P-07-64

Oskarshamn site investigation

Difference flow logging of boreholes KLX11B–F

Subarea Laxemar

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PRG-Tec Oy

February 2007

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Abstract

Difference flow logging is a swift method for 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 KLX11B–F at Oskarshamn, Sweden, in September and October 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 KLX11B–F. The measurements are a part of the interference difference flow logging test (Report P-07-65).

The flow rates into or out of 1 m and 5 m long test sections were measured in boreholes KLX11B–F during natural (un-pumped) as well as pumped conditions. The uppermost parts of the boreholes were flow logged with injection.

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

A high-resolution absolute pressure sensor was used to measure the total pressure along the boreholes. Also the electrical conductivity (EC) and temperature of borehole water were measured. These measurements were carried out together with the flow measurements.

The recovery of the groundwater level in the boreholes was measured after the pumpings of the boreholes were stopped.

Sammanfattning

Differensflödesloggning är en snabb metod för bestämning av transmissivitet och hydraulisk tryckhöjd i borrhålssektioner och sprickor /sprickzoner i kärnborrhål. Denna rapport presenterar huvudprinciperna för metoden och resultat av mätningar utförda i borrhål KLX11B–F i Oskarshamn, Sverige, i september och oktober 2006 med Posiva flödesloggningsmetod. Det primära syftet med mätningarna var att bestämma läget och flödet för vattenförande sprickor i borrhålen KLX11B–F. Mätningarna är en del av interferensdifferensflödesloggningstesten (Rapport P-07-65).

Flödet till eller från 1 m och 5 m långa testsektioner mättes i borrhålen KLX11B–F under såväl naturliga (icke-pumpade) som pumpade förhållanden. Övre delen av borrhålen loggades med injektion.

Längdkalibrering gjordes baserad på längdmärkena som frästs in i borrhålsväggen vid noggrant bestämda positioner längs borrhålet. Längmärkena 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 borrhål. Elektrisk konduktivitet och temperatur på borrhålsvattnet mättes också. Dessa mätningar utfördes tillsammans med flödesmätningarna.

Återhämtningen av grundvattennivån mättes efter att pumpningen i hålen avslutades.

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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 400-06-087. 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.

Two reports were produced concerning the activity plan AP PS 400-06-087. One of the reports presents the results of single hole tests, the other one of interference test. This document presents the results acquired from the single hole tests in boreholes KLX11B–F.

The difference flow logging in the core drilled boreholes KLX11B–F at Oskarshamn was conducted between September 4 and October 24, 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
Interference difference flow logging in boreholes KLX11B–F	AP PS 400-06-087	1.0
Method descriptions	**Number**	**Version**
Method description for difference flow logging	SKB MD 322.010e	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Instruction for length calibration in investigation of core boreholes	SKB MD 620.010e	2.0
Instruction for analysis of injection and single-hole puming tests	SKB MD 320.004e	1.0

Table 1-2. Borehole construction, KLX11B–F.

Borehole ID	Length (m)	Inclination (degrees)	Z coord. of the top of the casing (m.a.s.l.)
KLX11B	100.200	–89.869	27.274
KLX11C	120.150	–60.523	27.191
KLX11D	120.350	–58.997	25.574
KLX11E	121.300	–60.647	22.649
KLX11F	120.050	–60.982	24.465

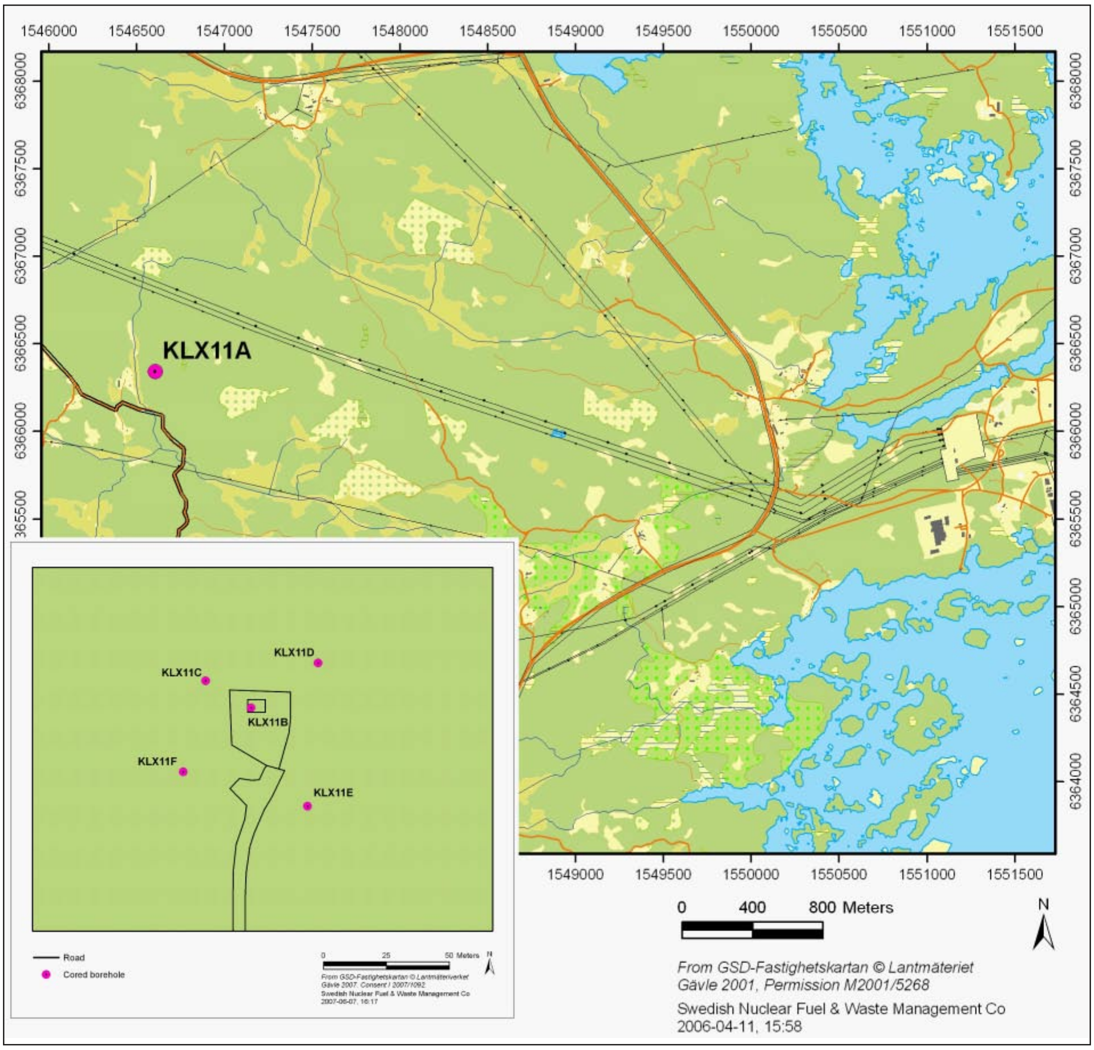


Figure 1-1. *Site map showing the locations of boreholes KLX11B–F situated in Laxemar. Boreholes KLX11B through KLX11F an located near KLX11A.*

2 Objective and scope

The main objective of the difference flow logging in KLX11B–F was to identify water-conductive sections/fractures. Secondly the results are utilised for interference flow logging test, which was conducted between the same boreholes. The results of the interference test are reported separately (Report P-07-65). In this report (P-07-64) only the single hole results are discussed. 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 KLX11B–F 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 a single-point resistance of the borehole wall and an 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.

Single-point resistance measurements were also combined with caliper (borehole diameter) measurements to detect length marks milled into the borehole wall at accurately determined positions. This procedure allowed for the length calibration of all other measurements.

3 Principles of measurement and interpretation

3.1 Measurements

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

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

The Difference flowmeter can be used in two modes, 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.

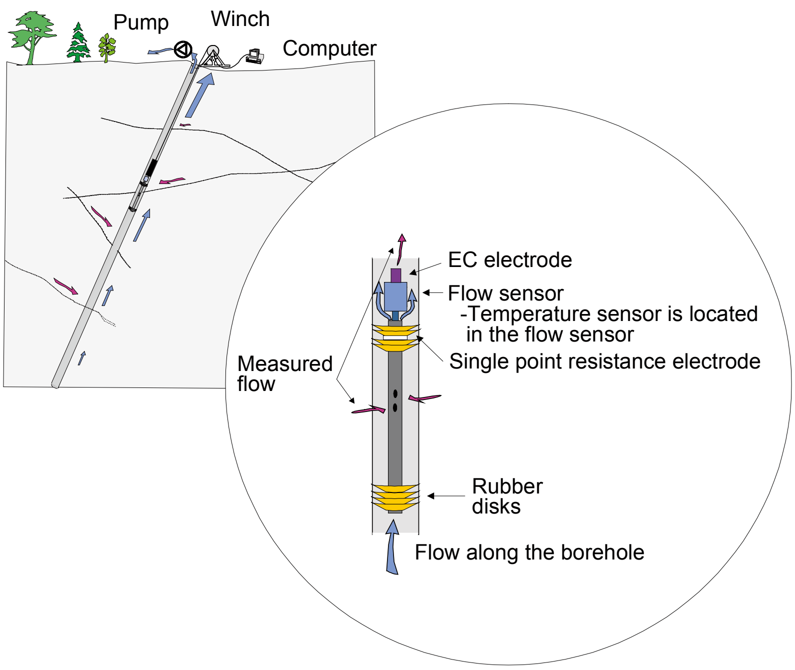


Figure 3-1. *Schematic of the downhole equipment used in the Difference flowmeter.*

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 measurement, were performed in KLX11B–F.

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

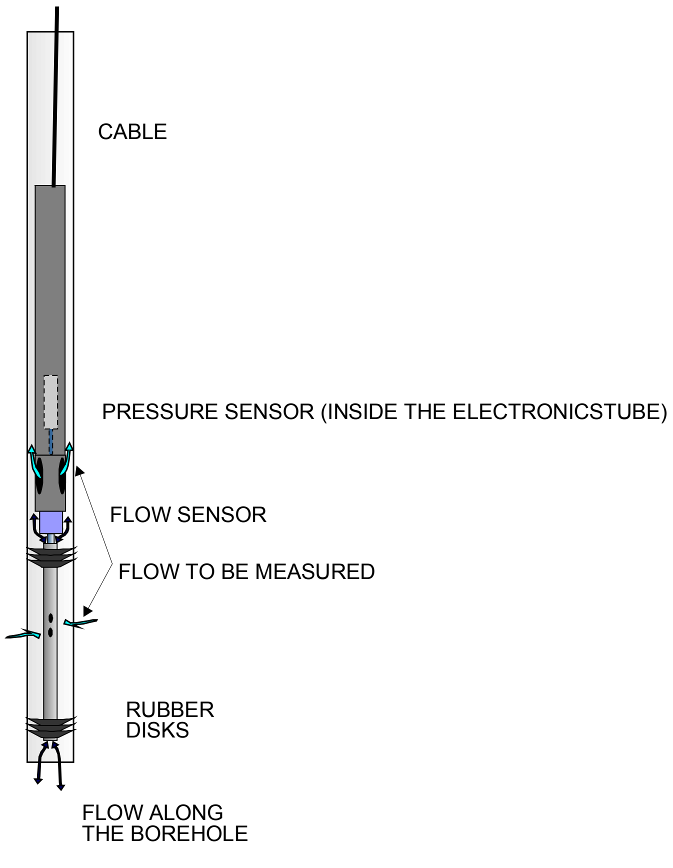


Figure 3-2. *The absolute pressure sensor is located inside the electronics tube and connected through a tube to the borehole water.*

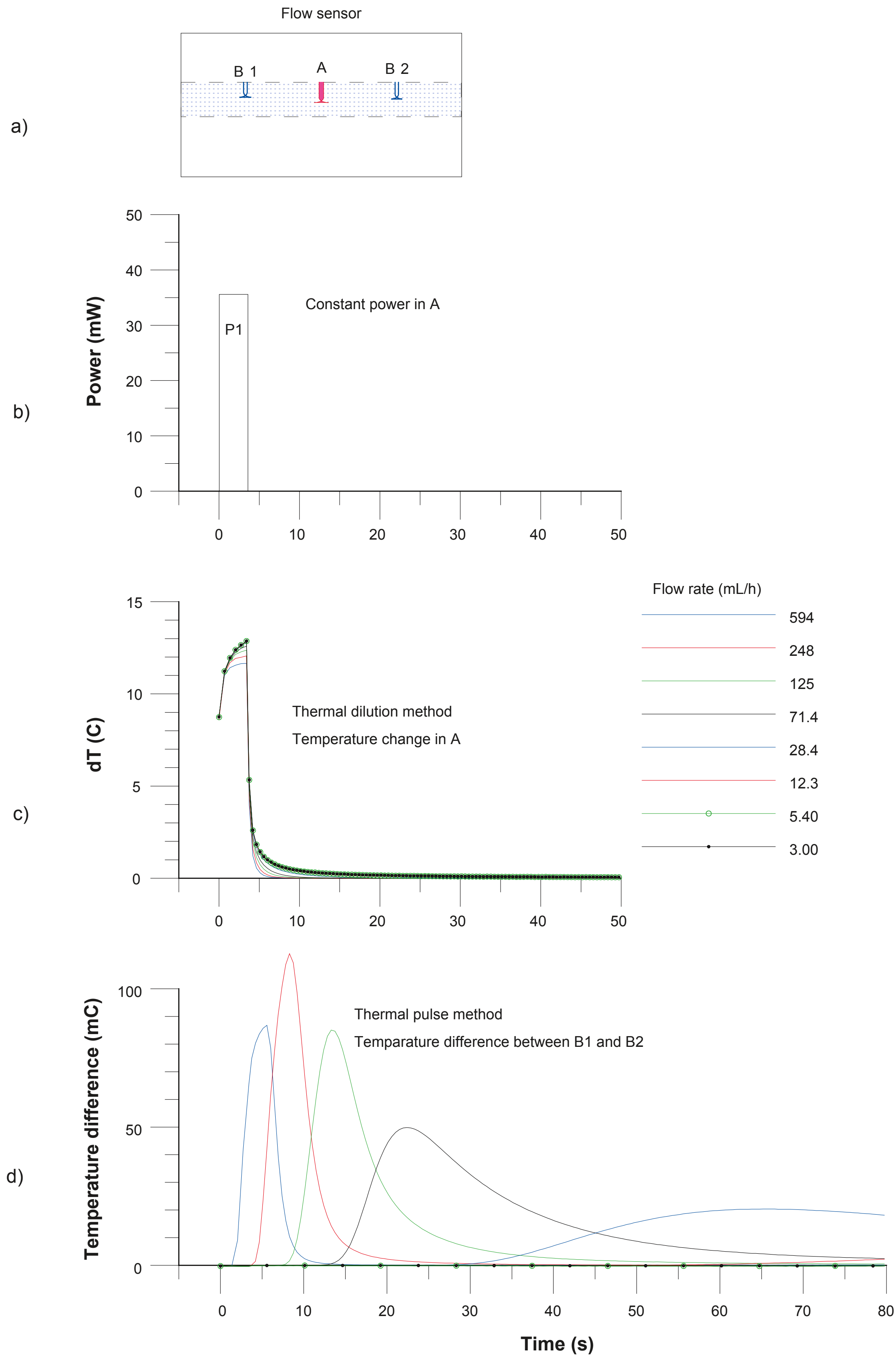


Figure 3-3. *Flow measurement, flow rate < 600 mL/h.*

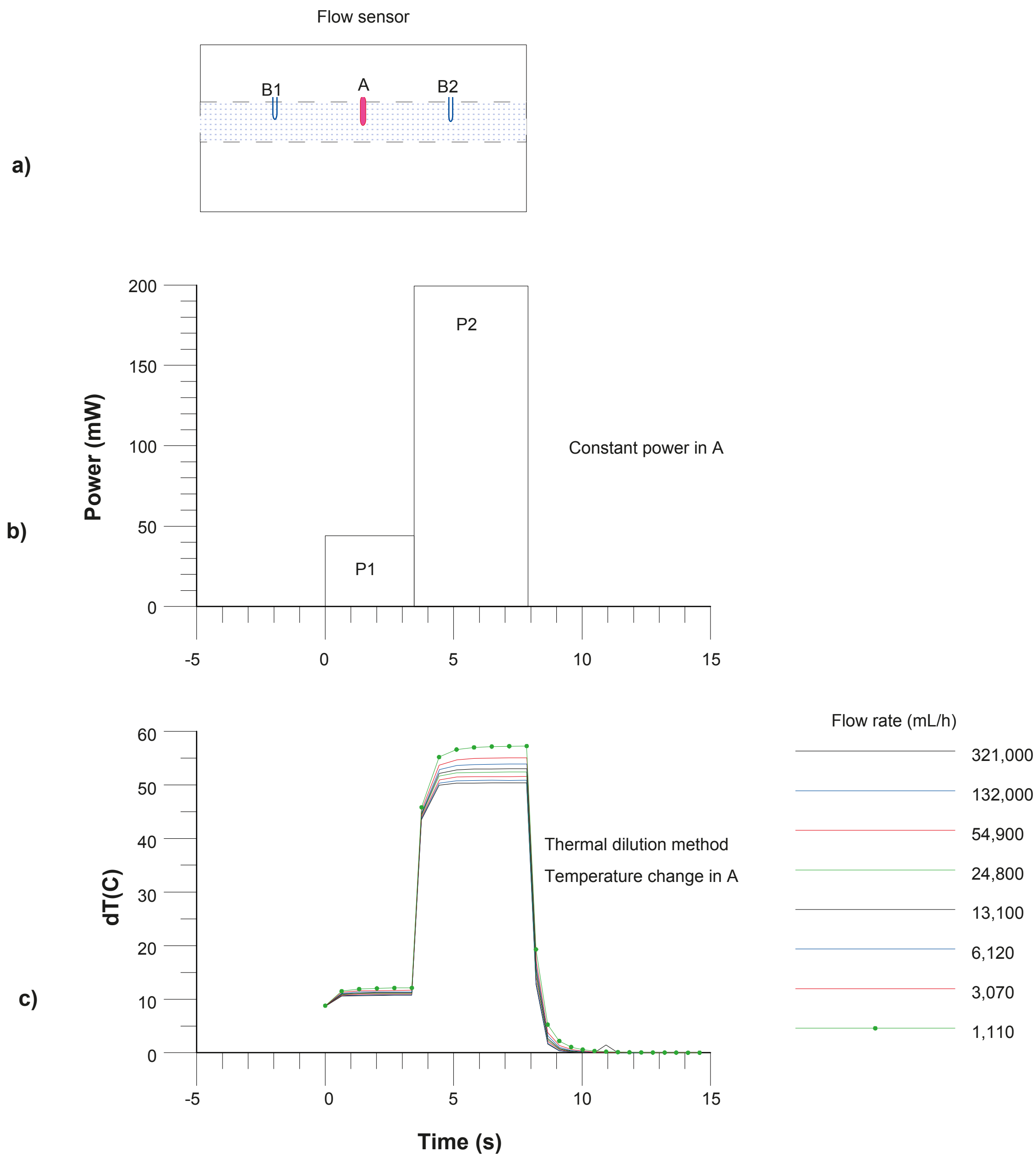


Figure 3-4. *Flow measurement, flow rate > 600 mL/h.*

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

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

The flow is measured when the tool is at rest. After the tool is transferred to a new position, there is a waiting time (the duration of which can be adjusted according to the prevailing circumstances) before the heat pulse (Figure 3-3b) is applied. The waiting time after the constant power 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. When flow above the measurement limit is encountered a remeasurement is performed at the specific anomaly with a reduced pumping, typically about half the original drawdown.

3.2 Interpretation

The interpretation is based on Thiems or Dupuits formula that describes a steady state and two dimensional radial flow into the borehole /Marsily 1986/:

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

where

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

Q is the flow rate into the borehole,

T is the transmissivity of the test section,

a is a constant depending on the assumed flow geometry.

For cylindrical flow, the constant a is:

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

where

r_0 is the radius of the well and

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

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

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

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

where

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

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

T_s is the transmissivity of the test section and

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

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

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

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

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

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

where

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

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

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

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

where

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

h_f and T_f are the hydraulic head (far away from borehole) and the transmissivity of a fracture, respectively. Since Q_{f0} is usually not measured, it is estimated from the Q_{s0} for some fractures, i.e. for those flowing fractures that are far away from the other flowing fractures or for the fractures that have much higher flow rate than surrounding fractures.

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/:

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

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:

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

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:	Variable length flow guides are 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, Electrical 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:	Based on MS Visual Basic.
Total power consumption:	1.5–2.5 kW depending on the pumps.
Calibrated:	Tool nr FL5 in April 2006, tool nr FL2 in August 2006.
Calibration of cable length:	Using length marks in the borehole.

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 400-06-087 (SKB internal controlling document) following the SKB Method Description 322.010e, Version 1.0 (Method description for difference flow logging). This report (P-07-64) only discusses the results of the single hole measurements. The results of the interference test are reported separately (Report P-07-65). Prior to the measurements, the downhole tools and the measurement cable were disinfected. Every clock was synchronized to the normal Swedish time. The activity schedule of the borehole measurements is presented in Table 5-1. The items and activities in Table 5-1 are the same as in the Activity Plan AP PS 400-06-087.

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 boreholes KLX11B–F, length marks were milled into the borehole walls 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.

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. Necessary conditions for a successful length calibration are that all length marks, or at least a 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 dummy loggings (Item 8) of the boreholes were performed before any other measurements were started. This was done to assure that the measurement tools do not get stuck in the boreholes.

The combined overlapping/sequential flow logging (Items 14–23) was carried out first in all the boreholes during natural (un-pumped) conditions. Both 1 m and 5 m section lengths were used. The length increment (step length) was 0.1 m with a 1 m section length and 0.5 m with a 5 m section length. Every tenth flow measurement (sequential mode) had a longer measurement time than normally in the overlapping mode. This was done to ensure the direction of the flow (into the borehole or out of it).

Pumping was started on September 11 in borehole KLX11B. Every borehole KLX11B–F was pumped and measured, and there was a waiting period during which the water level was allowed to recover. Overlapping flow logging (Items 24–33) was carried out in all the boreholes during pumped conditions with 1 m and 5 m section lengths. The length increment (step length) was 0.1 m with the 1 m section length and 0.5 m with the 5 m section length. The measurement order was KLX11B, KLX11E, KLX11D, KLX11C and KLX11F. Pumping in borehole KLX11F was stopped on the 18^{th} of October. Water level in the boreholes is presented on the date scale, see Appendices B.14–F.14.

The measurement programme was then continued with injection tests, which allow for a more complete characterisation of the upper parts of the boreholes which were subjected to drawdown during pumping. The upper parts of the boreholes were now flow logged (overlapping flow logging) with 1 m section length and 0.1 m step length (Items 63–67).

No separate steps were taken in order to measure the electrical conductivity of borehole water during the injection tests. However, EC and temperature results were obtained during other flow loggings.

The recovery of groundwater levels (Items 42, 51 and 60–62) was monitored only with a groundwater level sensor. The absolute pressure sensor located in the flow logging tool was not used.

Table 5-1. Flow logging and testing in KLX11B–F. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer.	2006-09-04
5, 7	Desinfection	Cable cleaning.	2006-09-04
8	Dummy soundering in boreholes KLX11B–F	Dummy logging. Logging without the lower rubber discs, no pumping. Depth interval 0–100.20 m at KLX11B, 0–120.15 m at KLX11C, 0–120.35 m at KLX11D, 0–121.30 m at KLX11E and 0–120.05 m at KLX11F.	2006-09-04–2006-09-11
9	Length calibration, KLX11B	Caliber logging (SKB Caliper and SPR). Logging without the lower rubber discs, no pumping. Depth interval 0–100.20 m.	2006-09-05
10	Length calibration, KLX11C	Caliber logging (SKB Caliper and SPR). Logging without the lower rubber discs, no pumping. Depth interval 0–120.15 m.	2006-09-07
12	Length calibration, KLX11D	Caliber logging (SKB Caliper and SPR). Logging without the lower rubber discs, no pumping. Depth interval 0–120.35 m.	2006-09-07
11	Length calibration, KLX11E	Caliber logging (SKB Caliper and SPR). Logging without the lower rubber discs, no pumping. Depth interval 0–121.30 m.	2006-09-09
13	Length calibration, KLX11F	Caliber logging (SKB Caliper and SPR). Logging without the lower rubber discs, no pumping. Depth interval 0–120.05 m.	2006-09-11
14	Combined Overlapping/Sequential flow logging, KLX11B	Section length L_w=5 m, Step length dL=0.5 m. No pumping.	2006-09-05
15	Combined Overlapping/Sequential flow logging, KLX11C	Section length L_w=5 m, Step length dL=0.5 m. No pumping.	2006-09-06
16	Combined Overlapping/Sequential flow logging, KLX11D	Section length L_w=5 m, Step length dL=0.5 m. No pumping.	2006-09-08
17	Combined Overlapping/Sequential flow logging, KLX11E	Section length L_w=5 m, Step length dL=0.5 m. No pumping.	2006-09-09
18	Combined Overlapping/Sequential flow logging, KLX11F	Section length L_w=5 m, Step length dL=0.5 m. No pumping.	2006-09-10
19	Combined Overlapping/Sequential flow logging, KLX11B	Section length L_w=1 m, Step length dL=0.1 m, No pumping.	2006-09-04–2006-09-05
20	Combined Overlapping/Sequential flow logging, KLX11C	Section length L_w=1 m, Step length dL=0.1 m. No pumping.	2006-09-06–2006-09-07
21	Combined Overlapping/Sequential flow logging, KLX11D	Section length L_w=1 m, Step length dL=0.1 m. No pumping.	2006-09-07–2006-09-08
22	Combined Overlapping/Sequential flow logging, KLX11E	Section length L_w=1 m, Step length dL=0.1 m. No pumping.	2006-09-08–2006-09-09
23	Combined Overlapping/Sequential flow logging, KLX11F	Section length L_w=1 m, Step length dL=0.1 m. No pumping.	2006-09-10–2006-09-11
24	Overlapping flow logging, KLX11B	Section length L_w=5 m, Step length dL=0.5 m at pumping.	2006-09-13
25	Overlapping flow logging, KLX11C	Section length L_w=5 m, Step length dL=0.5 m, at pumping.	2006-10-14

Item	Activity	Explanation	Date
26	Overlapping flow logging, KLX11D	Section length L_w=5 m, Step length dL=0.5 m, at pumping.	2006-10-04
27	Overlapping flow logging, KLX11E	Section length L_w=5 m, Step length dL=0.5 m, at pumping.	2006-09-24
28	Overlapping flow logging, KLX11F	Section length L_w=5 m, Step length dL=0.5 m, at pumping.	2006-10-17
29	Overlapping flow logging, KLX11B	Section length L_w=1 m, Step length dL=0.1 m, at pumping.	2006-09-12
30	Overlapping flow logging, KLX11C	Section length L_w=1 m, Step length dL=0.1 m, at pumping.	2006-10-13–2006-10-14
31	Overlapping flow logging, KLX11D	Section length L_w=1 m, Step length dL= 0.1 m, at pumping.	2006-10-03–2006-10-04
32	Overlapping flow logging, KLX11E	Section length L_w=1 m, Step length dL= 0.1 m, at pumping.	2006-09-23–2006-09-24
33	Overlapping flow logging, KLX11F	Section length L_w=1 m, Step length dL=0.1 m, at pumping.	2006-10-17
42	Recovery transient, KLX11B	Measurement of water level in the borehole after the pumping was stopped.	2006-09-19
51	Recovery transient, KLX11D	Measurement of water level in the borehole after the pumping was stopped.	2006-10-08–2006-10-12
60	Recovery transient, KLX11E	Measurement of water level in the borehole after the pumping was stopped.	2006-09-29–2006-10-02
61	Recovery transient, KLX11C	Measurement of water level in the borehole after the pumping was stopped.	2006-10-14–2006-10-16
62	Recovery transient, KLX11F	Measurement of water level in the borehole after the pumping was stopped.	2006-10-18–2006-10-19
63	Overlapping flow logging, KLX11B	Section length L_w=1 m, Step length dL=0.1 m, injection. PFL logging from casing bottom to part of borehole which was subjected to drawdown.	2006-10-22
63 Extra	Overlapping flow logging, KLX11B	Section length L_w=1 m, Step length dL=0.1 m, smaller injection. Re-measuring fracture flows that were over the measurement limit.	2006-10-22
64	Overlapping flow logging, KLX11C	Section length L_w=1 m, Step length dL=0.1 m, injection. PFL logging from casing bottom to part of borehole which was subjected to drawdown.	2006-10-20
65	Overlapping flow logging, KLX11D	Section length L_w=1 m, Step length dL=0.1 m, injection. PFL logging from casing bottom to part of borehole which was subjected to drawdown.	2006-10-21
65 Extra	Overlapping flow logging, KLX11D	Section length L_w=1 m, Step length dL=0.1 m, smaller injection. Re-measuring fracture flows that were over the measurement limit.	2006-10-20
66	Overlapping flow logging, KLX11E	Section length L_w=1 m, Step length dL=0.1 m, injection. PFL logging from casing bottom to part of borehole which was subjected to drawdown.	2006-10-19
67	Overlapping flow logging, KLX11F	Section length L_w=1 m, Step length dL=0.1 m, injection. PFL logging from casing bottom to part of borehole which was subjected to drawdown.	2006-10-21
67 Extra	Overlapping flow logging, KLX11F	Section length L_w=1 m, Step length dL=0.1 m, smaller injection. Re-measuring fracture flows that were over the measurement limit.	2006-10-21
68	Demobilisation		2006-10-23–2006-10-24

5.2 Nonconformities

The fractures where the flow rate had exceeded the measurement limit were re-measured with small injection. A section length of 1 m and a step length of 0.1 m were used (Items 63Extra, 65Extra and 67Extra). To be used in transmissivity and head calculations, also the undisturbed state just before the injection was measured.

Due to the length of the measuring probe and additional weights it is not physically possible to measure all the way down to the bottom of the hole. The distance between measurement point and lower end of the tool in borehole is presented in Table 5-3. For that reason the possible flow anomalies at the bottom of the borehole will not be detected.

Table 5-3. Unmeasured parts at bottom of boreholes.

KLX11B	KLX11C	KLX11D	KLX11E	KLX11F
3.65 m	3.65 m	3.65 m	3.65 m	3.65 m

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 a new cable, 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 (Items 9–13) were initially length corrected in relation to the known length marks, Appendices B–F.1, black curve. Corrections between the length marks were obtained by linear interpolation.
- The SPR curves of Items 9–13 were then compared with the SPR curves of Items 14–33 and 63–67 to obtain relative length errors of these measurement sequences.
- All SPR curves could then be synchronised, as can be seen in Appendices B–F.1.

The results of the caliper and single-point resistance measurements from all measurements are presented in Appendices B–F.1.1. The SPR curves are plotted together with the caliper-data.

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

Zoomed results of the caliper and SPR data are presented in Appendices B–F.1.2–1.11. The detected length marks are listed in Table 6-1. All the marks were detected by the caliper tool and in the single-point resistance measurements. 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 recognised. In this case there were no partially recognized length marks. Appendices B–F.1 also illustrate many natural anomalies which can help in synchronising the results.

The aim of the plots in Appendices B–F.1.2–1.11 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 B.1.9, C.1.11, D.1.10, E.1.12 and F.1.10. The negative values of the error represent the situation where the logging cable has been extended, i.e. the cable is longer than the nominal length marked on it.

Table 6-1. Detected length marks.

Borehole	Length marks given by SKB (m)	Length marks detected by caliper	Length marks detected by SPR
KLX11B	50	both	yes
KLX11B	80	both	yes
KLX11C	47	both	yes
KLX11C	98	both	yes
KLX11D	50	both	yes
KLX11D	100	both	yes
KLX11E	50	both	yes
KLX11E	100	both	yes
KLX11F	50	both	yes
KLX11F	101	both	yes

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 (Items 9–13).
4. SPR curves may be imperfectly synchronised. 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.

To know 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 electrical conductivity of borehole water (EC) was measured simultaneously with all flow logging measurements. Normally EC is measured as a separate activity. The difference between the separate and the simultaneous EC measurement is, that in the simultaneous measurement water changes slower in the test section. The measured EC value does not therefore represent the situation in the borehole as accurately as it does in separate measurement that is performed without the lower rubber discs.

The temperature of the borehole water was also measured during 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 B–F.3.2 correspond to the EC results in Appendices B–F.3.1.

6.3 Pressure measurements

Absolute pressure was registered with the flow measurements in Items 14–33 and 63–67. The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered separately, Appendices B–F.14. The hydraulic head along the borehole is determined in the following way. First, the monitored air pressure at the site is subtracted from the measured absolute pressure by the pressure sensor. The hydraulic head (h) at a certain elevation z is then calculated according to the following expression /Freeze and Cherry 1979/:

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

where

h_{fw} 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 is subtracted from absolute pressure raw data. With tool number FL5 offset was 2.46 kPa (Items 14–24, 26, 27, 29–32, 42, 51 and 60) and with FL2 offset was 2.30 kPa (Items 25, 28, 33 and 61–67).

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

The calculated head values are presented in a graph in Appendices B–F.13. h_{fw} is the head utilized in the calculations described in equations 3-1 to 3-10.

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) and the caliper plot (in the middle), see Appendices B–F.2. 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 without pumping in all the boreholes using both 1 m (light blue curve) and 5 m (dark blue curve) section lengths. The length increments (step lengths) were 0.1 m and 0.5 m respectively. After that, the measuring programme continued with the same measurement types under pumped conditions (1 m, violet curve; 5 m, red curve).

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. To obtain quick results, only the thermal dilution method is used for flow determination.

Under natural conditions or if the borehole isn't pumped using a sufficient drawdown the flow direction may be into the borehole or out from it. The direction of small flows (< 100 mL/h) cannot be detected in the normal overlapping mode (thermal dilution method). Therefore the measurement time was longer (so that the thermal pulse method could be used) at every section interval in both 5 m and 1 m section measurements under natural conditions and in 1 m section measurement under pumped conditions. The thermal pulse method was only used to detect the flow direction.

Detected fractures are shown in Appendices B–F.2 (in the middle) 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; a 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. If a fracture is not detected under pumped conditions, the line is grey. The grey marked fracture was detected during the interference test (Report P-07-65).

The coloured triangles in the illustrations show the magnitudes of the measured flows. The triangles have same colour than the corresponding curves.

The tables in Appendices B–F.10 were used to calculate conductive fracture frequency (CFF). The number of conductive fractures was counted on the same 5 meter sections as in Appendices B–F.7 before. 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 B–F.11.

The basic data for measurements is presented in Appendices B–F.6 and the explanations to the tables in Appendices B–F.6–8 in Appendices B–F.9.

6.4.2 Transmissivity and hydraulic head of borehole sections

The boreholes KLX11B–F were flow logged both with 1 m and 5 m section lengths. 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 B–F.7. Only the results with a 5 m length increment are used. Secup and Seclow in Appendices B–F.7 are the distances along the borehole from the reference level (top of the casing tube) to the upper end of the test section and to the lower end of the test section, respectively. The Secup and Seclow values for the two sequences (measurements at un-pumped and pumped conditions) are not exactly identical, due to a minor difference in the cable stretching. The difference between these two sequences was small. Secup and Seclow given in Appendices B–F.7 are calculated as the average of these two values. The same flow rates as in Appendices B–F.7, are also plotted in Appendices B–F.2.

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

The flow results in Appendices B–F.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.

It is possible to detect the existence of flow anomalies below the measurement limit (30 mL/h = $8.33 \cdot 10^{-9}$ m^3/s), even though the exact numerical values below the limit are uncertain.

The flow data is presented as a plot, see Appendices B–F.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 and in the tables. There are theoretical and practical lower limits of flow, see Section 6.4.4.

The hydraulic head and transmissivity (T_D) of borehole sections can be calculated from the flow data using the method described in Chapter 3. The hydraulic head of sections is presented in the plots if neither of the two flow values at the same length is equal to zero. Transmissivity is presented if none or just one of the flows is equal to zero, see Appendices B–F.4.2. The measurement limits of transmissivity are also shown in Appendices B–F.4.2 and in Appendices B–F.7. All the measurement limit values of transmissivity are based on the actual pressure difference in the borehole (h_{0FW} and h_{1FW} in Appendices B–F.7).

KLX11B

With the borehole at rest, 12 sections were detected as flow yielding, 2 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 10 of the detected flows were directed towards the borehole and during injection all 6 of the detected flows were directed towards the bedrock.

The sum of detected flows without pumping (Q_0) was $-2.8 \cdot 10^{-7}$ m^3/s (–1,020 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.

KLX11C

With the borehole at rest, 9 sections were detected as flow yielding, 2 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 13 of the detected flows were directed towards the borehole and during injection all 6 of the detected flows were directed towards the bedrock.

The sum of detected flows without pumping (Q_0) was $1.2 \cdot 10^{-7}$ m^3/s (440 mL/h).

KLX11D

With the borehole at rest, 14 sections were detected as flow yielding, 8 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 16 of the detected flows were directed towards the borehole and during injection all 4 of the detected flows were directed towards the bedrock.

The sum of detected flows without pumping (Q_0) was $4.4 \cdot 10^{-7}$ m^3/s (1,590 mL/h).

KLX11E

With the borehole at rest, 11 sections were detected as flow yielding, 3 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 13 of the detected flows were directed towards the borehole and during injection all 5 of the detected flows were directed towards the bedrock.

The sum of detected flows without pumping (Q_0) was $1.3 \cdot 10^{-6}$ m^3/s (4,560 mL/h).

KLX11F

With the borehole at rest, 9 sections were detected as flow yielding, 2 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 9 of the detected flows were directed towards the borehole and during injection all 3 of the detected flows were directed towards the bedrock.

The sum of detected flows without pumping (Q_0) was $1.0 \cdot 10^{-5}$ m^3/s (37,200 mL/h).

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 meter, it may be difficult to evaluate the flow rate. There are such cases for instance in Appendix B.2.4. In these cases a stepwise increase or decrease in the flow data plot equals the flow rate of a specific fracture (filled triangles in the Appendices).

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

Fracture-specific transmissivities were compared with the transmissivities of borehole sections in Appendices B–F.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.

KLX11B

The total amount of detected flowing fractures in the borehole was 37. 29 of them could be defined without pumping, 25 with pumping and 10 with injection. Two fractures were detected only during interference test. 29 of the fractures could be used for head estimations and 35 were used for transmissivity estimations, Appendix B.8.

KLX11C

The total amount of detected flowing fractures in the borehole was 41. 15 of them could be defined without pumping, 25 with pumping and 16 with injection. 15 of the fractures could be used for head estimations and all 41 were used for transmissivity estimations, Appendix C.8.

KLX11D

The total amount of detected flowing fractures in the borehole was 49. 30 of them could be defined without pumping, 41 with pumping and 8 with injection. 30 of the fractures could be used for head estimations and all 49 were used for transmissivity estimations, Appendix D.8.

KLX11E

The total amount of detected flowing fractures in the borehole was 37. 16 of them could be defined without pumping, 25 with pumping and 12 with injection. 16 of the fractures could be used for head estimations and all 37 were used for transmissivity estimations, Appendix E.8.

KLX11F

The total amount of detected flowing fractures in the borehole was 24. 16 of them could be defined without pumping, 18 with pumping and 5 with injection. 15 of the fractures could be used for head estimations and 23 were used for transmissivity estimations, Appendix F.8.

6.4.4 Theoretical and practical limits of flow measurements and transmissivity

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

In practice, the minimum measurable flow rate might, however, 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 B–F.2 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 boreholes KLX11B–F were low, see Table 6-2.

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, because the values of flow rate measured below 30 mL/h are uncertain.

In some boreholes the upper limit of the flow measurements (300,000 mL/h) may be exceeded. Such fractures or structures hardly remain undetected (as opposed to the fractures below the lower measurement limit). High flowing fractures were measured separately with small injection in boreholes KLX11B, KLX11D and KLX11F. These fractures are marked with "****" in the "Comments"-column in Appendices B.8, D.8 and F.8.

The practical minimum of the measurable flow rate is also presented in Appendices B–F.7 (Q-lower limit P). The value is the same as the Lower limit of flow rate in Appendices B–F.2. The Practical minimum of measurable transmissivity can be evaluated using Q-lower limit P and the head difference at each measurement location, see Appendices B–F.7 (TD-$measl_{LP}$). 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 B–F.7 (TD-$measl_{LT}$). 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 B–F.7 (TD-$measl_{U}$).

All three flow limits are also plotted with measured flow rates, see Appendices B–F.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 B–F.4.2.

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

6.4.5 Transmissivity of the entire borehole

The pumping phase for the logging and its subsequent recovery is utilized to evaluate the transmissivity of the entire borehole. This is done with the two steady state methods, described in Chapter 3. Drawdown used for both methods is the drawdown between measurements with and without pumping.

Table 6-2. Approximate noise level in flow in boreholes during pumping.

Borehole	Noise level in flow (mL/h)	Comments
KLX11B	30	
KLX11C	30	
KLX11D	30	
KLX11E	30	
KLX11F	30–100	30 mL/h below 73 m

KLX11B

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 16.0 L/min and s (drawdown) was 9.44 m. Transmissivity calculated with Dupuit's formula is $2.8 \cdot 10^{-5}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 98.99 m (1.21–100.20 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $3.7 \cdot 10^{-5}$ m^2/s.

KLX11C

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 1.8 L/min and s (drawdown) was 10.11 m. Transmissivity calculated with Dupuit's formula is $2.9 \cdot 10^{-6}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 118.15 m (2.00–120.15 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $3.9 \cdot 10^{-6}$ m^2/s.

KLX11D

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 21.1 L/min and s (drawdown) was 9.75 m. Transmissivity calculated with Dupuit's formula is $3.6 \cdot 10^{-5}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 118.35 m (2.00–120.35 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $4.8 \cdot 10^{-5}$ m^2/s.

KLX11E

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 2.3 L/min and s (drawdown) was 10.07 m. Transmissivity calculated with Dupuit's formula is $3.8 \cdot 10^{-6}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 119.30 m (2.00–121.30 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $5.1 \cdot 10^{-6}$ m^2/s.

KLX11F

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 33.3 L/min and s (drawdown) was 9.67 m. Transmissivity calculated with Dupuit's formula is $3.9 \cdot 10^{-5}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 118.05 m (2.00–120.05 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $5.2 \cdot 10^{-5}$ m^2/s.

The results of the two methods are given for each hole in Table 6-3.

Basic test data is in Appendices B–F.6.

Table 6-3. Transmissivities of the entire boreholes KLX11B–F.

	KLX11B	KLX11C	KLX11D	KLX11E	KLX11F
Dupuit (m^2/s)	$2.8 \cdot 10^{-5}$	$2.9 \cdot 10^{-6}$	$3.6 \cdot 10^{-5}$	$3.8 \cdot 10^{-6}$	$3.9 \cdot 10^{-5}$
Moye (m^2/s)	$3.7 \cdot 10^{-5}$	$3.9 \cdot 10^{-6}$	$4.8 \cdot 10^{-5}$	$5.1 \cdot 10^{-6}$	$5.2 \cdot 10^{-5}$

6.5 Groundwater level and pumping rate

The groundwater level and the pumping rate are illustrated in Appendices B–F.14 and the recovery plots are presented in Appendices B–F.15. The groundwater recovery was monitored with the groundwater level sensor. When using the PFL equipment in other boreholes, the water level was monitored with SKB's pressure sensors.

From 18th of September forward a rising trend in general groundwater level can be seen. This is caused by some external factors. Because measurements without pumping were performed in most of the cases weeks ahead of measurements with pumping, the natural water level had shifted between the measurements. The drawdown for the pumping was determined from the water level during measurement without pumping and do not therefore represent the real drawdown in all of the cases.

Individual borehole information is presented in Table 6-4. In Table 6-4 "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 6-4 are given as meters above sea level (metres above sea level) according to RHB70. Drawdown is calculated from water levels between measurements with and without pumping. The real drawdown was in most of the cases bigger than this, see Appendices B–F.14.

Table 6-4. 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 Casing (m.a.s.l.)	Approx. drawdown (m)	Recovery period
KLX11B	2006-09-11–2006-09-19	0.47	–1.78	27.274	9.44	2006-09-19–2006-09-22
KLX11C	2006-10-12–2006-10-14	0.67	–1.21	27.191	10.11	2006-10-14–2006-10-15
KLX11D	2006-10-02–2006-10-08	1.14	–0.78	25.574	9.75	2006-10-08–2006-10-12
KLX11E	2006-09-22–2006-09-29	0.34	–1.69	22.649	10.07	2006-09-29–2006-10-02
KLX11F	2006-10-16–2006-10-18	0.31	–1.70	24.465	9.67	2006-10-18–2006-10-19

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 KLX11B–F at Oskarshamn. The study is part of the interference difference flow logging test (Report P-07-65). The flow rates into or out of 1 m and 5 m long test sections were measured in boreholes KLX11B–F during natural (un-pumped) as well as pumped conditions. The uppermost parts of the boreholes were flow logged with injection. The level of the groundwater and its recovery after pumping were also monitored.

The distribution of saline water along the borehole was logged simultaneously with the flow measurements by electrical conductivity and temperature measurements of the borehole water.

Transmissivity and hydraulic head were calculated for borehole sections and fractures. The total amount of detected flowing fractures in KLX11B was 37, in KLX11C 41, in KLX11D 49, in KLX11E 37 and in KLX11F 24. High-transmissive fractures were found in KLX11B around the lengths of 43 m and 75 m, in KLX11C around 8 m, 45 m and 77 m, in KLX11D around 109 m, in KLX11E around 31 m, 42 m and 74 m and in KLX11F around 70 m.

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

References

Freeze R A, Cherry J A, 1979. Groundwater. Prentice Hall, Inc., United States of America.

Heikkonen J, Heikkinen E, Mäntynen M, 2002. Mathematical modelling of temperature adjustment algorithm for groundwater electrical conductivity on basis of synthetic water sample analysis. Helsinki, Posiva Oy. Working report 2002-10 (in Finnish).

Ludvigson J-E, Hansson K, Rouhiainen P, 2002. Methodology study of Posiva difference flowmeter in borehole KLX02 at Laxemar. SKB Rapport R-01-52, Svensk Kärnbränslehantering AB.

Marsily G, 1986. Quantitive Hydrology, Groundwater Hydrology for Engineers. Academic Press, Inc., London.

Moye D G, 1967. Diamond drilling for foundation exploration. Civil Engineering Trans., April. pp. 95–100.

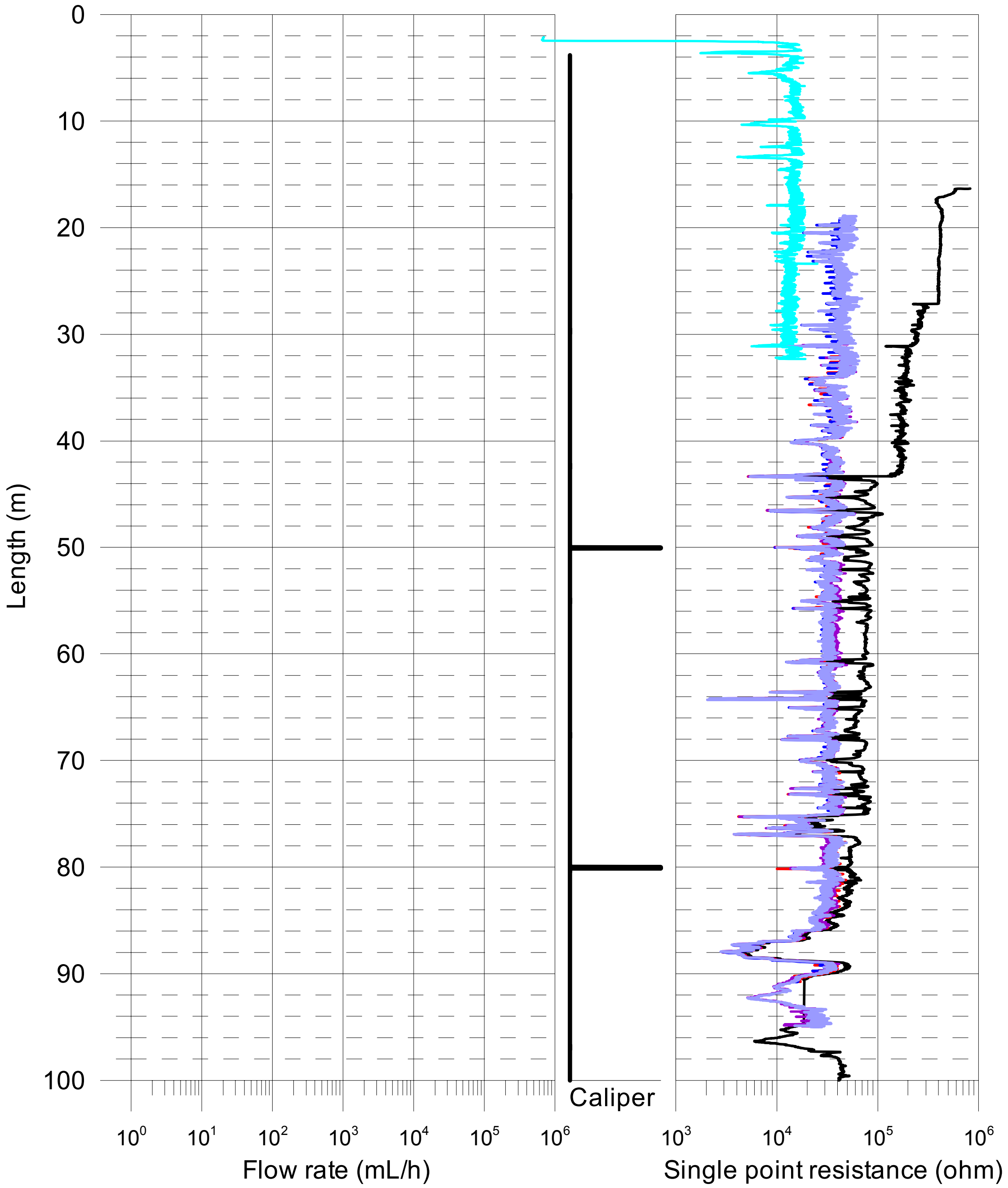
Öhberg A, Rouhiainen P, 2000. Posiva groundwater flow measuring techniques. Helsinki, Posiva Oy. Report POSIVA 2000-12.

Appendices, KLX11B

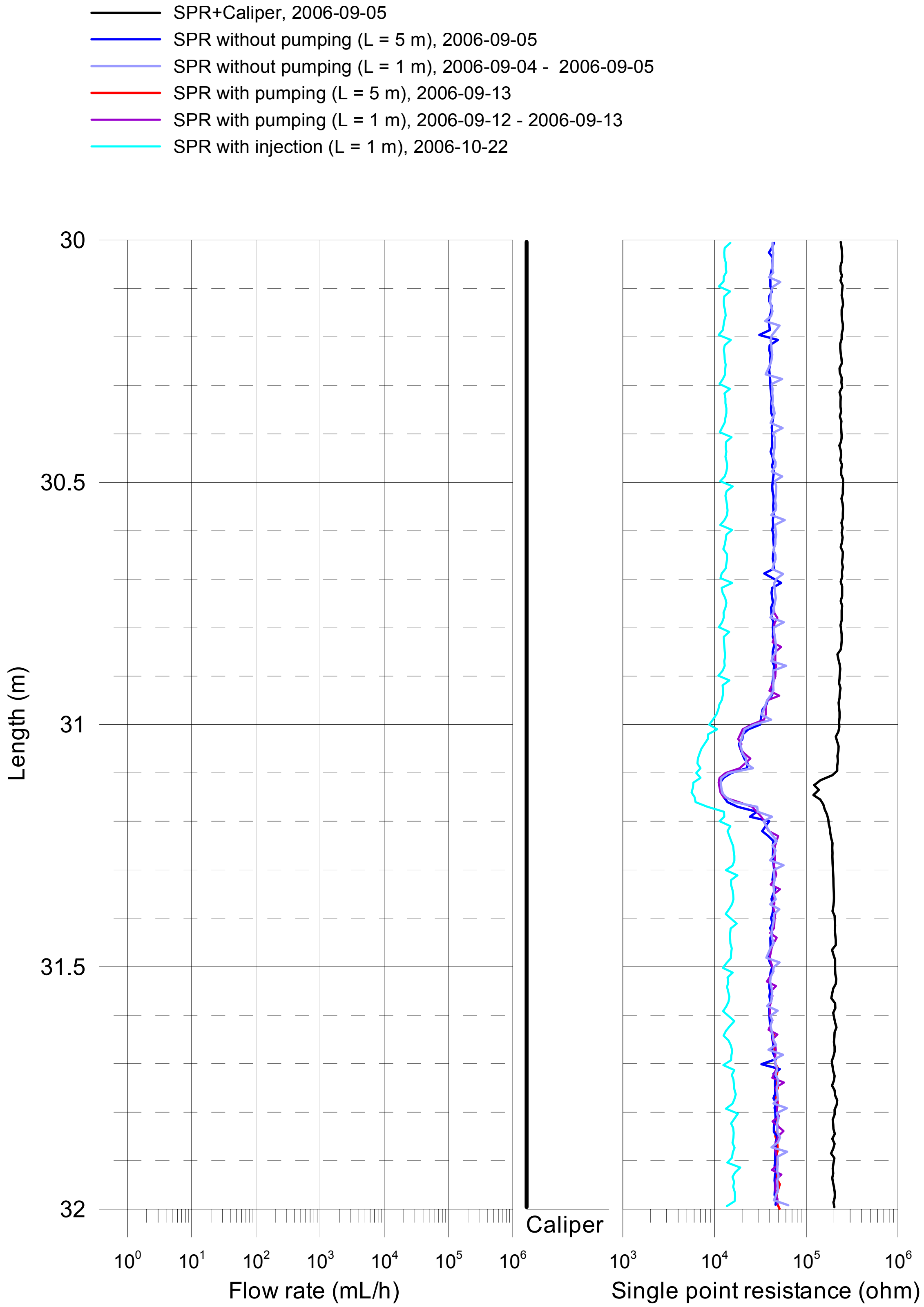
Appendices	B.1.1–B.1.8	SPR and Caliper results after length correction
Appendix	B.1.9	Length correction
Appendices	B.2.1–B.2.5	Flow rate, Caliper and Single point resistance
Appendix	B.3.1	Electric conductivity of borehole water
Appendix	B.3.2	Temperature of borehole water
Appendix	B.4.1	Plotted flow rates of 5 m sections
Appendix	B.4.2	Plotted transmissivity and head of 5 m sections
Appendix	B.5	Plotted transmissivity and head of detected fractures
Appendix	B.6	Basic test data
Appendix	B.7	Results of sequential flow logging
Appendix	B.8	Inferred flow anomalies from overlapping flow logging
Appendix	B.9	Explanations for the tables in Appendices 6–8
Appendix	B.10	Conductive fracture frequency
Appendix	B.11	Plotted conductive fracture frequency
Appendix	B.12	Comparison between section transmissivity and fracture transmissivity
Appendix	B.13	Head in the borehole during flow logging
Appendix	B.14	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	B.15	Groundwater recovery after pumping

Laxemar, borehole KLX11B
SPR and Caliper results after length correction

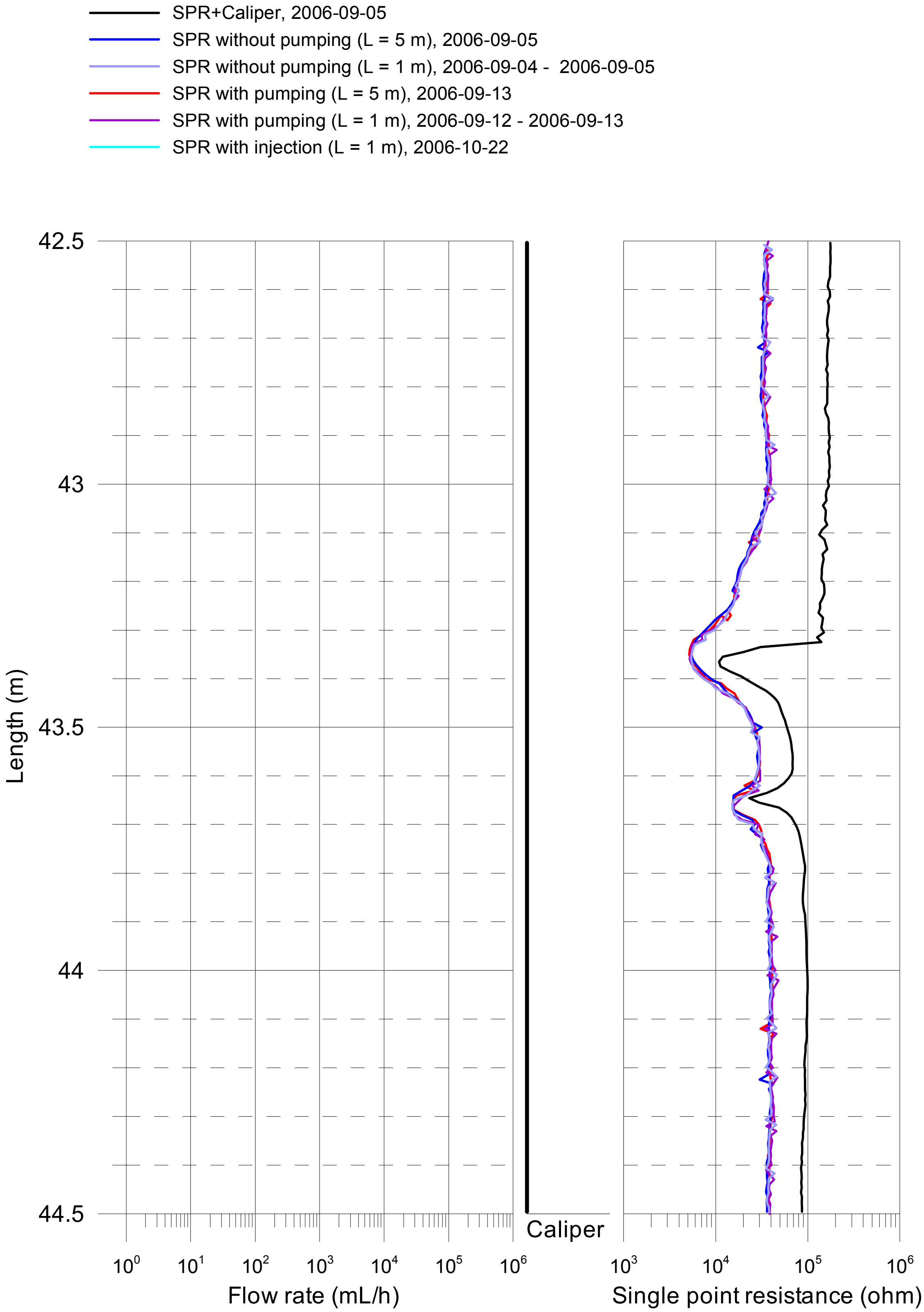
SPR+Caliper, 2006-09-05
SPR without pumping (L = 5 m), 2006-09-05
SPR without pumping (L = 1 m), 2006-09-04 - 2006-09-05
SPR with pumping (L = 5 m), 2006-09-13
SPR with pumping (L = 1 m), 2006-09-12 - 2006-09-13
SPR with injection (L = 1 m), 2006-10-22

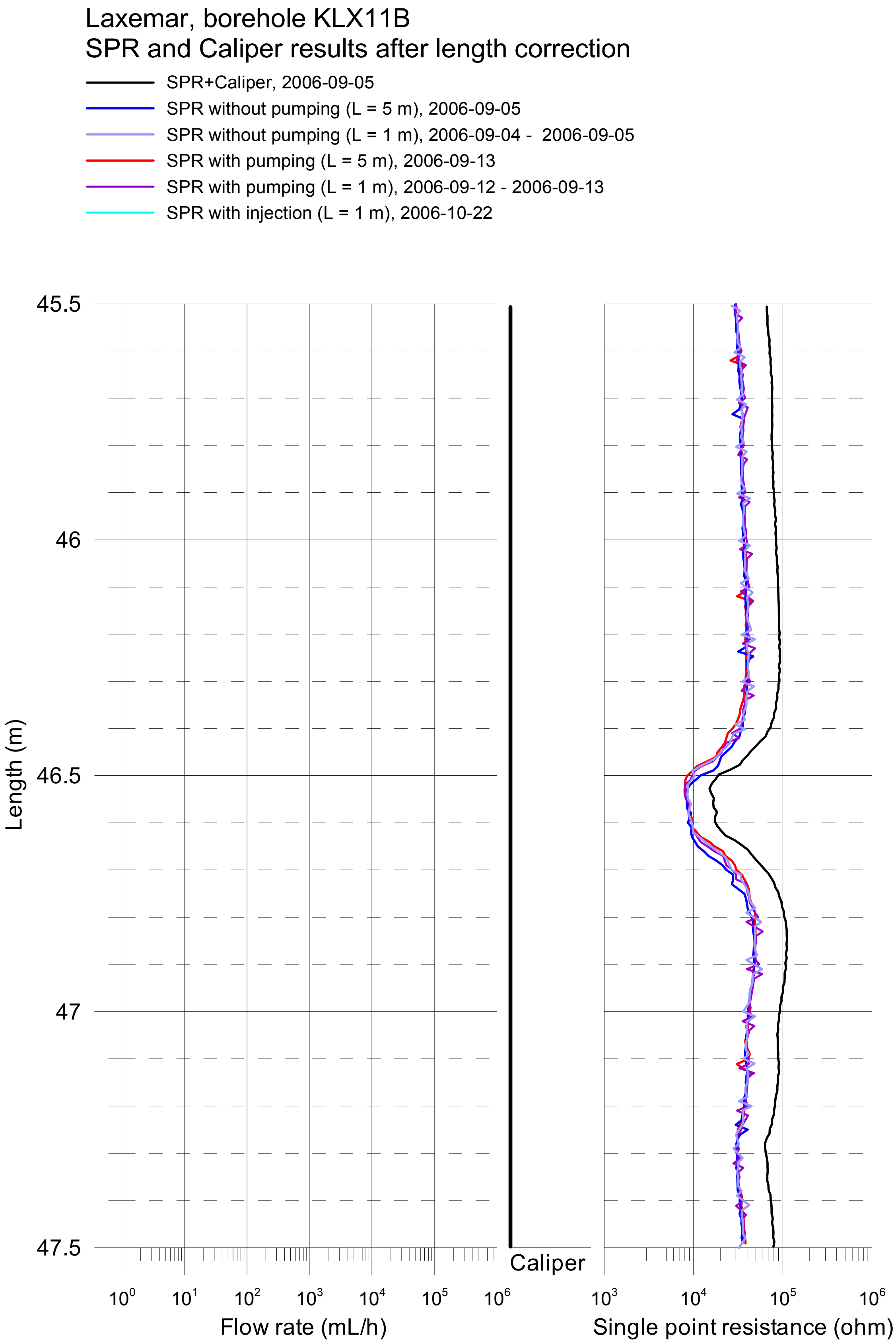


Laxemar, borehole KLX11B
SPR and Caliper results after length correction

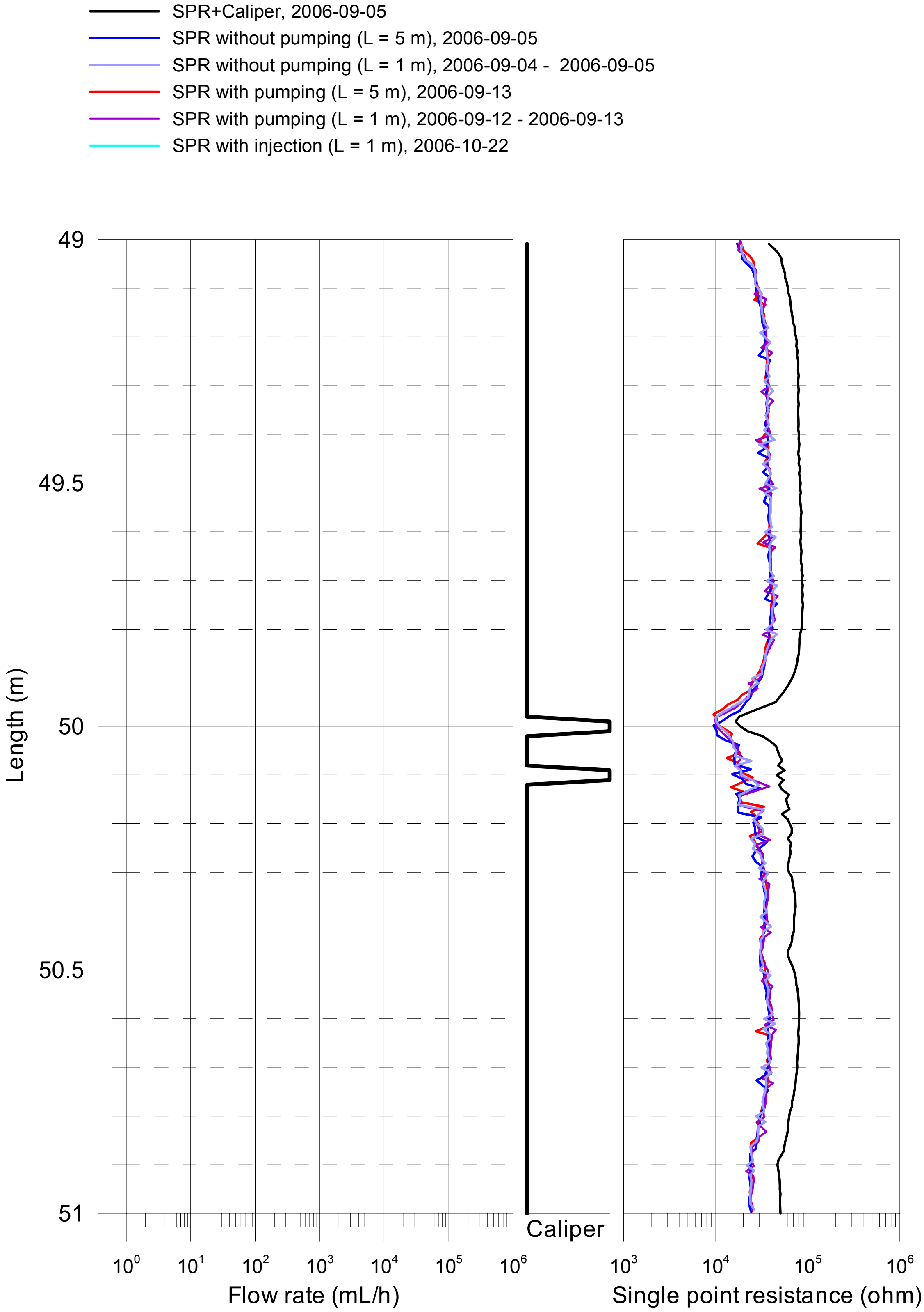


Laxemar, borehole KLX11B
SPR and Caliper results after length correction

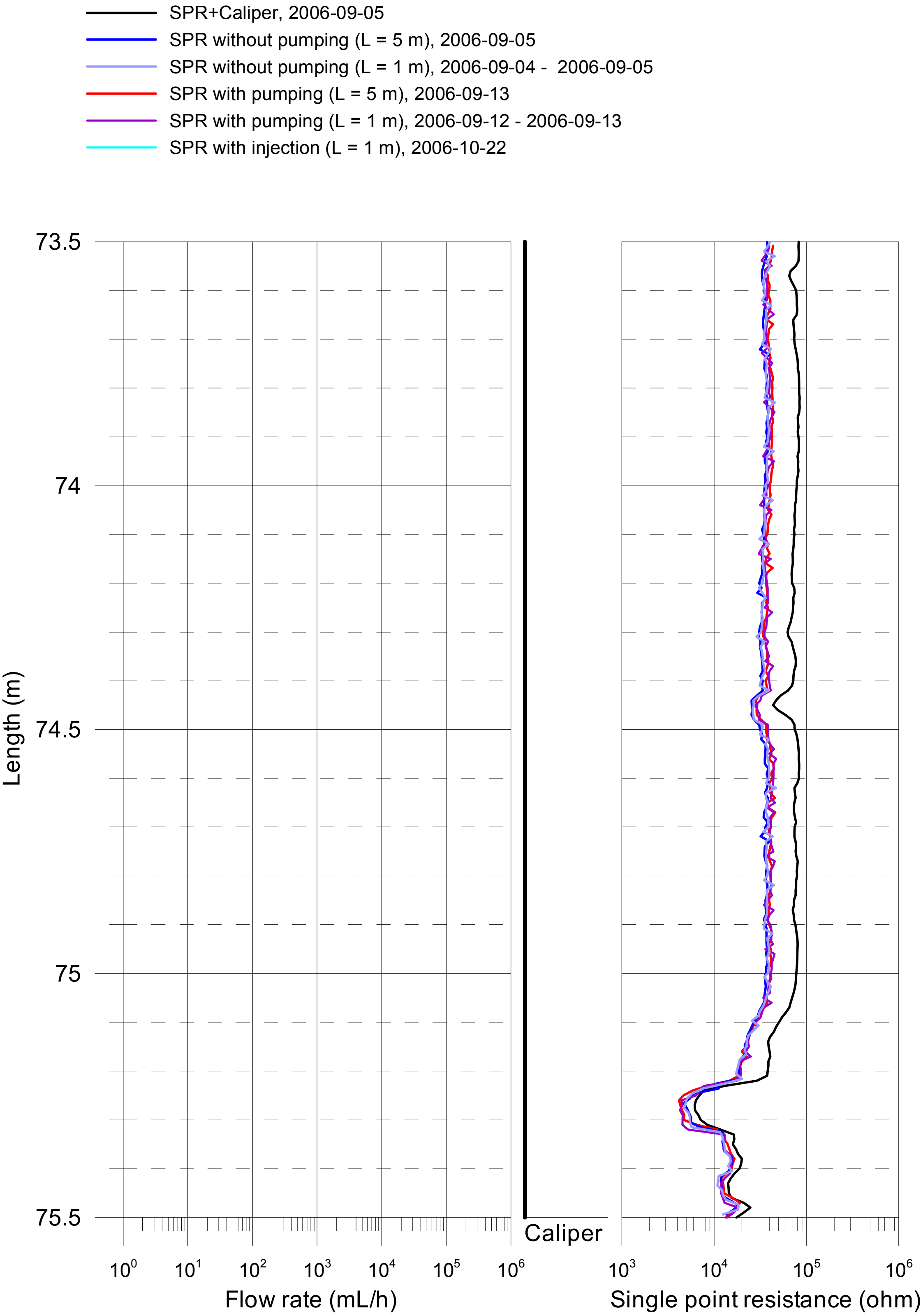



Laxemar, borehole KLX11B
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-05
SPR without pumping (L = 5 m), 2006-09-05
SPR without pumping (L = 1 m), 2006-09-04 - 2006-09-05
SPR with pumping (L = 5 m), 2006-09-13
SPR with pumping (L = 1 m), 2006-09-12 - 2006-09-13
SPR with injection (L = 1 m), 2006-10-22
Length (m)
45.5
46
46.5
47
47.5
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)

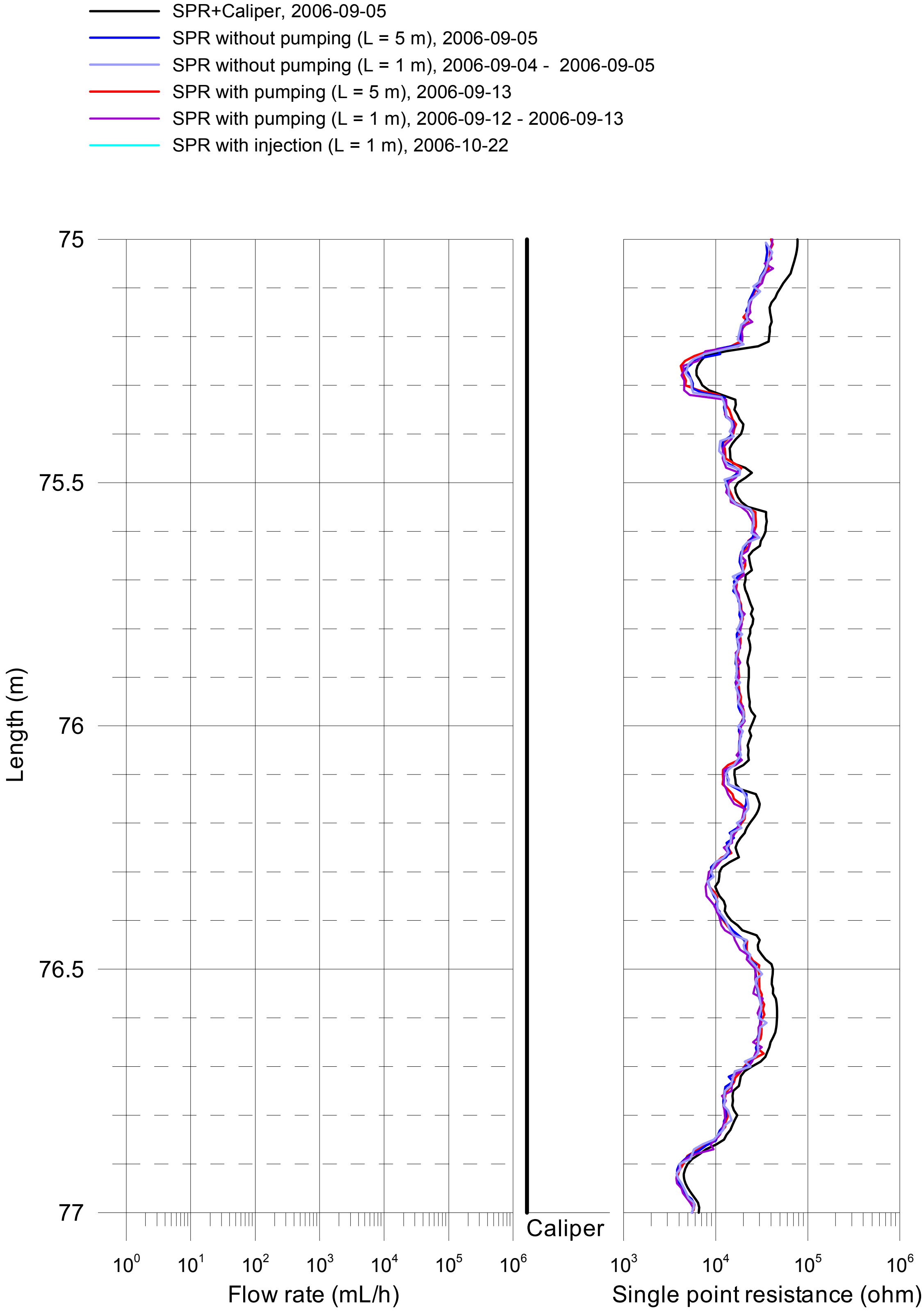
Laxemar, borehole KLX11B
SPR and Caliper results after length correction



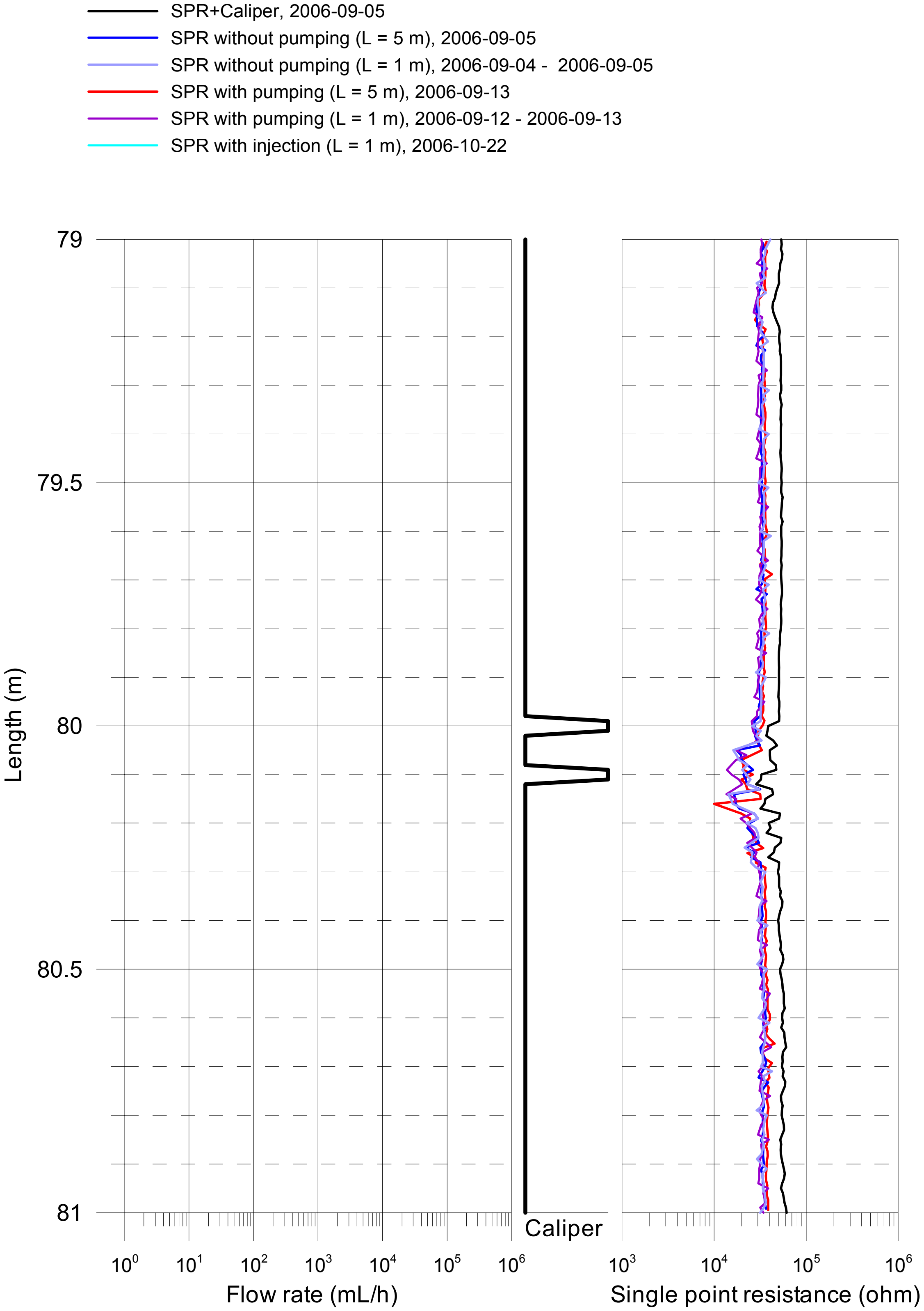
Laxemar, borehole KLX11B
SPR and Caliper results after length correction

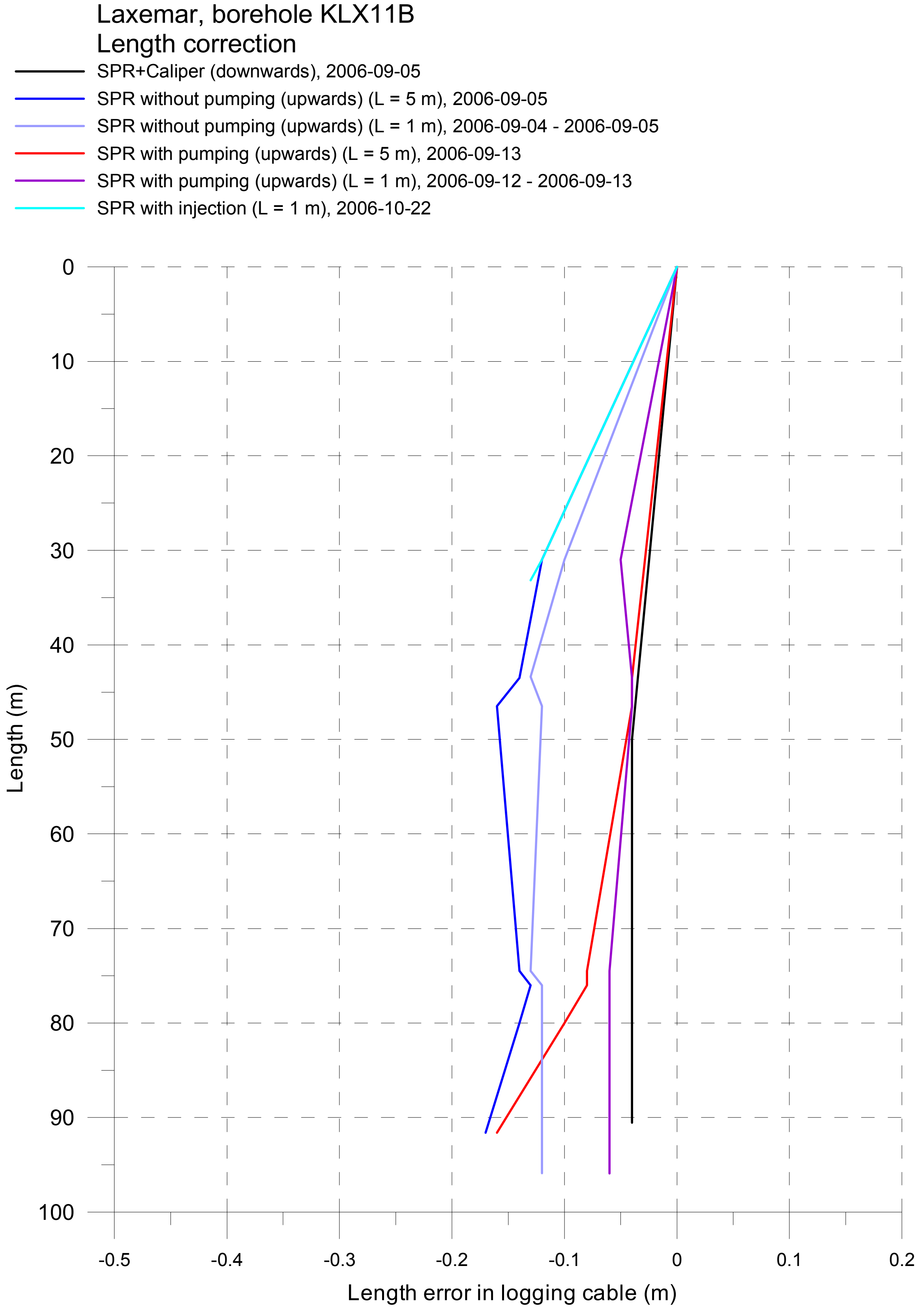


Laxemar, borehole KLX11B
SPR and Caliper results after length correction

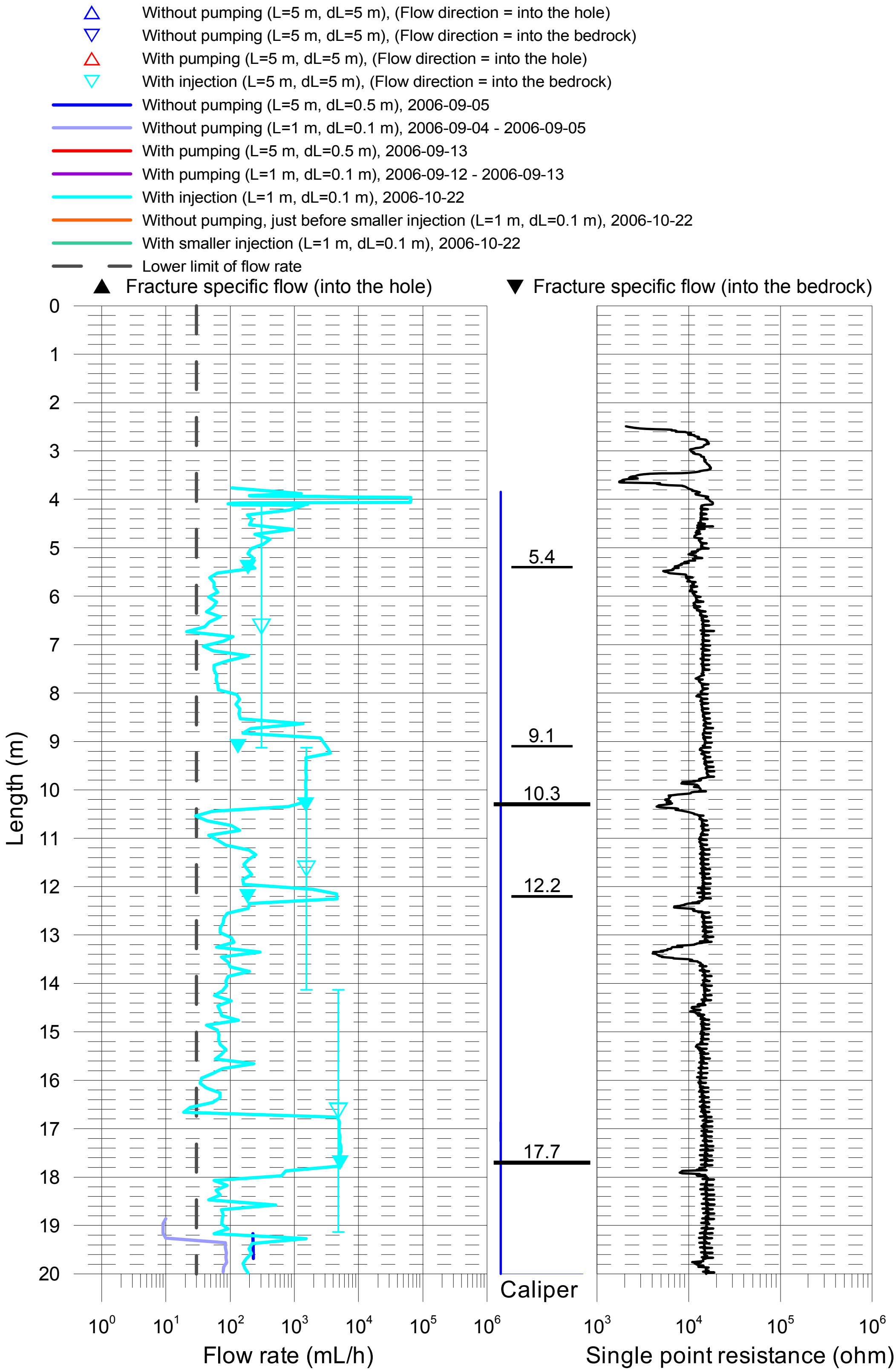


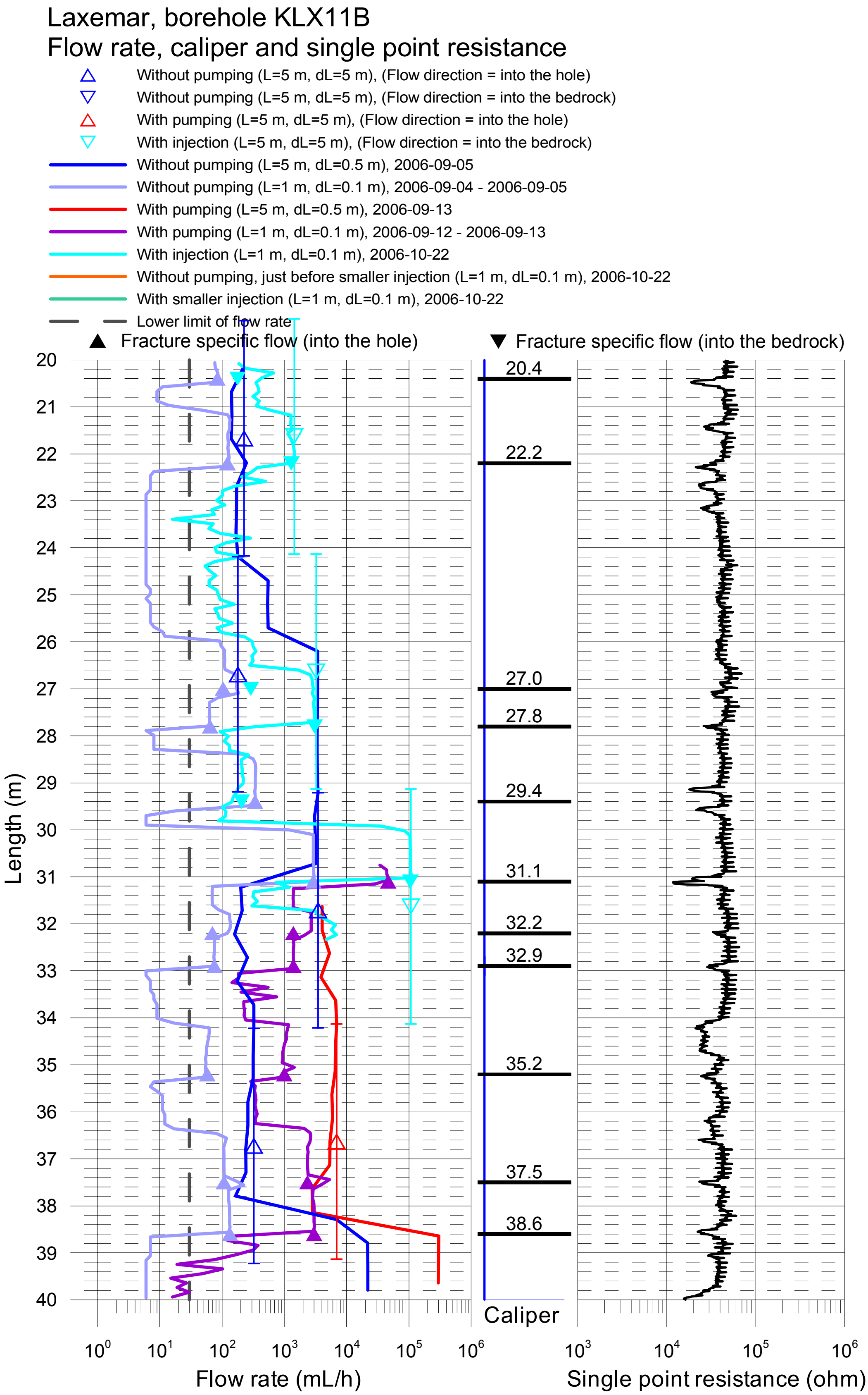
Laxemar, borehole KLX11B
SPR and Caliper results after length correction



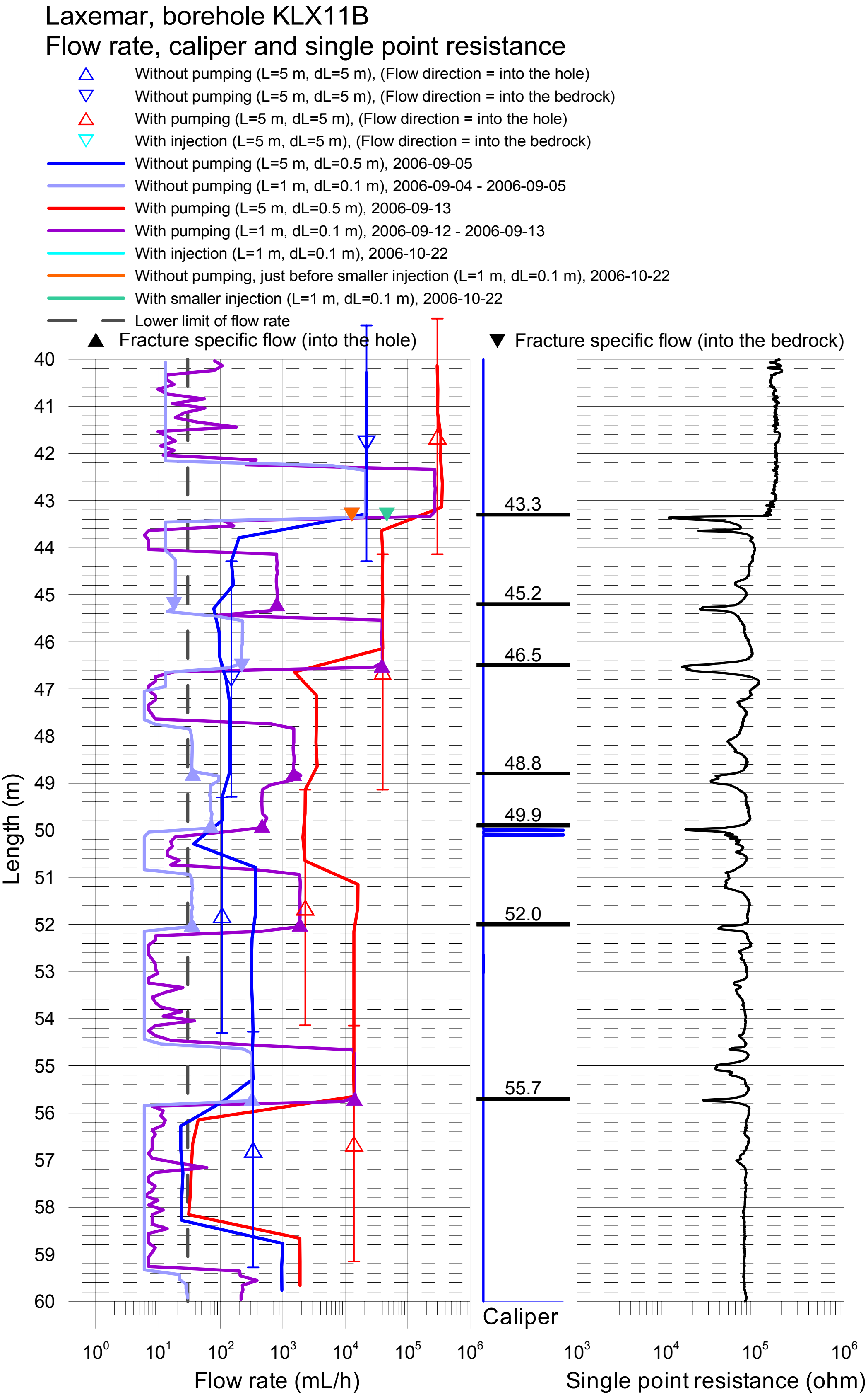

Laxemar, borehole KLX11B
Length correction
SPR+Caliper (downwards), 2006-09-05
SPR without pumping (upwards) (L = 5 m), 2006-09-05
SPR without pumping (upwards) (L = 1 m), 2006-09-04 - 2006-09-05
SPR with pumping (upwards) (L = 5 m), 2006-09-13
SPR with pumping (upwards) (L = 1 m), 2006-09-12 - 2006-09-13
SPR with injection (L = 1 m), 2006-10-22
0
10
20
30
40
50
60
70
80
90
100
Length (m)
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
Length error in logging cable (m)

Laxemar, borehole KLX11B
Flow rate, caliper and single point resistance

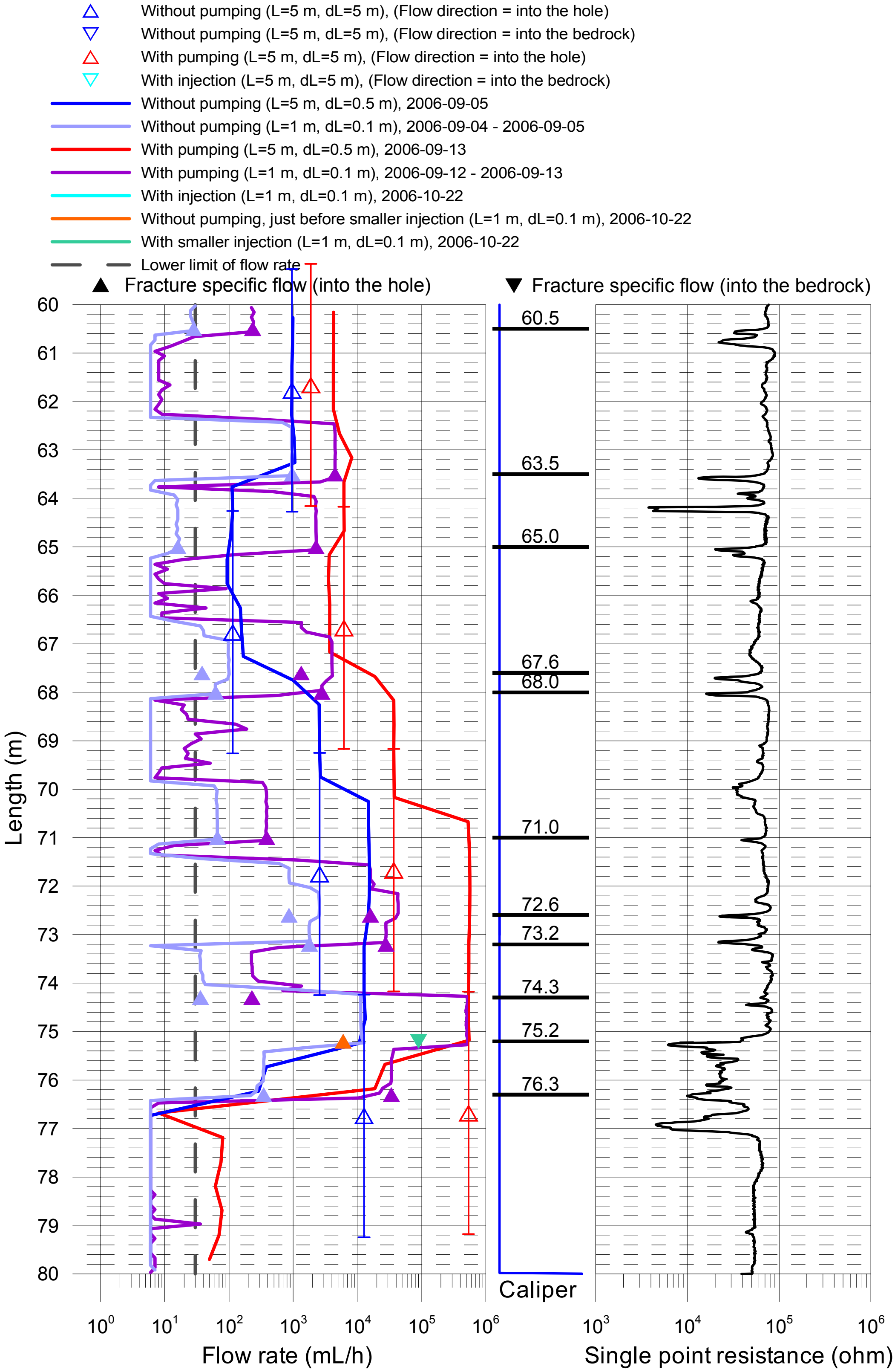


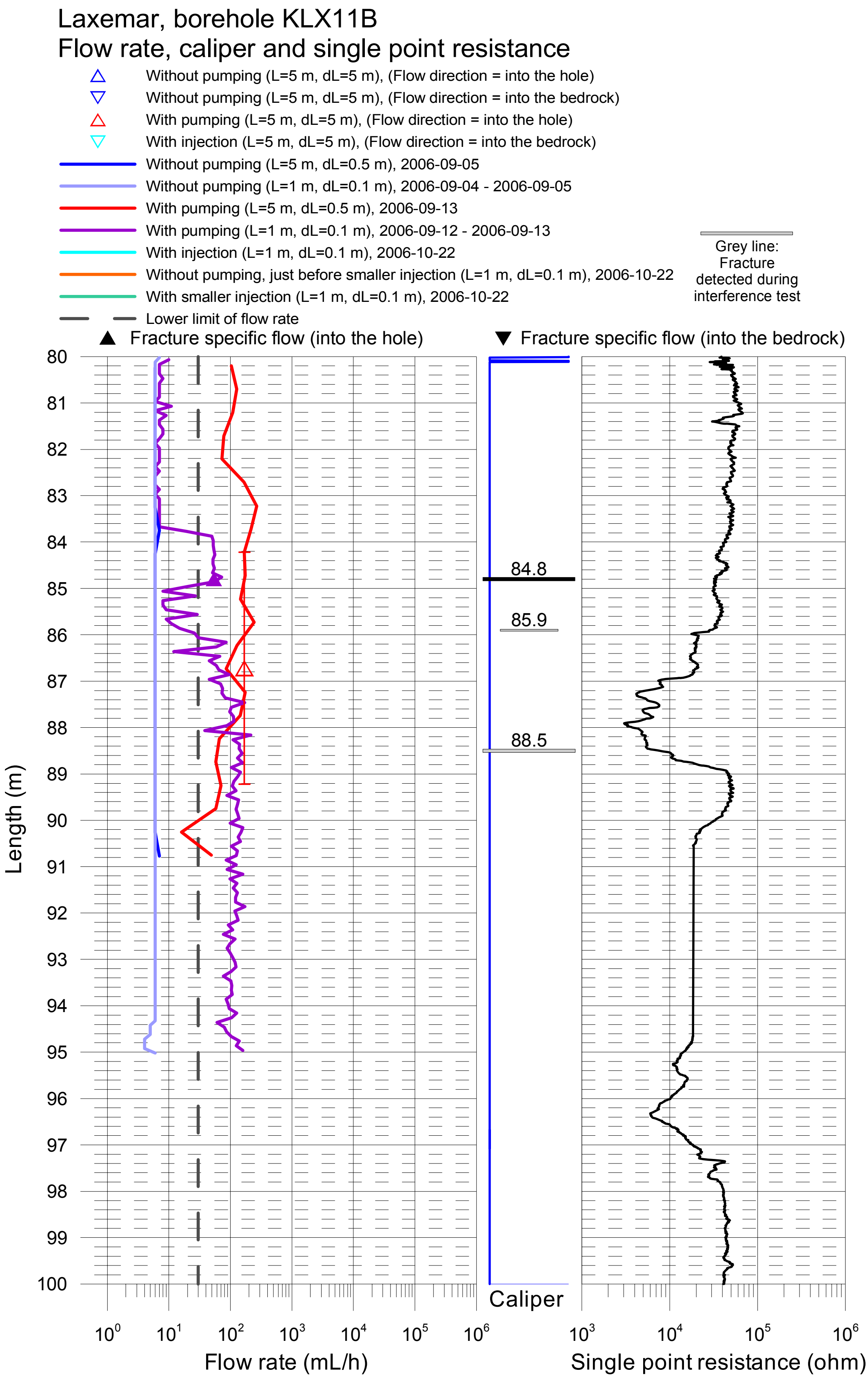


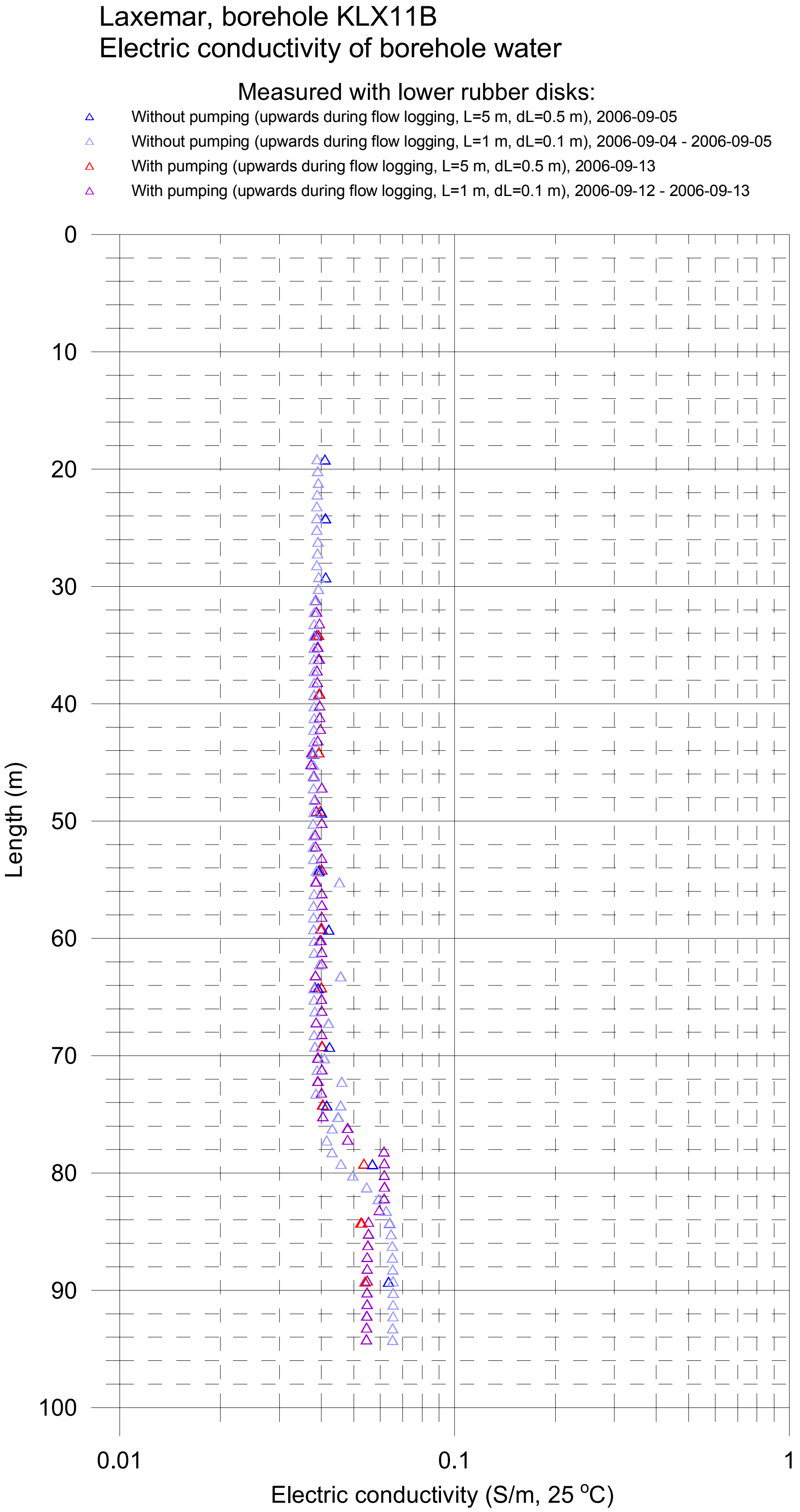
Laxemar, borehole KLX11B
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-05
Without pumping (L=1 m, dL=0.1 m), 2006-09-04 - 2006-09-05
With pumping (L=5 m, dL=0.5 m), 2006-09-13
With pumping (L=1 m, dL=0.1 m), 2006-09-12 - 2006-09-13
With injection (L=1 m, dL=0.1 m), 2006-10-22
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-22
With smaller injection (L=1 m, dL=0.1 m), 2006-10-22
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
20.4
22.2
27.0
27.8
29.4
31.1
32.2
32.9
35.2
37.5
38.6
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

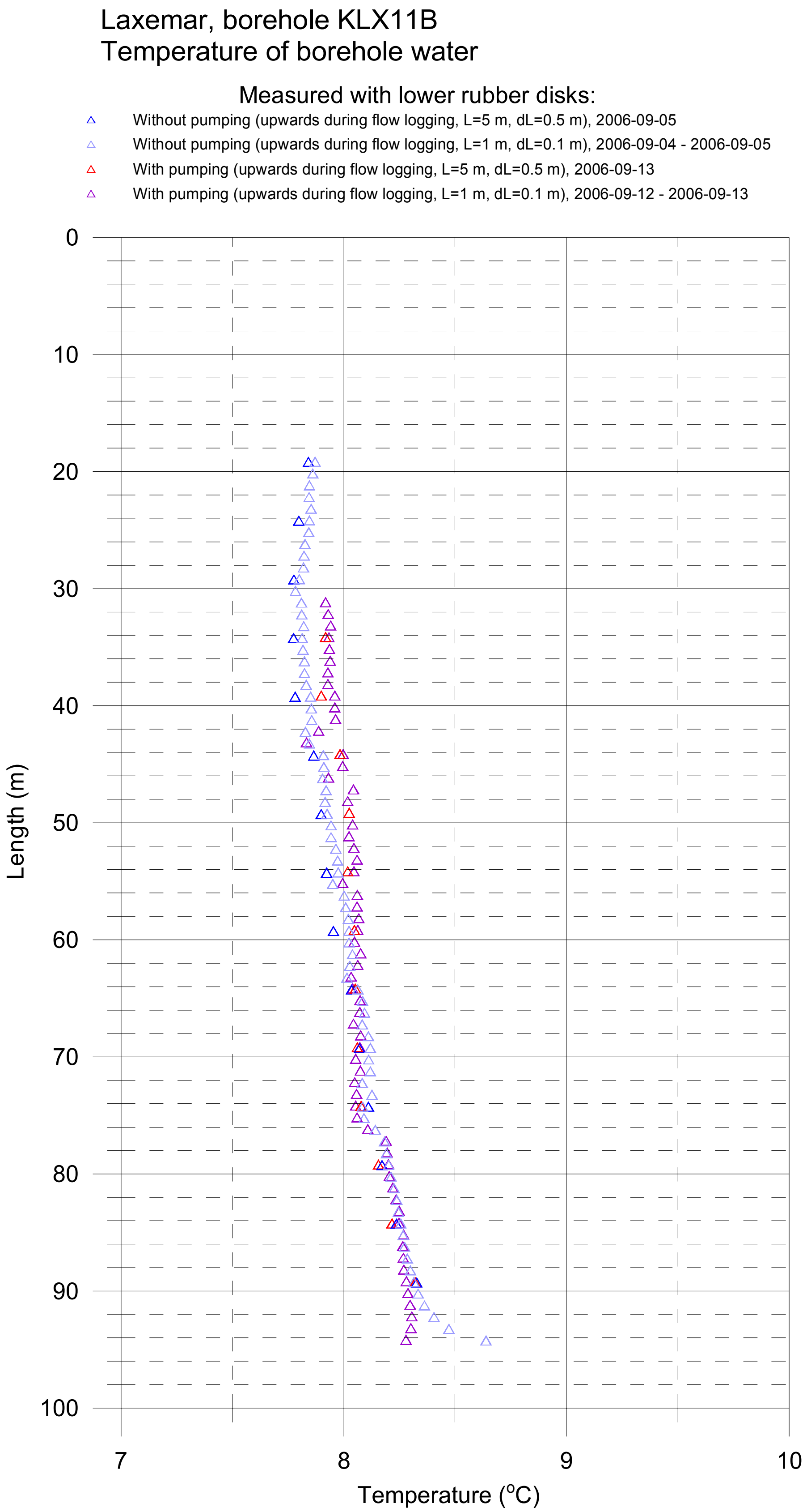

Laxemar, borehole KLX11B
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-05
Without pumping (L=1 m, dL=0.1 m), 2006-09-04 - 2006-09-05
With pumping (L=5 m, dL=0.5 m), 2006-09-13
With pumping (L=1 m, dL=0.1 m), 2006-09-12 - 2006-09-13
With injection (L=1 m, dL=0.1 m), 2006-10-22
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-22
With smaller injection (L=1 m, dL=0.1 m), 2006-10-22
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
43.3
45.2
46.5
48.8
49.9
52.0
55.7
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

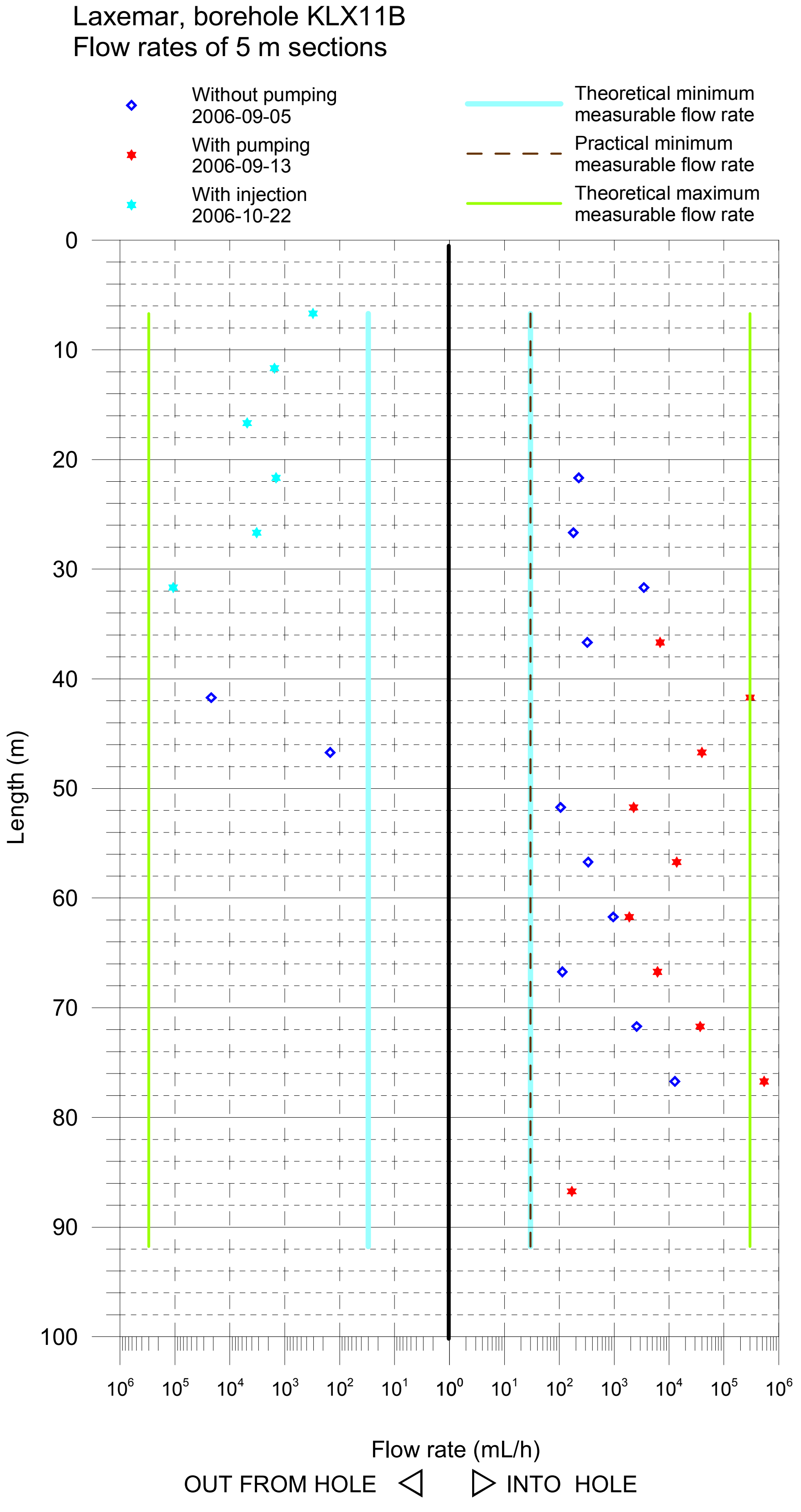
Laxemar, borehole KLX11B
Flow rate, caliper and single point resistance



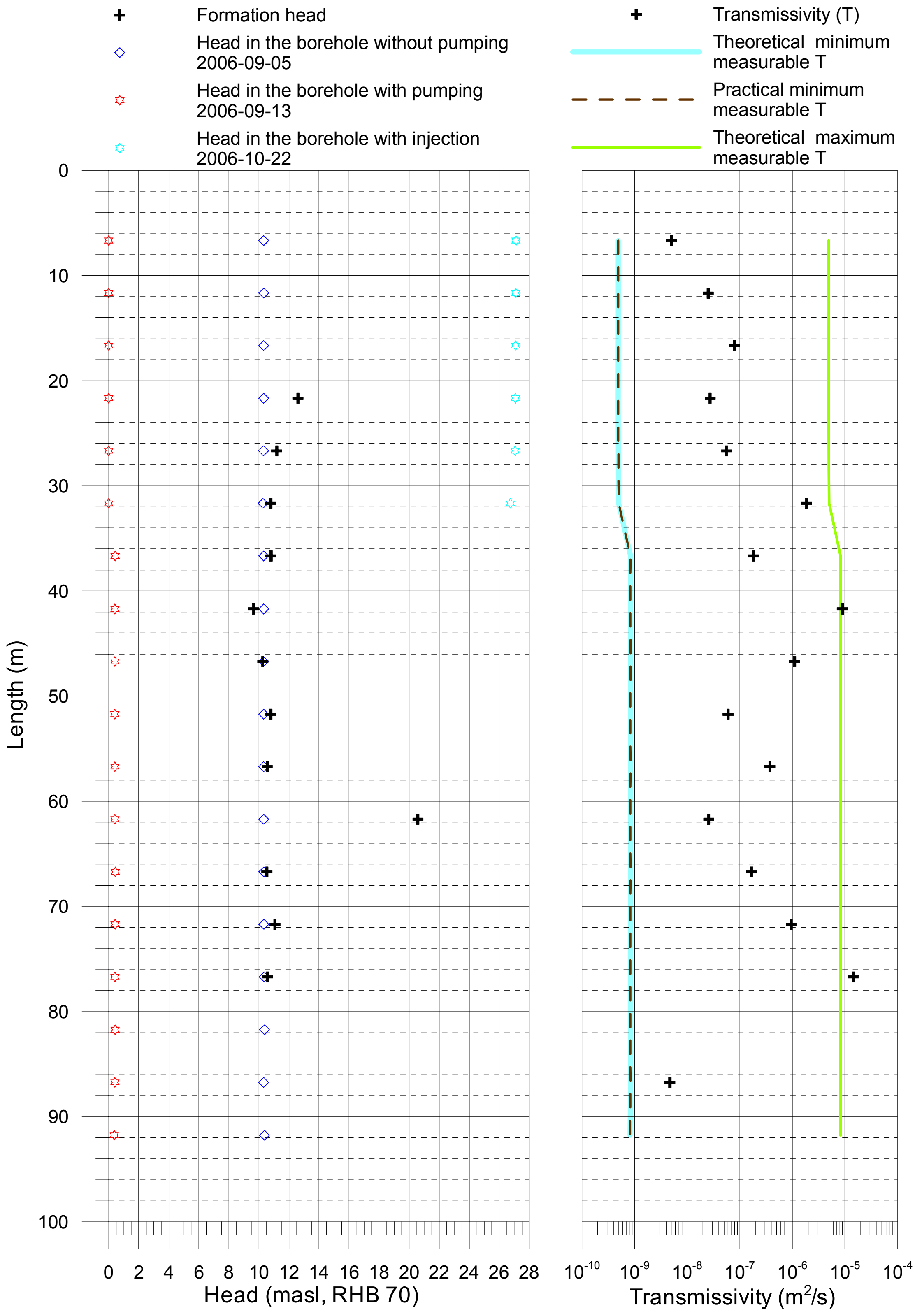

Laxemar, borehole KLX11B
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-05
Without pumping (L=1 m, dL=0.1 m), 2006-09-04 - 2006-09-05
With pumping (L=5 m, dL=0.5 m), 2006-09-13
With pumping (L=1 m, dL=0.1 m), 2006-09-12 - 2006-09-13
With injection (L=1 m, dL=0.1 m), 2006-10-22
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-22
With smaller injection (L=1 m, dL=0.1 m), 2006-10-22
Lower limit of flow rate
Grey line: Fracture detected during interference test
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
84.8
85.9
88.5
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 KLX11B
Electric conductivity of borehole water
Measured with lower rubber disks:
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-05
Without pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-04 - 2006-09-05
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-13
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-12 - 2006-09-13
Length (m)
0
10
20
30
40
50
60
70
80
90
100
0.01
0.1
1
Electric conductivity (S/m, 25 °C)

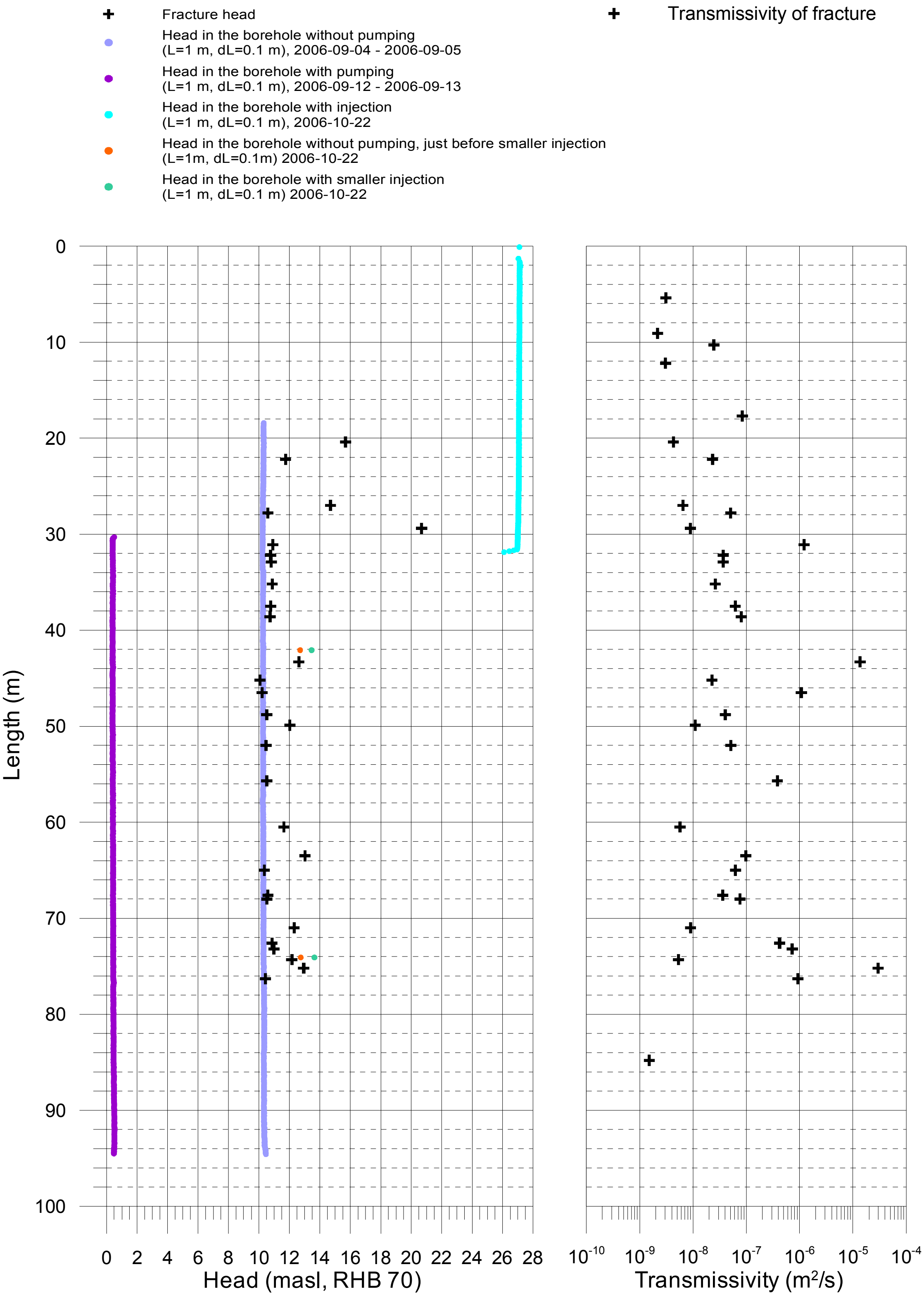

Laxemar, borehole KLX11B
Temperature of borehole water
Measured with lower rubber disks:
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-05
Without pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-04 - 2006-09-05
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-13
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-12 - 2006-09-13
Length (m)
0
10
20
30
40
50
60
70
80
90
100
7
8
9
10
Temperature (°C)


Laxemar, borehole KLX11B
Flow rates of 5 m sections
Without pumping
2006-09-05
With pumping
2006-09-13
With injection
2006-10-22
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 KLX11B
Transmissivity and head of 5 m sections



Laxemar, borehole KLX11B
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)
KLX11B	2.44	100.2	5A	20060911	11:54	20060913	14:10	20060919	9:14	5	0.5	2.67E–04	–3.93E–04

5. PFL-Difference flow logging – Basic test data

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (m.a.s.l.)	h_1 (m.a.s.l.)	h_2 (m.a.s.l.)	s_1 (m.a.s.l.)	s_2 (m.a.s.l.)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
681600	12600	262740	93600	9.97	0.53	27.28	–9.44	17.31	2.79E–05	–	–

Difference flow logging – Sequential flow logging

Borehole ID	Secup L (m)	Seclow L (m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D-measl$_{LP}$ (m^2/s)	T_D-measl$_U$ (m^2/s)	Comments
KLX11B	4.18	9.18	5	–	10.32	–5.22E–08	27.1	5.0E–09	–	30	4.9E–10	4.9E–10	4.9E–06	*,**
KLX11B	9.18	14.18	5	–	10.32	–3.67E–08	27.11	2.5E–08	–	30	4.9E–10	4.9E–10	4.9E–06	*,**
KLX11B	14.18	19.18	5	–	10.32	–4.17E–07	27.09	8.0E–08	–	30	4.9E–10	4.9E–10	4.9E–06	*,**
KLX11B	19.18	24.18	5	6.28E–08	10.32	–5.17E–08	27.09	2.7E–08	12.6	30	4.9E–10	4.9E–10	4.9E–06	*
KLX11B	24.18	29.18	5	5.00E–08	10.30	–1.42E–06	27.08	5.6E–08	11.2	30	4.9E–10	4.9E–10	4.9E–06	*
KLX11B	29.18	34.18	5	9.67E–07	10.27	–4.94E–08	27.06	1.9E–06	10.8	30	5.0E–10	5.0E–10	5.0E–06	*
KLX11B	34.18	39.18	5	9.00E–08	10.31	1.91E–06	0.43	1.8E–07	10.8	30	8.3E–10	8.3E–10	8.3E–06	
KLX11B	39.22	44.22	5	–6.08E–06	10.32	8.33E–05	0.42	8.9E–06	9.7	30	8.3E–10	8.3E–10	8.3E–06	***
KLX11B	44.22	49.22	5	–4.14E–08	10.29	1.10E–05	0.42	1.1E–06	10.3	30	8.4E–10	8.4E–10	8.4E–06	
KLX11B	49.22	54.22	5	2.94E–08	10.31	6.31E–07	0.41	6.0E–08	10.8	30	8.3E–10	8.3E–10	8.3E–06	
KLX11B	54.22	59.22	5	9.28E–08	10.31	3.83E–06	0.42	3.7E–07	10.6	30	8.3E–10	8.3E–10	8.3E–06	
KLX11B	59.22	64.22	5	2.67E–07	10.32	5.25E–07	0.42	2.6E–08	20.6	30	8.3E–10	8.3E–10	8.3E–06	****
KLX11B	64.22	69.22	5	3.17E–08	10.33	1.71E–06	0.44	1.7E–07	10.5	30	8.3E–10	8.3E–10	8.3E–06	
KLX11B	69.21	74.21	5	7.17E–07	10.33	1.03E–05	0.43	9.5E–07	11.1	30	8.3E–10	8.3E–10	8.3E–06	***
KLX11B	74.21	79.21	5	3.53E–06	10.35	1.50E–04	0.42	1.5E–05	10.6	30	8.3E–10	8.3E–10	8.3E–06	
KLX11B	79.22	84.22	5	–	10.37	–	0.43	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX11B	84.24	89.24	5	–	10.31	4.69E–08	0.42	4.7E–09	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX11B	89.26	94.26	5	–	10.37	–	0.37	–	–	30	8.2E–10	8.2E–10	8.2E–06	

* Q_1 value is from injection.

** Q_0 is evaluated to be zero since it is not measured in this section.

*** Q_1 is above measuring limit.

**** Q_1 flow do not conform with sum of flows from Appendix B.8.

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
KLX11B	5.4	1	0.1	–	10.32	–5.22E–08	27.10	3.1E–09	–	*,**,***
KLX11B	9.1	1	0.1	–	10.32	–3.67E–08	27.11	2.2E–09	–	*,**,***
KLX11B	10.3	1	0.1	–	10.32	–4.17E–07	27.09	2.5E–08	–	**,***
KLX11B	12.2	1	0.1	–	10.32	–5.17E–08	27.09	3.1E–09	–	*,**,***
KLX11B	17.7	1	0.1	–	10.32	–1.42E–06	27.08	8.4E–08	–	**,***
KLX11B	20.4	1	0.1	2.33E–08	10.32	–4.94E–08	27.06	4.3E–09	15.7	**
KLX11B	22.2	1	0.1	3.39E–08	10.31	–3.61E–07	27.07	2.3E–08	11.8	**
KLX11B	27.0	1	0.1	2.89E–08	10.27	–8.06E–08	27.04	6.5E–09	14.7	**
KLX11B	27.8	1	0.1	1.78E–08	10.25	–8.50E–07	27.04	5.1E–08	10.6	**
KLX11B	29.4	1	0.1	9.42E–08	10.24	–5.72E–08	27.02	8.9E–09	20.7	**
KLX11B	31.1	1	0.1	8.14E–07	10.25	1.29E–05	0.40	1.2E–06	10.9	
KLX11B	32.2	1	0.1	1.94E–08	10.24	3.86E–07	0.39	3.7E–08	10.8	
KLX11B	32.9	1	0.1	2.08E–08	10.25	3.89E–07	0.41	3.7E–08	10.8	
KLX11B	35.2	1	0.1	1.61E–08	10.27	2.78E–07	0.40	2.6E–08	10.9	
KLX11B	37.5	1	0.1	3.00E–08	10.29	6.53E–07	0.41	6.2E–08	10.8	
KLX11B	38.6	1	0.1	3.69E–08	10.28	8.39E–07	0.41	8.0E–08	10.7	
KLX11B	43.3	1	0.1	–3.53E–06	12.88	–1.29E–05	13.56	1.4E–05	12.6	****
KLX11B	45.2	1	0.1	–5.00E–09	10.29	2.21E–07	0.41	2.3E–08	10.1	
KLX11B	46.5	1	0.1	–6.11E–08	10.27	1.07E–05	0.40	1.1E–06	10.2	
KLX11B	48.8	1	0.1	1.00E–08	10.27	4.14E–07	0.40	4.1E–08	10.5	
KLX11B	49.9	1	0.1	1.94E–08	10.28	1.29E–07	0.41	1.1E–08	12.0	
KLX11B	52.0	1	0.1	9.72E–09	10.28	5.22E–07	0.40	5.1E–08	10.5	
KLX11B	55.7	1	0.1	8.89E–08	10.28	3.92E–06	0.41	3.8E–07	10.5	
KLX11B	60.5	1	0.1	7.78E–09	10.30	6.50E–08	0.41	5.7E–09	11.6	
KLX11B	63.5	1	0.1	2.70E–07	10.30	1.25E–06	0.43	9.8E–08	13.0	
KLX11B	65.0	1	0.1	4.44E–09	10.29	6.28E–07	0.44	6.3E–08	10.4	
KLX11B	67.6	1	0.1	1.06E–08	10.30	3.72E–07	0.41	3.6E–08	10.6	
KLX11B	68.0	1	0.1	1.72E–08	10.30	7.78E–07	0.43	7.6E–08	10.5	
KLX11B	71.0	1	0.1	1.83E–08	10.29	1.08E–07	0.44	9.0E–09	12.3	
KLX11B	72.6	1	0.1	2.40E–07	10.30	4.44E–06	0.44	4.2E–07	10.9	
KLX11B	73.2	1	0.1	5.00E–07	10.31	7.75E–06	0.44	7.3E–07	11.0	
KLX11B	74.3	1	0.1	1.00E–08	10.30	6.31E–08	0.45	5.3E–09	12.2	
KLX11B	75.2	1	0.1	1.67E–06	12.88	–2.49E–05	13.76	3.0E–05	12.9	****
KLX11B	76.3	1	0.1	9.61E–08	10.32	9.36E–06	0.45	9.3E–07	10.4	
KLX11B	84.8	1	0.1	–	10.32	1.50E–08	0.46	1.5E–09	–	
KLX11B	85.9	1	0.1	–	10.33	0.00E+00	0.47		–	*,*****
KLX11B	88.5	1	0.1	–	10.34	0.00E+00	0.48		–	*****

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

** Q_1 value is from injection.

*** Q_0 is evaluated to be zero since it is not measured in this section.

**** Q_1 is from smaller injection, Q_0 is undisturbed state just before smaller injection.

***** Fracture not detected with pumping in single hole test.

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.

Explanations

Header	Unit	Explanations
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).

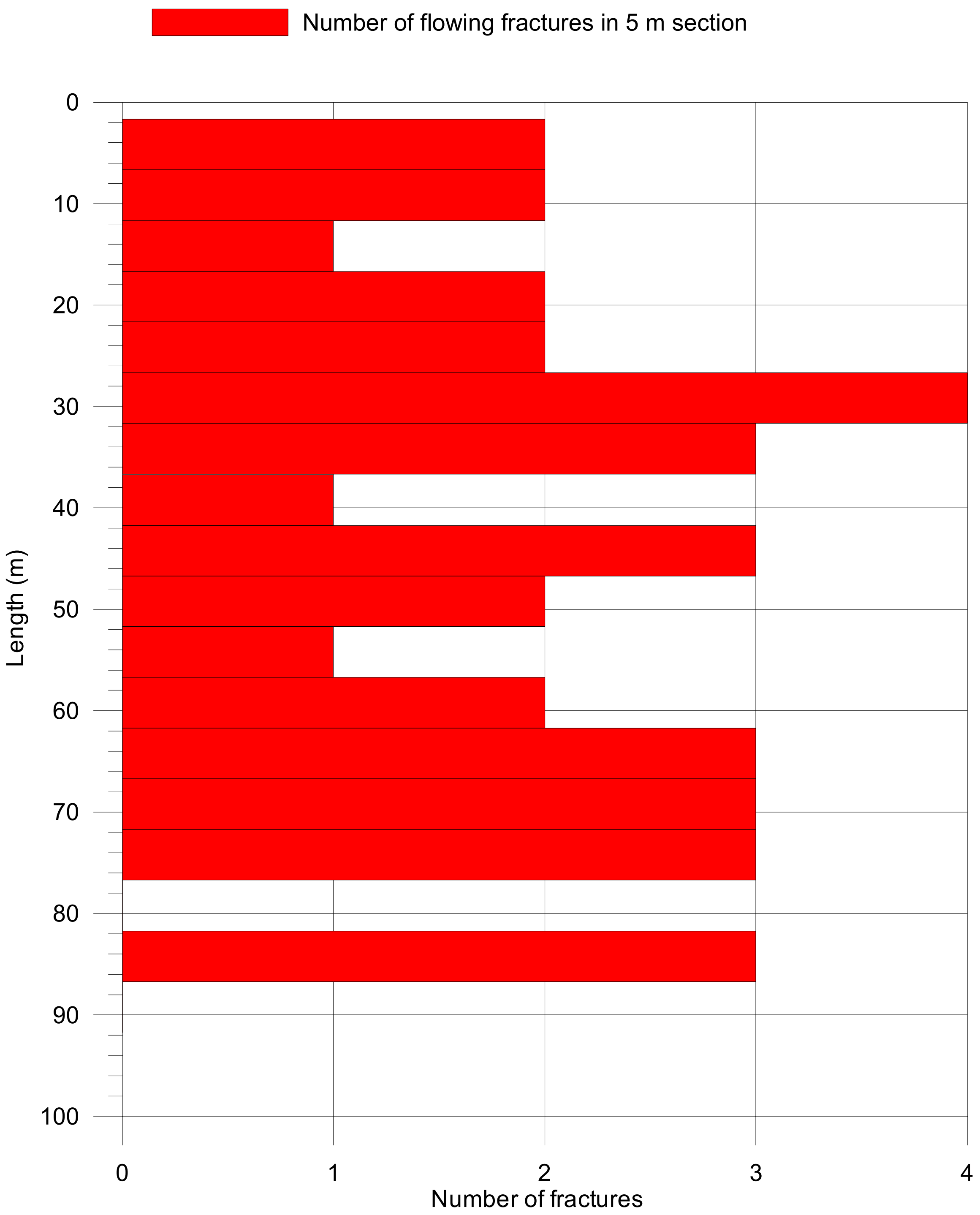
Calculation of conductive fracture frequency

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)
KLX11B	4.18	9.18	2	0	2*	0	0	0
KLX11B	9.18	14.18	2	0	1*	1*	0	0
KLX11B	14.18	19.18	1	0	0	1*	0	0
KLX11B	19.18	24.18	2	0	1*	1*	0	0
KLX11B	24.18	29.18	2	0	1*	1*	0	0
KLX11B	29.18	34.18	4	0	1*	2	1	0
KLX11B	34.18	39.18	3	0	1	2	0	0
KLX11B	39.22	44.22	1	0	0	0	0	1
KLX11B	44.22	49.22	3	0	1	1	1	0
KLX11B	49.22	54.22	2	0	1	1	0	0
KLX11B	54.22	59.22	1	0	0	0	1	0
KLX11B	59.22	64.22	2	0	1	1	0	0
KLX11B	64.22	69.22	3	0	0	3	0	0
KLX11B	69.21	74.21	3	0	1	0	2	0
KLX11B	74.21	79.21	3	0	1	0	1	1
KLX11B	79.22	84.22	0	0	0	0	0	0
KLX11B	84.24	89.24	3**	1	0	0	0	0
KLX11B	89.26	94.26	0	0	0	0	0	0

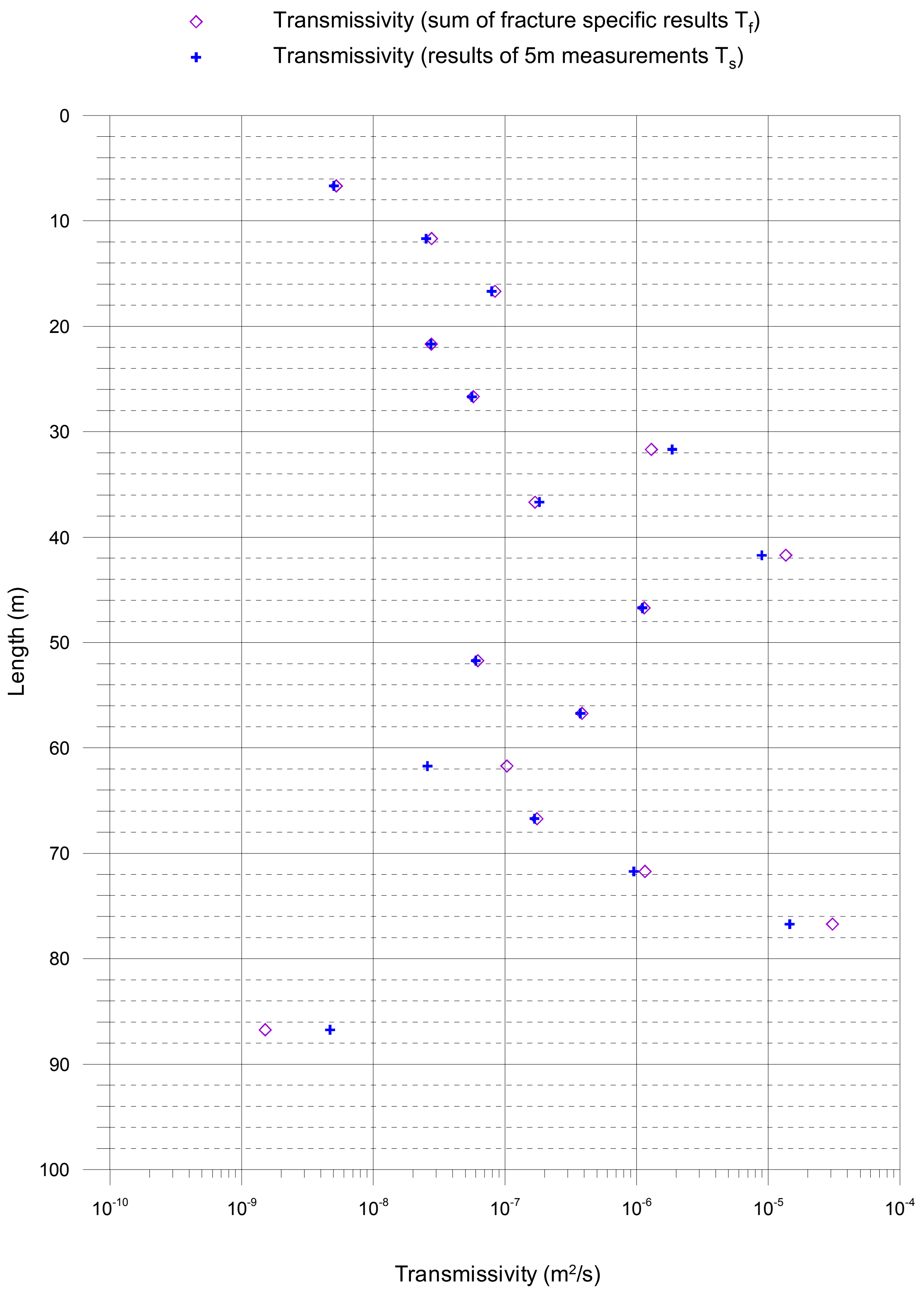
* During Injection (drawdown not the same as in the other measurements).

** Fractures found during interference test.

Laxemar, borehole KLX11B
Calculation of conductive fracture frequency

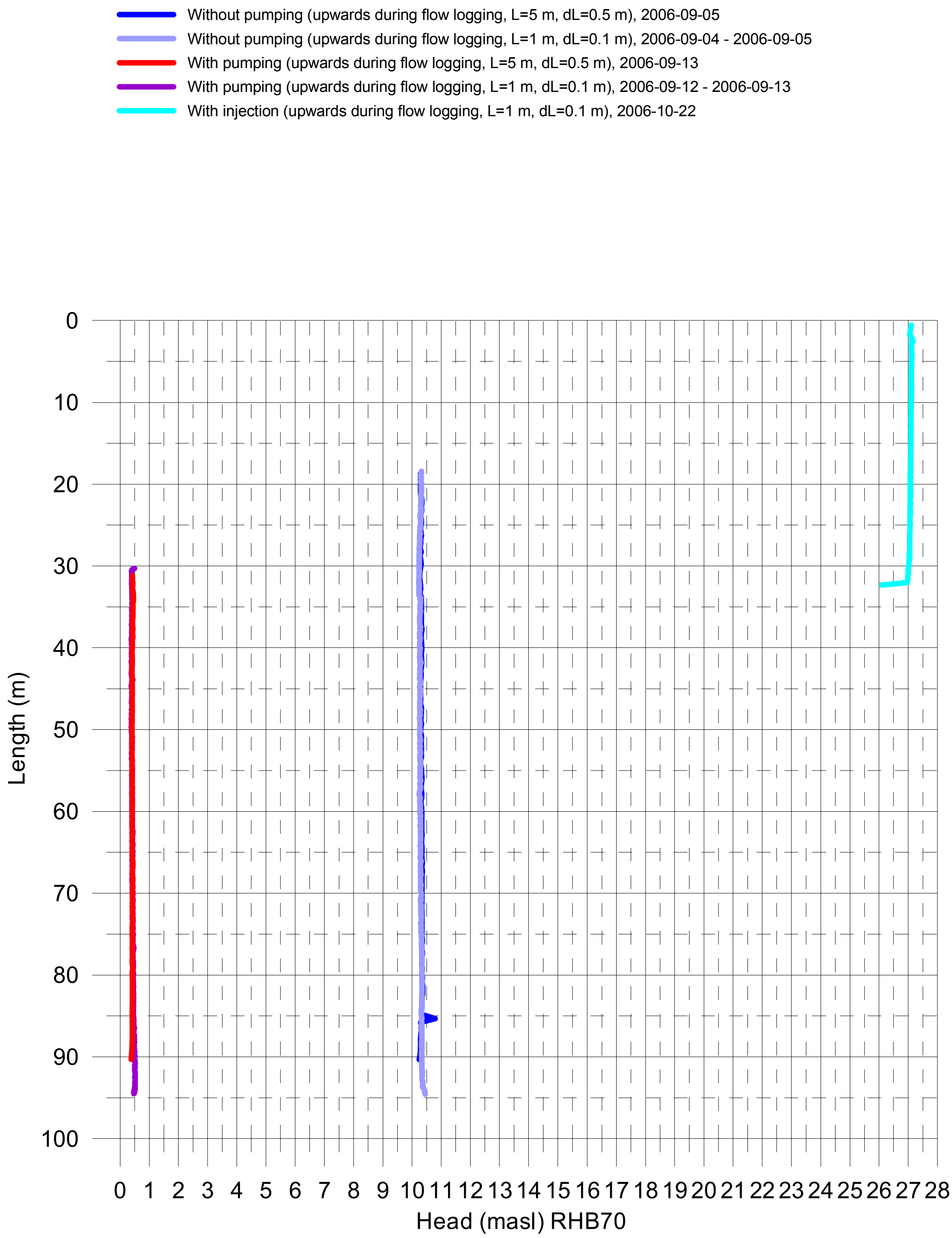


Laxemar, borehole KLX11B
Comparison between section transmissivity and fracture transmissivity

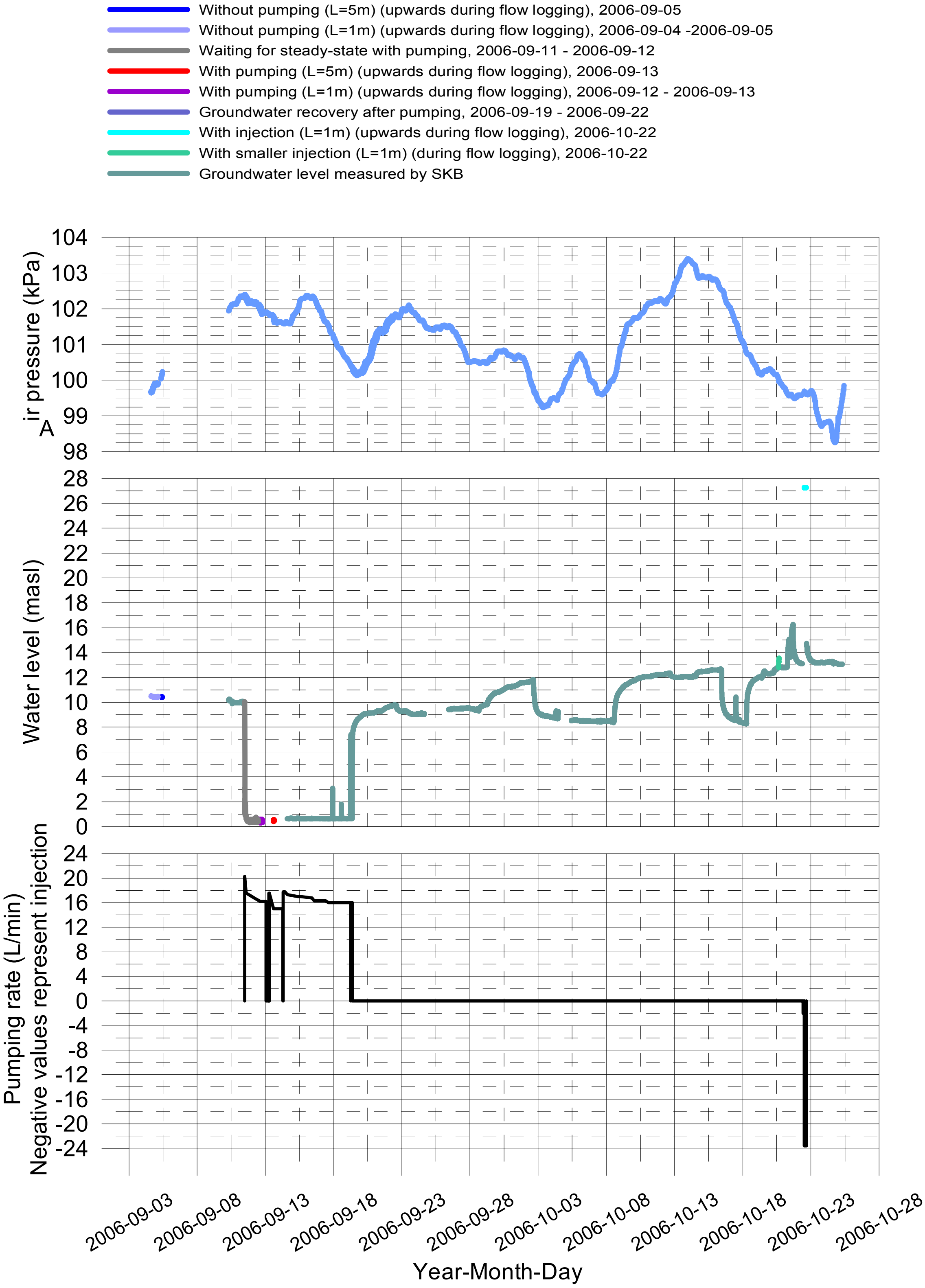


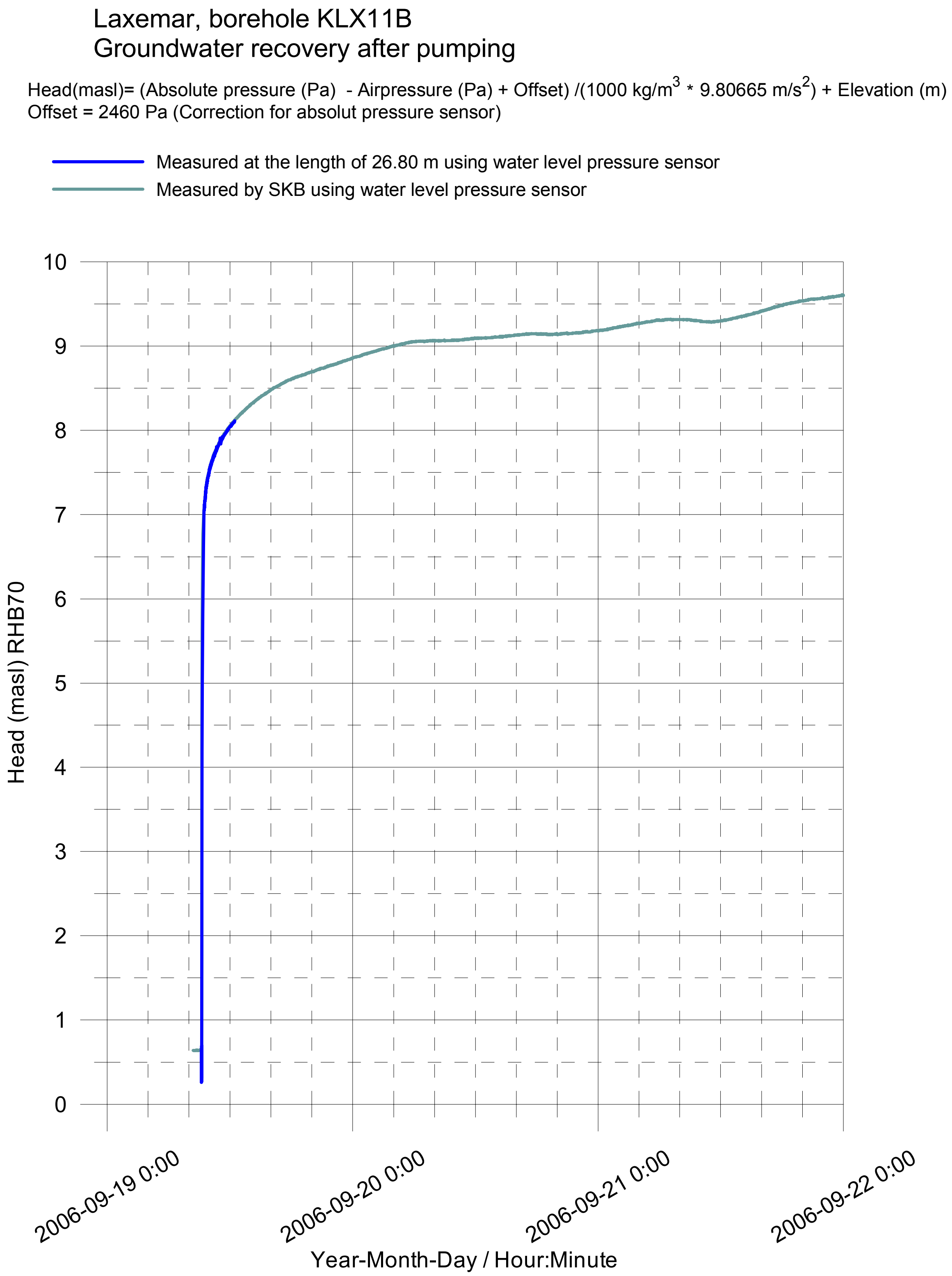
Laxemar, borehole KLX11B
Head in the borehole during flow logging

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 KLX11B
Air pressure, water level in the borehole and pumping rate during flow logging

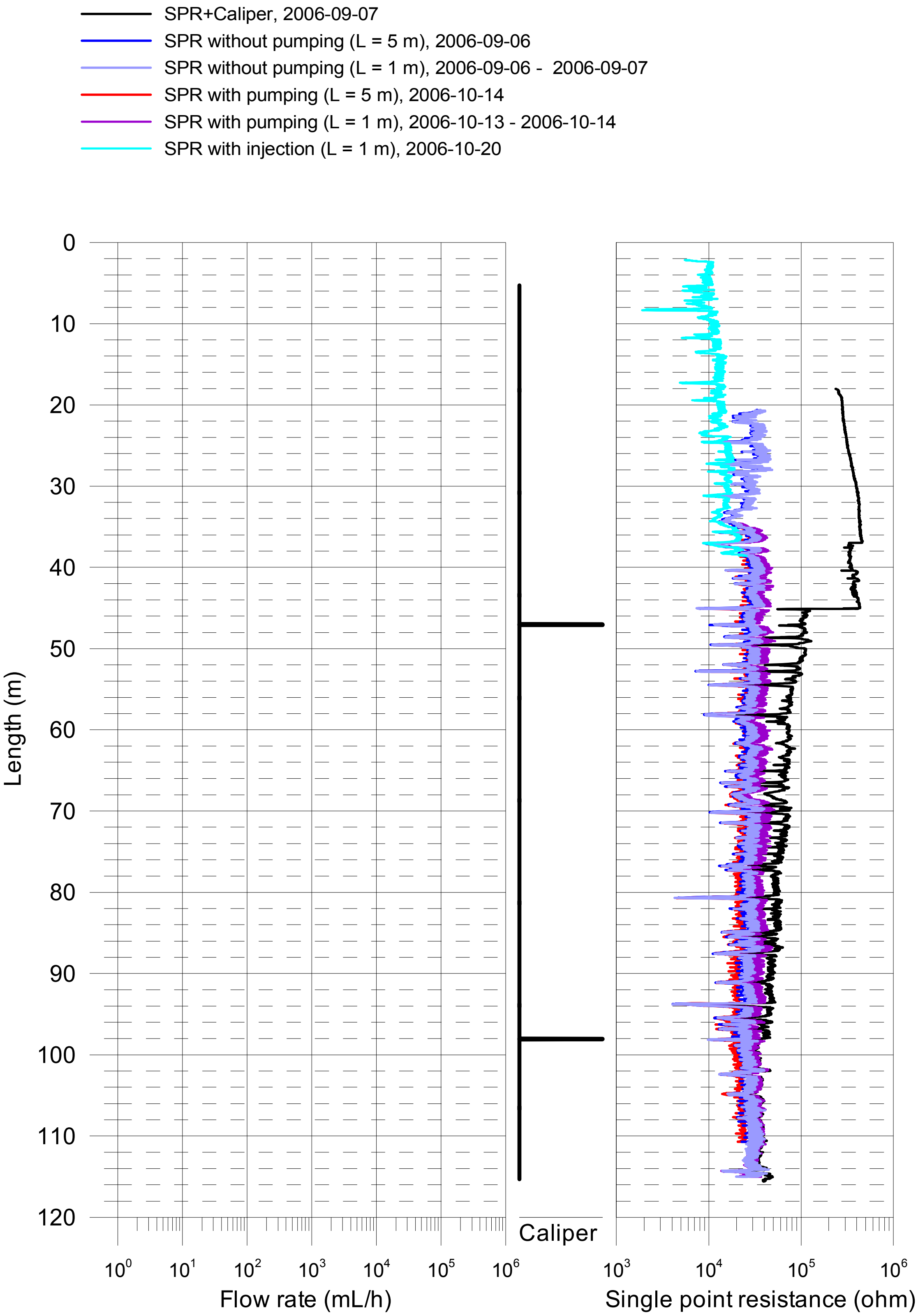


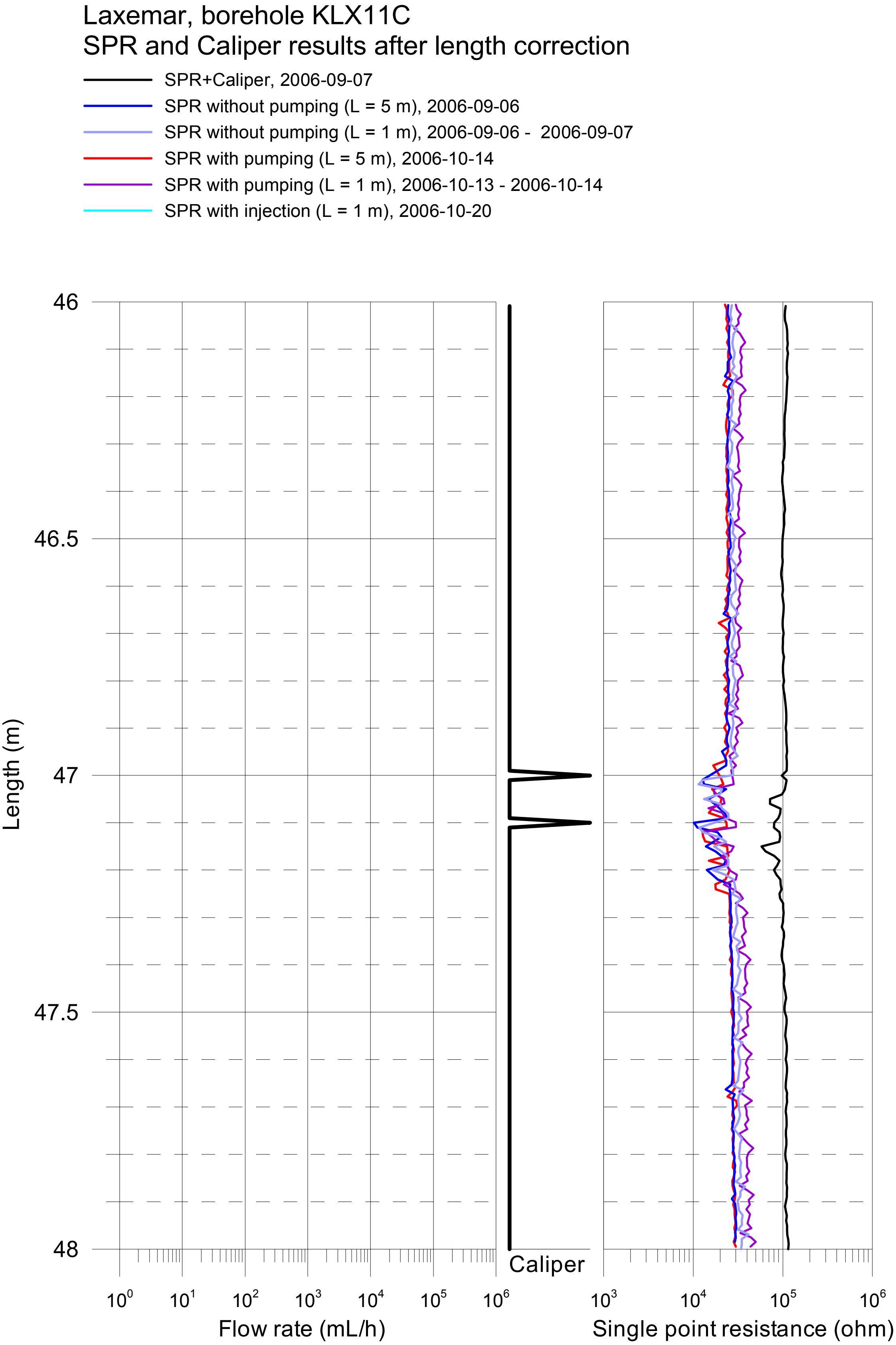

Laxemar, borehole KLX11B
Groundwater recovery after pumping
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)
Measured at the length of 26.80 m using water level pressure sensor
Measured by SKB using water level pressure sensor
10
9
8
7
6
5
4
3
2
1
0
Head (masl) RHB70
2006-09-19 0:00
2006-09-20 0:00
2006-09-21 0:00
2006-09-22 0:00
Year-Month-Day / Hour:Minute

Appendices, KLX11C

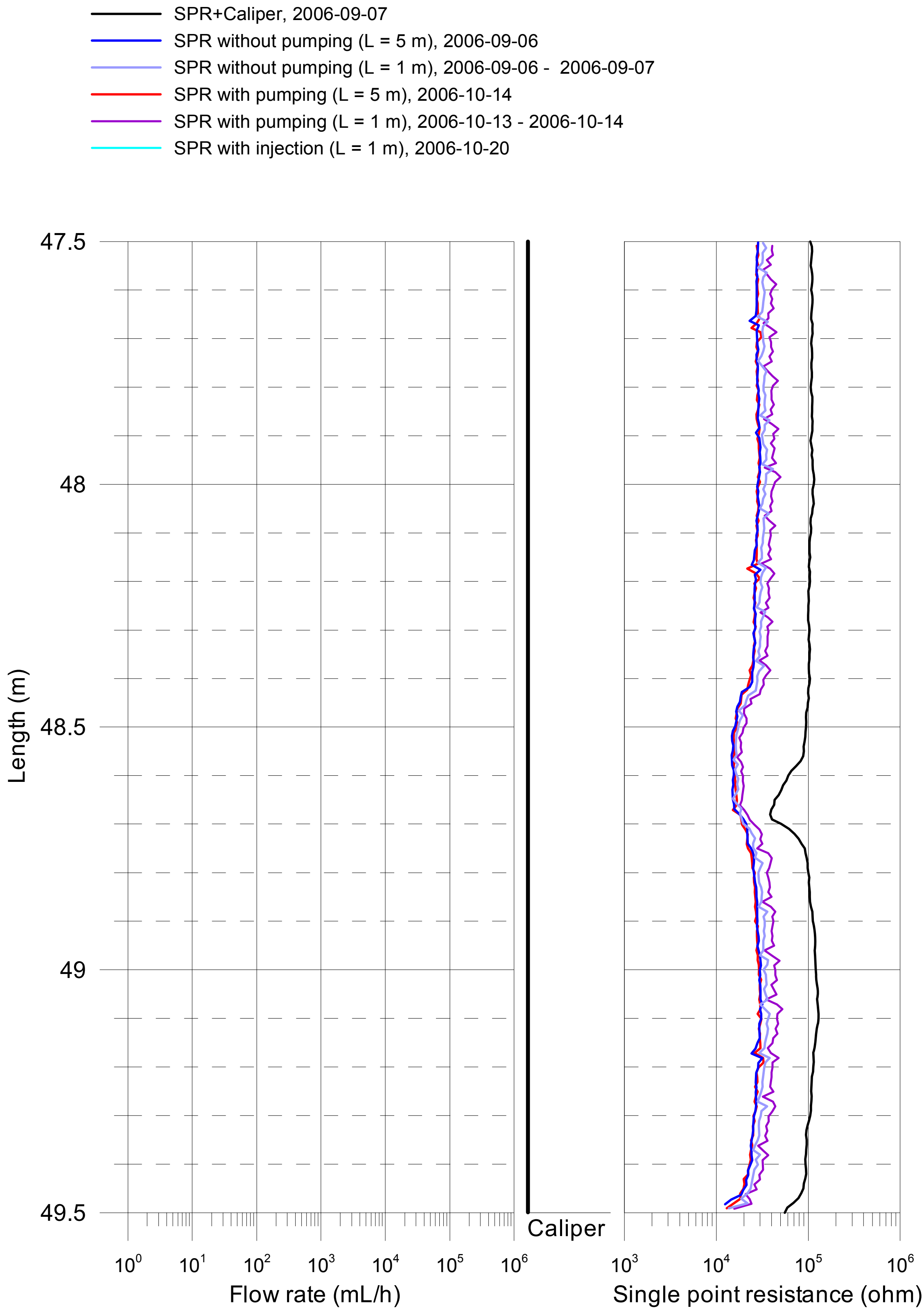
Appendices	C.1.1–C.1.10	SPR and Caliper results after length correction
Appendix	C.1.11	Length correction
Appendices	C.2.1–C.2.6	Flow rate, Caliper and Single point resistance
Appendix	C.3.1	Electric conductivity of borehole water
Appendix	C.3.2	Temperature of borehole water
Appendix	C.4.1	Plotted flow rates of 5 m sections
Appendix	C.4.2	Plotted transmissivity and head of 5 m sections
Appendix	C.5	Plotted transmissivity and head of detected fractures
Appendix	C.6	Basic test data
Appendix	C.7	Results of sequential flow logging
Appendix	C.8	Inferred flow anomalies from overlapping flow logging
Appendix	C.9	Explanations for the tables in Appendices 6–8
Appendix	C.10	Conductive fracture frequency
Appendix	C.11	Plotted conductive fracture frequency
Appendix	C.12	Comparison between section transmissivity and fracture transmissivity
Appendix	C.13	Head in the borehole during flow logging
Appendix	C.14	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	C.15	Groundwater recovery after pumping

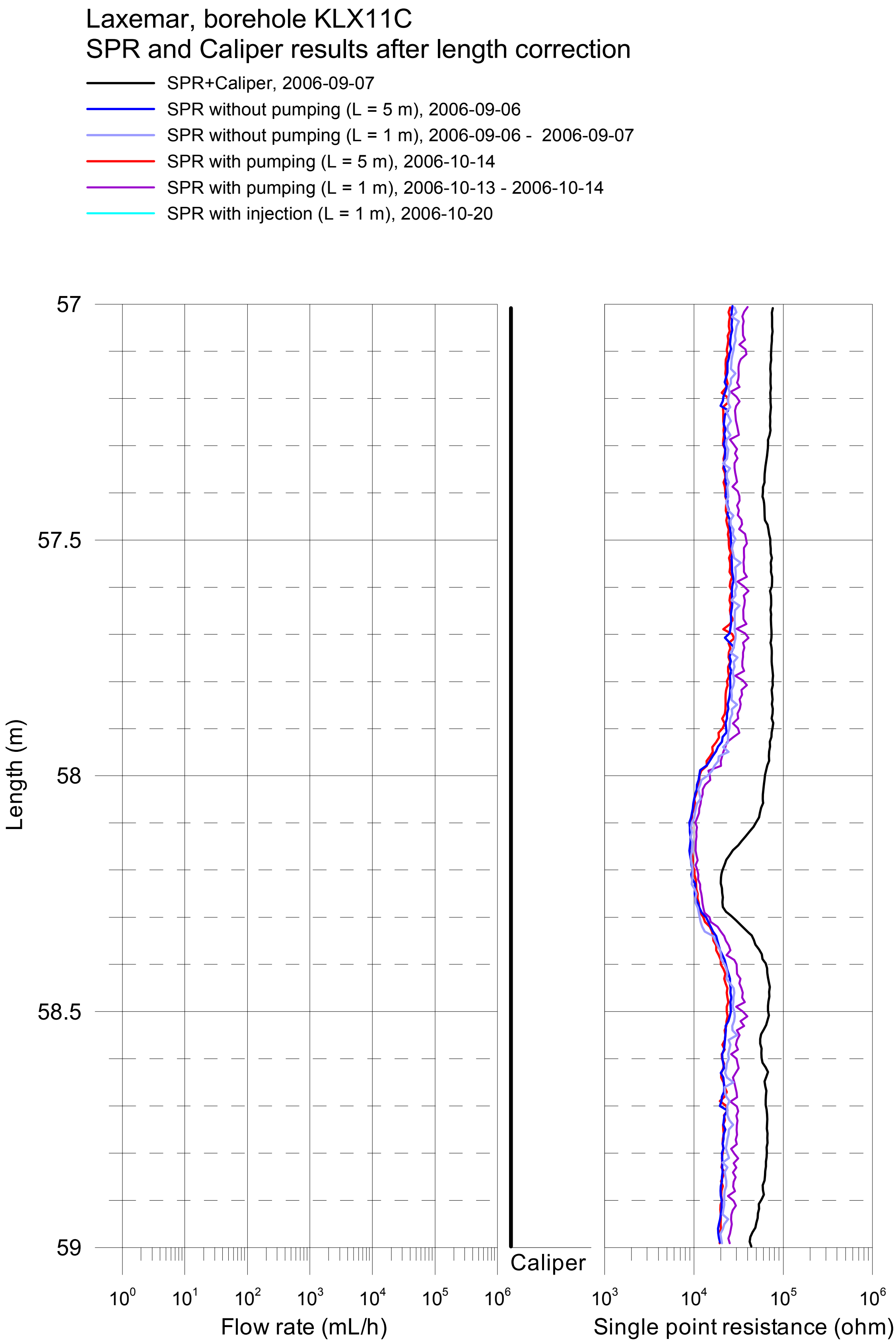
Laxemar, borehole KLX11C
SPR and Caliper results after length correction

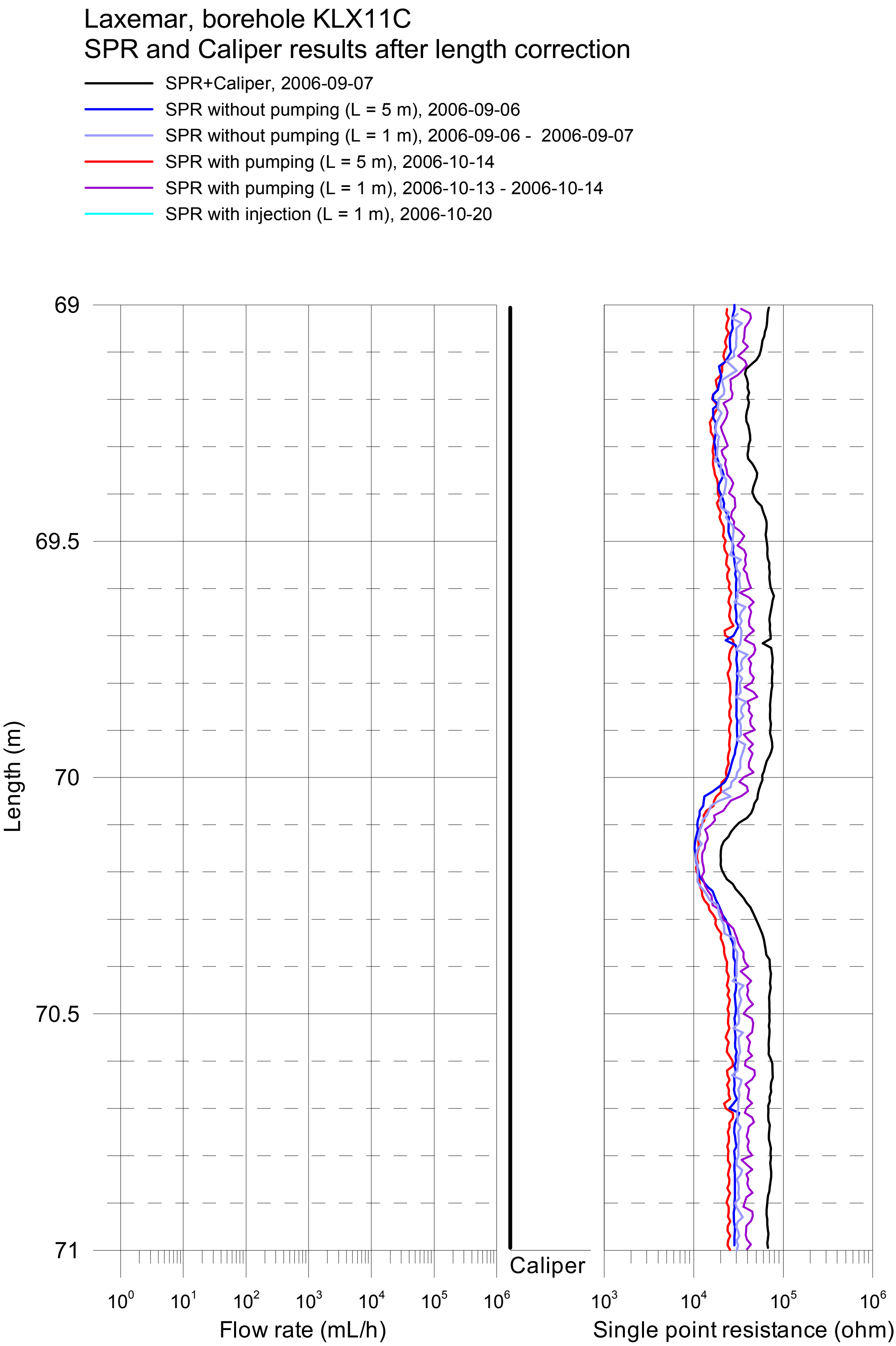



Laxemar, borehole KLX11C
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-06
SPR without pumping (L = 1 m), 2006-09-06 - 2006-09-07
SPR with pumping (L = 5 m), 2006-10-14
SPR with pumping (L = 1 m), 2006-10-13 - 2006-10-14
SPR with injection (L = 1 m), 2006-10-20
Length (m)
46
46.5
47
47.5
48
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

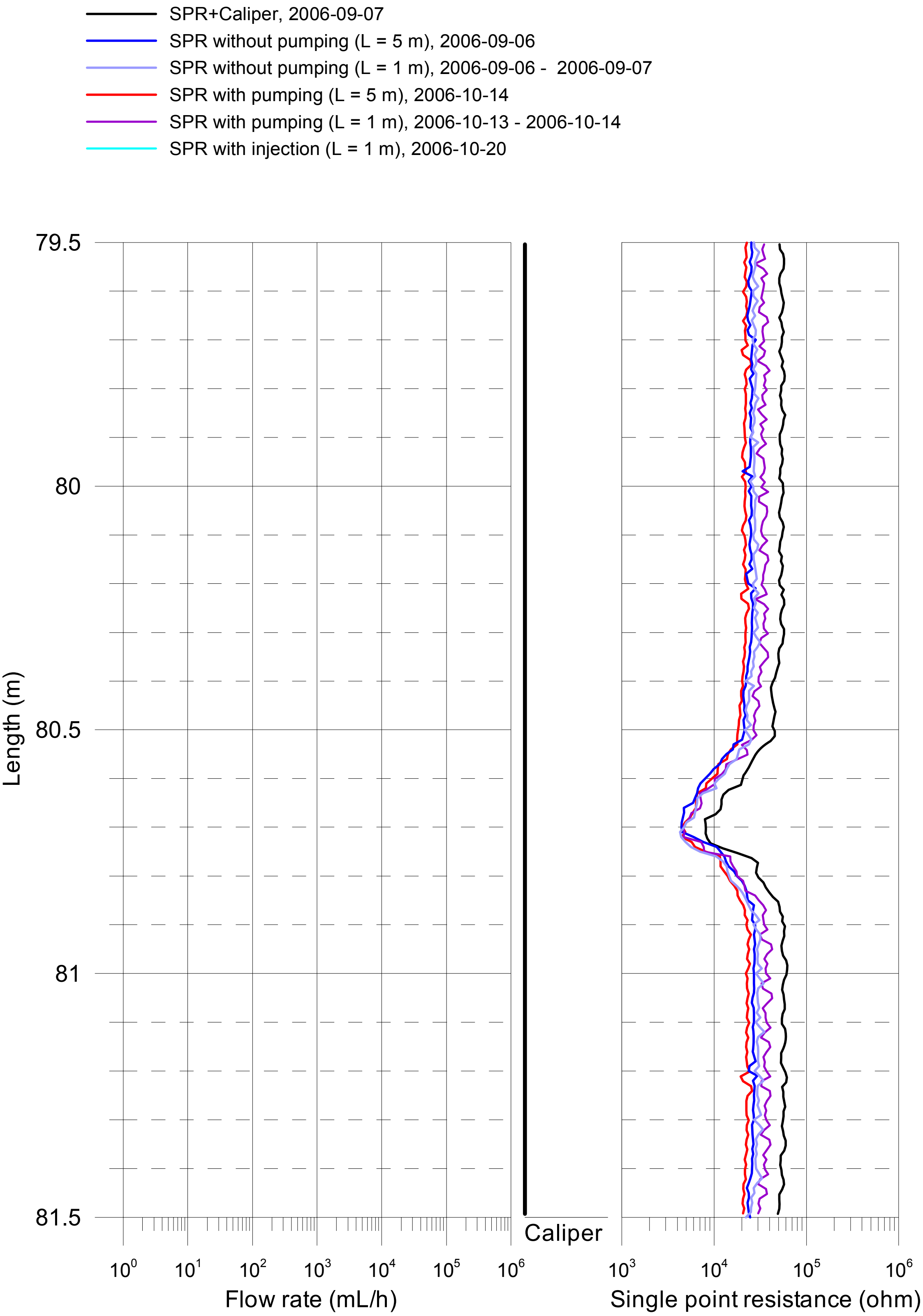
Laxemar, borehole KLX11C
SPR and Caliper results after length correction

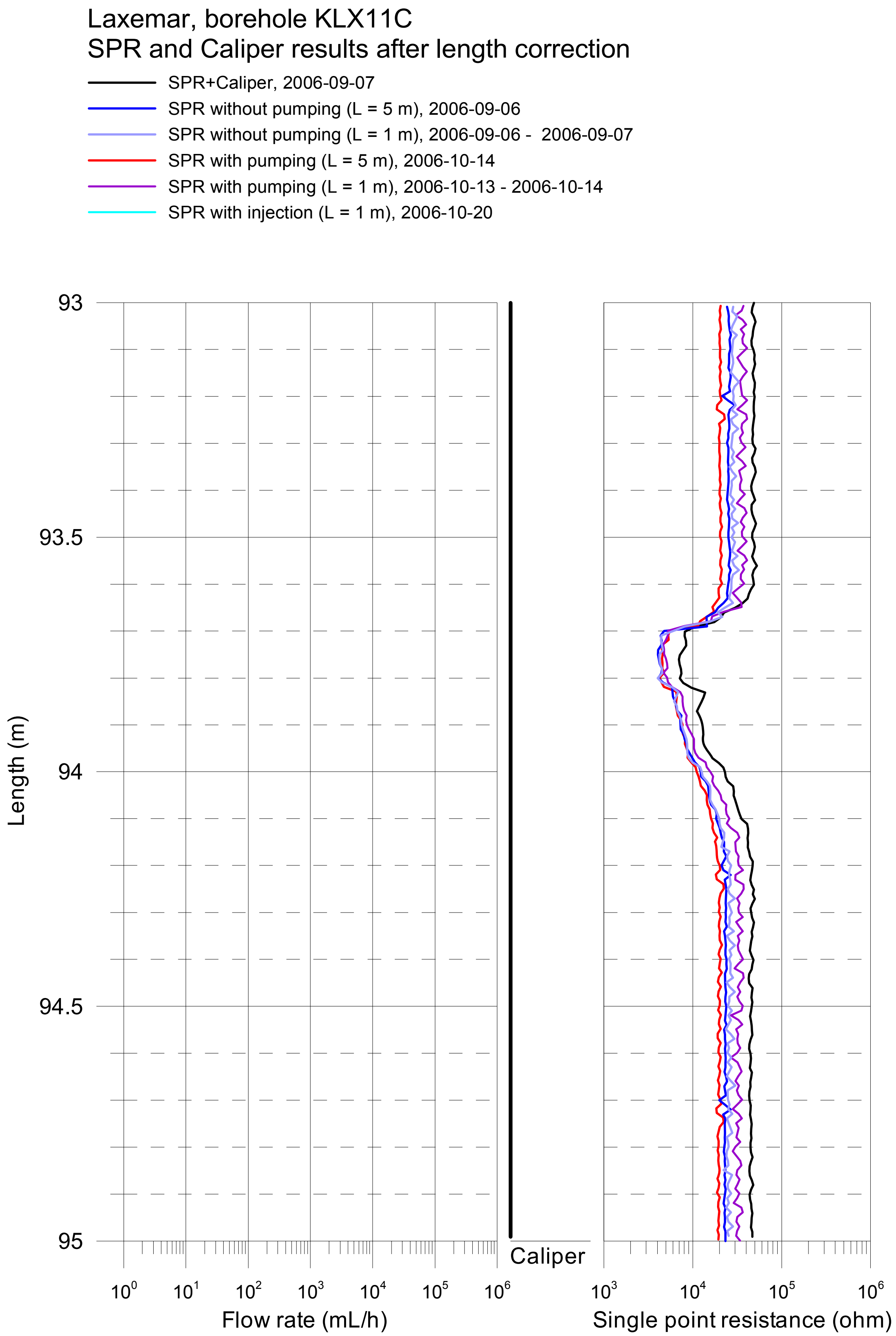


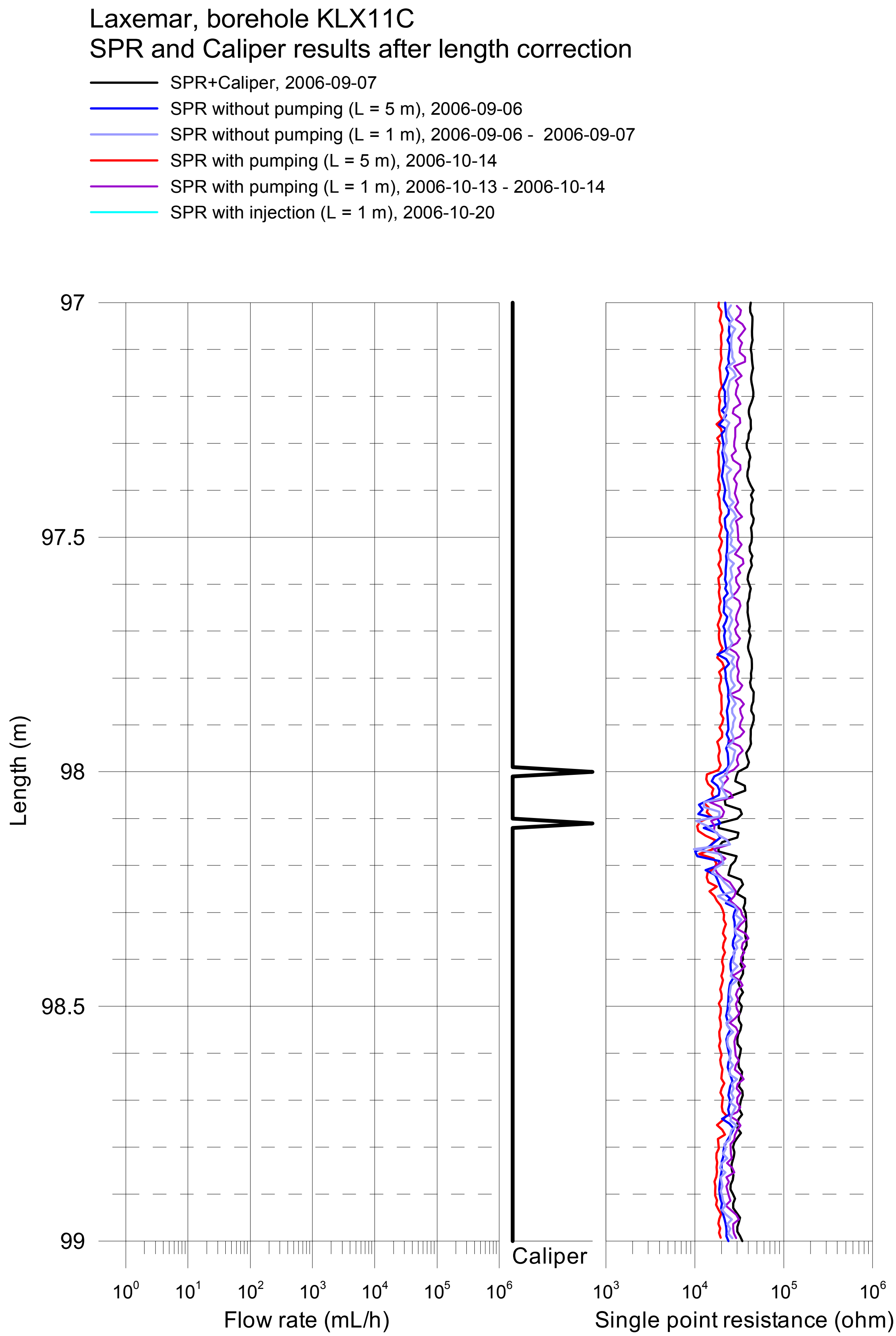

Laxemar, borehole KLX11C
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-06
SPR without pumping (L = 1 m), 2006-09-06 - 2006-09-07
SPR with pumping (L = 5 m), 2006-10-14
SPR with pumping (L = 1 m), 2006-10-13 - 2006-10-14
SPR with injection (L = 1 m), 2006-10-20
Length (m)
57
57.5
58
58.5
59
Caliper
Flow rate (mL/h)
Single point resistance (ohm)


Laxemar, borehole KLX11C
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-06
SPR without pumping (L = 1 m), 2006-09-06 - 2006-09-07
SPR with pumping (L = 5 m), 2006-10-14
SPR with pumping (L = 1 m), 2006-10-13 - 2006-10-14
SPR with injection (L = 1 m), 2006-10-20
Length (m)
69
69.5
70
70.5
71
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)

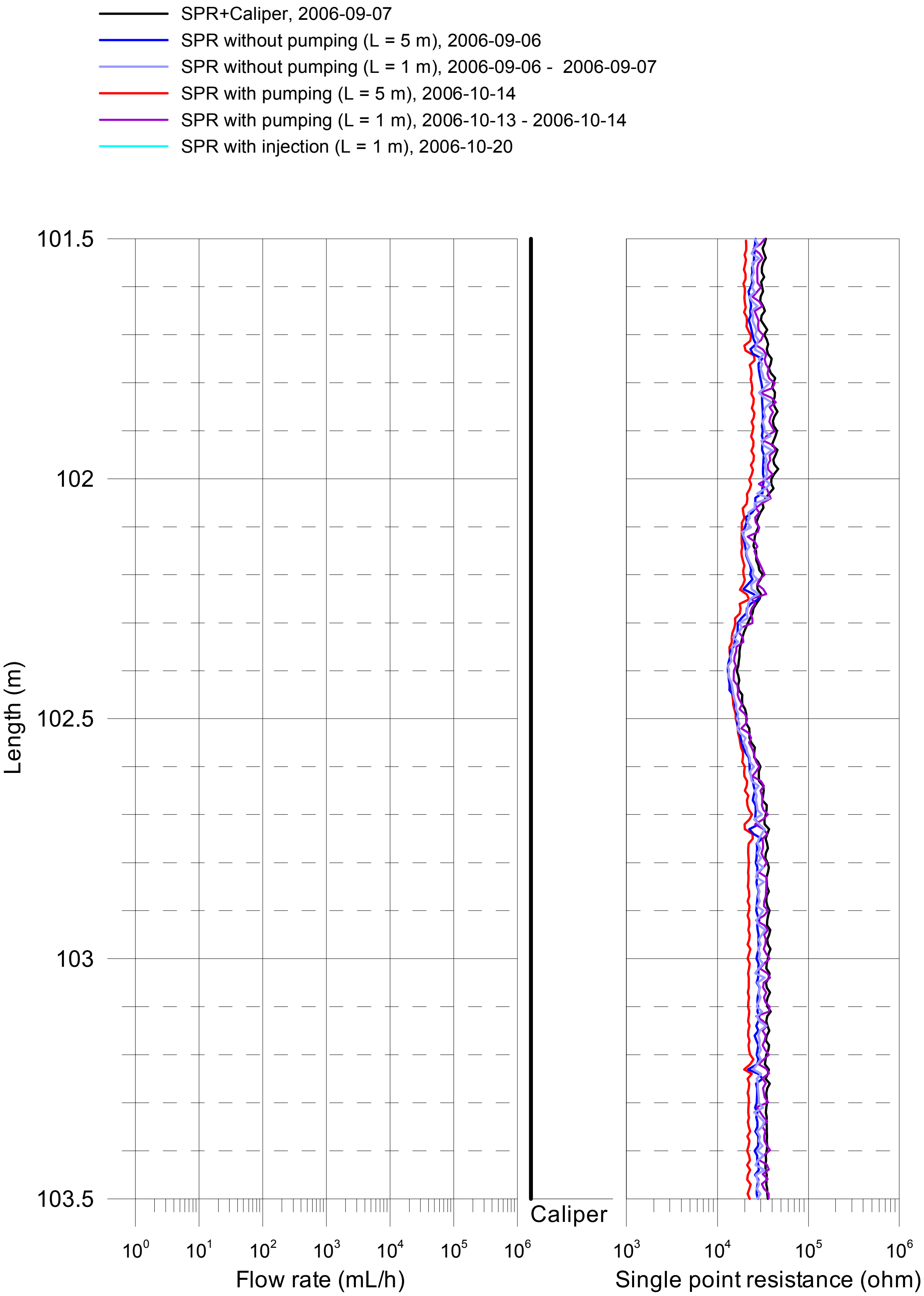
Laxemar, borehole KLX11C
SPR and Caliper results after length correction

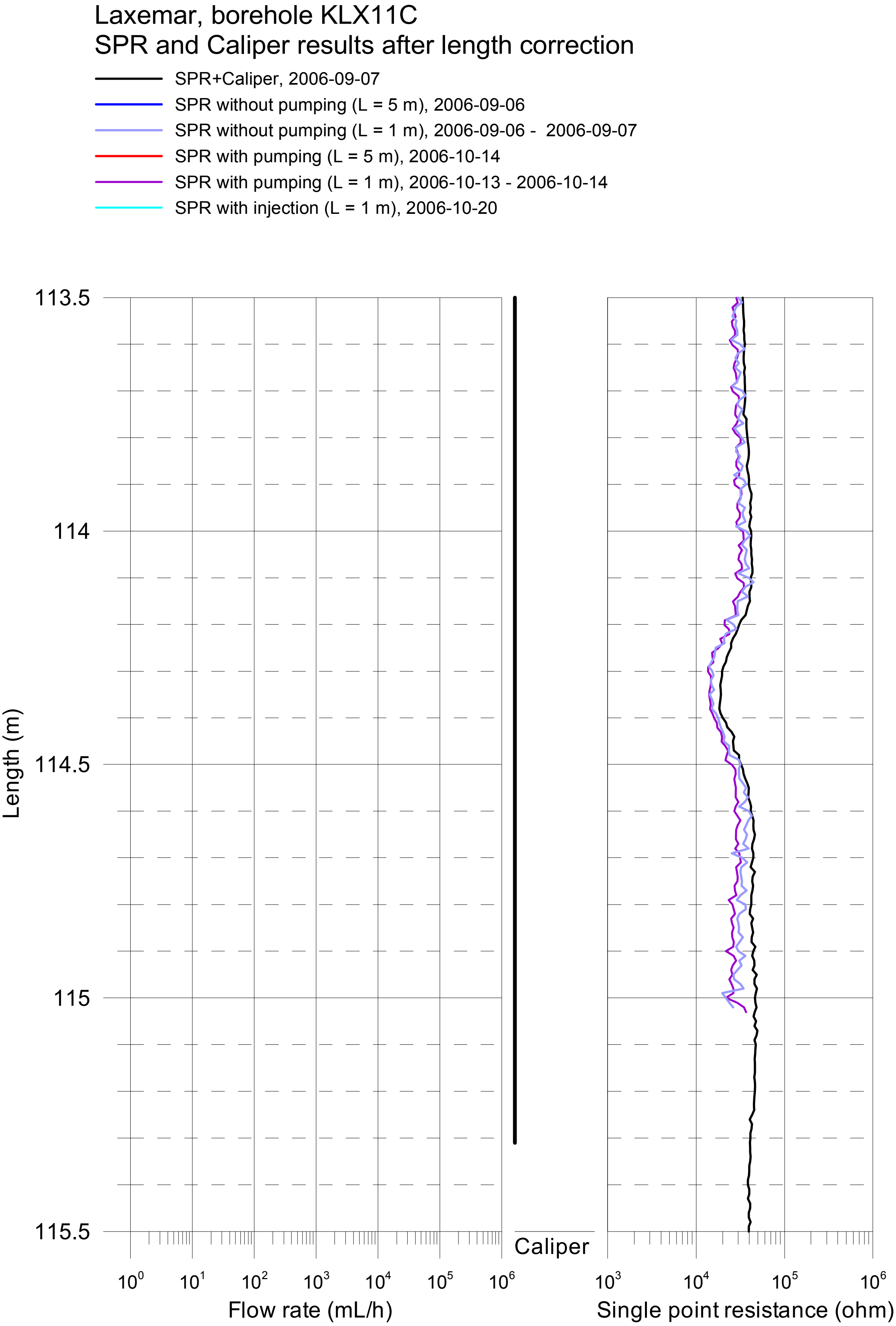



Laxemar, borehole KLX11C
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-06
SPR without pumping (L = 1 m), 2006-09-06 - 2006-09-07
SPR with pumping (L = 5 m), 2006-10-14
SPR with pumping (L = 1 m), 2006-10-13 - 2006-10-14
SPR with injection (L = 1 m), 2006-10-20
93
93.5
94
94.5
95
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)

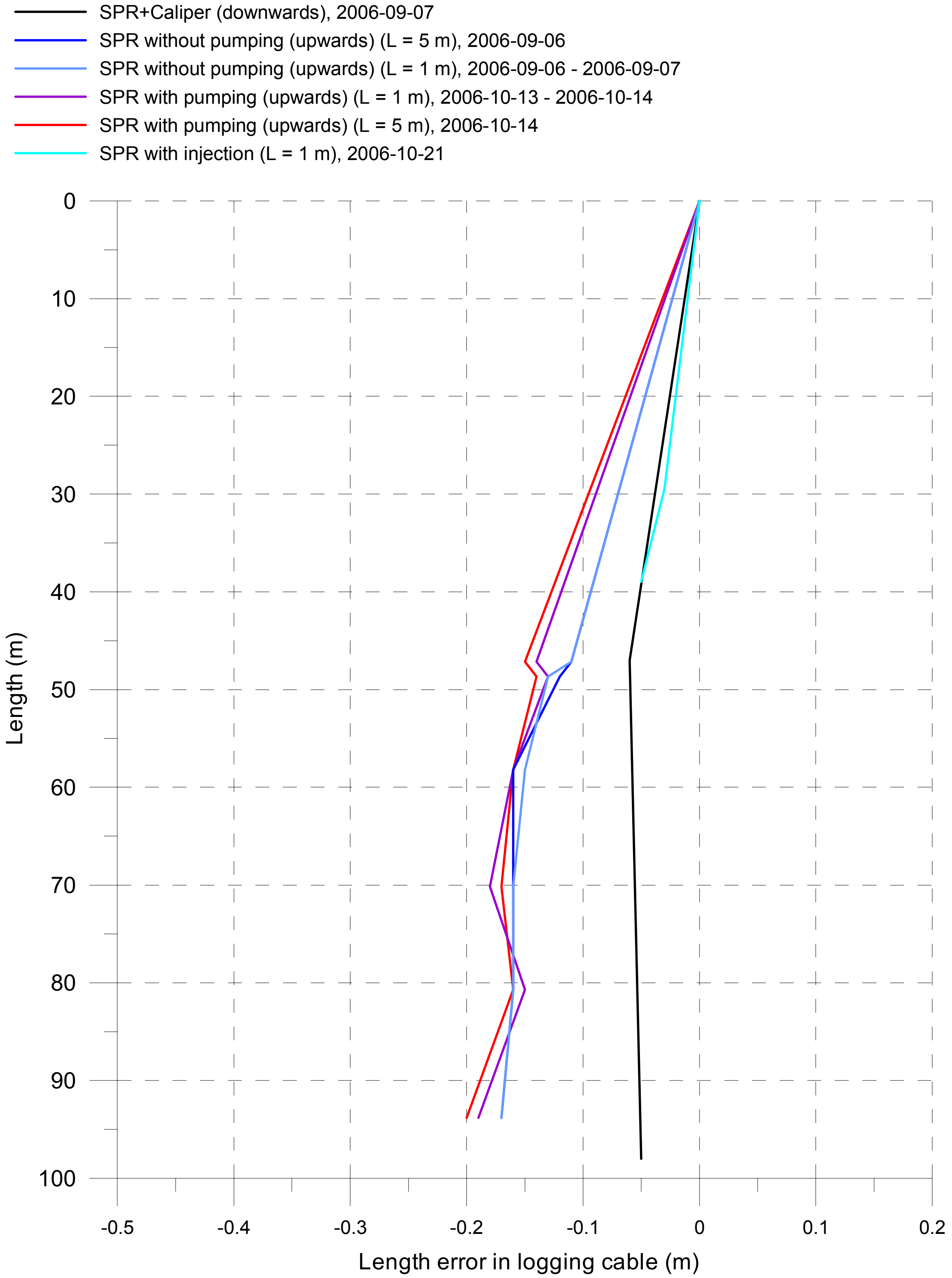

Laxemar, borehole KLX11C
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-06
SPR without pumping (L = 1 m), 2006-09-06 - 2006-09-07
SPR with pumping (L = 5 m), 2006-10-14
SPR with pumping (L = 1 m), 2006-10-13 - 2006-10-14
SPR with injection (L = 1 m), 2006-10-20
Length (m)
97
97.5
98
98.5
99
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

Laxemar, borehole KLX11C
SPR and Caliper results after length correction

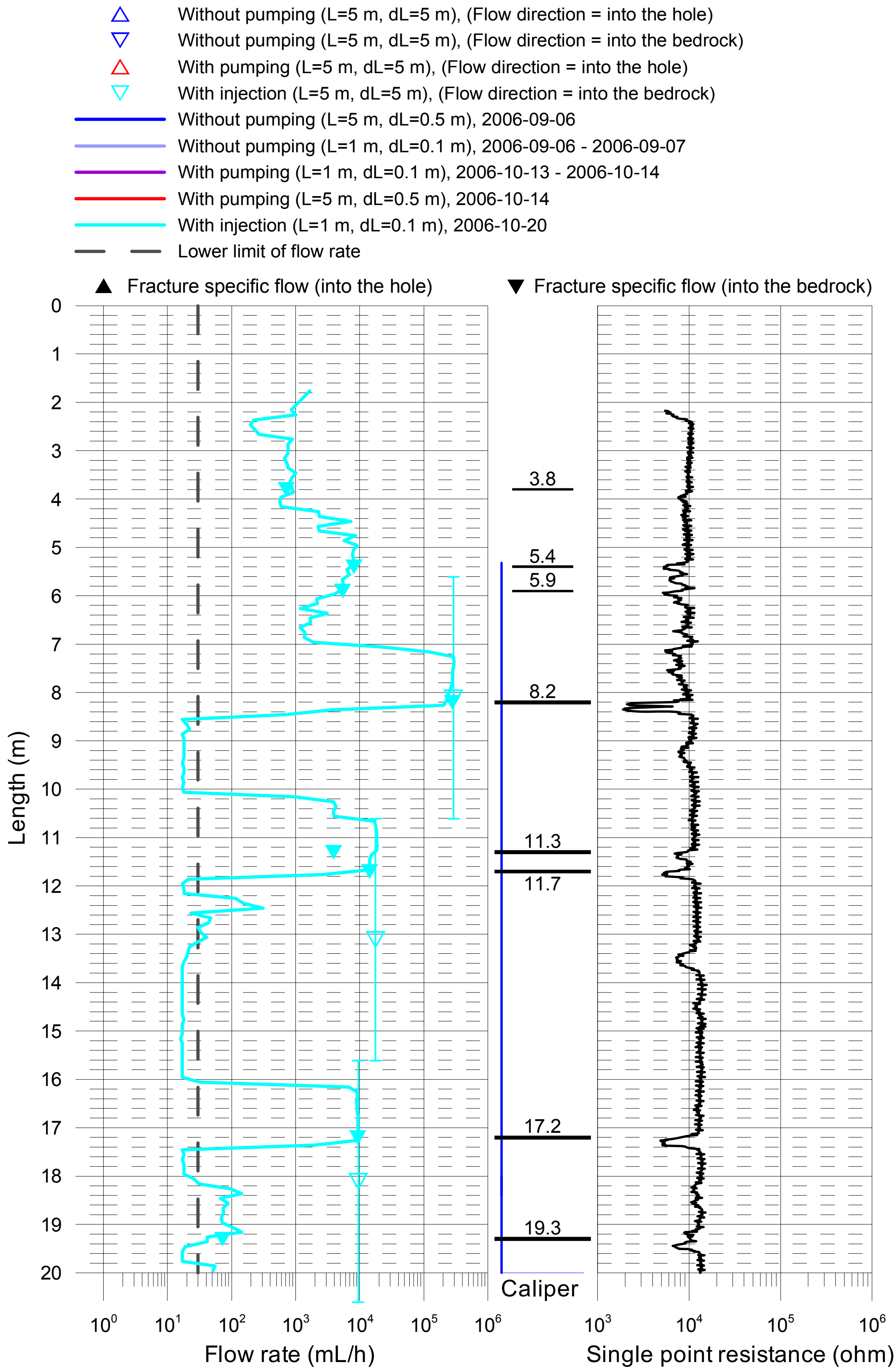



Laxemar, borehole KLX11C
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-06
SPR without pumping (L = 1 m), 2006-09-06 - 2006-09-07
SPR with pumping (L = 5 m), 2006-10-14
SPR with pumping (L = 1 m), 2006-10-13 - 2006-10-14
SPR with injection (L = 1 m), 2006-10-20
Length (m)
113.5
114
114.5
115
115.5
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)

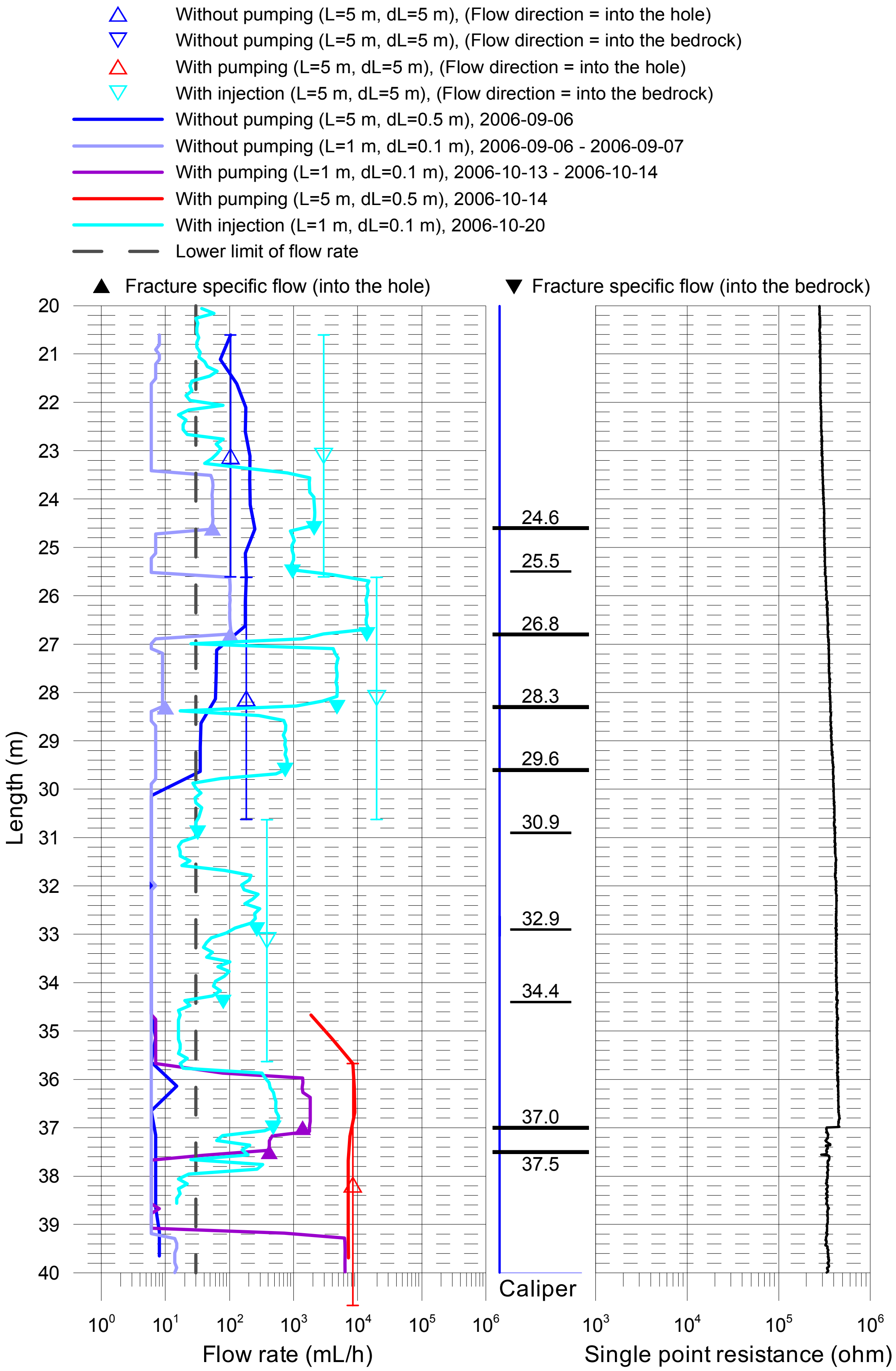
Laxemar, borehole KLX11C
Length correction



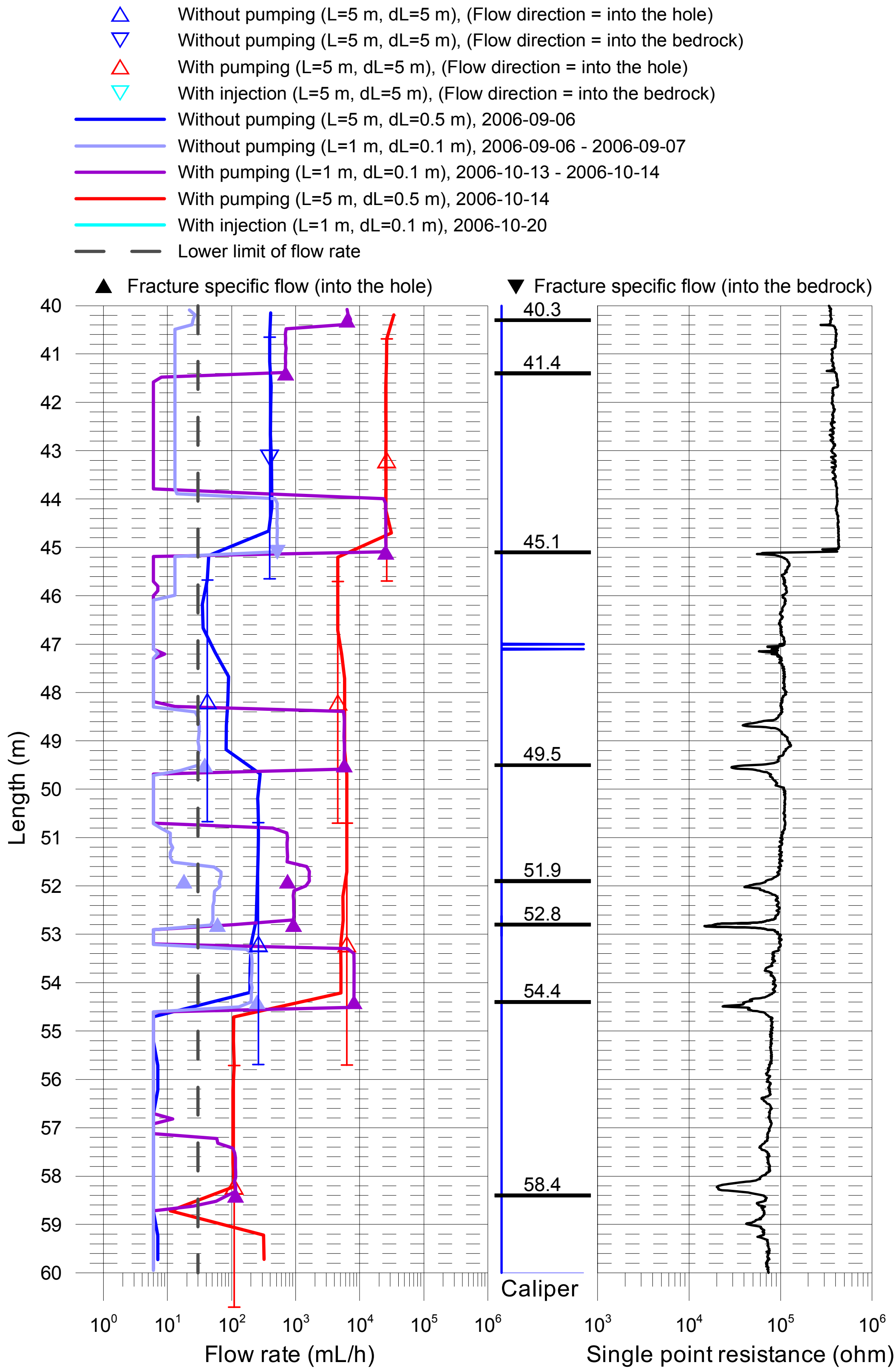
Laxemar, borehole KLX11C
Flow rate and single point resistance



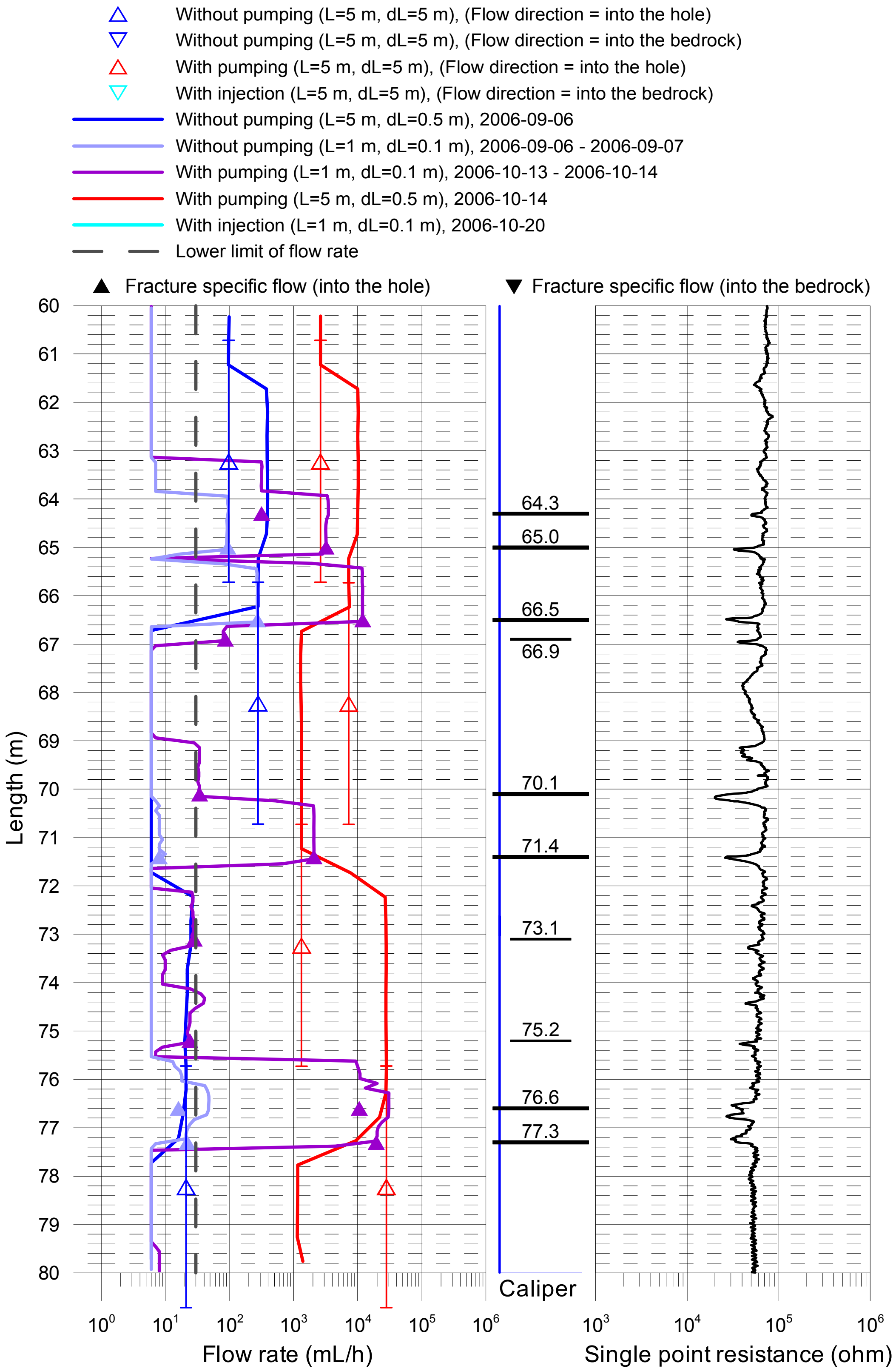
Laxemar, borehole KLX11C
Flow rate and single point resistance



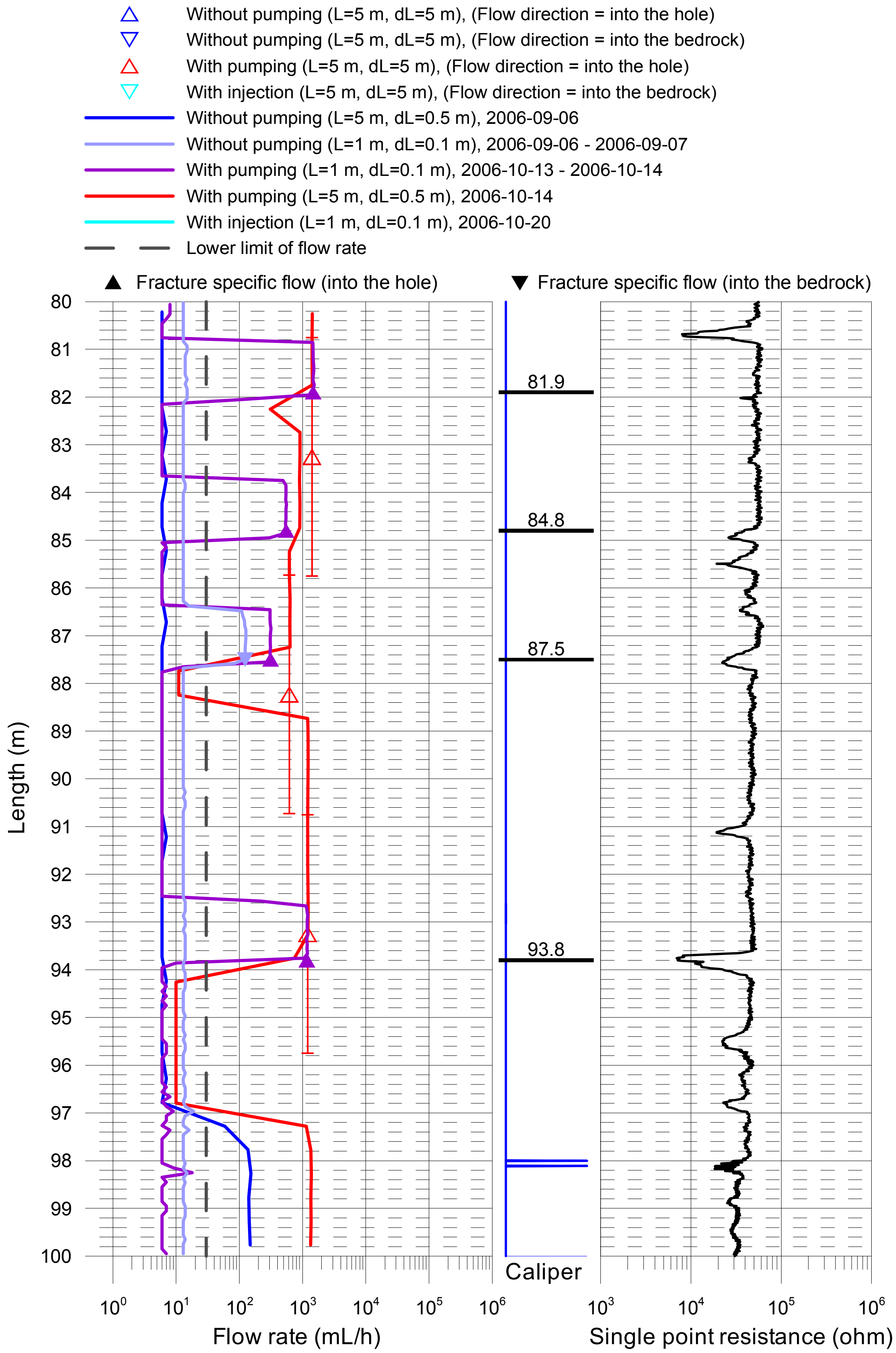
Laxemar, borehole KLX11C
Flow rate and single point resistance

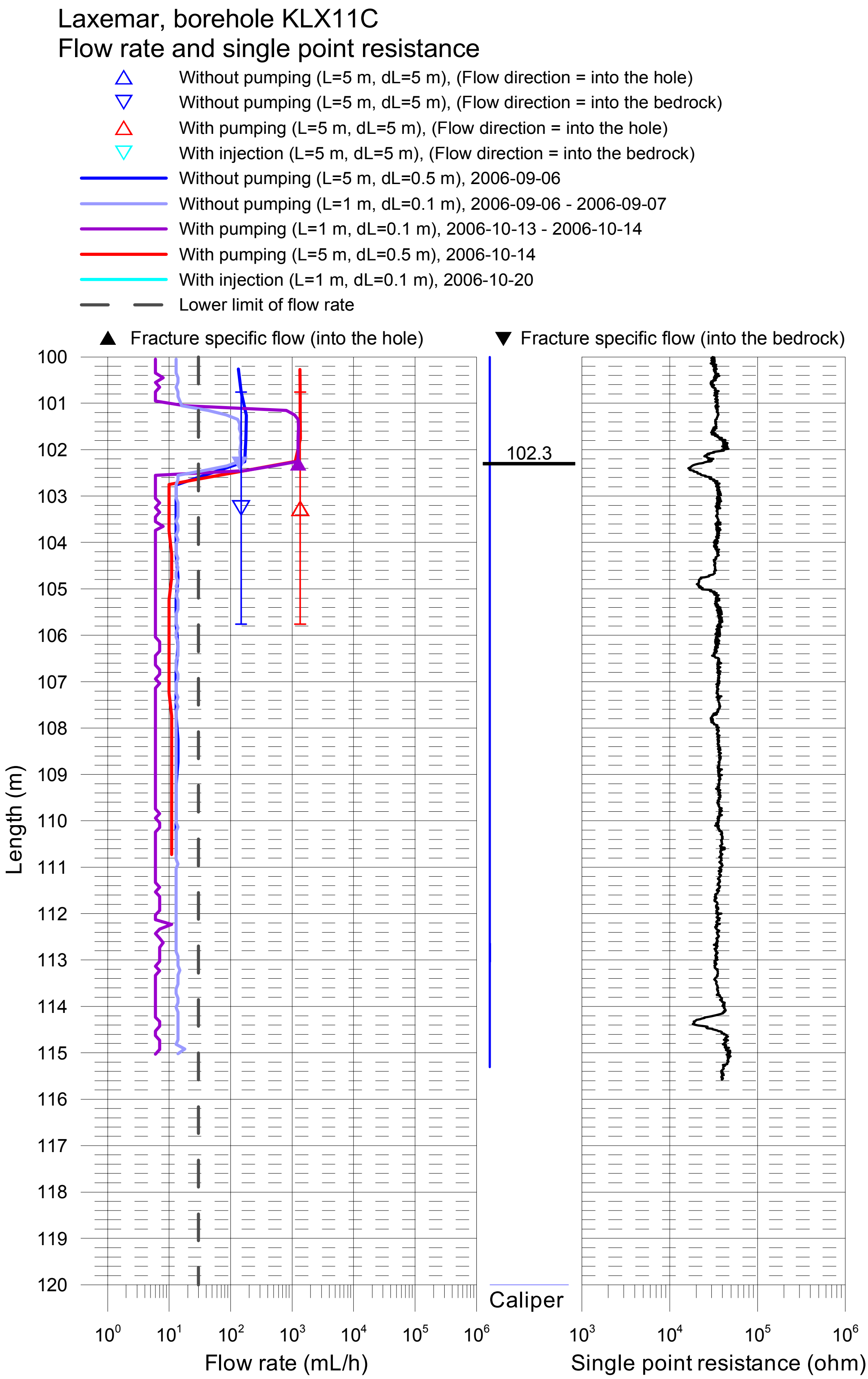


Laxemar, borehole KLX11C
Flow rate and single point resistance

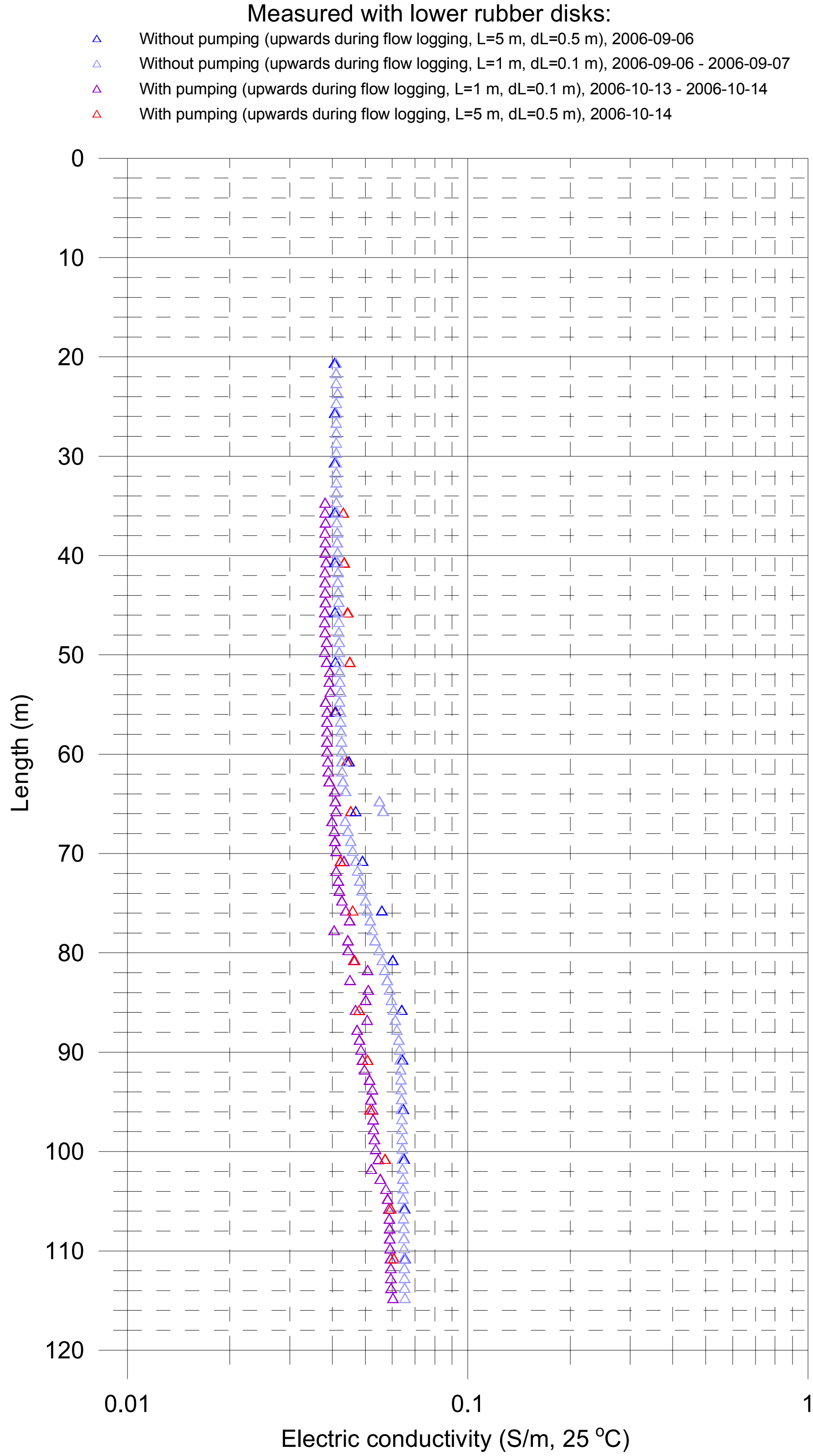


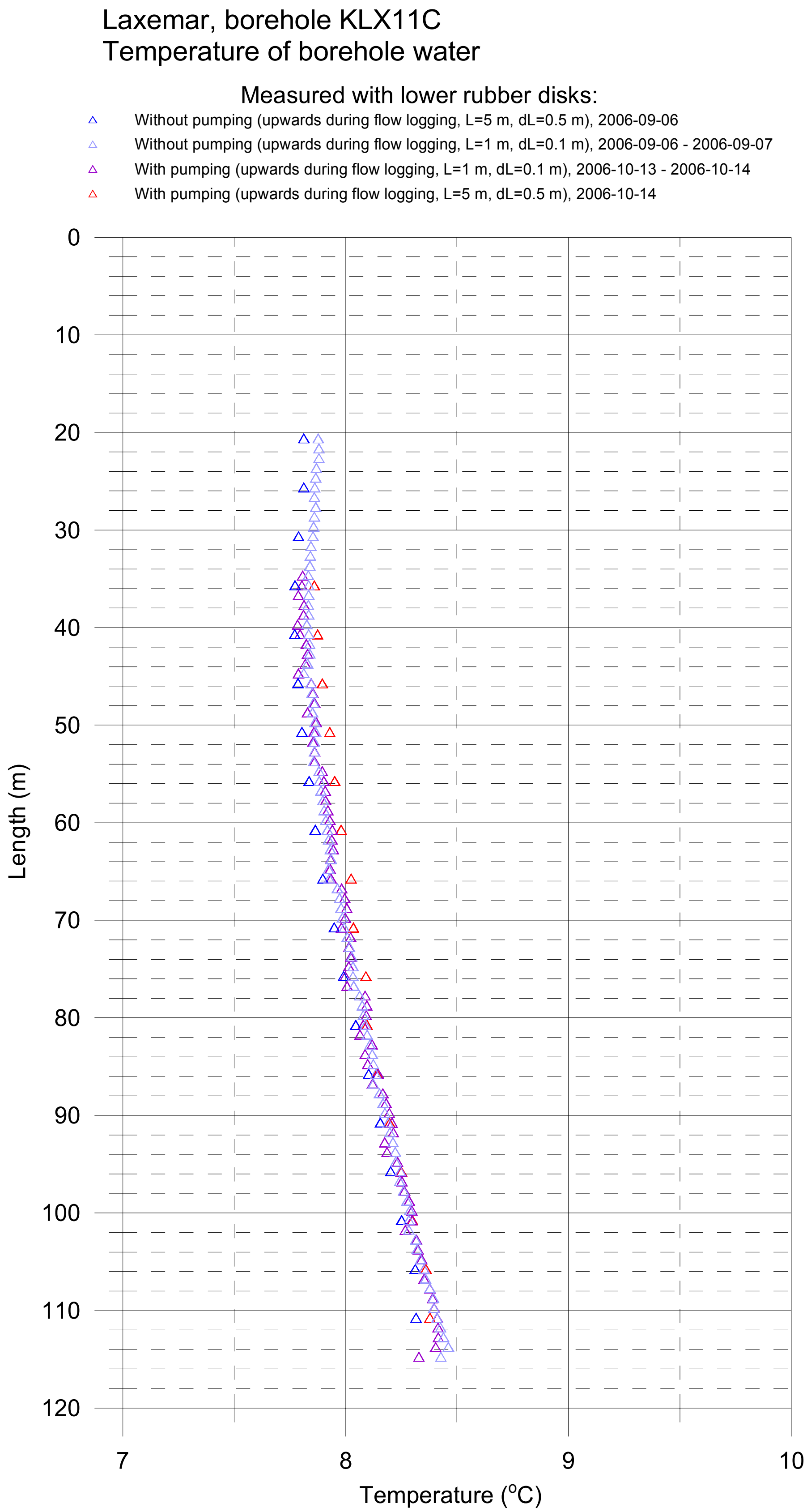
Laxemar, borehole KLX11C
Flow rate and single point resistance

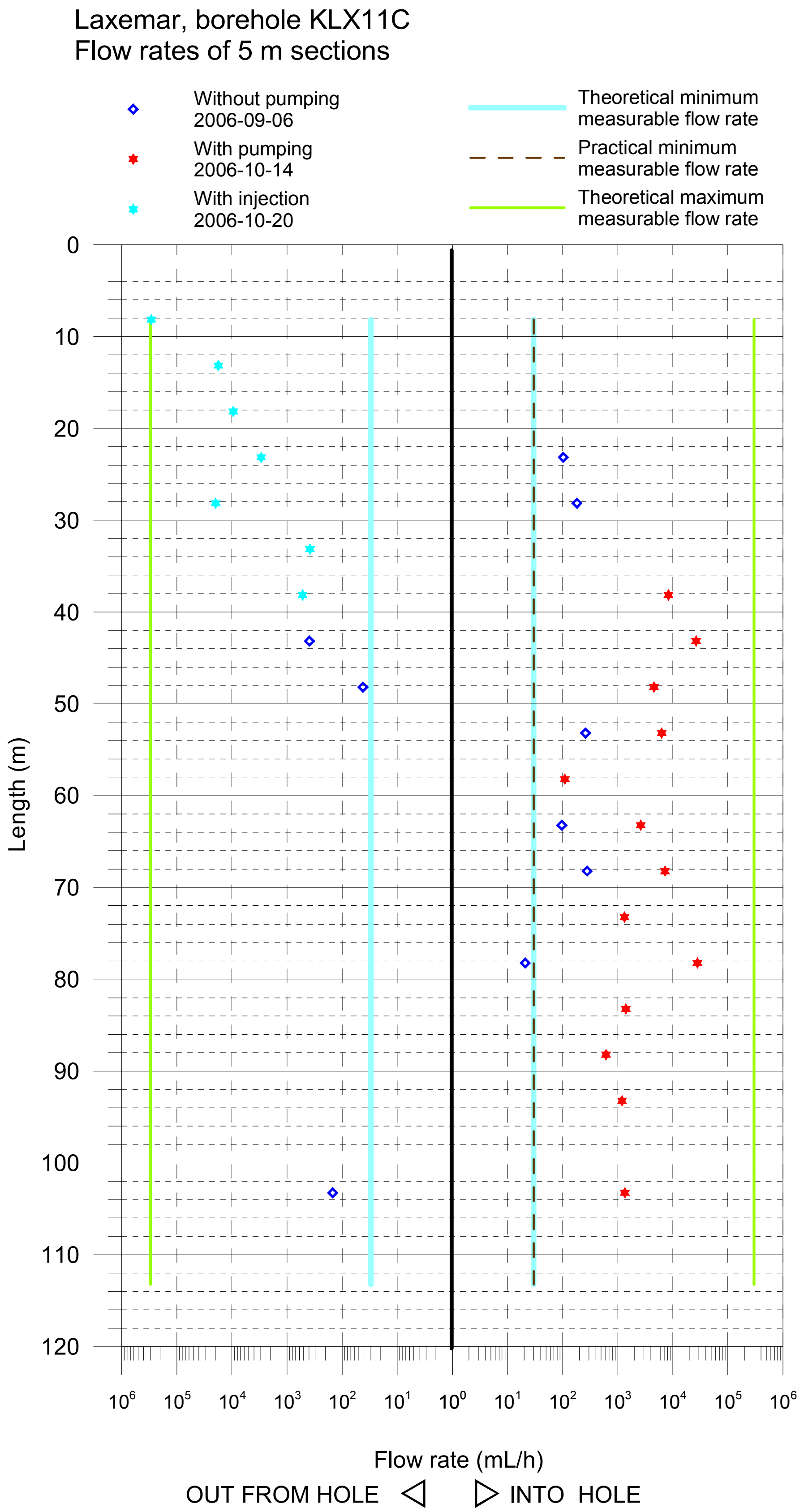


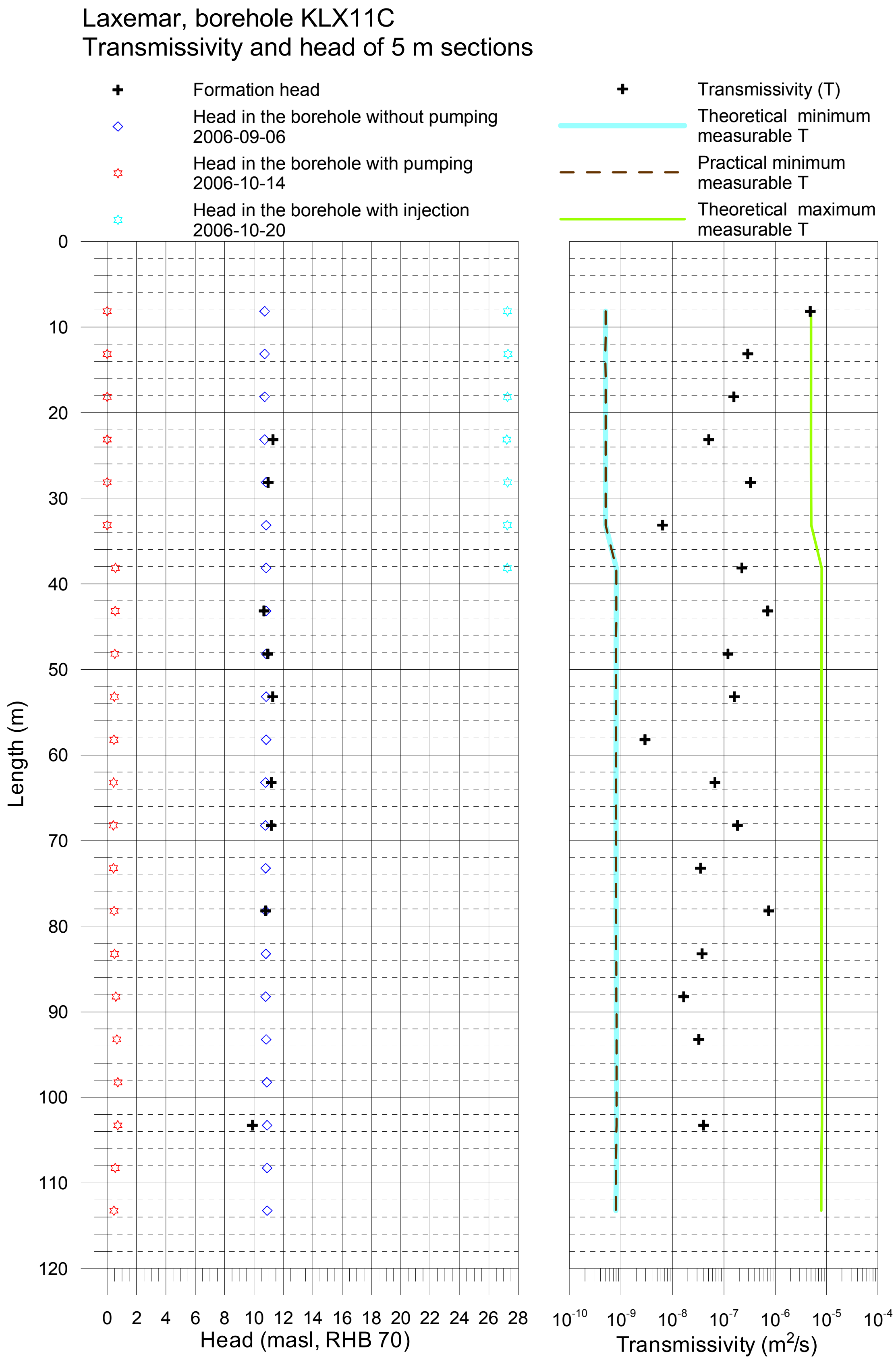

Laxemar, borehole KLX11C
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-06
Without pumping (L=1 m, dL=0.1 m), 2006-09-06 - 2006-09-07
With pumping (L=1 m, dL=0.1 m), 2006-10-13 - 2006-10-14
With pumping (L=5 m, dL=0.5 m), 2006-10-14
With injection (L=1 m, dL=0.1 m), 2006-10-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
102.3
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

Laxemar, borehole KLX11C
Electric conductivity of borehole water

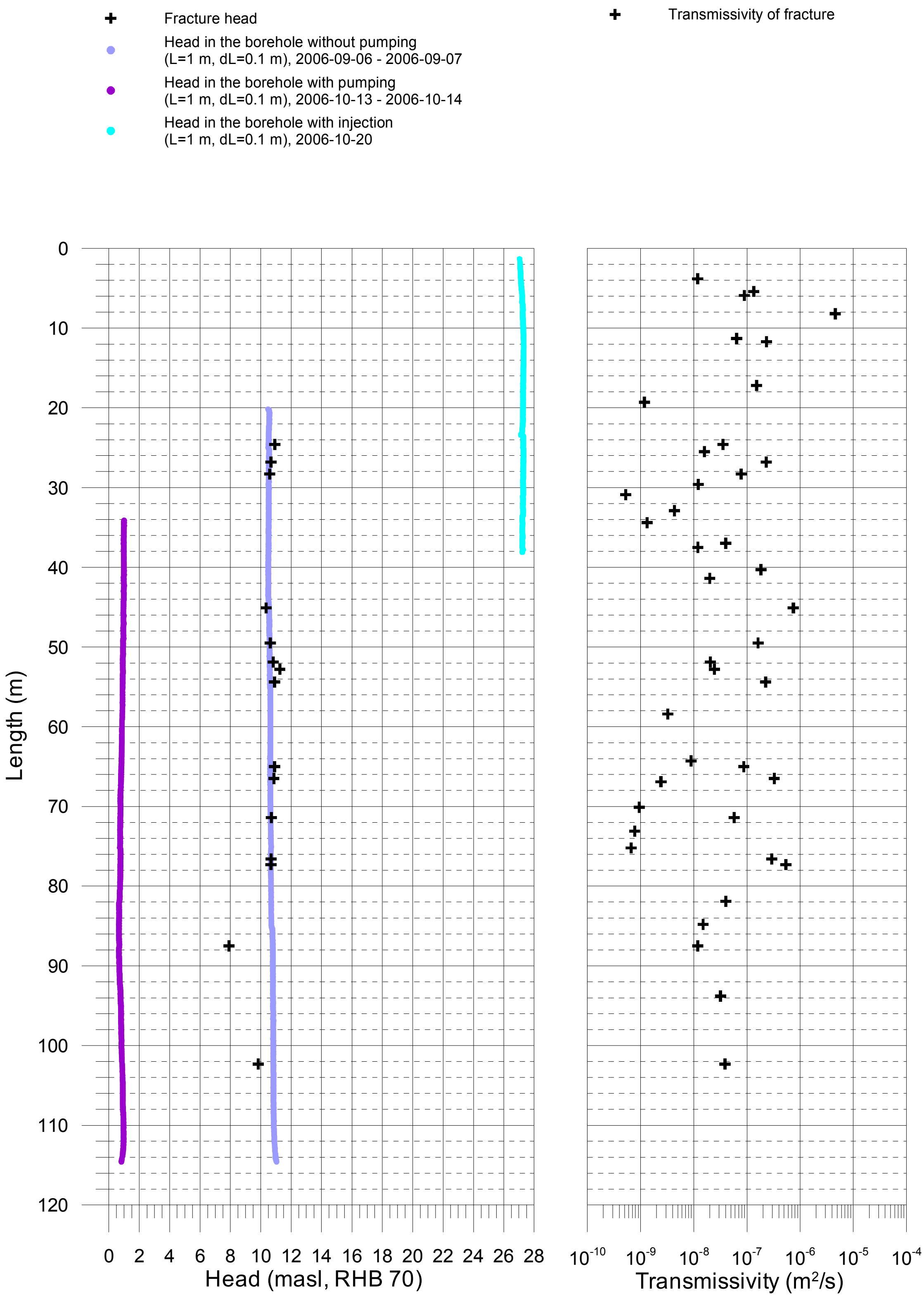



Laxemar, borehole KLX11C
Temperature of borehole water
Measured with lower rubber disks:
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-06
Without pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-06 - 2006-09-07
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-10-13 - 2006-10-14
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-10-14
Length (m)
Temperature (°C)
0
10
20
30
40
50
60
70
80
90
100
110
120
7
8
9
10


Laxemar, borehole KLX11C
Flow rates of 5 m sections
Without pumping 2006-09-06
With pumping 2006-10-14
With injection 2006-10-20
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
110
120
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 KLX11C
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-09-06
Head in the borehole with pumping 2006-10-14
Head in the borehole with injection 2006-10-20
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 KLX11C
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)
KLX11C	2	120.15	5A	20061012	11:54	20061014	10:26	20061014	9:14	5	0.5	2.92E–05	–5.00E–04

5. PFL-Difference flow logging – Basic test data

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (m.a.s.l.)	h_1 (m.a.s.l.)	h_2 (m.a.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
163200	23220	110160	212280	10.80	0.69	27.2	–10.11	16.40	2.85E–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)	T_D-$measl_{LT}$ (m^2/s)	T_D-$measl_{LP}$ (m^2/s)	T_D-$meas_{lU}$ (m^2/s)	Comments
KLX11C	5.66	10.66	5	–	10.73	–8.08E–05	27.26	4.8E–06	–	30	5.0E–10	5.0E–10	5.0E–06	*,**
KLX11C	10.66	15.66	5	–	10.73	–4.89E–06	27.3	2.9E–07	–	30	5.0E–10	5.0E–10	5.0E–06	*,**
KLX11C	15.66	20.66	5	–	10.73	–2.62E–06	27.26	1.6E–07	–	30	5.0E–10	5.0E–10	5.0E–06	*,**
KLX11C	20.66	25.66	5	2.86E–08	10.73	–8.19E–07	27.22	5.1E–08	11.3	30	5.0E–10	5.0E–10	5.0E–06	*
KLX11C	25.66	30.66	5	5.06E–08	10.82	–5.50E–06	27.27	3.3E–07	11.0	30	5.0E–10	5.0E–10	5.0E–06	*
KLX11C	30.66	35.66	5	–	10.83	–1.07E–07	27.25	6.4E–09	–	30	5.0E–10	5.0E–10	5.0E–06	*
KLX11C	35.66	40.66	5	–	10.82	2.32E–06	0.56	2.2E–07	–	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	40.67	45.67	5	–1.09E–07	10.83	7.33E–06	0.54	7.2E–07	10.7	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	45.69	50.69	5	1.17E–08	10.84	1.27E–06	0.52	1.2E–07	10.9	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	50.70	55.70	5	7.28E–08	10.82	1.75E–06	0.49	1.6E–07	11.3	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	55.71	60.71	5	–	10.83	3.06E–08	0.46	2.9E–09	–	30	7.9E–10	7.9E–10	7.9E–06	
KLX11C	60.72	65.72	5	2.69E–08	10.78	7.28E–07	0.44	6.7E–08	11.2	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	65.73	70.73	5	7.72E–08	10.77	2.01E–06	0.42	1.8E–07	11.2	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	70.73	75.73	5	–	10.79	3.69E–07	0.43	3.5E–08	–	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	75.72	80.72	5	5.83E–09	10.79	7.78E–06	0.47	7.4E–07	10.8	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	80.74	85.74	5	–	10.81	3.92E–07	0.50	3.8E–08	–	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	85.73	90.73	5	–	10.79	1.71E–07	0.60	1.7E–08	–	30	8.1E–10	8.1E–10	8.1E–06	
KLX11C	90.74	95.74	5	–	10.82	3.33E–07	0.66	3.2E–08	–	30	8.1E–10	8.1E–10	8.1E–06	
KLX11C	95.74	100.74	5	–	10.87	–	0.73	–	–	30	8.1E–10	8.1E–10	8.1E–06	
KLX11C	100.76	105.76	5	–4.11E–08	10.89	3.75E–07	0.72	4.0E–08	9.9	30	8.1E–10	8.1E–10	8.1E–06	
KLX11C	105.75	110.75	5	–	10.89	–	0.54	–	–	30	8.0E–10	8.0E–10	8.0E–06	
KLX11C	110.73	115.73	5	–	10.90	–	0.46	–	–	30	7.9E–10	7.9E–10	7.9E–06	

* Q_1 value is from injection.

** Q_0 is evaluated to be zero since it is not measured in this section.

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
KLX11C	3.8	1	0.1	–	10.50	–1.98E–07	27.12	1.2E–08	–	*,**,***
KLX11C	5.4	1	0.1	–	10.50	–2.26E–06	27.18	1.3E–07	–	*,**,***
KLX11C	5.9	1	0.1	–	10.50	–1.51E–06	27.20	8.9E–08	–	*,**,***
KLX11C	8.2	1	0.1	–	10.50	–7.78E–05	27.24	4.6E–06	–	**,***
KLX11C	11.3	1	0.1	–	10.50	–1.09E–06	27.29	6.4E–08	–	**,***
KLX11C	11.7	1	0.1	–	10.50	–3.97E–06	27.30	2.3E–07	–	**,***
KLX11C	17.2	1	0.1	–	10.50	–2.58E–06	27.27	1.5E–07	–	**,***
KLX11C	19.3	1	0.1	–	10.50	–2.00E–08	27.27	1.2E–09	–	**,***
KLX11C	24.6	1	0.1	1.50E–08	10.50	–5.83E–07	27.27	3.5E–08	10.9	**
KLX11C	25.5	1	0.1	–	10.55	–2.68E–07	27.28	1.6E–08	–	*,**
KLX11C	26.8	1	0.1	2.83E–08	10.55	–3.89E–06	27.29	2.3E–07	10.7	**
KLX11C	28.3	1	0.1	2.78E–09	10.54	–1.32E–06	27.27	7.8E–08	10.6	**
KLX11C	29.6	1	0.1	–	10.50	–2.06E–07	27.26	1.2E–08	–	**
KLX11C	30.9	1	0.1	–	10.52	–8.89E–09	27.28	5.3E–10	–	*,**
KLX11C	32.9	1	0.1	–	10.53	–7.33E–08	27.26	4.3E–09	–	*,**
KLX11C	34.4	1	0.1	–	10.52	–2.22E–08	27.23	1.3E–09	–	*,**
KLX11C	37.0	1	0.1	–	10.52	3.83E–07	0.97	4.0E–08	–	
KLX11C	37.5	1	0.1	–	10.51	1.16E–07	0.98	1.2E–08	–	
KLX11C	40.3	1	0.1	–	10.50	1.77E–06	0.98	1.8E–07	–	
KLX11C	41.4	1	0.1	–	10.50	1.94E–07	0.98	2.0E–08	–	
KLX11C	45.1	1	0.1	–1.43E–07	10.54	7.08E–06	0.96	7.5E–07	10.4	
KLX11C	49.5	1	0.1	1.06E–08	10.57	1.59E–06	0.94	1.6E–07	10.6	
KLX11C	51.9	1	0.1	5.00E–09	10.58	2.07E–07	0.92	2.1E–08	10.8	
KLX11C	52.8	1	0.1	1.67E–08	10.59	2.57E–07	0.92	2.5E–08	11.3	
KLX11C	54.4	1	0.1	6.94E–08	10.60	2.26E–06	0.91	2.2E–07	10.9	
KLX11C	58.4	1	0.1	–	10.63	3.19E–08	0.89	3.2E–09	–	
KLX11C	64.3	1	0.1	–	10.62	8.83E–08	0.82	8.9E–09	–	
KLX11C	65.0	1	0.1	2.61E–08	10.61	8.89E–07	0.81	8.7E–08	10.9	
KLX11C	66.5	1	0.1	7.56E–08	10.63	3.33E–06	0.79	3.3E–07	10.9	
KLX11C	66.9	1	0.1	–	10.61	2.39E–08	0.80	2.4E–09	–	*
KLX11C	70.1	1	0.1	–	10.64	9.44E–09	0.76	9.5E–10	–	
KLX11C	71.4	1	0.1	2.22E–09	10.65	5.78E–07	0.75	5.8E–08	10.7	
KLX11C	73.1	1	0.1	–	10.66	7.78E–09	0.74	7.8E–10	–	*
KLX11C	75.2	1	0.1	–	10.68	6.67E–09	0.73	6.6E–10	–	*
KLX11C	76.6	1	0.1	4.44E–09	10.67	2.94E–06	0.75	2.9E–07	10.7	
KLX11C	77.3	1	0.1	6.11E–09	10.66	5.42E–06	0.75	5.4E–07	10.7	
KLX11C	81.9	1	0.1	–	10.69	4.08E–07	0.70	4.0E–08	–	
KLX11C	84.8	1	0.1	–	10.70	1.52E–07	0.66	1.5E–08	–	
KLX11C	87.5	1	0.1	–3.44E–08	10.78	8.67E–08	0.69	1.2E–08	7.9	
KLX11C	93.8	1	0.1	–	10.81	3.25E–07	0.77	3.2E–08	–	
KLX11C	102.3	1	0.1	–3.89E–08	10.82	3.50E–07	0.88	3.9E–08	9.8	

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

** Q_1 value is from injection.

*** Q_0 is evaluated to be zero since it is not measured in this section.

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.

Explanations

Header	Unit	Explanations
s_1	m	Drawdown of the water level in the borehole during first pumping period. Difference between the actual hydraulic head and the initial head ($s_1=h_1–h_0$).
s_2	m	Drawdown of the water level in the borehole during second pumping period. Difference between the actual hydraulic head and the initial head ($s_2=h_2–h_0$).
T	m^2/s	Transmissivity of the entire borehole.
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with $h=h_0$ in the open borehole.
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period.
Q_2	m^3/s	Measured flow rate through the test section or flow anomaly during the second pumping period.
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid before pumping.
h_{1FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period.
h_{2FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the second pumping period.
EC_w	S/m	Measured electric conductivity of the borehole fluid in the test section during difference flow logging.
Te_w	°C	Measured borehole fluid temperature in the test section during difference flow logging.
EC_f	S/m	Measured fracture-specific electric conductivity of the fluid in flow anomaly during difference flow logging.
Te_f	°C	Measured fracture-specific fluid temperature in flow anomaly during difference flow logging.
T_D	m^2/s	Transmissivity of section or flow anomaly based on 2D model for evaluation of formation properties of the test section based on PFL-DIFF.
T-measl$_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-measl$_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-measl$_U$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

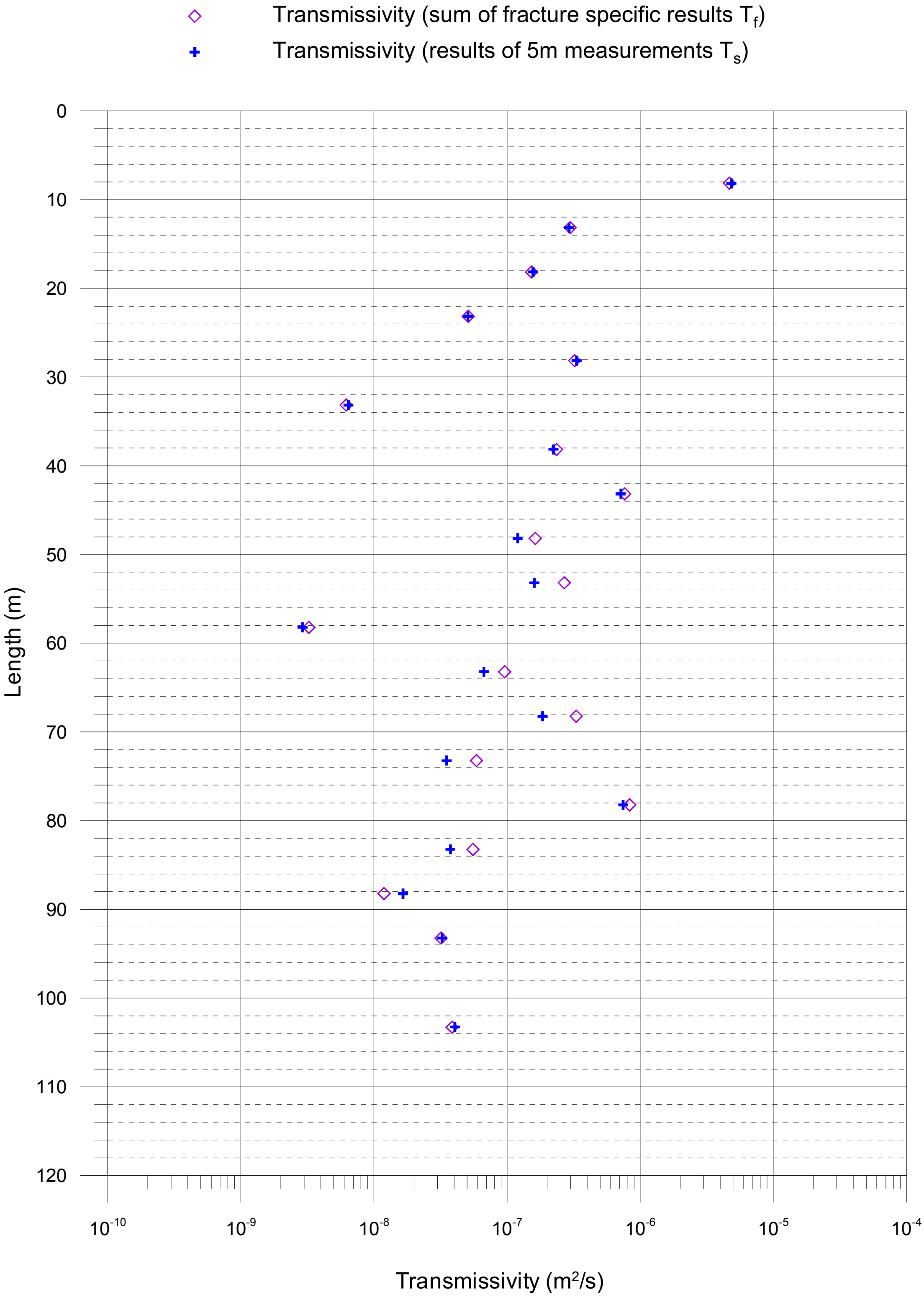
Calculation of conductive fracture frequency

Borehole ID	SecUp (m)	SecLow (m)	Number of fractures, total	Number of fractures 10–100 (mL/h)	Number of fractures 100–1,000 (mL/h)	Number of fractures 1,000–10,000 (mL/h)	Number of fractures 10,000–100,000 (mL/h)	Number of fractures 100,000–1,000,000 (mL/h)
KLX11C	5.66	10.66	4	0	1*	2*	0	1*
KLX11C	10.66	15.66	2	0	1*	1*	0	0
KLX11C	15.66	20.66	2	1*	0	1*	0	0
KLX11C	20.66	25.66	2	0	1*	1*	0	0
KLX11C	25.66	30.66	3	0	1*	1*	1*	0
KLX11C	30.66	35.66	3	2*	1*	0	0	0
KLX11C	35.66	40.66	3	0	1	2	0	0
KLX11C	40.67	45.67	2	0	1	0	1	0
KLX11C	45.69	50.69	1	0	0	1	0	0
KLX11C	50.70	55.70	3	0	2	1	0	0
KLX11C	55.71	60.71	1	0	1	0	0	0
KLX11C	60.72	65.72	2	0	1	1	0	0
KLX11C	65.73	70.73	3	2	0	0	1	0
KLX11C	70.73	75.73	3	2	0	1	0	0
KLX11C	75.72	80.72	2	0	0	0	2	0
KLX11C	80.74	85.74	2	0	1	1	0	0
KLX11C	85.73	90.73	1	0	1	0	0	0
KLX11C	90.74	95.74	1	0	0	1	0	0
KLX11C	95.74	100.74	0	0	0	0	0	0
KLX11C	100.76	105.76	1	0	0	1	0	0
KLX11C	105.75	110.75	0	0	0	0	0	0
KLX11C	110.73	115.73	0	0	0	0	0	0

* During Injection (drawdown not the same as in the other measurements).

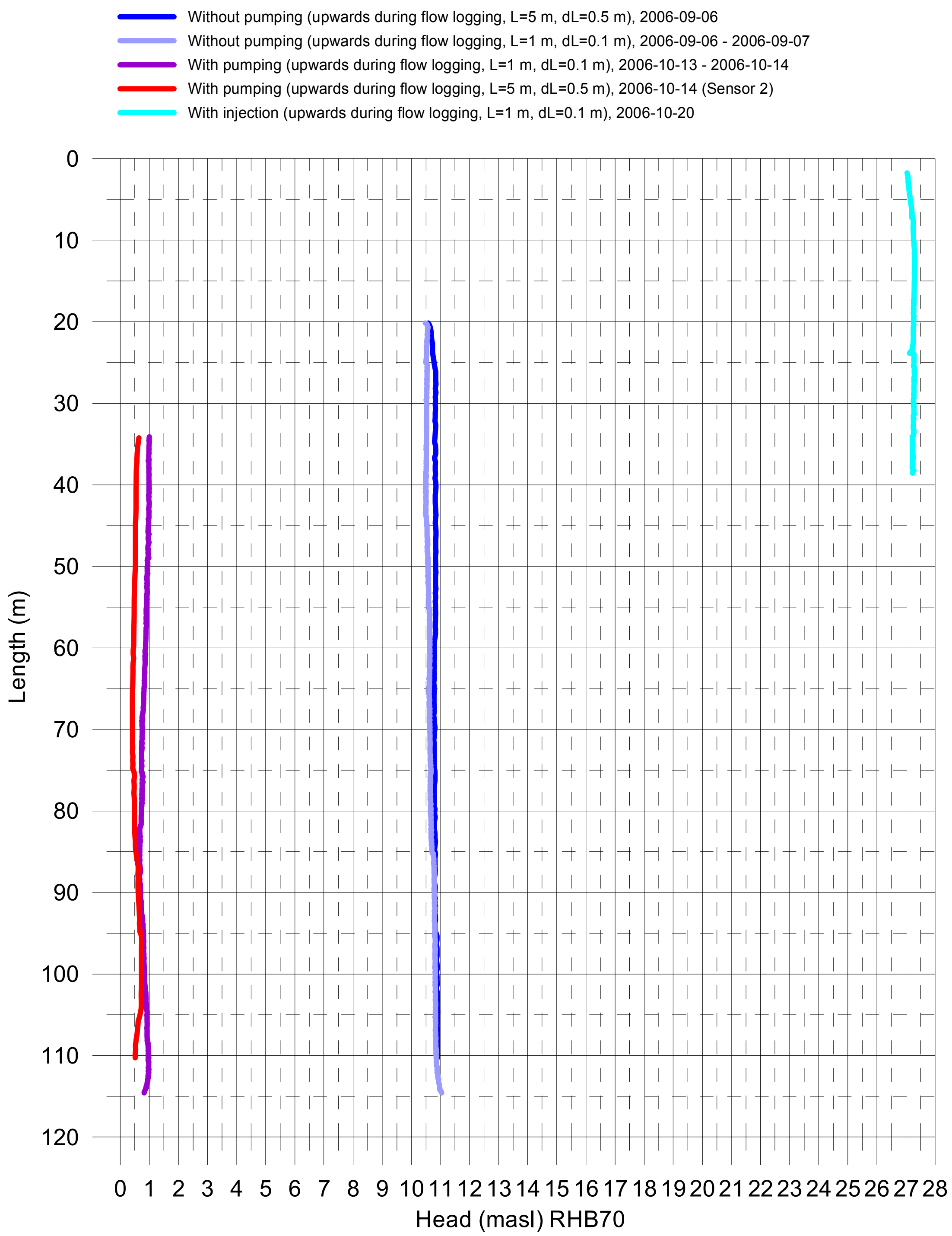
Laxemar, borehole KLX11C
Calculation of conductive fracture frequency

Laxemar, borehole KLX11C
Comparison between section transmissivity and fracture transmissivity

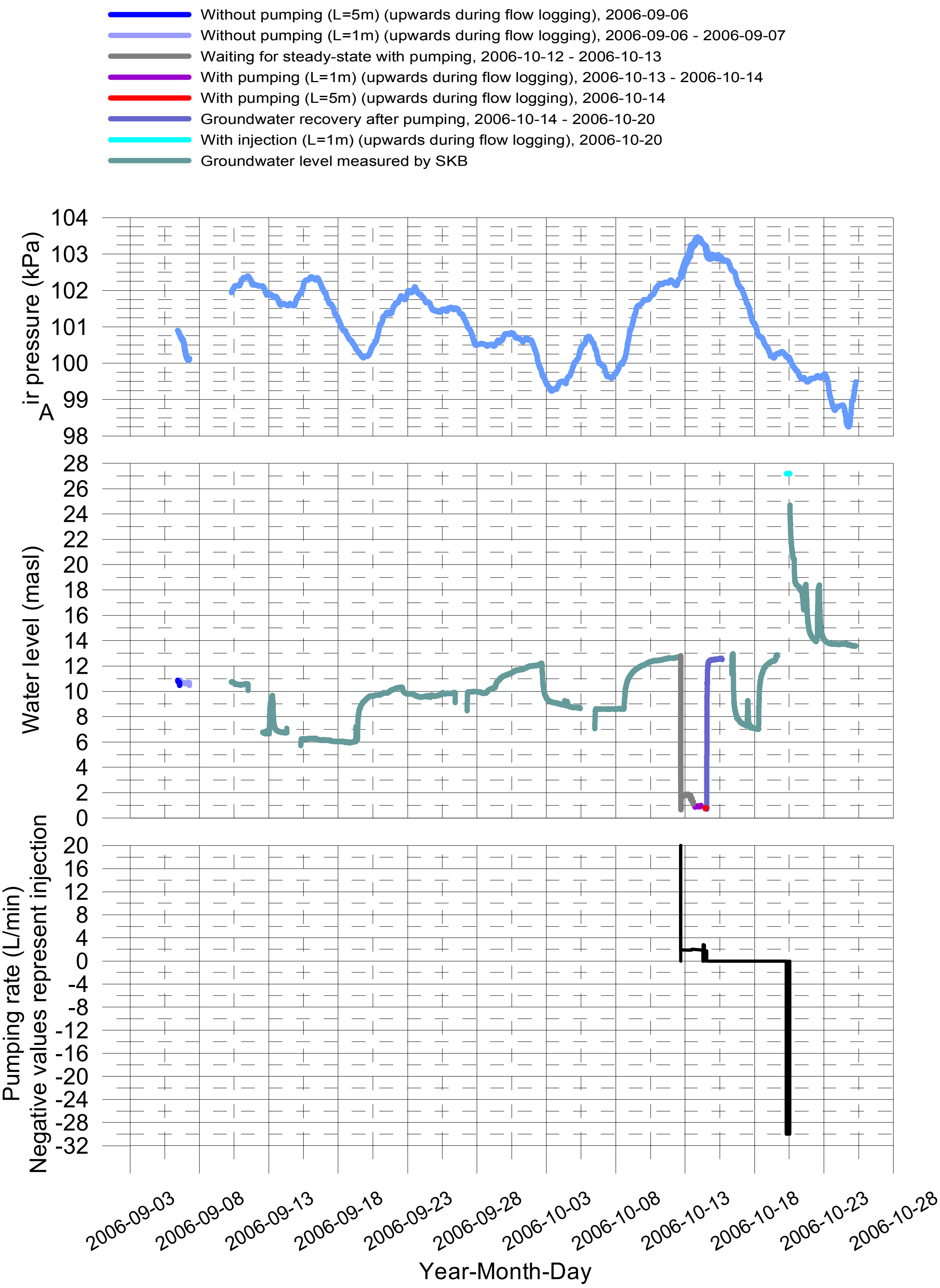


Laxemar, borehole KLX11C
Head in the borehole during flow logging

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)

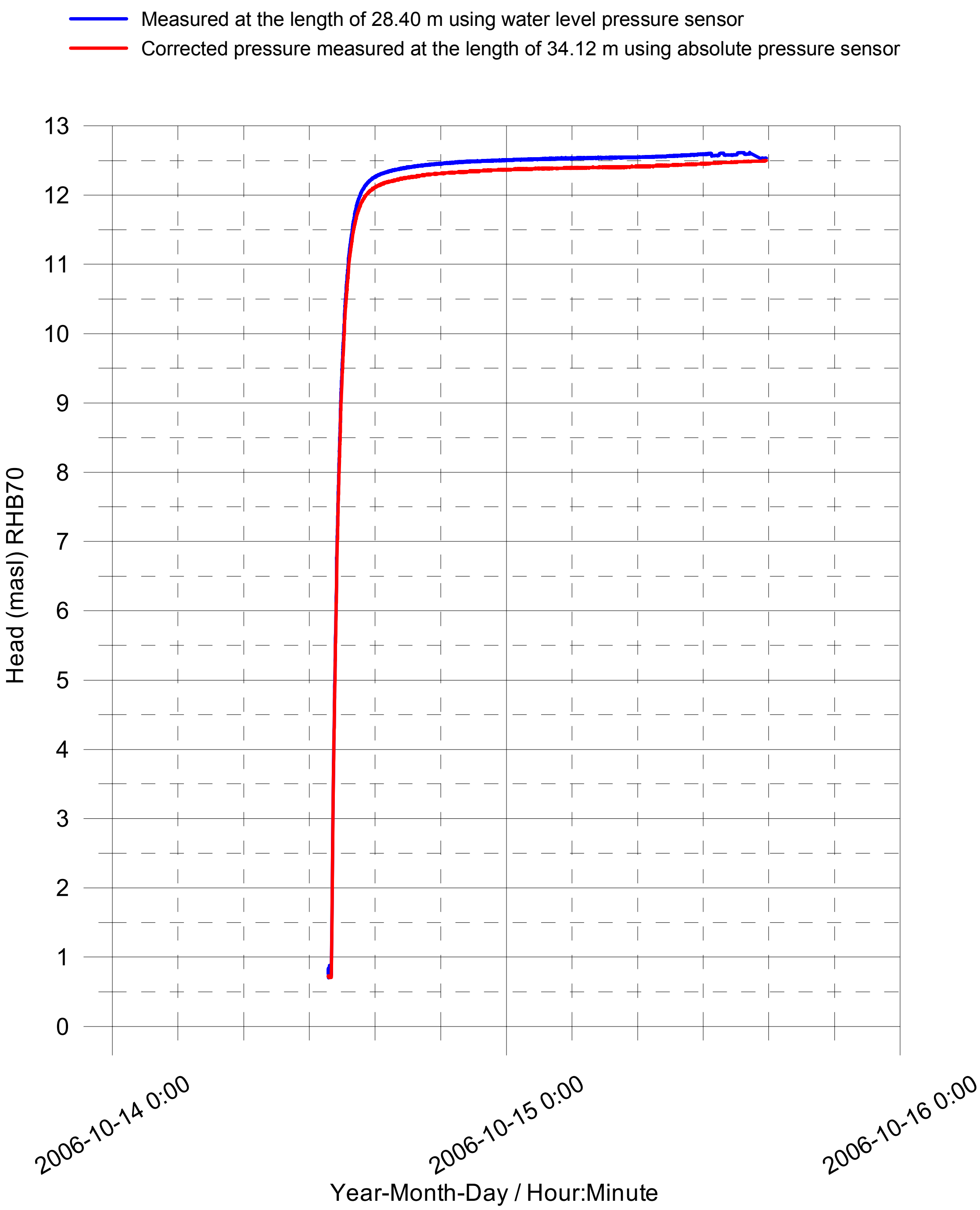


Laxemar, borehole KLX11C
Air pressure, water level in the borehole and pumping rate during flow logging



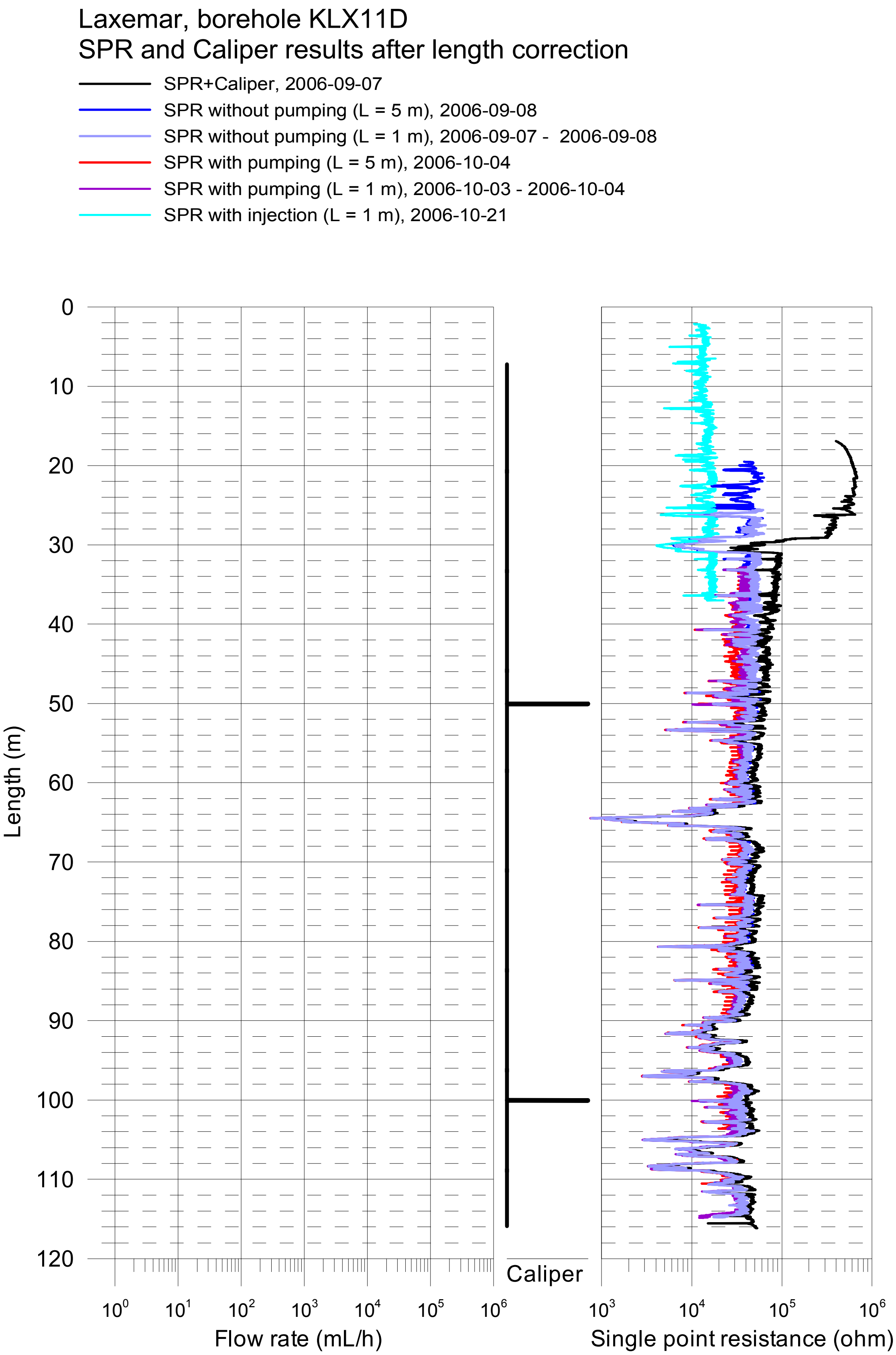
Laxemar, borehole KLX11C
Groundwater recovery after pumping

Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2300 Pa (Correction for absolut pressure sensor)

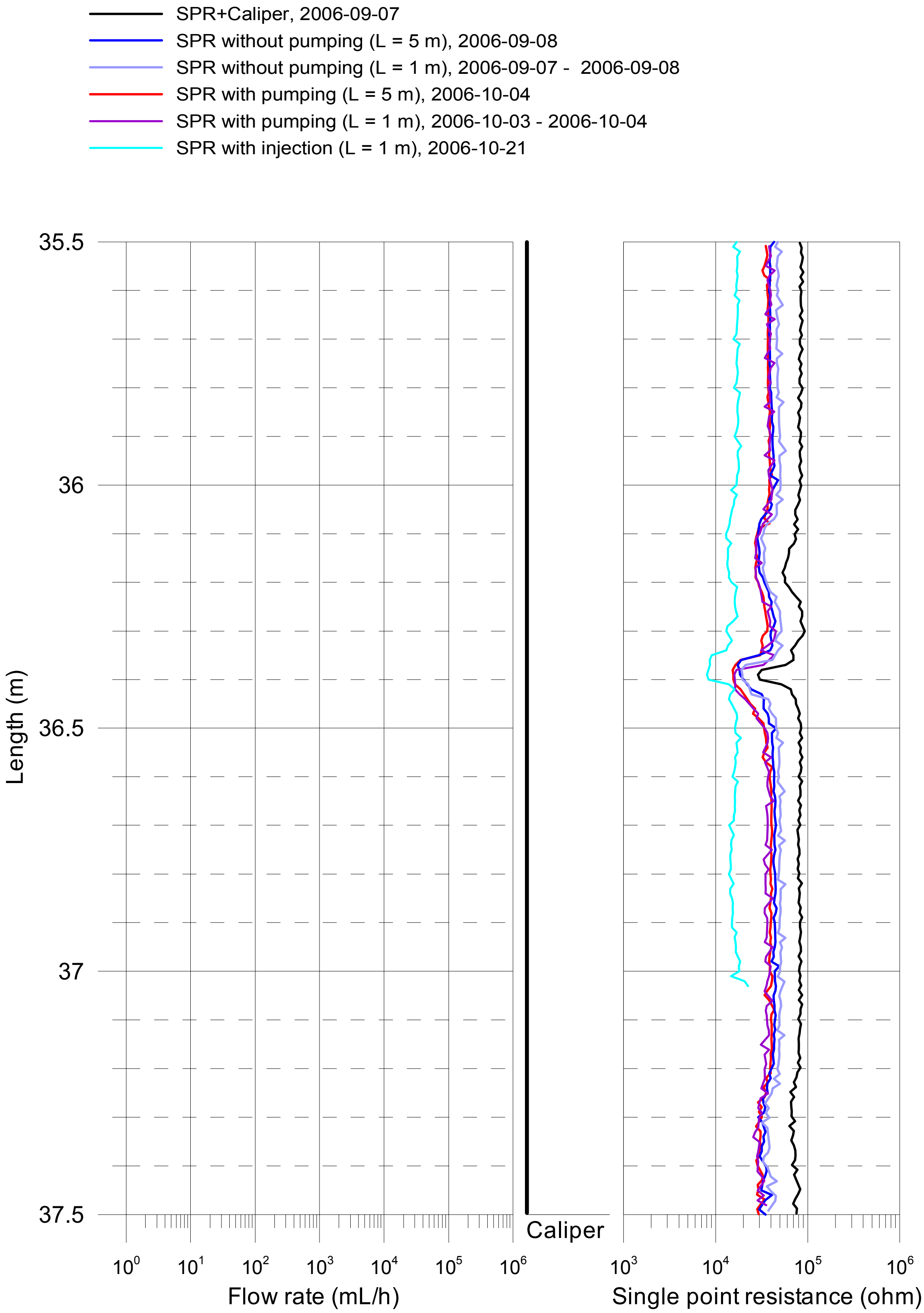


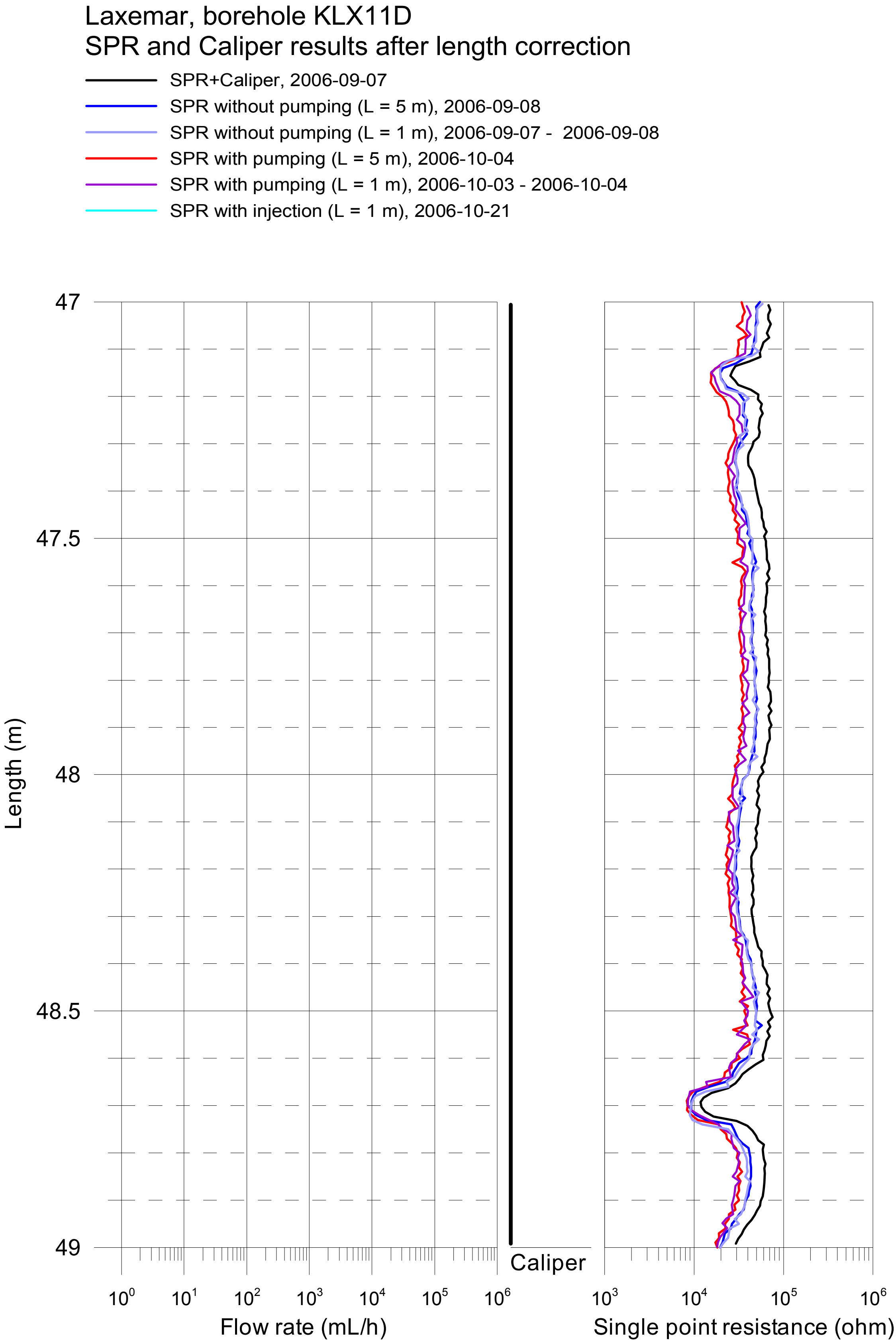
Appendices, KLX11D

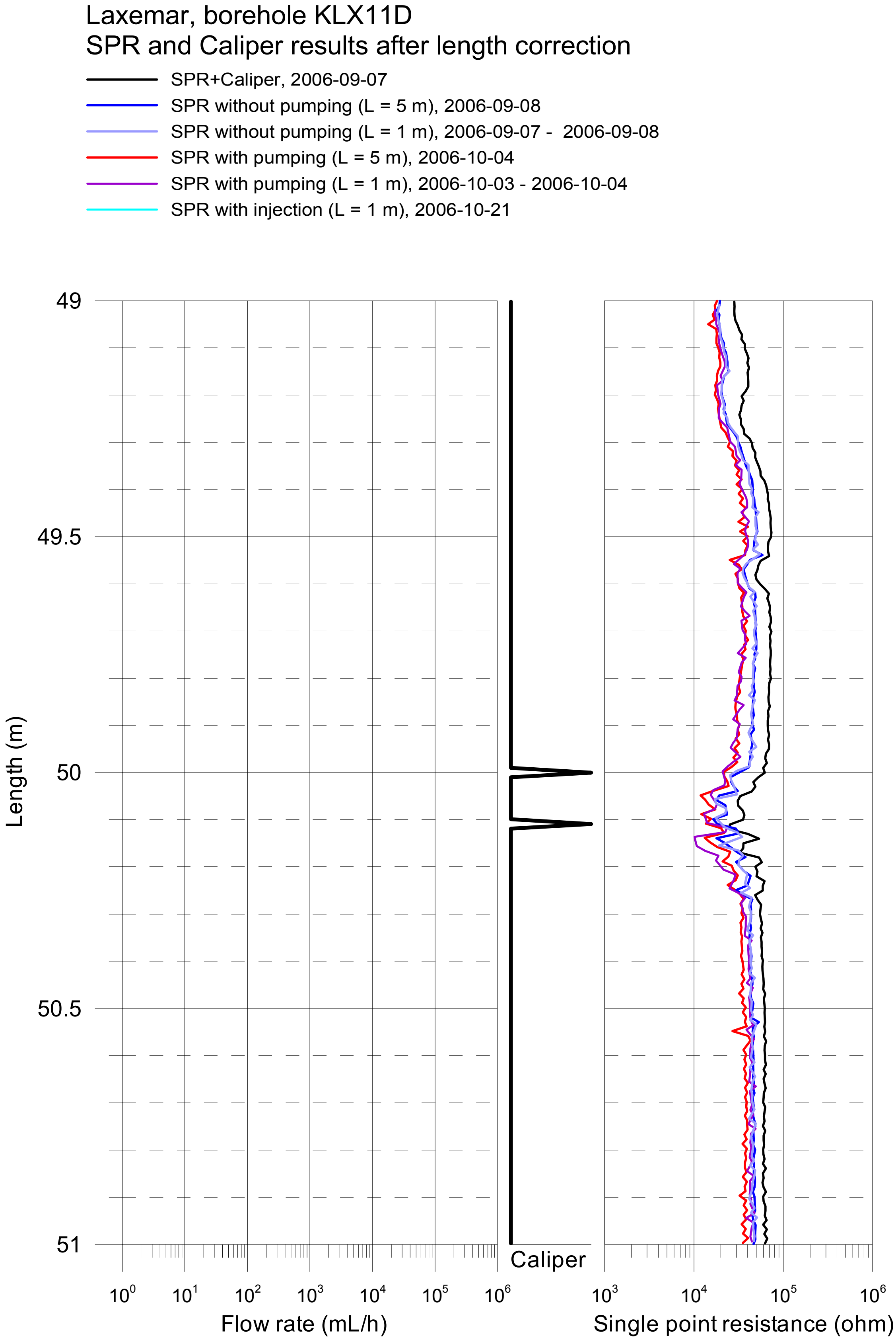
Appendices	D.1.1–D.1.9	SPR and Caliper results after length correction
Appendix	D.1.10	Length correction
Appendices	D.2.1–D.2.6	Flow rate, Caliper and Single point resistance
Appendix	D.3.1	Electric conductivity of borehole water
Appendix	D.3.2	Temperature of borehole water
Appendix	D.4.1	Plotted flow rates of 5 m sections
Appendix	D.4.2	Plotted transmissivity and head of 5 m sections
Appendix	D.5	Plotted transmissivity and head of detected fractures
Appendix	D.6	Basic test data
Appendix	D.7	Results of sequential flow logging
Appendix	D.8	Inferred flow anomalies from overlapping flow logging
Appendix	D.9	Explanations for the tables in Appendices 6–8
Appendix	D.10	Conductive fracture frequency
Appendix	D.11	Plotted conductive fracture frequency
Appendix	D.12	Comparison between section transmissivity and fracture transmissivity
Appendix	D.13	Head in the borehole during flow logging
Appendix	D.14	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	D.15	Groundwater recovery after pumping


Laxemar, borehole KLX11D
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-08
SPR without pumping (L = 1 m), 2006-09-07 - 2006-09-08
SPR with pumping (L = 5 m), 2006-10-04
SPR with pumping (L = 1 m), 2006-10-03 - 2006-10-04
SPR with injection (L = 1 m), 2006-10-21
Length (m)
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

Laxemar, borehole KLX11D
SPR and Caliper results after length correction

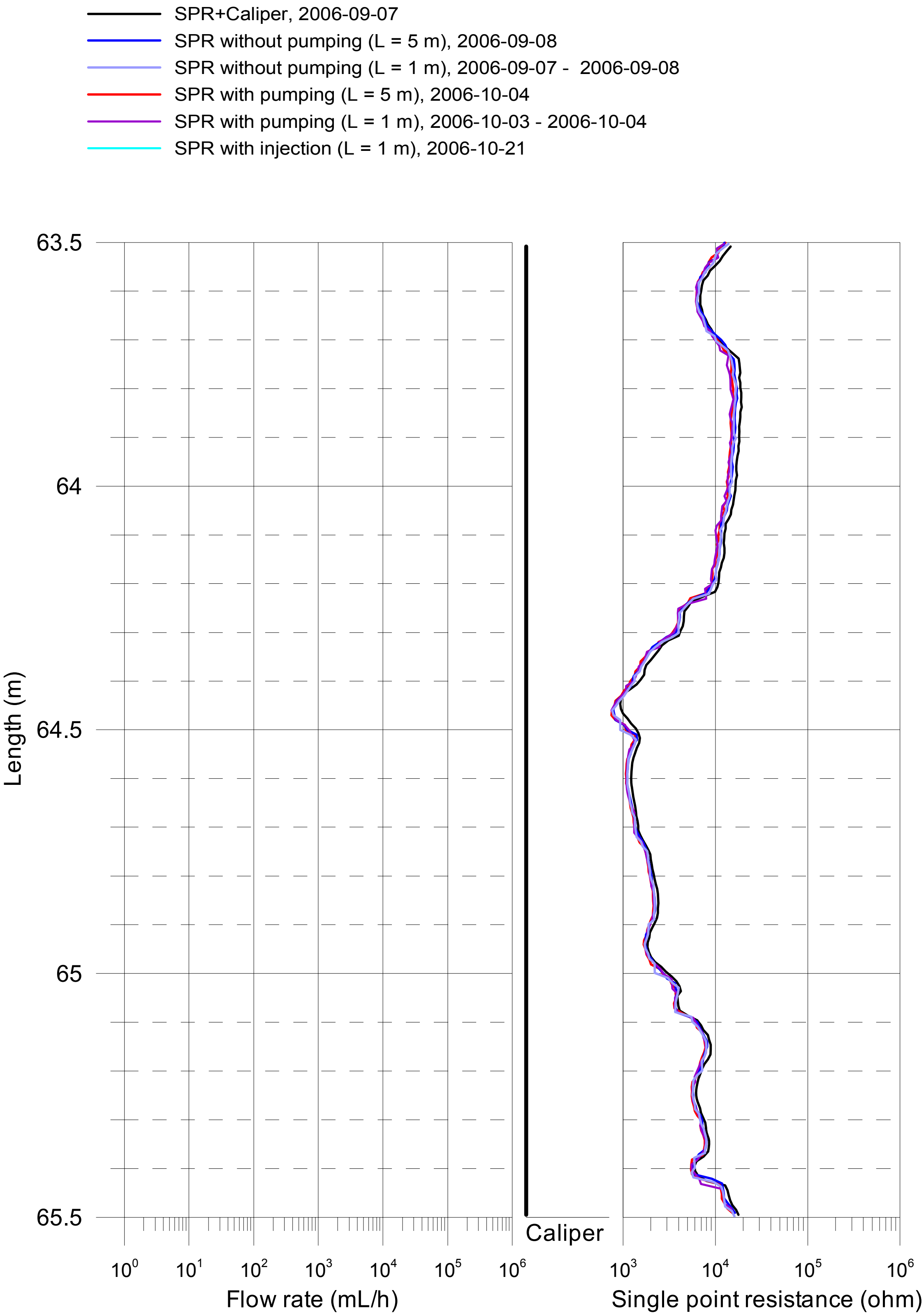



Laxemar, borehole KLX11D
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-08
SPR without pumping (L = 1 m), 2006-09-07 - 2006-09-08
SPR with pumping (L = 5 m), 2006-10-04
SPR with pumping (L = 1 m), 2006-10-03 - 2006-10-04
SPR with injection (L = 1 m), 2006-10-21
Length (m)
47
47.5
48
48.5
49
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

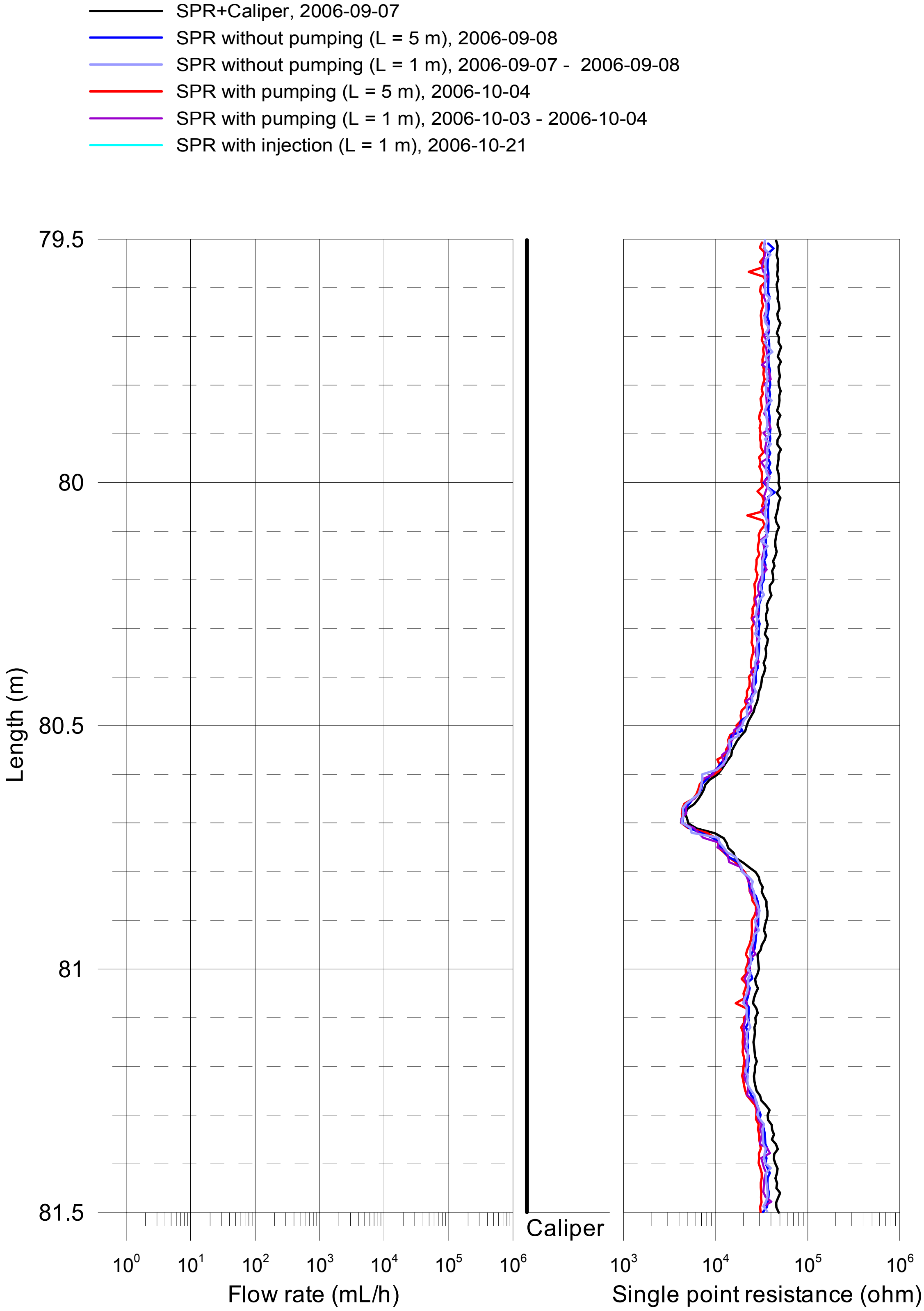


Laxemar, borehole KLX11D
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-08
SPR without pumping (L = 1 m), 2006-09-07 - 2006-09-08
SPR with pumping (L = 5 m), 2006-10-04
SPR with pumping (L = 1 m), 2006-10-03 - 2006-10-04
SPR with injection (L = 1 m), 2006-10-21
Length (m)
49
49.5
50
50.5
51
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)

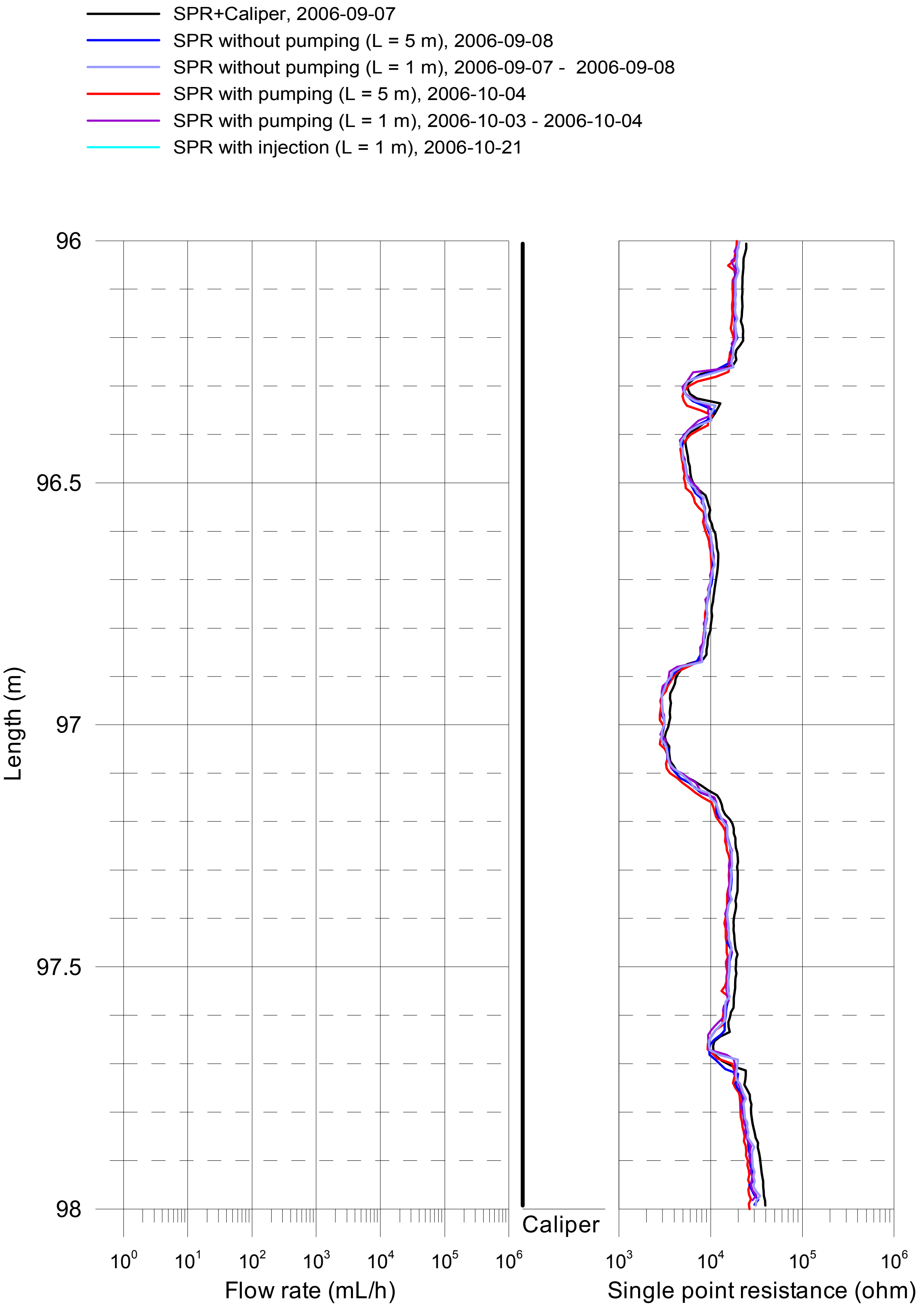
Laxemar, borehole KLX11D
SPR and Caliper results after length correction



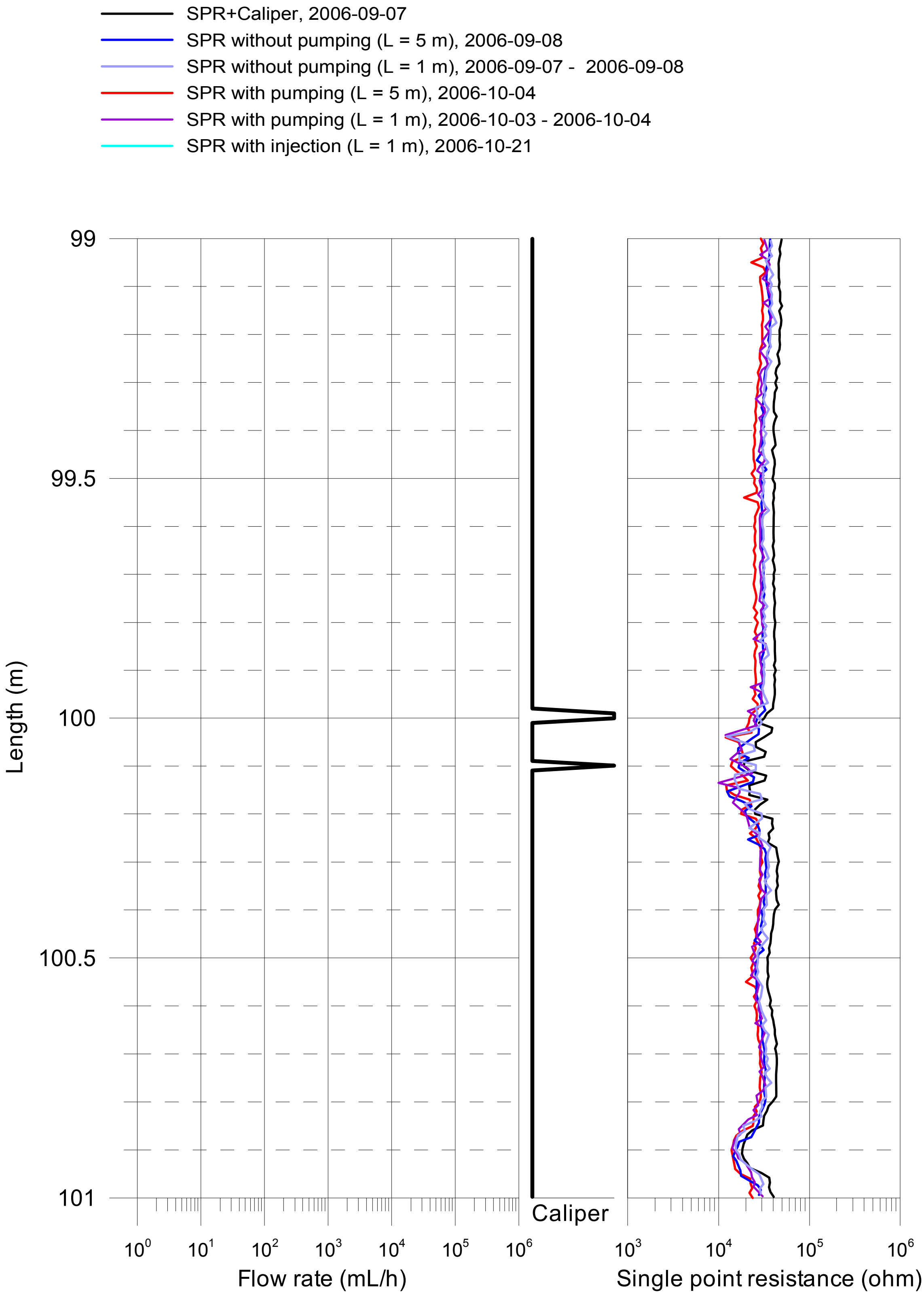
Laxemar, borehole KLX11D
SPR and Caliper results after length correction

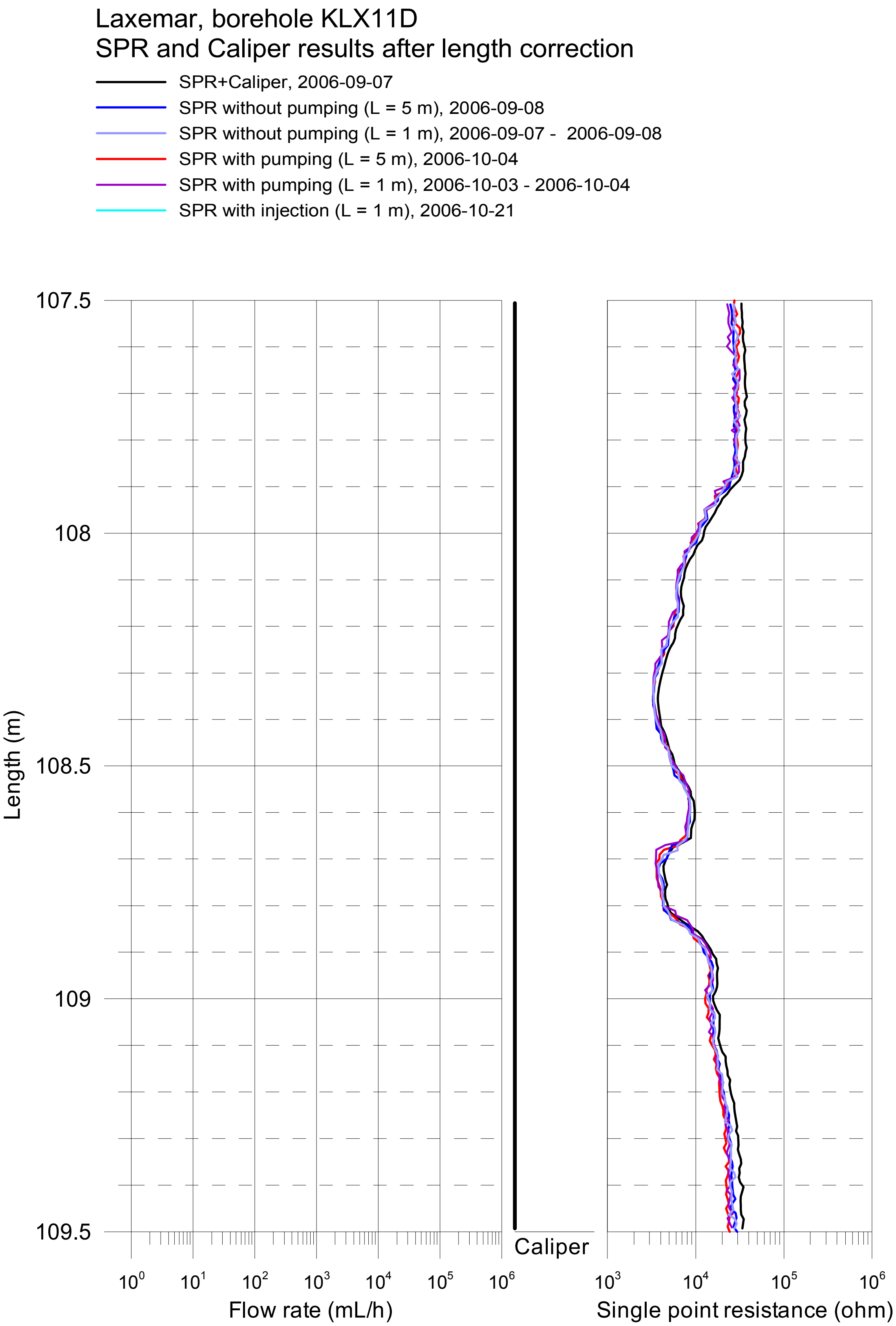


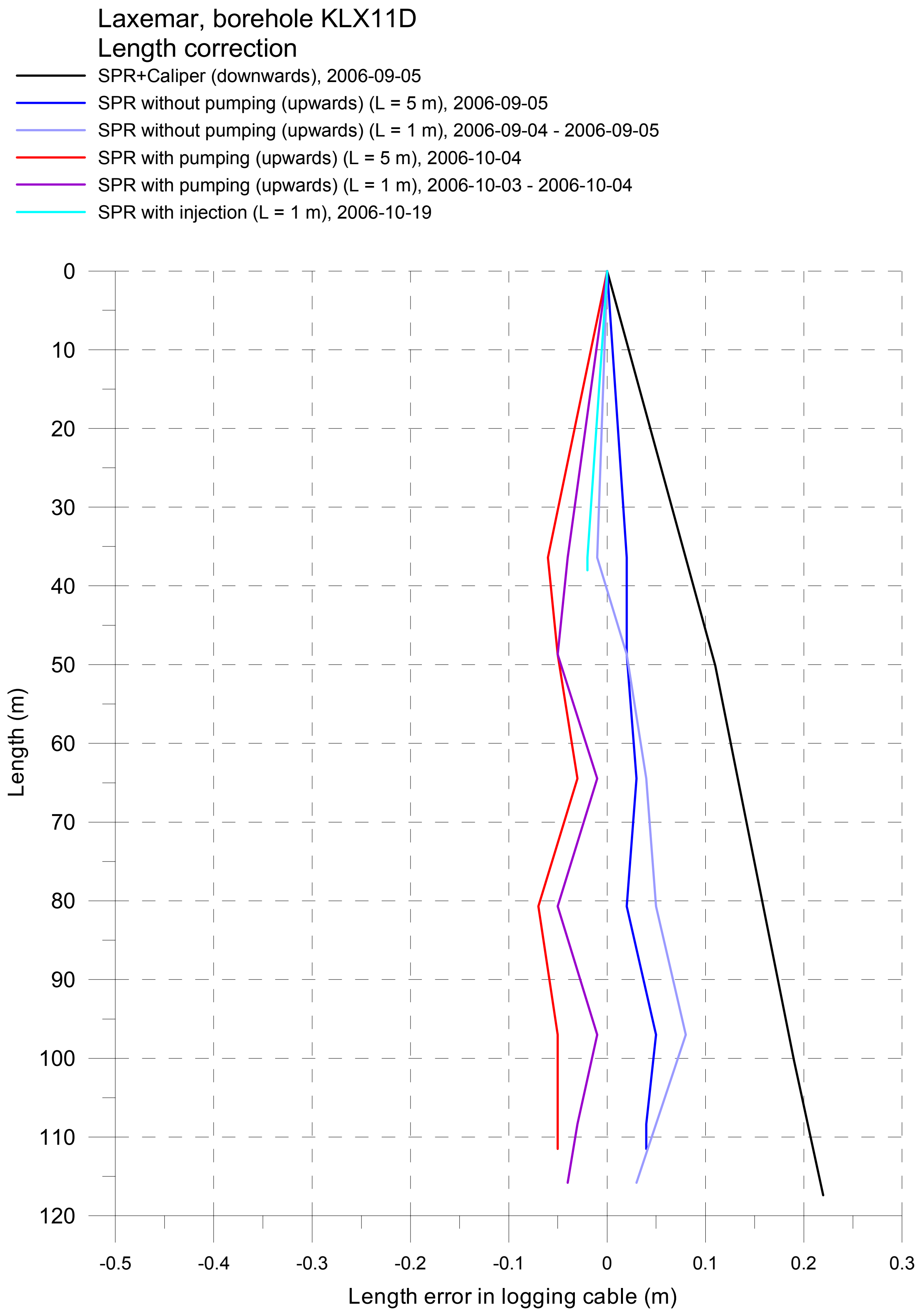
Laxemar, borehole KLX11D
SPR and Caliper results after length correction

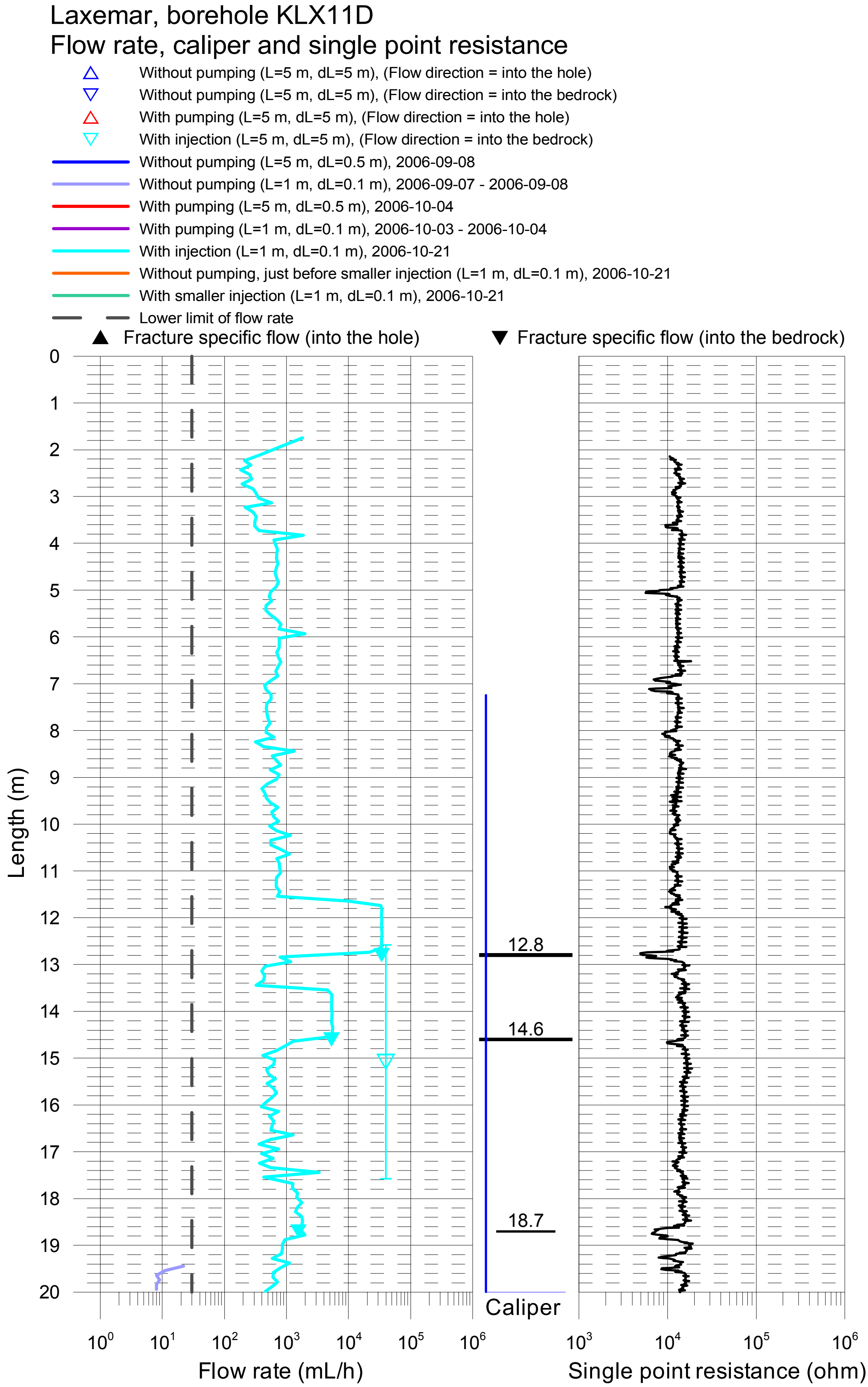


Laxemar, borehole KLX11D
SPR and Caliper results after length correction

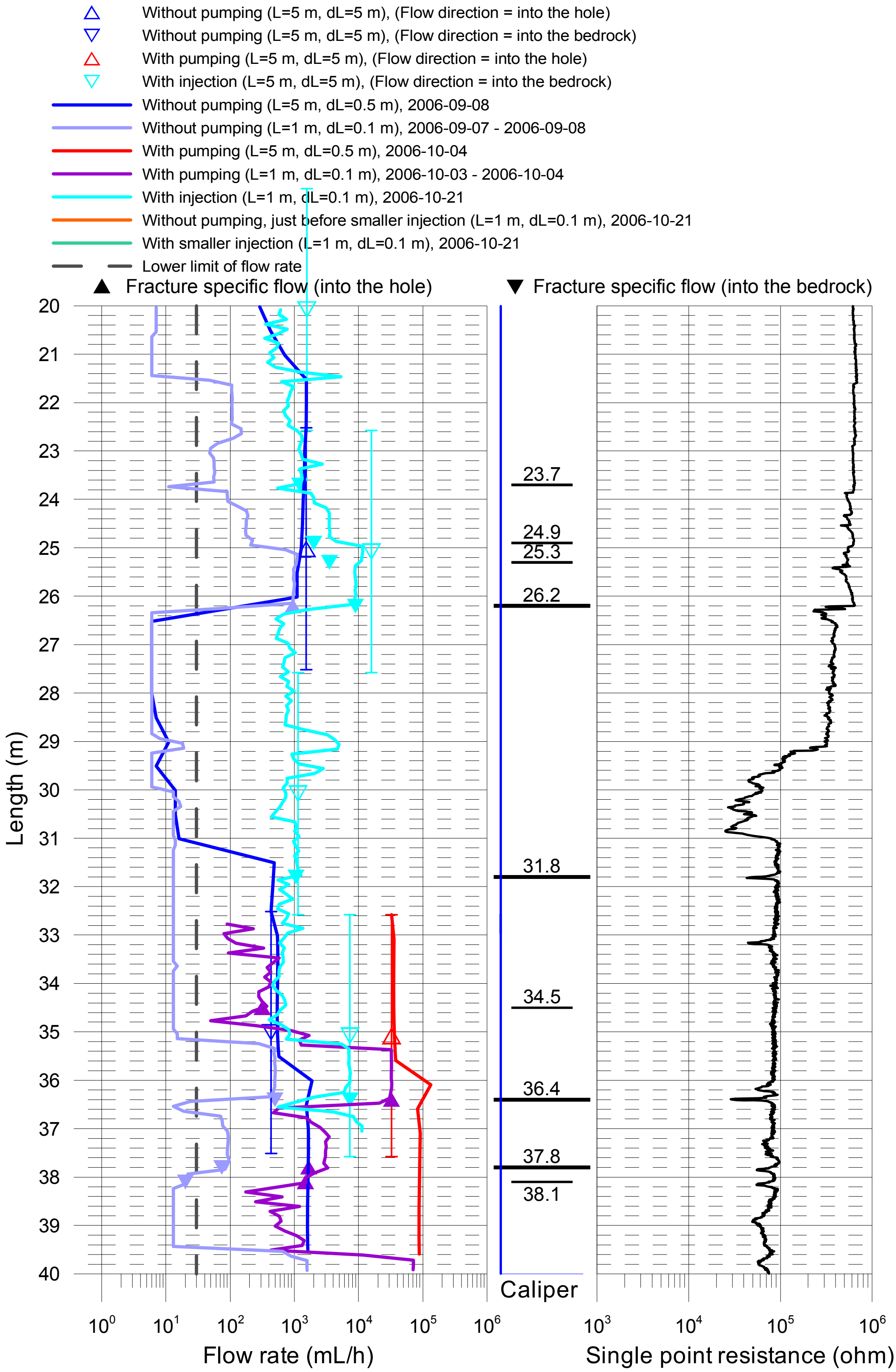


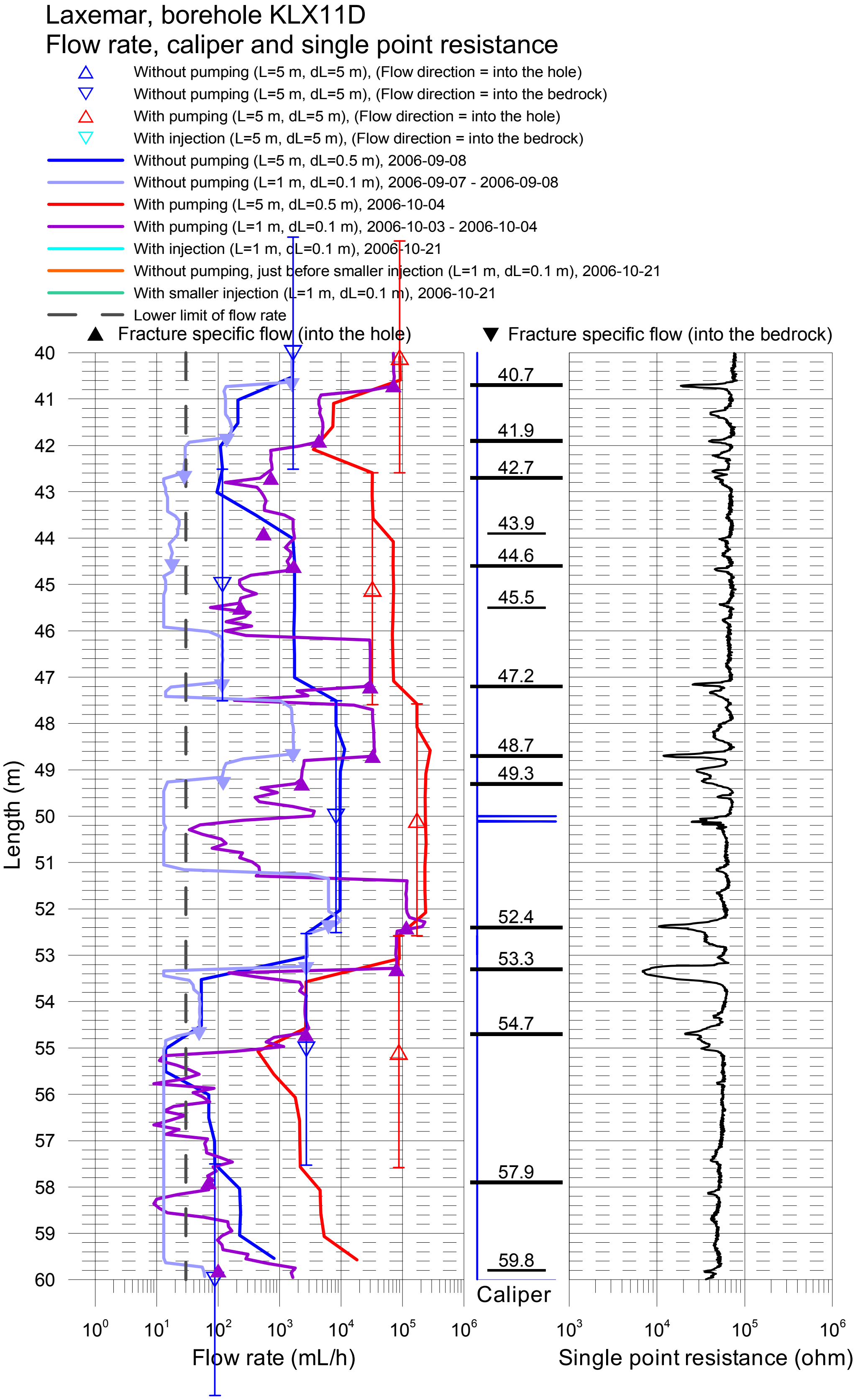

Laxemar, borehole KLX11D
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-07
SPR without pumping (L = 5 m), 2006-09-08
SPR without pumping (L = 1 m), 2006-09-07 - 2006-09-08
SPR with pumping (L = 5 m), 2006-10-04
SPR with pumping (L = 1 m), 2006-10-03 - 2006-10-04
SPR with injection (L = 1 m), 2006-10-21
Length (m)
107.5
108
108.5
109
109.5
Caliper
Flow rate (mL/h)
Single point resistance (ohm)


Laxemar, borehole KLX11D
Length correction
SPR+Caliper (downwards), 2006-09-05
SPR without pumping (upwards) (L = 5 m), 2006-09-05
SPR without pumping (upwards) (L = 1 m), 2006-09-04 - 2006-09-05
SPR with pumping (upwards) (L = 5 m), 2006-10-04
SPR with pumping (upwards) (L = 1 m), 2006-10-03 - 2006-10-04
SPR with injection (L = 1 m), 2006-10-19
Length (m)
Length error in logging cable (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3

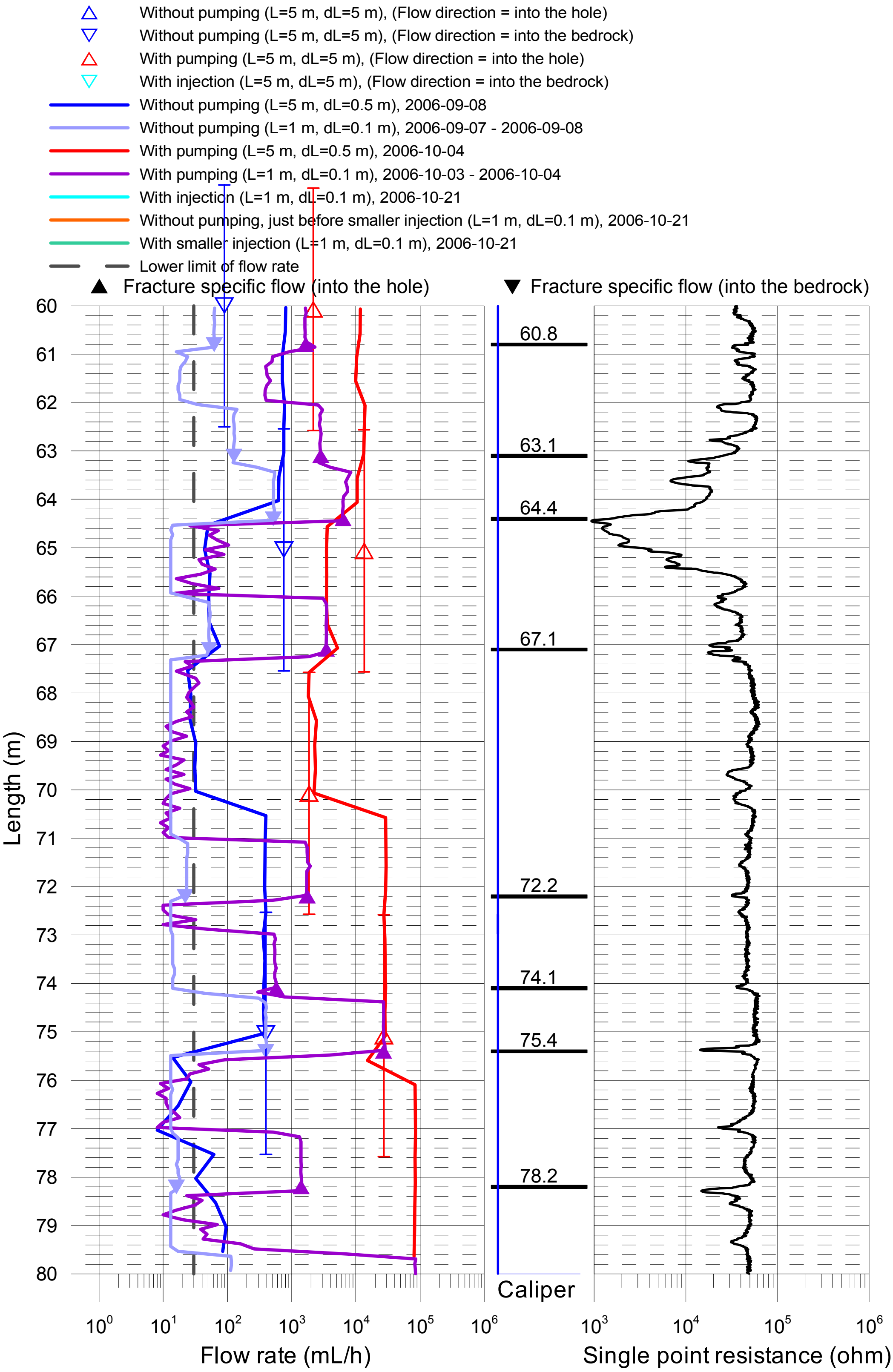

Laxemar, borehole KLX11D
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-08
Without pumping (L=1 m, dL=0.1 m), 2006-09-07 - 2006-09-08
With pumping (L=5 m, dL=0.5 m), 2006-10-04
With pumping (L=1 m, dL=0.1 m), 2006-10-03 - 2006-10-04
With injection (L=1 m, dL=0.1 m), 2006-10-21
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-21
With smaller injection (L=1 m, dL=0.1 m), 2006-10-21
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
12.8
14.6
18.7
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)

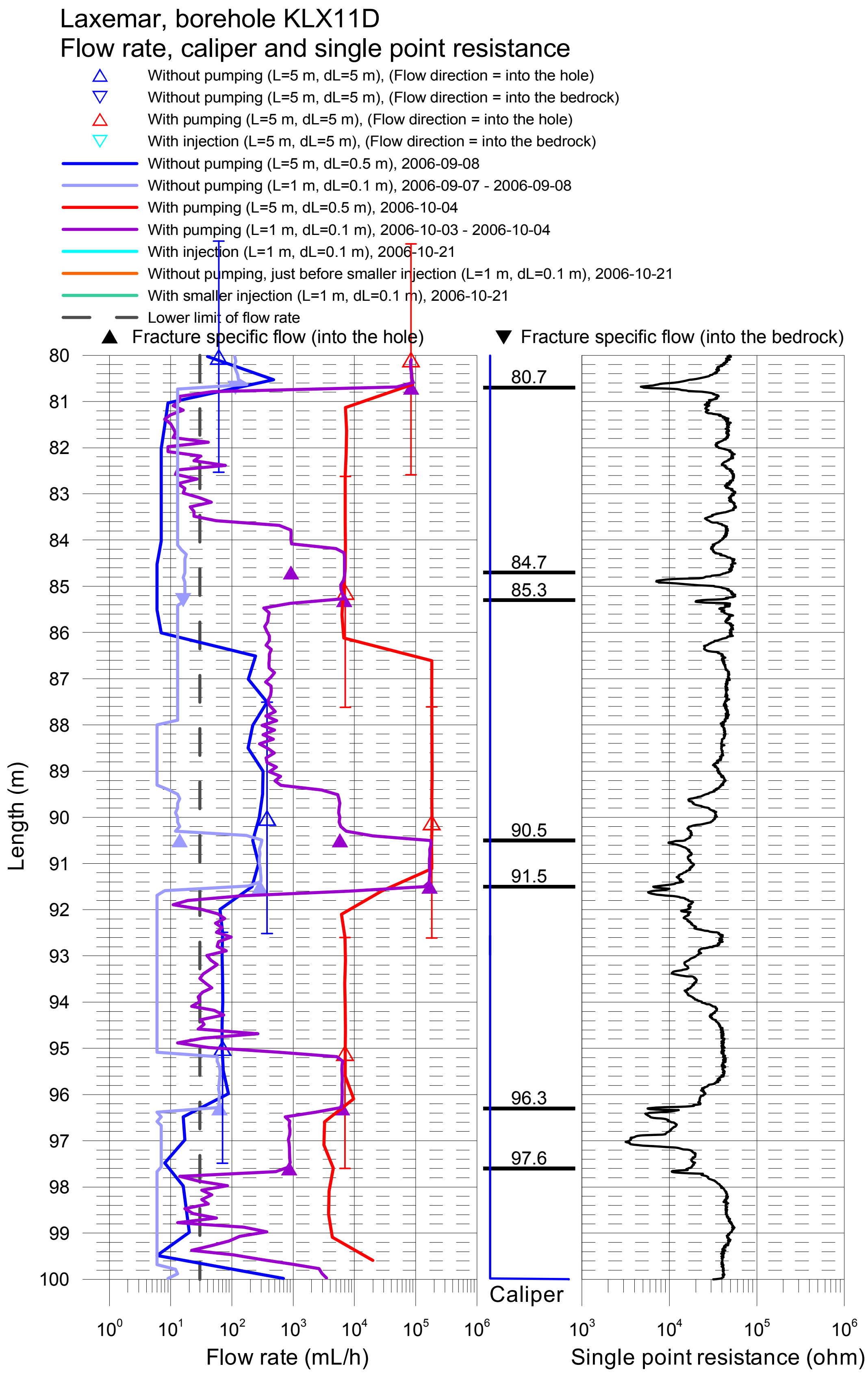
Laxemar, borehole KLX11D
Flow rate, caliper and single point resistance



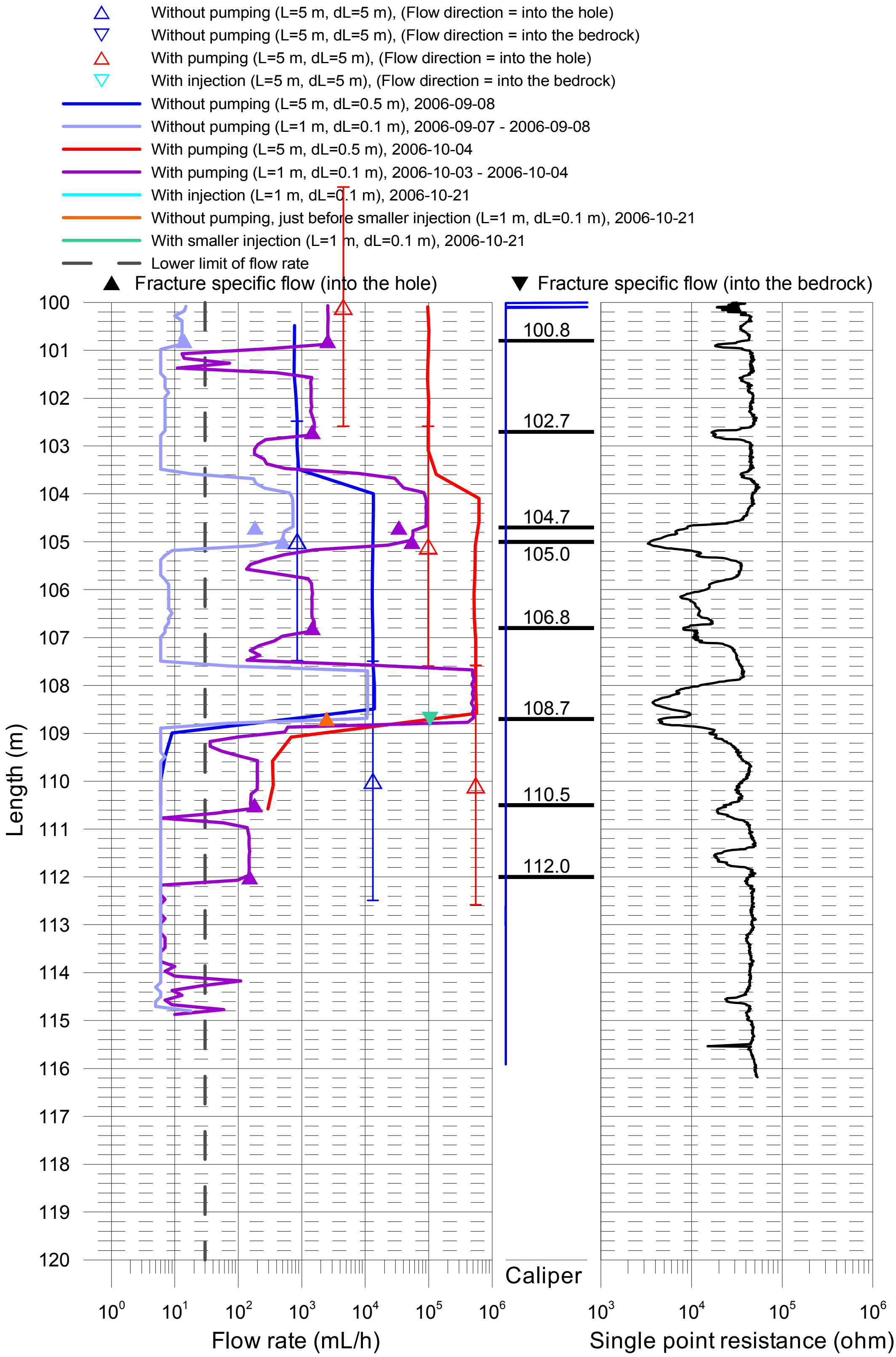

Laxemar, borehole KLX11D
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-08
Without pumping (L=1 m, dL=0.1 m), 2006-09-07 - 2006-09-08
With pumping (L=5 m, dL=0.5 m), 2006-10-04
With pumping (L=1 m, dL=0.1 m), 2006-10-03 - 2006-10-04
With injection (L=1 m, dL=0.1 m), 2006-10-21
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-21
With smaller injection (L=1 m, dL=0.1 m), 2006-10-21
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
40.7
41.9
42.7
43.9
44.6
45.5
47.2
48.7
49.3
52.4
53.3
54.7
57.9
59.8
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

Laxemar, borehole KLX11D
Flow rate, caliper and single point resistance

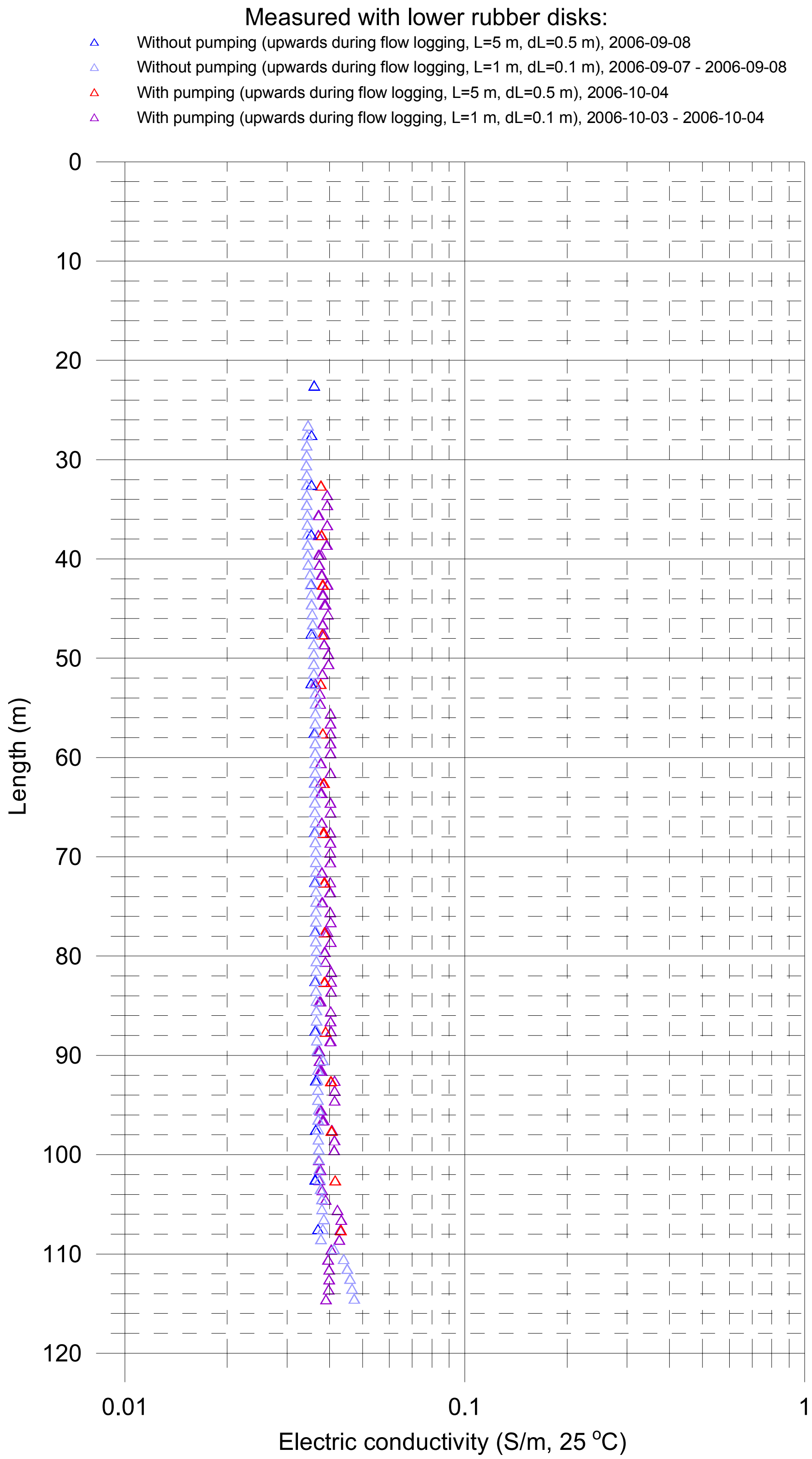



Laxemar, borehole KLX11D
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-08
Without pumping (L=1 m, dL=0.1 m), 2006-09-07 - 2006-09-08
With pumping (L=5 m, dL=0.5 m), 2006-10-04
With pumping (L=1 m, dL=0.1 m), 2006-10-03 - 2006-10-04
With injection (L=1 m, dL=0.1 m), 2006-10-21
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-21
With smaller injection (L=1 m, dL=0.1 m), 2006-10-21
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
80.7
84.7
85.3
90.5
91.5
96.3
97.6
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)

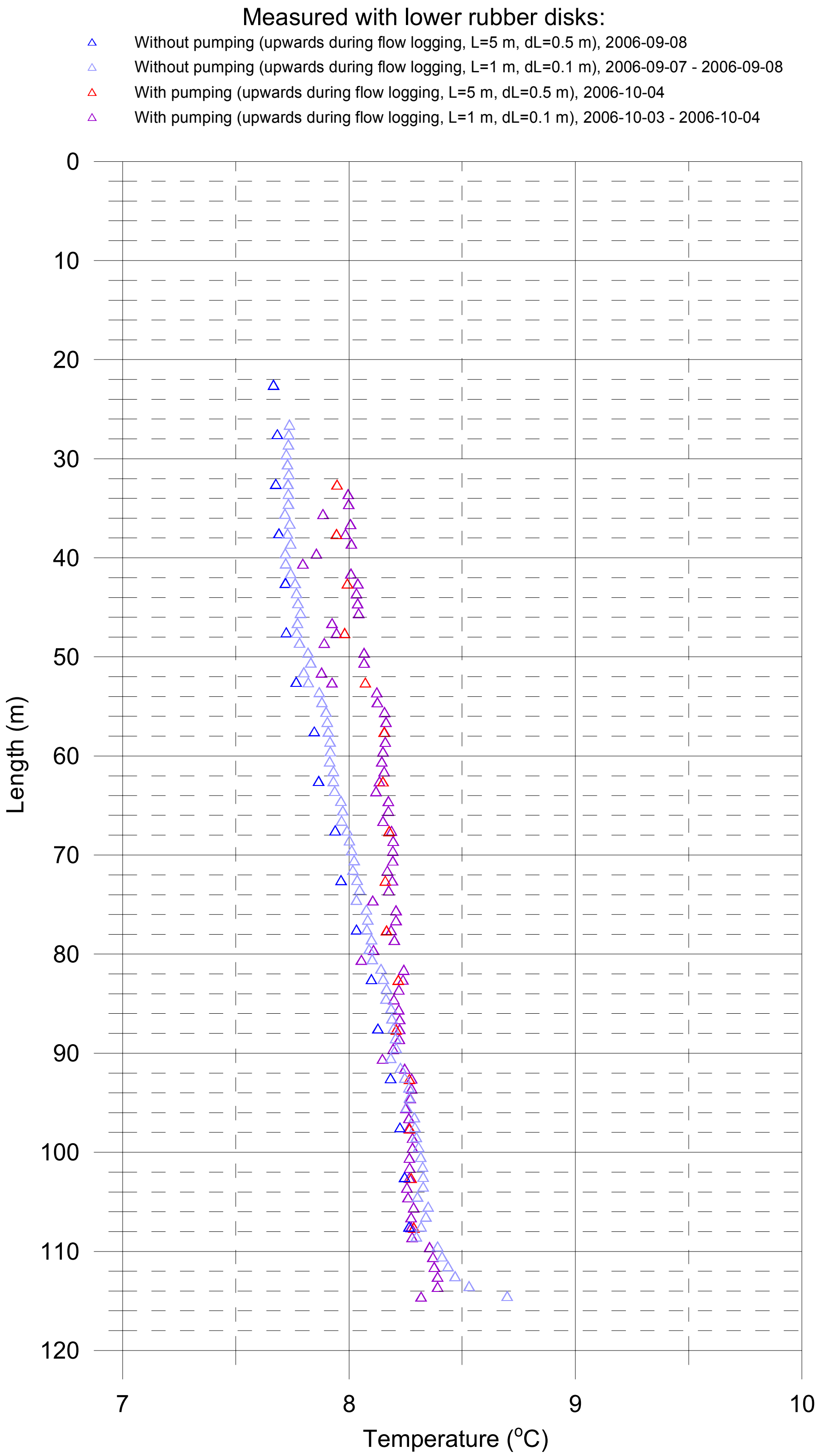
Laxemar, borehole KLX11D
Flow rate, caliper and single point resistance

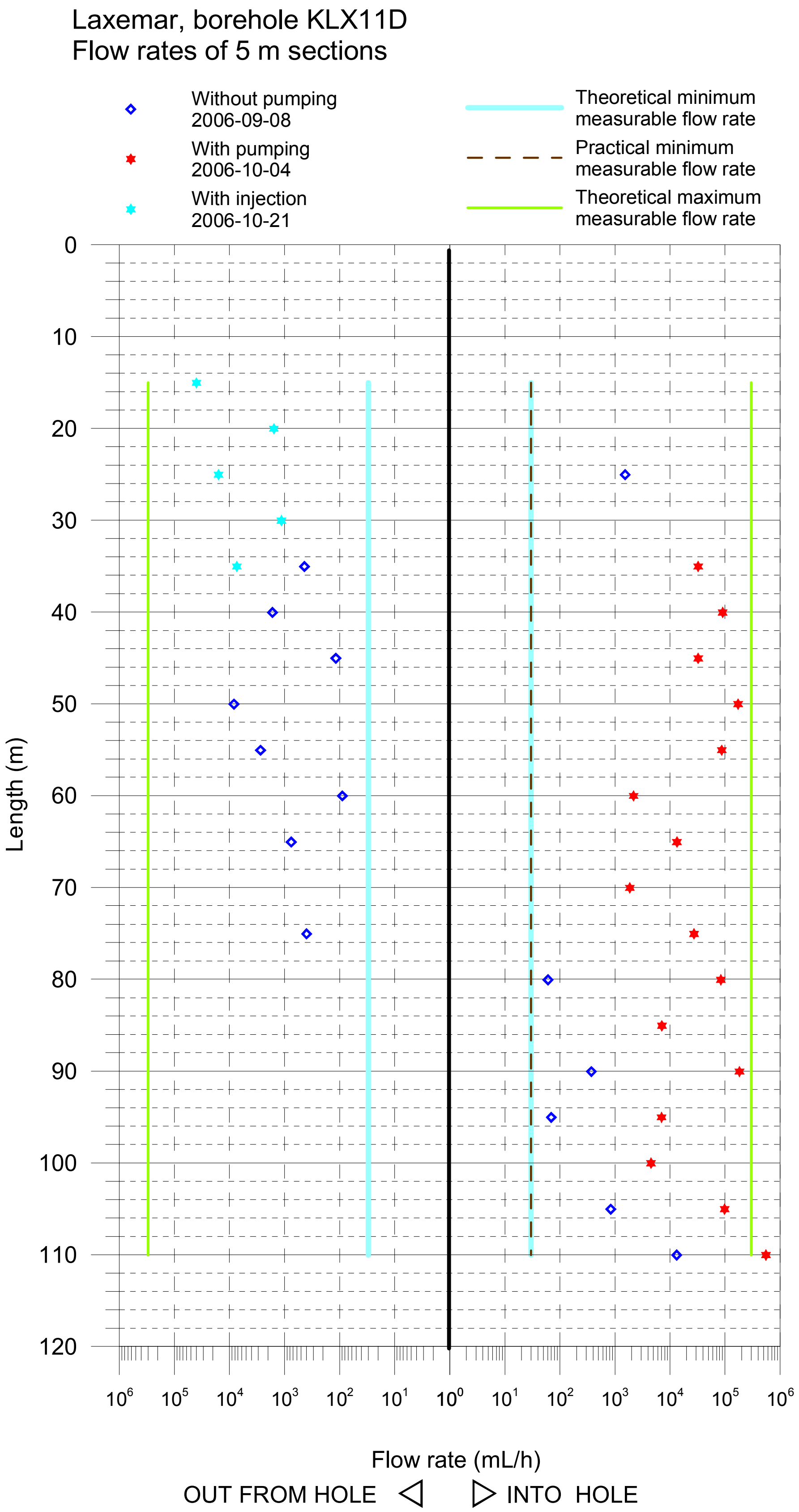


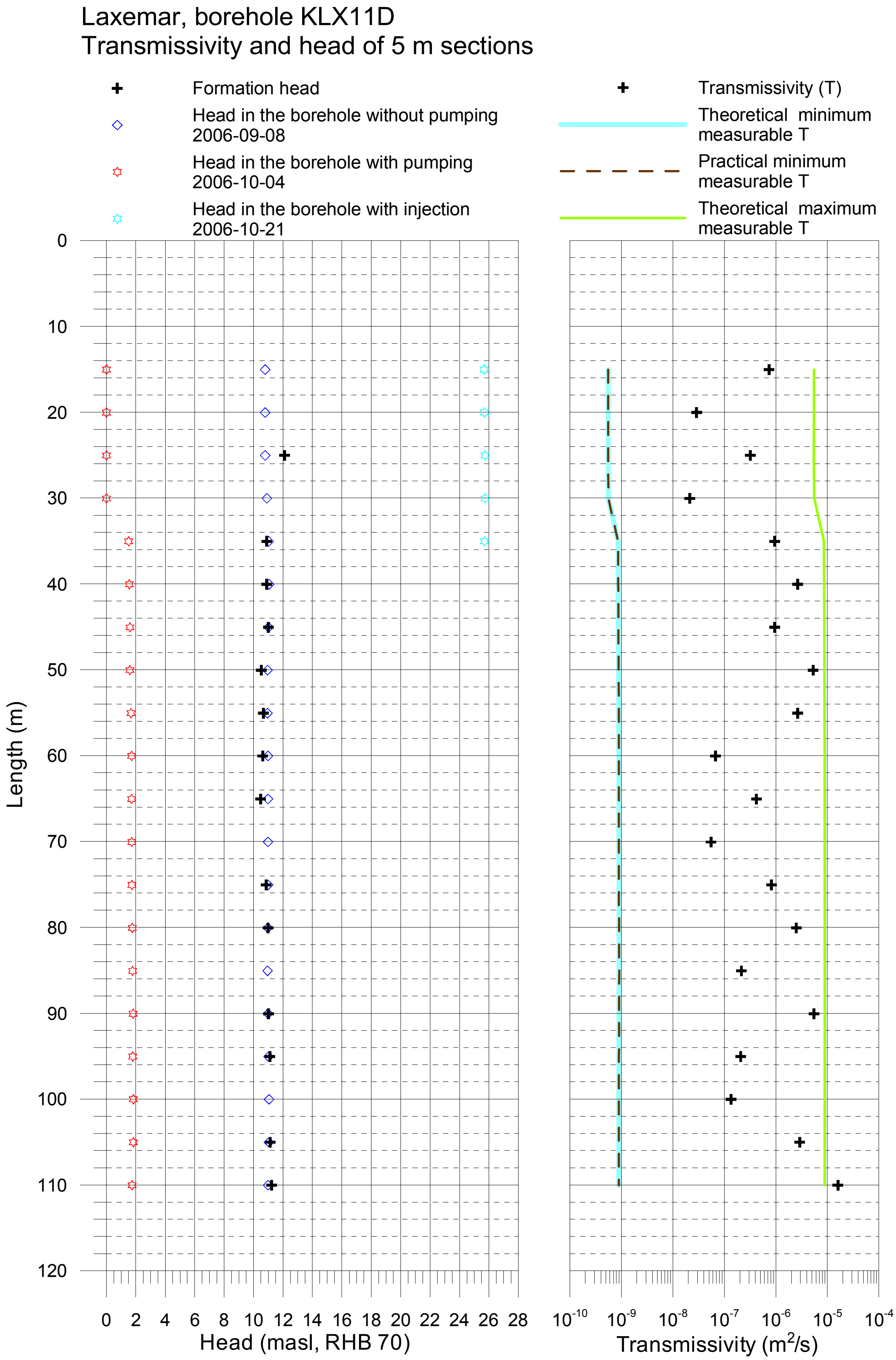
Laxemar, borehole KLX11D
Electric conductivity of borehole water



Laxemar, borehole KLX11D
Temperature of borehole water

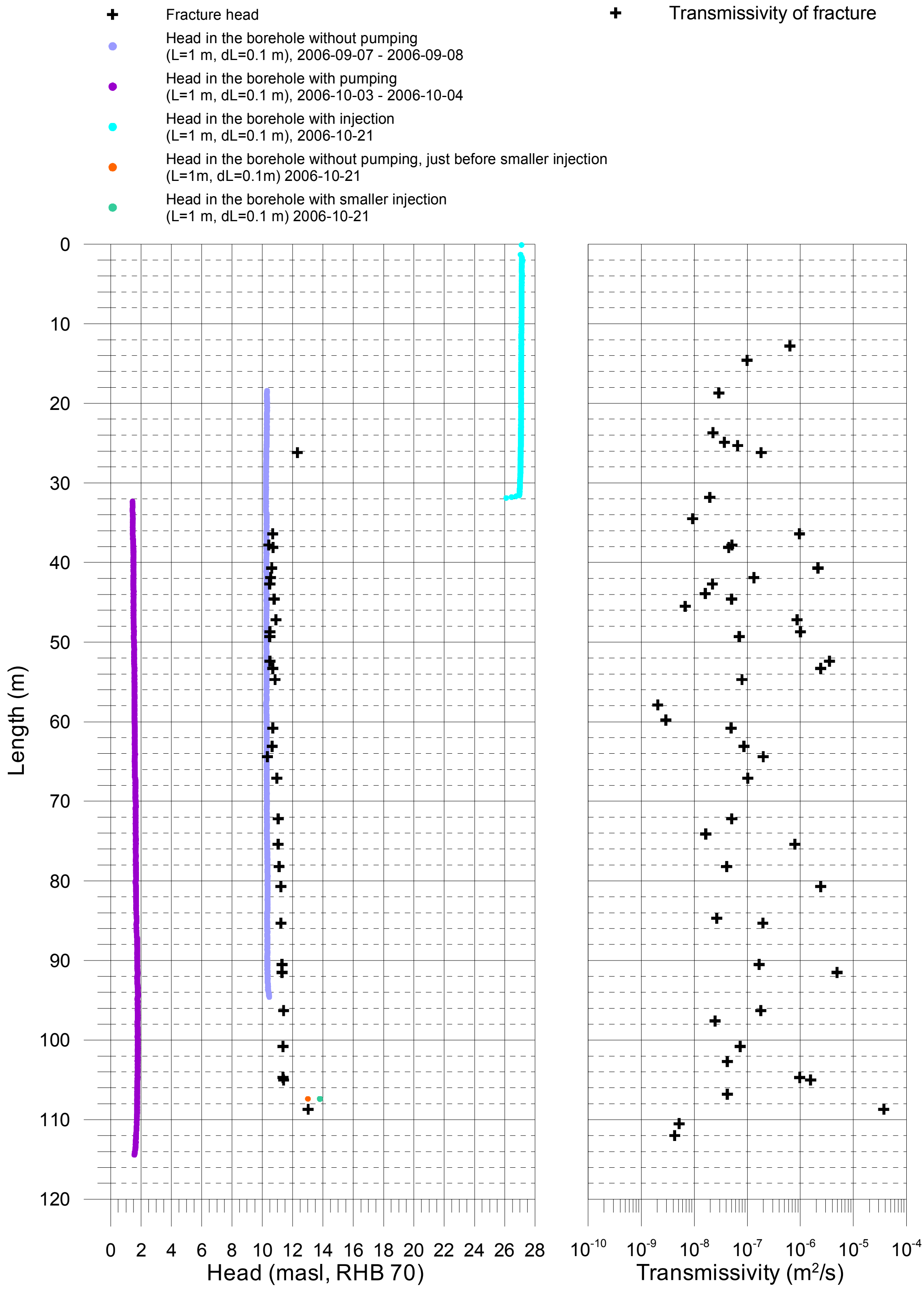



Laxemar, borehole KLX11D
Flow rates of 5 m sections
Without pumping
2006-09-08
With pumping
2006-10-04
With injection
2006-10-21
Theoretical minimum
measurable flow rate
Practical minimum
measurable flow rate
Theoretical maximum
measurable flow rate
Length (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
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 KLX11D
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-09-08
Head in the borehole with pumping 2006-10-04
Head in the borehole with injection 2006-10-21
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
110
120
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
Head (masl, RHB 70)
10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4}
Transmissivity (m^2/s)

Laxemar, borehole KLX11D
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)
KLX11D	2	120.35	5A	20061002	15:51	20061004	9:04	20061008	13:52	5	0.5	3.52E–04	–4.12E–04

5. PFL-Difference flow logging – Basic test data

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (m.a.s.l.)	h_1 (m.a.s.l.)	h_2 (m.a.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
511260	10980	340860	137820	10.80	1.05	25.58	–9.75	14.78	3.57E–05	–	–

Difference flow logging – Sequential flow logging

Borehole ID	Secup L (m)	Seclow L (m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	T_D-$measl_{LT}$ (m^2/s)	T_D-$measl_{LP}$ (m^2/s)	T_D-$measl_U$ (m^2/s)	Comments
KLX11D	12.55	17.55	5	–	10.78	–1.11E–05	25.67	7.3E–07	–	30	5.5E–10	5.5E–10	5.5E–06	*,**
KLX11D	17.55	22.55	5	–	10.78	–4.34E–07	25.70	2.9E–08	–	30	5.5E–10	5.5E–10	5.5E–06	*,**
KLX11D	22.55	27.55	5	4.25E–07	10.78	–4.39E–06	25.73	3.2E–07	12.1	30	5.5E–10	5.5E–10	5.5E–06	*
KLX11D	27.55	32.55	5	–	10.91	–3.17E–07	25.73	2.1E–08	–	30	5.6E–10	5.6E–10	5.6E–06	*
KLX11D	32.55	37.55	5	–1.21E–07	11.03	9.03E–06	1.50	9.5E–07	10.9	30	8.6E–10	8.6E–10	8.6E–06	
KLX11D	37.55	42.55	5	–4.61E–07	11.06	2.50E–05	1.56	2.7E–06	10.9	30	8.7E–10	8.7E–10	8.7E–06	
KLX11D	42.55	47.55	5	–3.25E–08	11.03	9.00E–06	1.60	9.5E–07	11.0	30	8.7E–10	8.7E–10	8.7E–06	
KLX11D	47.55	52.55	5	–2.31E–06	10.95	4.78E–05	1.59	5.3E–06	10.5	30	8.8E–10	8.8E–10	8.8E–06	
KLX11D	52.56	57.56	5	–7.58E–07	10.95	2.41E–05	1.67	2.7E–06	10.7	30	8.9E–10	8.9E–10	8.9E–06	
KLX11D	57.54	62.54	5	–2.47E–08	10.98	6.06E–07	1.71	6.7E–08	10.6	30	8.9E–10	8.9E–10	8.9E–06	
KLX11D	62.55	67.55	5	–2.10E–07	10.98	3.72E–06	1.71	4.2E–07	10.5	30	8.9E–10	8.9E–10	8.9E–06	
KLX11D	67.55	72.55	5	–	10.98	5.17E–07	1.72	5.5E–08	–	30	8.9E–10	8.9E–10	8.9E–06	
KLX11D	72.56	77.56	5	–1.10E–07	10.99	7.58E–06	1.73	8.2E–07	10.9	30	8.9E–10	8.9E–10	8.9E–06	
KLX11D	77.56	82.56	5	1.69E–08	10.97	2.33E–05	1.76	2.5E–06	11.0	30	9.0E–10	9.0E–10	9.0E–06	
KLX11D	82.57	87.57	5	–	10.95	1.98E–06	1.78	2.1E–07	–	30	9.0E–10	9.0E–10	9.0E–06	
KLX11D	87.56	92.56	5	1.04E–07	10.99	5.08E–05	1.81	5.5E–06	11.0	30	9.0E–10	9.0E–10	9.0E–06	
KLX11D	92.55	97.55	5	1.94E–08	11.02	1.95E–06	1.79	2.1E–07	11.1	30	8.9E–10	8.9E–10	8.9E–06	
KLX11D	97.54	102.54	5	–	11.05	1.26E–06	1.83	1.3E–07	–	30	8.9E–10	8.9E–10	8.9E–06	
KLX11D	102.54	107.54	5	2.34E–07	11.05	2.73E–05	1.83	2.9E–06	11.1	30	8.9E–10	8.9E–10	8.9E–06	
KLX11D	107.54	112.54	5	3.67E–06	10.99	1.53E–04	1.74	1.6E–05	11.2	30	8.9E–10	8.9E–10	8.9E–06	***

* Q_1 value is from injection.

** Q_0 is evaluated to be zero since it is not measured in this section.

*** Q_1 is above measuring 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
KLX11D	12.8	1	0.1	–	10.91	–9.47E–06	25.67	6.4E–07	–	**,***
KLX11D	14.6	1	0.1	–	10.91	–1.48E–06	25.67	9.9E–08	–	**,***
KLX11D	18.7	1	0.1	–	10.91	–4.33E–07	25.71	2.9E–08	–	**,***
KLX11D	23.7	1	0.1	–	10.91	–3.36E–07	25.72	2.2E–08	–	**,***
KLX11D	24.9	1	0.1	–	10.91	–5.56E–07	25.73	3.7E–08	–	**,***
KLX11D	25.3	1	0.1	–	10.91	–9.83E–07	25.72	6.6E–08	–	**
KLX11D	26.2	1	0.1	2.63E–07	10.89	–2.48E–06	25.72	1.8E–07	12.3	**
KLX11D	31.8	1	0.1	–	10.84	–2.94E–07	25.72	2.0E–08	–	**
KLX11D	34.5	1	0.1	–	10.83	8.78E–08	1.47	9.3E–09	–	**
KLX11D	36.4	1	0.1	–1.38E–07	10.82	9.00E–06	1.44	9.6E–07	10.7	
KLX11D	37.8	1	0.1	–2.06E–08	10.83	4.64E–07	1.49	5.1E–08	10.4	
KLX11D	38.1	1	0.1	–5.56E–09	10.82	4.14E–07	1.49	4.5E–08	10.7	*
KLX11D	40.7	1	0.1	–4.39E–07	10.82	1.98E–05	1.51	2.2E–06	10.6	
KLX11D	41.9	1	0.1	–3.81E–08	10.83	1.21E–06	1.50	1.3E–07	10.6	
KLX11D	42.7	1	0.1	–7.78E–09	10.84	2.00E–07	1.49	2.2E–08	10.5	
KLX11D	43.9	1	0.1	–	10.86	1.52E–07	1.50	1.6E–08	–	*
KLX11D	44.6	1	0.1	–5.00E–09	10.88	4.72E–07	1.51	5.0E–08	10.8	
KLX11D	45.5	1	0.1	–	10.88	6.39E–08	1.51	6.7E–09	–	*
KLX11D	47.2	1	0.1	–3.19E–08	10.94	8.25E–06	1.51	8.7E–07	10.9	
KLX11D	48.7	1	0.1	–4.56E–07	10.95	9.06E–06	1.53	1.0E–06	10.5	
KLX11D	49.3	1	0.1	–3.33E–08	10.96	6.39E–07	1.52	7.0E–08	10.5	
KLX11D	52.4	1	0.1	–1.74E–06	10.99	3.19E–05	1.54	3.5E–06	10.5	
KLX11D	53.3	1	0.1	–7.50E–07	11.00	2.22E–05	1.57	2.4E–06	10.7	
KLX11D	54.7	1	0.1	–1.36E–08	11.01	7.39E–07	1.57	7.9E–08	10.8	
KLX11D	57.9	1	0.1	–	11.02	1.94E–08	1.57	2.0E–09	–	
KLX11D	59.8	1	0.1	–	11.02	2.78E–08	1.58	2.9E–09	–	*
KLX11D	60.8	1	0.1	–1.72E–08	11.03	4.56E–07	1.58	5.0E–08	10.7	
KLX11D	63.1	1	0.1	–3.50E–08	11.05	7.86E–07	1.60	8.6E–08	10.7	
KLX11D	64.4	1	0.1	–1.44E–07	11.05	1.76E–06	1.59	2.0E–07	10.3	
KLX11D	67.1	1	0.1	–1.44E–08	11.10	9.64E–07	1.62	1.0E–07	11.0	
KLX11D	72.2	1	0.1	–6.11E–09	11.17	4.83E–07	1.64	5.1E–08	11.1	
KLX11D	74.1	1	0.1	–	11.18	1.59E–07	1.63	1.7E–08	–	
KLX11D	75.4	1	0.1	–1.09E–07	11.18	7.53E–06	1.65	7.9E–07	11.0	
KLX11D	78.2	1	0.1	–4.44E–09	11.22	3.89E–07	1.66	4.1E–08	11.1	
KLX11D	80.7	1	0.1	–3.17E–08	11.23	2.34E–05	1.66	2.4E–06	11.2	
KLX11D	84.7	1	0.1	–	11.25	2.56E–07	1.70	2.7E–08	–	
KLX11D	85.3	1	0.1	–4.44E–09	11.25	1.89E–06	1.70	2.0E–07	11.2	
KLX11D	90.5	1	0.1	3.89E–09	11.28	1.61E–06	1.76	1.7E–07	11.3	
KLX11D	91.5	1	0.1	7.89E–08	11.28	4.72E–05	1.78	4.9E–06	11.3	
KLX11D	96.3	1	0.1	1.75E–08	11.31	1.74E–06	1.77	1.8E–07	11.4	
KLX11D	97.6	1	0.1	–	11.32	2.39E–07	1.77	2.5E–08	–	
KLX11D	100.8	1	0.1	3.89E–09	11.32	7.11E–07	1.79	7.3E–08	11.4	
KLX11D	102.7	1	0.1	–	11.32	4.06E–07	1.78	4.2E–08	–	
KLX11D	104.7	1	0.1	5.06E–08	11.32	9.42E–06	1.78	9.7E–07	11.4	
KLX11D	105.0	1	0.1	1.40E–07	11.32	1.52E–05	1.77	1.6E–06	11.4	
KLX11D	106.8	1	0.1	–	11.32	4.08E–07	1.74	4.2E–08	–	
KLX11D	108.7	1	0.1	6.81E–07	13.01	–2.92E–05	13.80	3.7E–05	13.0	****
KLX11D	110.5	1	0.1	–	11.29	5.00E–08	1.71	5.2E–09	–	
KLX11D	112.0	1	0.1	–	11.29	4.17E–08	1.67	4.3E–09	–	

* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.
** Q_1 value is from injection.
*** Q_0 is evaluated to be zero since it is not measured in this section.
**** Q_1 is from smaller injection, Q_0 is undisturbed state just before smaller injection.

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.

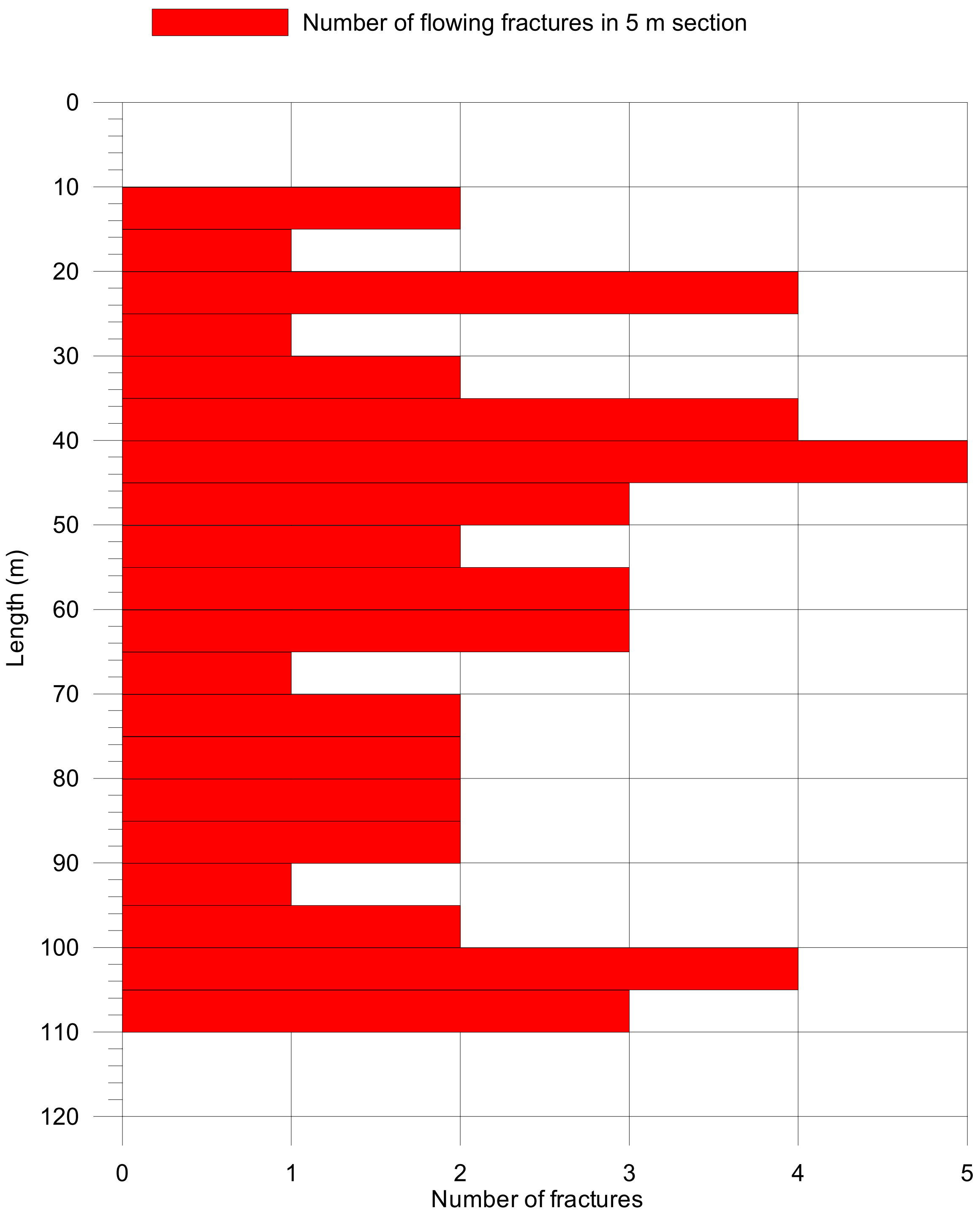
Explanations		
Header	**Unit**	**Explanations**
s_1	m	Drawdown of the water level in the borehole during first pumping period. Difference between the actual hydraulic head and the initial head ($s_1=h_1–h_0$).
s_2	m	Drawdown of the water level in the borehole during second pumping period. Difference between the actual hydraulic head and the initial head ($s_2=h_2–h_0$).
T	m^2/s	Transmissivity of the entire borehole.
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with $h=h_0$ in the open borehole.
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period.
Q_2	m^3/s	Measured flow rate through the test section or flow anomaly during the second pumping period.
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid before pumping.
h_{1FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period.
h_{2FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the second pumping period.
EC_w	S/m	Measured electric conductivity of the borehole fluid in the test section during difference flow logging.
Te_w	°C	Measured borehole fluid temperature in the test section during difference flow logging.
EC_f	S/m	Measured fracture-specific electric conductivity of the fluid in flow anomaly during difference flow logging.
Te_f	°C	Measured fracture-specific fluid temperature in flow anomaly during difference flow logging.
T_D	m^2/s	Transmissivity of section or flow anomaly based on 2D model for evaluation of formation properties of the test section based on PFL-DIFF.
T-measl$_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-measl$_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-measl$_U$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

Calculation of conductive fracture frequency

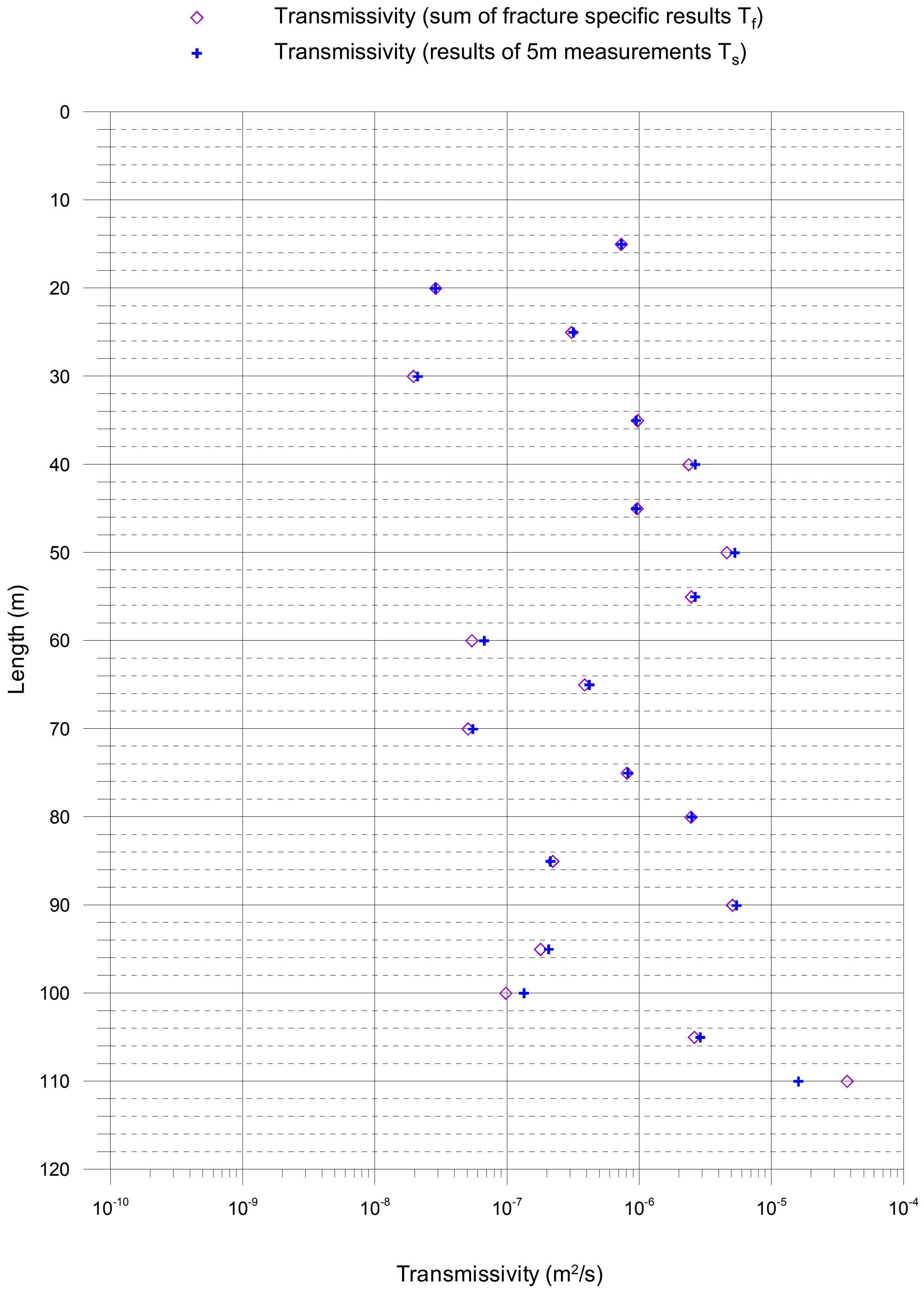
Borehole ID	SecUp (m)	SecLow (m)	Number of fractures, total	Number of fractures 10–100 (mL/h)	Number of fractures 100–1,000 (mL/h)	Number of fractures 1,000–10,000 (mL/h)	Number of fractures 10,000–100,000 (mL/h)	Number of fractures 100,000–1,000,000 (mL/h)
KLX11D	12.55	17.55	2	0	0	1*	1*	0
KLX11D	17.55	22.55	1	0	0	1*	0	0
KLX11D	22.55	27.55	4	0	0	4*	0	0
KLX11D	27.55	32.55	1	0	0	1*	0	0
KLX11D	32.55	37.55	2	0	1	0	1	0
KLX11D	37.55	42.55	4	0	0	3	1	0
KLX11D	42.55	47.55	5	0	3	1	1	0
KLX11D	47.55	52.55	3	0	0	1	1	1
KLX11D	52.56	57.56	2	0	0	1	1	0
KLX11D	57.54	62.54	3	2	0	1	0	0
KLX11D	62.55	67.55	3	0	0	3	0	0
KLX11D	67.55	72.55	1	0	0	1	0	0
KLX11D	72.56	77.56	2	0	1	0	1	0
KLX11D	77.56	82.56	2	0	0	1	1	0
KLX11D	82.57	87.57	2	0	1	1	0	0
KLX11D	87.56	92.56	2	0	0	1	0	1
KLX11D	92.55	97.55	1	0	0	1	0	0
KLX11D	97.54	102.54	2	0	1	1	0	0
KLX11D	102.54	107.54	4	0	0	2	2	0
KLX11D	107.54	112.54	3	0	2	0	0	0

* During Injection (drawdown not the same as in the other measurements).

Laxemar, borehole KLX11D
Calculation of conductive fracture frequency

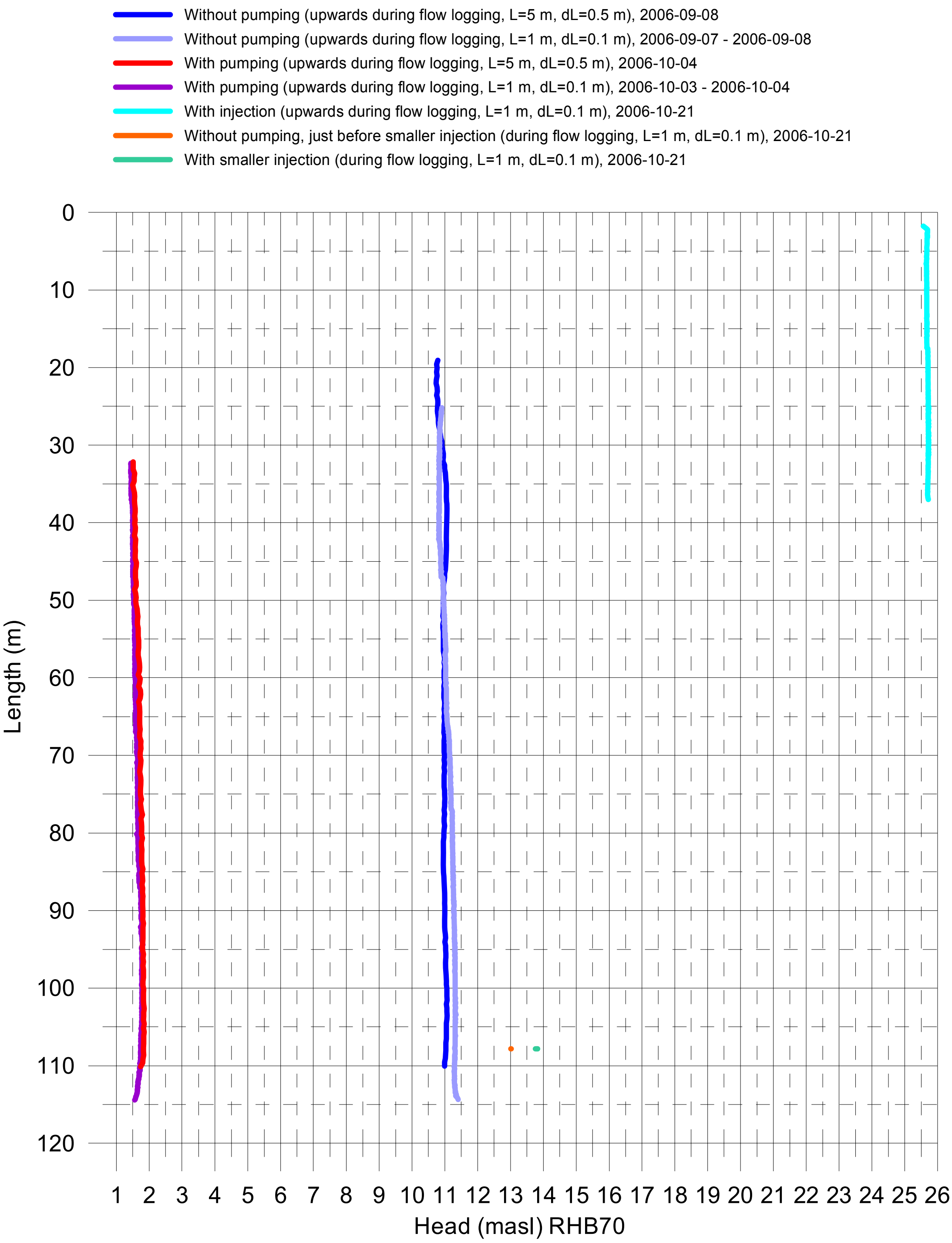


Laxemar, borehole KLX11D
Comparison between section transmissivity and fracture transmissivity

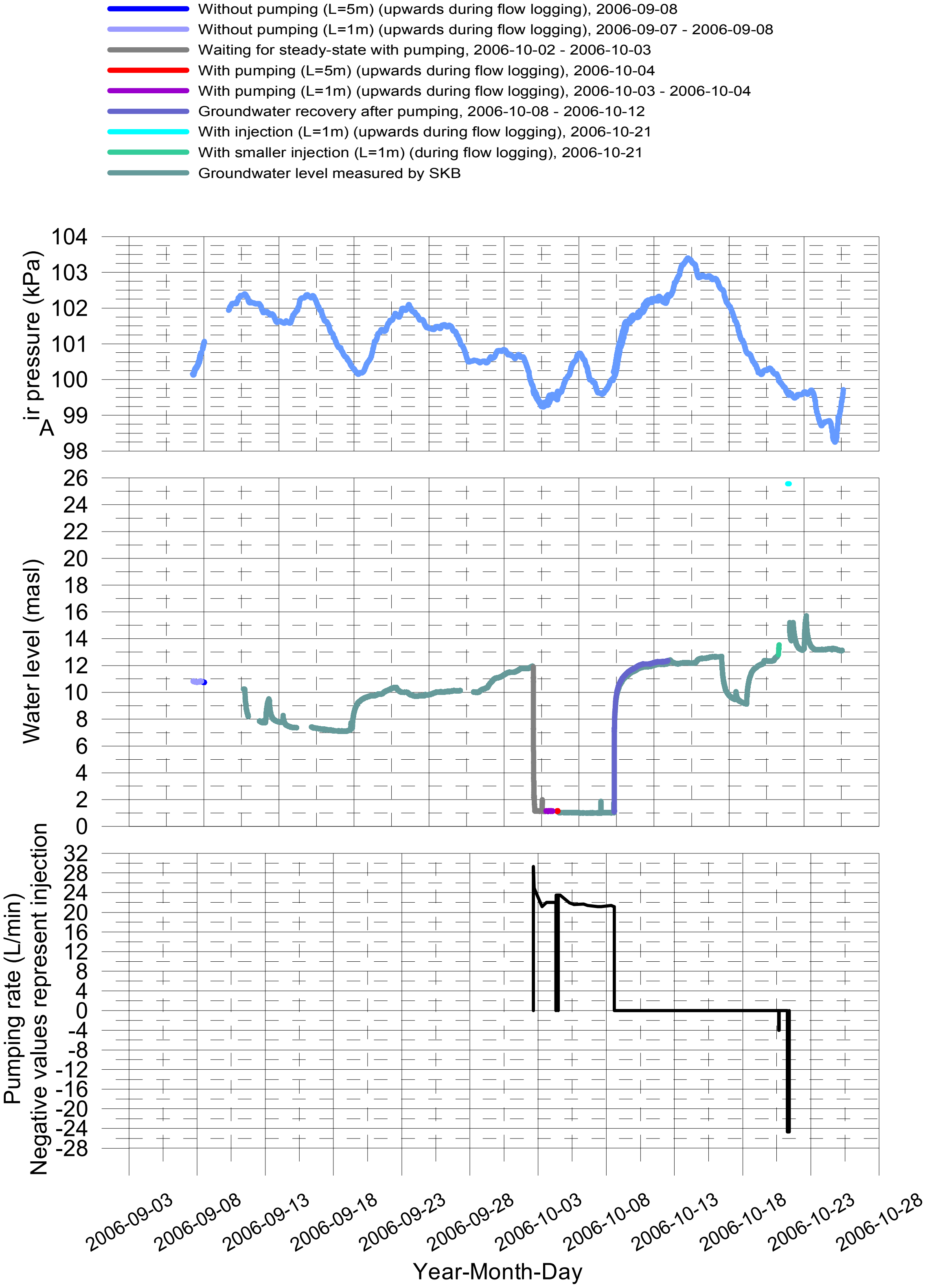


Laxemar, borehole KLX11D
Head in the borehole during flow logging

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)

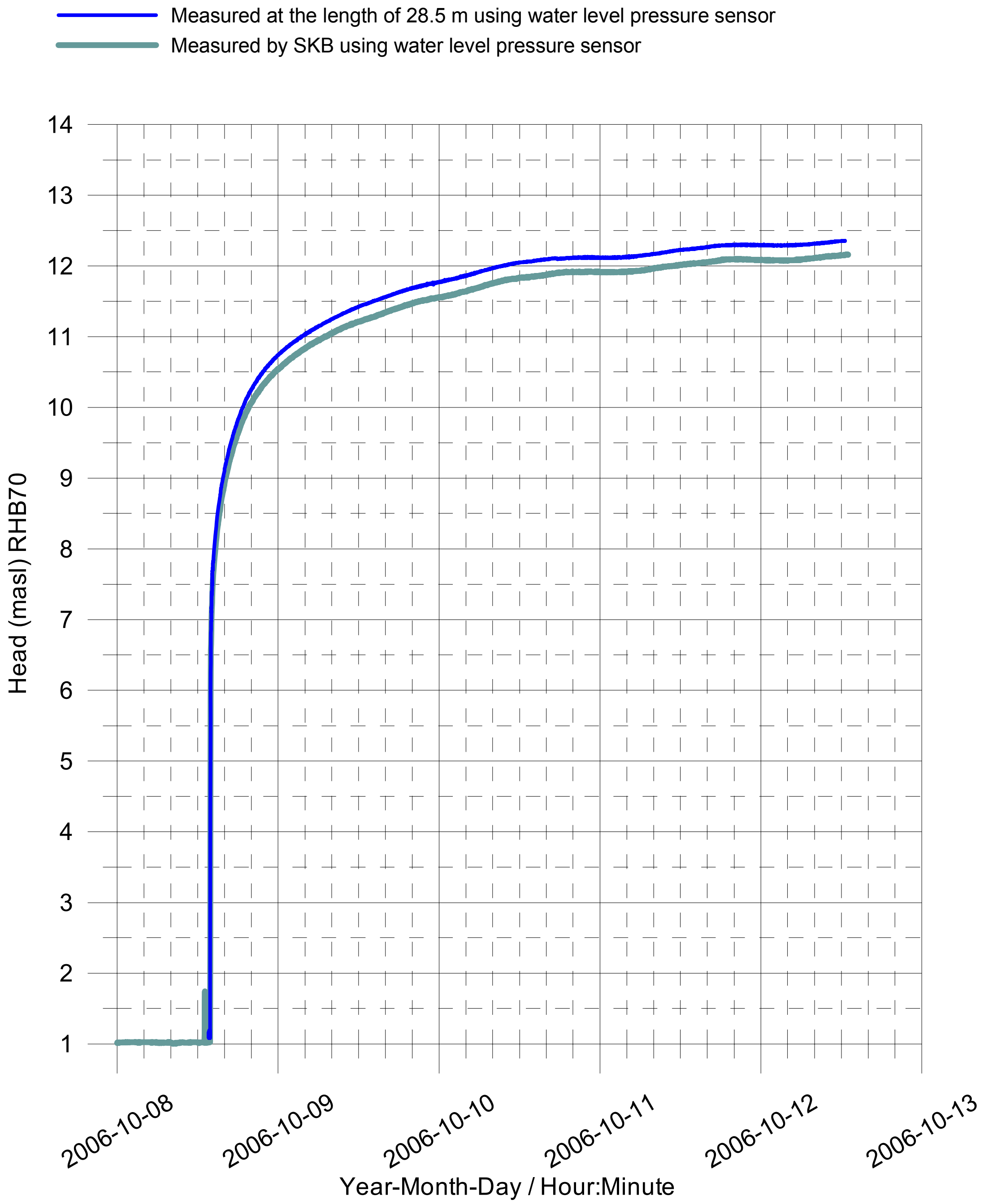


Laxemar, borehole KLX11D
Air pressure, water level in the borehole and pumping rate during flow logging



Laxemar, borehole KLX11D
Groundwater recovery after pumping

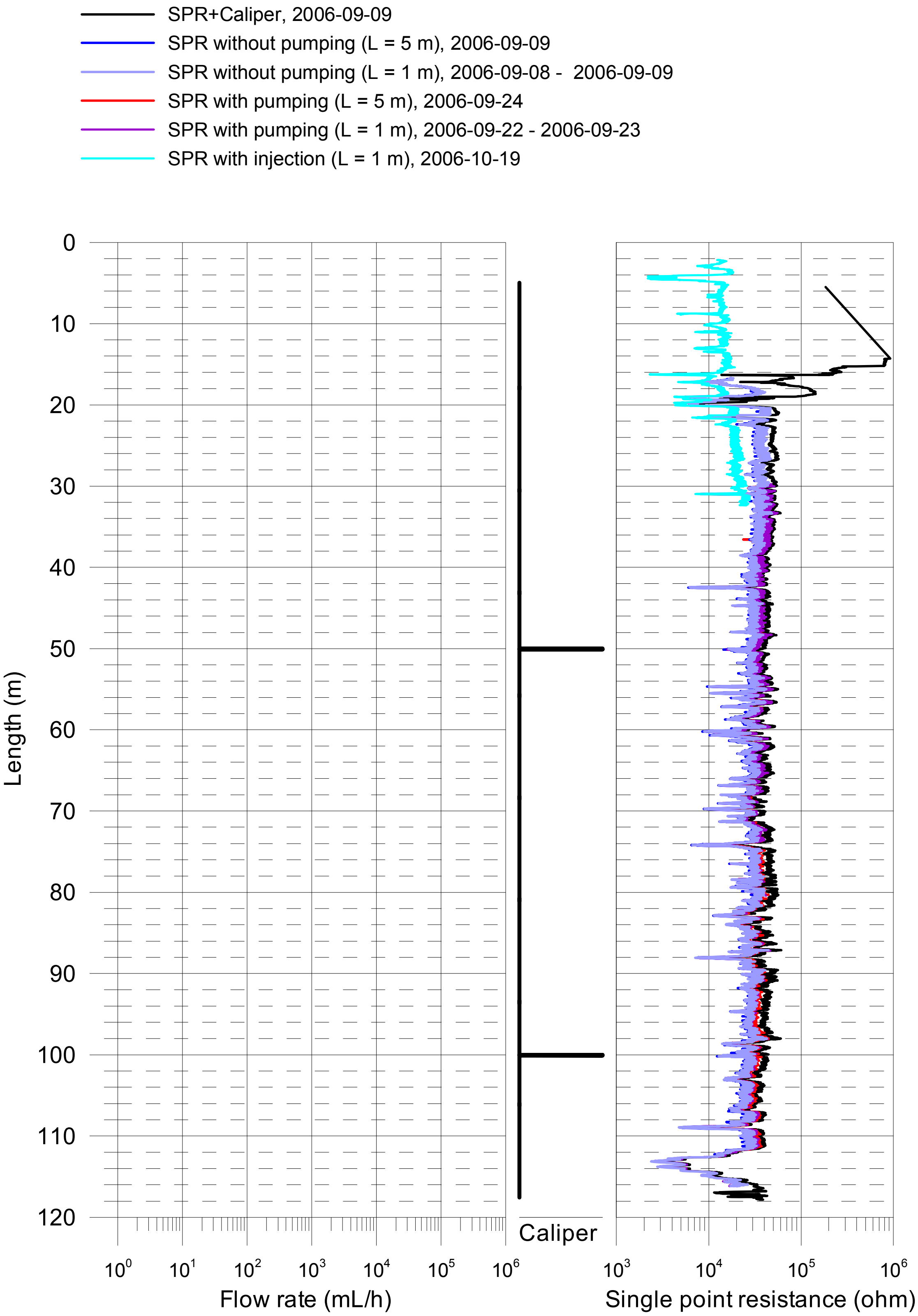
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)



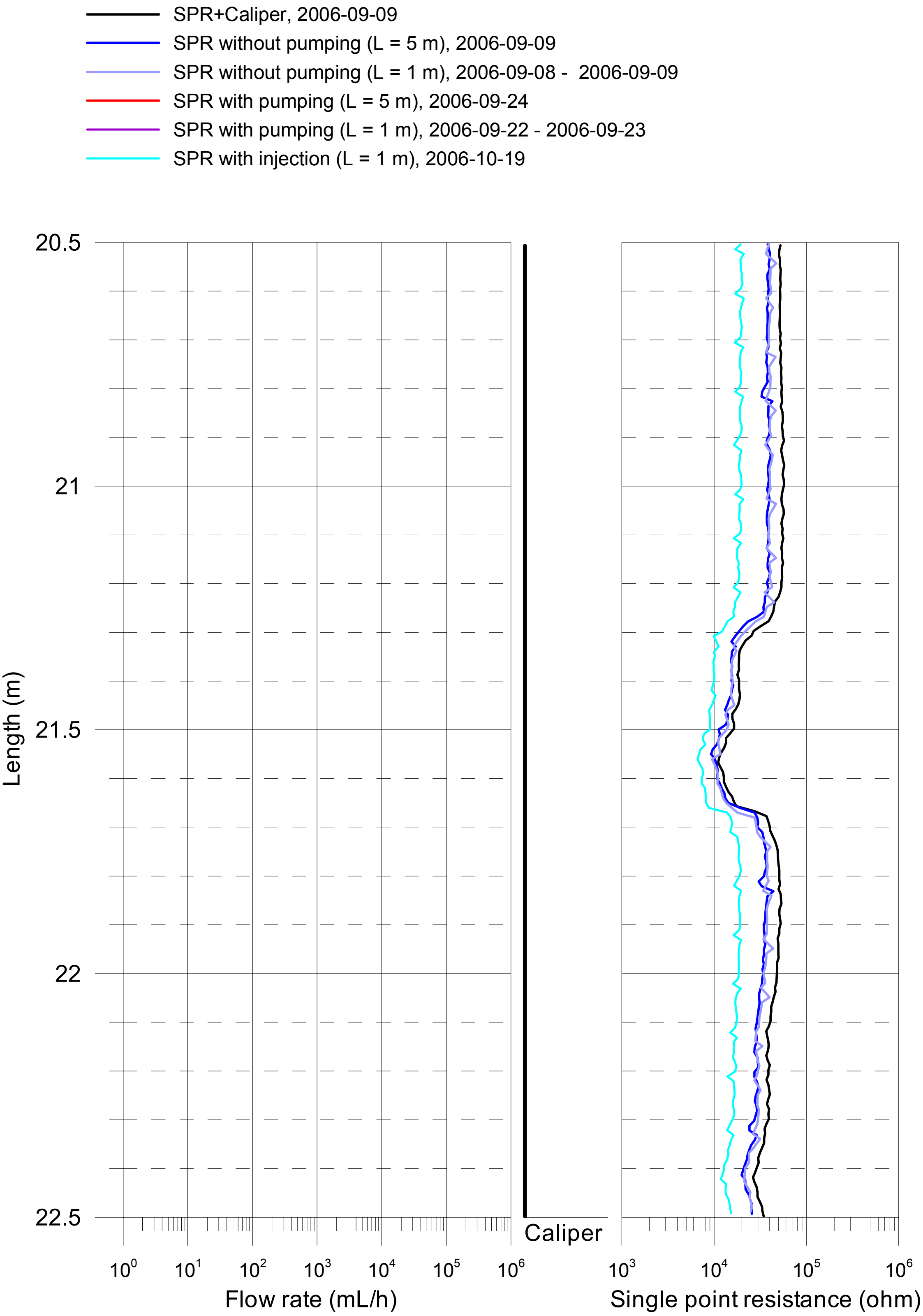
Appendices, KLX11E

Appendices	E.1.1–E.1.11	SPR and Caliper results after length correction
Appendix	E.1.12	Length correction
Appendices	E.2.1–E.2.6	Flow rate, Caliper and Single point resistance
Appendix	E.3.1	Electric conductivity of borehole water
Appendix	E.3.2	Temperature of borehole water
Appendix	E.4.1	Plotted flow rates of 5 m sections
Appendix	E.4.2	Plotted transmissivity and head of 5 m sections
Appendix	E.5	Plotted transmissivity and head of detected fractures
Appendix	E.6	Basic test data
Appendix	E.7	Results of sequential flow logging
Appendix	E.8	Inferred flow anomalies from overlapping flow logging
Appendix	E.9	Explanations for the tables in Appendices 6–8
Appendix	E.10	Conductive fracture frequency
Appendix	E.11	Plotted conductive fracture frequency
Appendix	E.12	Comparison between section transmissivity and fracture transmissivity
Appendix	E.13	Head in the borehole during flow logging
Appendix	E.14	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	E.15	Groundwater recovery after pumping

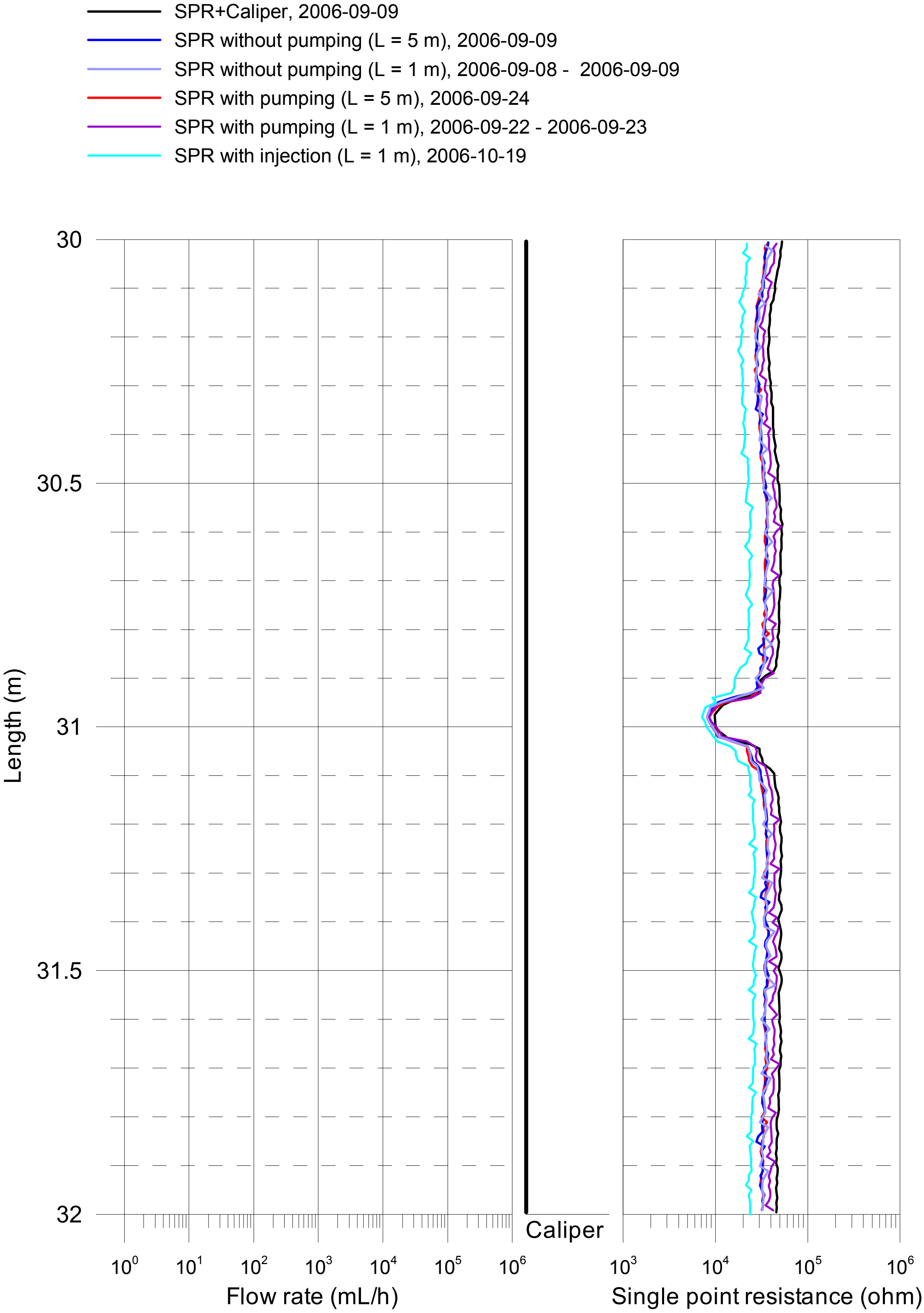
Laxemar, borehole KLX11E
SPR and Caliper results after length correction

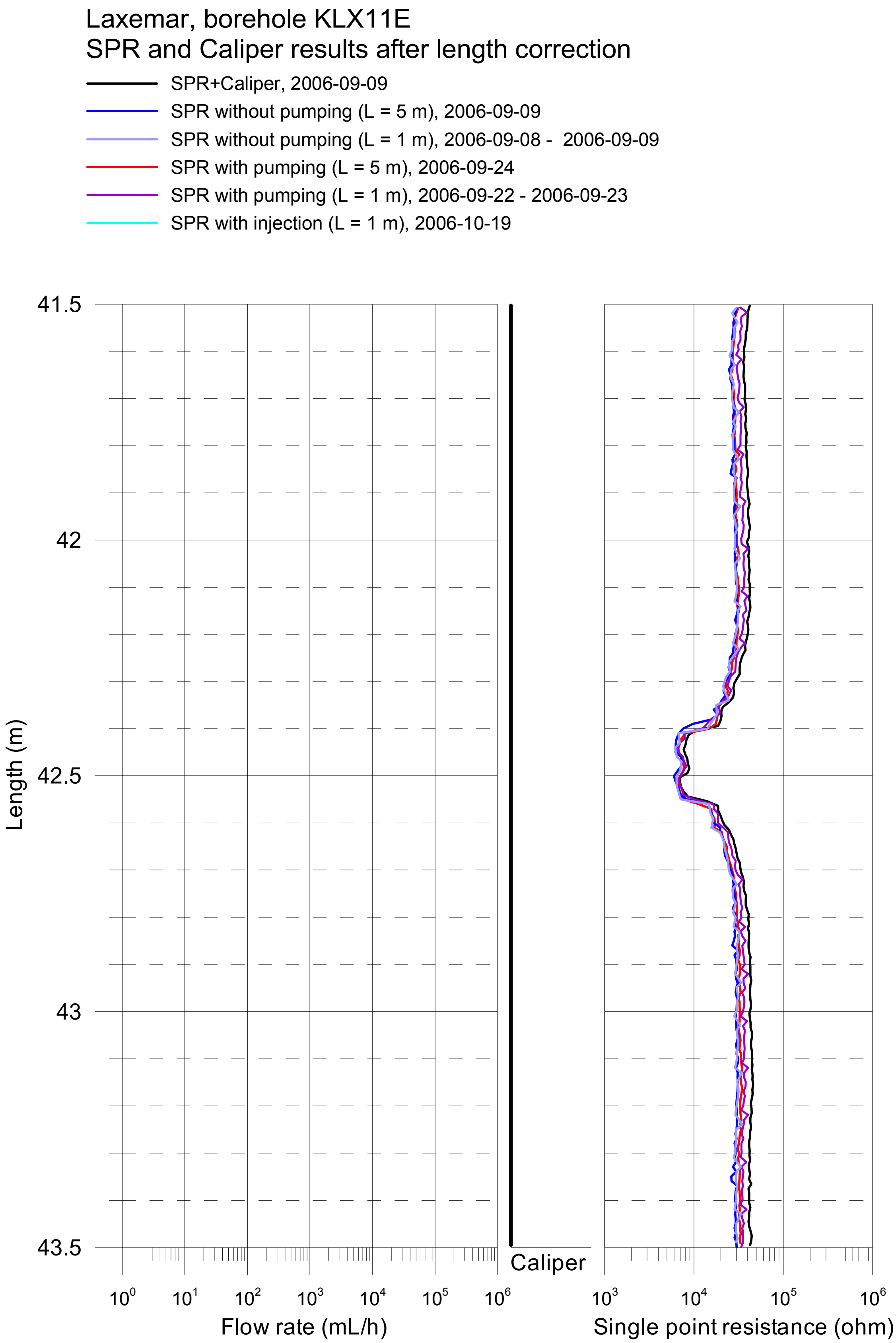


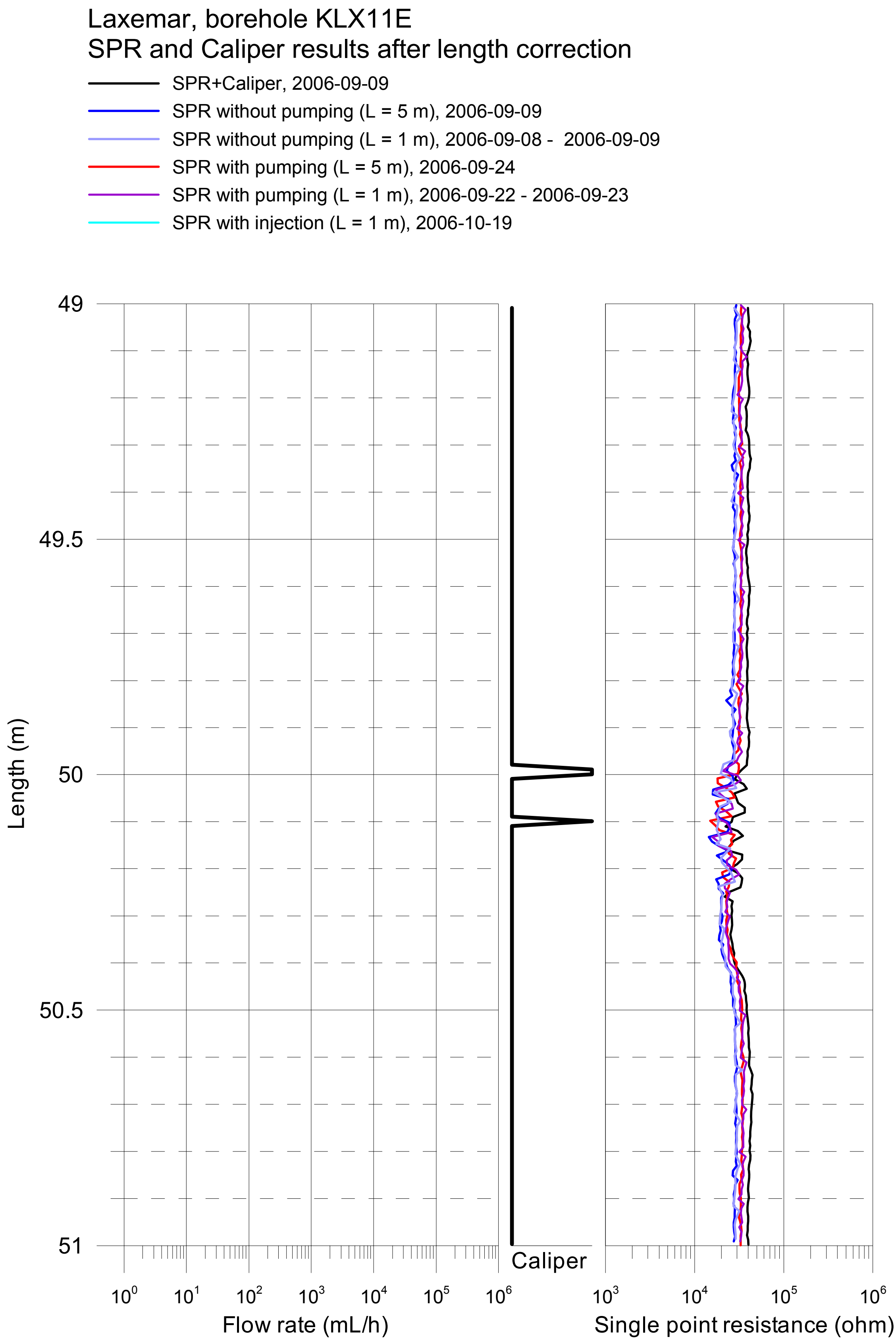
Laxemar, borehole KLX11E
SPR and Caliper results after length correction

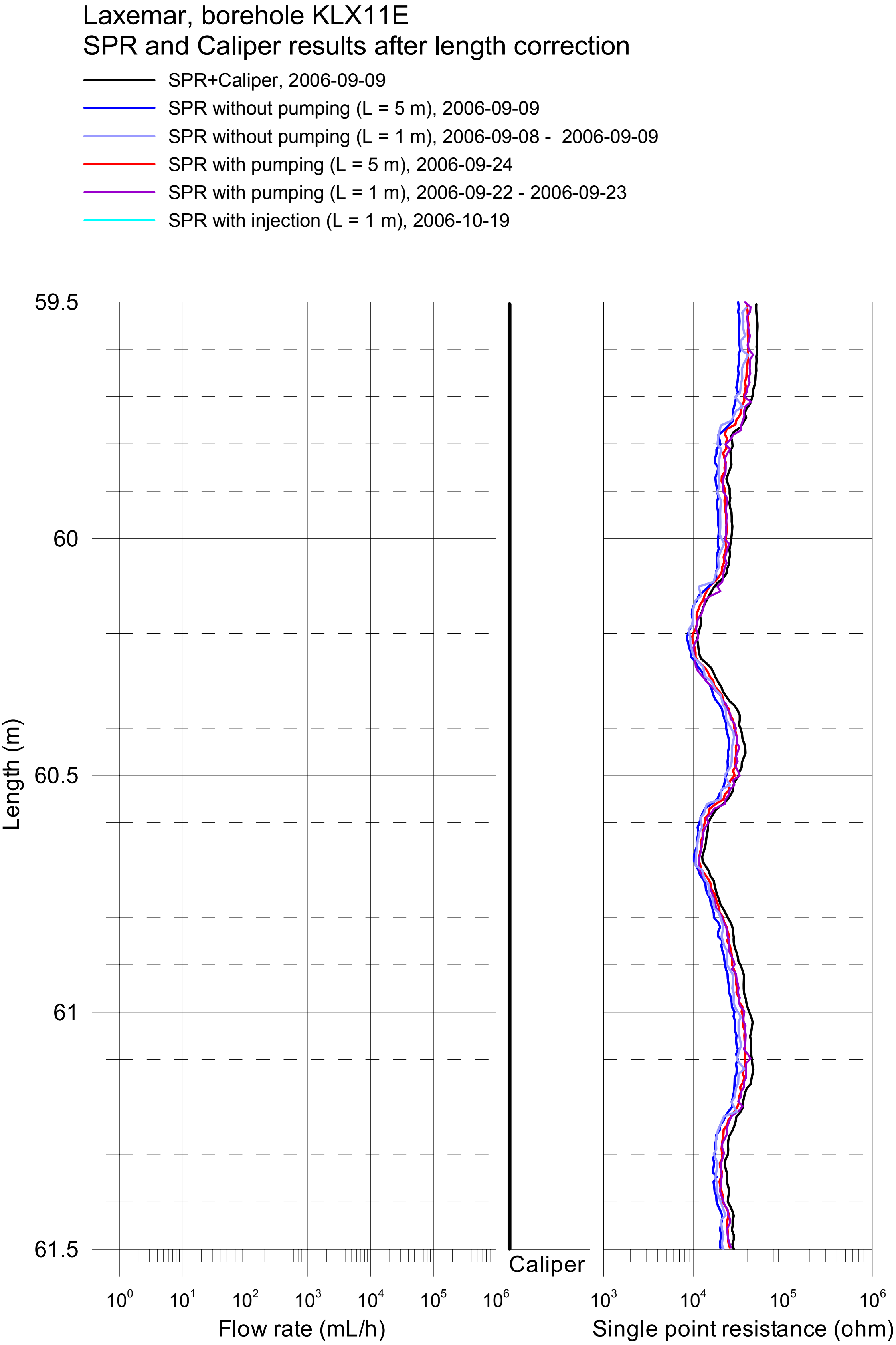


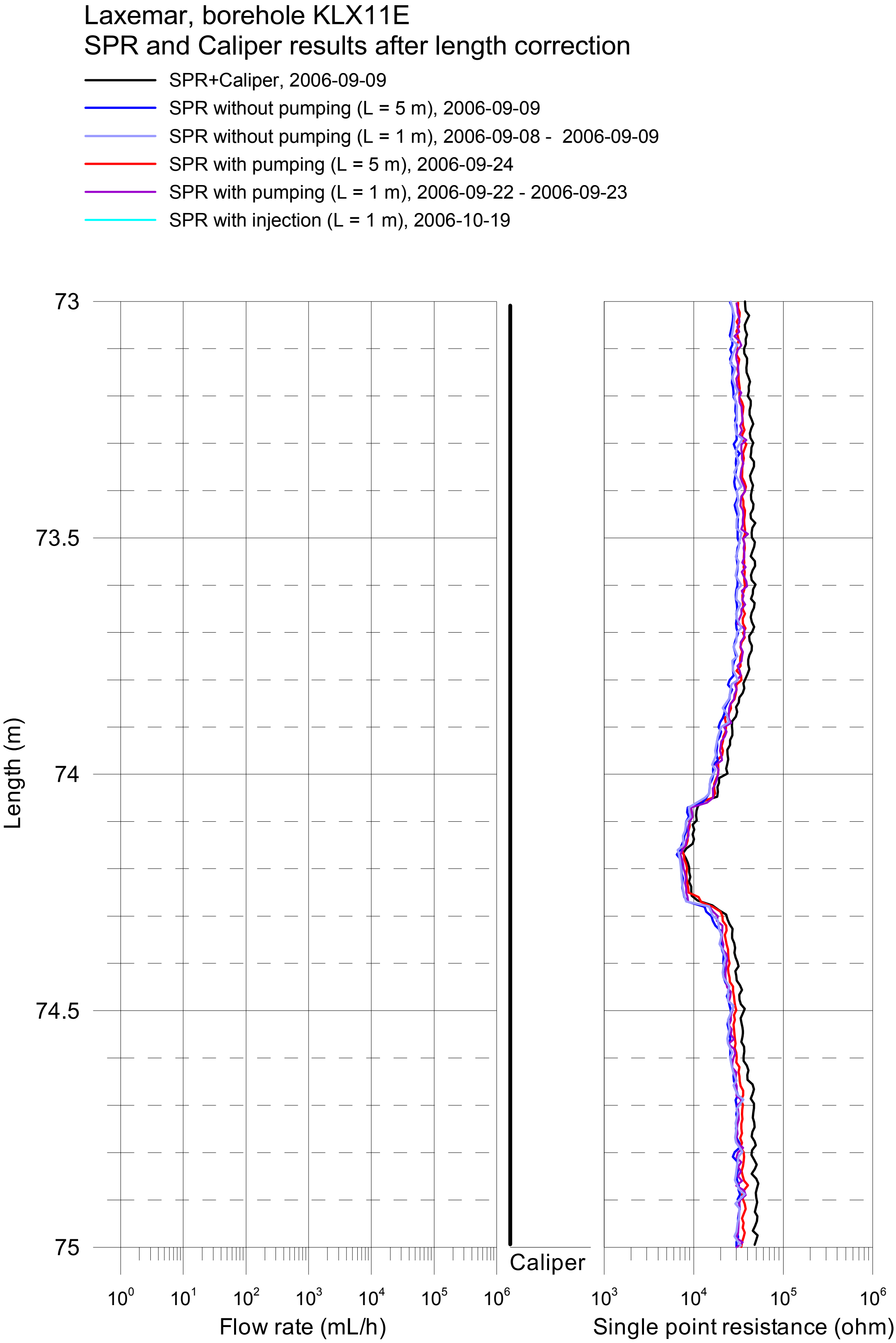
Laxemar, borehole KLX11E
SPR and Caliper results after length correction

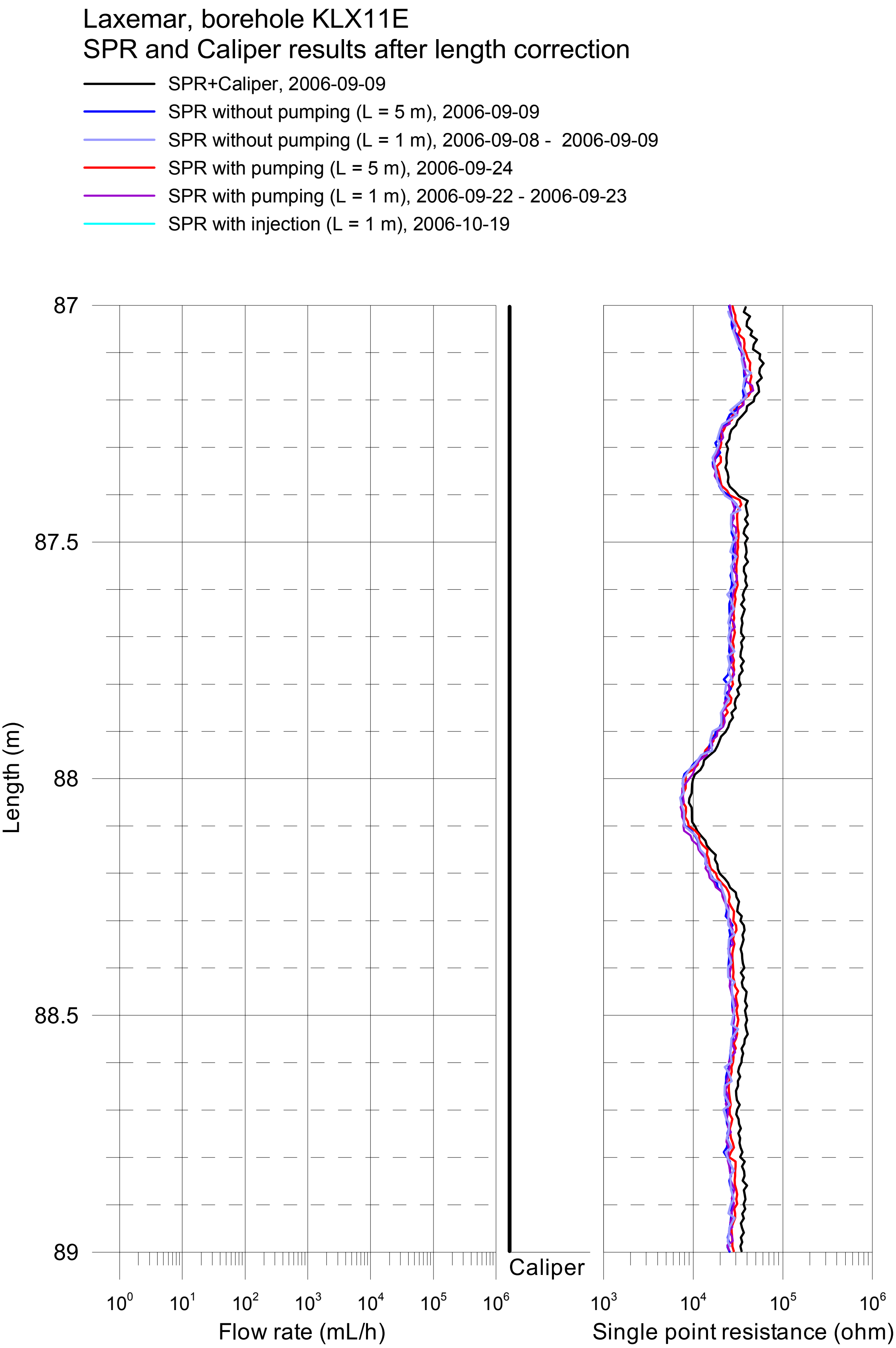



Laxemar, borehole KLX11E
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-09
SPR without pumping (L = 5 m), 2006-09-09
SPR without pumping (L = 1 m), 2006-09-08 - 2006-09-09
SPR with pumping (L = 5 m), 2006-09-24
SPR with pumping (L = 1 m), 2006-09-22 - 2006-09-23
SPR with injection (L = 1 m), 2006-10-19
Length (m)
41.5
42
42.5
43
43.5
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)

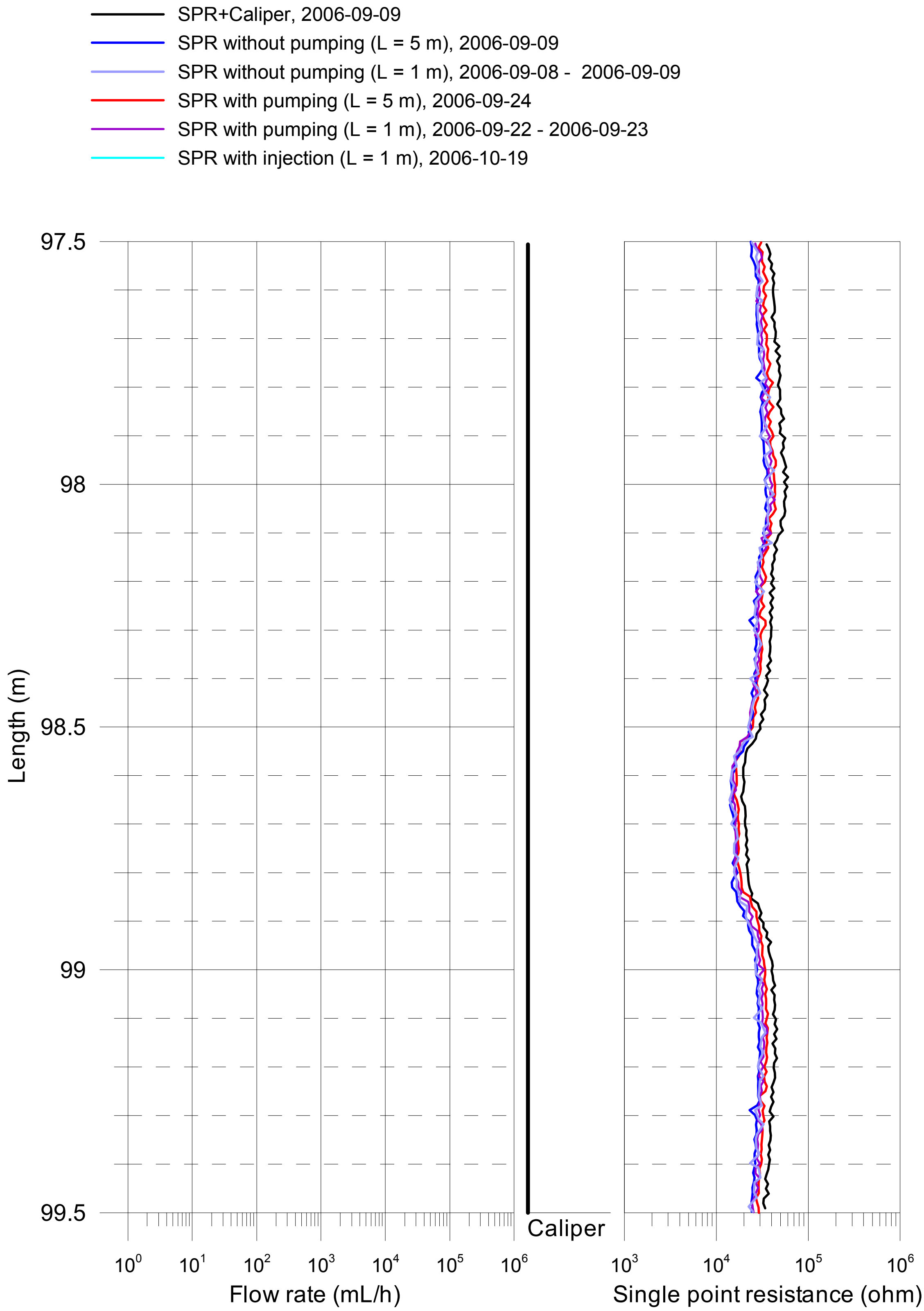

Laxemar, borehole KLX11E
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-09
SPR without pumping (L = 5 m), 2006-09-09
SPR without pumping (L = 1 m), 2006-09-08 - 2006-09-09
SPR with pumping (L = 5 m), 2006-09-24
SPR with pumping (L = 1 m), 2006-09-22 - 2006-09-23
SPR with injection (L = 1 m), 2006-10-19
Length (m)
49
49.5
50
50.5
51
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 KLX11E
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-09
SPR without pumping (L = 5 m), 2006-09-09
SPR without pumping (L = 1 m), 2006-09-08 - 2006-09-09
SPR with pumping (L = 5 m), 2006-09-24
SPR with pumping (L = 1 m), 2006-09-22 - 2006-09-23
SPR with injection (L = 1 m), 2006-10-19
Length (m)
59.5
60
60.5
61
61.5
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)

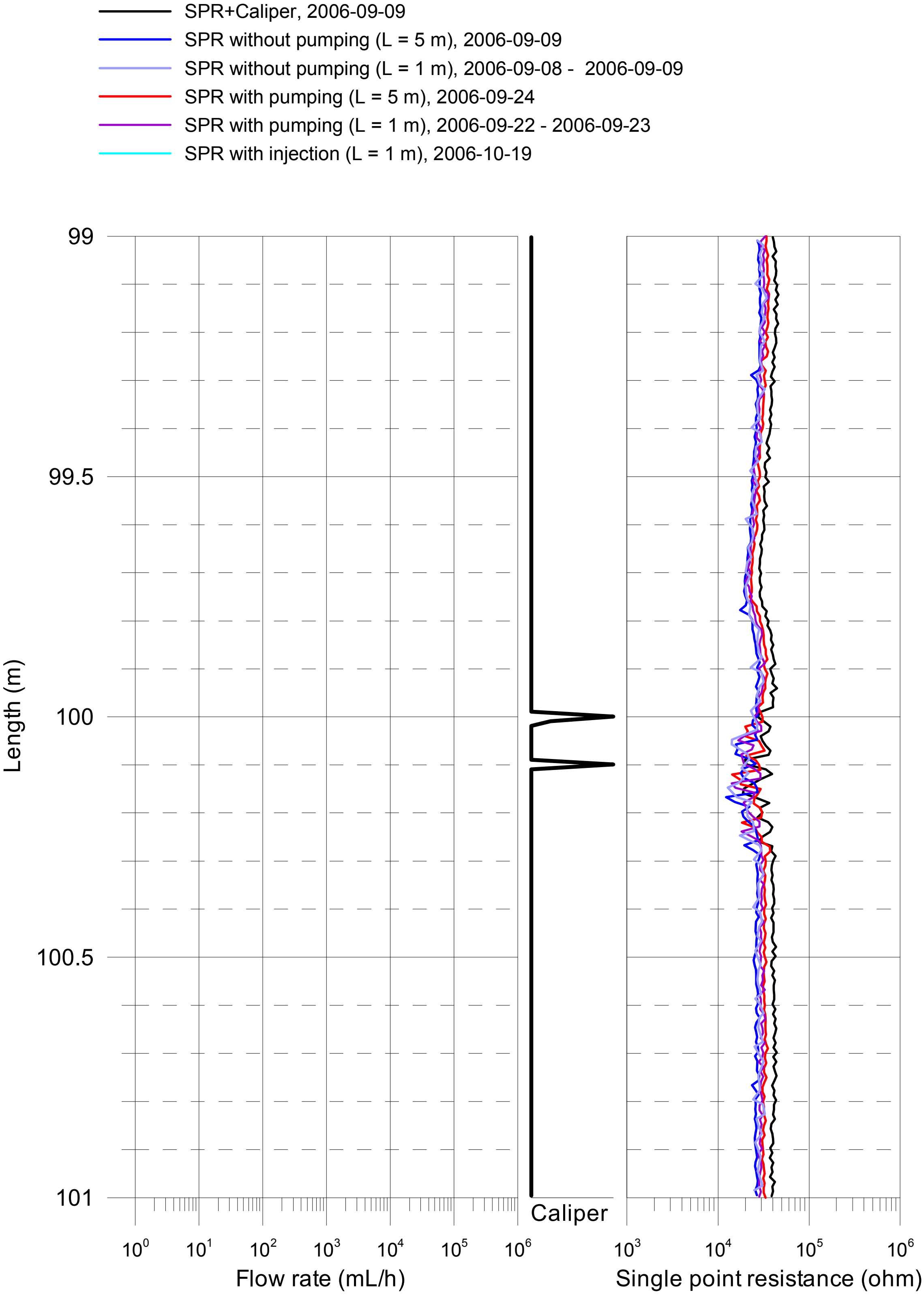

Laxemar, borehole KLX11E
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-09
SPR without pumping (L = 5 m), 2006-09-09
SPR without pumping (L = 1 m), 2006-09-08 - 2006-09-09
SPR with pumping (L = 5 m), 2006-09-24
SPR with pumping (L = 1 m), 2006-09-22 - 2006-09-23
SPR with injection (L = 1 m), 2006-10-19
Length (m)
73
73.5
74
74.5
75
Caliper
Flow rate (mL/h)
Single point resistance (ohm)


Laxemar, borehole KLX11E
SPR and Caliper results after length correction
SPR+Caliper, 2006-09-09
SPR without pumping (L = 5 m), 2006-09-09
SPR without pumping (L = 1 m), 2006-09-08 - 2006-09-09
SPR with pumping (L = 5 m), 2006-09-24
SPR with pumping (L = 1 m), 2006-09-22 - 2006-09-23
SPR with injection (L = 1 m), 2006-10-19
Length (m)
87
87.5
88
88.5
89
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

Laxemar, borehole KLX11E
SPR and Caliper results after length correction

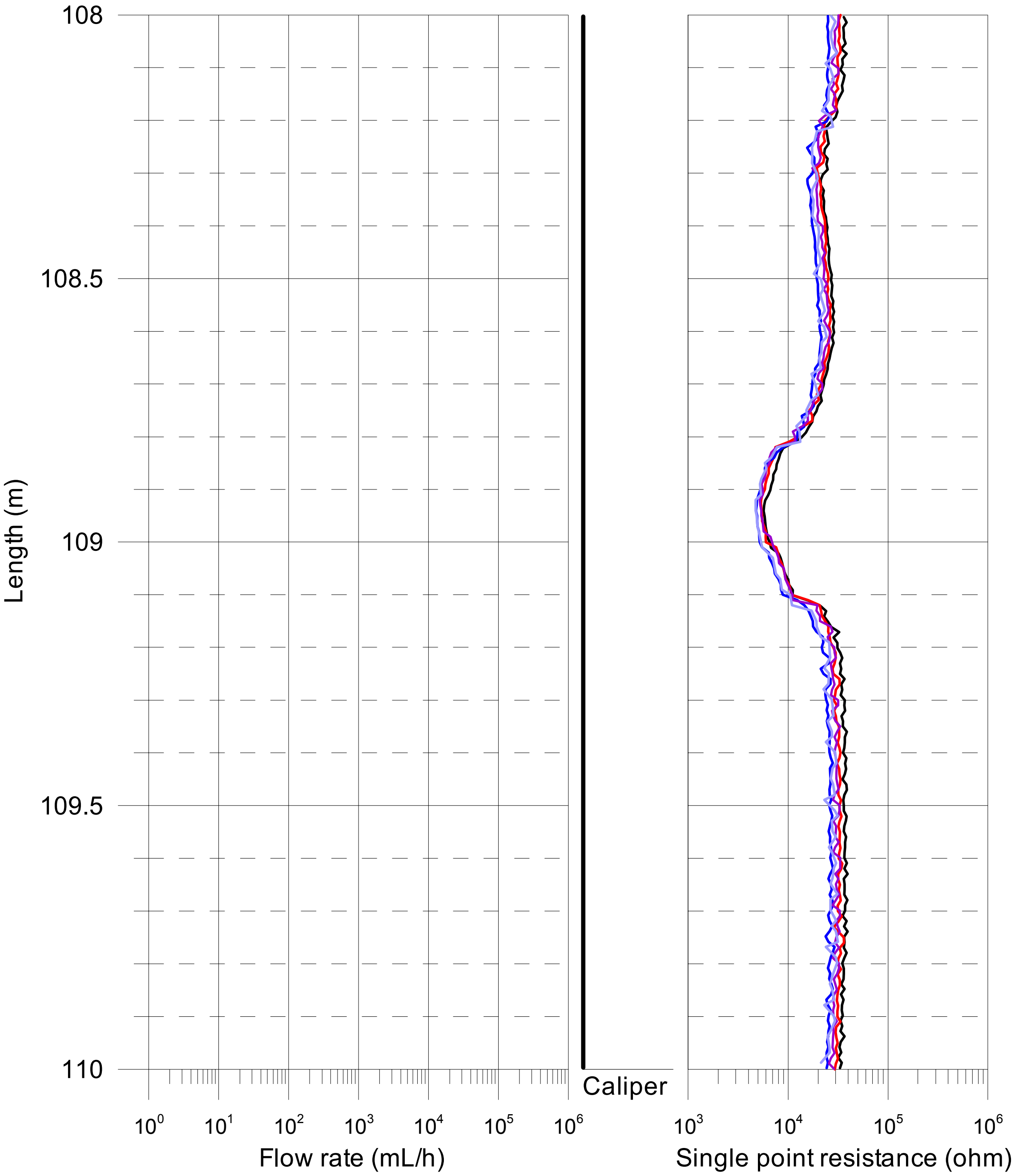


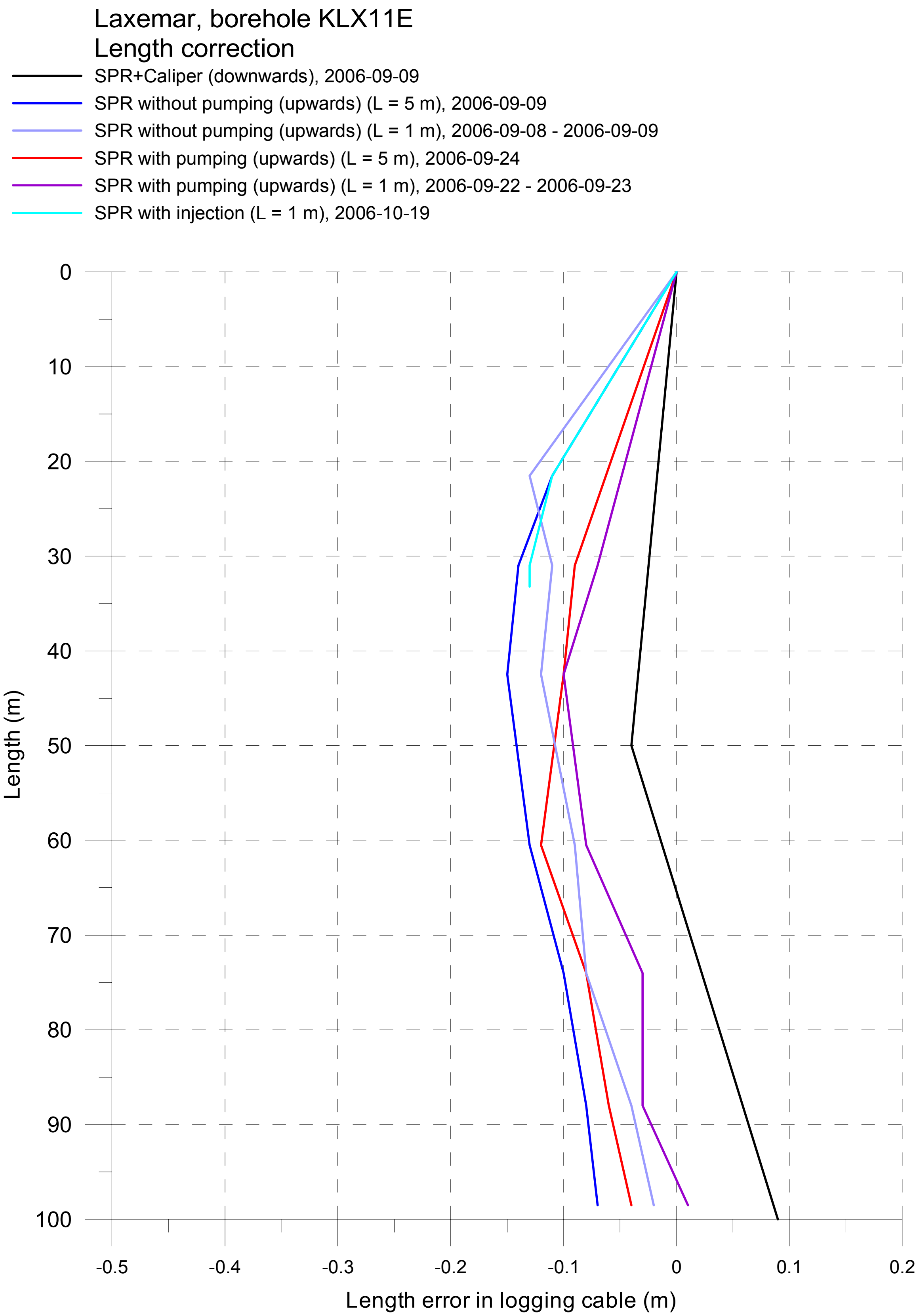
Laxemar, borehole KLX11E
SPR and Caliper results after length correction



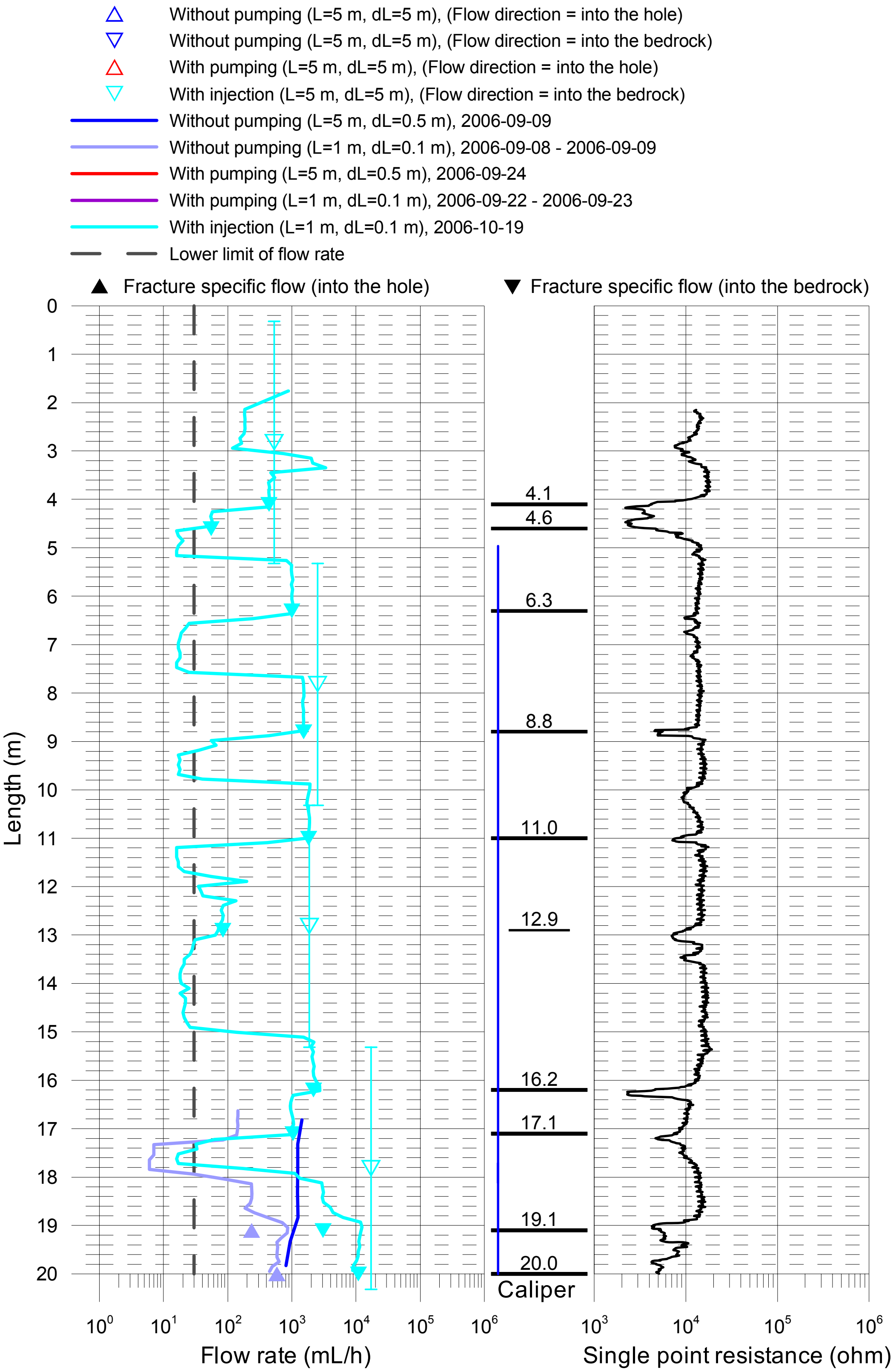
Laxemar, borehole KLX11E
SPR and Caliper results after length correction

SPR+Caliper, 2006-09-09
SPR without pumping (L = 5 m), 2006-09-09
SPR without pumping (L = 1 m), 2006-09-08 - 2006-09-09
SPR with pumping (L = 5 m), 2006-09-24
SPR with pumping (L = 1 m), 2006-09-22 - 2006-09-23
SPR with injection (L = 1 m), 2006-10-19

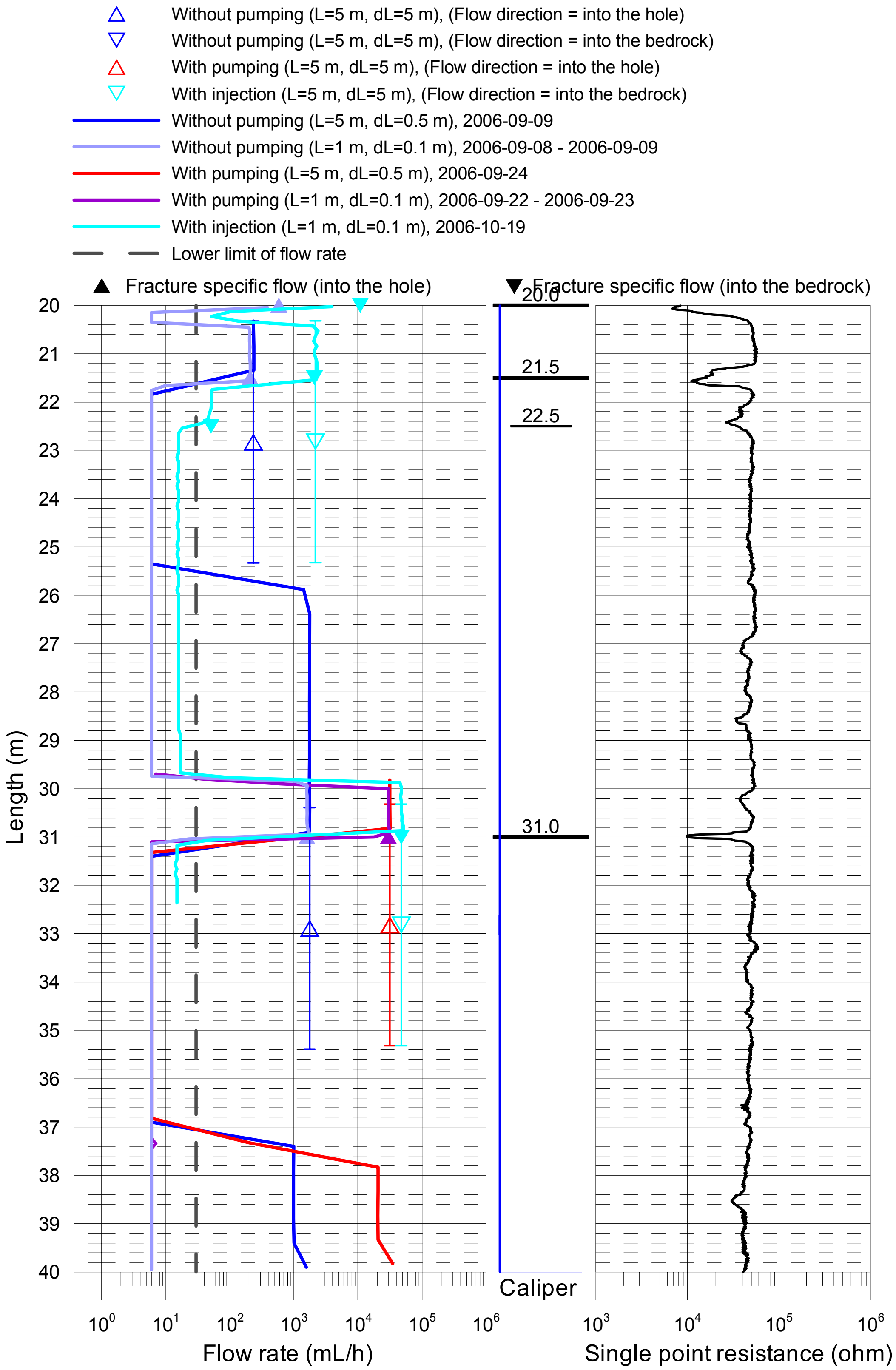


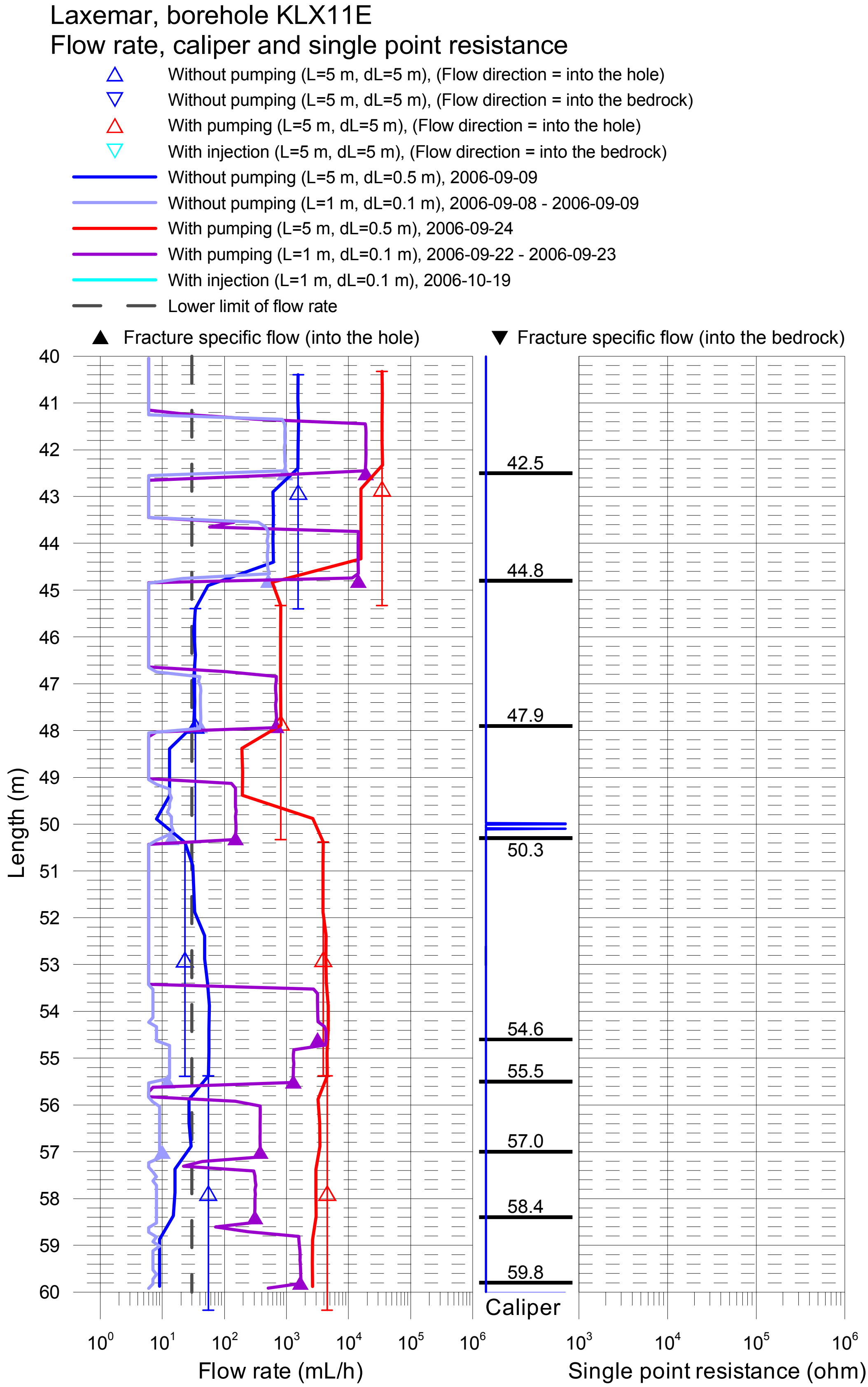

Laxemar, borehole KLX11E
Length correction
SPR+Caliper (downwards), 2006-09-09
SPR without pumping (upwards) (L = 5 m), 2006-09-09
SPR without pumping (upwards) (L = 1 m), 2006-09-08 - 2006-09-09
SPR with pumping (upwards) (L = 5 m), 2006-09-24
SPR with pumping (upwards) (L = 1 m), 2006-09-22 - 2006-09-23
SPR with injection (L = 1 m), 2006-10-19
Length (m)
0
10
20
30
40
50
60
70
80
90
100
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
Length error in logging cable (m)

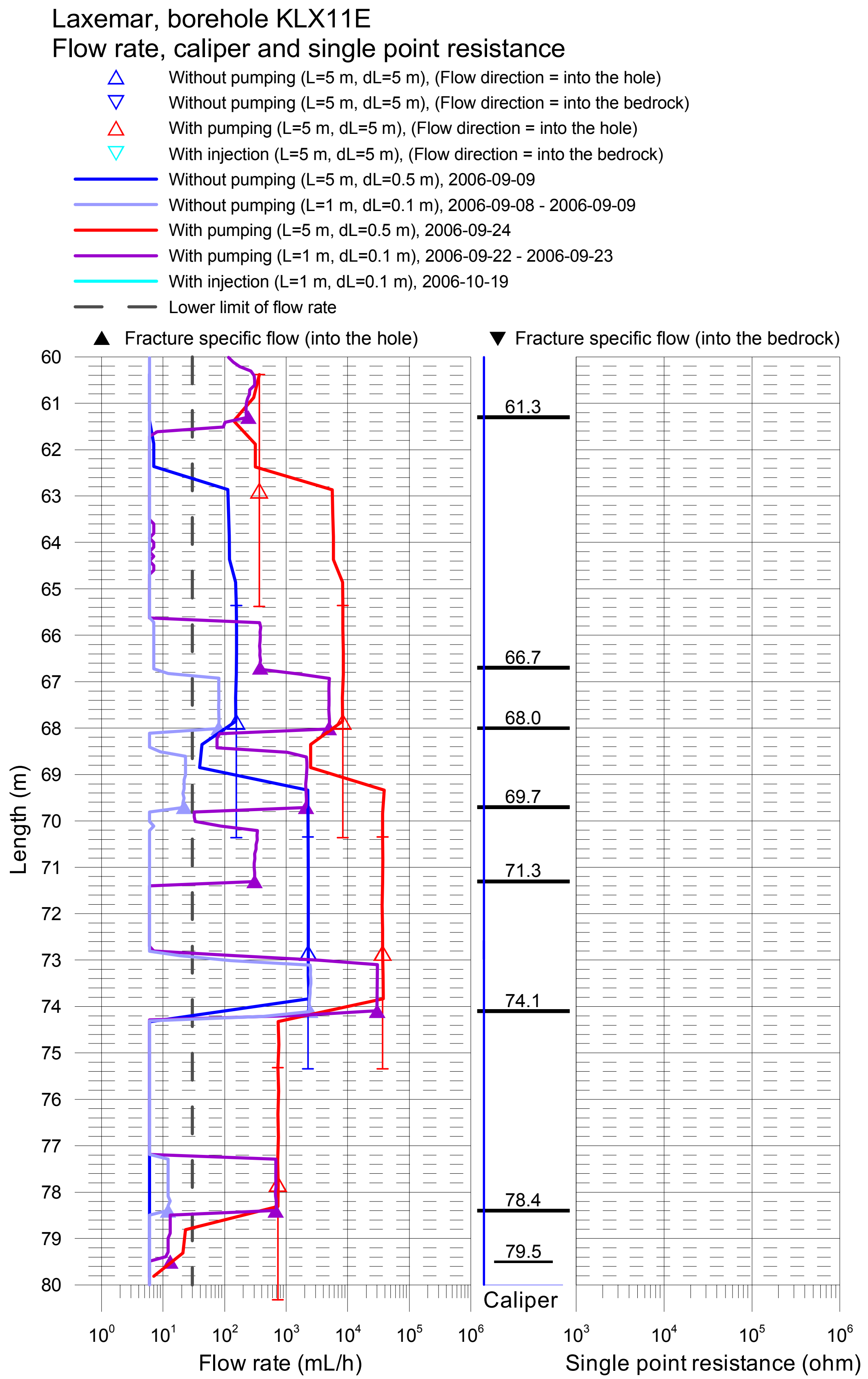
Laxemar, borehole KLX11E
Flow rate, caliper and single point resistance



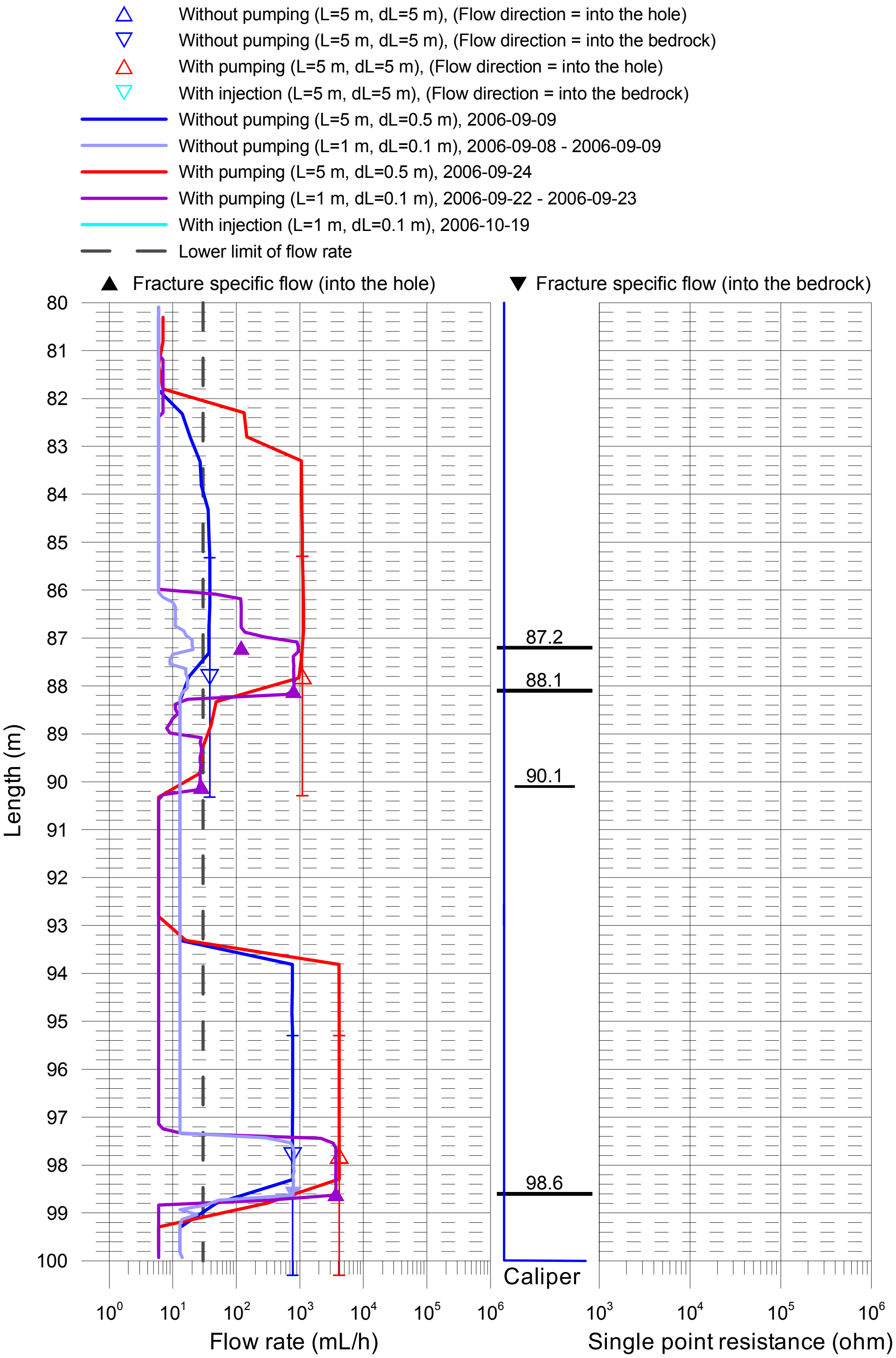
Laxemar, borehole KLX11E
Flow rate, caliper and single point resistance



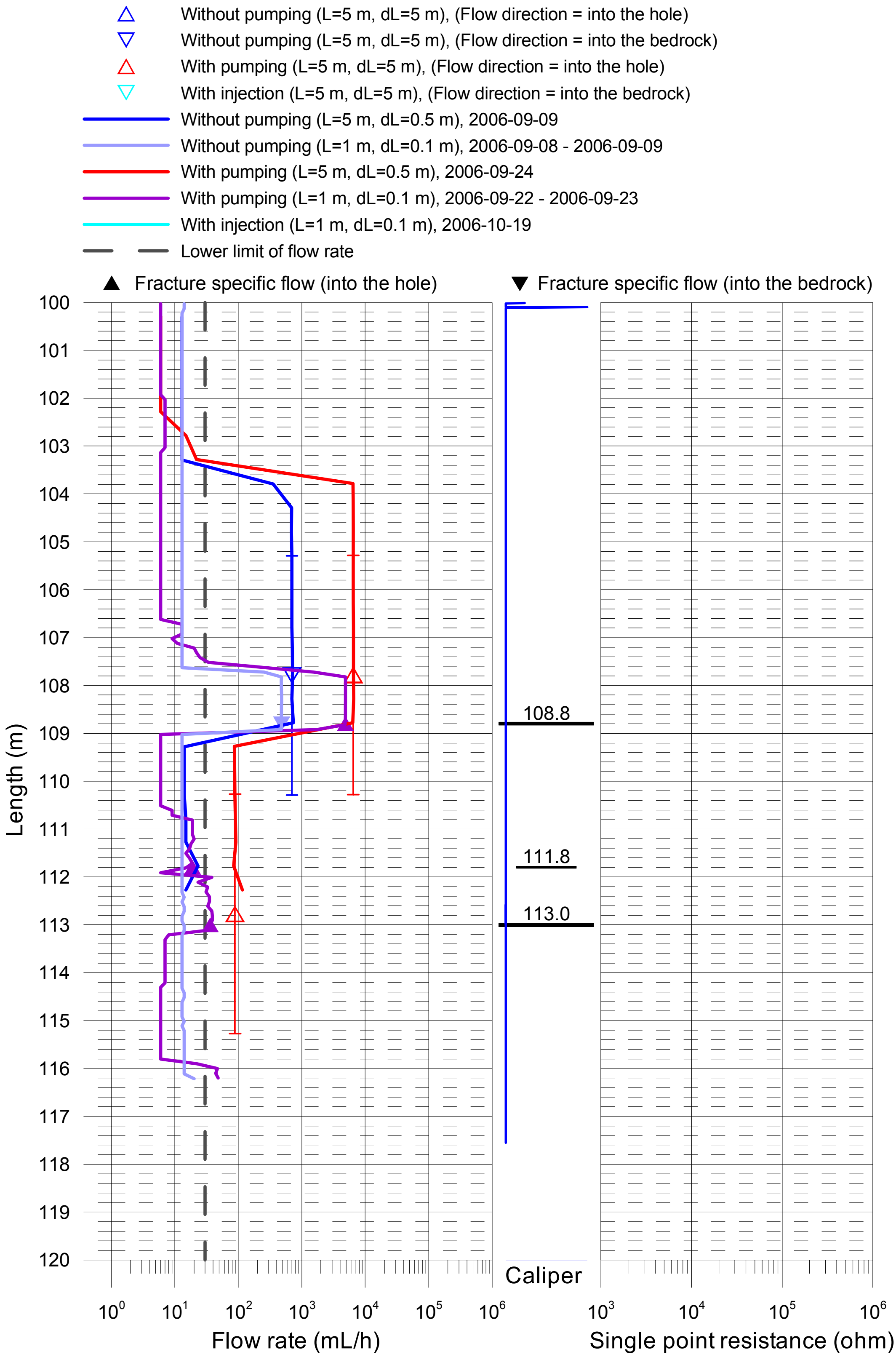

Laxemar, borehole KLX11E
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-09
Without pumping (L=1 m, dL=0.1 m), 2006-09-08 - 2006-09-09
With pumping (L=5 m, dL=0.5 m), 2006-09-24
With pumping (L=1 m, dL=0.1 m), 2006-09-22 - 2006-09-23
With injection (L=1 m, dL=0.1 m), 2006-10-19
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
42.5
44.8
47.9
50.3
54.6
55.5
57.0
58.4
59.8
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)

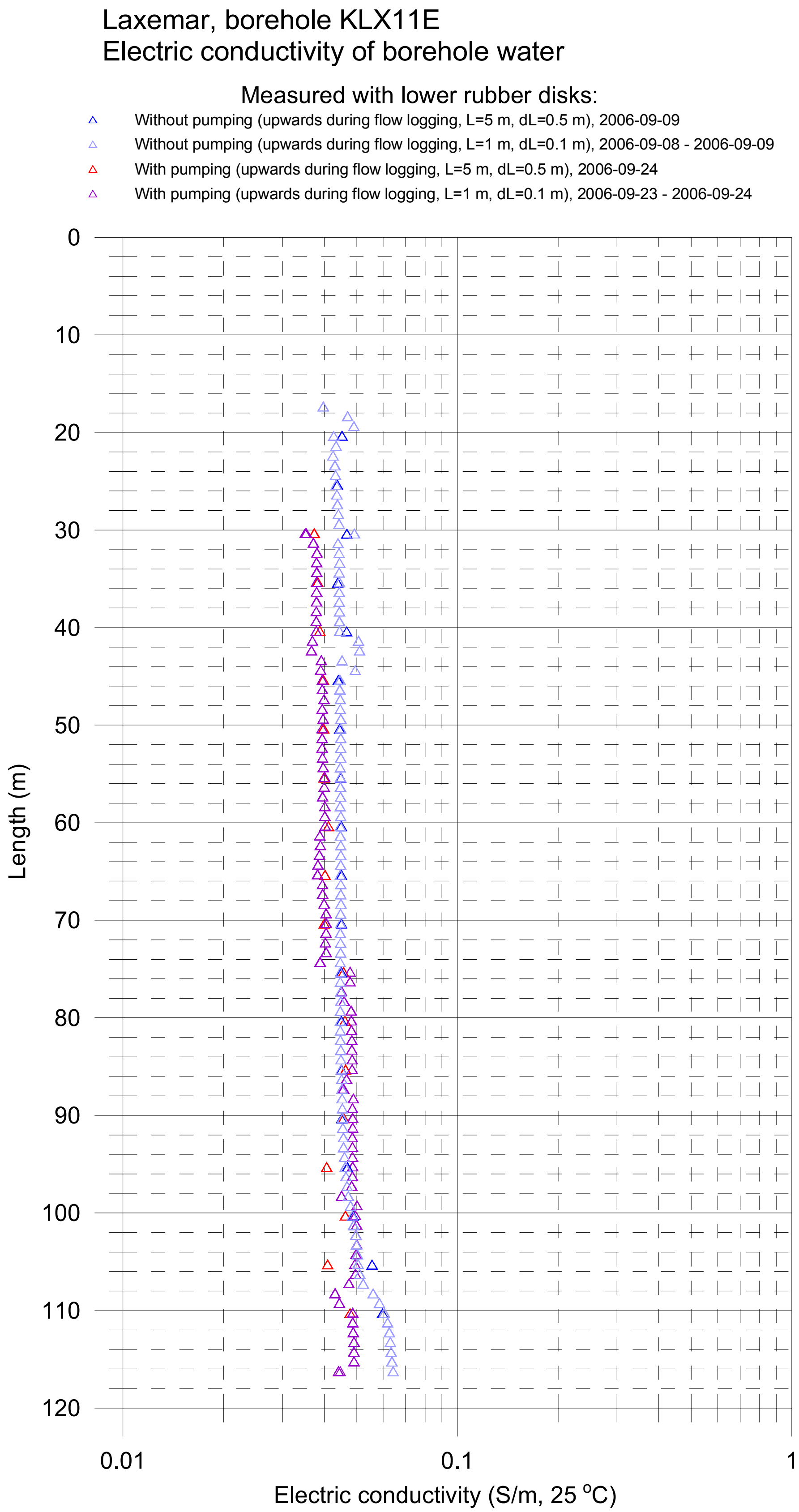

Laxemar, borehole KLX11E
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-09
Without pumping (L=1 m, dL=0.1 m), 2006-09-08 - 2006-09-09
With pumping (L=5 m, dL=0.5 m), 2006-09-24
With pumping (L=1 m, dL=0.1 m), 2006-09-22 - 2006-09-23
With injection (L=1 m, dL=0.1 m), 2006-10-19
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
61.3
66.7
68.0
69.7
71.3
74.1
78.4
79.5
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)

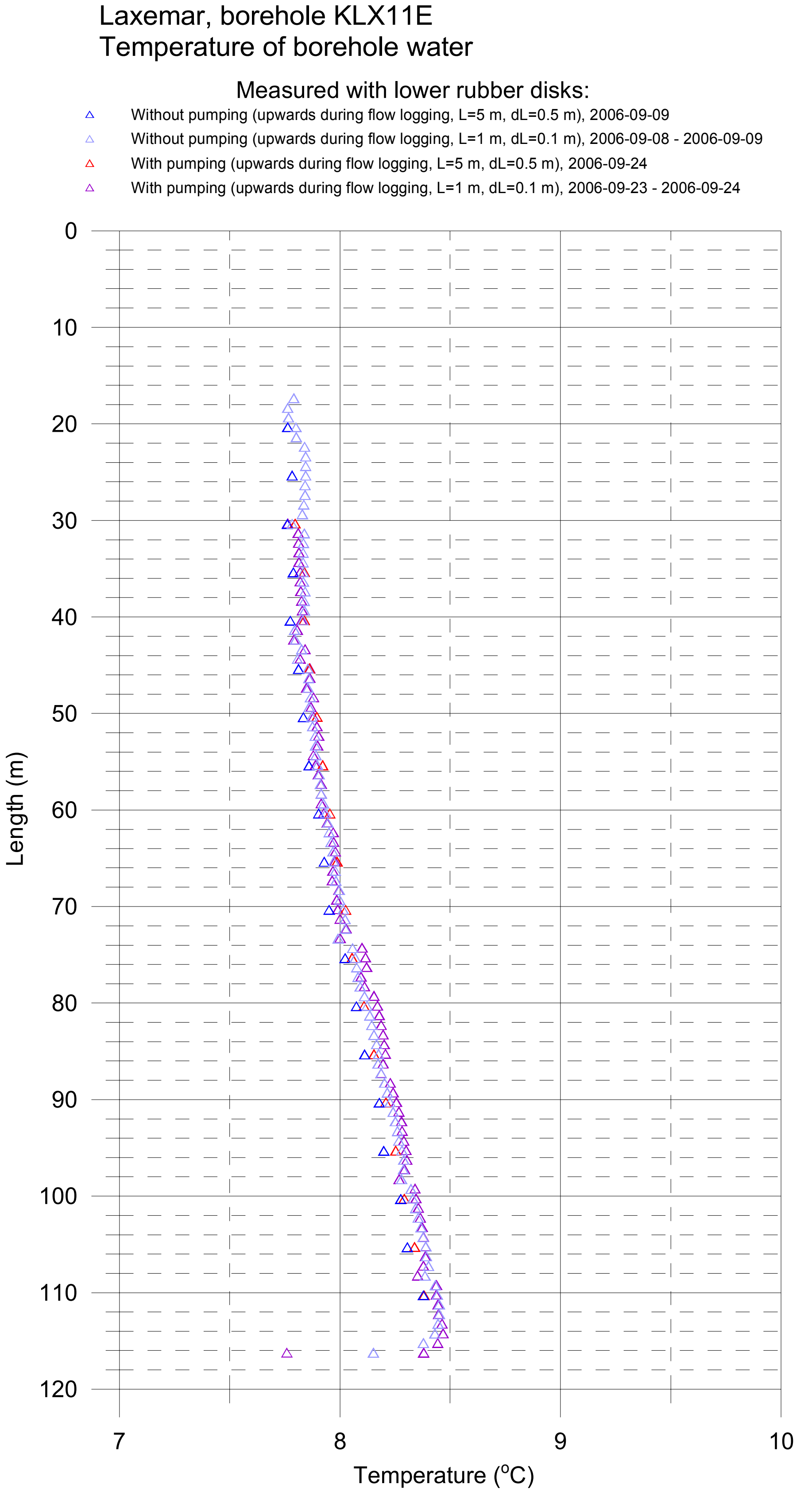
Laxemar, borehole KLX11E
Flow rate, caliper and single point resistance

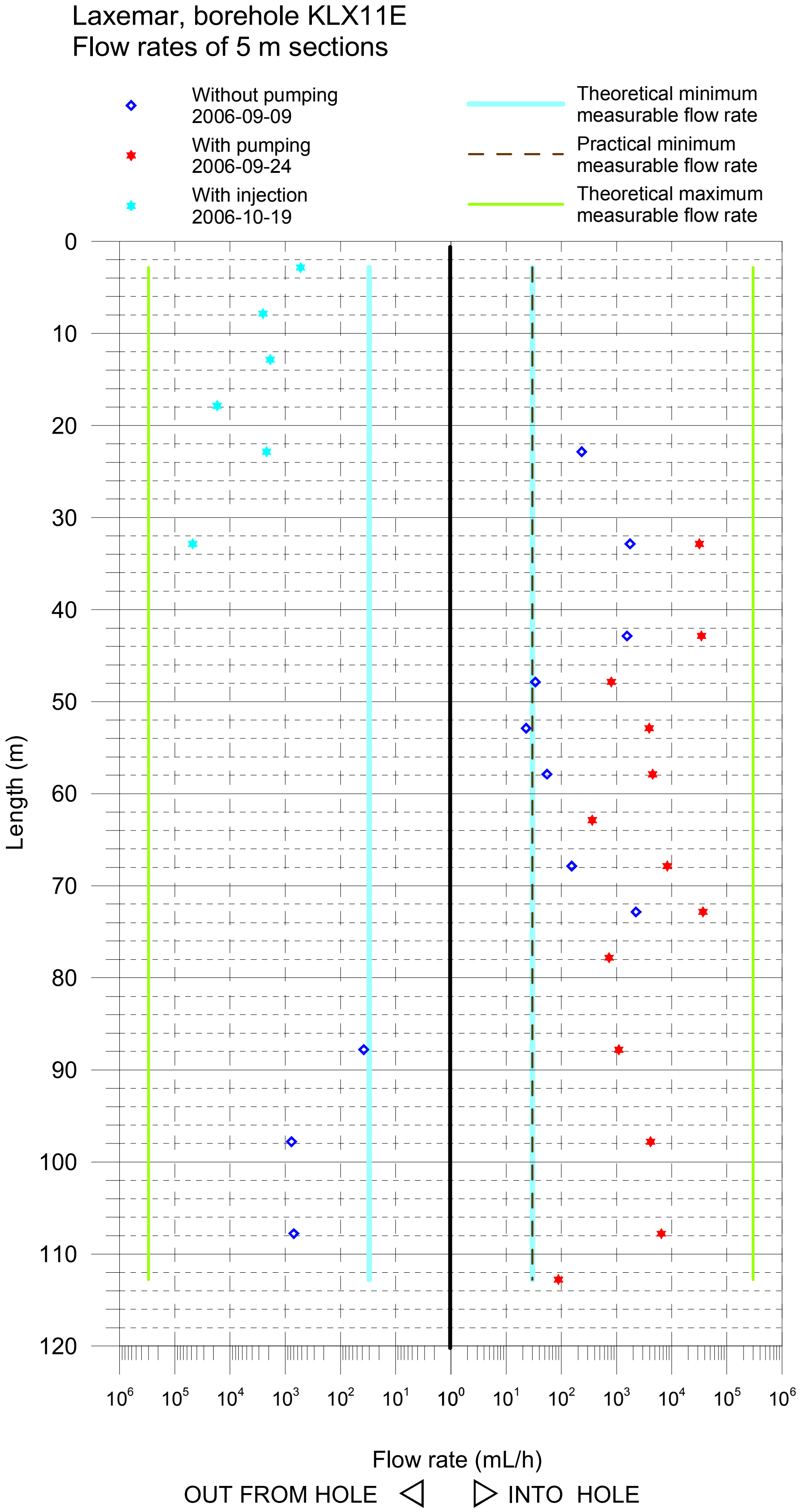


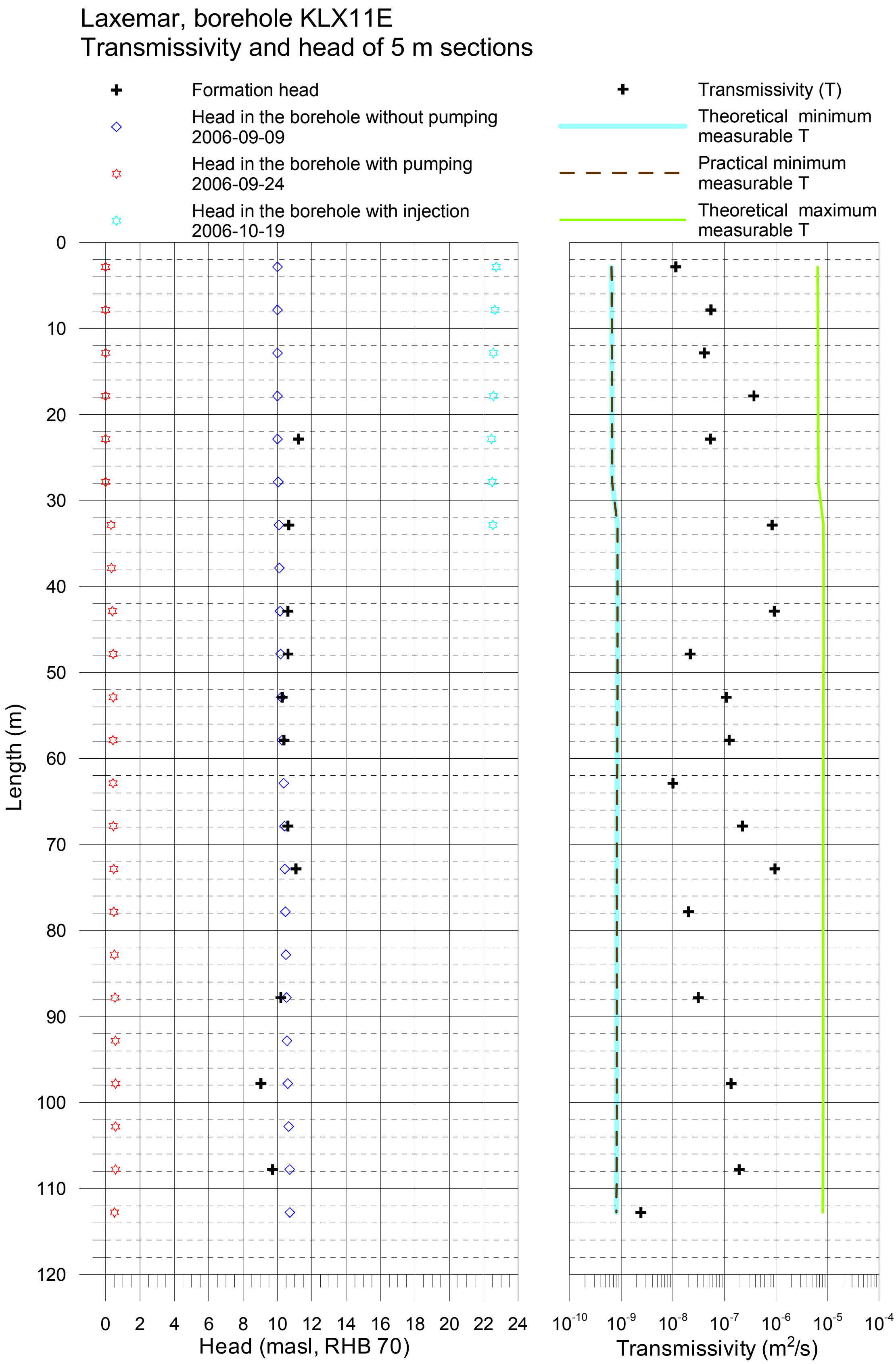
Laxemar, borehole KLX11E
Flow rate, caliper and single point resistance



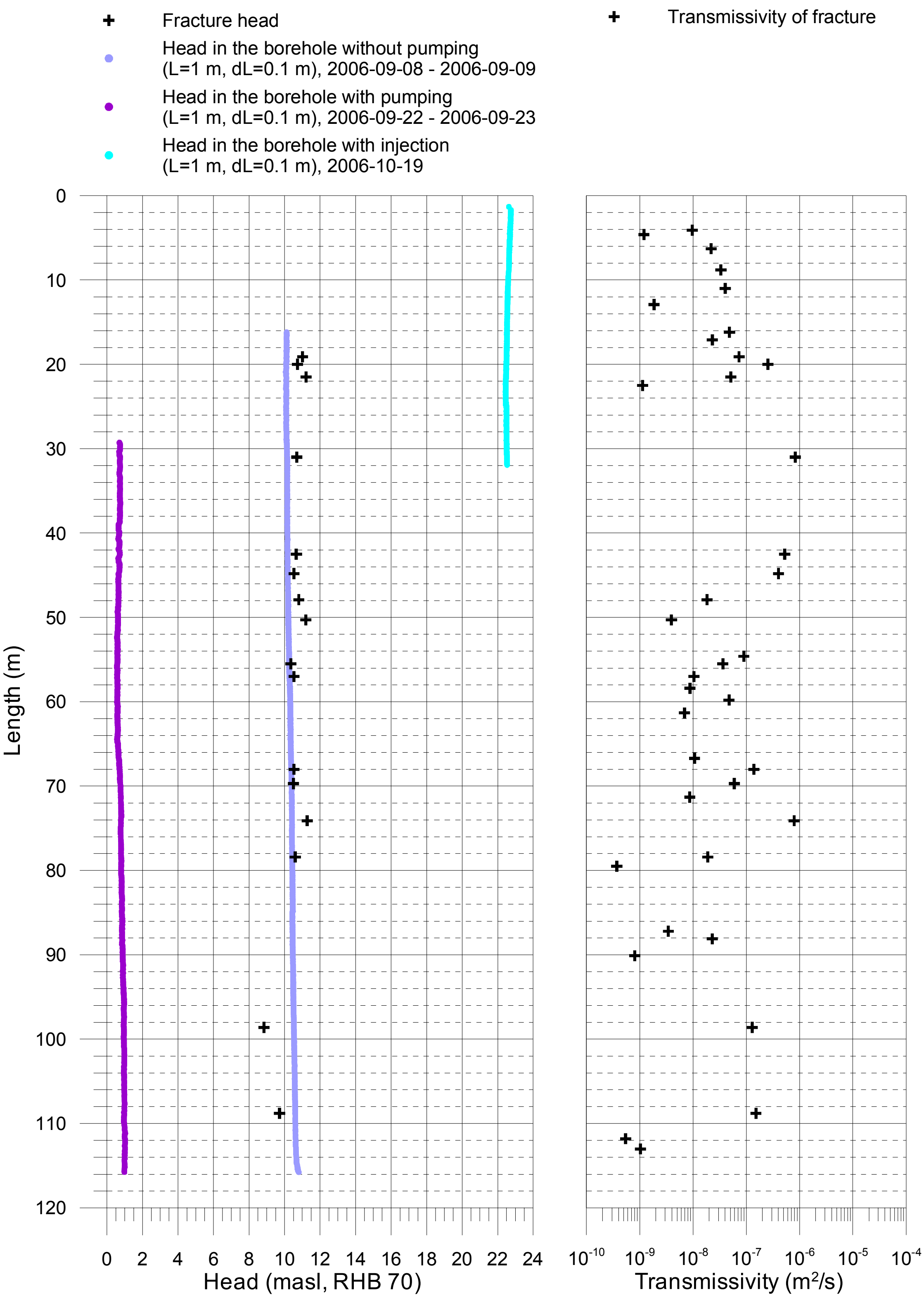

Laxemar, borehole KLX11E
Electric conductivity of borehole water
Measured with lower rubber disks:
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-09
Without pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-08 - 2006-09-09
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-24
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-23 - 2006-09-24
Length (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
0.01
0.1
1
Electric conductivity (S/m, 25 °C)


Laxemar, borehole KLX11E
Temperature of borehole water
Measured with lower rubber disks:
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-09
Without pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-08 - 2006-09-09
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-24
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-23 - 2006-09-24
Length (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
7
8
9
10
Temperature (°C)


Laxemar, borehole KLX11E
Flow rates of 5 m sections
Without pumping 2006-09-09
With pumping 2006-09-24
With injection 2006-10-19
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
110
120
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 KLX11E
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-09-09
Head in the borehole with pumping 2006-09-24
Head in the borehole with injection 2006-10-19
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 KLX11E
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)
KLX11E	2	121.3	5A	20060922	14:50	20061004	9:04	20060929	13:52	5	0.5	3.77E–05	–5.83E–05

5. PFL-Difference flow logging – Basic test data

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (m.a.s.l.)	h_1 (m.a.s.l.)	h_2 (m.a.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
1378920	10140	667200	292560	10.26	0.19	22.71	–10.07	12.45	3.70E–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)	T_D-measl$_{LT}$ (m^2/s)	T_D-measl$_{LP}$ (m^2/s)	T_D-measl$_U$ (m^2/s)	Comments
KLX11E	0.36	5.36	5	–	10.00	–1.47E–07	22.73	1.1E–08	–	30	6.5E–10	6.5E–10	6.5E–06	*,**
KLX11E	5.36	10.36	5	–	10.00	–7.00E–07	22.65	5.5E–08	–	30	6.5E–10	6.5E–10	6.5E–06	*,**
KLX11E	10.36	15.36	5	–	10.00	–5.19E–07	22.56	4.1E–08	–	30	6.6E–10	6.6E–10	6.6E–06	*,**
KLX11E	15.36	20.36	5	–	10.00	–4.75E–06	22.56	3.7E–07	–	30	6.6E–10	6.6E–10	6.6E–06	*,**
KLX11E	20.36	25.36	5	6.50E–08	10.00	–6.06E–07	22.45	5.3E–08	11.2	30	6.6E–10	6.6E–10	6.6E–06	*
KLX11E	25.36	30.36	5	–	10.05	–	22.50	–	–	30	6.6E–10	6.6E–10	6.6E–06	*
KLX11E	30.36	35.36	5	4.89E–07	10.09	8.81E–06	0.32	8.4E–07	10.7	30	8.4E–10	8.4E–10	8.4E–06	
KLX11E	35.36	40.36	5	–	10.11	–	0.34	–	–	30	8.4E–10	8.4E–10	8.4E–06	
KLX11E	40.37	45.37	5	4.31E–07	10.14	9.61E–06	0.40	9.3E–07	10.6	30	8.5E–10	8.5E–10	8.5E–06	
KLX11E	45.36	50.36	5	9.44E–09	10.18	2.24E–07	0.44	2.2E–08	10.6	30	8.5E–10	8.5E–10	8.5E–06	
KLX11E	50.39	55.39	5	6.39E–09	10.22	1.09E–06	0.44	1.1E–07	10.3	30	8.4E–10	8.4E–10	8.4E–06	
KLX11E	55.38	60.38	5	1.53E–08	10.26	1.26E–06	0.43	1.2E–07	10.4	30	8.4E–10	8.4E–10	8.4E–06	
KLX11E	60.38	65.38	5	–	10.37	1.01E–07	0.43	1.0E–08	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX11E	65.36	70.36	5	4.28E–08	10.41	2.31E–06	0.45	2.2E–07	10.6	30	8.3E–10	8.3E–10	8.3E–06	
KLX11E	70.34	75.34	5	6.28E–07	10.43	1.03E–05	0.47	9.6E–07	11.1	30	8.3E–10	8.3E–10	8.3E–06	
KLX11E	75.33	80.33	5	–	10.46	2.03E–07	0.48	2.0E–08	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX11E	80.32	85.32	5	–	10.49	–	0.51	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX11E	85.31	90.31	5	–1.06E–08	10.52	3.06E–07	0.55	3.1E–08	10.2	30	8.3E–10	8.3E–10	8.3E–06	
KLX11E	90.32	95.32	5	–	10.55	–	0.57	–	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX11E	95.30	100.30	5	–2.14E–07	10.60	1.15E–06	0.58	1.4E–07	9.0	30	8.2E–10	8.2E–10	8.2E–06	
KLX11E	100.30	105.30	5	–	10.66	–	0.58	–	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX11E	105.29	110.29	5	–1.95E–07	10.71	1.80E–06	0.58	1.9E–07	9.7	30	8.1E–10	8.1E–10	8.1E–06	
KLX11E	110.28	115.28	5	–	10.72	2.47E–08	0.52	2.4E–09	–	30	8.1E–10	8.1E–10	8.1E–06	

* Q_1 value is from injection.

** Q_0 is evaluated to be zero since it is not measured in this section.

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
KLX11E	4.1	1	0.1	–	10.11	–1.23E–07	22.70	9.7E–09	–	**,***
KLX11E	4.6	1	0.1	–	10.11	–1.53E–08	22.70	1.2E–09	–	**,***
KLX11E	6.3	1	0.1	–	10.11	–2.78E–07	22.66	2.2E–08	–	**,***
KLX11E	8.8	1	0.1	–	10.11	–4.22E–07	22.63	3.3E–08	–	**,***
KLX11E	11.0	1	0.1	–	10.11	–5.08E–07	22.57	4.0E–08	–	**,***
KLX11E	12.9	1	0.1	–	10.11	–2.33E–08	22.55	1.9E–09	–	**,***
KLX11E	16.2	1	0.1	–	10.11	–6.06E–07	22.52	4.8E–08	–	**,***
KLX11E	17.1	1	0.1	–	10.11	–2.89E–07	22.52	2.3E–08	–	**,***
KLX11E	19.1	1	0.1	6.56E–08	10.12	–8.50E–07	22.50	7.3E–08	11.0	**
KLX11E	20.0	1	0.1	1.62E–07	10.10	–3.03E–06	22.50	2.5E–07	10.7	**
KLX11E	21.5	1	0.1	5.78E–08	10.10	–5.83E–07	22.47	5.1E–08	11.2	**
KLX11E	22.5	1	0.1	–	10.08	–1.42E–08	22.46	1.1E–09	–	**
KLX11E	31.0	1	0.1	4.44E–07	10.16	8.33E–06	0.75	8.3E–07	10.7	
KLX11E	42.5	1	0.1	2.60E–07	10.17	5.28E–06	0.72	5.3E–07	10.7	
KLX11E	44.8	1	0.1	1.42E–07	10.18	4.00E–06	0.67	4.0E–07	10.5	
KLX11E	47.9	1	0.1	1.11E–08	10.20	1.88E–07	0.63	1.8E–08	10.8	
KLX11E	50.3	1	0.1	3.89E–09	10.22	4.19E–08	0.62	3.9E–09	11.2	
KLX11E	54.6	1	0.1	–	10.26	8.78E–07	0.60	9.0E–08	–	
KLX11E	55.5	1	0.1	3.33E–09	10.26	3.58E–07	0.59	3.6E–08	10.4	
KLX11E	57.0	1	0.1	2.78E–09	10.27	1.05E–07	0.58	1.0E–08	10.5	
KLX11E	58.4	1	0.1	–	10.31	8.61E–08	0.61	8.8E–09	–	
KLX11E	59.8	1	0.1	–	10.31	4.64E–07	0.59	4.7E–08	–	
KLX11E	61.3	1	0.1	–	10.33	6.78E–08	0.61	6.9E–09	–	
KLX11E	66.7	1	0.1	–	10.36	1.05E–07	0.67	1.1E–08	–	
KLX11E	68.0	1	0.1	2.22E–08	10.37	1.38E–06	0.70	1.4E–07	10.5	
KLX11E	69.7	1	0.1	6.11E–09	10.40	5.86E–07	0.75	5.9E–08	10.5	
KLX11E	71.3	1	0.1	–	10.40	8.44E–08	0.78	8.7E–09	–	
KLX11E	74.1	1	0.1	6.81E–07	10.42	8.39E–06	0.78	7.9E–07	11.3	
KLX11E	78.4	1	0.1	3.33E–09	10.43	1.87E–07	0.80	1.9E–08	10.6	
KLX11E	79.5	1	0.1	–	10.44	3.61E–09	0.81	3.7E–10	–	*
KLX11E	87.2	1	0.1	–	10.45	3.33E–08	0.86	3.4E–09	–	
KLX11E	88.1	1	0.1	–	10.46	2.22E–07	0.86	2.3E–08	–	
KLX11E	90.1	1	0.1	–	10.47	7.78E–09	0.89	8.0E–10	–	*
KLX11E	98.6	1	0.1	–2.18E–07	10.52	1.03E–06	0.95	1.3E–07	8.8	
KLX11E	108.8	1	0.1	–1.34E–07	10.59	1.34E–06	0.96	1.5E–07	9.7	
KLX11E	111.8	1	0.1	–	10.62	5.28E–09	1.01	5.4E–10	–	*
KLX11E	113.0	1	0.1	–	10.63	1.00E–08	1.02	1.0E–09	–	

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

** Q_1 value is from injection.

*** Q_0 is evaluated to be zero since it is not measured in this section.

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.

Explanations Header	Unit	Explanations
s_1	m	Drawdown of the water level in the borehole during first pumping period. Difference between the actual hydraulic head and the initial head ($s_1=h_1–h_0$).
s_2	m	Drawdown of the water level in the borehole during second pumping period. Difference between the actual hydraulic head and the initial head ($s_2=h_2–h_0$).
T	m^2/s	Transmissivity of the entire borehole.
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with $h=h_0$ in the open borehole.
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period.
Q_2	m^3/s	Measured flow rate through the test section or flow anomaly during the second pumping period.
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid before pumping
h_{1FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period.
h_{2FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the second pumping period.
EC_w	S/m	Measured electric conductivity of the borehole fluid in the test section during difference flow logging.
Te_w	°C	Measured borehole fluid temperature in the test section during difference flow logging.
EC_f	S/m	Measured fracture-specific electric conductivity of the fluid in flow anomaly during difference flow logging.
Te_f	°C	Measured fracture-specific fluid temperature in flow anomaly during difference flow logging.
T_D	m^2/s	Transmissivity of section or flow anomaly based on 2D model for evaluation of formation properties of the test section based on PFL-DIFF.
T-$measl_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-$measl_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-$measl_U$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

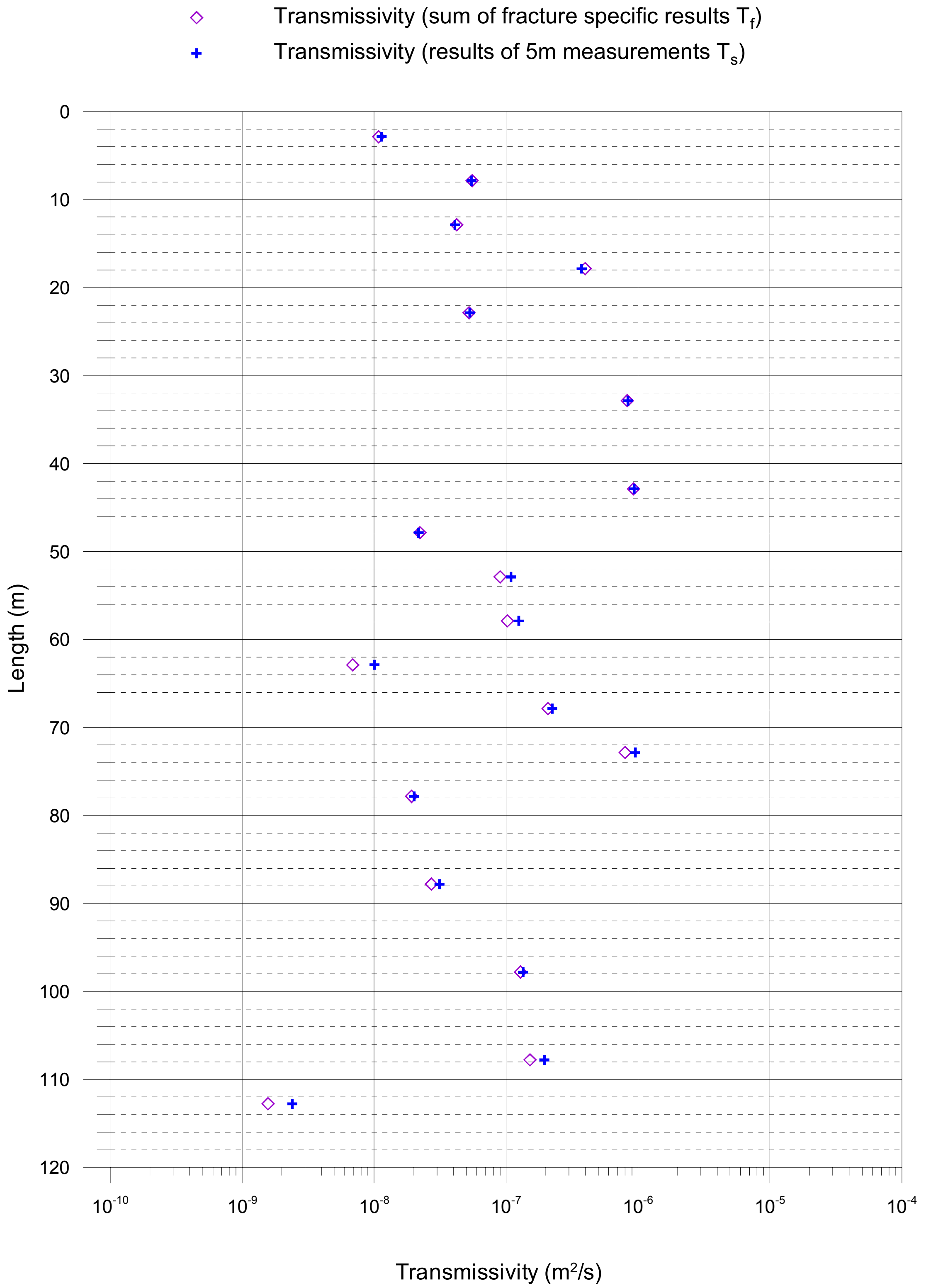
Calculation of conductive fracture frequency

Borehole ID	SecUp (m)	SecLow (m)	Number of fractures, total	Number of fractures 10–100 (mL/h)	Number of fractures 100–1,000 (mL/h)	Number of fractures 1,000–10,000 (mL/h)	Number of fractures 10,000–100,000 (mL/h)	Number of fractures 100,000–1,000,000 (mL/h)
KLX11E	0.36	5.36	2	1*	1*	0	0	0
KLX11E	5.36	10.36	2	0	0	2*	0	0
KLX11E	10.36	15.36	2	1*	0	1*	0	0
KLX11E	15.36	20.36	4	0	0	3*	1*	0
KLX11E	20.36	25.36	2	1*	0	1*	0	0
KLX11E	25.36	30.36	0	0	0	0	0	0
KLX11E	30.36	35.36	1	0	0	0	1	0
KLX11E	35.36	40.36	0	0	0	0	0	0
KLX11E	40.37	45.37	2	0	0	0	2	0
KLX11E	45.36	50.36	2	0	2	0	0	0
KLX11E	50.39	55.39	1	0	0	1	0	0
KLX11E	55.38	60.38	4	0	2	2	0	0
KLX11E	60.38	65.38	1	0	1	0	0	0
KLX11E	65.36	70.36	3	0	1	2	0	0
KLX11E	70.34	75.34	2	0	1	0	1	0
KLX11E	75.33	80.33	2	1	1	0	0	0
KLX11E	80.32	85.32	0	0	0	0	0	0
KLX11E	85.31	90.31	3	1	2	0	0	0
KLX11E	90.32	95.32	0	0	0	0	0	0
KLX11E	95.30	100.30	1	0	0	1	0	0
KLX11E	100.30	105.30	0	0	0	0	0	0
KLX11E	105.29	110.29	1	0	0	1	0	0
KLX11E	110.28	115.28	2	2	0	0	0	0

* During Injection (drawdown not the same as in the other measurements).

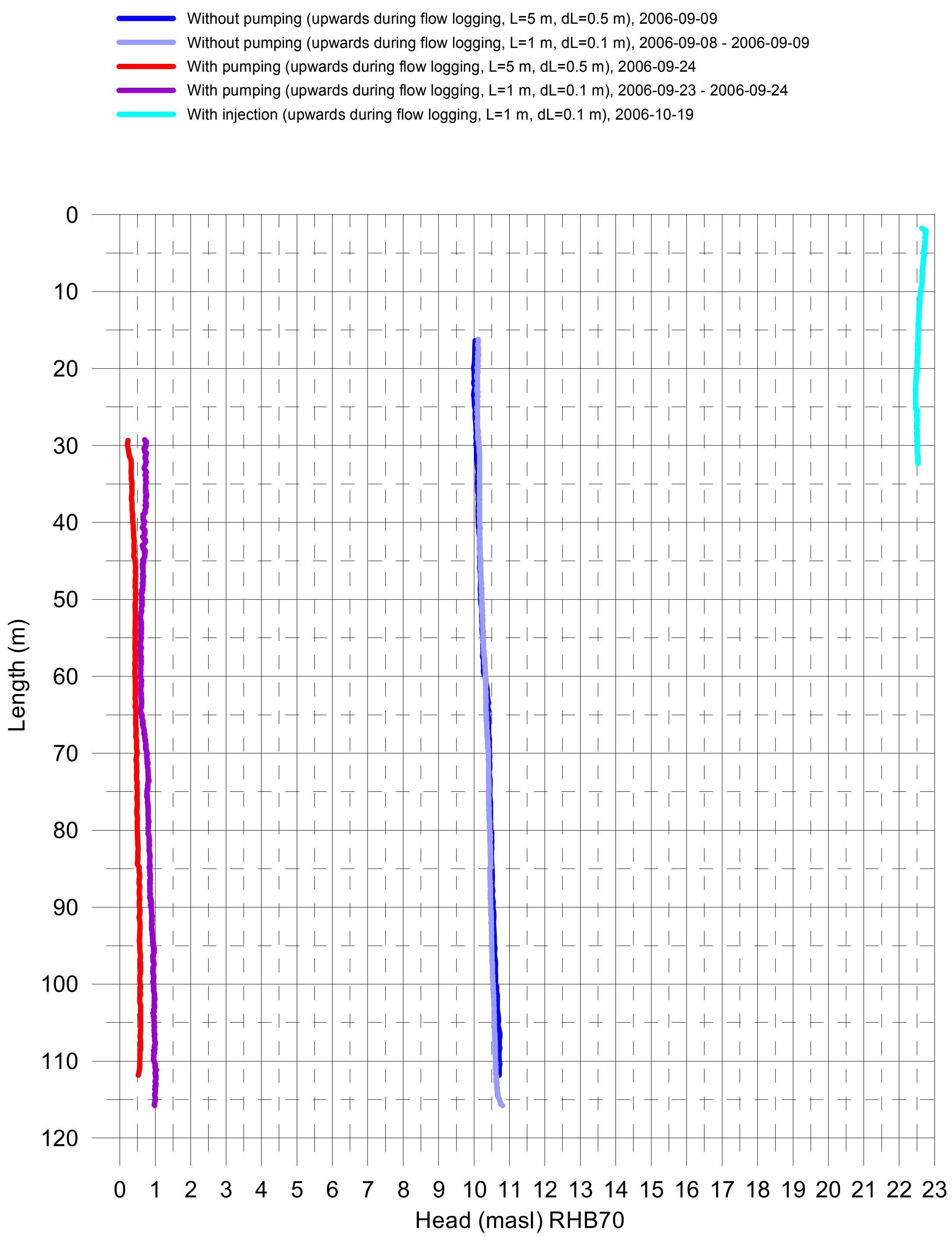
Laxemar, borehole KLX11E
Calculation of conductive fracture frequency

Laxemar, borehole KLX11E
Comparison between section transmissivity and fracture transmissivity

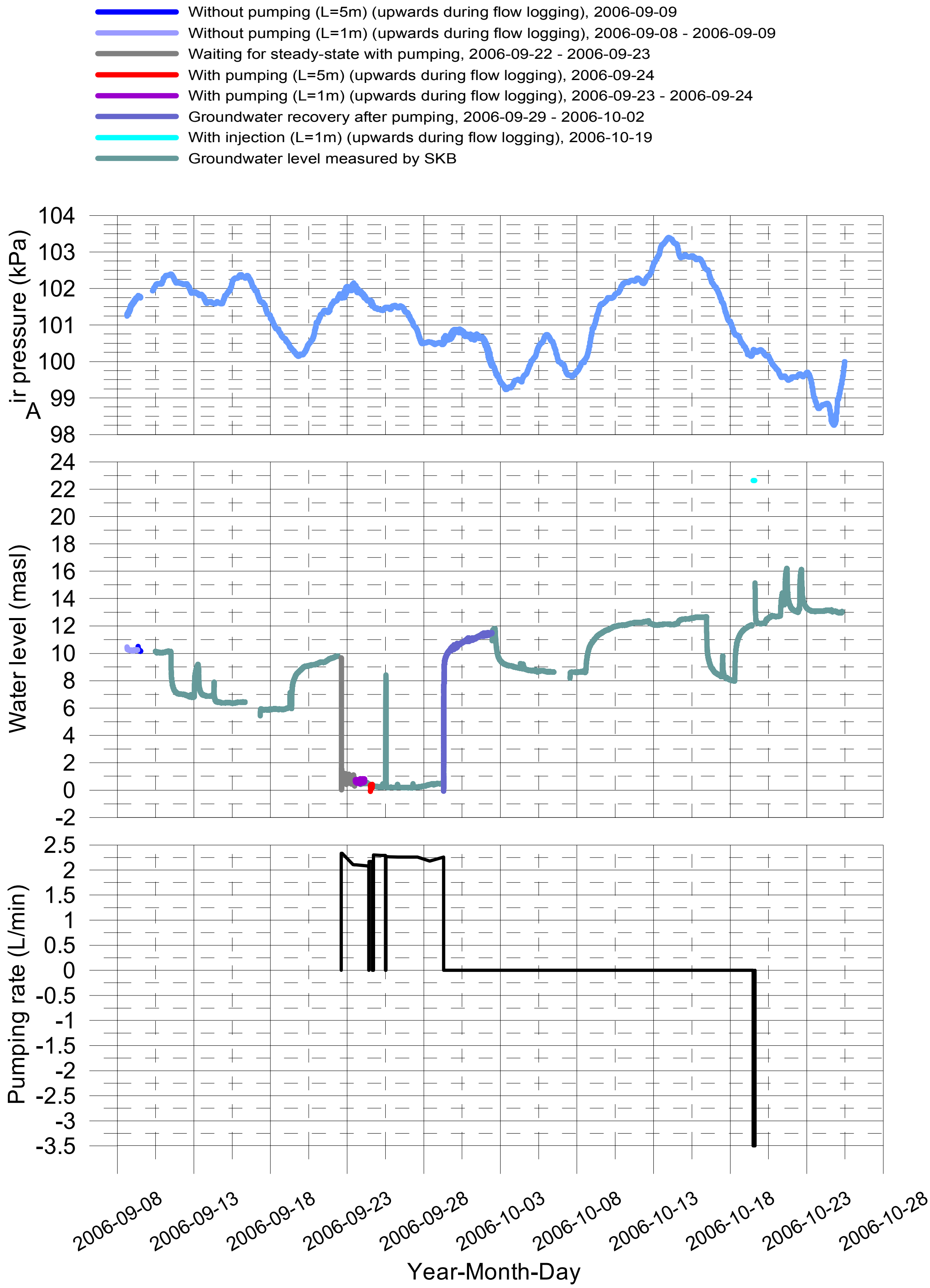


Laxemar, borehole KLX11E
Head in the borehole during flow logging

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)

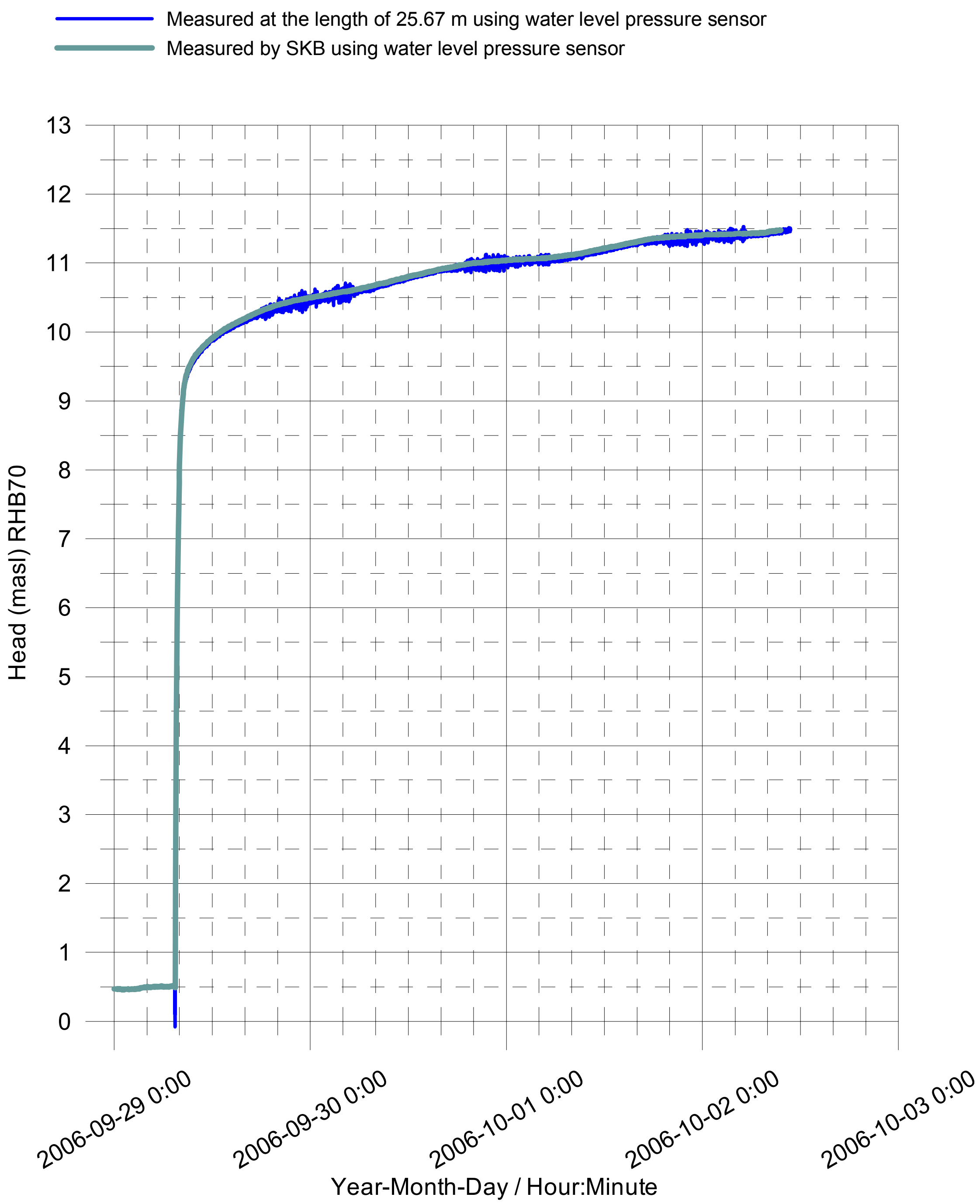


Laxemar, borehole KLX11E
Air pressure, water level in the borehole and pumping rate during flow logging



Laxemar, borehole KLX11E
Groundwater recovery after pumping

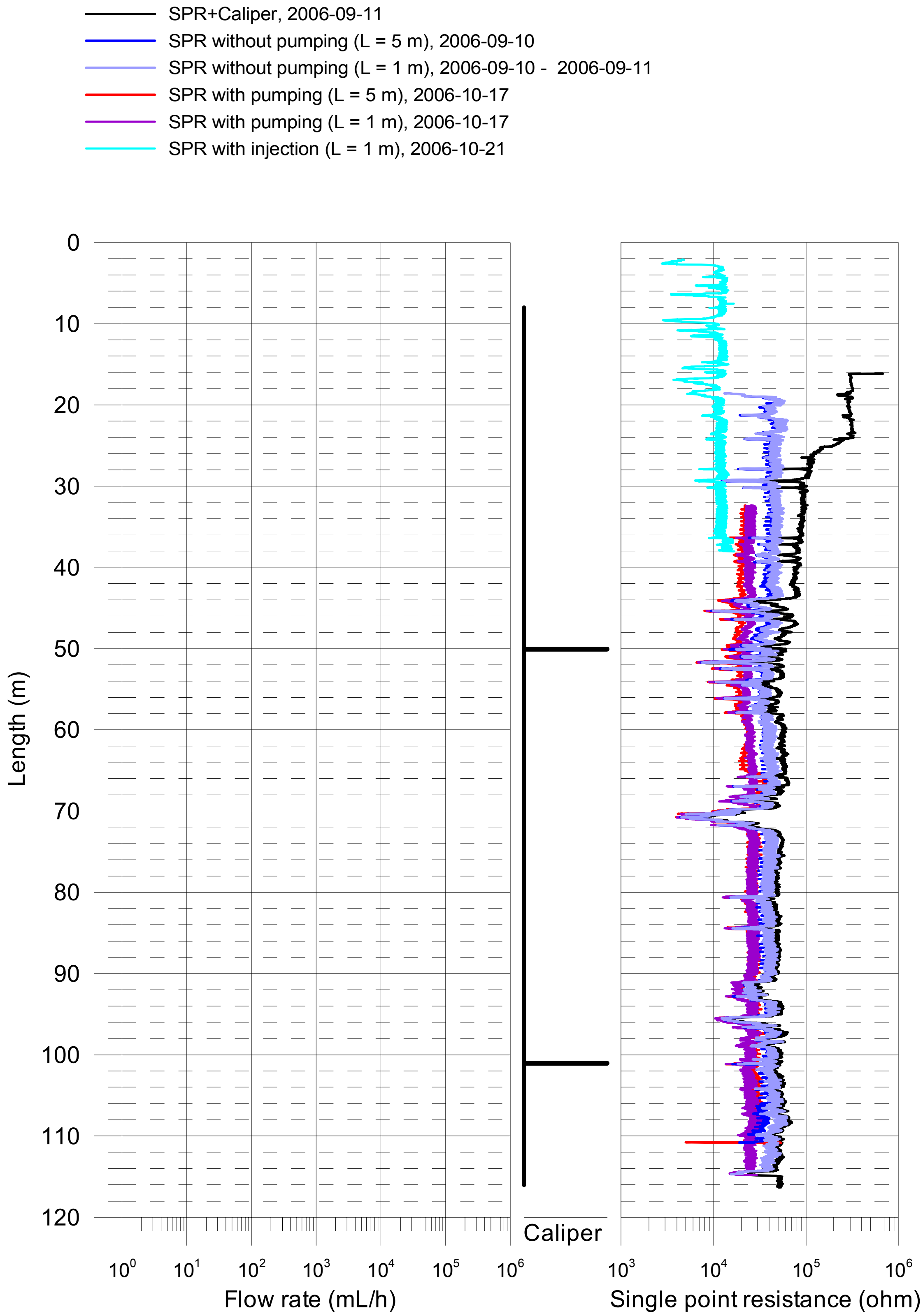
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)



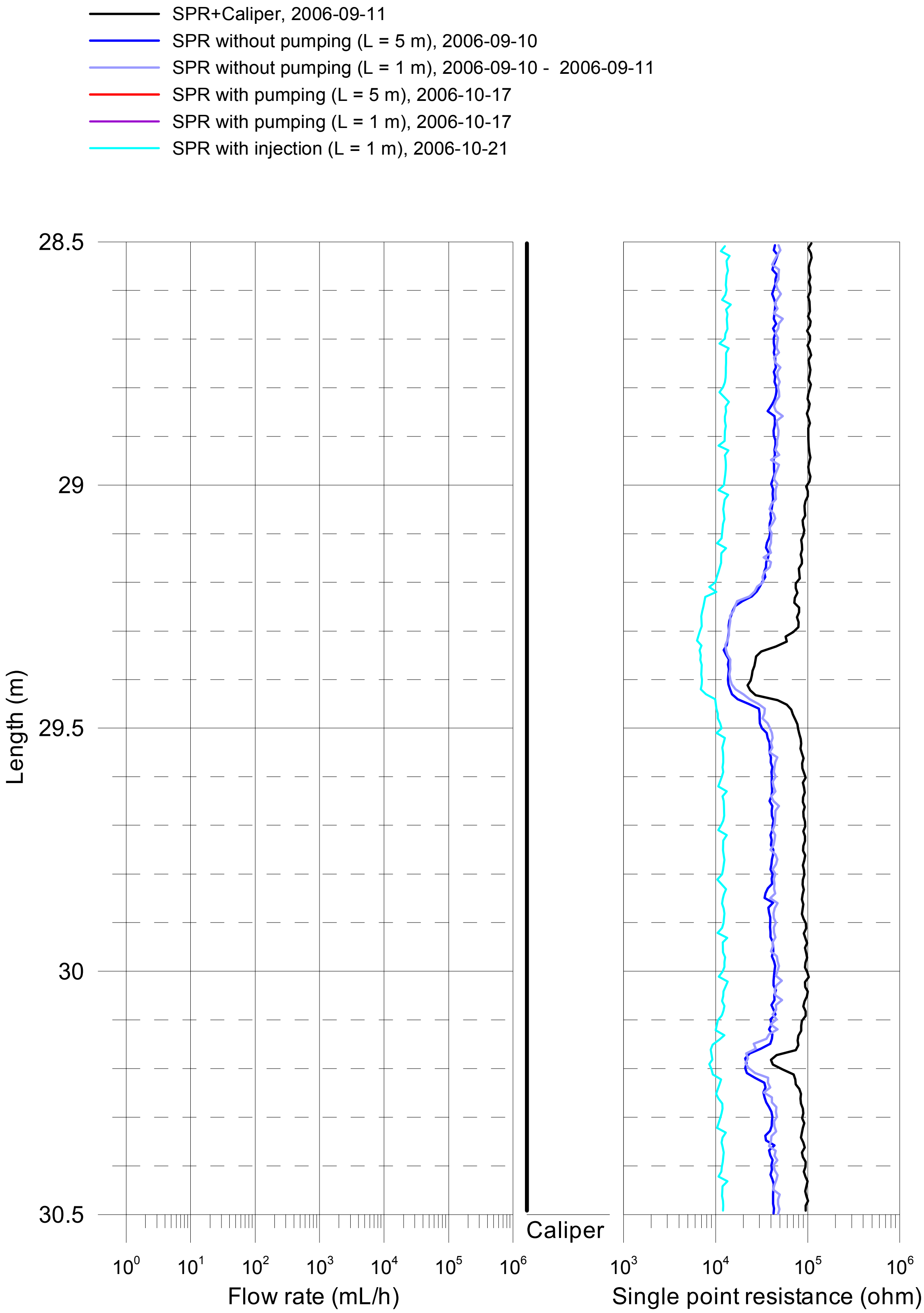
Appendices, KLX11F

Appendices	F.1.1–F.1.9	SPR and Caliper results after length correction
Appendix	F.1.10	Length correction
Appendices	F.2.1–F.2.6	Flow rate, Caliper and Single point resistance
Appendix	F.3.1	Electric conductivity of borehole water
Appendix	F.3.2	Temperature of borehole water
Appendix	F.4.1	Plotted flow rates of 5 m sections
Appendix	F.4.2	Plotted transmissivity and head of 5 m sections
Appendix	F.5	Plotted transmissivity and head of detected fractures
Appendix	F.6	Basic test data
Appendix	F.7	Results of sequential flow logging
Appendix	F.8	Inferred flow anomalies from overlapping flow logging
Appendix	F.9	Explanations for the tables in Appendices 6–8
Appendix	F.10	Conductive fracture frequency
Appendix	F.11	Plotted conductive fracture frequency
Appendix	F.12	Comparison between section transmissivity and fracture transmissivity
Appendix	F.13	Head in the borehole during flow logging
Appendix	F.14	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	F.15	Groundwater recovery after pumping

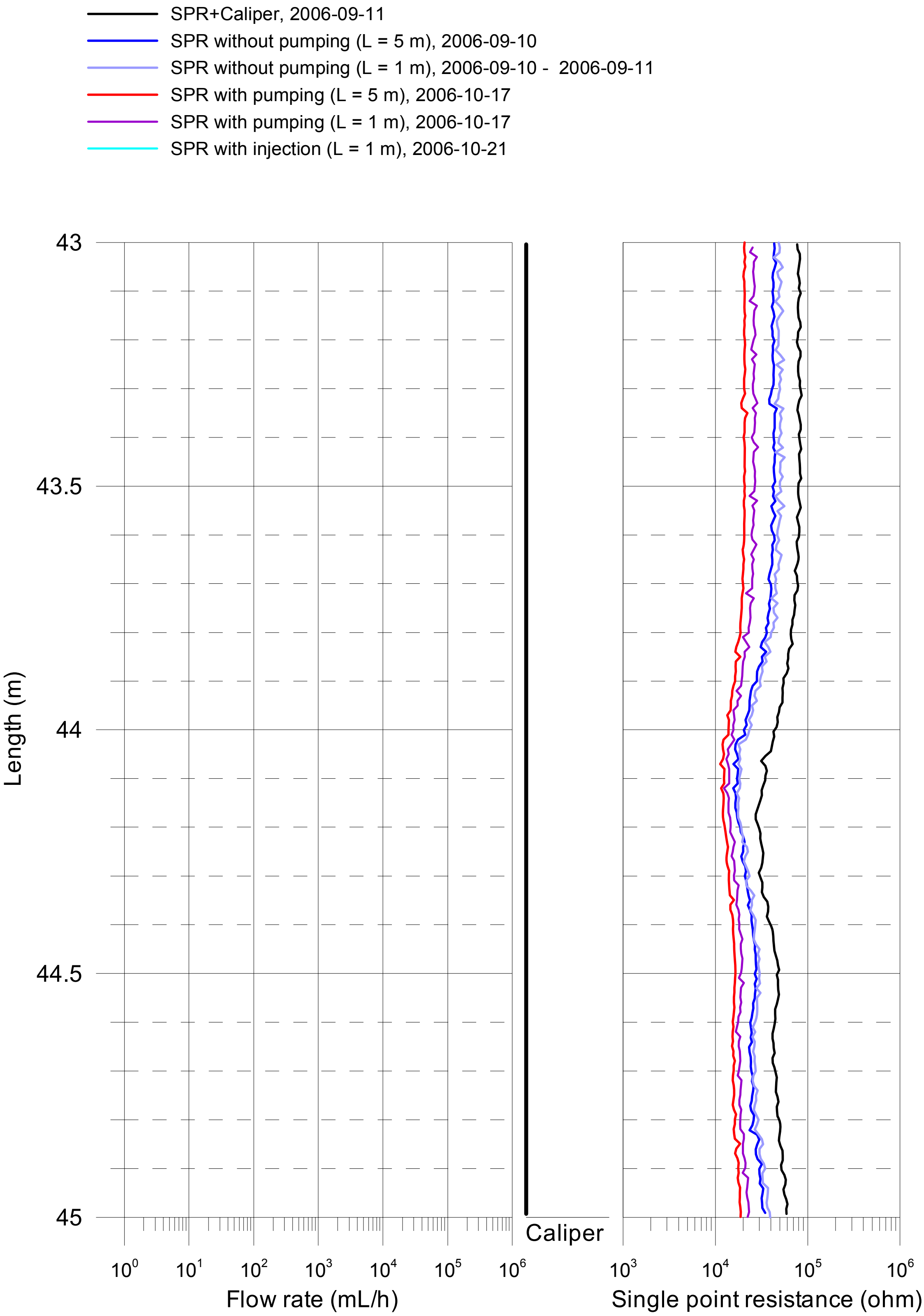
Laxemar, borehole KLX11F
SPR and Caliper results after length correction



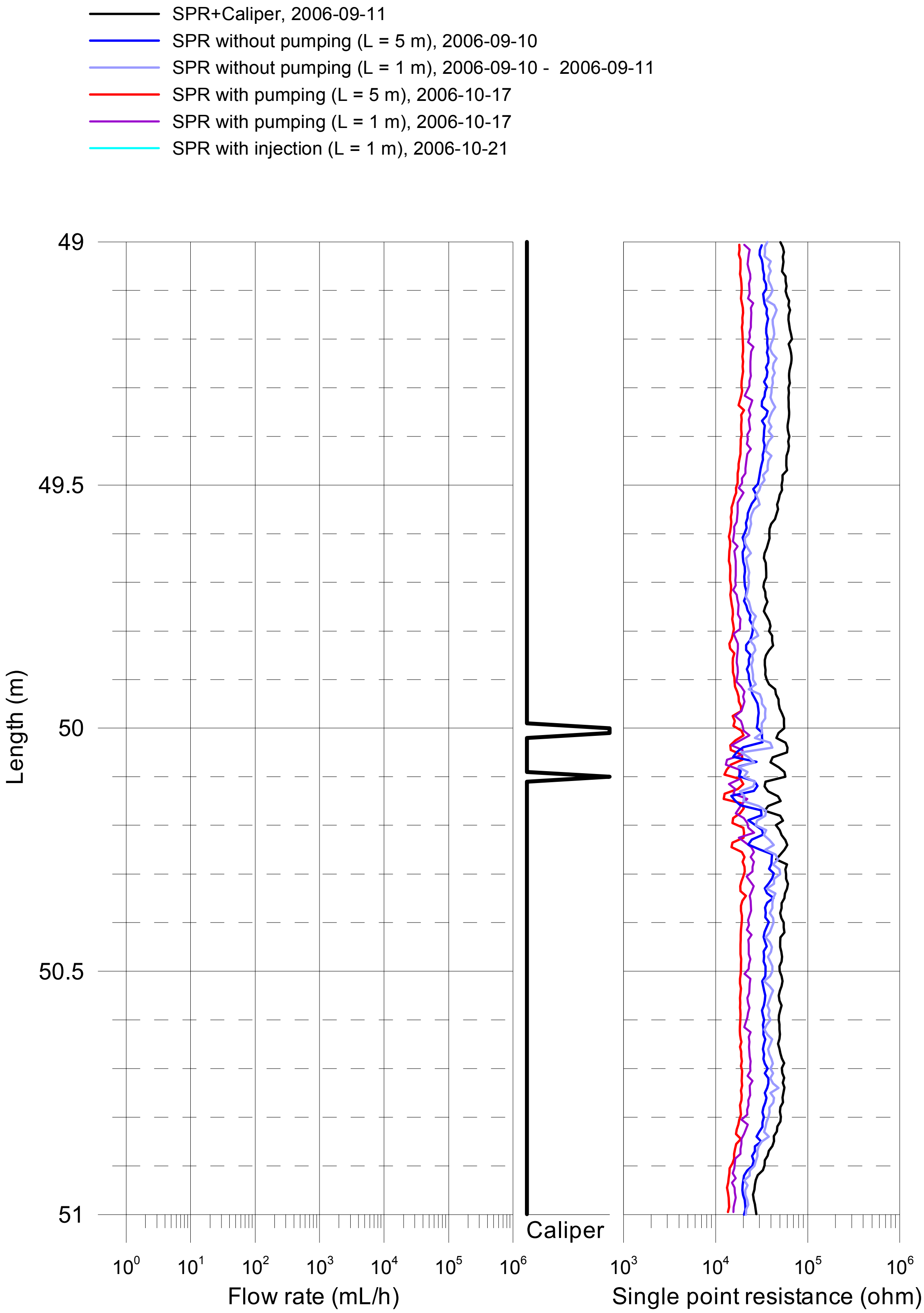
Laxemar, borehole KLX11F
SPR and Caliper results after length correction



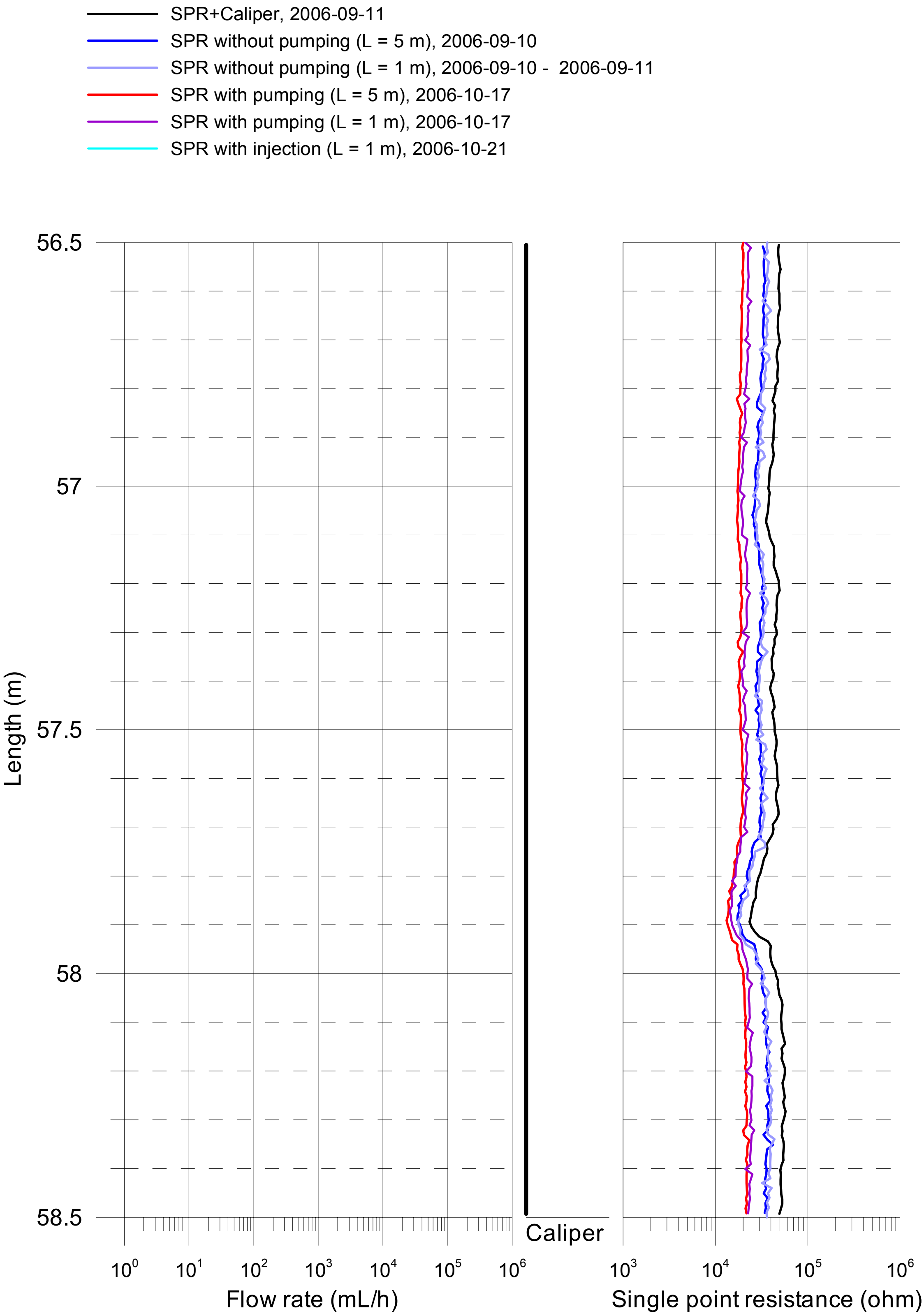
Laxemar, borehole KLX11F
SPR and Caliper results after length correction



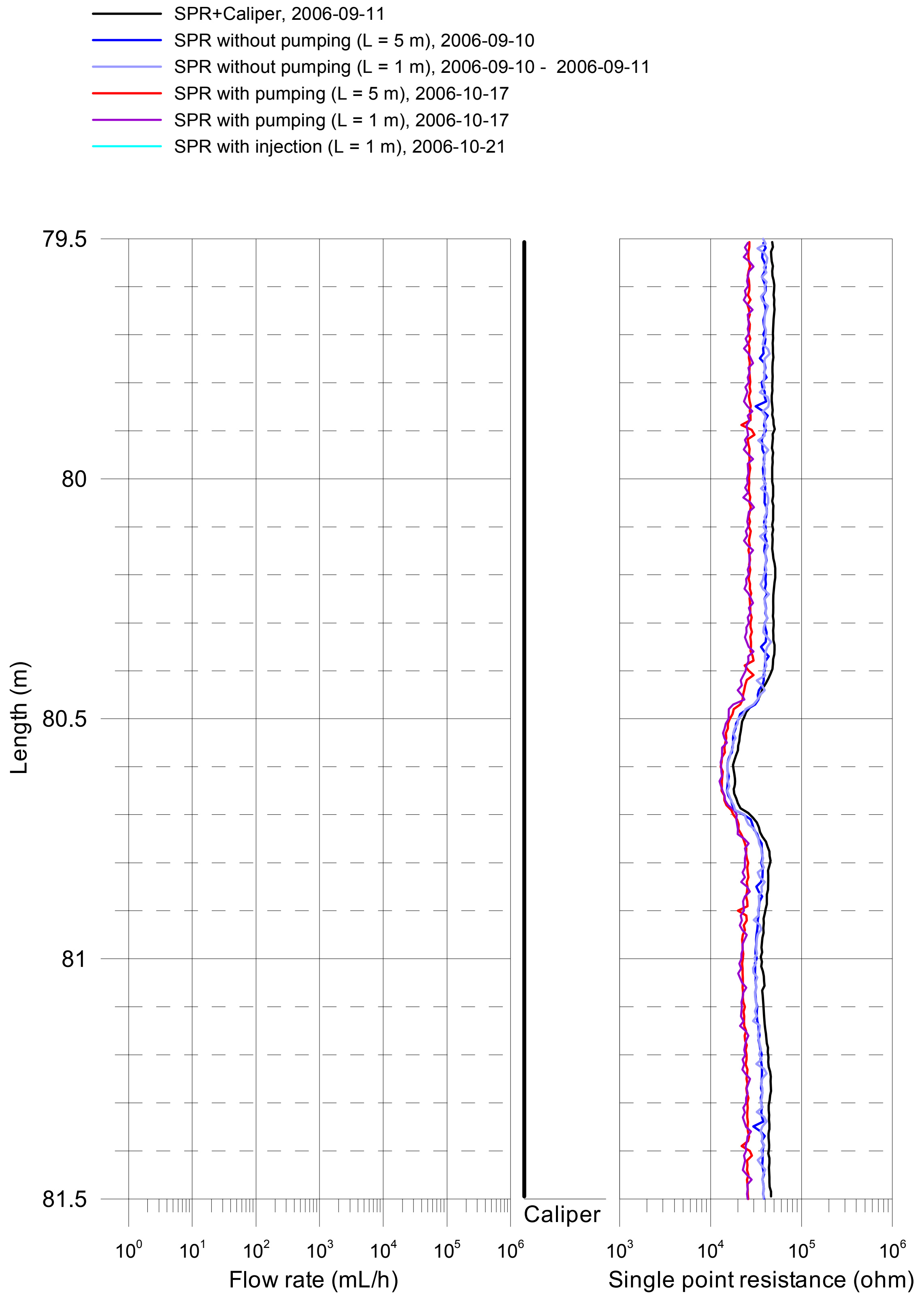
Laxemar, borehole KLX11F
SPR and Caliper results after length correction



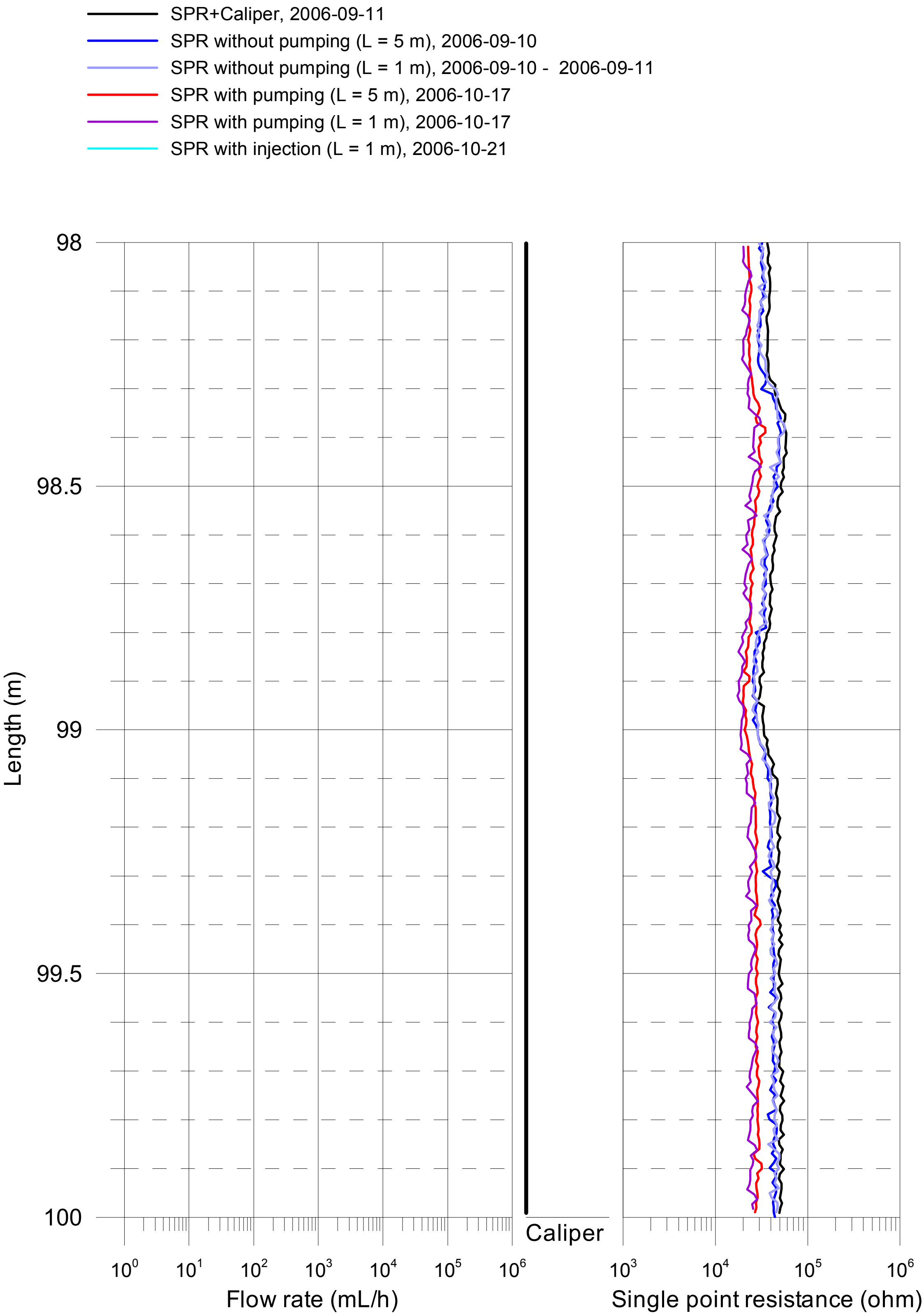
Laxemar, borehole KLX11F
SPR and Caliper results after length correction



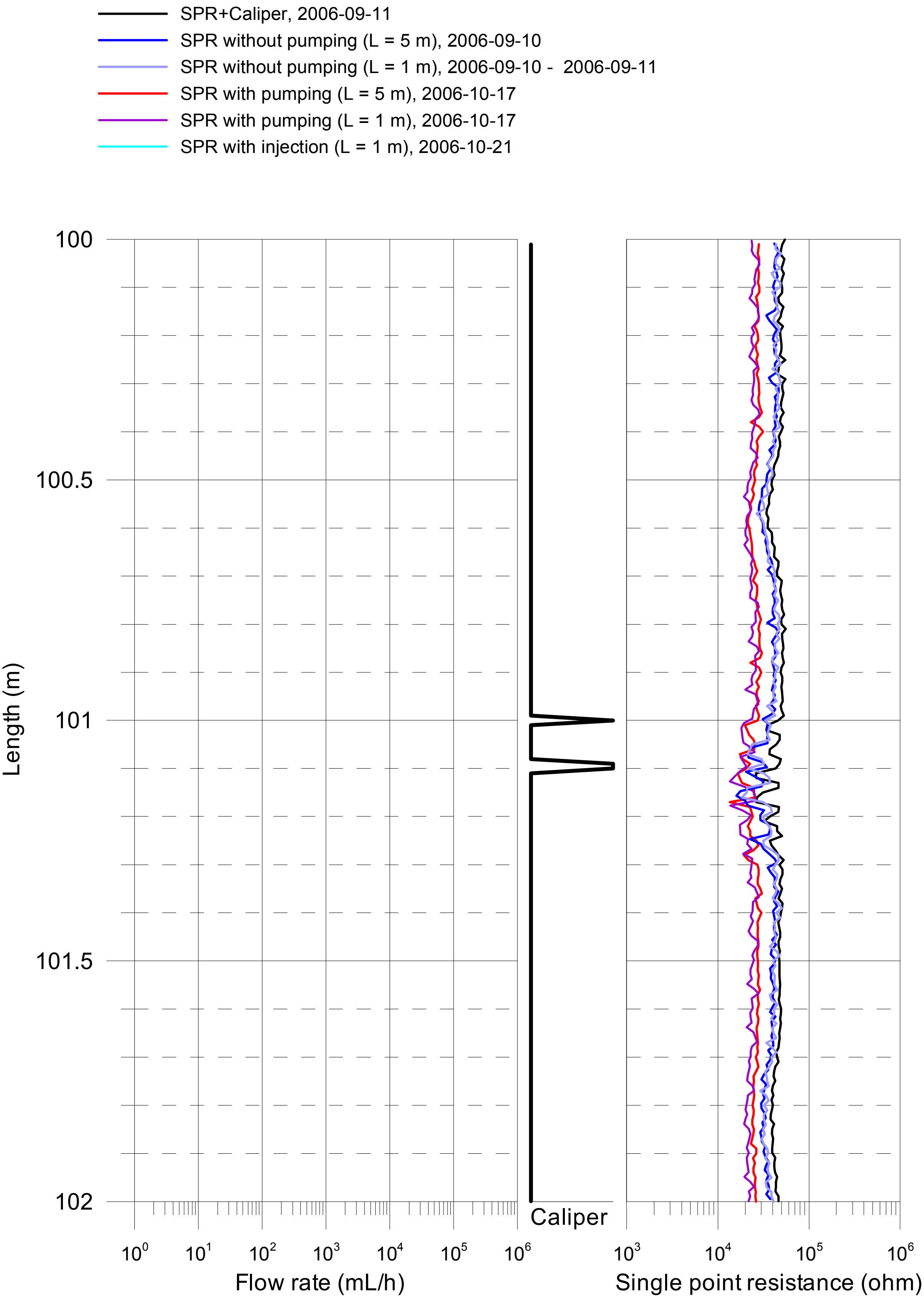
Laxemar, borehole KLX11F
SPR and Caliper results after length correction



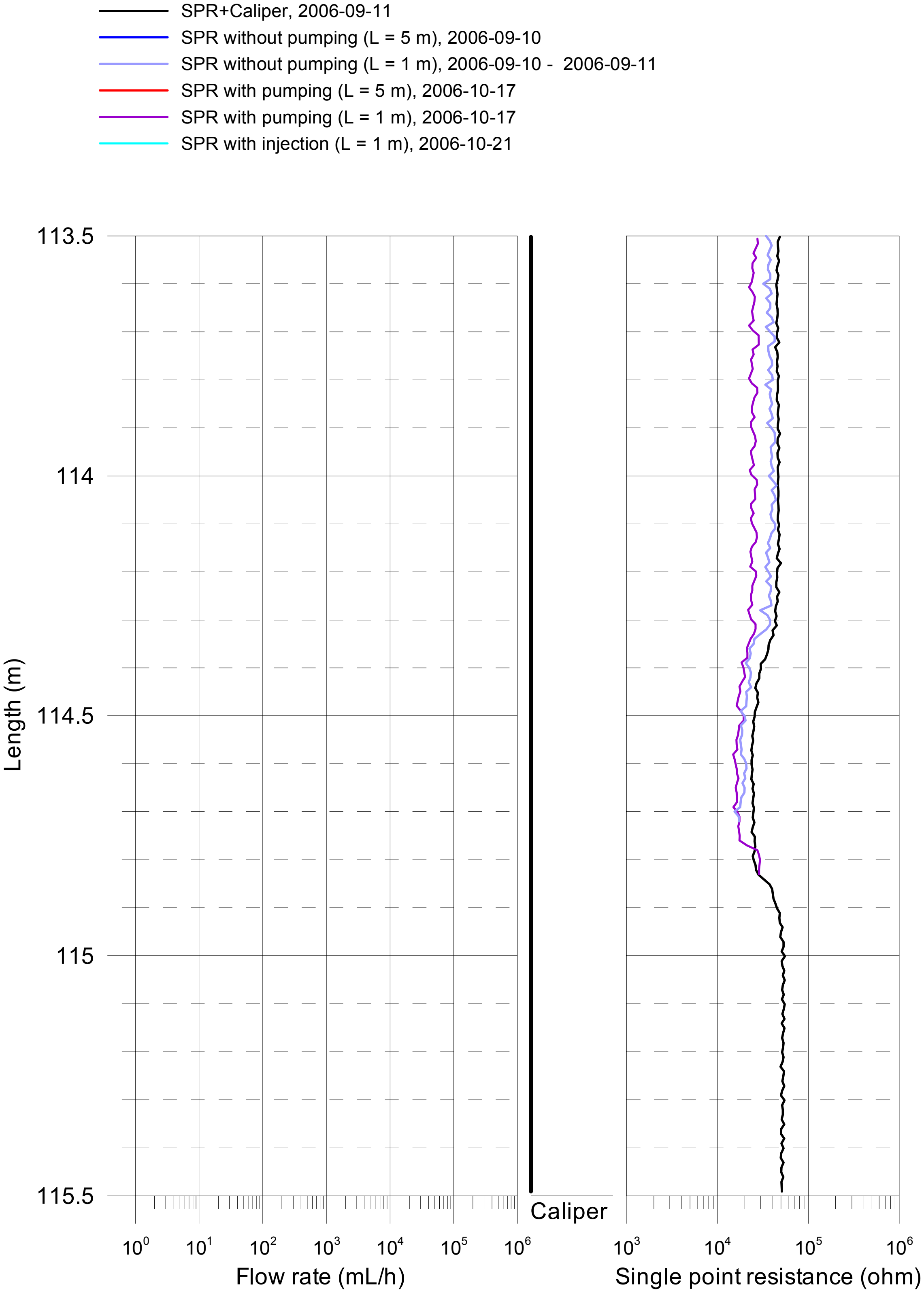
Laxemar, borehole KLX11F
SPR and Caliper results after length correction

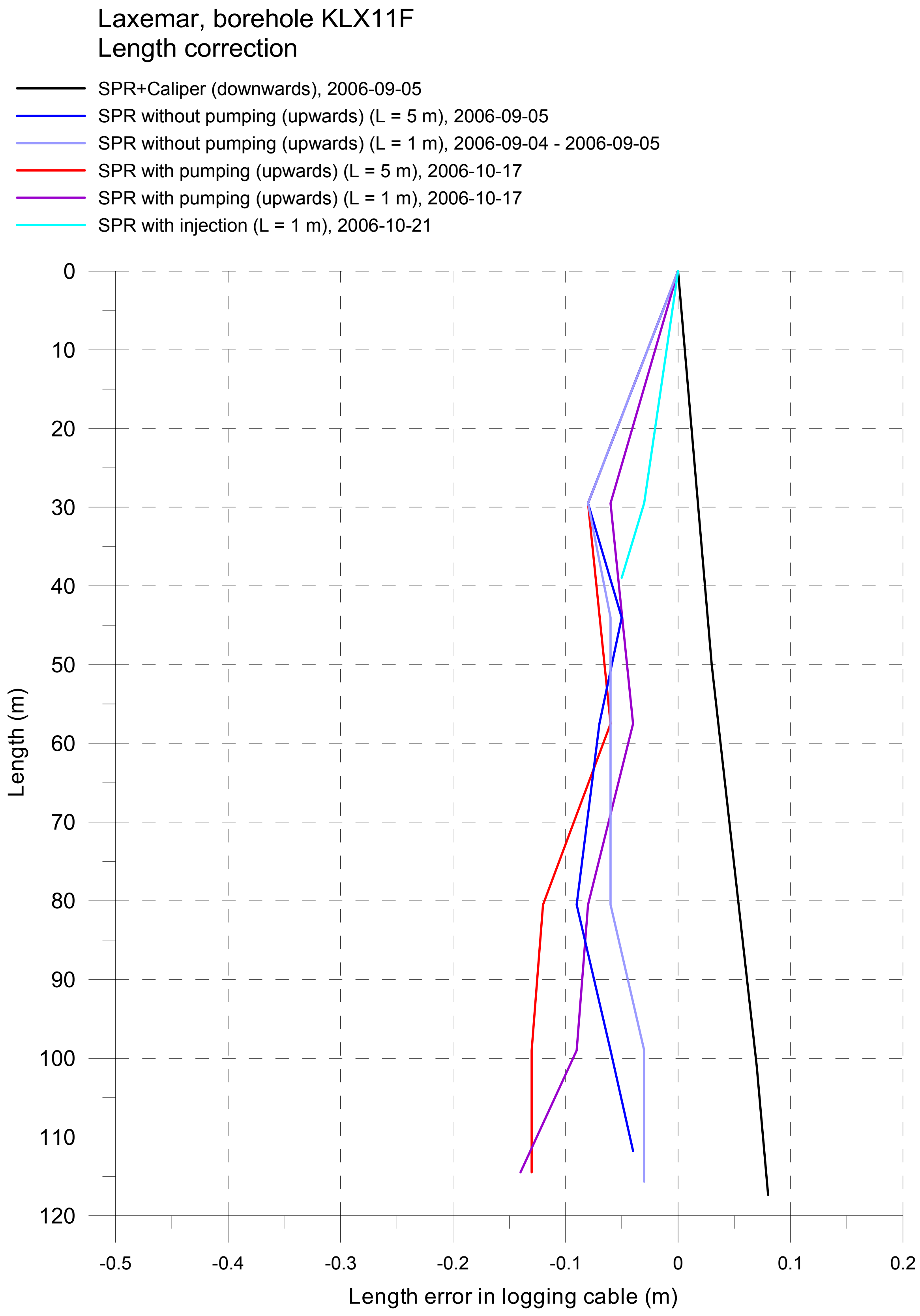


Laxemar, borehole KLX11F
SPR and Caliper results after length correction

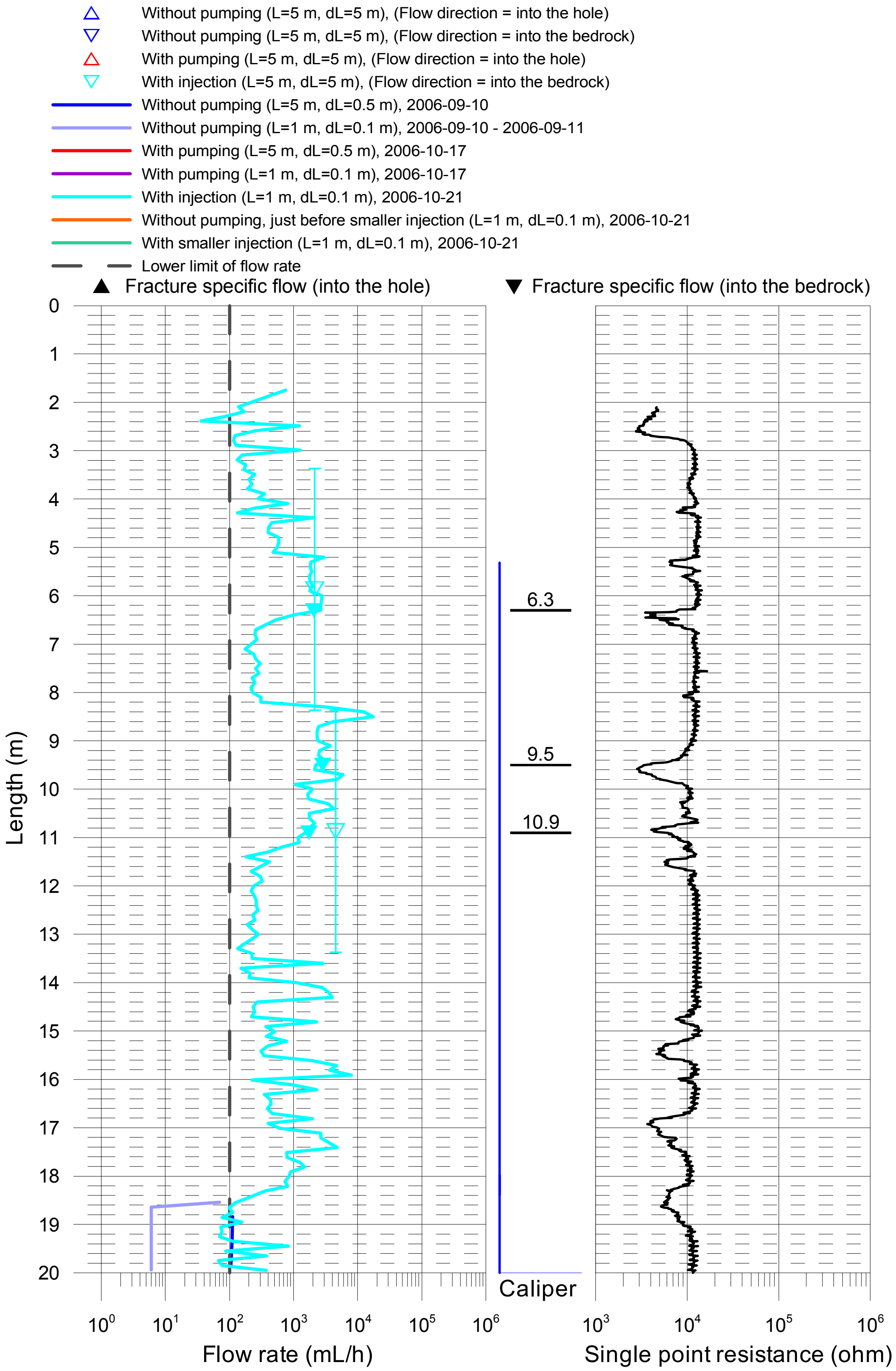


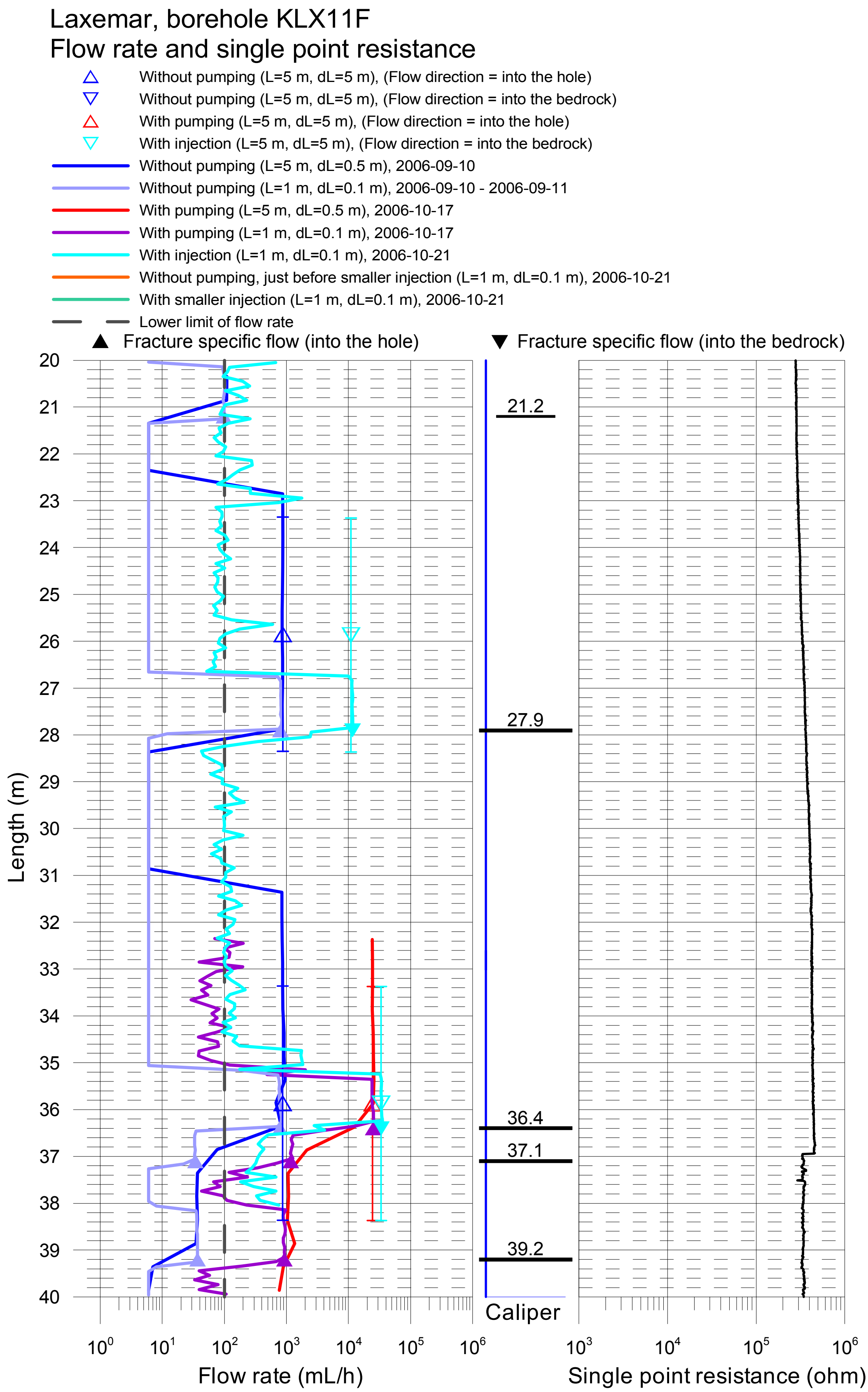
Laxemar, borehole KLX11F
SPR and Caliper results after length correction



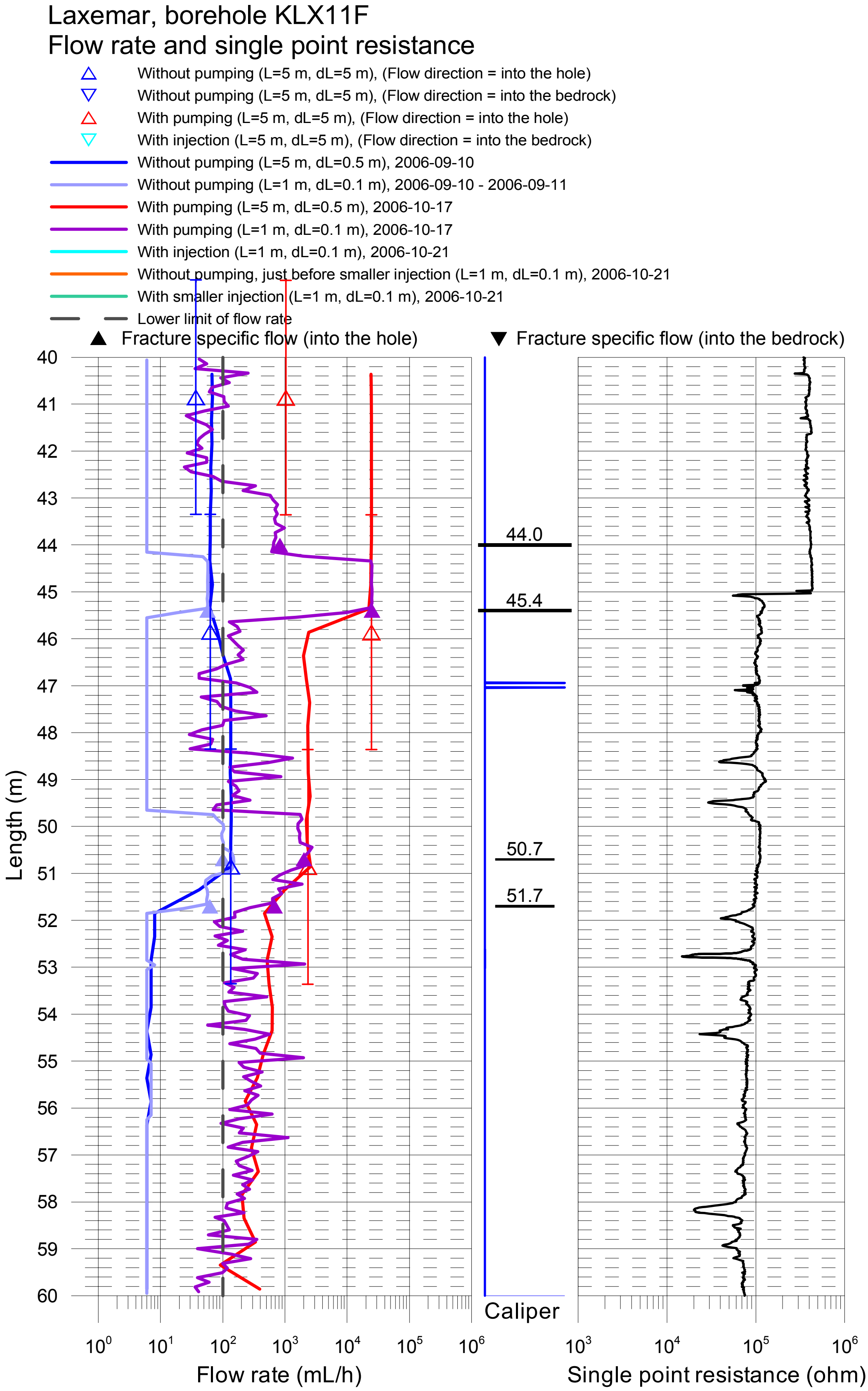

Laxemar, borehole KLX11F
Length correction
SPR+Caliper (downwards), 2006-09-05
SPR without pumping (upwards) (L = 5 m), 2006-09-05
SPR without pumping (upwards) (L = 1 m), 2006-09-04 - 2006-09-05
SPR with pumping (upwards) (L = 5 m), 2006-10-17
SPR with pumping (upwards) (L = 1 m), 2006-10-17
SPR with injection (L = 1 m), 2006-10-21
Length (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
Length error in logging cable (m)

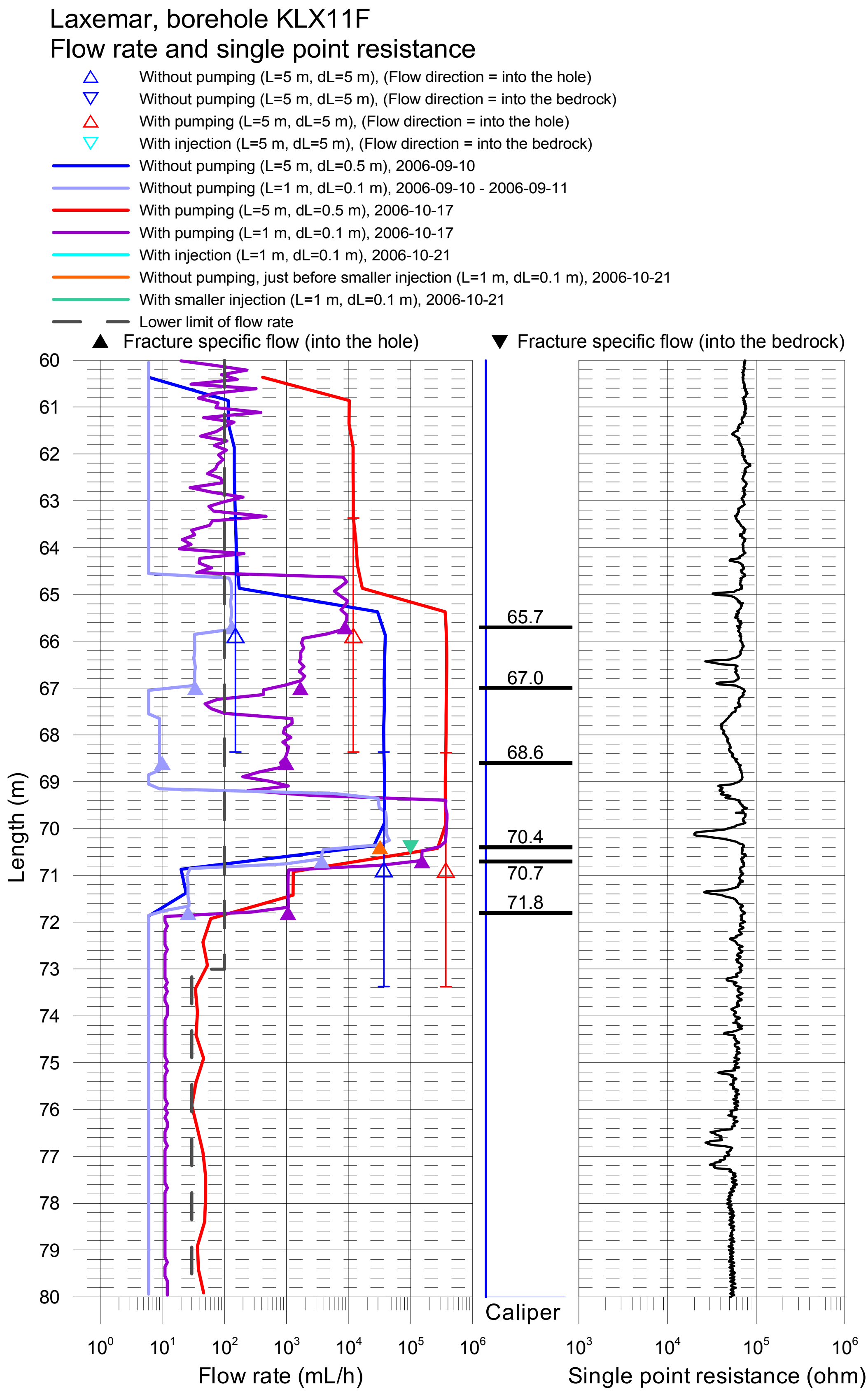
Laxemar, borehole KLX11F
Flow rate and single point resistance

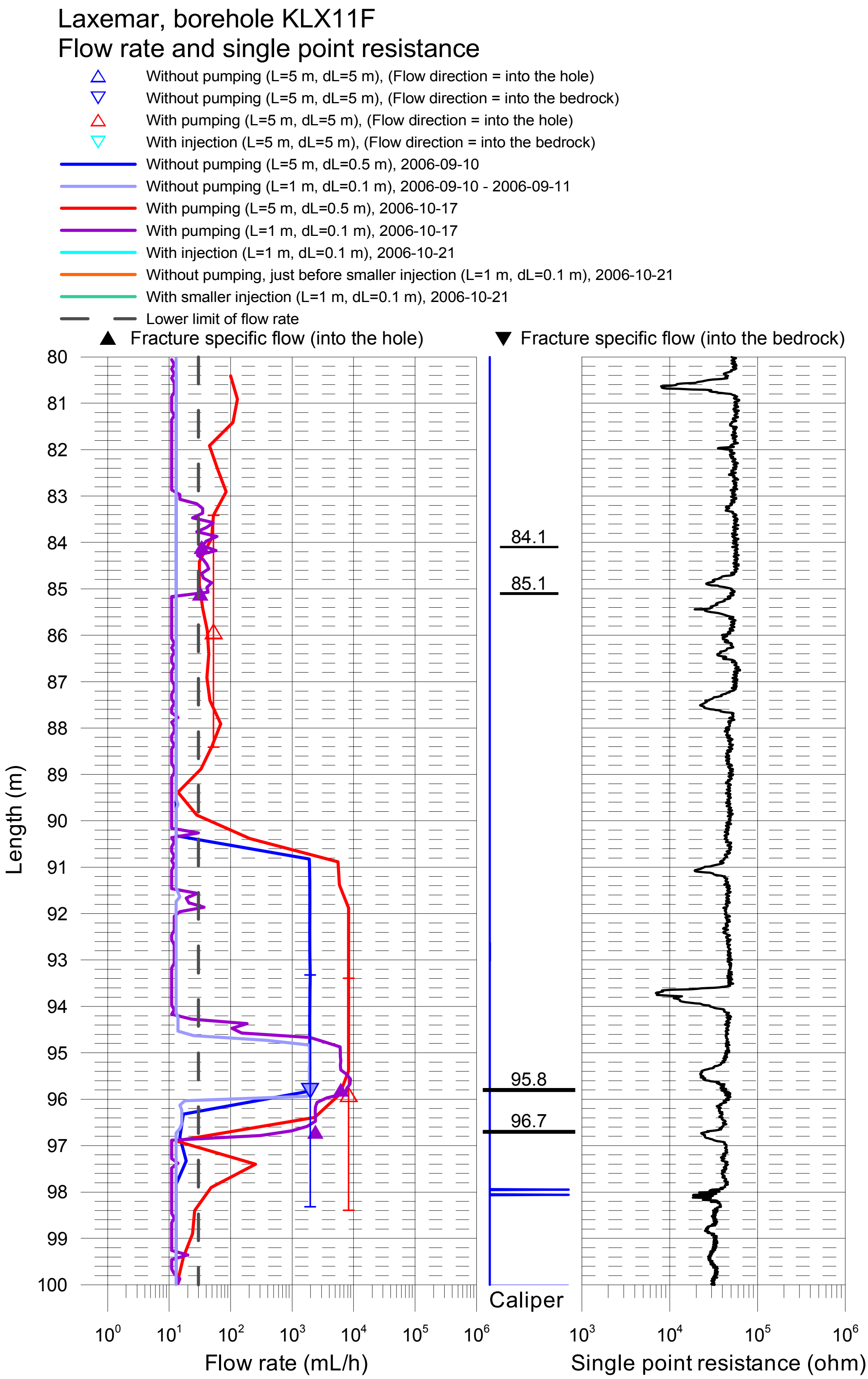




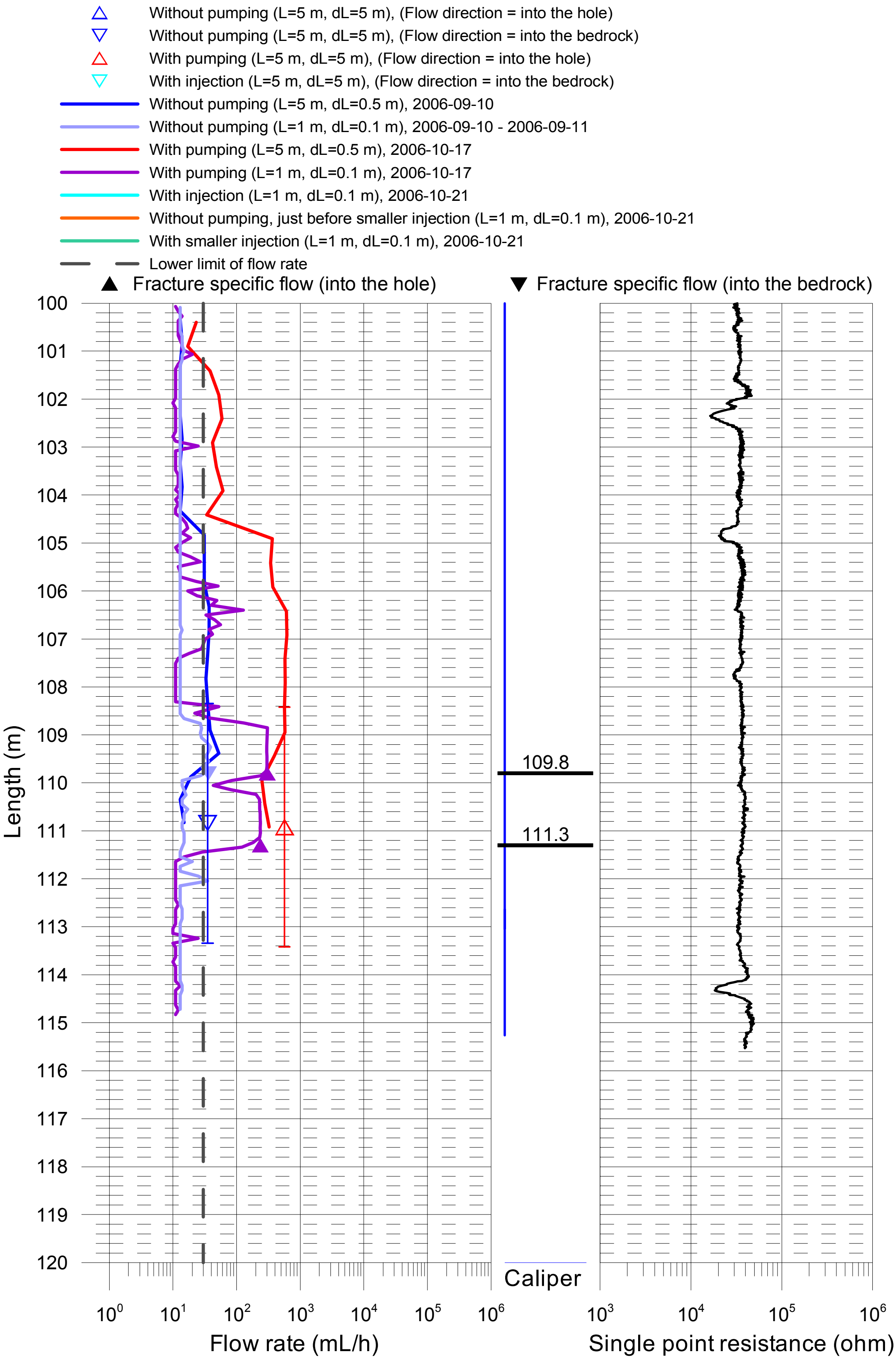
Laxemar, borehole KLX11F
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-10
Without pumping (L=1 m, dL=0.1 m), 2006-09-10 - 2006-09-11
With pumping (L=5 m, dL=0.5 m), 2006-10-17
With pumping (L=1 m, dL=0.1 m), 2006-10-17
With injection (L=1 m, dL=0.1 m), 2006-10-21
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-21
With smaller injection (L=1 m, dL=0.1 m), 2006-10-21
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
21.2
27.9
36.4
37.1
39.2
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)

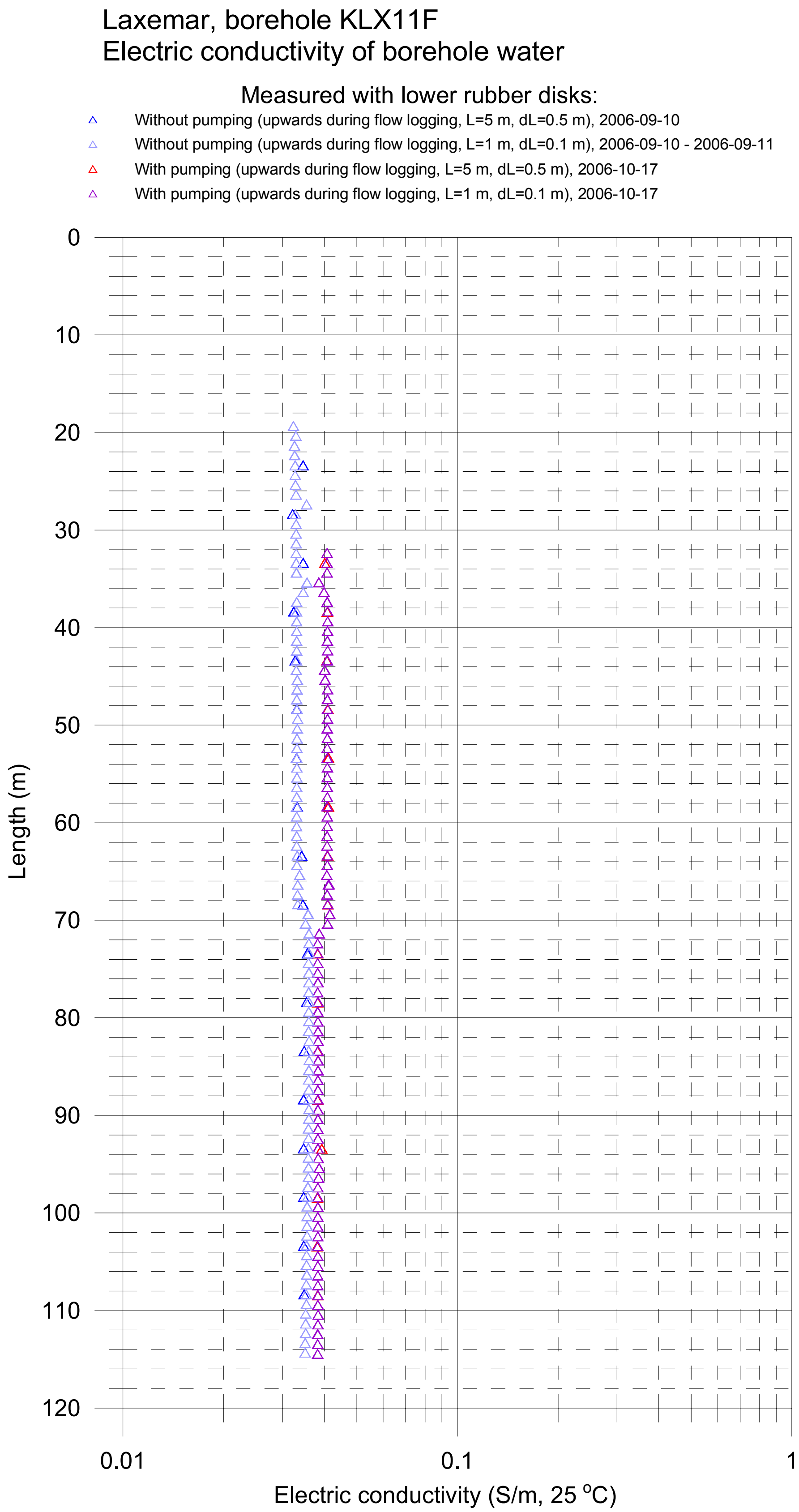

Laxemar, borehole KLX11F
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-10
Without pumping (L=1 m, dL=0.1 m), 2006-09-10 - 2006-09-11
With pumping (L=5 m, dL=0.5 m), 2006-10-17
With pumping (L=1 m, dL=0.1 m), 2006-10-17
With injection (L=1 m, dL=0.1 m), 2006-10-21
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-21
With smaller injection (L=1 m, dL=0.1 m), 2006-10-21
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
44.0
45.4
50.7
51.7
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)

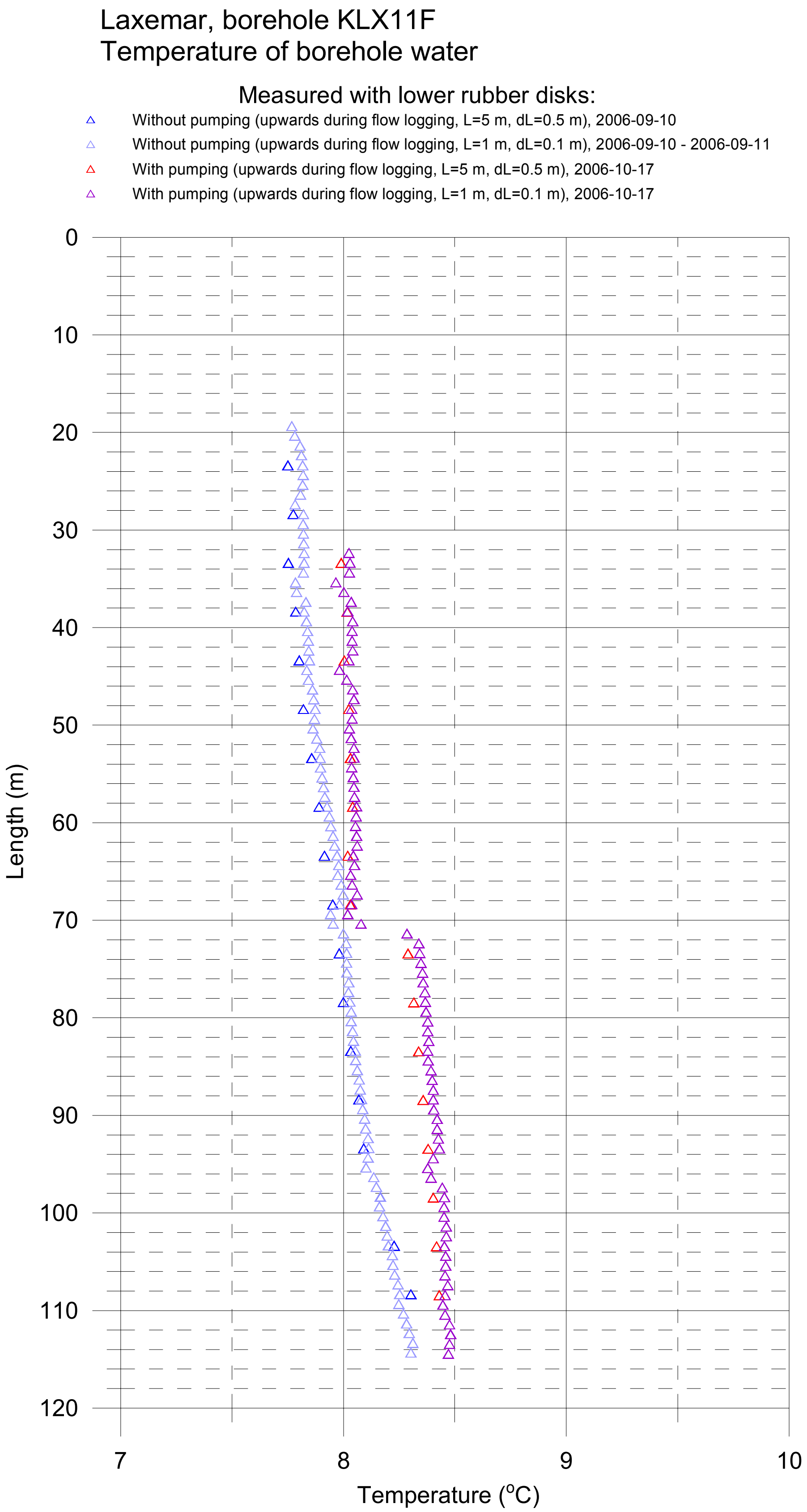

Laxemar, borehole KLX11F
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-10
Without pumping (L=1 m, dL=0.1 m), 2006-09-10 - 2006-09-11
With pumping (L=5 m, dL=0.5 m), 2006-10-17
With pumping (L=1 m, dL=0.1 m), 2006-10-17
With injection (L=1 m, dL=0.1 m), 2006-10-21
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-21
With smaller injection (L=1 m, dL=0.1 m), 2006-10-21
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
65.7
67.0
68.6
70.4
70.7
71.8
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)

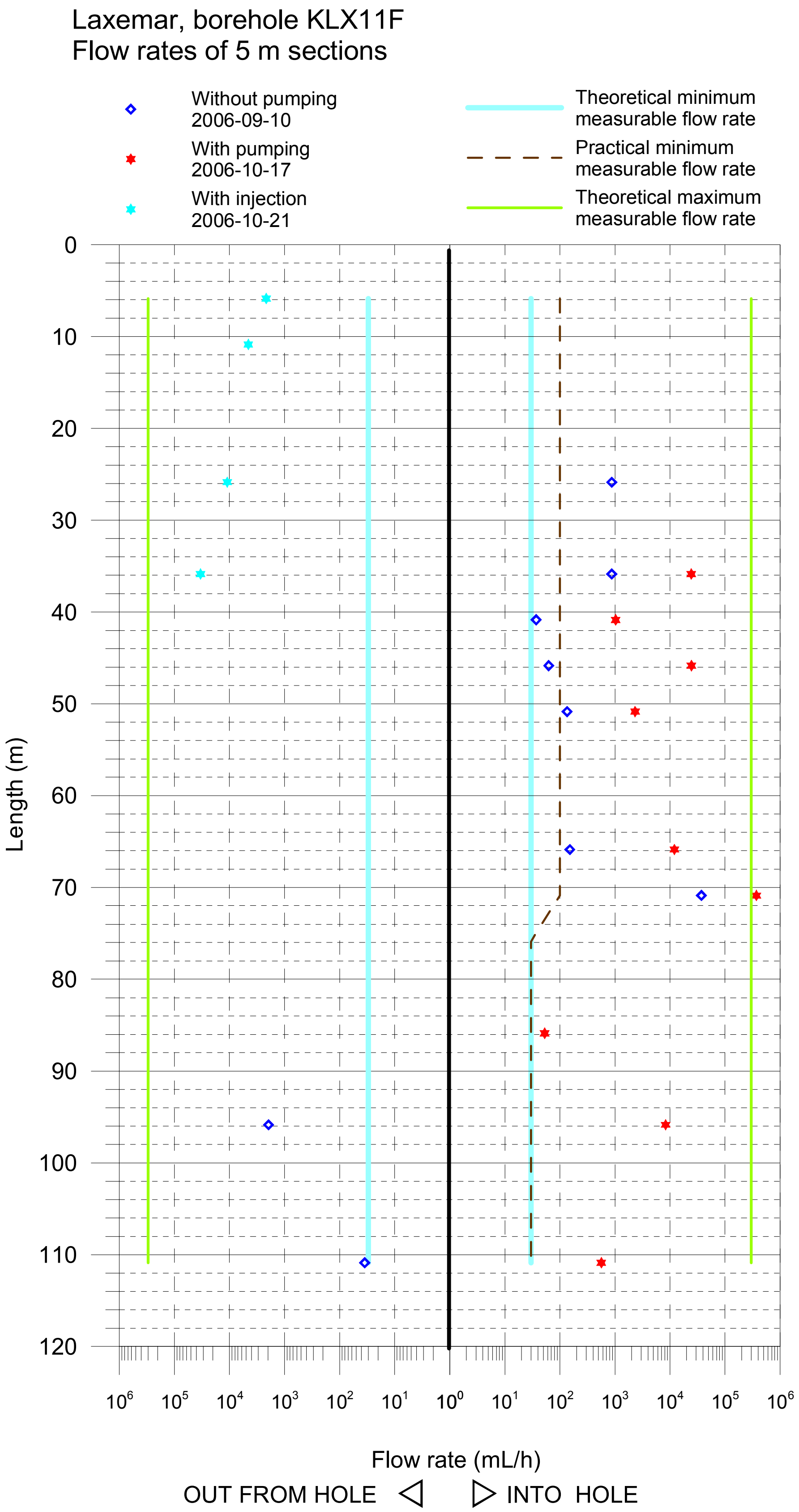

Laxemar, borehole KLX11F
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-09-10
Without pumping (L=1 m, dL=0.1 m), 2006-09-10 - 2006-09-11
With pumping (L=5 m, dL=0.5 m), 2006-10-17
With pumping (L=1 m, dL=0.1 m), 2006-10-17
With injection (L=1 m, dL=0.1 m), 2006-10-21
Without pumping, just before smaller injection (L=1 m, dL=0.1 m), 2006-10-21
With smaller injection (L=1 m, dL=0.1 m), 2006-10-21
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
84.1
85.1
95.8
96.7
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)

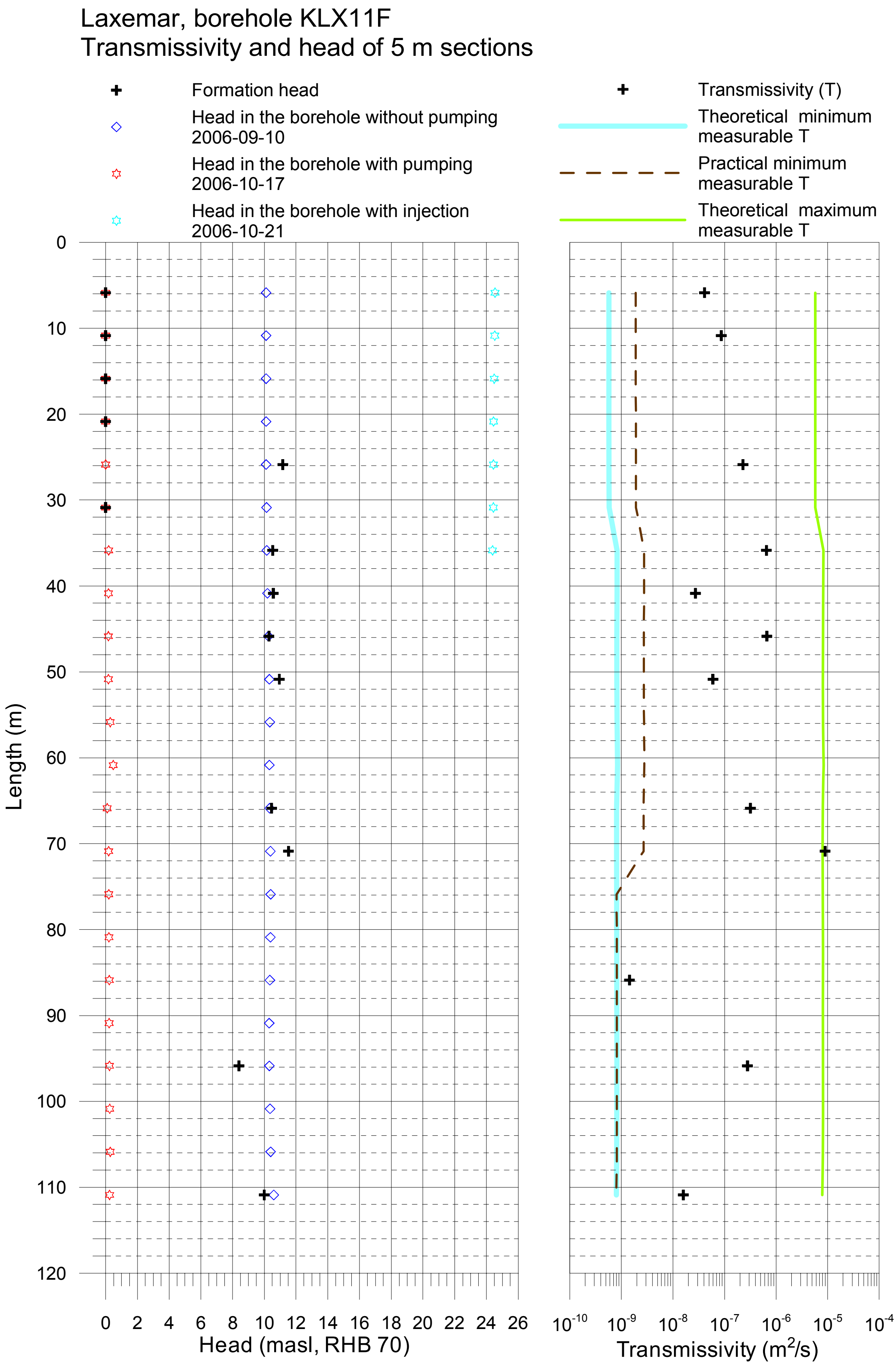
Laxemar, borehole KLX11F
Flow rate and single point resistance




Laxemar, borehole KLX11F
Electric conductivity of borehole water
Measured with lower rubber disks:
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-10
Without pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-10 - 2006-09-11
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-10-17
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-10-17
Length (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
0.01
0.1
1
Electric conductivity (S/m, 25 °C)

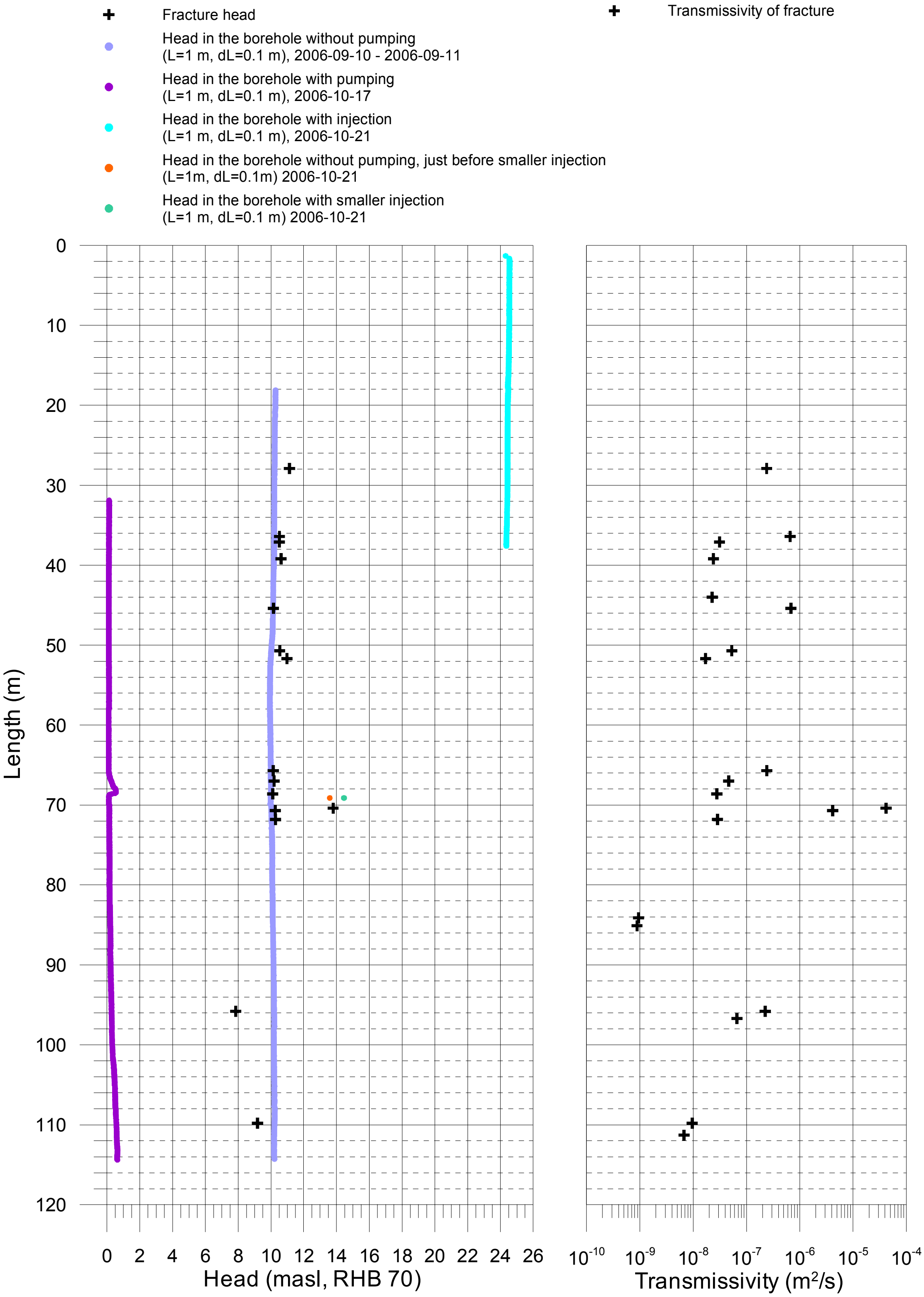

Laxemar, borehole KLX11F
Temperature of borehole water
Measured with lower rubber disks:
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-09-10
Without pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-09-10 - 2006-09-11
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2006-10-17
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2006-10-17
Length (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
7
8
9
10
Temperature (°C)


Laxemar, borehole KLX11F
Flow rates of 5 m sections
Without pumping 2006-09-10
With pumping 2006-10-17
With injection 2006-10-21
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
110
120
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 KLX11F
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-09-10
Head in the borehole with pumping 2006-10-17
Head in the borehole with injection 2006-10-21
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 KLX11F
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)
KLX11F	2	120.05	5A	20061016	10:50	20061017	9:00	20061018	6:55	5	0.5	3.80E–04	–4.12E–04

5. PFL-Difference flow logging – Basic test data

t_{p1} (s)	t_{p2} (s)	t_{F1} (s)	t_{F2} (s)	h_0 (m.a.s.l.)	h_1 (m.a.s.l.)	h_2 (m.a.s.l.)	s_1 (m)	s_2 (m)	T Entire hole (m^2/s)	Reference (–)	Comments (–)
158700	11820	91380	112440	10.05	0.38	24.47	–9.67	14.42	3.89E–05	–	–

Difference flow logging – Sequential flow logging

Borehole ID	Secup L (m)	Seclow L (m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D-measl$_{LP}$ (m^2/s)	T_D-measl$_U$ (m^2/s)	Comments
KLX11F	3.37	8.37	5	–	10.11	–5.97E–07	24.54	4.1E–08	–	100	5.7E–10	1.9E–09	5.7E–06	*,**
KLX11F	8.37	13.37	5	–	10.11	–1.26E–06	24.52	8.7E–08	–	100	5.7E–10	1.9E–09	5.7E–06	*,**
KLX11F	13.37	18.37	5	–	10.11	–	24.49	–	–	100	5.7E–10	1.9E–09	5.7E–06	*,**
KLX11F	18.37	23.37	5	–	10.11	–	24.45	–	–	100	5.7E–10	1.9E–09	5.7E–06	*,**
KLX11F	23.37	28.37	5	2.43E–07	10.11	–3.06E–06	24.44	2.3E–07	11.2	100	5.8E–10	1.9E–09	5.8E–06	*
KLX11F	28.37	33.37	5	–	10.14	–	24.43	–	–	100	5.8E–10	1.9E–09	5.8E–06	*
KLX11F	33.37	38.37	5	2.42E–07	10.16	6.78E–06	0.19	6.5E–07	10.5	100	8.3E–10	2.8E–09	8.3E–06	
KLX11F	38.36	43.36	5	1.03E–08	10.20	2.86E–07	0.18	2.7E–08	10.6	100	8.2E–10	2.7E–09	8.2E–06	
KLX11F	43.36	48.36	5	1.75E–08	10.26	6.81E–06	0.17	6.7E–07	10.3	100	8.2E–10	2.7E–09	8.2E–06	
KLX11F	48.36	53.36	5	3.75E–08	10.32	6.47E–07	0.17	5.9E–08	10.9	100	8.1E–10	2.7E–09	8.1E–06	
KLX11F	53.35	58.35	5	–	10.34	–	0.29	–	–	100	8.2E–10	2.7E–09	8.2E–06	
KLX11F	58.36	63.36	5	–	10.32	–	0.48	–	–	100	8.4E–10	2.8E–09	8.4E–06	
KLX11F	63.37	68.37	5	4.19E–08	10.33	3.33E–06	0.10	3.2E–07	10.5	100	8.1E–10	2.7E–09	8.1E–06	
KLX11F	68.38	73.38	5	1.03E–05	10.38	1.03E–04	0.19	9.0E–06	11.5	100	8.1E–10	2.7E–09	8.1E–06	***
KLX11F	73.40	78.40	5	–	10.40	–	0.20	–	–	30	8.1E–10	8.1E–10	8.1E–06	
KLX11F	78.39	83.39	5	–	10.38	–	0.21	–	–	30	8.1E–10	8.1E–10	8.1E–06	
KLX11F	83.39	88.39	5	–	10.35	1.47E–08	0.23	1.4E–09	–	30	8.1E–10	8.1E–10	8.1E–06	
KLX11F	88.39	93.39	5	–	10.31	–	0.22	–	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX11F	93.36	98.36	5	–5.44E–07	10.32	2.31E–06	0.24	2.8E–07	8.4	30	8.2E–10	8.2E–10	8.2E–06	
KLX11F	98.37	103.37	5	–	10.36	–	0.26	–	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX11F	103.37	108.37	5	–	10.40	–	0.29	–	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX11F	108.38	113.38	5	–9.72E–09	10.60	1.57E–07	0.25	1.6E–08	10.0	30	8.0E–10	8.0E–10	8.0E–06	

* Q_1 value is from injection.

** Q_0 is evaluated to be zero since it is not measured in this section.

*** Q_1 is above measuring 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
KLX11F	6.3	1	0.1	–	10.26	–5.72E–07	24.54	4.0E–08	–	**,***
KLX11F	9.5	1	0.1	–	10.26	–7.86E–07	24.53	5.5E–08	–	**,***
KLX11F	10.9	1	0.1	–	10.26	–4.81E–07	24.52	3.3E–08	–	**,***
KLX11F	21.2	1	0.1	2.72E–08	10.26	–	–	–	–	*****
KLX11F	27.9	1	0.1	2.23E–07	10.21	–3.22E–06	24.43	2.4E–07	11.1	**
KLX11F	36.4	1	0.1	2.18E–07	10.20	6.97E–06	0.13	6.6E–07	10.5	
KLX11F	37.1	1	0.1	9.44E–09	10.21	3.28E–07	0.13	3.1E–08	10.5	
KLX11F	39.2	1	0.1	1.03E–08	10.20	2.56E–07	0.13	2.4E–08	10.6	
KLX11F	44.0	1	0.1	–	10.14	2.31E–07	0.12	2.3E–08	–	
KLX11F	45.4	1	0.1	1.58E–08	10.13	6.94E–06	0.11	6.8E–07	10.2	
KLX11F	50.7	1	0.1	2.78E–08	10.02	5.58E–07	0.11	5.3E–08	10.5	*
KLX11F	51.7	1	0.1	1.72E–08	9.99	1.88E–07	0.12	1.7E–08	11.0	*
KLX11F	65.7	1	0.1	3.67E–08	9.99	2.44E–06	0.10	2.4E–07	10.1	
KLX11F	67.0	1	0.1	9.44E–09	10.00	4.67E–07	0.26	4.6E–08	10.2	
KLX11F	68.6	1	0.1	2.78E–09	10.01	2.75E–07	0.33	2.8E–08	10.1	
KLX11F	70.4	1	0.1	8.97E–06	13.58	–2.77E–05	14.45	4.2E–05	13.8	****
KLX11F	70.7	1	0.1	1.03E–06	10.02	4.25E–05	0.15	4.2E–06	10.3	
KLX11F	71.8	1	0.1	7.22E–09	10.03	2.94E–07	0.14	2.9E–08	10.3	
KLX11F	84.1	1	0.1	–	10.10	9.44E–09	0.20	9.4E–10	–	*
KLX11F	85.1	1	0.1	–	10.12	8.89E–09	0.20	8.9E–10	–	*
KLX11F	95.8	1	0.1	–5.33E–07	10.19	1.72E–06	0.28	2.3E–07	7.9	
KLX11F	96.7	1	0.1	–	10.21	6.64E–07	0.30	6.6E–08	–	
KLX11F	109.8	1	0.1	–1.00E–08	10.21	8.36E–08	0.57	9.6E–09	9.2	
KLX11F	111.3	1	0.1	–	10.20	6.56E–08	0.60	6.8E–09	–	

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

** Q_1 value is from injection.

*** Q_0 is evaluated to be zero since it is not measured in this section.

**** Q_1 is from smaller injection, Q_0 is undisturbed state just before smaller injection.

***** Fracture could not be seen during injection.

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.

Explanations

Header	Unit	Explanations
s_1	m	Drawdown of the water level in the borehole during first pumping period. Difference between the actual hydraulic head and the initial head ($s_1=h_1–h_0$).
s_2	m	Drawdown of the water level in the borehole during second pumping period. Difference between the actual hydraulic head and the initial head ($s_2=h_2–h_0$).
T	m^2/s	Transmissivity of the entire borehole.
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with $h=h_0$ in the open borehole.
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period.
Q_2	m^3/s	Measured flow rate through the test section or flow anomaly during the second pumping period.
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid before pumping.
h_{1FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period.
h_{2FW}	m.a.s.l.	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the second pumping period.
EC_w	S/m	Measured electric conductivity of the borehole fluid in the test section during difference flow logging.
Te_w	°C	Measured borehole fluid temperature in the test section during difference flow logging.
EC_f	S/m	Measured fracture-specific electric conductivity of the fluid in flow anomaly during difference flow logging.
Te_f	°C	Measured fracture-specific fluid temperature in flow anomaly during difference flow logging.
T_D	m^2/s	Transmissivity of section or flow anomaly based on 2D model for evaluation of formation properties of the test section based on PFL-DIFF.
T-measl$_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-measl$_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-measl$_U$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

Calculation of conductive fracture frequency

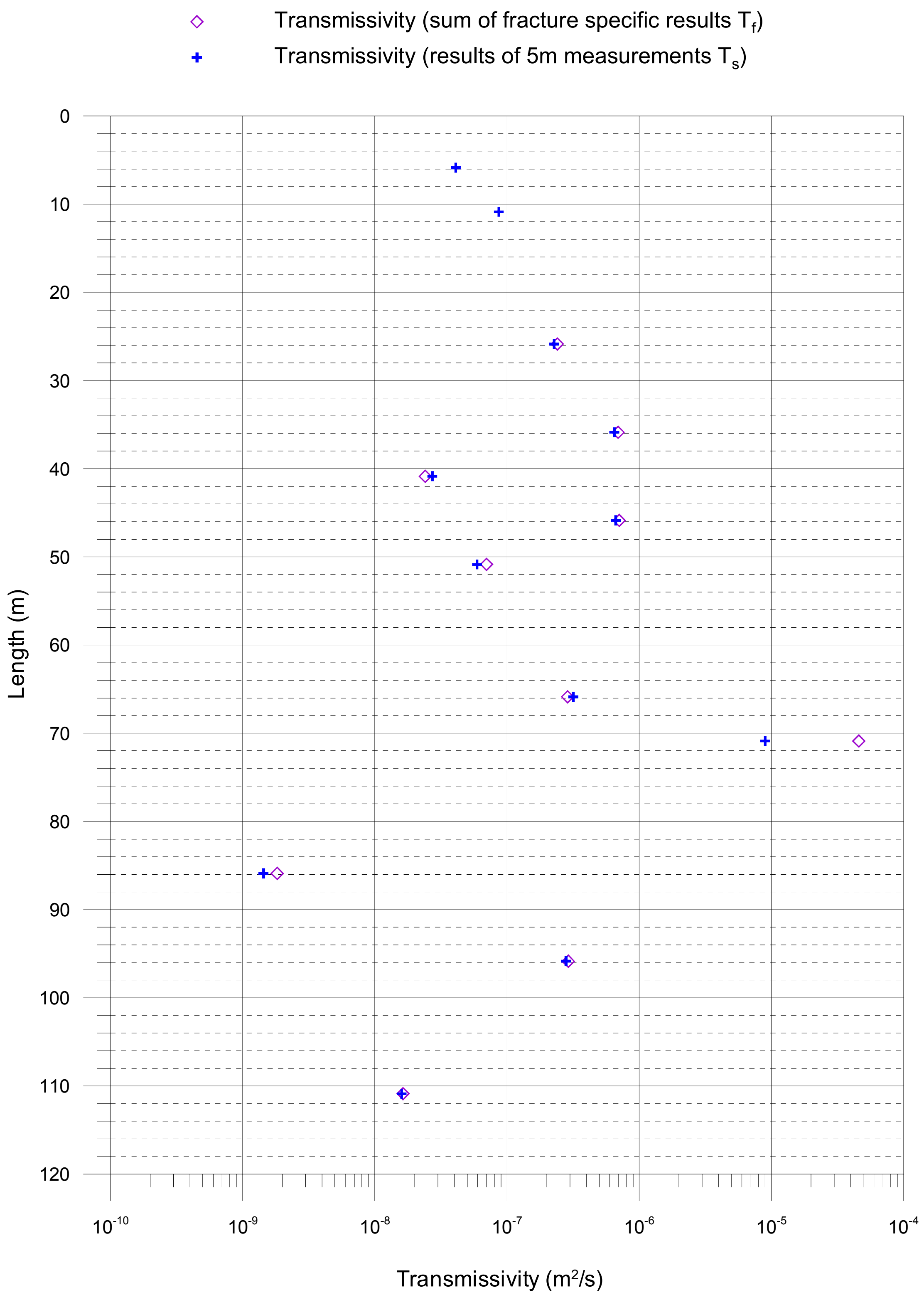
Borehole ID	SecUp (m)	SecLow (m)	Number of fractures, total	Number of fractures 10–100 (mL/h)	Number of fractures 100–1,000 (mL/h)	Number of fractures 1,000–10,000 (mL/h)	Number of fractures 10,000–100,000 (mL/h)	Number of fractures 100,000–1,000,000 (mL/h)
KLX11F	3.37	8.37	1	0	0	1*	0	0
KLX11F	8.37	13.37	2	0	0	2*	0	0
KLX11F	13.37	18.37	0	0	0	0	0	0
KLX11F	18.37	23.37	1**	0	0	0	0	0
KLX11F	23.37	28.37	1	0	0	1*	0	0
KLX11F	28.37	33.37	0	0	0	0	0	0
KLX11F	33.37	38.37	2	0	0	1	1	0
KLX11F	38.36	43.36	1	0	1	0	0	0
KLX11F	43.36	48.36	2	0	1	0	1	0
KLX11F	48.36	53.36	2	0	1	1	0	0
KLX11F	53.35	58.35	0	0	0	0	0	0
KLX11F	58.36	63.36	0	0	0	0	0	0
KLX11F	63.37	68.37	2	0	0	2	0	0
KLX11F	68.38	73.38	4	0	1	1	0	1
KLX11F	73.40	78.40	0	0	0	0	0	0
KLX11F	78.39	83.39	0	0	0	0	0	0
KLX11F	83.39	88.39	2	2	0	0	0	0
KLX11F	88.39	93.39	0	0	0	0	0	0
KLX11F	93.36	98.36	2	0	0	2	0	0
KLX11F	98.37	103.37	0	0	0	0	0	0
KLX11F	103.37	108.37	0	0	0	0	0	0
KLX11F	108.38	113.38	2	0	2	0	0	0

* During Injection (drawdown not the same as in the other measurements).

** Fracture could not be seen during injection due to noise.

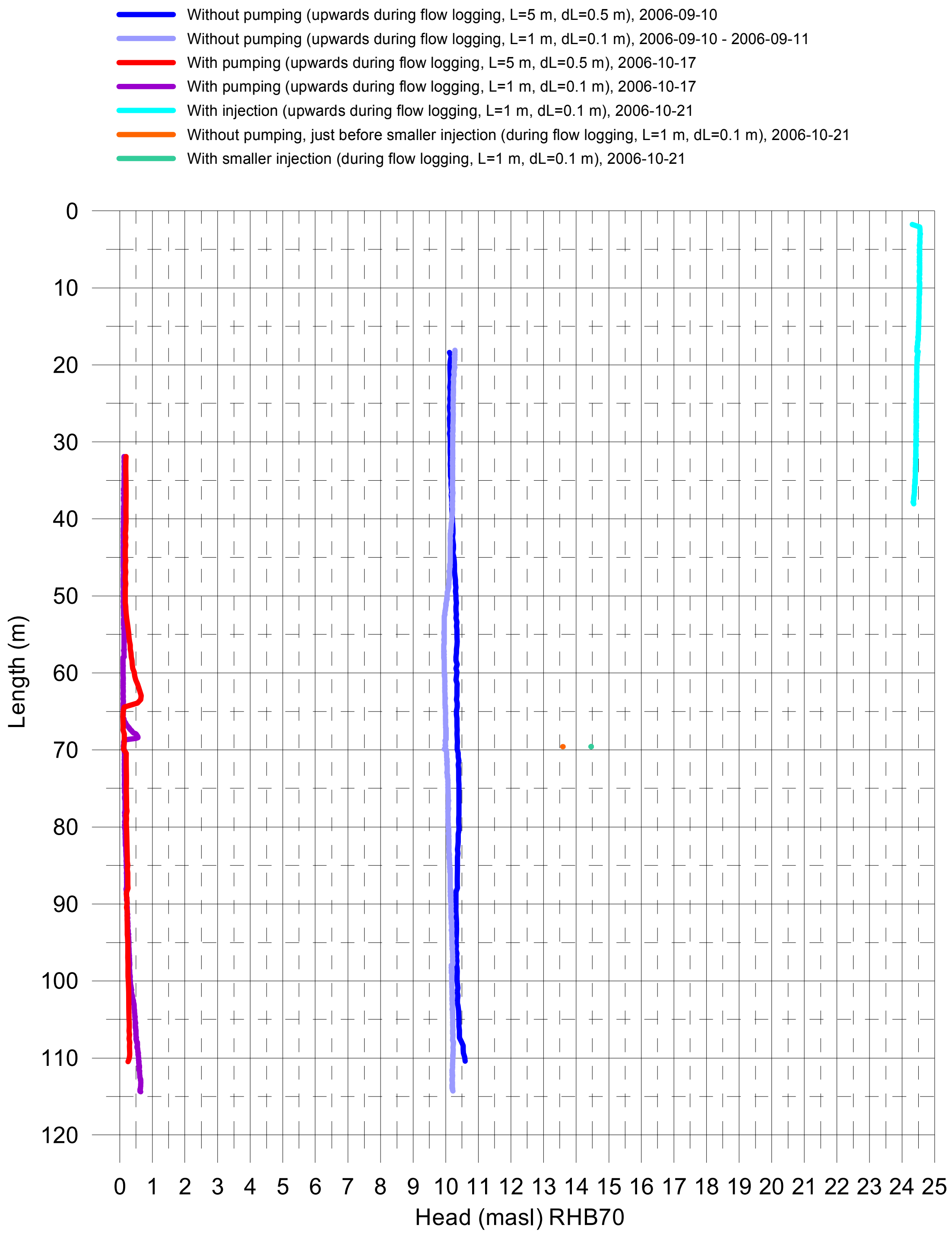
Laxemar, borehole KLX11F
Calculation of conductive fracture frequency

Laxemar, borehole KLX11F
Comparison between section transmissivity and fracture transmissivity

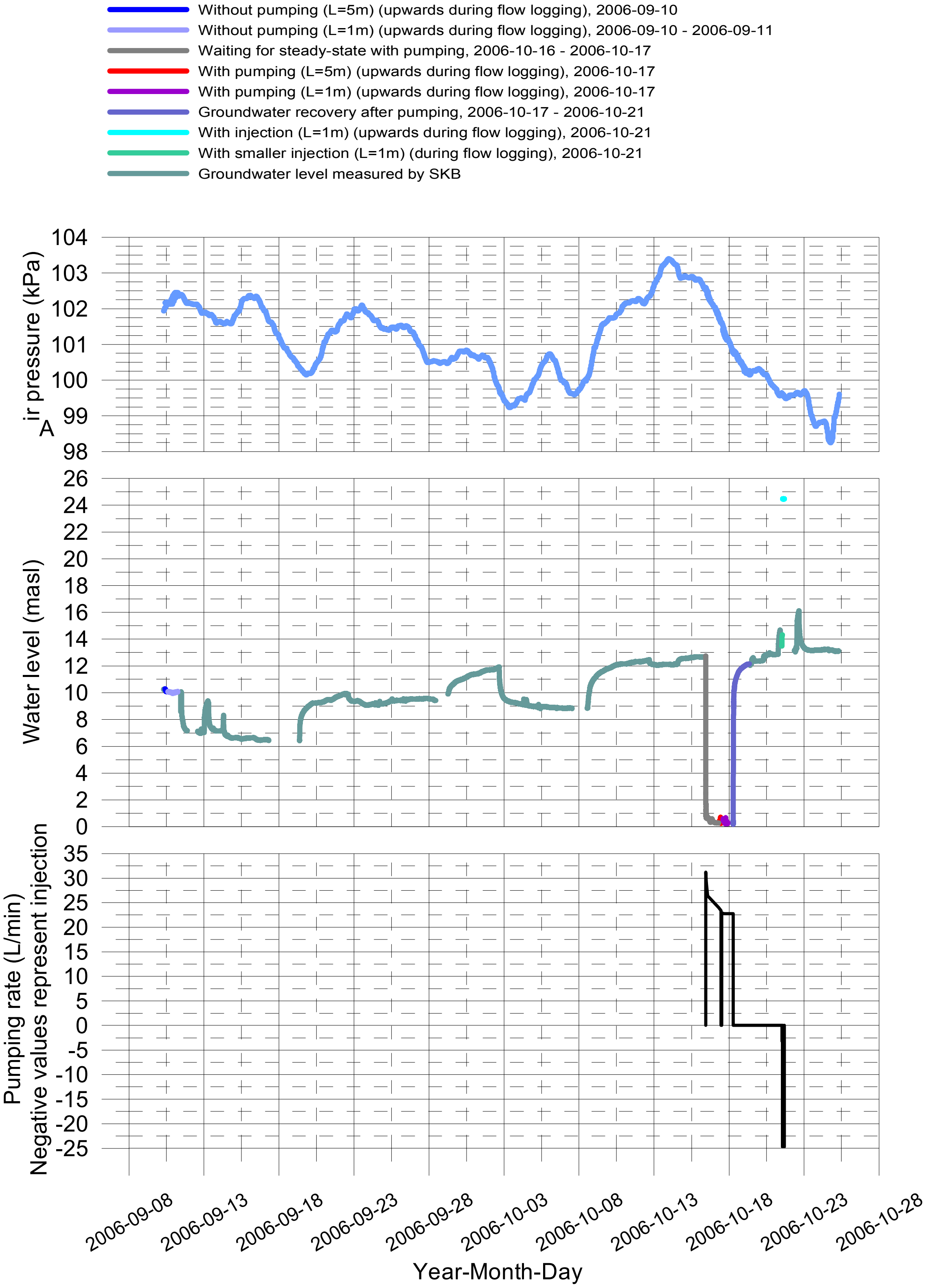


Laxemar, borehole KLX11F
Head in the borehole during flow logging

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 KLX11F
Air pressure, water level in the borehole and pumping rate during flow logging



Laxemar, borehole KLX11F
Groundwater recovery after pumping

Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2300 Pa (Correction for absolut pressure sensor)