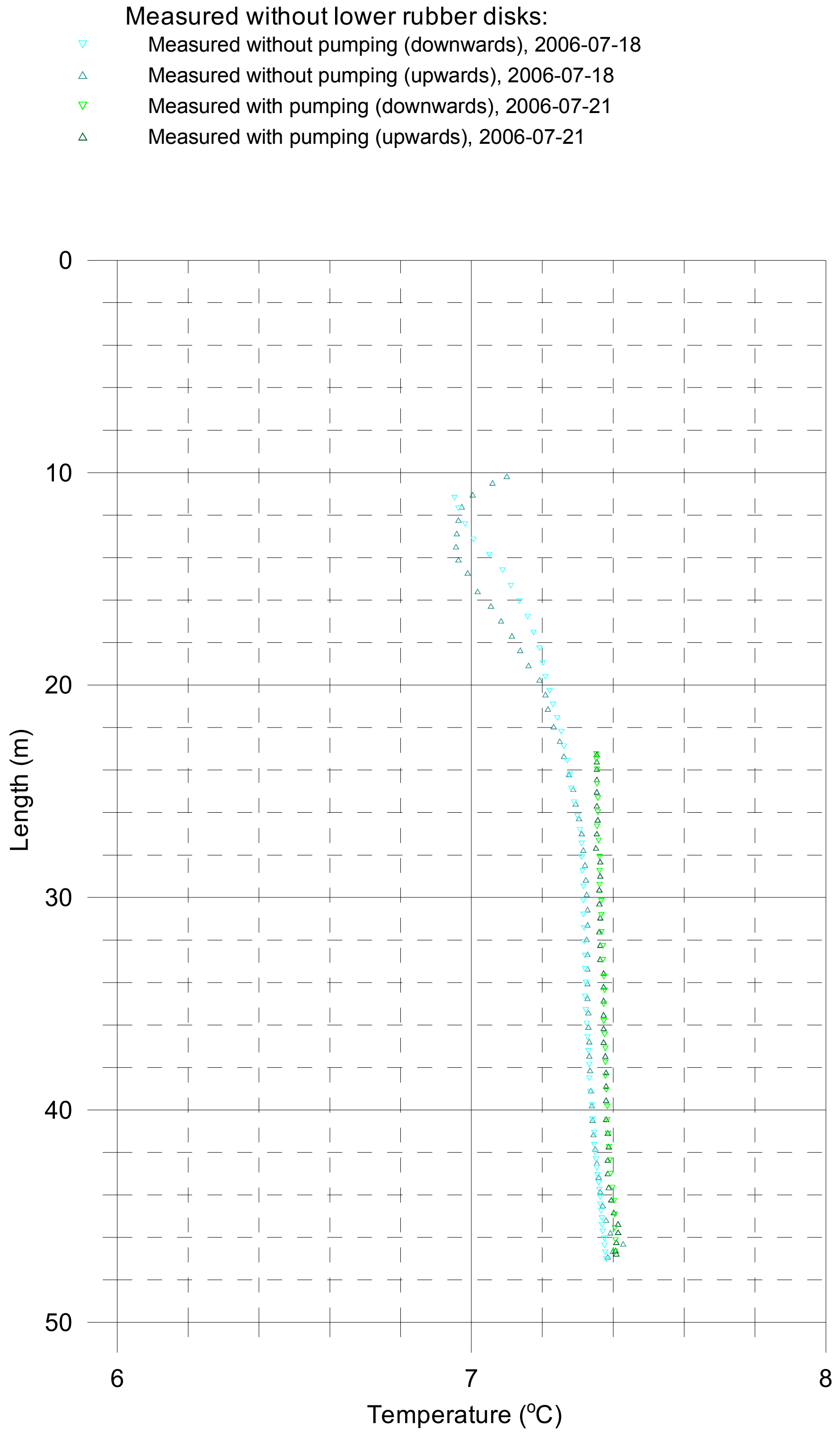
Appendix 10B.1

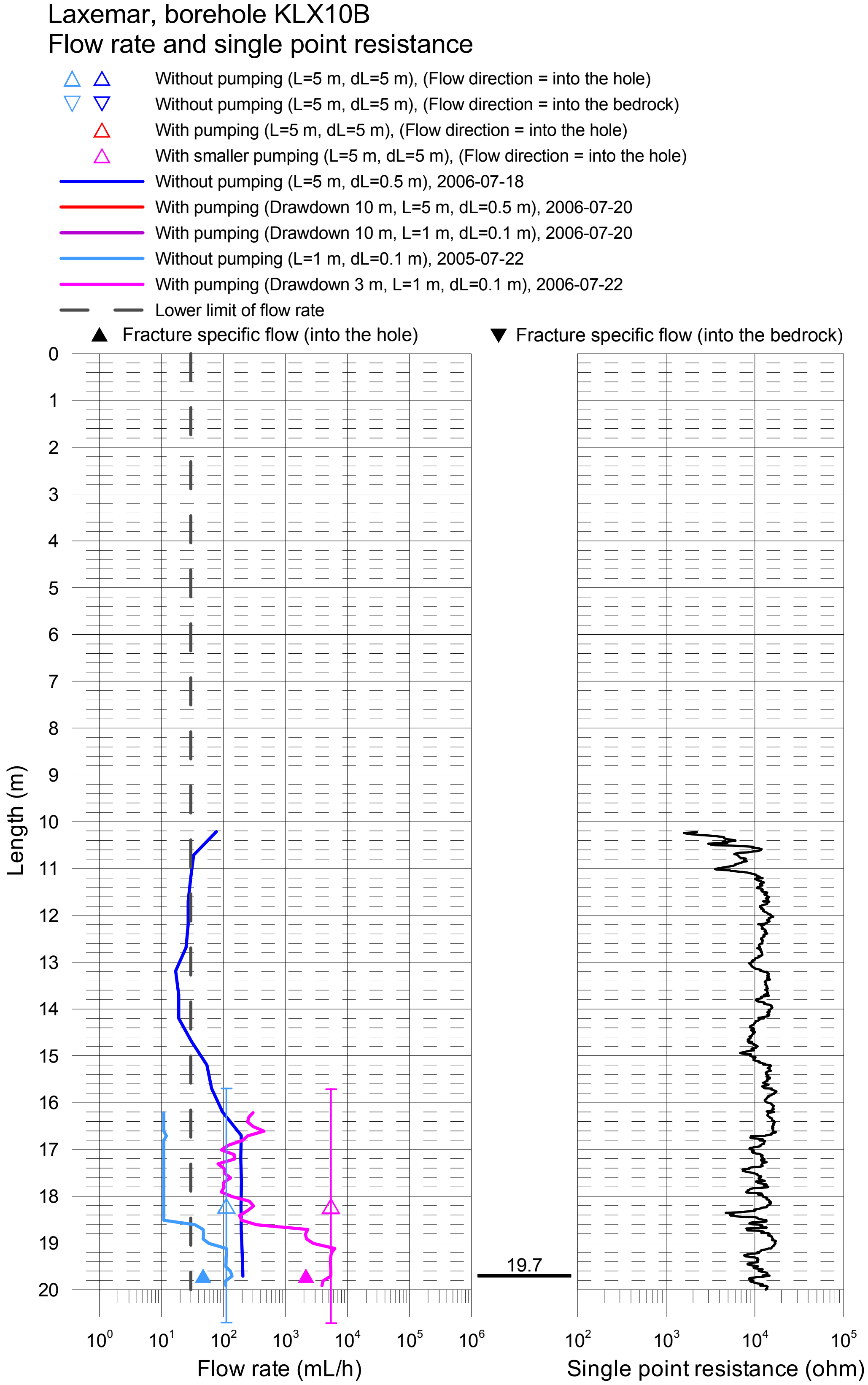


Laxemar, borehole KLX10B
Electric conductivity of borehole water

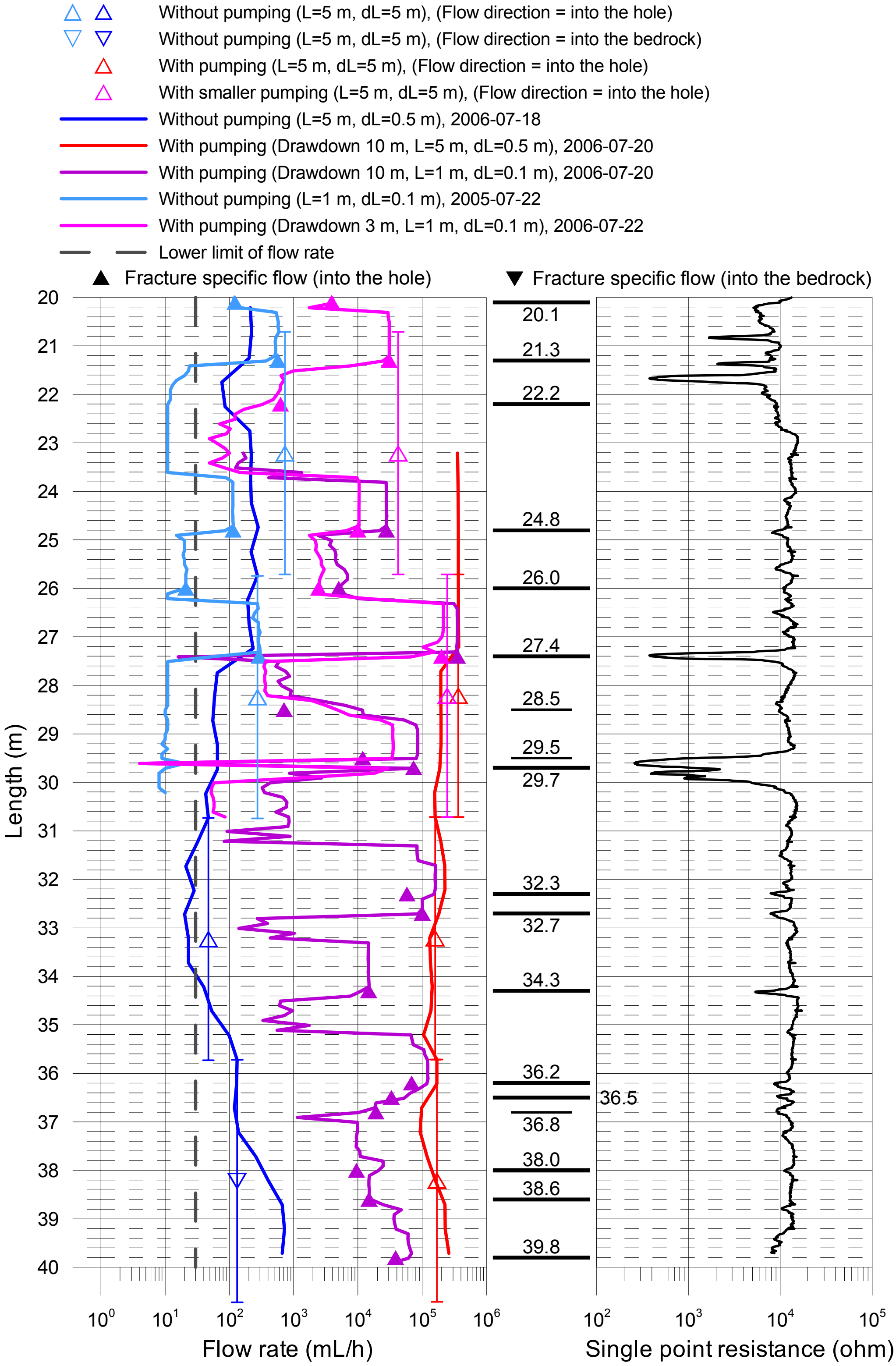


Laxemar, borehole KLX10B
Temperature of borehole water

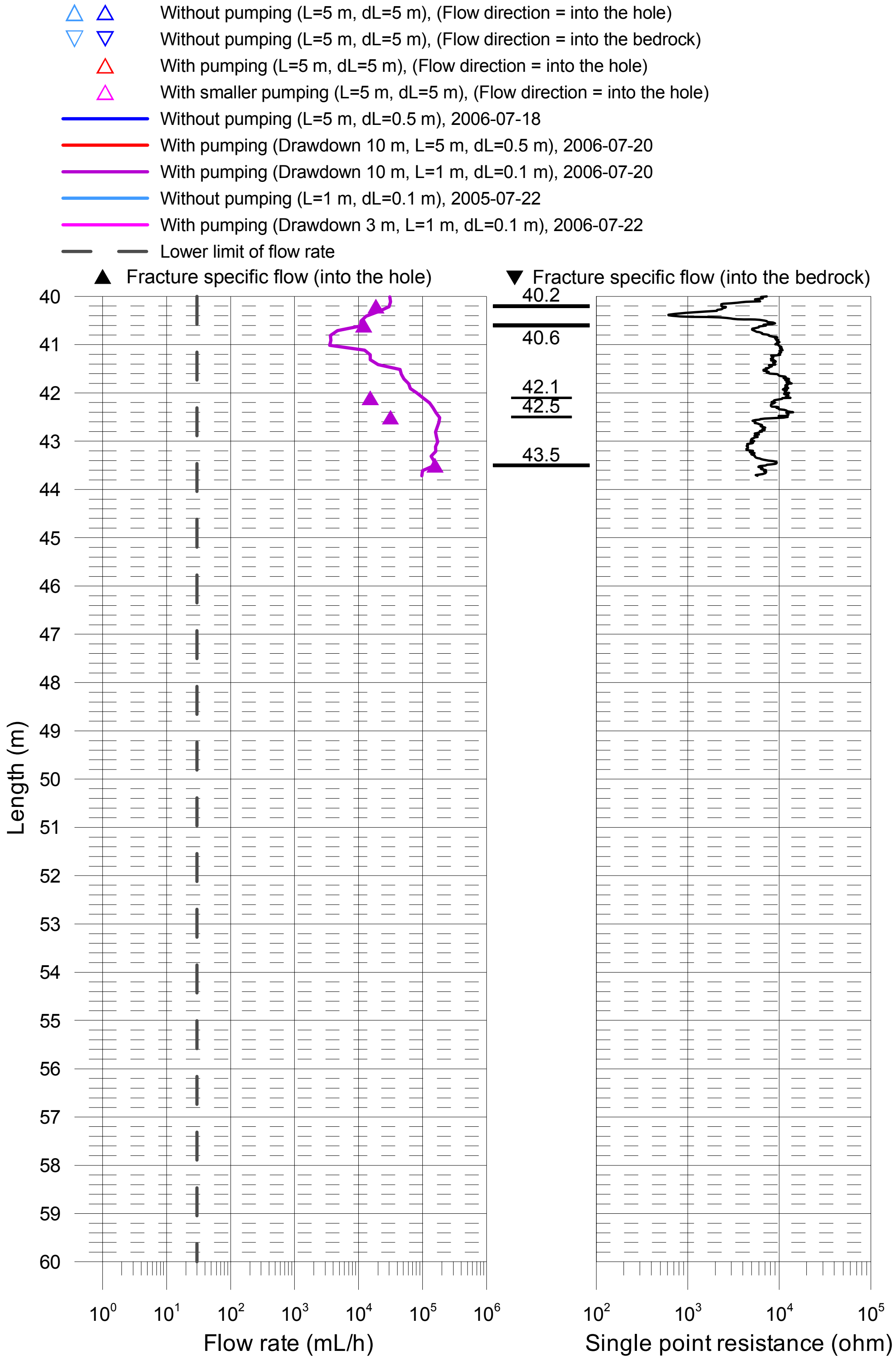


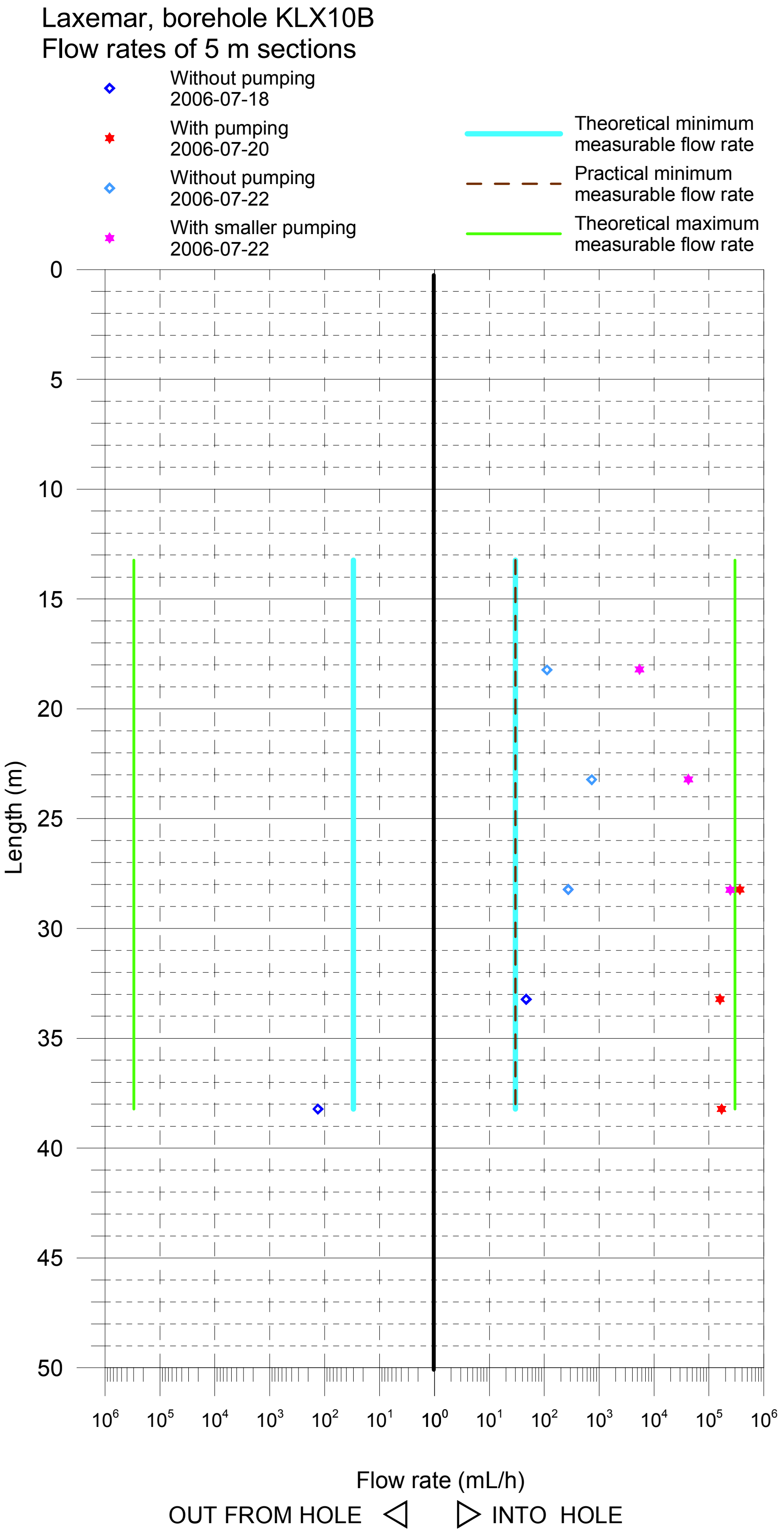

Laxemar, borehole KLX10B
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With smaller pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2006-07-18
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2006-07-20
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2006-07-20
Without pumping (L=1 m, dL=0.1 m), 2005-07-22
With pumping (Drawdown 3 m, L=1 m, dL=0.1 m), 2006-07-22
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
19.7
Flow rate (mL/h)
Single point resistance (ohm)

Laxemar, borehole KLX10B
Flow rate and single point resistance



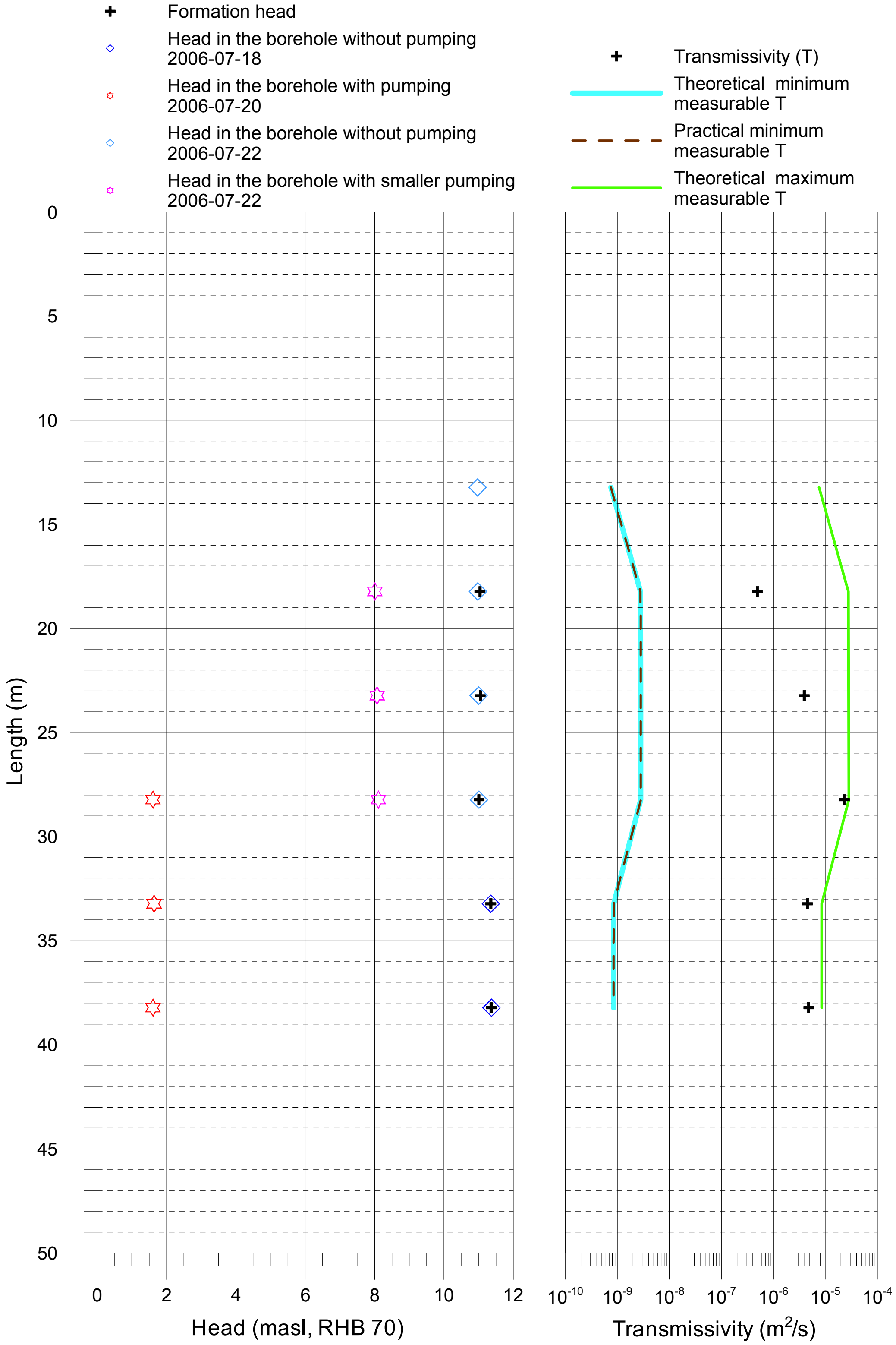
Laxemar, borehole KLX10B
Flow rate and single point resistance

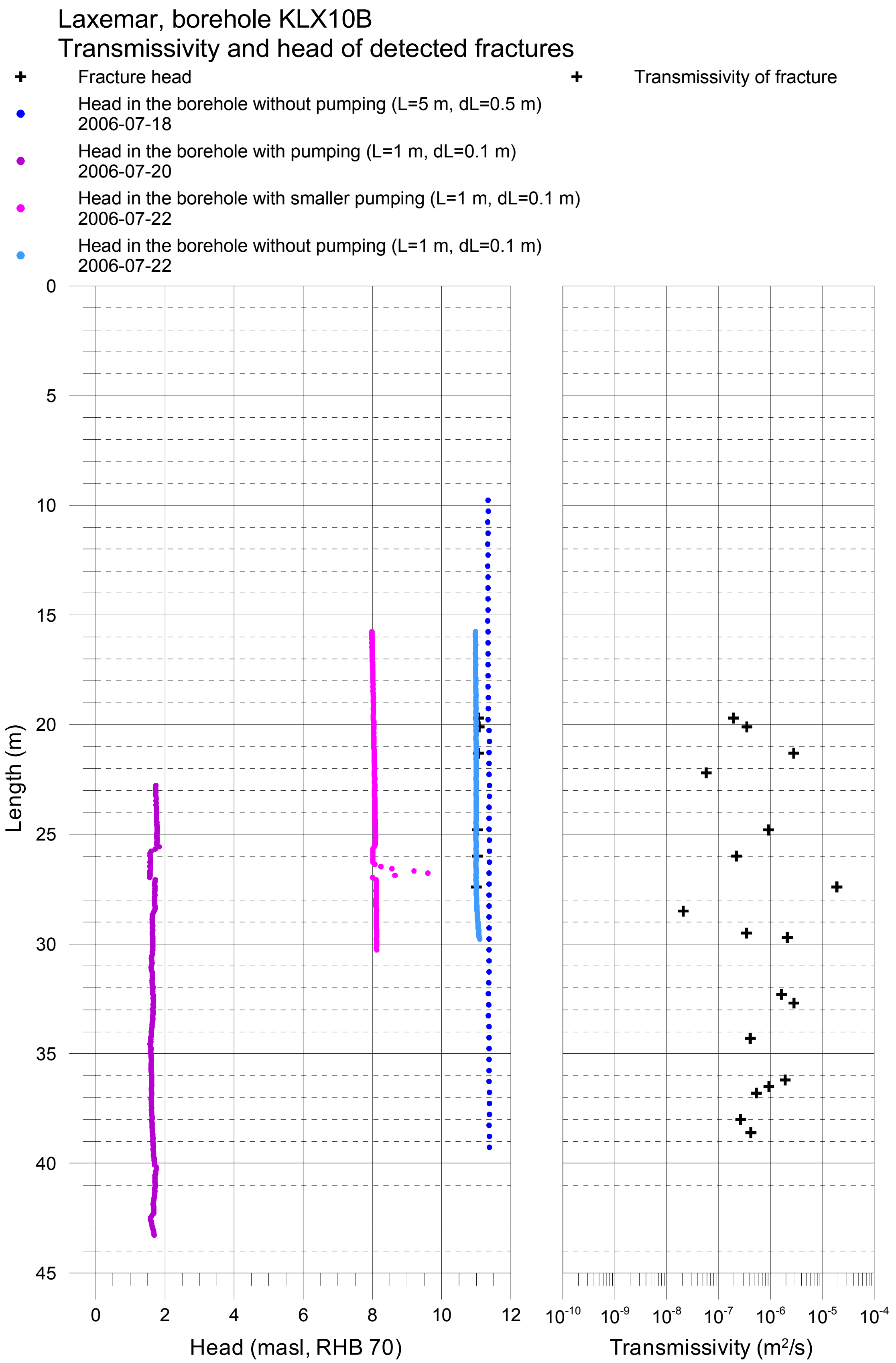




Laxemar, borehole KLX10B
Flow rates of 5 m sections
Without pumping 2006-07-18
With pumping 2006-07-20
Without pumping 2006-07-22
With smaller pumping 2006-07-22
Theoretical minimum measurable flow rate
Practical minimum measurable flow rate
Theoretical maximum measurable flow rate
Length (m)
0
5
10
15
20
25
30
35
40
45
50
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 KLX10B
Transmissivity and head of 5 m sections




Laxemar, borehole KLX10B
Transmissivity and head of detected fractures
Fracture head
Head in the borehole without pumping (L=5 m, dL=0.5 m) 2006-07-18
Head in the borehole with pumping (L=1 m, dL=0.1 m) 2006-07-20
Head in the borehole with smaller pumping (L=1 m, dL=0.1 m) 2006-07-22
Head in the borehole without pumping (L=1 m, dL=0.1 m) 2006-07-22
Transmissivity of fracture
Length (m)
0
5
10
15
20
25
30
35
40
45
0
2
4
6
8
10
12
Head (masl, RHB 70)
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Transmissivity (m²/s)

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)
KLX10B	9	50.25	5A	20060719	10:51	20060720	11:13	20060721	11:50	5	0.5	4.63E–04	2.02E–04

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

tp_1 (s)	tp_2 (s)	tF_1 (s)	tF_2 (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 (–)
176,340	101,820	93,540	210,960	11.57	1.69	8.31	–9.88	–3.26	4.64E–05	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q0 (m^3/s)	h0FW (m.a.s.l.)	Q1 (m^3/s)	h1FW (m.a.s.l.)	TD (m^2/s)	hi (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measlLT (m^2/s)	TD-measlLP (m^2/s)	TD-measlU (m^2/s)	Comments
KLX10B	10.73	15.73	5	–	10.97	–	–	–	–	30	7.5E–10	7.5E–10	7.5E–06	
KLX10B	15.73	20.73	5	3.11E–08	10.98	1.51E–06	8.01	4.9E–07	11.0	30	2.8E–09	2.8E–09	2.8E–05	**
KLX10B	20.73	25.73	5	2.03E–07	11.00	1.18E–05	8.07	3.9E–06	11.1	30	2.8E–09	2.8E–09	2.8E–05	**
KLX10B	25.73	30.73	5	7.61E–08	11.01	1.01E–04	1.61	2.3E–05	11.0	30	2.8E–09	2.8E–09	2.8E–05	*
KLX10B	30.72	35.72	5	1.31E–08	11.35	4.42E–05	1.64	4.5E–06	11.4	30	8.5E–10	8.5E–10	8.5E–06	
KLX10B	35.72	40.72	5	-3.67E–08	11.37	4.72E–05	1.61	4.8E–06	11.4	30	8.4E–10	8.4E–10	8.4E–06	

* Values from the measurement with smaller pumping (original pumped flow over measurement limit).

** Values from the measurement with smaller pumping (drawdown during the first pumping prevented those sections to be measured).

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

Borehole ID	Length to flow anom. L (m)	Lw (m)	dL (m)	Q0 (m³/s)	h0FW (m.a.s.l.)	Q1 (m³/s)	h1FW (m.a.s.l.)	TD (m²/s)	hi (m.a.s.l.)	Comments
KLX10B	19.7	1	0.1	1.31E–08	10.99	5.94E–07	8.02	1.9E–07	11.1	**
KLX10B	20.1	1	0.1	3.39E–08	10.99	1.09E–06	8.04	3.5E–07	11.1	**
KLX10B	21.3	1	0.1	1.57E–07	11.00	8.53E–06	8.05	2.8E–06	11.1	**
KLX10B	22.2	1	0.1	–	11.00	1.74E–07	8.05	5.8E–08	-	**
KLX10B	24.8	1	0.1	3.17E–08	11.00	2.74E–06	8.08	9.2E–07	11.0	**
KLX10B	26.0	1	0.1	5.83E–09	11.00	6.78E–07	8.01	2.2E–07	11.0	**
KLX10B	27.4	1	0.1	8.06E–08	11.00	5.56E–05	8.11	1.9E–05	11.0	**
KLX10B	28.5	1	0.1	–	11.02	1.97E–07	1.69	2.1E–08	–	
KLX10B	29.5	1	0.1	–	11.07	3.31E–06	1.64	3.5E–07	–	*
KLX10B	29.7	1	0.1	–	11.09	2.04E–05	1.65	2.1E–06	–	
KLX10B	32.3	1	0.1	–	11.35	1.61E–05	1.66	1.6E–06	–	
KLX10B	32.7	1	0.1	–	11.36	2.78E–05	1.67	2.8E–06	–	
KLX10B	34.3	1	0.1	–	11.37	4.06E–06	1.59	4.1E–07	–	
KLX10B	36.2	1	0.1	–	11.37	1.90E–05	1.62	1.9E–06	–	
KLX10B	36.5	1	0.1	–	11.37	9.19E–06	1.62	9.3E–07	–	
KLX10B	36.8	1	0.1	–	11.38	5.31E–06	1.62	5.4E–07	–	*
KLX10B	38.0	1	0.1	–	11.38	2.63E–06	1.63	2.7E–07	–	
KLX10B	38.6	1	0.1	–	11.38	4.14E–06	1.64	4.2E–07	–	
KLX10B	39.8	1	0.1	–	–	1.07E–05	1.69		–	
KLX10B	40.2	1	0.1	–	–	5.19E–06	1.75		–	
KLX10B	40.6	1	0.1	–	–	3.33E–06	1.71		–	
KLX10B	42.1	1	0.1	–	–	4.22E–06	1.68		–	*
KLX10B	42.5	1	0.1	–	–	8.72E–06	1.59		–	*
KLX10B	43.5	1	0.1	–	–	4.33E–05	1.69		–	

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

** Values from the measurement with smaller pumping (original pumped flow over measurement limit or drawdown during the first pumping prevented those fractures to be measured).

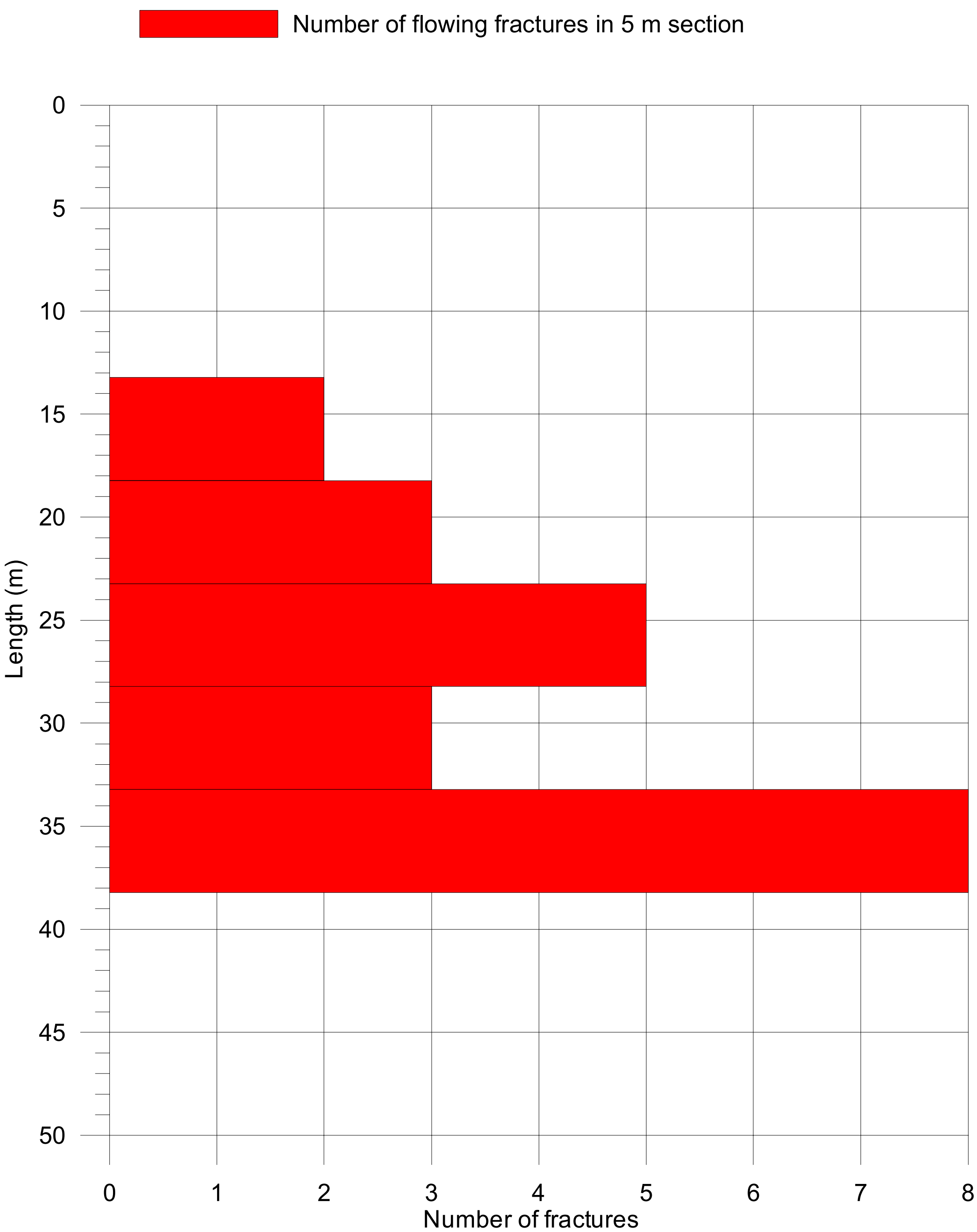
Explanations.

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-$meas_{lLP}$	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-$meas_{lU}$	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)

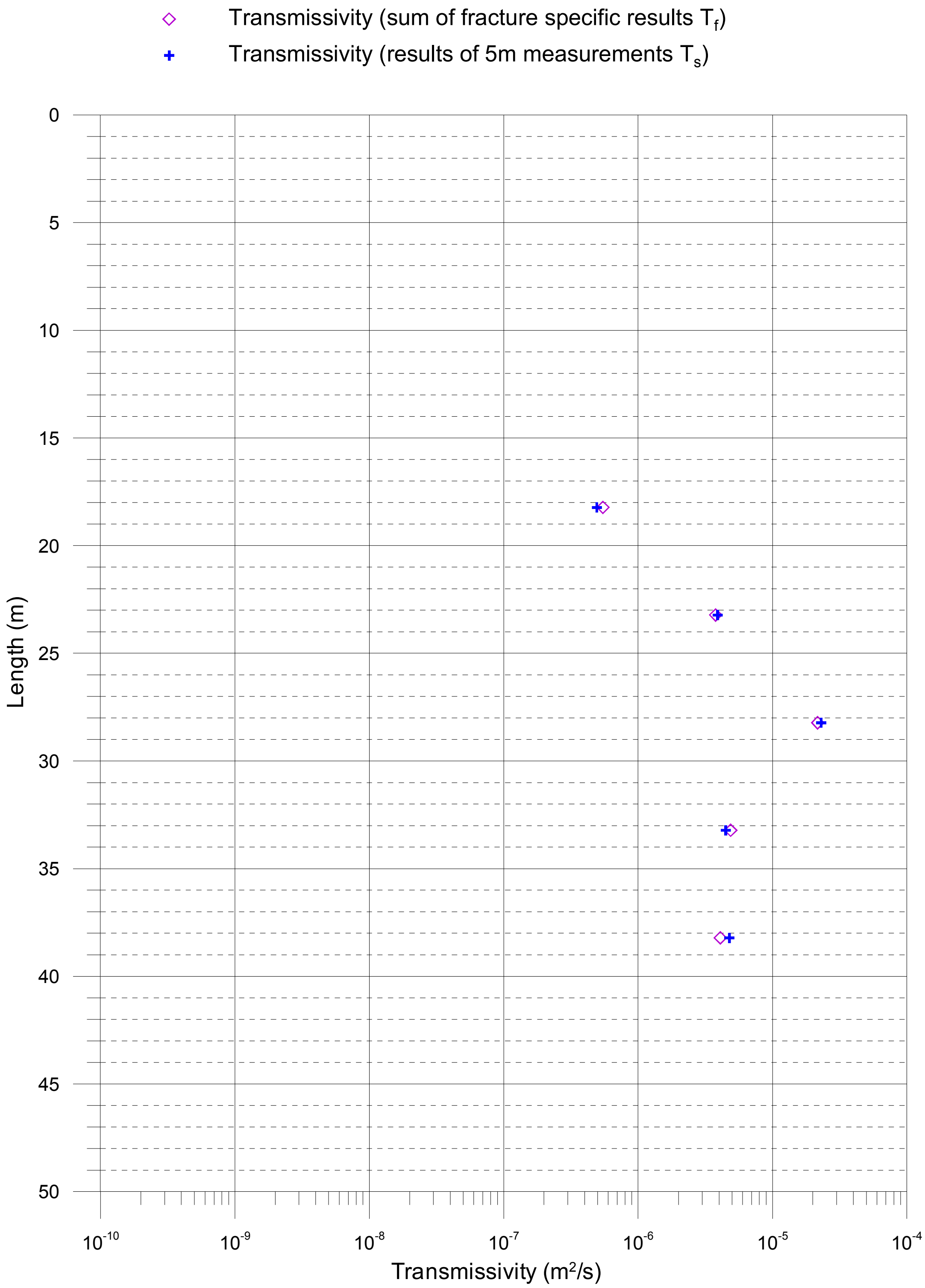
Calculation of conductive fracture frequency.

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)
KLX10B	10.73	15.73	0	0	0	0	0	0
KLX10B	15.73	20.73	2	0	0	2	0	0
KLX10B	20.73	25.73	3	0	1	1	1	0
KLX10B	25.73	30.73	5	0	1	1	2	1
KLX10B	30.72	35.72	3	0	0	0	3	0
KLX10B	35.72	40.72	8	0	0	1	7	0

Laxemar, borehole KLX10B
Calculation of conductive fracture frequency

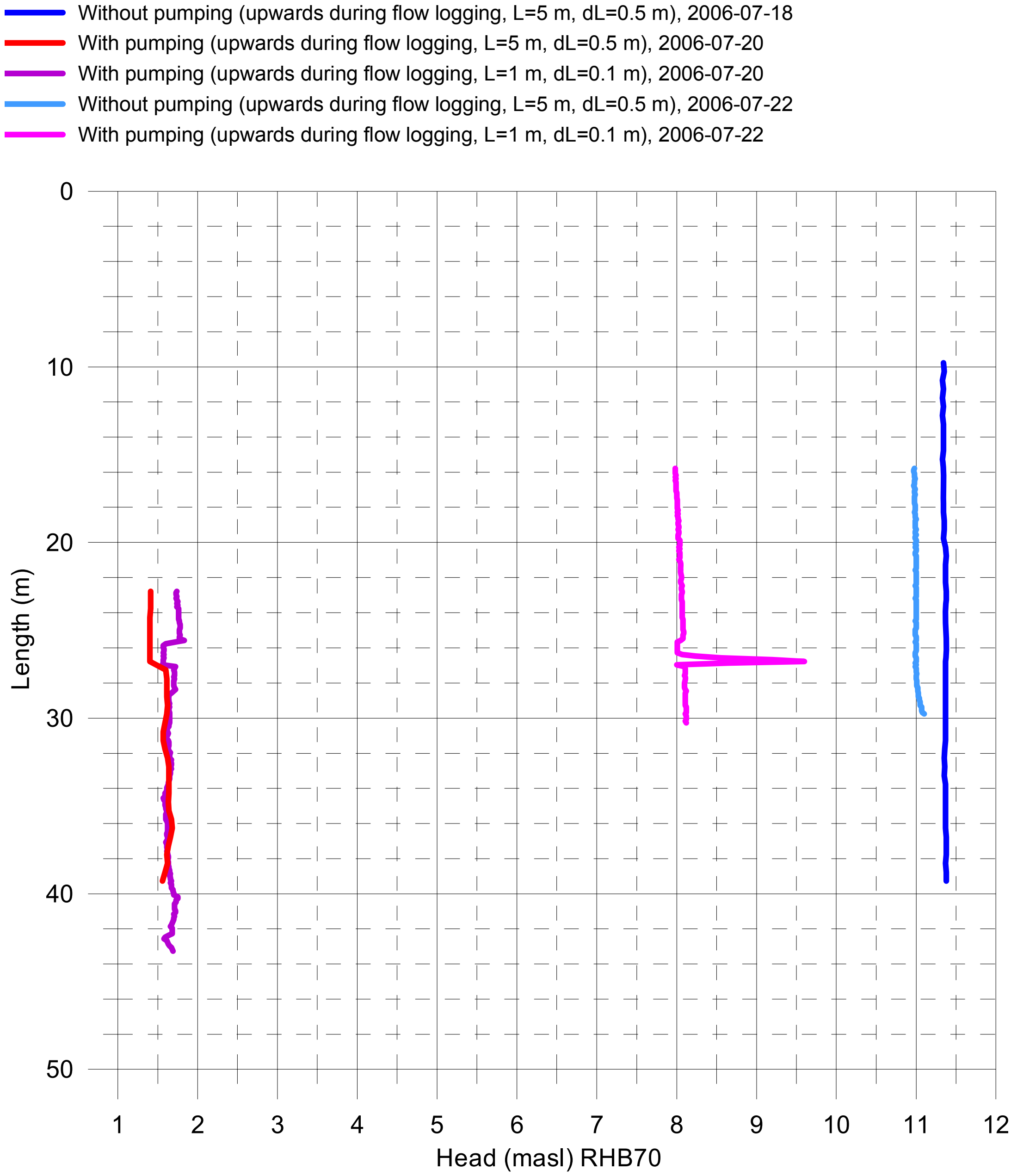


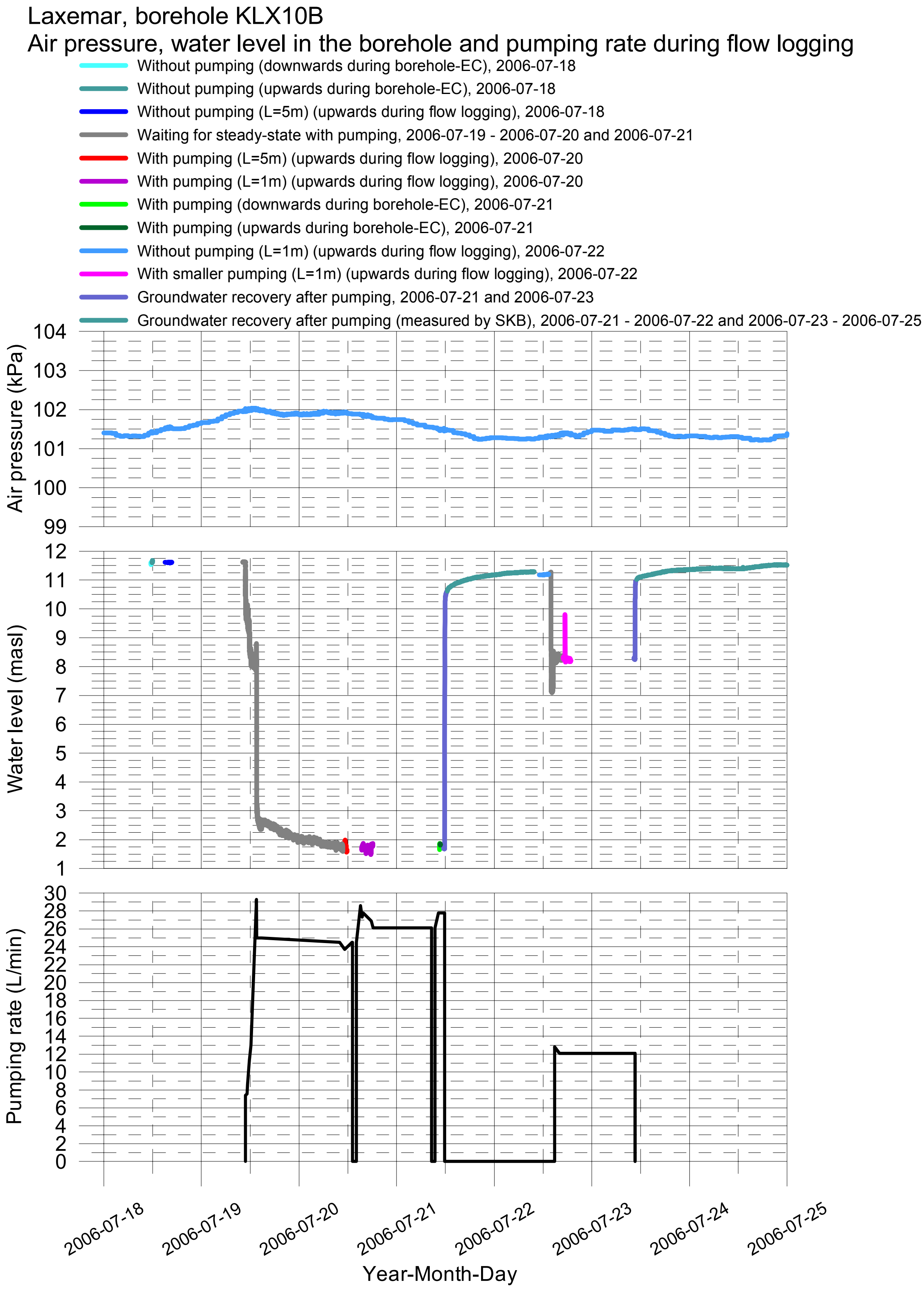
Laxemar, borehole KLX10B
Comparison between section transmissivity and fracture transmissivity

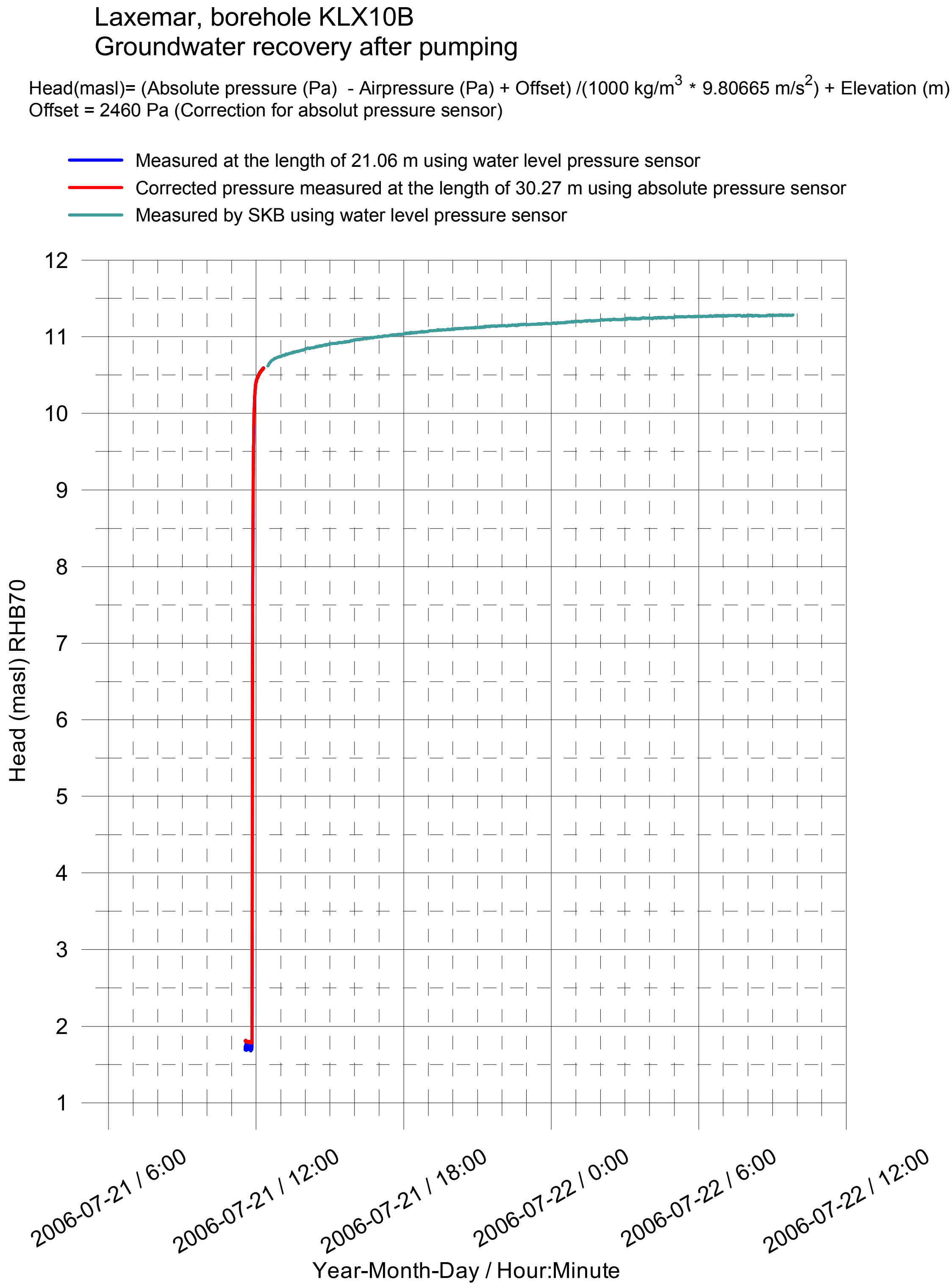


Laxemar, borehole KLX10B
Head in the borehole during flow logging

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)

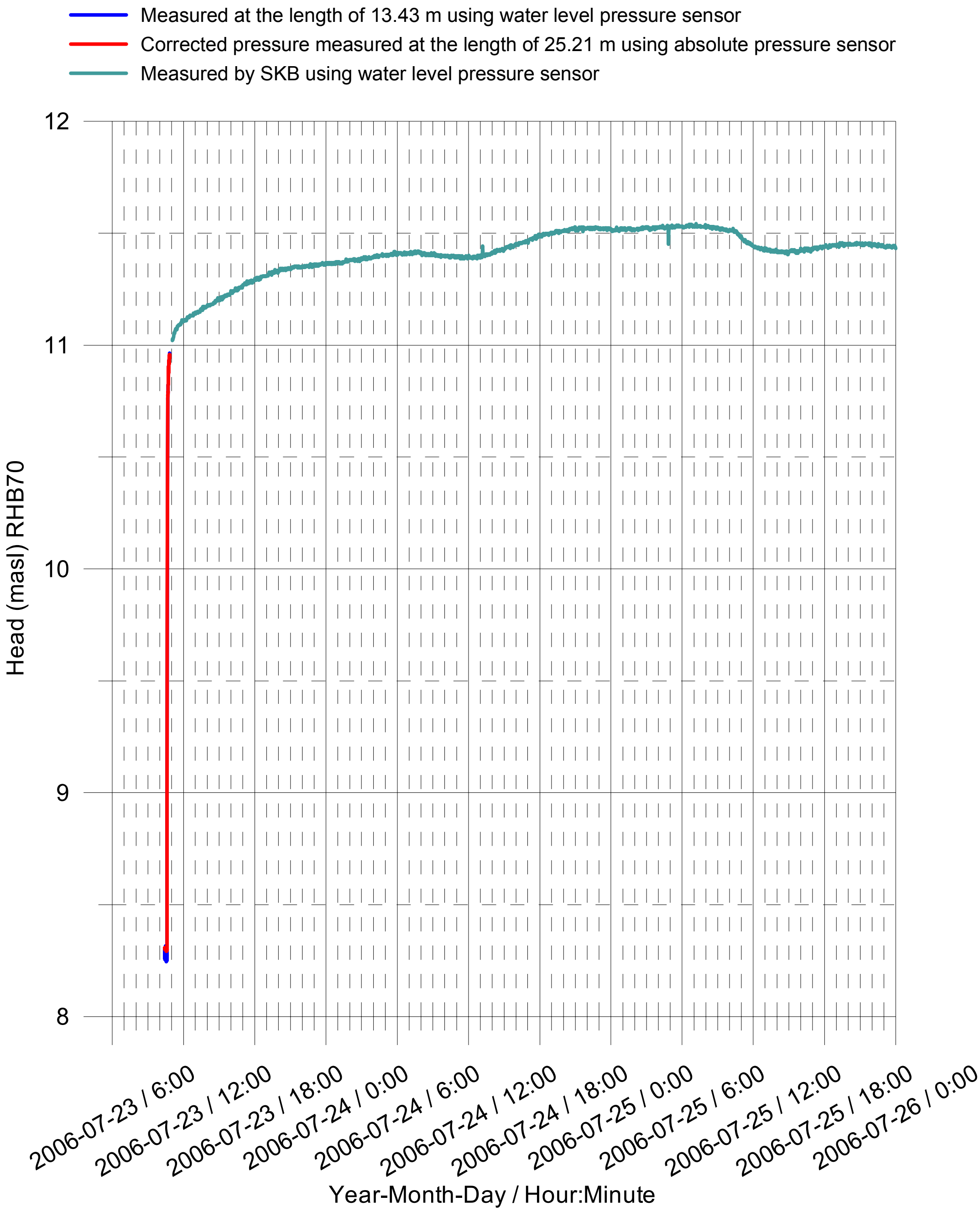



Laxemar, borehole KLX10B
Air pressure, water level in the borehole and pumping rate during flow logging
Without pumping (downwards during borehole-EC), 2006-07-18
Without pumping (upwards during borehole-EC), 2006-07-18
Without pumping (L=5m) (upwards during flow logging), 2006-07-18
Waiting for steady-state with pumping, 2006-07-19 - 2006-07-20 and 2006-07-21
With pumping (L=5m) (upwards during flow logging), 2006-07-20
With pumping (L=1m) (upwards during flow logging), 2006-07-20
With pumping (downwards during borehole-EC), 2006-07-21
With pumping (upwards during borehole-EC), 2006-07-21
Without pumping (L=1m) (upwards during flow logging), 2006-07-22
With smaller pumping (L=1m) (upwards during flow logging), 2006-07-22
Groundwater recovery after pumping, 2006-07-21 and 2006-07-23
Groundwater recovery after pumping (measured by SKB), 2006-07-21 - 2006-07-22 and 2006-07-23 - 2006-07-25
Air pressure (kPa)
104
103
102
101
100
99
Water level (masl)
12
11
10
9
8
7
6
5
4
3
2
1
Pumping rate (L/min)
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
2006-07-18
2006-07-19
2006-07-20
2006-07-21
2006-07-22
2006-07-23
2006-07-24
2006-07-25
Year-Month-Day


Laxemar, borehole KLX10B
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 21.06 m using water level pressure sensor
Corrected pressure measured at the length of 30.27 m using absolute pressure sensor
Measured by SKB using water level pressure sensor
Head (masl) RHB70
12
11
10
9
8
7
6
5
4
3
2
1
2006-07-21 / 6:00
2006-07-21 / 12:00
2006-07-21 / 18:00
2006-07-22 / 0:00
2006-07-22 / 6:00
2006-07-22 / 12:00
Year-Month-Day / Hour:Minute

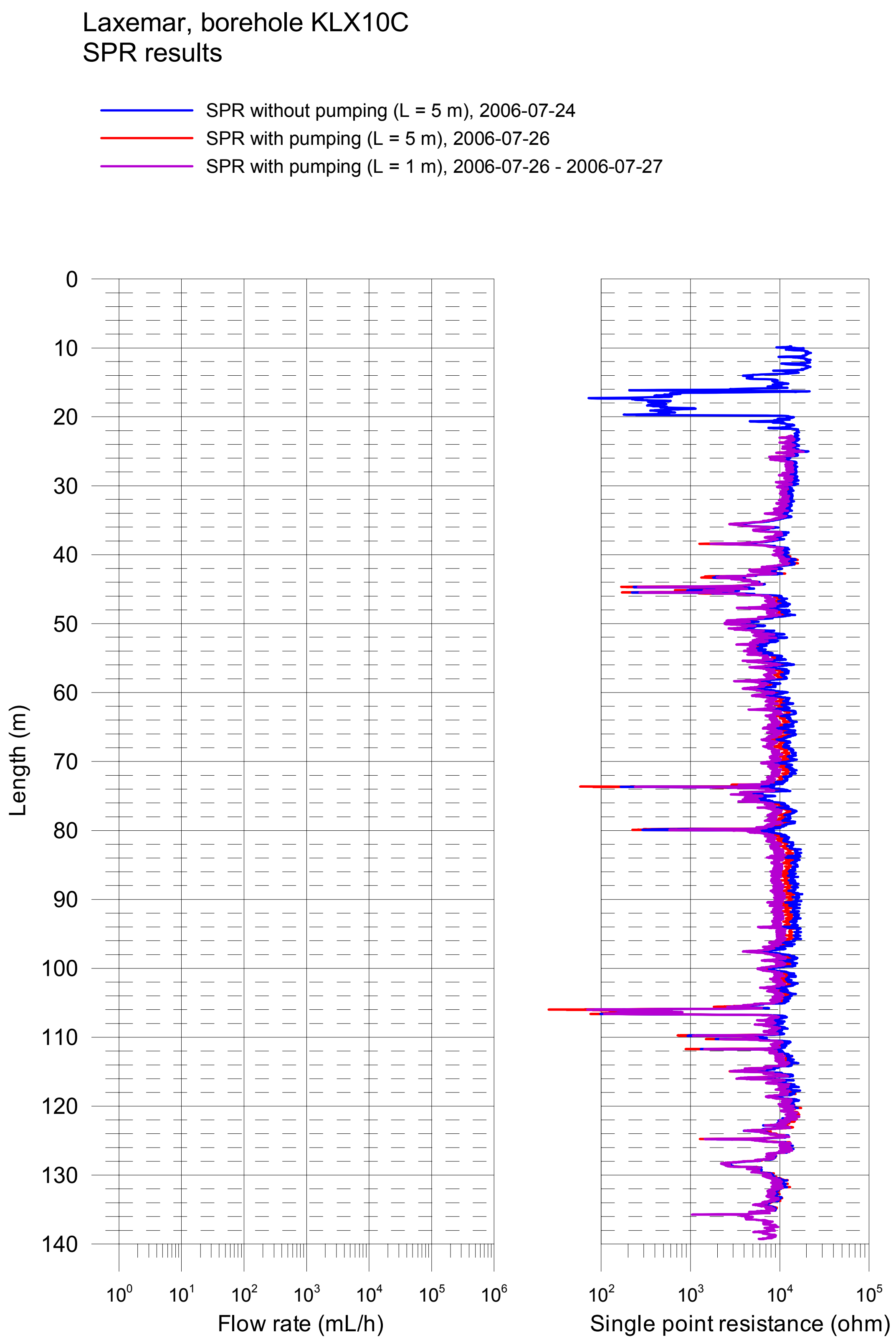
Laxemar, borehole KLX10B
Groundwater recovery after smaller pumping

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)

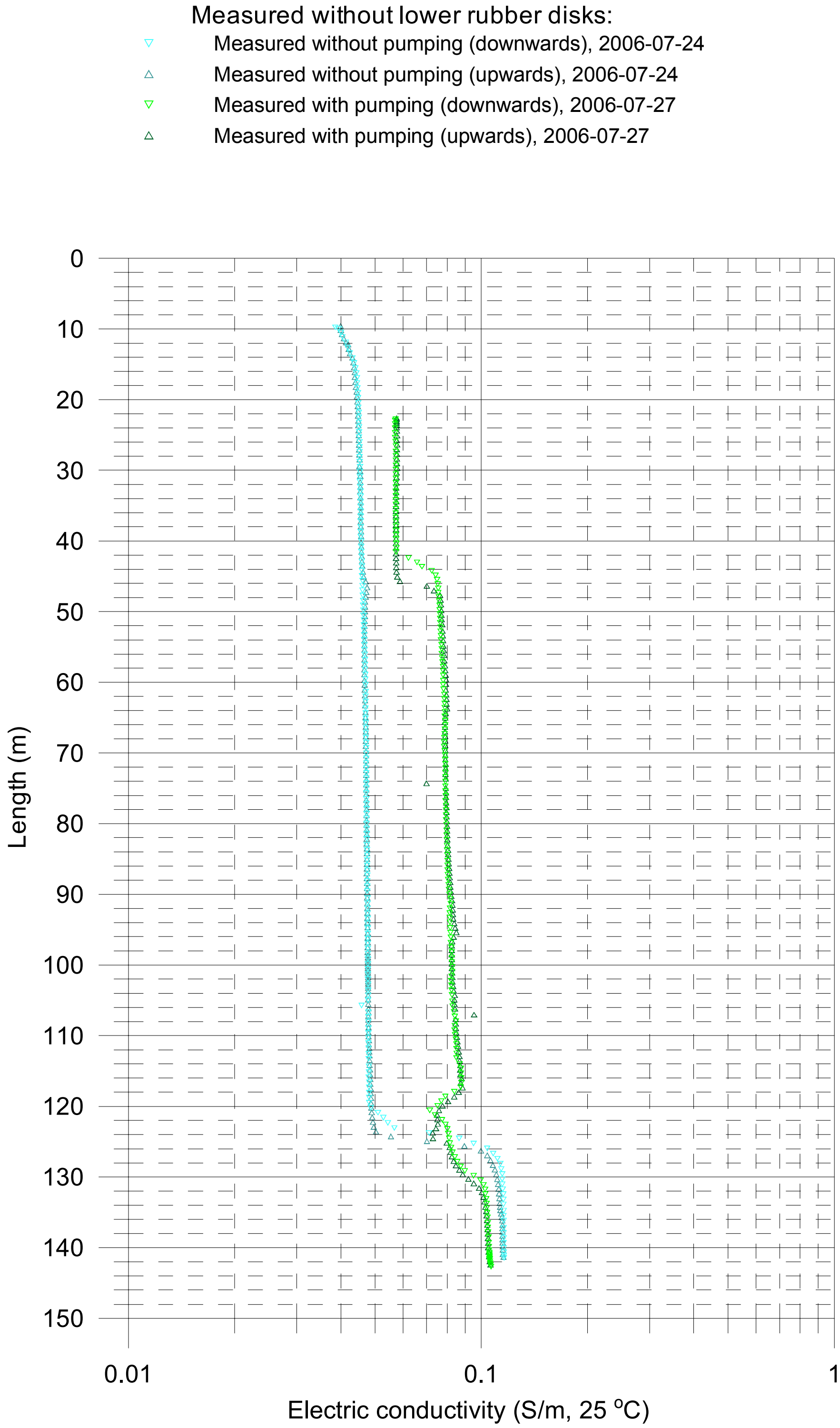


PFL results

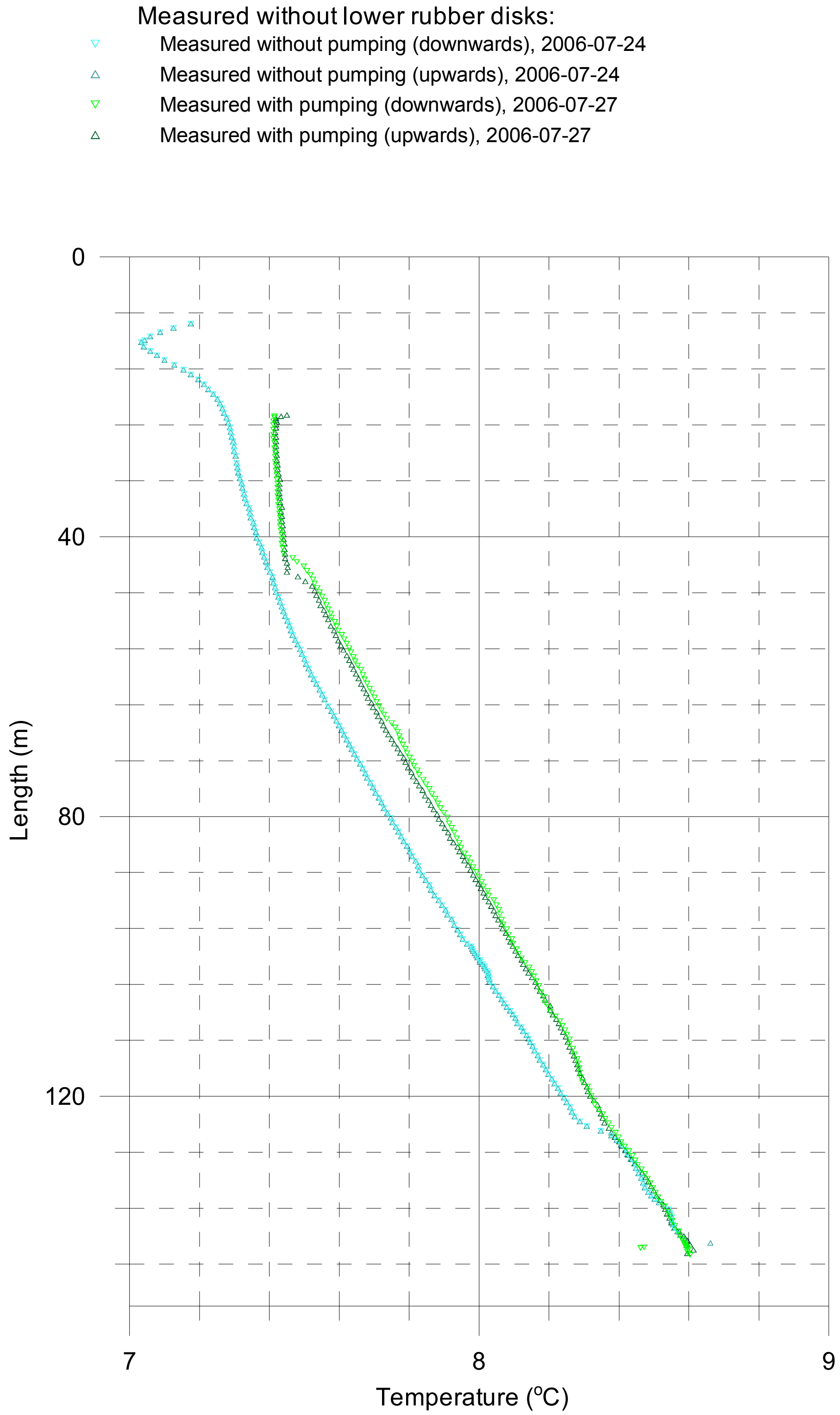
Appendix 10C.1



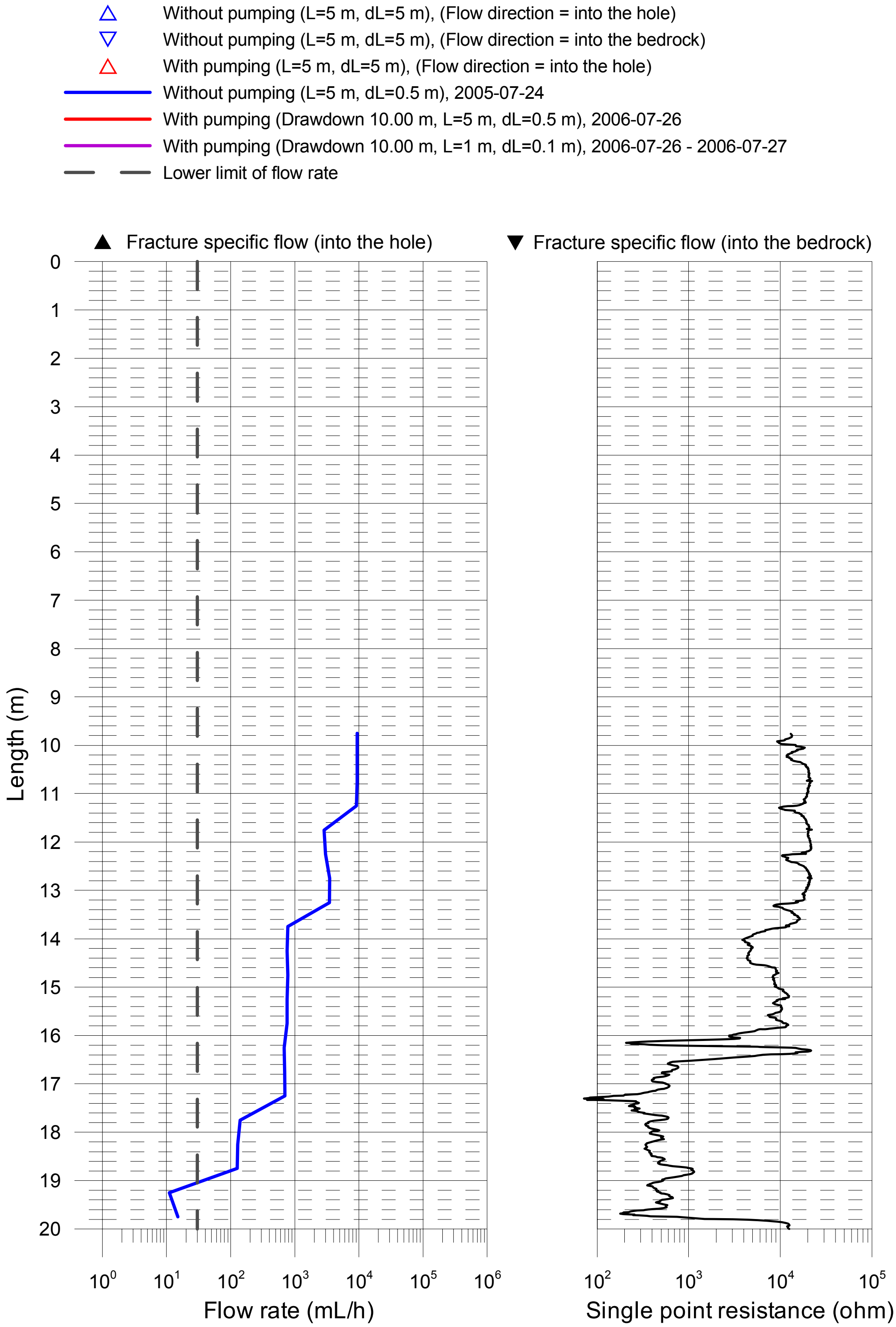
Laxemar, borehole KLX10C
Electric conductivity of borehole water



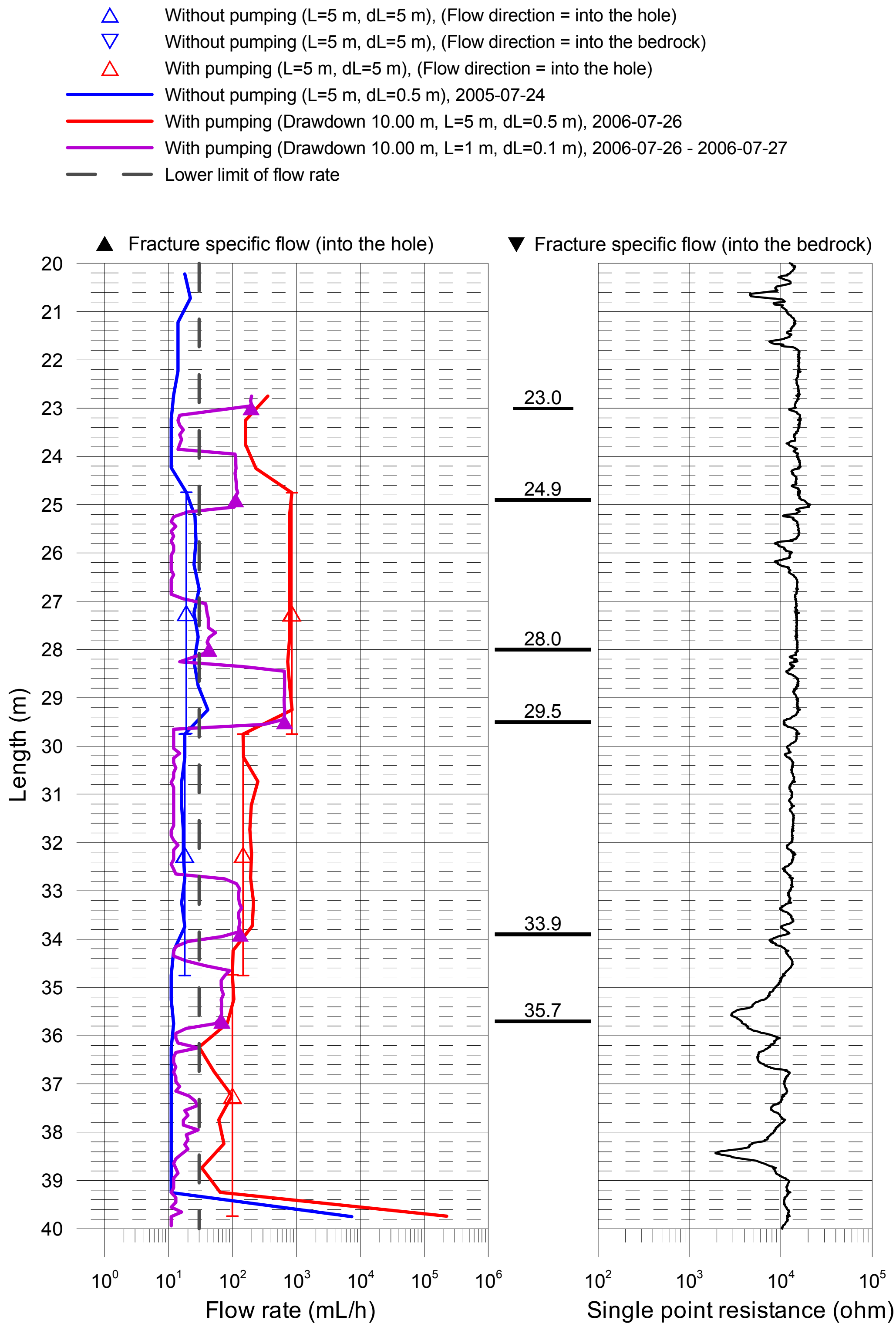
Laxemar, borehole KLX10C
Temperature of borehole water



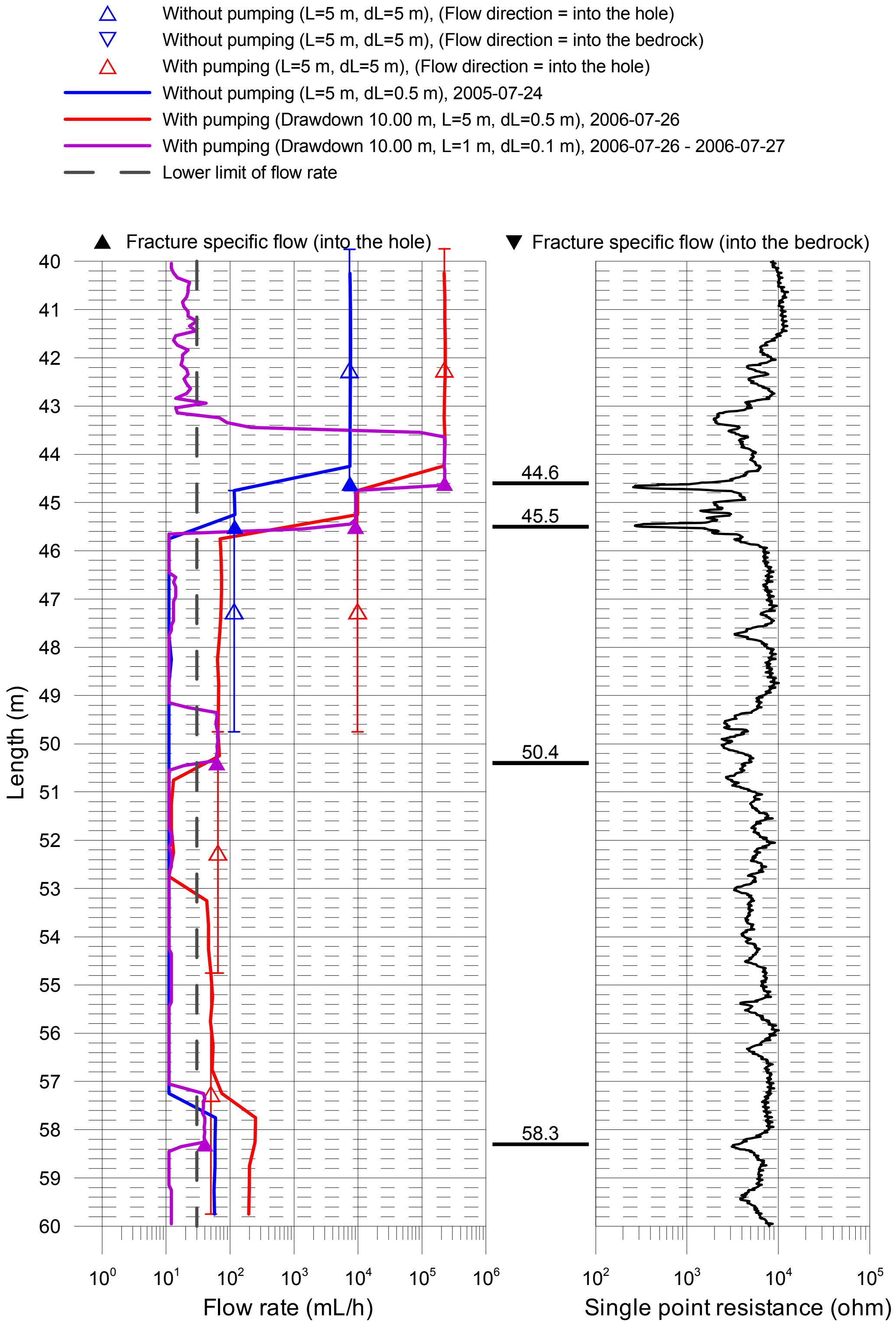
Laxemar, borehole KLX10C
Flow rate and single point resistance



Laxemar, borehole KLX10C
Flow rate and single point resistance

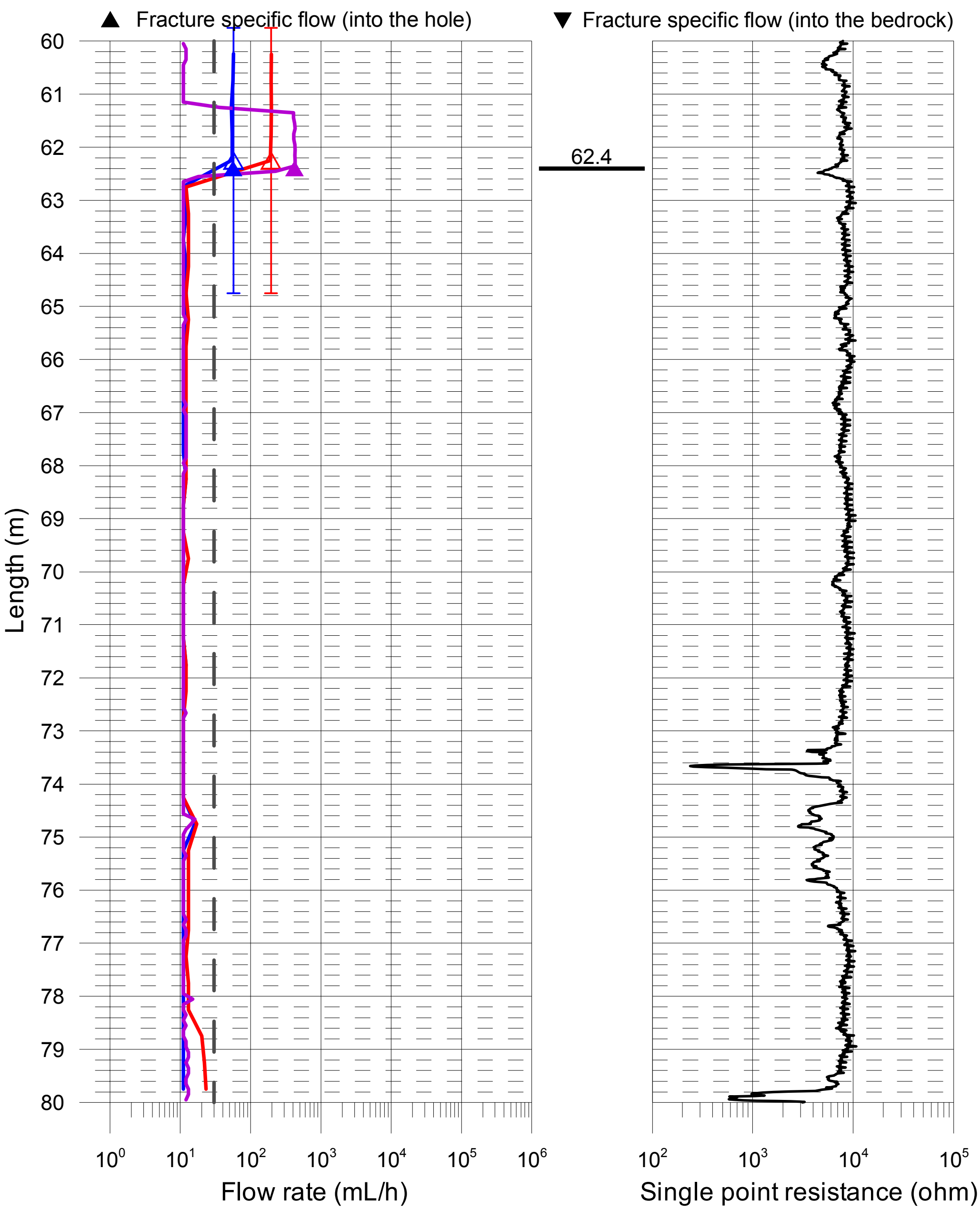


Laxemar, borehole KLX10C
Flow rate and single point resistance

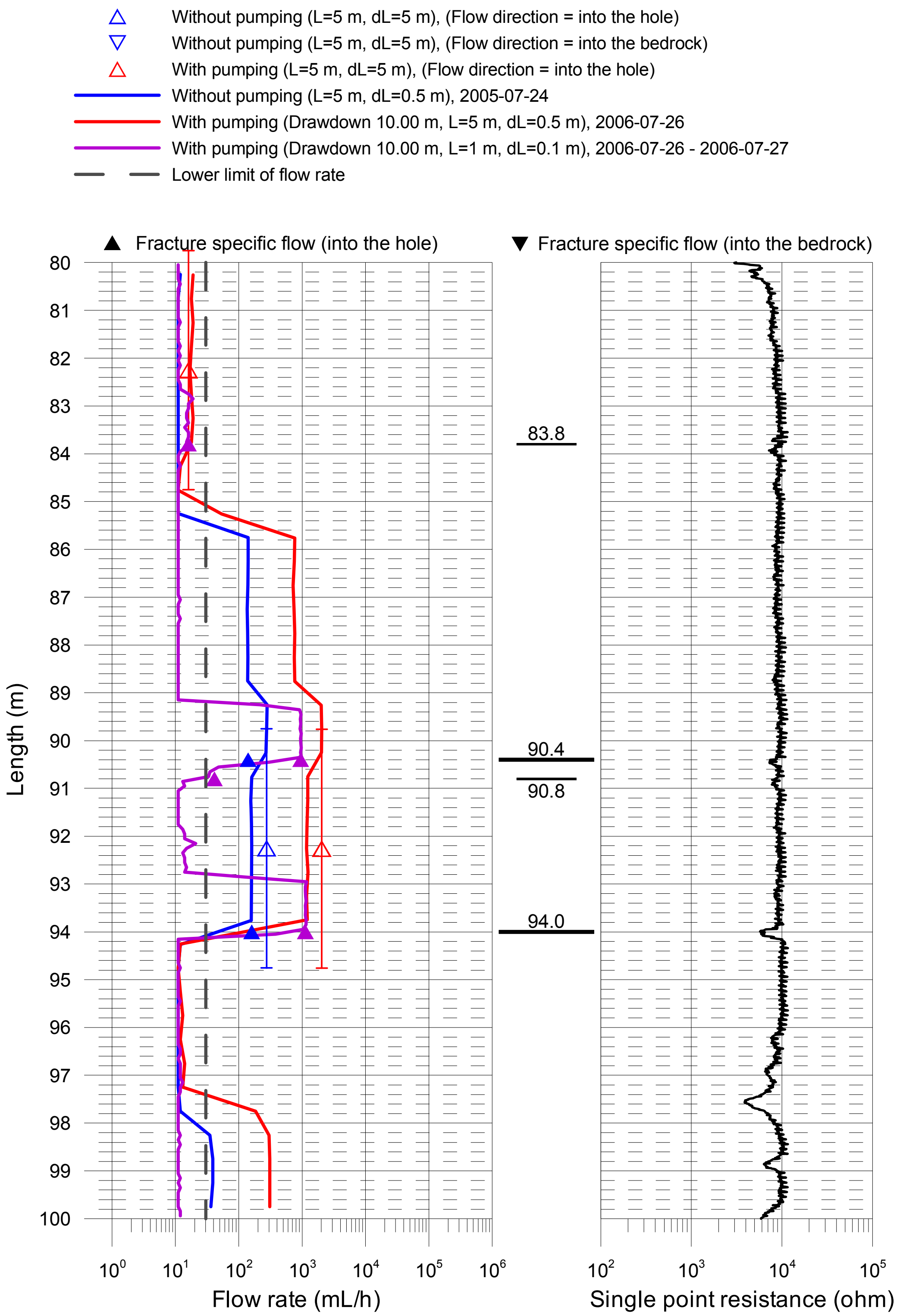


Laxemar, borehole KLX10C
Flow rate and single point resistance

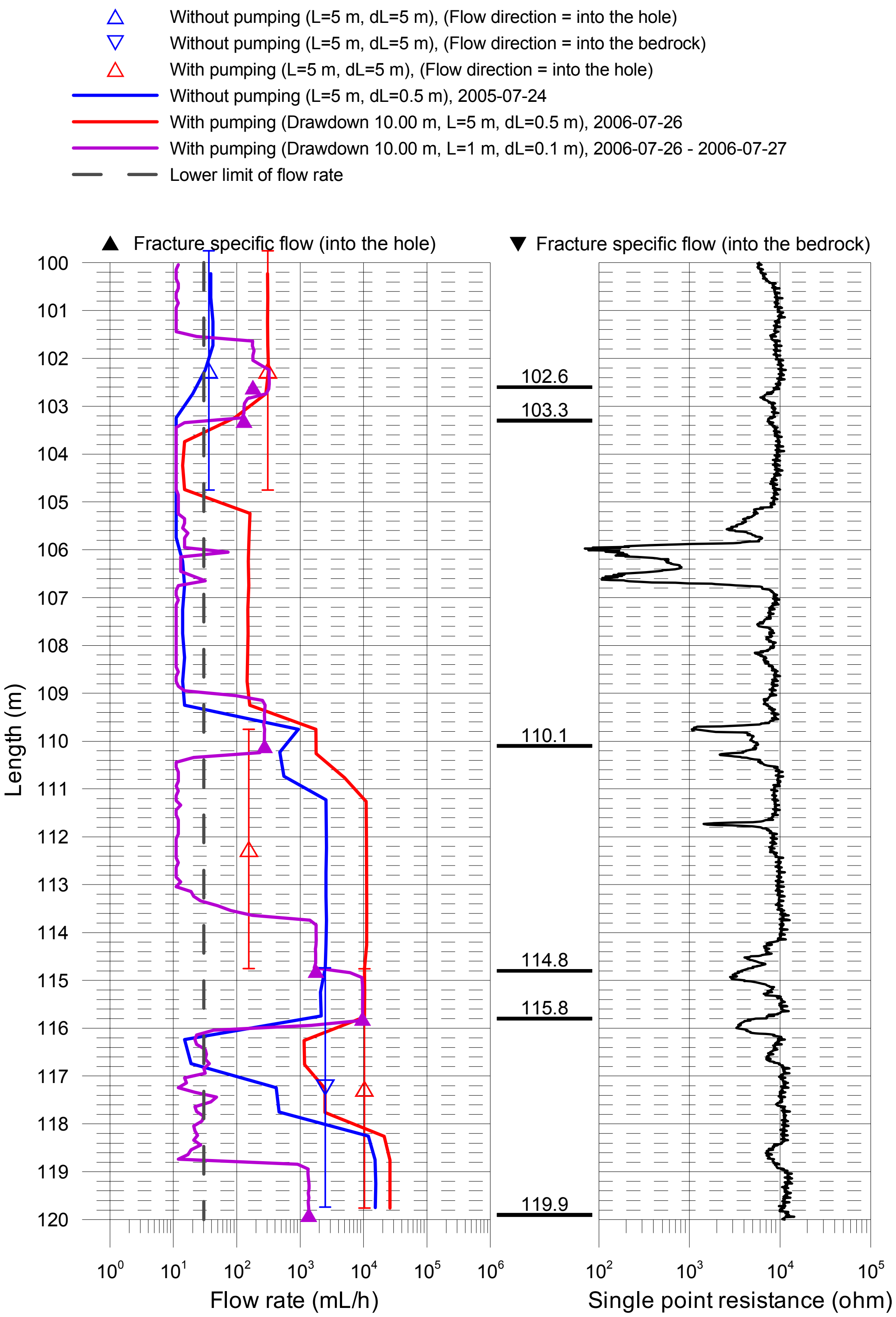
- △ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- ▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
- △ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
- Without pumping (L=5 m, dL=0.5 m), 2005-07-24
- With pumping (Drawdown 10.00 m, L=5 m, dL=0.5 m), 2006-07-26
- With pumping (Drawdown 10.00 m, L=1 m, dL=0.1 m), 2006-07-26 - 2006-07-27
- Lower limit of flow rate



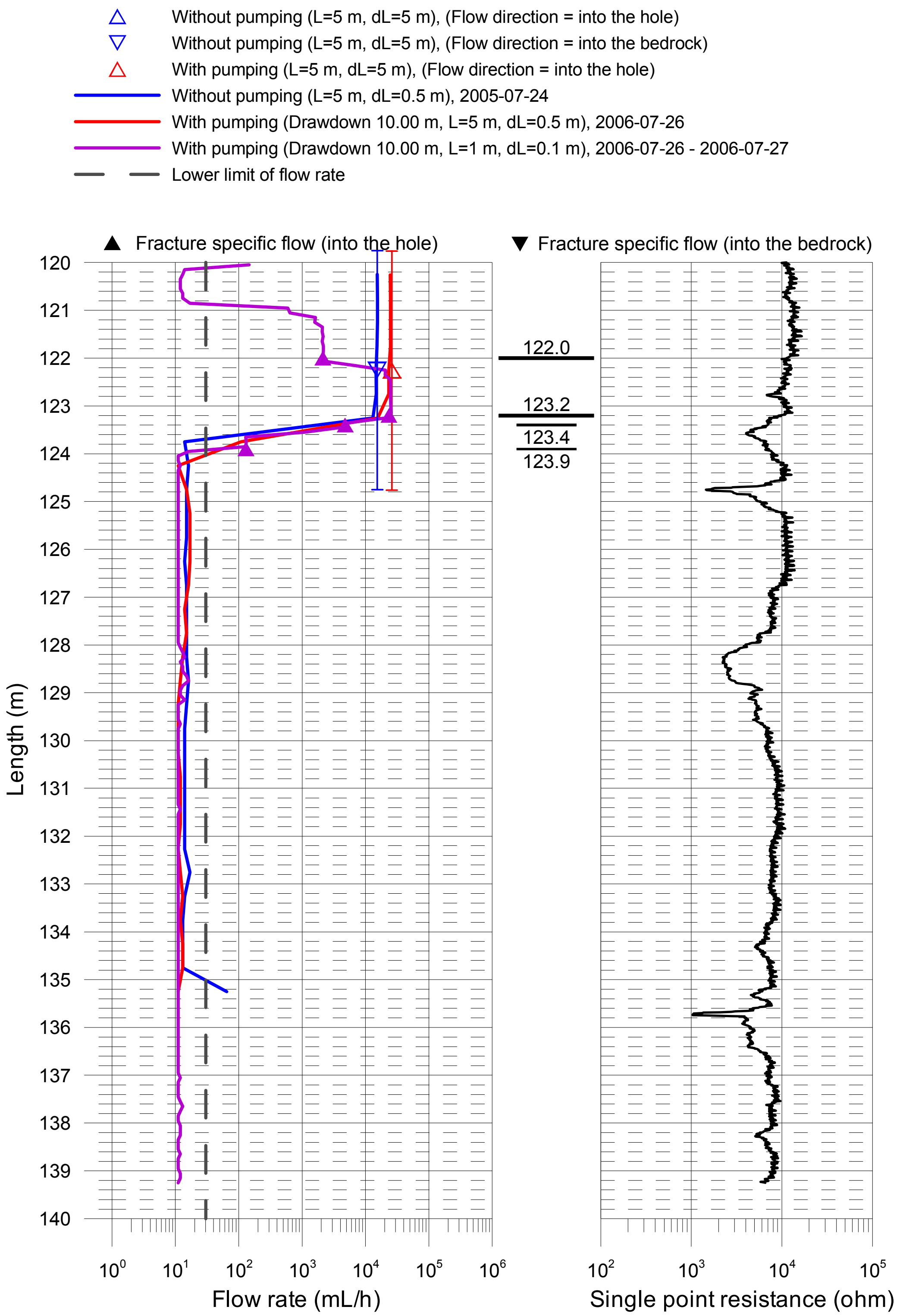
Laxemar, borehole KLX10C
Flow rate and single point resistance



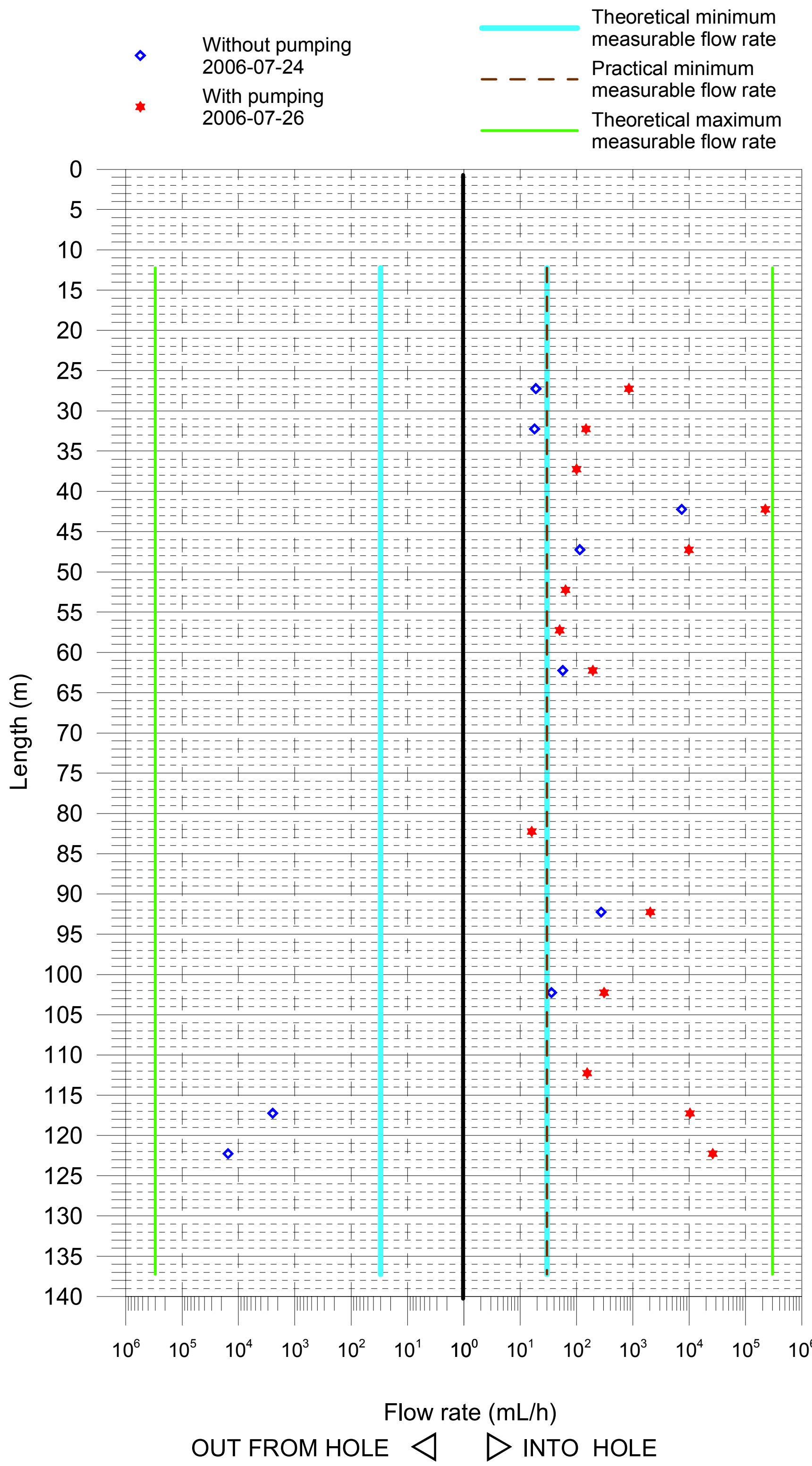
Laxemar, borehole KLX10C
Flow rate and single point resistance

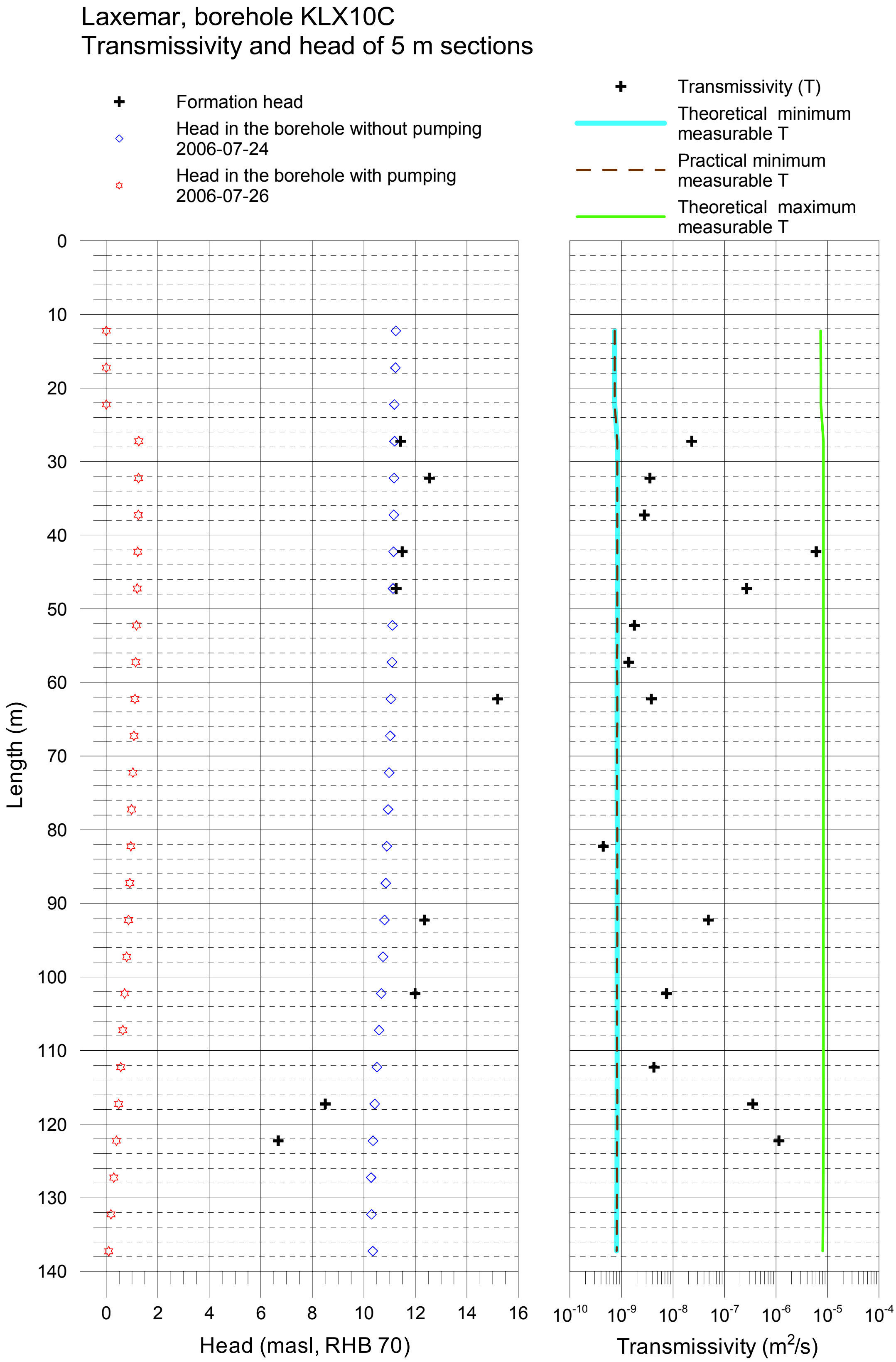


Laxemar, borehole KLX10C
Flow rate and single point resistance

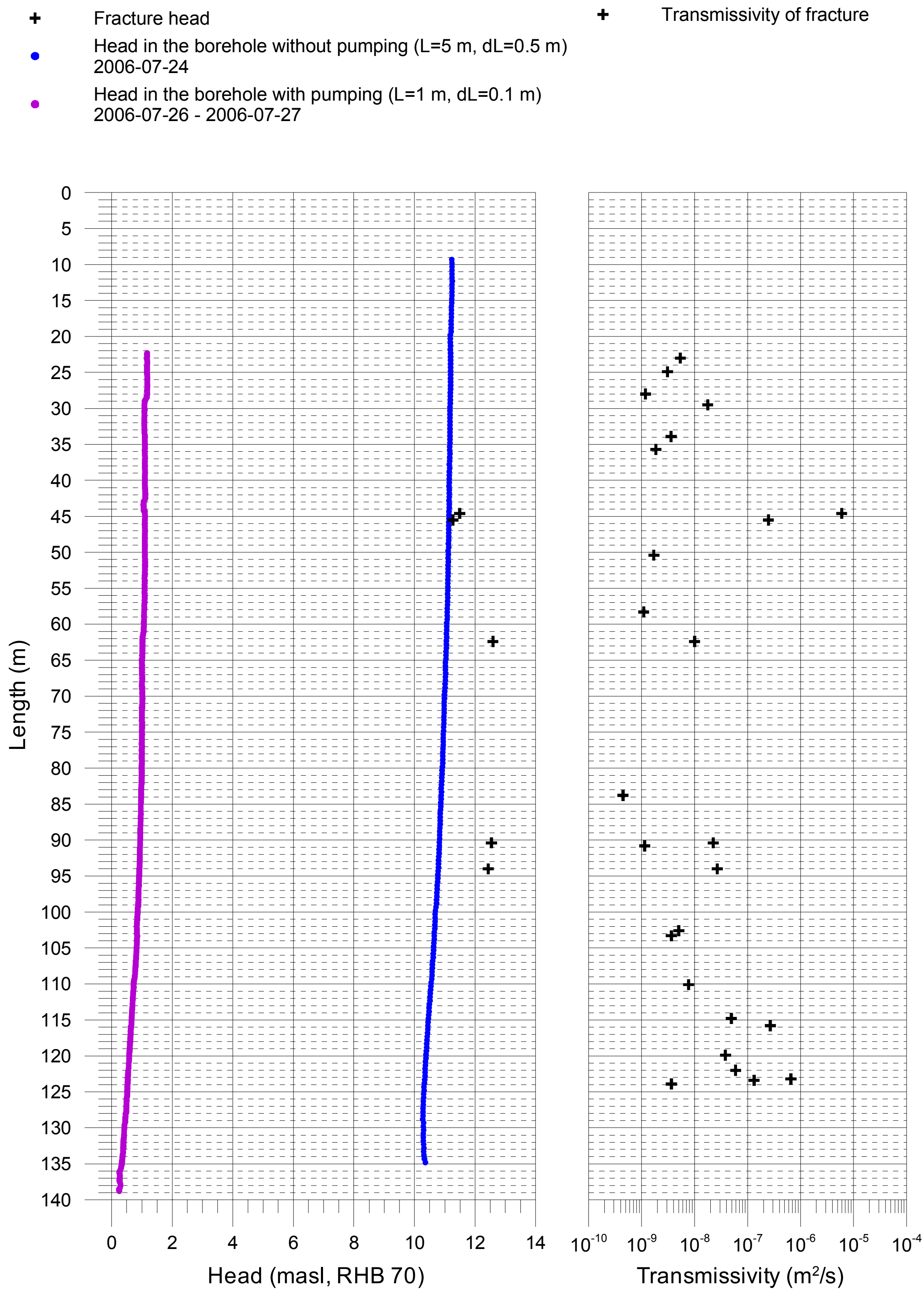


Laxemar, borehole KLX10C
Flow rates of 5 m sections




Laxemar, borehole KLX10C
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-07-24
Head in the borehole with pumping 2006-07-26
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 KLX10C
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)
KLX10C	9	146.25	5A	20060725	10:26	20060726	10:46	20060727	13:32	5	0.5	1.13E–04	–

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 (–)
183,960		307,920		11.29	1.28		–10.01	–	1.11E–05	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q0 (m^3/s)	h0FW (m.a.s.l.)	Q1 (m^3/s)	h1FW (m.a.s.l.)	TD (m^2/s)	hi (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measlLT (m^2/s)	TD-measlLP (m^2/s)	TD-measlU (m^2/s)	Comments
KLX10C	9.75	14.75	5	–	11.24	–	–	–	–	30	7.3E–10	7.3E–10	7.3E–06	
KLX10C	14.75	19.75	5	–	11.22	–	–	–	–	30	7.3E–10	7.3E–10	7.3E–06	
KLX10C	19.75	24.75	5	–	11.18	–	–	–	–	30	7.4E–10	7.4E–10	7.4E–06	
KLX10C	24.75	29.75	5	5.28E–09	11.19	2.36E–07	1.26	2.3E–08	11.4	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	29.75	34.75	5	5.00E–09	11.17	4.08E–08	1.25	3.6E–09	12.6	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	34.75	39.75	5	–	11.16	2.78E–08	1.24	2.8E–09	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	39.75	44.75	5	2.03E–06	11.15	6.22E–05	1.22	6.0E–06	11.5	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	44.75	49.75	5	3.19E–08	11.13	2.73E–06	1.20	2.7E–07	11.3	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	49.75	54.75	5	–	11.11	1.78E–08	1.17	1.8E–09	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	54.75	59.75	5	–	11.09	1.39E–08	1.14	1.4E–09	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	59.75	64.75	5	1.58E–08	11.05	5.39E–08	1.11	3.8E–09	15.2	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	64.75	69.75	5	–	11.02	–	1.07	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	69.75	74.75	5	–	10.98	–	1.03	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	74.75	79.75	5	–	10.94	–	0.98	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	79.75	84.75	5	–	10.89	4.44E–09	0.95	4.4E–10	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	84.76	89.76	5	–	10.85	–	0.91	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	89.76	94.76	5	7.61E–08	10.80	5.64E–07	0.86	4.9E–08	12.4	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	94.76	99.76	5	–	10.74	–	0.79	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	99.75	104.75	5	1.00E–08	10.67	8.56E–08	0.71	7.5E–09	12.0	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	104.74	109.74	5	–	10.59	–	0.64	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	109.75	114.75	5	–	10.51	4.31E–08	0.56	4.3E–09	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	114.75	119.75	5	–6.86E–07	10.42	2.86E–06	0.48	3.5E–07	8.5	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	119.76	124.76	5	–4.25E–06	10.35	7.25E–06	0.39	1.1E–06	6.7	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	124.75	129.75	5	–	10.28	–	0.29	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX10C	129.75	134.75	5	–	10.29	–	0.18	–	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX10C	134.75	139.75	5	–	10.34	–	0.09	–	–	30	8.0E–10	8.0E–10	8.0E–06	

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

Borehole ID	Length to flow anom. L (m)	Lw (m)	dL (m)	Q0 (m³/s)	h0FW (m.a.s.l.)	Q1 (m³/s)	h1FW (m.a.s.l.)	TD (m²/s)	hi (m.a.s.l.)	Comments
KLX10C	23.0	1	0.1	–	11.19	5.44E–08	1.16	5.4E–09	–	*
KLX10C	24.9	1	0.1	–	11.19	3.11E–08	1.16	3.1E–09	–	
KLX10C	28.0	1	0.1	–	11.18	1.19E–08	1.17	1.2E–09	–	
KLX10C	29.5	1	0.1	–	11.18	1.81E–07	1.08	1.8E–08	–	
KLX10C	33.9	1	0.1	–	11.17	3.67E–08	1.09	3.6E–09	–	
KLX10C	35.7	1	0.1	–	11.16	1.89E–08	1.09	1.9E–09	–	
KLX10C	44.6	1	0.1	2.08E–06	11.14	6.25E–05	1.09	6.0E–06	11.5	
KLX10C	45.5	1	0.1	3.28E–08	11.14	2.54E–06	1.10	2.5E–07	11.3	
KLX10C	50.4	1	0.1	–	11.12	1.72E–08	1.09	1.7E–09	–	
KLX10C	58.3	1	0.1	–	11.08	1.11E–08	1.07	1.1E–09	–	
KLX10C	62.4	1	0.1	1.56E–08	11.05	1.17E–07	1.02	1.0E–08	12.6	
KLX10C	83.8	1	0.1	–	10.88	4.44E–09	0.98	4.4E–10	–	*
KLX10C	90.4	1	0.1	3.89E–08	10.82	2.62E–07	0.94	2.2E–08	12.5	
KLX10C	90.8	1	0.1	–	10.82	1.14E–08	0.94	1.1E–09	–	*
KLX10C	94.0	1	0.1	4.44E–08	10.79	3.11E–07	0.91	2.7E–08	12.4	
KLX10C	102.6	1	0.1	–	10.66	5.00E–08	0.84	5.0E–09	–	
KLX10C	103.3	1	0.1	–	10.65	3.61E–08	0.85	3.7E–09	–	
KLX10C	110.1	1	0.1	–	10.54	7.61E–08	0.72	7.7E–09	–	
KLX10C	114.8	1	0.1	–	10.46	4.92E–07	0.66	5.0E–08	–	
KLX10C	115.8	1	0.1	–	10.44	2.67E–06	0.64	2.7E–07	–	
KLX10C	119.9	1	0.1	–	10.38	3.78E–07	0.58	3.8E–08	–	
KLX10C	122.0	1	0.1	–	10.35	5.89E–07	0.55	5.9E–08	–	
KLX10C	123.2	1	0.1	–	10.34	6.50E–06	0.53	6.6E–07	–	
KLX10C	123.4	1	0.1	–	10.34	1.32E–06	0.53	1.3E–07	–	*
KLX10C	123.9	1	0.1	–	10.33	3.61E–08	0.52	3.6E–09	–	*

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

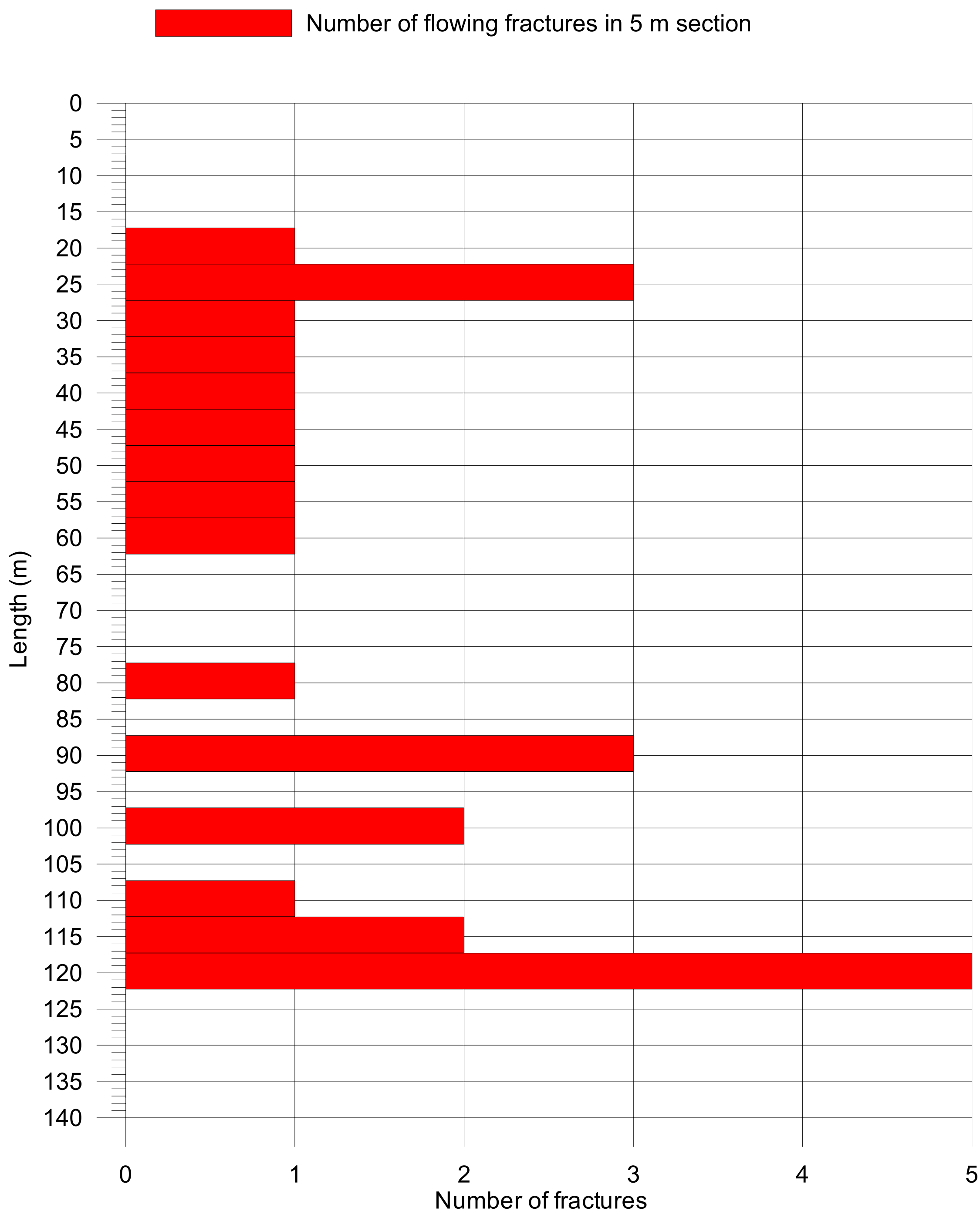
Explanations.

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.	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.
$T\text{-measl}_{LT}$	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.
$T\text{-meas}_{lLP}$	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.
$T\text{-meas}_{lU}$	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)

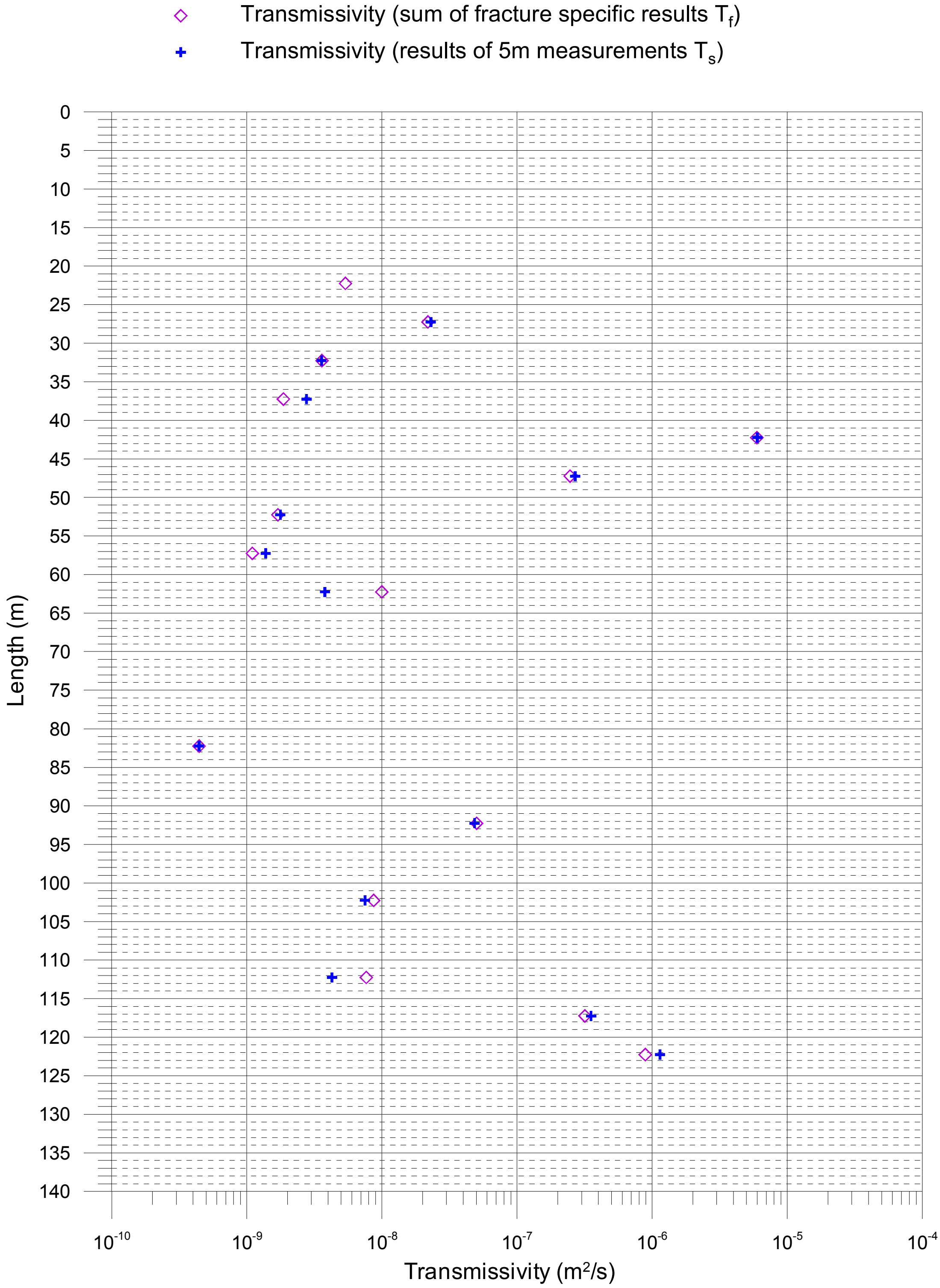
Calculation of conductive fracture frequency.

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)
KLX10C	9.75	14.75	0	0	0	0	0	0
KLX10C	14.75	19.75	0	0	0	0	0	0
KLX10C	19.75	24.75	1	0	1	0	0	0
KLX10C	24.75	29.75	3	1	2	0	0	0
KLX10C	29.75	34.75	1	0	1	0	0	0
KLX10C	34.75	39.75	1	1	0	0	0	0
KLX10C	39.75	44.75	1	0	0	0	0	1
KLX10C	44.75	49.75	1	0	0	1	0	0
KLX10C	49.75	54.75	1	1	0	0	0	0
KLX10C	54.75	59.75	1	1	0	0	0	0
KLX10C	59.75	64.75	1	0	1	0	0	0
KLX10C	64.75	69.75	0	0	0	0	0	0
KLX10C	69.75	74.75	0	0	0	0	0	0
KLX10C	74.75	79.75	0	0	0	0	0	0
KLX10C	79.75	84.75	1	1	0	0	0	0
KLX10C	84.76	89.76	0	0	0	0	0	0
KLX10C	89.76	94.76	3	1	1	1	0	0
KLX10C	94.76	99.76	0	0	0	0	0	0
KLX10C	99.75	104.75	2	0	2	0	0	0
KLX10C	104.74	109.74	0	0	0	0	0	0
KLX10C	109.75	114.75	1	0	1	0	0	0
KLX10C	114.75	119.75	2	0	0	2	0	0
KLX10C	119.76	124.76	5	0	1	3	1	0
KLX10C	124.75	129.75	0	0	0	0	0	0
KLX10C	129.75	134.75	0	0	0	0	0	0
KLX10C	134.75	139.75	0	0	0	0	0	0

Laxemar, borehole KLX10C
Calculation of conductive fracture frequency

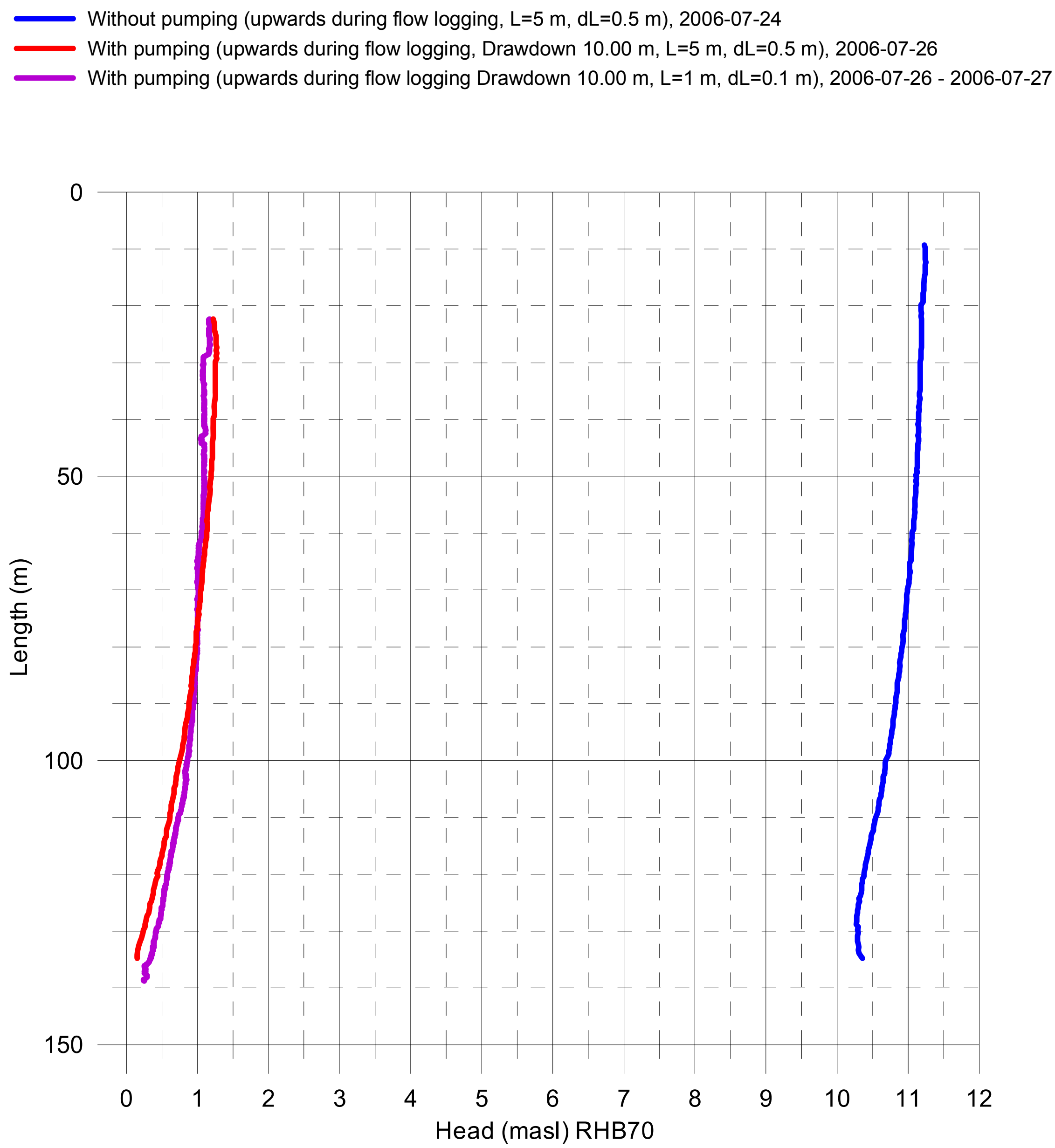


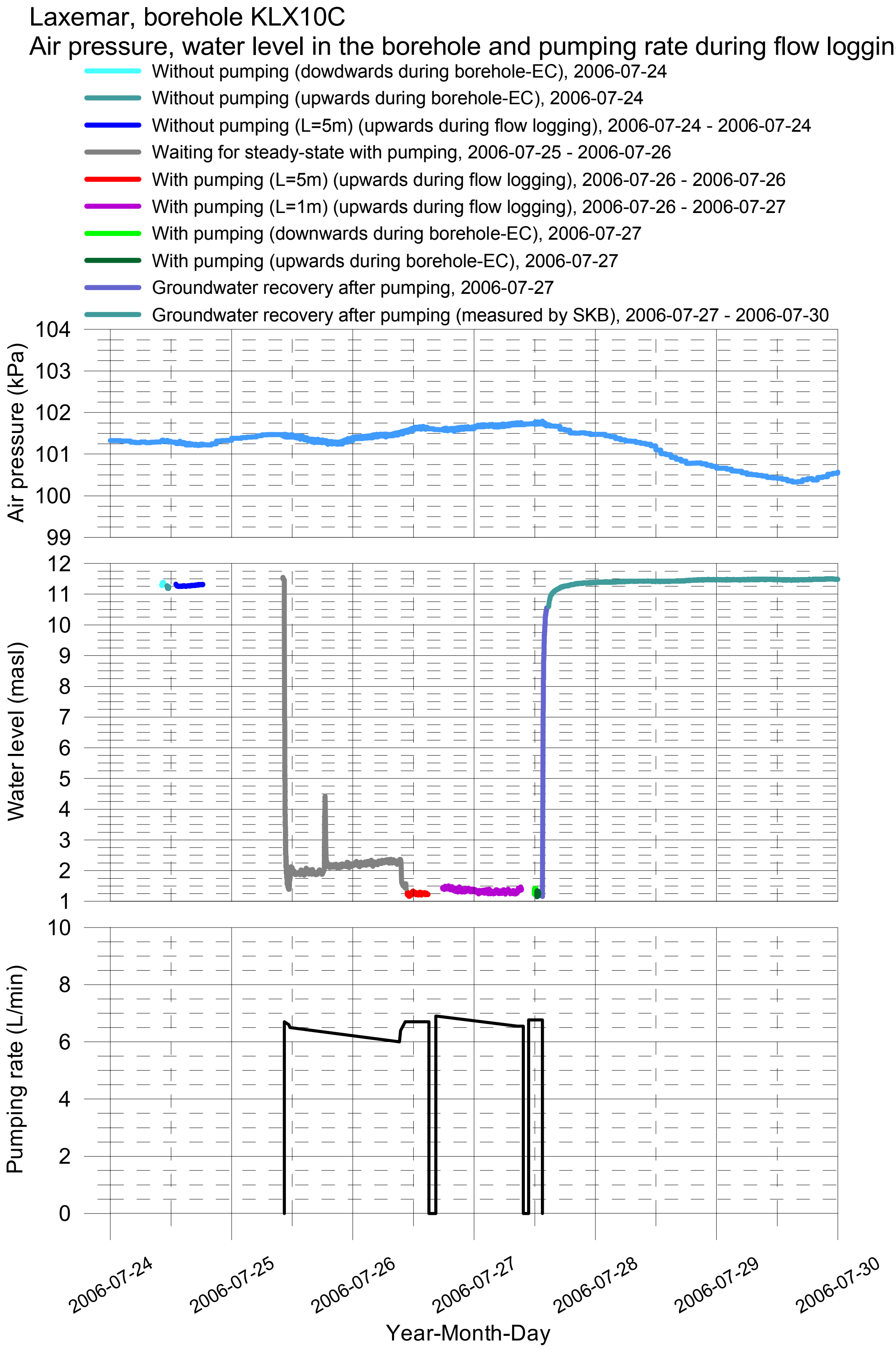
Laxemar, borehole KLX10C
Comparison between section transmissivity and fracture transmissivity



Laxemar, borehole KLX10C
Head in the borehole during flow logging

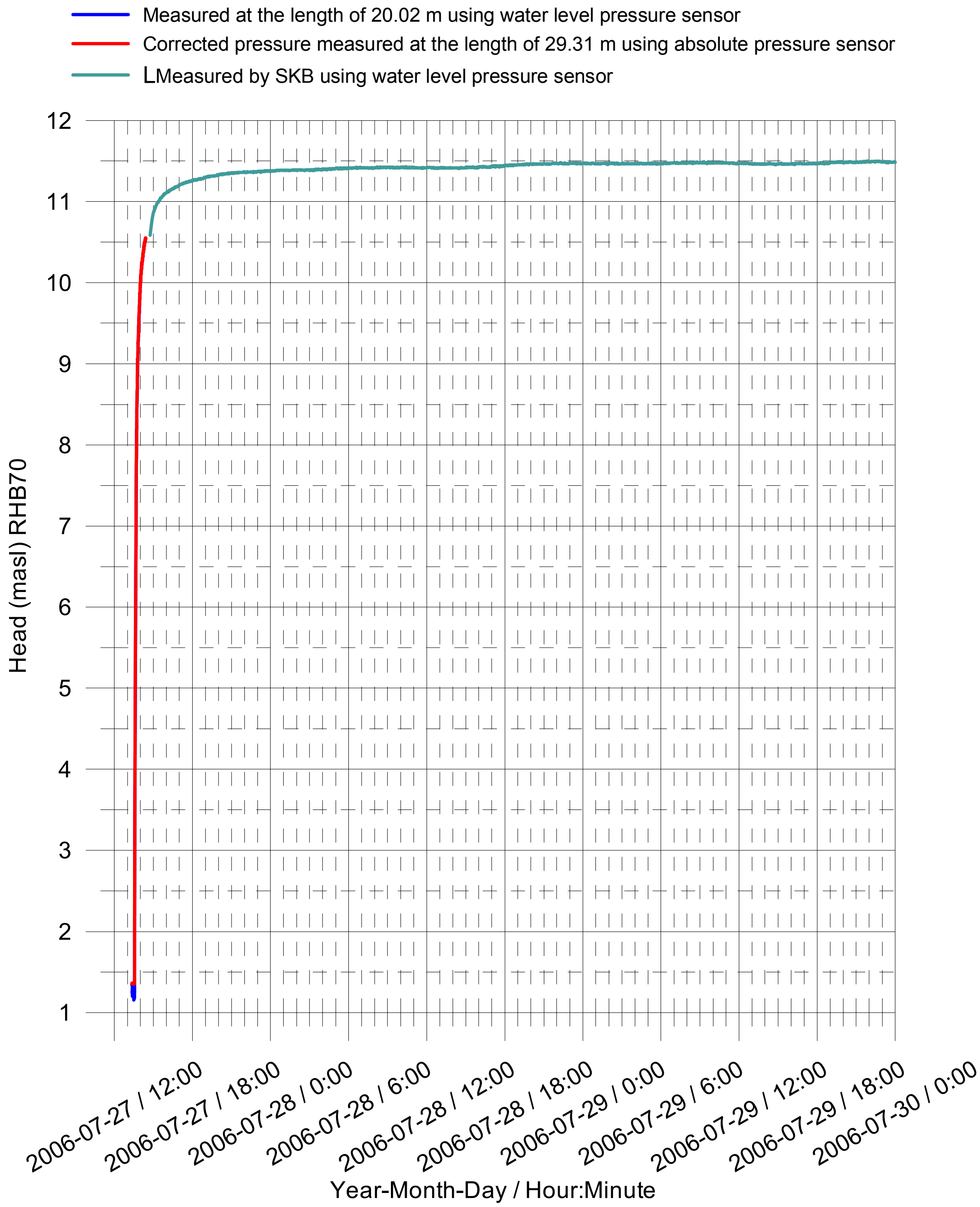
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)




Laxemar, borehole KLX10C
Air pressure, water level in the borehole and pumping rate during flow logging
Without pumping (dowdwards during borehole-EC), 2006-07-24
Without pumping (upwards during borehole-EC), 2006-07-24
Without pumping (L=5m) (upwards during flow logging), 2006-07-24 - 2006-07-24
Waiting for steady-state with pumping, 2006-07-25 - 2006-07-26
With pumping (L=5m) (upwards during flow logging), 2006-07-26 - 2006-07-26
With pumping (L=1m) (upwards during flow logging), 2006-07-26 - 2006-07-27
With pumping (downwards during borehole-EC), 2006-07-27
With pumping (upwards during borehole-EC), 2006-07-27
Groundwater recovery after pumping, 2006-07-27
Groundwater recovery after pumping (measured by SKB), 2006-07-27 - 2006-07-30
Air pressure (kPa)
104
103
102
101
100
99
Water level (masl)
12
11
10
9
8
7
6
5
4
3
2
1
Pumping rate (L/min)
10
8
6
4
2
0
2006-07-24
2006-07-25
2006-07-26
2006-07-27
2006-07-28
2006-07-29
2006-07-30
Year-Month-Day

Laxemar, borehole KLX10C
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)



Appendix SKB.1

Water level and pumping rate in observation holes KLX10B and KLX10C