P-06-199

Oskarshamn site investigation

Difference flow logging of boreholes KLX09B–F

Subarea Laxemar

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PRG-Tec Oy

November 2006

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Abstract

Difference flow logging is a swift method for the determination of the transmissivity and the hydraulic head in borehole sections and fractures/fracture zones in core drilled boreholes. This report presents the main principles of the methods as well as the results of the measurements carried out in boreholes KLX09B–F at Oskarshamn, Sweden, in February, March and April 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 KLX09B–F. The measurements are a part of the interference difference flow logging test (Report P-06-146).

The flow rates into or out of 1 m and 5 m long test sections were measured in boreholes KLX09B–F during natural (un-pumped) as well as pumped conditions. The uppermost parts of the boreholes were flow logged with injection.

The lengths of boreholes KLX09B–F are relatively short, between c 100–150 m. No length calibration was made since there are no length marks milled into the borehole wall.

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

The electrical conductivity (EC) and temperature of borehole water were also measured. The EC measurements were used to study the occurrence of saline water in the borehole during natural as well as pumped conditions.

Sammanfattning

Differensflödesloggning är en snabb metod för bestämning av transmissivitet och hydraulisk head i borrhålssektioner och sprickor/sprickzoner i kärnborrhål. Denna rapport presenterar huvudprinciperna för metoden och resultat av mätningar utförda i borrhål KLX09B–F i Oskarshamn, Sverige, i februari, mars och april 2005 med Posiva flödesloggningsmetod. Det primära syftet med mätningarna var att bestämma läget och flödet för vattenförande sprickor i borrhålen KLX09B–F. Mätningarna är en del av interferensdifferensflödesloggningstesten (Rapport P-06-146).

Flödet till eller från 1 m och 5 m långa testsektioner mättes i borrhålen KLX09B–F under såväl naturliga (icke-pumpade) som pumpade förhållanden. Övre delen av borrhålen loggades med injektion.

Borrhålen KLX09B–F är relativt korta, ca 100–150 m. Ingen längdkalibrering har gjorts eftersom ingen spårfräsning var gjord i borrhålsväggen.

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

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

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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 400-05-106. 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 400-05-106. 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 KLX09B–F.

The difference flow logging in the core drilled boreholes KLX09B–F at Oskarshamn was conducted between February 15 and April 12, 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 KLX09B–F	AP PS 400-05-106	1.0
Method descriptions	**Number**	**Version**
Method description for difference flow logging	SKB MD 322.010	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	
Instruktion för längdkalibrering vid undersökningar i kärnborrhål	SKB MD 620.010	
Instruktion för analys av injektions- och enhålspumptester	SKB MD 320.004	

Table 1-2. Borehole construction, KLX09B–F.

Borehole ID	Length (m)	Inclination (degrees)	Z coord. of the top of the casing (m.a.s.l)
KLX09B	100.200	–89.540	23.615
KLX09C	120.050	–58.719	23.751
KLX09D	121.020	–59.621	23.101
KLX09E	120.000	–59.932	22.156
KLX09F	152.300	–59.144	19.571

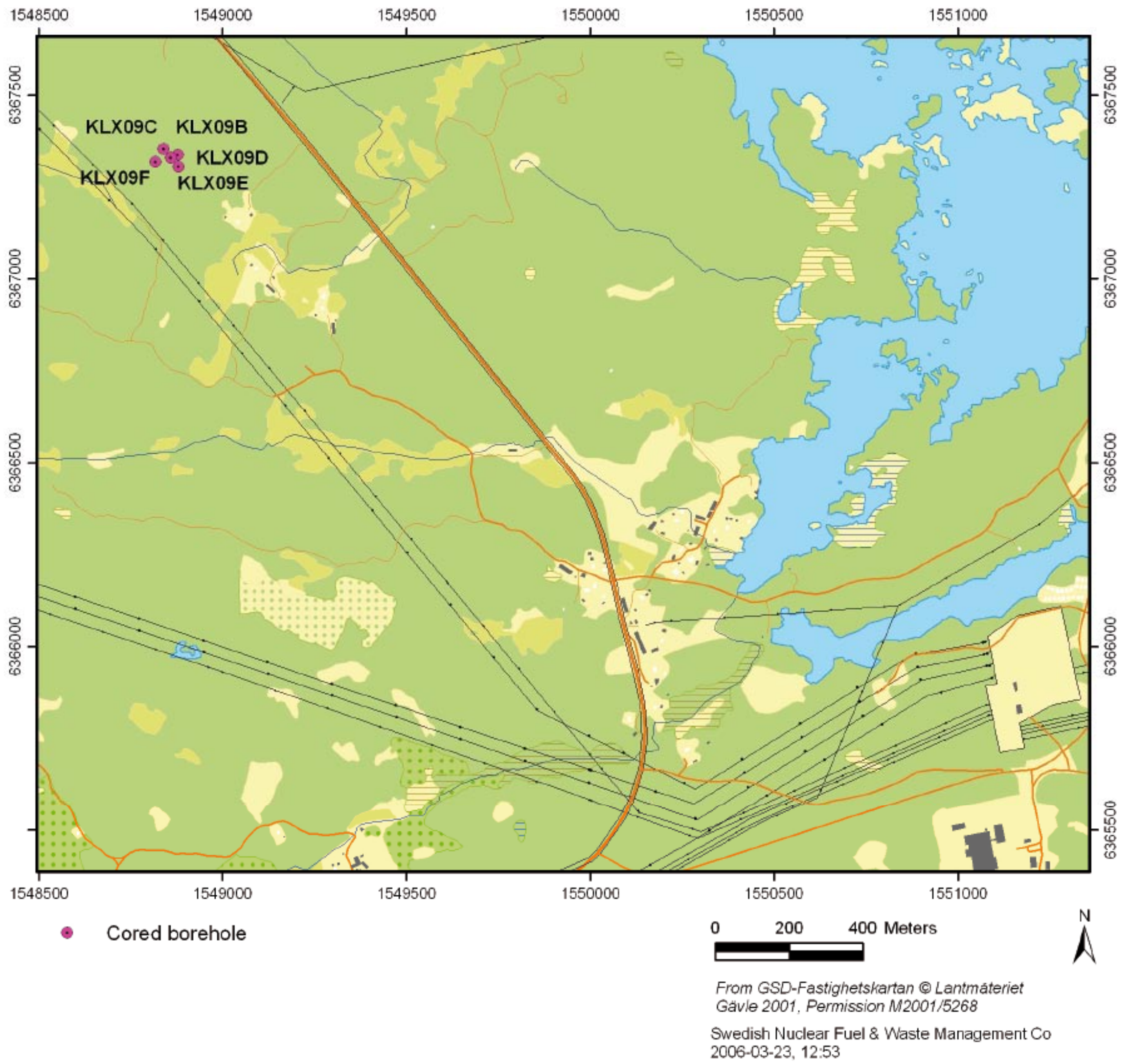

Figure 1-1. *Site map showing the locations of boreholes KLX09B-F situated in the subarea of Laxemar.*

2 Objective and scope

The main objective of the difference flow logging in KLX09B–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-06-146). In this report (P-06-199) 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 KLX09B–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 the single point resistance of the borehole wall and the electrical conductivity of the borehole water. Furthermore, the recovery of the groundwater level after pumping was registered and interpreted hydraulically.

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

3 Principles of measurement and interpretation

3.1 Measurements

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

Rubber disks at both ends of the downhole tool are used to isolate the flow rate in the test section from the flow rate in the rest of the borehole, see Figure 3-1. The flow rate along the borehole outside the isolated test section passes through the test section by means of a bypass pipe and is discharged at the upper end of the downhole tool.

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

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

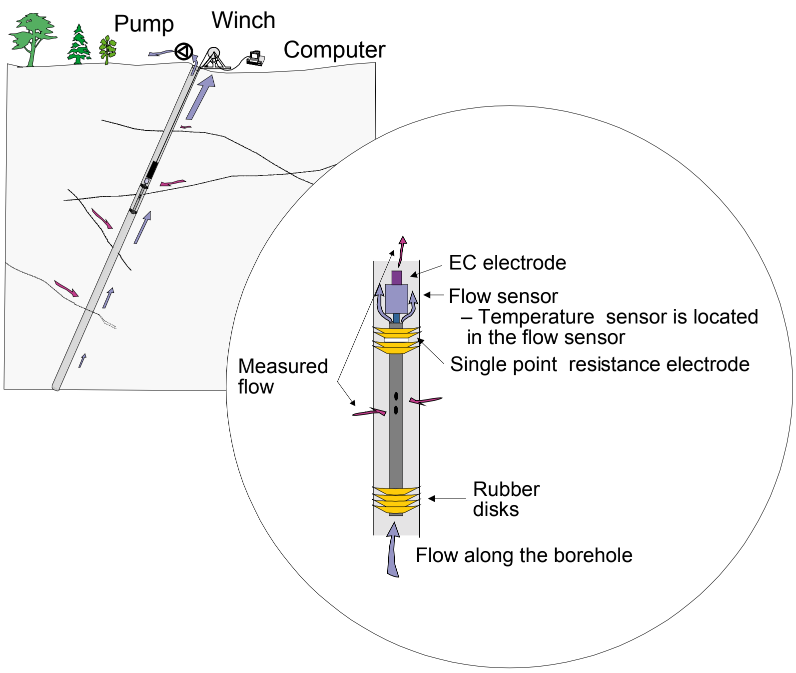

Figure 3-1. *Schematic of the downhole equipment used in the Difference flowmeter.*

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

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

All of the above measurements, except fracture-specific EC and caliper measurements, were performed in KLX09B–F.

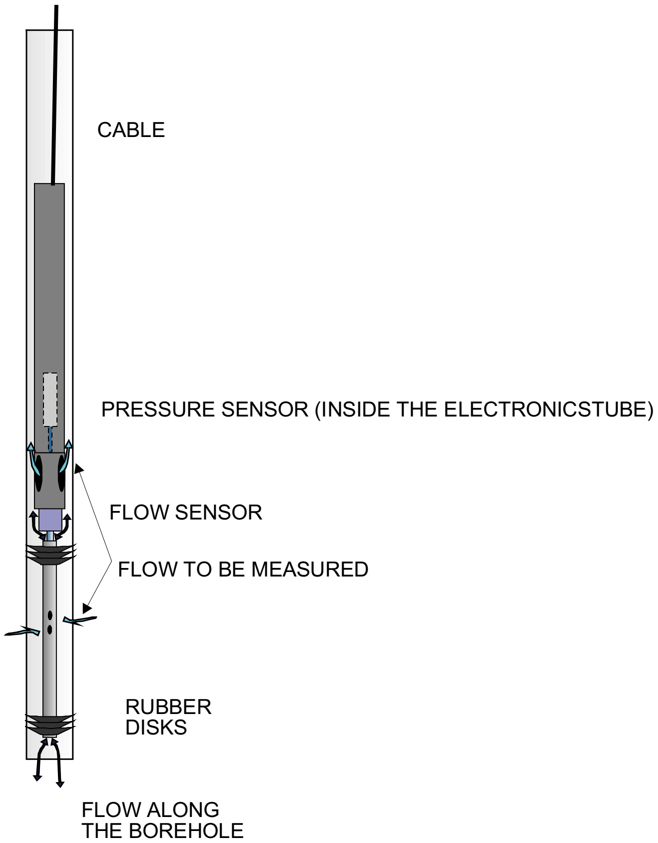

Figure 3-2. *The absolute pressure sensor is located inside the electronics tube and connected through a tube to the borehole water.*

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

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

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

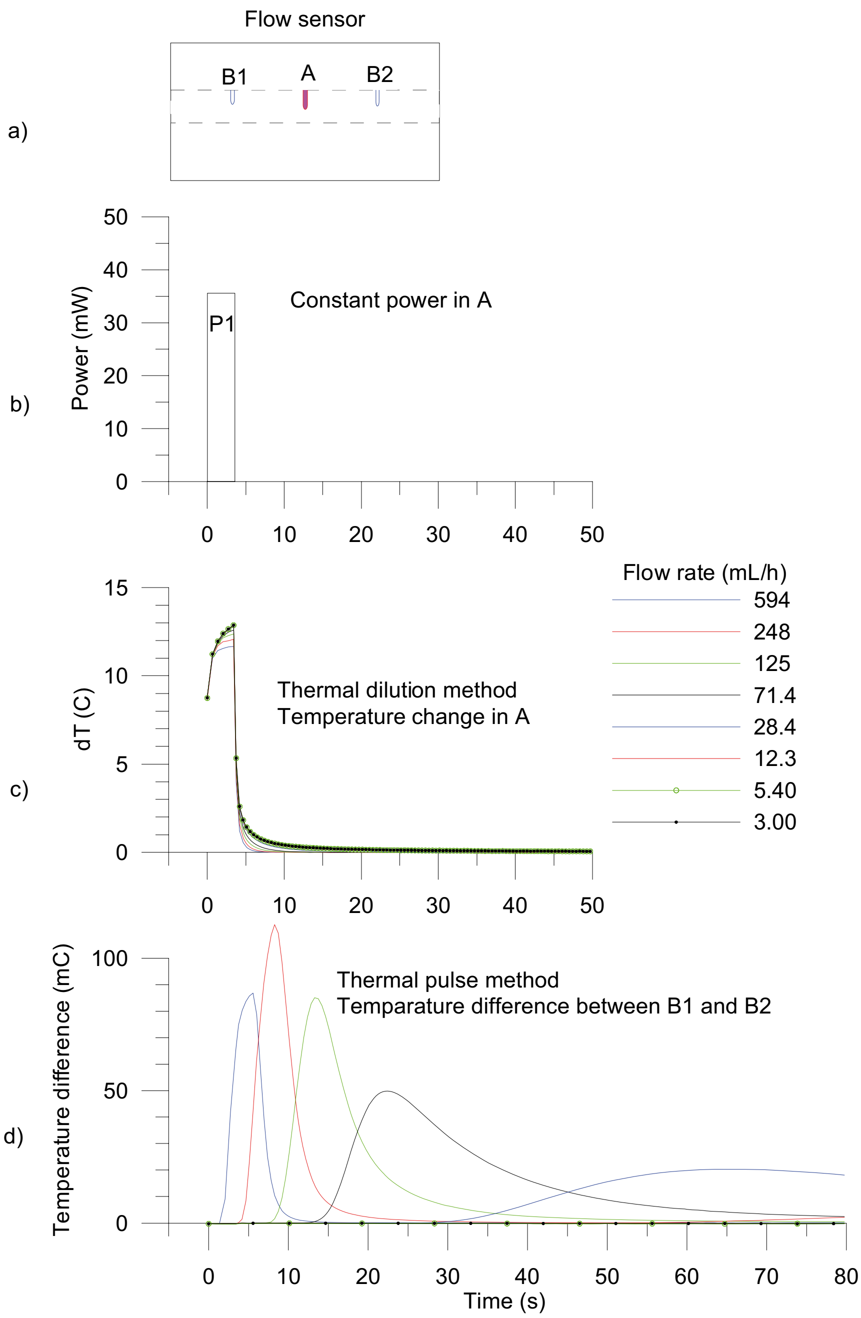

Figure 3-3. *Flow measurement, flow rate < 600 mL/h.*

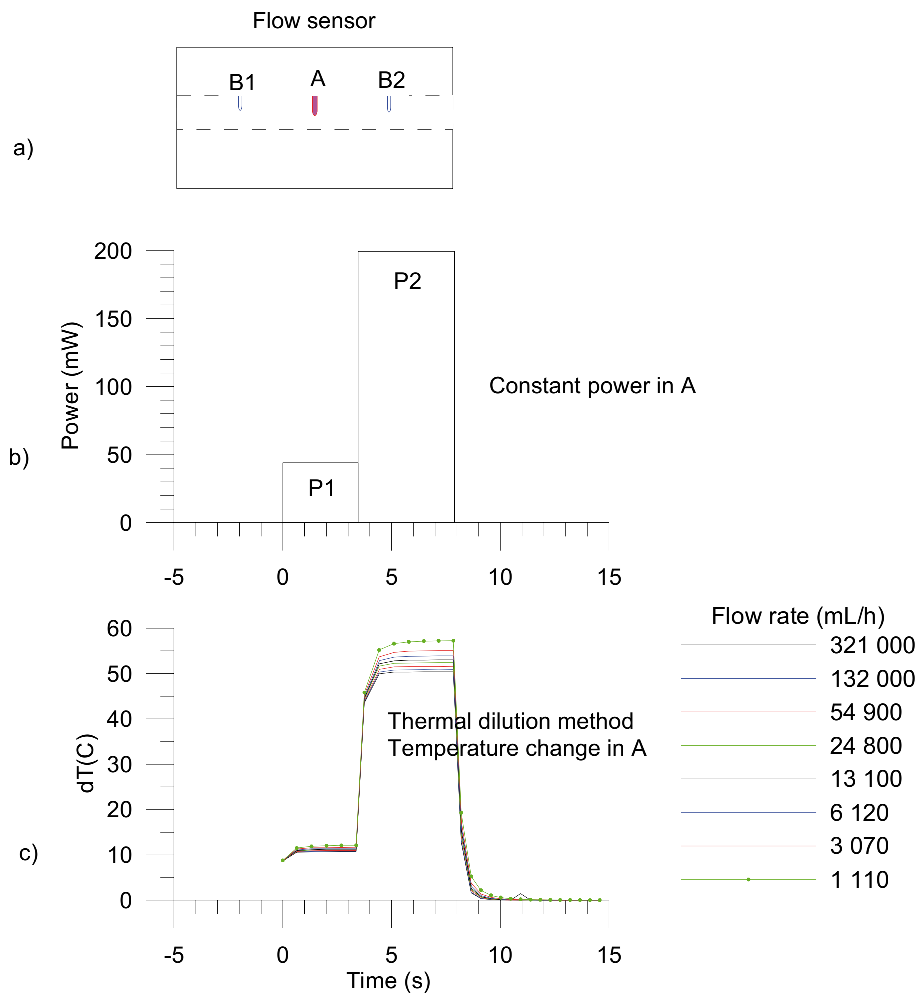

Figure 3-4. *Flow measurement, flow rate > 600 mL/h.*

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

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.

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

3.2 Interpretation

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

$h_s - h = Q/(T \cdot a)$ 3-1

where

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

Q is the flow rate into the borehole,

T is the transmissivity of the test section,

a is a constant depending on the assumed flow geometry.

For cylindrical flow, the constant a is:

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

where

r_0 is the radius of the well and

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

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

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

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

where

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

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

T_s is the transmissivity of the test section and

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

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

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

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

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

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

where

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

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

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

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

where

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

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

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

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

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

where

s is drawdown and

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

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

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

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

4 Equipment specifications

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

Type of instrument:	Posiva Flow Log/Difference Flowmeter.
Borehole diameters:	56 mm, 66 mm and 76 mm.
Length of test section:	A variable length flow guide is used.
Method of flow measurement:	Thermal pulse and/or thermal dilution.
Range and accuracy of measurement:	Table 4-1.
Additional measurements:	Temperature, Single point resistance, 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 2000.
Software:	Based on MS Visual Basic.
Total power consumption:	1.5–2.5 kW depending on the pumps.
Calibrated:	November 2005.
Calibration of cable length:	Using length marks in the borehole.

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

Table 4-1. Range and accuracy of sensors.

Sensor	Range	Accuracy
Flow	6 – 300,000 mL/h	± 10% curr.value
Temperature (middle thermistor)	0 – 50°C	0.1°C
Temperature difference (between outer thermistors)	–2 – +2°C	0.0001°C
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 400-05-106 (SKB internal controlling document) following the SKB Method Description 322.010, Version 1.0 (Method description for difference flow logging). This report (P-06-199) only discusses the results of the single hole measurements. The results of the interference test are reported separately (Report P-06-146). Prior to the measurements, the downhole tools and the measurement cable were disinfected. Every clock was synchronized to the official Swedish time. The activity schedule of the borehole measurements is presented in Table 5-1. The items and activities in Table 5-1 are the same as in the Activity Plan.

Logging cables, wires, and pipe strings are exposed to stretching when lowered into a vertical or sub-vertical borehole. This will introduce a certain error in defining the position of a test tool connected to the end of a logging cable. Normally, the length calibration of logging tools is made by using the known positions of the length marks milled in the borehole wall. Boreholes KLX09B–F are however relatively short, between c 100–150 m, and no length marks were drilled on the borehole wall. Thereby no length calibration was possible in the measurements in boreholes KLX09B–F.

The combined overlapping/sequential flow logging (Items 8–17) 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 February 22 in borehole KLX09B. Every borehole KLX09B–F was pumped and measured, and there was a waiting period during which the water level was allowed to recover. Overlapping flow logging (Items 18–27) 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 KLX09B, KLX09C, KLX09E, KLX09D and KLX09F. Pumping in borehole KLX09F was stopped on the 6th of April. Water level in the boreholes is presented on the date scale, see Appendices B.12.2–F.12.2.

The measurement programme was then continued with injection tests, which allow for a more complete characterization 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 53–57).

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 54Extra, 55Extra, 56Extra and 57Extra).

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 48–52) 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 KLX09B-F. Activity schedule.

Item	Activity	Explanation	Date
1	Mobilisation at site	Unpacking the trailer	2006-02-15
8	Combined Overlapping/Sequential flow logging, KLX09B	Section length L_w=5 m, Step length dL=0.5 m. No pumping	2006-02-21
9	Combined Overlapping/Sequential flow logging, KLX09C	Section length L_w=5 m, Step length dL=0.5 m. No pumping	2006-02-16
10	Combined Overlapping/Sequential flow logging, KLX09D	Section length L_w=5 m, Step length dL=0.5 m. No pumping	2006-02-17
11	Combined Overlapping/Sequential flow logging, KLX09E	Section length L_w=5 m, Step length dL=0.5 m. No pumping	2006-02-18
12	Combined Overlapping/Sequential flow logging, KLX09F	Section length L_w=5 m, Step length dL=0.5 m. No pumping	2006-02-20
13	Combined Overlapping/Sequential flow logging, KLX09B	Section length L_w=1 m, Step length dL=0.1 m. No pumping	2006-02-21 2006-02-22
14	Combined Overlapping/Sequential flow logging, KLX09C	Section length L_w=1 m, Step length dL=0.1 m. No pumping	2006-02-16 2006-02-17
15	Combined Overlapping/Sequential flow logging, KLX09D	Section length L_w=1 m, Step length dL=0.1 m. No pumping	2006-02-17 2006-02-18
16	Combined Overlapping/Sequential flow logging, KLX09E	Section length L_w=1 m, Step length dL=0.1 m. No pumping	2006-02-18 2006-02-19
17	Combined Overlapping/Sequential flow logging, KLX09F	Section length L_w=1 m, Step length dL=0.1 m. No pumping	2006-02-20 2006-02-21
18	Overlapping flow logging, KLX09B	Section length L_w=5 m, Step length dL=0.5 m, pumping (includes 1 day of waiting after the pumping was begun)	2006-02-23
19	Overlapping flow logging, KLX09C	Section length L_w=5 m, Step length dL=0.5 m, pumping (includes 1 day of waiting after the pumping was begun)	2006-03-04
20	Overlapping flow logging, KLX09D	Section length L_w=5 m, Step length dL=0.5 m, pumping (includes 1 day of waiting after the pumping was begun)	2006-03-23
21	Overlapping flow logging, KLX09E	Section length L_w=5 m, Step length dL=0.5 m, pumping (includes 1 day of waiting after the pumping was begun)	2006-03-14
22	Overlapping flow logging, KLX09F	Section length L_w=5 m, Step length dL=0.5 m, pumping (includes 1 day of waiting after the pumping was begun)	2006-04-01
23	Overlapping flow logging, KLX09B	Section length L_w=1 m, Step length dL=0.1 m, pumping	2006-02-23
24	Overlapping flow logging, KLX09C	Section length L_w=1 m, Step length dL=0.1 m, pumping	2006-03-04 2006-03-05
25	Overlapping flow logging, KLX09D	Section length L_w=1 m, Step length dL=0.1 m, pumping	2006-03-23 2006-03-24
26	Overlapping flow logging, KLX09E	Section length L_w=1 m, Step length dL=0.1 m, pumping	2006-03-14
27	Overlapping flow logging, KLX09F	Section length L_w=1 m, Step length dL=0.1 m, pumping	2006-04-01 2006-04-02
48	Recovery transient, KLX09B	Measurement of water level in the borehole after the pumping was stopped.	2006-02-28 2006-03-03
49	Recovery transient, KLX09C	Measurement of water level in the borehole after the pumping was stopped.	2006-03-09 2006-03-13
50	Recovery transient, KLX09D	Measurement of water level in the borehole after the pumping was stopped.	2006-03-28 2006-03-31
51	Recovery transient, KLX09E	Measurement of water level in the borehole after the pumping was stopped.	2006-03-19 2006-03-22
52	Recovery transient, KLX09F	Measurement of water level in the borehole after the pumping was stopped.	2006-04-06 2006-04-08
55 Extra1	Overlapping flow logging, KLX09D	Section length L_w=1 m, Step length dL=0.1 m, smaller injection	2006-04-08
55 Extra2	Overlapping flow logging, KLX09D	Section length L_w=1 m, Step length dL=0.1 m, smaller injection	2006-04-08
55	Overlapping flow logging, KLX09D	Section length L_w=1 m, Step length dL=0.1 m, injection	2006-04-08
53	Overlapping flow logging, KLX09B	Section length L_w=1 m, Step length dL=0.1 m, injection	2006-04-09
56	Overlapping flow logging, KLX09E	Section length L_w=1 m, Step length dL=0.1 m, injection	2006-04-09
56 Extra1	Overlapping flow logging, KLX09E	Section length L_w=1 m, Step length dL=0.1 m, smaller injection	2006-04-10
56 Extra2	Overlapping flow logging, KLX09E	Section length L_w=1 m, Step length dL=0.1 m, smaller injection	2006-04-10
54 Extra1	Overlapping flow logging, KLX09C	Section length L_w=1 m, Step length dL=0.1 m, smaller injection	2006-04-10
54 Extra2	Overlapping flow logging, KLX09C	Section length L_w=1 m, Step length dL=0.1 m, smaller injection	2006-04-10
54	Overlapping flow logging, KLX09C	Section length L_w=1 m, Step length dL=0.1 m, injection	2006-04-10
57	Overlapping flow logging, KLX09F	Section length L_w=1 m, Step length dL=0.1 m, injection	2006-04-10
57 Extra1	Overlapping flow logging, KLX09F	Section length L_w=1 m, Step length dL=0.1 m, smaller injection	2006-04-11
57 Extra2	Overlapping flow logging, KLX09F	Section length L_w=1 m, Step length dL=0.1 m, smaller injection	2006-04-11

Daylight saving time begun March 26 at 03:00 (at which time the clocks were moved one hour ahead to 04:00). This change did not affect the results of this report in any significant way. The only ongoing measurement was the measurement of the pumping rate in Appendix D.12.2, and no data was gathered during the night. The times in this report are given in standard Swedish time (GMT +1) before the change and in daylight saving time (GMT +2) after the change. The same also applies for the raw data since the measurement computer automatically changed the time to daylight saving time.

5.2 Nonconformance

Relatively high noise levels were encountered under pumped conditions, except in the vertical borehole KLX09B. This was 10–100 times higher than what is usually measured for this method. See Section 6.4.4 for details.

6 Results

6.1 Length calibration

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

Length marks on the borehole wall can be used to minimise the length errors. Lengths of boreholes KLX09B–F are relatively short, between c 100–150 m. Cable stretching is not significant at those lengths and no length marks were drilled on the borehole wall. Thereby no length calibration was applied in measurements in boreholes KLX09B–F.

Length errors in KLX09B–F are caused by the following reasons:

1. The point interval in flow measurements is 0.1 m in overlapping mode. This could cause an error of ± 0.05 m.
2. The length of the test section is not exact. The section length is specified as the distance between the nearest upper and lower rubber disks. Effectively, the section length can be larger. At the upper end of the test section there are four rubber disks. The distance between them is 5 cm. This may cause rounded flow anomalies: a flow may be detected already when a fracture is between the upper rubber disks. This phenomenon can only be seen in the short step length (0.1 m) measurements and it can cause an error of ± 0.05 m.
3. Stretching of the logging cable. This could cause an error of ± 0.2 m at the length of 150 m. The error is linear and approaches zero when moving closer to the ground level.

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

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

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

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

6.2 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. Difference between the separate and the simultaneous EC measurement is, that in simultaneous measurement water changes slower in the test section . The measured EC value does not therefore represent the situation in borehole so accurately than 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.2.2–F.2.2 correspond to the EC results in Appendices B.2.1–F.2.1.

6.3 Pressure measurements

Absolute pressure was registered with the flow measurements in Items 8–27 and 55–57. The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered separately, Appendices B.12.2–F.12.2. The hydraulic head along the borehole is determined in the following way. First, the monitored air pressure at the site is subtracted from the measured absolute pressure by the pressure sensor. The hydraulic head (h) at a certain elevation z is then calculated according to the following expression /Freeze and Cherry 1979/:

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

where

h is the hydraulic head (m.a.s.l.) according to the RHB 70 reference system,

p_{abs} is absolute pressure (Pa),

p_b is barometric (air) pressure (Pa),

ρ_{fw} is unit density 1,000 kg/m^3,

g is standard gravity 9.80665 m/s^2 and

z is the elevation of measurement (m.a.s.l.) according to the RHB 70 reference system.

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

Exact z-coordinates are important in head calculation, 10 cm error in z-coordinate means 10 cm error in head. Z-coordinates for boreholes KLX09B–F are calculated from the inclinations of borehole starting points. The calculated head results are presented in graphs in Appendices B.12.1–F.12.1.

In the interpretation of the flow logging results, measured during the smaller injection in borehole KLX09C (Items 54 Extra 1 and 54 Extra 2), the pressure difference of the water level pressure sensor was used instead of the hydraulic head (Appendices C.4 and C.12.1). The reason is that the used absolute pressure sensor is sensitive to the rotation of the tool, and gave too noisy results.

6.4 Flow logging

6.4.1 General comments on results

The flow results are presented together with the single point resistance results (right hand side), see Appendices B.1–F.1. 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, the flow direction may be into the borehole or out from it. For small flow rates (< 100 ml/h) the flow direction can not be seen in the normal overlapping mode (thermal dilution method). Therefore the waiting time was longer for the thermal pulse method to determine the flow direction at every 1 or 5 m interval (sequential mode). The thermal pulse method was only used to detect the flow direction and not the flow rate, which would take a longer time to measure. The longer flow direction measurement has to be done in un-pumped conditions and during the interference tests.

Detected fractures are shown in Appendices B.1–F.1 (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. The short line is used if the flow rate is less than 30 mL/h, if the flow anomalies are overlapping or if they are unclear because of noise. If a fracture is not detected under pumped conditions, the line is grey. Many of the grey marked fractures were detected during the interference test (Report P-06-146).

The tables in Appendices B.9–F.9 were used to calculate conductive fracture frequency (CFF). The number of conductive fractures was counted on the same 5 m sections as in Appendices B.6–F.6 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.10–F.10.

6.4.2 Transmissivity and hydraulic head of borehole sections

The boreholes KLX09B–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.6–F.6. Only the results with a 5 m length increment are used. Secup presented in Appendices B.6–F.6 is calculated as the distance along the borehole from the reference level (top of the casing tube) to the upper end of the test section. Seclow is calculated respectively to the lower end of the test section. The same flow rates as in Appendices B.6–F.6, are also plotted in Appendices B.1–F.1.

Pressure was measured and calculated as described in Section 6.3. Borehole head h_{0FW} and borehole head h_{1FW} in Appendices B.6–F.6 represent the heads determined without and respectively with pumping. The head in the borehole and the calculated heads of borehole sections are given in RHB 70 scale.

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

The flow data is presented as a plot, see Appendices B.3.1–F.3.1. The left hand side of each diagram represents flow from the borehole into the bedrock for the respective test sections, whereas the right hand side represents the opposite. If the measured flow was zero (below the measurement limit), it is not visible in the logarithmic scale of the appendices. The lower and upper measurement limits of the flow are also presented in the plots. Both the theoretical and practical lower limits the flow are given, see Section 6.4.4.

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

KLX09B

With the borehole at rest, 8 sections were detected as flow yielding, 5 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 12 of the detected flows were directed towards the borehole and during injection all 3 of the detected flows were directed towards the bedrock.

At the depth of c 24 m the flow anomaly of injection does not perfectly correspond with the anomalies in pumped and un-pumped conditions, e.g. the calculated transmissivity of a fracture at 25.1 m in the pumped situation is $1.4 \cdot 10^{-08}$ m^2/s and $2.4 \cdot 10^{-08}$ m^2/s in the injected situation. A probable reason is the clearance and opening of fractures from drilling mud during pumping.

KLX09C

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 12 of the detected flows were directed towards the borehole and during injection both 2 of the detected flows were directed towards the bedrock.

KLX09D

With the borehole at rest, 11 sections were detected as flow yielding, 6 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 15 of the detected flows were directed towards the borehole and during injection all 3 of the detected flows were directed towards the bedrock.

KLX09E

With the borehole at rest, 13 sections were detected as flow yielding, 1 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping all 15 of the detected flows were directed towards the borehole. During injection no flows were detected.

KLX09F

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 1 flow was detected and it was directed towards the bedrock.

6.4.3 Transmissivity and hydraulic head of fractures

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

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

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

The high noise level caused by the pumping affected the measurement so that some of the fractures could not be defined under pumped conditions. Transmissivity or hydraulic head were not specified for these fractures. The existence of these fractures was detected from measurements in un-pumped conditions or from the interference difference flow logging test (Report P-06-146).

Fracture-specific transmissivities were compared with the transmissivities of borehole sections in Appendices B.11–F.11. 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.

KLX09B

The total amount of detected flowing fractures in the borehole was 44. 13 of them could be defined without pumping, 37 with pumping and 7 with injection. 12 of the fractures could be used for head estimations and 43 were used for transmissivity estimations, Appendix B.7.

The sum of the detected flows in the un-pumped circumstances (Q_0) was $-6.0\cdot10^{-08}$ m^3/s (–215 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. In this case the sum is close to zero.

KLX09C

The total amount of detected flowing fractures in the borehole was 36. 17 of them could be defined without pumping, 20 with pumping and 2 with injection. 12 of the fractures could be used for head estimations and 21 were used for transmissivity estimations, Appendix C.7.

The sum of the detected flows in un-pumped circumstances (Q_0) was $4.3\cdot10^{-07}$ m^3/s (1,545 mL/h). Due to the structure of the measurement equipment (weights and the lower part of the flow guide), the lowest part of the borehole cannot be measured and a possible reason for the detected flow is the existence of flowing fractures in this part.

KLX09D

The total amount of detected flowing fractures in the borehole was 41. 18 of them could be defined without pumping, 35 with pumping and 5 with injection. 18 of the fractures could be used for head estimations and 40 were used for transmissivity estimations, Appendix D.7.

The sum of the detected flows in un-pumped conditions (Q_0) was $4.9\cdot10^{-08}$ m^3/s (177 mL/h) that is close to zero.

KLX09E

The total amount of detected flowing fractures in the borehole was 34. 16 of them could be defined without pumping, 24 with pumping and none with injection. 14 of the fractures could be used for head estimations and 24 were used for transmissivity estimations, Appendix E.7.

The sum of the detected flows in un-pumped conditions (Q_0) was $2.1\cdot10^{-07}$ m^3/s (762 mL/h). The reason for this unbalance is unknown, but it is again possible that there were flows at the lowest part of the borehole.

KLX09F

The total amount of detected flowing fractures in the borehole was 43. 18 of them could be defined without pumping, 23 with pumping and 2 with injection. 13 of the fractures could be used for head estimations and 25 were used for transmissivity estimations, Appendix F.7.

The sum of the detected flows in un-pumped conditions (Q_0) was $-3.2 \cdot 10^{-07}$ m^3/s (–1,157 mL/h). In this case the value was small compared to the highest flow rates in the borehole.

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

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

There are several known reasons for increased noise levels:

1) Rough borehole wall.
2) Solid particles in the water such as clay or drilling mud.
3) Gas bubbles in the water.
4) High flow rate along the borehole.

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

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

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

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

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

The practical minimum of the measurable flow rate is evaluated and presented in Appendices B.1–F.1 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 were relatively high under pumped conditions, except in the vertical borehole KLX09B, see Table 6-1. Noise level was nearly the same with L=5 m and L=1 m during pumping. A probable reason for the high noise level is drilling debris that was known to exist in the wall of lower side of the inclined boreholes. The drilling mud can be seen in the BIPS-pictures of the boreholes. It could cause minor leaks at the rubber disks. Even minor leaks can increase noise level when the borehole is pumped and when there is high flowing fractures below the tool. In such cases there is high flow along the borehole (in upward direction) at the tool and minor leak flows at lower rubber disks enter into the test section and into the flow sensor increasing noise level.

In some places the noise level fell below 30 mL/h, i.e. below the theoretical limit of the thermal dilution method. However, the values measured below this limit can not be considered qualitative, so the noise line (grey dashed line) was never drawn below 30 mL/h.

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 KLX09C–F. These fractures are marked with "****" in the "Comments"-column in Appendices C.7–F.7.

The practical minimum of the measurable flow rate is also presented in Appendices B.6–F.6 (Q-lower limit P). The value is the same as the Lower limit of flow rate in Appendices B.1–F.1. 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.6–F.6 (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.6–F.6 (TD-$measl_{LT}$). The upper measurement limit oftransmissivity can be evaluated using the maximum flow rate (300,000 mL/h) at the actual head difference as above, see Appendices B.6–F.6 (TD-$measl_{U}$).

All three flow limits are also plotted with measured flow rates, see Appendices B.3.1–F.3.1. 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.3.2–F.3.2.

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

Table 6-1. Approximate noise level in flow in boreholes during pumping.

Borehole	Noise level in flow (mL/h)	Comments
KLX09B	< 30	Vertical borehole
KLX09C	500–1,000	
KLX09D	100	10 mL/h below 75 m
KLX09E	500	
KLX09F	1,000	

6.4.5 Transmissivity of the entire borehole

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

KLX09B

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 9.8 L/min and s (drawdown) was 10.01 m. Transmissivity calculated with Dupuit's formula is $1.6 \cdot 10^{-05}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 89.2m (11–100.2 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $2.1 \cdot 10^{-05}$ m^2/s.

KLX09C

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 31.7 L/min and s (drawdown) was 5.23 m. Transmissivity calculated with Dupuit's formula is $1{,}0 \cdot 10^{-04}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 111.05 m (9–120.05 m) and he borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $1.3 \cdot 10^{-04}$ m^2/s.

KLX09D

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 13.9 L/min and s (drawdown) was 9.96 m. Transmissivity calculated with Dupuit's formula is $2.3 \cdot 10^{-05}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 111.27 m (9.75–121.02 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $3.1 \cdot 10^{-05}$ m^2/s.

KLX09E

For Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500, Q was 31.25 L/min and s (drawdown) was 5.95 m. Transmissivity calculated with Dupuit's formula is $8.7 \cdot 10^{-05}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 111.00 m (9.00–120.00 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $1.2 \cdot 10^{-04}$ m^2/s.

KLX09F

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 3.37 m. Transmissivity calculated with Dupuit's formula is $1.6 \cdot 10^{-04}$ m^2/s.

In Moye's formula (equation 3-10) the length of the test section L is 143.30 m (9.00–152.30 m) and the borehole diameter $2r_0$ is 0.076 m. Transmissivity calculated with Moye's formula is $2.2 \cdot 10^{-04}$ m^2/s.

The results of the two methods are given for each hole in Table 6-2.

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

Table 6-2. Transmissivities of the entire boreholes KLX09B–F.

	KLX09B	KLC09C	KLX09D	KLX09E	KLX09F
Dupuit (m^2/s)	$1.6 \cdot 10^{-05}$	$1.0 \cdot 10^{-04}$	$2.3 \cdot 10^{-05}$	$8.7 \cdot 10^{-05}$	$1.6 \cdot 10^{-04}$
Moye (m^2/s)	$2.1 \cdot 10^{-05}$	$1.3 \cdot 10^{-04}$	$3.1 \cdot 10^{-05}$	$1.2 \cdot 10^{-04}$	$2.2 \cdot 10^{-04}$

6.5 Groundwater level and pumping rate

The groundwater level and the pumping rate are illustrated in Appendices B.12.2–F.12.2 and the recovery plots are presented in Appendices B.12.3–F.12.3. Water level data was not gathered during the entire period, since the measurement equipment was used for the interference flow logging test. The groundwater recovery was monitored with the groundwater level sensor.

Individual borehole information is also presented in Table 6-3. In Table 6-3 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 6-3 are given as metres above sea level (m.a.s.l.) according to RHB70.

Table 6-3. Pumping and recovery periods and measurement setups.

Bore-hole	Pumping period	Pump intake level (m.a.s.l.)	Groundwater level sensor location (m.a.s.l.)	Top of C (m.a.s.l.)	Approx. drawdown (m)	Recovery period
B	2006-02-22–2006-02-28	3.2	1.1	23.615	10.0	2006-02-28–2006-03-03
C	2006-03-03–2006-03-09	8.2	6.3	23.751	5.2	2006-03-09–2006-03-13
D	2006-03-22–2006-03-28	3.4	1.6	23.101	10.0	2006-03-28–2006-03-31
E	2006-03-13–2006-03-19	7.3	5.4	22.156	6.0	2006-03-19–2006-03-22
F	2006-03-31–2006-04-06	9.8	7.9	19.571	3.4	2006-04-06–2006-04-08

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 KLX09B–F at Oskarshamn. The study is part of the interference difference flow logging test (Report P-06-146). The flow rates into or out of 1 m and 5 m long test sections were measured in boreholes KLX09B–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 KLX09B was 44, in KLX09C 36, in KLX09D 41, in KLX09E 34 and in KLX09F 43. High-transmissive fractures were found in KLX09B around the lengths of 60 m and 80 m, in KLX09C around 70 m and 120 m, in KLX09D around 70 m, in KLX09E around 100 m and 110 m and in KLX09F around 80 m, 110 m and 150 m.

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

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Appendices KLX09B

B.1.1–B.1.5	Flow rate and single point resistance
B.2.1	Electric conductivity of borehole water
B.2.2	Temperature of borehole water
B.3.1	Plotted flow rates of 5 m sections
B.3.2	Plotted transmissivity and head of 5 m sections
B.4	Plotted transmissivity and head of detected fractures
B.5	Basic test data
B.6	Results of sequential flow logging
B.7	Inferred flow anomalies from overlapping flow logging
B.8	Explanations for the tables in Appendices 5–7
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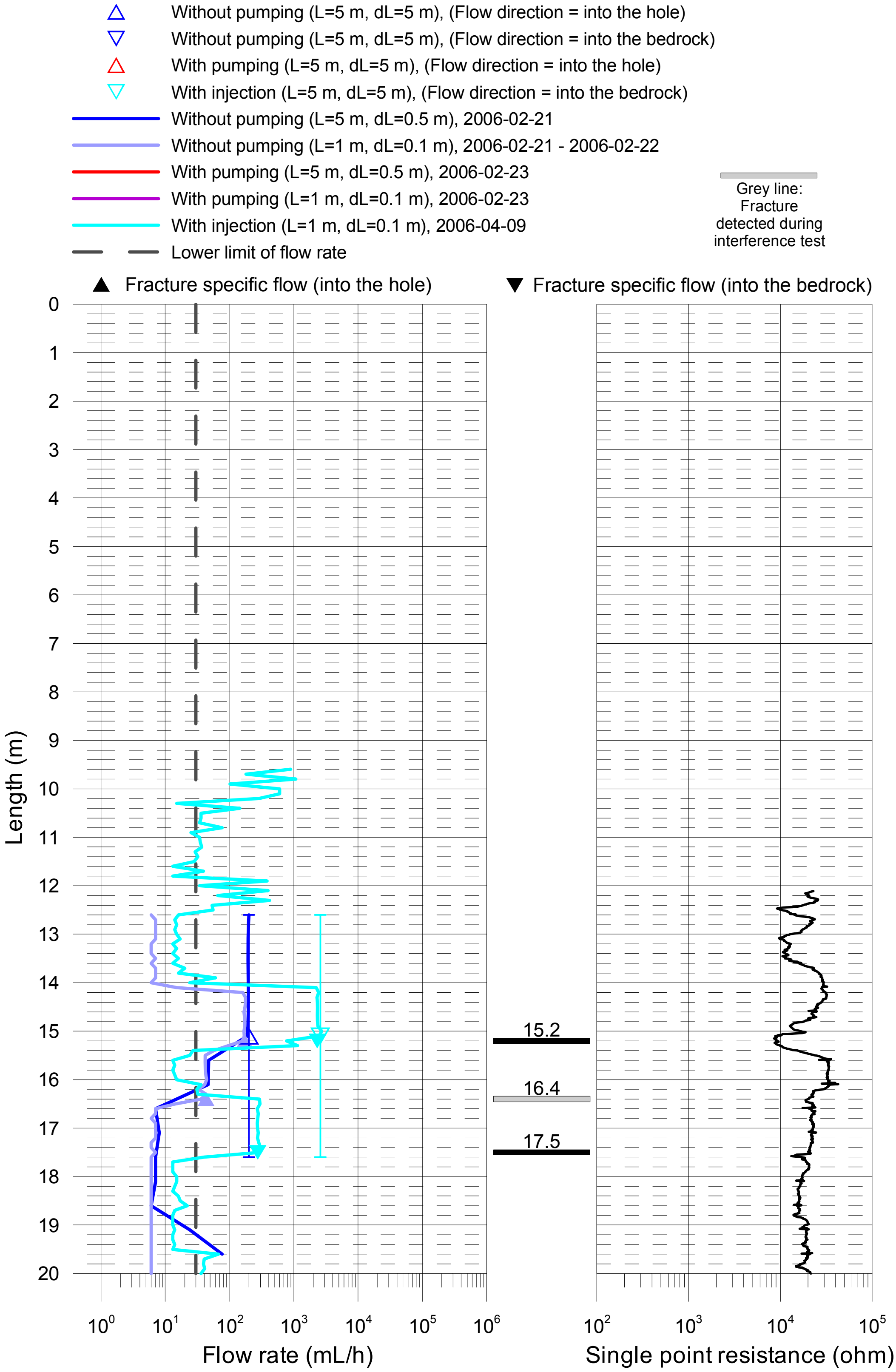
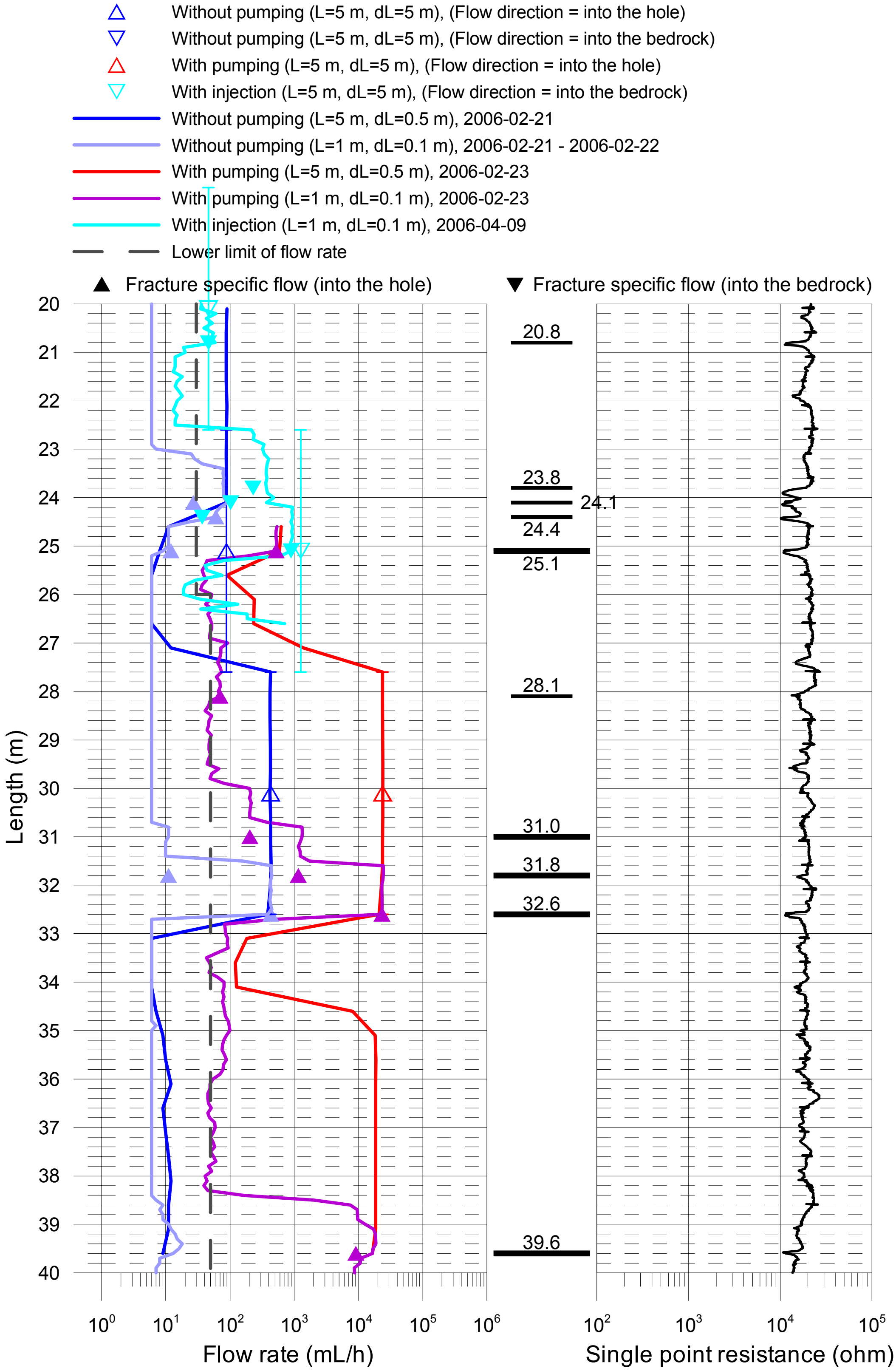
B.11	Comparison between section transmissivity and fracture transmissivity
B.12.1	Head in the borehole during flow logging
B.12.2	Air pressure, water level in the borehole and pumping rate during flow logging
B.12.3	Groundwater recovery after pumping

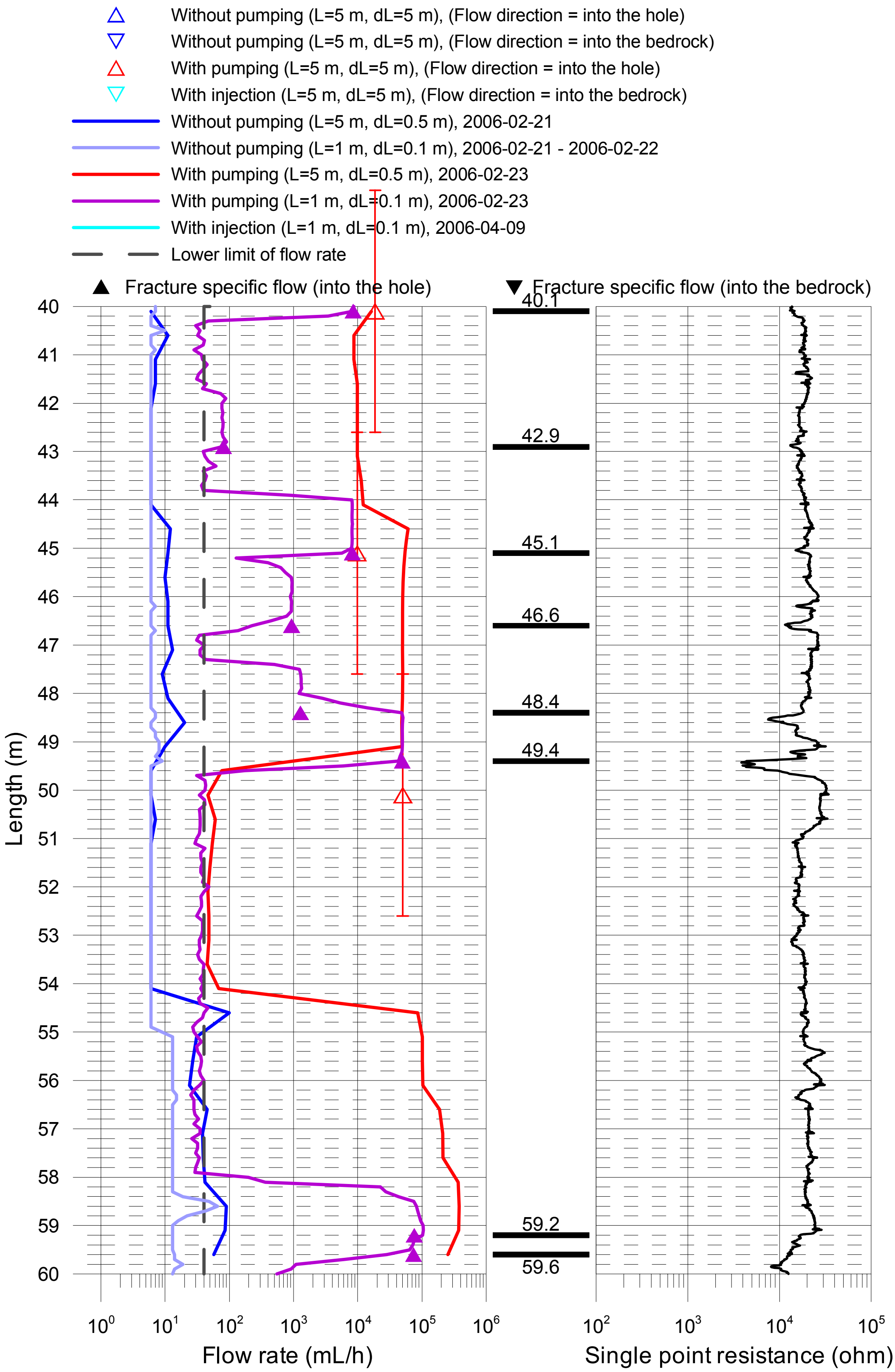
Laxemar, borehole KLX09B
Flow rate and single point resistance



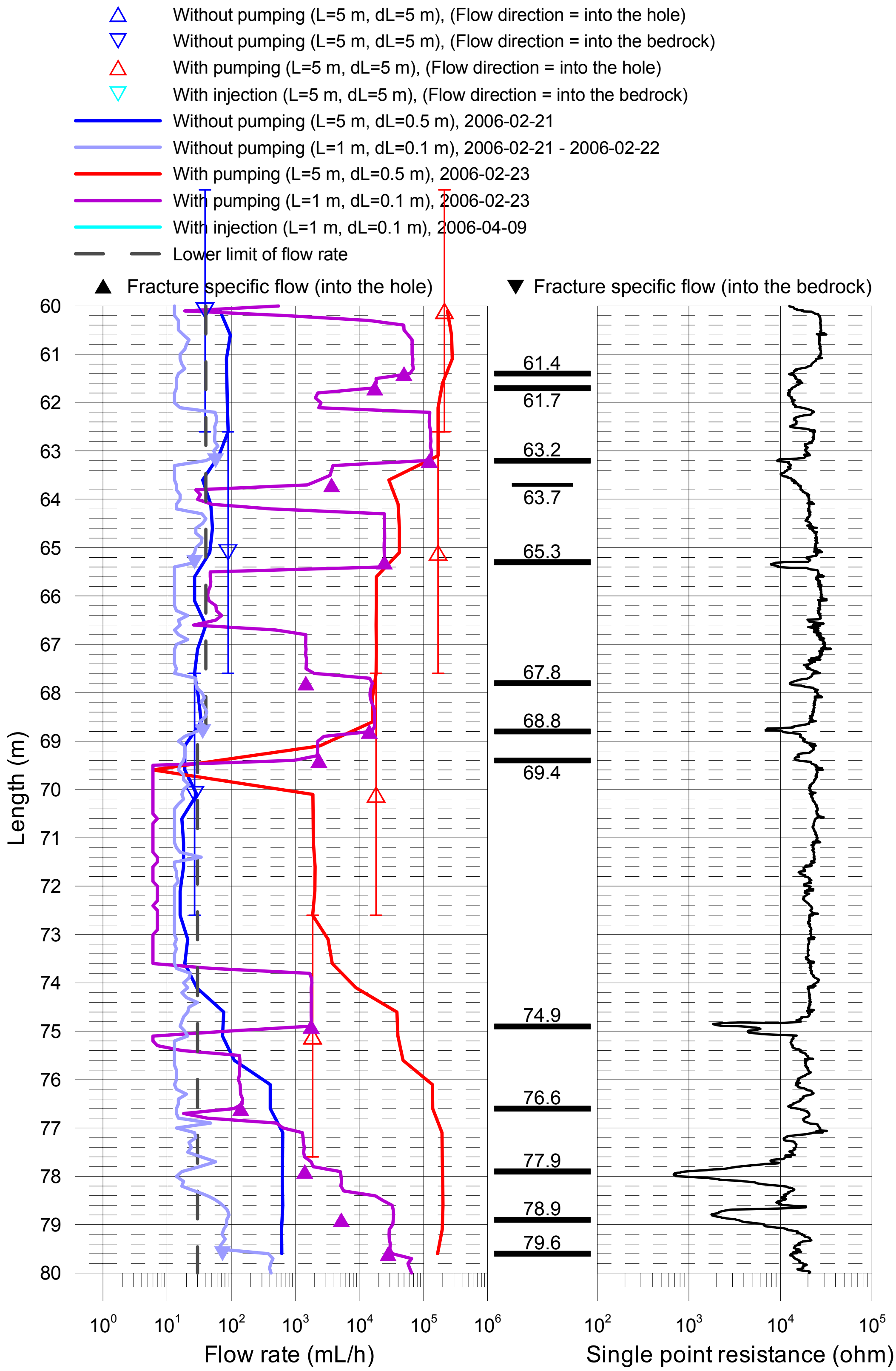
Laxemar, borehole KLX09B
Flow rate and single point resistance



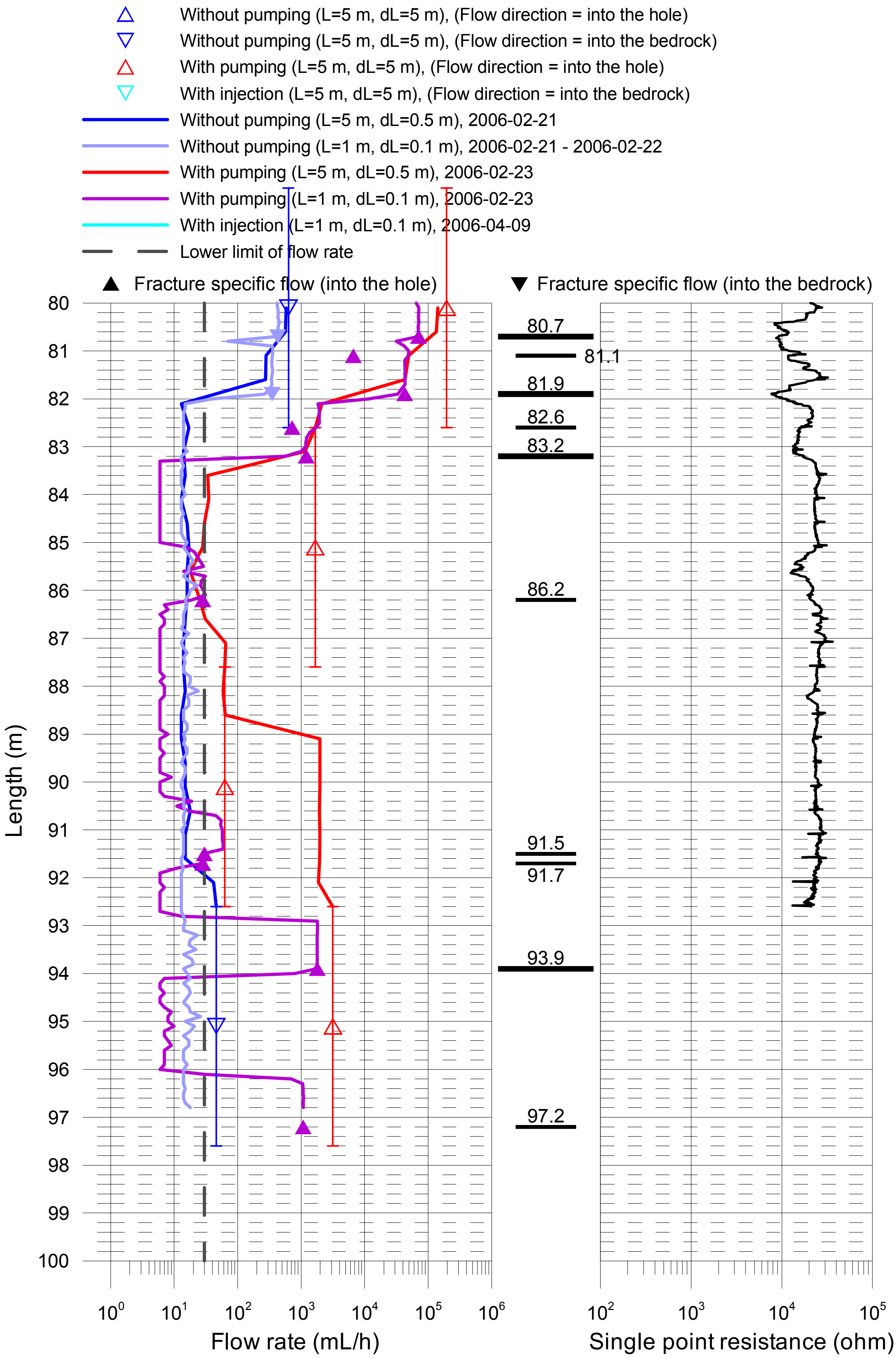
Laxemar, borehole KLX09B
Flow rate and single point resistance



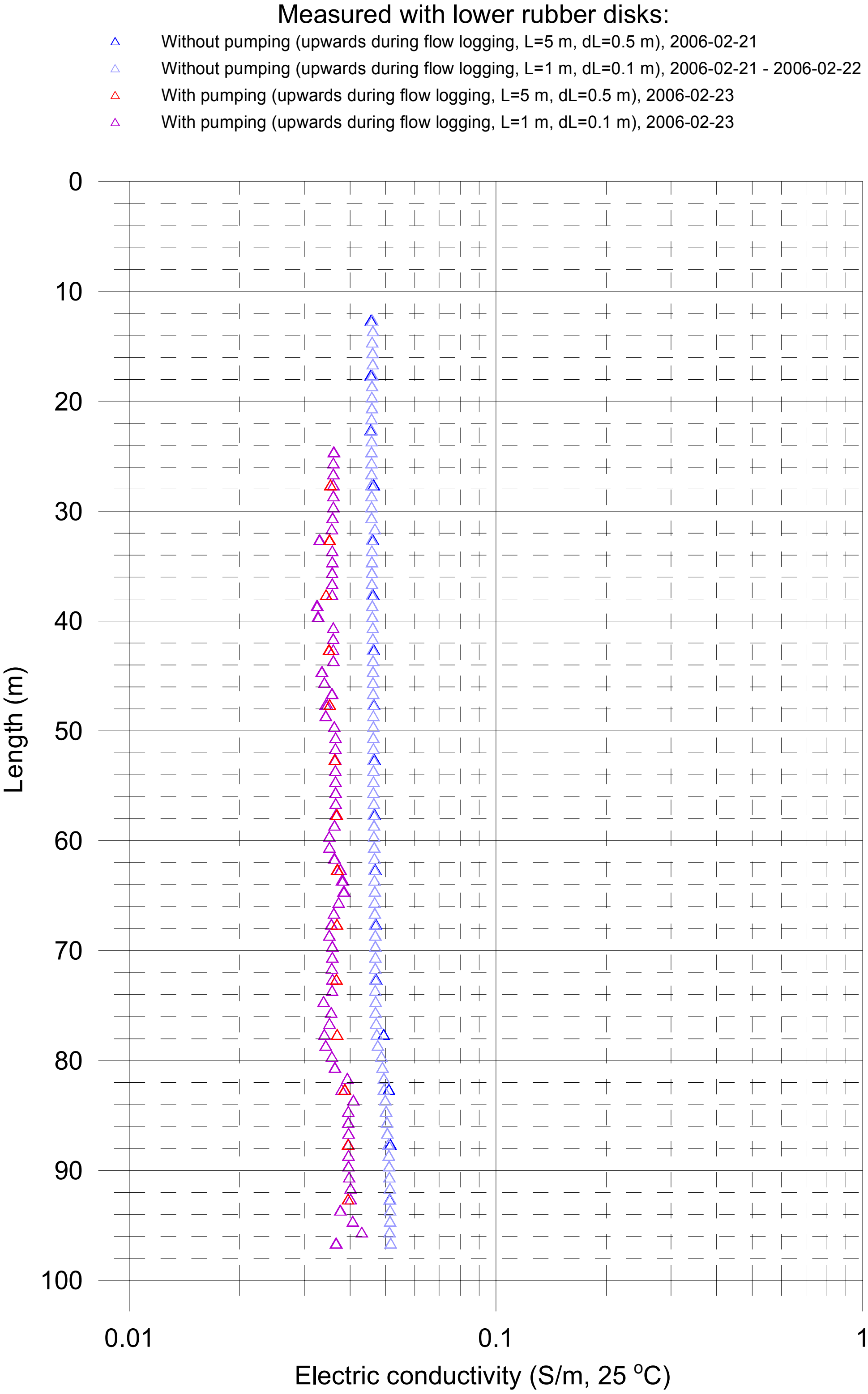
Laxemar, borehole KLX09B
Flow rate and single point resistance



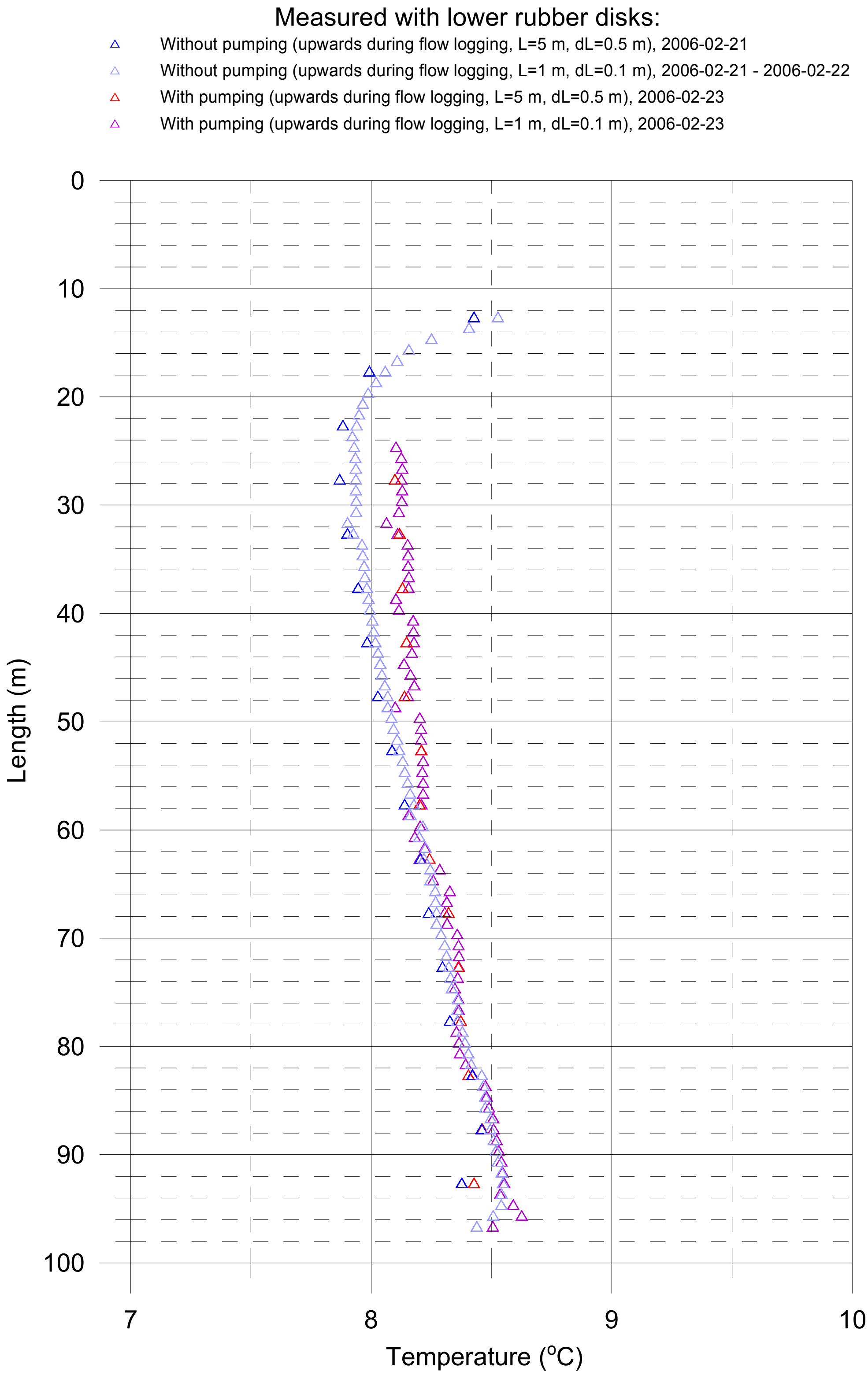
Laxemar, borehole KLX09B
Flow rate and single point resistance

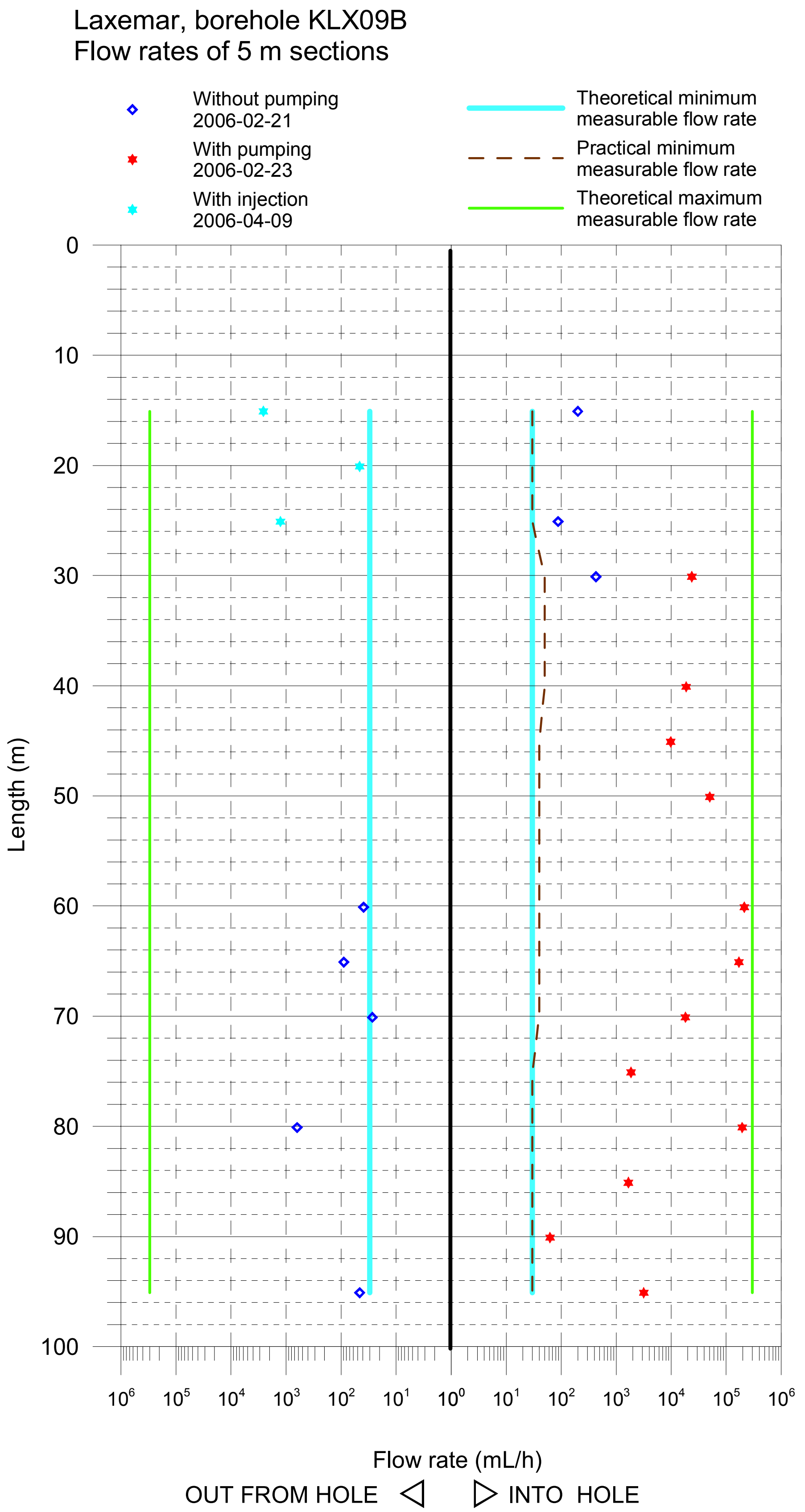


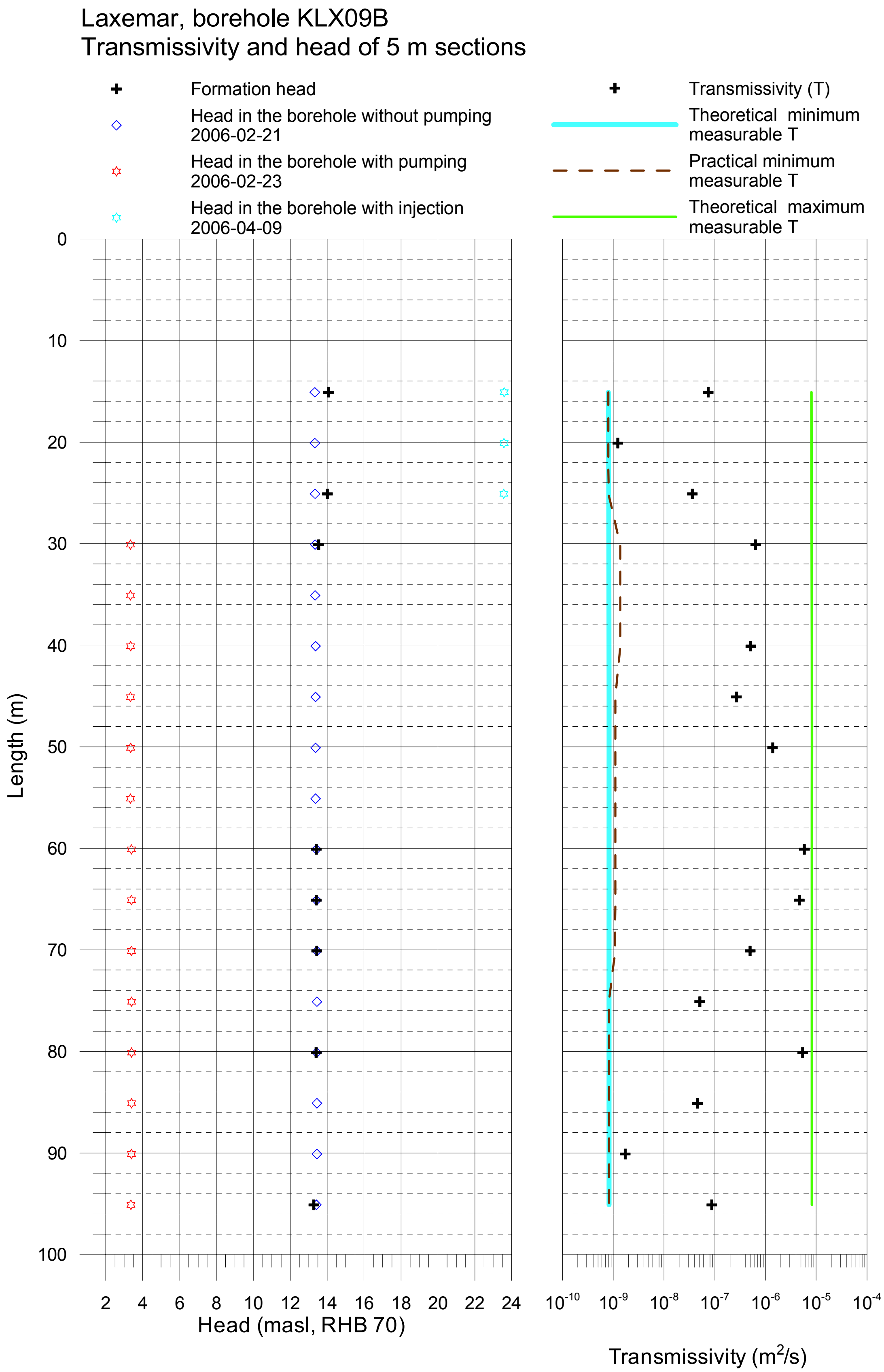
Laxemar, borehole KLX09B
Electric conductivity of borehole water

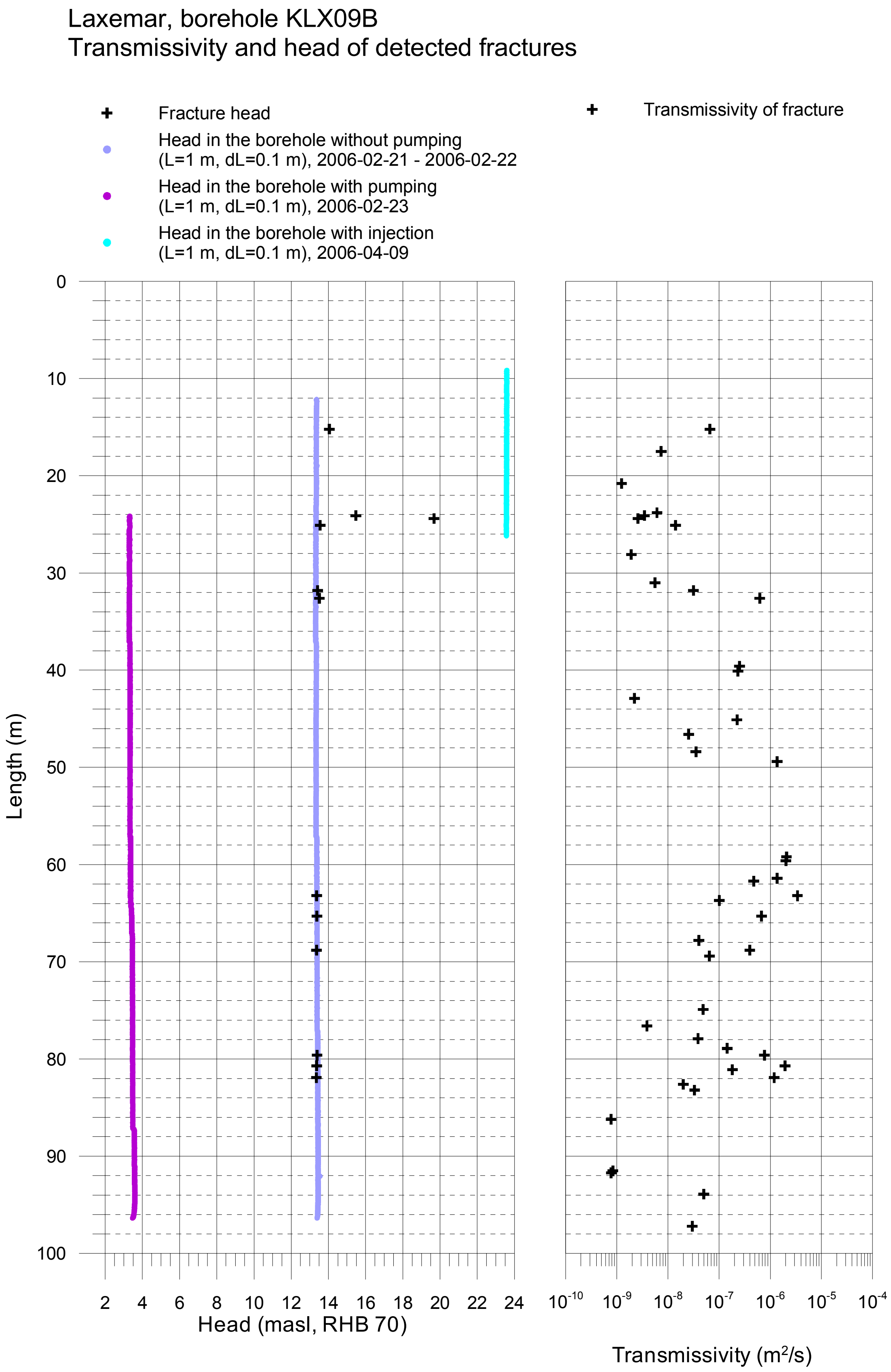


Laxemar, borehole KLX09B
Temperature of borehole water




Laxemar, borehole KLX09B
Flow rates of 5 m sections
Without pumping 2006-02-21
With pumping 2006-02-23
With injection 2006-04-09
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 KLX09B
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-02-21
Head in the borehole with pumping 2006-02-23
Head in the borehole with injection 2006-04-09
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
2
4
6
8
10
12
14
16
18
20
22
24
Head (masl, RHB 70)
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Transmissivity (m^2/s)


Laxemar, borehole KLX09B
Transmissivity and head of detected fractures
Fracture head
Head in the borehole without pumping (L=1 m, dL=0.1 m), 2006-02-21 - 2006-02-22
Head in the borehole with pumping (L=1 m, dL=0.1 m), 2006-02-23
Head in the borehole with injection (L=1 m, dL=0.1 m), 2006-04-09
Transmissivity of fracture
Length (m)
Head (masl, RHB 70)
Transmissivity (m²/s)

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

Borehole ID	Logged interval Secup (m)	Seclow (m)	Test type (1–6)	Date of test, start YYYYMMDD	Time of test, start hh:mm	Date of flowl., start YYYYMMDD	Time of flowl., start hh:mm	Date of test, stop YYYYMMDD	Time of test, stop hh:mm	L_w (m)	dL (m)	Q_{p1} (m^3/s)	Q_{p2} (m^3/s)
KLX09B	12.60	97.60	5A	20060222	10:50	20060223	08:15	20060228	08:18	5	5	1.63E–4	

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 (–)
509,280		259,893		13.35	3.34		–10.01		1.6E–5		

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KLX09B	12.6	17.6	5	5.56E–08	13.33	–7.15E–07	23.59	7.4E–08	14.1	30	8.0E–10	8.0E–10	8.0E–06	**
KLX09B	17.6	22.6	5	–	13.33	–1.28E–08	23.58	1.2E–09	–	30	8.0E–10	8.0E–10	8.0E–06	**
KLX09B	22.6	27.6	5	2.44E–08	13.34	–3.50E–07	23.57	3.6E–08	14.0	30	8.1E–10	8.1E–10	8.1E–06	**
KLX09B	27.6	32.6	5	1.19E–07	13.35	6.58E–06	3.34	6.4E–07	13.5	50	8.2E–10	1.4E–09	8.2E–06	
KLX09B	32.6	37.6	5	–	13.35	–	3.34	–	–	50	8.2E–10	1.4E–09	8.2E–06	
KLX09B	37.6	42.6	5	–	13.37	5.19E–06	3.35	5.1E–07	–	50	8.2E–10	1.4E–09	8.2E–06	
KLX09B	42.6	47.6	5	–	13.37	2.71E–06	3.34	2.7E–07	–	40	8.2E–10	1.1E–09	8.2E–06	
KLX09B	47.6	52.6	5	–	13.37	1.40E–05	3.35	1.4E–06	–	40	8.2E–10	1.1E–09	8.2E–06	
KLX09B	52.6	57.6	5	–	13.37	–	3.34	–	–	40	8.2E–10	1.1E–09	8.2E–06	
KLX09B	57.6	62.6	5	–1.08E–08	13.41	5.92E–05	3.39	5.8E–06	13.4	40	8.2E–10	1.1E–09	8.2E–06	
KLX09B	62.6	67.6	5	–2.47E–08	13.42	4.72E–05	3.39	4.7E–06	13.4	40	8.2E–10	1.1E–09	8.2E–06	
KLX09B	67.6	72.6	5	–7.50E–09	13.44	5.06E–06	3.39	5.0E–07	13.4	40	8.2E–10	1.1E–09	8.2E–06	
KLX09B	72.6	77.6	5	–	13.44	5.17E–07	3.4	5.1E–08	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX09B	77.6	82.6	5	–1.75E–07	13.43	5.44E–05	3.4	5.4E–06	13.4	30	8.2E–10	8.2E–10	8.2E–06	
KLX09B	82.6	87.6	5	–	13.44	4.64E–07	3.4	4.6E–08	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX09B	87.6	92.6	5	–	13.44	1.75E–08	3.39	1.7E–09	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX09B	92.6	97.6	5	–1.28E–08	13.41	8.81E–07	3.36	8.8E–08	13.3	30	8.2E–10	8.2E–10	8.2E–06	

** Values from the measurement with injection.

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
KLX09B	15.2	1	0.1	4.75E–08	13.34	–6.39E–07	23.58	6.6E–08	14.1	**
KLX09B	16.4	1	0.1	1.19E–08	13.35	–	23.58	–	–	**, ***
KLX09B	17.5	1	0.1	–	13.34	–7.64E–08	23.58	7.4E–09	–	**
KLX09B	20.8	1	0.1	–	13.36	–1.28E–08	23.58	1.2E–09	–	*, **
KLX09B	23.8	1	0.1	–	13.35	–6.33E–08	23.57	6.1E–09	–	*, **
KLX09B	24.1	1	0.1	7.50E–09	13.33	–2.83E–08	23.57	3.5E–09	15.5	*, **
KLX09B	24.4	1	0.1	1.67E–08	13.34	–1.03E–08	23.58	2.6E–09	19.7	*, **
KLX09B	25.1	1	0.1	3.33E–09	13.33	1.46E–07	3.32	1.4E–08	13.6	
KLX09B	28.1	1	0.1	–	13.33	1.94E–08	3.3	1.9E–09	–	*
KLX09B	31.0	1	0.1	–	13.33	5.67E–08	3.31	5.6E–09	–	
KLX09B	31.8	1	0.1	3.06E–09	13.32	3.22E–07	3.31	3.2E–08	13.4	
KLX09B	32.6	1	0.1	1.20E–07	13.32	6.47E–06	3.3	6.3E–07	13.5	
KLX09B	39.6	1	0.1	–	13.35	2.53E–06	3.32	2.5E–07	–	
KLX09B	40.1	1	0.1	–	13.35	2.36E–06	3.34	2.3E–07	–	
KLX09B	42.9	1	0.1	–	13.34	2.25E–08	3.33	2.2E–09	–	
KLX09B	45.1	1	0.1	–	13.33	2.27E–06	3.33	2.2E–07	–	
KLX09B	46.6	1	0.1	–	13.33	2.58E–07	3.33	2.6E–08	–	
KLX09B	48.4	1	0.1	–	13.33	3.56E–07	3.34	3.5E–08	–	
KLX09B	49.4	1	0.1	–	13.33	1.37E–05	3.33	1.4E–06	–	
KLX09B	59.2	1	0.1	–	13.37	2.10E–05	3.36	2.1E–06	–	
KLX09B	59.6	1	0.1	–	13.38	2.05E–05	3.37	2.0E–06	–	
KLX09B	61.4	1	0.1	–	13.38	1.38E–05	3.37	1.4E–06	–	
KLX09B	61.7	1	0.1	–	13.38	4.81E–06	3.36	4.7E–07	–	
KLX09B	63.2	1	0.1	–1.58E–08	13.37	3.44E–05	3.36	3.4E–06	13.4	
KLX09B	63.7	1	0.1	–	13.38	1.02E–06	3.37	1.0E–07	–	*
KLX09B	65.3	1	0.1	–7.50E–09	13.39	6.81E–06	3.43	6.8E–07	13.4	
KLX09B	67.8	1	0.1	–	13.39	4.06E–07	3.46	4.0E–08	–	
KLX09B	68.8	1	0.1	–1.00E–08	13.38	3.97E–06	3.45	4.0E–07	13.4	
KLX09B	69.4	1	0.1	–	13.39	6.50E–07	3.46	6.5E–08	–	
KLX09B	74.9	1	0.1	–	13.39	4.92E–07	3.46	4.9E–08	–	
KLX09B	76.6	1	0.1	–	13.39	3.89E–08	3.47	3.9E–09	–	
KLX09B	77.9	1	0.1	–	13.42	3.92E–07	3.46	3.9E–08	–	
KLX09B	78.9	1	0.1	–	13.43	1.46E–06	3.46	1.4E–07	–	
KLX09B	79.6	1	0.1	–2.03E–08	13.42	7.78E–06	3.47	7.8E–07	13.4	
KLX09B	80.7	1	0.1	–1.19E–07	13.43	1.96E–05	3.47	2.0E–06	13.4	
KLX09B	81.1	1	0.1	–	13.42	1.83E–06	3.47	1.8E–07	–	*
KLX09B	81.9	1	0.1	–9.69E–08	13.43	1.19E–05	3.47	1.2E–06	13.4	
KLX09B	82.6	1	0.1	–	13.43	2.00E–07	3.47	2.0E–08	–	*
KLX09B	83.2	1	0.1	–	13.43	3.33E–07	3.47	3.3E–08	–	
KLX09B	86.2	1	0.1	–	13.42	7.78E–09	3.48	7.7E–10	–	*
KLX09B	91.5	1	0.1	–	13.44	8.33E–09	3.58	8.4E–10	–	*
KLX09B	91.7	1	0.1	–	13.44	7.78E–09	3.58	7.8E–10	–	*
KLX09B	93.9	1	0.1	–	13.44	5.00E–07	3.59	5.0E–08	–	
KLX09B	97.2	1	0.1	–	13.39	3.00E–07	3.47	3.0E–08	–	*

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

** Values from the measurement with injection.

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

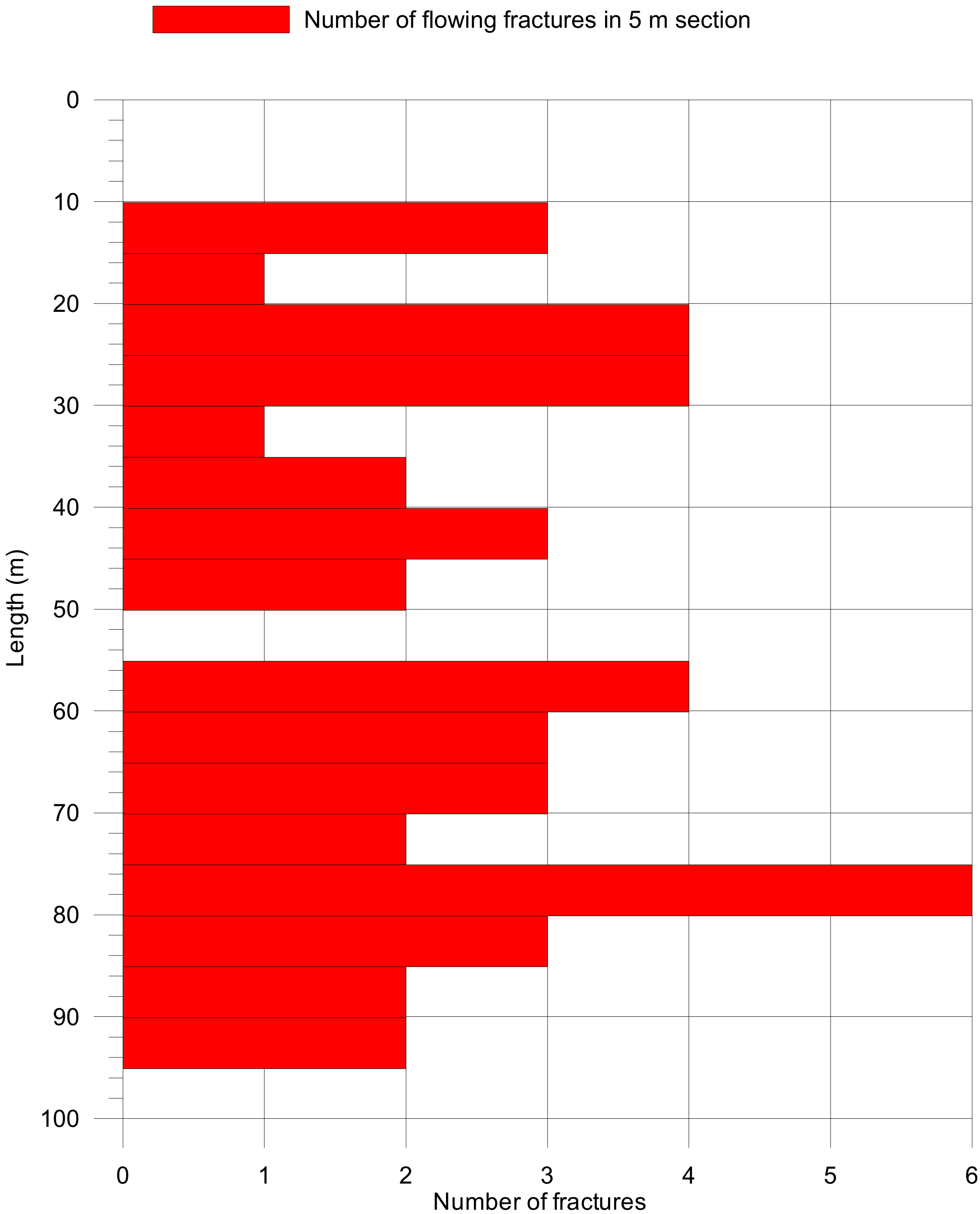
Explanations.

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.
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).

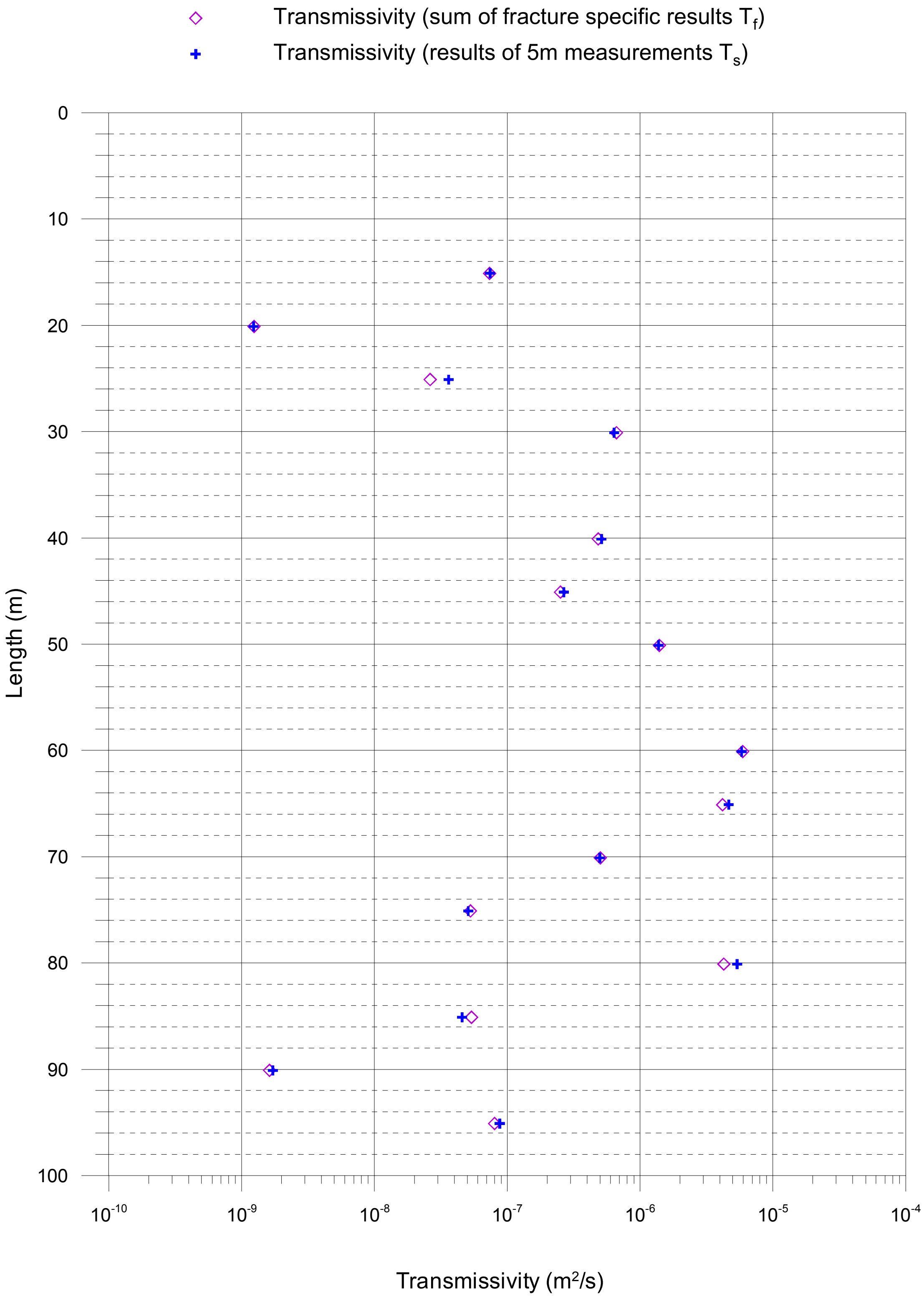
Calculation of conductive fracture frequency.

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)
KLX09B	12.6	17.6	3	0	0	0	0	0
KLX09B	17.6	22.6	1	0	0	0	0	0
KLX09B	22.6	27.6	4	0	1	0	0	0
KLX09B	27.6	32.6	4	1	1	1	1	0
KLX09B	32.6	37.6	0	0	0	0	0	0
KLX09B	37.6	42.6	2	0	0	2	0	0
KLX09B	42.6	47.6	3	1	1	1	0	0
KLX09B	47.6	52.6	2	0	0	1	1	0
KLX09B	52.6	57.6	0	0	0	0	0	0
KLX09B	57.6	62.6	4	0	0	0	4	0
KLX09B	62.6	67.6	3	0	0	1	1	1
KLX09B	67.6	72.6	3	0	0	2	1	0
KLX09B	72.6	77.6	2	0	1	1	0	0
KLX09B	77.6	82.6	6	0	0	3	3	0
KLX09B	82.6	87.6	3	1	1	1	0	0
KLX09B	87.6	92.6	2	2	0	0	0	0
KLX09B	92.6	97.6	2	0	0	2	0	0

Laxemar, borehole KLX09B
Calculation of conductive fracture frequency

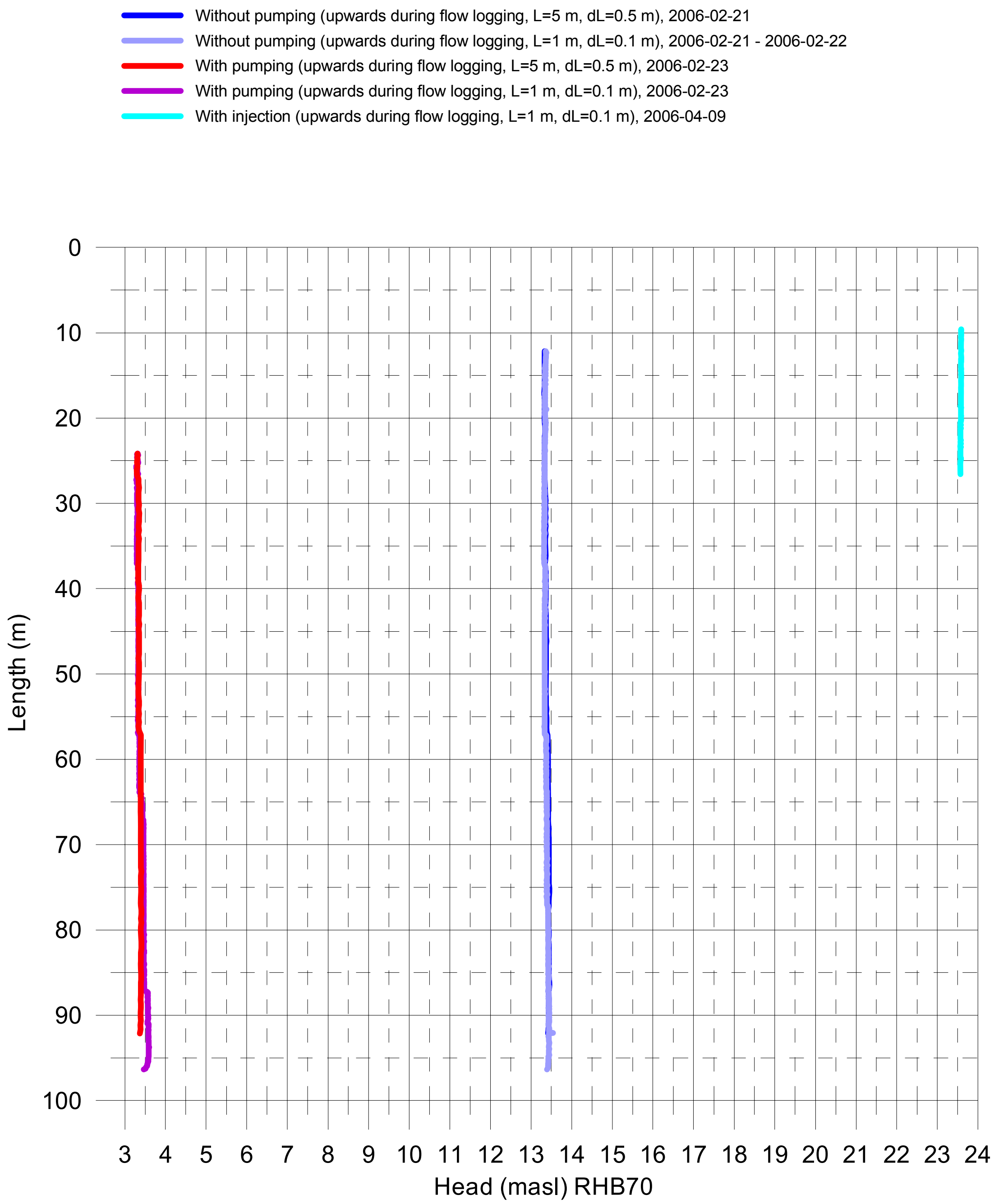


Laxemar, borehole KLX09B
Comparison between section transmissivity and fracture transmissivity

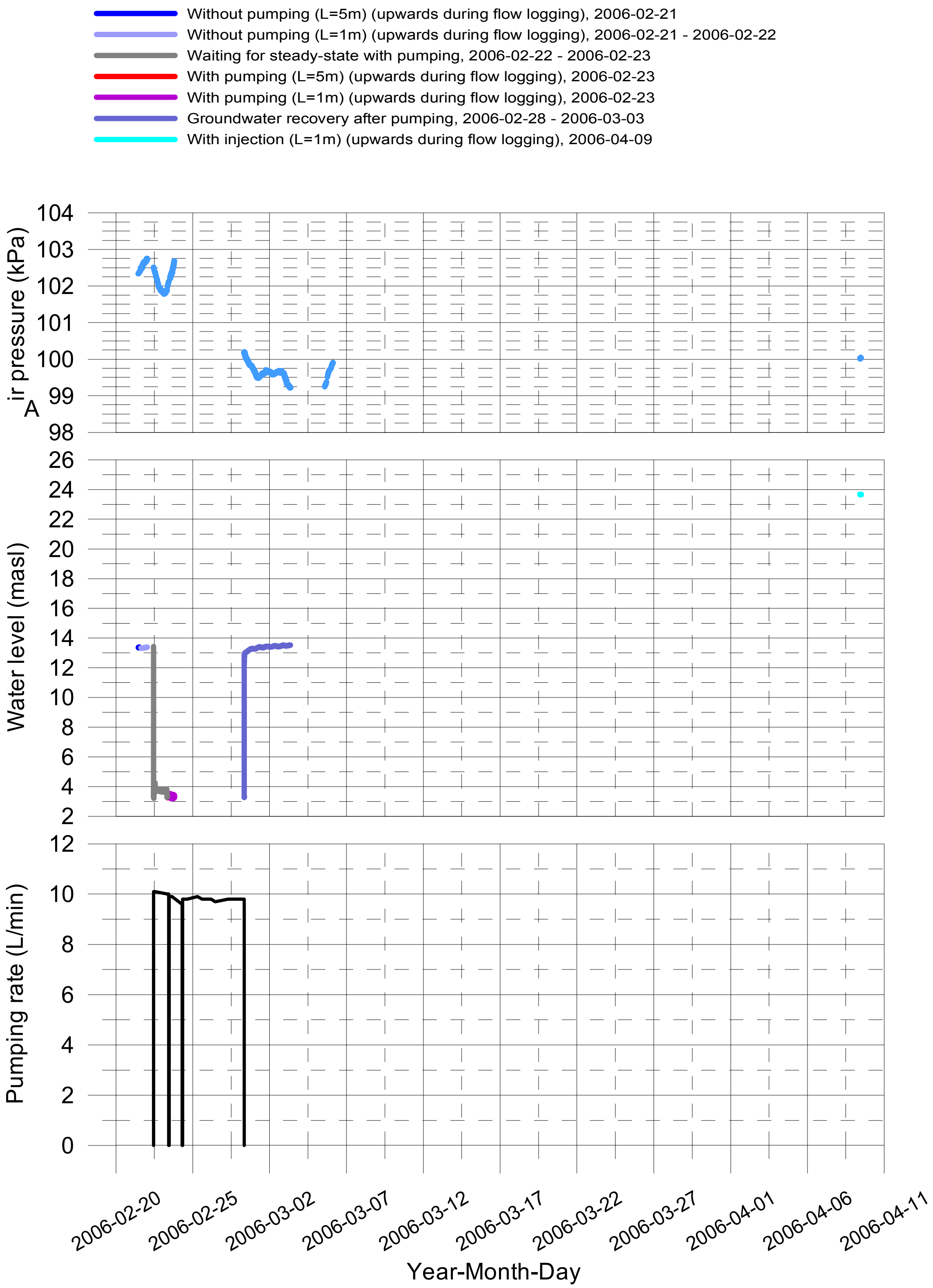


Laxemar, borehole KLX09B
Head in the borehole during flow logging

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)

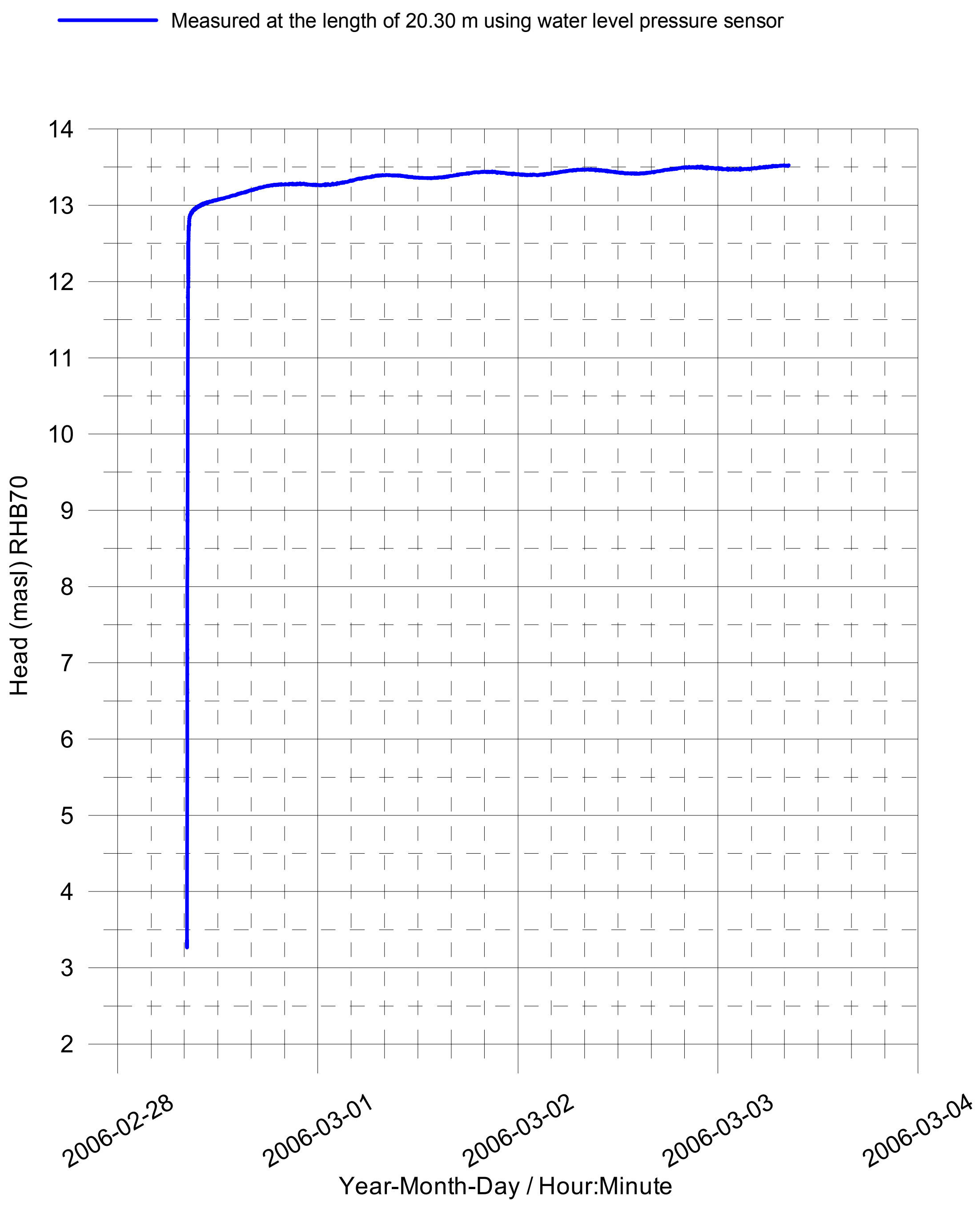


Laxemar, borehole KLX09B
Air pressure, water level in the borehole and pumping rate during flow logging



Laxemar, borehole KLX09B
Groundwater recovery after pumping

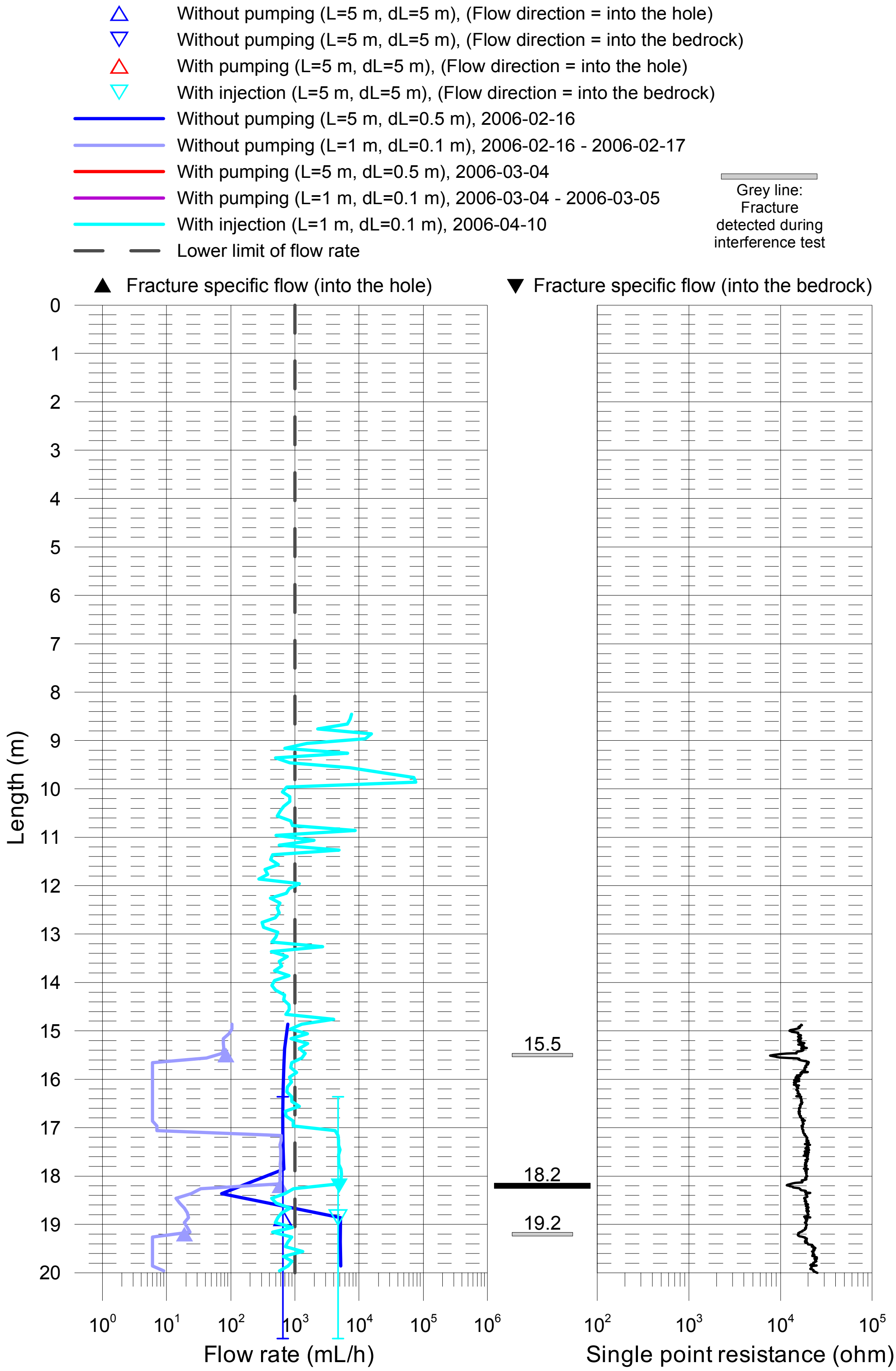
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)

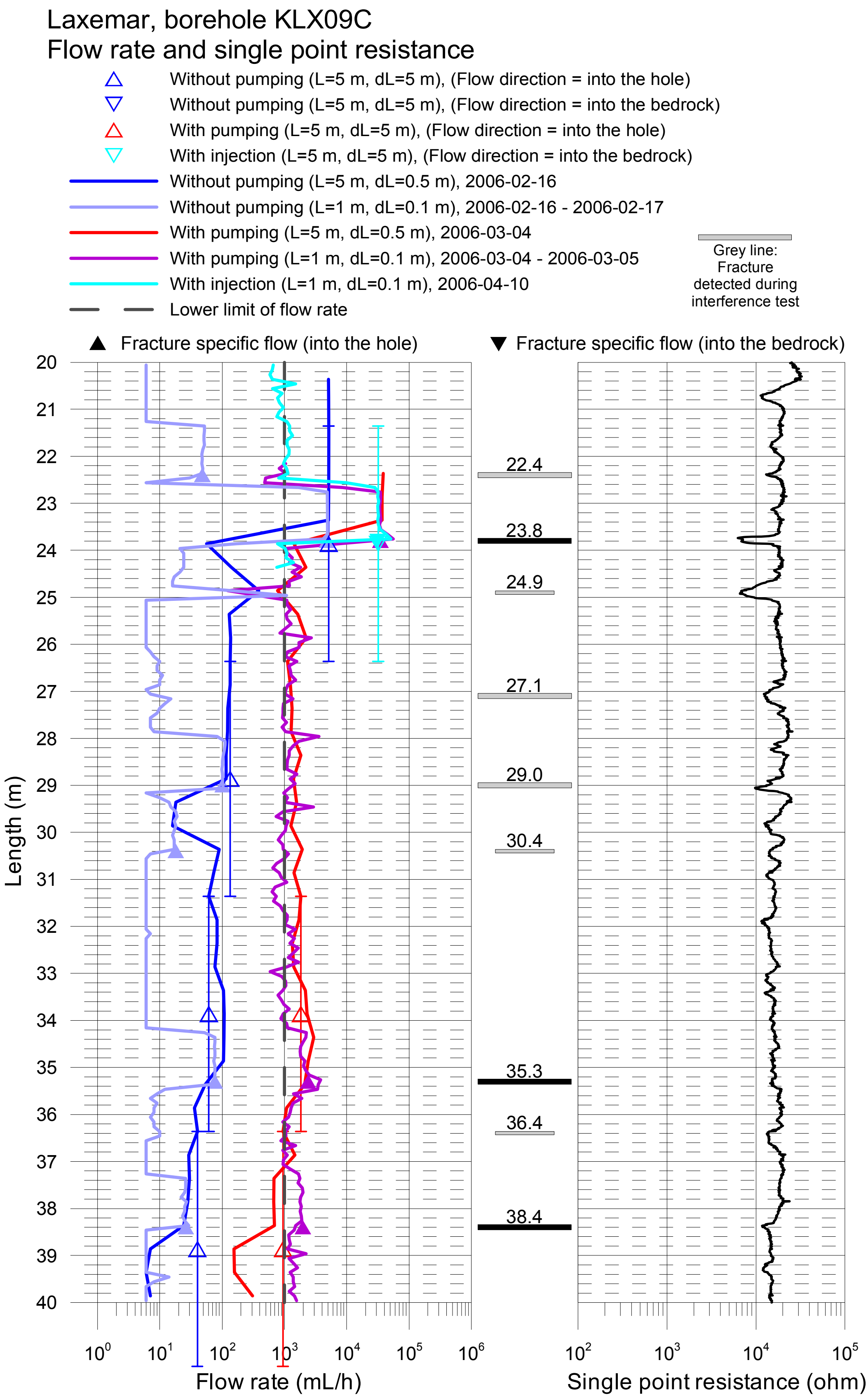


Appendices KLX09C

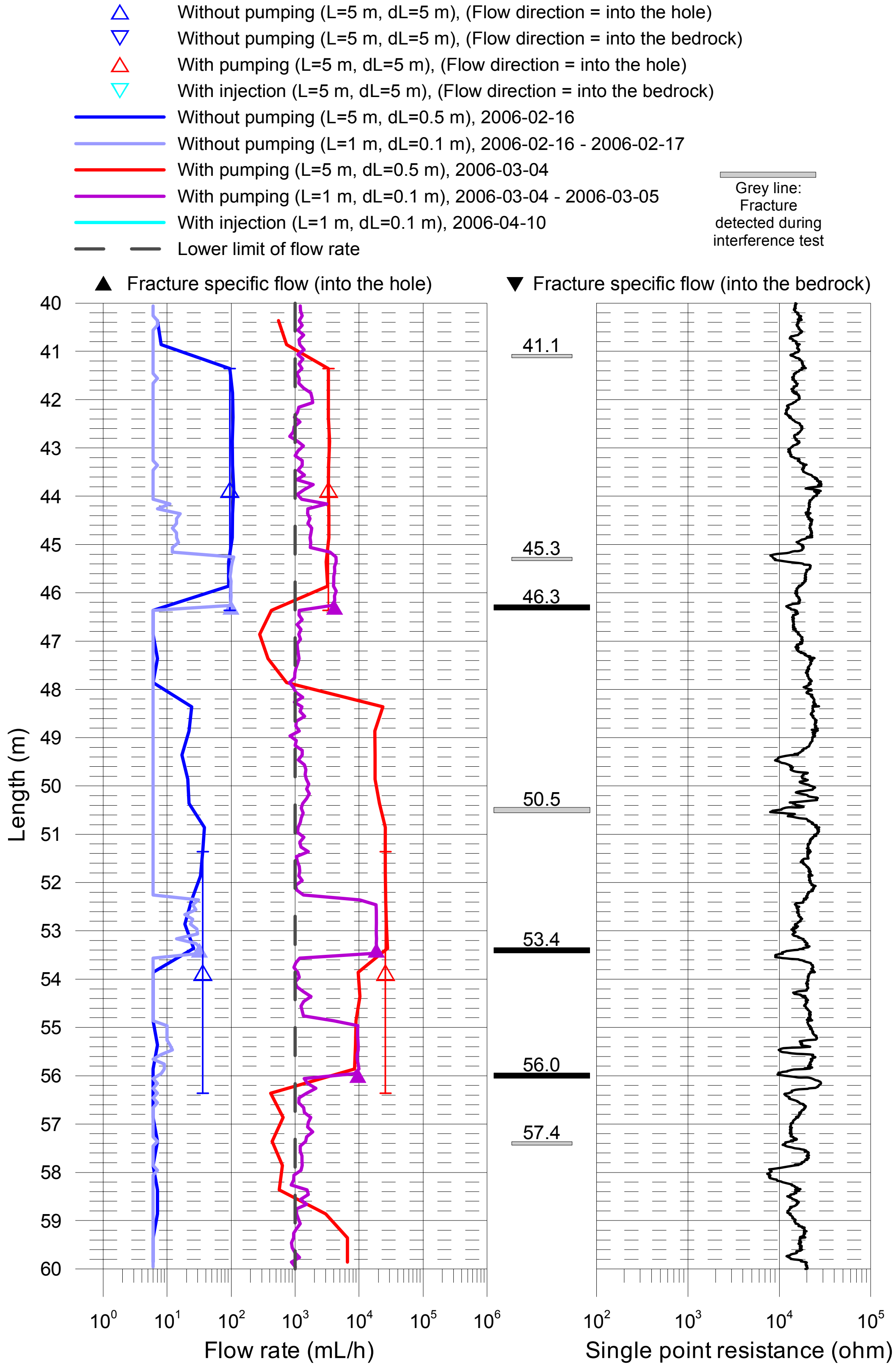
C.1.1–C.1.6	Flow rate and single point resistance
C.2.1	Electric conductivity of borehole water
C.2.2	Temperature of borehole water
C.3.1	Plotted flow rates of 5 m sections
C.3.2	Plotted transmissivity and head of 5 m sections
C.4	Plotted transmissivity and head of detected fractures
C.5	Basic test data
C.6	Results of sequential flow logging
C.7	Inferred flow anomalies from overlapping flow logging
C.8	Explanations for the tables in Appendices 5–7
C.9	Conductive fracture frequency
C.10	Plotted conductive fracture frequency
C.11	Comparison between section transmissivity and fracture transmissivity
C.12.1	Head in the borehole during flow logging
C.12.2	Air pressure, water level in the borehole and pumping rate during flow logging
C.12.3	Groundwater recovery after pumping
C.13.1–C.13.2	Flow logging with smaller injection

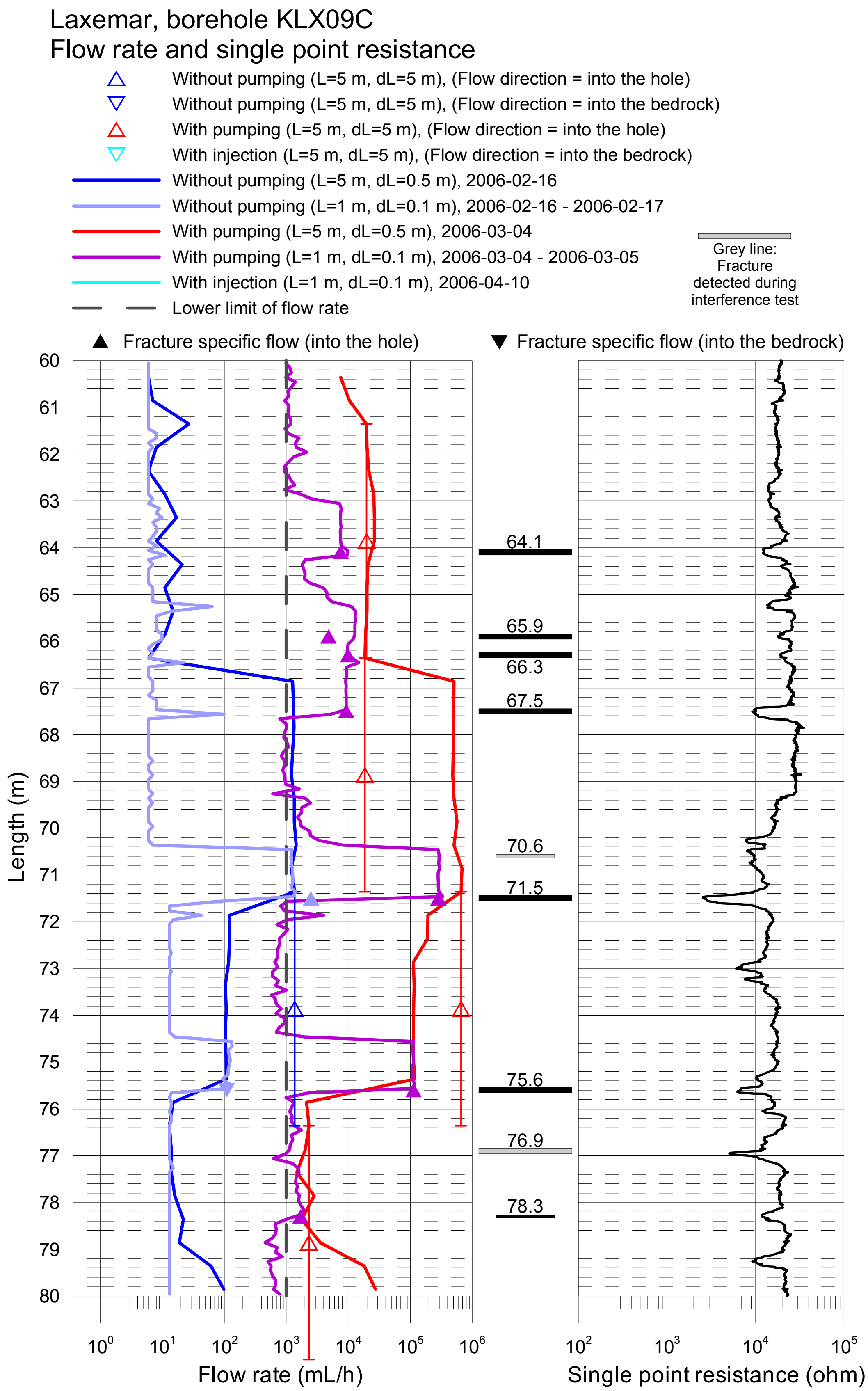
Laxemar, borehole KLX09C
Flow rate and single point resistance



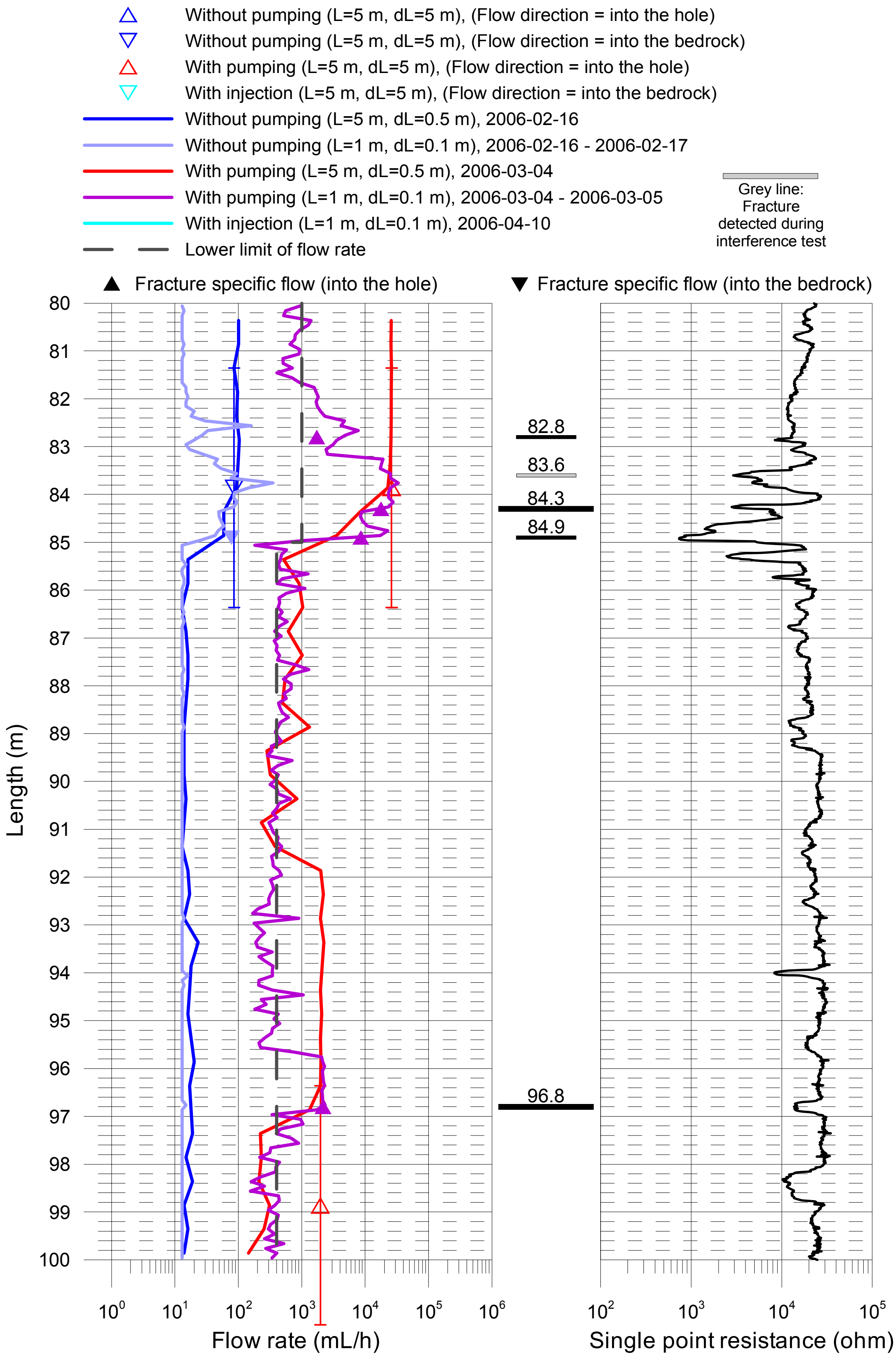

Laxemar, borehole KLX09C
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-02-16
Without pumping (L=1 m, dL=0.1 m), 2006-02-16 - 2006-02-17
With pumping (L=5 m, dL=0.5 m), 2006-03-04
With pumping (L=1 m, dL=0.1 m), 2006-03-04 - 2006-03-05
With injection (L=1 m, dL=0.1 m), 2006-04-10
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)
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
22.4
23.8
24.9
27.1
29.0
30.4
35.3
36.4
38.4
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

Laxemar, borehole KLX09C
Flow rate and single point resistance

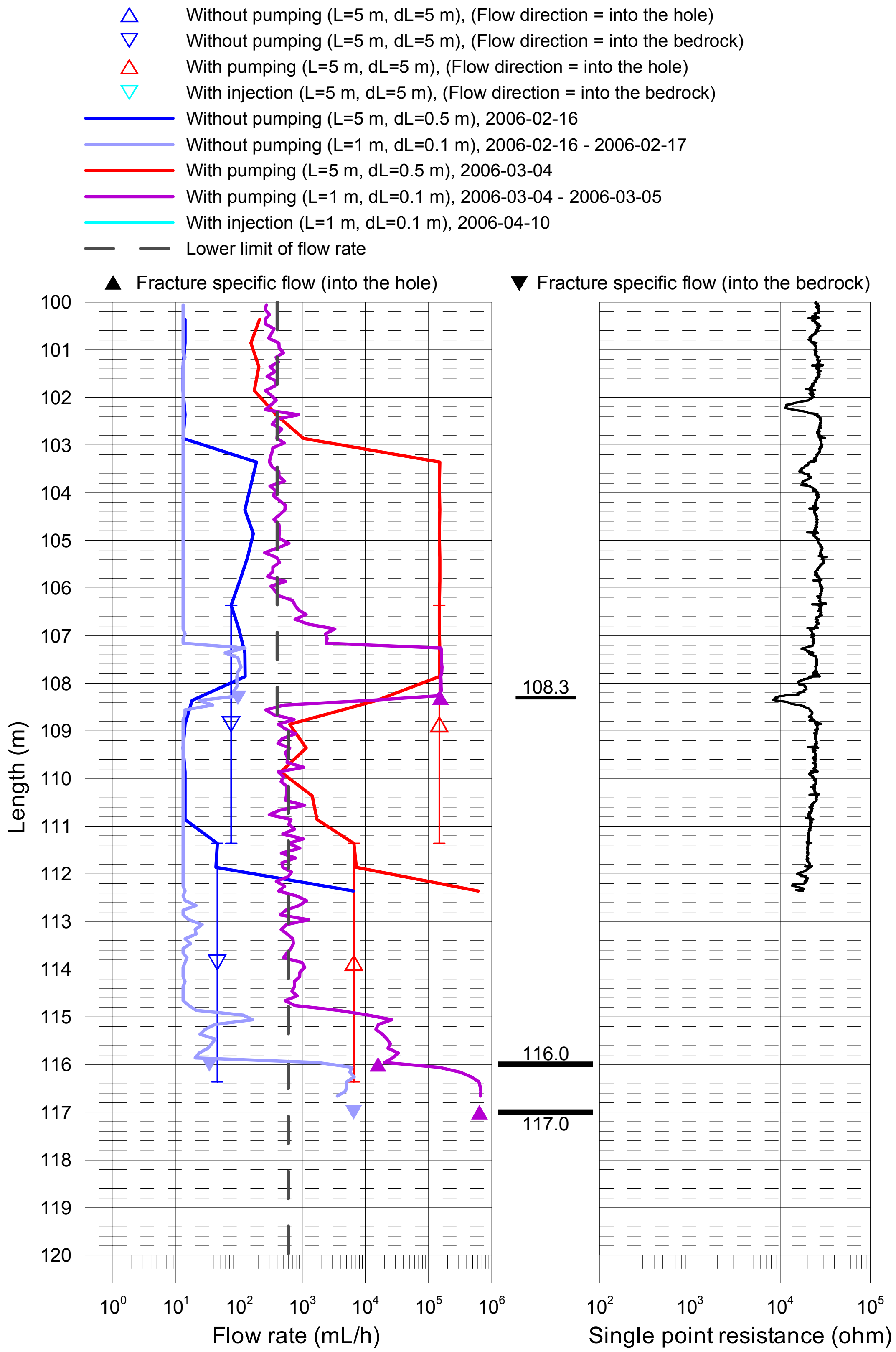



Laxemar, borehole KLX09C
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-02-16
Without pumping (L=1 m, dL=0.1 m), 2006-02-16 - 2006-02-17
With pumping (L=5 m, dL=0.5 m), 2006-03-04
With pumping (L=1 m, dL=0.1 m), 2006-03-04 - 2006-03-05
With injection (L=1 m, dL=0.1 m), 2006-04-10
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)
64.1
65.9
66.3
67.5
70.6
71.5
75.6
76.9
78.3
Flow rate (mL/h)
Single point resistance (ohm)

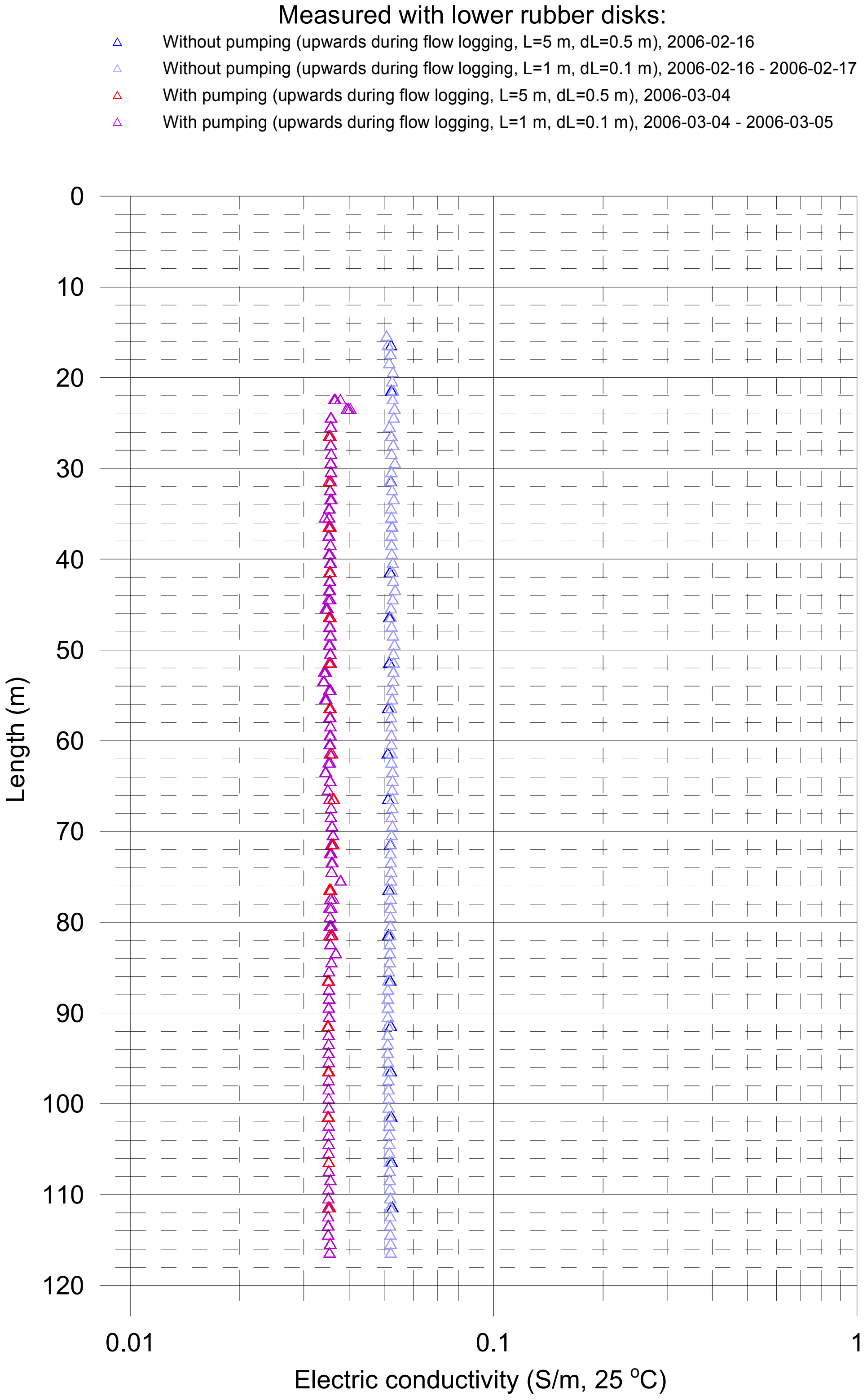
Laxemar, borehole KLX09C
Flow rate and single point resistance



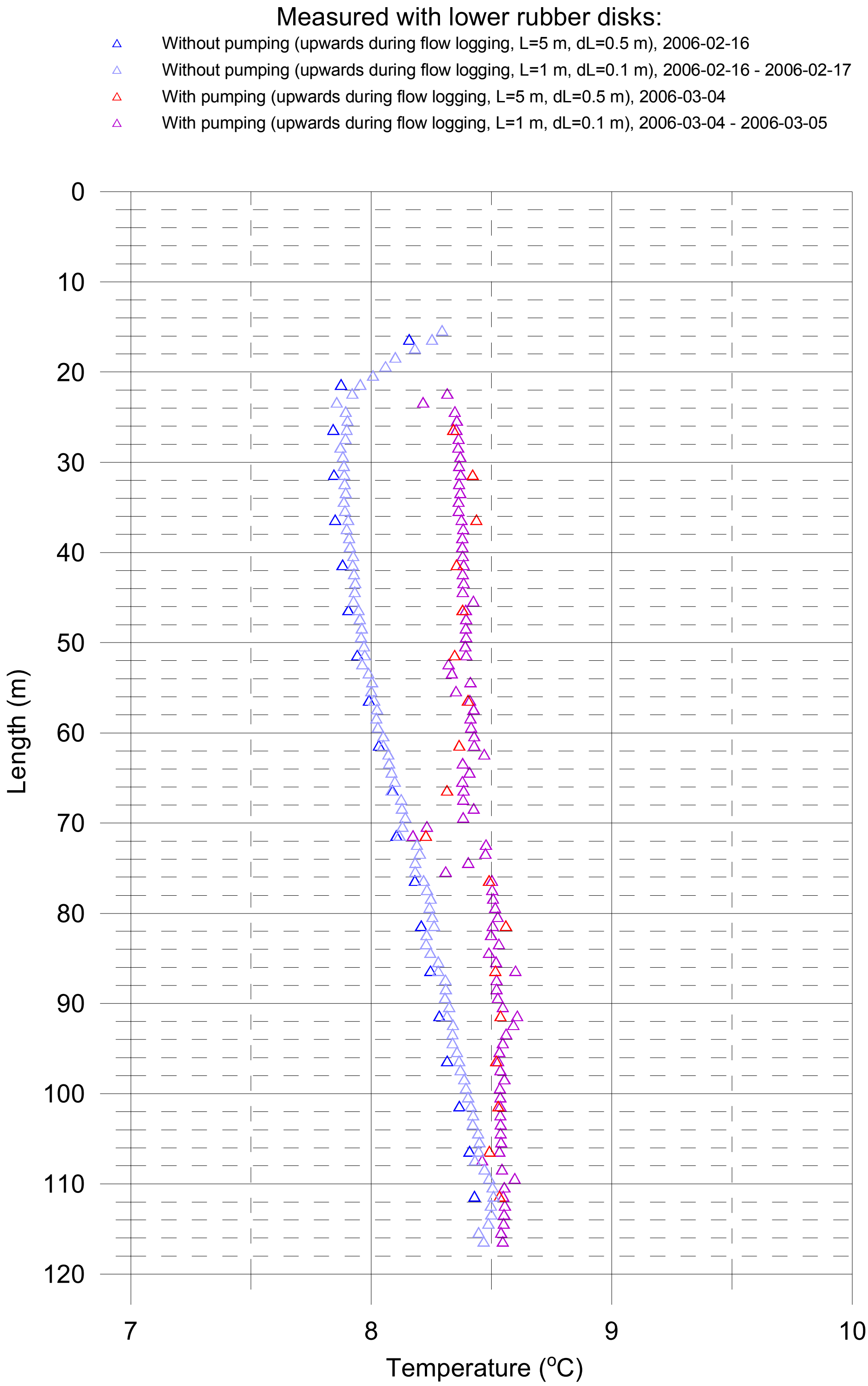
Laxemar, borehole KLX09C
Flow rate and single point resistance

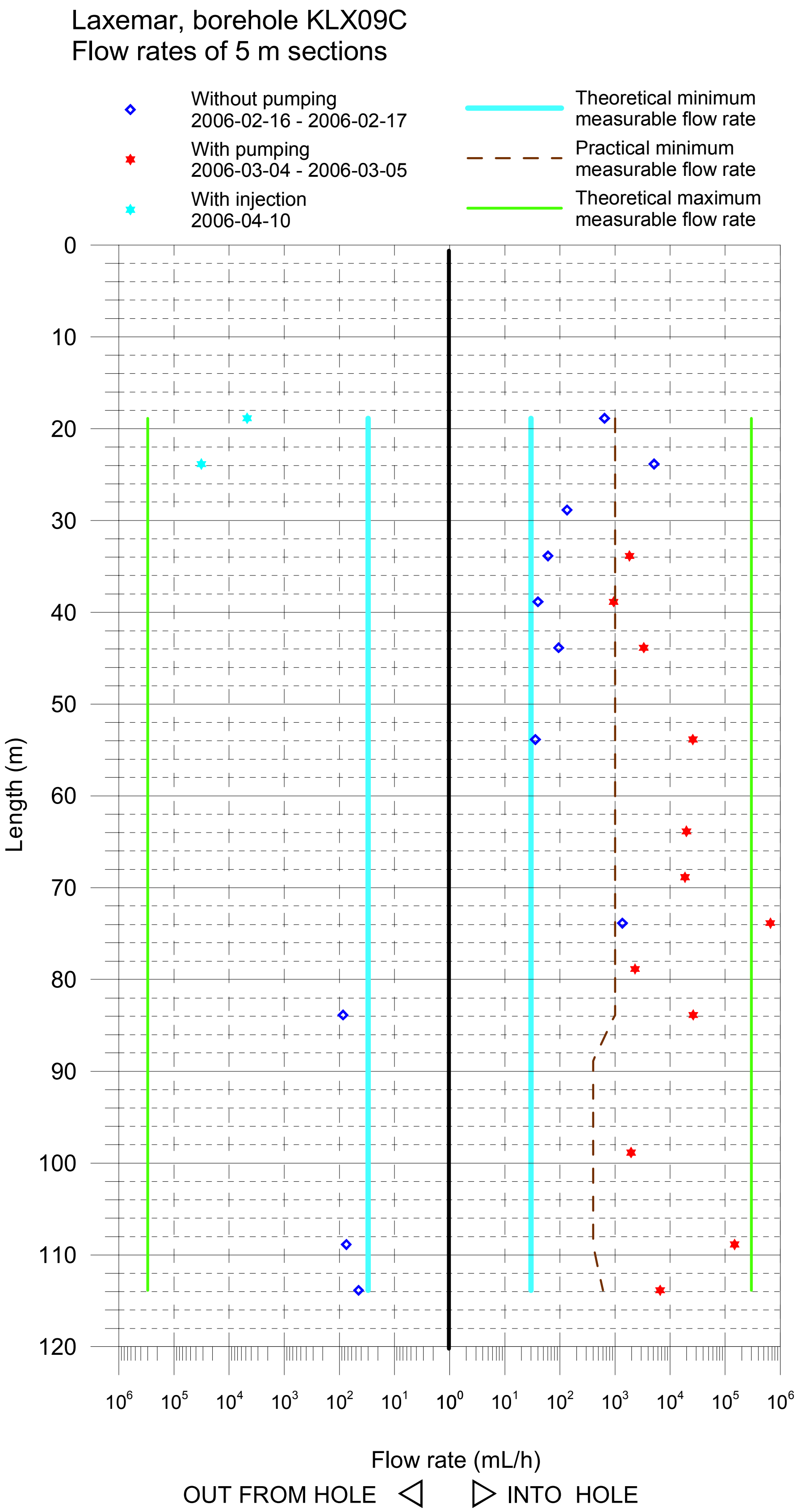


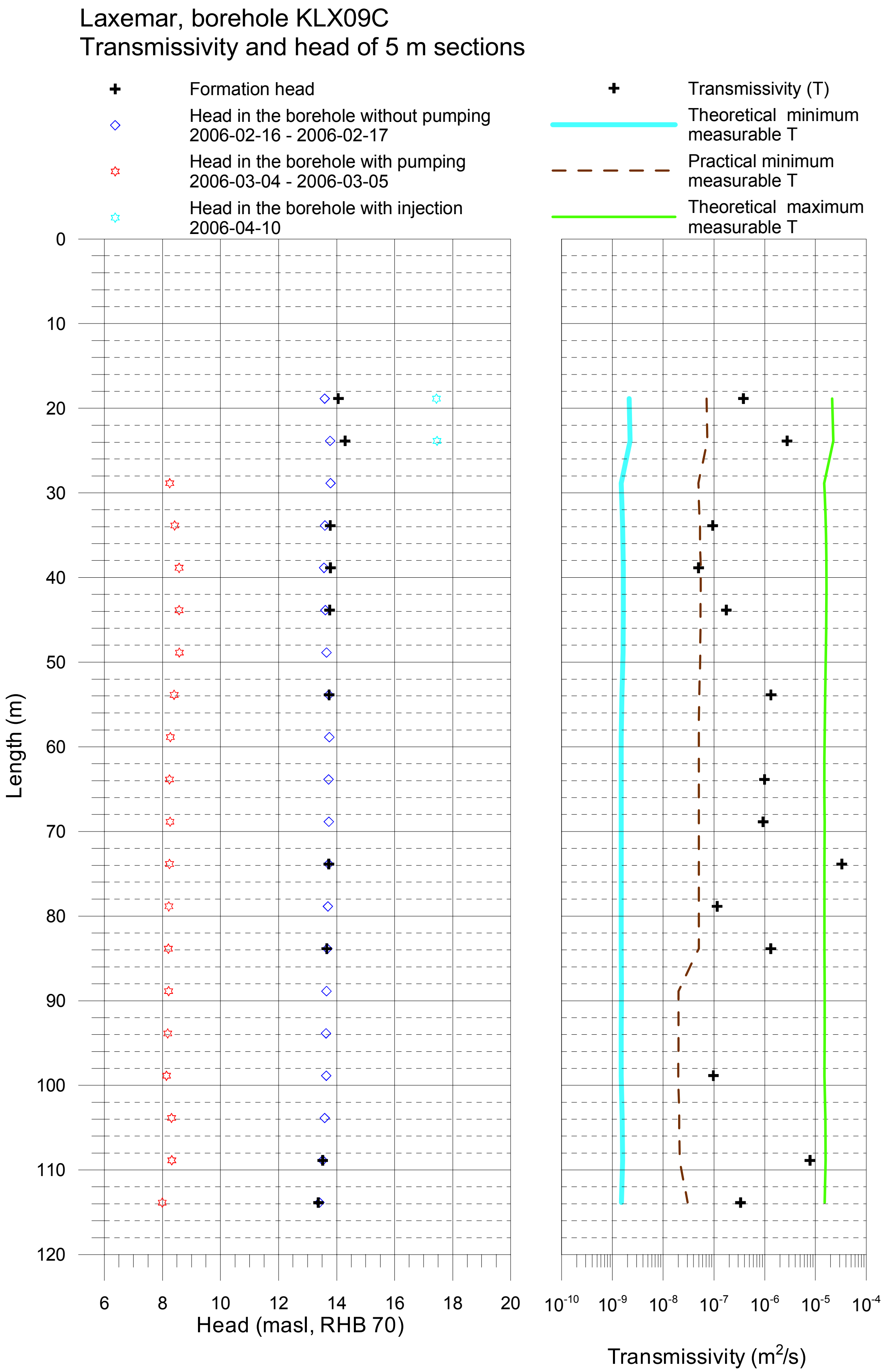
Laxemar, borehole KLX09C
Electric conductivity of borehole water



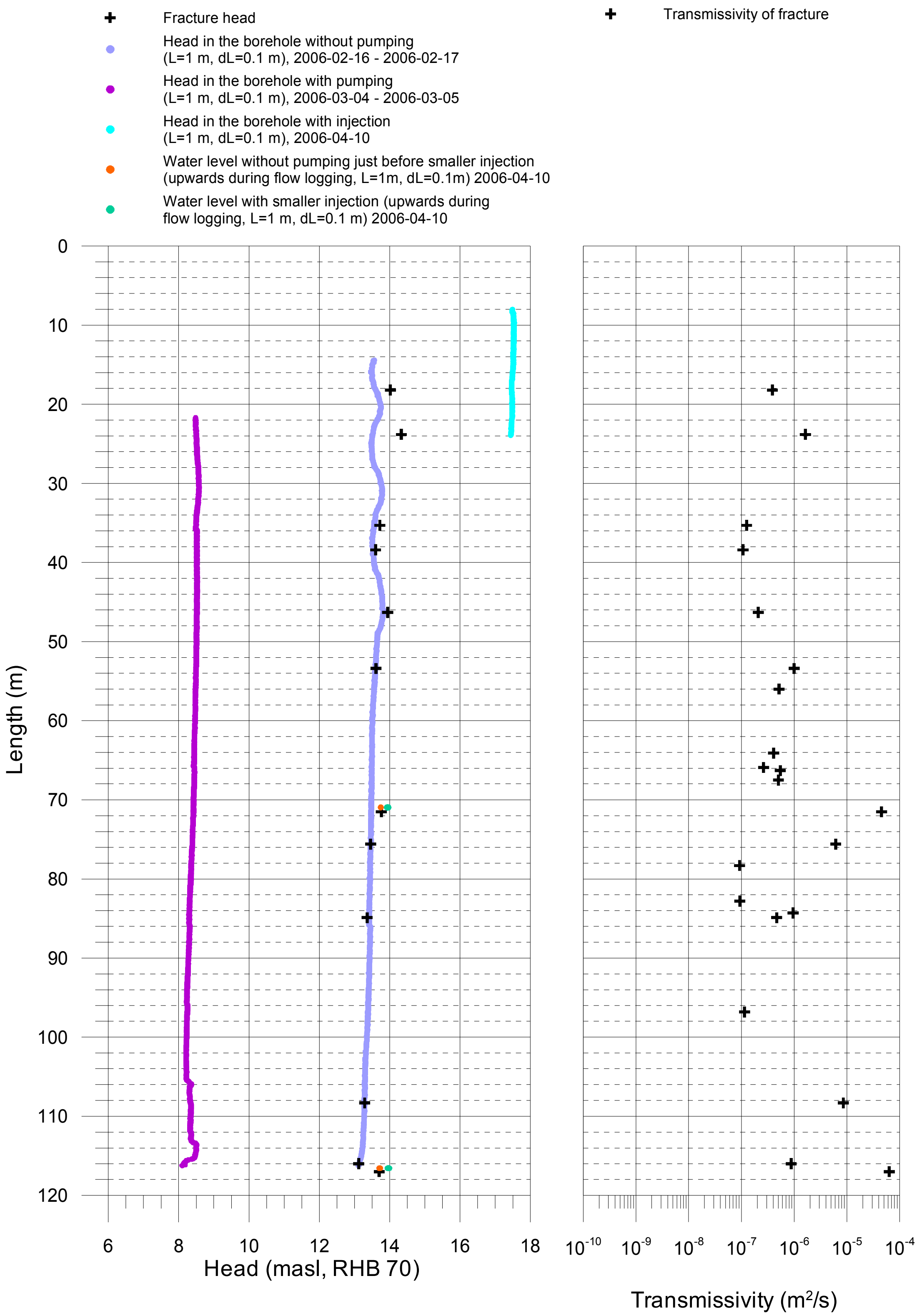
Laxemar, borehole KLX09C
Temperature of borehole water




Laxemar, borehole KLX09C
Flow rates of 5 m sections
Without pumping
2006-02-16 - 2006-02-17
With pumping
2006-03-04 - 2006-03-05
With injection
2006-04-10
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 KLX09C
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping
2006-02-16 - 2006-02-17
Head in the borehole with pumping
2006-03-04 - 2006-03-05
Head in the borehole with injection
2006-04-10
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 KLX09C
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)
KLX09C	16.36	116.36	5A	20060303	14:29	20060304	11:05	20060309	08:45	5	5	5.28E–4	

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 (–)
497,760		340,346		13.54	8.31		–5.23		1.0E–4		

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m³/s)	h_{0FW} (m.a.s.l.)	Q_1 (m³/s)	h_{1FW} (m.a.s.l.)	T_D (m²/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m²/s)	TD-measl$_{LP}$ (m²/s)	TD-measl$_U$ (m²/s)	Comments
KLX09C	16.36	21.36	5	1.79E–07	13.59	–1.31E–06	17.44	3.8E–07	14.1	1,000	2.1E–09	7.1E–08	2.1E–05	**
KLX09C	21.36	26.36	5	1.42E–06	13.78	–8.89E–06	17.46	2.8E–06	14.3	1,000	2.2E–09	7.5E–08	2.2E–05	**
KLX09C	26.36	31.36	5	3.75E–08	13.79	–	8.25	–	–	1,000	1.5E–09	5.0E–08	1.5E–05	
KLX09C	31.36	36.36	5	1.69E–08	13.60	5.11E–07	8.42	9.4E–08	13.8	1,000	1.6E–09	5.3E–08	1.6E–05	
KLX09C	36.36	41.36	5	1.11E–08	13.57	2.63E–07	8.57	5.0E–08	13.8	1,000	1.7E–09	5.5E–08	1.7E–05	
KLX09C	41.36	46.36	5	2.64E–08	13.61	9.25E–07	8.57	1.8E–07	13.8	1,000	1.6E–09	5.5E–08	1.6E–05	
KLX09C	46.36	51.36	5	–	13.65	–	8.58	–	–	1,000	1.6E–09	5.4E–08	1.6E–05	
KLX09C	51.36	56.36	5	1.00E–08	13.73	7.19E–06	8.40	1.3E–06	13.7	1,000	1.6E–09	5.2E–08	1.6E–05	
KLX09C	56.36	61.36	5	–	13.75	–	8.27	–	–	1,000	1.5E–09	5.0E–08	1.5E–05	
KLX09C	61.36	66.36	5	–	13.72	5.5E–06	8.24	9.9E–07	–	1,000	1.5E–09	5.0E–08	1.5E–05	
KLX09C	66.36	71.36	5	–	13.73	5.17E–06	8.26	9.3E–07	–	1,000	1.5E–09	5.0E–08	1.5E–05	
KLX09C	71.36	76.36	5	3.81E–07	13.72	1.83E–04	8.24	3.3E–05	13.7	1,000	1.5E–09	5.0E–08	1.5E–05	
KLX09C	76.36	81.36	5	–	13.70	6.44E–07	8.22	1.2E–07	–	1,000	1.5E–09	5.0E–08	1.5E–05	
KLX09C	81.36	86.36	5	–2.39E–08	13.68	7.28E–06	8.20	1.3E–06	13.7	1,000	1.5E–09	5.0E–08	1.5E–05	
KLX09C	86.36	91.36	5	–	13.65	–	8.21	–	–	400	1.5E–09	2.0E–08	1.5E–05	
KLX09C	91.36	96.36	5	–	13.63	–	8.18	–	–	400	1.5E–09	2.0E–08	1.5E–05	
KLX09C	96.36	101.36	5	–	13.64	5.44E–07	8.14	9.8E–08	–	400	1.5E–09	2.0E–08	1.5E–05	
KLX09C	101.36	106.36	5	–	13.59	–	8.31	–	–	400	1.6E–09	2.1E–08	1.6E–05	
KLX09C	106.36	111.36	5	–2.08E–08	13.52	4.11E–05	8.32	7.8E–06	13.5	400	1.6E–09	2.1E–08	1.6E–05	
KLX09C	111.36	116.36	5	–1.25E–08	13.41	1.82E–06	7.99	3.4E–07	13.4	600	1.5E–09	3.0E–08	1.5E–05	

** Values from the measurement with injection.

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
KLX09C	15.5	1	0.1	2.33E–08	13.49	–	17.51	–	–	*, **, ***
KLX09C	18.2	1	0.1	1.64E–07	13.60	–1.35E–06	17.47	3.9E–07	14.0	**
KLX09C	19.2	1	0.1	5.28E–09	13.69	–	17.48	–	–	*, **, ***
KLX09C	22.4	1	0.1	1.33E–08	13.59	–	17.46	–	–	**, ***
KLX09C	23.8	1	0.1	1.33E–06	13.52	9.61E–06	8.50	1.6E–06	14.3	
KLX09C	24.9	1	0.1	–	13.50	–	8.51	–	–	*, ***
KLX09C	27.1	1	0.1	–	13.52	–	8.54	–	–	***
KLX09C	29.0	1	0.1	2.81E–08	13.70	–	8.57	–	–	***
KLX09C	30.4	1	0.1	5.00E–09	13.78	–	8.58	–	–	*, ***
KLX09C	35.3	1	0.1	2.11E–08	13.55	6.64E–07	8.49	1.3E–07	13.7	
KLX09C	36.4	1	0.1	–	13.52	–	8.51	–	–	*, ***
KLX09C	38.4	1	0.1	7.22E–09	13.53	5.47E–07	8.52	1.1E–07	13.6	
KLX09C	41.1	1	0.1	–	13.62	–	8.52	–	–	*, ***
KLX09C	45.3	1	0.1	–	13.80	–	8.52	–	–	*, ***
KLX09C	46.3	1	0.1	2.75E–08	13.81	1.15E–06	8.52	2.1E–07	13.9	
KLX09C	50.5	1	0.1	–	13.63	–	8.50	–	–	***
KLX09C	53.4	1	0.1	8.89E–09	13.60	5.17E–06	8.49	1.0E–06	13.6	
KLX09C	56.0	1	0.1	–	13.56	2.65E–06	8.48	5.2E–07	–	
KLX09C	57.4	1	0.1	–	13.54	–	8.48	–	–	*, ***
KLX09C	64.1	1	0.1	–	13.50	2.09E–06	8.44	4.1E–07	–	
KLX09C	65.9	1	0.1	–	13.48	1.34E–06	8.45	2.6E–07	–	
KLX09C	66.3	1	0.1	–	13.49	2.78E–06	8.44	5.4E–07	–	
KLX09C	67.5	1	0.1	–	13.49	2.57E–06	8.44	5.0E–07	–	
KLX09C	70.6	1	0.1	–	13.47	–	8.43	–	–	*, ***
KLX09C	71.5	1	0.1	6.94E–07	13.74	–9.88E–06	13.97	4.6E–05	13.8	****
KLX09C	75.6	1	0.1	–3.06E–08	13.46	3.14E–05	8.39	6.1E–06	13.5	
KLX09C	76.9	1	0.1	–	13.44	–	8.37	–	–	***
KLX09C	78.3	1	0.1	–	13.44	4.72E–07	8.35	9.2E–08	–	*
KLX09C	82.8	1	0.1	–	13.42	4.81E–07	8.32	9.3E–08	–	*
KLX09C	83.6	1	0.1	–	13.43	–	8.31	–	–	*, ***
KLX09C	84.3	1	0.1	–	13.41	4.92E–06	8.30	9.5E–07	–	
KLX09C	84.9	1	0.1	–2.17E–08	13.41	2.39E–06	8.30	4.7E–07	13.4	*
KLX09C	96.8	1	0.1	–	13.38	6.00E–07	8.24	1.2E–07	–	
KLX09C	108.3	1	0.1	–2.67E–08	13.29	4.28E–05	8.34	8.6E–06	13.3	*
KLX09C	116.0	1	0.1	–9.44E–09	13.13	4.42E–06	8.14	8.8E–07	13.1	
KLX09C	117.0	1	0.1	–1.81E–06	13.73	–1.71E–05	13.97	6.3E–05	13.7	****

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

** Values from the measurement with injection.

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

**** Values from the measurement with smaller injection, water level used instead of head for pressure difference.

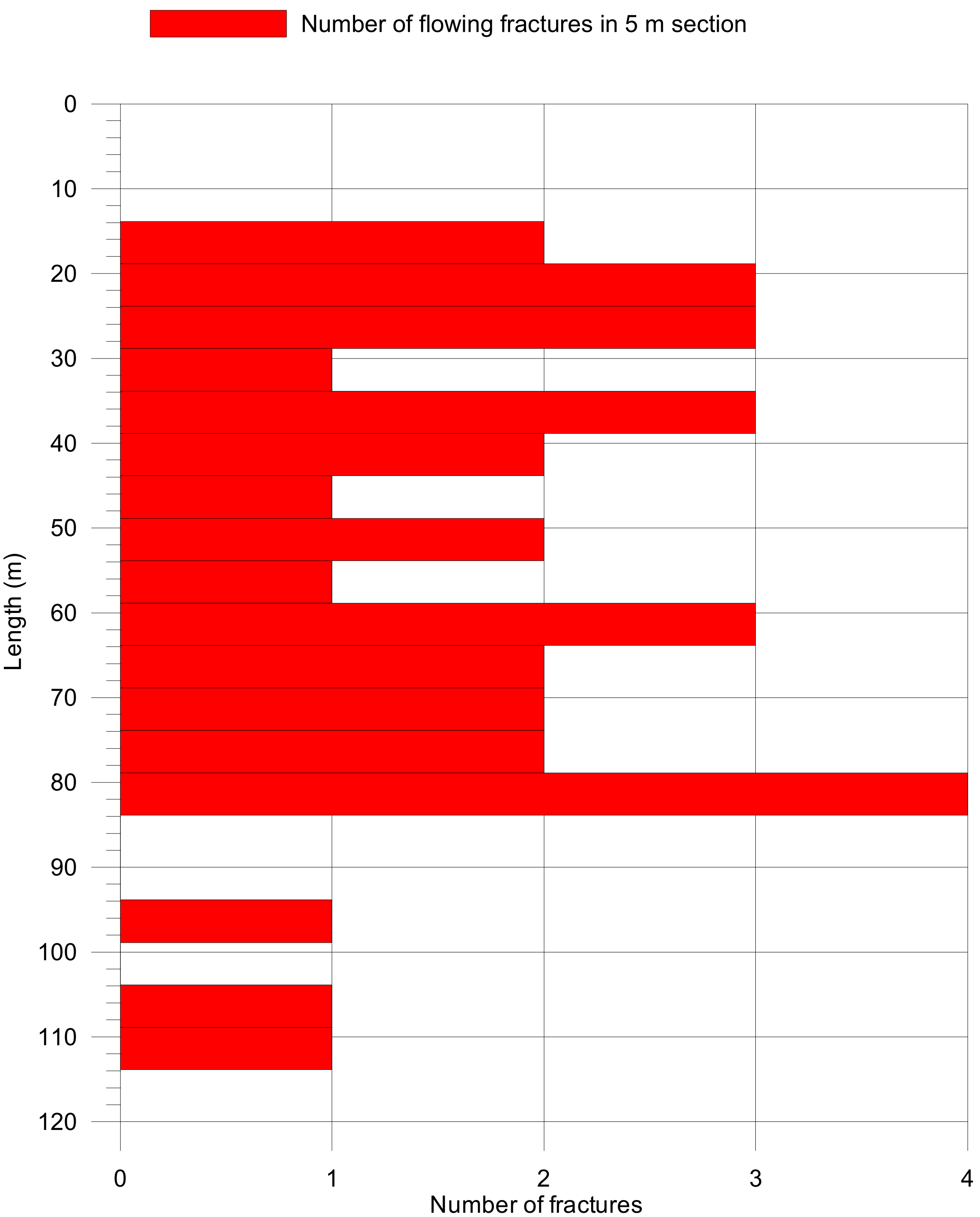
Explanations.

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

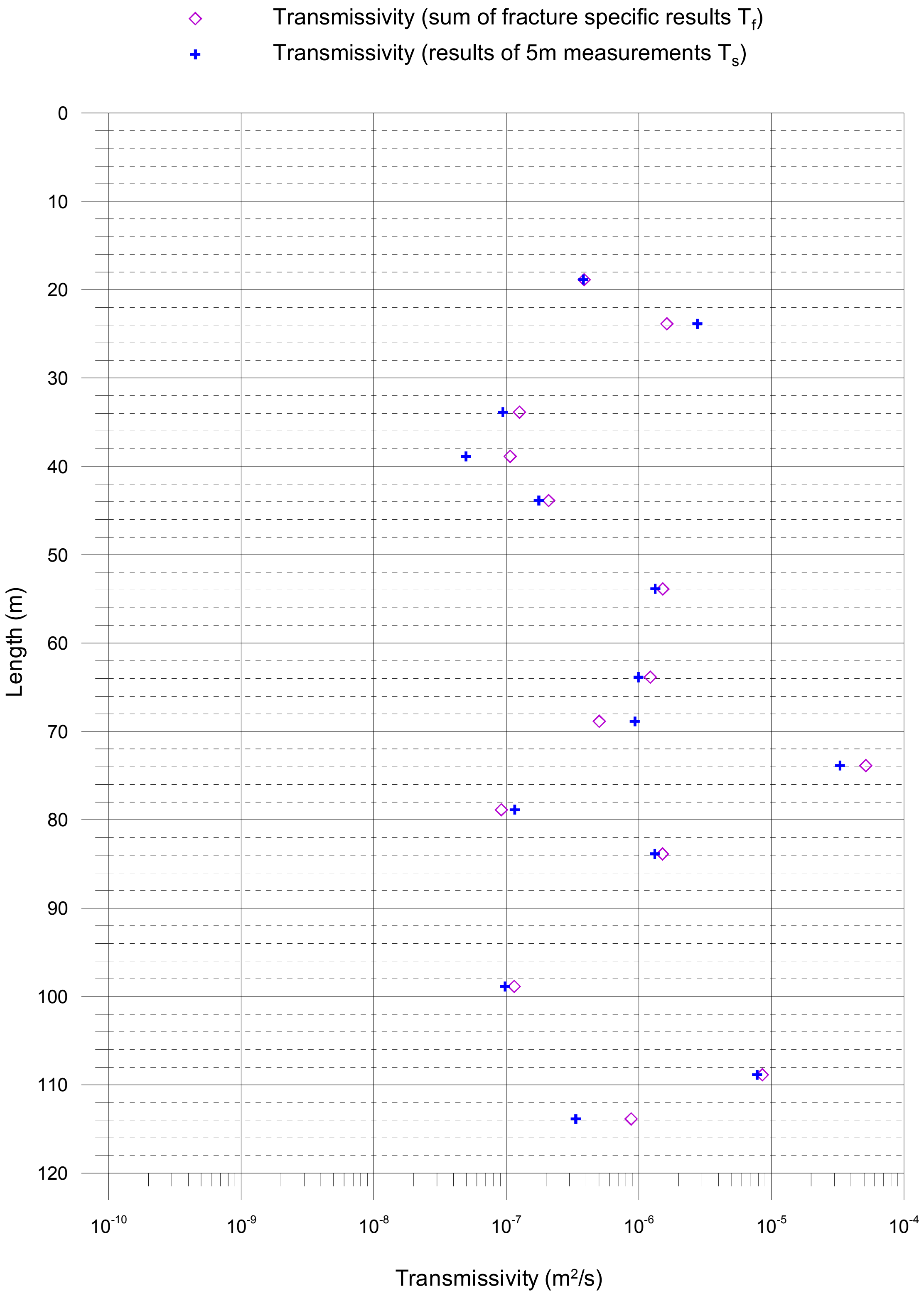
Calculation of conductive fracture frequency.

Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)
KLX09C	16.36	21.36	2	0	0	0	0	0
KLX09C	21.36	26.36	3	0	0	0	1	0
KLX09C	26.36	31.36	3	0	0	0	0	0
KLX09C	31.36	36.36	1	0	0	1	0	0
KLX09C	36.36	41.36	3	0	0	1	0	0
KLX09C	41.36	46.36	2	0	0	1	0	0
KLX09C	46.36	51.36	1	0	0	0	0	0
KLX09C	51.36	56.36	2	0	0	1	1	0
KLX09C	56.36	61.36	1	0	0	0	0	0
KLX09C	61.36	66.36	3	0	0	3	0	0
KLX09C	66.36	71.36	2	0	0	1	0	0
KLX09C	71.36	76.36	2	0	0	0	0	1
KLX09C	76.36	81.36	2	0	0	1	0	0
KLX09C	81.36	86.36	4	0	0	2	1	0
KLX09C	86.36	91.36	0	0	0	0	0	0
KLX09C	91.36	96.36	0	0	0	0	0	0
KLX09C	96.36	101.36	1	0	0	1	0	0
KLX09C	101.36	106.36	0	0	0	0	0	0
KLX09C	106.36	111.36	1	0	0	0	0	1
KLX09C	111.36	116.36	1	0	0	0	1	0

Laxemar, borehole KLX09C
Calculation of conductive fracture frequency

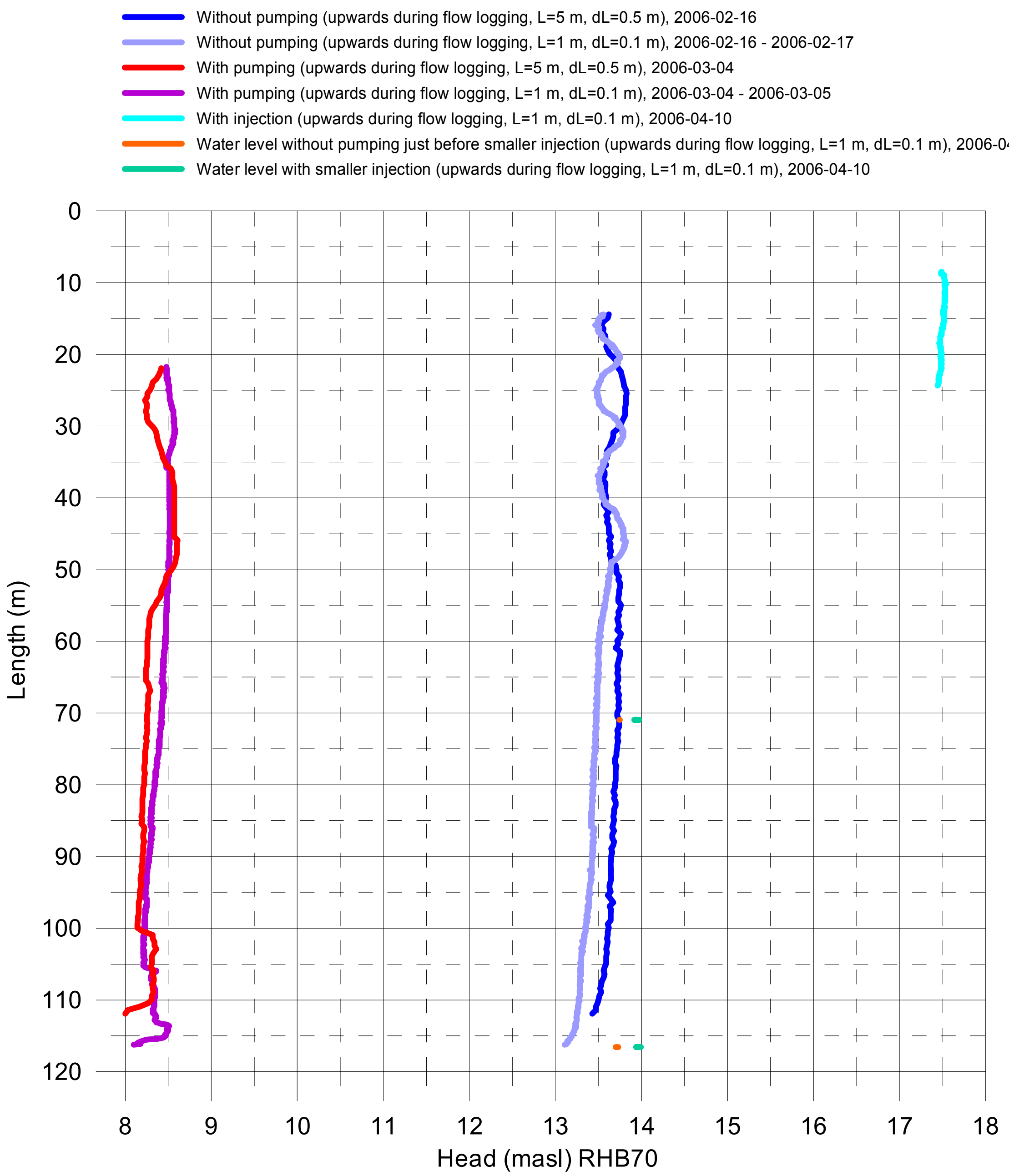


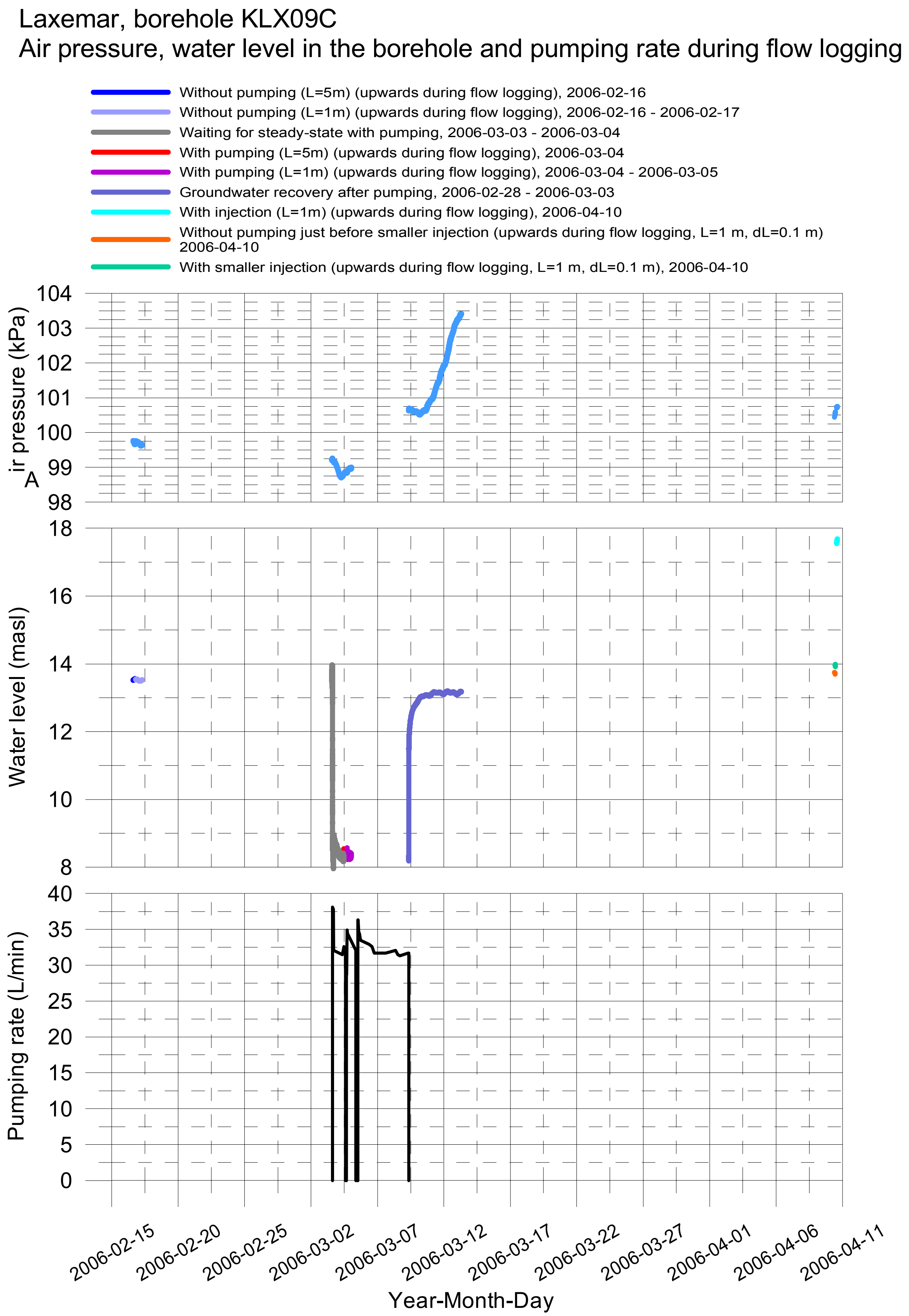
Laxemar, borehole KLX09C
Comparison between section transmissivity and fracture transmissivity



Laxemar, borehole KLX09C
Head in the borehole during flow logging

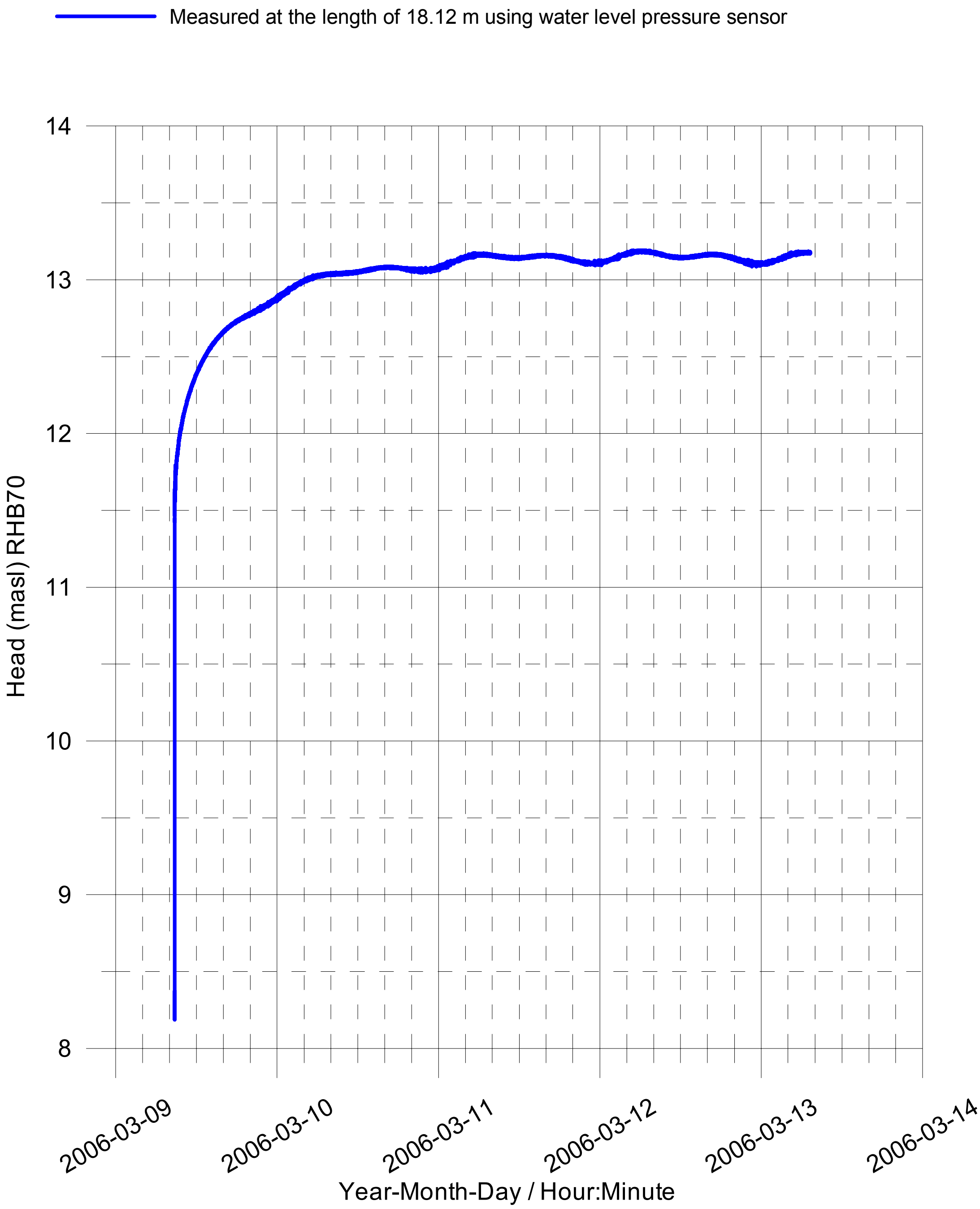
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)



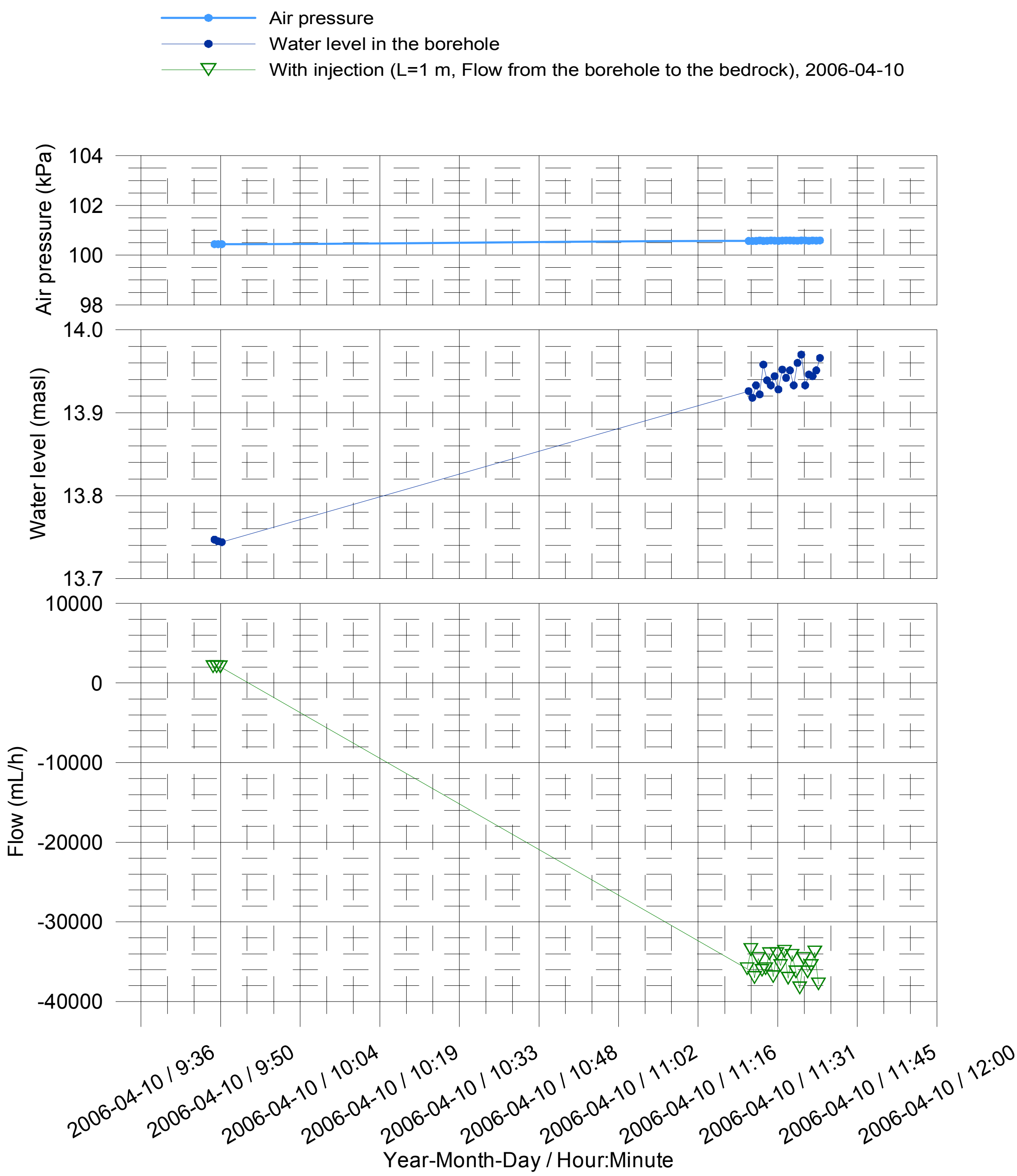

Laxemar, borehole KLX09C
Air pressure, water level in the borehole and pumping rate during flow logging
Without pumping (L=5m) (upwards during flow logging), 2006-02-16
Without pumping (L=1m) (upwards during flow logging), 2006-02-16 - 2006-02-17
Waiting for steady-state with pumping, 2006-03-03 - 2006-03-04
With pumping (L=5m) (upwards during flow logging), 2006-03-04
With pumping (L=1m) (upwards during flow logging), 2006-03-04 - 2006-03-05
Groundwater recovery after pumping, 2006-02-28 - 2006-03-03
With injection (L=1m) (upwards during flow logging), 2006-04-10
Without pumping just before smaller injection (upwards during flow logging, L=1 m, dL=0.1 m) 2006-04-10
With smaller injection (upwards during flow logging, L=1 m, dL=0.1 m), 2006-04-10
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
18
16
14
12
10
8
Pumping rate (L/min)
40
35
30
25
20
15
10
5
0
2006-02-15
2006-02-20
2006-02-25
2006-03-02
2006-03-07
2006-03-12
2006-03-17
2006-03-22
2006-03-27
2006-04-01
2006-04-06
2006-04-11
Year-Month-Day

Laxemar, borehole KLX09C
Groundwater recovery after pumping

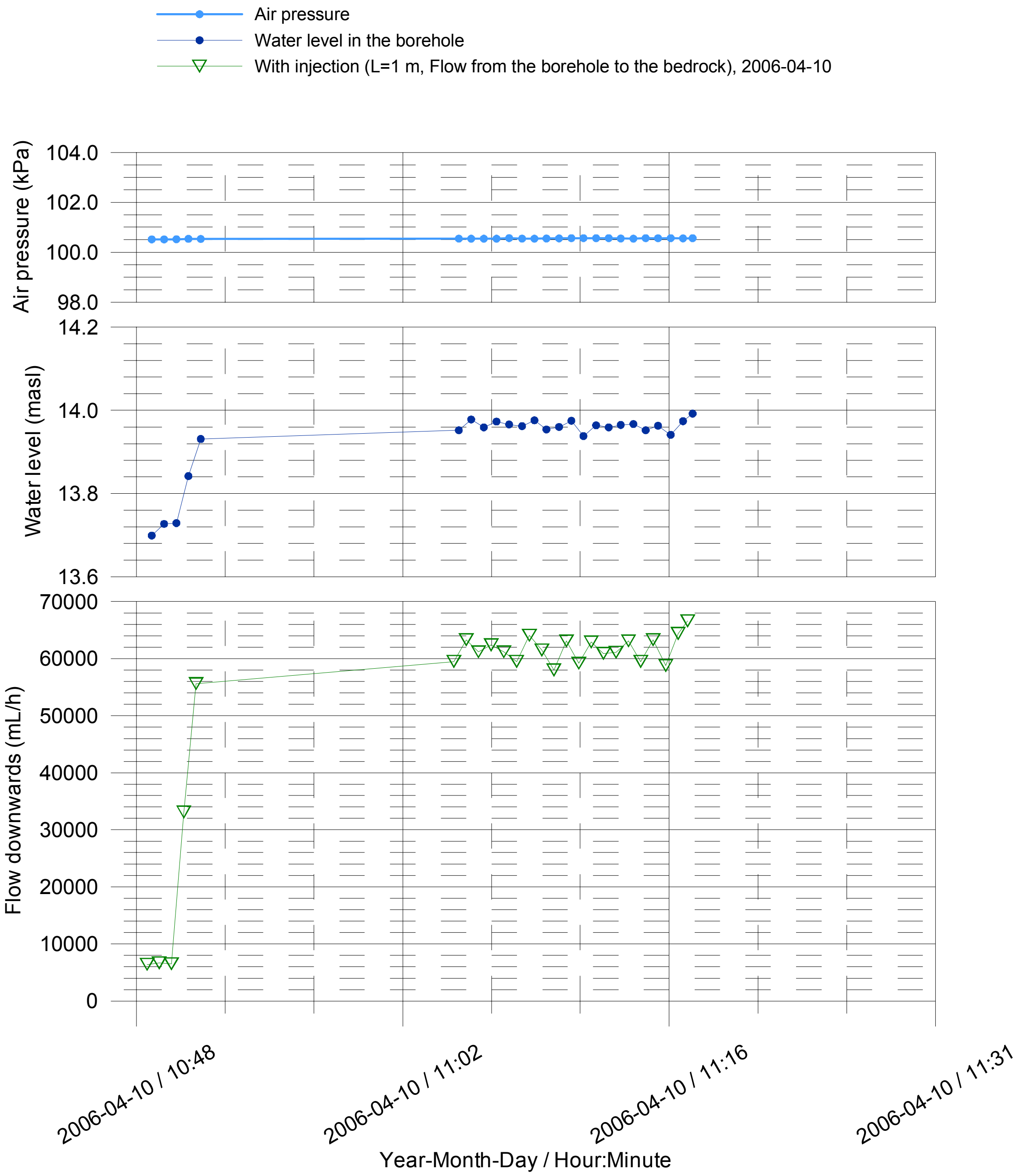
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)



Laxemar, borehole KLX09C
Flow logging with smaller injection at the length 71.0 m

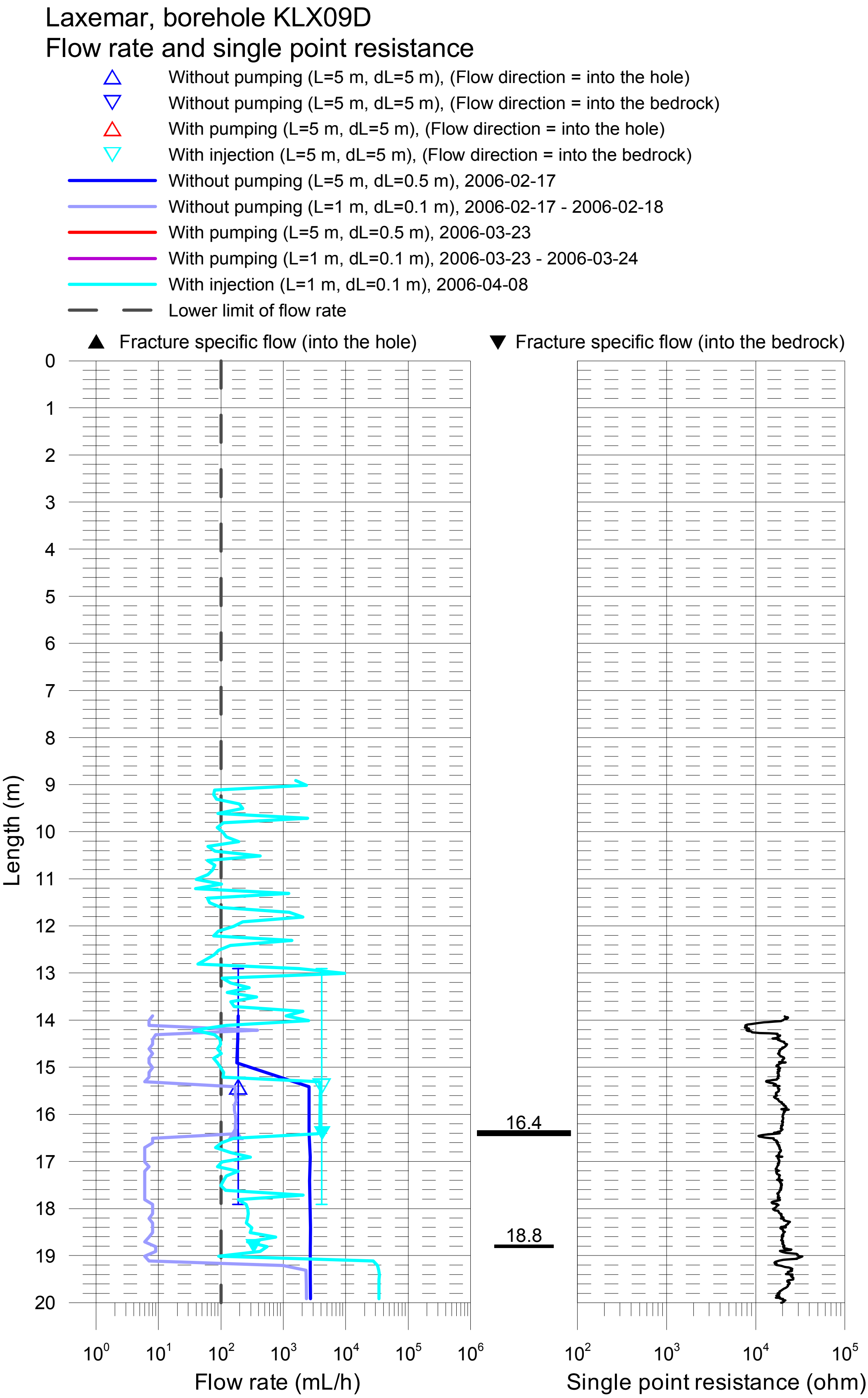


Laxemar, borehole KLX09C
Flow logging with smaller injection at the length 116.6 m

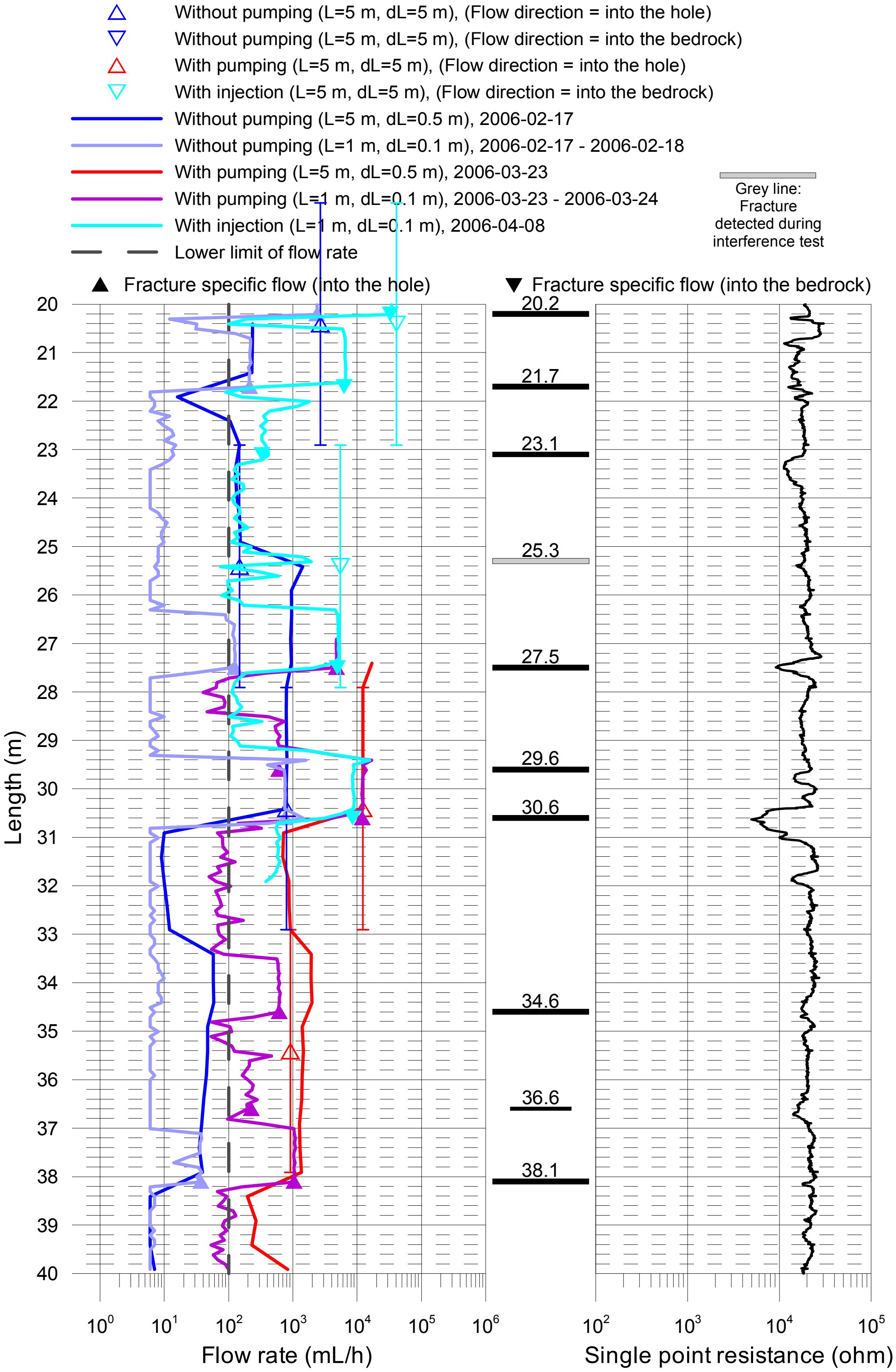


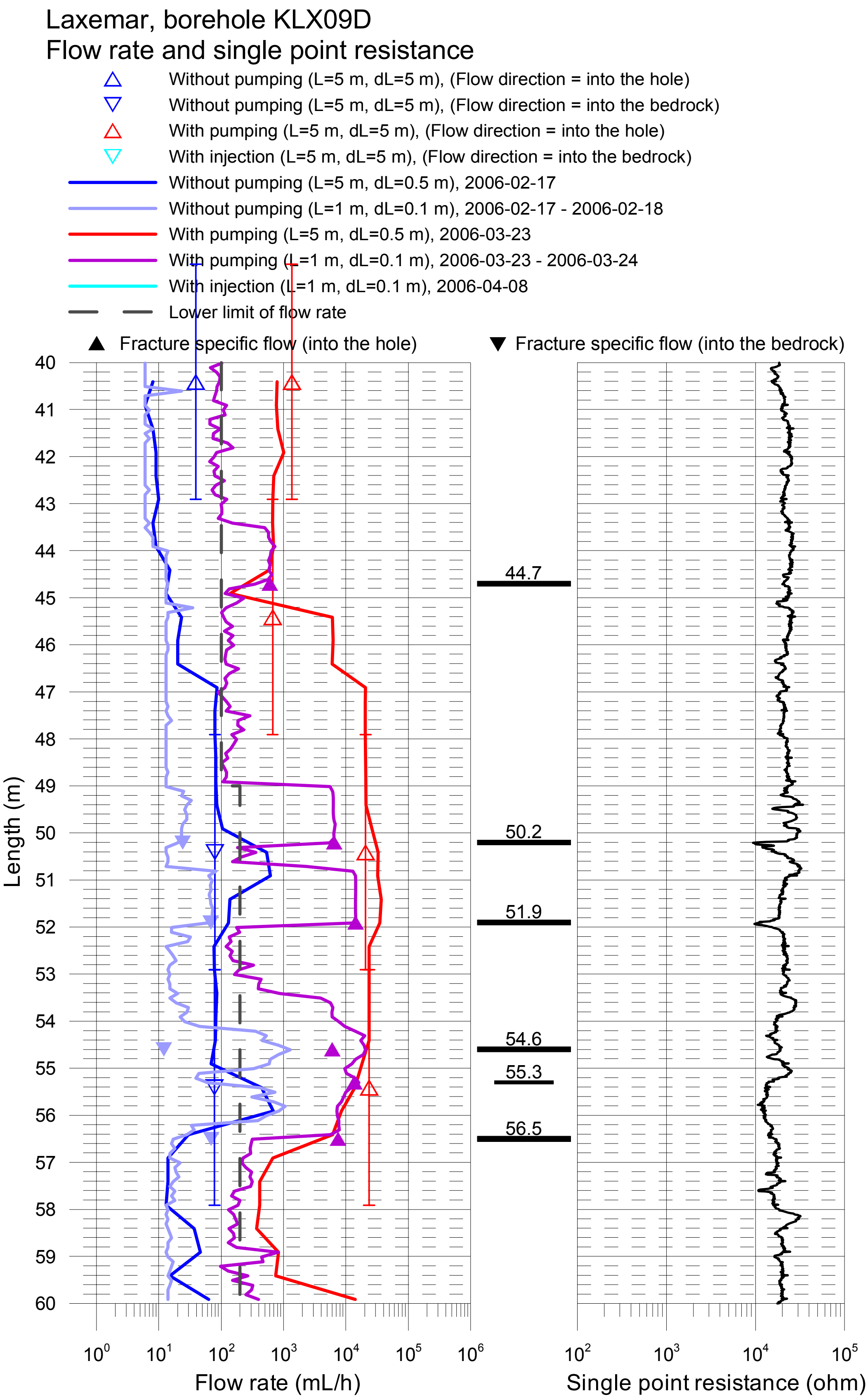
Appendices KLX09D

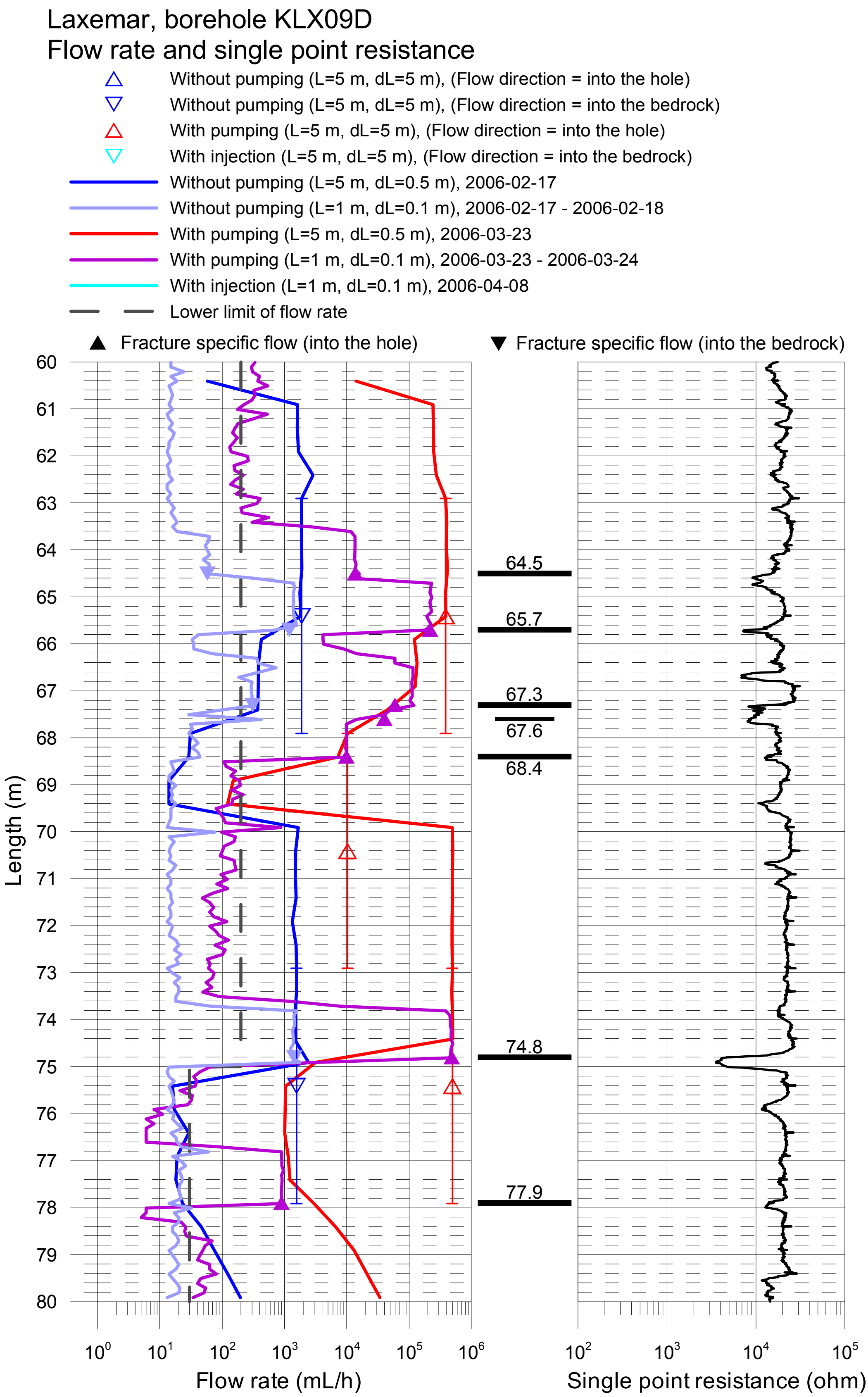
D.1.1–D.1.6	Flow rate and single point resistance
D.2.1	Electric conductivity of borehole water
D.2.2	Temperature of borehole water
D.3.1	Plotted flow rates of 5 m sections
D.3.2	Plotted transmissivity and head of 5 m sections
D.4	Plotted transmissivity and head of detected fractures
D.5	Basic test data
D.6	Results of sequential flow logging
D.7	Inferred flow anomalies from overlapping flow logging
D.8	Explanations for the tables in Appendices 5–7
D.9	Conductive fracture frequency
D.10	Plotted conductive fracture frequency
D.11	Comparison between section transmissivity and fracture transmissivity
D.12.1	Head in the borehole during flow logging
D.12.2	Air pressure, water level in the borehole and pumping rate during flow logging
D.12.3	Groundwater recovery after pumping
D.13.1–D.13.2	Flow logging with smaller injection


Laxemar, borehole KLX09D
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), 2006-02-17
Without pumping (L=1 m, dL=0.1 m), 2006-02-17 - 2006-02-18
With pumping (L=5 m, dL=0.5 m), 2006-03-23
With pumping (L=1 m, dL=0.1 m), 2006-03-23 - 2006-03-24
With injection (L=1 m, dL=0.1 m), 2006-04-08
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
16.4
18.8
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

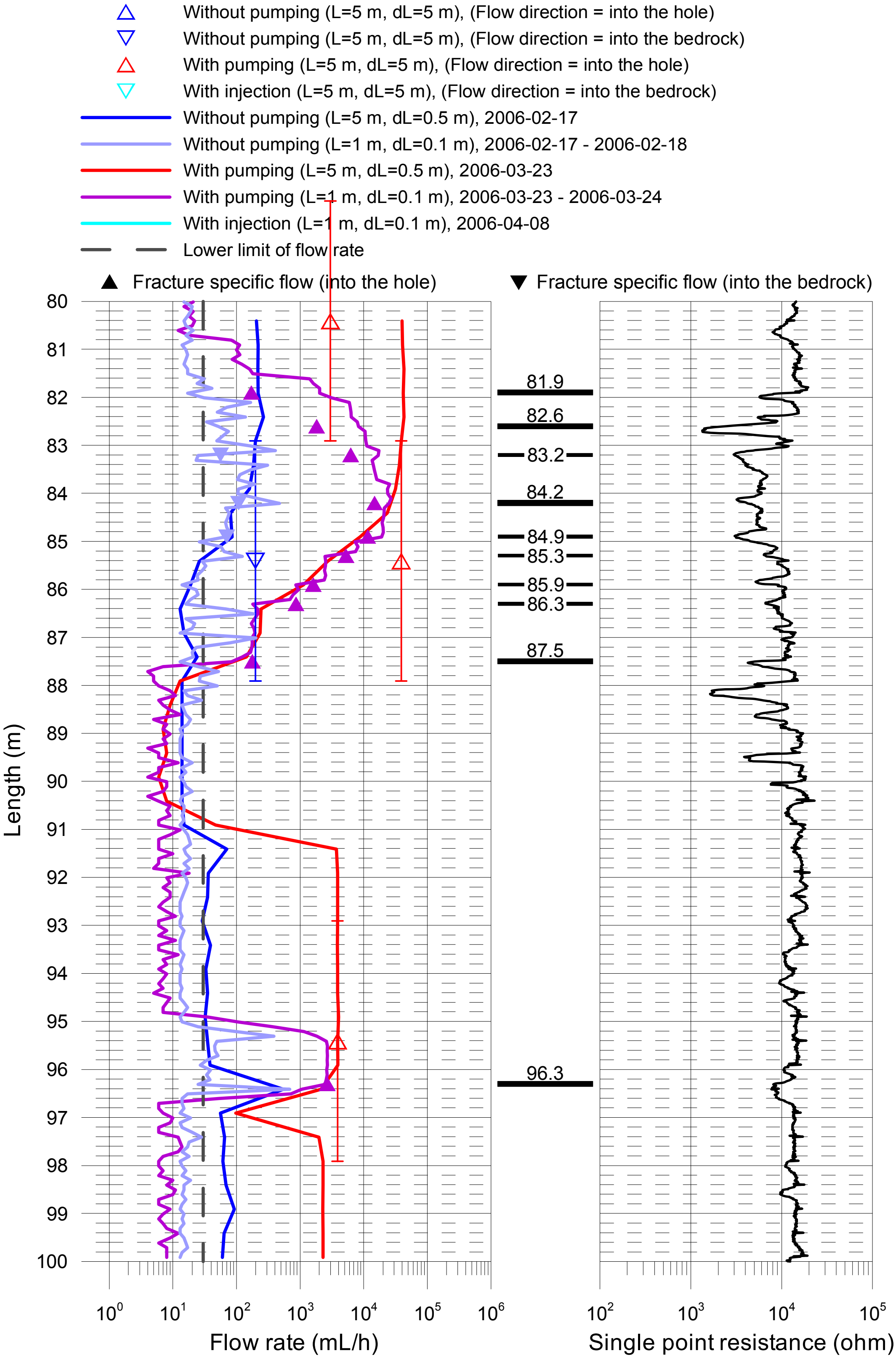
Laxemar, borehole KLX09D
Flow rate and single point resistance



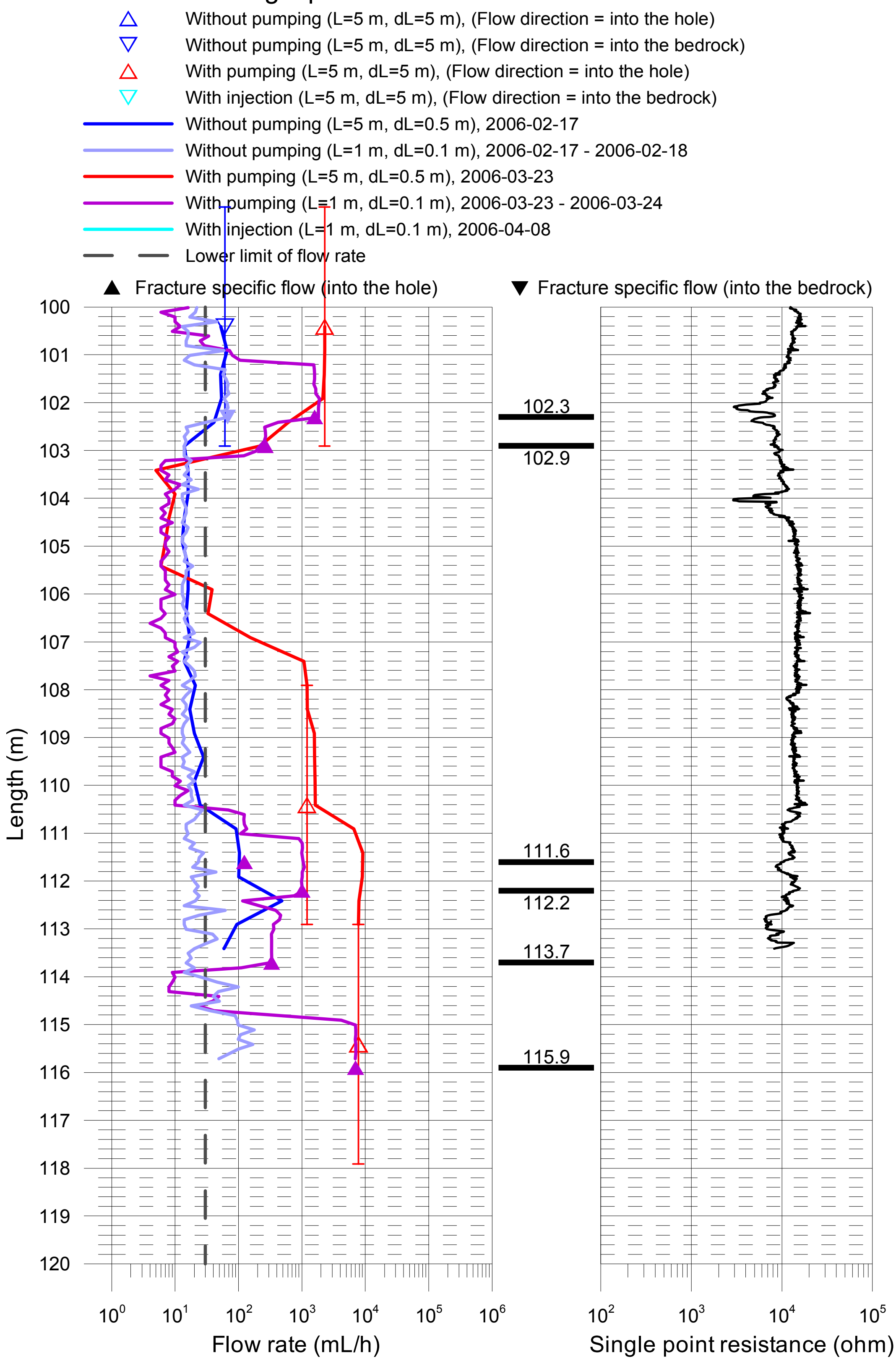

Laxemar, borehole KLX09D
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-02-17
Without pumping (L=1 m, dL=0.1 m), 2006-02-17 - 2006-02-18
With pumping (L=5 m, dL=0.5 m), 2006-03-23
With pumping (L=1 m, dL=0.1 m), 2006-03-23 - 2006-03-24
With injection (L=1 m, dL=0.1 m), 2006-04-08
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
44.7
50.2
51.9
54.6
55.3
56.5
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)


Laxemar, borehole KLX09D
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), 2006-02-17
Without pumping (L=1 m, dL=0.1 m), 2006-02-17 - 2006-02-18
With pumping (L=5 m, dL=0.5 m), 2006-03-23
With pumping (L=1 m, dL=0.1 m), 2006-03-23 - 2006-03-24
With injection (L=1 m, dL=0.1 m), 2006-04-08
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
64.5
65.7
67.3
67.6
68.4
74.8
77.9
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
10^2
10^3
10^4
10^5
Single point resistance (ohm)

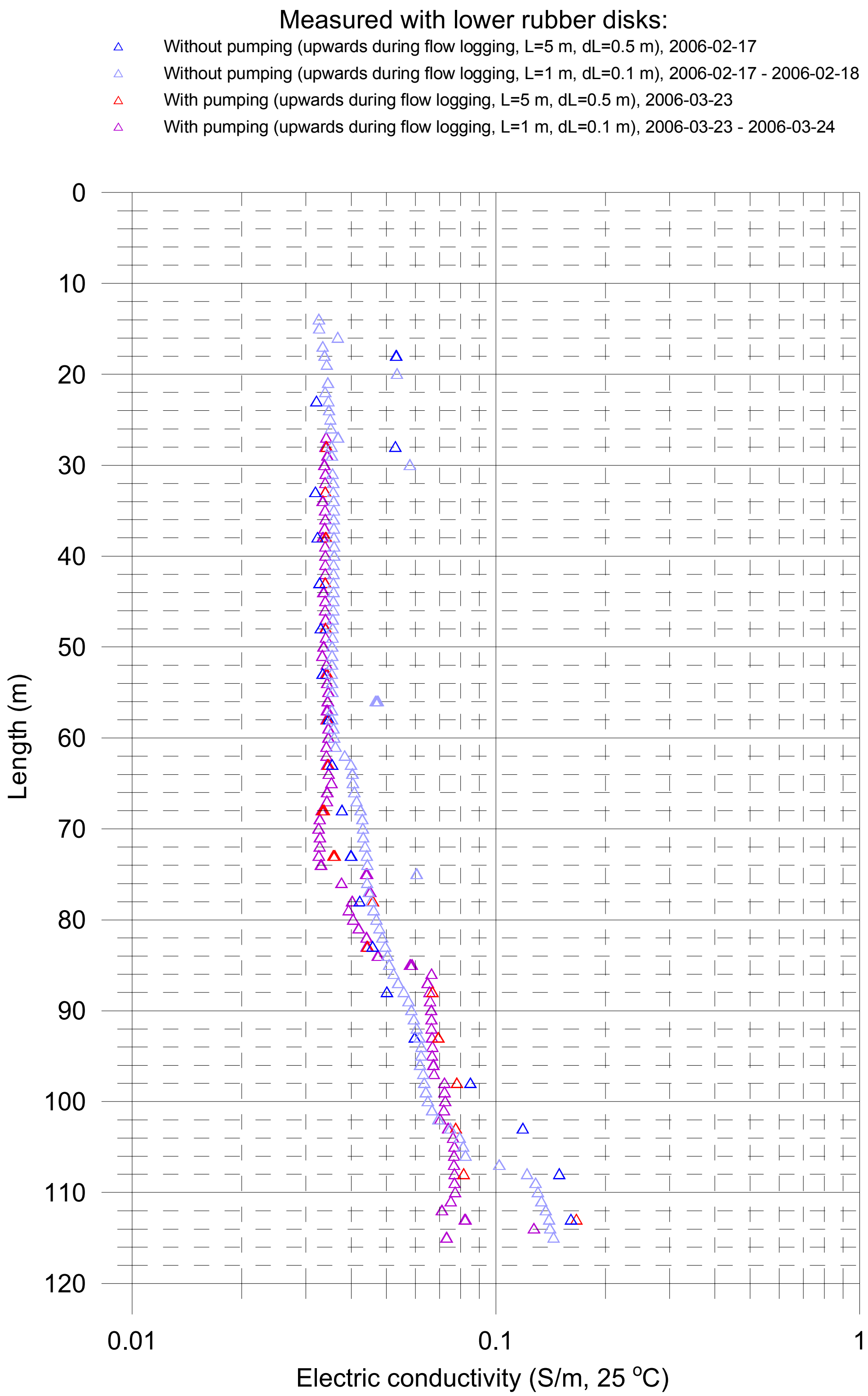
Laxemar, borehole KLX09D
Flow rate and single point resistance



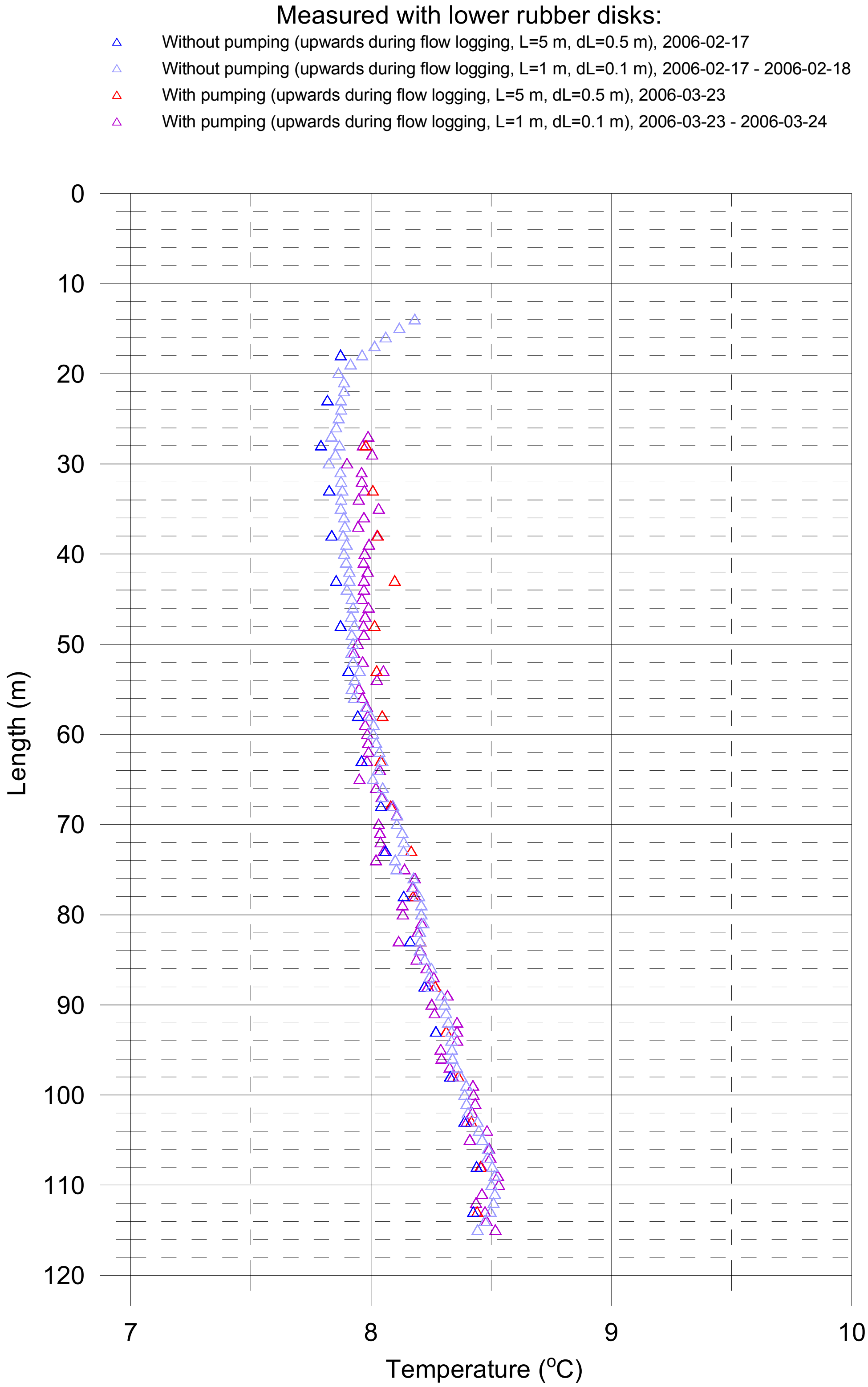
Laxemar, borehole KLX09D
Flow rate and single point resistance

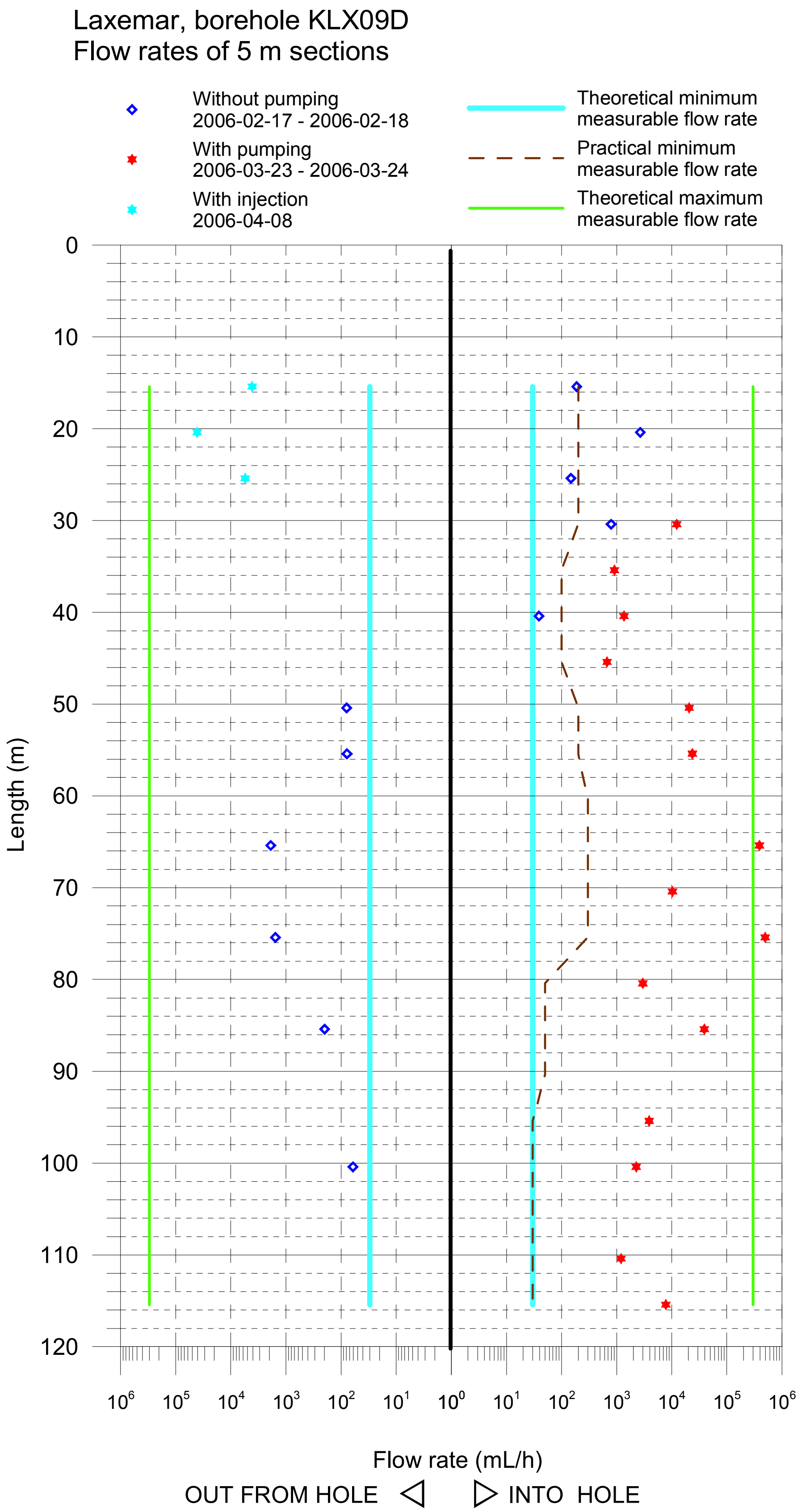


Laxemar, borehole KLX09D
Electric conductivity of borehole water

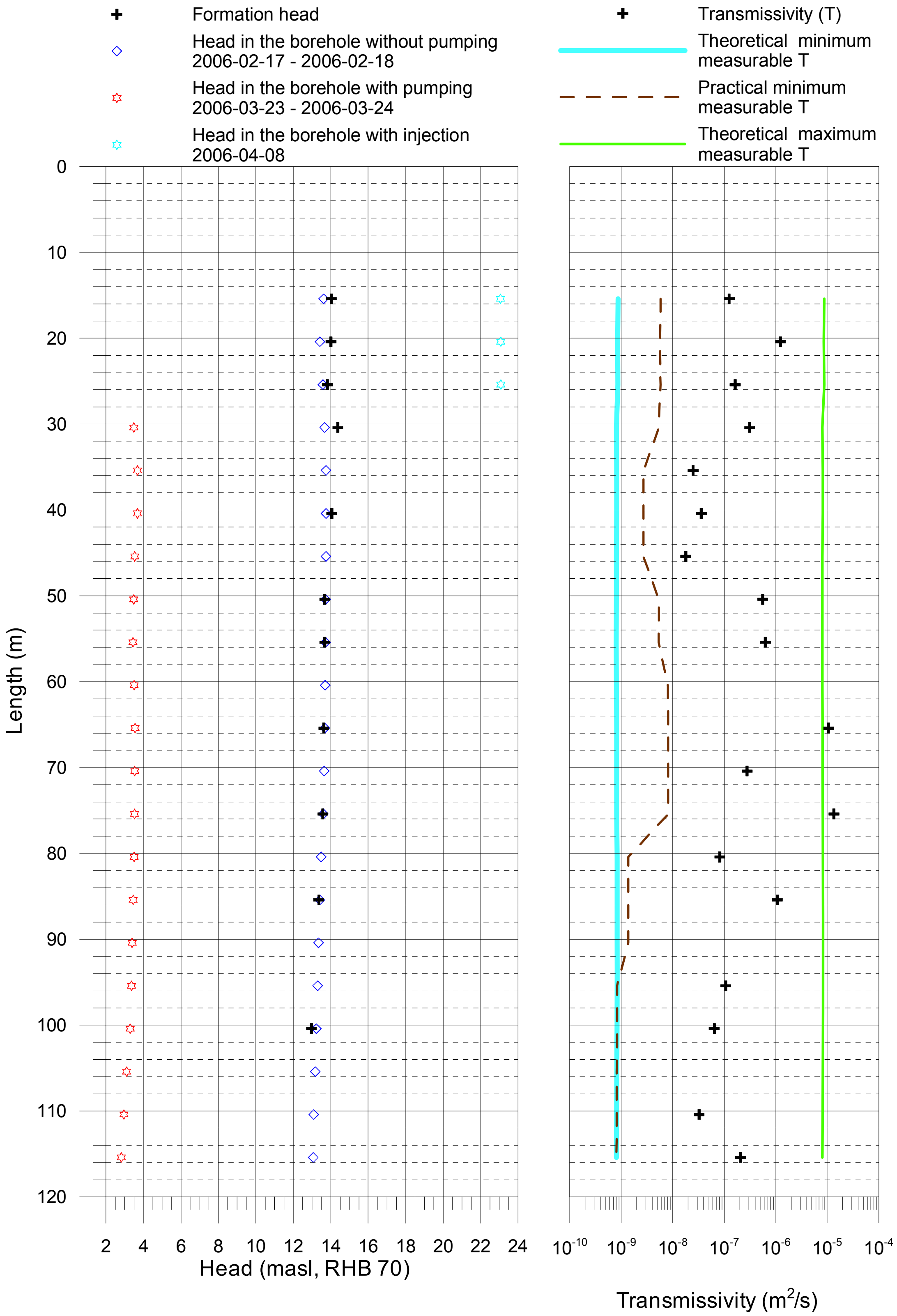


Laxemar, borehole KLX09D
Temperature of borehole water

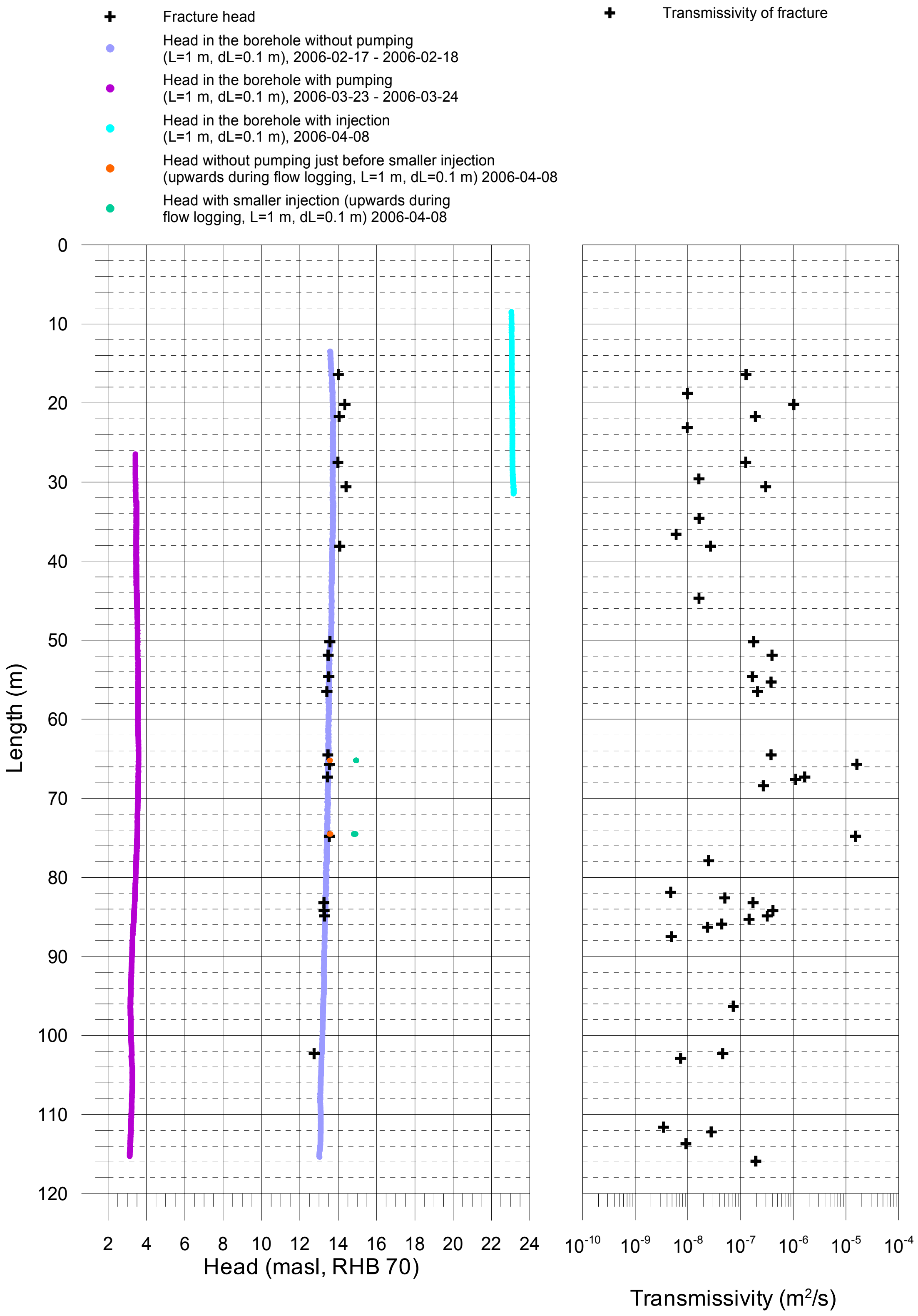



Laxemar, borehole KLX09D
Flow rates of 5 m sections
Without pumping
2006-02-17 - 2006-02-18
With pumping
2006-03-23 - 2006-03-24
With injection
2006-04-08
Theoretical minimum
measurable flow rate
Practical minimum
measurable flow rate
Theoretical maximum
measurable flow rate
Length (m)
0
10
20
30
40
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 KLX09D
Transmissivity and head of 5 m sections



Laxemar, borehole KLX09D
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)
KLX09D	12.91	117.91	5A	20060322	14:37	20060323	09:00	20060328	11:44	5	5	2.32E–4	

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 (–)
508,020		243,890		13.50	3.54		–9.96		2.3E–5		

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KLX09D	12.91	17.91	5	5.22E–08	13.62	–1.14E–06	23.06	1.3E–07	14.0	200	8.7E–10	5.8E–09	8.7E–06	**
KLX09D	17.91	22.91	5	7.42E–07	13.42	–1.14E–05	23.07	1.2E–06	14.0	200	8.5E–10	5.7E–09	8.5E–06	**
KLX09D	22.91	27.91	5	4.11E–08	13.57	–1.53E–06	23.08	1.6E–07	13.8	200	8.7E–10	5.8E–09	8.7E–06	**
KLX09D	27.91	32.91	5	2.20E–07	13.67	3.42E–06	3.49	3.1E–07	14.4	200	8.1E–10	5.4E–09	8.1E–06	
KLX09D	32.91	37.91	5	–	13.74	2.53E–07	3.68	2.5E–08	–	100	8.2E–10	2.7E–09	8.2E–06	
KLX09D	37.91	42.91	5	1.08E–08	13.75	3.78E–07	3.68	3.6E–08	14.1	100	8.2E–10	2.7E–09	8.2E–06	
KLX09D	42.91	47.91	5	–	13.74	1.86E–07	3.54	1.8E–08	–	100	8.1E–10	2.7E–09	8.1E–06	
KLX09D	47.91	52.91	5	–2.19E–08	13.72	5.75E–06	3.48	5.6E–07	13.7	200	8.1E–10	5.4E–09	8.1E–06	
KLX09D	52.91	57.91	5	–2.17E–08	13.71	6.56E–06	3.44	6.3E–07	13.7	200	8.0E–10	5.4E–09	8.0E–06	
KLX09D	57.91	62.91	5	–	13.70	–	3.50	–	–	300	8.1E–10	8.1E–09	8.1E–06	
KLX09D	62.91	67.91	5	–5.25E–07	13.68	1.08E–04	3.55	1.1E–05	13.6	300	8.1E–10	8.1E–09	8.1E–06	
KLX09D	67.91	72.91	5	–	13.65	2.86E–06	3.54	2.8E–07	–	300	8.2E–10	8.2E–09	8.2E–06	
KLX09D	72.91	77.91	5	–4.33E–07	13.60	1.38E–04	3.52	1.4E–05	13.6	300	8.2E–10	8.2E–09	8.2E–06	
KLX09D	77.91	82.91	5	–	13.49	8.28E–07	3.50	8.2E–08	–	50	8.3E–10	1.4E–09	8.3E–06	
KLX09D	82.91	87.91	5	–5.50E–08	13.41	1.08E–05	3.45	1.1E–06	13.4	50	8.3E–10	1.4E–09	8.3E–06	
KLX09D	87.91	92.91	5	–	13.35	–	3.40	–	–	50	8.3E–10	1.4E–09	8.3E–06	
KLX09D	92.91	97.91	5	–	13.29	1.08E–06	3.36	1.1E–07	–	30	8.3E–10	8.3E–10	8.3E–06	
KLX09D	97.91	102.91	5	–1.69E–08	13.23	6.31E–07	3.29	6.4E–08	13.0	30	8.3E–10	8.3E–10	8.3E–06	
KLX09D	102.91	107.91	5	–	13.17	–	3.10	–	–	30	8.2E–10	8.2E–10	8.2E–06	
KLX09D	107.91	112.91	5	–	13.09	3.33E–07	2.96	3.3E–08	–	30	8.1E–10	8.1E–10	8.1E–06	
KLX09D	112.91	117.91	5	–	13.06	2.16E–06	2.82	2.1E–07	–	30	8.1E–10	8.1E–10	8.1E–06	

** Values from the measurement with injection.

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
KLX09D	16.4	1	0.1	4.75E–08	13.64	–1.16E–06	23.06	1.3E–07	14.0	**
KLX09D	18.8	1	0.1	–	13.71	–9.31E–08	23.07	9.8E–09	–	*, **
KLX09D	20.2	1	0.1	6.56E–07	13.72	–9.03E–06	23.08	1.0E–06	14.4	**
KLX09D	21.7	1	0.1	5.89E–08	13.74	–1.74E–06	23.08	1.9E–07	14.1	**
KLX09D	23.1	1	0.1	–	13.72	–9.19E–08	23.08	9.7E–09	–	**
KLX09D	25.3	1	0.1	–	13.73	–	23.08	–	–	**, ***
KLX09D	27.5	1	0.1	3.47E–08	13.71	1.33E–06	3.42	1.3E–07	14.0	
KLX09D	29.6	1	0.1	–	13.71	1.68E–07	3.43	1.6E–08	–	
KLX09D	30.6	1	0.1	2.09E–07	13.72	3.33E–06	3.42	3.0E–07	14.4	
KLX09D	34.6	1	0.1	–	13.73	1.70E–07	3.47	1.6E–08	–	
KLX09D	36.6	1	0.1	–	13.70	6.19E–08	3.47	6.0E–09	–	*
KLX09D	38.1	1	0.1	1.03E–08	13.70	2.89E–07	3.46	2.7E–08	14.1	
KLX09D	44.7	1	0.1	–	13.65	1.67E–07	3.49	1.6E–08	–	
KLX09D	50.2	1	0.1	–6.67E–09	13.61	1.80E–06	3.54	1.8E–07	13.6	
KLX09D	51.9	1	0.1	–1.89E–08	13.53	3.97E–06	3.54	4.0E–07	13.5	
KLX09D	54.6	1	0.1	–3.33E–09	13.53	1.68E–06	3.56	1.7E–07	13.5	
KLX09D	55.3	1	0.1	–	13.52	3.81E–06	3.56	3.8E–07	–	*
KLX09D	56.5	1	0.1	–1.92E–08	13.50	2.09E–06	3.56	2.1E–07	13.4	
KLX09D	64.5	1	0.1	–1.61E–08	13.50	3.78E–06	3.58	3.8E–07	13.5	
KLX09D	65.7	1	0.1	–3.33E–07	13.57	–2.23E–05	14.93	1.6E–05	13.6	****
KLX09D	67.3	1	0.1	–8.56E–08	13.49	1.64E–05	3.56	1.7E–06	13.4	
KLX09D	67.6	1	0.1	–	13.47	1.11E–05	3.57	1.1E–06	–	*
KLX09D	68.4	1	0.1	–	13.47	2.73E–06	3.56	2.7E–07	–	
KLX09D	74.8	1	0.1	–4.00E–07	13.57	–2.08E–05	14.89	1.5E–05	13.5	****
KLX09D	77.9	1	0.1	–	13.40	2.49E–07	3.46	2.5E–08	–	
KLX09D	81.9	1	0.1	–	13.34	4.75E–08	3.40	4.7E–09	–	
KLX09D	82.6	1	0.1	–	13.33	5.06E–07	3.39	5.0E–08	–	
KLX09D	83.2	1	0.1	–1.56E–08	13.34	1.73E–06	3.38	1.7E–07	13.3	
KLX09D	84.2	1	0.1	–3.00E–08	13.33	4.11E–06	3.36	4.1E–07	13.3	
KLX09D	84.9	1	0.1	–1.94E–08	13.34	3.22E–06	3.34	3.2E–07	13.3	
KLX09D	85.3	1	0.1	–	13.32	1.46E–06	3.34	1.5E–07	–	
KLX09D	85.9	1	0.1	–	13.31	4.44E–07	3.32	4.4E–08	–	
KLX09D	86.3	1	0.1	–	13.31	2.39E–07	3.31	2.4E–08	–	
KLX09D	87.5	1	0.1	–	13.29	4.92E–08	3.27	4.9E–09	–	
KLX09D	96.3	1	0.1	–	13.22	7.39E–07	3.15	7.3E–08	–	
KLX09D	102.3	1	0.1	–1.86E–08	13.15	4.42E–07	3.23	4.6E–08	12.8	
KLX09D	102.9	1	0.1	–	13.13	7.33E–08	3.21	7.3E–09	–	
KLX09D	111.6	1	0.1	–	13.09	3.44E–08	3.18	3.4E–09	–	
KLX09D	112.2	1	0.1	–	13.09	2.78E–07	3.19	2.8E–08	–	
KLX09D	113.7	1	0.1	–	13.07	9.22E–08	3.14	9.2E–09	–	
KLX09D	115.9	1	0.1	–	13.03	1.95E–06	3.12	2.0E–07	–	

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

** Values from the measurement with injection.

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

**** Values from the measurement with smaller injection, water level used instead of head for pressure difference.

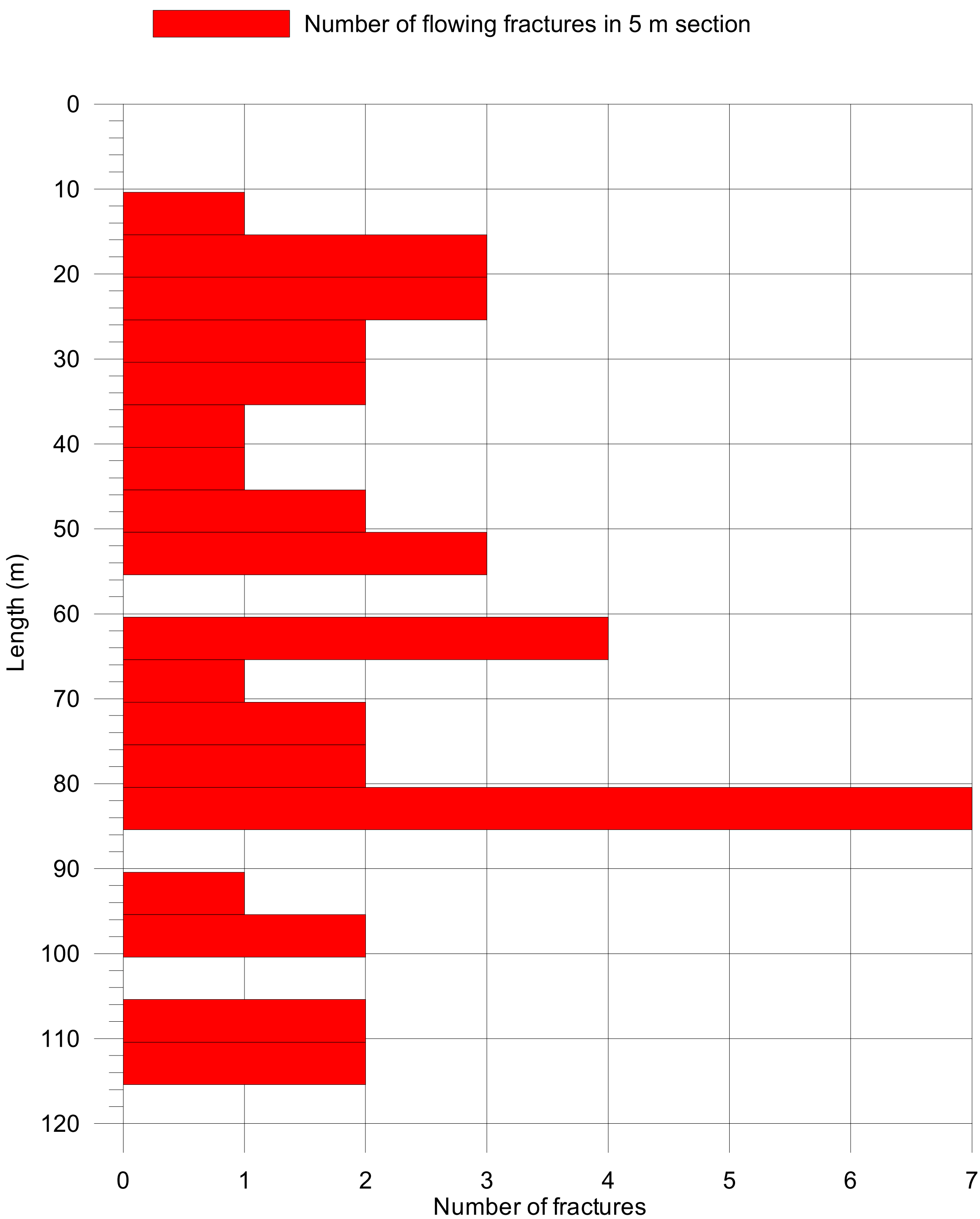
Explanations.

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

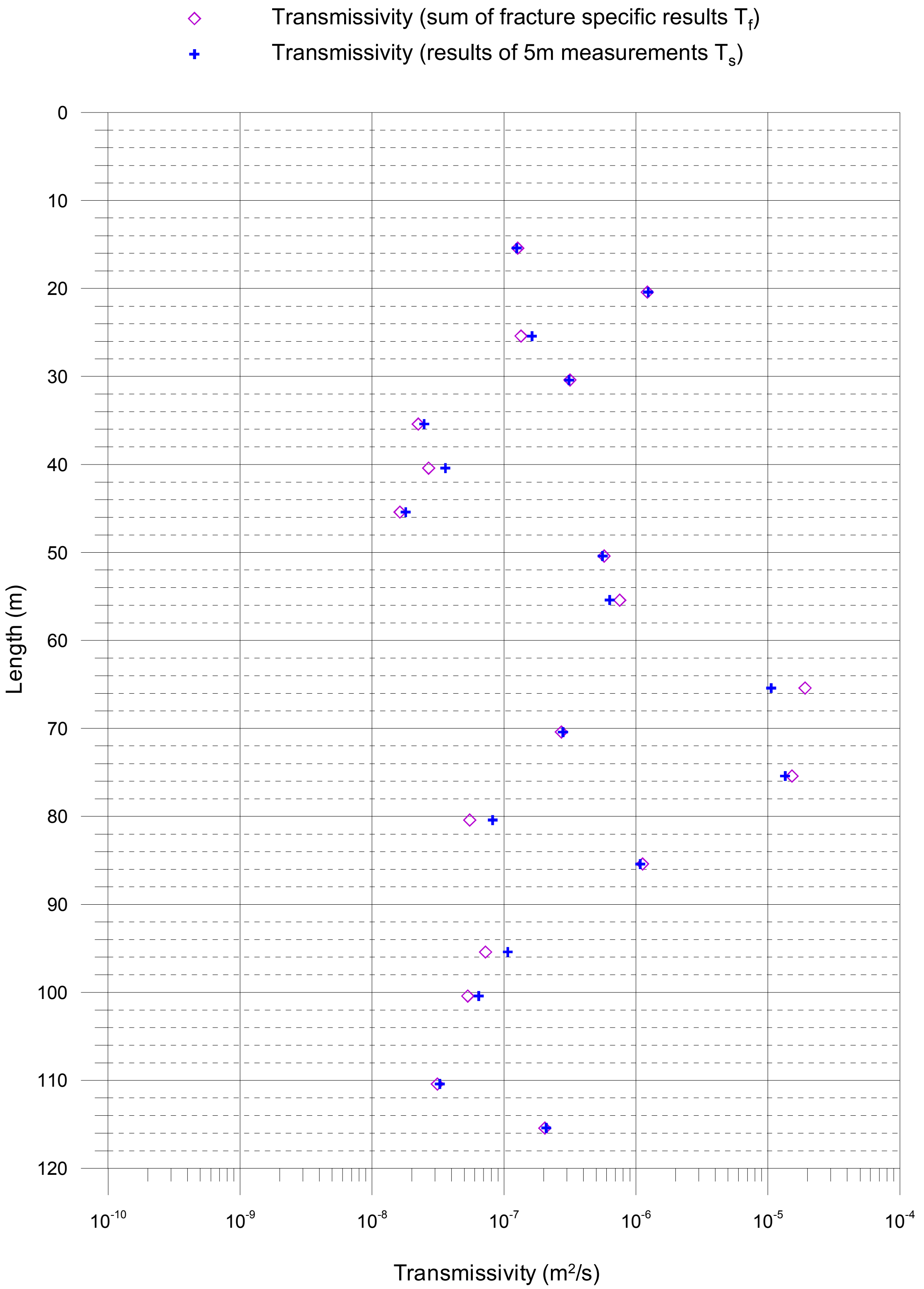
Calculation of conductive fracture frequency.

Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)
KLX09D	12.91	17.91	1	0	0	0	0	0
KLX09D	17.91	22.91	3	0	0	0	0	0
KLX09D	22.91	27.91	3	0	0	1	0	0
KLX09D	27.91	32.91	2	0	1	0	1	0
KLX09D	32.91	37.91	2	0	2	0	0	0
KLX09D	37.91	42.91	1	0	0	1	0	0
KLX09D	42.91	47.91	1	0	1	0	0	0
KLX09D	47.91	52.91	2	0	0	1	1	0
KLX09D	52.91	57.91	3	0	0	2	1	0
KLX09D	57.91	62.91	0	0	0	0	0	0
KLX09D	62.91	67.91	4	0	0	0	3	0
KLX09D	67.91	72.91	1	0	0	1	0	0
KLX09D	72.91	77.91	2	0	1	0	0	0
KLX09D	77.91	82.91	2	0	1	1	0	0
KLX09D	82.91	87.91	7	0	2	3	2	0
KLX09D	87.91	92.91	0	0	0	0	0	0
KLX09D	92.91	97.91	1	0	0	1	0	0
KLX09D	97.91	102.91	2	0	1	1	0	0
KLX09D	102.91	107.91	0	0	0	0	0	0
KLX09D	107.91	112.91	2	0	2	0	0	0
KLX09D	112.91	117.91	2	0	1	1	0	0

Laxemar, borehole KLX09D
Calculation of conductive fracture frequency

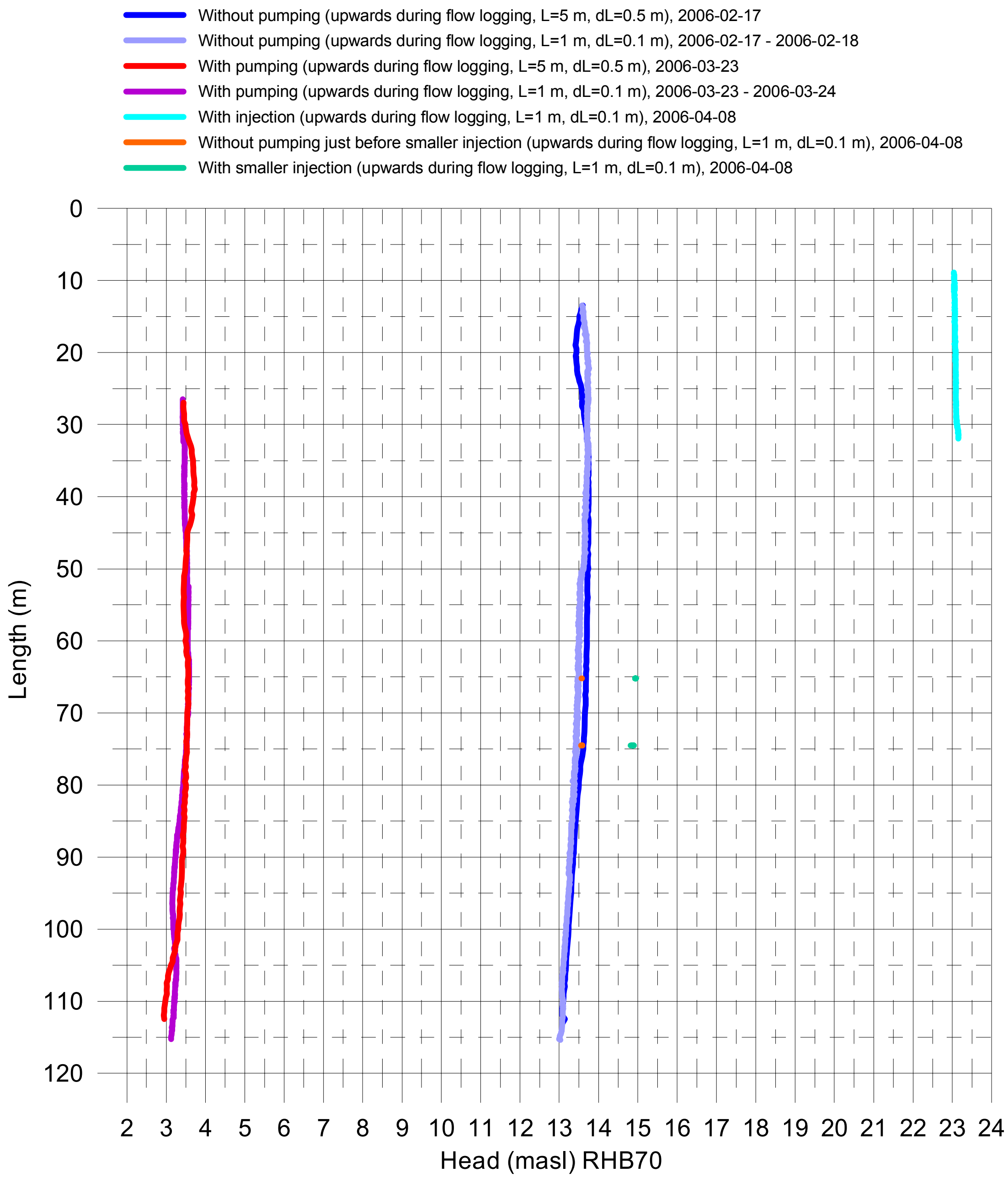


Laxemar, borehole KLX09D
Comparison between section transmissivity and fracture transmissivity

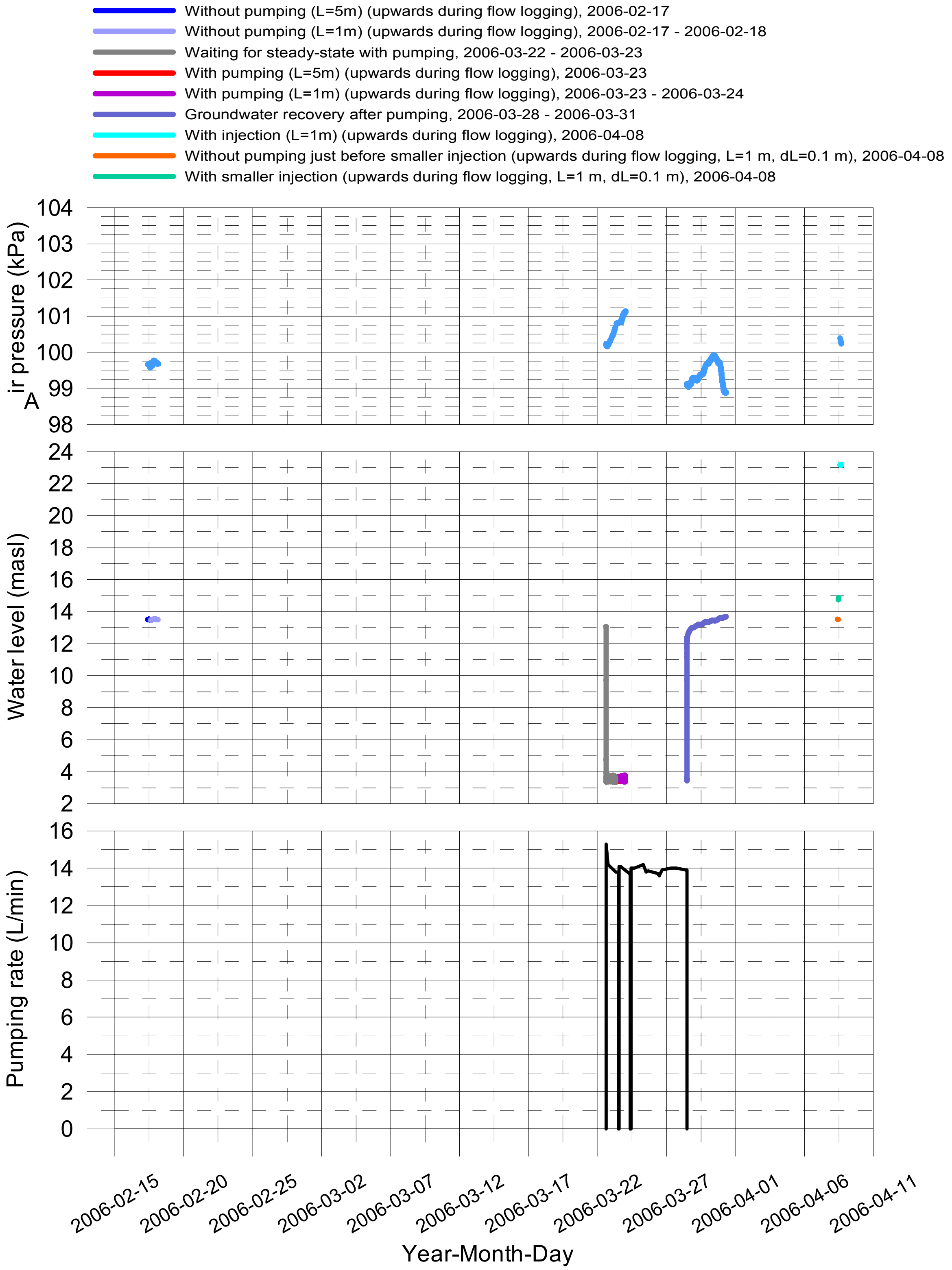


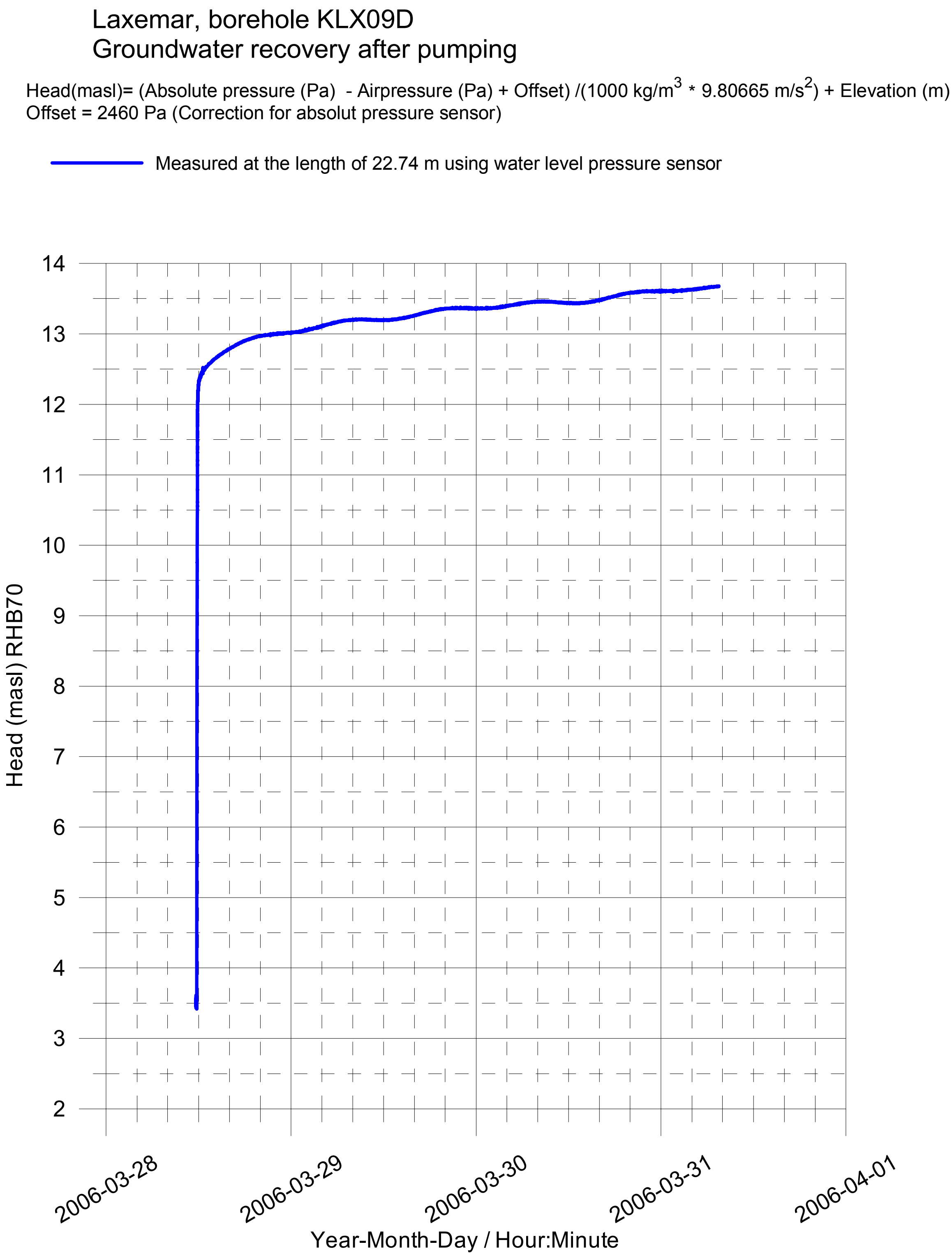
Laxemar, borehole KLX09D
Head in the borehole during flow logging

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)



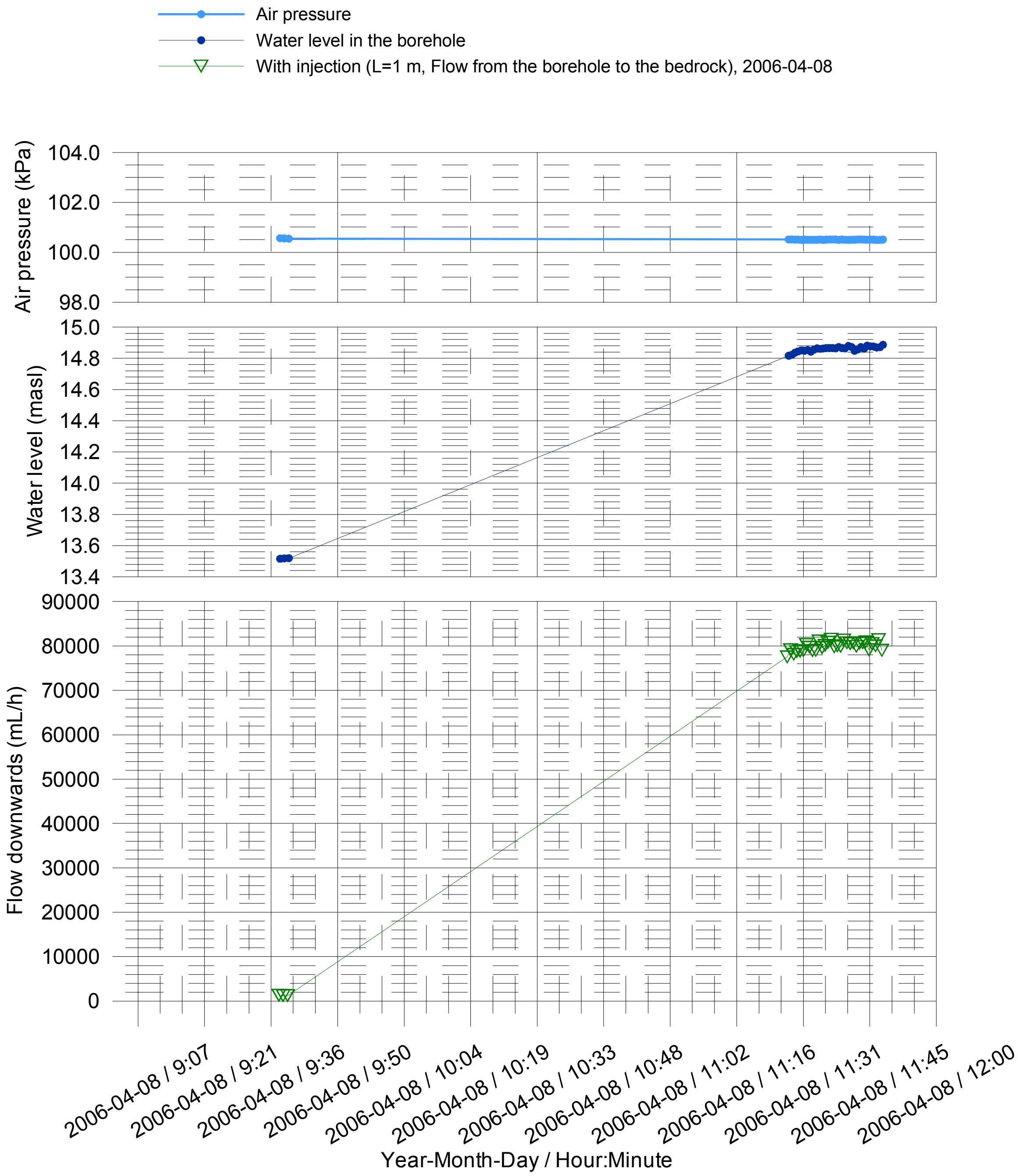
Laxemar, borehole KLX09D
Air pressure, water level in the borehole and pumping rate during flow logging



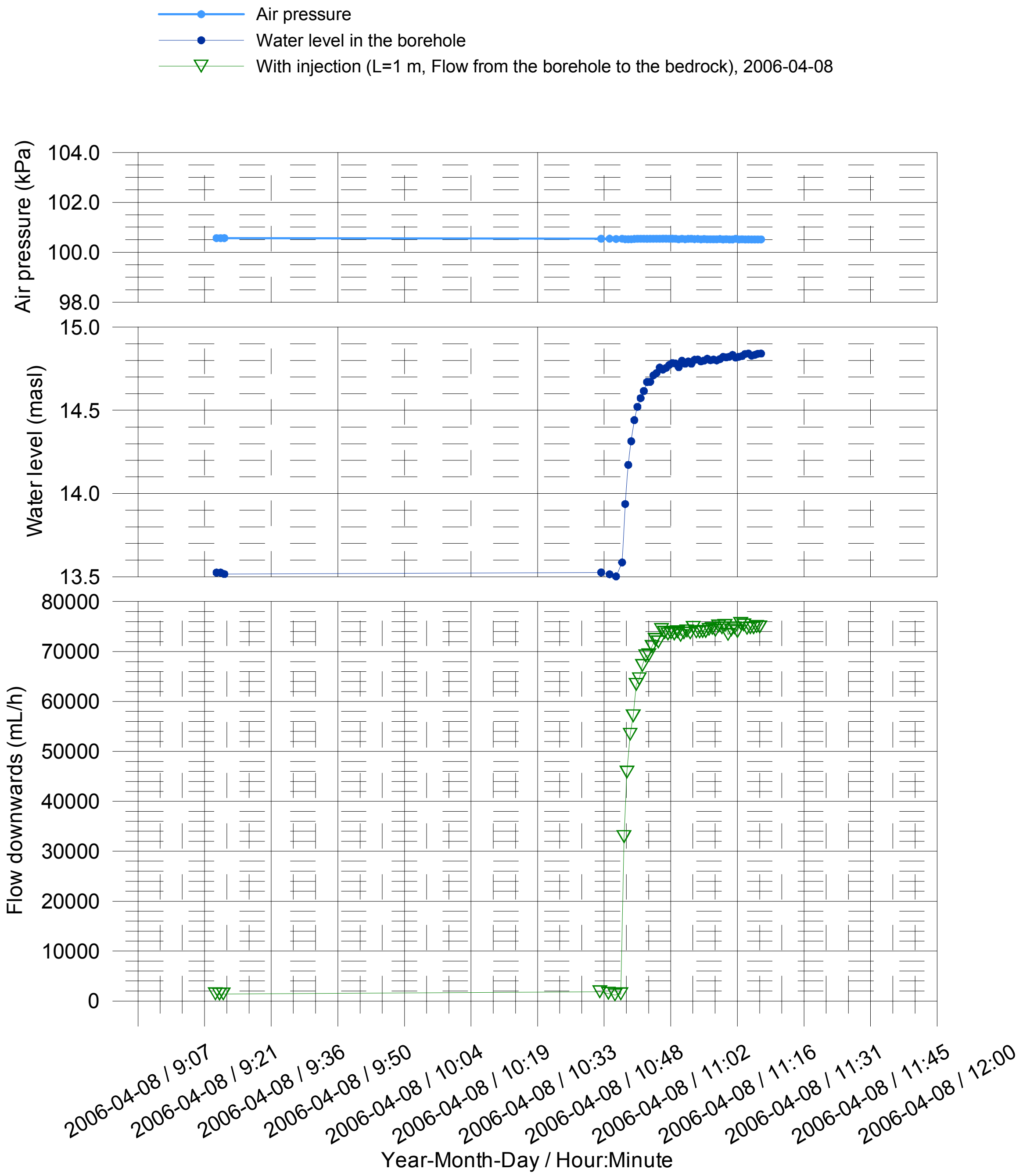


Laxemar, borehole KLX09D
Groundwater recovery after pumping
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)
Measured at the length of 22.74 m using water level pressure sensor
Head (masl) RHB70
14
13
12
11
10
9
8
7
6
5
4
3
2
2006-03-28
2006-03-29
2006-03-30
2006-03-31
2006-04-01
Year-Month-Day / Hour:Minute

Laxemar, borehole KLX09D
Vertical flow along the borehole at the length of 65.2 m

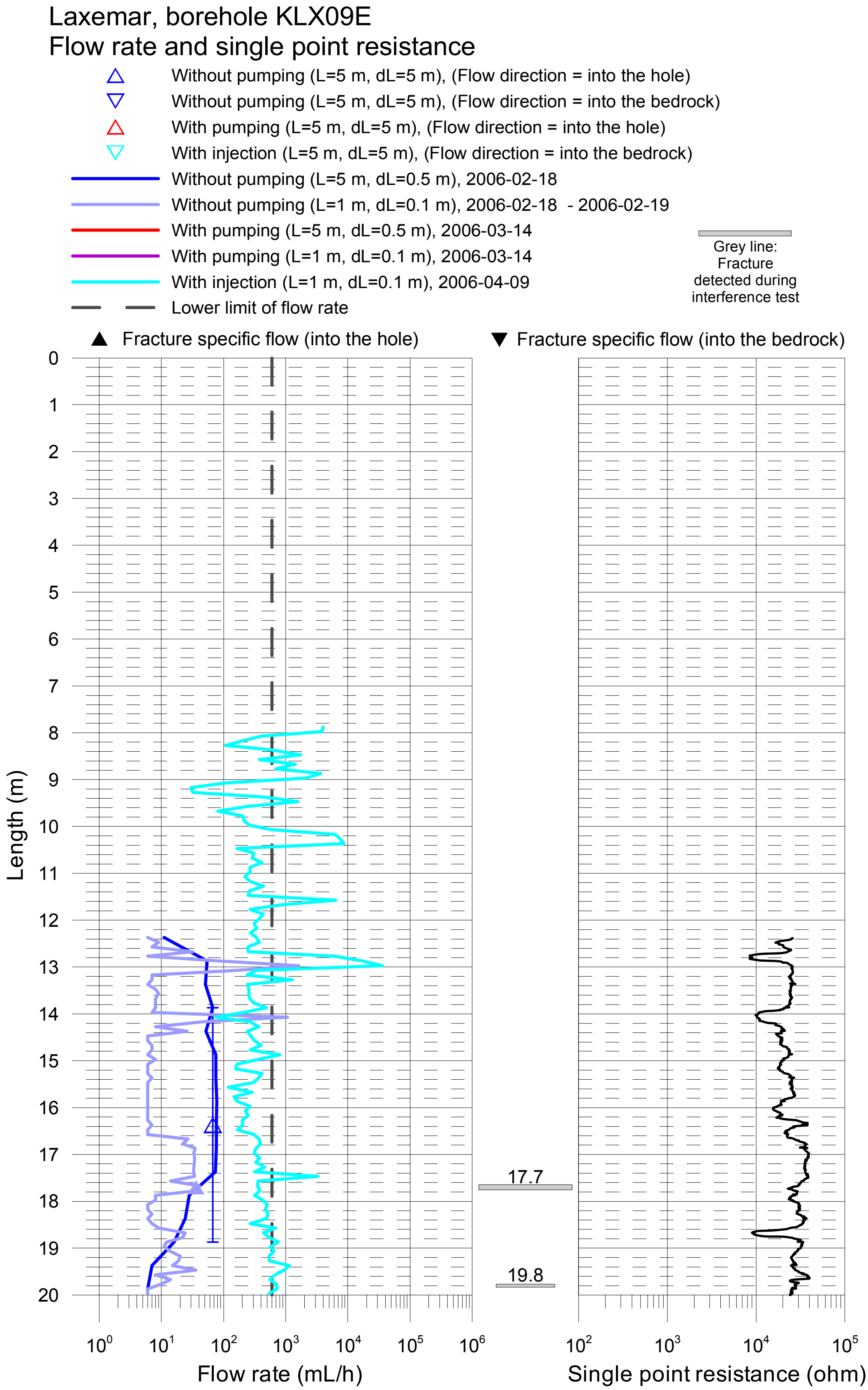


Laxemar, borehole KLX09D
Vertical flow along the borehole at the length of 74.5 m

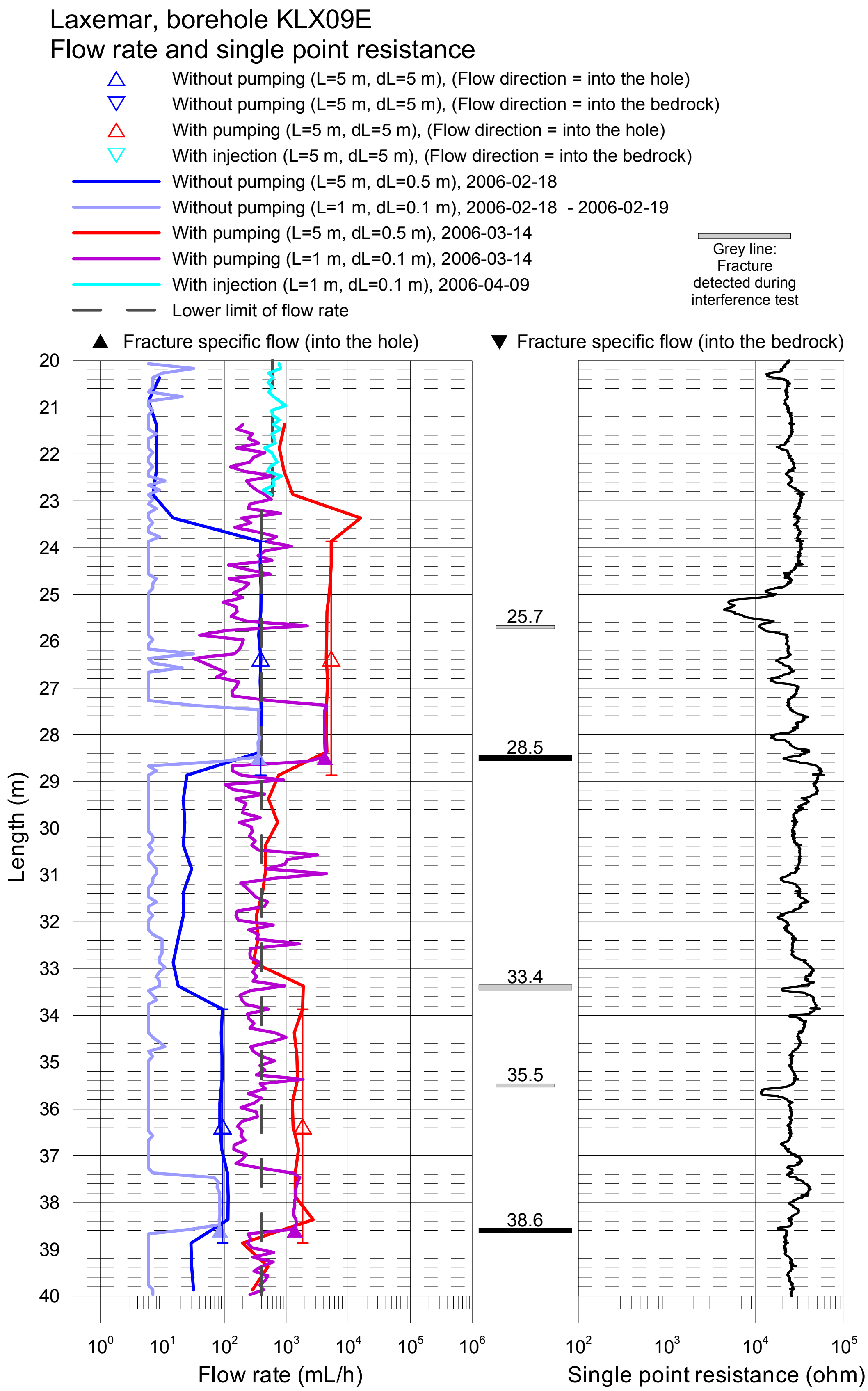


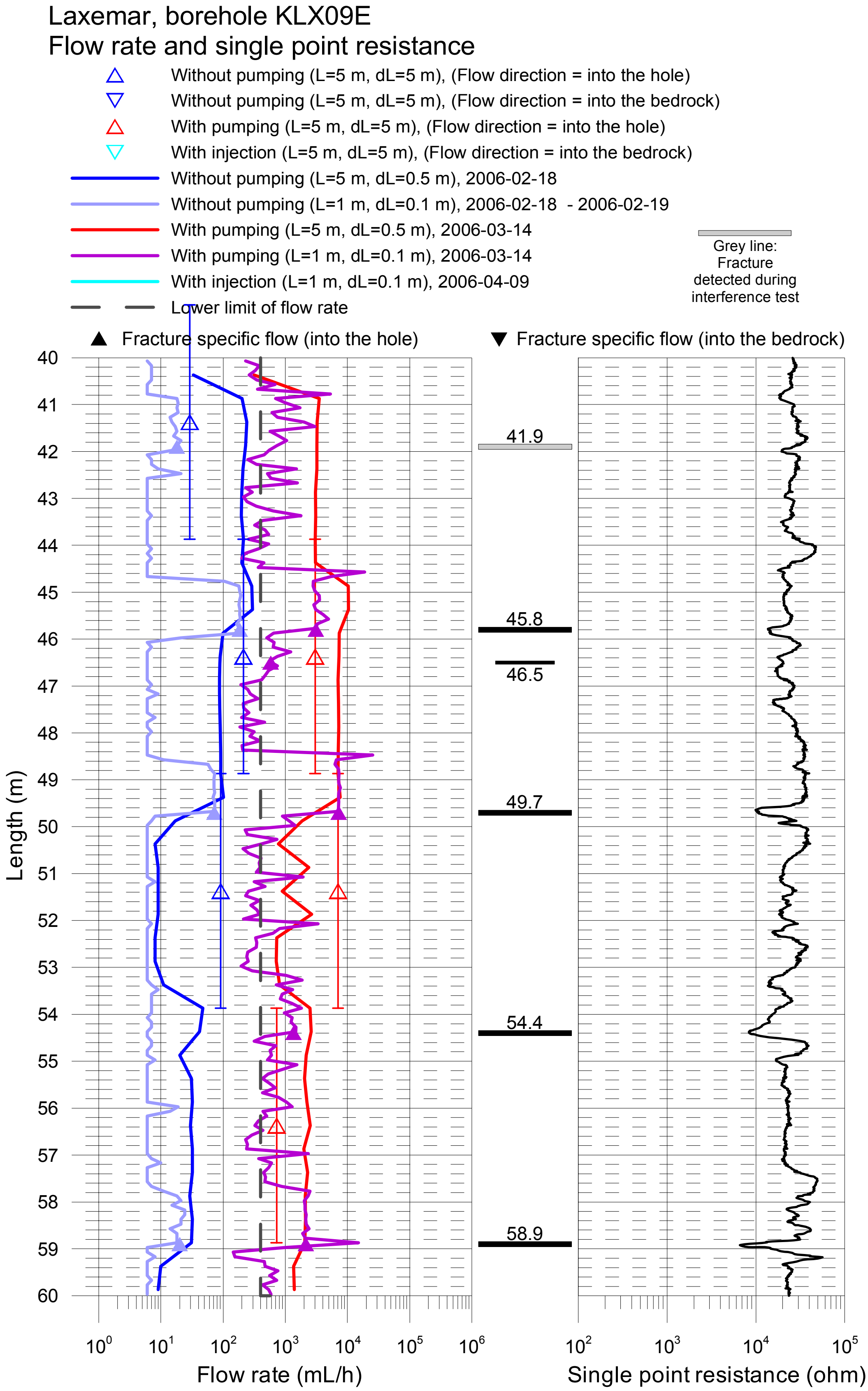
Appendices KLX09E

E.1.1–E.1.6	Flow rate and single point resistance
E.2.1	Electric conductivity of borehole water
E.2.2	Temperature of borehole water
E.3.1	Plotted flow rates of 5 m sections
E.3.2	Plotted transmissivity and head of 5 m sections
E.4	Plotted transmissivity and head of detected fractures
E.5	Basic test data
E.6	Results of sequential flow logging
E.7	Inferred flow anomalies from overlapping flow logging
E.8	Explanations for the tables in Appendices 5–7
E.9	Conductive fracture frequency
E.10	Plotted conductive fracture frequency
E.11	Comparison between section transmissivity and fracture transmissivity
E.12.1	Head in the borehole during flow logging
E.12.2	Air pressure, water level in the borehole and pumping rate during flow logging
E.12.3	Groundwater recovery after pumping
E.13.1–E.13.2	Flow logging with smaller injection

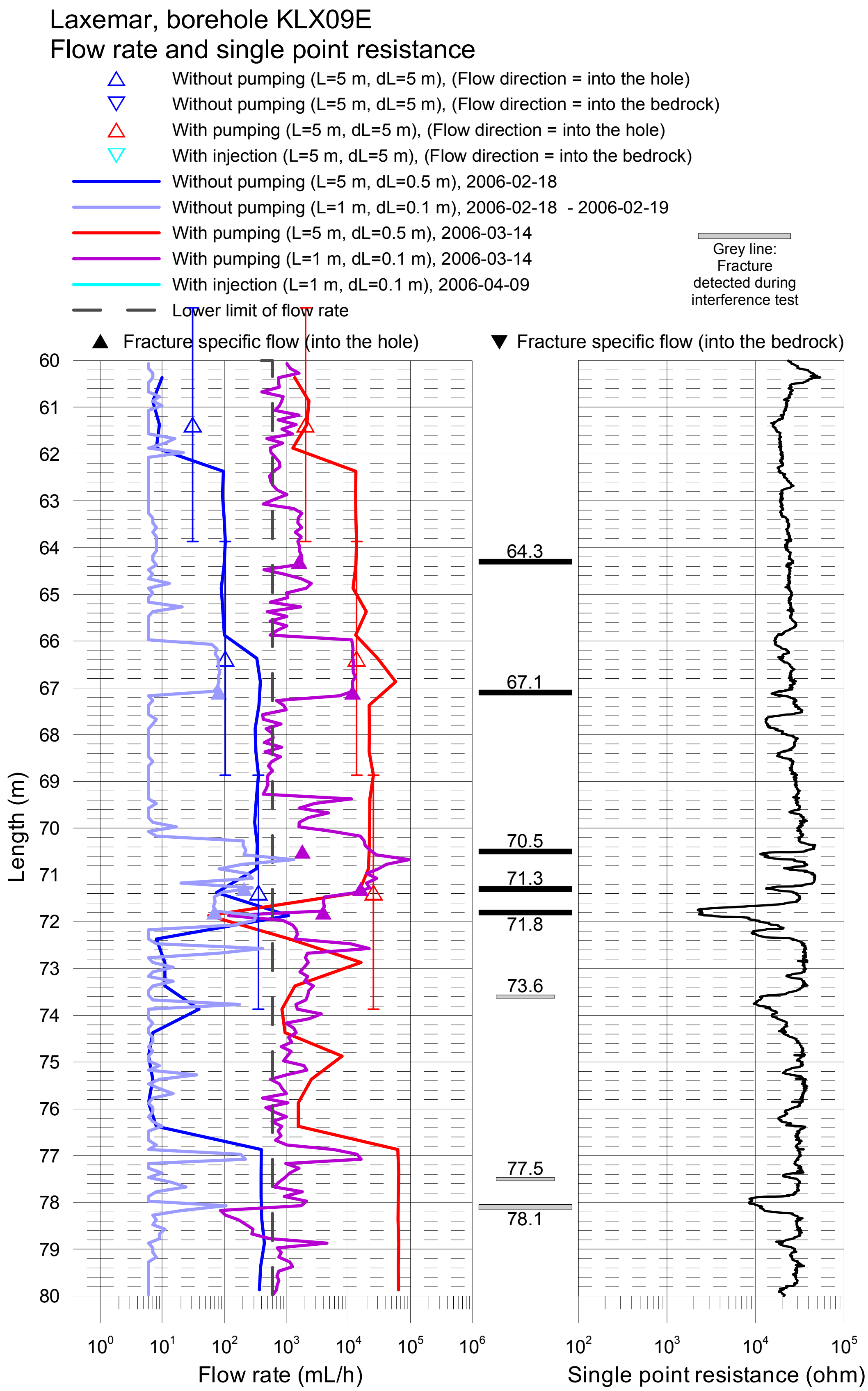


Laxemar, borehole KLX09E
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-02-18
Without pumping (L=1 m, dL=0.1 m), 2006-02-18 - 2006-02-19
With pumping (L=5 m, dL=0.5 m), 2006-03-14
With pumping (L=1 m, dL=0.1 m), 2006-03-14
With injection (L=1 m, dL=0.1 m), 2006-04-09
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)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
17.7
19.8
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

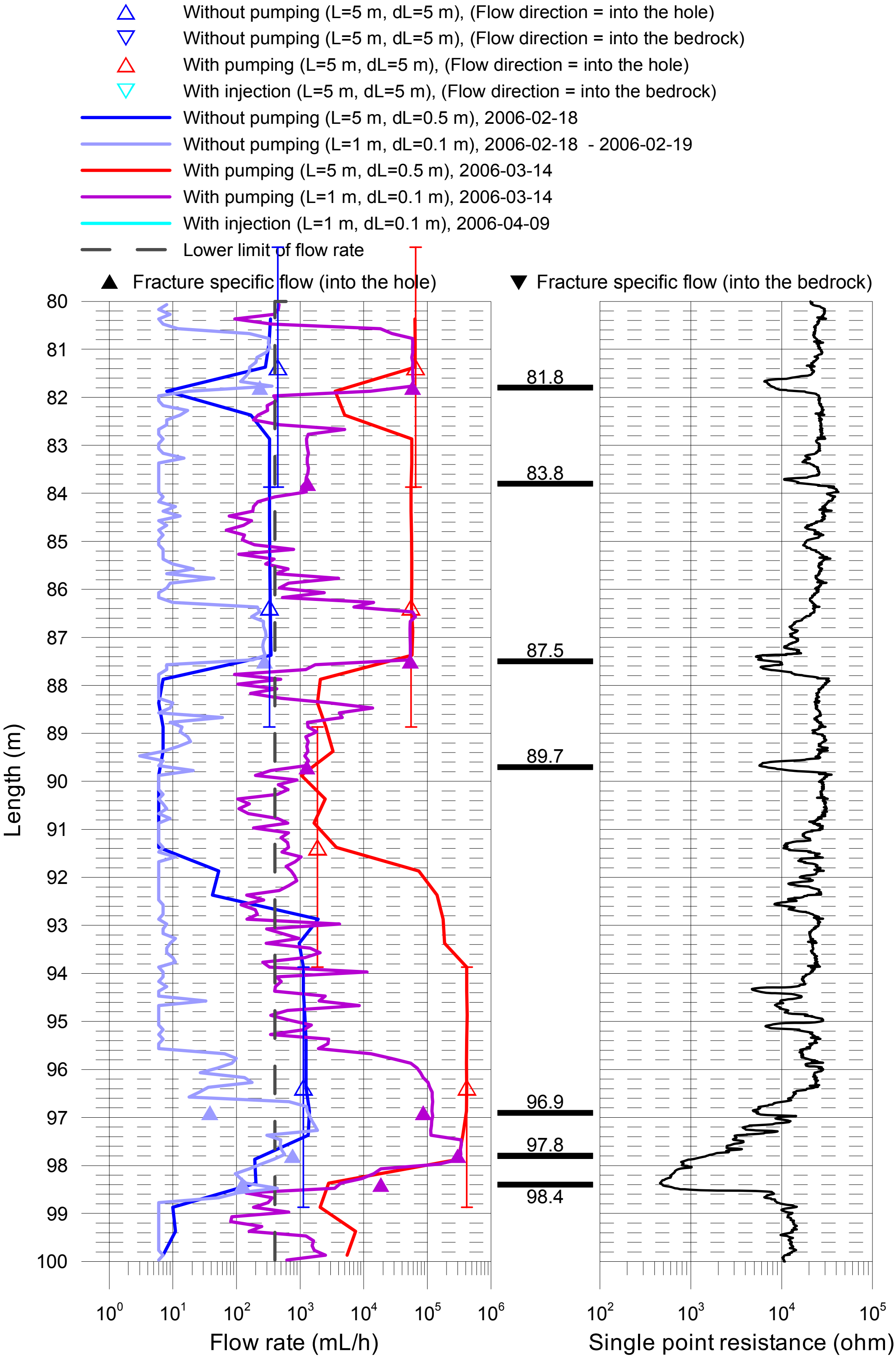

Laxemar, borehole KLX09E
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-02-18
Without pumping (L=1 m, dL=0.1 m), 2006-02-18 - 2006-02-19
With pumping (L=5 m, dL=0.5 m), 2006-03-14
With pumping (L=1 m, dL=0.1 m), 2006-03-14
With injection (L=1 m, dL=0.1 m), 2006-04-09
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)
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
25.7
28.5
33.4
35.5
38.6
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)



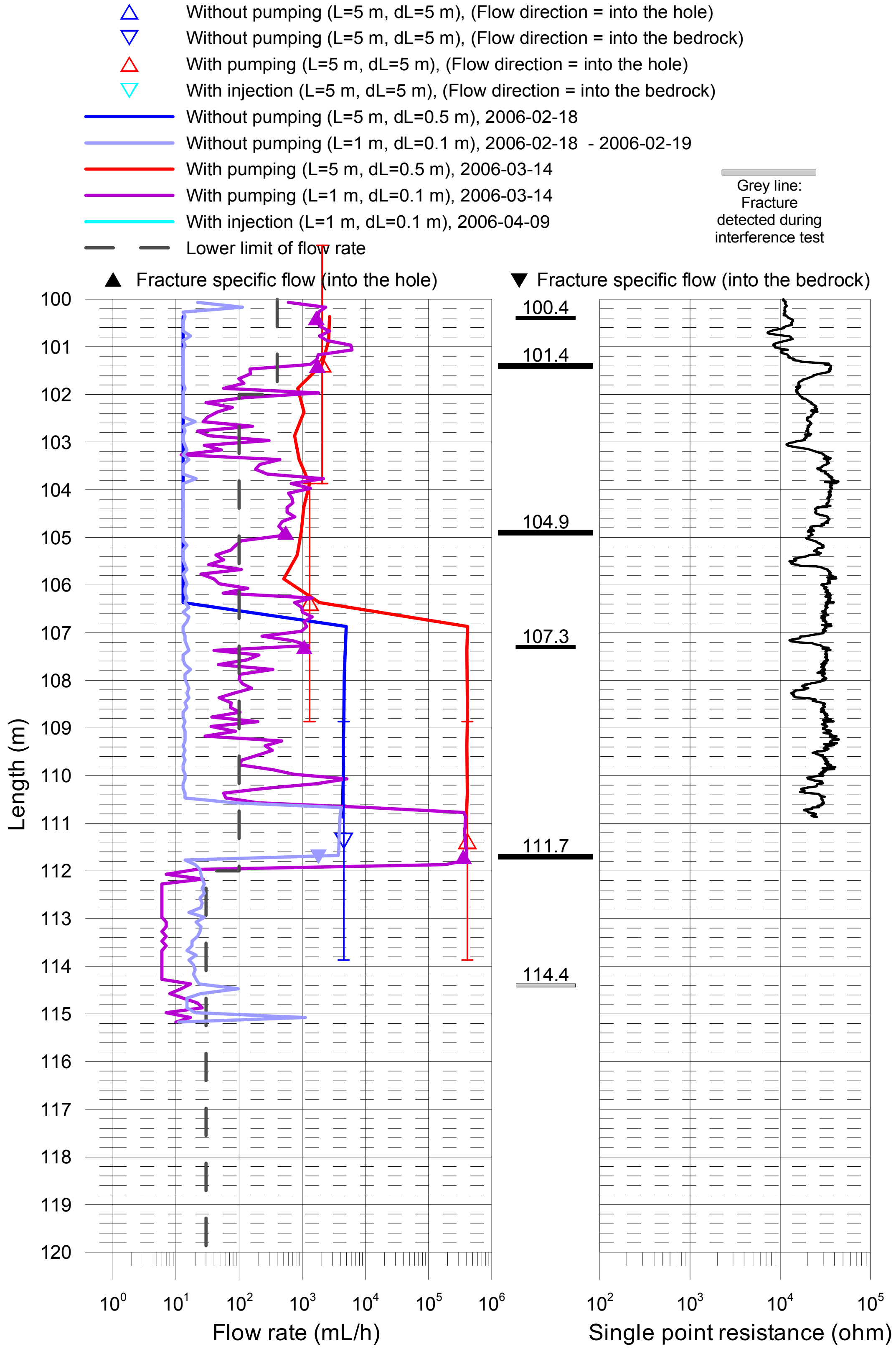
Laxemar, borehole KLX09E
Flow rate and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With injection (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2006-02-18
Without pumping (L=1 m, dL=0.1 m), 2006-02-18 - 2006-02-19
With pumping (L=5 m, dL=0.5 m), 2006-03-14
With pumping (L=1 m, dL=0.1 m), 2006-03-14
With injection (L=1 m, dL=0.1 m), 2006-04-09
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)
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
41.9
45.8
46.5
49.7
54.4
58.9
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)


Laxemar, borehole KLX09E
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), 2006-02-18
Without pumping (L=1 m, dL=0.1 m), 2006-02-18 - 2006-02-19
With pumping (L=5 m, dL=0.5 m), 2006-03-14
With pumping (L=1 m, dL=0.1 m), 2006-03-14
With injection (L=1 m, dL=0.1 m), 2006-04-09
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)
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
64.3
67.1
70.5
71.3
71.8
73.6
77.5
78.1
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

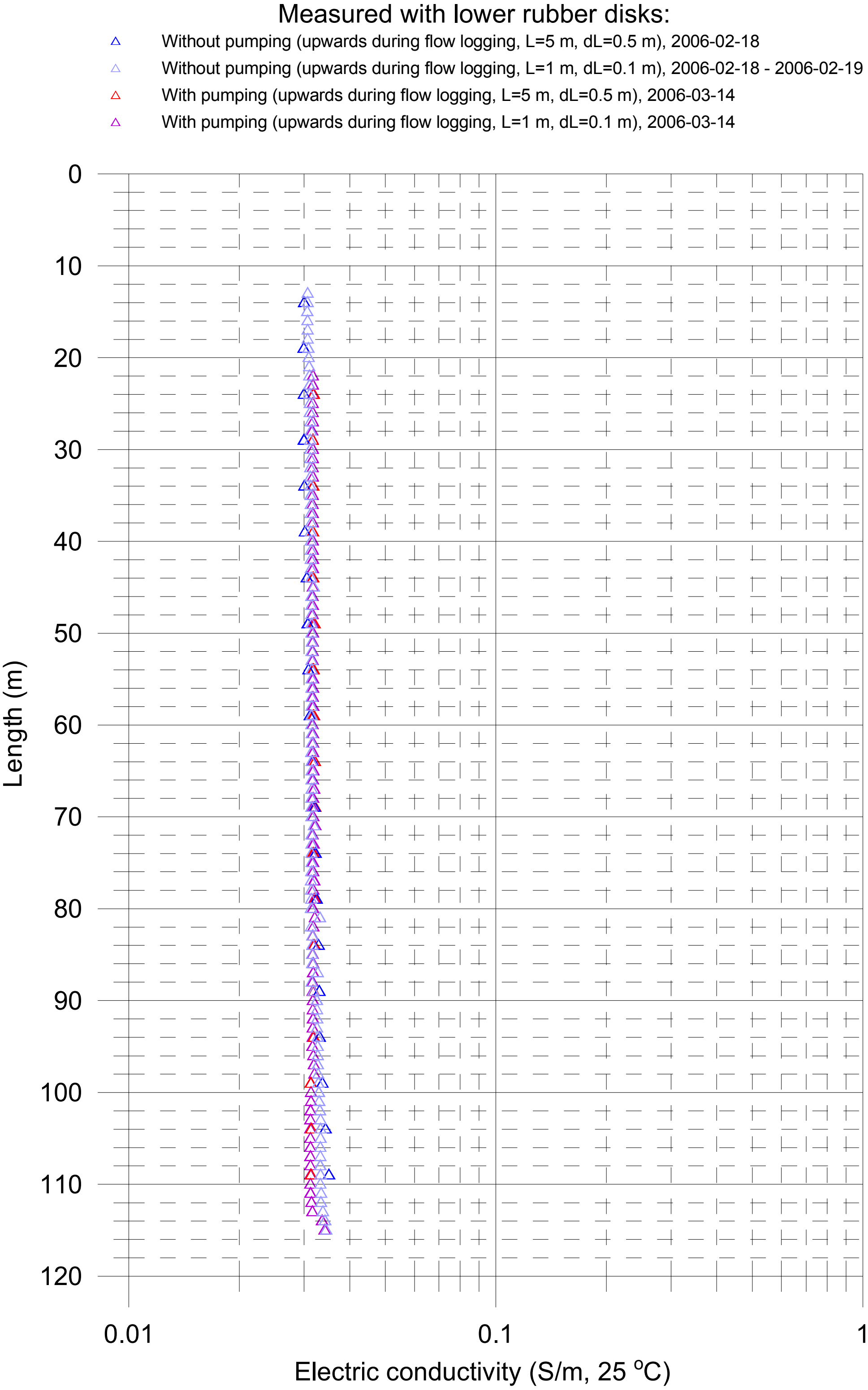
Laxemar, borehole KLX09E
Flow rate and single point resistance



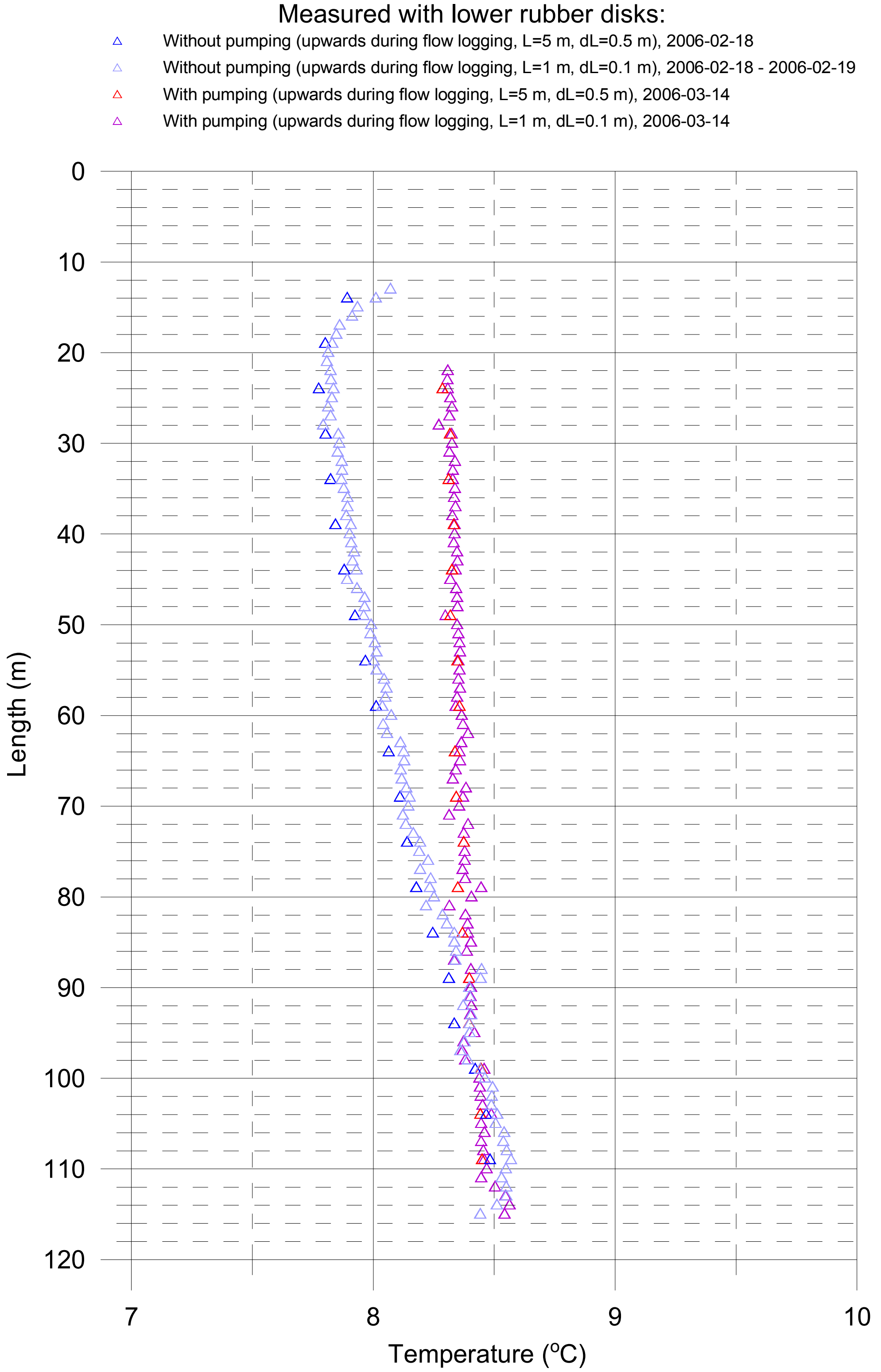
Laxemar, borehole KLX09E
Flow rate and single point resistance

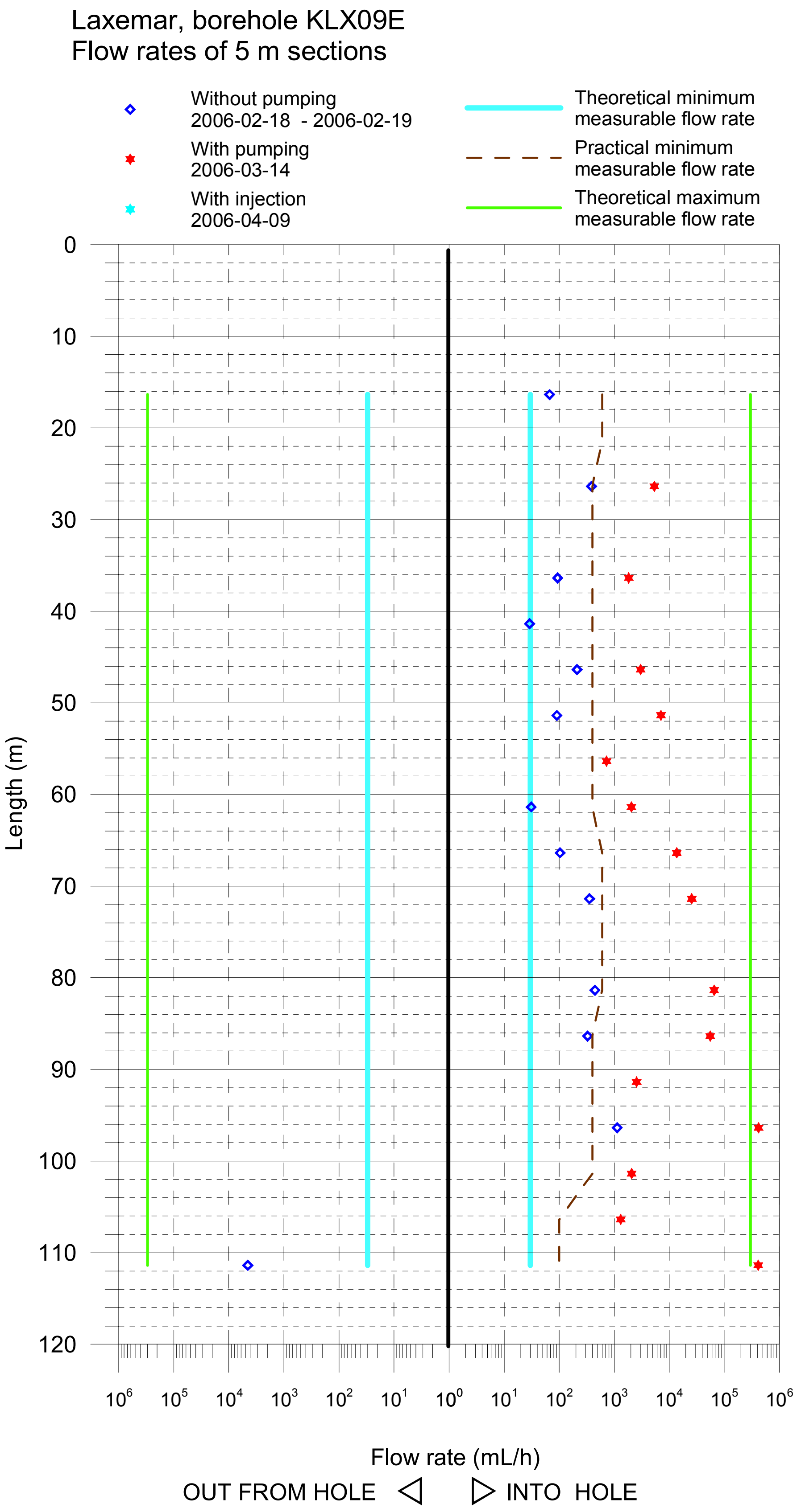


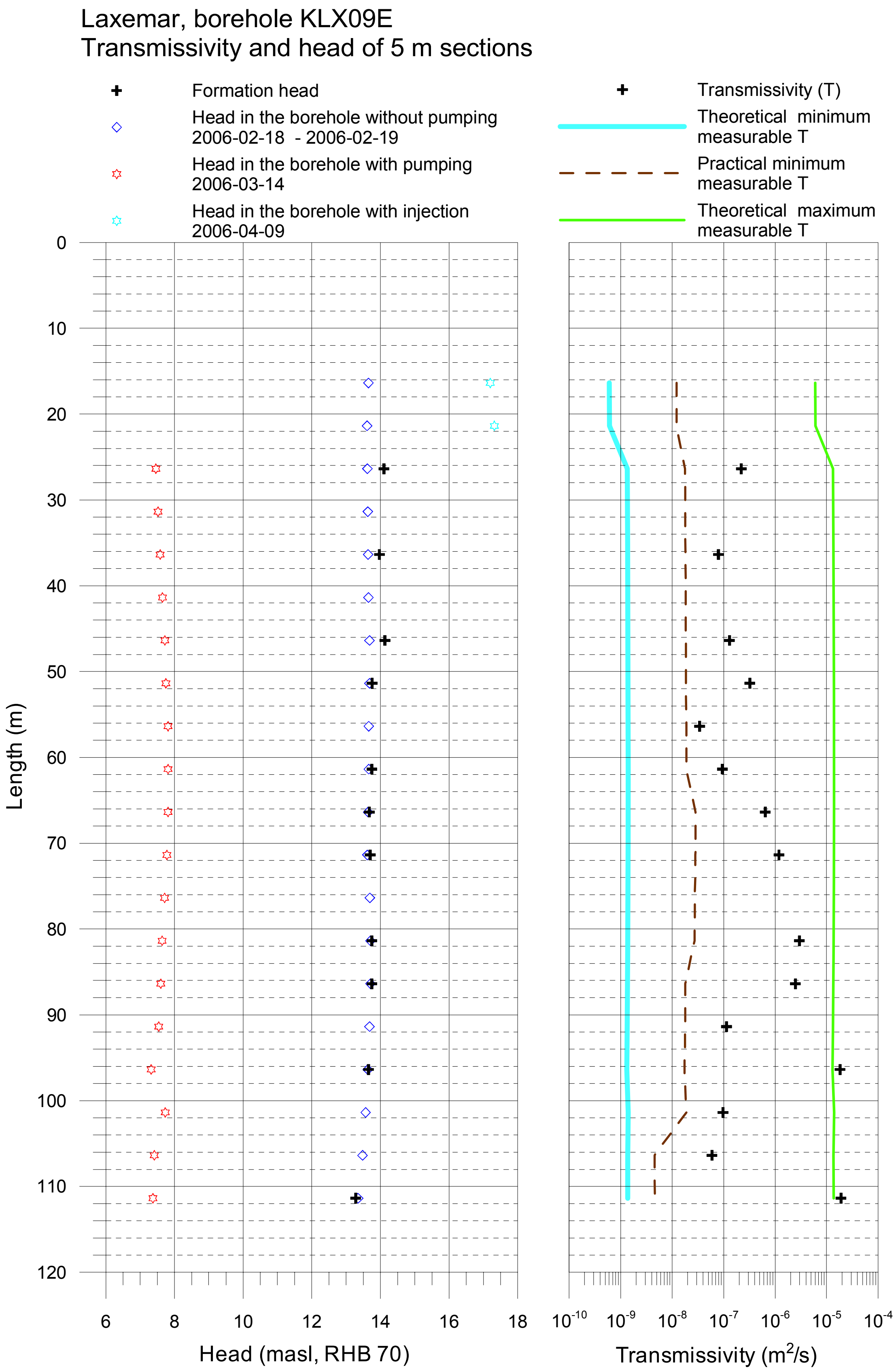
Laxemar, borehole KLX09E
Electric conductivity of borehole water



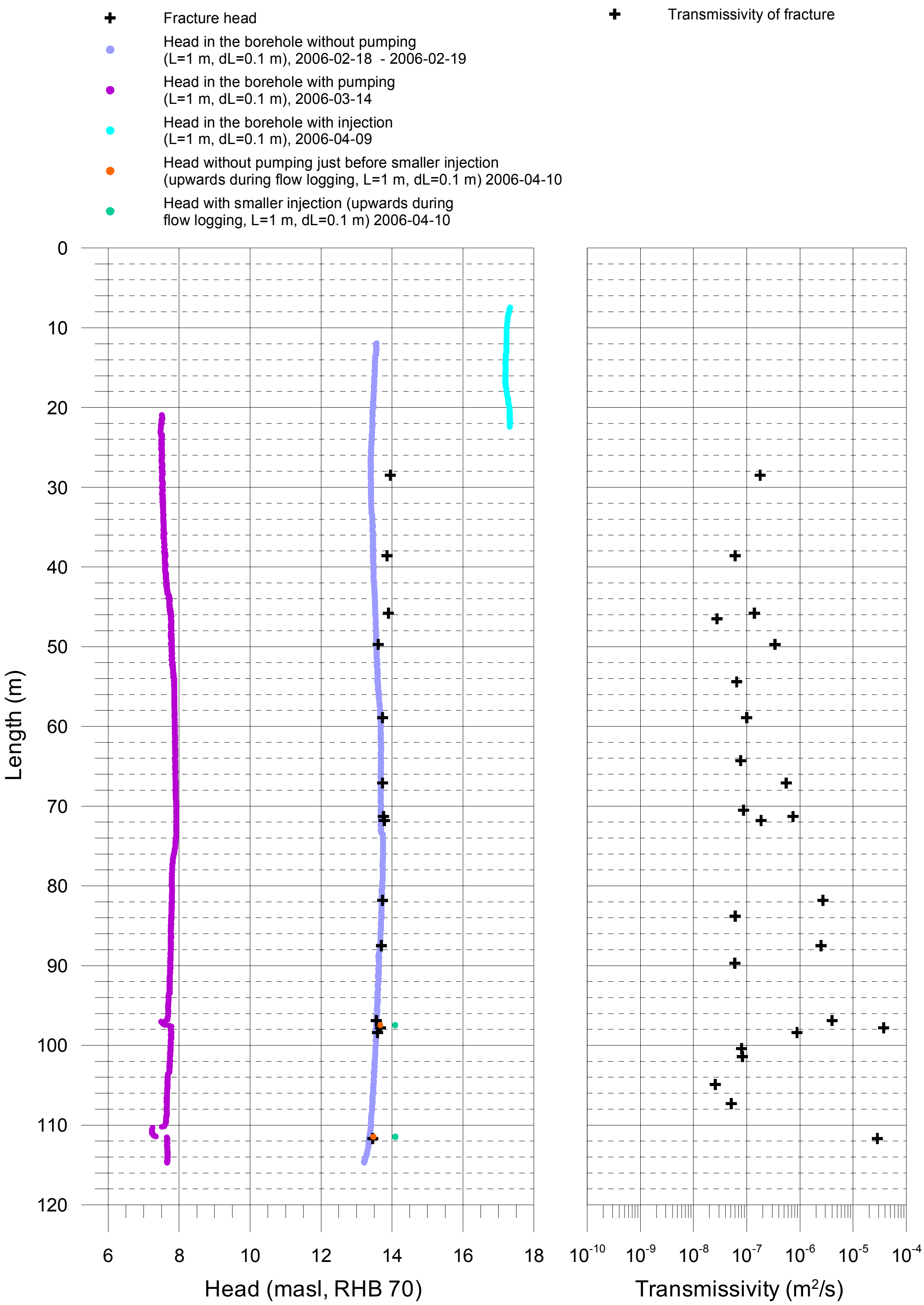
Laxemar, borehole KLX09E
Temperature of borehole water




Laxemar, borehole KLX09E
Flow rates of 5 m sections
Without pumping
2006-02-18 - 2006-02-19
With pumping
2006-03-14
With injection
2006-04-09
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 KLX09E
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping 2006-02-18 - 2006-02-19
Head in the borehole with pumping 2006-03-14
Head in the borehole with injection 2006-04-09
Transmissivity (T)
Theoretical minimum measurable T
Practical minimum measurable T
Theoretical maximum measurable T
Length (m)
Head (masl, RHB 70)
Transmissivity (m2/s)
0
10
20
30
40
50
60
70
80
90
100
110
120
6
8
10
12
14
16
18
10-10
10-9
10-8
10-7
10-6
10-5
10-4

Laxemar, borehole KLX09E
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)
KLX09E	13.87	113.87	5A	20060313	11:11	20060314	08:23	20060319	08:46	5	5	5.21E–4	

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 (–)
509,700		257,188		13.42	7.47		–5.95		8.7E–5		

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KLX09E	13.87	18.87	5	1.86E–08	13.65	–	17.20	–	–	600	6.0E–10	1.2E–08	6.0E–06	**
KLX09E	18.87	23.87	5	–	13.61	–	17.32	–	–	600	6.1E–10	1.2E–08	6.1E–06	**
KLX09E	23.87	28.87	5	1.07E–07	13.62	1.48E–06	7.46	2.2E–07	14.1	400	1.3E–09	1.8E–08	1.3E–05	
KLX09E	28.87	33.87	5	–	13.63	–	7.52	–	–	400	1.4E–09	1.8E–08	1.4E–05	
KLX09E	33.87	38.87	5	2.61E–08	13.64	5.11E–07	7.58	7.9E–08	14.0	400	1.4E–09	1.8E–08	1.4E–05	
KLX09E	38.87	43.87	5	8.06E–09	13.65	–	7.65	–	–	400	1.4E–09	1.8E–08	1.4E–05	
KLX09E	43.87	48.87	5	5.89E–08	13.68	8.42E–07	7.72	1.3E–07	14.1	400	1.4E–09	1.8E–08	1.4E–05	
KLX09E	48.87	53.87	5	2.53E–08	13.68	1.96E–06	7.75	3.2E–07	13.8	400	1.4E–09	1.9E–08	1.4E–05	
KLX09E	53.87	58.87	5	–	13.66	2.01E–07	7.81	3.4E–08	–	400	1.4E–09	1.9E–08	1.4E–05	
KLX09E	58.87	63.87	5	8.61E–09	13.66	5.69E–07	7.81	9.5E–08	13.8	400	1.4E–09	1.9E–08	1.4E–05	
KLX09E	63.87	68.87	5	2.89E–08	13.64	3.81E–06	7.81	6.4E–07	13.7	600	1.4E–09	2.8E–08	1.4E–05	
KLX09E	68.87	73.87	5	9.89E–08	13.62	7.11E–06	7.78	1.2E–06	13.7	600	1.4E–09	2.8E–08	1.4E–05	
KLX09E	73.87	78.87	5	–	13.69	–	7.71	–	–	600	1.4E–09	2.8E–08	1.4E–05	
KLX09E	78.87	83.87	5	1.24E–07	13.71	1.82E–05	7.64	3.0E–06	13.8	600	1.4E–09	2.7E–08	1.4E–05	
KLX09E	83.87	88.87	5	9.11E–08	13.71	1.54E–05	7.60	2.5E–06	13.8	400	1.4E–09	1.8E–08	1.4E–05	
KLX09E	88.87	93.87	5	–	13.68	5.19E–07	7.54	8.4E–08	–	400	1.3E–09	1.8E–08	1.3E–05	
KLX09E	93.87	98.87	5	3.14E–07	13.63	1.16E–04	7.32	1.8E–05	13.7	400	1.3E–09	1.7E–08	1.3E–05	
KLX09E	98.87	103.87	5	–	13.57	5.75E–07	7.73	9.7E–08	–	400	1.4E–09	1.9E–08	1.4E–05	
KLX09E	103.87	108.87	5	–	13.48	3.64E–07	7.41	5.9E–08	–	100	1.4E–09	4.5E–09	1.4E–05	
KLX09E	108.87	113.87	5	–1.26E–06	13.35	1.14E–04	7.37	1.9E–05	13.3	100	1.4E–09	4.6E–09	1.4E–05	

** Values from the measurement with injection.

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
KLX09E	17.7	1	0.1	1.00E–08	13.49	–	17.23	–	–	**, ***
KLX09E	19.8	1	0.1	–	13.46	–	17.30	–	–	*, **, ***
KLX09E	25.7	1	0.1	–	13.41	–	7.51	–	–	*, ***
KLX09E	28.5	1	0.1	9.89E–08	13.40	1.16E–06	7.52	1.8E–07	14.0	
KLX09E	33.4	1	0.1	–	13.43	–	7.56	–	–	***
KLX09E	35.5	1	0.1	–	13.45	–	7.57	–	–	*, ***
KLX09E	38.6	1	0.1	2.36E–08	13.47	3.81E–07	7.61	6.0E–08	13.9	
KLX09E	41.9	1	0.1	5.00E–09	13.49	–	7.63	–	–	***
KLX09E	45.8	1	0.1	5.14E–08	13.53	8.61E–07	7.75	1.4E–07	13.9	
KLX09E	46.5	1	0.1	–	13.54	1.61E–07	7.76	2.8E–08	–	*
KLX09E	49.7	1	0.1	2.00E–08	13.55	2.00E–06	7.77	3.4E–07	13.6	
KLX09E	54.4	1	0.1	–	13.58	3.75E–07	7.85	6.5E–08	–	
KLX09E	58.9	1	0.1	5.56E–09	13.68	5.94E–07	7.87	1.0E–07	13.7	
KLX09E	64.3	1	0.1	–	13.68	4.50E–07	7.89	7.7E–08	–	
KLX09E	67.1	1	0.1	2.28E–08	13.69	3.28E–06	7.90	5.6E–07	13.7	
KLX09E	70.5	1	0.1	–	13.68	5.08E–07	7.91	8.7E–08	–	
KLX09E	71.3	1	0.1	5.83E–08	13.68	4.39E–06	7.91	7.4E–07	13.8	
KLX09E	71.8	1	0.1	1.94E–08	13.68	1.10E–06	7.92	1.9E–07	13.8	
KLX09E	73.6	1	0.1	–	13.74	–	7.91	–	–	*, ***
KLX09E	77.5	1	0.1	–	13.74	–	7.81	–	–	*, ***
KLX09E	78.1	1	0.1	–	13.73	–	7.80	–	–	***
KLX09E	81.8	1	0.1	6.47E–08	13.71	1.63E–05	7.80	2.7E–06	13.7	
KLX09E	83.8	1	0.1	–	13.70	3.64E–07	7.78	6.1E–08	–	
KLX09E	87.5	1	0.1	7.67E–08	13.67	1.49E–05	7.77	2.5E–06	13.7	
KLX09E	89.7	1	0.1	–	13.63	3.56E–07	7.75	6.0E–08	–	
KLX09E	96.9	1	0.1	1.06E–08	13.56	2.40E–05	7.63	4.0E–06	13.6	
KLX09E	97.8	1	0.1	2.11E–07	13.67	–1.57E–05	14.09	3.8E–05	13.7	****
KLX09E	98.4	1	0.1	3.44E–08	13.55	5.17E–06	7.78	8.8E–07	13.6	
KLX09E	100.4	1	0.1	–	13.53	4.64E–07	7.76	8.0E–08	–	*
KLX09E	101.4	1	0.1	–	13.52	4.83E–07	7.74	8.3E–08	–	
KLX09E	104.9	1	0.1	–	13.48	1.51E–07	7.67	2.6E–08	–	
KLX09E	107.3	1	0.1	–	13.44	3.00E–07	7.65	5.1E–08	–	*
KLX09E	111.7	1	0.1	–5.01E–07	13.48	–1.81E–05	14.09	2.9E–05	13.5	****
KLX09E	114.4	1	0.1	–	13.24	–	7.67	–	–	*, ***

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

** Values from the measurement with injection.

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

**** Values from the measurement with smaller injection, water level used instead of head for pressure difference.

Explanations.

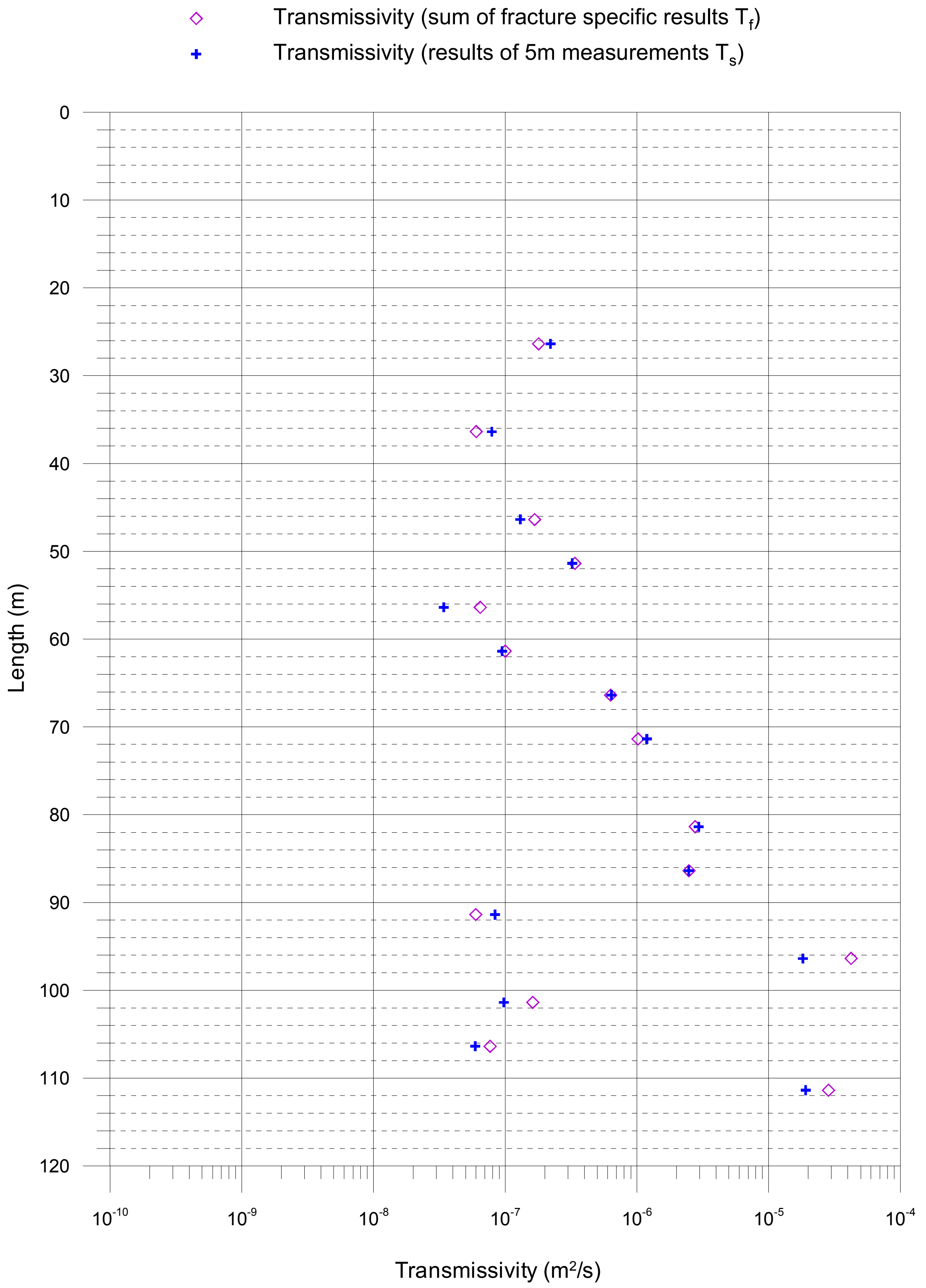
Header	Unit	Explanations
Borehole		ID for borehole.
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L).
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L).
L	m	Corrected length along borehole based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

Calculation of conductive fracture frequency

Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)
KLX09E	13.87	18.87	1	0	0	0	0	0
KLX09E	18.87	23.87	1	0	0	0	0	0
KLX09E	23.87	28.87	2	0	0	1	0	0
KLX09E	28.87	33.87	1	0	0	0	0	0
KLX09E	33.87	38.87	2	0	0	1	0	0
KLX09E	38.87	43.87	1	0	0	0	0	0
KLX09E	43.87	48.87	2	0	1	1	0	0
KLX09E	48.87	53.87	1	0	0	1	0	0
KLX09E	53.87	58.87	1	0	0	1	0	0
KLX09E	58.87	63.87	1	0	0	1	0	0
KLX09E	63.87	68.87	2	0	0	1	1	0
KLX09E	68.87	73.87	4	0	0	2	1	0
KLX09E	73.87	78.87	2	0	0	0	0	0
KLX09E	78.87	83.87	2	0	0	1	1	0
KLX09E	83.87	88.87	1	0	0	0	1	0
KLX09E	88.87	93.87	1	0	0	1	0	0
KLX09E	93.87	98.87	3	0	0	0	2	0
KLX09E	98.87	103.87	2	0	0	2	0	0
KLX09E	103.87	108.87	2	0	1	1	0	0
KLX09E	108.87	113.87	1	0	0	0	0	0

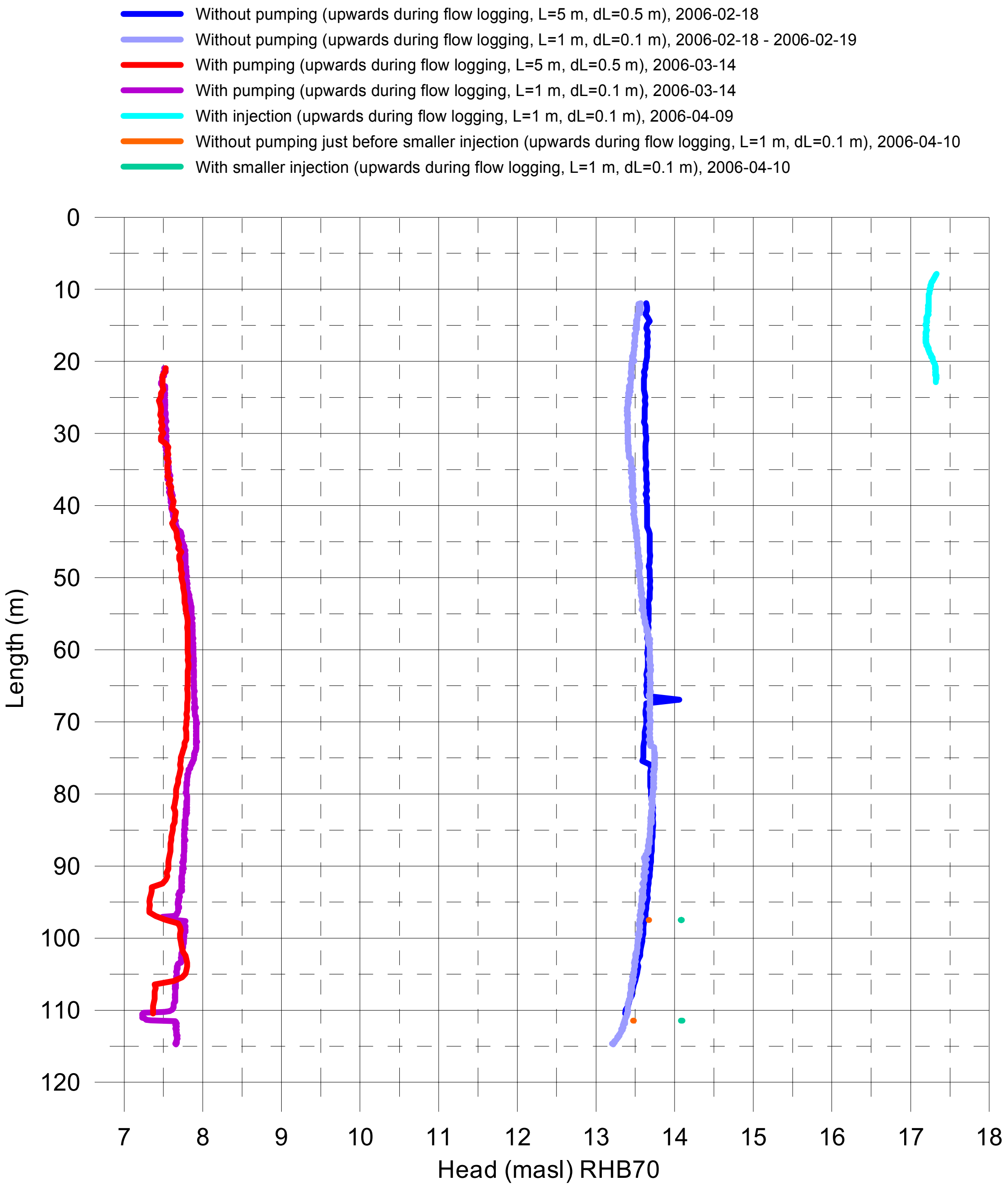
Laxemar, borehole KLX09E
Calculation of conductive fracture frequency

Laxemar, borehole KLX09E
Comparison between section transmissivity and fracture transmissivity

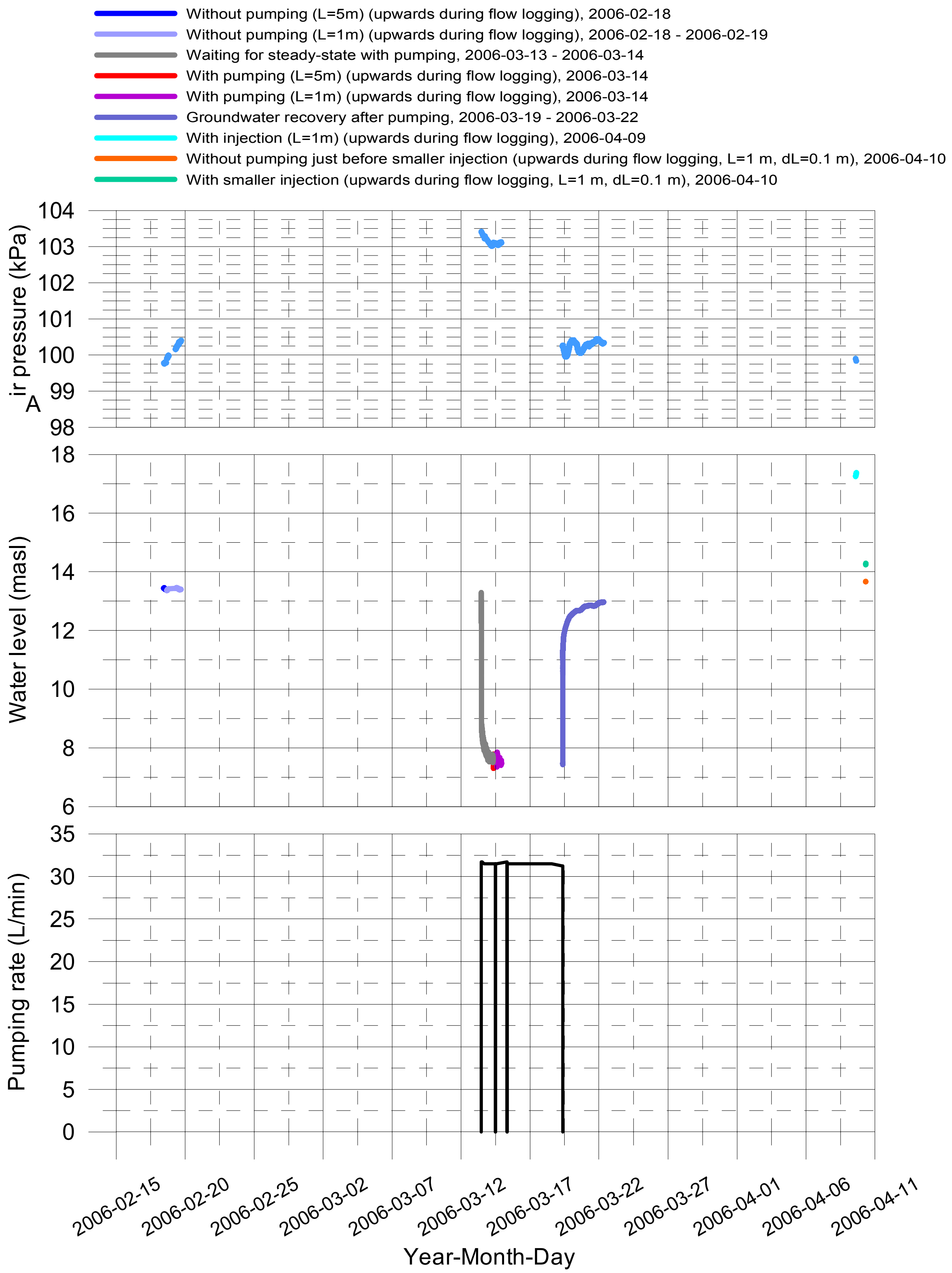


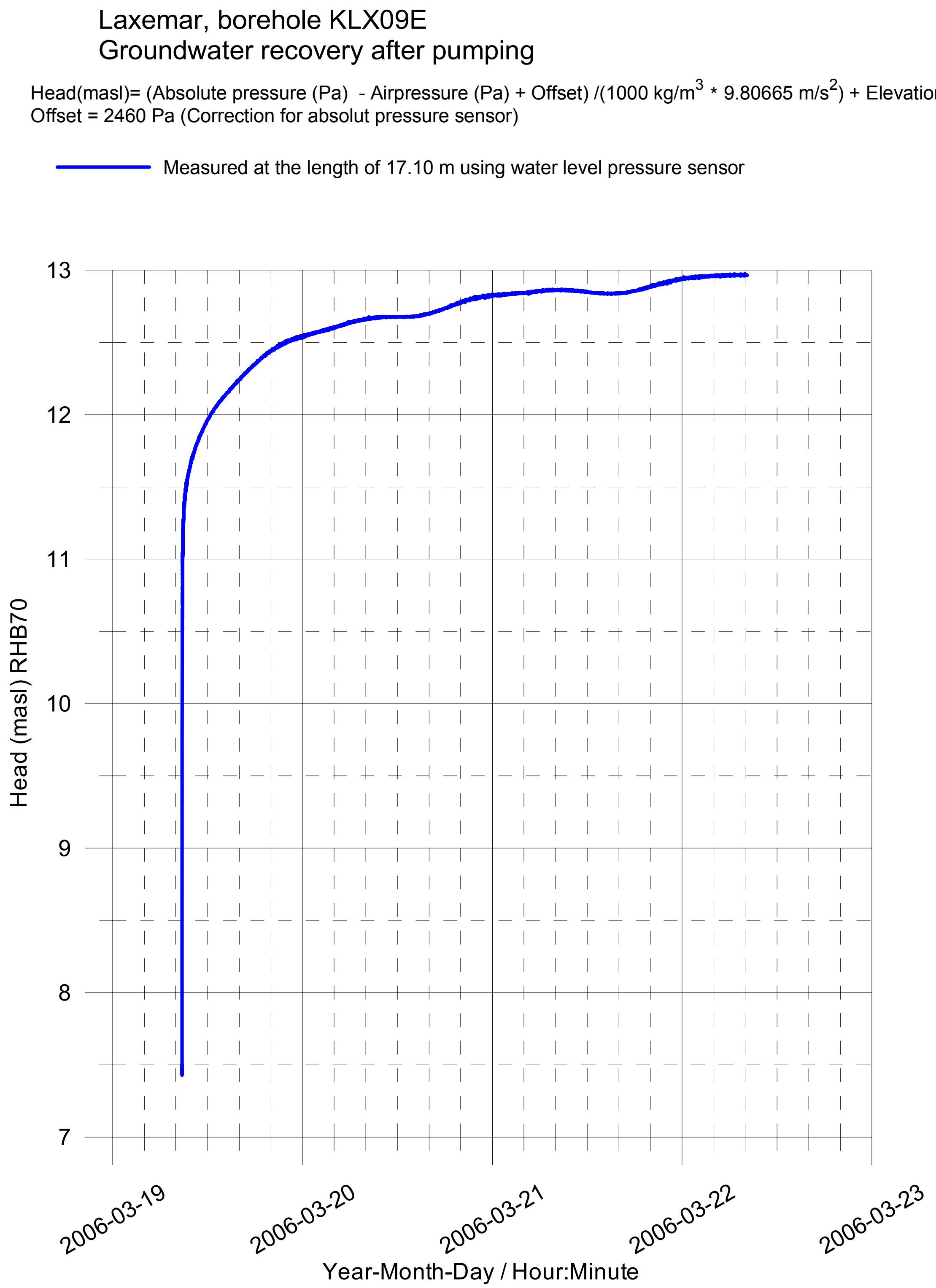
Laxemar, borehole KLX09E
Head in the borehole during flow logging

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)

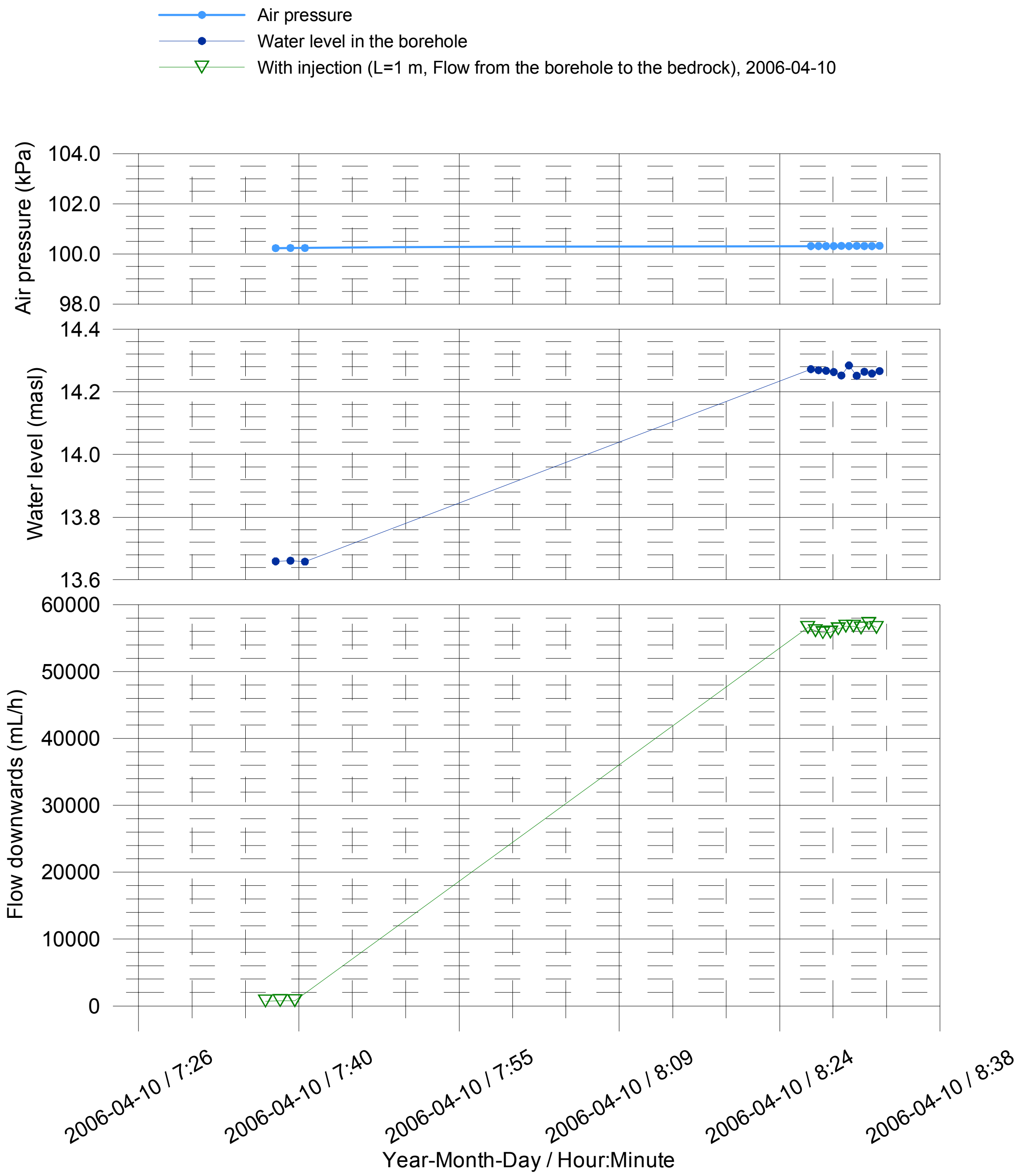


Laxemar, borehole KLX09E
Air pressure, water level in the borehole and pumping rate during flow logging

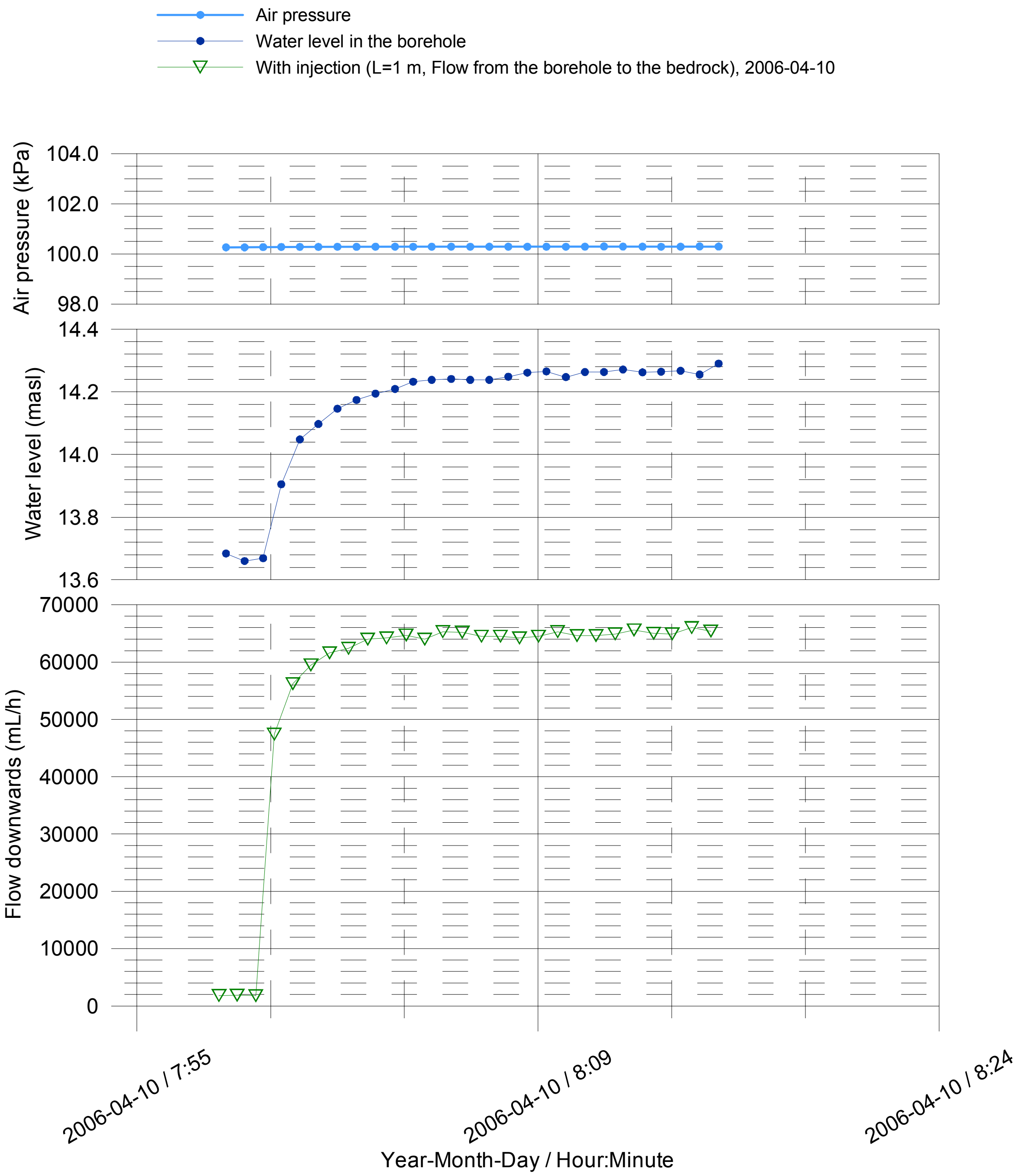



Laxemar, borehole KLX09E
Groundwater recovery after pumping
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)
Measured at the length of 17.10 m using water level pressure sensor
13
12
11
10
9
8
7
Head (masl) RHB70
2006-03-19
2006-03-20
2006-03-21
2006-03-22
2006-03-23
Year-Month-Day / Hour:Minute

Laxemar, borehole KLX09E
Vertical flow along the borehole at the length of 97.5 m



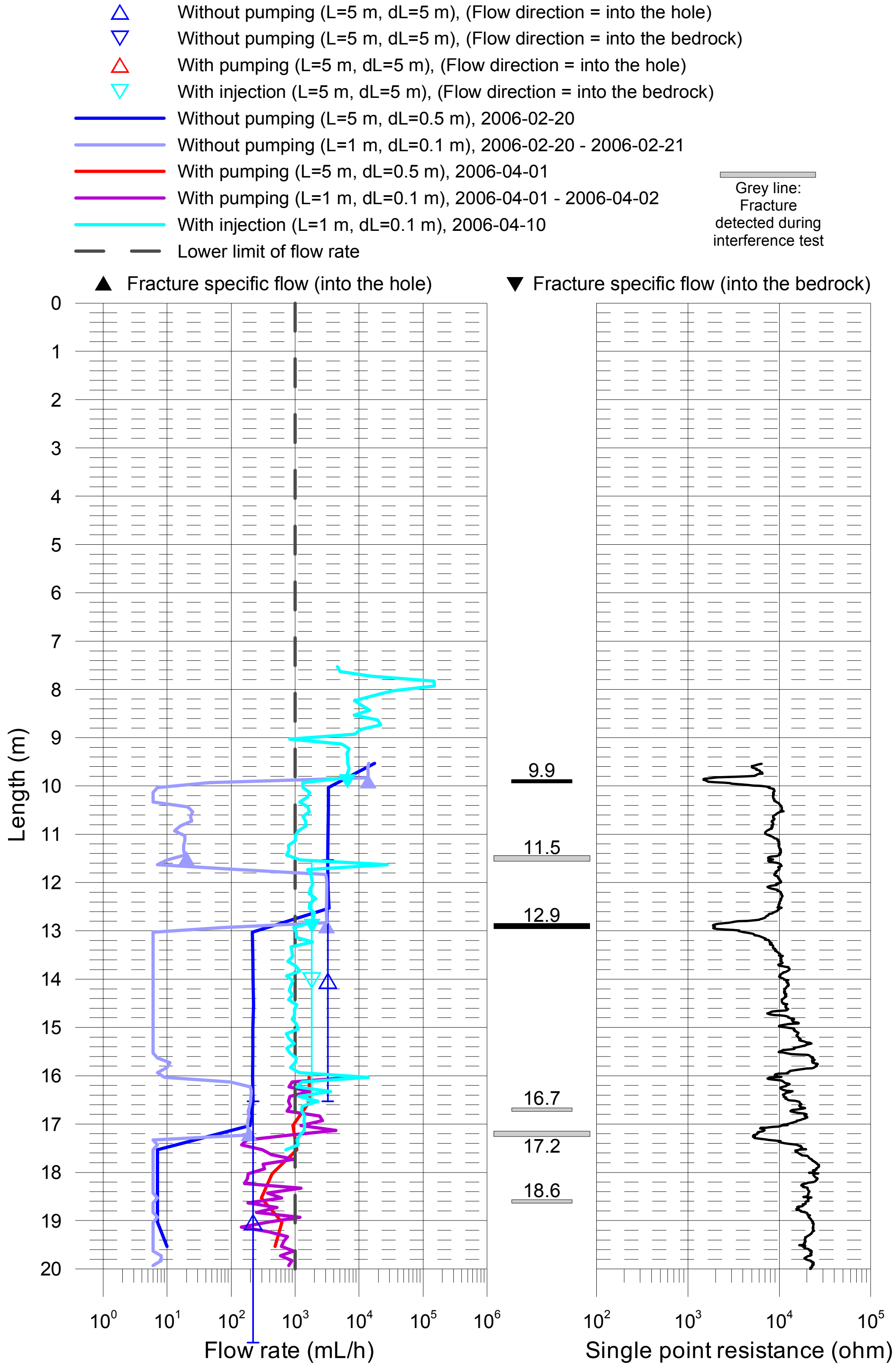
Laxemar, borehole KLX09E
Flow logging with injection at the length 111.5 m



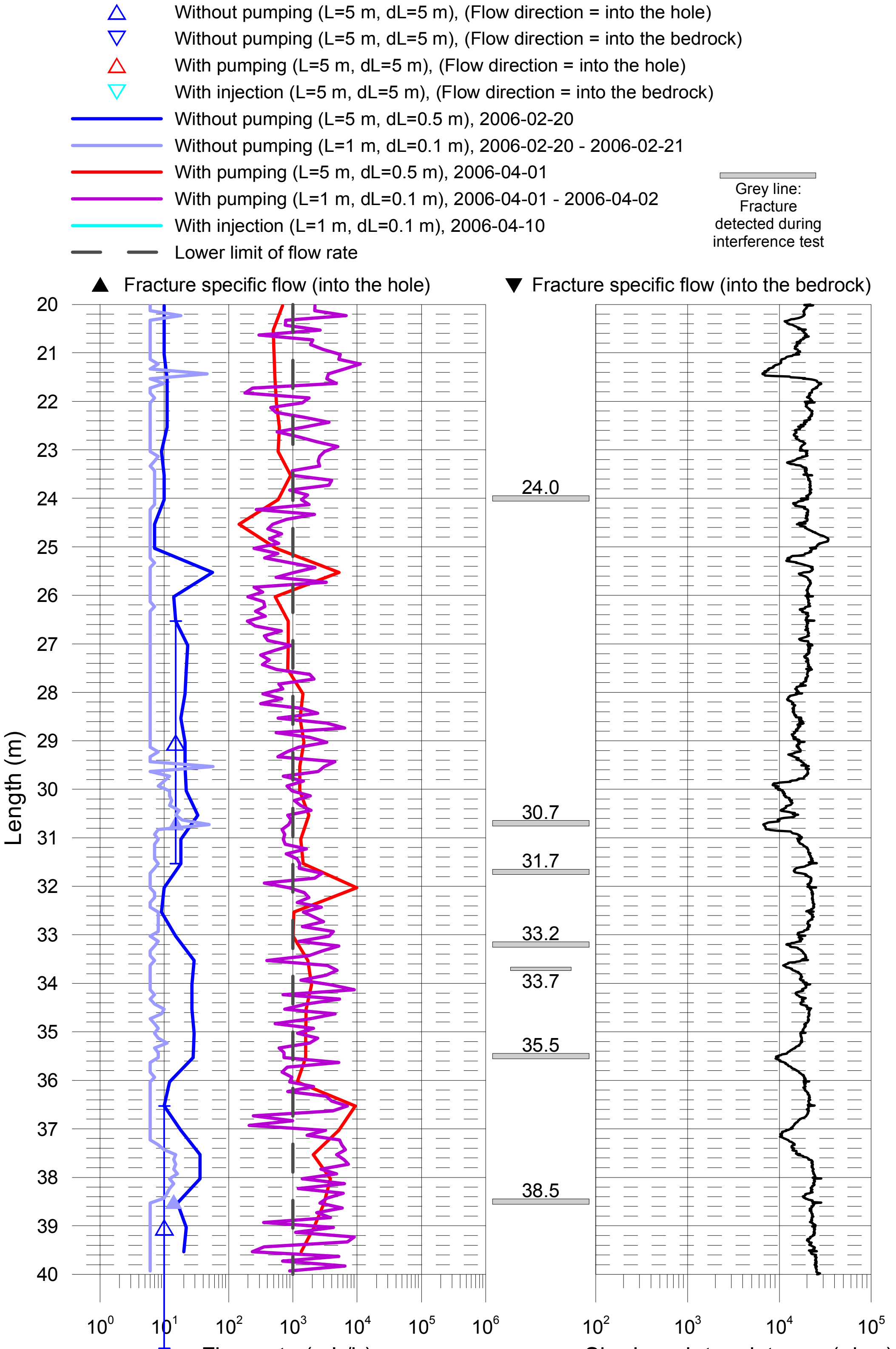
Appendices KLX09F

F.1.1–F.1.8	Flow rate and single point resistance
F.2.1	Electric conductivity of borehole water
F.2.2	Temperature of borehole water
F.3.1	Plotted flow rates of 5 m sections
F.3.2	Plotted transmissivity and head of 5 m sections
F.4	Plotted transmissivity and head of detected fractures
F.5	Basic test data
F.6	Results of sequential flow logging
F.7	Inferred flow anomalies from overlapping flow logging
F.8	Explanations for the tables in Appendices 5–7
F.9	Conductive fracture frequency
F.10	Plotted conductive fracture frequency
F.11	Comparison between section transmissivity and fracture transmissivity
F.12.1	Head in the borehole during flow logging
F.12.2	Air pressure, water level in the borehole and pumping rate during flow logging
F.12.3	Groundwater recovery after pumping
F.13.1–F.13.2	Flow logging with smaller injection

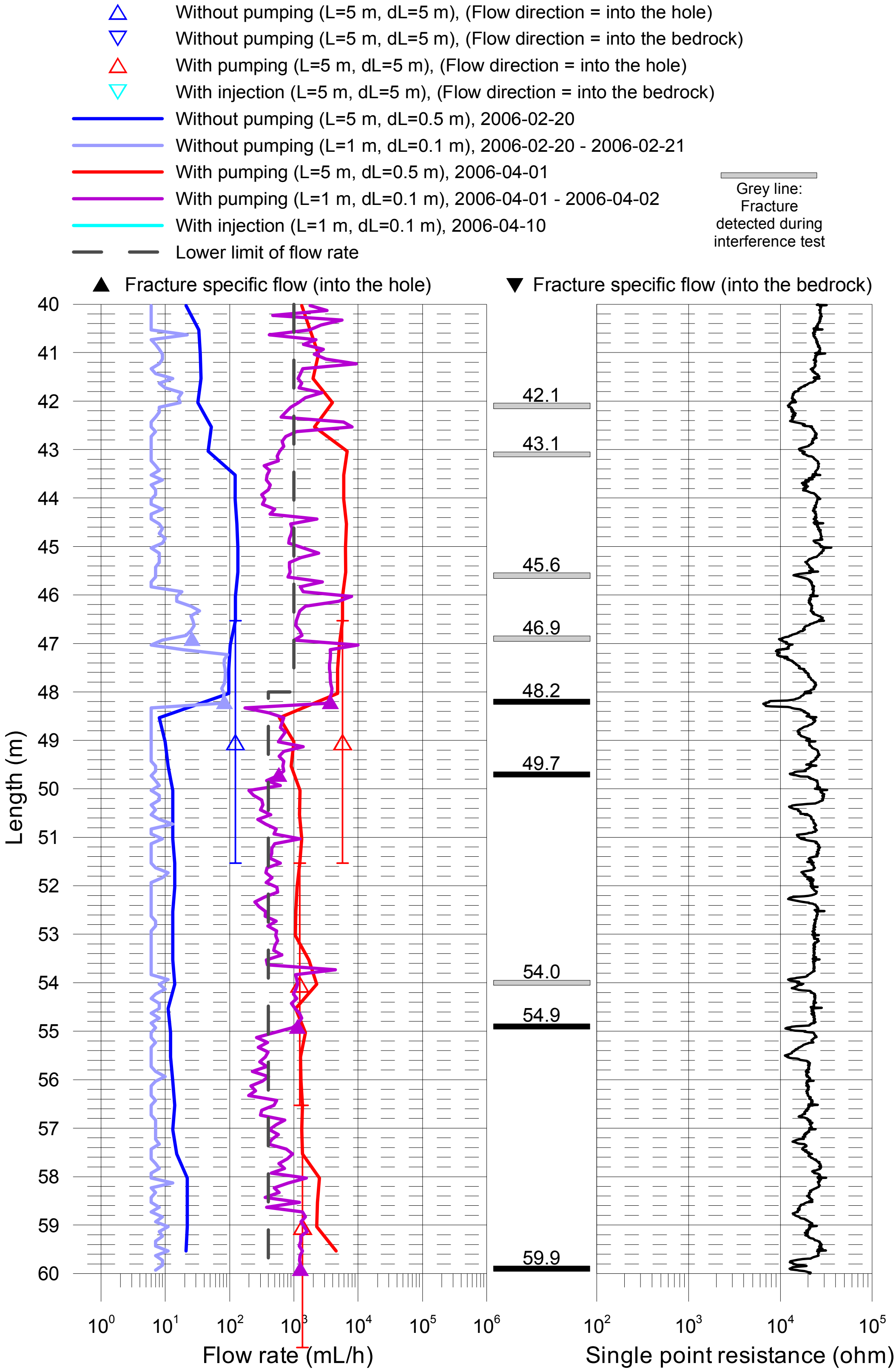
Laxemar, borehole KLX09F
Flow rate and single point resistance



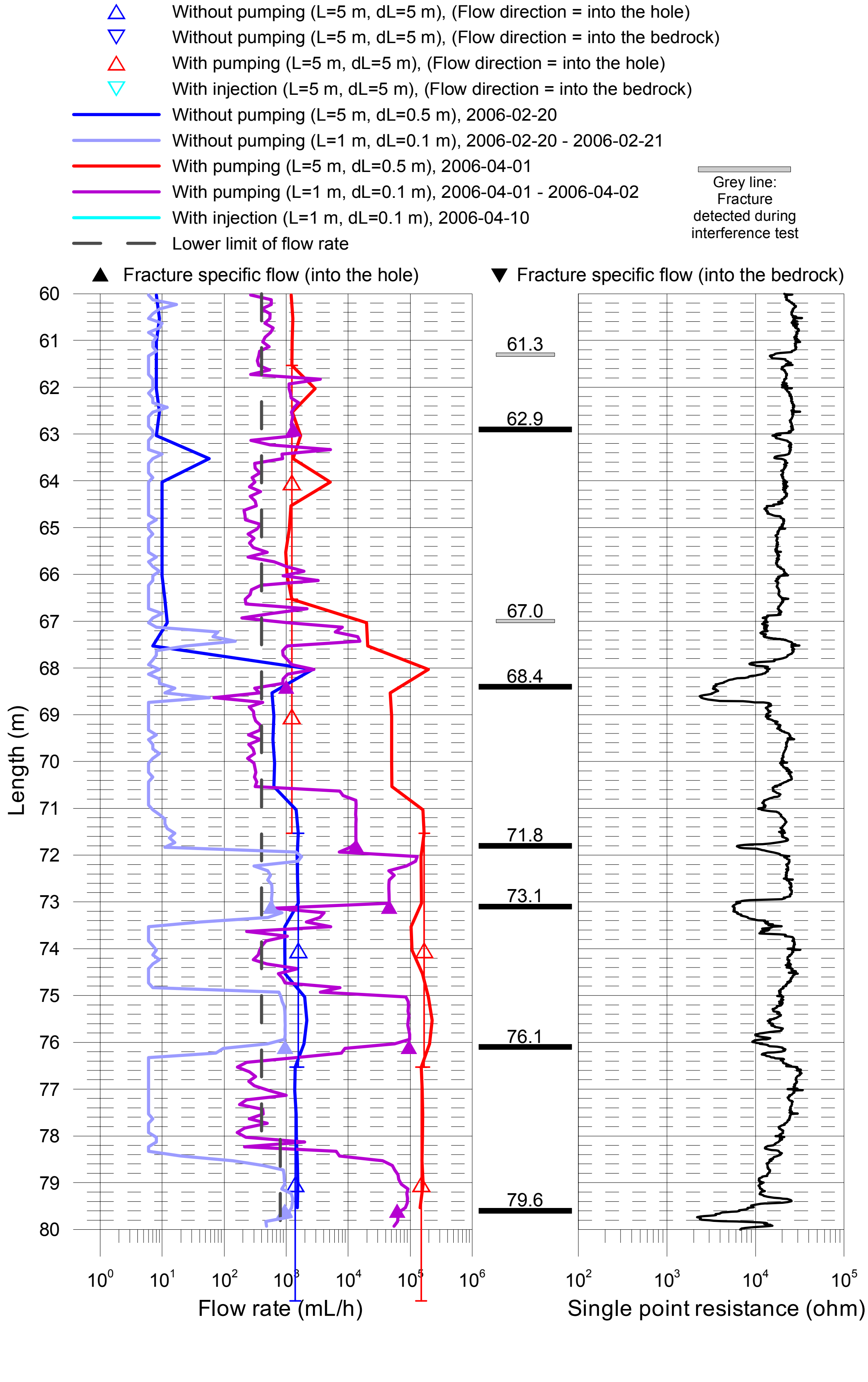
Laxemar, borehole KLX09F
Flow rate and single point resistance



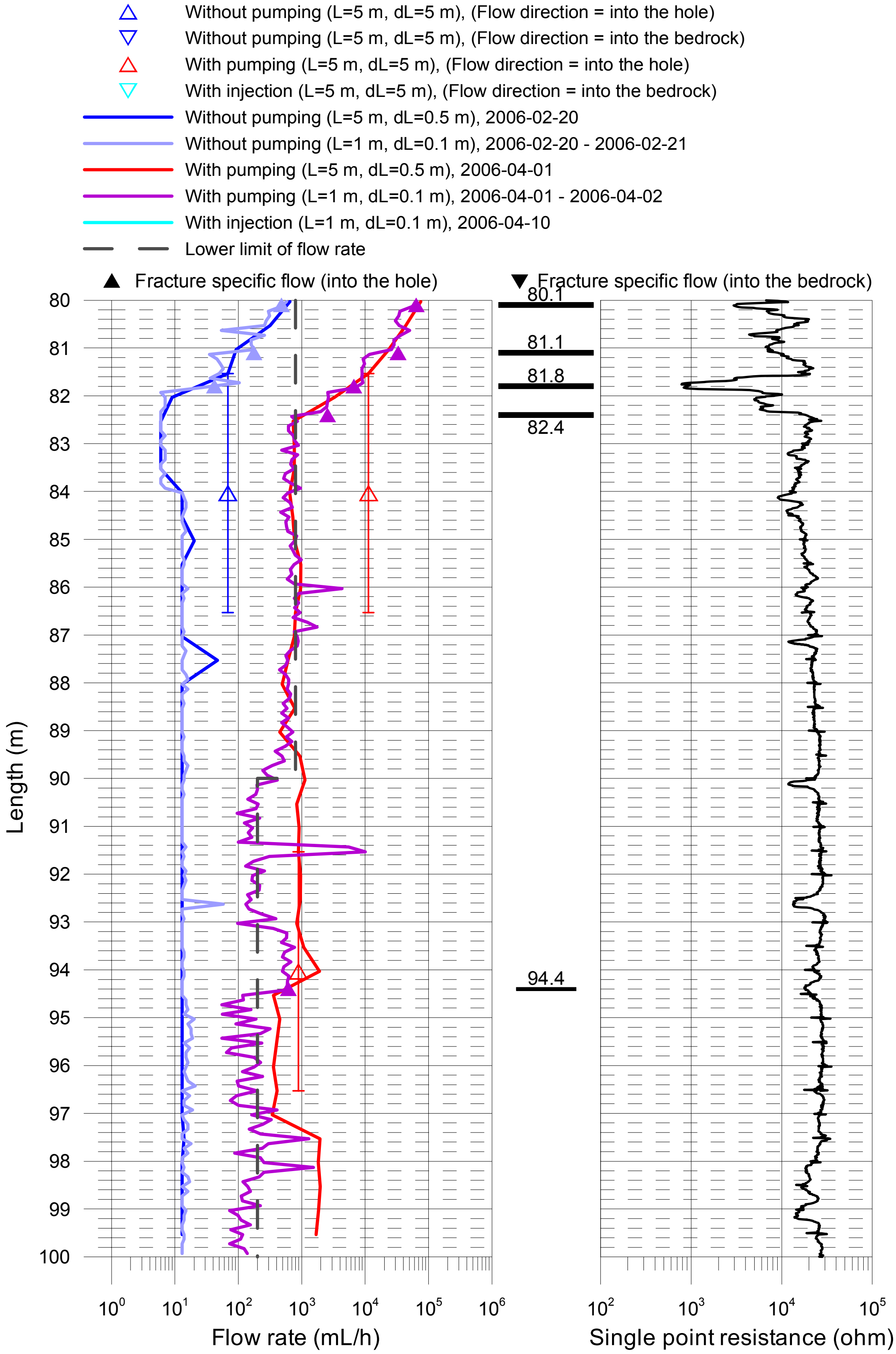
Laxemar, borehole KLX09F
Flow rate and single point resistance



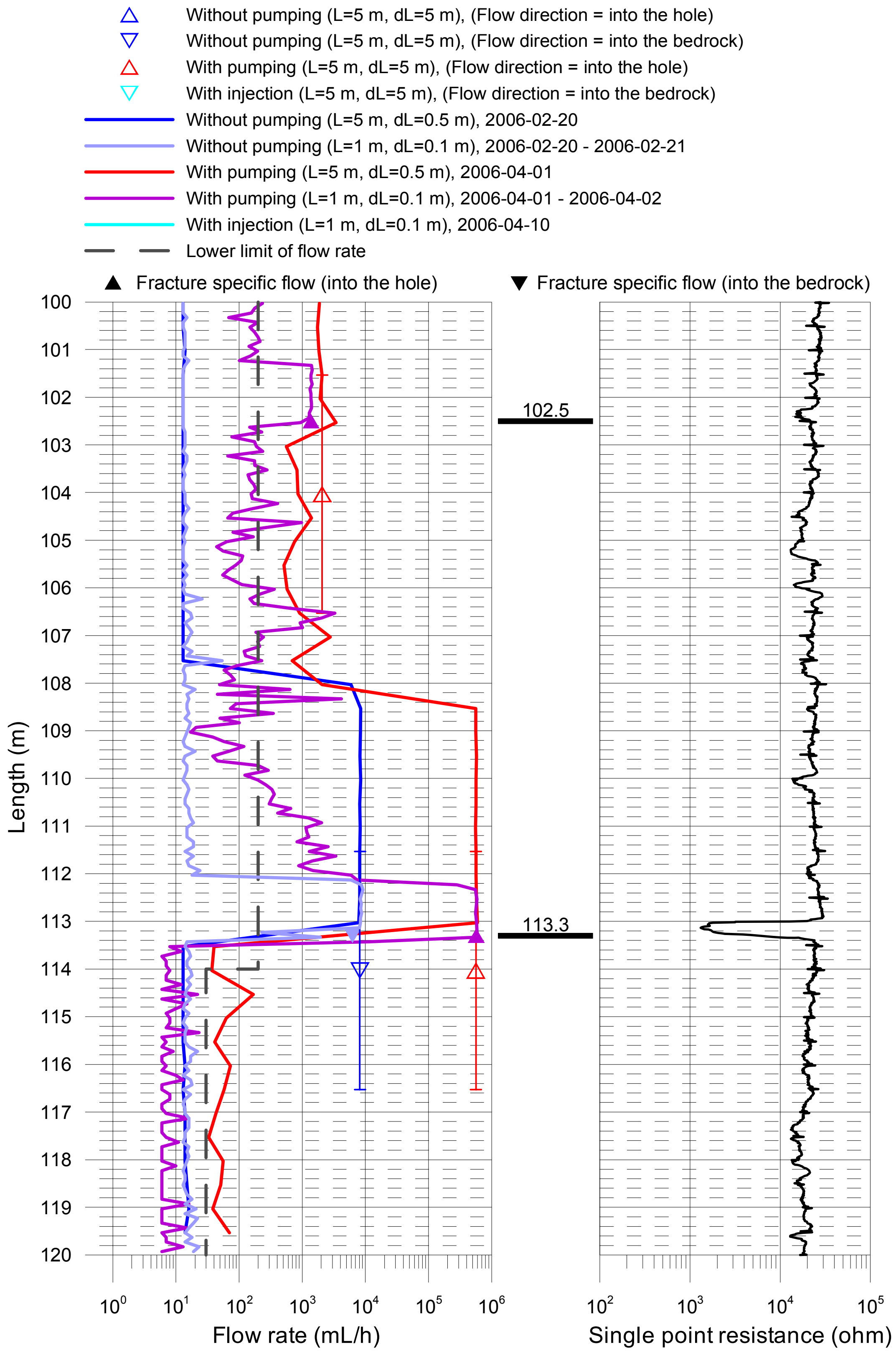
Laxemar, borehole KLX09F
Flow rate and single point resistance



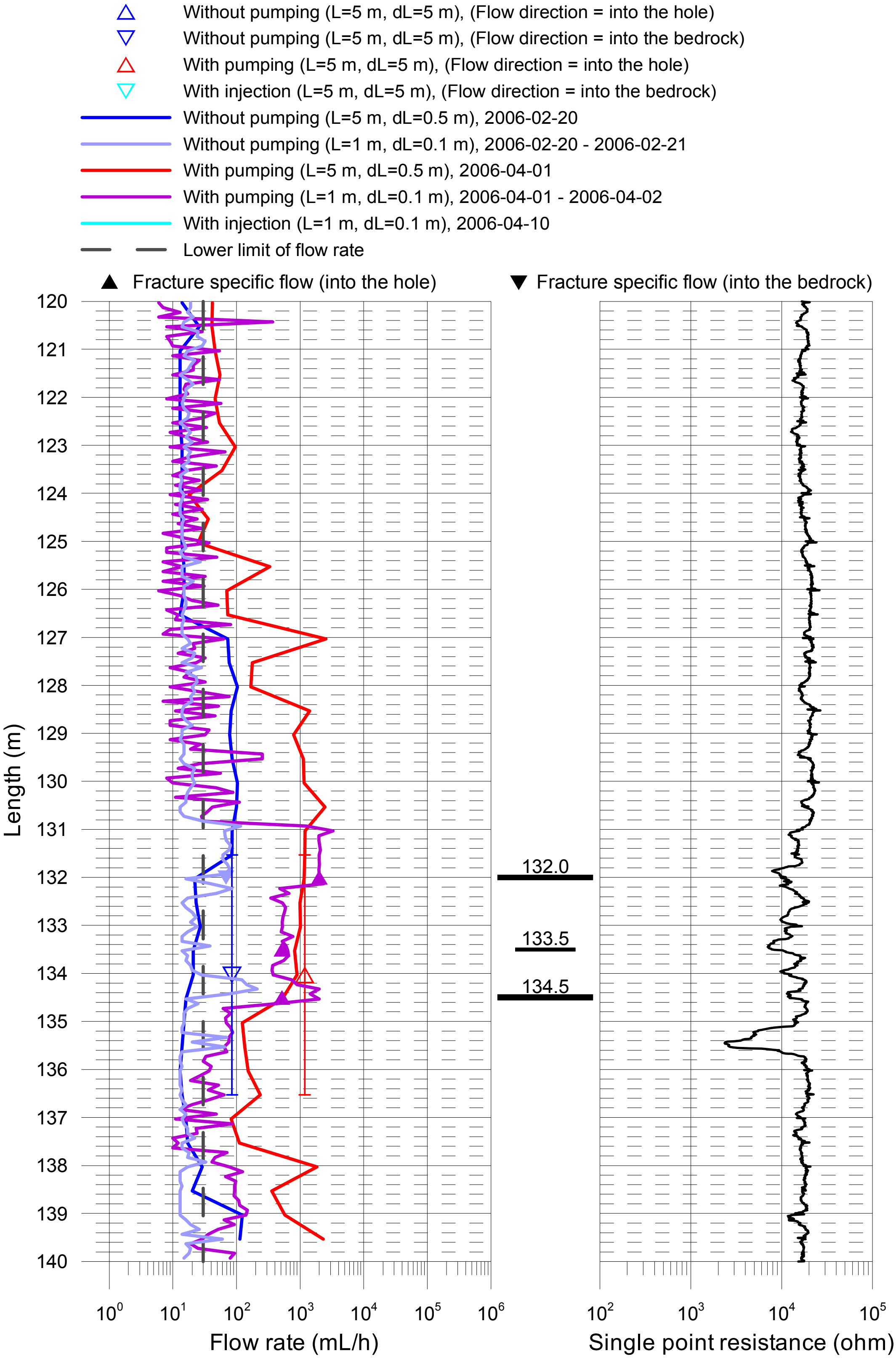
Laxemar, borehole KLX09F
Flow rate and single point resistance



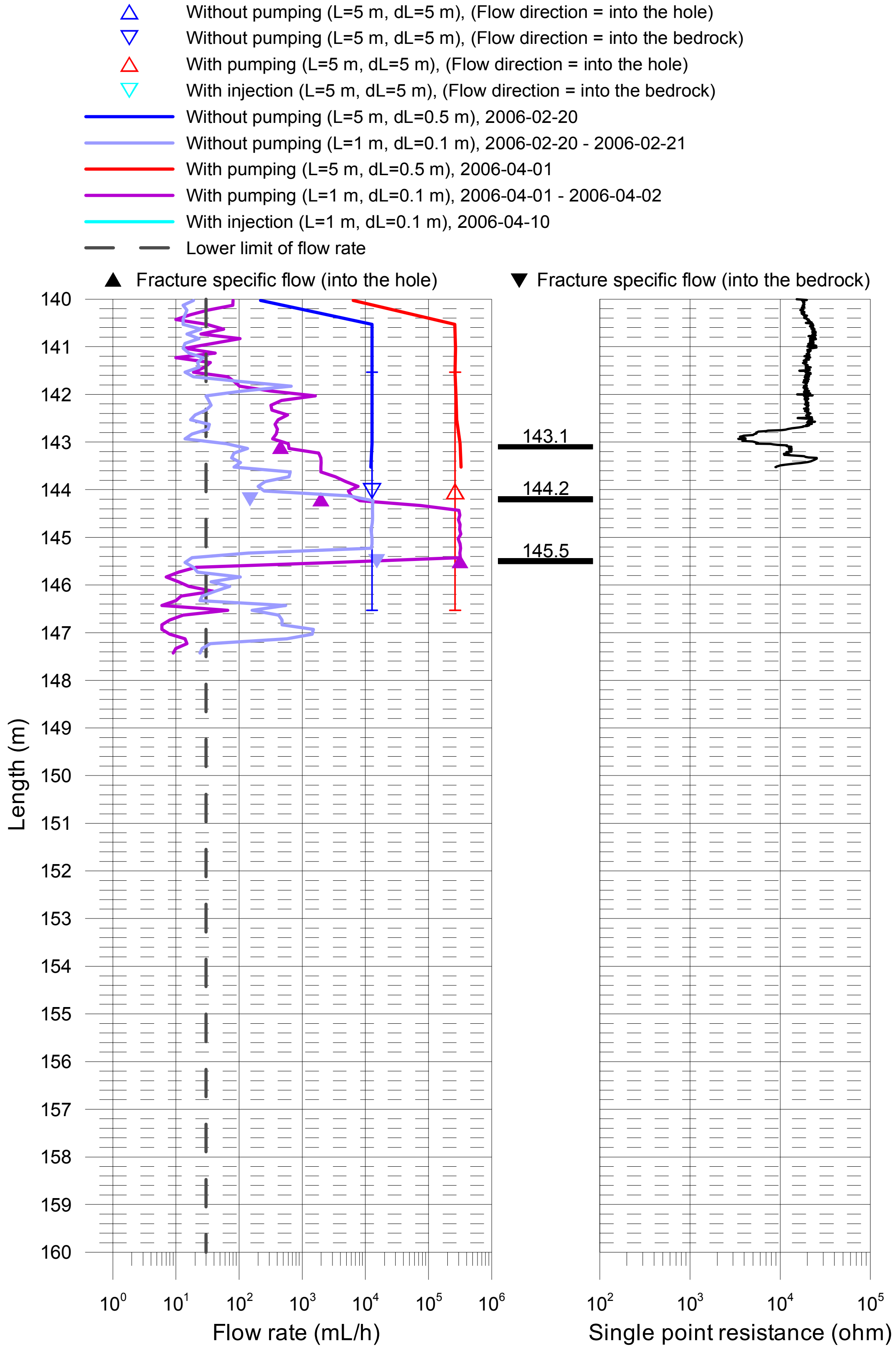
Laxemar, borehole KLX09F
Flow rate and single point resistance



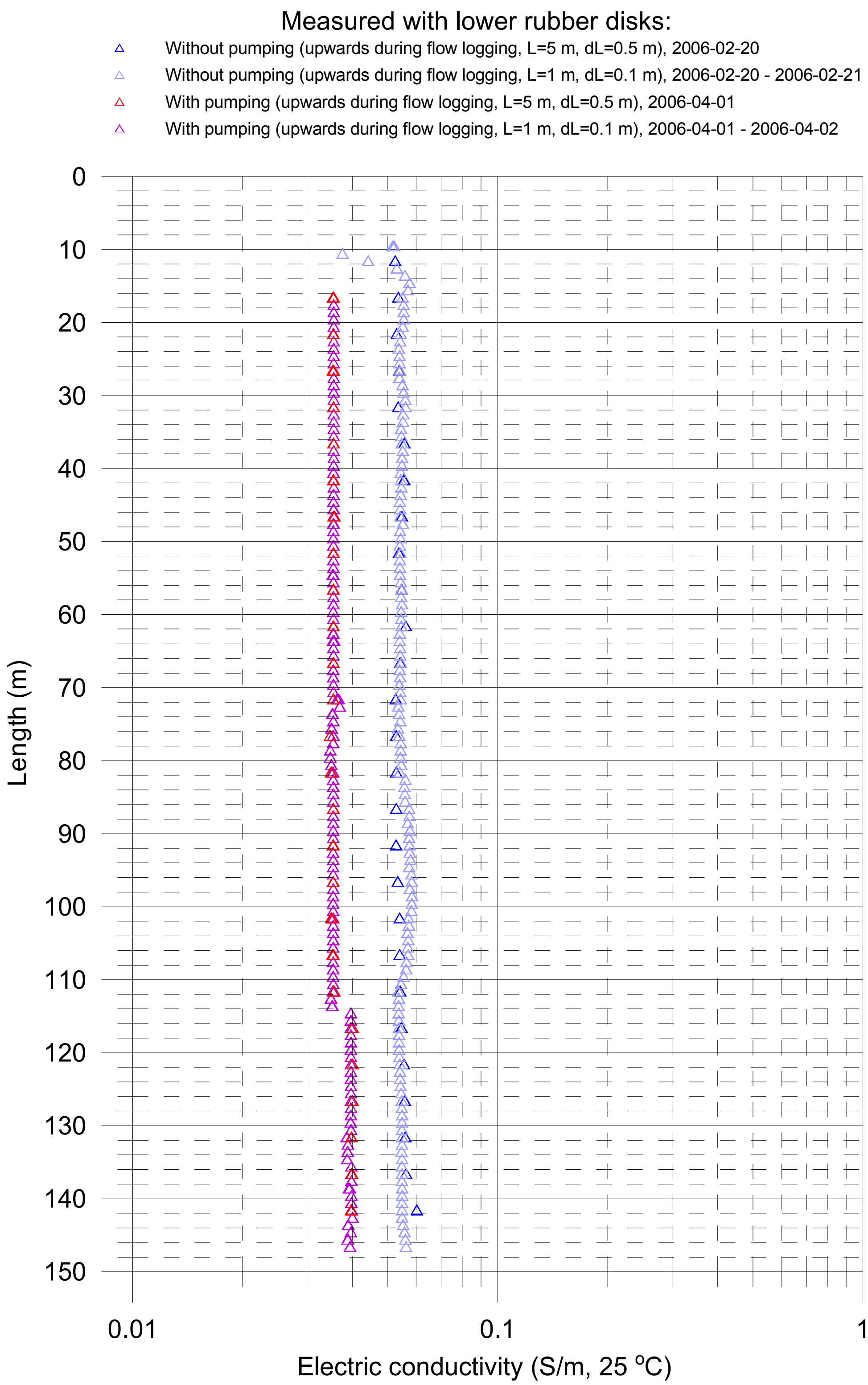
Laxemar, borehole KLX09F
Flow rate and single point resistance



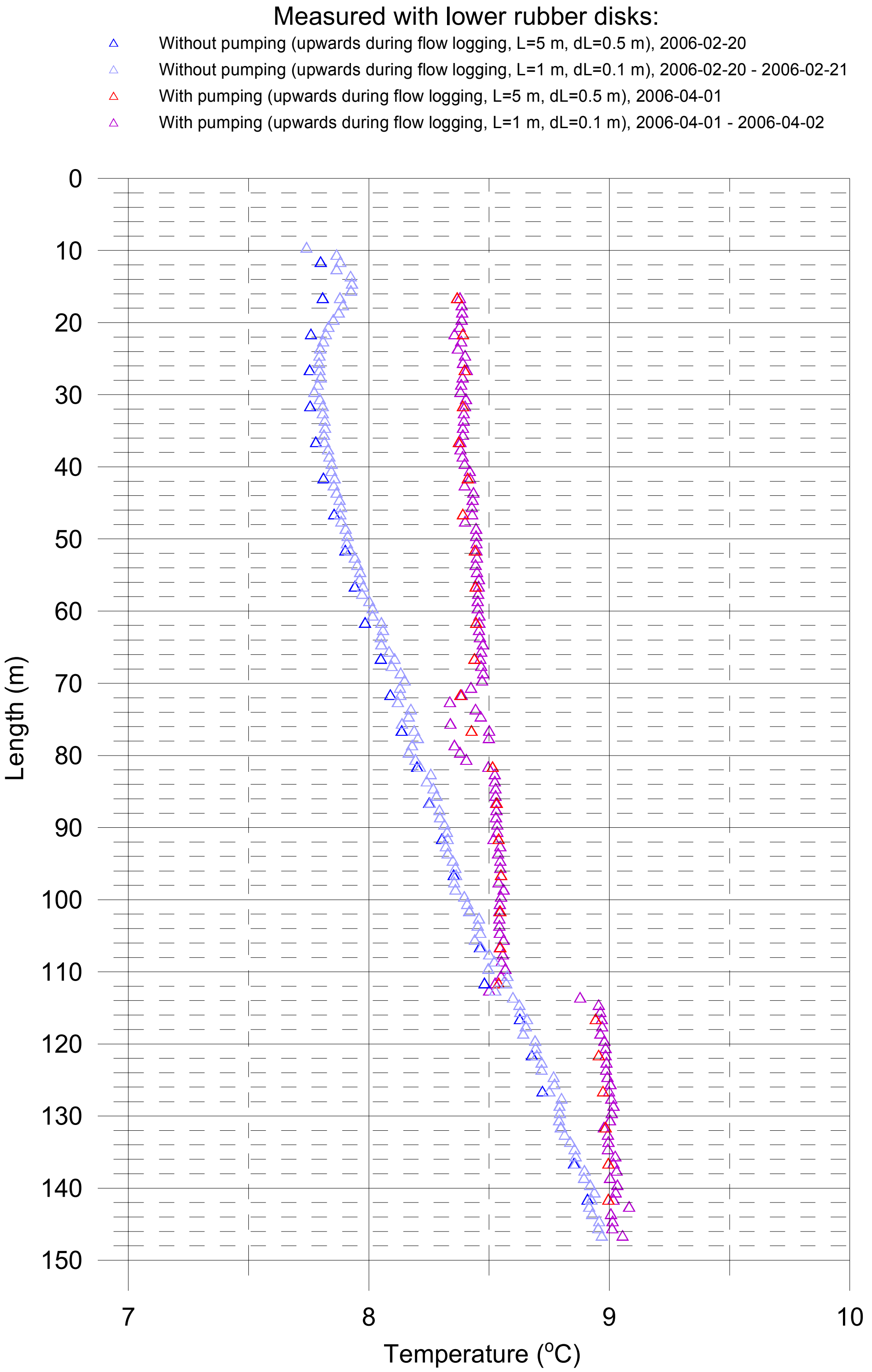
Laxemar, borehole KLX09F
Flow rate and single point resistance

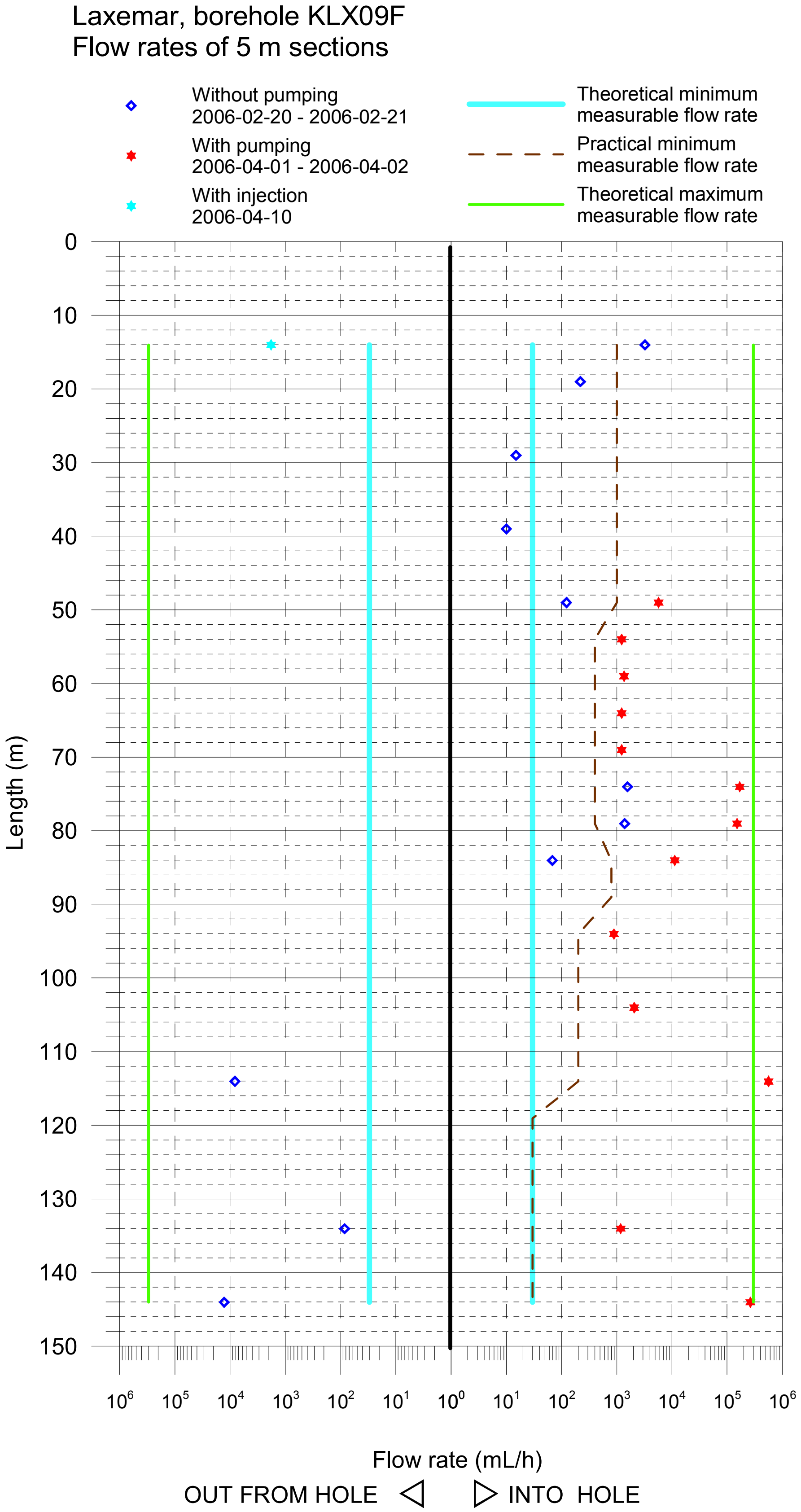


Laxemar, borehole KLX09F
Electric conductivity of borehole water

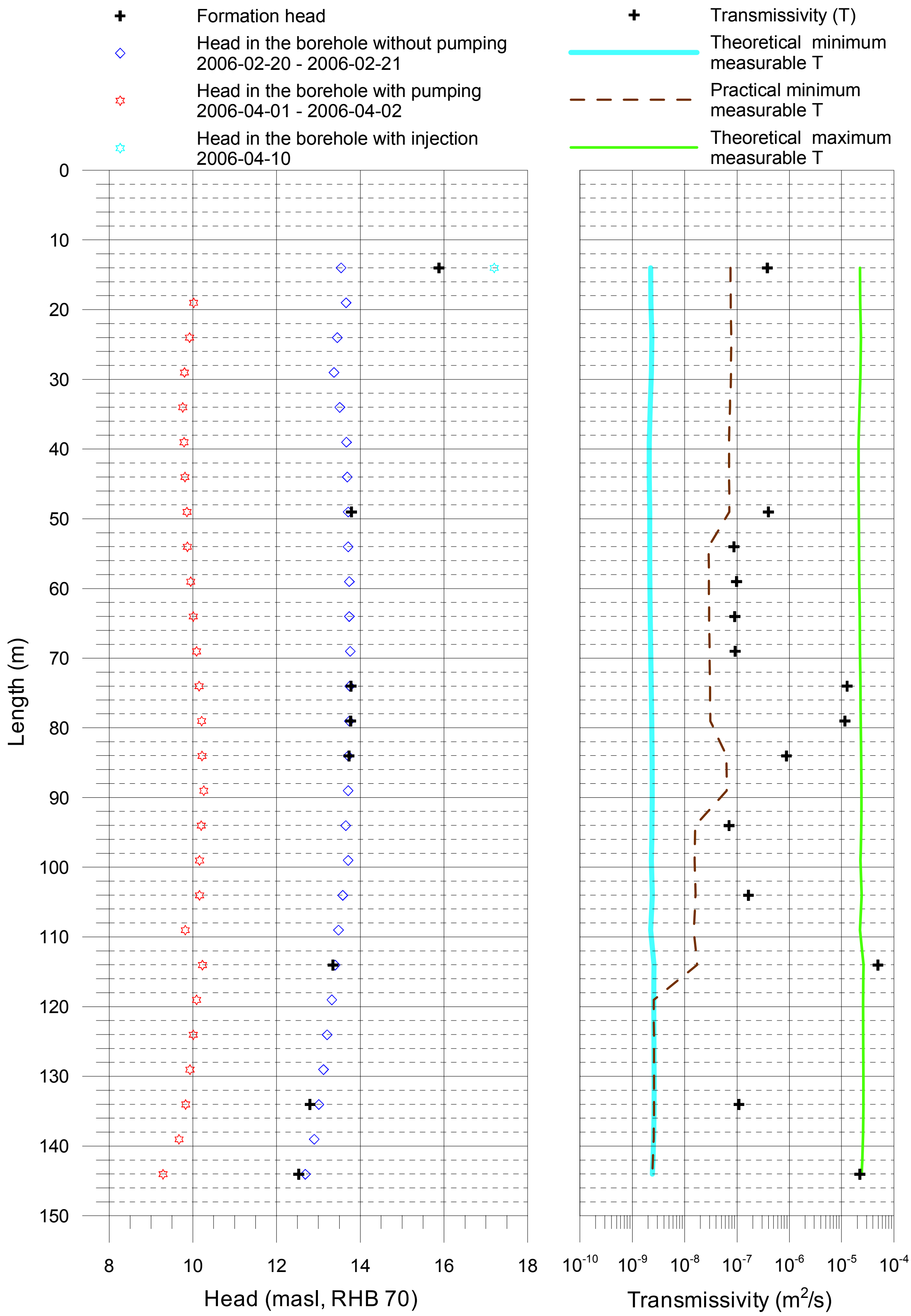


Laxemar, borehole KLX09F
Temperature of borehole water

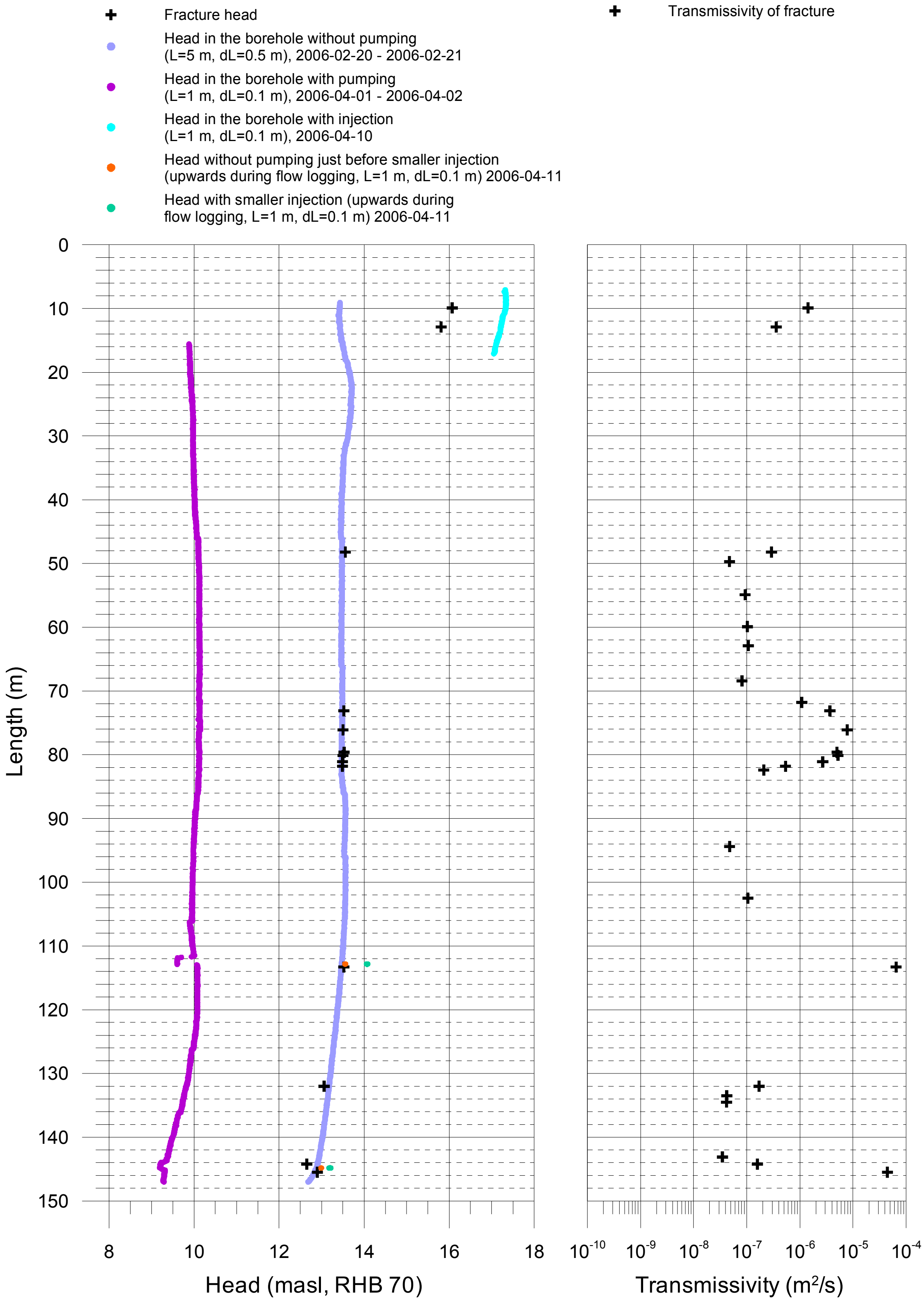



Laxemar, borehole KLX09F
Flow rates of 5 m sections
Without pumping
2006-02-20 - 2006-02-21
With pumping
2006-04-01 - 2006-04-02
With injection
2006-04-10
Theoretical minimum
measurable flow rate
Practical minimum
measurable flow rate
Theoretical maximum
measurable flow rate
Length (m)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
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 KLX09F
Transmissivity and head of 5 m sections



Laxemar, borehole KLX09F
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)
KLX09F	11.53	146.53	5A	20060331	09:13	20060401	09:30	20060406	08:20	5	5	5.55E–4	

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 (–)
515,220		171,371		13.43	10.06		–3.37		1.6E–4		

Difference flow logging – Sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KLX09F	11.53	16.53	5	9.00E–07	13.54	–5.06E–07	17.20	3.8E–07	15.9	1,000	2.3E–09	7.5E–08	2.3E–05	**
KLX09F	16.53	21.53	5	6.11E–08	13.66	–	10.02	–	–	1,000	2.3E–09	7.6E–08	2.3E–05	
KLX09F	21.53	26.53	5	–	13.45	–	9.92	–	–	1,000	2.3E–09	7.8E–08	2.3E–05	
KLX09F	26.53	31.53	5	4.17E–09	13.37	–	9.80	–	–	1,000	2.3E–09	7.7E–08	2.3E–05	
KLX09F	31.53	36.53	5	–	13.51	–	9.76	–	–	1,000	2.2E–09	7.3E–08	2.2E–05	
KLX09F	36.53	41.53	5	2.78E–09	13.67	–	9.79	–	–	1,000	2.1E–09	7.1E–08	2.1E–05	
KLX09F	41.53	46.53	5	–	13.69	–	9.81	–	–	1,000	2.1E–09	7.1E–08	2.1E–05	
KLX09F	46.53	51.53	5	3.42E–08	13.71	1.59E–06	9.86	4.0E–07	13.8	1,000	2.1E–09	7.1E–08	2.1E–05	
KLX09F	51.53	56.53	5	–	13.71	3.42E–07	9.87	8.8E–08	–	400	2.2E–09	2.9E–08	2.2E–05	
KLX09F	56.53	61.53	5	–	13.74	3.78E–07	9.95	9.9E–08	–	400	2.2E–09	2.9E–08	2.2E–05	
KLX09F	61.53	66.53	5	–	13.74	3.42E–07	10.01	9.1E–08	–	400	2.2E–09	3.0E–08	2.2E–05	
KLX09F	66.53	71.53	5	–	13.76	3.42E–07	10.09	9.2E–08	–	400	2.3E–09	3.0E–08	2.3E–05	
KLX09F	71.53	76.53	5	4.36E–07	13.75	4.69E–05	10.15	1.3E–05	13.8	400	2.3E–09	3.1E–08	2.3E–05	
KLX09F	76.53	81.53	5	3.89E–07	13.74	4.19E–05	10.21	1.2E–05	13.8	400	2.3E–09	3.1E–08	2.3E–05	
KLX09F	81.53	86.53	5	1.89E–08	13.71	3.14E–06	10.22	8.8E–07	13.7	800	2.4E–09	6.3E–08	2.4E–05	
KLX09F	86.53	91.53	5	–	13.71	–	10.26	–	–	800	2.4E–09	6.4E–08	2.4E–05	
KLX09F	91.53	96.53	5	–	13.65	2.47E–07	10.20	7.1E–08	–	200	2.4E–09	1.6E–08	2.4E–05	
KLX09F	96.53	101.53	5	–	13.71	–	10.16	–	–	200	2.3E–09	1.6E–08	2.3E–05	
KLX09F	101.53	106.53	5	–	13.58	5.75E–07	10.16	1.7E–07	–	200	2.4E–09	1.6E–08	2.4E–05	
KLX09F	106.53	111.53	5	–	13.48	–	9.82	–	–	200	2.3E–09	1.5E–08	2.3E–05	
KLX09F	111.53	116.53	5	–2.28E–06	13.40	1.56E–04	10.23	4.9E–05	13.4	200	2.6E–09	1.7E–08	2.6E–05	
KLX09F	116.53	121.53	5	–	13.32	–	10.09	–	–	30	2.6E–09	2.6E–09	2.6E–05	
KLX09F	121.53	126.53	5	–	13.21	–	10.01	–	–	30	2.6E–09	2.6E–09	2.6E–05	
KLX09F	126.53	131.53	5	–	13.12	–	9.93	–	–	30	2.6E–09	2.6E–09	2.6E–05	
KLX09F	131.53	136.53	5	–2.36E–08	13.01	3.28E–07	9.83	1.1E–07	12.8	30	2.6E–09	2.6E–09	2.6E–05	
KLX09F	136.53	141.53	5	–	12.90	–	9.67	–	–	30	2.6E–09	2.6E–09	2.6E–05	
KLX09F	141.53	146.53	5	–3.56E–06	12.69	7.33E–05	9.29	2.2E–05	12.5	30	2.4E–09	2.4E–09	2.4E–05	

** Values from the measurement with injection

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
KLX09F	9.9	1	0.1	3.83E–06	13.42	–1.82E–06	17.33	1.4E–06	16.1	*, **
KLX09F	11.5	1	0.1	5.56E–09	13.42	0.00E+00	17.26		–	**, ***
KLX09F	12.9	1	0.1	8.64E–07	13.43	–5.11E–07	17.22	3.6E–07	15.8	**
KLX09F	16.7	1	0.1	–	13.53	0.00E+00	9.89		–	*, ***
KLX09F	17.2	1	0.1	5.28E–08	13.54	0.00E+00	9.90		–	***
KLX09F	18.6	1	0.1	–	13.61	0.00E+00	9.90		–	*, ***
KLX09F	24.0	1	0.1	–	13.69	0.00E+00	9.95		–	***
KLX09F	30.7	1	0.1	4.17E–09	13.60	0.00E+00	9.97		–	***
KLX09F	31.7	1	0.1	–	13.56	0.00E+00	9.97		–	***
KLX09F	33.2	1	0.1	–	13.53	0.00E+00	9.97		–	***
KLX09F	33.7	1	0.1	–	13.52	0.00E+00	9.98		–	*, ***
KLX09F	35.5	1	0.1	–	13.51	0.00E+00	9.98		–	***
KLX09F	38.5	1	0.1	3.89E–09	13.49	0.00E+00	10.01		–	***
KLX09F	42.1	1	0.1	–	13.45	0.00E+00	10.03		–	***
KLX09F	43.1	1	0.1	–	13.44	0.00E+00	10.03		–	***
KLX09F	45.6	1	0.1	–	13.46	0.00E+00	10.06		–	***
KLX09F	46.9	1	0.1	7.22E–09	13.48	0.00E+00	10.09		–	***
KLX09F	48.2	1	0.1	2.31E–08	13.48	1.02E–06	10.11	2.9E–07	13.6	
KLX09F	49.7	1	0.1	–	13.48	1.61E–07	10.11	4.7E–08	–	
KLX09F	54.0	1	0.1	–	13.48	0.00E+00	10.12		–	***
KLX09F	54.9	1	0.1	–	13.48	3.17E–07	10.12	9.3E–08	–	
KLX09F	59.9	1	0.1	–	13.47	3.47E–07	10.12	1.0E–07	–	
KLX09F	61.3	1	0.1	–	13.46	0.00E+00	10.13		–	*, ***
KLX09F	62.9	1	0.1	–	13.46	3.61E–07	10.12	1.1E–07	–	
KLX09F	67.0	1	0.1	–	13.49	0.00E+00	10.13		–	*, ***
KLX09F	68.4	1	0.1	–	13.49	2.78E–07	10.12	8.2E–08	–	
KLX09F	71.8	1	0.1	–	13.48	3.69E–06	10.13	1.1E–06	–	
KLX09F	73.1	1	0.1	1.58E–07	13.48	1.26E–05	10.13	3.7E–06	13.5	
KLX09F	76.1	1	0.1	2.66E–07	13.47	2.64E–05	10.15	7.8E–06	13.5	
KLX09F	79.6	1	0.1	2.61E–07	13.48	1.71E–05	10.13	5.0E–06	13.5	
KLX09F	80.1	1	0.1	1.33E–07	13.47	1.78E–05	10.12	5.2E–06	13.5	
KLX09F	81.1	1	0.1	4.89E–08	13.47	9.17E–06	10.12	2.7E–06	13.5	
KLX09F	81.8	1	0.1	1.17E–08	13.47	1.83E–06	10.11	5.4E–07	13.5	
KLX09F	82.4	1	0.1	–	13.47	7.11E–07	10.12	2.1E–07	–	
KLX09F	94.4	1	0.1	–	13.54	1.71E–07	9.99	4.8E–08	–	*
KLX09F	102.5	1	0.1	–	13.56	3.83E–07	9.96	1.1E–07	–	
KLX09F	113.3	1	0.1	–1.74E–06	13.55	–3.58E–05	14.07	6.5E–05	13.5	****
KLX09F	132.0	1	0.1	–1.89E–08	13.17	5.58E–07	9.82	1.7E–07	13.1	
KLX09F	133.5	1	0.1	–	13.15	1.44E–07	9.77	4.2E–08	–	*
KLX09F	134.5	1	0.1	–	13.13	1.43E–07	9.73	4.2E–08	–	
KLX09F	143.1	1	0.1	–	12.94	1.26E–07	9.38	3.5E–08	–	
KLX09F	144.2	1	0.1	–4.14E–08	12.91	5.50E–07	9.21	1.6E–07	12.7	
KLX09F	145.5	1	0.1	–4.19E–06	12.99	–1.36E–05	13.20	4.4E–05	12.9	****

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

** Values from the measurement with injection.

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

**** Values from the measurement with smaller injection, water level used instead of head for pressure difference.

Explanations.

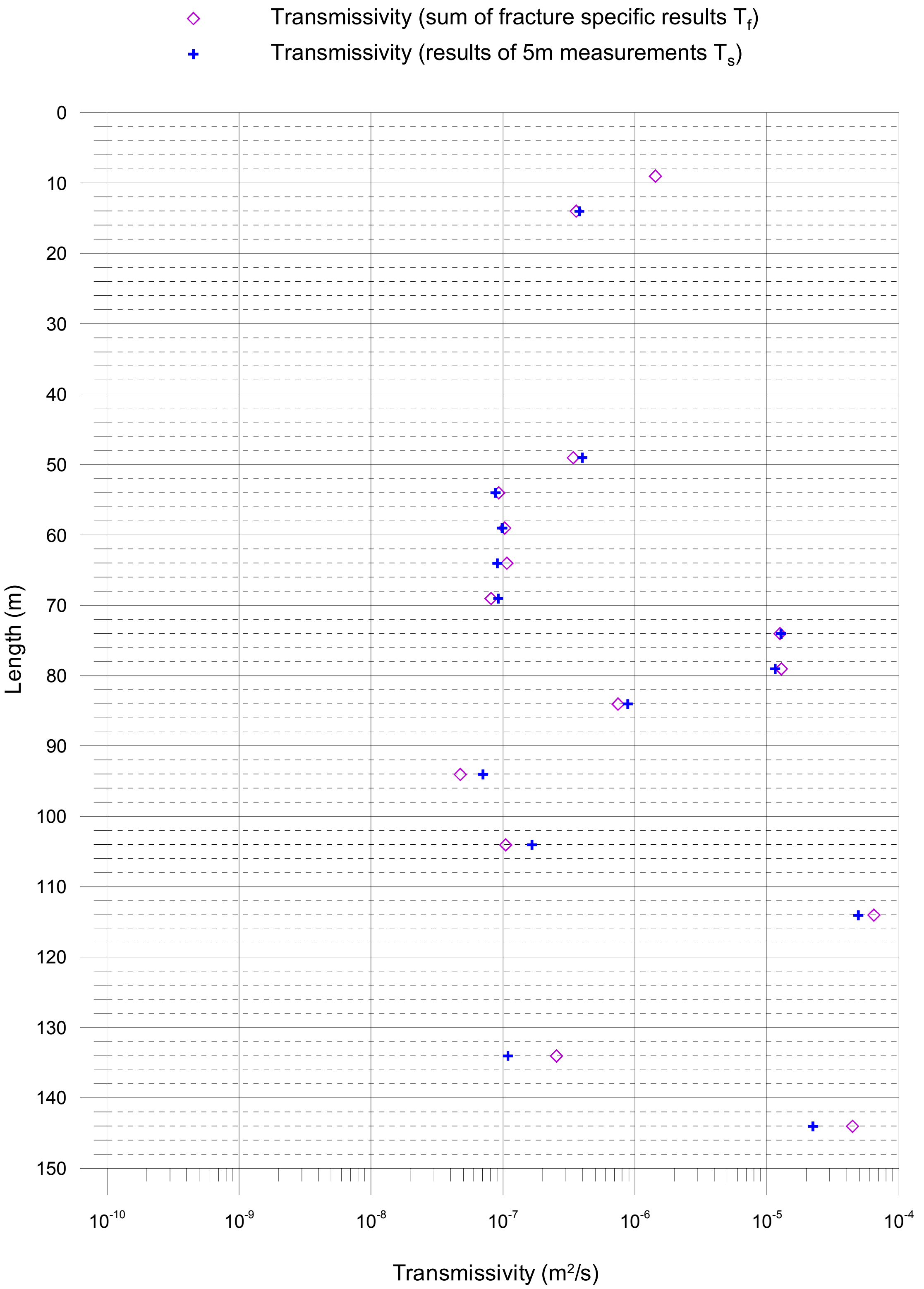
Header	Unit	Explanations
Borehole		ID for borehole.
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L).
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L).
L	m	Corrected length along borehole based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

Calculation of conductive fracture frequency.

Borehole ID	Secup (m)	Seclow (m)	Number of fractures total	Number of fractures 10–100 (ml/h)	Number of fractures 100–1,000 (ml/h)	Number of fractures 1,000–10,000 (ml/h)	Number of fractures 10,000–100,000 (ml/h)	Number of fractures 100,000–1,000,000 (ml/h)
KLX09F	6.53	11.53	2	0	0	0	0	0
KLX09F	11.53	16.53	1	0	0	0	0	0
KLX09F	16.53	21.53	3	0	0	0	0	0
KLX09F	21.53	26.53	1	0	0	0	0	0
KLX09F	26.53	31.53	1	0	0	0	0	0
KLX09F	31.53	36.53	4	0	0	0	0	0
KLX09F	36.53	41.53	1	0	0	0	0	0
KLX09F	41.53	46.53	3	0	0	0	0	0
KLX09F	46.53	51.53	3	0	1	1	0	0
KLX09F	51.53	56.53	2	0	0	1	0	0
KLX09F	56.53	61.53	2	0	0	1	0	0
KLX09F	61.53	66.53	1	0	0	1	0	0
KLX09F	66.53	71.53	2	0	1	0	0	0
KLX09F	71.53	76.53	3	0	0	0	3	0
KLX09F	76.53	81.53	3	0	0	0	3	0
KLX09F	81.53	86.53	2	0	0	2	0	0
KLX09F	86.53	91.53	0	0	0	0	0	0
KLX09F	91.53	96.53	1	0	1	0	0	0
KLX09F	96.53	101.53	0	0	0	0	0	0
KLX09F	101.53	106.53	1	0	0	1	0	0
KLX09F	106.53	111.53	0	0	0	0	0	0
KLX09F	111.53	116.53	1	0	0	0	0	0
KLX09F	116.53	121.53	0	0	0	0	0	0
KLX09F	121.53	126.53	0	0	0	0	0	0
KLX09F	126.53	131.53	0	0	0	0	0	0
KLX09F	131.53	136.53	3	0	2	1	0	0
KLX09F	136.53	141.53	0	0	0	0	0	0
KLX09F	141.53	146.53	3	0	1	1	0	0

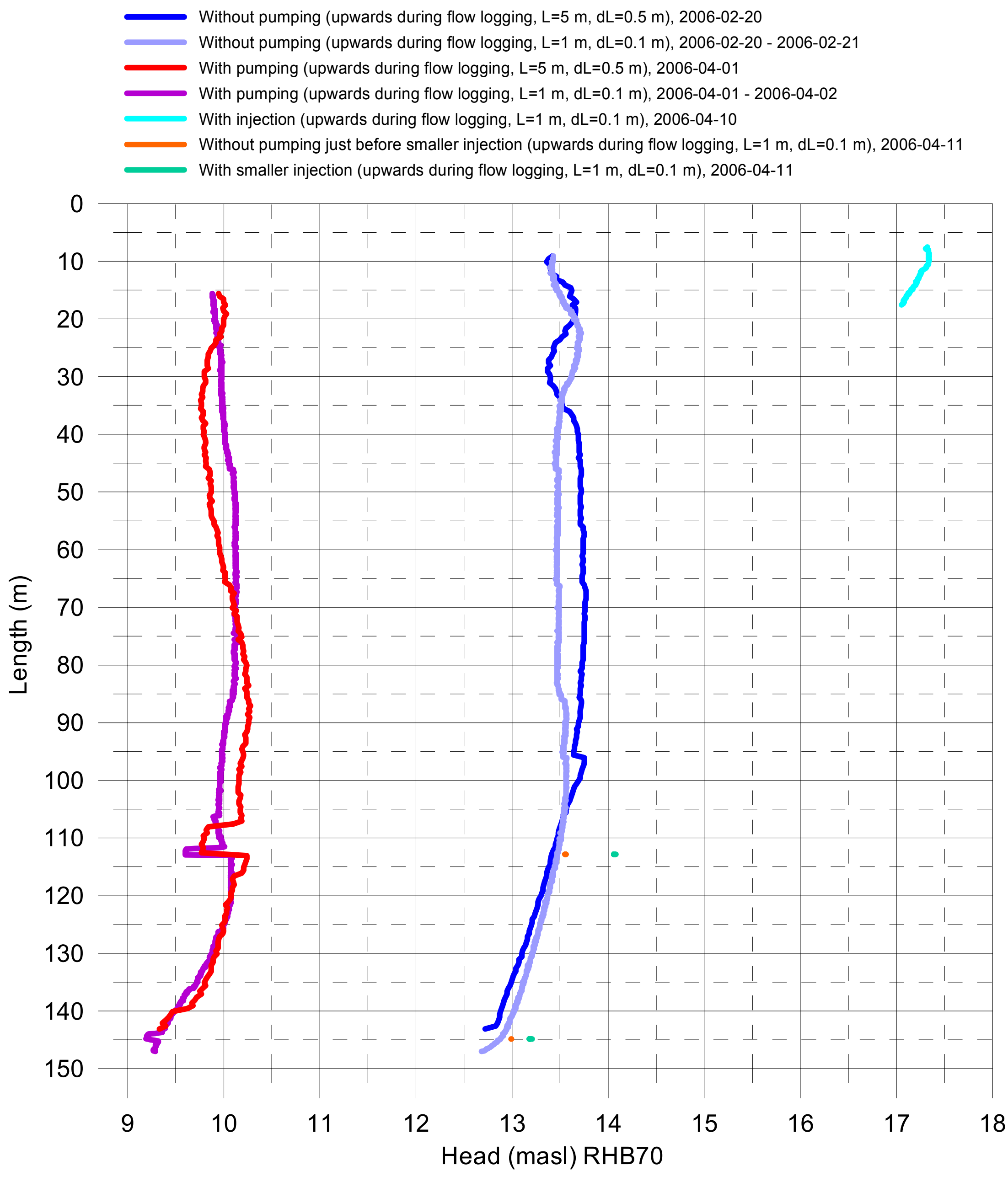
Laxemar, borehole KLX09F
Calculation of conductive fracture frequency

Laxemar, borehole KLX09F
Comparison between section transmissivity and fracture transmissivity

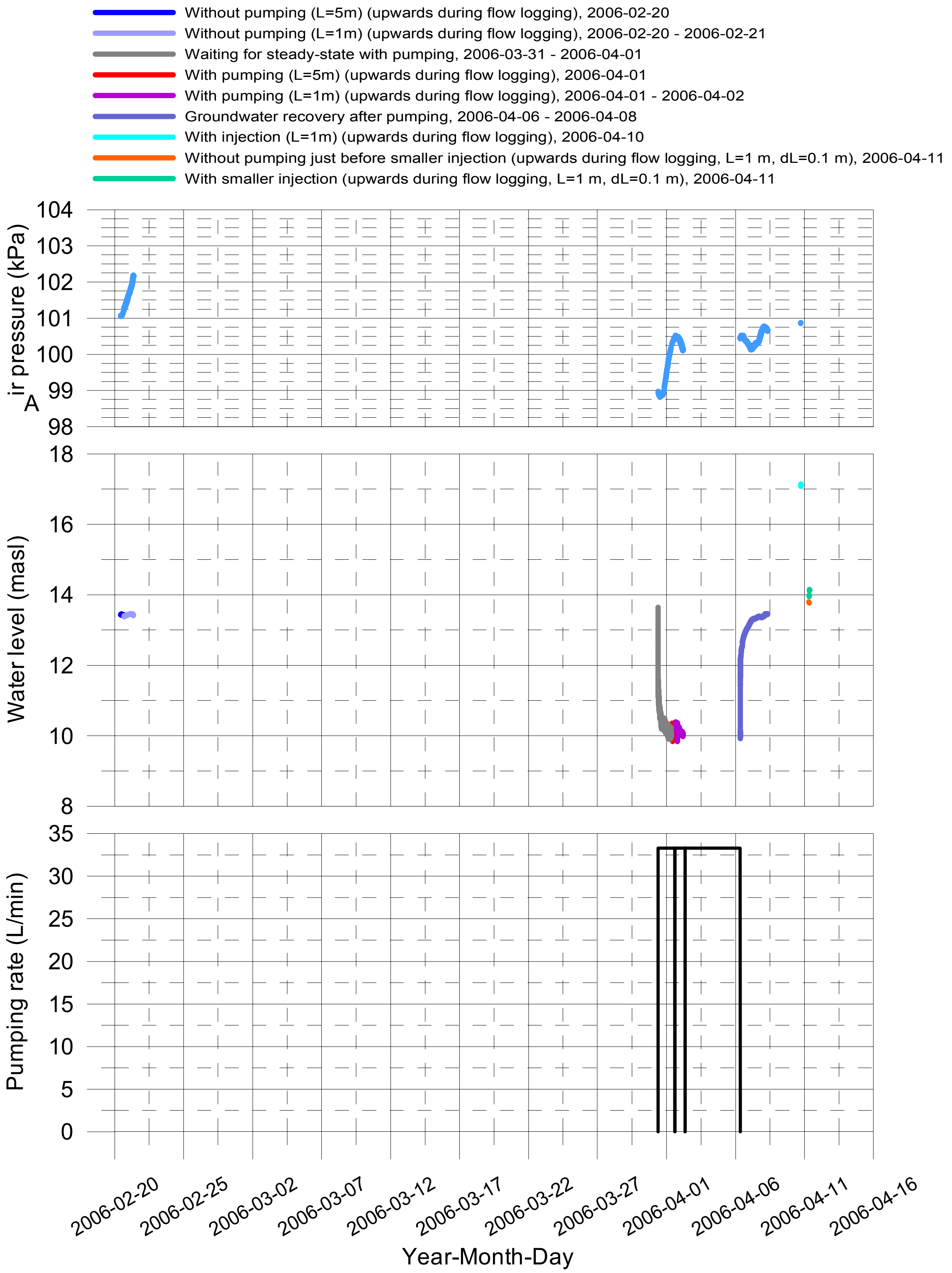


Laxemar, borehole KLX09F
Head in the borehole during flow logging

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)

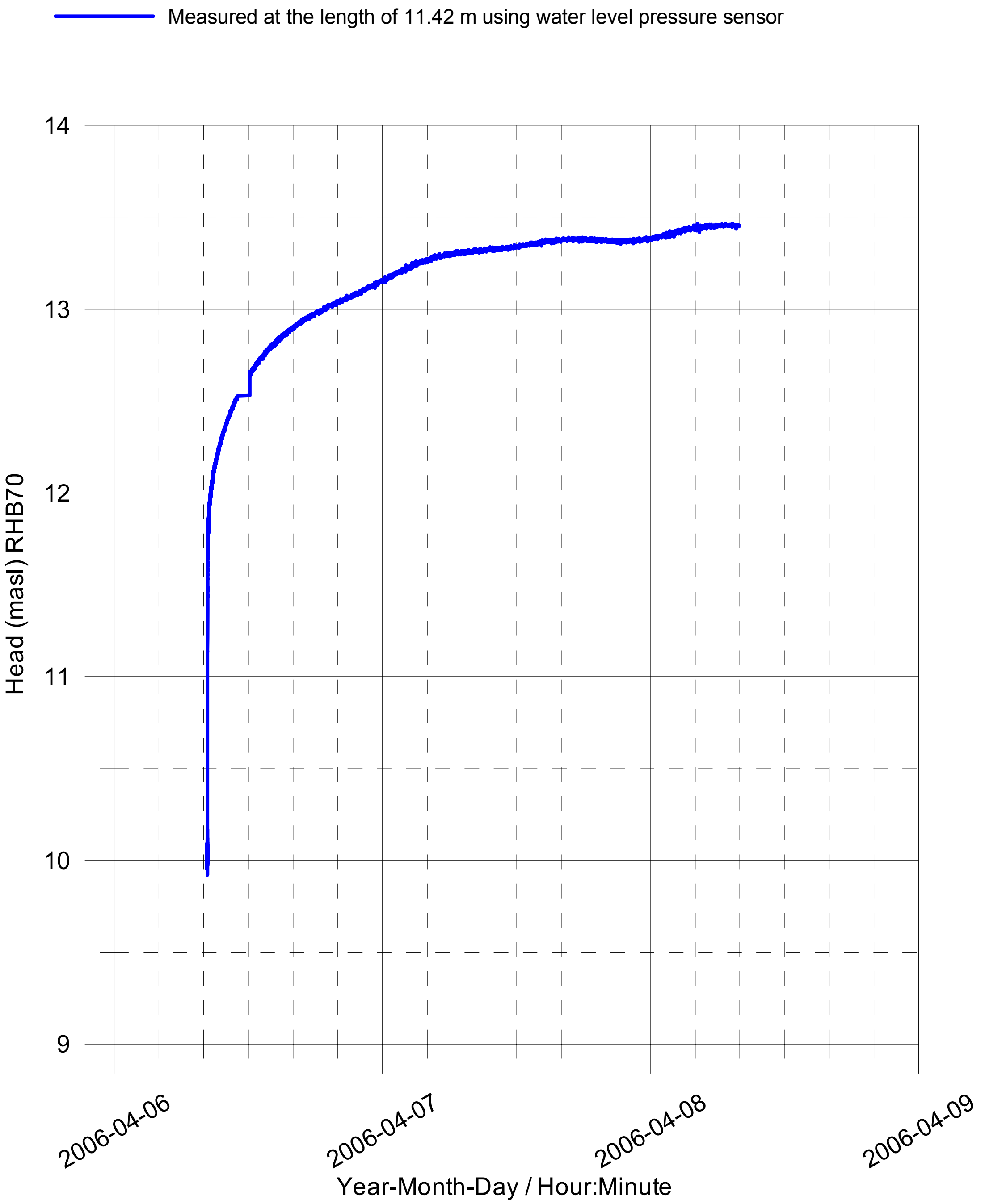


Laxemar, borehole KLX09F
Air pressure, water level in the borehole and pumping rate during flow logging

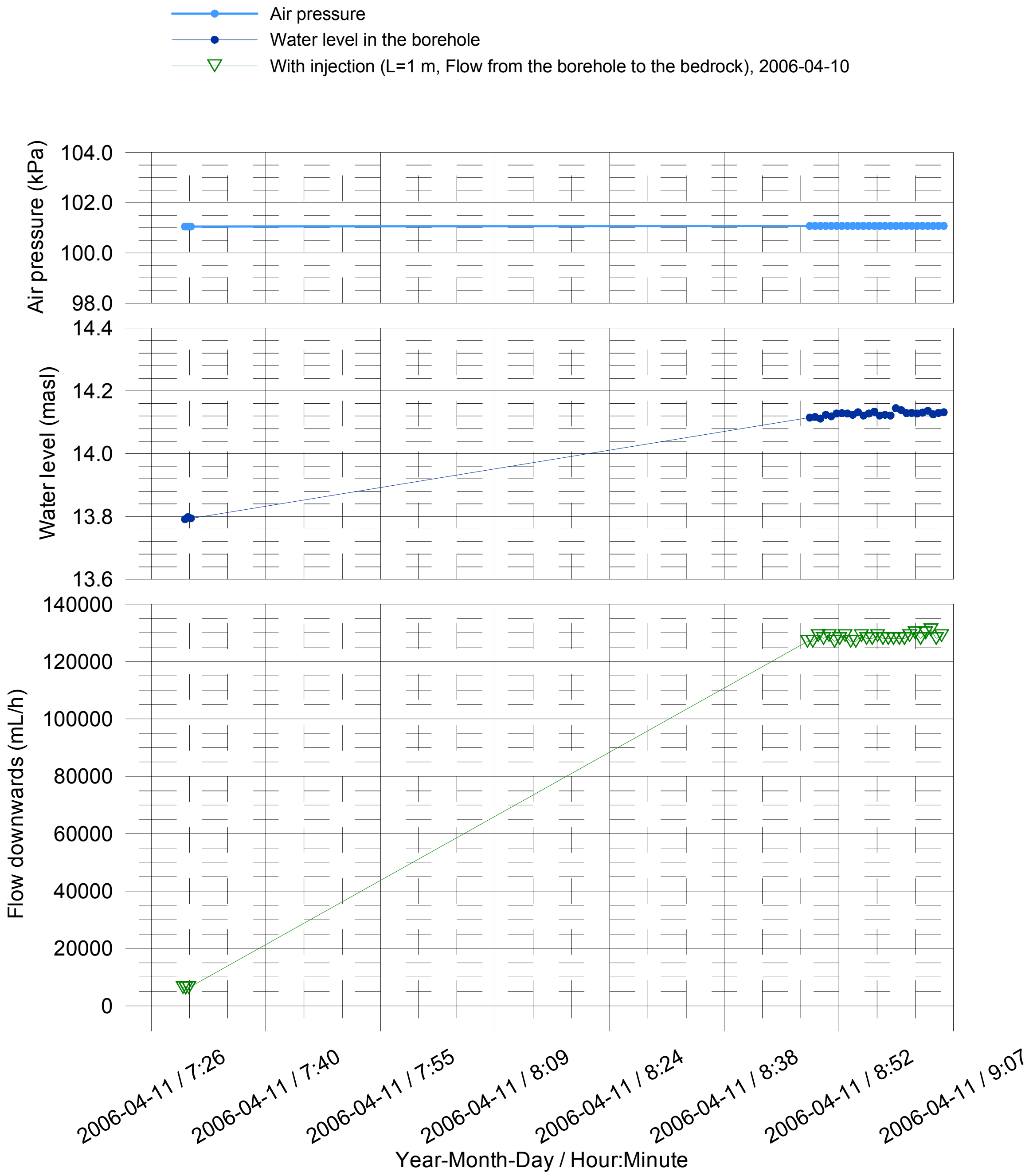


Laxemar, borehole KLX09F
Groundwater recovery after pumping

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)



Laxemar, borehole KLX09F
Flow logging with injection at the length 112.8 m



Laxemar, borehole KLX09F
Flow logging with injection at the length 144.8 m