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Subarea Laxemar

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December 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 KLX22A–B, KLX23A–B, KLX24A and KLX25A at Oskarshamn, Sweden, in June, July and August 2006, using Posiva flow log; a 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 boreholes KLX22A–B, KLX23A–B, KLX24A and KLX25A.

The first flow logging measurements were done with a 5 metres test section by moving the measurement tool in 0.5 metres 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 metre long test section. In these selective measurements the borehole was pumped and measurement tool was moved in 0.1 metres steps.

Length calibrations were made based on length marks milled into the borehole wall at accurately determined positions along the borehole. The length marks were detected by caliper and single point resistance measurements using sensors connected to the flow logging tool.

A high-resolution absolute pressure sensor was used to measure the total pressure along the borehole. 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 borehole during natural as well as pumped conditions.

The recovery of the groundwater level in the borehole was measured after the pumping of the borehole was stopped.

Sammanfattning

Differensflödesloggning är en snabb metod för bestämning av transmissivitet och hydraulisk head i borrhålssektioner och sprickor/sprickzoner i kärnborrhål. Denna rapport presenterar huvudprinciperna för metoden och resultat av mätningar utförda i borrhål KLX20A i Oskarshamn, Sverige, i juni och augusti 2006 med Posiva flödesloggningsmetod. Det primära syftet med mätningarna var att bestämma läget och flödet för vattenförande sprickor i borrhålen KLX22A–B, KLX23A–B, KLX24A and KLX25A.

Flödet till eller från en 5 meter lång testsektion (som förflyttades successivt med 0,5 meter) mättes i borrhålen KLX22A–B, KLX23A–B, KLX24A and KLX25A under såväl naturliga (icke-pumpade) som pumpade förhållanden. Flödesmätningarna upprepades vid lägena för de detekterade flödesanomalierna med en 1 meter lång testsektion som förflyttades successivt med 0,1 meter.

Längdkalibrering gjordes baserad på de längdmärken som frästs in i borrhålsväggen vid noggrant bestämda positioner längs borrhålet. Längdmärkena detekterades med caliper-mätningar och med punktresistansmätningar med hjälp av sensorer anslutna på flödesloggningssonden.

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 avslutats.

Contents

1 Introduction

This document reports the results acquired by difference flow logging, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-06-092. The controlling documents for performing according to this activity plan are listed in Table 1-1. The list of 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 boreholes KLX22A–B, KLX23A–B, KLX24A and KLX25A at Oskarshamn was conducted between June 16 and August 28, 2006. Detailed dimensions of the boreholes are presented in Table 1-2. The diameter of each borehole is 76 mm. The locations of the boreholes at the drill site in the subarea of Laxemar at Oskarshamn are shown in Figure 1-1.

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

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

Activity plan	Number	Version
Difference flow logging in boreholes KLX22A–B, KLX23A–B, KLX24A and KLX25A	AP PS 400-06-092	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, KLX22A–B, KLX23A–B, KLX24A AND KLX25A.

Borehole ID	Length (m)	Inclination (degrees)	Z coord. of the top of the casing (m.a.s.l.)
KLX22A	100.45	60.34	21.967
KLX22B	100.25	61.61	21.575
KLX23A	100.15	61.46	22.263
KLX23B	50.27	60.90	22.317
KLX24A	100.17	59.14	21.290
KLX25A	50.24	59.46	22.839

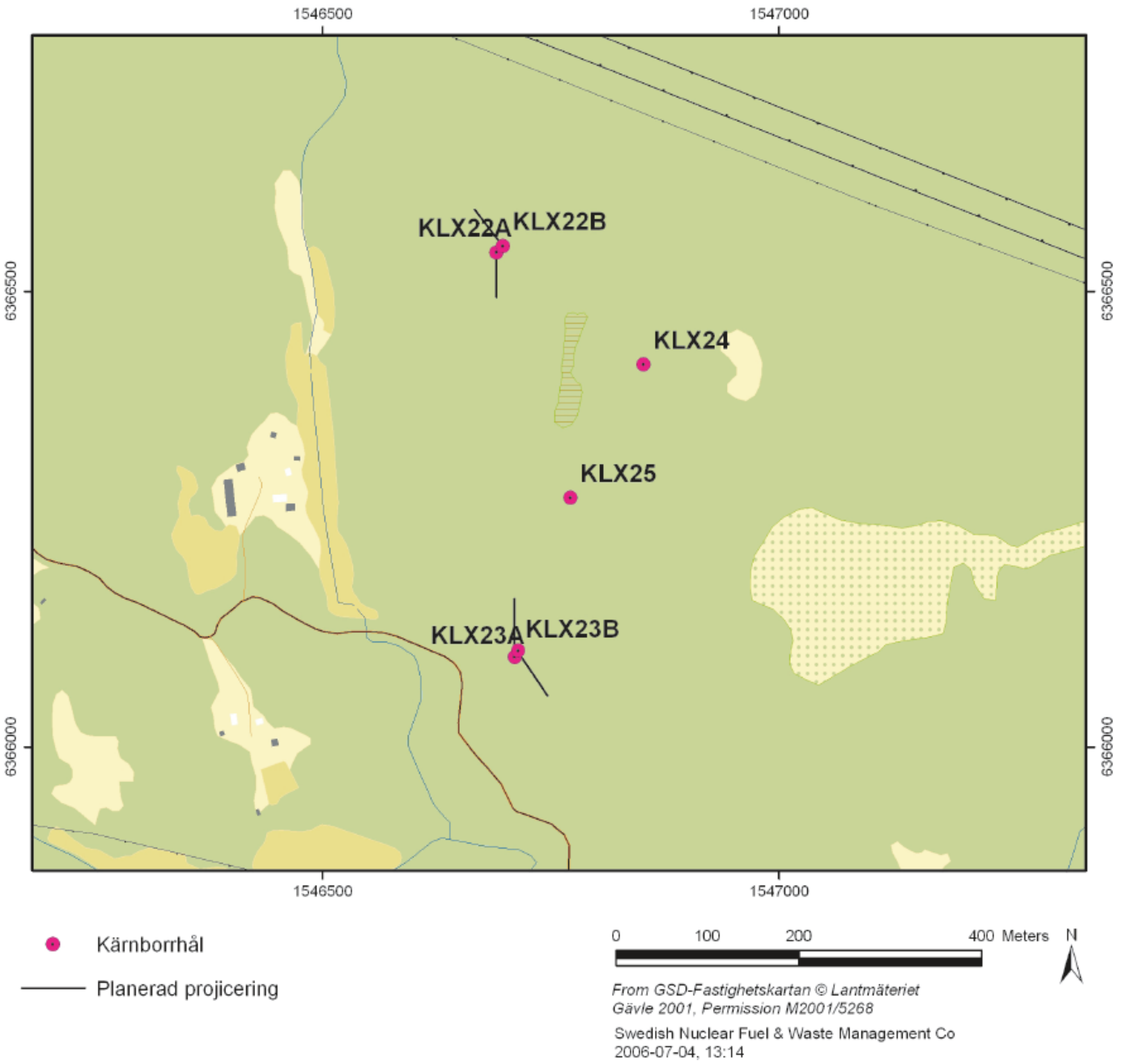

Figure 1-1. *Site map showing the location of boreholes KLX22A, KLX22B, KLX23A, KLX23B, KLX24A and KLX25A situated in Laxemar.*

2 Objective and scope

The main objective of the difference flow logging in KLX22A–B, KLX23A–B, KLX24A and KLX25A was to identify water-conductive sections/fractures. The measurements aim at a hydrogeological characterisation, including the prevailing water flow balance in the borehole. Based on the results of these investigations, a more detailed characterisation of flow anomalies along the borehole, e.g. an estimate of the conductive fracture frequency (CFF), may be obtained.

Besides difference flow logging, the measuring programme for boreholes KLX22A–B, KLX23A–B, KLX24A and KLX25A 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 electrical 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 borehole. These measurements were carried out together with the flow measurements. The results are used in the calculation of the hydraulic head along the borehole.

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 rate 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.

The Difference flowmeter can be used in two modes, 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 to 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.

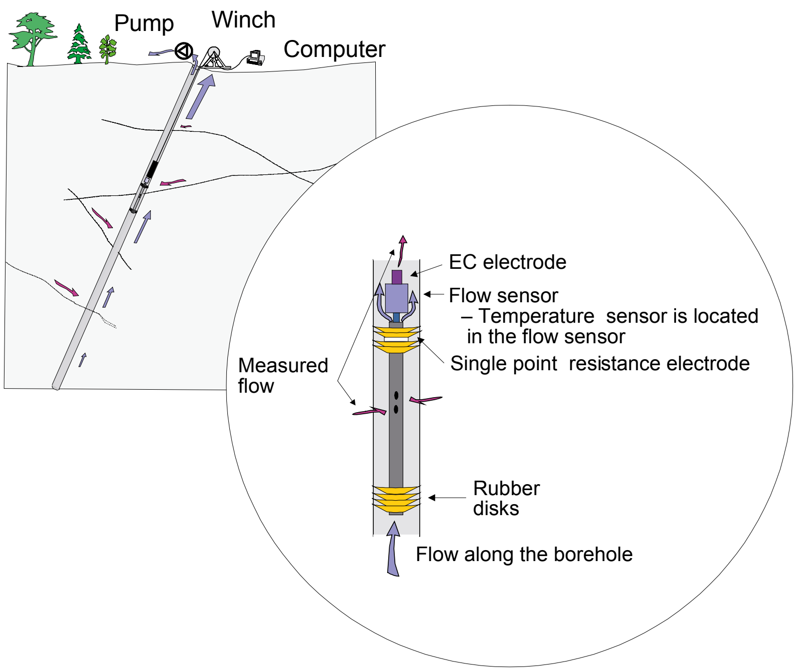

***Figure 3-1.** Schematic of the downhole equipment used in the Difference flowmeter.*

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

- The electrical 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, were performed in KLX22A–B and KLX24A

All of the above measurements, except fracture-specific EC and caliper-measurement, were performed in KLX23A–B and KLX25A.

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.

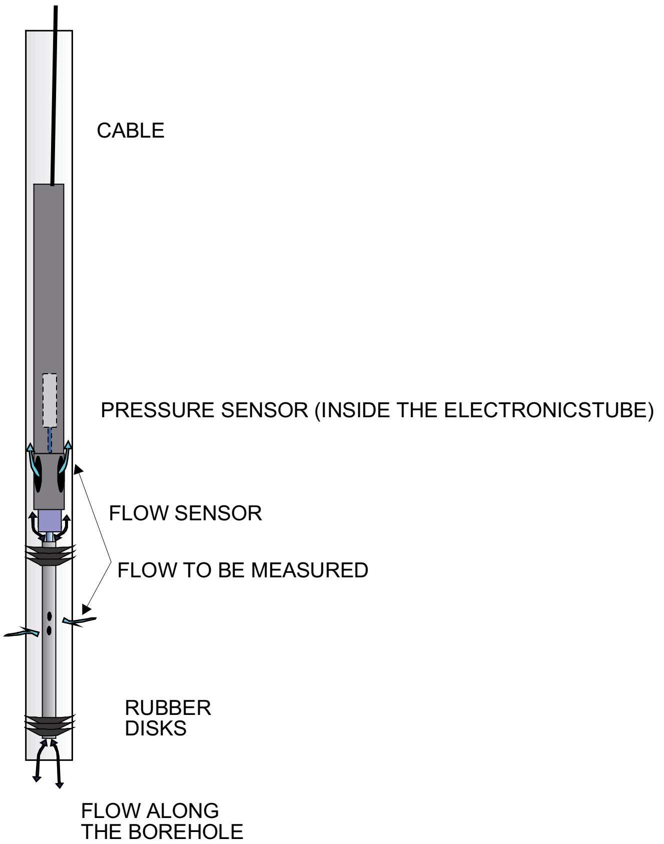

Figure 3-2. *The absolute pressure sensor is located inside the electronics tube and connected through a tube to the borehole water.*

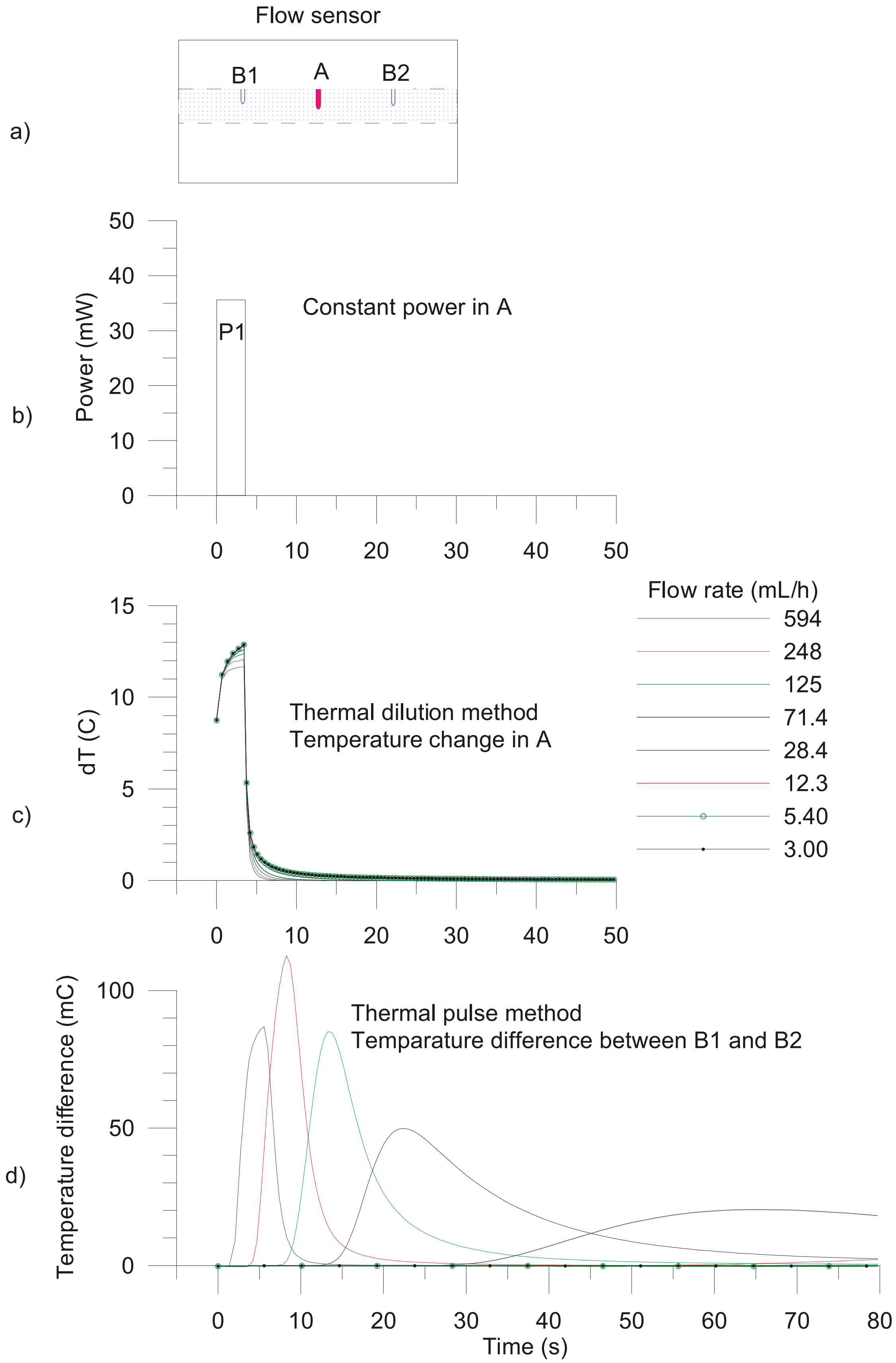

Figure 3-3. Flow measurement, flow rate < 600 mL/h.

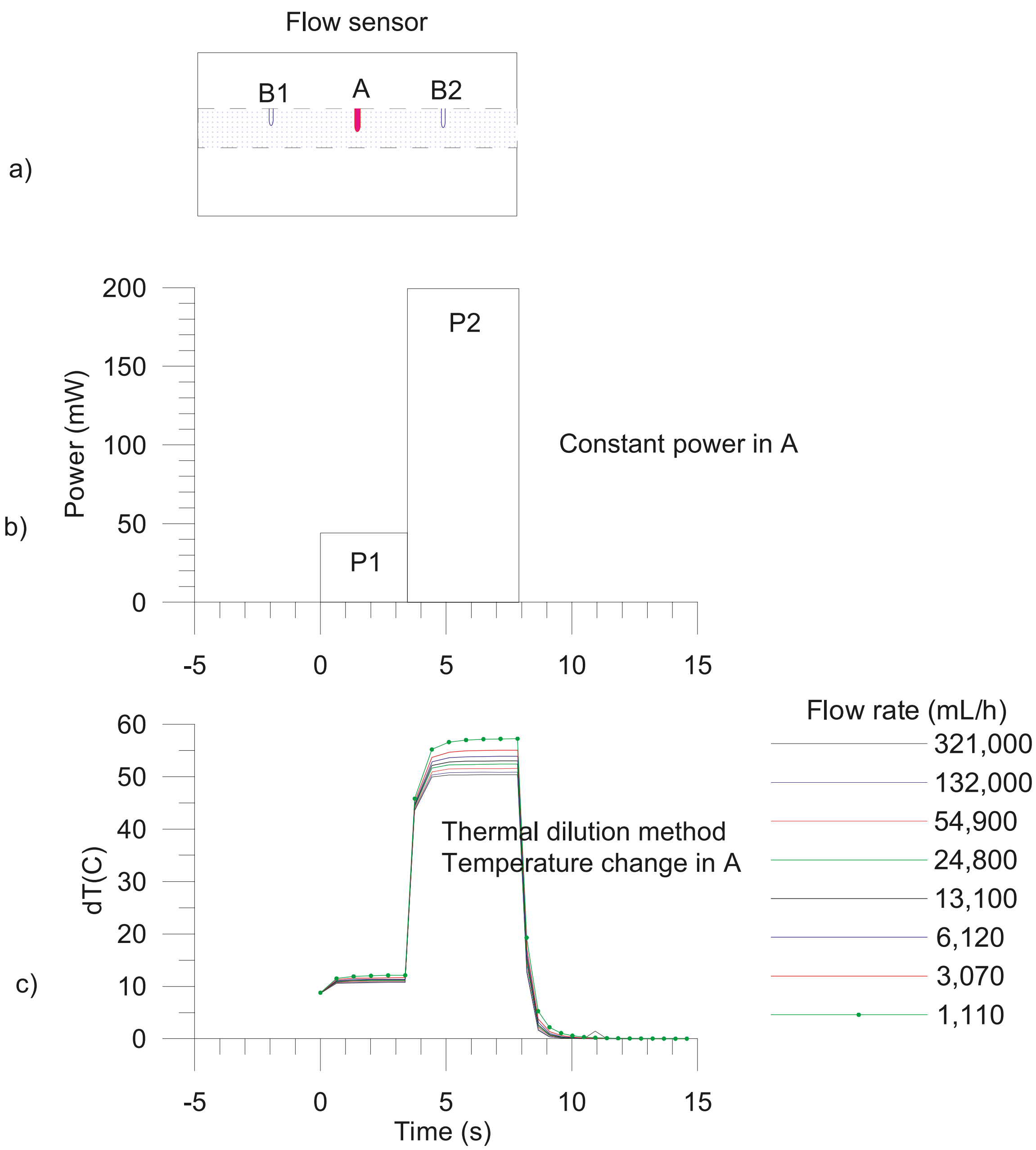

***Figure 3-4.** Flow measurement, flow rate > 600 mL/h.*

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 thermal dilution transient (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 Thiems or Dupuits 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 are 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
Electrical 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% fullscale
Absolute pressure sensor	0–20 MPa	± 0.01% fullscale

5 Performance

5.1 Execution of the field work

The commission was performed according to Activity Plan AP PS 400-06-092 (SKB internal controlling document) following the SKB Method Description 322.010, Version 1.0 (Method description for difference flow logging). Prior to the measurements, the downhole tools and the measurement cable were disinfected. Every clock was synchronized to the official Swedish time. The activity schedule of the borehole measurements is presented in Table 5-2–Table 5-7. The items and activities in Table 5-2–Table 5-7 are the same as in the Activity Plan.

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. Immediately after the completion of the drilling operations in borehole KLX22A–B, KLX23A and KLX24A, length marks were milled into the borehole wall at certain intervals to be used for length calibration of various logging tools. By using the known positions of the length marks, logging cables etc can be calibrated in order to obtain an accurate length correction of the testing tool. KLX23B and KLX25A are only c 50 m long, so no length marks were milled into the borehole walls.

Each length mark consists of two 20 mm wide tracks in the borehole wall. The distance between the tracks is 100 mm. The upper track defines a reference level. An inevitable condition for a successful length calibration is that all length marks, or at least the major part of them, are detectable. The Difference Flowmeter system uses caliper measurements in combination with single point resistance measurements for this purpose. These methods also reveal parts of the borehole widened for some reason (fracture zones, breakouts etc). The length calibration (Item 9) of KLX22A–B and KLX24A was performed before any other measurements were started. The only exception was the dummy logging (Item 8) of the borehole which is done in order to assure that the measurement tools do not get stuck in the borehole. In KLX23A no caliper measurement was done. The length correction was performed by identifying the groove millings from the single point resistance measurement done during the first flow logging measurement. After that the rest of the measurements could be calibrated accordingly.

The caliper/SPR-measurements in the measurement schedule were 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 12) was carried out in the borehole 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)

Pumping in KLX22A–B, KLX23A–B, KLX24A and KLX25A was started according to Table 5-1. After a waiting time of c 24 hours, overlapping flow logging (Item 13) was conducted using the same section and step lengths as before.

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 14).

The EC of borehole water (Item 16) was measured while the borehole was still pumped. After this, the pump was stopped and the recovery of the groundwater level was monitored (Item 17).

Borehole KLX22A 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 12 was done in natural conditions and the measurements of Item Extra 14 was done with a 4 m drawdown. After the extra flow logging measurements the recovery transient was also measured again (Item Extra 17).

In addition to all these measurements the SKB pressure sensor was used in boreholes KLX22A–KLX22B and KLX23A–KLX23B to measure interference between each pair of holes. The sensor was always located in the hole that was not being measured (using the flow logging device) at that particular time. The results are presented separately in Appendices SKB.1.1–SKB.1.2.

Table 5-1. Pumping in KLX22A–B, KLX23A–B, KLX24A and KLX25A.

Borehole	Pumping started
KLX22A	2006-07-18
KLX22B	2006-07-26
KLX23A	2006-08-03
KLX23B	2006-07-30
KLX24A	2006-08-24
KLX25A	2006-08-17

Table 5-2. Flow logging and testing in KLX22A. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer	2006-07-16
8	Dummy logging	Borehole stability risk evaluation	2006-07-17
9	Length calibration of the downhole tool	SKB caliper and SPR. Logging without the lower rubber discs, no pumping	2006-07-17
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, no pumping	2006-07-18
12	Combined overlapping/sequential flow logging	Section length L_w=5 m, step length dL=0.5 m. No pumping	2006-07-18
13	Overlapping flow logging	Section length L_w=5 m, step length dL=0.5 m at pumping (includes 1 day waiting after beginning of pumping)	2006-07-19
14	Overlapping flow logging	Section length L_w=1 m, step length dL=0.1 m, at pumping	2006-07-20
16	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, at pumping	2006-07-21
17	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping.	2006-07-21 2006-07-22
12 Extra	Combined overlapping/sequential flow logging	Section length L_w=1 m, step length dL=0.1 m. No pumping	2006-07-22
14 Extra	Overlapping flow logging	Section length L_w=1 m, step length dL=0.1 m, at pumping	2006-07-23
17 Extra	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping.	2006-07-23 2006-07-24

Table 5-3. Flow logging and testing in KLX22B. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer	2006-07-24
8	Dummy logging	Borehole stability/risk evaluation	2006-07-24
9	Length calibration of the downhole tool	(SKB caliper and SPR). Logging without the lower rubber discs, no pumping	2006-07-25
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, no pumping	2006-07-25
12	Combined overlapping/sequential flow logging	Section length L_w=5 m, step length dL=0.5 m. No pumping	2006-07-26
13	Overlapping flow logging	Section length L_w=5 m, step length dL=0.5 m at pumping (includes 1 day waiting after beginning of pumping)	2006-07-27
14	Overlapping flow logging	Section length L_w=1 m, step length dL=0.1 m, at pumping	2006-07-28
16	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, at pumping	2006-07-29
17	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping.	2006-07-29 2006-07-30

Table 5-4. Flow logging and testing in KLX23A. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer	2006-08-02
8	Dummy logging	Borehole stability/risk evaluation	2006-08-02
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, no pumping	2006-08-02
12	Combined overlapping/sequential flow logging	Section length L_w=5 m, step length dL=0.5 m. No pumping	2006-08-03
13	Overlapping flow logging	Section length L_w=5 m, step length dL=0.5 m at pumping (includes 1 day waiting after beginning of pumping)	2006-08-04
14	Overlapping flow logging	Section length L_w=1 m, step length dL=0.1 m, at pumping	2006-08-04 2006-08-05
16	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, at pumping	2006-08-05
17	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping.	2006-08-05 2006-08-06

Table 5-5. Flow logging and testing in KLX23B. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer	2006-07-28
8	Dummy logging	Borehole stability/risk evaluation	2006-07-29
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, no pumping	2006-07-29
12	Combined overlapping/sequential flow logging	Section length L_w=5 m, step length dL=0.5 m. No pumping	2006-07-30
13	Overlapping flow logging	Section length L_w=5 m, step length dL=0.5 m at pumping (includes 1 day waiting after beginning of pumping)	2006-07-30 2006-07-31
14	Overlapping flow logging	Section length L_w=1 m, step length dL=0.1 m, at pumping	2006-07-31
16	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, at pumping	2006-08-01
17	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping.	2006-08-01 2006-08-02

Table 5-6. Flow logging and testing in KLX24A. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer	2006-08-21
8 and 9	Length calibration of the downhole tool	Dummy logging	2006-08-21
		(SKB caliper and SPR). Logging without the lower rubber discs, no pumping	2006-08-21 2006-08-22
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, no pumping	2006-08-22
11	Combined overlapping/sequential flow logging	Section length L_w=5 m, step length dL=0.5 m. No pumping	2006-08-23
12	Overlapping flow logging	Section length L_w=5 m, step length dL=0.5 m at pumping (includes 1 day waiting after beginning of pumping)	2006-08-25
13	Overlapping flow logging	Section length L_w=1 m, step length dL=0.1 m, at pumping	2006-08-26
14	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, at pumping	2006-08-27
15	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping.	2006-08-27 2006-08-28

Table 5-7. Flow logging and testing in KLX25A. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer	2006-08-15
8	Dummy logging	Dummy logging	2006-08-15
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, no pumping	2006-08-16
11	Combined overlapping/sequential flow logging	Section length L_w=5 m, step length dL=0.5 m. No pumping	2006-08-16
12	Overlapping flow logging	Section length L_w=5 m, step length dL=0.5 m at pumping (includes 1 day waiting after beginning of pumping)	2006-08-18
13	Overlapping flow logging	Section length L_w=1 m, step length dL=0.1 m, at pumping	2006-08-18
14	EC- and temp-logging of the borehole fluid	Logging without the lower rubber discs, at pumping	2006-08-19
15	Recovery transient	Measurement of water level and absolute pressure in the borehole after stopping of pumping.	2006-08-19 2006-08-20

5.2 Nonconformities

Caliper marks in KLX23A were not measured even though they exist. The reason for this was that the caliper marks were not listed in the activity plan, therefore it was wrongly assumed that they were missing altogether in the borehole. This however, does not affect the results of the other measurements in any way. Length correction could successfully be done based on single point resistance data.

6 Results

6.1 Length calibration

6.1.1 Caliper and SPR measurement

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 which in turn depends, among other things, on the inclination of the borehole and the roughness (friction properties) of the borehole wall. The cable tension is higher when the borehole is measured upwards. The cables, especially new cables, may also stretch out permanently.

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

The procedure of the length correction was the following:

- The caliper/SPR-measurements (Item 9) were initially length corrected in relation to the known length marks, Appendices 22A.1.8, 22B.1.7 and 24A.1.7, black curve. Corrections between the length marks were obtained by linear interpolation.
- The SPR curve of Item 9 was then compared with the SPR curves of Items 12, 13 and 14 to obtain relative length errors of these measurement sequences.
- All SPR curves could then be synchronized, as can be seen in Appendices 22A.1.1–22A.1.7, 22B.1.1–22B.1.6 and 24A.1.1–24A.1.6.

The results of the caliper and single point resistance measurements from all measurements in the entire borehole are presented in Appendices 22A.1.1, 22B.1.1 and 24A.1.1. The five SPR-curves are plotted together with the caliper-data. Appendices 23A.1.1, 23B.1.1 and 25A.1.1 show the same thing, but without the caliper-data. These measurements correspond to Items 9, 12, 13 and 14 in Table 5-2–Table 5-5.

The caliper tool outputs a high voltage value when the borehole diameter is below 77 mm and a low value when the borehole diameter is over 77 mm.

Zoomed results of the caliper and SPR data are presented in Appendices 22A.1.1–22A.1.7, 22B.1.1–22B.1.6, 23A.1.1–23A.1.2 and 24A.1.1–24A.1.6. The detected length marks are listed in Table 6-1–Table 6-4. The detected length marks can also be seen in the SPR results. However, the SPR-anomaly is complicated due to the four rubber disks used at the upper end of the section, two at each side of the resistance electrode. If only one length mark is detected, the decision whether it is the lower or the upper mark is made based on the shape of the SPR-anomaly. The SPR-anomaly at the length marks has a distinctive shape, which can usually be recognized. In this case there were no partially recognized length marks. The caliper-measurement was not performed in KLX23A, instead the SPR-anomaly was studied and the position of the length mark could be deduced from that.

Table 6-1. Detected length marks in KLX22A.

Length marks given by SKB (m)	Length marks detected by caliper	Length marks detected by SPR
50	Both	Yes
80	Both	Yes

Table 6-2. Detected length marks in KLX22B.

Length marks given by SKB (m)	Length marks detected by caliper	Length marks detected by SPR
50	Both	Yes
80	Both	Yes

Table 6-3. Detected length marks in KLX23A.

Length marks given by SKB (m)	Length marks detected by caliper	Length marks detected by SPR
50	Not measured	Yes
80	Not measured	Yes

Table 6-4. Detected length marks in KLX24A.

Length marks given by SKB (m)	Length marks detected by caliper	Length marks detected by SPR
50	Both	Yes
80	Both	Yes

The aim of the plots in Appendices 22A.1.1–22A.1.7, 22B.1.1–22B.1.6, 23A.1.1–23A.1.2 and 24A.1.1–24A.1.6 is to verify the accuracy of the length correction. The curves in these plots are the length corrected results.

The magnitude of the length correction along the borehole is presented in Appendices 22A.1.1–22A.1.7, 22B.1.1–22B.1.6, 23A.1.3 and 24A.1.1–24A.1.6. The negative values of the error represent the situation where the logging cable has been extended, i.e. the cable is longer than the nominal length marked on

6.1.2 Estimated error in the location of detected fractures

In spite of the length correction described above, there can still be length errors due to the following reasons:

1. The point interval in the overlapping mode flow measurements is 0.1 m. This could cause an error of ±0.05 m.
2. The length of the test section is not exact. The specified section length denotes 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 will cause rounded flow anomalies: a flow may be detected already when a fracture is situated between the upper rubber disks. These phenomena can cause an error of ±0.05 m when the short step length (0.1 m) is used.

3. There could sometimes be a need for the corrections between the length marks to be other than linear. This could cause an error of ± 0.1 m in the caliper/SPR-measurement (Item 9).
4. SPR curves may be imperfectly synchronized. This could cause an error of ± 0.1 m

In the worst case, the errors from sources 1, 2, 3 and 4 are summed and the total estimated error between the length marks would be ± 0.3 m.

The situation is slightly better near the length marks. In the worst case, the errors from sources 1, 2 and 4 are summed and the total estimated error would be ± 0.2 m.

Knowing the location accurately is important when different measurements are compared, for instance flow logging and borehole TV. In a case like that the situation may not be as severe as in 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 caused by source 1 is random.

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 Electrical conductivity and temperature of borehole water

The electric conductivity of the borehole water was initially measured when the borehole was at rest, i.e. at natural, un-pumped conditions. The measurement was performed downwards and upwards, see Appendices 22B.2.1–25A.2.1.

The EC measurement was repeated during pumping (after a pumping period of about five days), see Appendices 22B.2.1–25A.2.1, green curves. The results show clear change to less saline water above the length of about 150 m.

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 22B.2.2–25A.2.2 have the same length axis as the EC results in Appendices 22B.2.1–25A.2.1.

The length calibration of the borehole electric conductivity measurements is not as accurate as in other measurements because single point resistance is not registered. The length correction of the caliper/SPR-measurement was applied to the borehole EC measurements, black curve in Appendices 22A.1.1–22A.1.7, 22B.1.1–22B.1.6 and 24A.1.1–24A.1.6.

6.3 Pressure measurements

Absolute pressure was registered with the other measurements in Items 10–17 (and all the extra measurements in KLX22A). The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered separately, Appendices 22A.13.2–25A.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 (metres above sea level) according to the RHB 70 reference system,

p_{abs} is absolute pressure (Pa),

p_b is barometric (air) pressure (Pa),

ρ_{fw} is unit density 1,000 kg/m^3

g is standard gravity 9.80665 m/s^2 and

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

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

Exact z-coordinates are important in head calculation, 10 cm error in z-coordinate means 10 cm error in head. The calculated head results are presented in graphs in Appendices 22A.13.1–25A.13.1.

The results of the SKB's interference test between holes KLX22A–KLX22B and KLX23A–KLX23B are presented in Appendices SKB.1.1–SKB.1.2. In these measurements the SKB pressure sensor was always located in the hole that was not being measured with the flow logging device.

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 22A.3–25A.3. Single point resistance is usually lower in value on a fracture where a flow is detected. There are also many other resistance anomalies from other fractures and geological features. The electrode of the single point resistance tool is located in between the upper rubber disks. Thus, the locations of the resistance anomalies of leaky fractures coincide with the lower end of the flow anomalies in the data plot.

The flow logging was first performed with a 5 m section length and with 0.5 m length increments, see Appendices 22A.3.1–22A.3.5, 22B.3.1–22B.3.5, 23A.3.1–23A.3.5, 23B.3.1–23B.3.3, 24A.3.1–24A.3.5 and 25A.3.1–25A.3.3. The method (overlapping flow logging) gives the length and the thickness of conductive zones with a length resolution of 0.5 m. To obtain quick results, only the thermal dilution method is used for flow determination.

Under natural conditions, the flow direction may be into the borehole or out from it. For small flow rates (< 100 mL/h) the flow direction can not be seen in the normal overlapping mode (thermal dilution method). Therefore the waiting time was longer for the thermal pulse method to determine the flow direction at every 5 m interval. The thermal pulse method was only used to detect the flow direction and not the flow rate, which would take a longer time to measure. It is necessary to do the longer flow direction measurement 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 22A.3.1–22A.3.5, 22B.3.1–22B.3.5, 23A.3.1–23A.3.5, 23B.3.1–23B.3.3, 24A.3.1–24A.3.5 and 25A.3.1–25A.3.3 (violet curve).

Detected fractures are shown on the caliper scale 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 22A.10–25A.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 22A.7–25A.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 Appendices 22A.11–25A.11.

6.4.2 Transmissivity and hydraulic head of borehole sections

The boreholes KLX22A–B, KLX23A–B, KLX24A and KLX25A were flow logged with a 5 m section length and with 0.5 m length increments. All the flow logging results presented in this report are derived from the measurements that utilized the thermal dilution method.

The results of the measurements with a 5 m section length are presented in tables, see Appendices 22A.7–25A.7. Only the results with a 5 m length increment are used. Secup presented in Appendices 22A.7–25A.7 is calculated as the distance along the borehole from the reference level (top of the casing tube) to the upper end of the test section. Seclow is calculated respectively to the lower end of the test section. The same flow rates as in Appendices 22A.7–25A.7, are also plotted in Appendices 22A.3–25A.3.

Pressure was measured and calculated as described in Section 6.3. Borehole head h_{0FW} and borehole head h_{1FW} in Appendices 22A.7–25A.7 represent the heads determined without and respectively with pumping. The head in the borehole and the calculated heads of borehole sections are given in RHB 70 scale.

The flow results in Appendices 22A.7–25A.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.

The flow data is presented as a plot, see Appendices 22A.4.1–25A.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 (below the measurement limit), 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. Both the theoretical and practical lower limits the flow are given, see Section 6.4.4.

Hydraulic head and transmissivity of borehole sections can be calculated from 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 given if none or just one of the flows is equal to zero, see Appendices 22A.4.2–25A.4.2. The measurement limits of transmissivity are also shown in Appendices 22A.4.2–25A.4.2 and in Appendices 22A.7–25A.7. All the measurement limit values of transmissivity are based on the actual pressure difference in the borehole (borehole head h_{0FW} and borehole head h_{1FW} in Appendices 22A.7–25A.7).

KLX22A

The sum of the detected flows in the un-pumped circumstances (Q_0) was $-2.6 \cdot 10^{-06}$ m^3/s (–9,360 mL/h). This sum should normally be zero if all the flows are measured, the measurements are correct, 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. The exact reason for this unbalance in the flows are unknown, but the last couple of metres near the surface could not be measured due to that pressure measuring equipment is in the way.

KLX22B

The sum of the detected flows in the un-pumped circumstances (Q_0) was $-1.4 \cdot 10^{-06}$ m^3/s (–2,030 mL/h). It is worth noticing is that no positive flows were detected. This indicates that there are flows outside of the measurable part of the borehole.

KLX23A

The sum of the detected flows in the un-pumped circumstances (Q_0) was $4.8 \cdot 10^{-06}$ m^3/s (17,500 L/h). When the sensor is at 34 m where the largest flow in the borehole is, the water level changes 0.5 m. Such a large change in the water level most likely causes the unbalance in the flows. The reason for the change in water level is not known, it could be caused by moving the sensor over the fracture. Surrounding influences could also be the cause, Appendix 23A.13.2 suggests that this could be a possible explanation.

KLX23B

The sum of the detected flows in the un-pumped circumstances (Q_0) was $-4.1 \cdot 10^{-07}$ m^3/s (–1,460 mL/h). This is relatively close to zero, and it can be seen in the flow results, Appendix 23B.3.1, that there are flows above the measurable part of the borehole.

KLX24A

The sum of the detected flows in the un-pumped circumstances (Q_0) was $-1.5 \cdot 10^{-06}$ m^3/s (–5,470 mL/h). The exact reason for this unbalance in the flows are unknown, but there could be again flows above the measurable part of the borehole.

KLX25A

The sum of the detected flows in the un-pumped circumstances (Q_0) was $-4.9 \cdot 10^{-07}$ m^3/s (–1,760 mL/h). The measurement ends in the middle of the most upper sector, therefore the fracture seen at 16.8 m was not included in the sector evaluation. This fracture has a flow of 1,760 mL/h, so the borehole is at balance.

6.4.3 Transmissivity and hydraulic head of fractures

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

In cases where the fracture distance is less than one metre, it may be difficult to evaluate the flow rate. In such 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. 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 22A.8–25A.8. The flow direction is evaluated as well. The results of the evaluation are plotted in Appendices 22A.3–25A.3, blue filled triangle.

Some fracture-specific results were classified to be "uncertain". The basis for the classification was in part of the cases a minor flow rate (< 30 mL/h), but in most of the cases unclear fracture anomalies. The anomalies were unclear because the distance between them was less than one metre or the nature of an anomaly was unclear because of noise.

Fracture-specific transmissivities were compared with the transmissivities of borehole sections in Appendices 22A.12–25A.12. All fracture-specific transmissivities within each 5 m interval were first summed up 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.

KLX22A

The total amount of detected flowing fractures was 40, but only 4 could be defined without pumping. These 4 fractures could be used for head estimation and all 40 were used for transmissivity estimations, Appendix 22A.8. The transmissivity and hydraulic head of fractures are plotted in Appendix 22A.5.

KLX22B

The total amount of detected flowing fractures was 31. When the borehole was pumped, only 29 of those could be defined. The remaining 2 fractures could only be defined when the borehole was at rest. The reason for this was that the drawdown during pumping prevented them from being measured. A total of 6 fractures were defined without pumping. The 4 fractures that could be defined by both measurements were used for head estimations and the 29 fractures that were defined only by the measurements with pumping were used for transmissivity estimations, Appendix 22B.8. The transmissivity and hydraulic head of fractures are plotted in Appendix 22B.5.

KLX23A

The total amount of detected flowing fractures was 17. When the borehole was pumped, only 16 of those could be defined. The remaining fracture could only be defined when the borehole was at rest. The reason for this was that the drawdown during pumping prevented it from being measured. A total of 7 fractures were defined without pumping. The 6 fractures that could be defined by both measurements were used for head estimations and the 16 fractures that were defined only by the measurements with pumping were used for transmissivity estimations, Appendix 23A.8. The transmissivity and hydraulic head of fractures are plotted in Appendix 23A.5.

KLX23B

The total amount of detected flowing fractures was 4. When the borehole was pumped, only 2 of those could be defined. The remaining 2 fractures could only be defined when the borehole was at rest. The reason for this was that the drawdown during pumping prevented them from being measured. A total of 3 fractures were defined without pumping. The fracture that could be defined by both measurements were used for head estimations and the 2 fractures that were defined only by the measurements with pumping were used for transmissivity estimations, Appendix 23B.8.

The transmissivity and hydraulic head of fractures are plotted in Appendix 23B.5.

KLX24A

The total amount of detected flowing fractures was 41. When the borehole was pumped, only 38 fractures could be defined. The remaining 3 fractures could only be defined when the borehole was at rest. The reason for this was that the drawdown during pumping prevented them from being measured. A total of 8 fractures were defined without pumping. The 5 fractures that could be defined by both measurements were used for head estimations and the 38 fractures that were defined only by the measurements with pumping were used for transmissivity estimations, Appendix 24A.8. The transmissivity and hydraulic head of fractures are plotted in Appendix 24A.5.

KLX25A

The total amount of detected flowing fractures was 8. When the borehole was pumped, only 7 fractures could be defined. The remaining fracture could only be defined when the borehole was at rest. The reason for this was that the drawdown during pumping prevented it from being measured. A total of 4 fractures were defined without pumping. The 3 fractures that could be defined by both measurements were used for head estimations and the 4 fractures that were defined only by the measurements with pumping were used for transmissivity estimations, Appendix 25A.8. The transmissivity and hydraulic head of fractures are plotted in Appendix 25A.5.

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 has a theoretical lower limit of 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 22A.3–25A.3 using a grey dashed line (Lower limit of flow rate). The practical minimum level of the measurable flow is always evaluated in pumped conditions since this measurement is the most important for transmissivity calculations. The limit is an approximation. It is evaluated to obtain a limit below which there may be fractures or structures that remain undetected.

The noise levels in KLX22A–B, KLX23A–B, KLX24A and KLX25A was near 30 mL/h. In some places anomalies below the theoretical limit of the thermal dilution method (30 mL/h) could be detected. The noise line (grey dashed line) was never drawn below 30 mL/h. Although fractures may be detected, the flow rates measured below 30 mL/h are uncertain.

In some boreholes the upper limit of flow measurement (300,000 mL/h) may be exceeded. Such fractures or structures hardly remain undetected (as the fractures below the lower limit). High flow fractures can be measured separately at a smaller drawdown.

The practical minimum of the measurable flow rate is also presented in Appendices 22A.7–25A.7 (Q-lower limit P). The value is the same as the Lower limit of flow rate in Appendices 22A.3–25A.3. The Practical minimum of measurable transmissivity can be evaluated using Q-lower limit P and the head difference at each measurement location, see Appendices 22A.7–25A.7 ($TD\text{-}measl_{LP}$). The theoretical minimum measurable transmissivity can also be evaluated using a Q value of 30 mL/h (minimum theoretical flow rate with the thermal dilution method) instead of Q-lower limit Practical, see Appendices 22A.7–25A.7 ($TD\text{-}measl_{LT}$). 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 22A.7–25A.7 ($TD\text{-}measl_{U}$).

All three flow limits are also plotted with measured flow rates, see Appendices 22A.4.1–25A.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 22A.4.2–25A.4.2.

Similar flow and transmissivity limits are not given for the fracture-specific results, Appendices 22A.5–25A.5 and 22A.8–25A.8. Approximately the same limits would be valid also 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 are used to evaluate the transmissivity of the entire borehole. This is done with the two steady state methods, described in Chapter 3.

KLX22A

Steady state analysis

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 8.63 L/min and s (drawdown) was 10.03 m. Transmissivity calculated with Dupuit's formula is $1.4 \cdot 10^{-05}$ m^2/s.

In Moye's formula (Equation 3-10) the length of the test section L is 98.45 m (2.00–100.45 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $1.9 \cdot 10^{-05}$ m^2/s.

KLX22B

Steady state analysis

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 3.1 L/min and s (drawdown) was 10.00 m. Transmissivity calculated with Dupuit's formula is $5,0 \cdot 10^{-06}$ m^2/s.

In Moye's formula (Equation 3-10) the length of the test section L is 98.25 m (2.00–100.25 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $6.6 \cdot 10^{-06}$ m^2/s.

KLX23A

Steady state analysis

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 6.7 L/min and s (drawdown) was 10.79 m. Transmissivity calculated with Dupuit's formula is $1.0 \cdot 10^{-05}$ m^2/s.

In Moye's formula (Equation 3-10) the length of the test section L is 97.85 m (2.30–100.15 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $1.3 \cdot 10^{-05}$ m^2/s.

KLX23B

Steady state analysis

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 1.00 L/min and s (drawdown) was 9.89 m. Transmissivity calculated with Dupuit's formula is $1.7 \cdot 10^{-06}$ m^2/s.

In Moye's formula (Equation 3-10) the length of the test section L is 47.97 m (2.30–50.27 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $2.0 \cdot 10^{-06}$ m^2/s.

KLX24A

Steady state analysis

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 15.9 L/min and s (drawdown) was 9.91 m. Transmissivity calculated with Dupuit's formula is $2.6 \cdot 10^{-05}$ m^2/s.

In Moye's formula (Equation 3-10) the length of the test section L is 97.76 m (2.41–100.17 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $3.5 \cdot 10^{-05}$ m^2/s.

KLX25A

Steady state analysis

For Dupuit's formula (Equation 3-9) R/r_0 is chosen to be 500, Q was 0.65 L/min and s (drawdown) was 4.18 m. Transmissivity calculated with Dupuit's formula is $2.6 \cdot 10^{-06}$ m^2/s.

In Moye's formula (Equation 3-10) the length of the test section L is 48.04 m (2.20–50.24 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $3.1 \cdot 10^{-06}$ m^2/s.

The results of the two methods are given for each hole in Table 6-5.

Basic test data is in Appendices 22A.6–25A.6.

6.5 Groundwater level and pumping rate

The groundwater level and the pumping rate are illustrated in Appendices 22A.13.2–25A.13.2 and the recovery plots are presented in Appendices 22A.13.3–25A.13.3. The groundwater recovery was monitored with the groundwater level sensor.

Individual borehole information is also presented in Table 6-6. In Table 6-6 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 6-6 are given as metres above sea level (m.a.s.l.) according to RHB 70. During the pumping in KLX22A–B and KLX23A–B the pressure was recorded in the nearby observation hole, Appendix SKB1.1 for KLX22A and KLX22B and Appendix SKB 1.2 for KLX23A and KLX23B.

Table 6-5. Transmissivity of the entire borehole in [m^2/s].

Method	KLX22A	KLX22B	KLX23A	KLX23B	KLX24A	KLX25A
Dupuit	$1.4 \cdot 10^{-05}$	$5.0 \cdot 10^{-06}$	$1.0 \cdot 10^{-05}$	$1.7 \cdot 10^{-06}$	$2.6 \cdot 10^{-05}$	$2.6 \cdot 10^{-06}$
Moye	$1.9 \cdot 10^{-05}$	$6.6 \cdot 10^{-06}$	$1.3 \cdot 10^{-05}$	$2.20 \cdot 10^{-06}$	$3.5 \cdot 10^{-05}$	$3.1 \cdot 10^{-06}$

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

Borehole	Pumping period	Pump intake level (m.a.s.l.)	Groundwater level sensor location (m.a.s.l.)	Top of C (m.a.s.l.)	Approx. drawdown (m)	Recovery period
KLX22A	2006-07-18–2006-07-21 and 2006-07-23	3.6	1.6	21.97	10.0	2006-07-21–2006-07-22 and 2006-07-23–2006-07-24
KLX22B	2006-07-26–2006-07-29	6.1	3.8	21.58	10.0	2006-07-29–2006-08-02
KLX23A	2006-08-03–2006-08-05	0.7	–1.6	21.26	10.8	2006-08-05–2006-08-09
KLX23B	2006-07-30–2006-08-01	2.9	0.1	21.31	9.9	2006-08-01–2006-08-08
KLX24A	2006-08-24–2006-08-27	0.1	–1.7	21.29	9.9	2006-08-27–2006-09-06
KLX25A	2006-08-17–2006-08-18	10.4	7.8	22.84	4.2	2006-08-19–2006-08-20

7 Summary

In this study, the Posiva Flow Log/Difference Flow method has been used to determine the location and flow rate of flowing fractures or structures in boreholes KLX22A–B, KLX23A–B, KLX24 and KLX25A 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.

Length calibration was made using the length marks on the borehole wall. The length marks were detected by caliper and in single point resistance logging. The latter method was also performed simultaneously with the flow measurements, and thus all flow results could be length calibrated by synchronizing the single point resistance logs.

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 KLX22A was 40, in KLX22B 31, in KLX23A 17, in KLX23B 4, in KLX24A 41 and in KLX25A 8. Fractures with a significant transmissivity were found in KLX22A around 80 m, in KLX22B around 30 m and 60 m, in KLX23A around 30 m, 70 m and 80 m, in KLX23B around 40 m, in KLX24A around 60 m and in KLX25A around 25 m and 40 m.

The transmissivity of the entire borehole was calculated for each borehole using two steady state methods.

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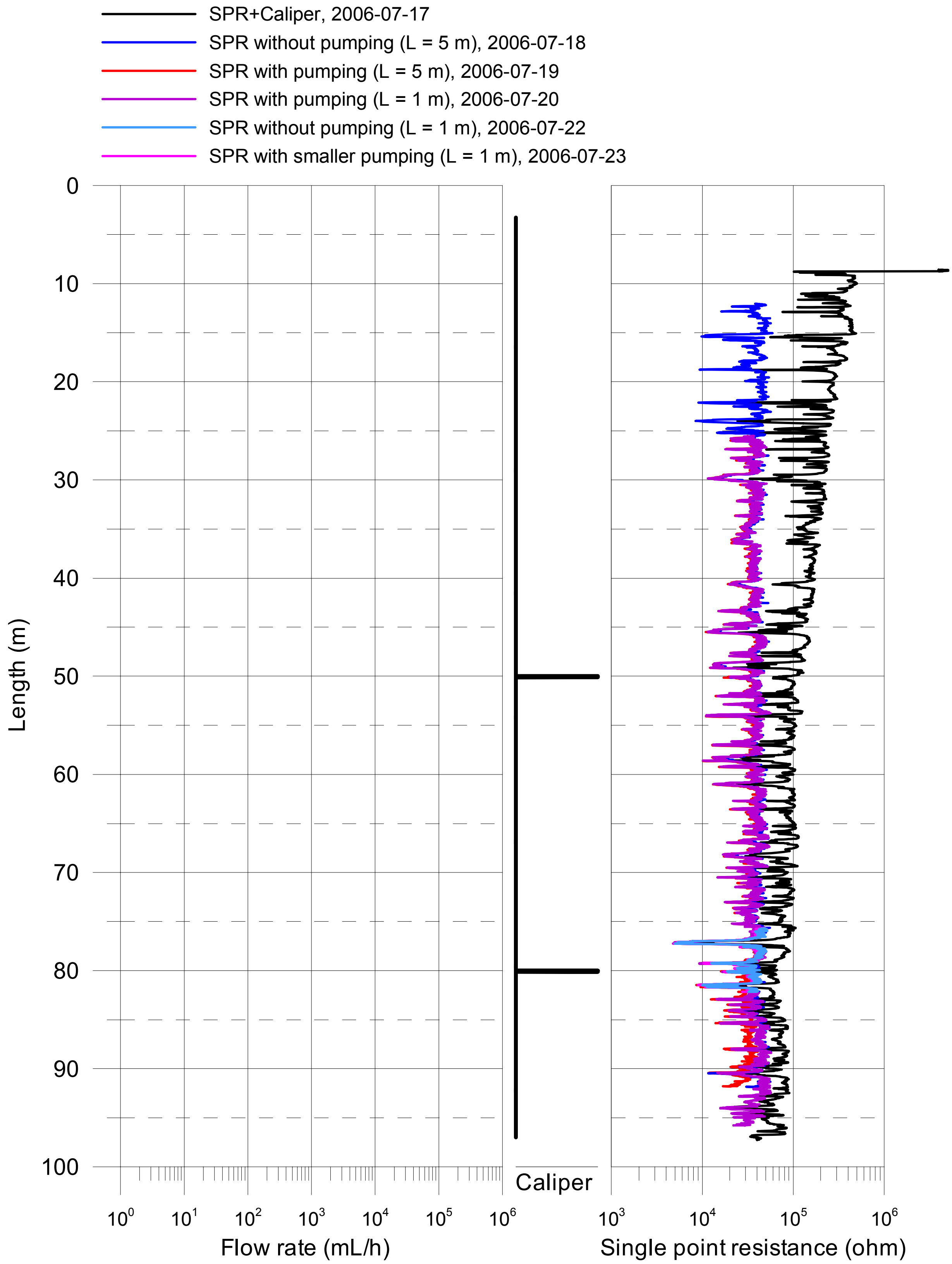
Öhberg A, Rouhiainen P, 2000. Posiva groundwater flow measuring techniques. Helsinki, Posiva Oy. Report POSIVA 2000-12.

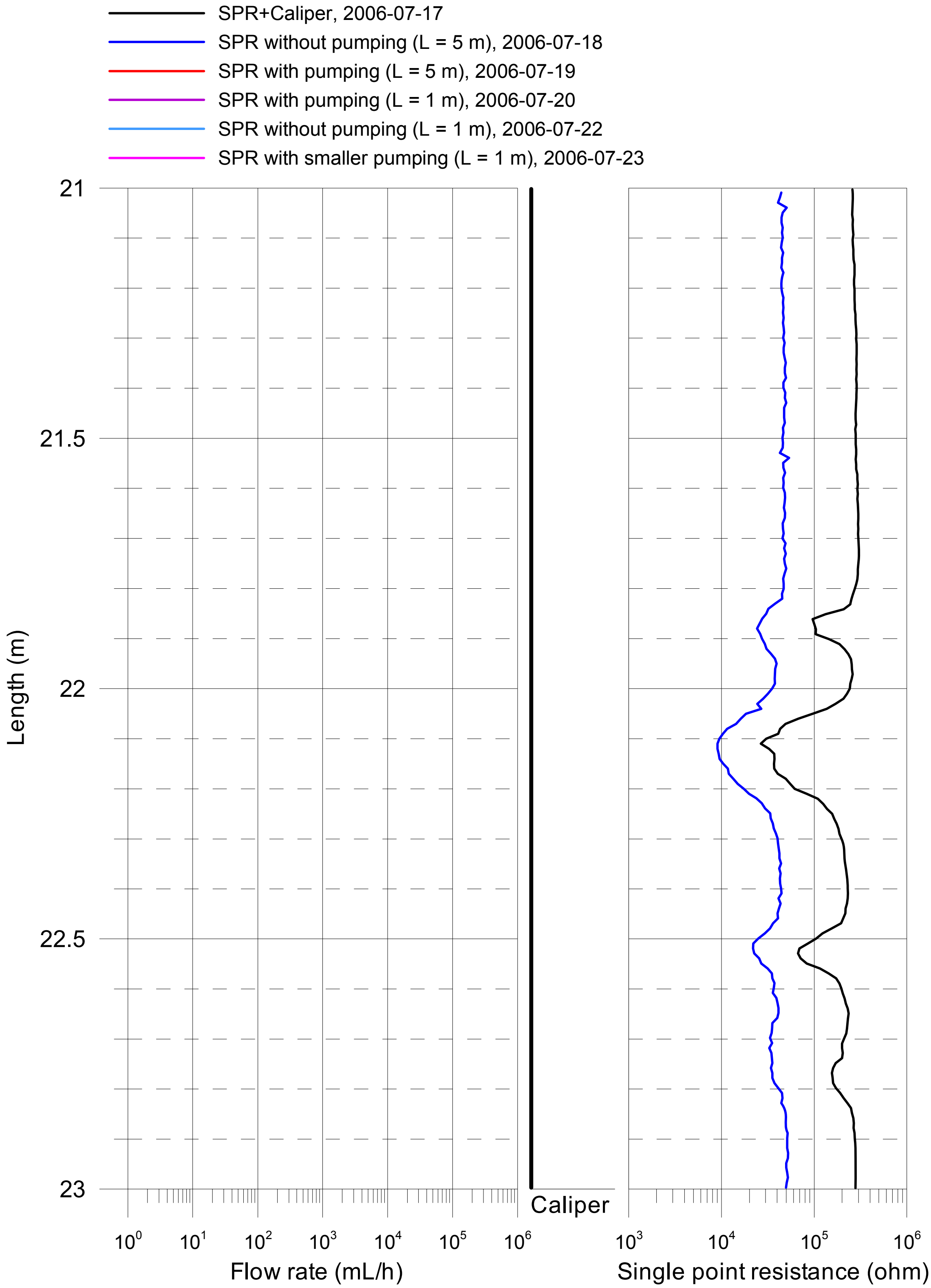
Appendices KLX22A

Appendices	22A.1.1–22A.1.7	SPR and caliper results after length correction
Appendices	22A.1.8	Length correction
Appendix	22A.2.1	Electric conductivity of borehole water
Appendix	22A.2.2	Temperature of borehole water
Appendix	22A.3.1–22A.3.5	Flow rate, caliper and single point resistance
Appendix	22A.4.1	Plotted flow rates of 5 m sections
Appendix	22A.4.2	Plotted transmissivity and head of 5 m sections
Appendix	22A.5	Plotted transmissivity and head of detected fractures
Appendix	22A.6	Basic test data
Appendix	22A.7	Results of sequential flow logging
Appendices	22A.8.1	Inferred flow anomalies from overlapping flow logging
Appendix	22A.9	Explanations for the tables in Appendices 6–8
Appendix	22A.10	Conductive fracture frequency
Appendix	22A.11	Plotted conductive fracture frequency
Appendix	22A.12	Comparison between section transmissivity and fracture transmissivity
Appendix	22A.13.1	Head in the borehole during flow logging
Appendix	22A.13.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	22A.13.3	Groundwater recovery after pumping

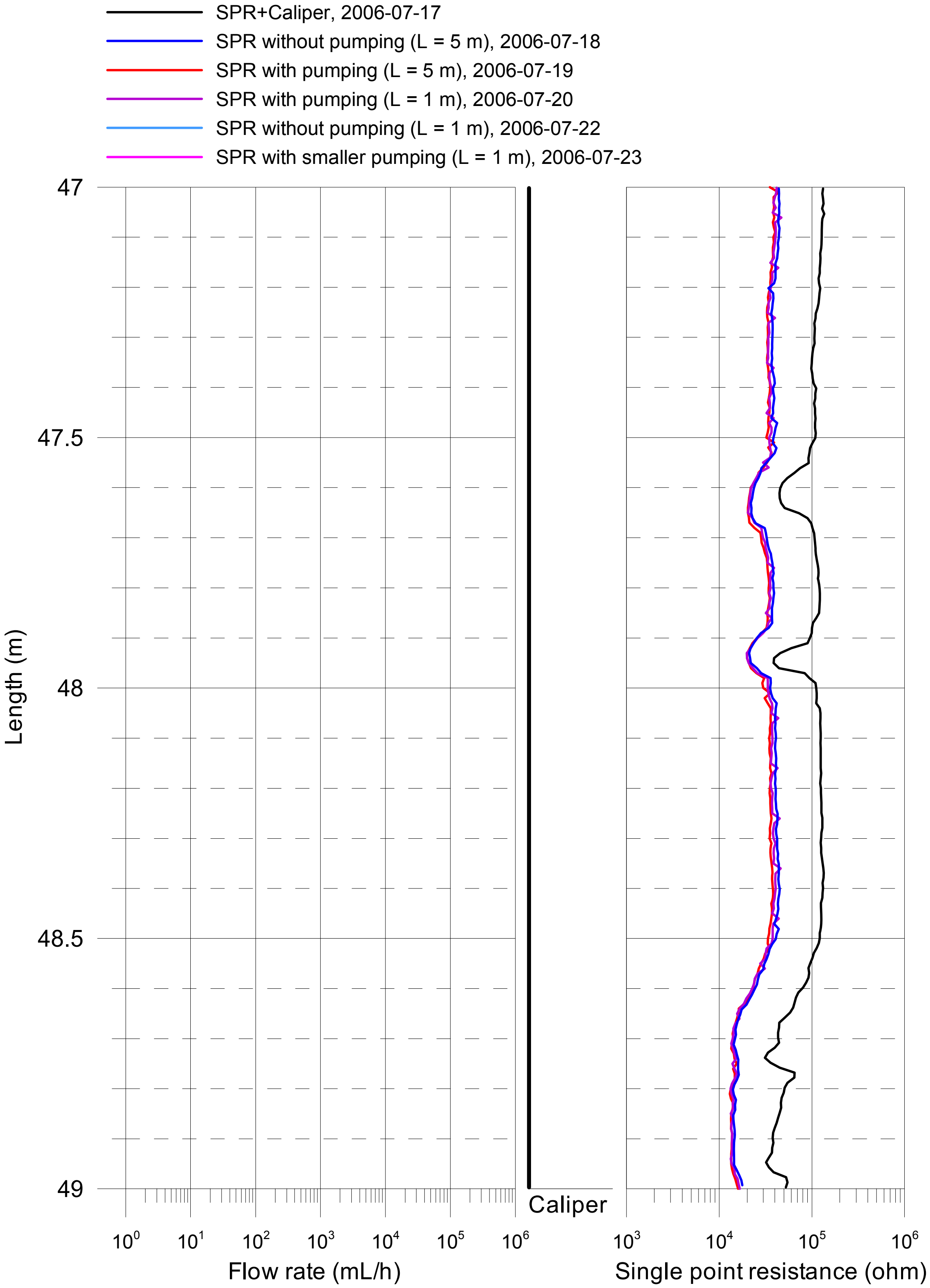
Laxemar, borehole KLX22A
SPR and Caliper results after length correction

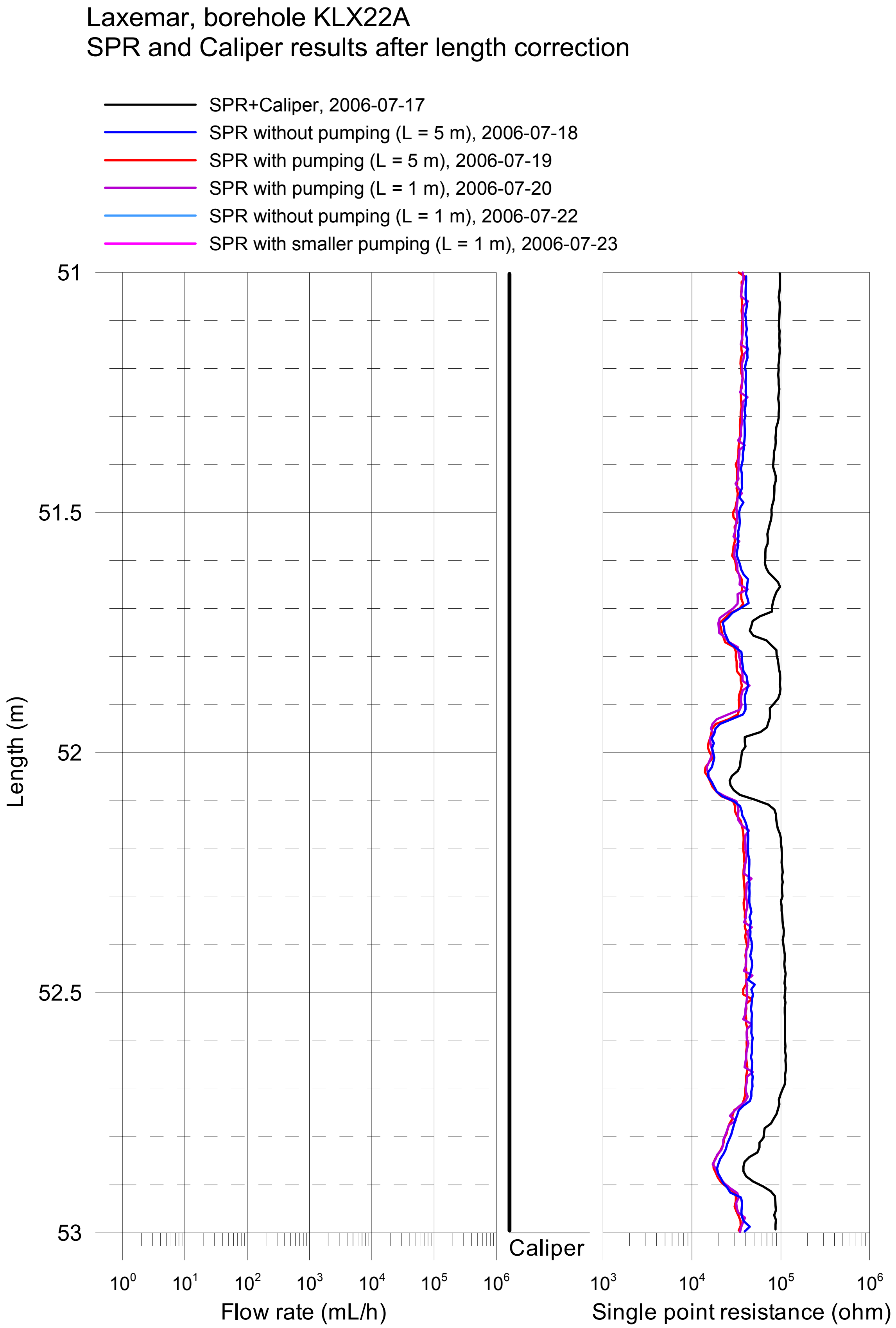


Laxemar, borehole KLX22A
SPR and Caliper results after length correction

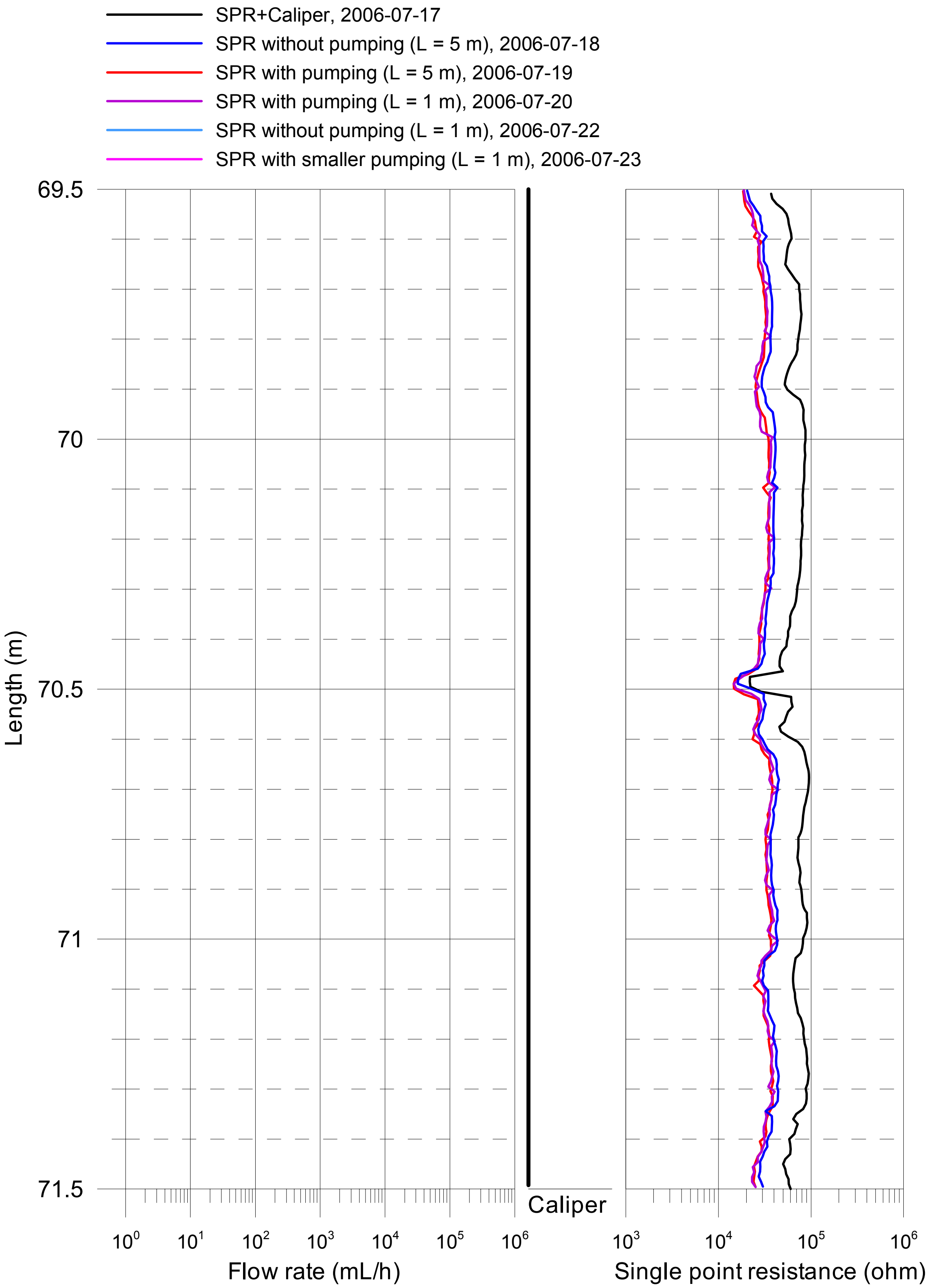


Laxemar, borehole KLX22A
SPR and Caliper results after length correction

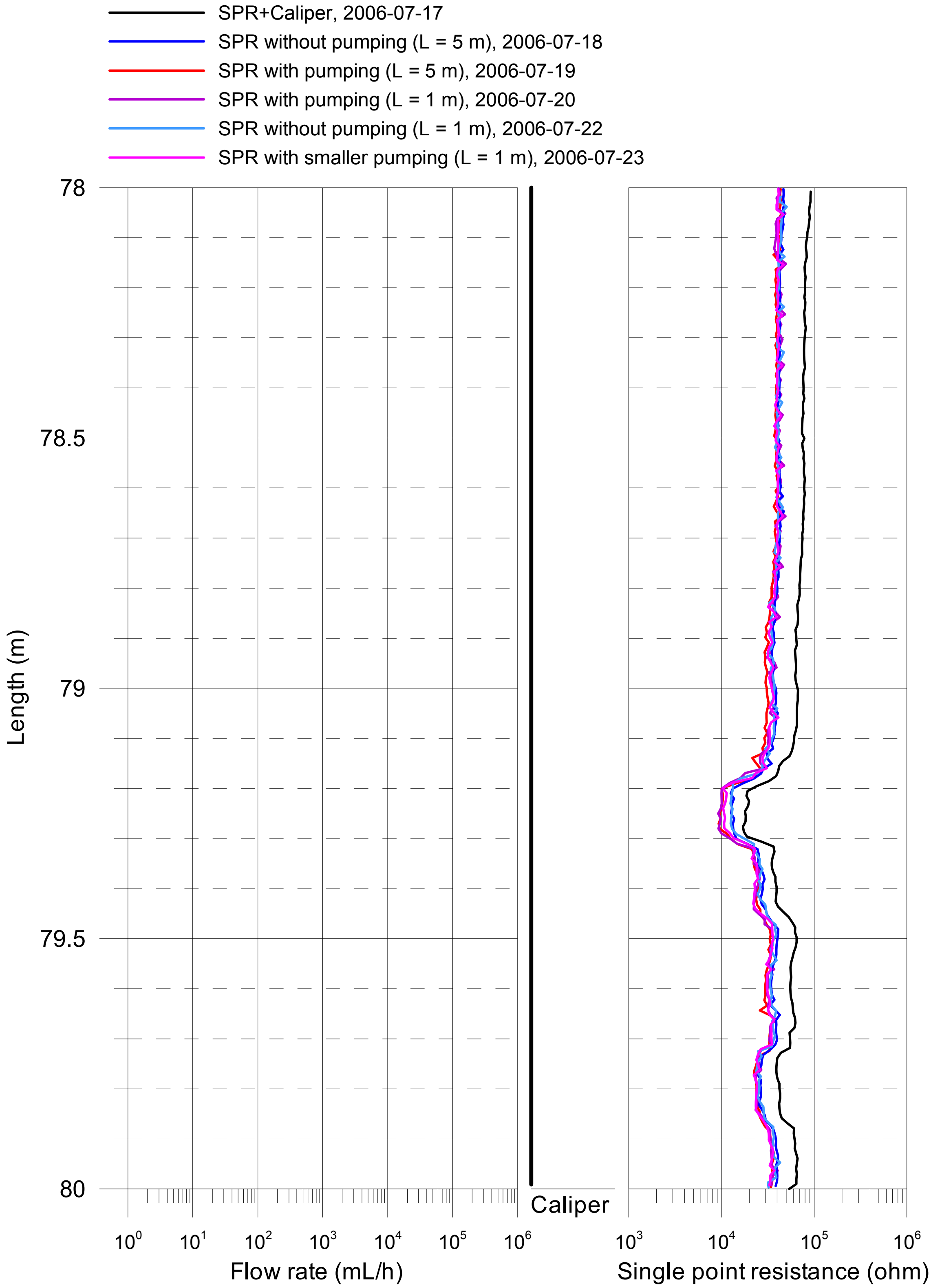


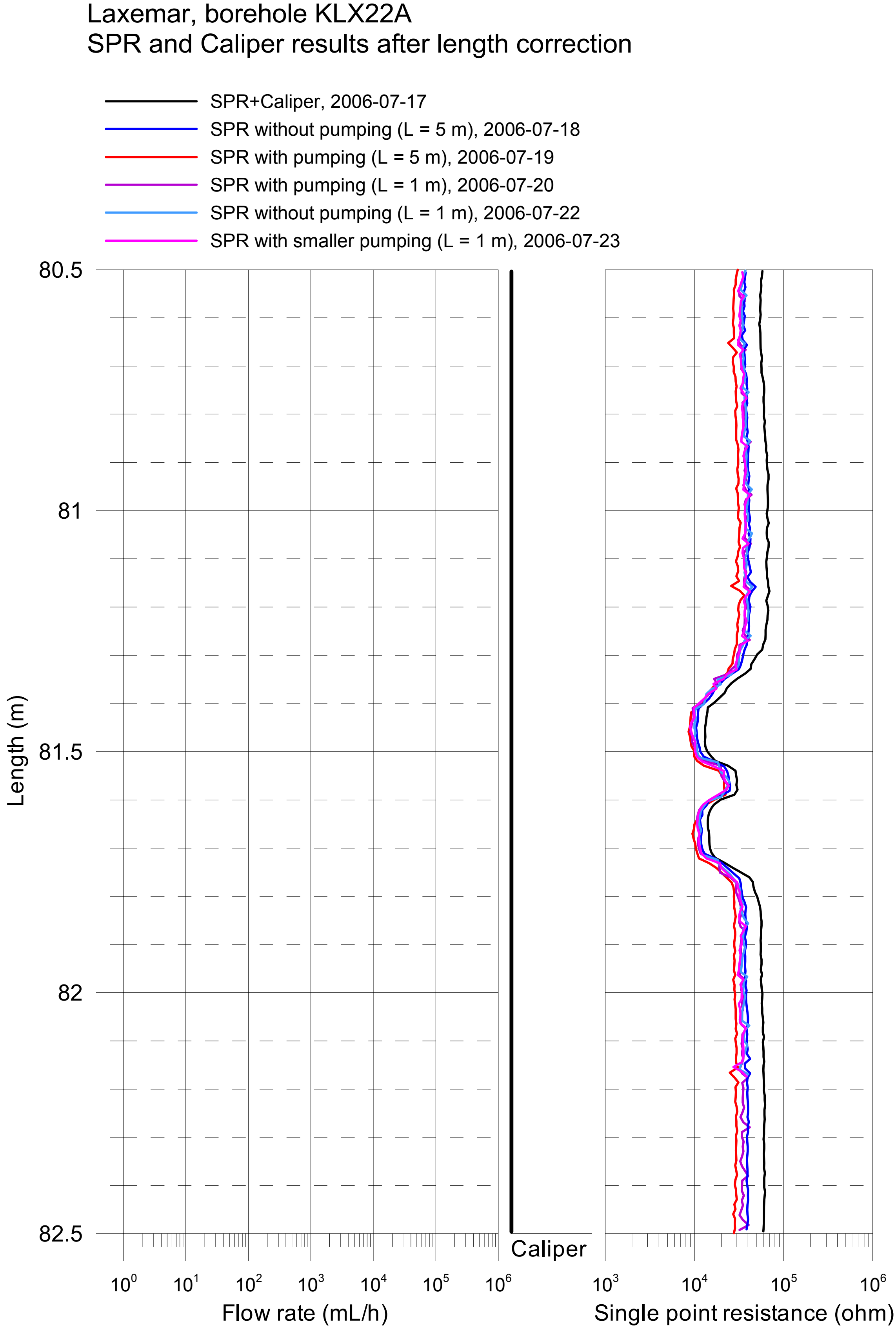

Laxemar, borehole KLX22A
SPR and Caliper results after length correction
SPR+Caliper, 2006-07-17
SPR without pumping (L = 5 m), 2006-07-18
SPR with pumping (L = 5 m), 2006-07-19
SPR with pumping (L = 1 m), 2006-07-20
SPR without pumping (L = 1 m), 2006-07-22
SPR with smaller pumping (L = 1 m), 2006-07-23
Length (m)
51
51.5
52
52.5
53
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^3 10^4 10^5 10^6
Single point resistance (ohm)

Laxemar, borehole KLX22A
SPR and Caliper results after length correction



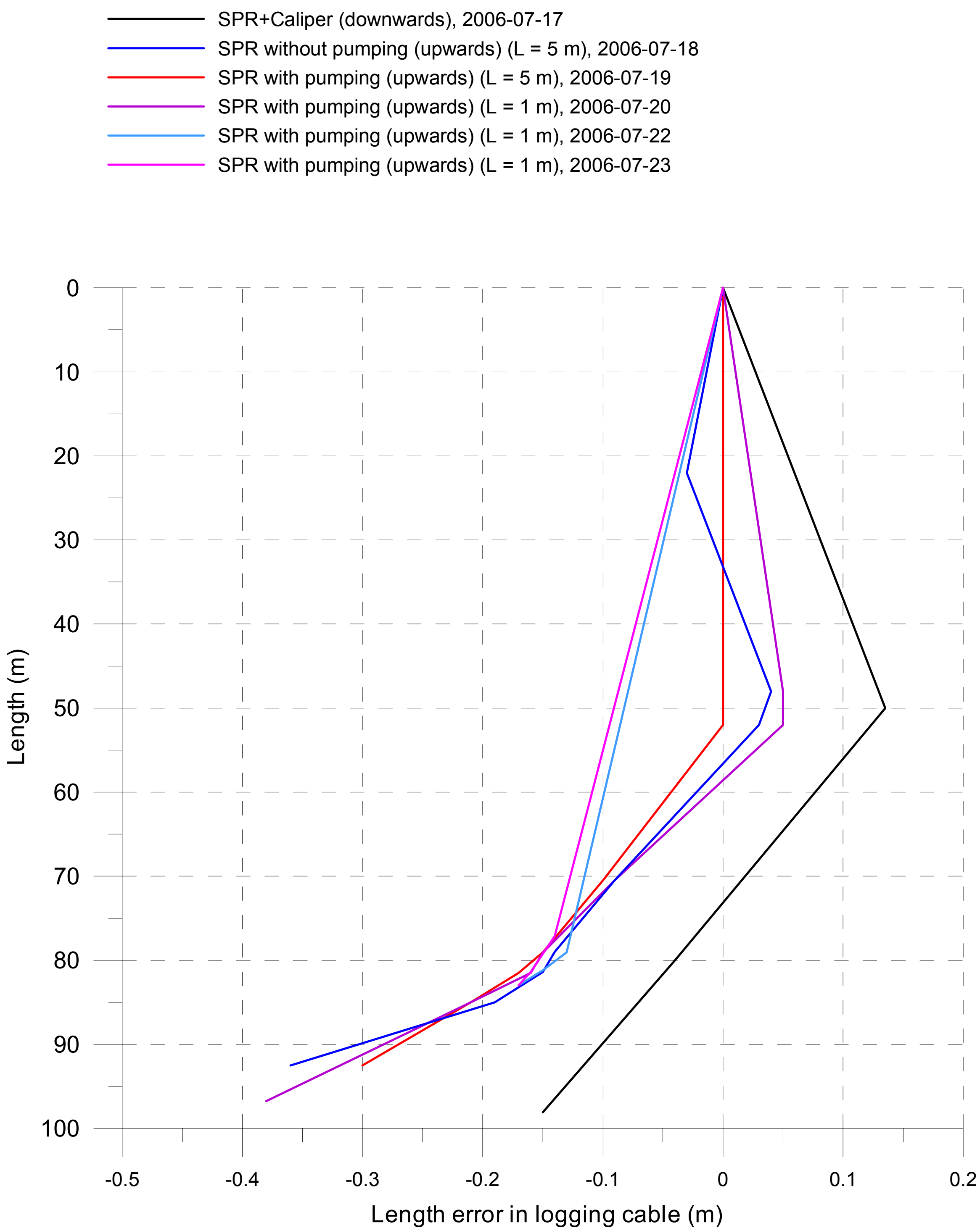
Laxemar, borehole KLX22A
SPR and Caliper results after length correction



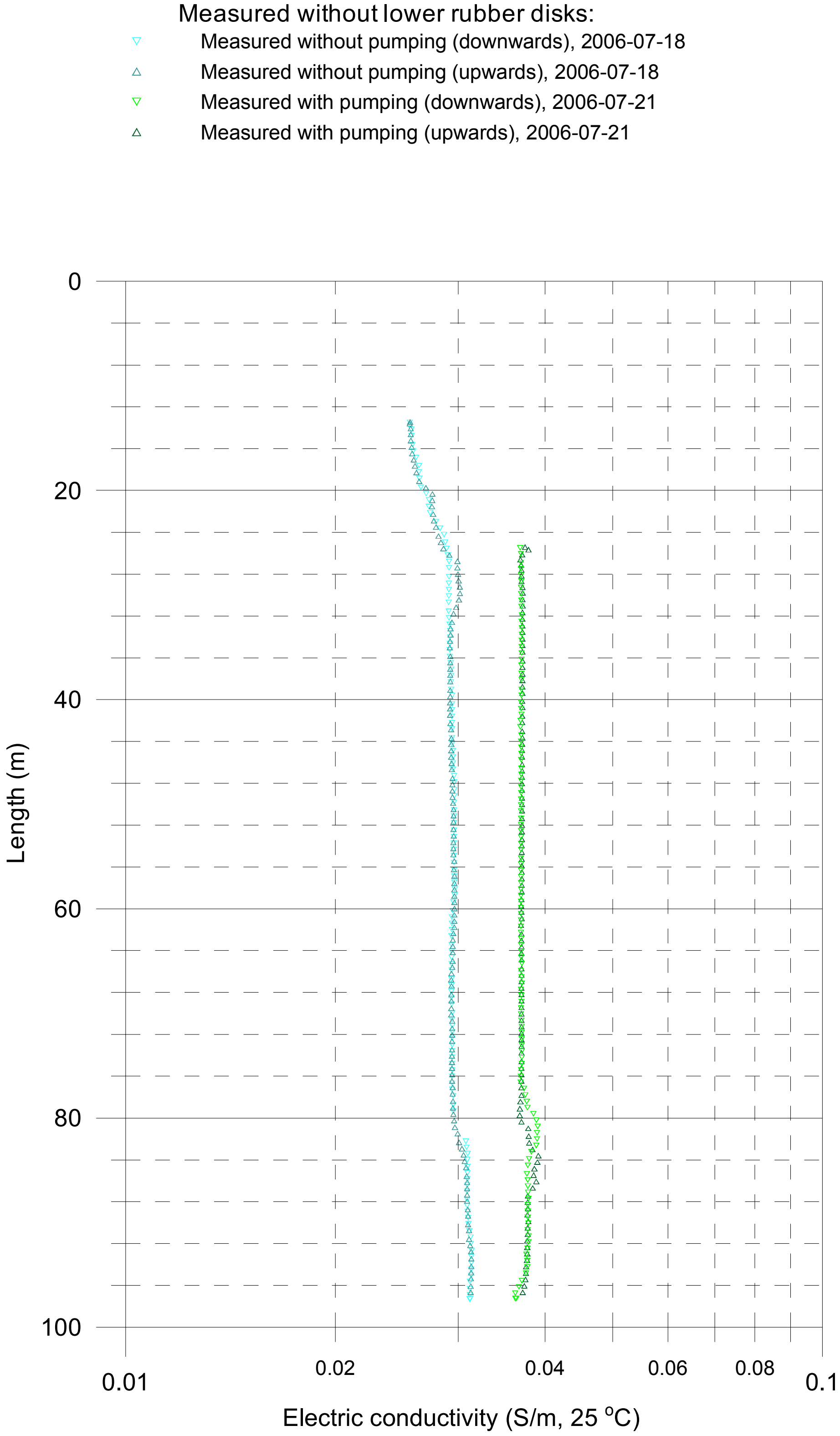


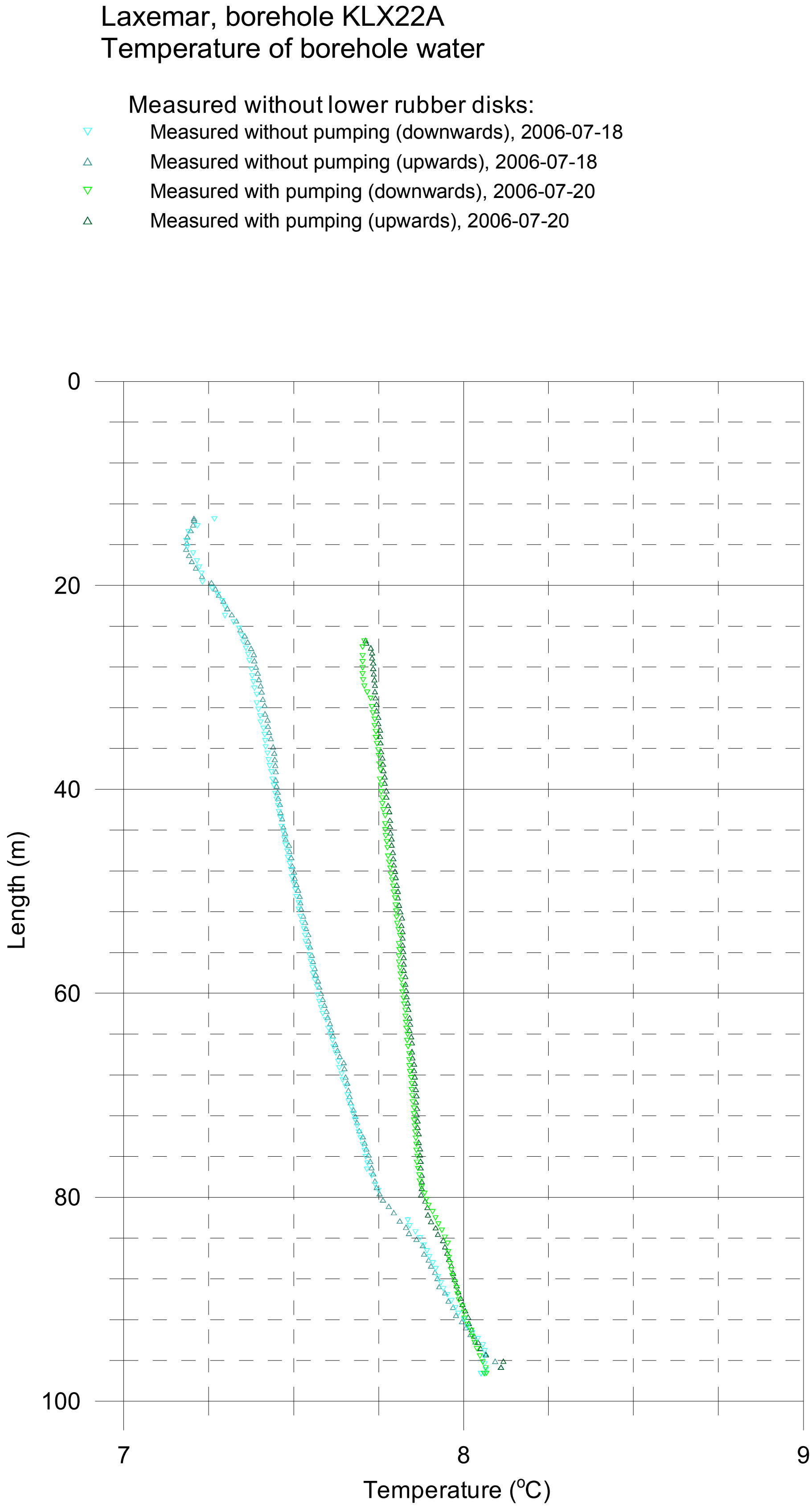
Laxemar, borehole KLX22A
SPR and Caliper results after length correction
SPR+Caliper, 2006-07-17
SPR without pumping (L = 5 m), 2006-07-18
SPR with pumping (L = 5 m), 2006-07-19
SPR with pumping (L = 1 m), 2006-07-20
SPR without pumping (L = 1 m), 2006-07-22
SPR with smaller pumping (L = 1 m), 2006-07-23
80.5
81
81.5
82
82.5
Length (m)
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^3 10^4 10^5 10^6
Single point resistance (ohm)

Laxemar, borehole KLX22A
Length correction

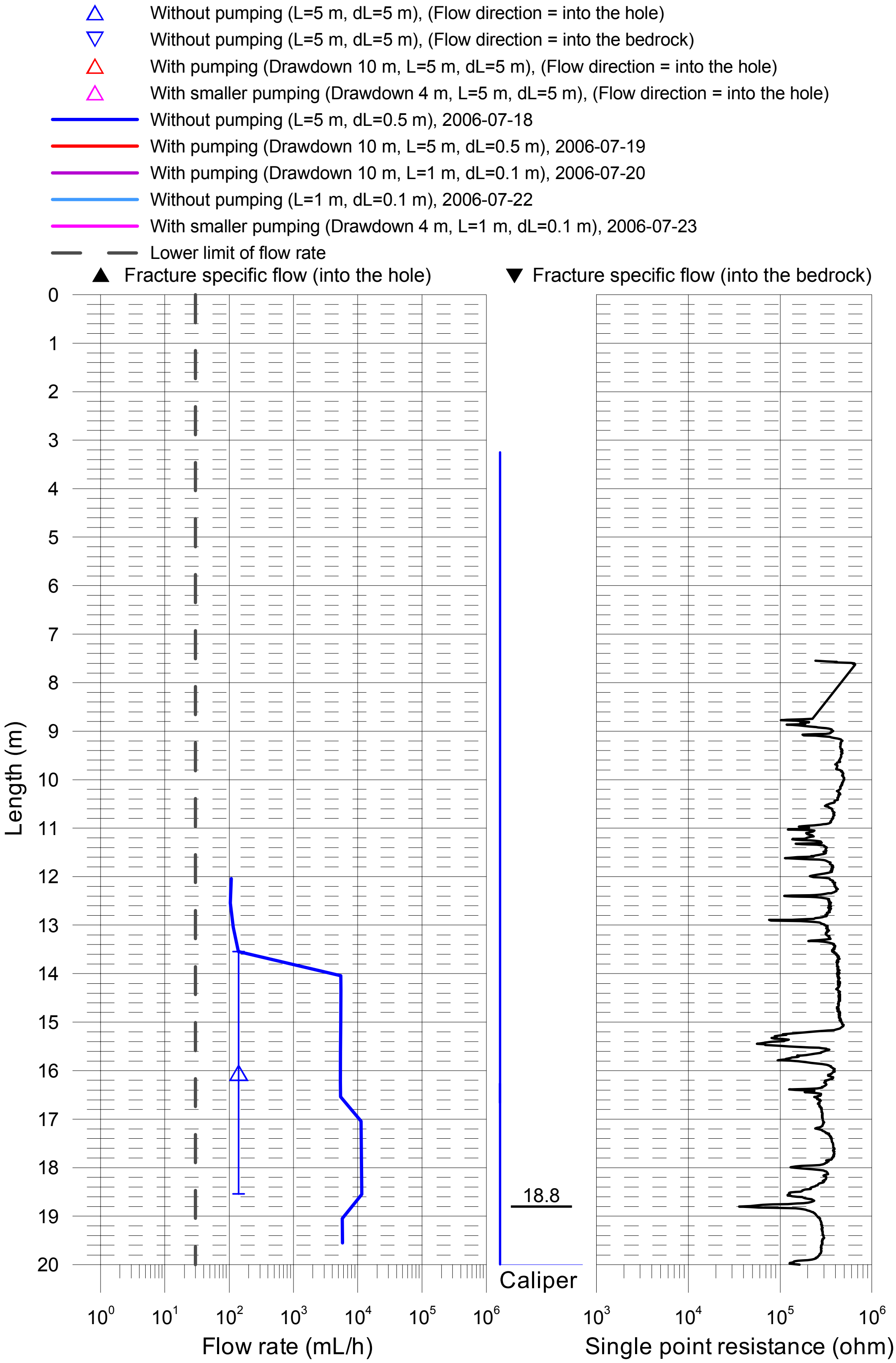


Laxemar, borehole KLX22A
Electric conductivity of borehole water

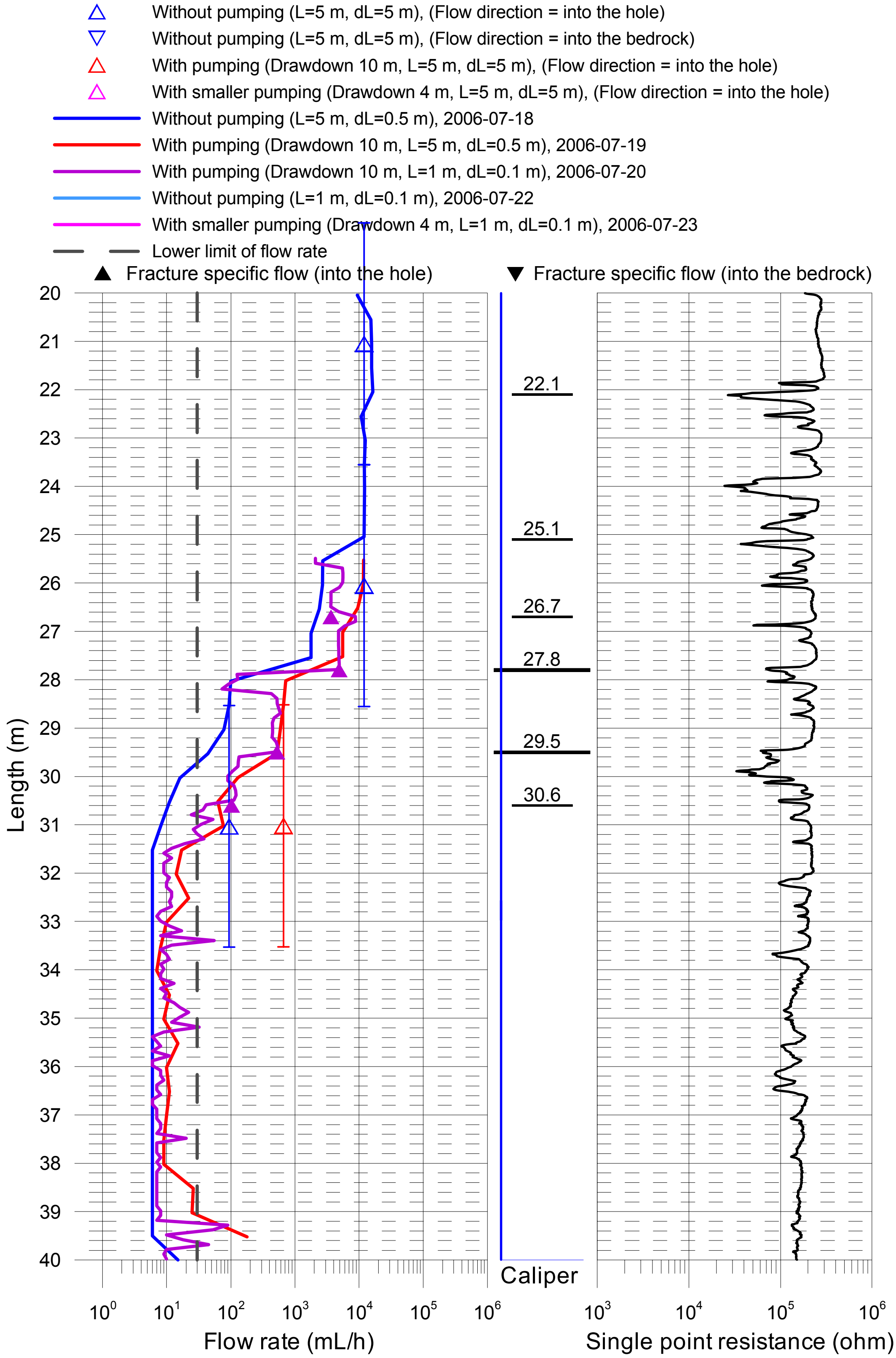



Laxemar, borehole KLX22A
Temperature of borehole water
Measured without lower rubber disks:
Measured without pumping (downwards), 2006-07-18
Measured without pumping (upwards), 2006-07-18
Measured with pumping (downwards), 2006-07-20
Measured with pumping (upwards), 2006-07-20
0
20
40
60
80
100
Length (m)
7
8
9
Temperature (oC)

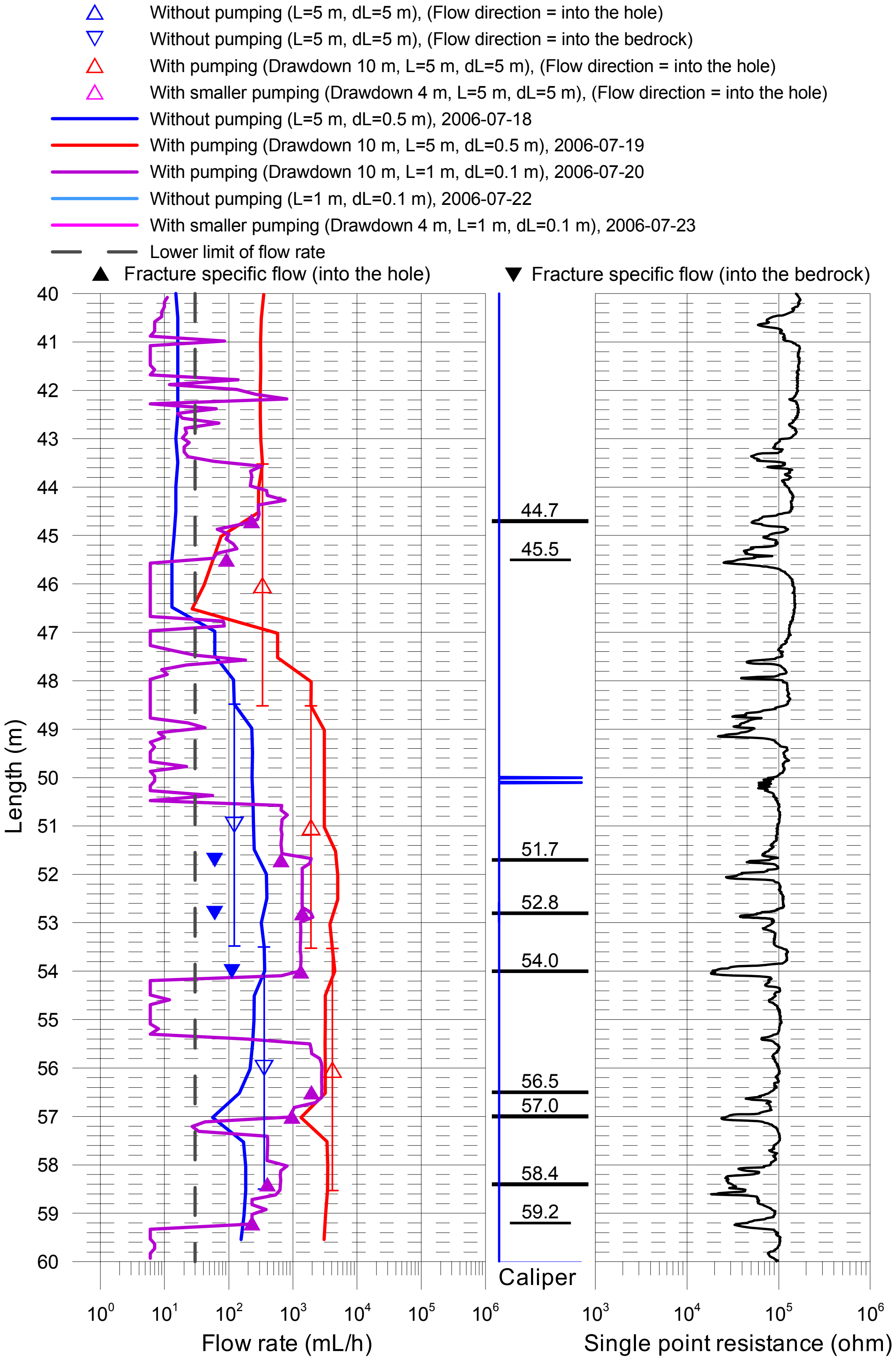
Laxemar, borehole KLX22A
Flow rate, caliper and single point resistance



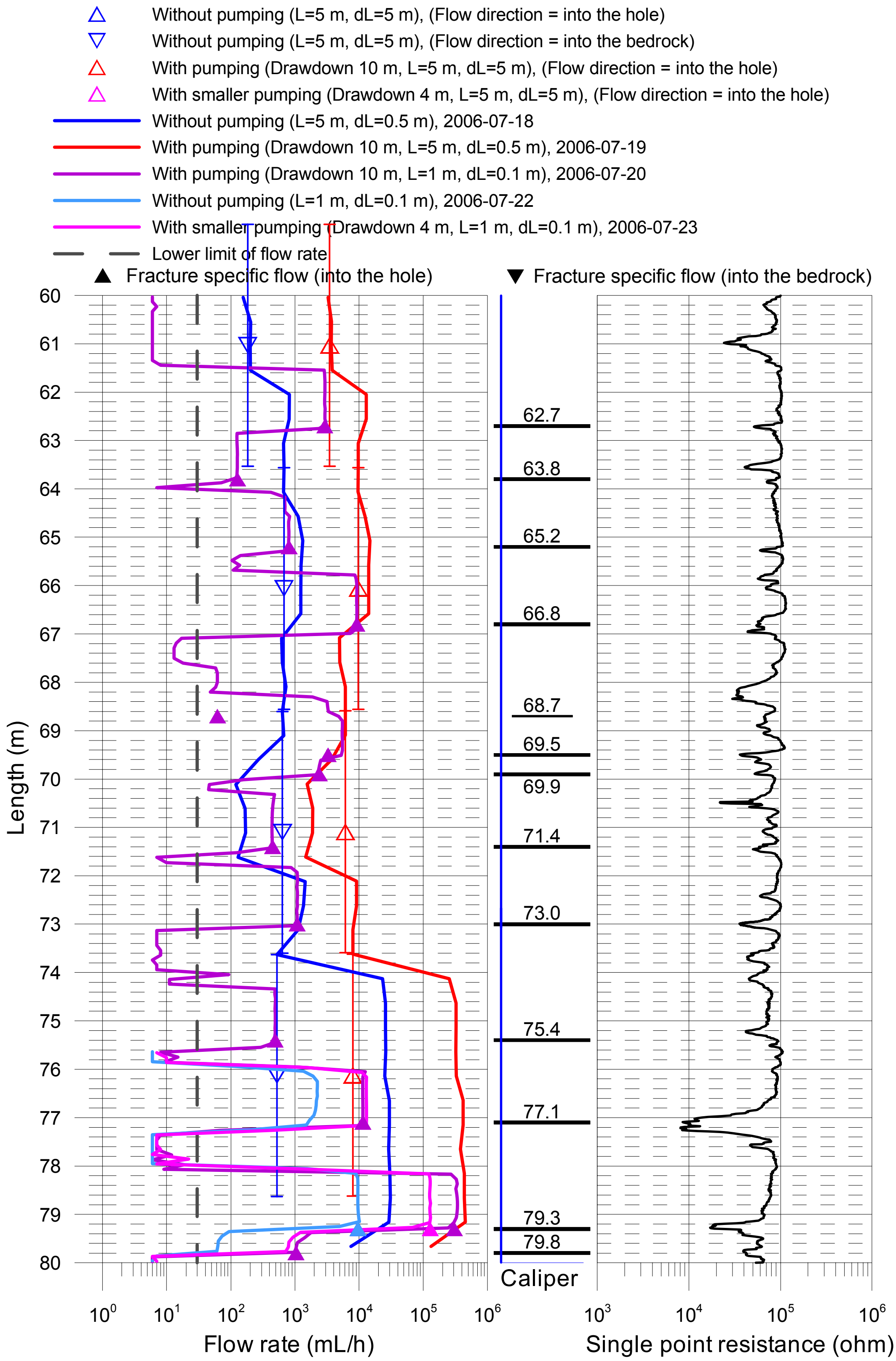
Laxemar, borehole KLX22A
Flow rate, caliper and single point resistance



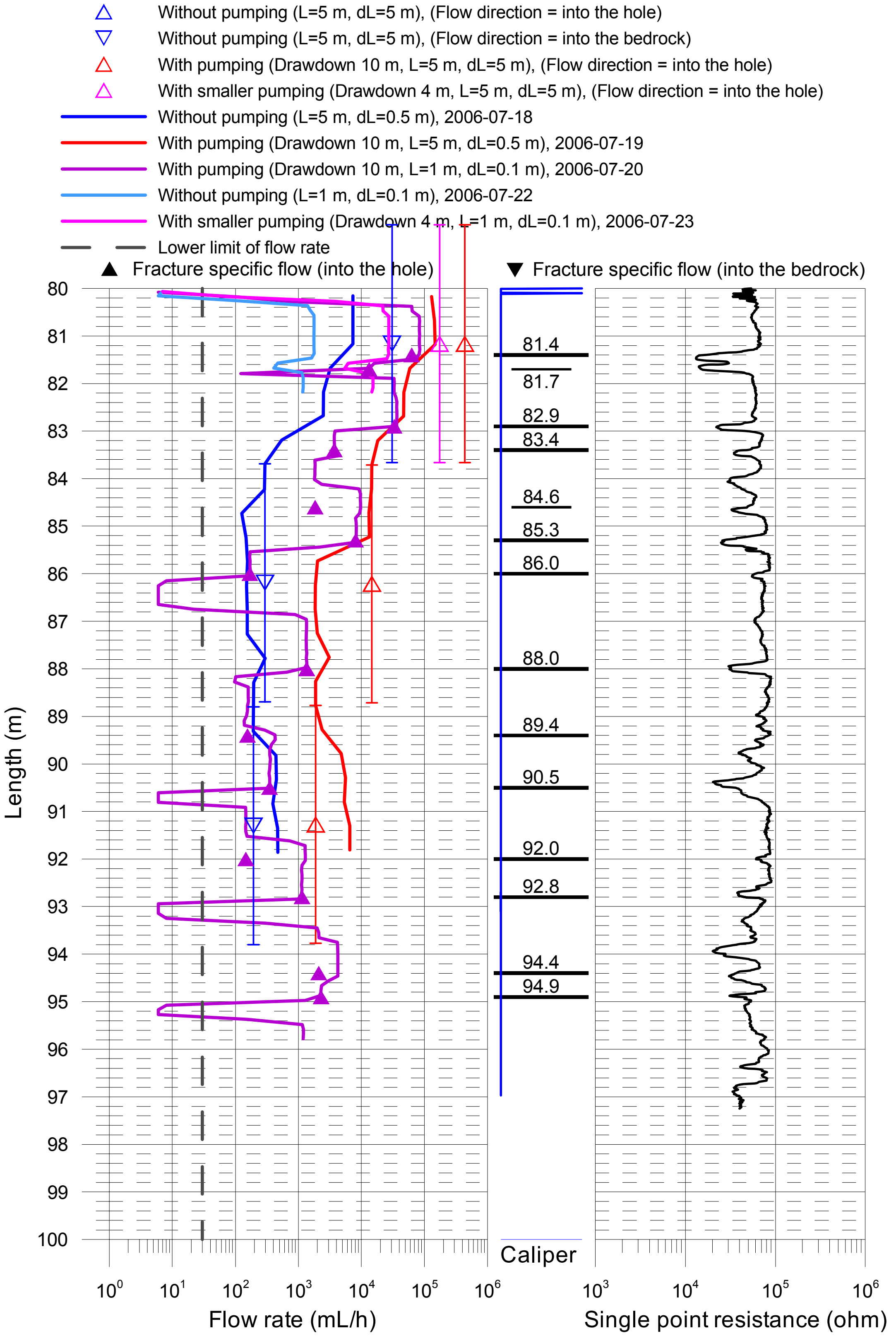
Laxemar, borehole KLX22A
Flow rate, caliper and single point resistance

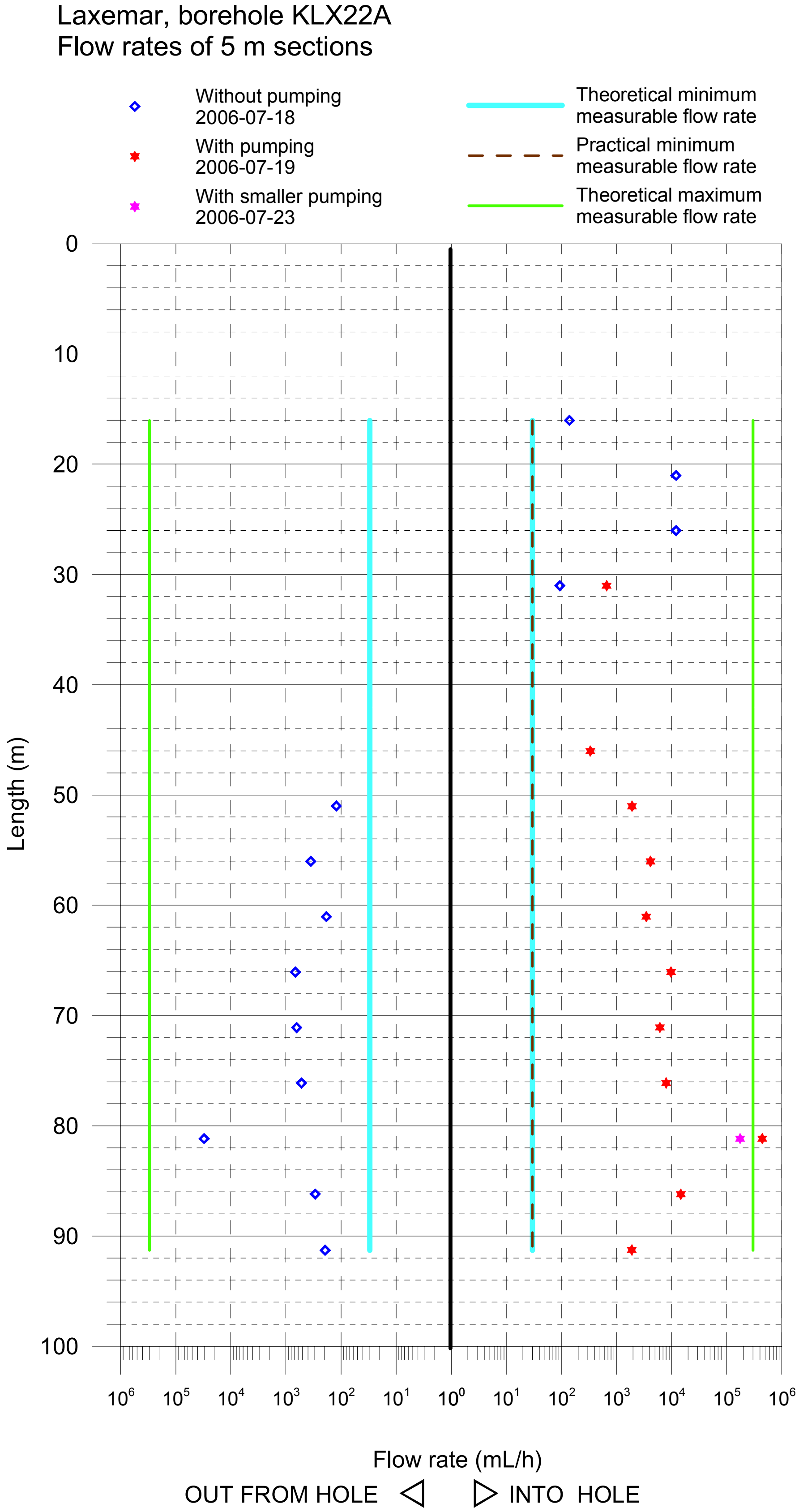


Laxemar, borehole KLX22A
Flow rate, caliper and single point resistance

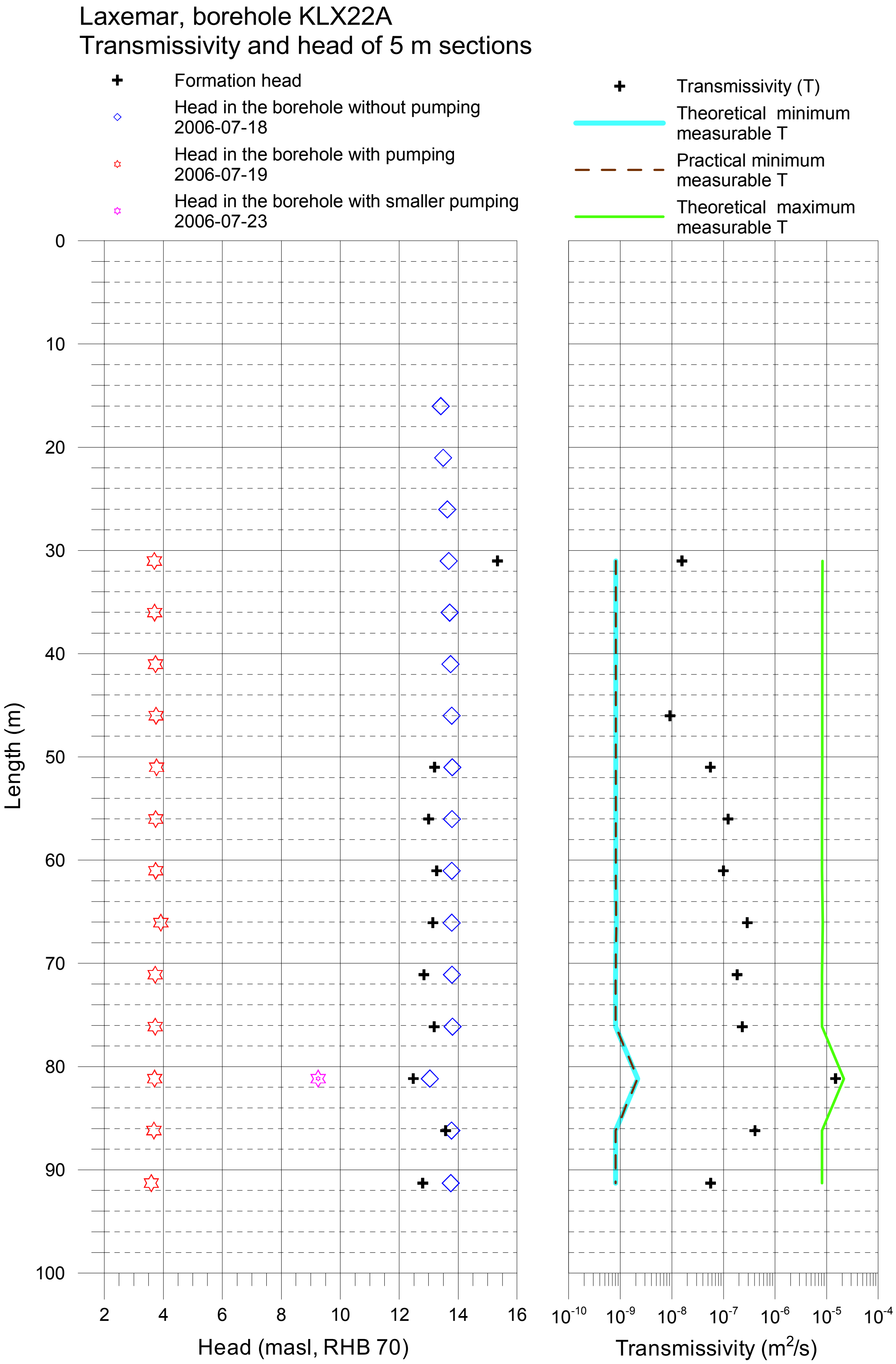


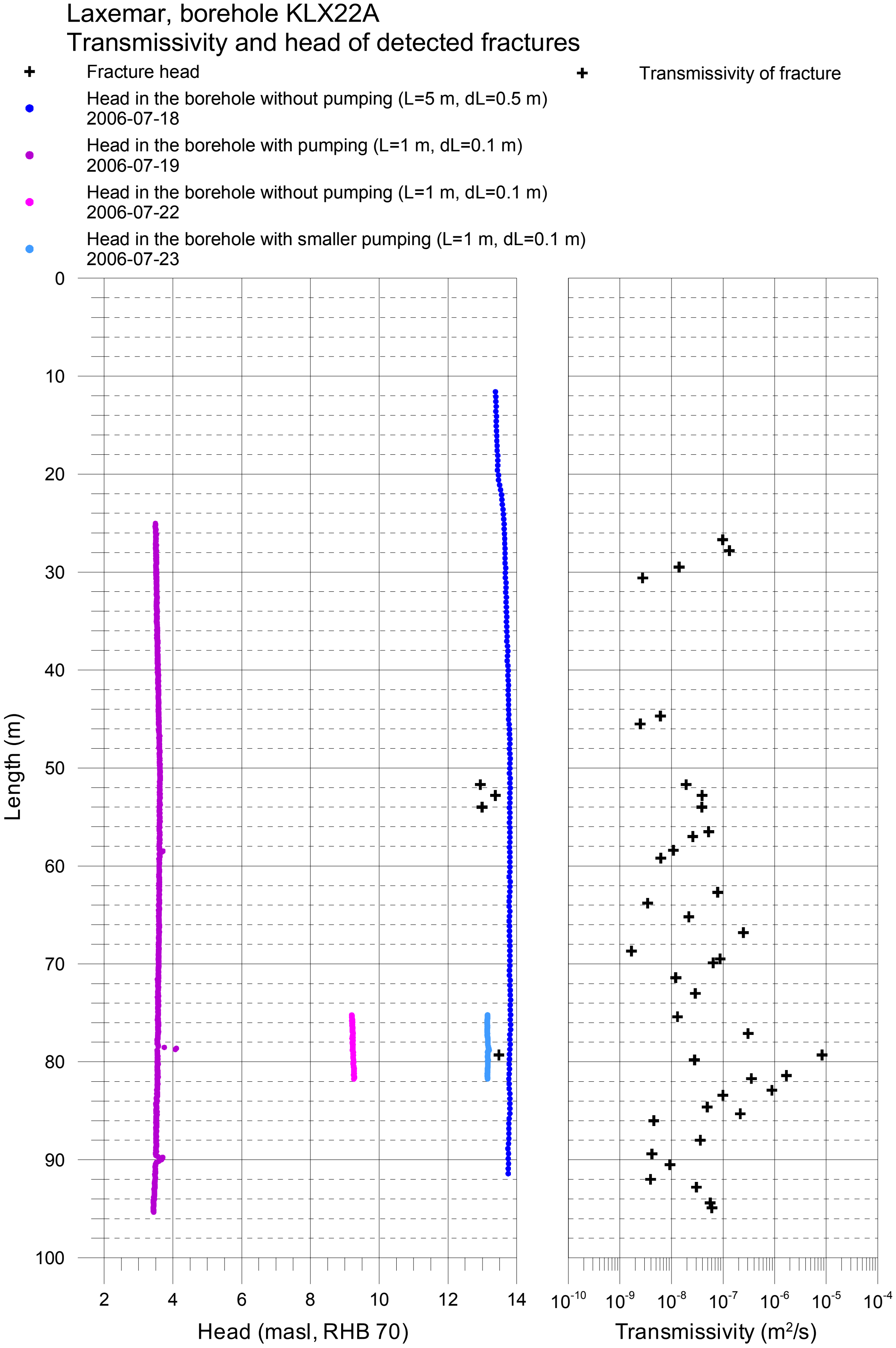
Laxemar, borehole KLX22A
Flow rate, caliper and single point resistance





Laxemar, borehole KLX22A
Flow rates of 5 m sections
Without pumping 2006-07-18
With pumping 2006-07-19
With smaller pumping 2006-07-23
Theoretical minimum measurable flow rate
Practical minimum measurable flow rate
Theoretical maximum measurable flow rate
Length (m)
0
10
20
30
40
50
60
70
80
90
100
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 KLX22A
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-07-18
Head in the borehole with pumping 2006-07-19
Head in the borehole with smaller pumping 2006-07-23
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 KLX22A
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) 2006-07-19
Head in the borehole without pumping (L=1 m, dL=0.1 m) 2006-07-22
Head in the borehole with smaller pumping (L=1 m, dL=0.1 m) 2006-07-23
Transmissivity of fracture
Length (m)
0
10
20
30
40
50
60
70
80
90
100
2
4
6
8
10
12
14
Head (masl, RHB 70)
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Transmissivity (m^2/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)
KLX22A	2	100.45	5A	20060718	15:36	20060719	15:28	20060721	10:13	5	0.5	1.44E–04	8.92E–05

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

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (ma.s.l.)	h_1 (ma.s.l.)	h_2 (ma.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
239,820	21,180	84,060	54,360	13.60	3.57	9.13	–10.03	–4.47	1.42E–05	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KLX22A	13.53	18.53	5	3.89E–08	13.41	–	–	–	–	30	–	–	–	*
KLX22A	18.53	23.53	5	3.33E–06	13.49	–	–	–	–	30	–	–	–	*
KLX22A	23.53	28.53	5	3.33E–06	13.63	–	–	–	–	30	–	–	–	*
KLX22A	28.53	33.53	5	2.61E–08	13.68	1.84E–07	3.69	1.6E–08	15.3	30	8.3E–10	8.3E–10	8.3E–06	
KLX22A	33.52	38.52	5	–	13.71	–	3.70	–	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	38.52	43.52	5	–	13.74	–	3.73	–	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	43.51	48.51	5	–	13.78	9.33E–08	3.75	9.2E–09	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	48.50	53.50	5	–3.39E–08	13.80	5.33E–07	3.77	5.6E–08	13.2	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	53.52	58.52	5	–9.83E–08	13.79	1.15E–06	3.74	1.2E–07	13.0	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	58.53	63.53	5	–5.11E–08	13.78	9.64E–07	3.74	1.0E–07	13.3	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	63.56	68.56	5	–1.87E–07	13.78	2.71E–06	3.91	2.9E–07	13.1	30	8.4E–10	8.4E–10	8.4E–06	
KLX22A	68.60	73.60	5	–1.78E–07	13.79	1.70E–06	3.72	1.8E–07	12.8	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	73.63	78.63	5	–1.46E–07	13.81	2.21E–06	3.72	2.3E–07	13.2	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	78.66	83.66	5	–8.50E–06	13.04	1.23E–04	3.70	1.5E–05	12.5	30	2.2E–09	2.2E–09	2.2E–05	**
KLX22A	83.70	88.70	5	–8.17E–08	13.77	4.08E–06	3.68	4.1E–07	13.6	30	8.2E–10	8.2E–10	8.2E–06	
KLX22A	88.79	93.79	5	–5.39E–08	13.75	5.25E–07	3.59	5.6E–08	12.8	30	8.1E–10	8.1E–10	8.1E–06	

* Only results from measurement without pumping, no transmissivity calculations has been done (drawdown during pumping prevented those sections to be measured).

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

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

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KLX22A	18.8	1	0.1	–	13.59	–	–	–	–	***
KLX22A	22.1	1	0.1	–	13.59	–	–	–	–	***
KLX22A	25.1	1	0.1	–	13.59	–	–	–	–	***
KLX22A	26.7	1	0.1	–	13.65	1.01E–06	3.51	9.8E–08	–	*
KLX22A	27.8	1	0.1	–	13.66	1.35E–06	3.51	1.3E–07	–	
KLX22A	29.5	1	0.1	–	13.68	1.45E–07	3.51	1.4E–08	–	
KLX22A	30.6	1	0.1	–	13.67	2.83E–08	3.52	2.8E–09	–	*
KLX22A	44.7	1	0.1	–	13.77	6.28E–08	3.58	6.1E–09	–	
KLX22A	45.5	1	0.1	–	13.78	2.56E–08	3.58	2.5E–09	–	*
KLX22A	51.7	1	0.1	–1.67E–08	13.80	1.81E–07	3.62	1.9E–08	12.9	
KLX22A	52.8	1	0.1	–1.67E–08	13.80	3.89E–07	3.62	3.9E–08	13.4	
KLX22A	54.0	1	0.1	–3.11E–08	13.79	3.67E–07	3.61	3.9E–08	13.0	
KLX22A	56.5	1	0.1	–	13.80	5.42E–07	3.61	5.3E–08	–	
KLX22A	57.0	1	0.1	–	13.80	2.67E–07	3.61	2.6E–08	–	
KLX22A	58.4	1	0.1	–	13.80	1.12E–07	3.63	1.1E–08	–	
KLX22A	59.2	1	0.1	–	13.80	6.39E–08	3.61	6.2E–09	–	*
KLX22A	62.7	1	0.1	–	13.80	8.11E–07	3.60	7.9E–08	–	
KLX22A	63.8	1	0.1	–	13.78	3.53E–08	3.61	3.4E–09	–	
KLX22A	65.2	1	0.1	–	13.79	2.24E–07	3.59	2.2E–08	–	
KLX22A	66.8	1	0.1	–	13.79	2.56E–06	3.60	2.5E–07	–	
KLX22A	68.7	1	0.1	–	13.80	1.72E–08	3.59	1.7E–09	–	*
KLX22A	69.5	1	0.1	–	13.80	9.11E–07	3.57	8.8E–08	–	
KLX22A	69.9	1	0.1	–	13.80	6.61E–07	3.59	6.4E–08	–	
KLX22A	71.4	1	0.1	–	13.80	1.25E–07	3.58	1.2E–08	–	
KLX22A	73.0	1	0.1	–	13.81	3.00E–07	3.57	2.9E–08	–	
KLX22A	75.4	1	0.1	–	13.82	1.36E–07	3.56	1.3E–08	–	
KLX22A	77.1	1	0.1	–	13.80	3.17E–06	3.57	3.1E–07	–	
KLX22A	79.3	1	0.1	2.67E–06	13.16	3.56E–05	9.25	8.3E–06	13.5	**
KLX22A	79.8	1	0.1	–	13.79	2.89E–07	3.55	2.8E–08	–	
KLX22A	81.4	1	0.1	–	13.78	1.75E–05	3.55	1.7E–06	–	
KLX22A	81.7	1	0.1	–	13.77	3.67E–06	3.54	3.6E–07	–	*
KLX22A	82.9	1	0.1	–	13.79	9.17E–06	3.53	8.8E–07	–	
KLX22A	83.4	1	0.1	–	13.80	1.03E–06	3.55	1.0E–07	–	
KLX22A	84.6	1	0.1	–	13.80	5.11E–07	3.52	4.9E–08	–	*
KLX22A	85.3	1	0.1	–	13.80	2.24E–06	3.52	2.2E–07	–	
KLX22A	86.0	1	0.1	–	13.78	4.72E–08	3.51	4.6E–09	–	
KLX22A	88.0	1	0.1	–	13.77	3.75E–07	3.52	3.6E–08	–	
KLX22A	89.4	1	0.1	–	13.76	4.33E–08	3.49	4.2E–09	–	
KLX22A	90.5	1	0.1	–	13.76	9.67E–08	3.49	9.3E–09	–	
KLX22A	92.0	1	0.1	–	13.75	4.08E–08	3.48	3.9E–09	–	
KLX22A	92.8	1	0.1	–	13.75	3.17E–07	3.47	3.1E–08	–	
KLX22A	94.4	1	0.1	–	13.74	5.86E–07	3.44	5.6E–08	–	
KLX22A	94.9	1	0.1	–	13.74	6.36E–07	3.43	6.1E–08	–	

* 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).

*** Fracture detected during measurement without pumping (drawdown prevented fracture to be measured with pumping)

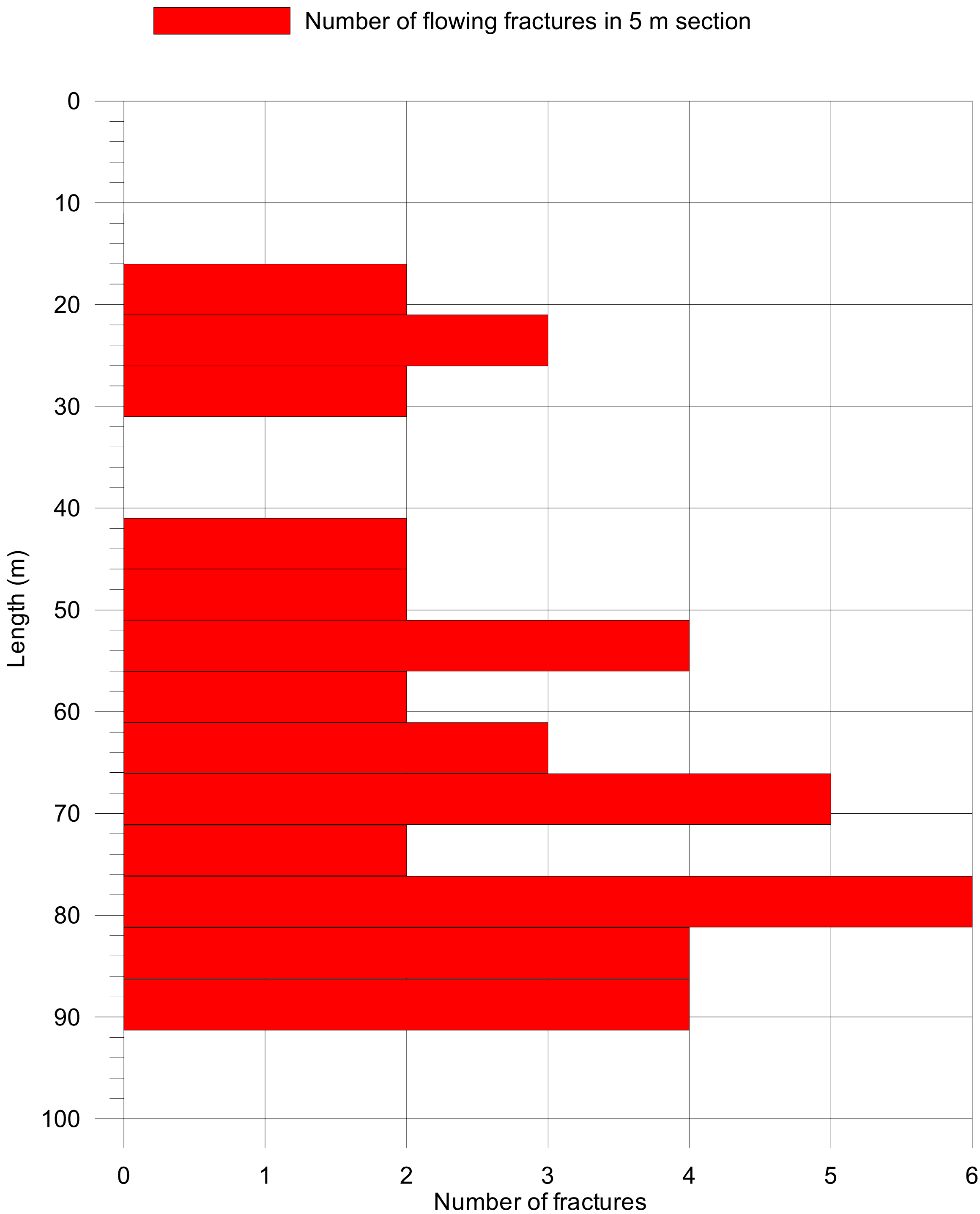
Explanations.

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.
$T\text{-measl}_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
$T\text{-measl}_U$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

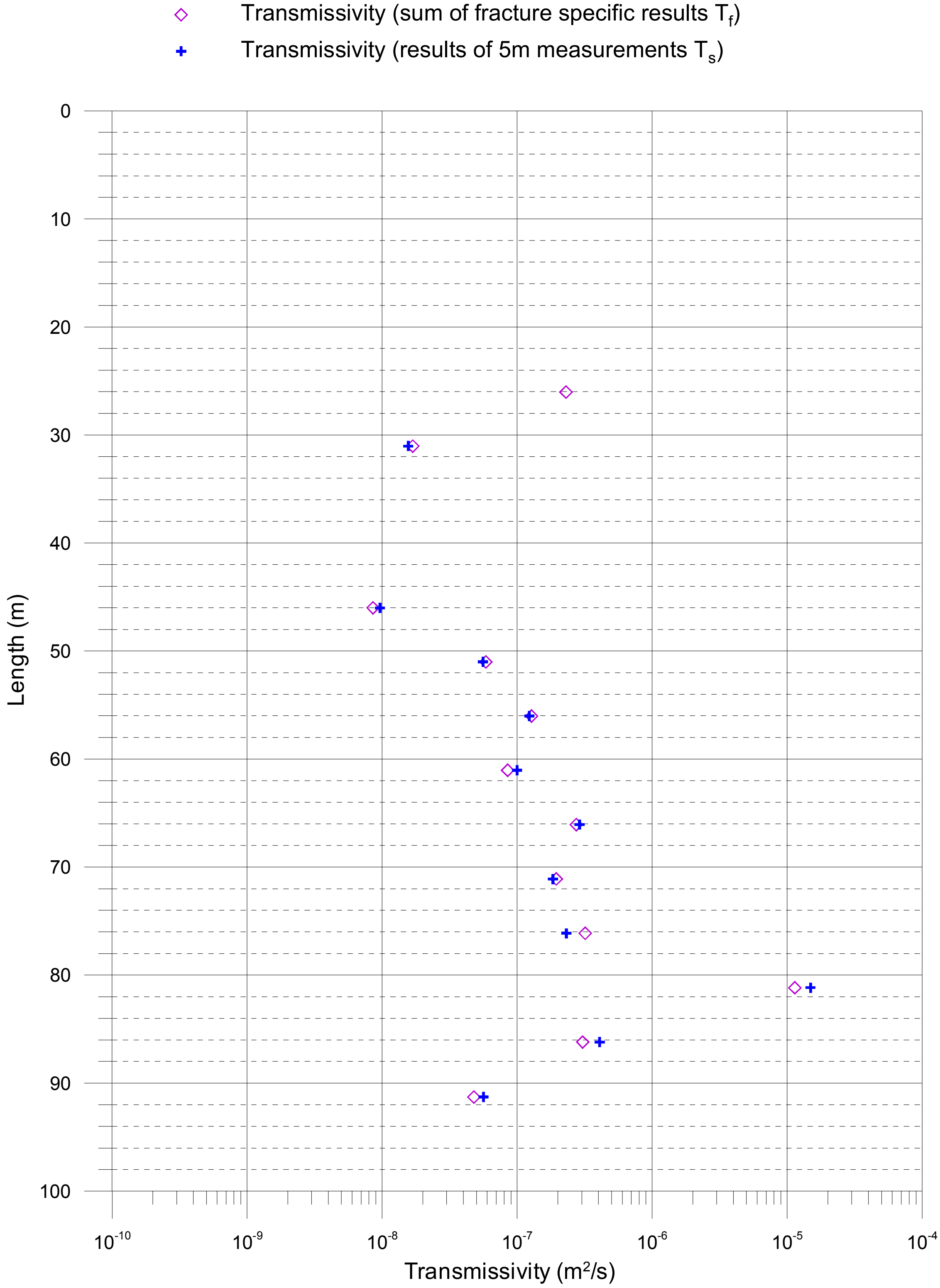
Calculation of conductive fracture frequency

Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)
KLX22A	13.53	18.53	0	0	0	0	0	0
KLX22A	18.53	23.53	2	0	0	0	0	0
KLX22A	23.53	28.53	3	0	0	2	0	0
KLX22A	28.53	33.53	2	0	2	0	0	0
KLX22A	33.52	38.52	0	0	0	0	0	0
KLX22A	38.52	43.52	0	0	0	0	0	0
KLX22A	43.51	48.51	2	1	1	0	0	0
KLX22A	48.50	53.50	2	0	1	1	0	0
KLX22A	53.52	58.52	4	0	2	2	0	0
KLX22A	58.53	63.53	2	0	1	1	0	0
KLX22A	63.56	68.56	3	0	2	1	0	0
KLX22A	68.60	73.60	5	1	1	3	0	0
KLX22A	73.63	78.63	2	0	1	0	1	0
KLX22A	78.66	83.66	6	0	0	2	3	1
KLX22A	83.70	88.70	4	0	1	3	0	0
KLX22A	88.79	93.79	4	0	3	1	0	0

Laxemar, borehole KLX22A
Calculation of conductive fracture frequency

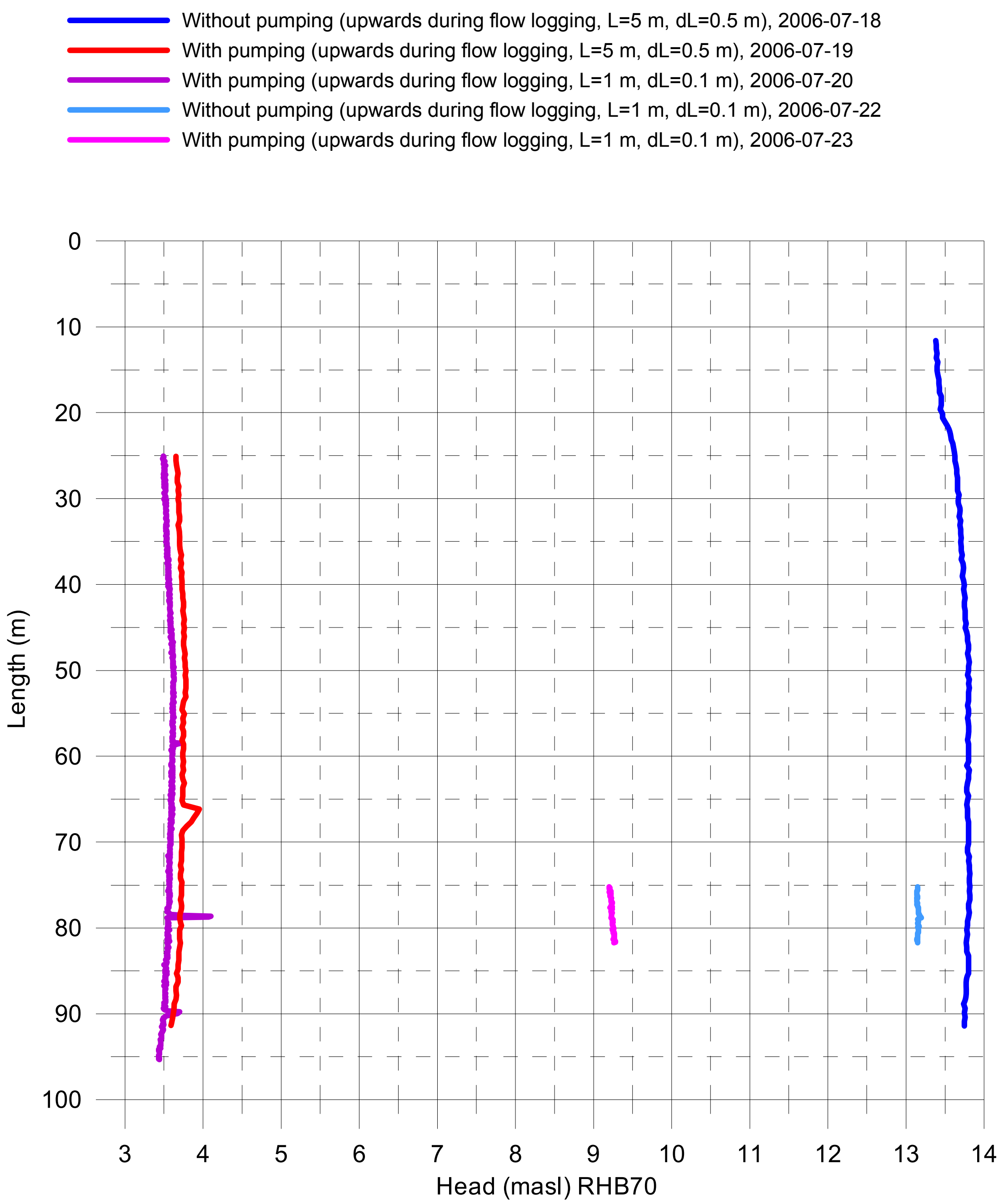


Laxemar, borehole KLX22A
Comparison between section transmissivity and fracture transmissivity

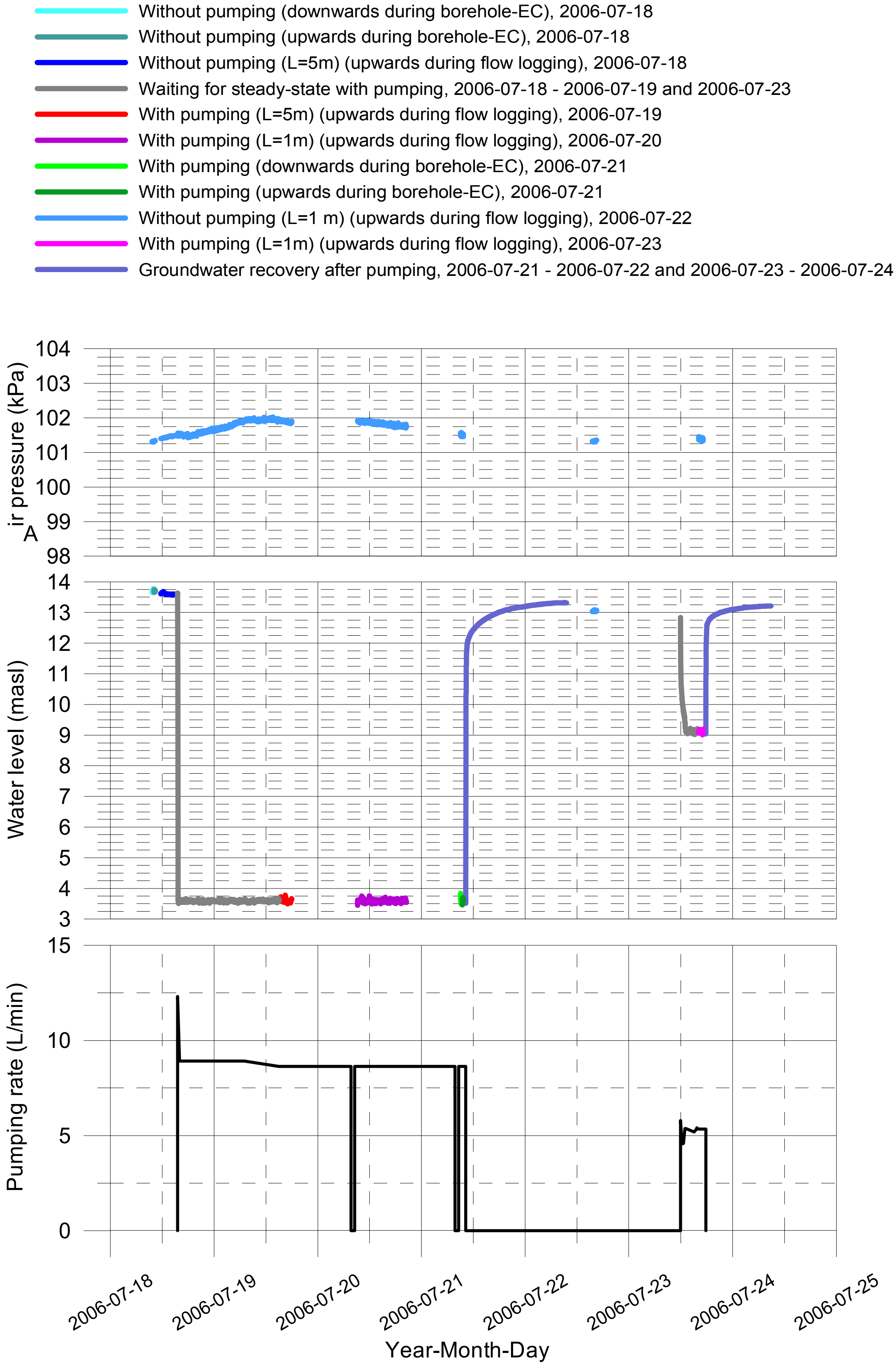


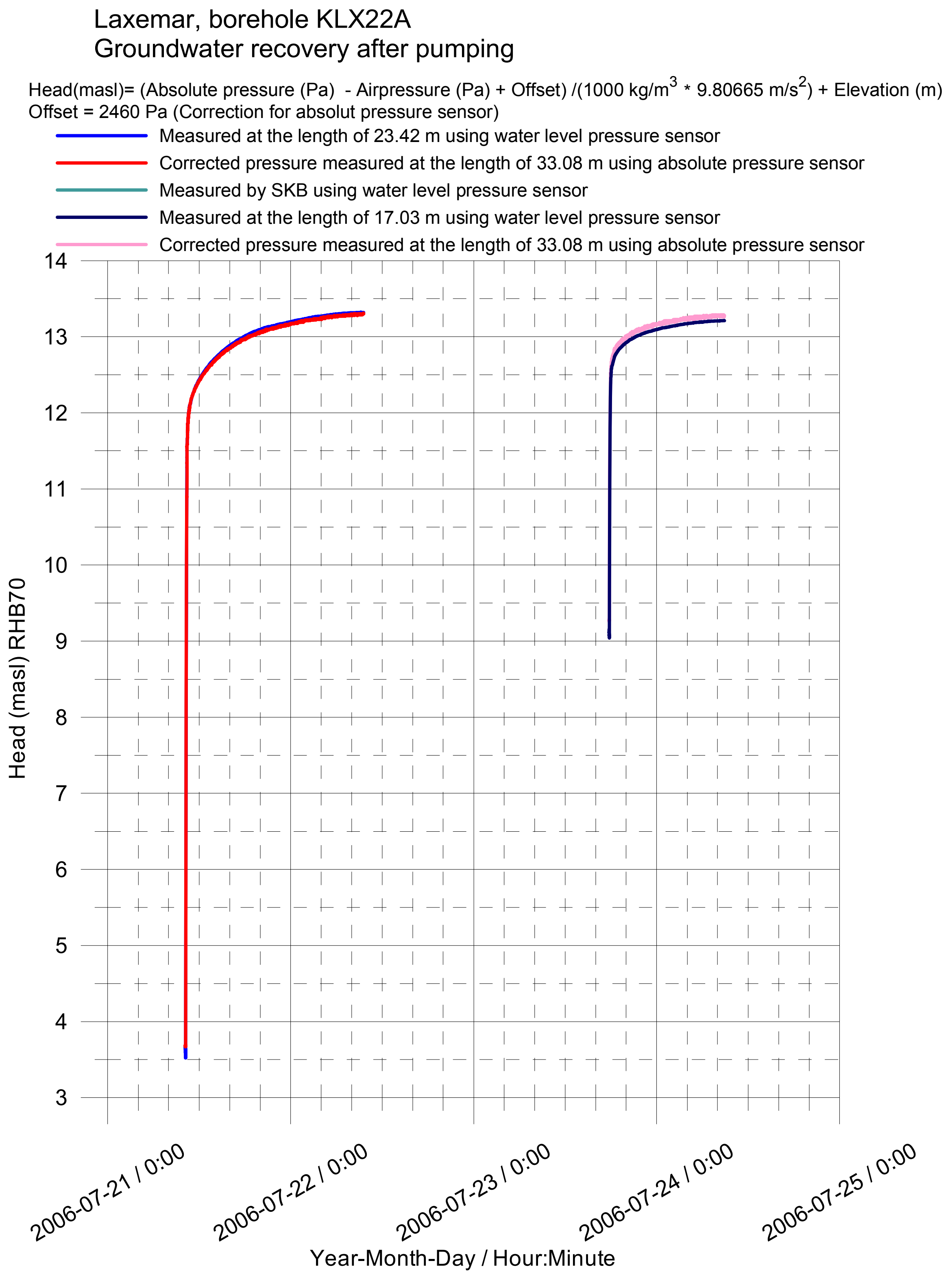
Laxemar, borehole KLX22A
Head in the borehole during flow logging

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 KLX22A
Air pressure, water level in the borehole and pumping rate during flow logging



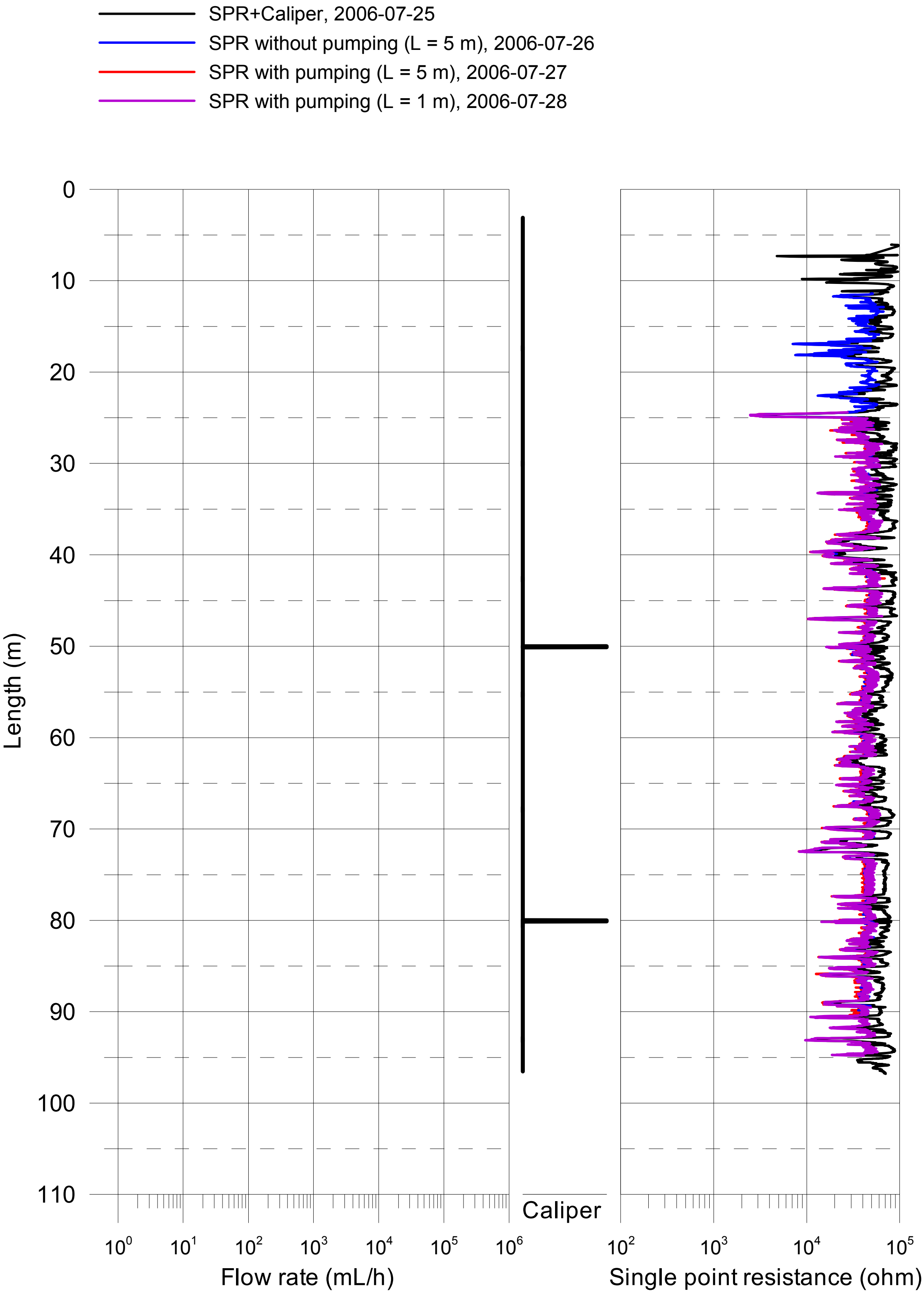


Laxemar, borehole KLX22A
Groundwater recovery after pumping
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)
Measured at the length of 23.42 m using water level pressure sensor
Corrected pressure measured at the length of 33.08 m using absolute pressure sensor
Measured by SKB using water level pressure sensor
Measured at the length of 17.03 m using water level pressure sensor
Corrected pressure measured at the length of 33.08 m using absolute pressure sensor
Head (masl) RHB70
14
13
12
11
10
9
8
7
6
5
4
3
2006-07-21 / 0:00
2006-07-22 / 0:00
2006-07-23 / 0:00
2006-07-24 / 0:00
2006-07-25 / 0:00
Year-Month-Day / Hour:Minute

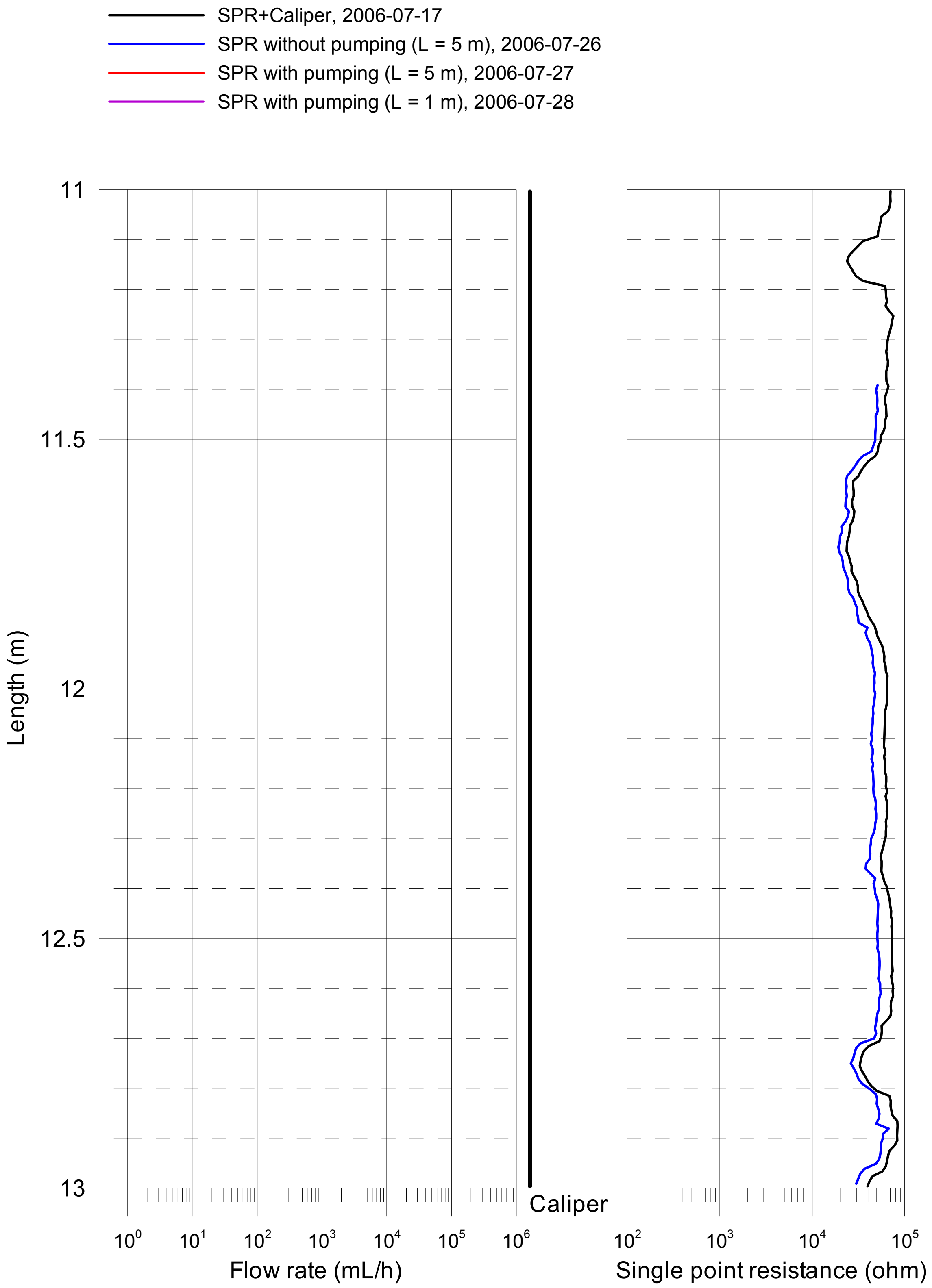
Appendices KLX22B

Appendices	22B.1.1–22B.1.6	SPR and caliper results after length correction
Appendices	22B.1.7	Length correction
Appendix	22B.2.1	Electric conductivity of borehole water
Appendix	22B.2.2	Temperature of borehole water
Appendix	22B.3.1–22B.3.5	Flow rate, caliper and single point resistance
Appendix	22B.4.1	Plotted flow rates of 5 m sections
Appendix	22B.4.2	Plotted transmissivity and head of 5 m sections
Appendix	22B.5	Plotted transmissivity and head of detected fractures
Appendix	22B.6	Basic test data
Appendix	22B.7	Results of sequential flow logging
Appendices	22B.8	Inferred flow anomalies from overlapping flow logging
Appendix	22B.9	Explanations for the tables in Appendices 6–8
Appendix	22B.10	Conductive fracture frequency
Appendix	22B.11	Plotted conductive fracture frequency
Appendix	22B.12	Comparison between section transmissivity and fracture transmissivity
Appendix	22B.13.1	Head in the borehole during flow logging
Appendix	22B.13.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	22B.13.3	Groundwater recovery after pumping

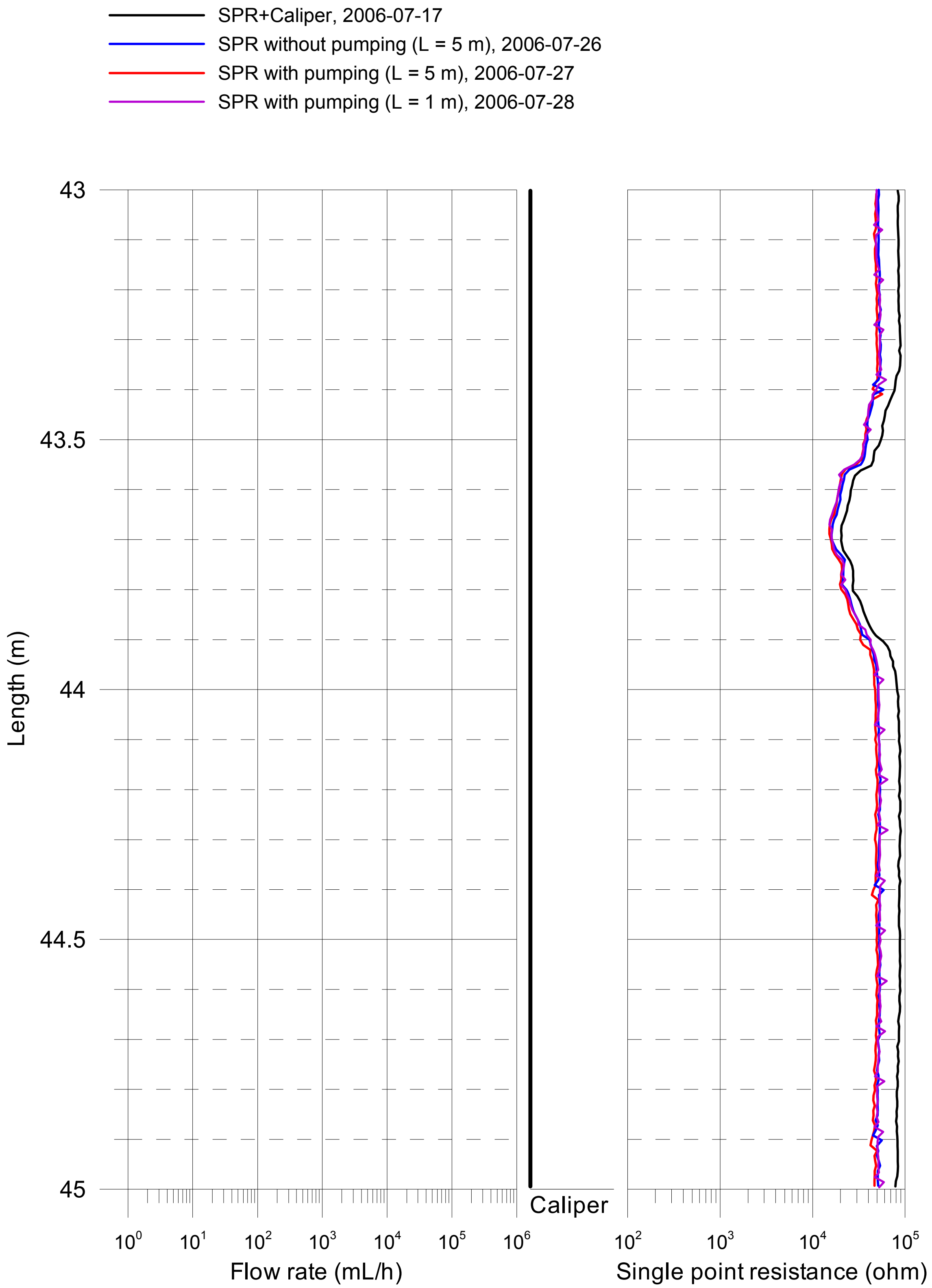
Laxemar, borehole KLX22B
SPR and Caliper results after length correction



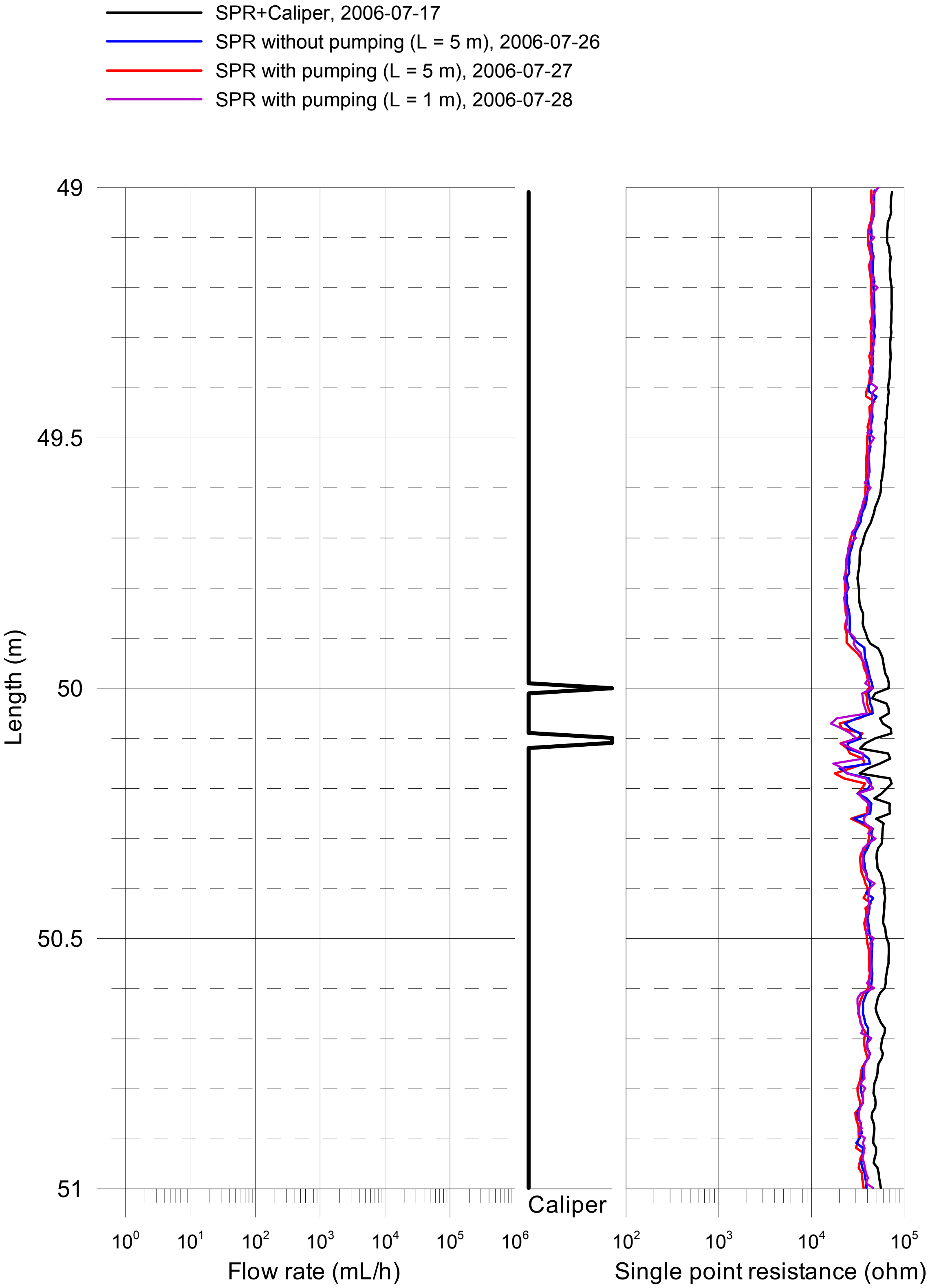
Laxemar, borehole KLX22B
SPR and Caliper results after length correction



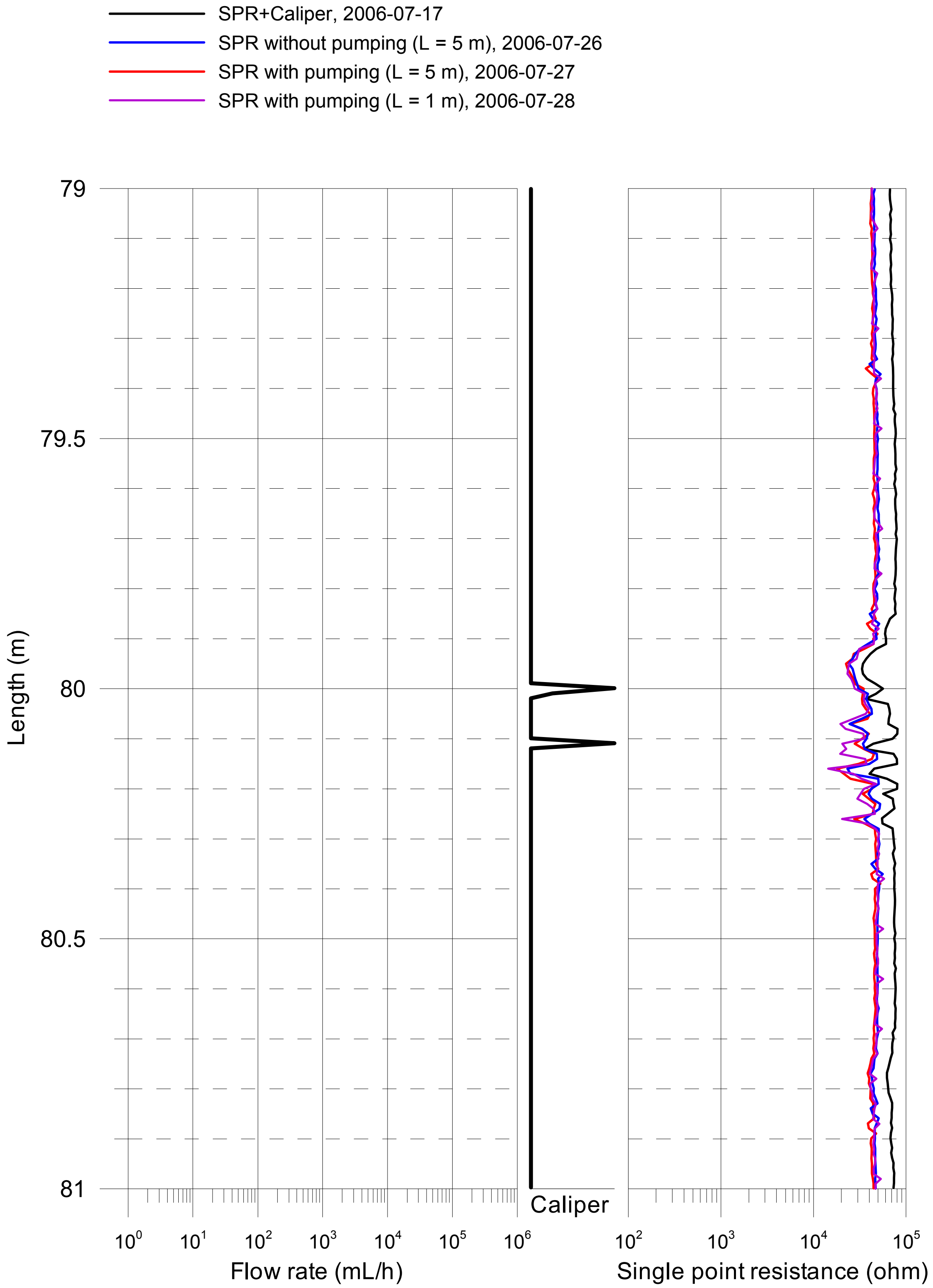
Laxemar, borehole KLX22B
SPR and Caliper results after length correction



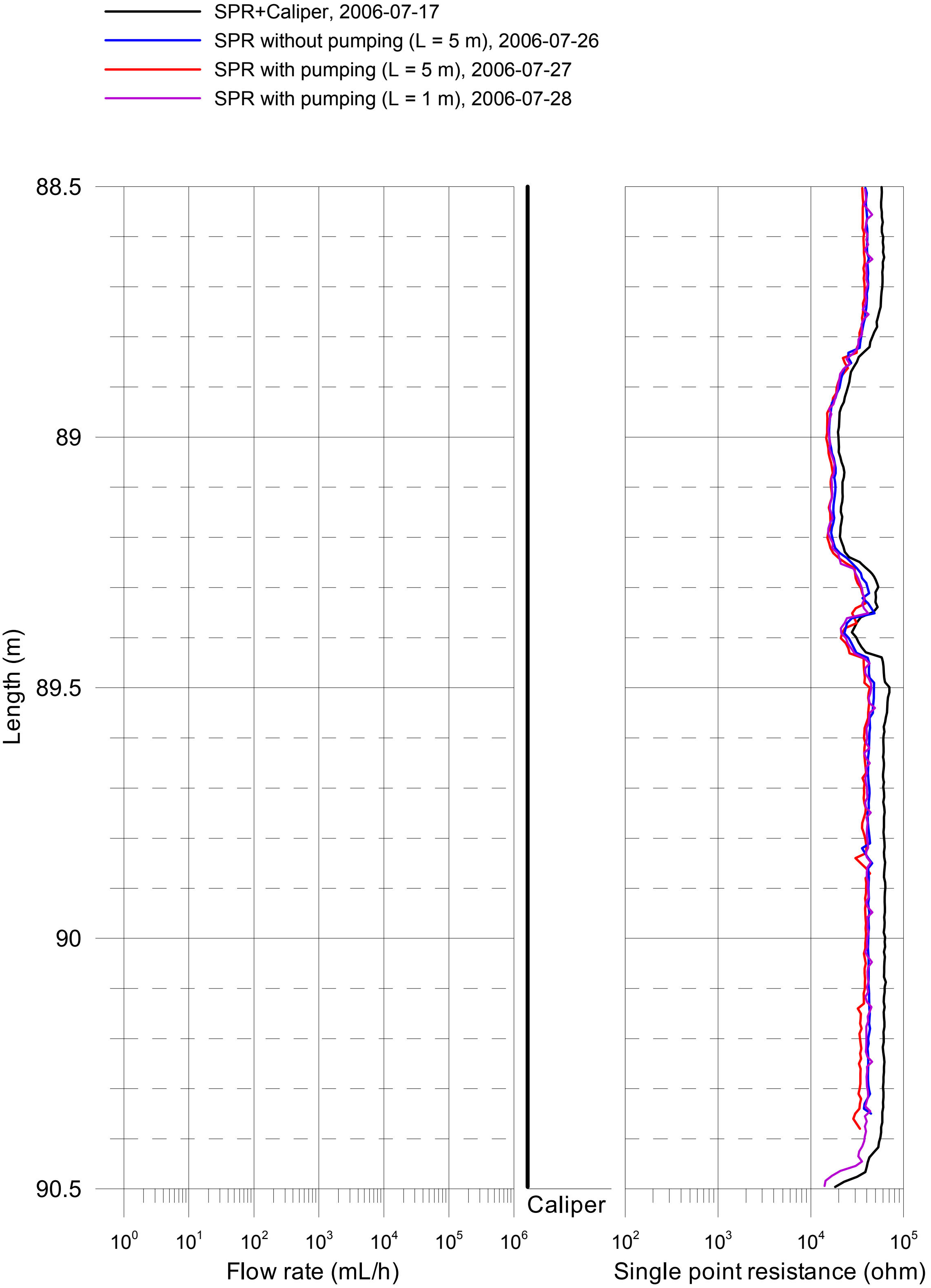
Laxemar, borehole KLX22B
SPR and Caliper results after length correction



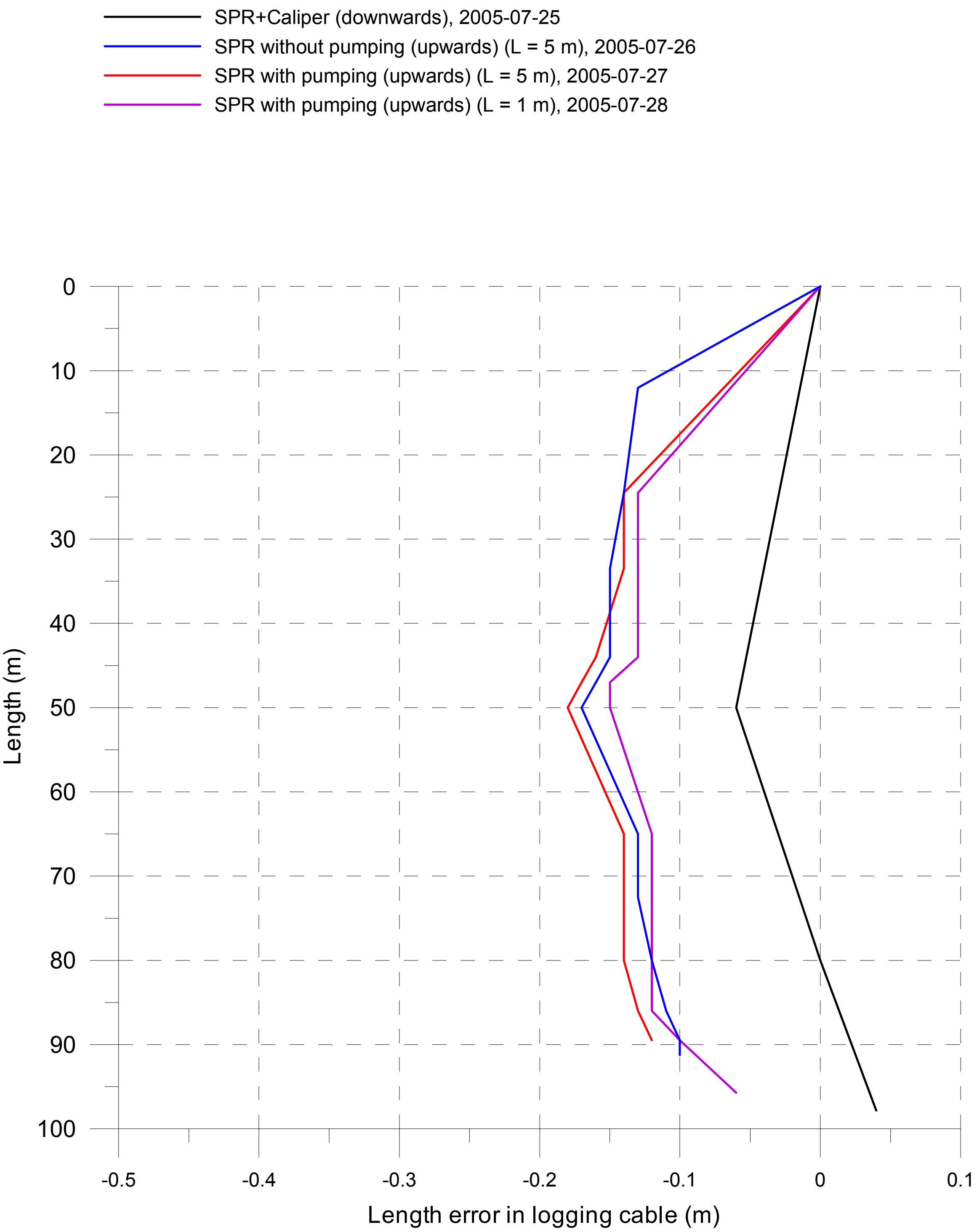
Laxemar, borehole KLX22B
SPR and Caliper results after length correction



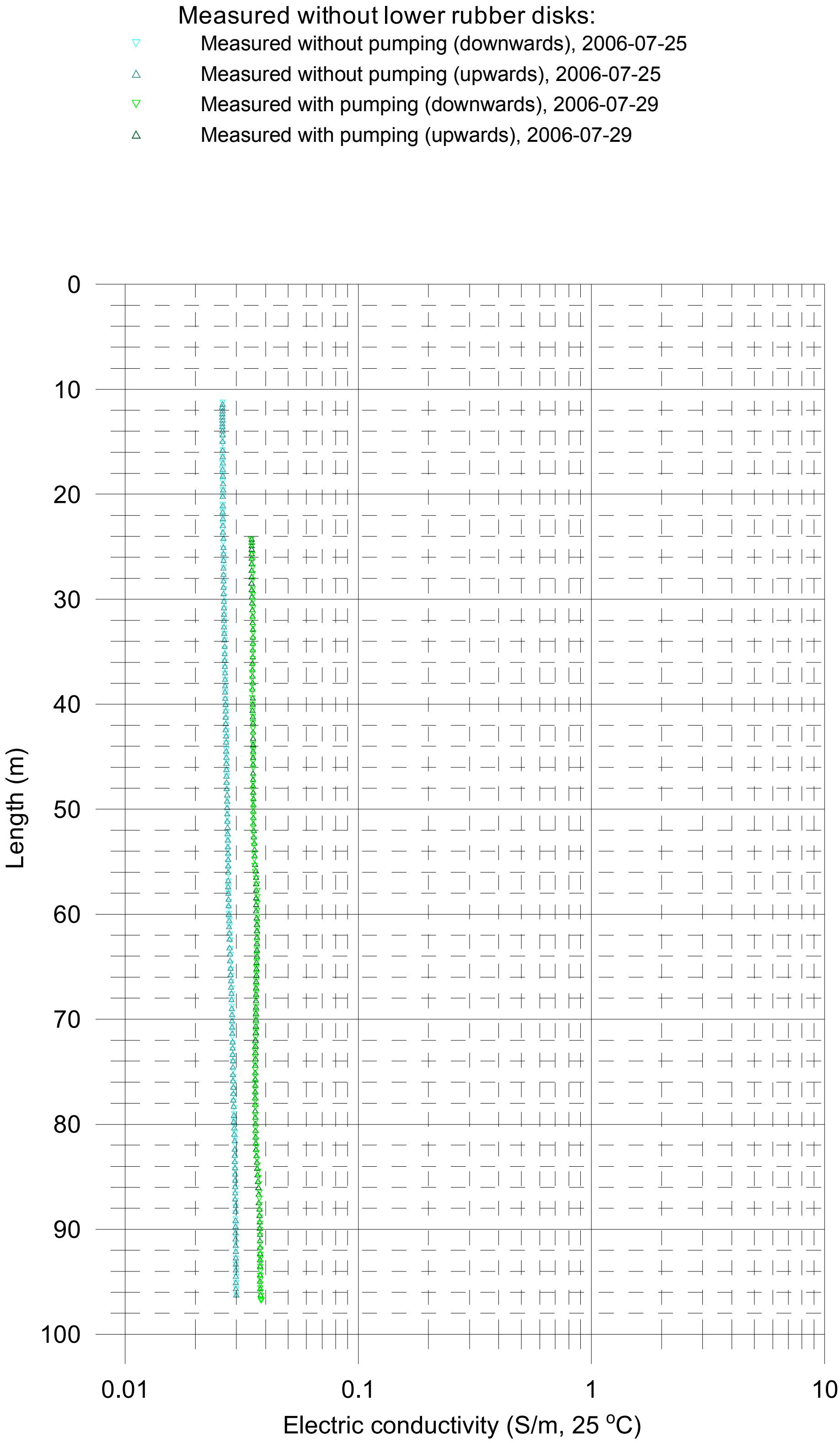
Laxemar, borehole KLX22B
SPR and Caliper results after length correction



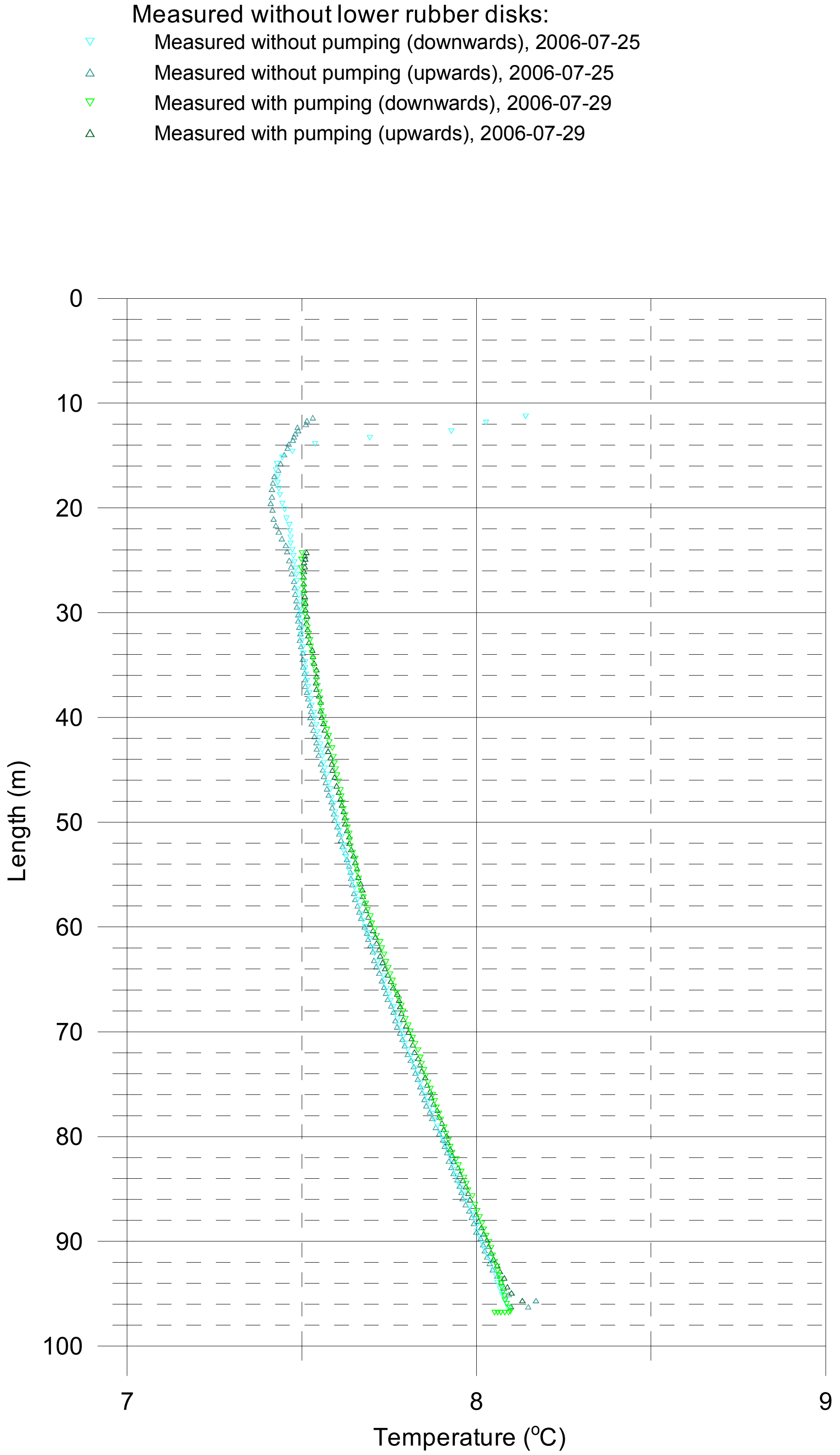
Laxemar, borehole KLX22B
Length correction



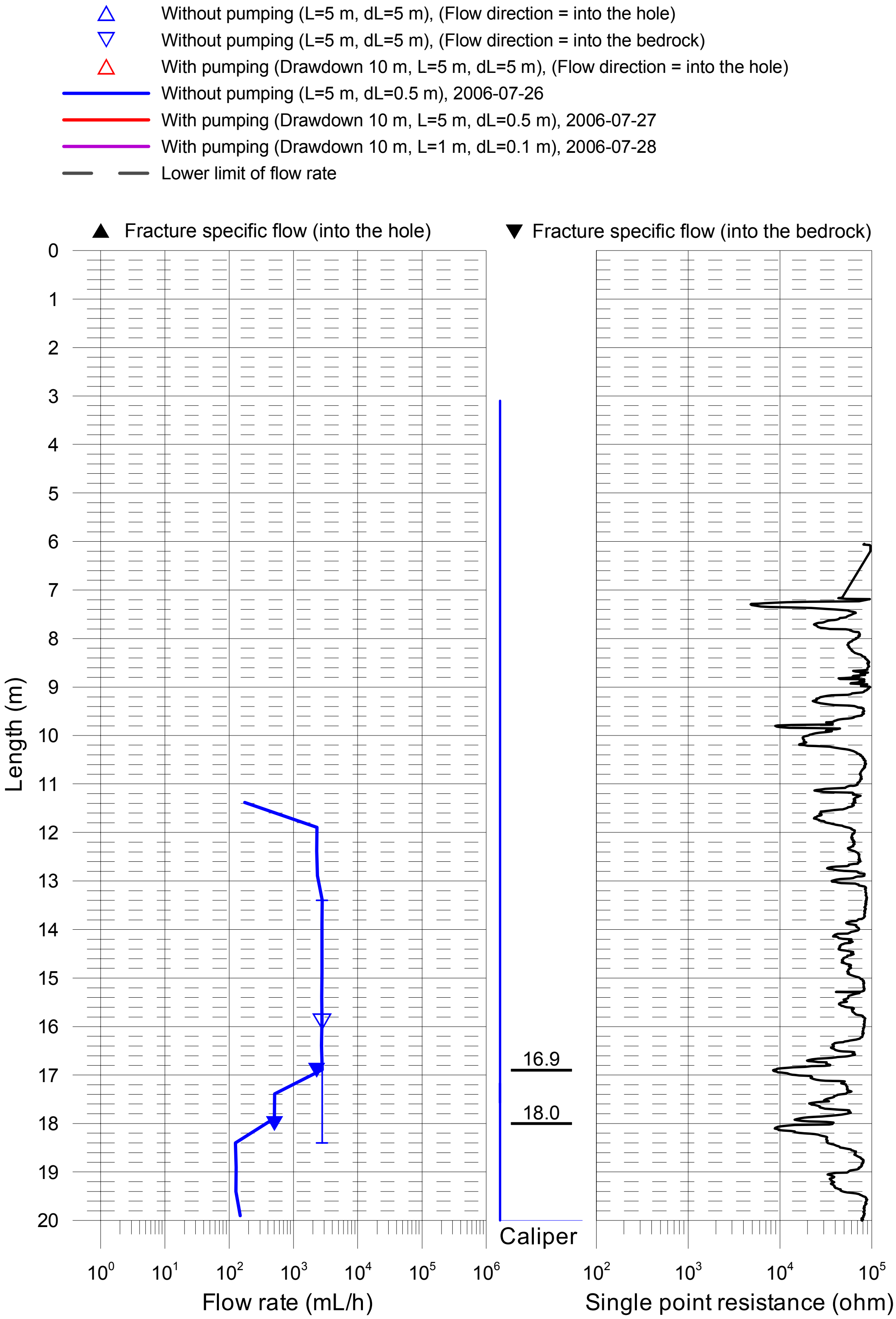
Laxemar, borehole KLX22B
Electric conductivity of borehole water



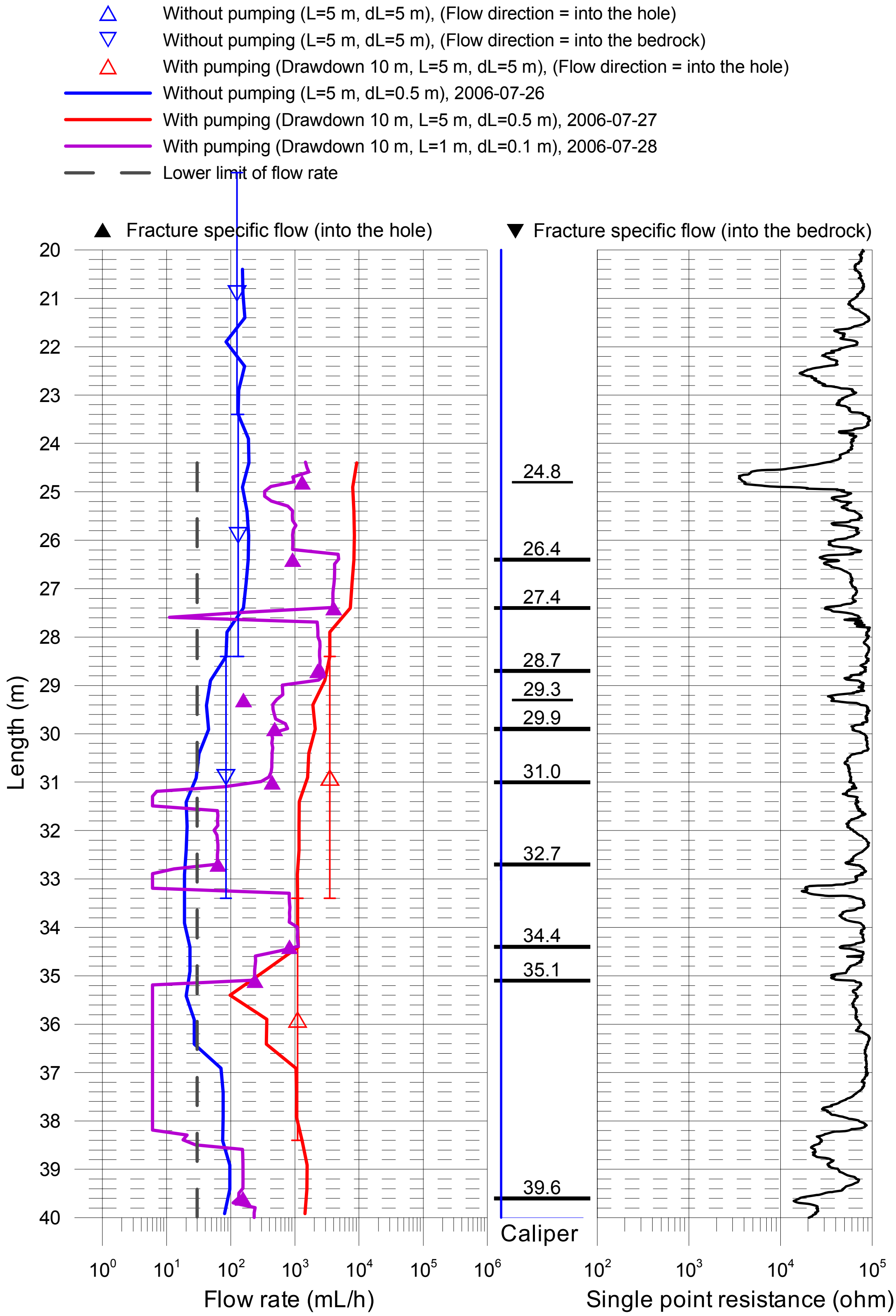
Laxemar, borehole KLX22B
Temperature of borehole water



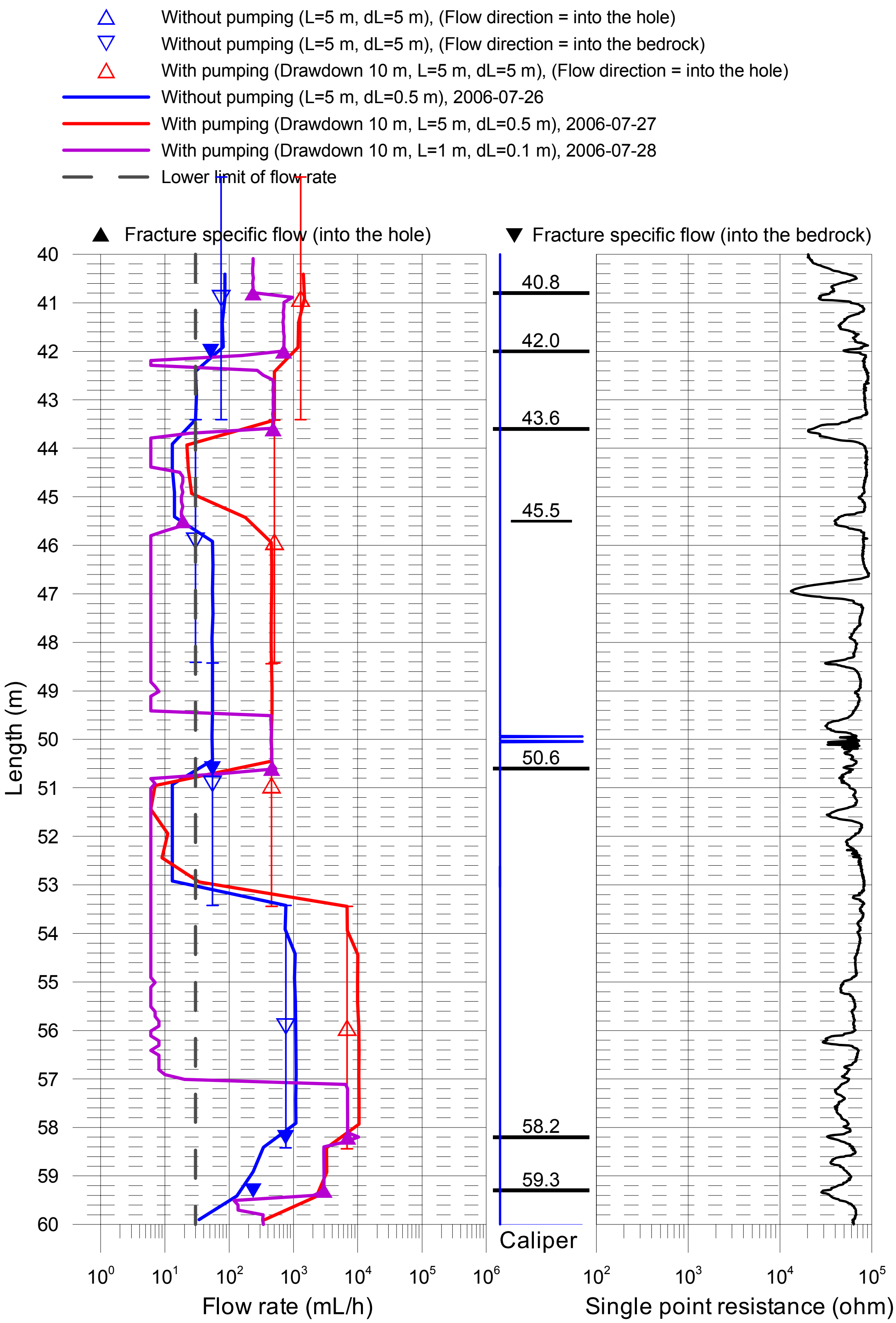
Laxemar, borehole KLX22B
Flow rate, caliper and single point resistance



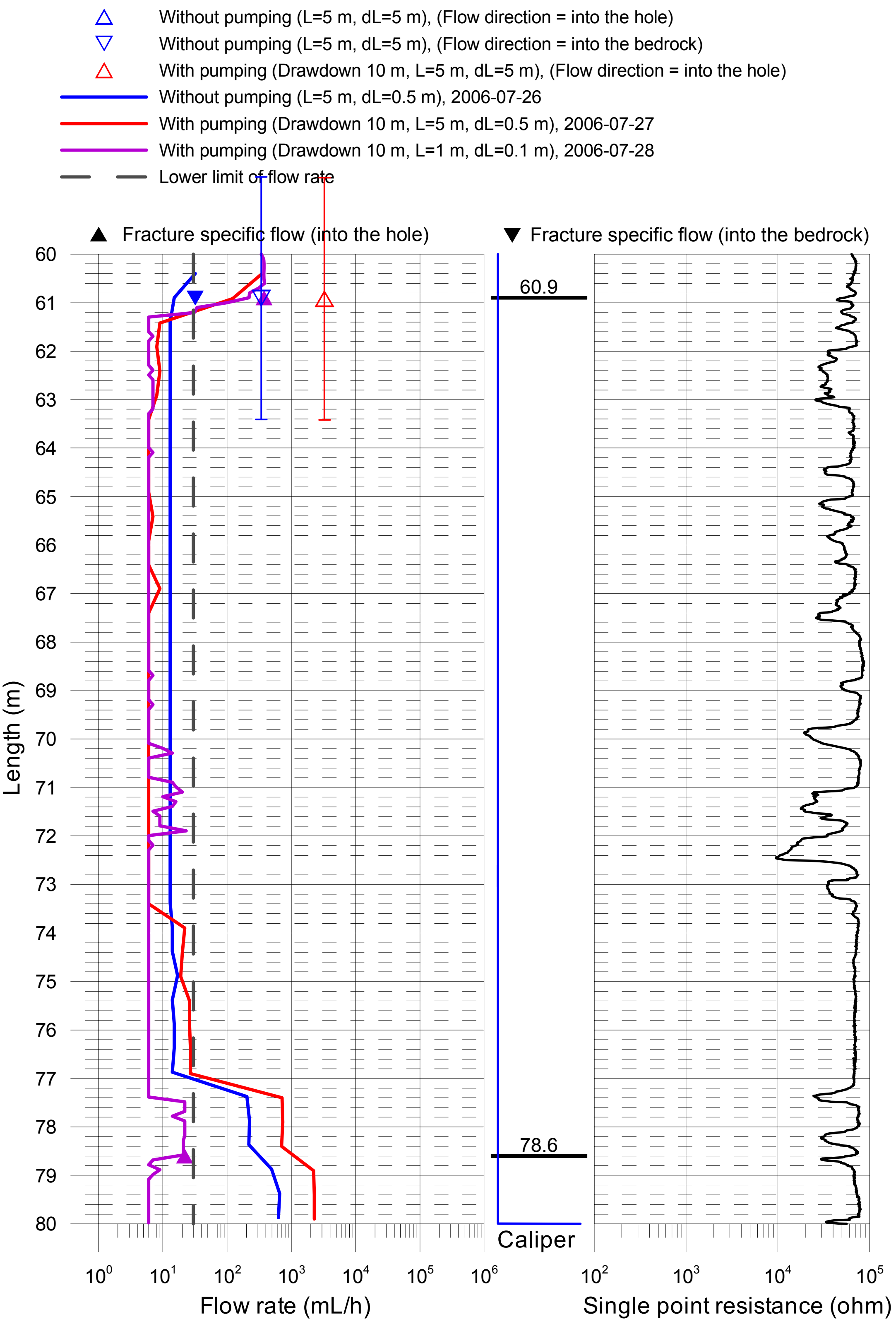
Laxemar, borehole KLX22B
Flow rate, caliper and single point resistance



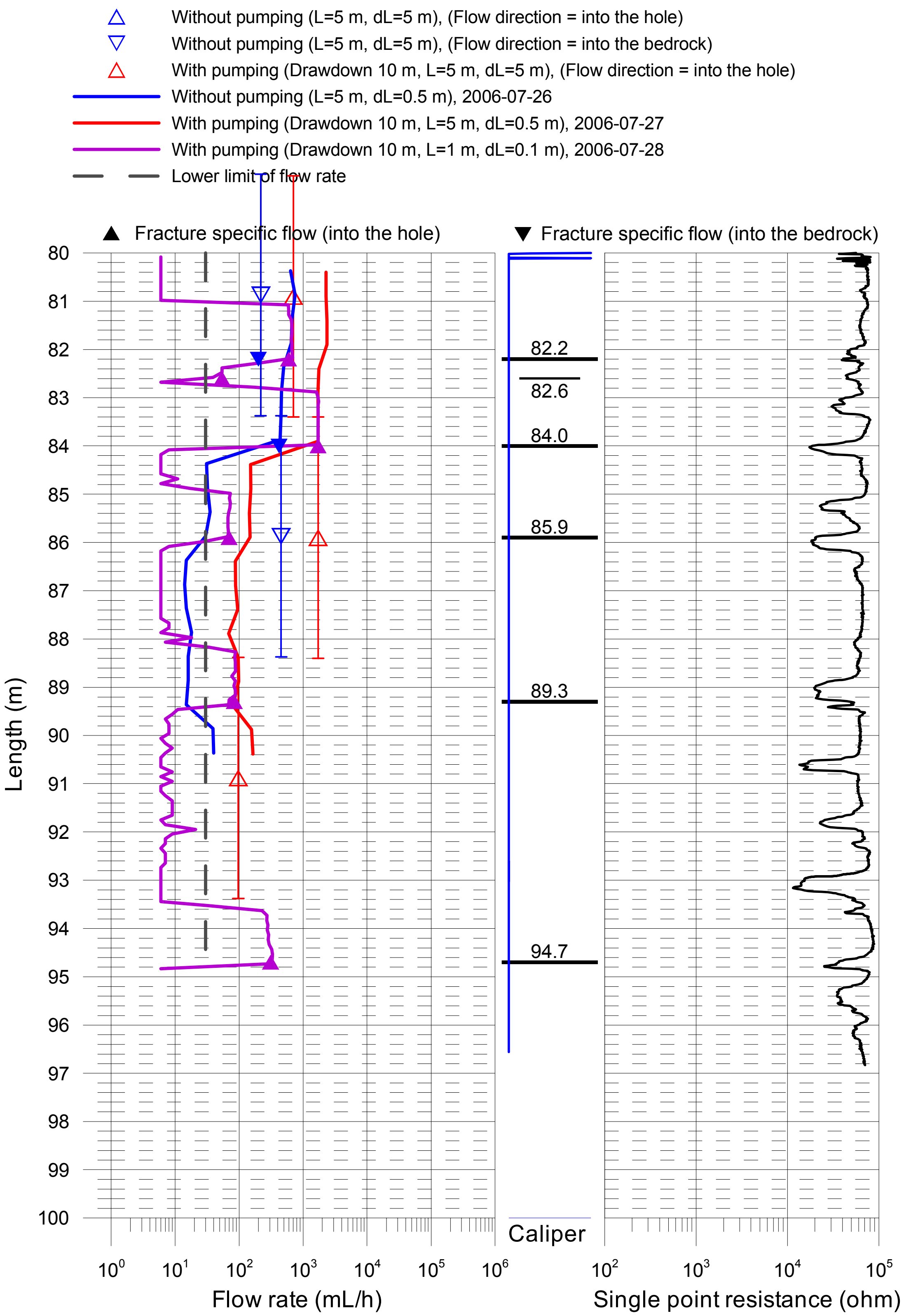
Laxemar, borehole KLX22B
Flow rate, caliper and single point resistance

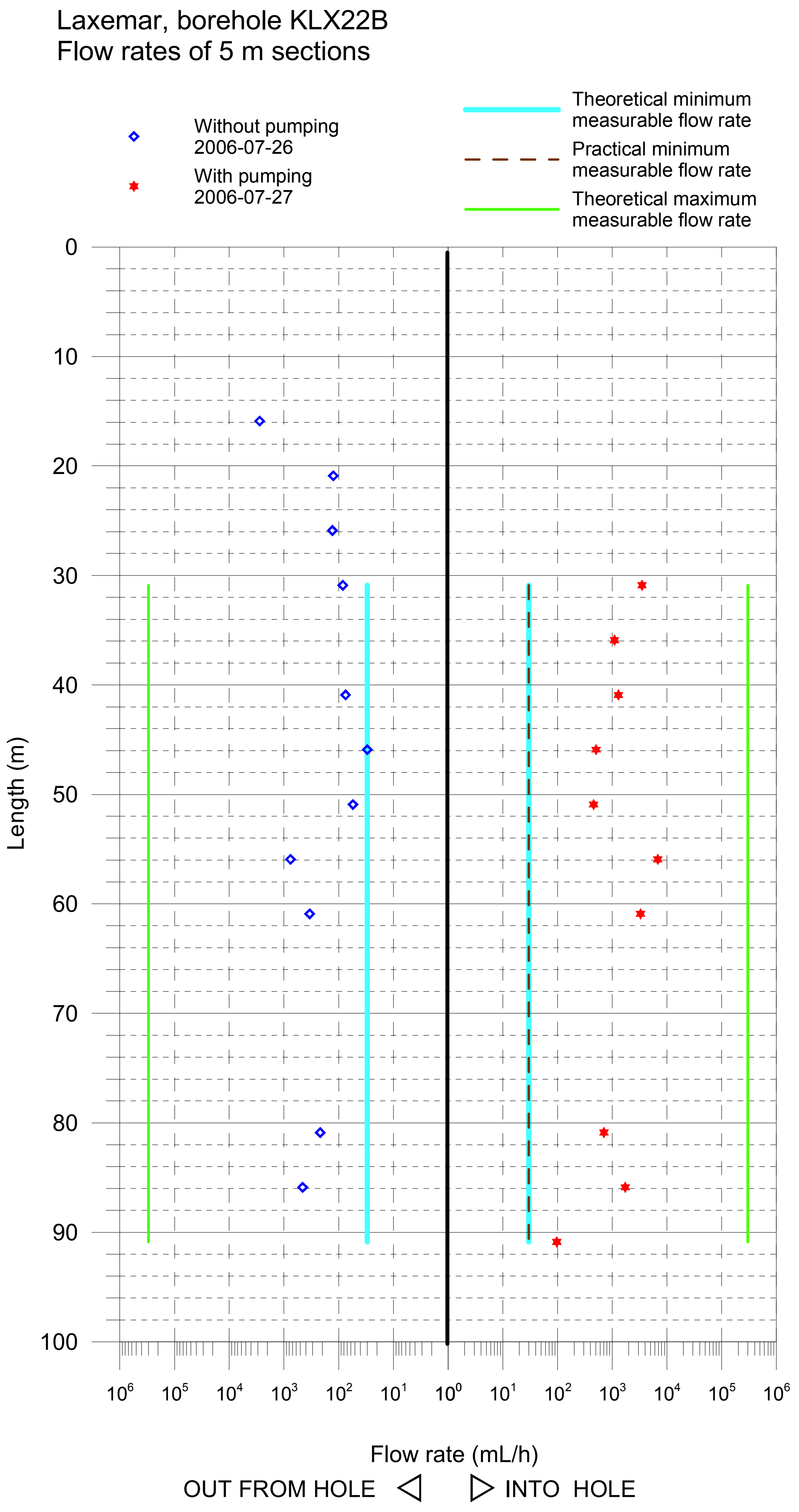


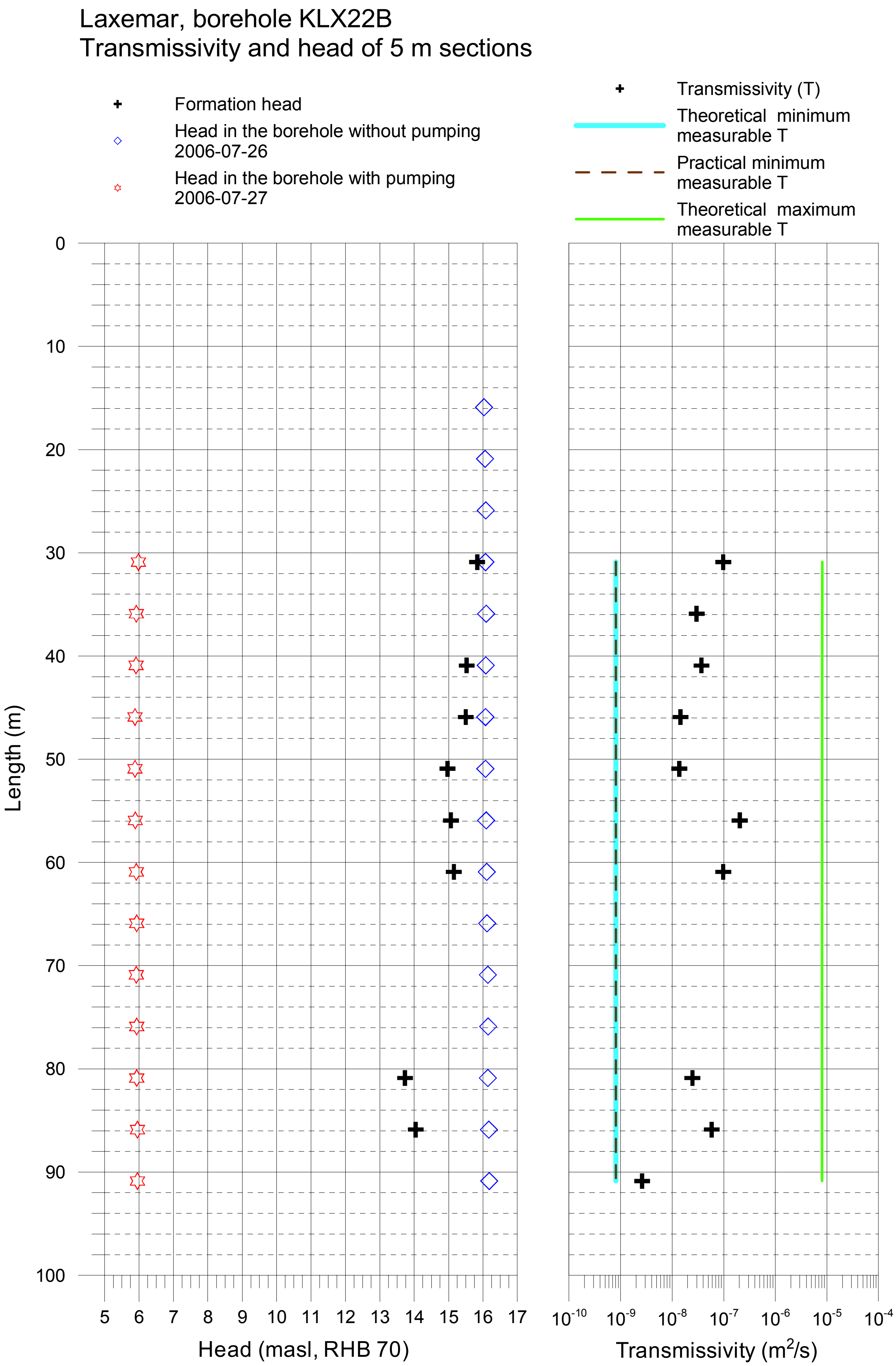
Laxemar, borehole KLX22B
Flow rate, caliper and single point resistance



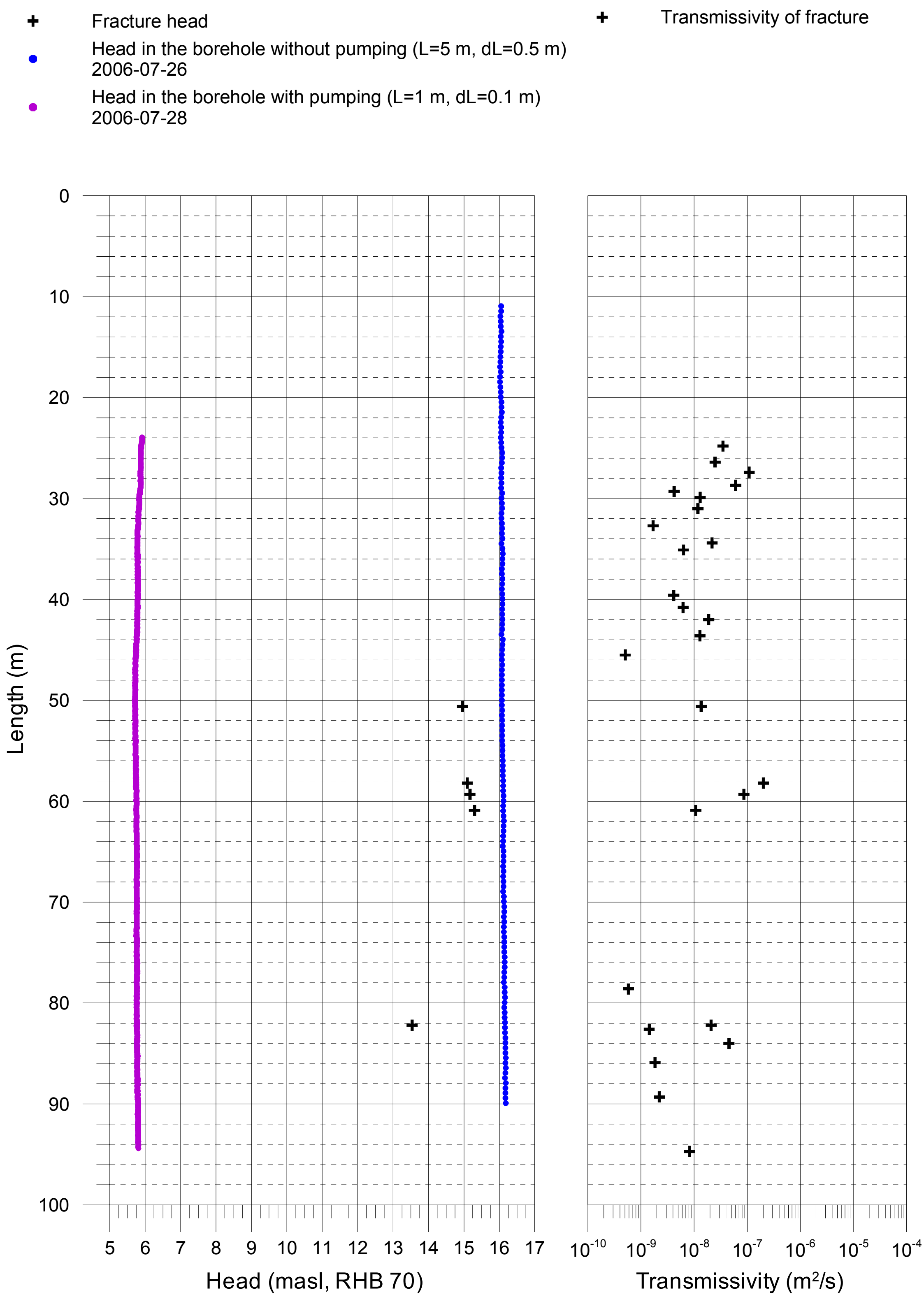
Laxemar, borehole KLX22B
Flow rate, caliper and single point resistance




Laxemar, borehole KLX22B
Flow rates of 5 m sections
Without pumping
2006-07-26
With pumping
2006-07-27
Theoretical minimum
measurable flow rate
Practical minimum
measurable flow rate
Theoretical maximum
measurable flow rate
Length (m)
0
10
20
30
40
50
60
70
80
90
100
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 KLX22B
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-07-26
Head in the borehole with pumping 2006-07-27
Transmissivity (T)
Theoretical minimum measurable T
Practical minimum measurable T
Theoretical maximum measurable T
Length (m)
0
10
20
30
40
50
60
70
80
90
100
5
6
7
8
9
10
11
12
13
14
15
16
17
Head (masl, RHB 70)
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Transmissivity (m^2/s)

Laxemar, borehole KLX22B
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)
KLX22B	2	100.25	5A	20060726	16:41	20060727	16:10	20060729	13:59	5	0.5	5.10E–05	–

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

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (ma.s.l.)	h_1 (ma.s.l.)	h_2 (ma.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
249,480	–	295,260	–	16.08	6.08		–10.00	–	5.04E–06	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m³/s)	h_{0FW} (m.a.s.l.)	Q_1 (m³/s)	h_{1FW} (m.a.s.l.)	T_D (m²/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m²/s)	TD-measl$_{LP}$ (m²/s)	TD-measl$_U$ (m²/s)
KLX22B	13.40	18.4	5	–7.72E–07	16.03	–	–	–	–	–	–	–	–
KLX22B	18.40	23.40	5	–3.47E–08	16.06	–	–	–	–	–	–	–	–
KLX22B	23.40	28.40	5	–3.61E–08	16.08	–	–	–	–	–	–	–	–
KLX22B	28.40	33.40	5	–2.33E–08	16.07	9.72E–07	5.98	9.8E–08	15.8	30	8.2E–10	8.2E–10	8.2E–06
KLX22B	33.41	38.41	5	–	16.09	3.06E–07	5.92	3E–08	–	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	38.41	43.41	5	–2.08E–08	16.08	3.58E–07	5.91	3.7E–08	15.5	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	43.42	48.42	5	–8.33E–09	16.07	1.41E–07	5.88	1.5E–08	15.5	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	48.43	53.43	5	–1.53E–08	16.07	1.27E–07	5.88	1.4E–08	15.0	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	53.43	58.43	5	–2.11E–07	16.09	1.89E–06	5.89	2E–07	15.1	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	58.42	63.42	5	–9.44E–08	16.11	9.11E–07	5.92	9.8E–08	15.2	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	63.40	68.40	5	–	16.12	–	5.93	–	–	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	68.39	73.39	5	–	16.14	–	5.92	–	–	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	73.39	78.39	5	–	16.15	–	5.93	–	–	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	78.39	83.39	5	–6.06E–08	16.14	1.96E–07	5.93	2.5E–08	13.7	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	83.39	88.39	5	–1.26E–07	16.17	4.78E–07	5.95	5.8E–08	14.0	30	8.1E–10	8.1E–10	8.1E–06
KLX22B	88.37	93.37	5	–	16.18	2.69E–08	5.95	2.60E–09	–	30	8.1E–10	8.1E–10	8.1E–06

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

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KLX22B	16.9	1	0.1	–6.39E–07	16.02	–	–	–	–	*
KLX22B	18.0	1	0.1	–1.41E–07	16.02	–	–	–	–	*
KLX22B	24.8	1	0.1	–	16.06	3.61E–07	5.88	3.5E–08	–	*
KLX22B	26.4	1	0.1	–	16.07	2.57E–07	5.87	2.5E–08	–	
KLX22B	27.4	1	0.1	–	16.06	1.12E–06	5.86	1.1E–07	–	
KLX22B	28.7	1	0.1	–	16.06	6.28E–07	5.87	6.1E–08	–	
KLX22B	29.3	1	0.1	–	16.07	4.36E–08	5.85	4.2E–09	–	*
KLX22B	29.9	1	0.1	–	16.06	1.34E–07	5.83	1.3E–08	–	
KLX22B	31.0	1	0.1	–	16.08	1.22E–07	5.83	1.2E–08	–	
KLX22B	32.7	1	0.1	–	16.07	1.75E–08	5.80	1.7E–09	–	
KLX22B	34.4	1	0.1	–	16.06	2.28E–07	5.78	2.2E–08	–	
KLX22B	35.1	1	0.1	–	16.09	6.58E–08	5.78	6.3E–09	–	
KLX22B	39.6	1	0.1	–	16.08	4.31E–08	5.79	4.1E–09	–	
KLX22B	40.8	1	0.1	–	16.08	6.47E–08	5.79	6.2E–09	–	
KLX22B	42.0	1	0.1	–1.42E–08	16.09	1.96E–07	5.78	1.9E–08	–	
KLX22B	43.6	1	0.1	–	16.07	1.34E–07	5.77	1.3E–08	–	
KLX22B	45.5	1	0.1	–	16.07	5.28E–09	5.74	5.1E–10	–	*
KLX22B	50.6	1	0.1	–1.53E–08	16.07	1.27E–07	5.71	1.4E–08	15.0	
KLX22B	58.2	1	0.1	–2.08E–07	16.11	1.92E–06	5.75	2.0E–07	15.1	
KLX22B	59.3	1	0.1	–6.50E–08	16.12	8.28E–07	5.75	8.7E–08	15.2	
KLX22B	60.9	1	0.1	–8.89E–09	16.11	1.04E–07	5.75	1.1E–08	15.3	
KLX22B	78.6	1	0.1	–	16.15	6.11E–09	5.76	5.8E–10	–	
KLX22B	82.2	1	0.1	–5.56E–08	16.16	1.65E–07	5.76	2.1E–08	13.5	
KLX22B	82.6	1	0.1	–	16.16	1.50E–08	5.76	1.4E–09	–	*
KLX22B	84.0	1	0.1	–1.17E–07	16.17	4.78E–07	5.76	4.5E–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.

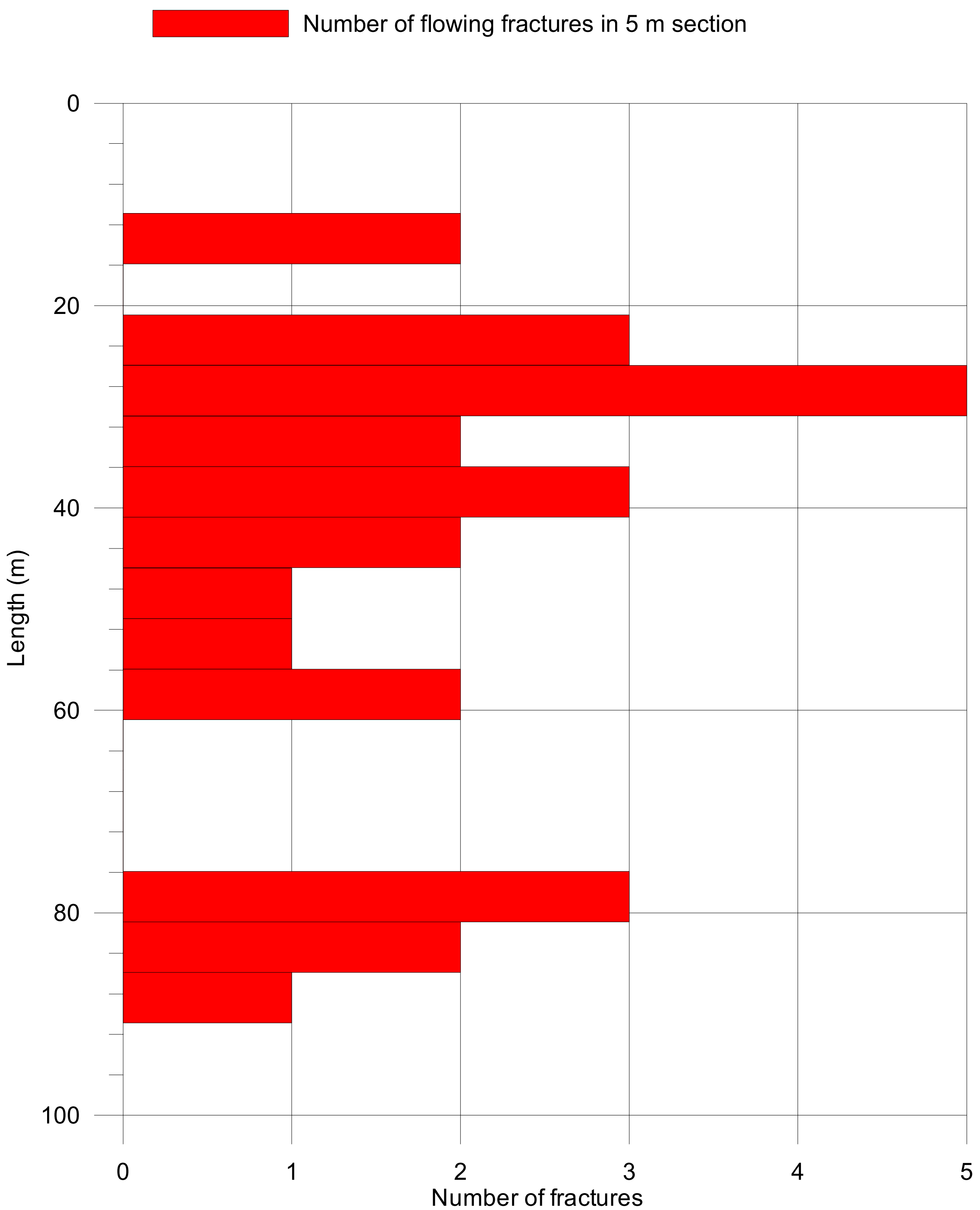
Header	Unit	Explanations
Borehole		ID for borehole.
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L).
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L).
L	m	Corrected length along borehole based 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.	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.
$T\text{-measl}_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
$T\text{-measl}_{U}$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

Calculation of conductive fracture frequency.

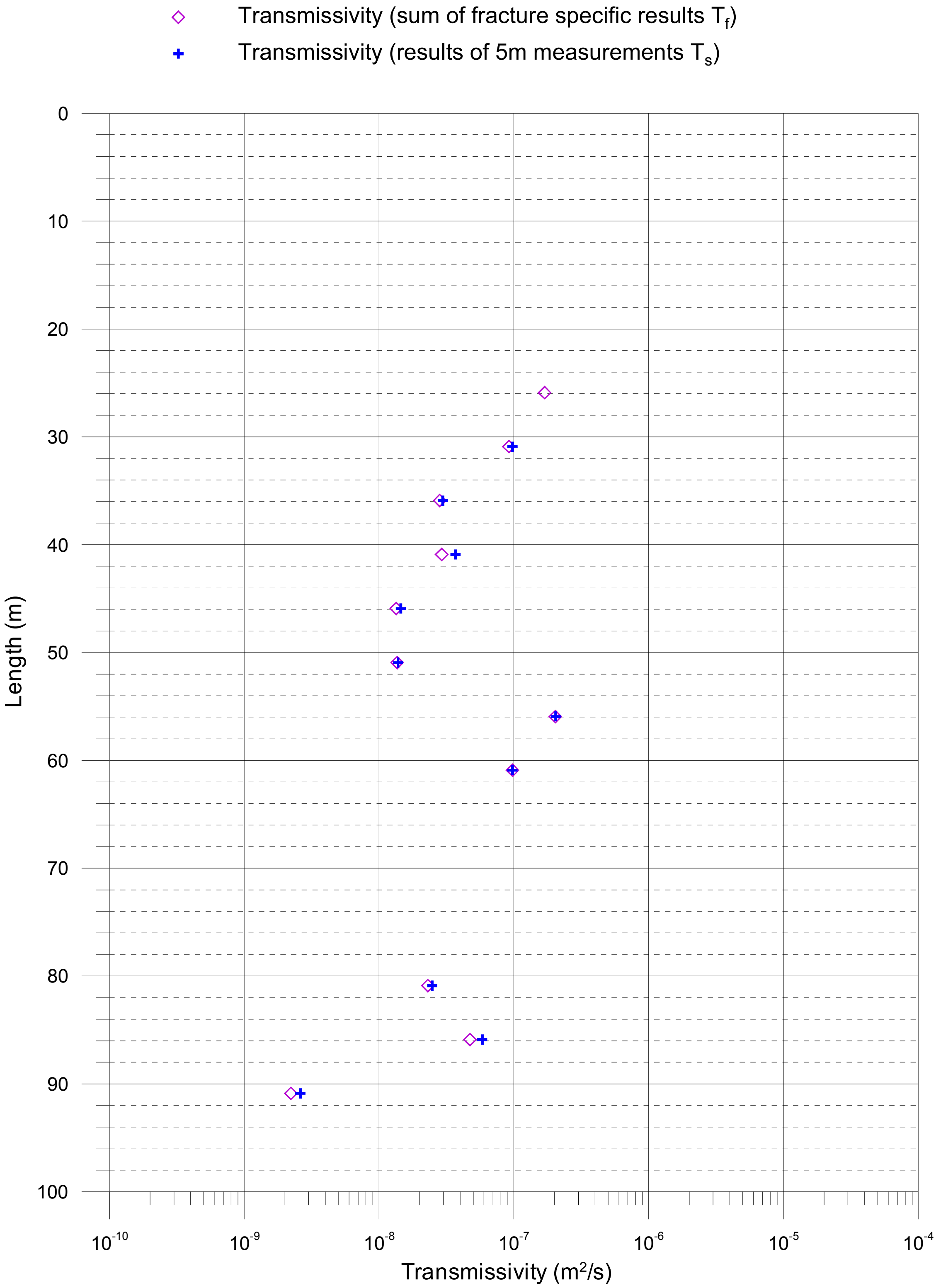
Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)	Comments
KLX22B	13.40	18.40	2	–	–	–	–	–	*
KLX22B	18.40	23.40	0	–	–	–	–	–	*
KLX22B	23.40	28.40	3	0	1	2	0	0	
KLX22B	28.40	33.40	5	1	3	1	0	0	
KLX22B	33.41	38.41	2	0	2	0	0	0	
KLX22B	38.41	43.41	3	0	3	0	0	0	
KLX22B	43.42	48.42	2	1	1	0	0	0	
KLX22B	48.43	53.43	1	0	1	0	0	0	
KLX22B	53.43	58.43	1	0	0	1	0	0	
KLX22B	58.42	63.42	2	0	1	1	0	0	
KLX22B	63.40	68.40	0	0	0	0	0	0	
KLX22B	68.39	73.39	0	0	0	0	0	0	
KLX22B	73.39	78.39	0	0	0	0	0	0	
KLX22B	78.39	83.39	3	2	1	0	0	0	
KLX22B	83.39	88.39	2	1	0	1	0	0	
KLX22B	88.37	93.37	1	1	0	0	0	0	

* Measurements done without pumping.

Laxemar, borehole KLX22B
Calculation of conductive fracture frequency

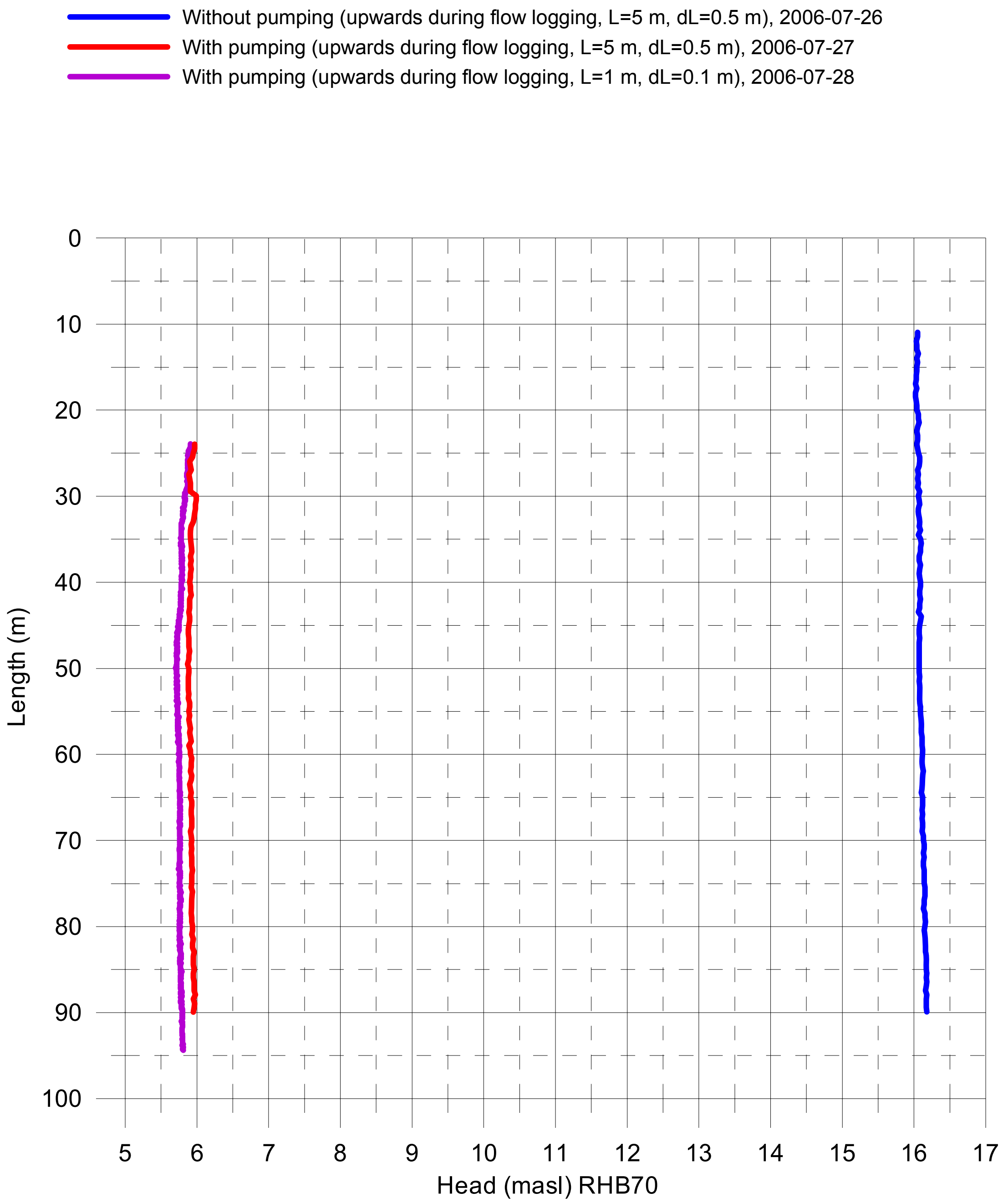


Laxemar, borehole KLX22B
Comparison between section transmissivity and fracture transmissivity

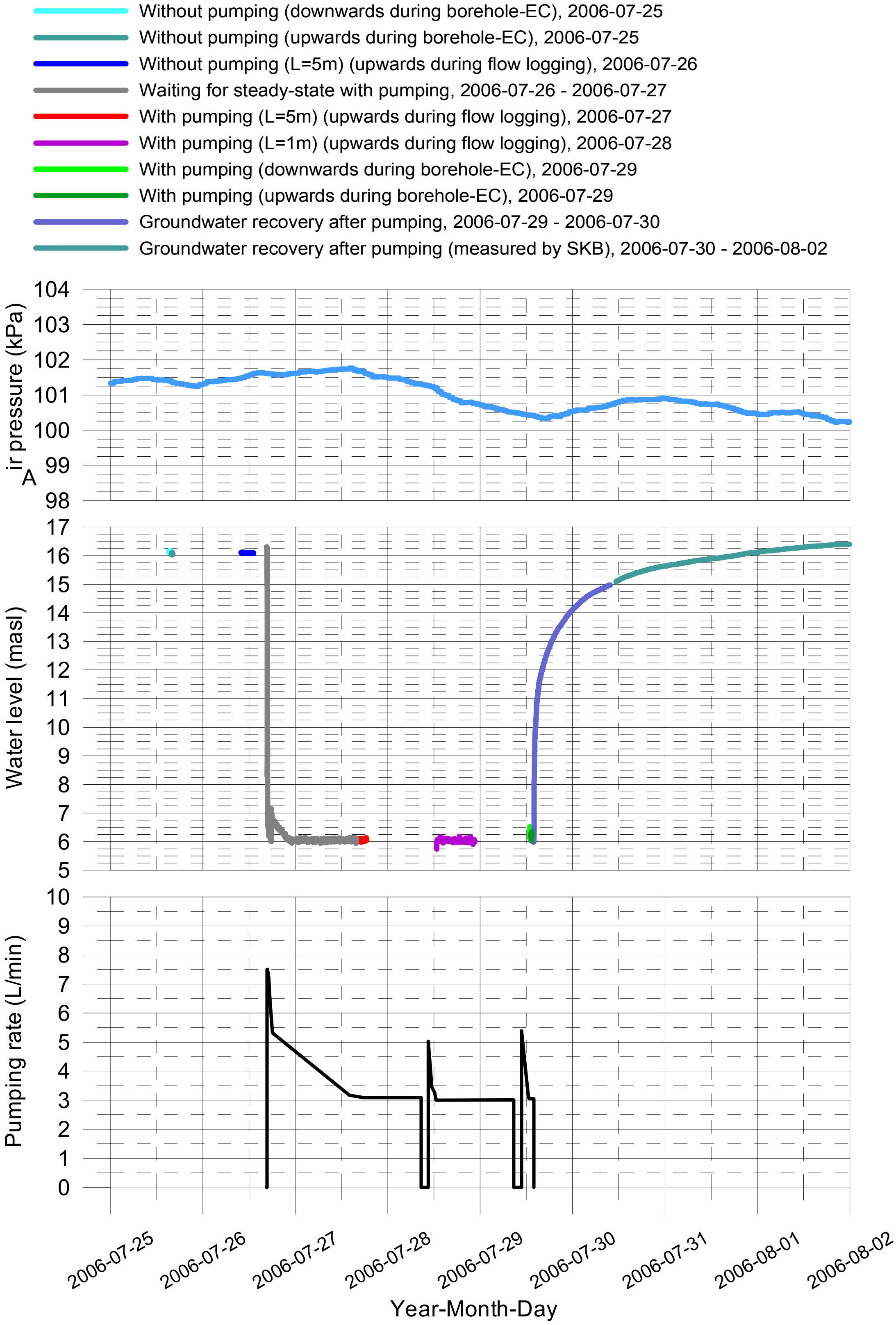


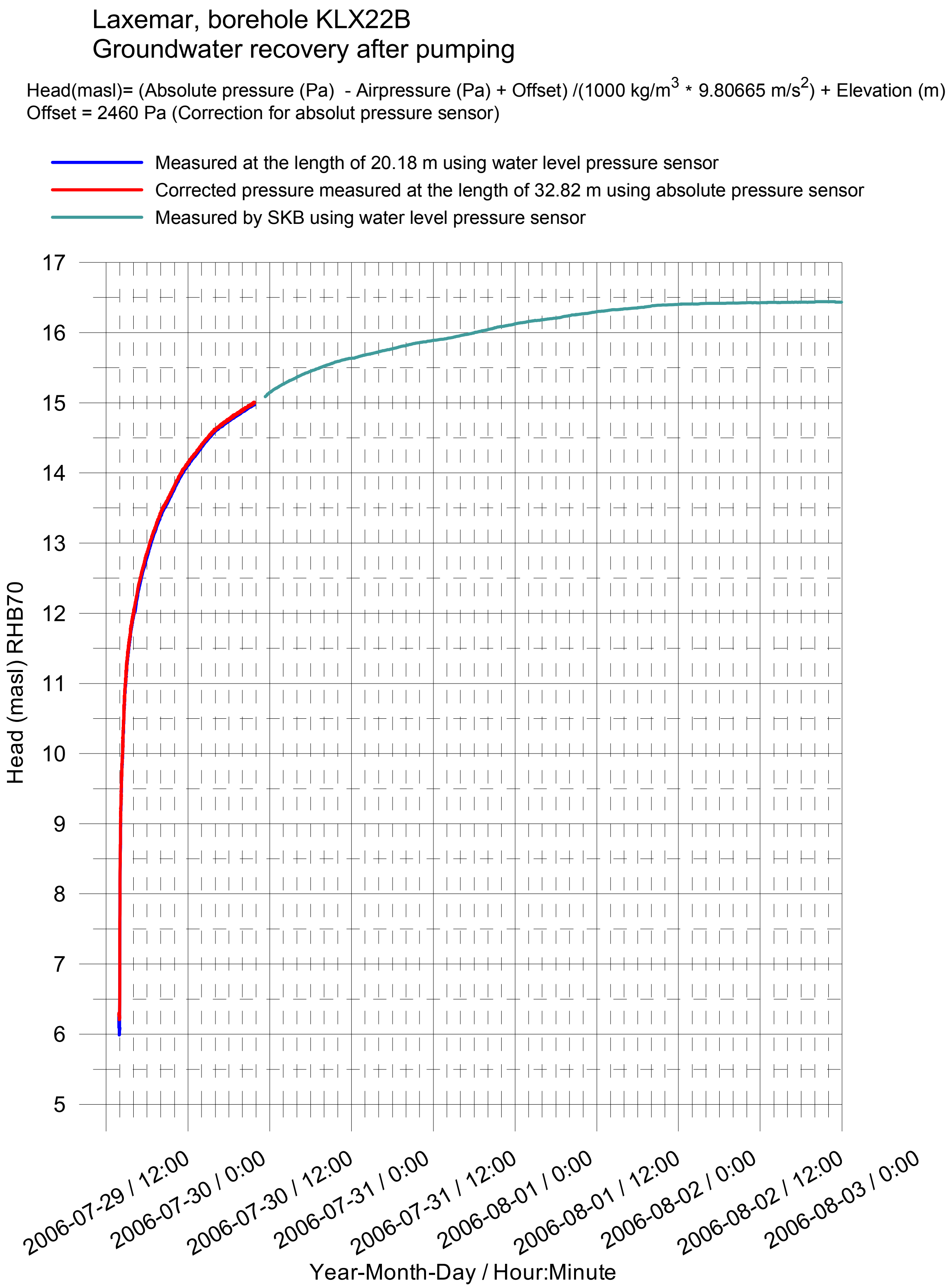
Laxemar, borehole KLX22B
Head in the borehole during flow logging

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 KLX22B
Air pressure, water level in the borehole and pumping rate during flow logging

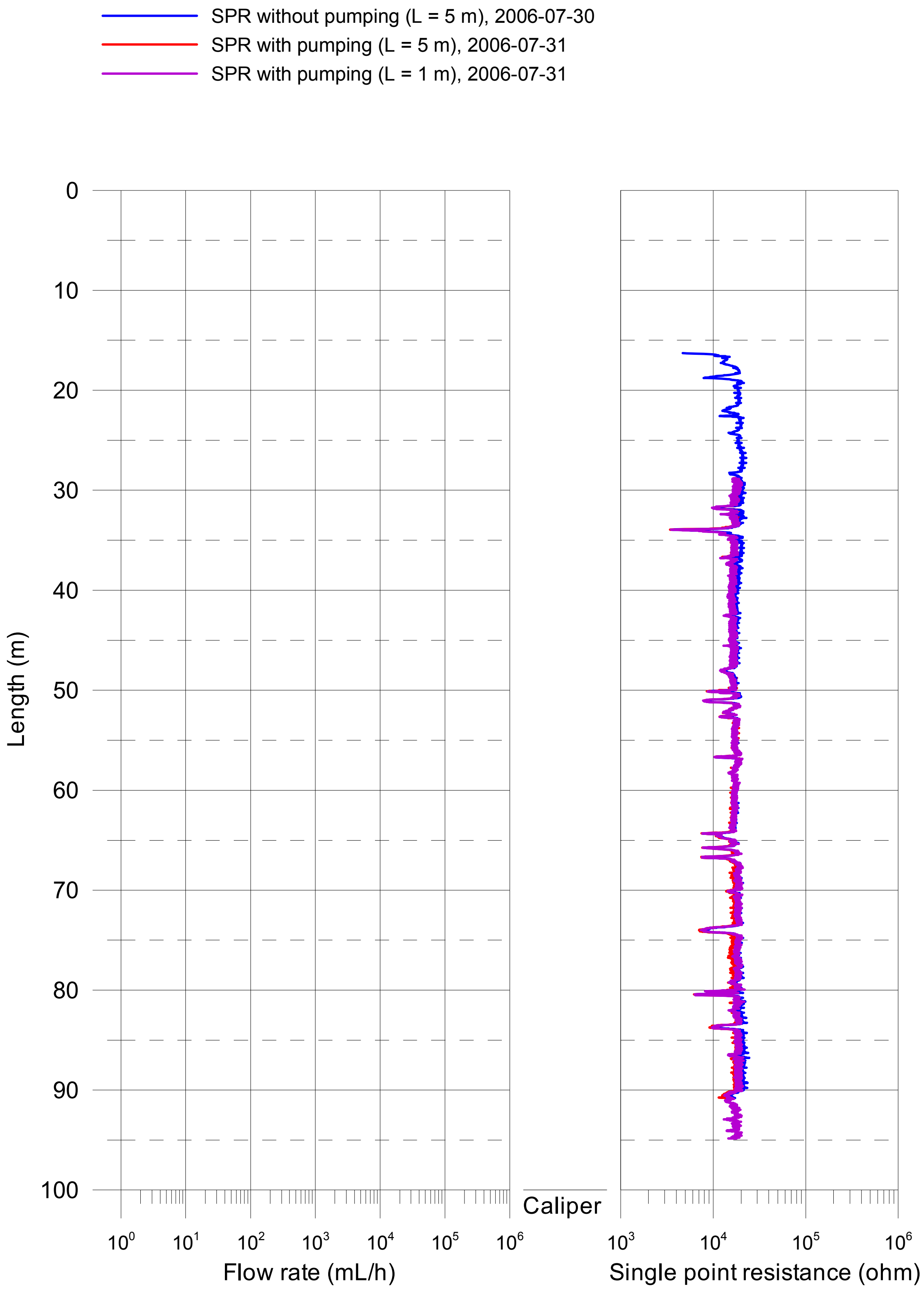



Laxemar, borehole KLX22B
Groundwater recovery after pumping
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)
Measured at the length of 20.18 m using water level pressure sensor
Corrected pressure measured at the length of 32.82 m using absolute pressure sensor
Measured by SKB using water level pressure sensor
Head (masl) RHB70
17
16
15
14
13
12
11
10
9
8
7
6
5
2006-07-29 / 12:00
2006-07-30 / 0:00
2006-07-30 / 12:00
2006-07-31 / 0:00
2006-07-31 / 12:00
2006-08-01 / 0:00
2006-08-01 / 12:00
2006-08-02 / 0:00
2006-08-02 / 12:00
2006-08-03 / 0:00
Year-Month-Day / Hour:Minute

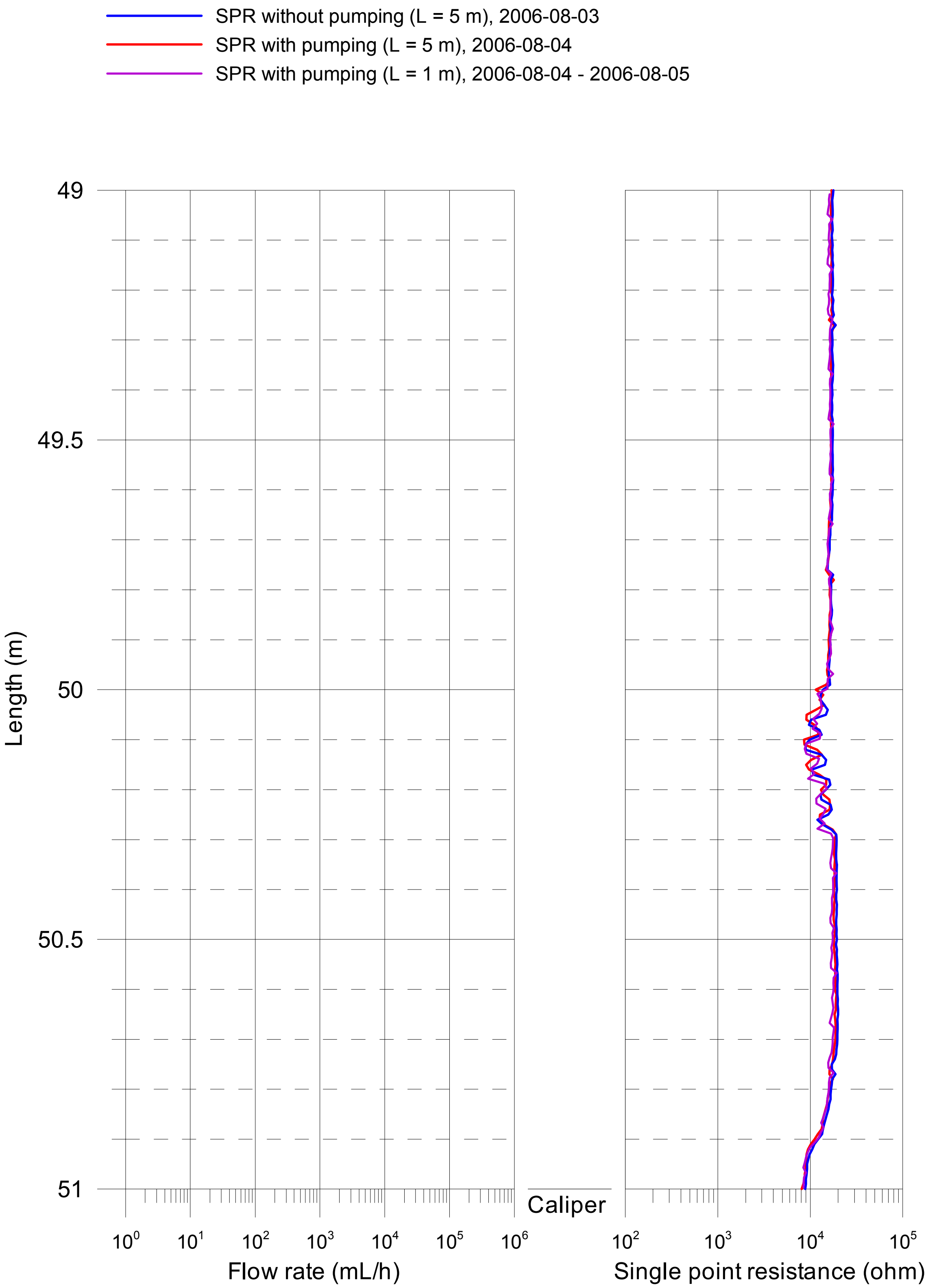
Appendices KLX23A

Appendices	23A.1.1–23A.1.3	SPR and caliper results after length correction
Appendices	23A.1.4	Length correction
Appendix	23A.2.1	Electric conductivity of borehole water
Appendix	23A.2.2	Temperature of borehole water
Appendix	23A.3.1–23A.3.5	Flow rate, caliper and single point resistance
Appendix	23A.4.1	Plotted flow rates of 5 m sections
Appendix	23A.4.2	Plotted transmissivity and head of 5 m sections
Appendix	23A.5	Plotted transmissivity and head of detected fractures
Appendix	23A.6	Basic test data
Appendix	23A.7	Results of sequential flow logging
Appendices	23A.8	Inferred flow anomalies from overlapping flow logging
Appendix	23A.9	Explanations for the tables in Appendices 6–8
Appendix	23A.10	Conductive fracture frequency
Appendix	23A.11	Plotted conductive fracture frequency
Appendix	23A.12	Comparison between section transmissivity and fracture transmissivity
Appendix	23A.13.1	Head in the borehole during flow logging
Appendix	23A.13.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	23A.13.3	Groundwater recovery after pumping

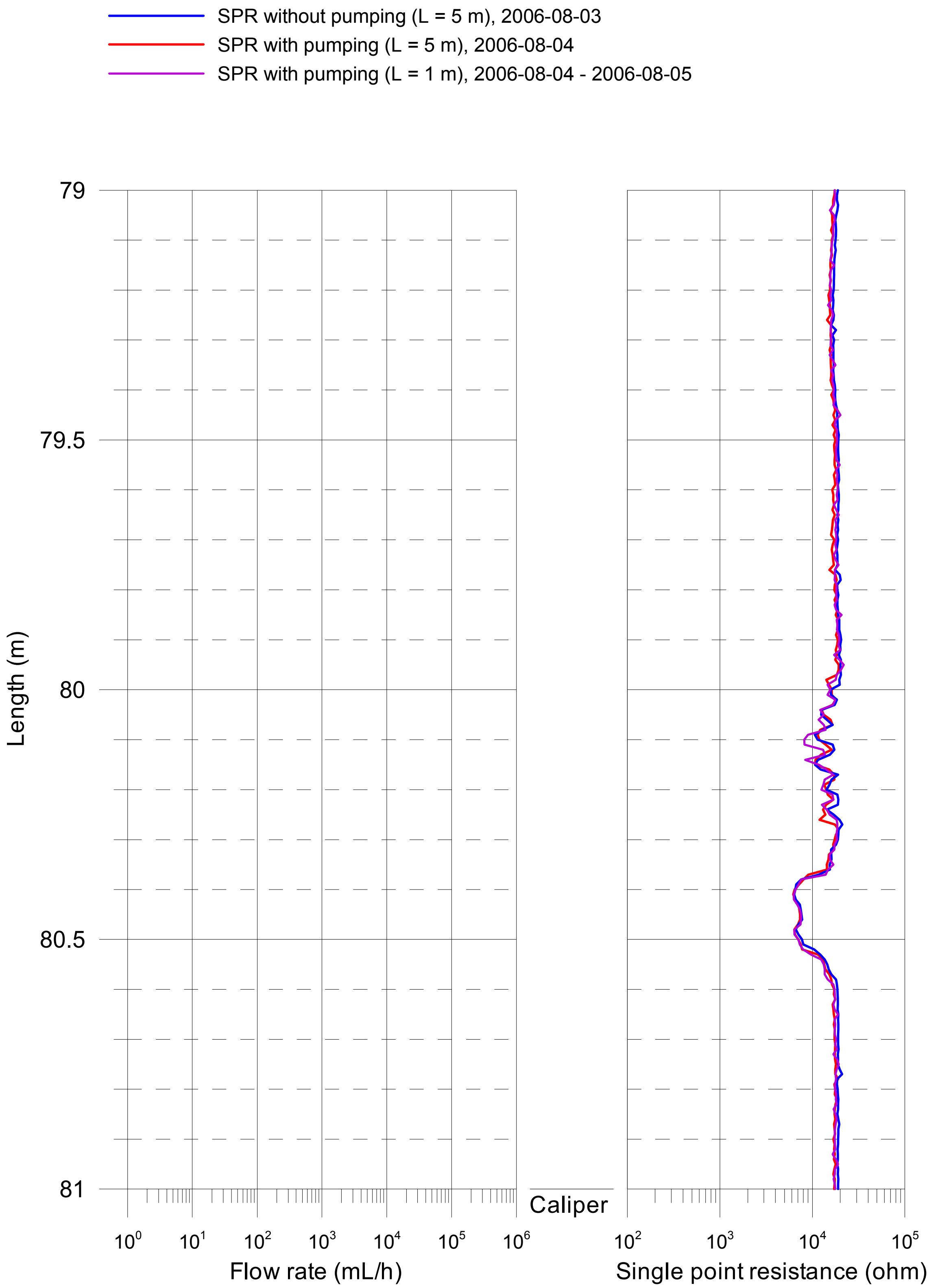
Laxemar, borehole KLX23A
SPR and Caliper results after length correction



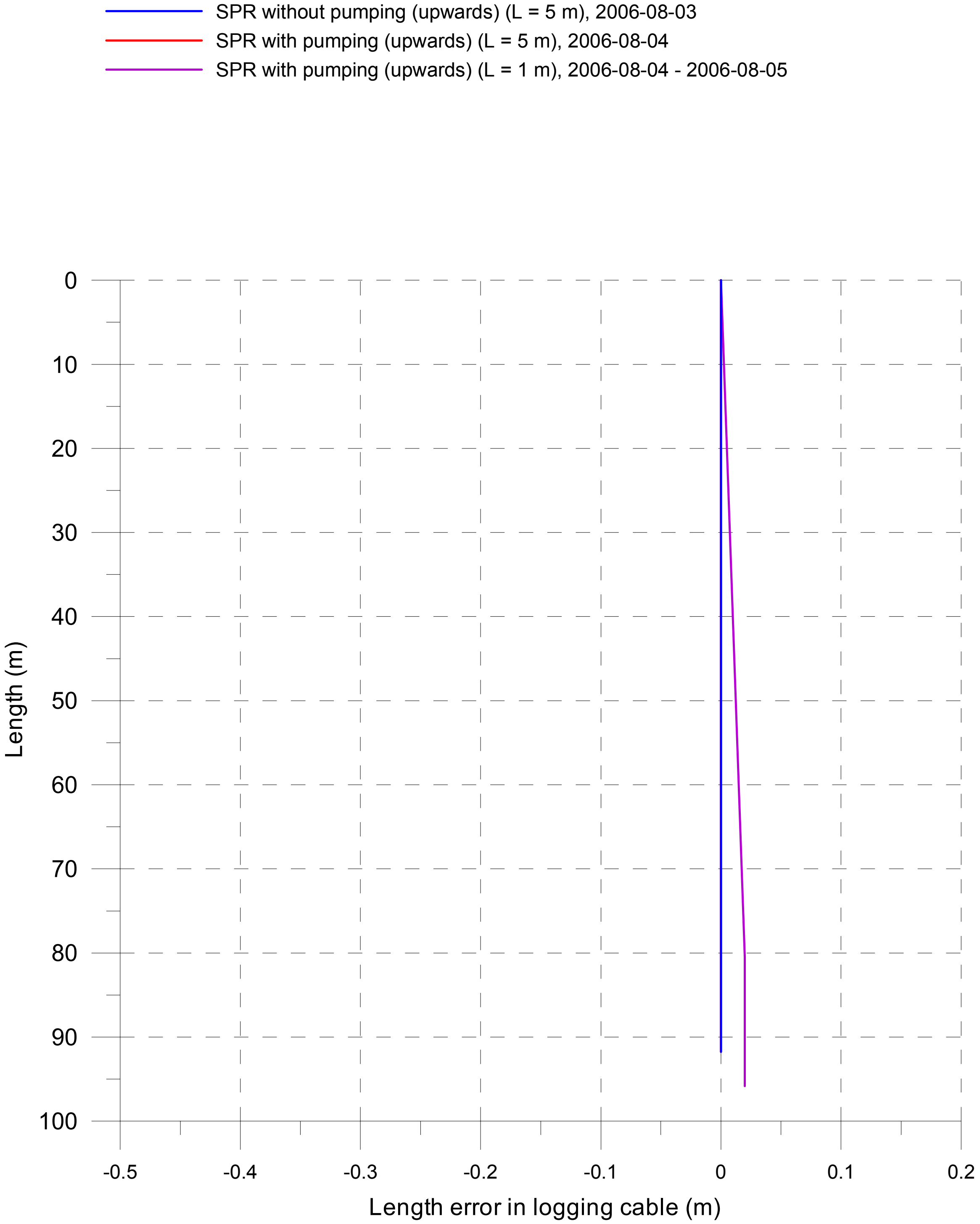
Laxemar, borehole KLX23A
SPR and Caliper results after length correction



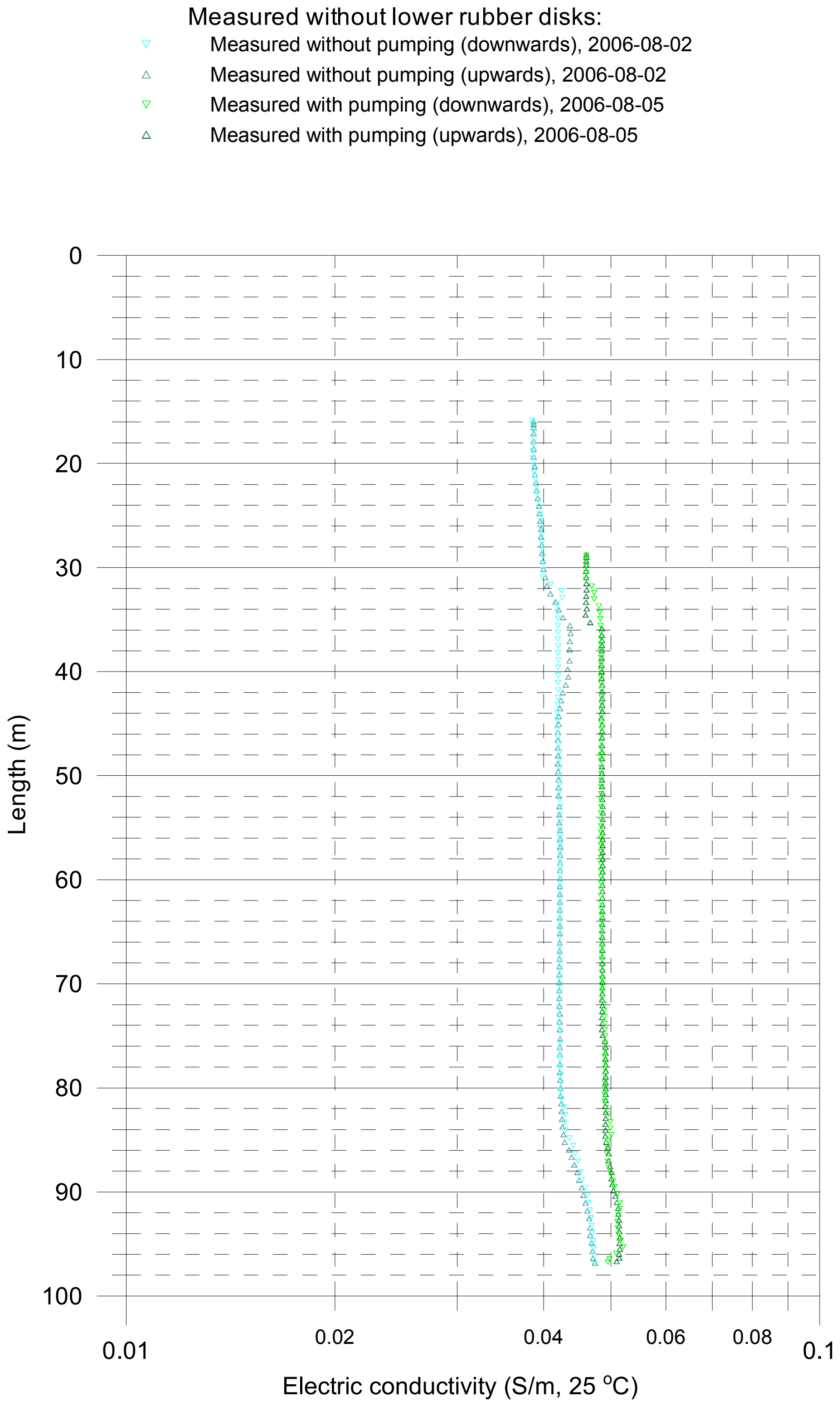
Laxemar, borehole KLX23A
SPR and Caliper results after length correction



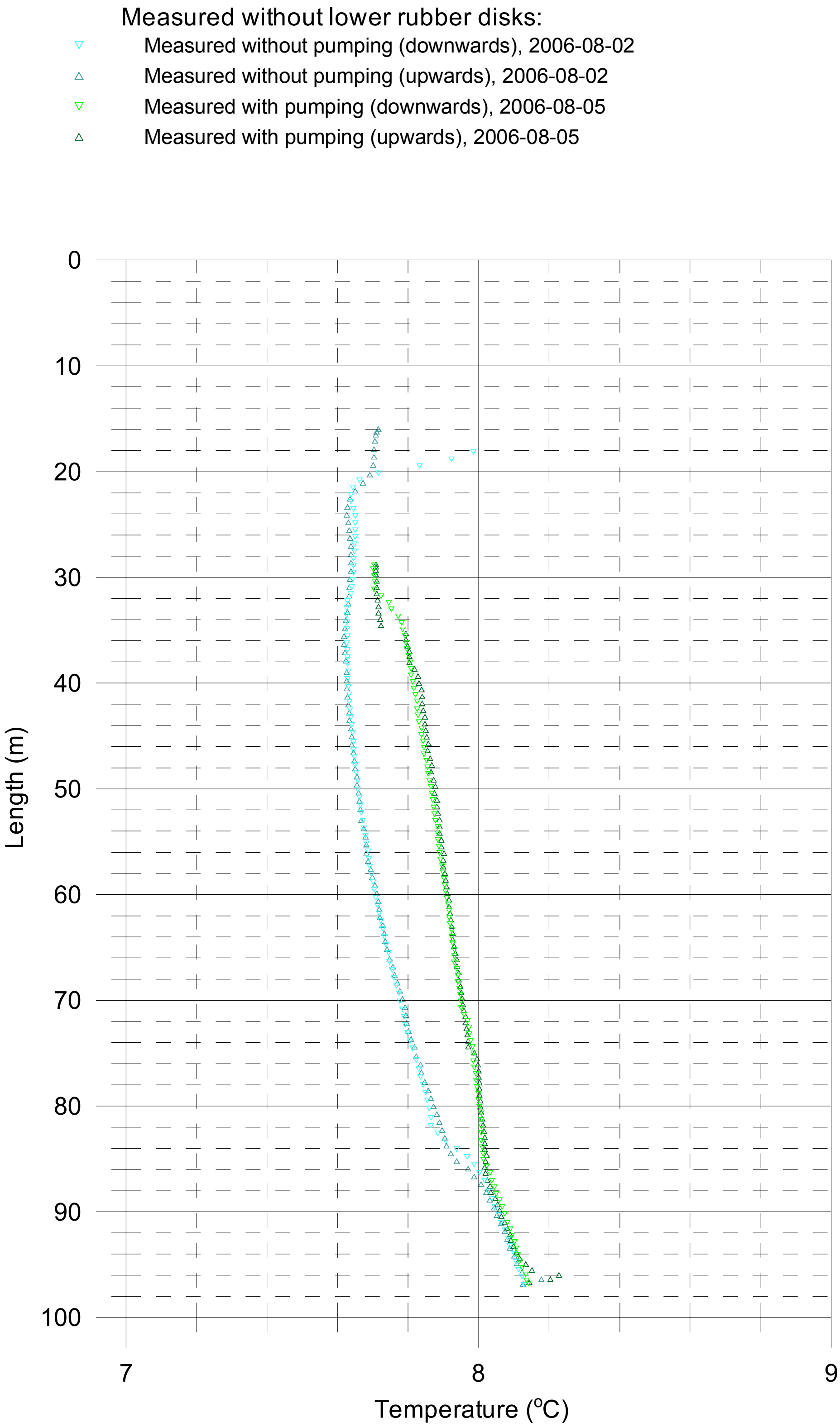
Laxemar, borehole KLX23A
Length correction



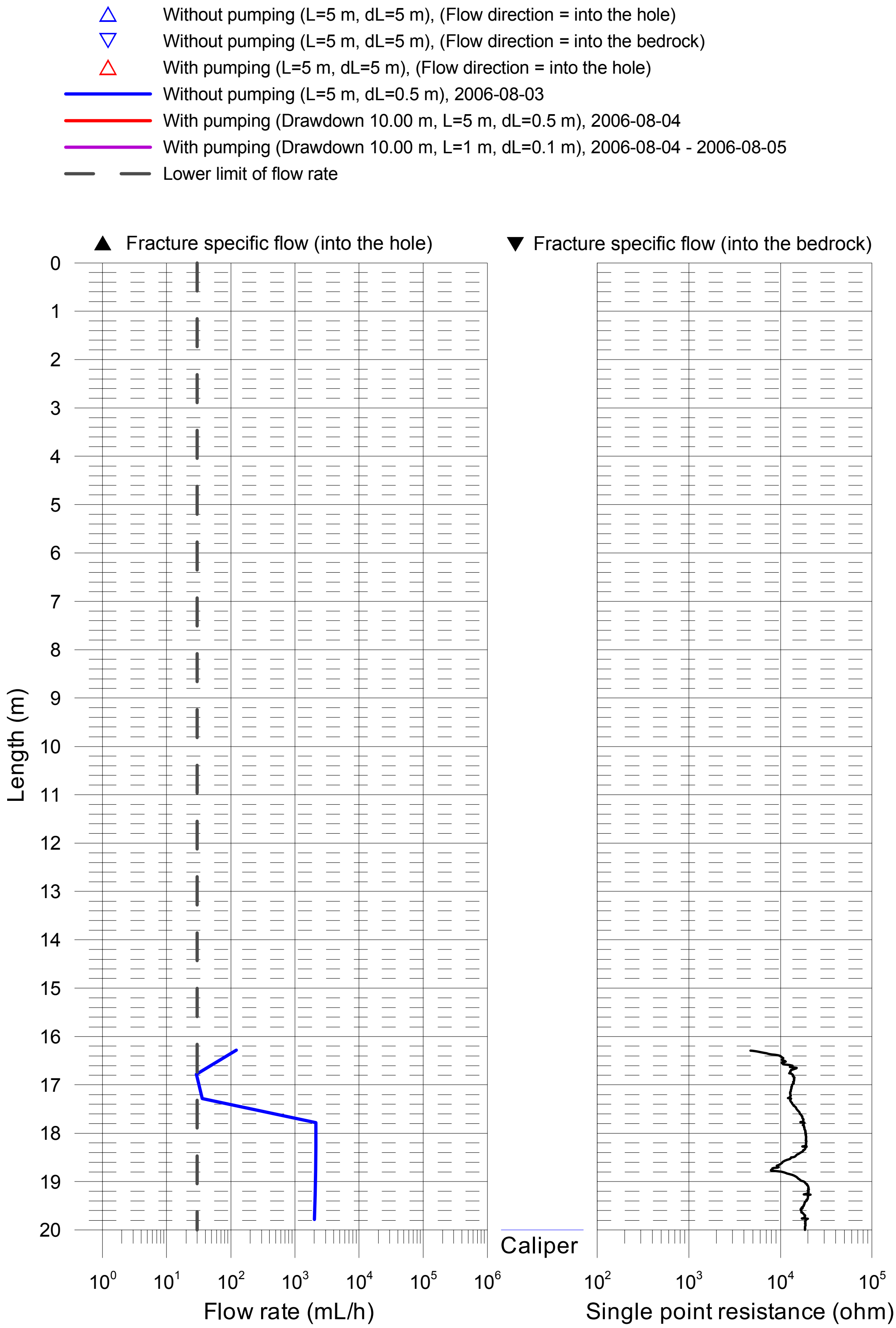
Laxemar, borehole KLX23A
Electric conductivity of borehole water



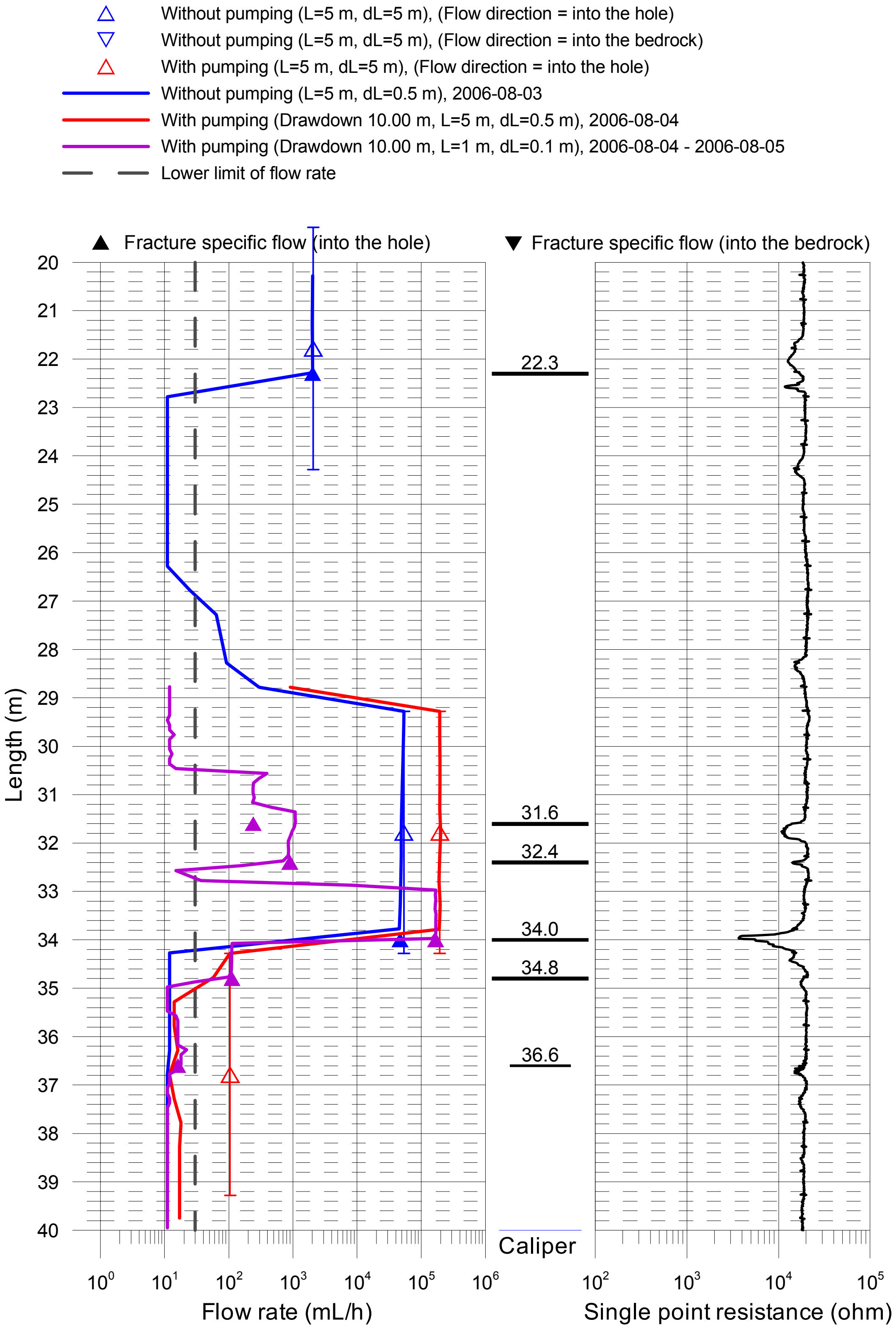
Laxemar, borehole KLX23A
Temperature of borehole water



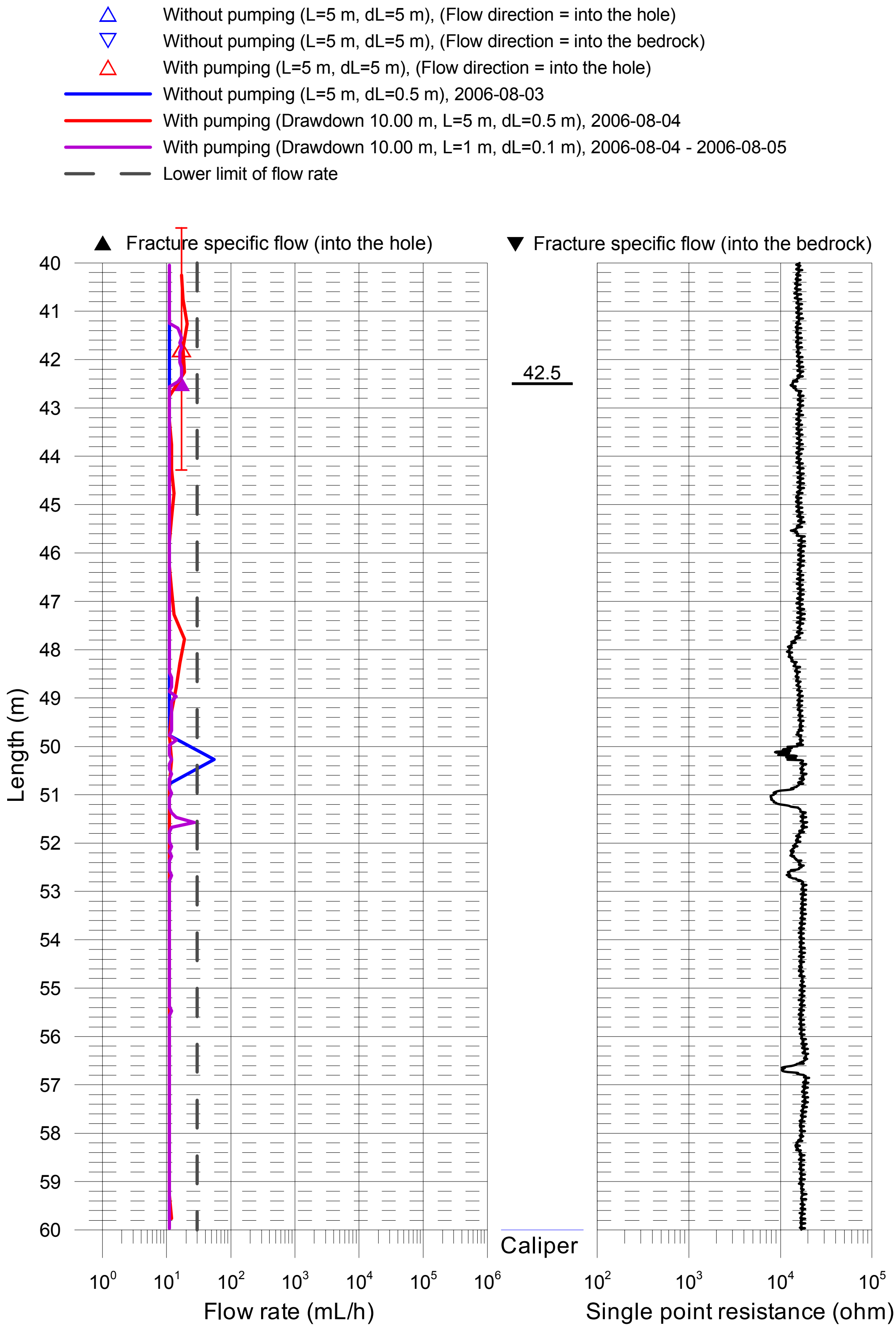
Laxemar, borehole KLX23A
Flow rate, caliper and single point resistance



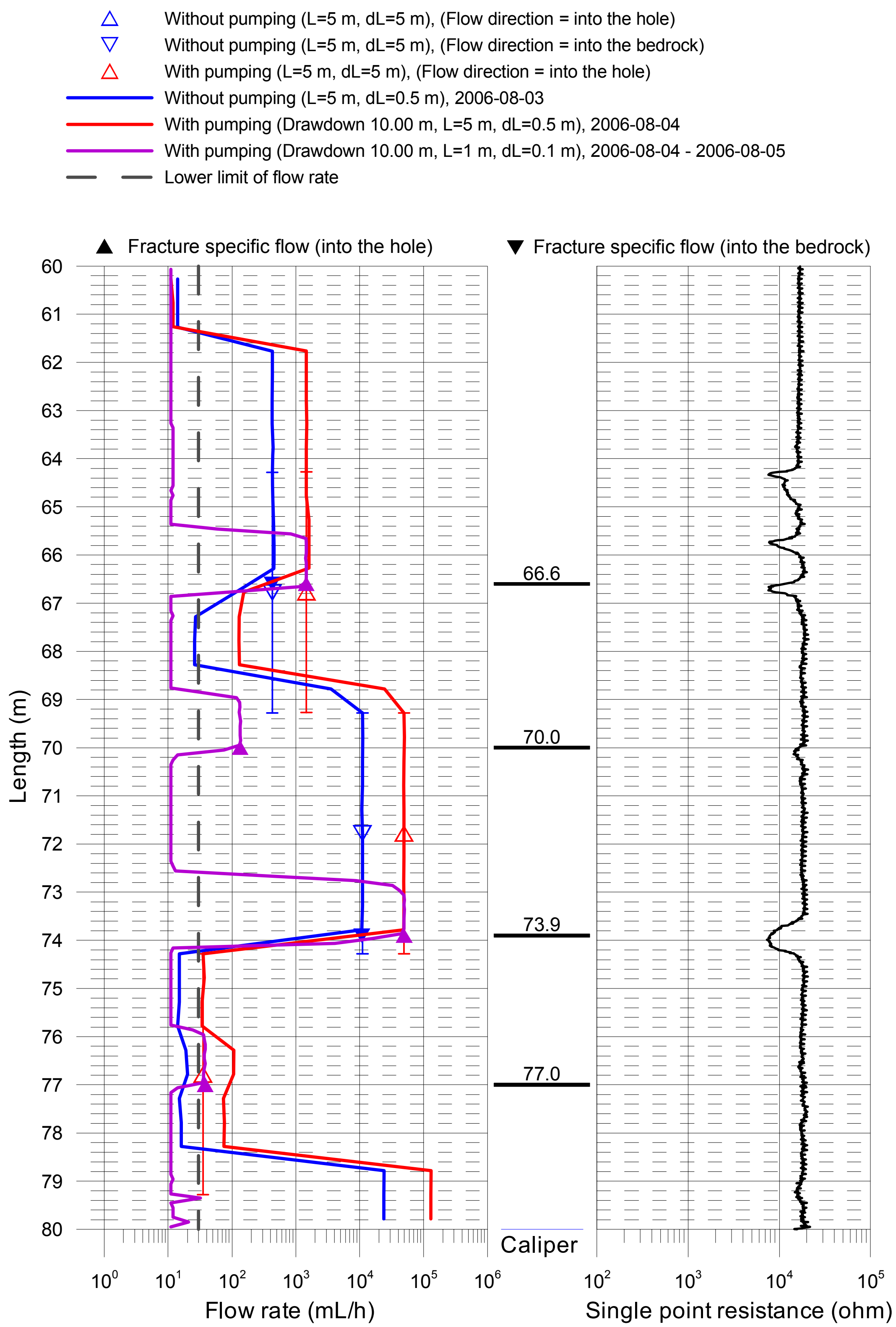
Laxemar, borehole KLX23A
Flow rate, caliper and single point resistance



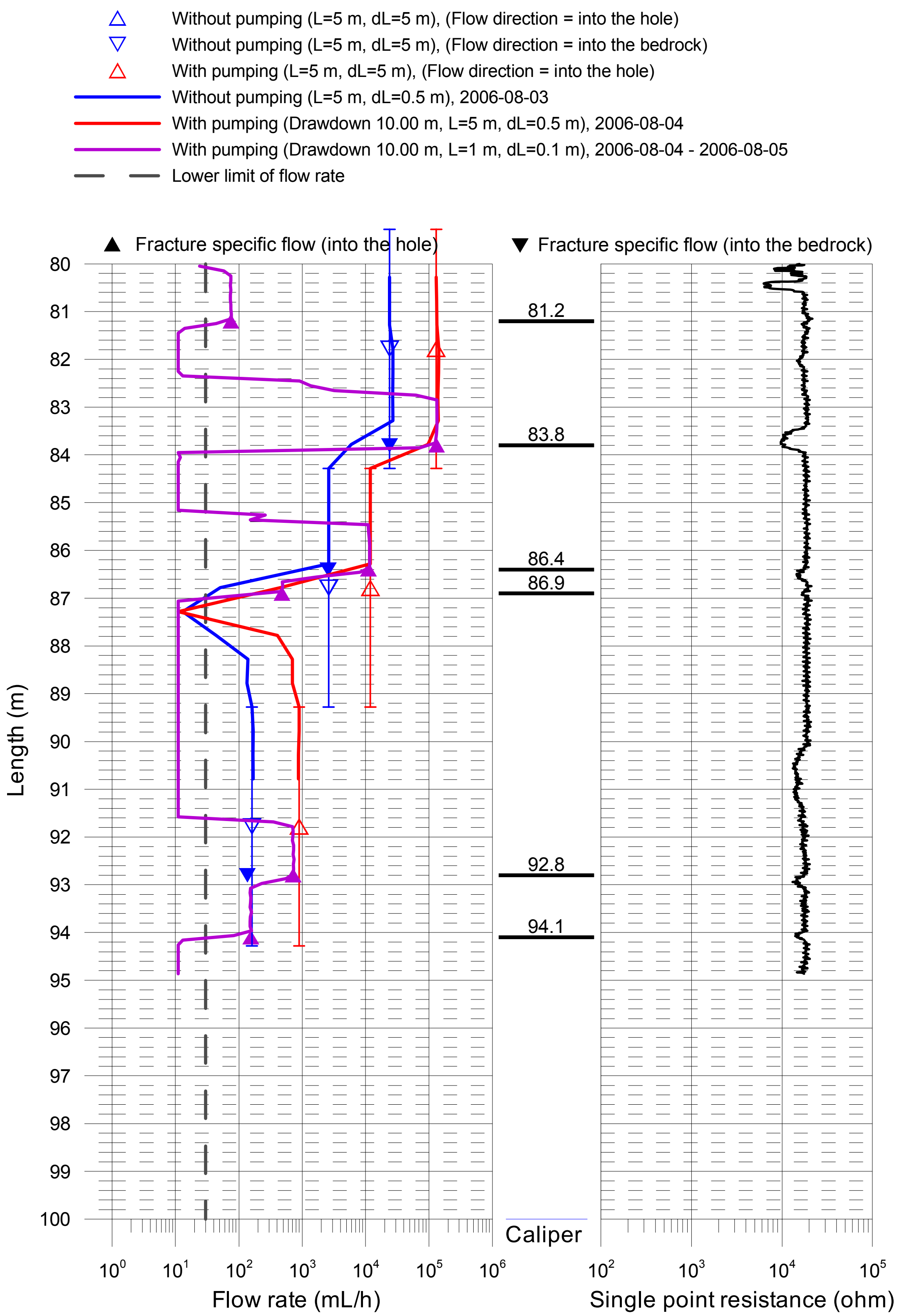
Laxemar, borehole KLX23A
Flow rate, caliper and single point resistance

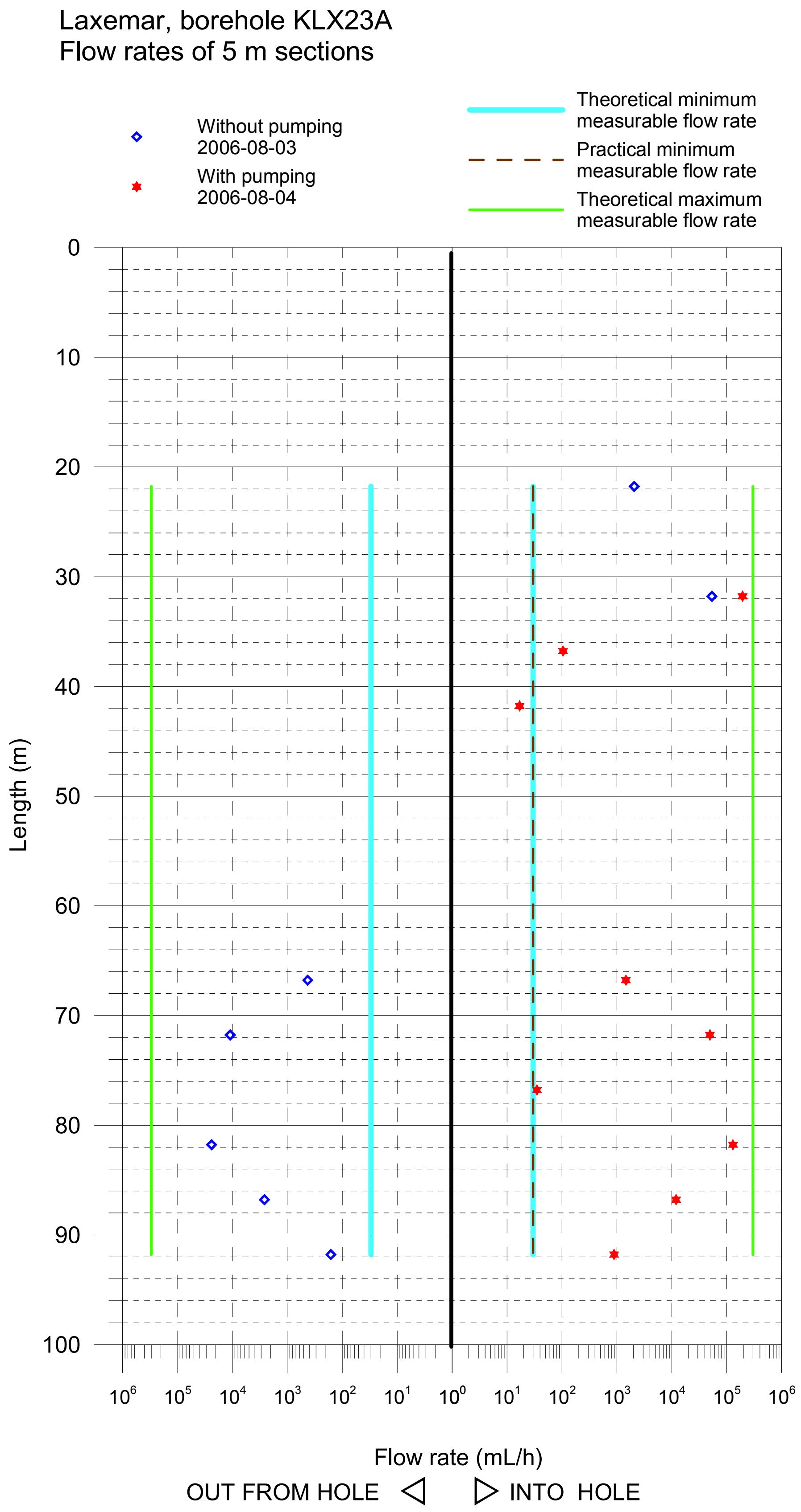


Laxemar, borehole KLX23A
Flow rate, caliper and single point resistance

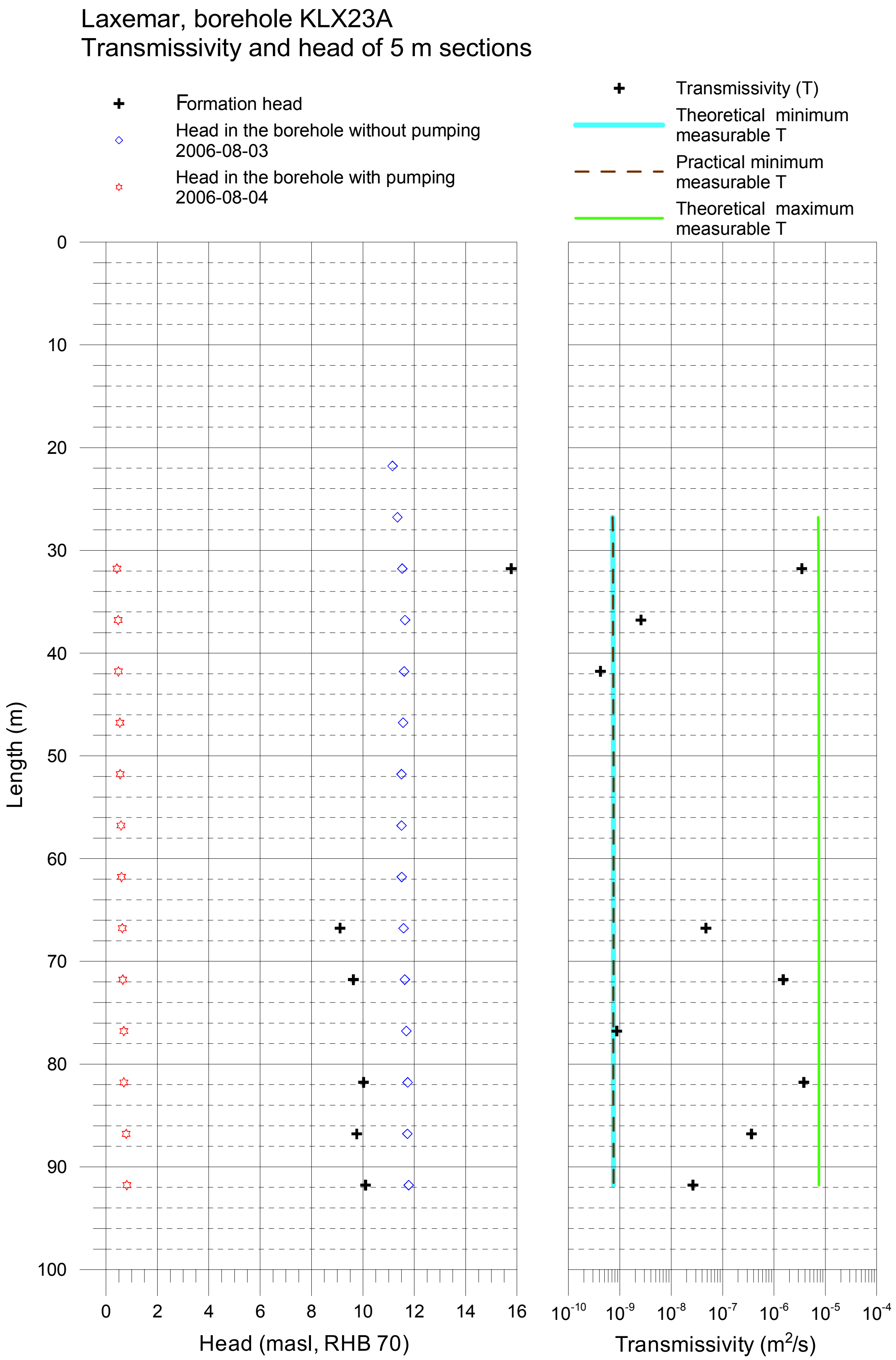


Laxemar, borehole KLX23A
Flow rate, caliper and single point resistance

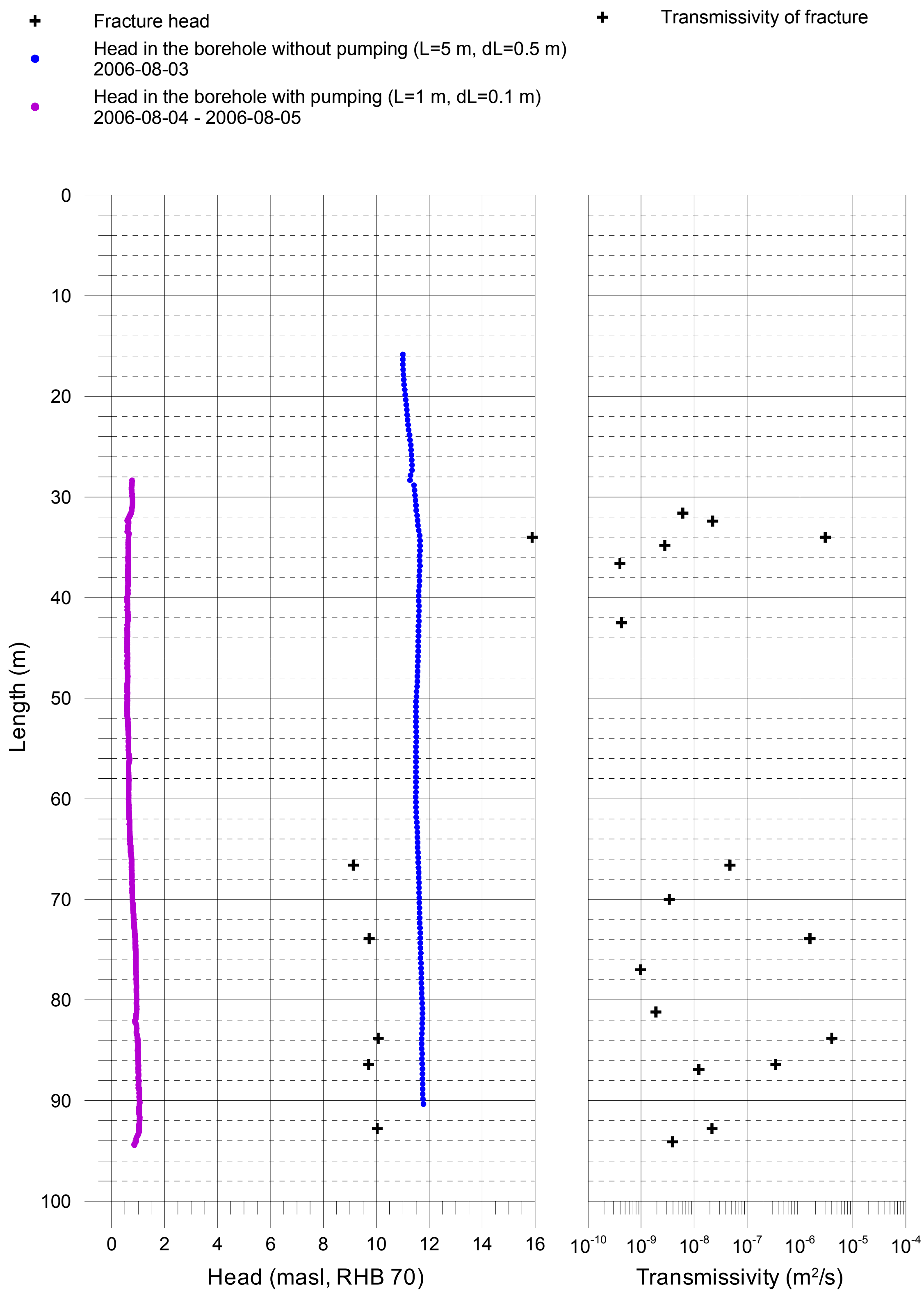




Laxemar, borehole KLX23A
Flow rates of 5 m sections
Without pumping
2006-08-03
With pumping
2006-08-04
Theoretical minimum
measurable flow rate
Practical minimum
measurable flow rate
Theoretical maximum
measurable flow rate
Length (m)
0
10
20
30
40
50
60
70
80
90
100
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
OUT FROM HOLE
INTO HOLE


Laxemar, borehole KLX23A
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-08-03
Head in the borehole with pumping 2006-08-04
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 KLX23A
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)
KLX23A	2.3	100.15	5A	20060803	15:36	20060804	15:01	20060805	14:44	5	0.5	1.11E–04	–

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

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (ma.s.l.)	h_1 (ma.s.l.)	h_2 (ma.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
169,680	–	292,560	–	11.58	0.79	–	–10.79	–	1.02E–05	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KLX23A	19.28	24.28	5	5.75E–07	11.15	–	–	–	–	30	7.3E–10	7.3E–10	7.3E–06	*
KLX23A	24.28	29.28	5	–	11.34	–	–	–	–	30	7.3E–10	7.3E–10	7.3E–06	
KLX23A	29.28	34.28	5	1.49E–05	11.53	5.39E–05	0.42	3.5E–06	15.8	30	7.4E–10	7.4E–10	7.4E–06	
KLX23A	34.28	39.28	5	–	11.64	2.92E–08	0.47	2.6E–09	–	30	7.4E–10	7.4E–10	7.4E–06	
KLX23A	39.28	44.28	5	–	11.60	4.72E–09	0.48	4.2E–10	–	30	7.4E–10	7.4E–10	7.4E–06	
KLX23A	44.27	49.27	5	–	11.56	–	0.54	–	–	30	7.5E–10	7.5E–10	7.5E–06	
KLX23A	49.28	54.28	5	–	11.50	–	0.55	–	–	30	7.5E–10	7.5E–10	7.5E–06	
KLX23A	54.28	59.28	5	–	11.50	–	0.58	–	–	30	7.5E–10	7.5E–10	7.5E–06	
KLX23A	59.28	64.28	5	–	11.51	–	0.60	–	–	30	7.6E–10	7.6E–10	7.6E–06	
KLX23A	64.28	69.28	5	–1.18E–07	11.58	4.06E–07	0.63	4.7E–08	9.1	30	7.5E–10	7.5E–10	7.5E–06	
KLX23A	69.28	74.28	5	–3.06E–06	11.63	1.37E–05	0.65	1.5E–06	9.6	30	7.5E–10	7.5E–10	7.5E–06	
KLX23A	74.28	79.28	5	–	11.69	9.72E–09	0.69	8.7E–10	–	30	7.5E–10	7.5E–10	7.5E–06	
KLX23A	79.28	84.28	5	–6.67E–06	11.74	3.61E–05	0.69	3.8E–06	10.0	30	7.5E–10	7.5E–10	7.5E–06	
KLX23A	84.28	89.28	5	–7.25E–07	11.73	3.31E–06	0.78	3.6E–07	9.8	30	7.5E–10	7.5E–10	7.5E–06	
KLX23A	89.28	94.28	5	–4.47E–08	11.78	2.48E–07	0.81	2.6E–08	10.1	30	7.5E–10	7.5E–10	7.5E–06	

* Only results from measurement without pumping, no transmissivity calculations has been done (drawdown during 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)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KLX23A	22.3	1	0.1	5.64E–07	11.18	–	–	–	–	**
KLX23A	31.6	1	0.1	–	11.53	6.67E–08	0.73	6.1E–09	–	
KLX23A	32.4	1	0.1	–	11.56	2.49E–07	0.60	2.3E–08	–	
KLX23A	34.0	1	0.1	1.30E–05	11.64	4.67E–05	0.64	3.0E–06	15.9	
KLX23A	34.8	1	0.1	–	11.65	3.11E–08	0.63	2.8E–09	–	
KLX23A	36.6	1	0.1	–	11.65	4.44E–09	0.63	4.0E–10	–	*
KLX23A	42.5	1	0.1	–	11.60	4.72E–09	0.60	4.3E–10	–	*
KLX23A	66.6	1	0.1	–1.19E–07	11.59	4.03E–07	0.76	4.8E–08	9.1	
KLX23A	70.0	1	0.1	–	11.62	3.72E–08	0.79	3.4E–09	–	
KLX23A	73.9	1	0.1	–3.00E–06	11.66	1.38E–05	0.89	1.5E–06	9.7	
KLX23A	77.0	1	0.1	–	11.69	1.06E–08	0.92	9.7E–10	–	
KLX23A	81.2	1	0.1	–	11.74	2.08E–08	0.94	1.9E–09	–	
KLX23A	83.8	1	0.1	–6.64E–06	11.71	3.67E–05	0.98	4.0E–06	10.1	
KLX23A	86.4	1	0.1	–7.14E–07	11.73	3.08E–06	1.01	3.5E–07	9.7	
KLX23A	86.9	1	0.1	–	11.74	1.33E–07	1.01	1.2E–08	–	
KLX23A	92.8	1	0.1	–3.78E–08	11.75	1.99E–07	1.04	2.2E–08	10.0	
KLX23A	94.1	1	0.1	–	11.75	4.28E–08	0.92	3.9E–09	–	

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

** Fracture detected during measurement without pumping (drawdown prevented fracture to be measured with pumping)

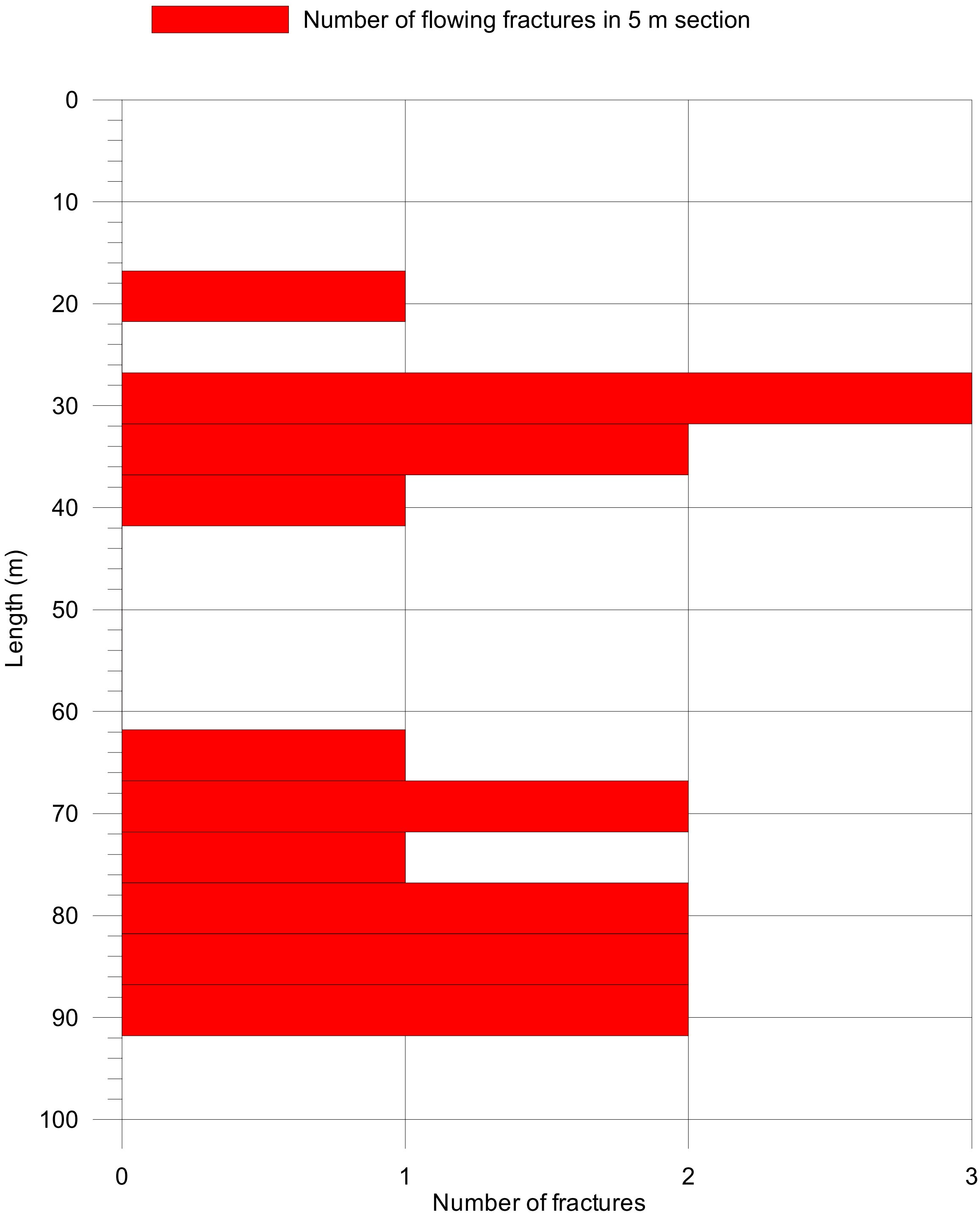
Explanations.

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.
$T\text{-measl}_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
$T\text{-measl}_{U}$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

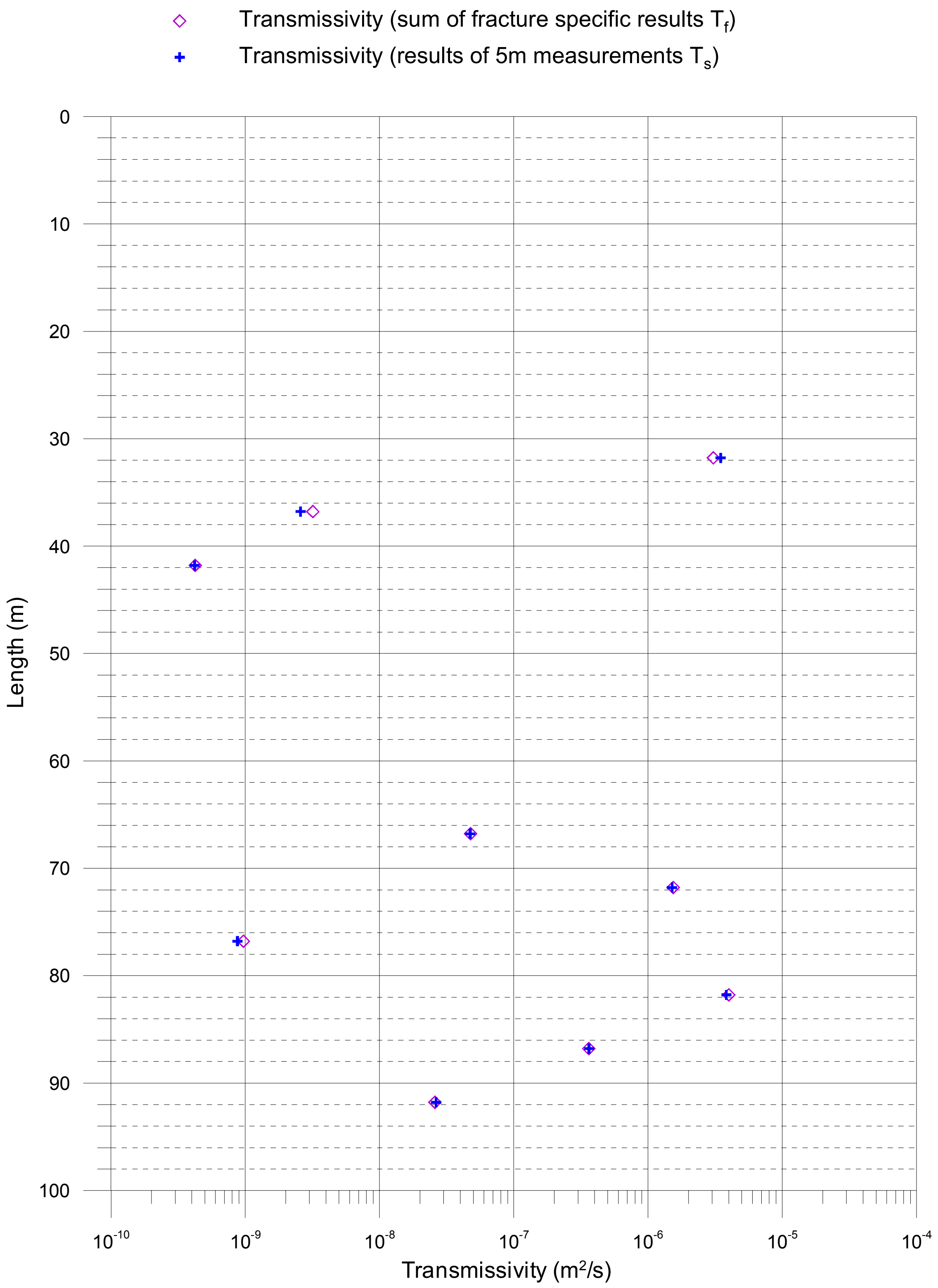
Calculation of conductive fracture frequency.

Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)
KLX23A	19.28	24.28	1	0	0	0	0	0
KLX23A	24.28	29.28	0	0	0	0	0	0
KLX23A	29.28	34.28	3	0	2	0	0	1
KLX23A	34.28	39.28	2	1	1	0	0	0
KLX23A	39.28	44.28	1	1	0	0	0	0
KLX23A	44.27	49.27	0	0	0	0	0	0
KLX23A	49.28	54.28	0	0	0	0	0	0
KLX23A	54.28	59.28	0	0	0	0	0	0
KLX23A	59.28	64.28	0	0	0	0	0	0
KLX23A	64.28	69.28	1	0	0	1	0	0
KLX23A	69.28	74.28	2	0	1	0	1	0
KLX23A	74.28	79.28	1	1	0	0	0	0
KLX23A	79.28	84.28	2	1	0	0	0	1
KLX23A	84.28	89.28	2	0	1	0	1	0
KLX23A	89.28	94.28	2	0	2	0	0	0

Laxemar, borehole KLX23A
Calculation of conductive fracture frequency

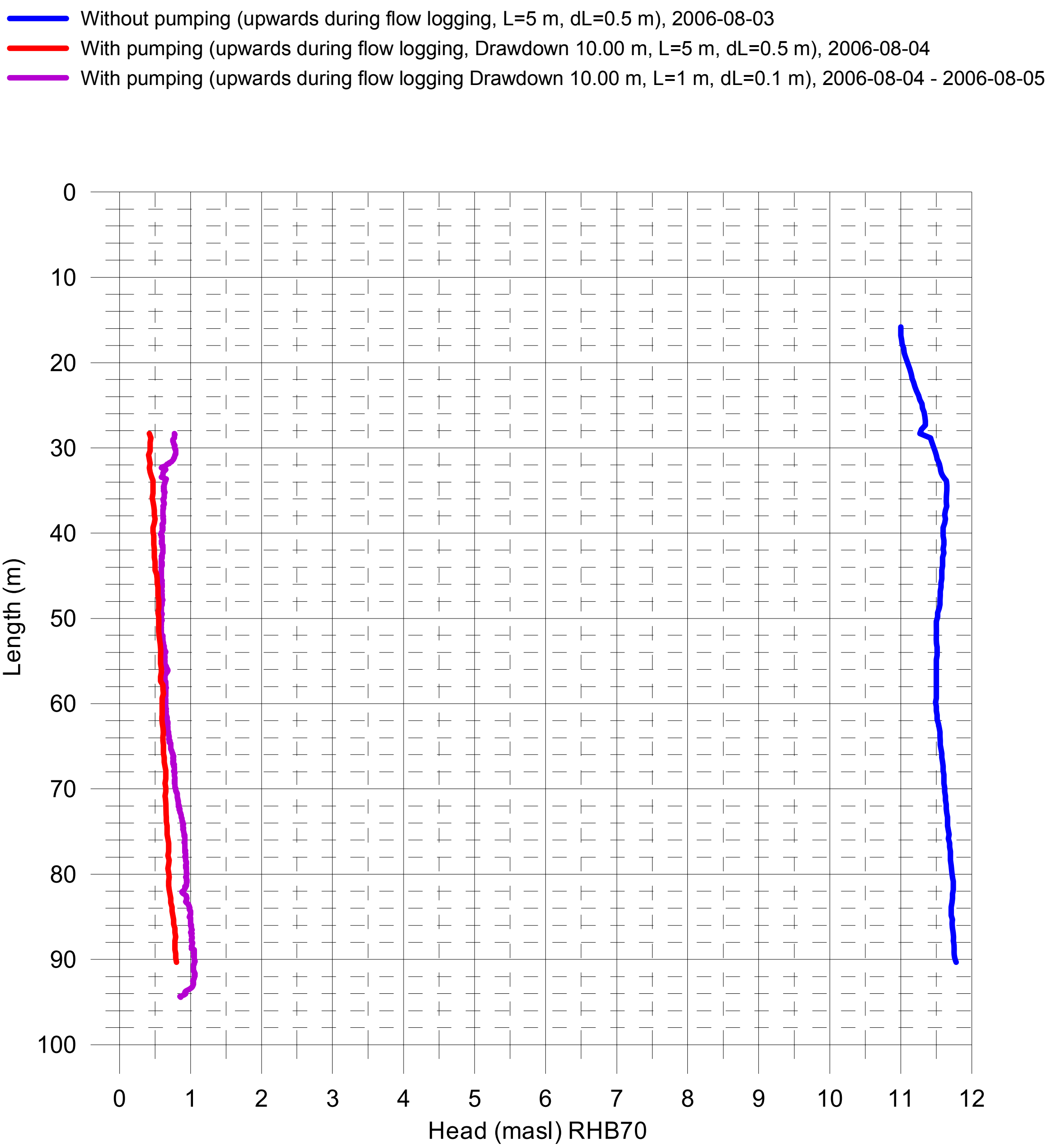


Laxemar, borehole KLX23A
Comparison between section transmissivity and fracture transmissivity

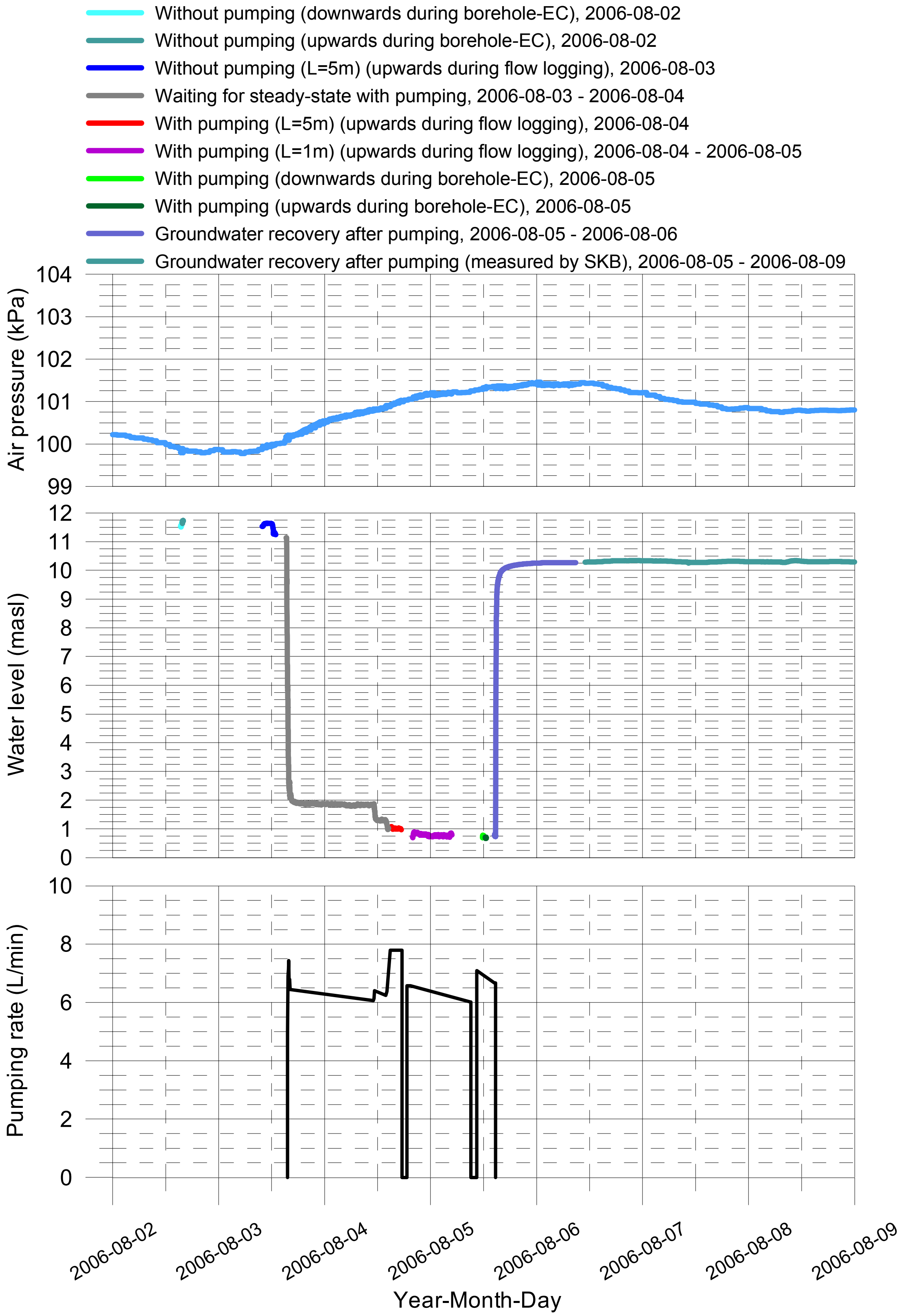


Laxemar, borehole KLX23A
Head in the borehole during flow logging

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)

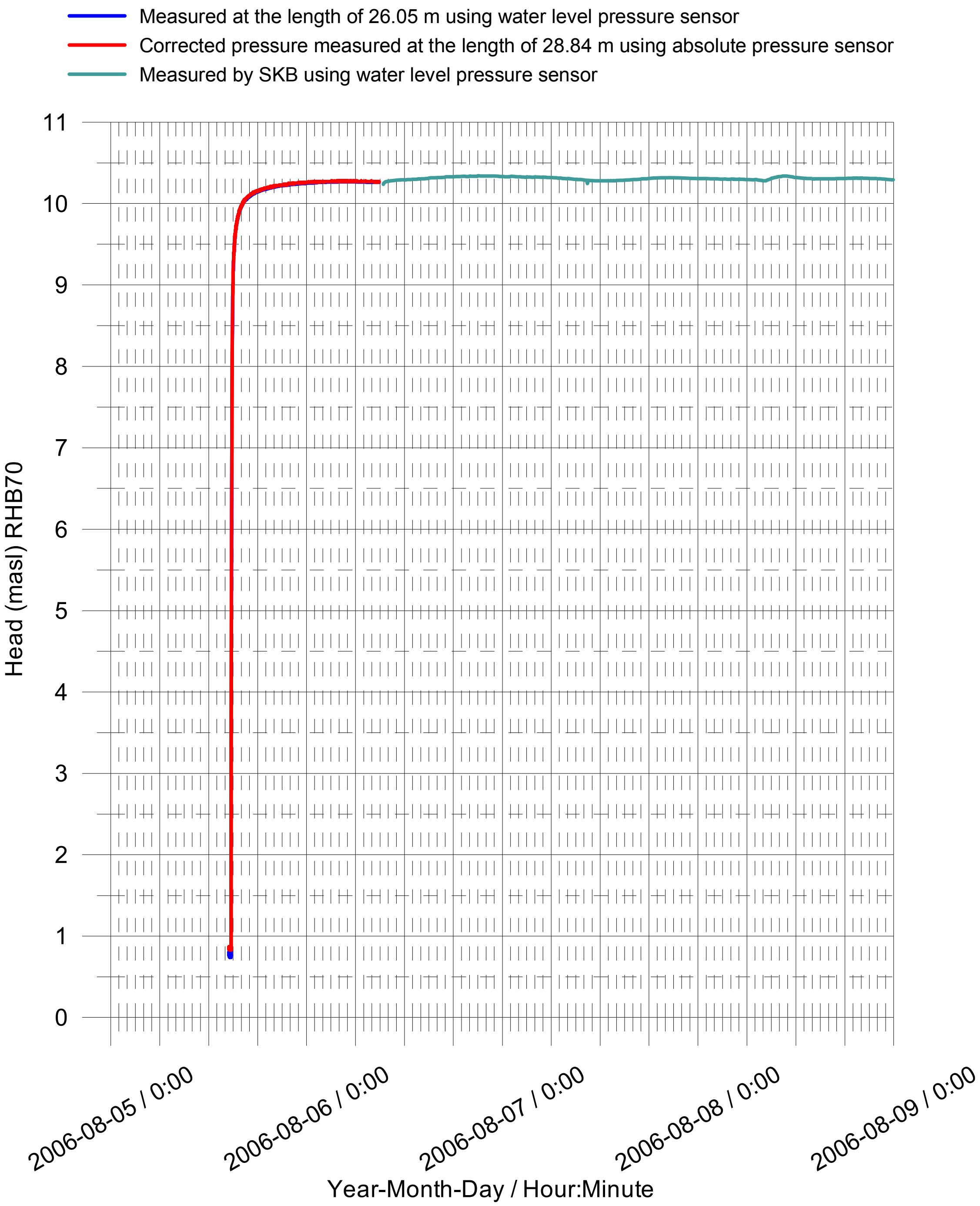


Laxemar, borehole KLX23A
Air pressure, water level in the borehole and pumping rate during flow logging



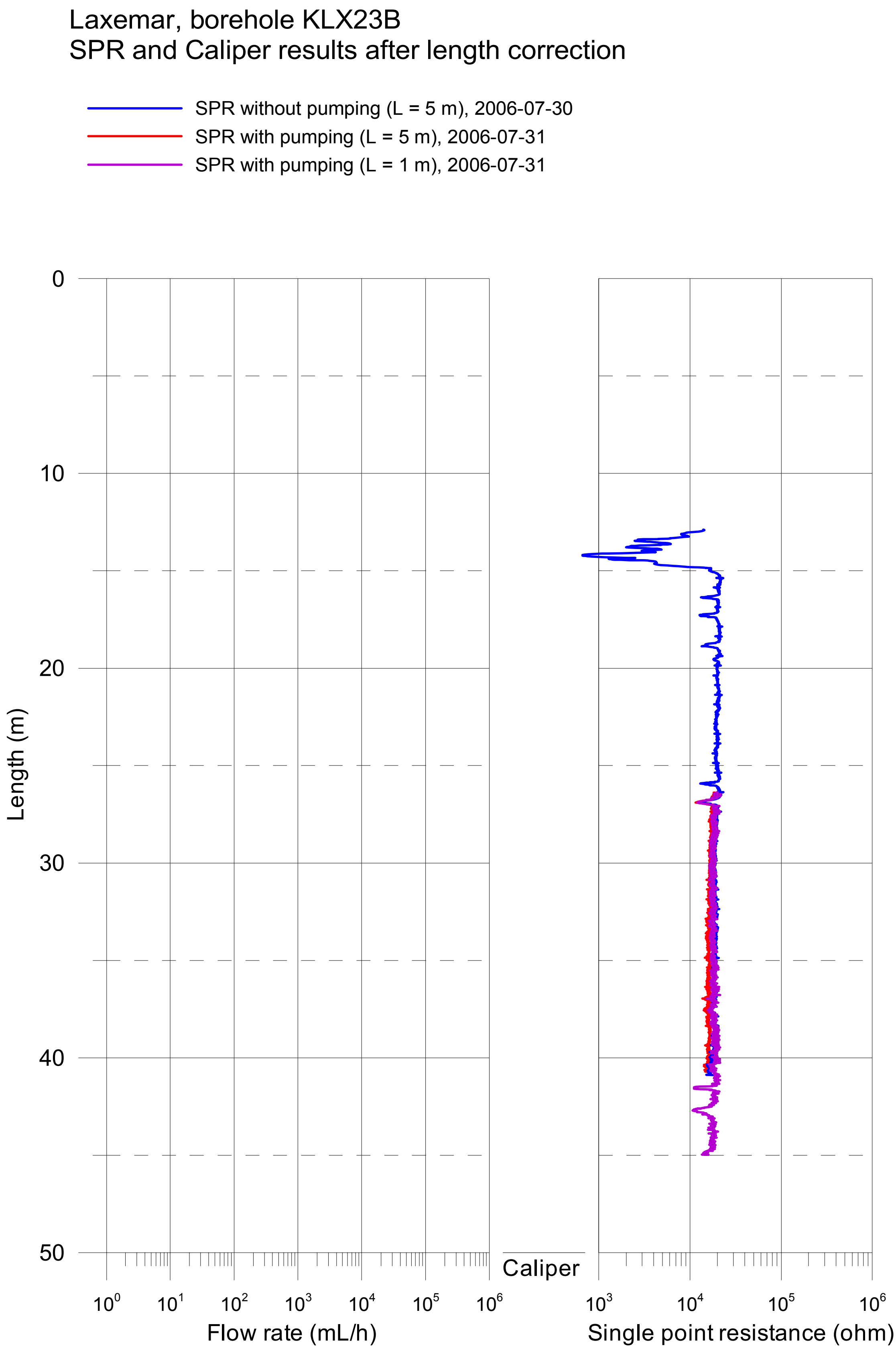
Laxemar, borehole KLX23A
Groundwater recovery after pumping

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

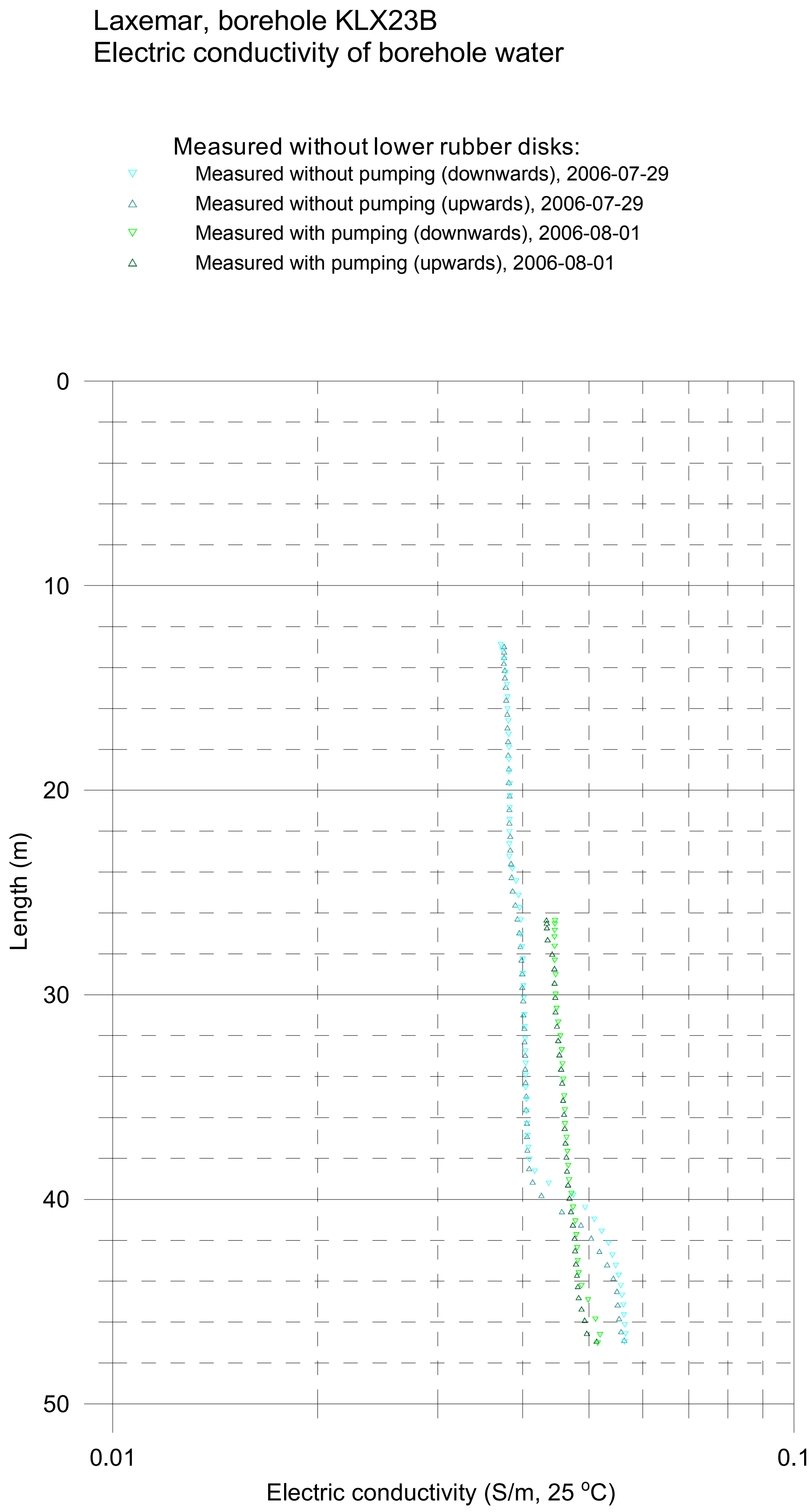


Appendices KLX23B

Appendices	23B.1	SPR results
Appendix	23B.2.1	Electric conductivity of borehole water
Appendix	23B.2.2	Temperature of borehole water
Appendix	23B.3.1–23B.3.3	Flow rate and single point resistance
Appendix	23B.4.1	Plotted flow rates of 5 m sections
Appendix	23B.4.2	Plotted transmissivity and head of 5 m sections
Appendix	23B.5	Plotted transmissivity and head of detected fractures
Appendix	23B.6	Basic test data
Appendix	23B.7	Results of sequential flow logging
Appendices	23B.8	Inferred flow anomalies from overlapping flow logging
Appendix	23B.9	Explanations for the tables in Appendices 6–8
Appendix	23B.10	Conductive fracture frequency
Appendix	23B.11	Plotted conductive fracture frequency
Appendix	23B.12	Comparison between section transmissivity and fracture transmissivity
Appendix	23B.13.1	Head in the borehole during flow logging
Appendix	23B.13.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	23B.13.3	Groundwater recovery after pumping

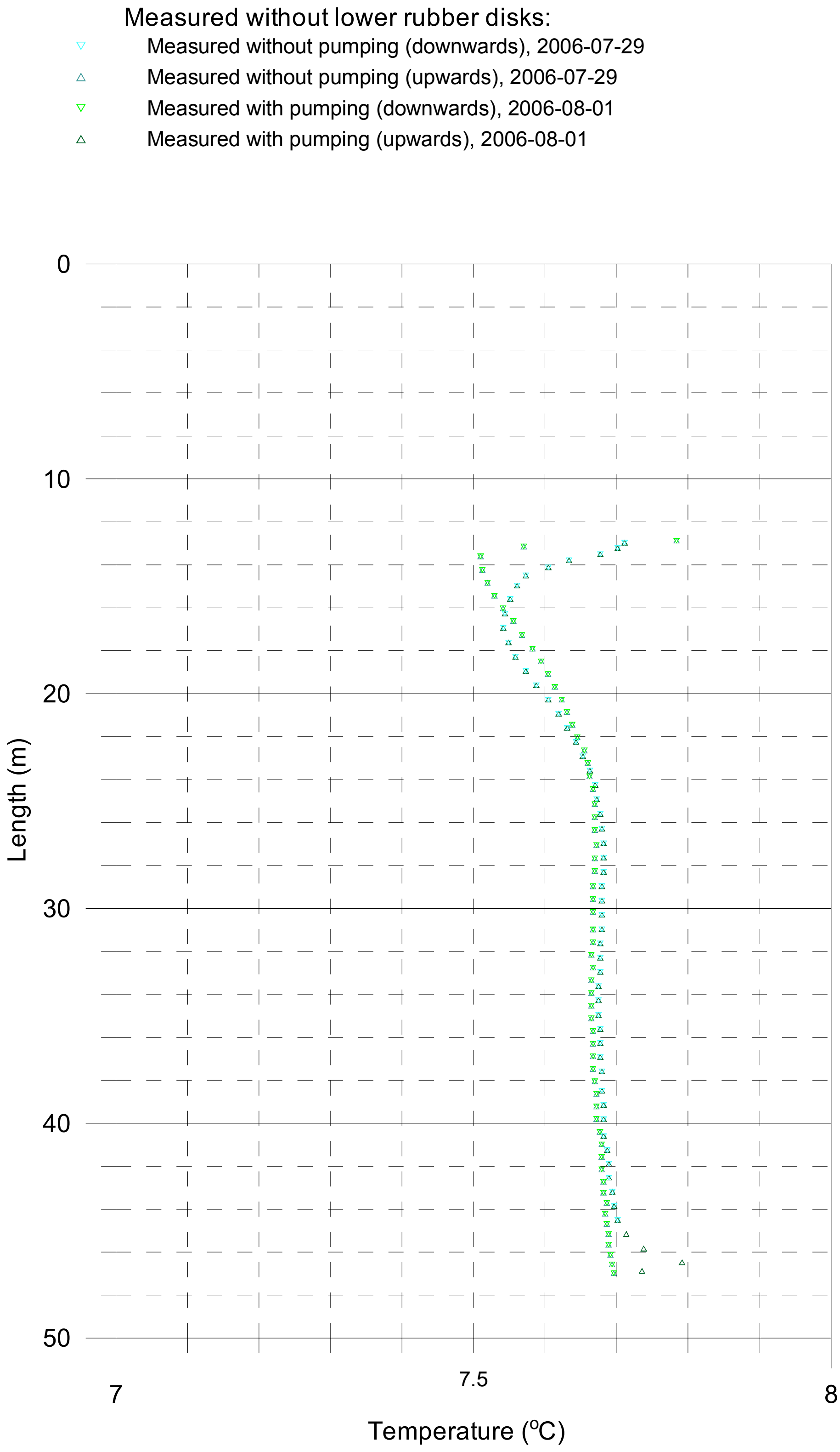


Laxemar, borehole KLX23B
SPR and Caliper results after length correction
SPR without pumping (L = 5 m), 2006-07-30
SPR with pumping (L = 5 m), 2006-07-31
SPR with pumping (L = 1 m), 2006-07-31
Length (m)
0
10
20
30
40
50
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^3 10^4 10^5 10^6
Single point resistance (ohm)

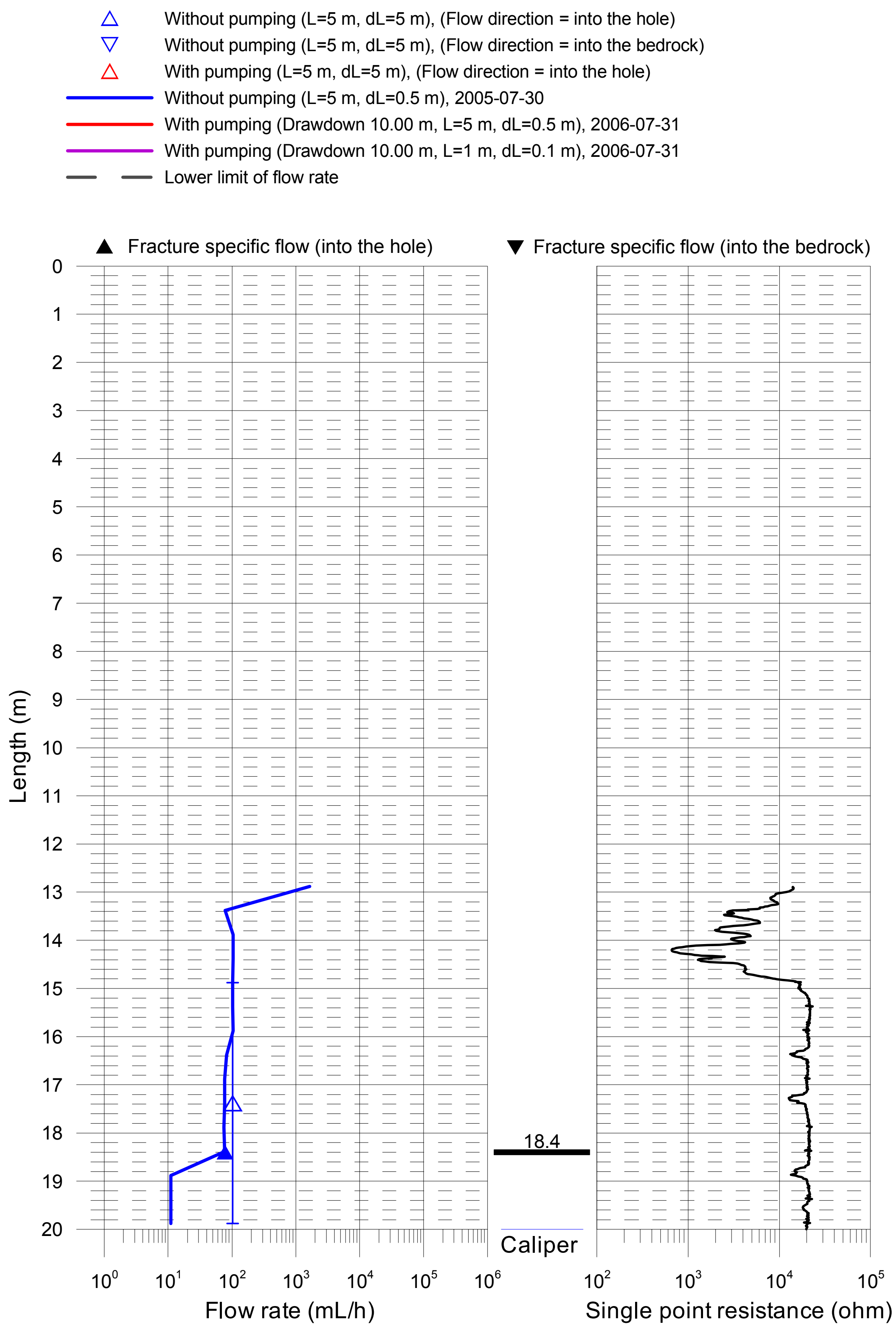


Laxemar, borehole KLX23B
Electric conductivity of borehole water
Measured without lower rubber disks:
Measured without pumping (downwards), 2006-07-29
Measured without pumping (upwards), 2006-07-29
Measured with pumping (downwards), 2006-08-01
Measured with pumping (upwards), 2006-08-01
0
10
20
30
40
50
Length (m)
0.01
0.1
Electric conductivity (S/m, 25 °C)

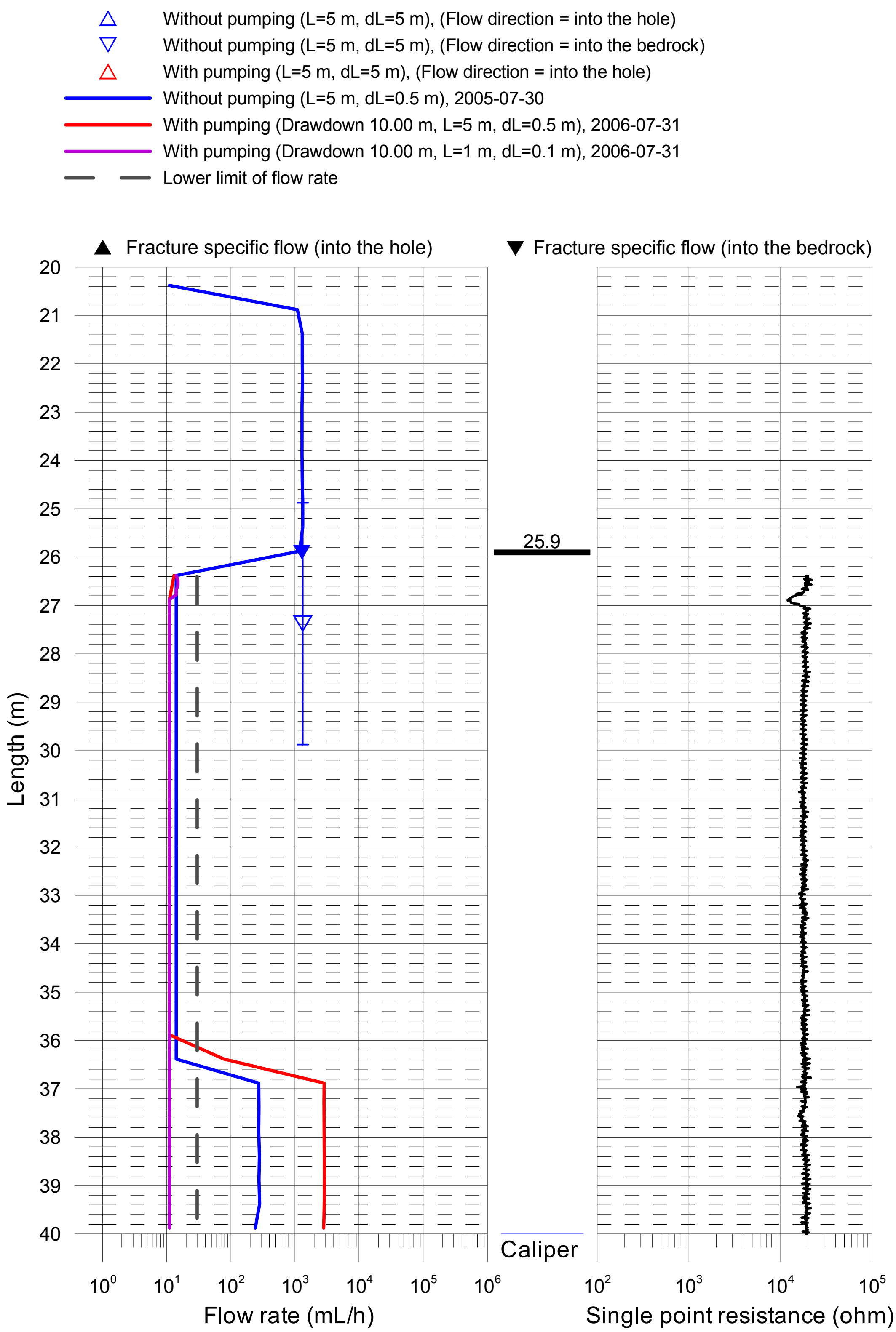
Laxemar, borehole KLX23B
Temperature of borehole water



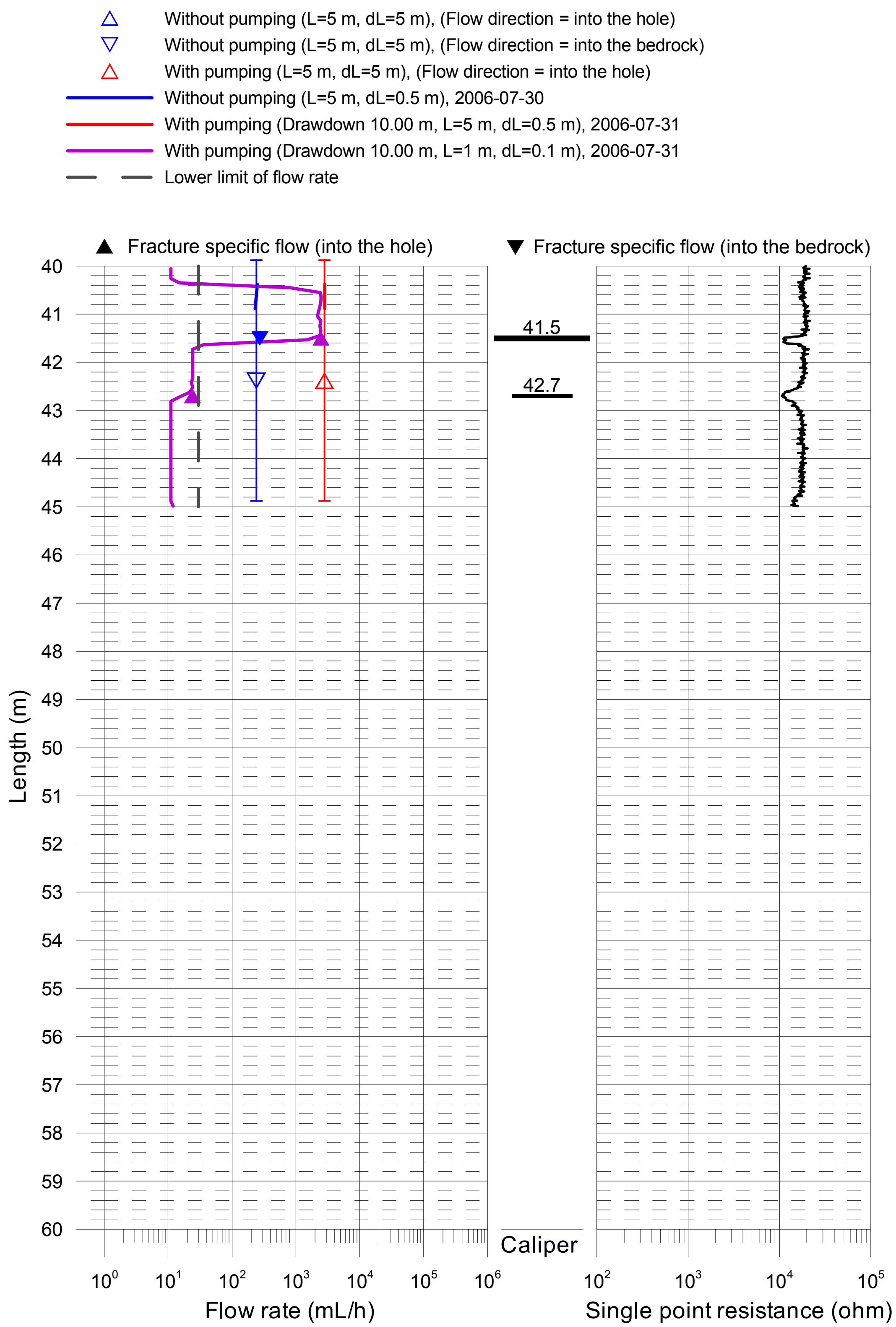
Laxemar, borehole KLX23B
Flow rate, caliper and single point resistance

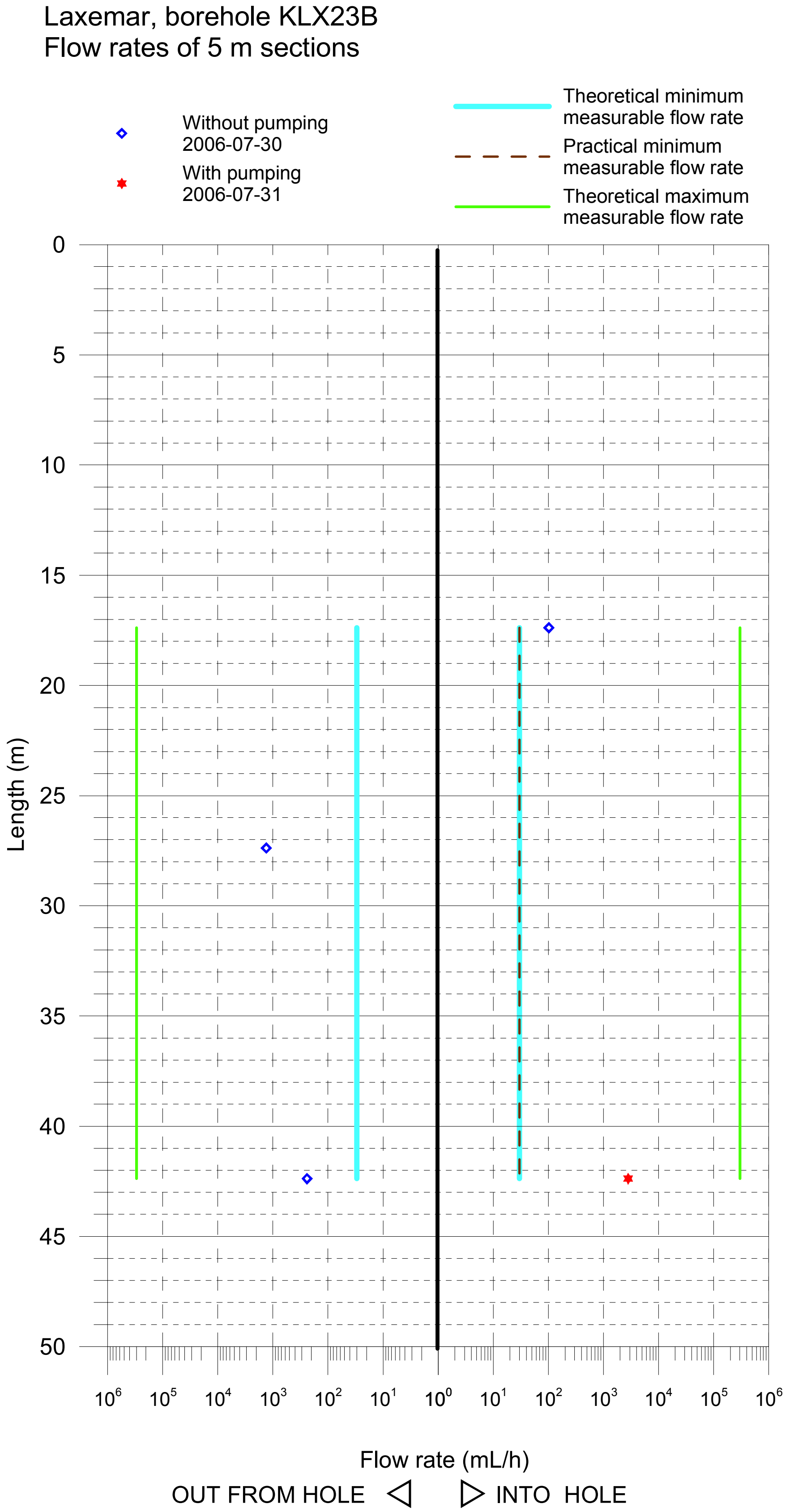


Laxemar, borehole KLX23B
Flow rate, caliper and single point resistance

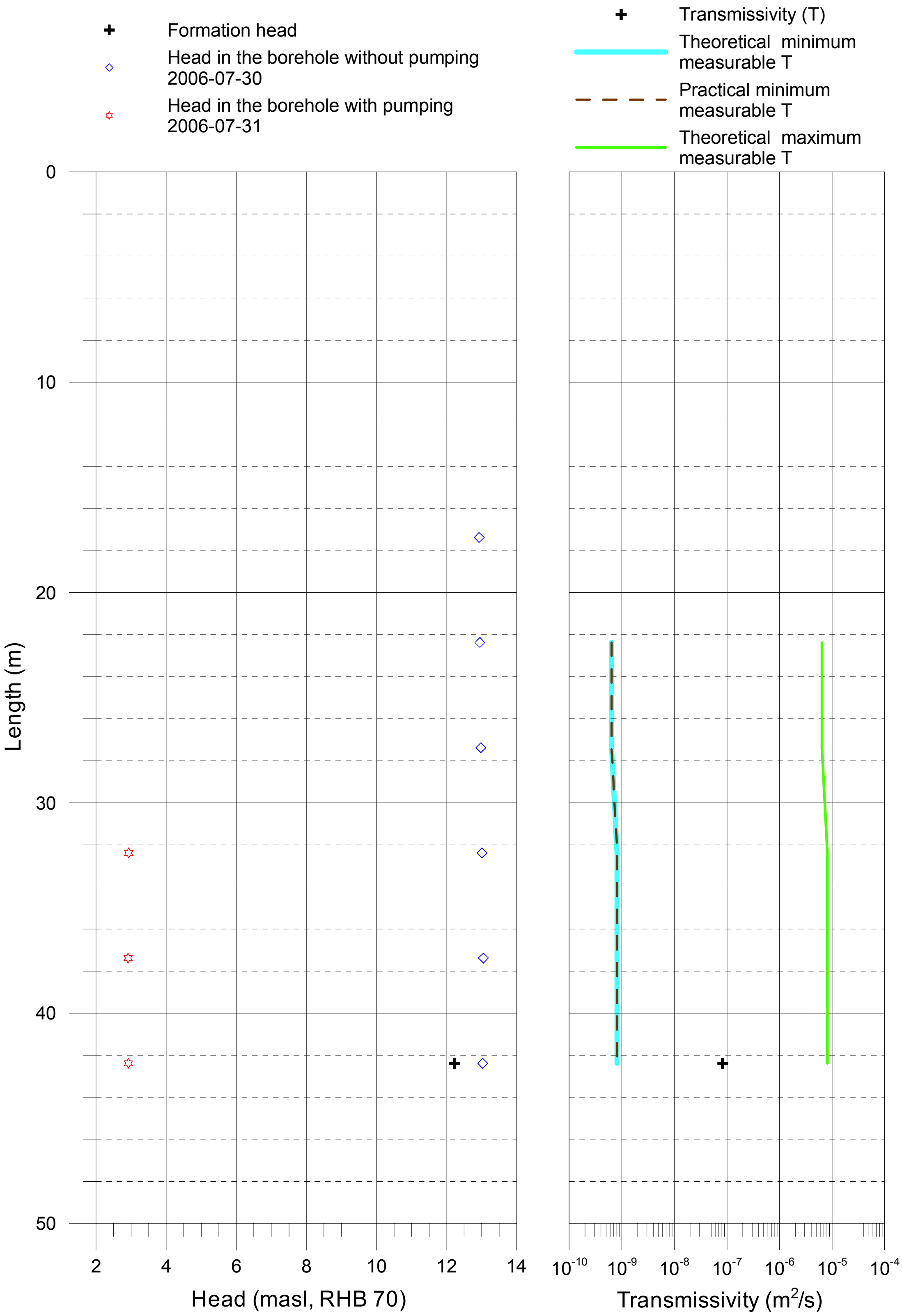


Laxemar, borehole KLX23B
Flow rate, caliper and single point resistance

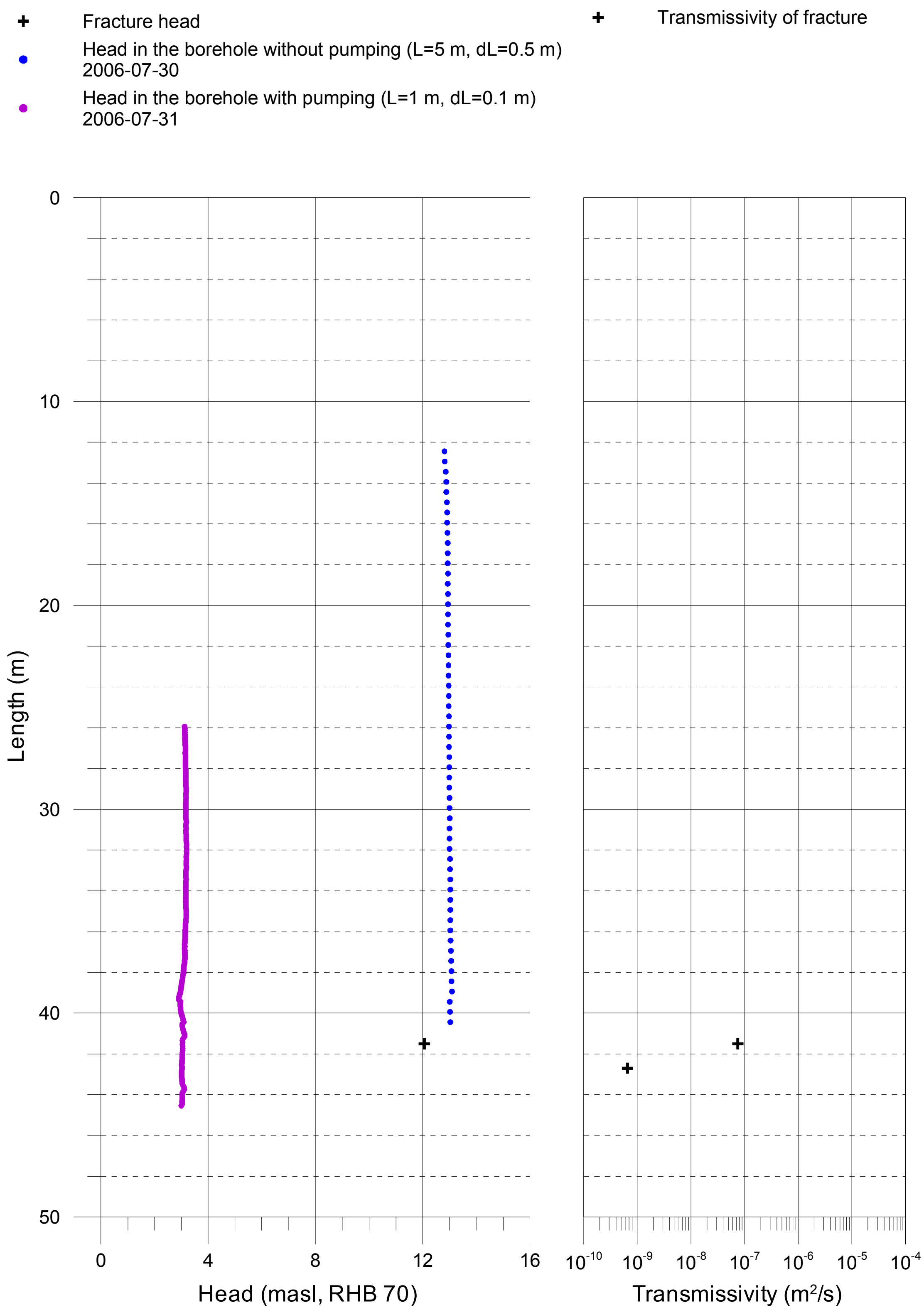



Laxemar, borehole KLX23B
Flow rates of 5 m sections
Without pumping
2006-07-30
With pumping
2006-07-31
Theoretical minimum
measurable flow rate
Practical minimum
measurable flow rate
Theoretical maximum
measurable flow rate
0
5
10
15
20
25
30
35
40
45
50
Length (m)
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
OUT FROM HOLE
INTO HOLE

Laxemar, borehole KLX23B
Transmissivity and head of 5 m sections



Laxemar, borehole KLX23B
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)
KLX23B	2.3	50.27	5A	20060730	15:38	20060731	15:44:00	20060801	13:02	5	0.5	1.67E–05	–

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

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (ma.s.l.)	h_1 (ma.s.l.)	h_2 (ma.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
163,440	–	1,732,920	–	12.99	3.10		–9.89	–	1.67E–06	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)
KLX23B	14.88	19.88	5	2.83E–08	12.93	–	–	–	–	30	–	–	–
KLX23B	19.88	24.88	5	–	12.95	–	–	–	–	30	–	–	–
KLX23B	24.88	29.88	5	–3.67E–07	12.98	–	–	–	–	30	–	–	–
KLX23B	29.88	34.88	5	–	13.01	–	2.93	–	–	30	8.2E–10	8.2E–10	8.2E–06
KLX23B	34.88	39.88	5	–	13.05	–	2.91	–	–	30	8.1E–10	8.1E–10	8.1E–06
KLX23B	39.88	44.88	5	–6.67E–08	13.03	7.81E–07	2.92	8.3E–08	12.2	30	8.2E–10	8.2E–10	8.2E–06

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

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KLX23B	18.4	1	0.1	2.17E–08	12.94	–	–	–	–	
KLX23B	25.9	1	0.1	–3.56E–07	12.98	–	–	–	–	
KLX23B	41.5	1	0.1	–7.58E–08	13.06	6.83E–07	3.04	7.5E–08	12.1	
KLX23B	42.7	1	0.1	–	13.07	6.67E–09	3.02	6.6E–10	–	*

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

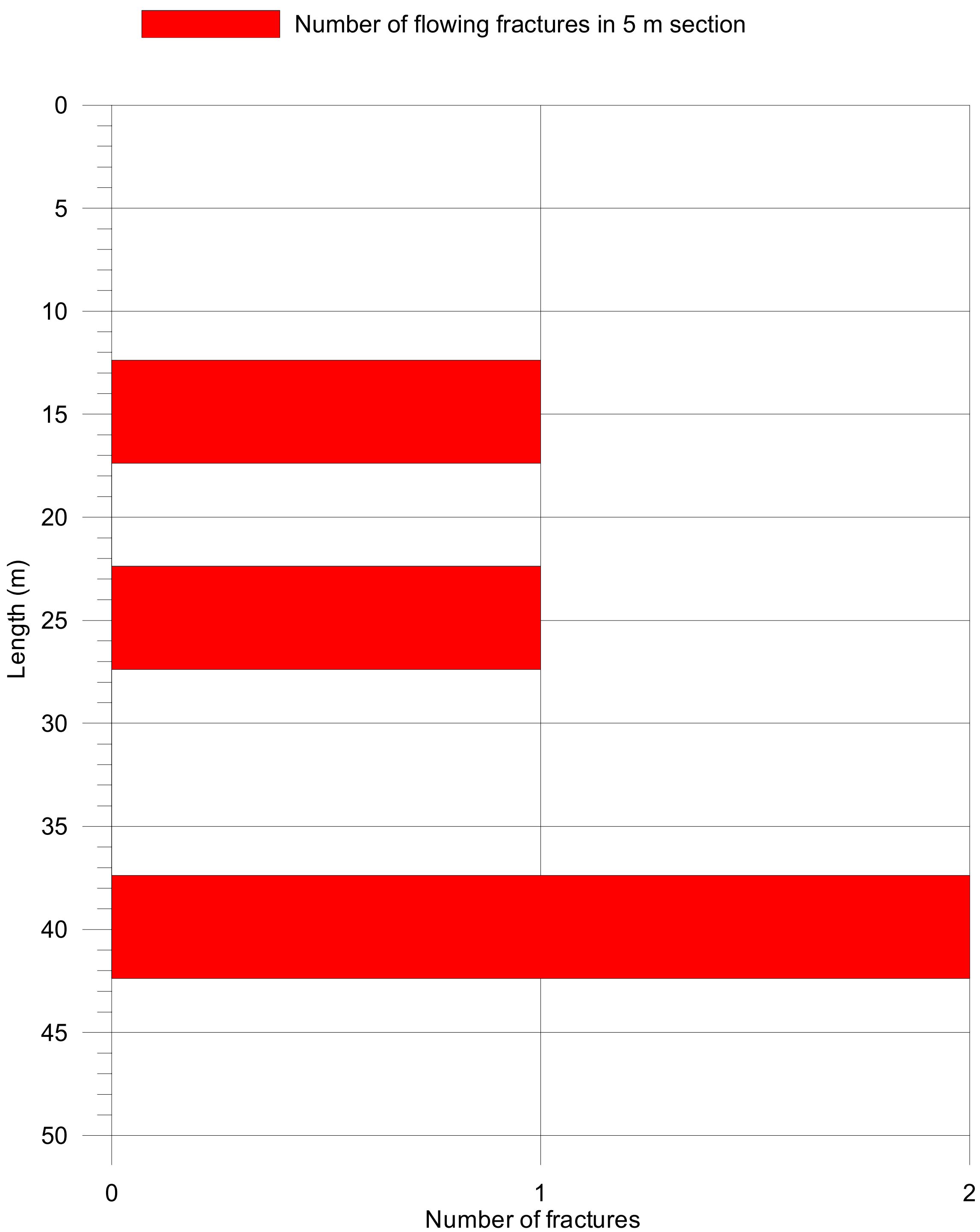
Explanations.

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.
$T\text{-measl}_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
$T\text{-measl}_{U}$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

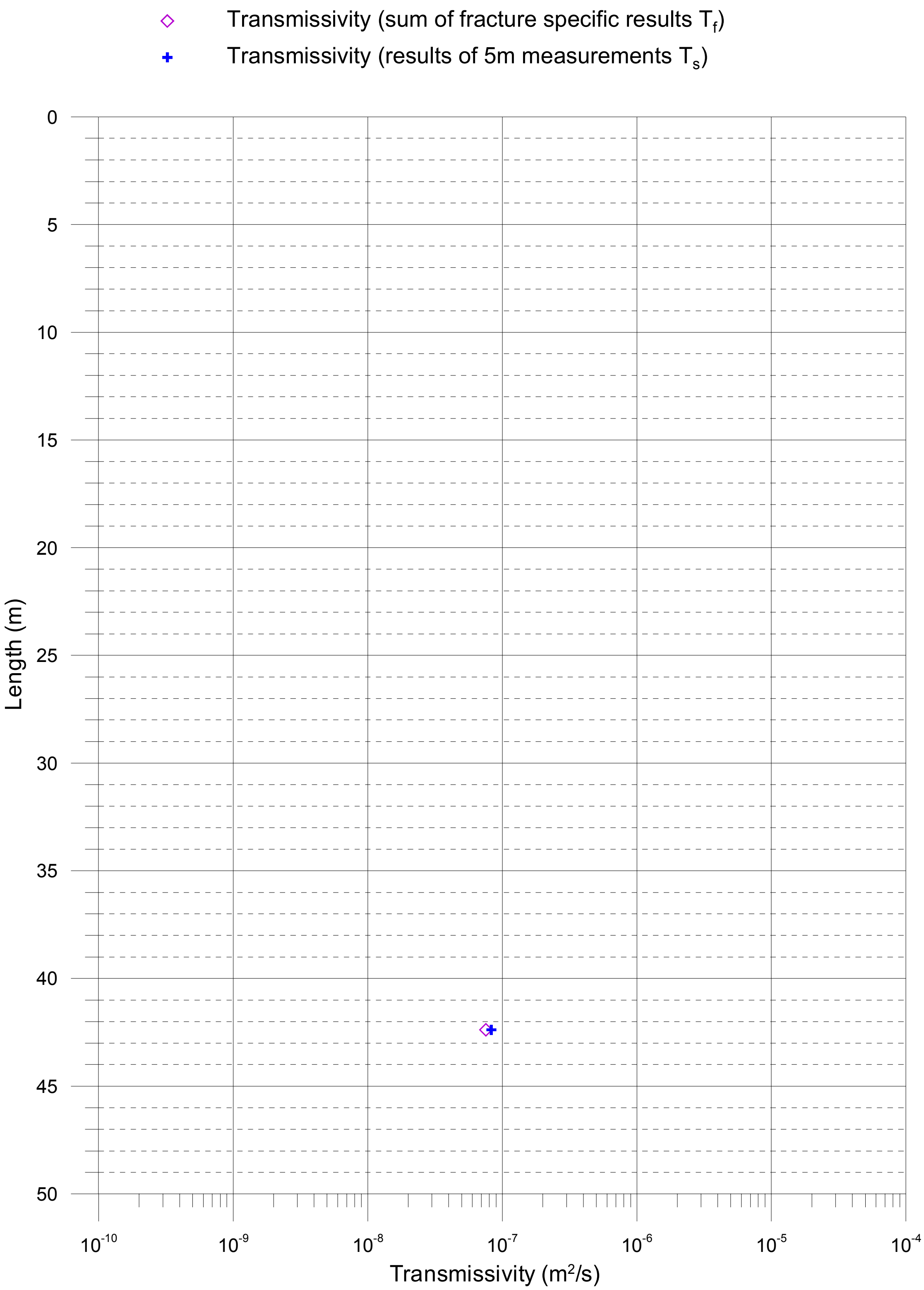
Calculation of conductive fracture frequency.

Borehole ID	SecUp (m)	SecLow (m)	Number Of Fractures, Total	Number Of Fractures 10–100 (mL/h)	Number Of Fractures 100–1000 (mL/h)	Number Of Fractures 1000–10000 (mL/h)	Number Of Fractures 10000–100000 (mL/h)	Number Of Fractures 100000–1000000 (mL/h)
KLX23B	14.88	19.88	1	–	–	–	–	–
KLX23B	19.88	24.88	0	–	–	–	–	–
KLX23B	24.88	29.88	1	–	–	–	–	–
KLX23B	29.88	34.88	0	0	0	0	0	0
KLX23B	34.88	39.88	0	0	0	0	0	0
KLX23B	39.88	44.88	2	1	0	1	0	0

Laxemar, borehole KLX23B
Calculation of conductive fracture frequency

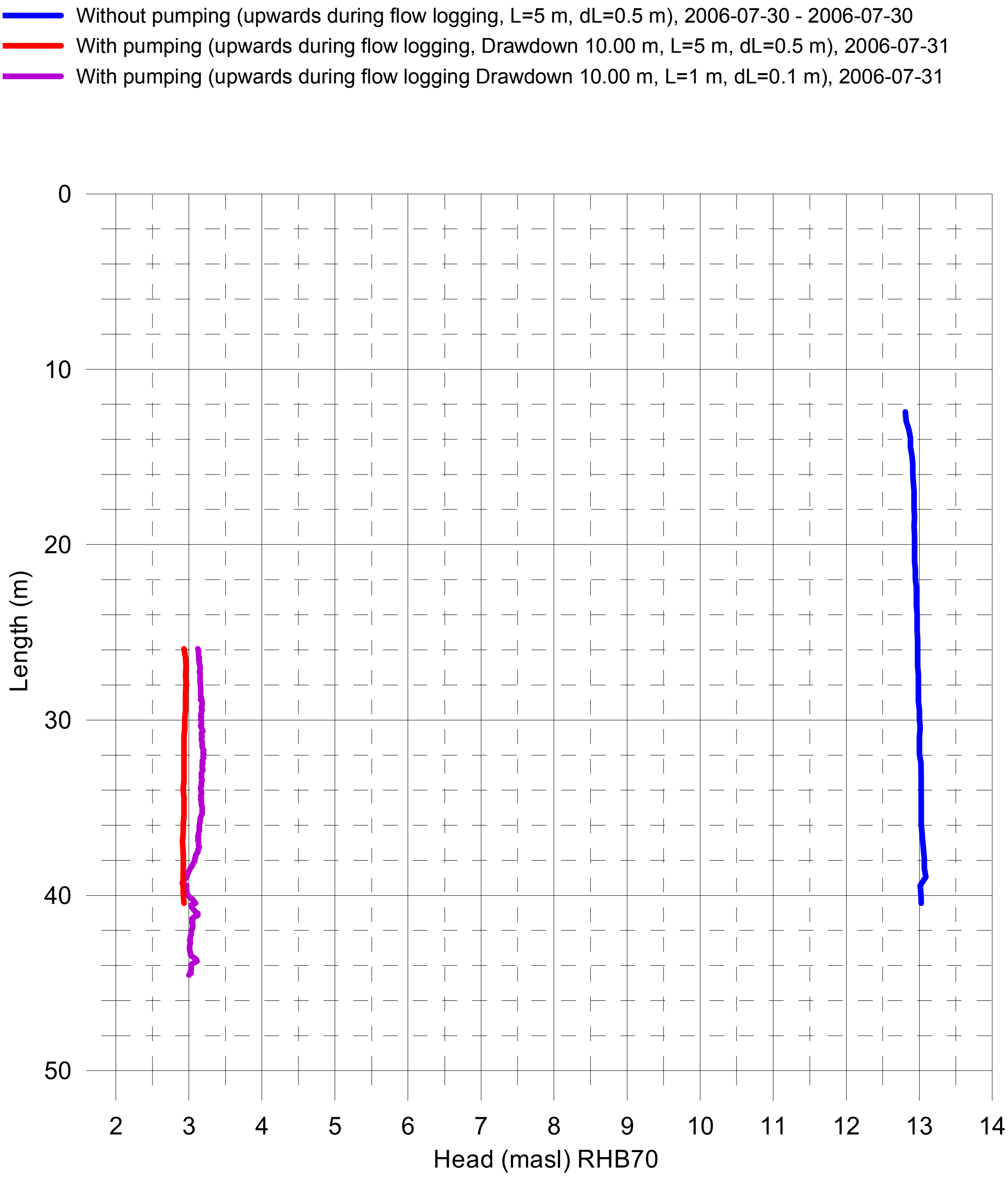


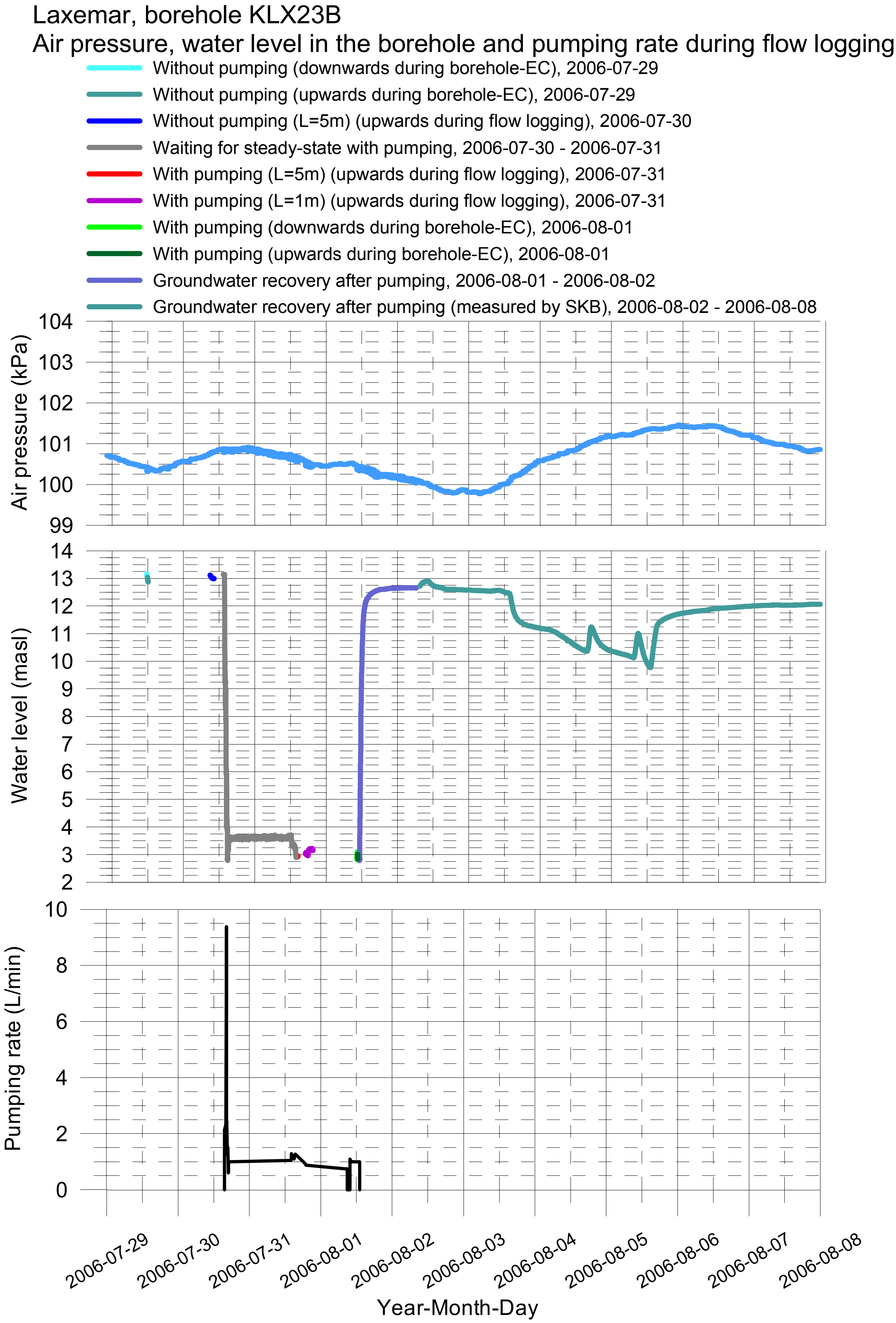
Laxemar, borehole KLX23B
Comparison between section transmissivity and fracture transmissivity



Laxemar, borehole KLX23B
Head in the borehole during flow logging

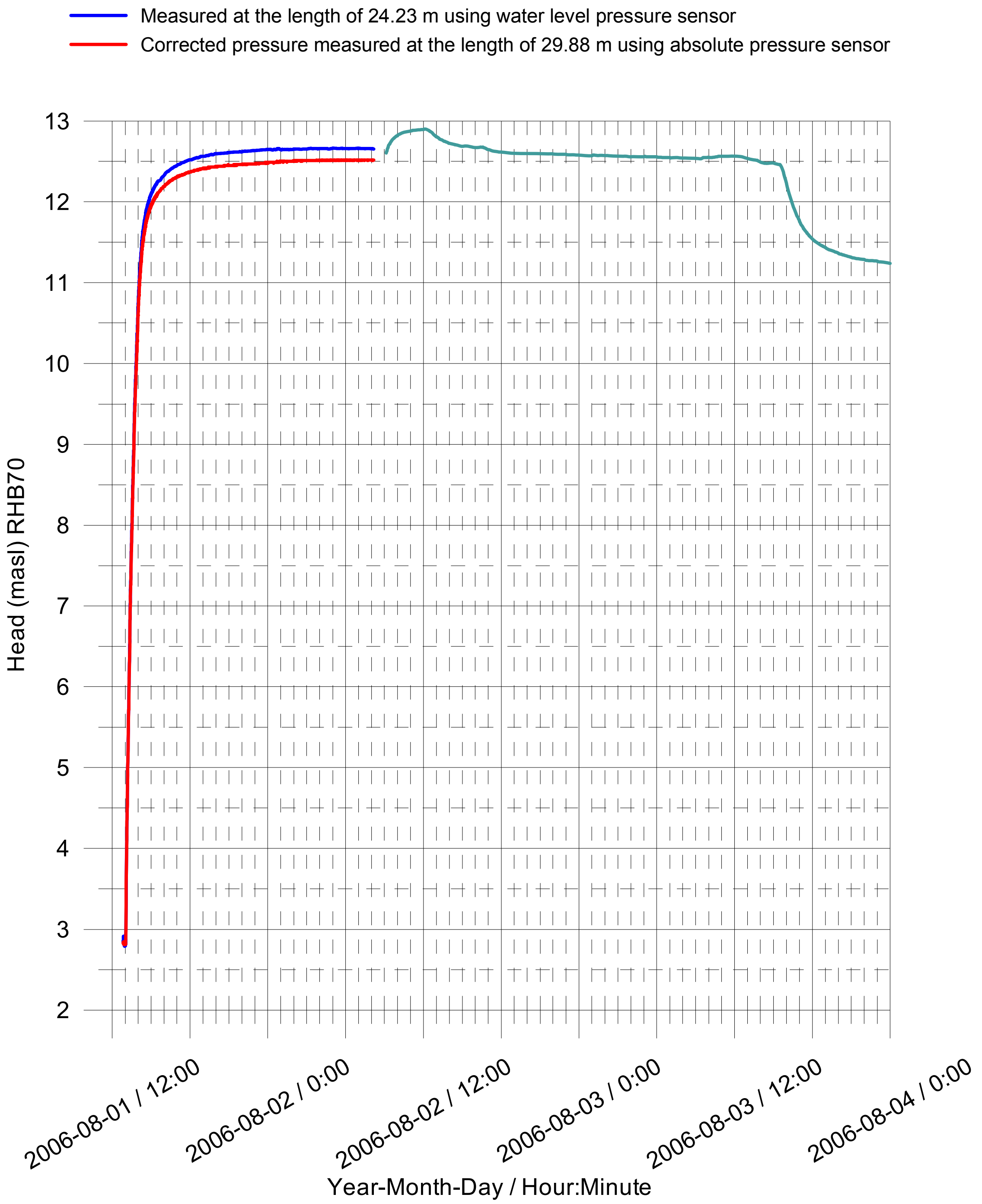
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)




Laxemar, borehole KLX23B
Air pressure, water level in the borehole and pumping rate during flow logging
Without pumping (downwards during borehole-EC), 2006-07-29
Without pumping (upwards during borehole-EC), 2006-07-29
Without pumping (L=5m) (upwards during flow logging), 2006-07-30
Waiting for steady-state with pumping, 2006-07-30 - 2006-07-31
With pumping (L=5m) (upwards during flow logging), 2006-07-31
With pumping (L=1m) (upwards during flow logging), 2006-07-31
With pumping (downwards during borehole-EC), 2006-08-01
With pumping (upwards during borehole-EC), 2006-08-01
Groundwater recovery after pumping, 2006-08-01 - 2006-08-02
Groundwater recovery after pumping (measured by SKB), 2006-08-02 - 2006-08-08
Air pressure (kPa)
104
103
102
101
100
99
Water level (masl)
14
13
12
11
10
9
8
7
6
5
4
3
2
Pumping rate (L/min)
10
8
6
4
2
0
2006-07-29
2006-07-30
2006-07-31
2006-08-01
2006-08-02
2006-08-03
2006-08-04
2006-08-05
2006-08-06
2006-08-07
2006-08-08
Year-Month-Day

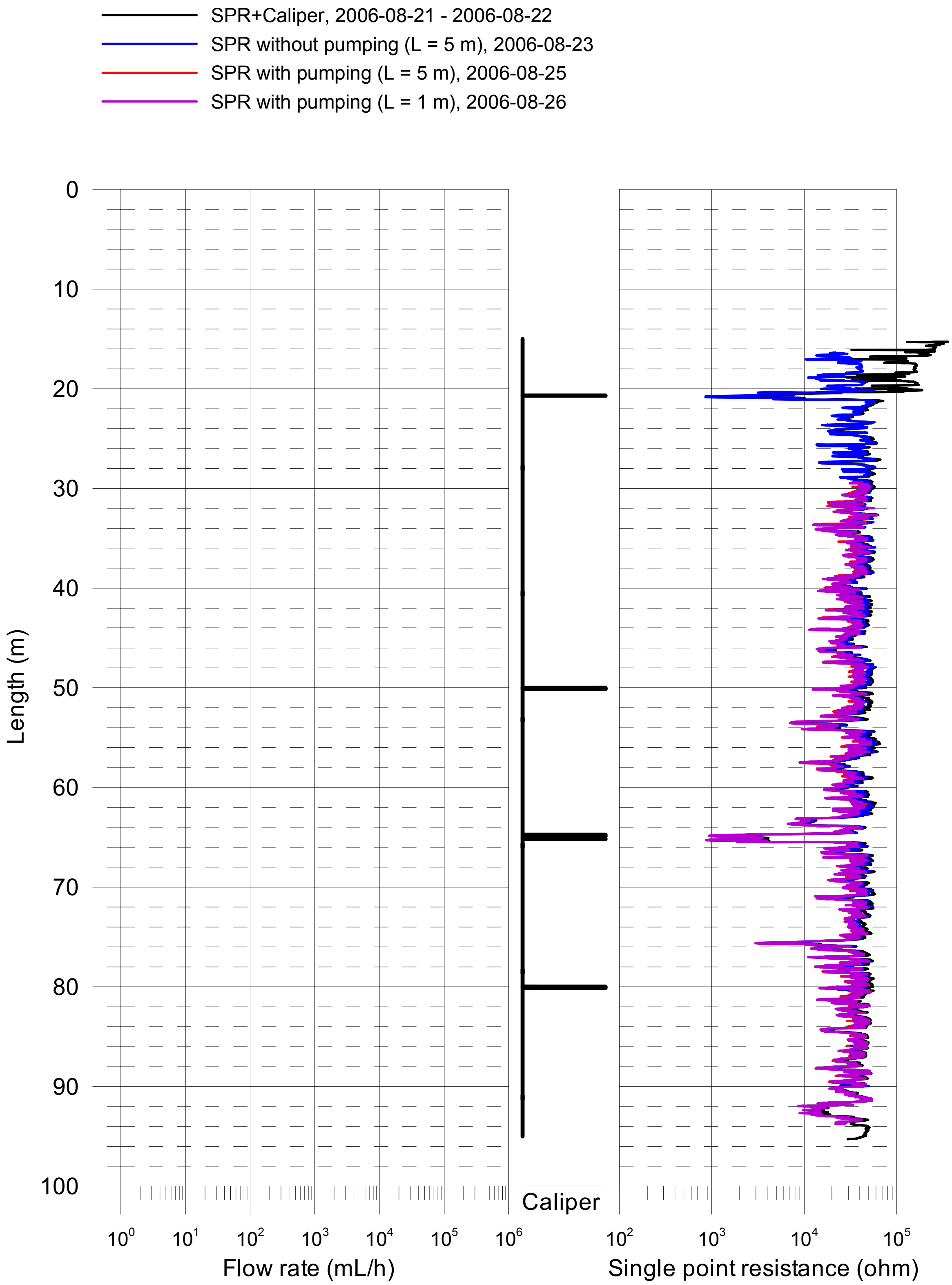
Laxemar, borehole KLX23B
Groundwater recovery after pumping

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)

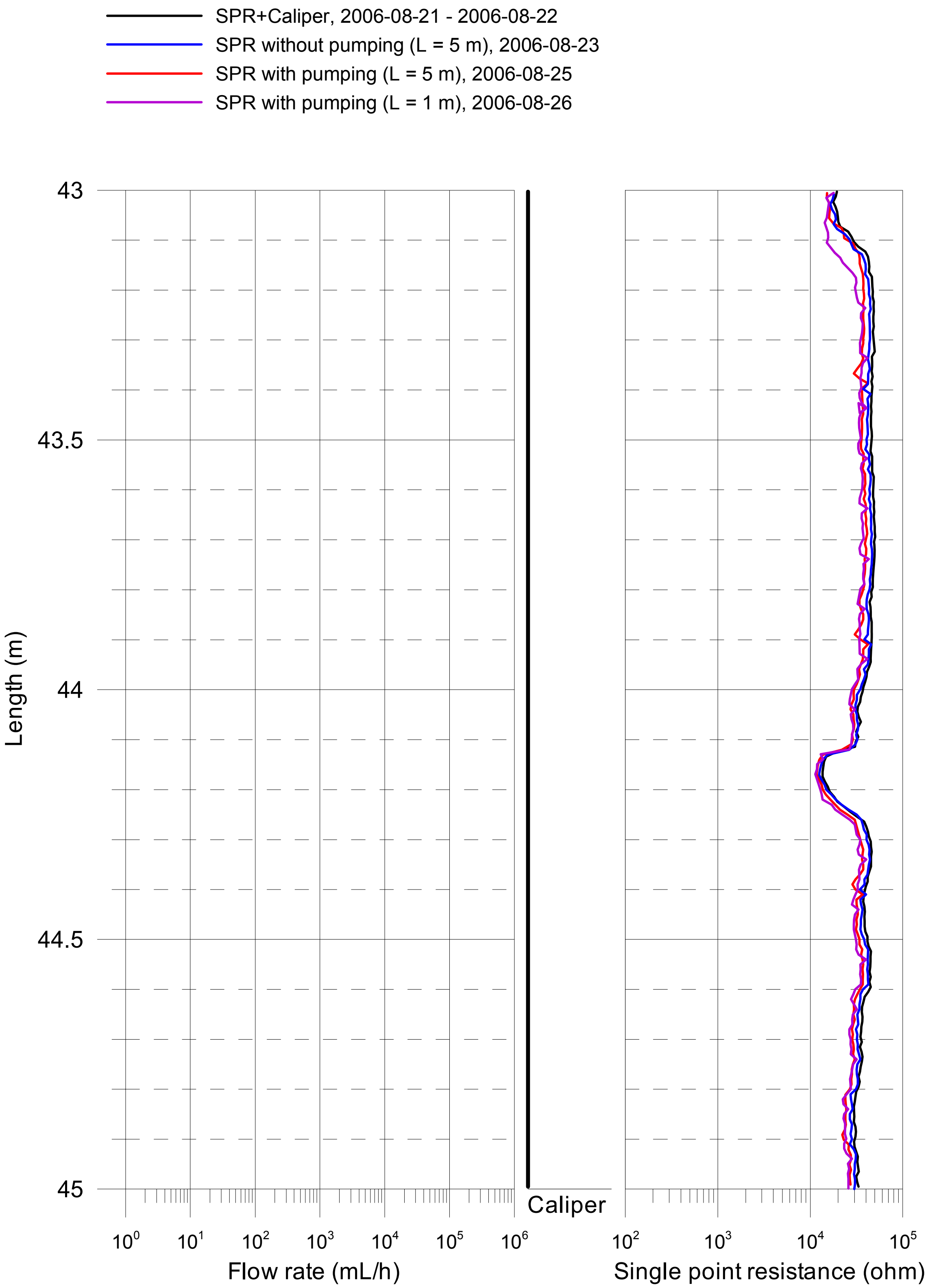


Appendices KLX24A

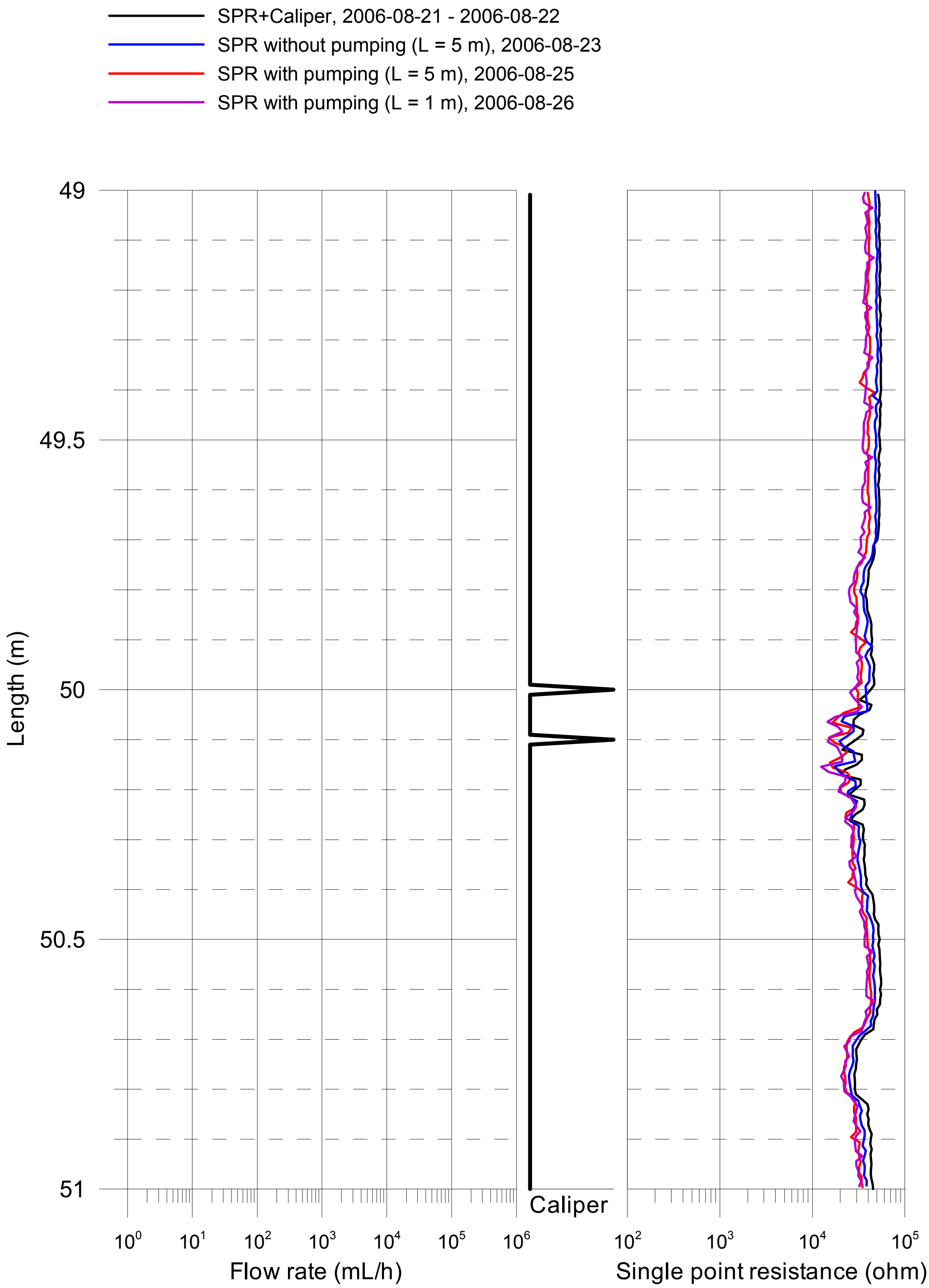
Laxemar, borehole KLX24A
SPR and Caliper results after length correction



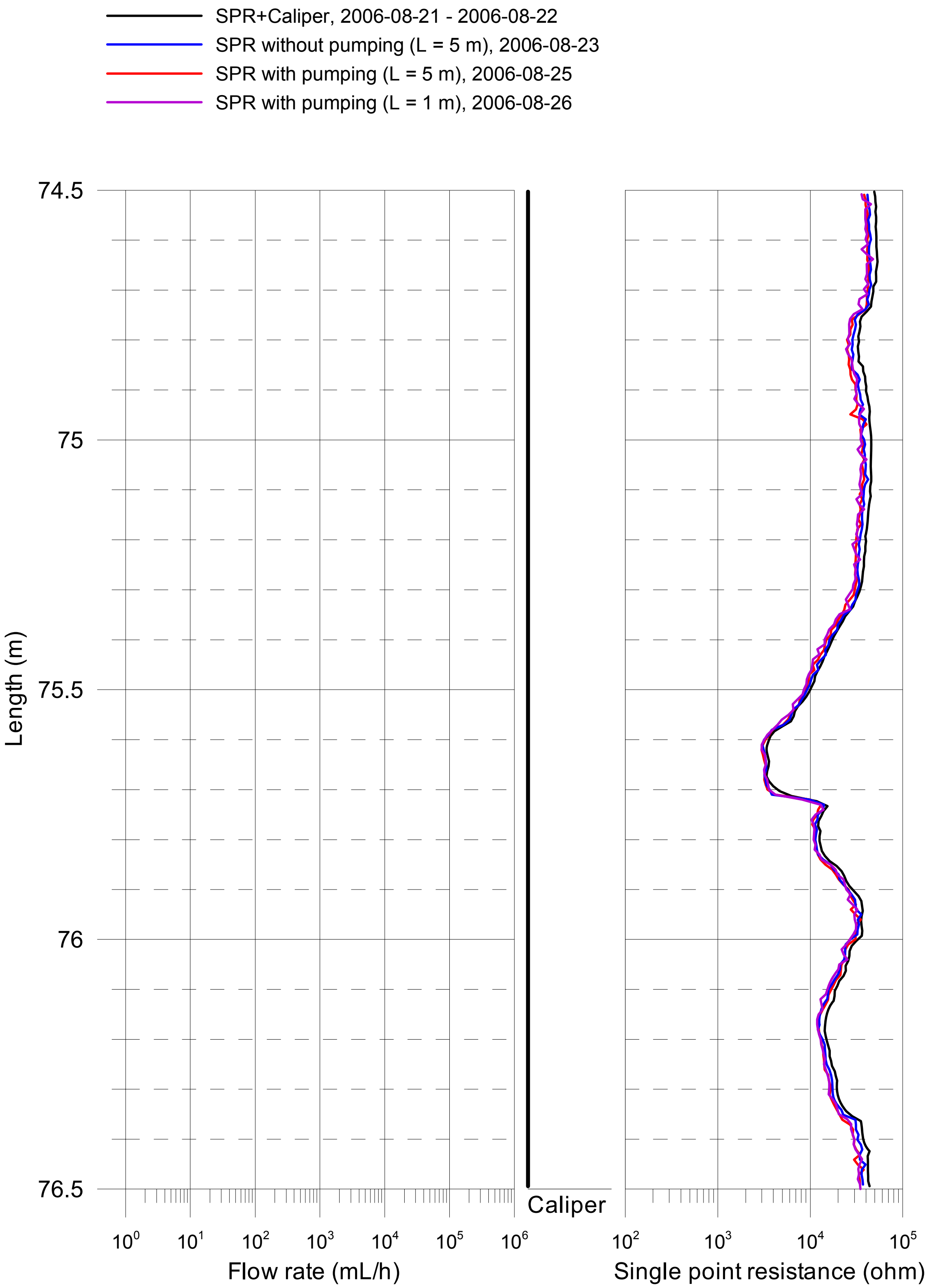
Laxemar, borehole KLX24A
SPR and Caliper results after length correction



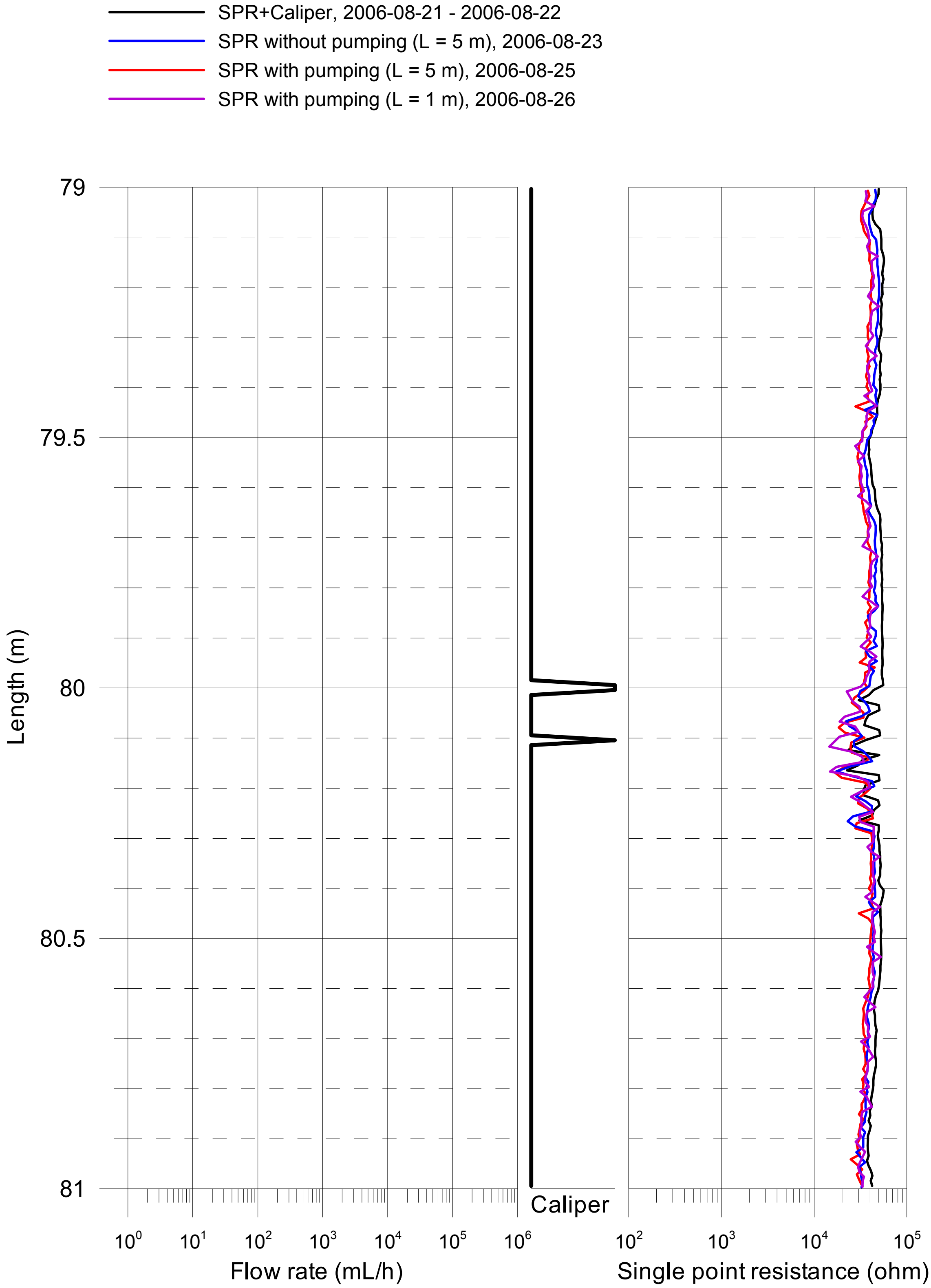
Laxemar, borehole KLX24A
SPR and Caliper results after length correction



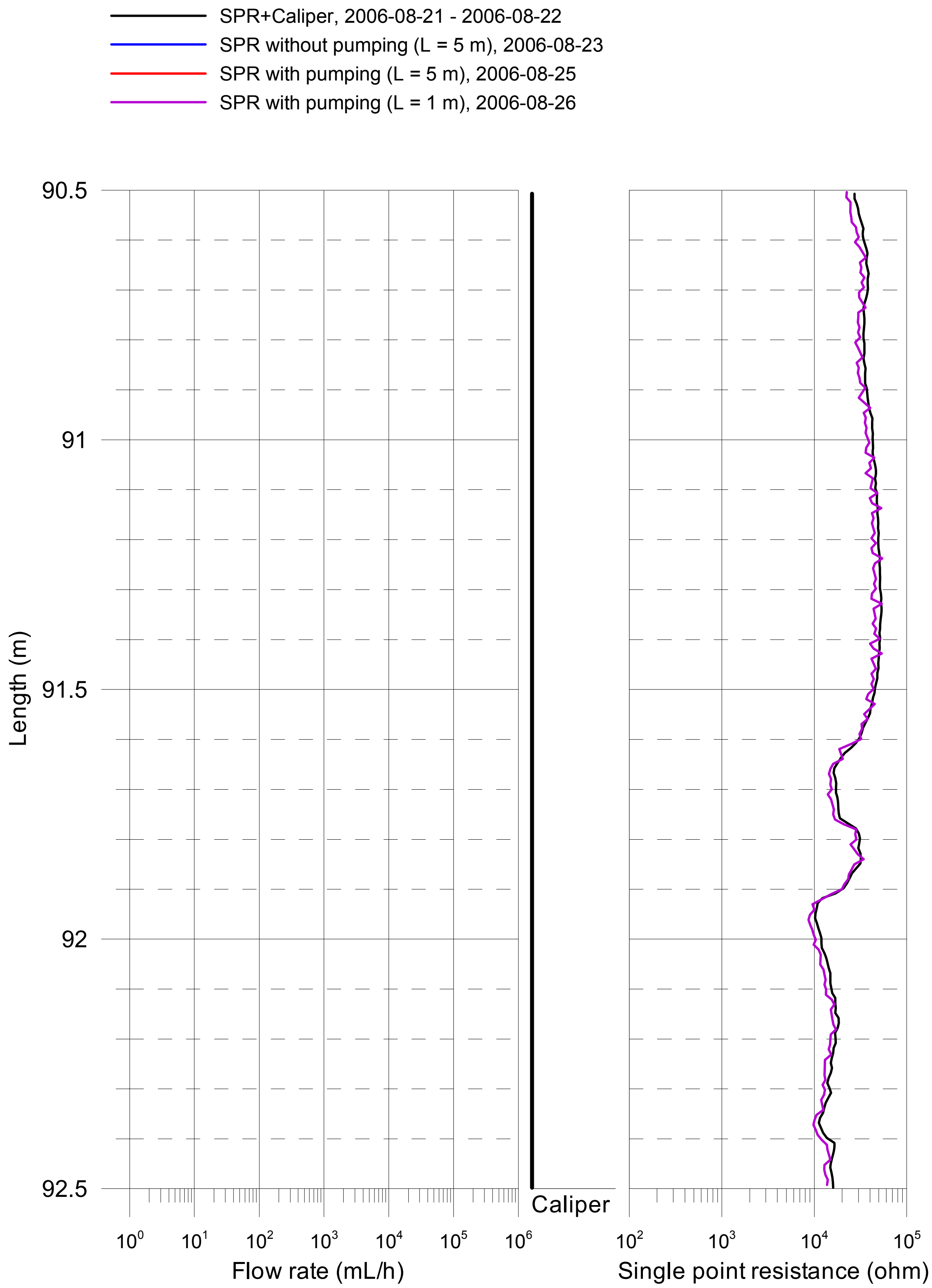
Laxemar, borehole KLX24A
SPR and Caliper results after length correction



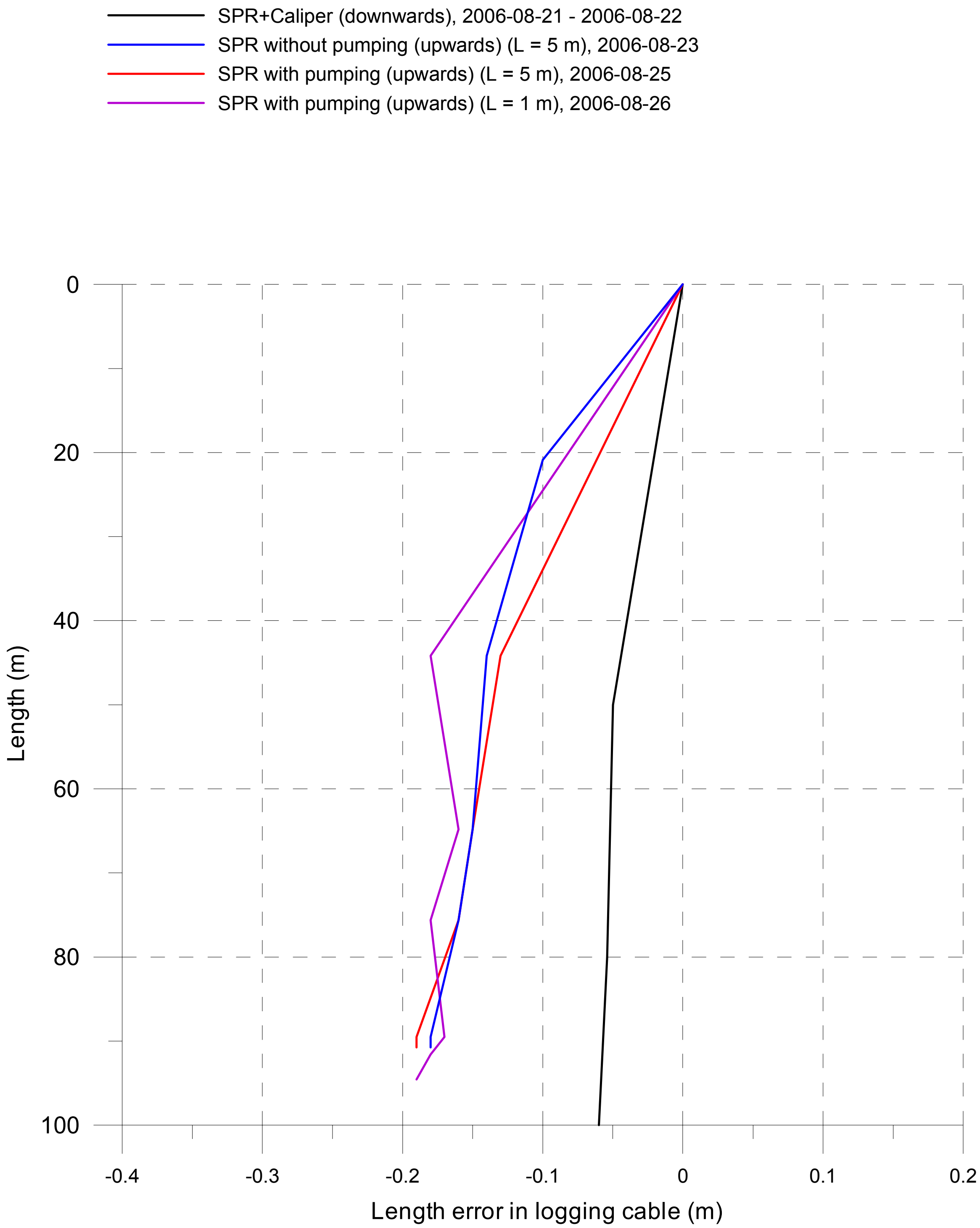
Laxemar, borehole KLX24A
SPR and Caliper results after length correction



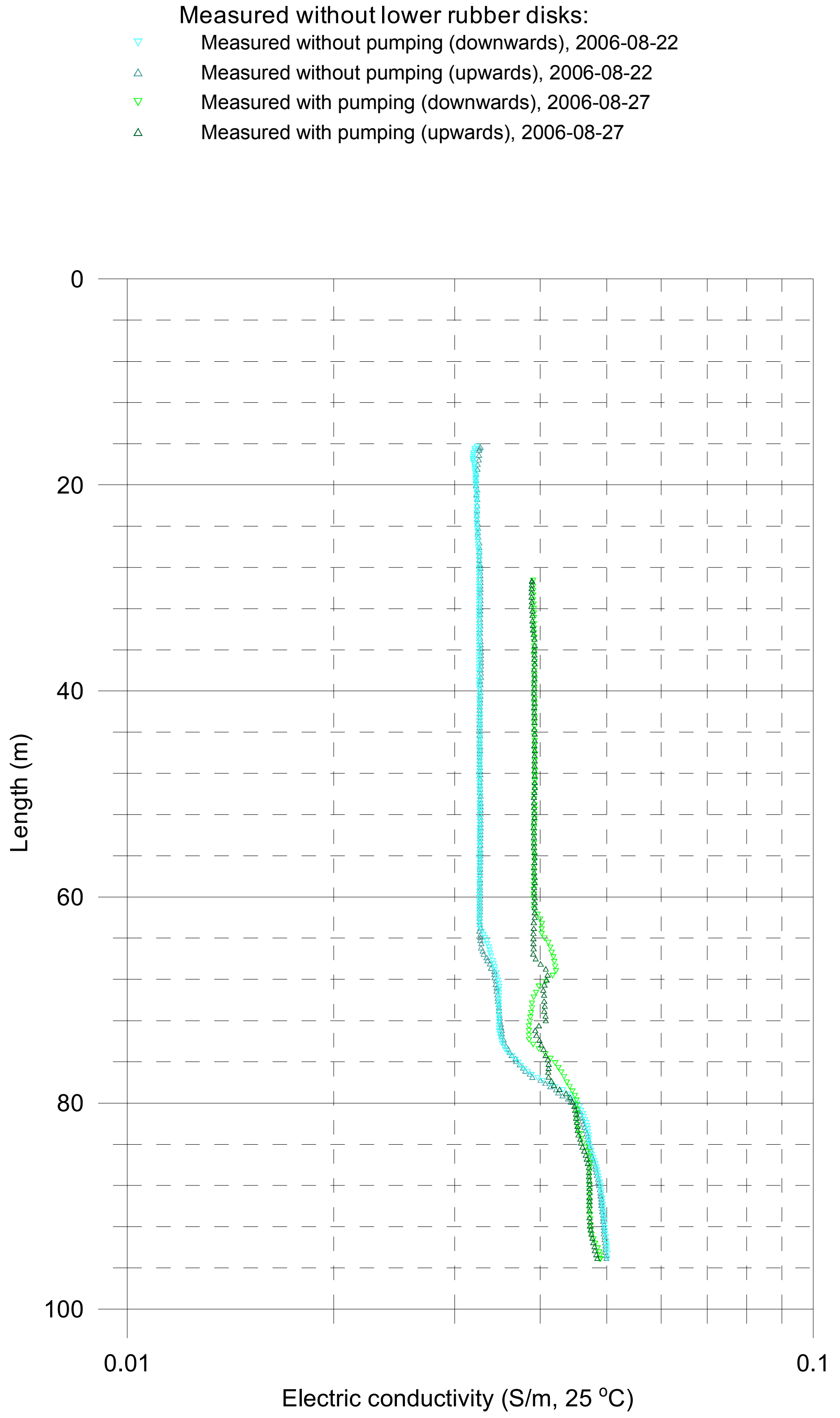
Laxemar, borehole KLX24A
SPR and Caliper results after length correction



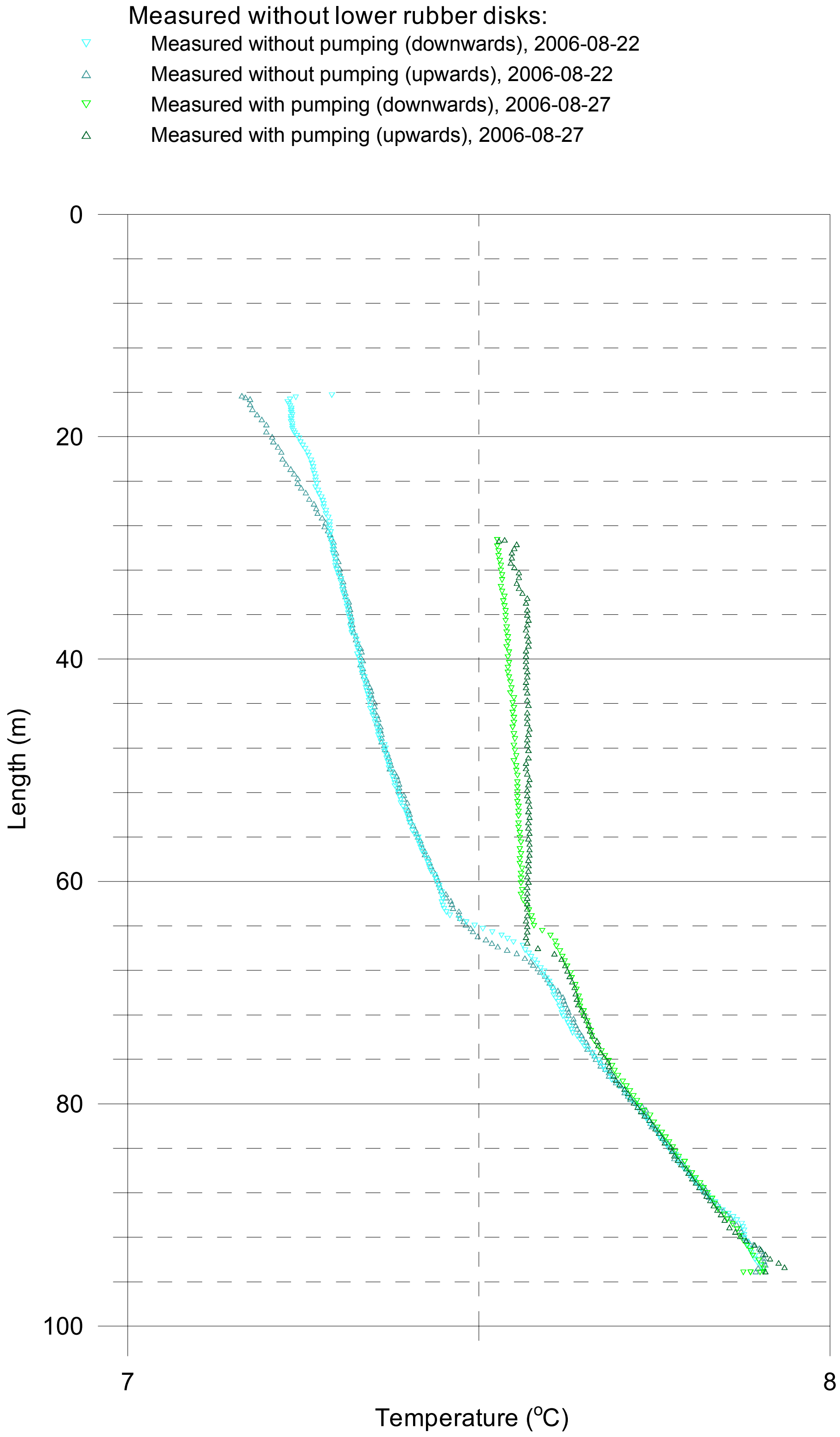
Laxemar, borehole KLX24A
Length correction



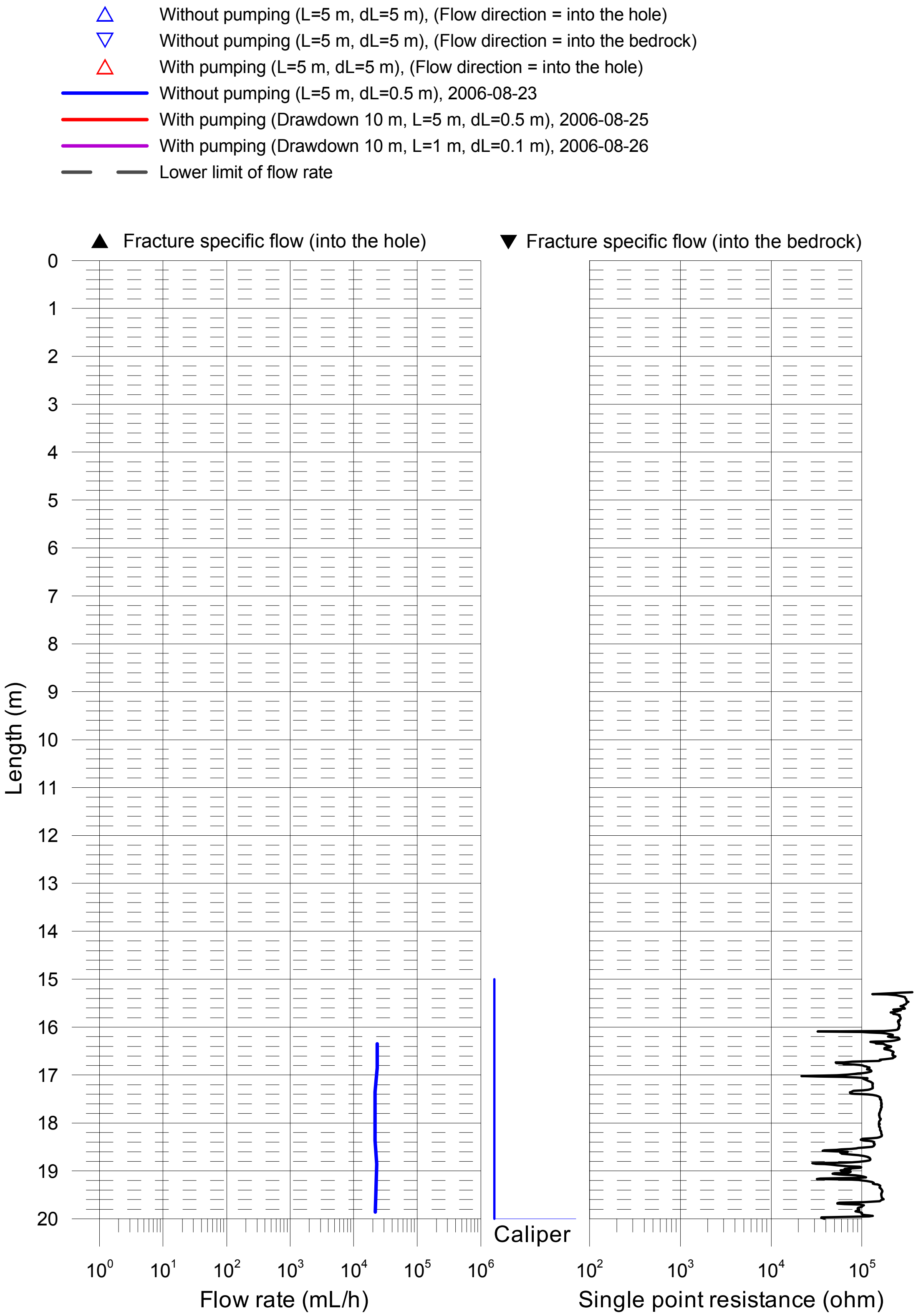
Laxemar, borehole KLX24A
Electric conductivity of borehole water



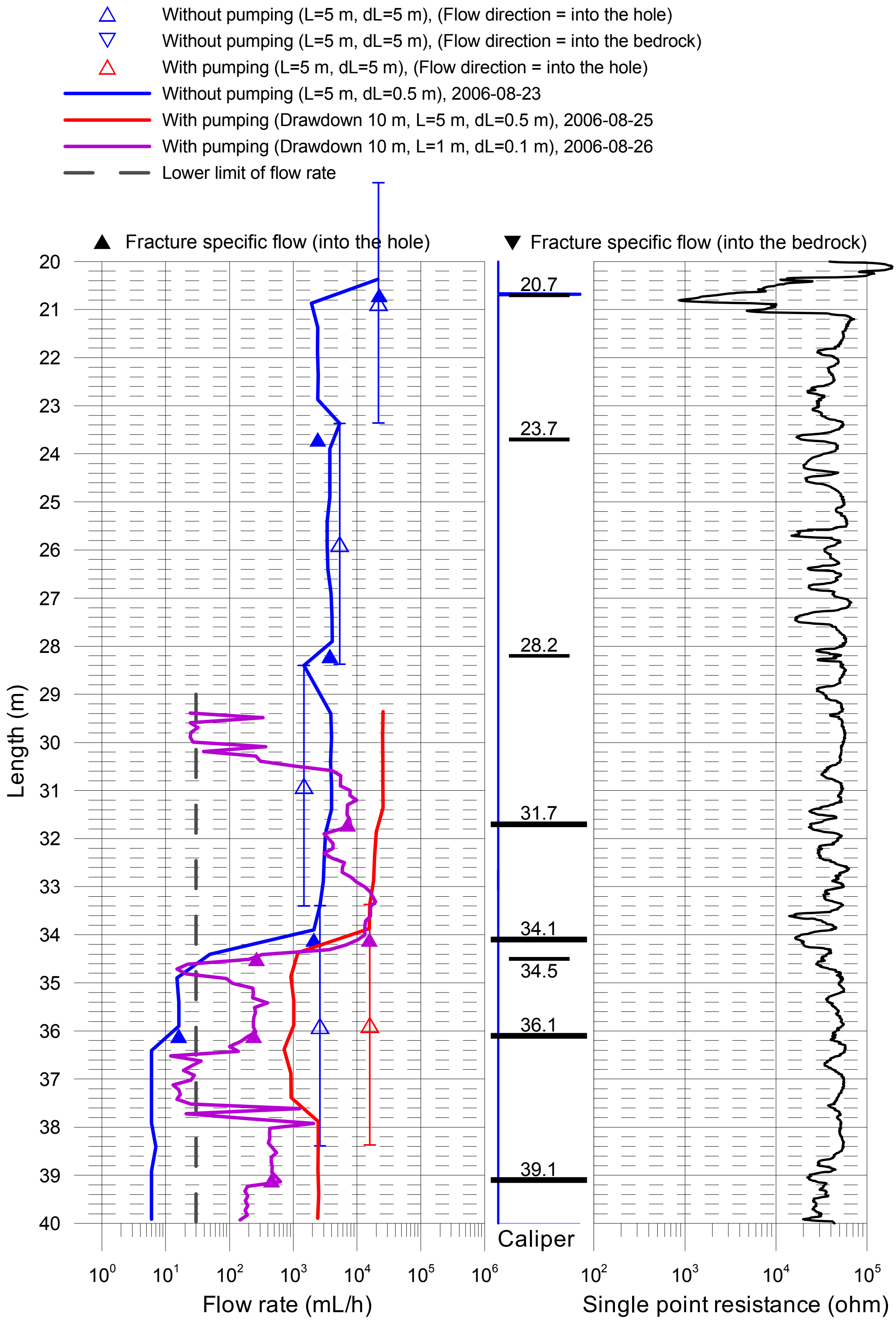
Laxemar, borehole KLX24A
Temperature of borehole water



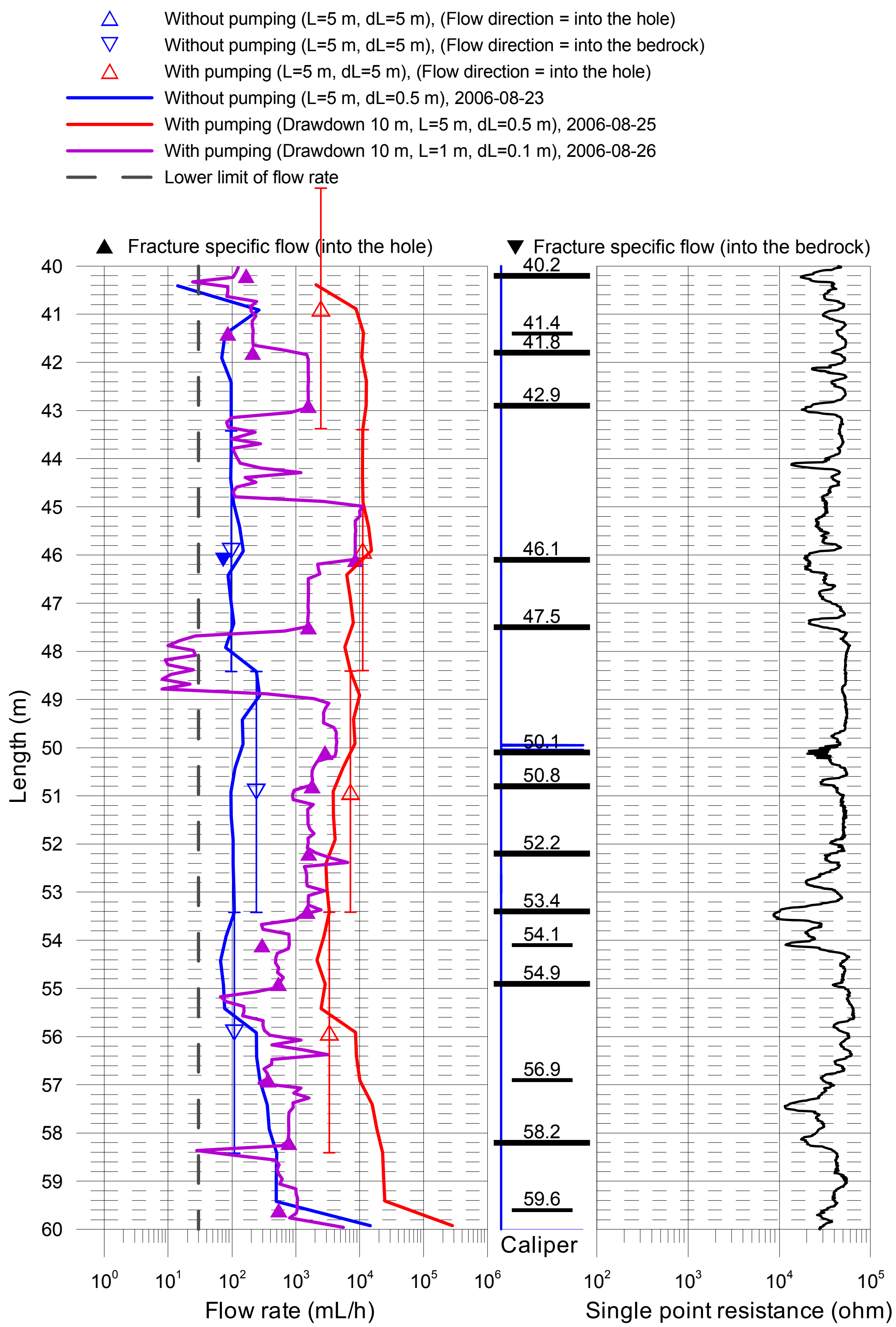
Laxemar, borehole KLX24A
Flow rate, caliper and single point resistance



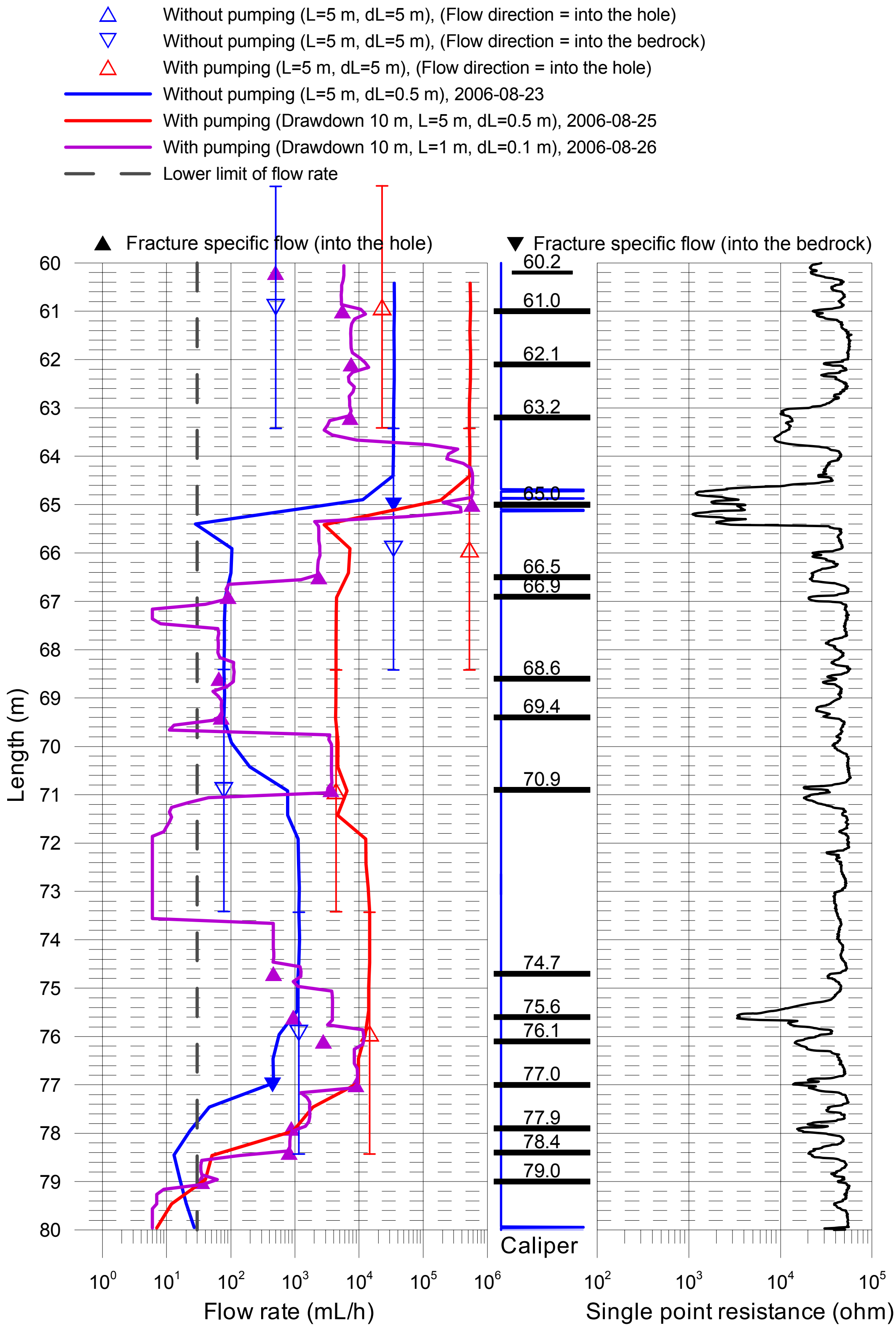
Laxemar, borehole KLX24A
Flow rate, caliper and single point resistance



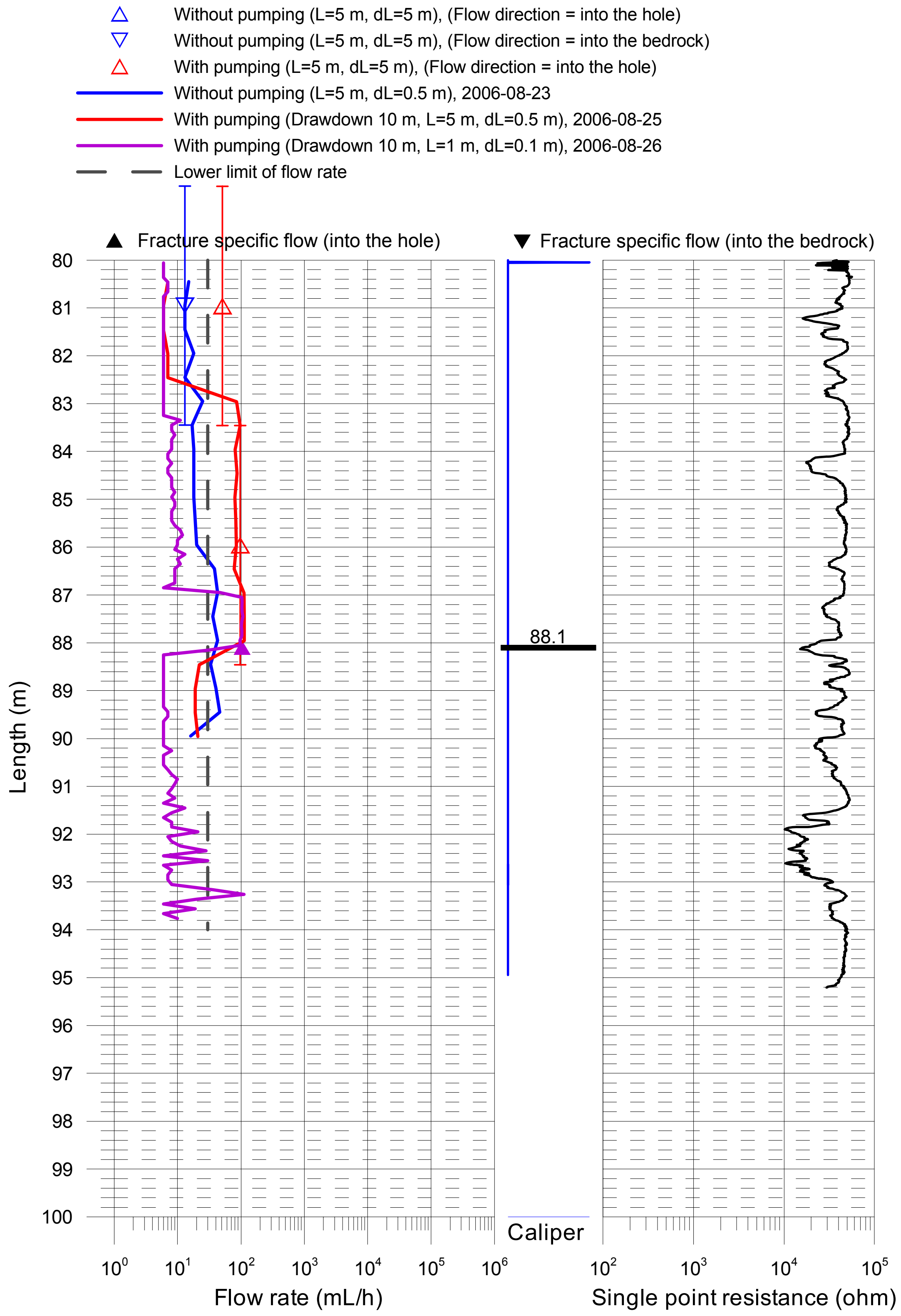
Laxemar, borehole KLX24A
Flow rate, caliper and single point resistance

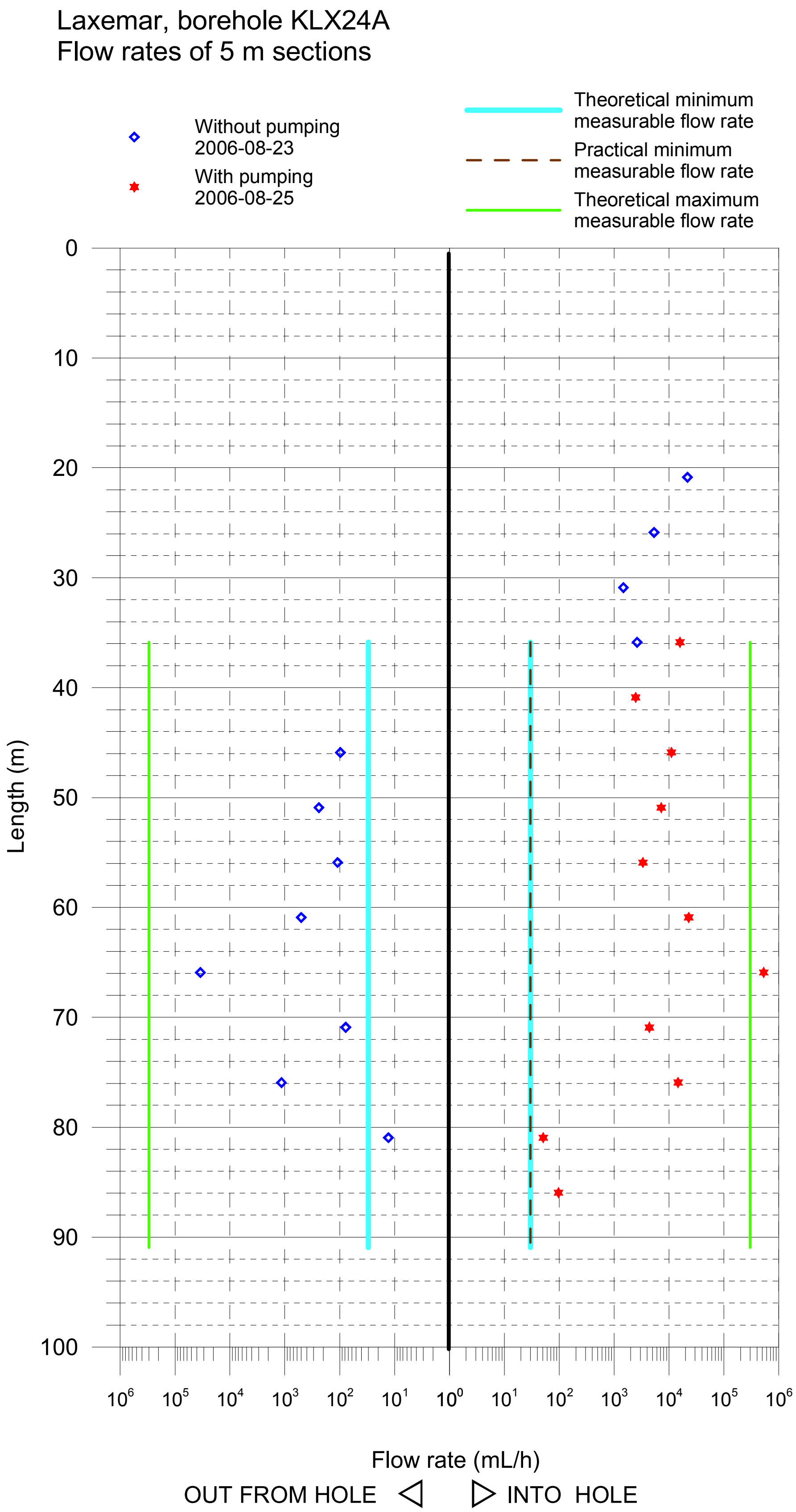


Laxemar, borehole KLX24A
Flow rate, caliper and single point resistance



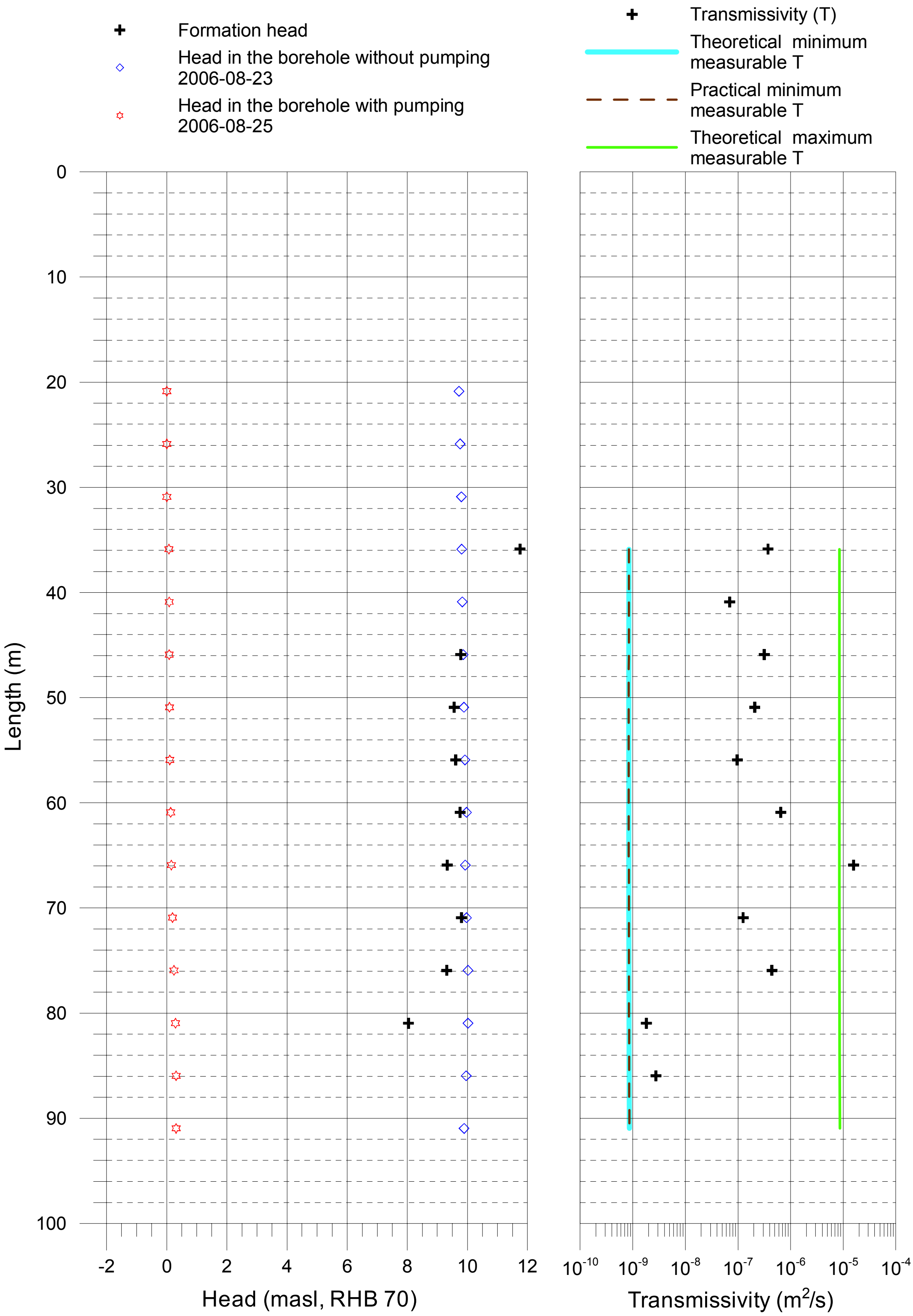
Laxemar, borehole KLX24A
Flow rate, caliper and single point resistance



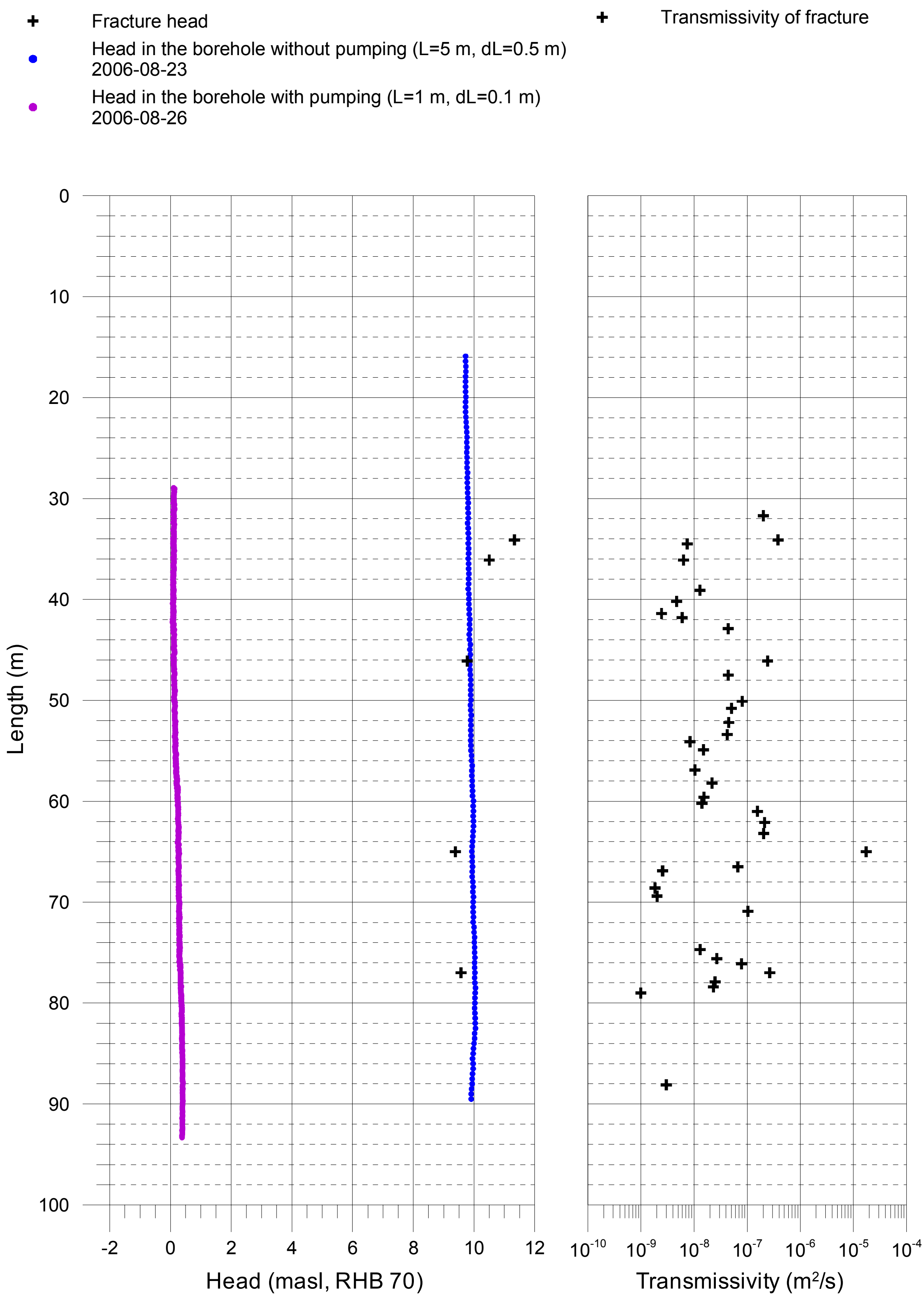


Laxemar, borehole KLX24A
Flow rates of 5 m sections
Without pumping 2006-08-23
With pumping 2006-08-25
Theoretical minimum measurable flow rate
Practical minimum measurable flow rate
Theoretical maximum measurable flow rate
Length (m)
0
10
20
30
40
50
60
70
80
90
100
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
OUT FROM HOLE
INTO HOLE

Laxemar, borehole KLX24A
Transmissivity and head of 5 m sections



Laxemar, borehole KLX24A
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)
KLX24A	2.41	100.17	5A	20060824	17:31	20060825	16:31	20060827	16:45	5	0.5	2.64E–04	–

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

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (ma.s.l.)	h_1 (ma.s.l.)	h_2 (ma.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
256,440	–	855,300	–	10.00	0.09	–	–9.91	–	2.63E–05	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)
KLX24A	18.36	23.36	5	6.03E–06	9.72	–	–	–	–	–	–	–	–
KLX24A	23.37	28.37	5	1.48E–06	9.76	–	–	–	–	–	–	–	–
KLX24A	28.40	33.40	5	4.08E–07	9.80	–	–	–	–	–	–	–	–
KLX24A	33.38	38.38	5	7.28E–07	9.81	4.39E–06	0.07	3.7E–07	11.8	30	8.5E–10	8.5E–10	8.5E–06
KLX24A	38.40	43.40	5	–	9.83	6.83E–07	0.08	6.9E–08	–	30	8.5E–10	8.5E–10	8.5E–06
KLX24A	43.41	48.41	5	–2.69E–08	9.86	3.08E–06	0.08	3.1E–07	9.8	30	8.4E–10	8.4E–10	8.4E–06
KLX24A	48.42	53.42	5	–6.67E–08	9.88	1.99E–06	0.09	2.1E–07	9.6	30	8.4E–10	8.4E–10	8.4E–06
KLX24A	53.42	58.42	5	–3.03E–08	9.92	9.28E–07	0.10	9.7E–08	9.6	30	8.4E–10	8.4E–10	8.4E–06
KLX24A	58.42	63.42	5	–1.39E–07	9.97	6.33E–06	0.13	6.5E–07	9.8	30	8.4E–10	8.4E–10	8.4E–06
KLX24A	63.42	68.42	5	–9.56E–06	9.93	1.47E–04	0.15	1.6E–05	9.3	30	8.4E–10	8.4E–10	8.4E–06
KLX24A	68.42	73.42	5	–2.17E–08	9.97	1.22E–06	0.19	1.3E–07	9.8	30	8.4E–10	8.4E–10	8.4E–06
KLX24A	73.43	78.43	5	–3.19E–07	10.02	4.06E–06	0.24	4.4E–07	9.3	30	8.4E–10	8.4E–10	8.4E–06
KLX24A	78.46	83.46	5	–3.61E–09	10.02	1.42E–08	0.29	1.8E–09	8.0	30	8.5E–10	8.5E–10	8.5E–06
KLX24A	83.46	88.46	5	–	9.96	2.69E–08	0.31	2.8E–09	–	30	8.5E–10	8.5E–10	8.5E–06
KLX24A	88.46	93.46	5	–	9.89	–	0.31	–	–	30	8.6E–10	8.6E–10	8.6E–06

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

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KLX24A	20.7	1	0.1	6.19E–06	9.72	–	–	–	–	*
KLX24A	23.7	1	0.1	6.75E–07	9.77	–	–	–	–	*
KLX24A	28.2	1	0.1	1.04E–06	9.78	–	–	–	–	*
KLX24A	31.7	1	0.1	–	9.81	1.99E–06	0.12	2.0E–07	–	
KLX24A	34.1	1	0.1	5.83E–07	9.82	4.33E–06	0.10	3.8E–07	11.3	
KLX24A	34.5	1	0.1	–	9.81	7.33E–08	0.09	7.5E–09	–	*
KLX24A	36.1	1	0.1	4.44E–09	9.81	6.67E–08	0.10	6.3E–09	10.5	
KLX24A	39.1	1	0.1	–	9.82	1.26E–07	0.11	1.3E–08	–	
KLX24A	40.2	1	0.1	–	9.83	4.61E–08	0.09	4.7E–09	–	
KLX24A	41.4	1	0.1	–	9.84	2.39E–08	0.10	2.4E–09	–	*
KLX24A	41.8	1	0.1	–	9.85	5.86E–08	0.10	6.0E–09	–	
KLX24A	42.9	1	0.1	–	9.86	4.33E–07	0.09	4.4E–08	–	
KLX24A	46.1	1	0.1	–2.03E–08	9.86	2.37E–06	0.11	2.4E–07	9.8	
KLX24A	47.5	1	0.1	–	9.88	4.36E–07	0.12	4.4E–08	–	
KLX24A	50.1	1	0.1	–	9.89	7.97E–07	0.12	8.1E–08	–	
KLX24A	50.8	1	0.1	–	9.89	5.00E–07	0.14	5.1E–08	–	
KLX24A	52.2	1	0.1	–	9.89	4.42E–07	0.15	4.5E–08	–	
KLX24A	53.4	1	0.1	–	9.90	4.17E–07	0.16	4.2E–08	–	
KLX24A	54.1	1	0.1	–	9.89	8.22E–08	0.16	8.4E–09	–	*
KLX24A	54.9	1	0.1	–	9.90	1.49E–07	0.16	1.5E–08	–	
KLX24A	56.9	1	0.1	–	9.93	1.03E–07	0.19	1.0E–08	–	*
KLX24A	58.2	1	0.1	–	9.94	2.15E–07	0.19	2.2E–08	–	
KLX24A	59.6	1	0.1	–	9.96	1.50E–07	0.24	1.5E–08	–	*
KLX24A	60.2	1	0.1	–	9.98	1.39E–07	0.25	1.4E–08	–	*
KLX24A	61.0	1	0.1	–	9.98	1.53E–06	0.25	1.6E–07	–	
KLX24A	62.1	1	0.1	–	9.98	2.09E–06	0.26	2.1E–07	–	
KLX24A	63.2	1	0.1	–	9.97	2.01E–06	0.26	2.0E–07	–	
KLX24A	65.0	1	0.1	–9.58E–06	9.93	1.60E–04	0.28	1.7E–05	9.4	
KLX24A	66.5	1	0.1	–	9.95	6.53E–07	0.28	6.7E–08	–	
KLX24A	66.9	1	0.1	–	9.94	2.50E–08	0.25	2.6E–09	–	
KLX24A	68.6	1	0.1	–	9.97	1.81E–08	0.27	1.8E–09	–	
KLX24A	69.4	1	0.1	–	9.98	1.97E–08	0.26	2.0E–09	–	
KLX24A	70.9	1	0.1	–	9.97	1.01E–06	0.27	1.0E–07	–	
KLX24A	74.7	1	0.1	–	10.02	1.28E–07	0.29	1.3E–08	–	
KLX24A	75.6	1	0.1	–	10.03	2.62E–07	0.31	2.7E–08	–	
KLX24A	76.1	1	0.1	–	10.02	7.69E–07	0.31	7.8E–08	–	
KLX24A	77.0	1	0.1	–1.25E–07	10.03	2.48E–06	0.34	2.7E–07	9.6	
KLX24A	77.9	1	0.1	–	10.03	2.44E–07	0.33	2.5E–08	–	
KLX24A	78.4	1	0.1	–	10.05	2.25E–07	0.35	2.3E–08	–	
KLX24A	79.0	1	0.1	–	10.04	9.72E–09	0.34	9.9E–10	–	
KLX24A	88.1	1	0.1	–	9.94	2.89E–08	0.40	3.0E–09	–	

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

Explanations.

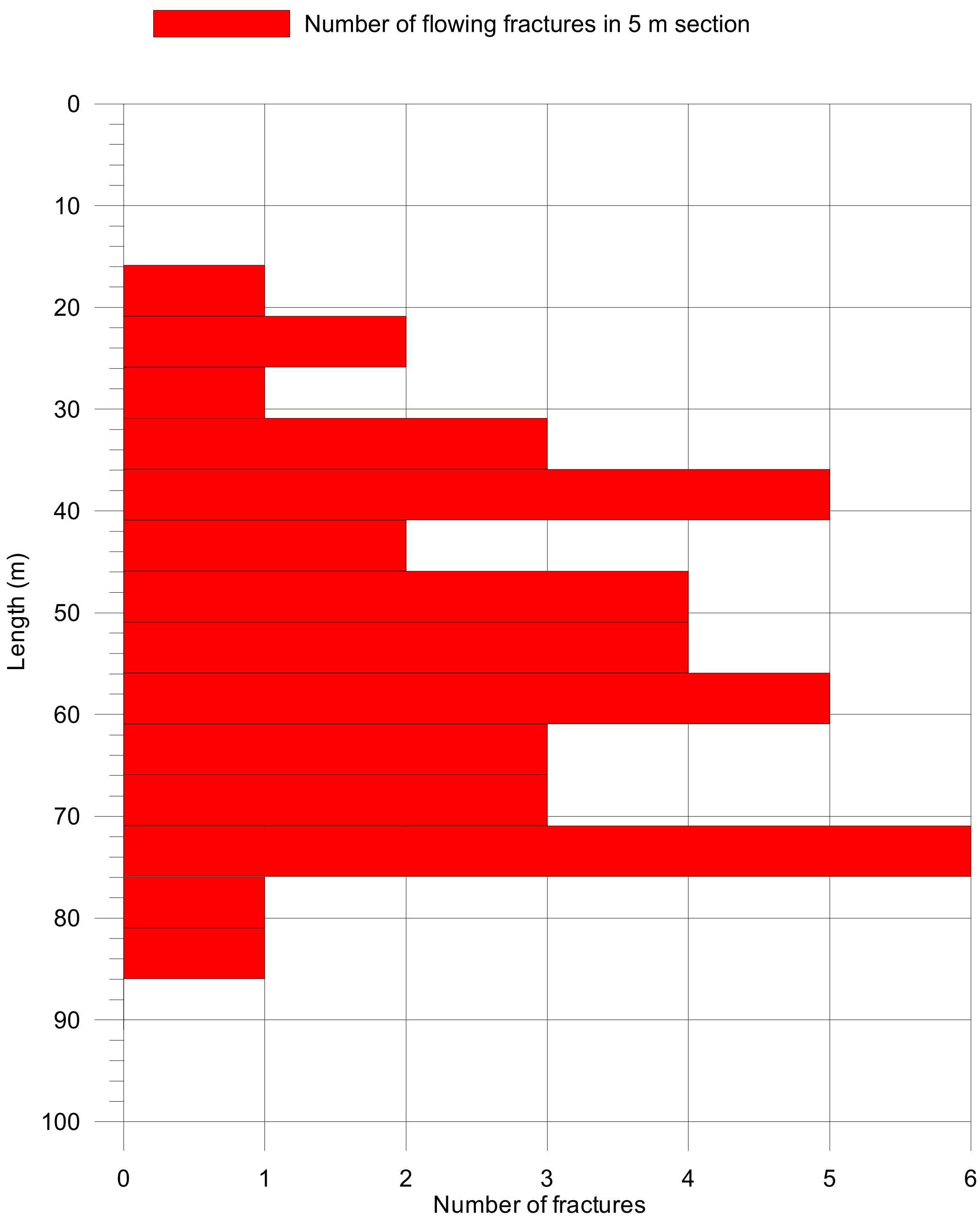
Header	Unit	Explanations
Borehole		ID for borehole.
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L).
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L).
L	m	Corrected length along borehole based on SKB procedures for length correction.
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging.
Test type (1–6)	(–)	1A: Pumping test – wire-line eq., 1B: Pumping test-submersible pump, 1C: Pumping test-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging – PFL-DIFF-Sequential, 5B: Difference flow logging – PFL-DIFF-Overlapping, 6: Flow logging-Impeller.
Date of test, start	YY-MM-DD	Date for start of pumping.
Time of test, start	hh:mm	Time for start of pumping.
Date of flowl., start	YY-MM-DD	Date for start of the flow logging.
Time of flowl., start	hh:mm	Time for start of the flow logging.
Date of test, stop	YY-MM-DD	Date for stop of the test.
Time of test, stop	hh:mm	Time for stop of the test.
L_w	m	Section length used in the difference flow logging.
dL	m	Step length (increment) used in the difference flow logging.
Q_{p1}	m^3/s	Flow rate at surface by the end of the first pumping period of the flow logging.
Q_{p2}	m^3/s	Flow rate at surface by the end of the second pumping period of the flow logging.
t_{p1}	s	Duration of the first pumping period.
t_{p2}	s	Duration of the second pumping period.
t_{F1}	s	Duration of the first recovery period.
t_{F2}	s	Duration of the second recovery period.
h_0	m.a.s.l.	Initial hydraulic head before pumping. Elevation of water level in open borehole in the local co-ordinates system with z=0 m.
h_1	m.a.s.l.	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.
$T\text{-measl}_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
$T\text{-measl}_{U}$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

Calculation of conductive fracture frequency.

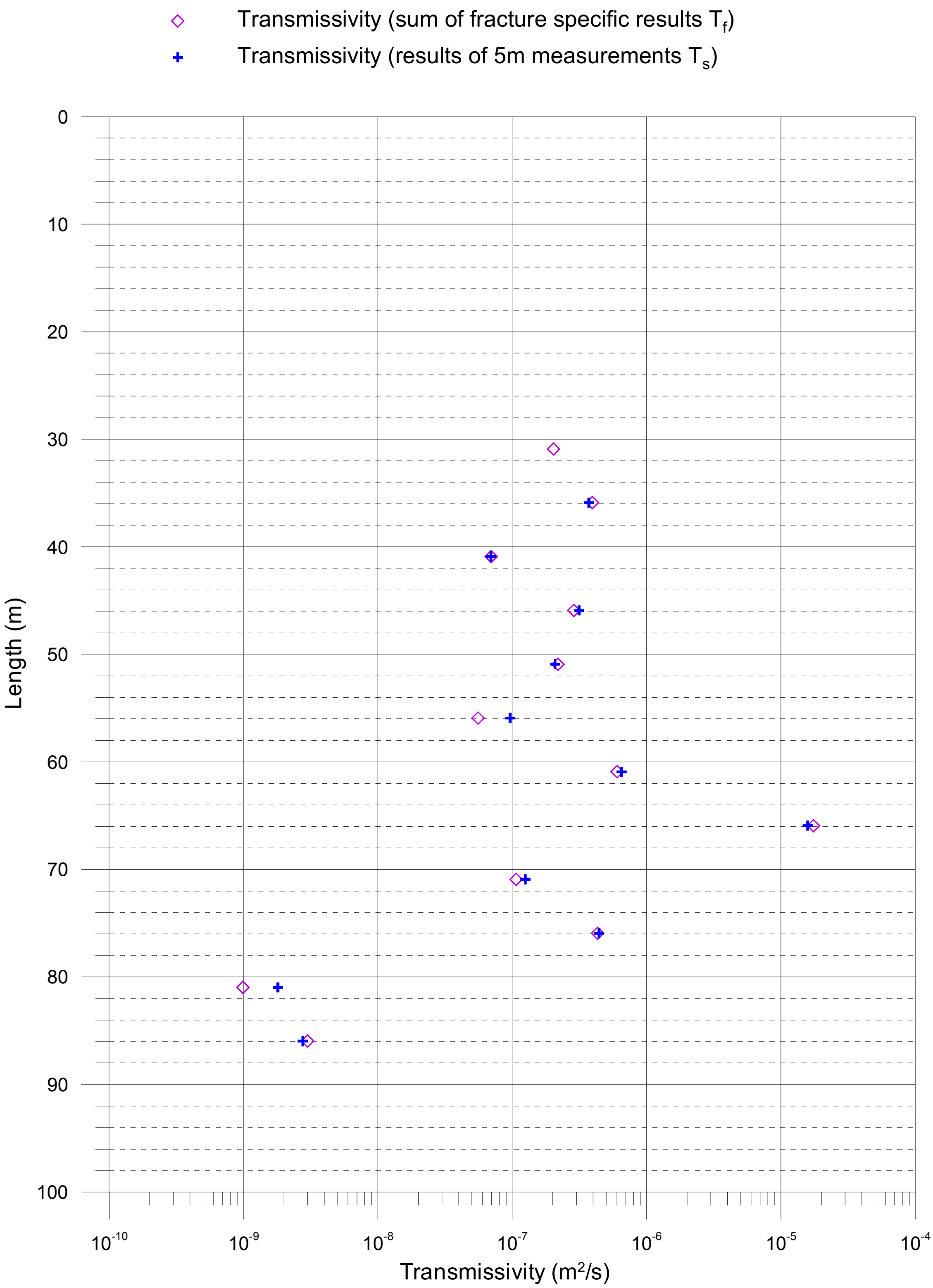
Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)
KLX24A	18.36	23.36	1 *	0	0	0	0	0
KLX24A	23.37	28.37	2 *	0	0	0	0	0
KLX24A	28.40	33.40	1	0	0	1	0	0
KLX24A	33.38	38.38	3	0	2	0	1	0
KLX24A	38.40	43.40	5	1	3	1	0	0
KLX24A	43.41	48.41	2	0	0	2	0	0
KLX24A	48.42	53.42	4	0	0	4	0	0
KLX24A	53.42	58.42	4	0	4	0	0	0
KLX24A	58.42	63.42	5	0	2	3	0	0
KLX24A	63.42	68.42	3	1	0	1	0	1
KLX24A	68.42	73.42	3	2	0	1	0	0
KLX24A	73.43	78.43	6	0	4	2	0	0
KLX24A	78.46	83.46	1	1	0	0	0	0
KLX24A	83.46	88.46	1	0	1	0	0	0
KLX24A	88.46	93.46	0	0	0	0	0	0

* No flow value is given, because the fractures were not measured during pumping.

Laxemar, borehole KLX24A
Calculation of conductive fracture frequency

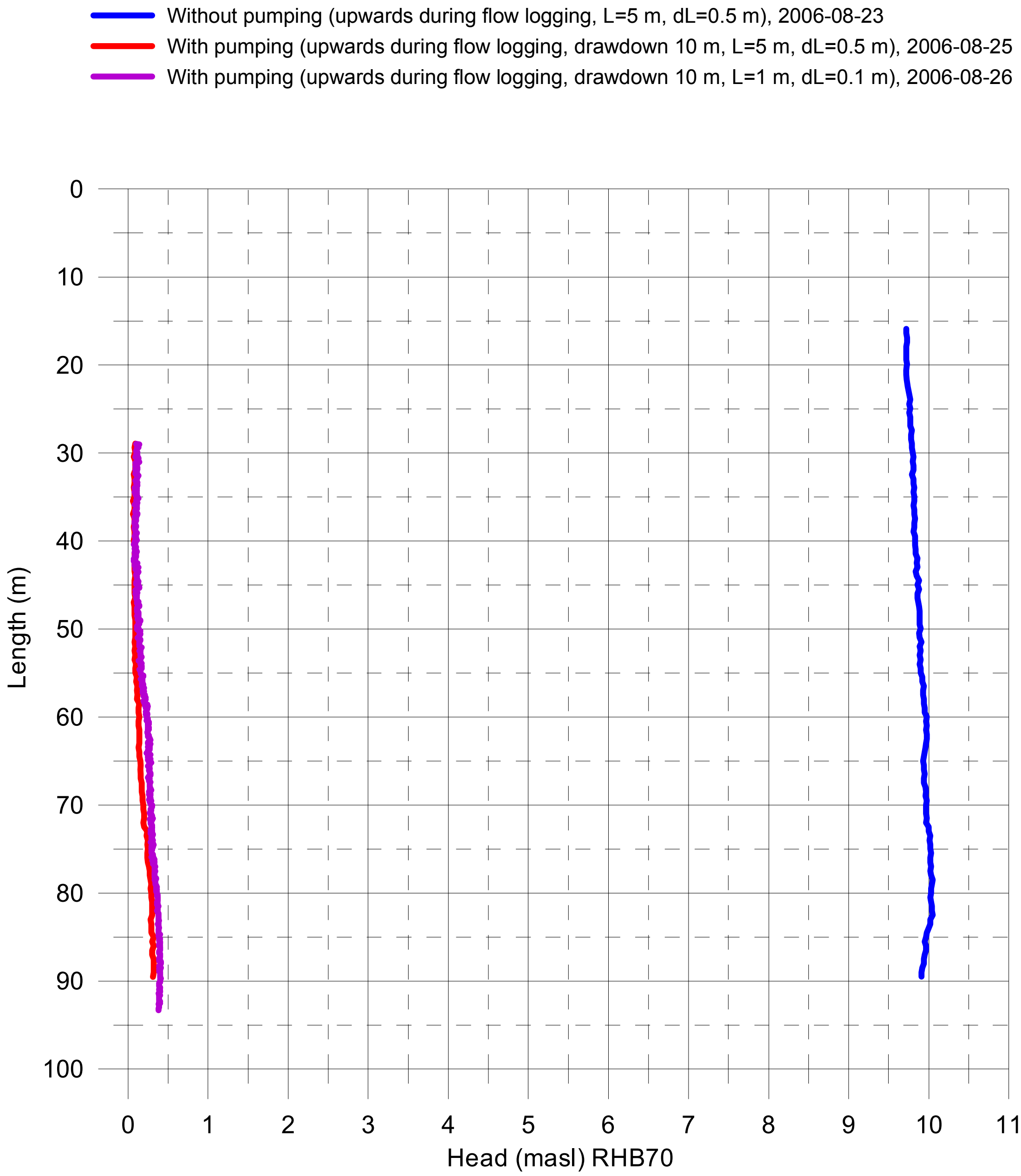


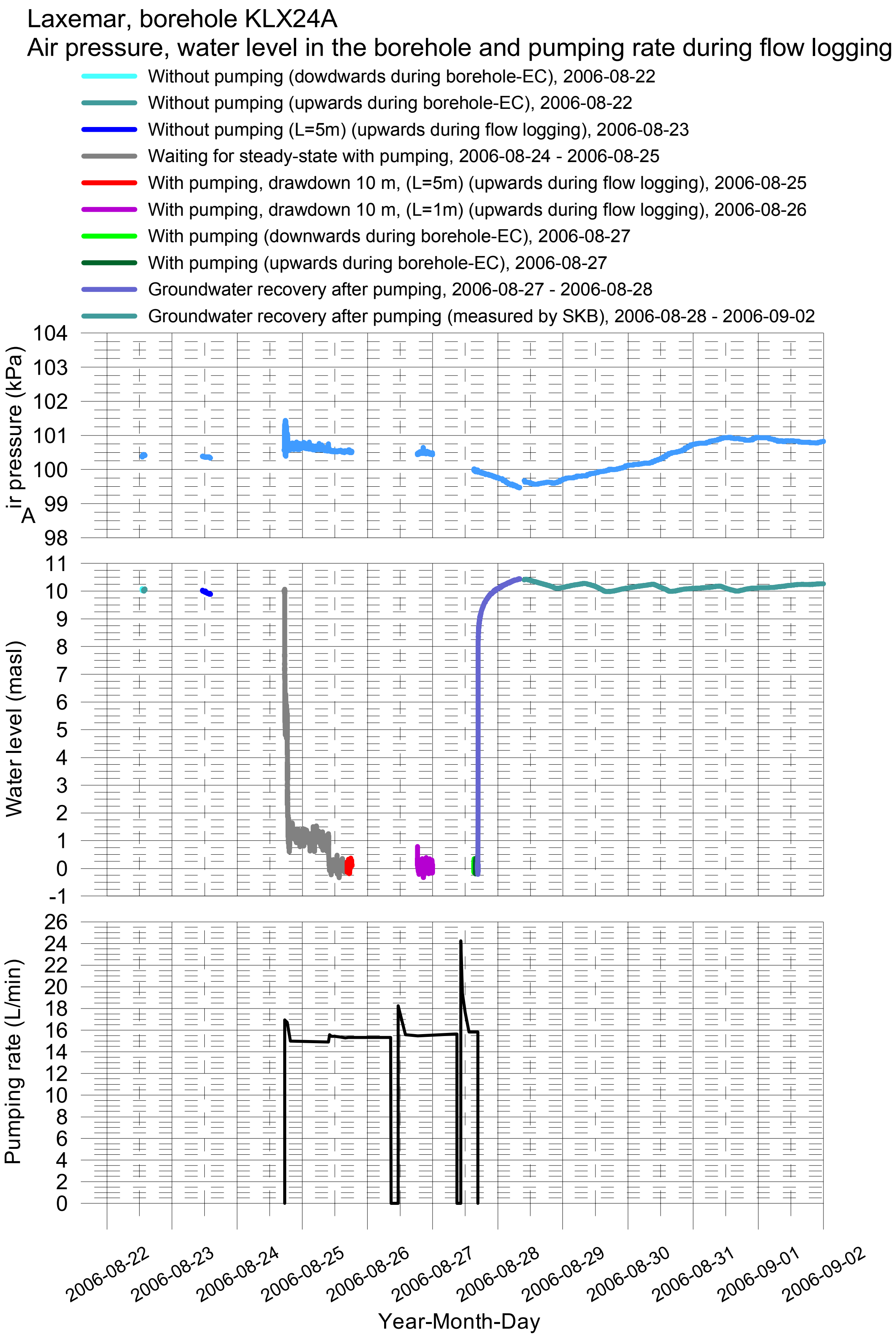
Laxemar, borehole KLX24A
Comparison between section transmissivity and fracture transmissivity



Laxemar, borehole KLX24A
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 absolute pressure sensor)

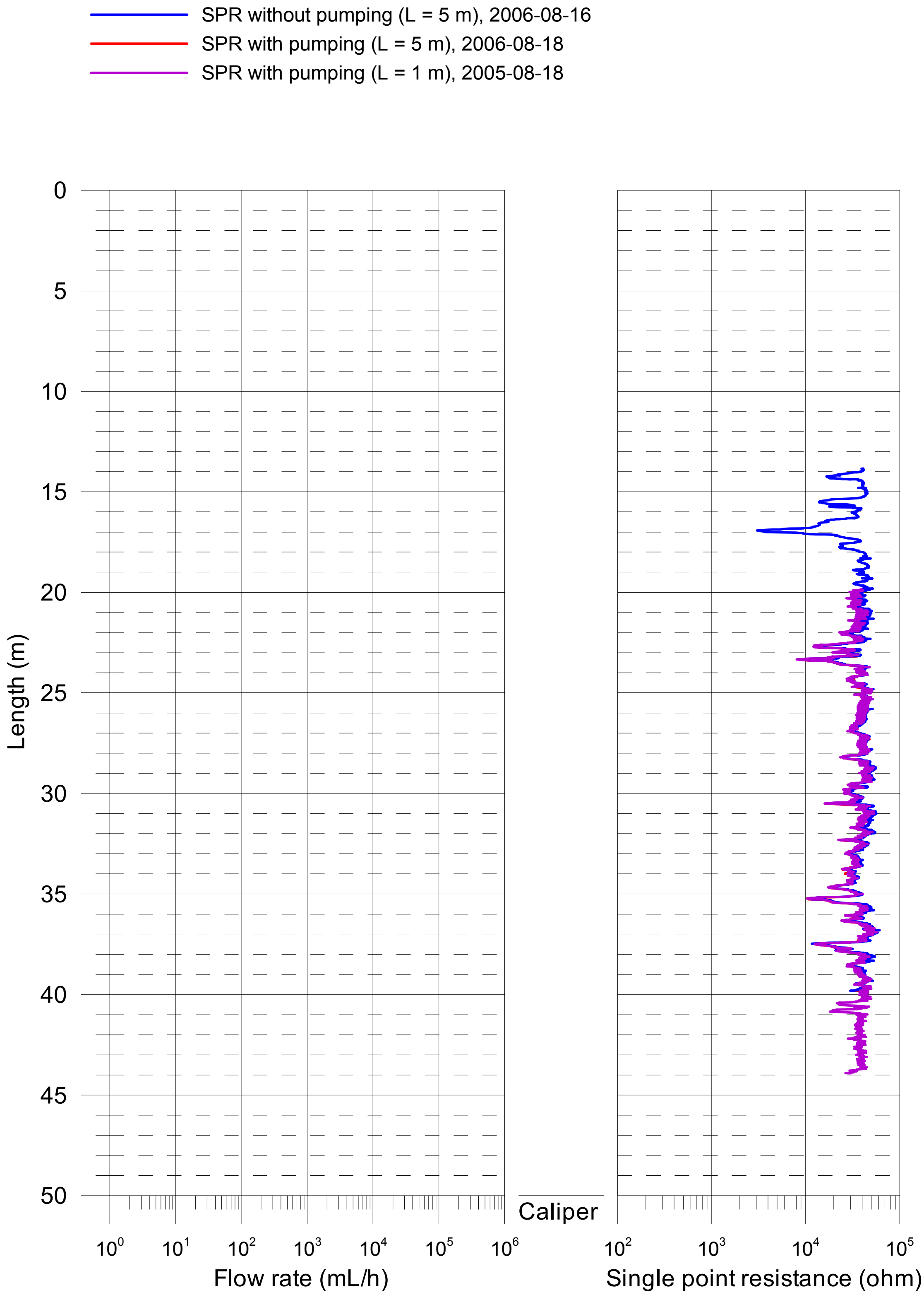



Laxemar, borehole KLX24A
Air pressure, water level in the borehole and pumping rate during flow logging
Without pumping (dowdwards during borehole-EC), 2006-08-22
Without pumping (upwards during borehole-EC), 2006-08-22
Without pumping (L=5m) (upwards during flow logging), 2006-08-23
Waiting for steady-state with pumping, 2006-08-24 - 2006-08-25
With pumping, drawdown 10 m, (L=5m) (upwards during flow logging), 2006-08-25
With pumping, drawdown 10 m, (L=1m) (upwards during flow logging), 2006-08-26
With pumping (downwards during borehole-EC), 2006-08-27
With pumping (upwards during borehole-EC), 2006-08-27
Groundwater recovery after pumping, 2006-08-27 - 2006-08-28
Groundwater recovery after pumping (measured by SKB), 2006-08-28 - 2006-09-02
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
11
10
9
8
7
6
5
4
3
2
1
0
-1
Pumping rate (L/min)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
2006-08-22
2006-08-23
2006-08-24
2006-08-25
2006-08-26
2006-08-27
2006-08-28
2006-08-29
2006-08-30
2006-08-31
2006-09-01
2006-09-02
Year-Month-Day

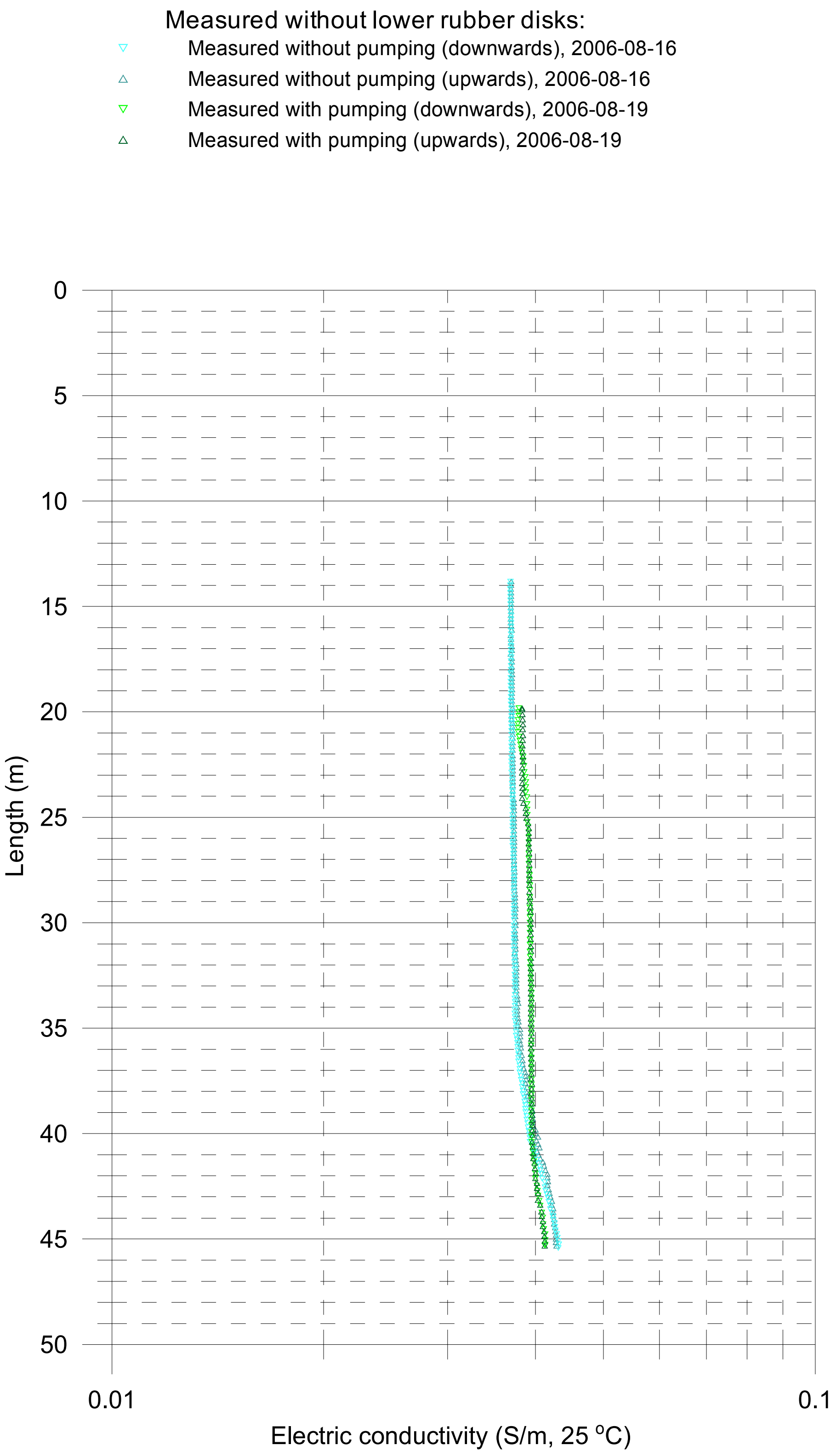
Appendices KLX25A

Appendices	25A.1	SPR results
Appendix	25A.2.1	Electric conductivity of borehole water
Appendix	25A.2.2	Temperature of borehole water
Appendix	25A.3.1–25A.3.3	Flow rate and single point resistance
Appendix	25A.4.1	Plotted flow rates of 5 m sections
Appendix	25A.4.2	Plotted transmissivity and head of 5 m sections
Appendix	25A.5	Plotted transmissivity and head of detected fractures
Appendix	25A.6	Basic test data
Appendix	25A.7	Results of sequential flow logging
Appendices	25A.8	Inferred flow anomalies from overlapping flow logging
Appendix	25A.9	Explanations for the tables in Appendices 6–8
Appendix	25A.10	Conductive fracture frequency
Appendix	25A.11	Plotted conductive fracture frequency
Appendix	25A.12	Comparison between section transmissivity and fracture transmissivity
Appendix	25A.13.1	Head in the borehole during flow logging
Appendix	25A.13.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	25A.13.3	Groundwater recovery after pumping

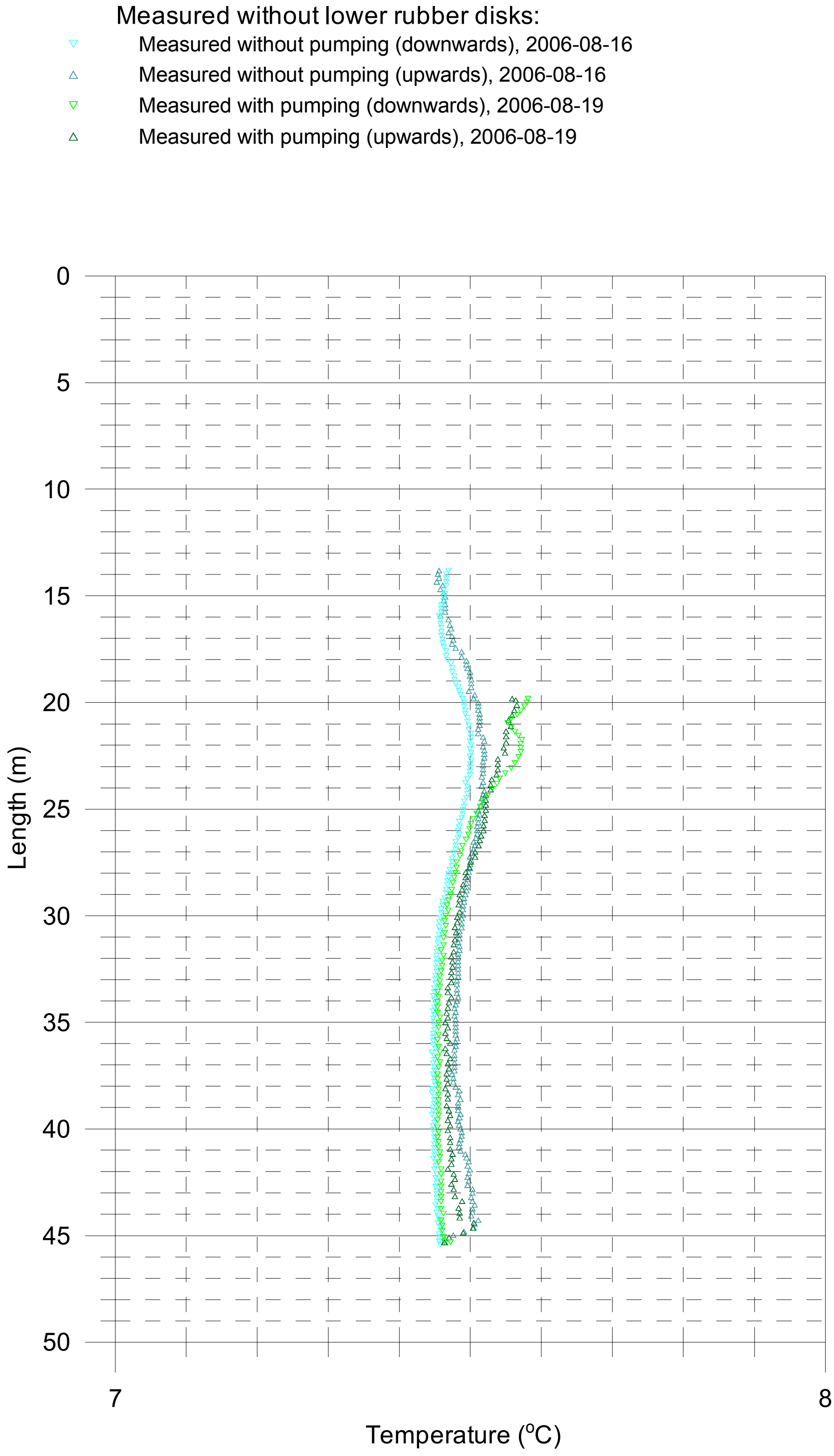
Laxemar, borehole KLX25A
SPR results



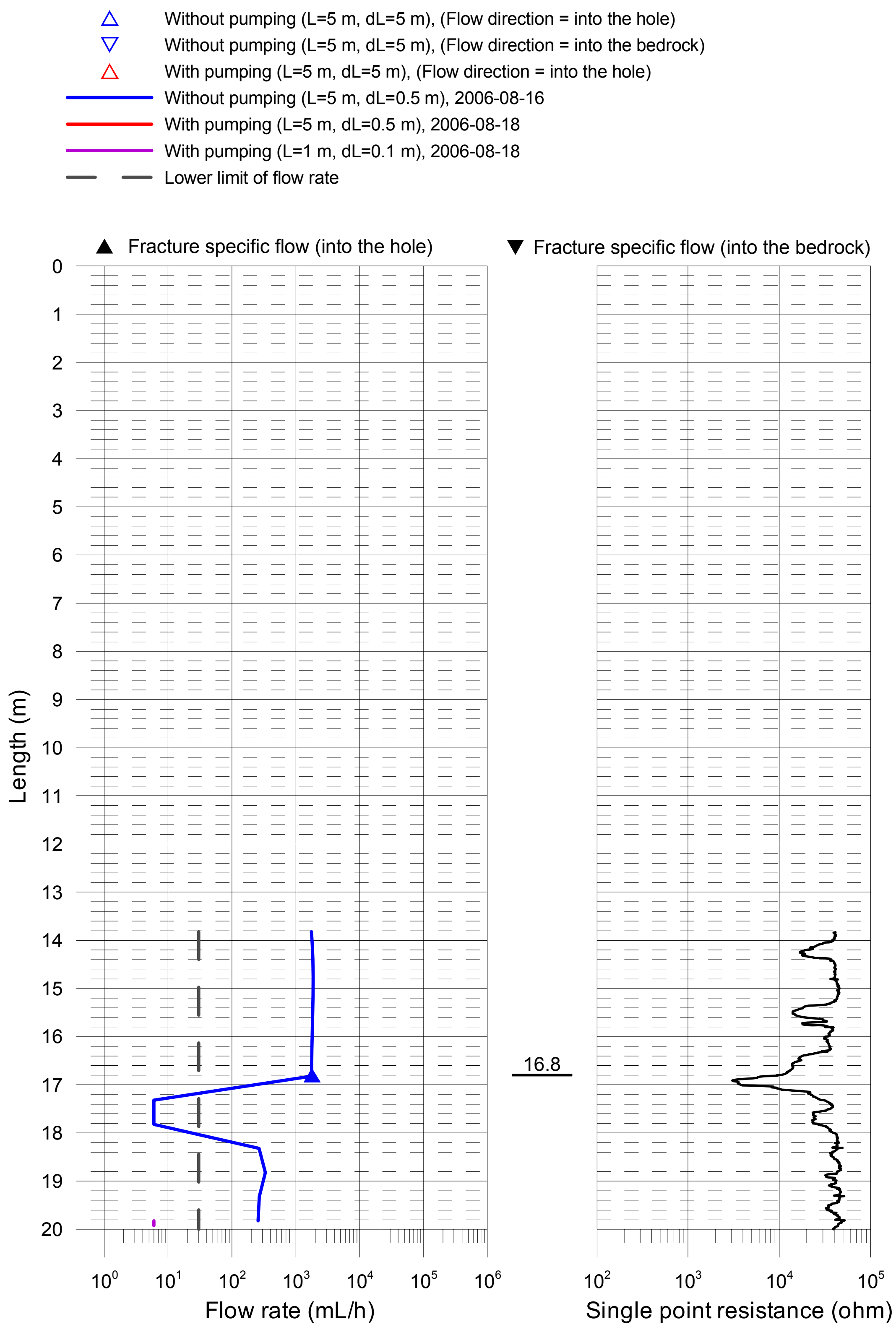
Laxemar, borehole KLX25A
Electric conductivity of borehole water



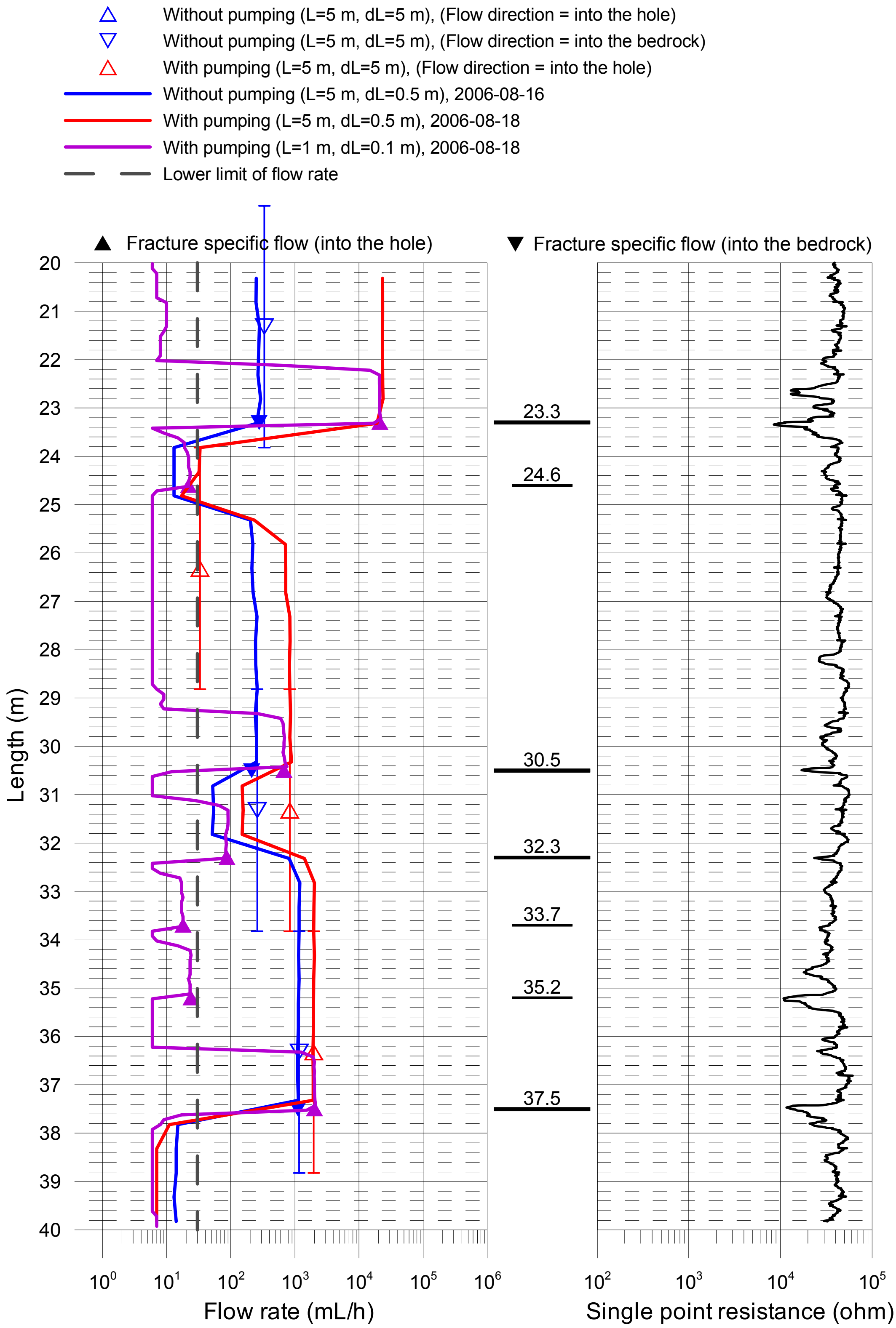
Laxemar, borehole KLX25A
Temperature of borehole water



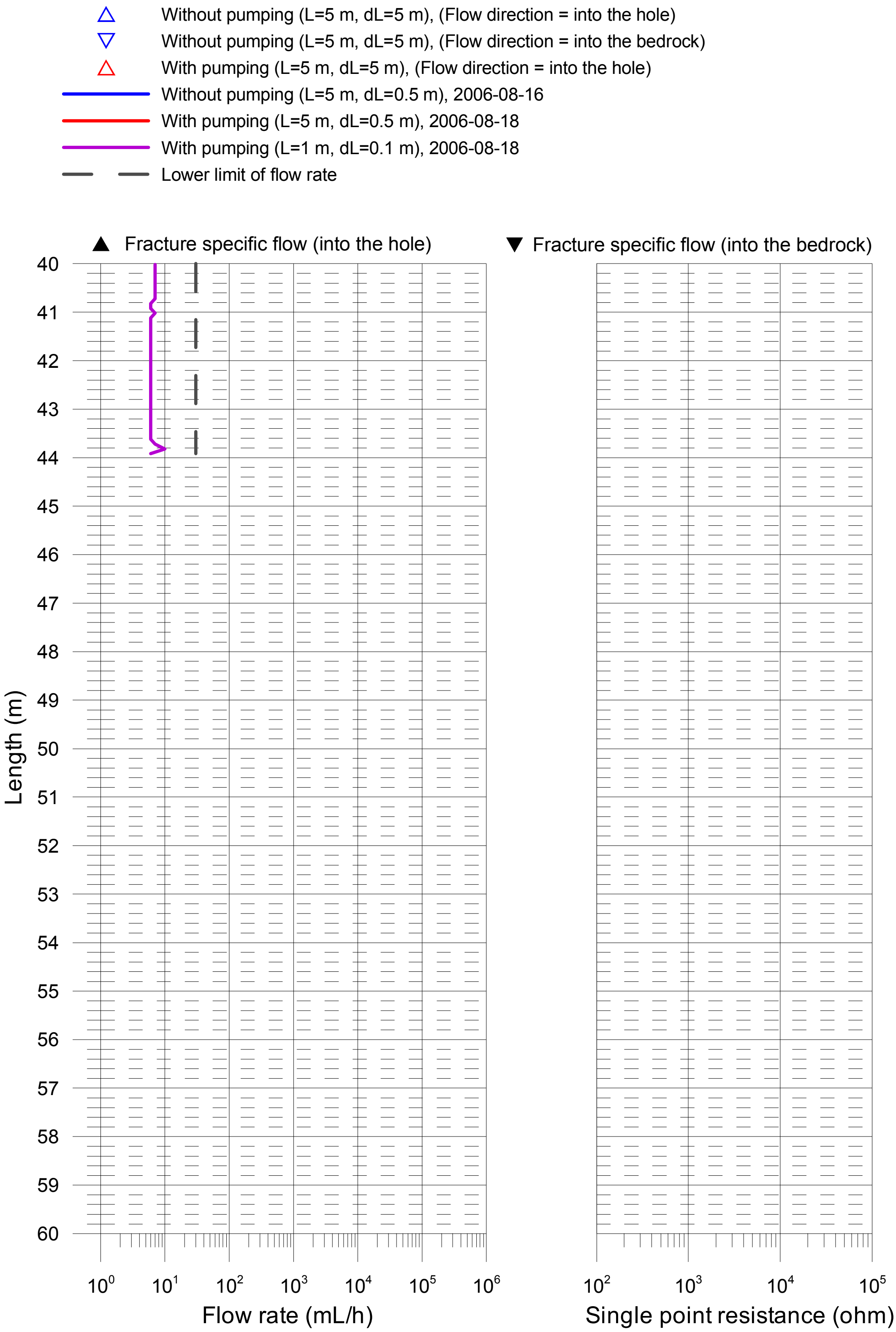
Laxemar, borehole KLX25A
Flow rate and single point resistance



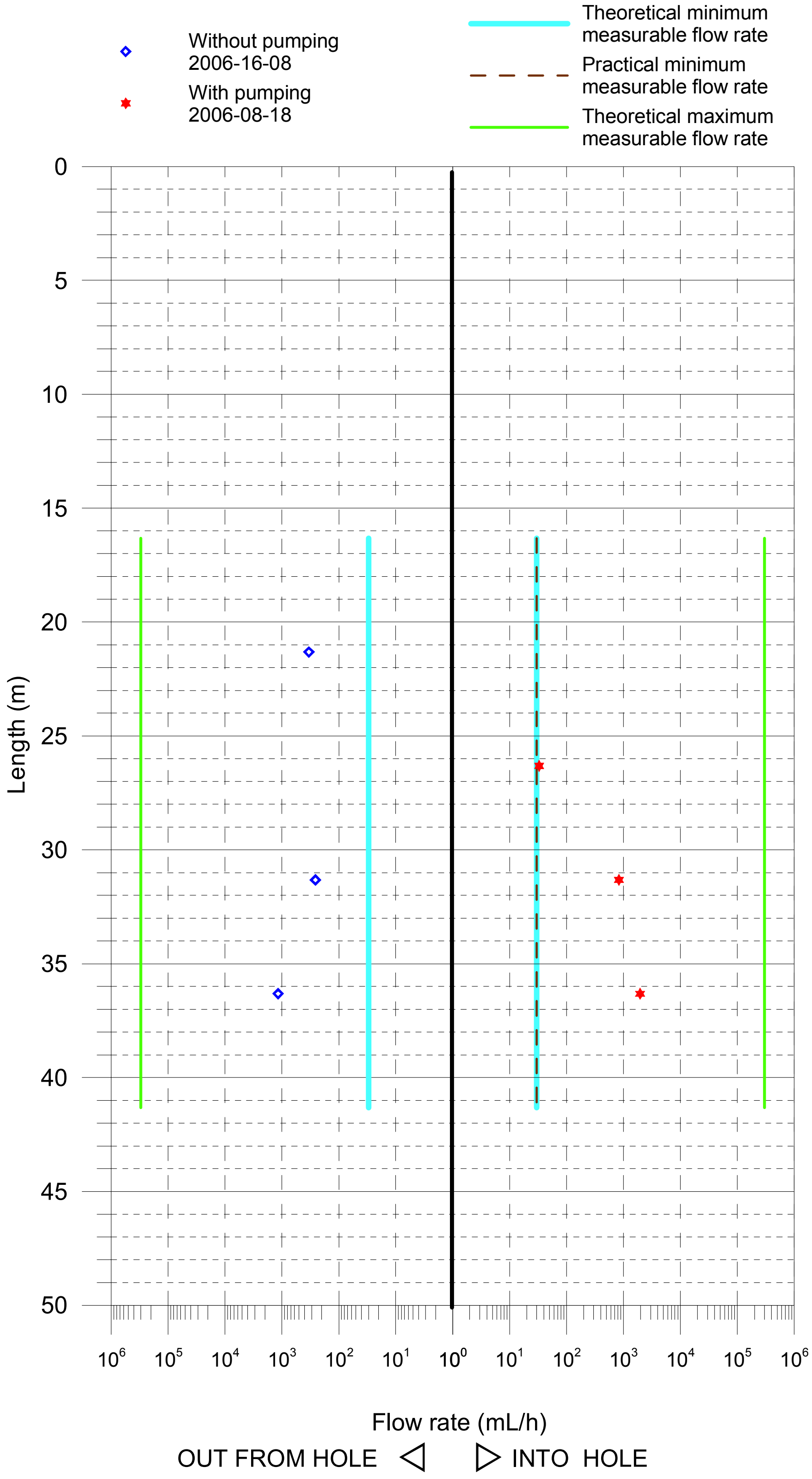
Laxemar, borehole KLX25A
Flow rate and single point resistance

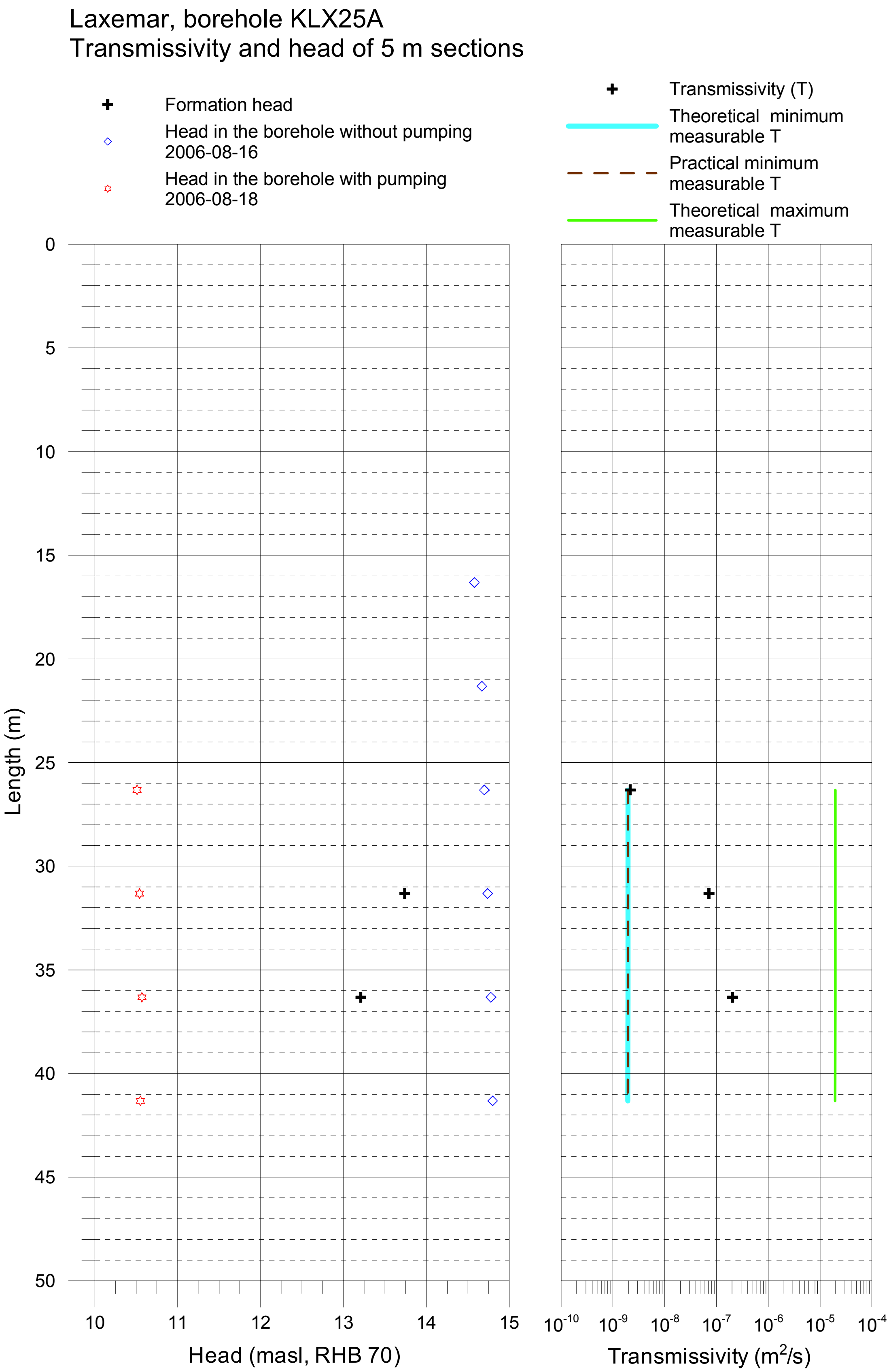


Laxemar, borehole KLX25A
Flow rate and single point resistance

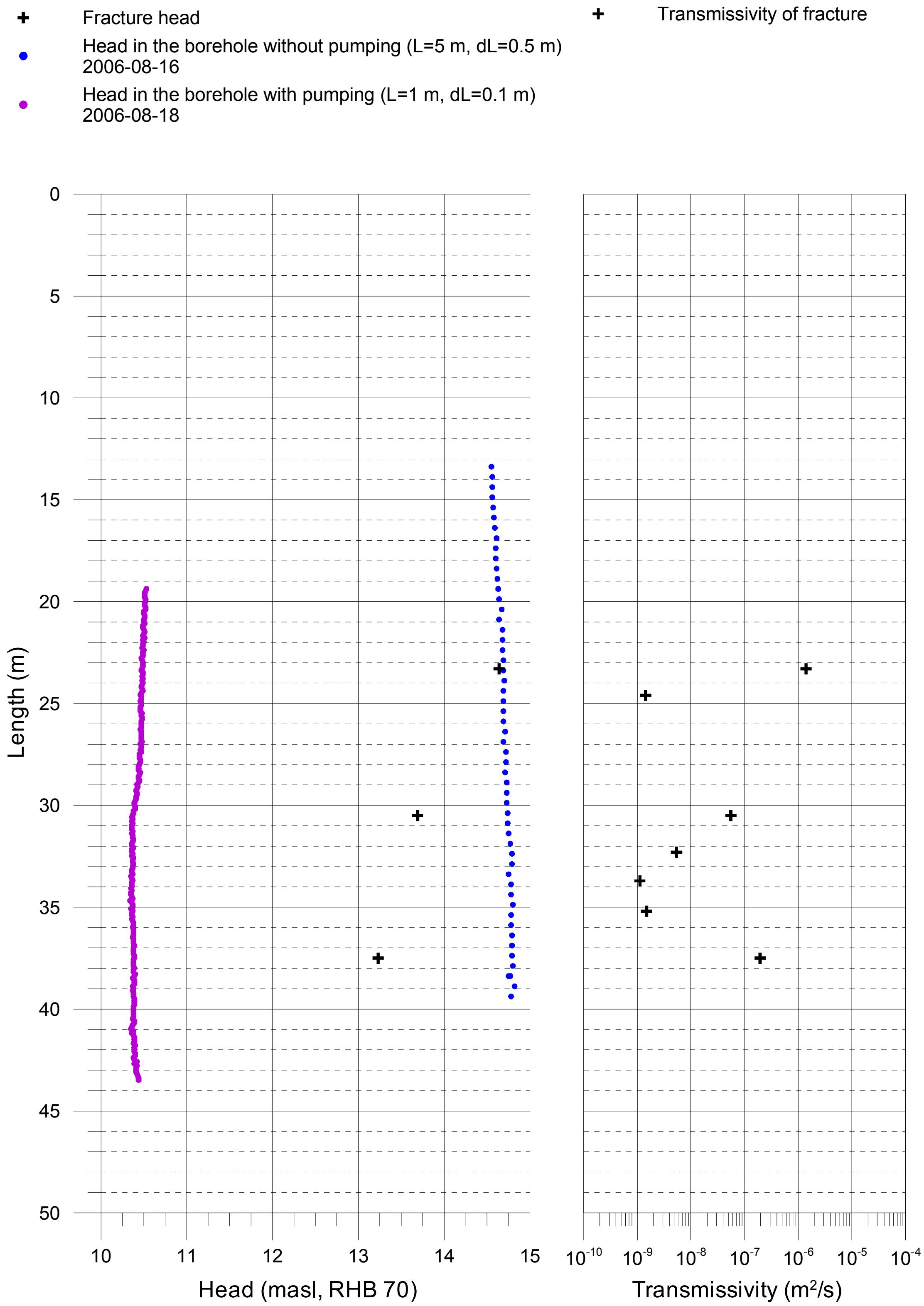


Laxemar, borehole KLX25A
Flow rates of 5 m sections




Laxemar, borehole KLX25A
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-08-16
Head in the borehole with pumping 2006-08-18
Transmissivity (T)
Theoretical minimum measurable T
Practical minimum measurable T
Theoretical maximum measurable T
Length (m)
0
5
10
15
20
25
30
35
40
45
50
10
11
12
13
14
15
Head (masl, RHB 70)
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Transmissivity (m^2/s)

Laxemar, borehole KLX25A
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)
KLX25A	2.2	50.24	5A	20060817	9:02	20060818	9:02	20060819	10:55	5	0.5	1.08E–05	–

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

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (ma.s.l.)	h_1 (ma.s.l.)	h_2 (ma.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
179,580	–	86,400	–	14.56	10.38		–4.18	–	2.56E–06	–	–

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KLX25A	13.82	18.82	5	–	14.58	–	–	–	–	30				*
KLX25A	18.82	23.82	5	–9.28E–08	14.67	–	–	–	–	30				*
KLX25A	23.82	28.82	5	–	14.70	9.17E–09	10.51	2.2E–09	–	30	2.00E–09	2.00E–09	2.00E–05	
KLX25A	28.82	33.82	5	–7.17E–08	14.74	2.31E–07	10.54	7.1E–08	13.70	30	2.00E–09	2.00E–09	2.00E–05	
KLX25A	33.82	38.82	5	–3.25E–07	14.78	5.44E–07	10.57	2.0E–07	13.20	30	2.00E–09	2.00E–09	2.00E–05	
KLX25A	38.82	43.82	5	–	14.80	–	10.55	–	–	30	1.90E–09	1.90E–09	1.90E–05	

* Was not measured during pumping

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

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KLX25A	16.8	1	0.1	4.97E–07	14.61	–	–		–	**
KLX25A	23.3	1	0.1	–7.67E–08	14.69	5.86E–06	10.48	1.40E–06	14.60	
KLX25A	24.6	1	0.1	–	14.69	6.11E–09	10.46	1.40E–09	–	*
KLX25A	30.5	1	0.1	–5.89E–08	14.74	1.86E–07	10.37	5.60E–08	13.60	
KLX25A	32.3	1	0.1	–	14.79	2.42E–08	10.36	5.40E–09	–	
KLX25A	33.7	1	0.1	–	14.77	5.00E–09	10.37	1.10E–09	–	*
KLX25A	35.2	1	0.1	–	14.79	6.67E–09	10.37	1.50E–09	–	*
KLX25A	37.5	1	0.1	–3.08E–07	14.79	5.61E–07	10.39	2.00E–07	13.20	

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

** Was not measured during pumping.

Explanations.

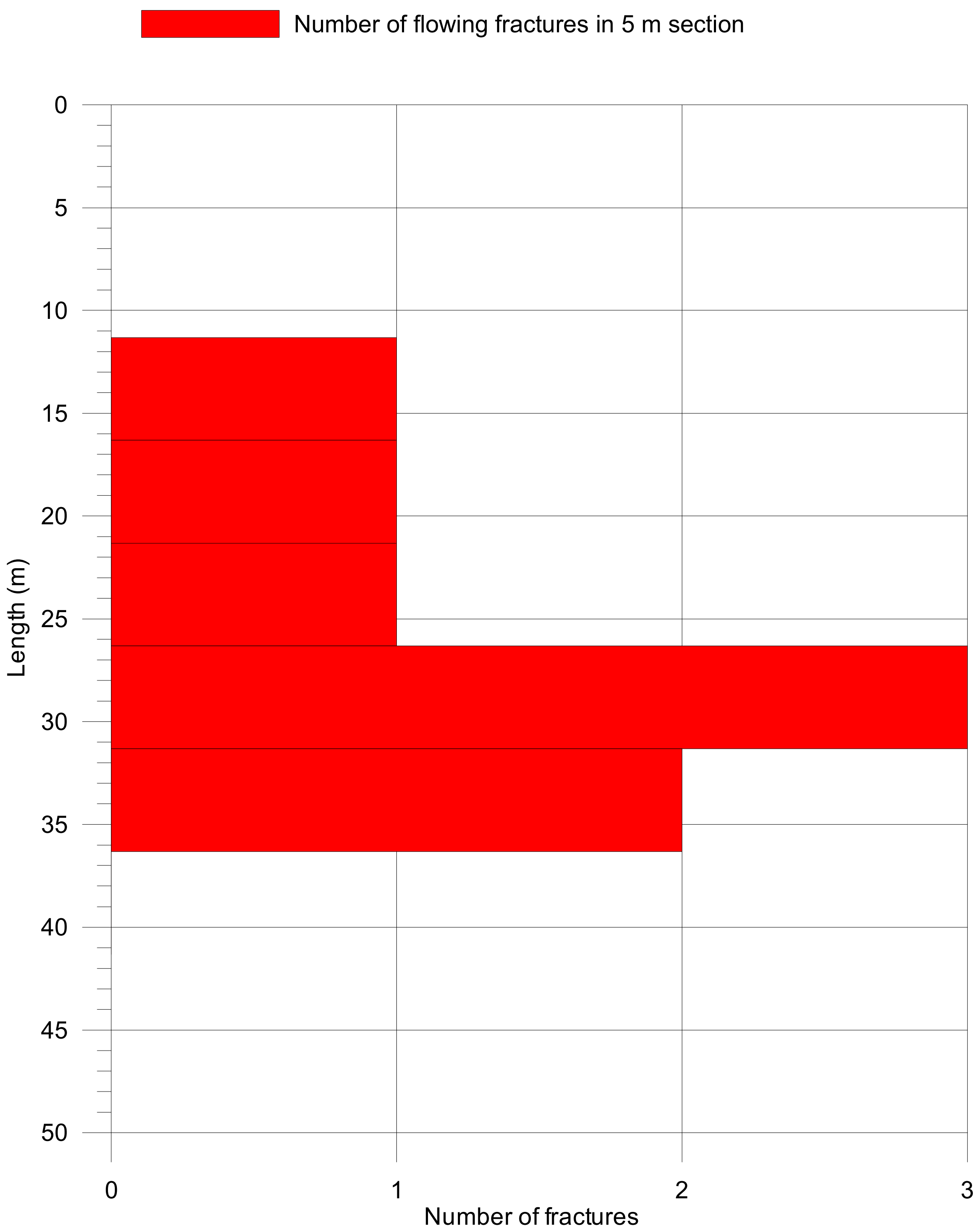
Header	Unit	Explanations
Borehole		ID for borehole.
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L).
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L).
L	m	Corrected length along borehole based 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.
$T\text{-measl}_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
$T\text{-measl}_{U}$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

Calculation of conductive fracture frequency.

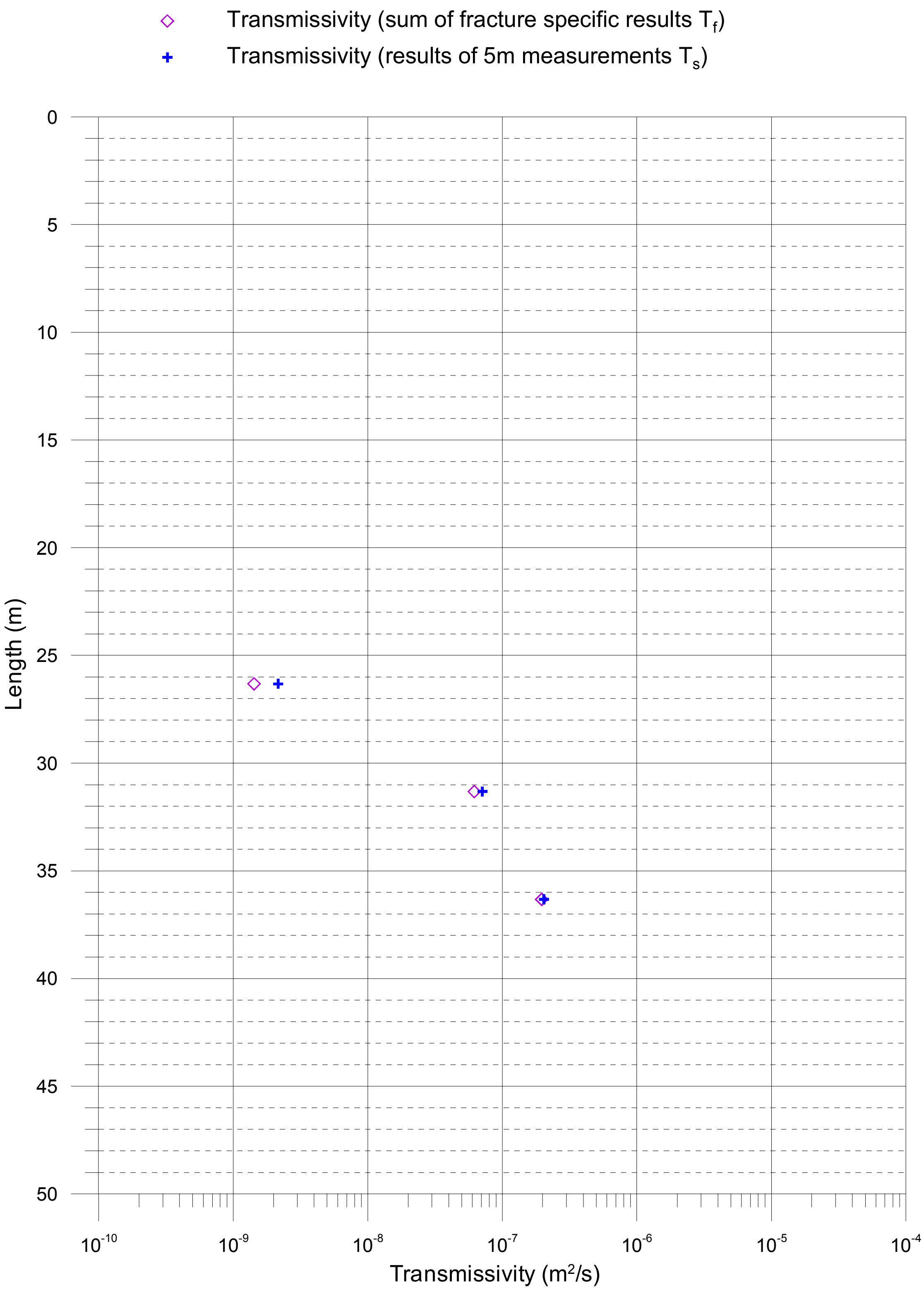
Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)
KLX25A	13.82	18.82	1*	–	–	–	–	–
KLX25A	18.82	23.82	1	0	0	0	1	0
KLX25A	23.82	28.82	1	1	0	0	0	0
KLX25A	28.82	33.82	3	2	1	0	0	0
KLX25A	33.82	38.82	2	1	0	1	0	0
KLX25A	38.82	43.82	0	0	0	0	0	0

* No flow value is given because the fracture was not measured during pumping.

Laxemar, borehole KLX25A
Calculation of conductive fracture frequency

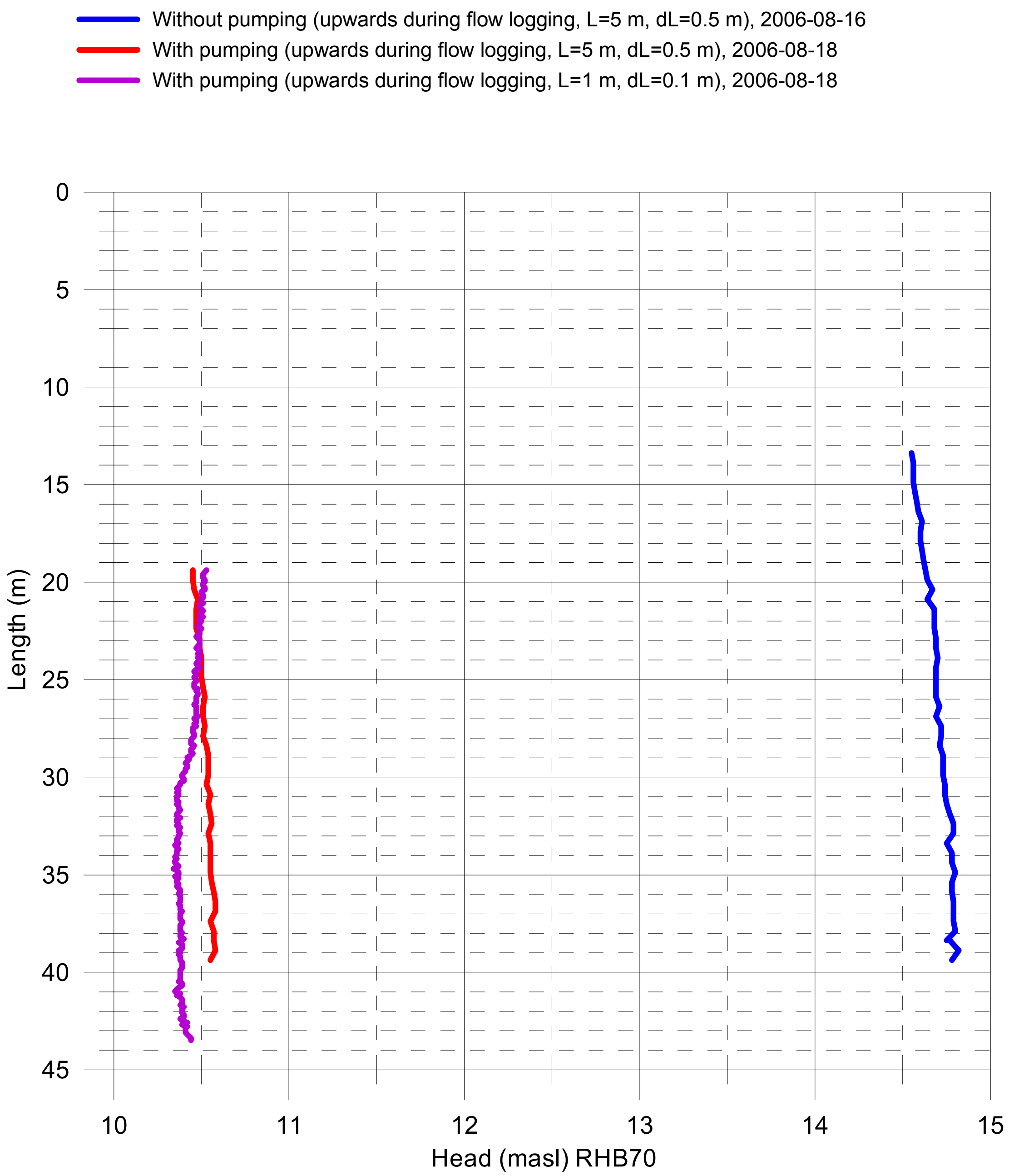


Laxemar, borehole KLX25A
Comparison between section transmissivity and fracture transmissivity

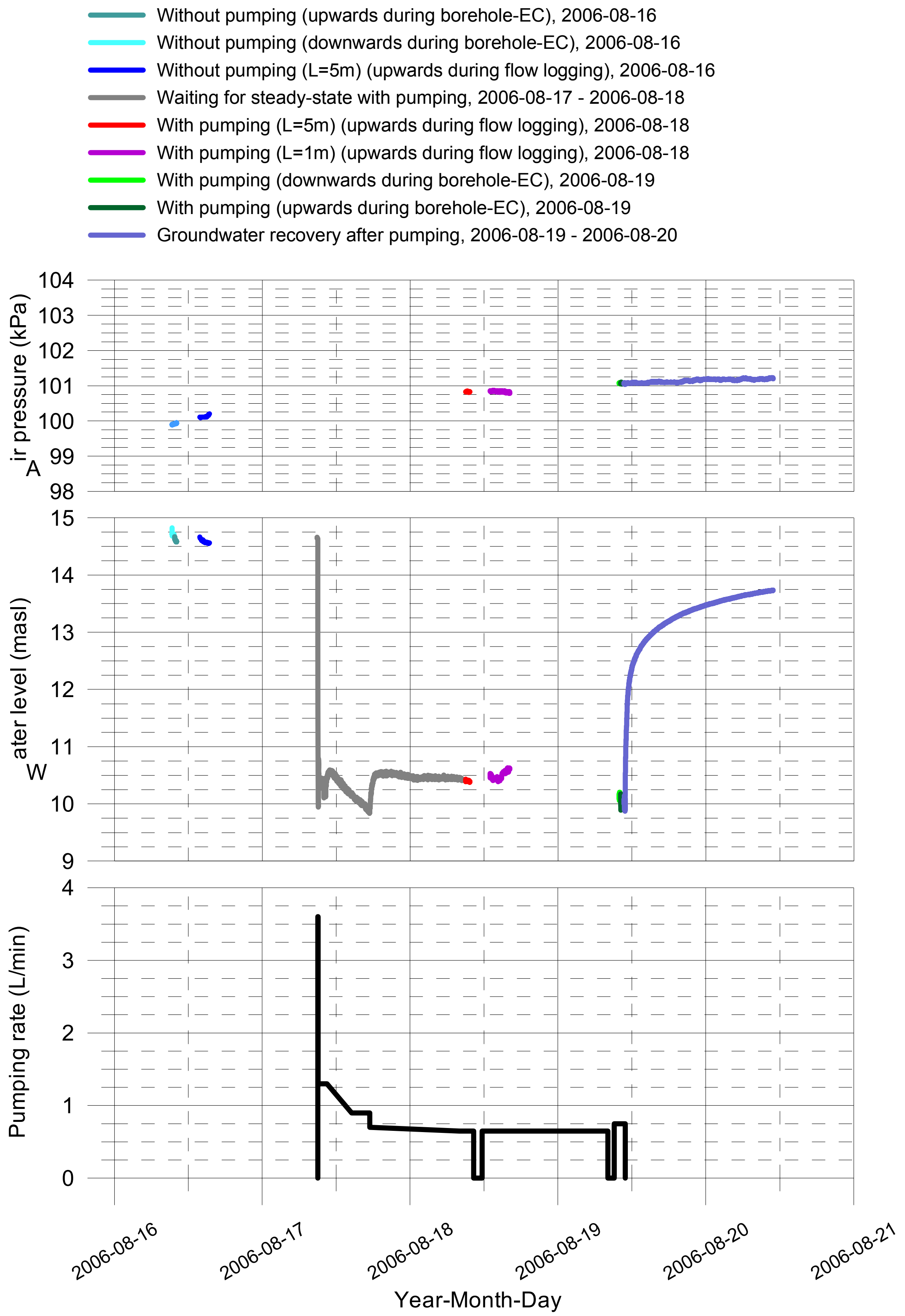


Laxemar, borehole KLX25A
Head in the borehole during flow logging

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)

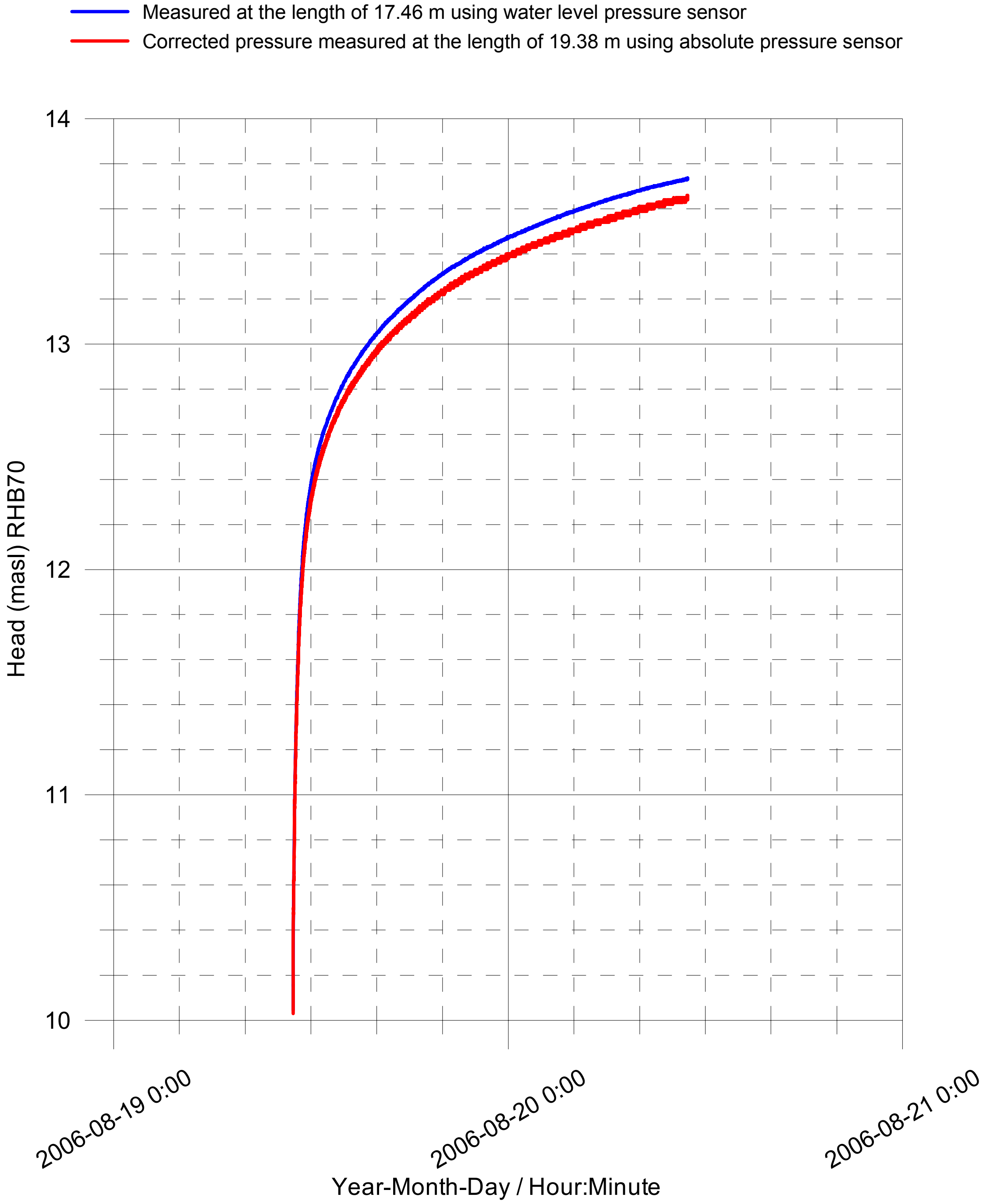


Laxemar, borehole KLX25A
Air pressure, water level in the borehole and pumping rate during flow logging

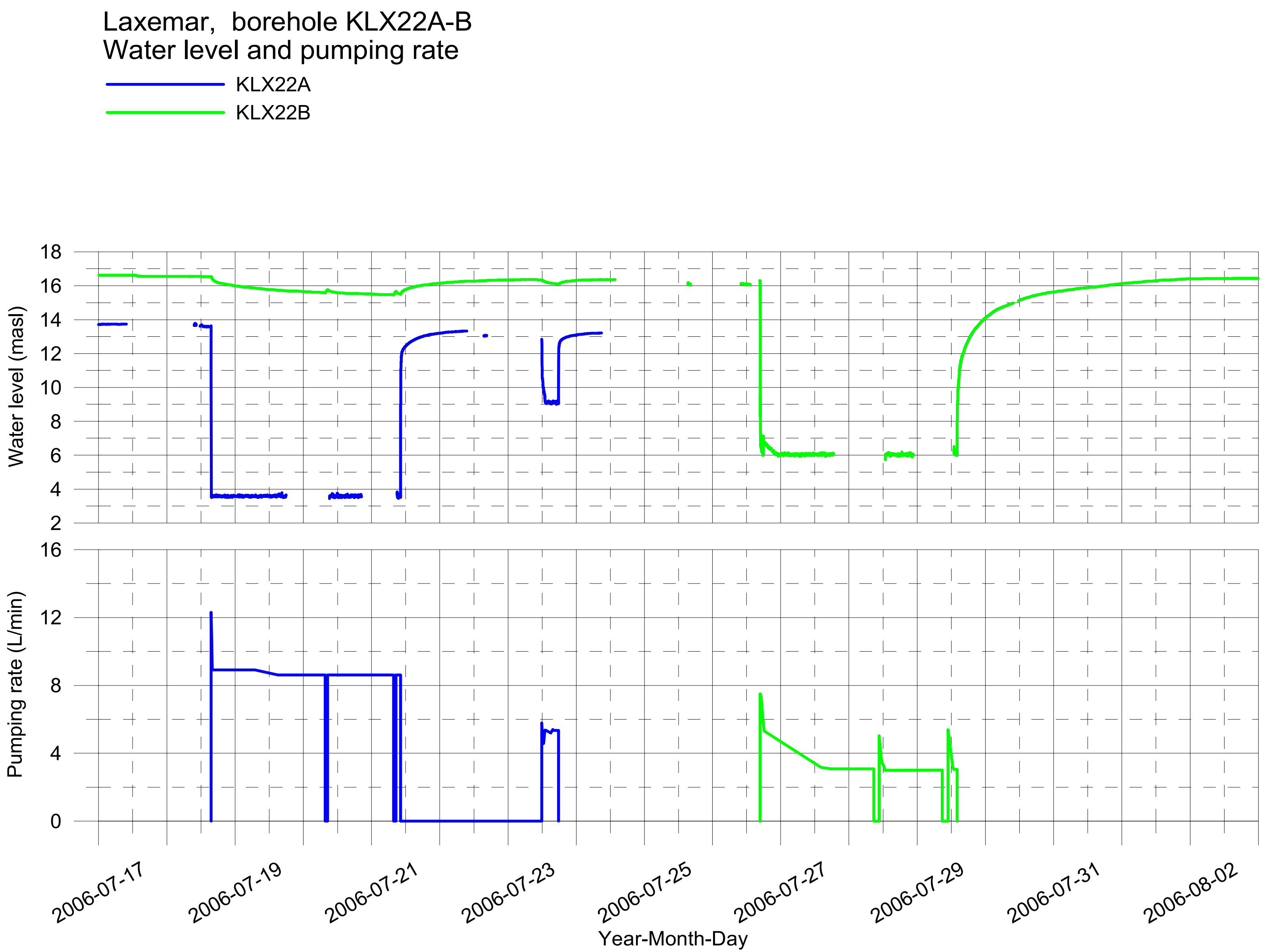


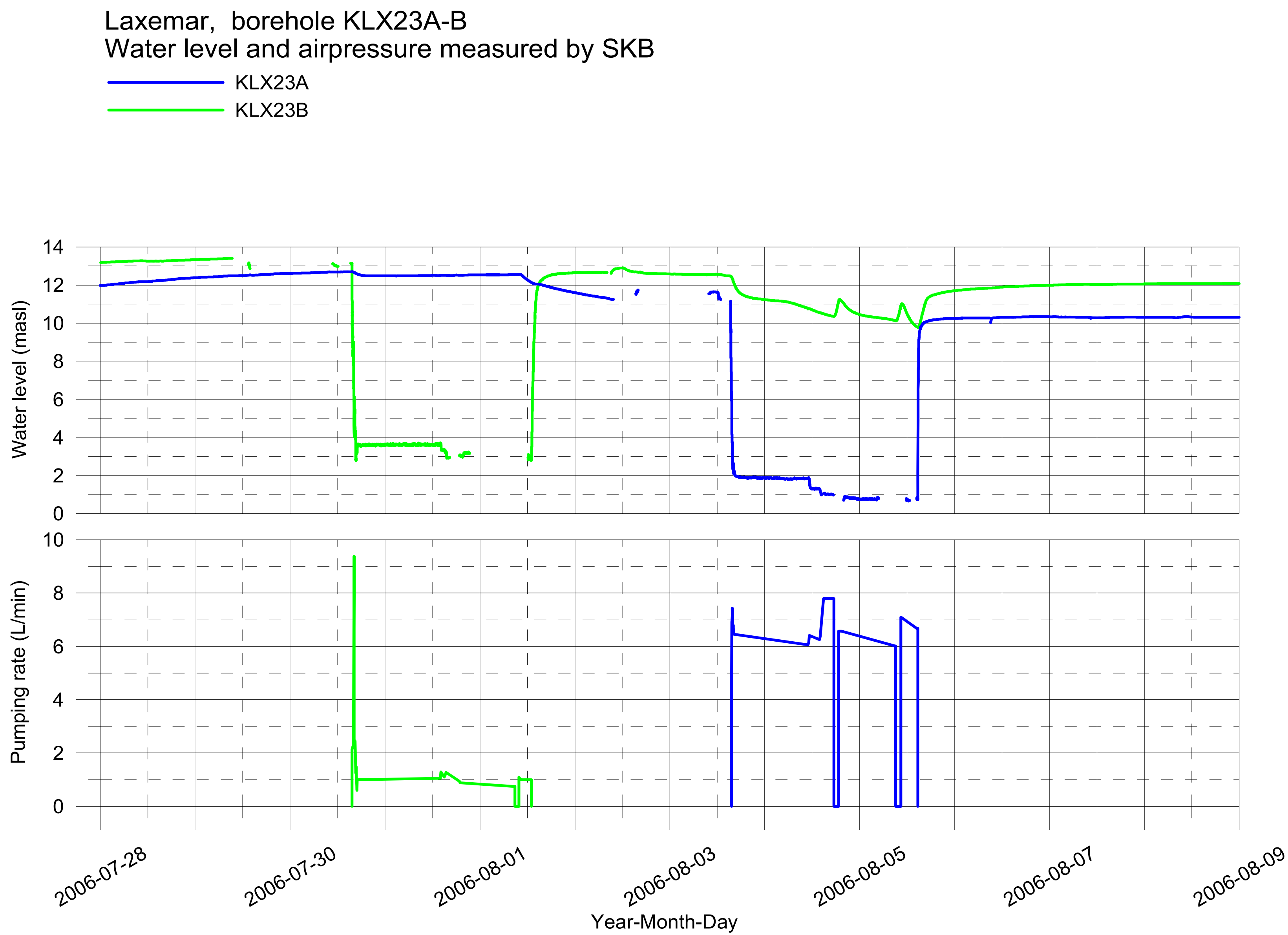
Laxemar, borehole KLX25A
Groundwater recovery after pumping

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



Appendices SKB (Interference)


Laxemar, borehole KLX22A-B
Water level and pumping rate
KLX22A
KLX22B
Water level (masl)
18
16
14
12
10
8
6
4
2
Pumping rate (L/min)
16
12
8
4
0
2006-07-17
2006-07-19
2006-07-21
2006-07-23
2006-07-25
2006-07-27
2006-07-29
2006-07-31
2006-08-02
Year-Month-Day


Laxemar, borehole KLX23A-B
Water level and airpressure measured by SKB
KLX23A
KLX23B
Water level (masl)
14
12
10
8
6
4
2
0
Pumping rate (L/min)
10
8
6
4
2
0
2006-07-28
2006-07-30
2006-08-01
2006-08-03
2006-08-05
2006-08-07
2006-08-09
Year-Month-Day