P-09-20

Site investigation SFR

Difference flow logging in boreholes KFR104 and KFR27 (extension)

Eemeli Hurmerinta, Juha Väisäsvaara
PRG-Tec Oy

March 2009

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-09-20

Site investigation SFR

Difference flow logging in boreholes KFR104 and KFR27 (extension)

Eemeli Hurmerinta, Juha Väisäsvaara
PRG-Tec Oy

March 2009

Keywords: P-report SKBDoc id 1207449. Review statement SKBDoc id 1207631, Forsmark, Hydrogeology, Hydraulic tests, Difference flow measurements, KFR104, KFR27, AP SFR-08-025, Project SFR extension.

Abstract

The Posiva Flow Log, Difference Flow Method (PFL DIFF) uses a flowmeter that incorporates a flow guide and can be used for relatively quick determinations of hydraulic conductivity and hydraulic head in fractures/fractured zones in cored boreholes. This report presents the main principles of the methods as well as the results of measurements carried out in boreholes KFR104 and KFR27 at Forsmark, Sweden, in November 2008.

The first flow logging measurements were done with a 5 m test section by moving the measurement tool in 0.5 m steps. This method was used to flow log the entire measurable part of borehole KFR104 during natural (un-pumped) as well as pumped conditions. Only the extended part of the borehole KFR27 was measured. The flow measurements in pumped conditions were repeated, at the location of detected flow anomalies using a 1 m long test section, which was moved in 0.1 m steps.

Length calibration was made based on length marks milled into the borehole wall at accurately determined positions along the borehole. The length marks were detected by caliper measurements and by single-point resistance (SPR) measurements using the SPR sensor of the PFL DIFF probe.

A high-resolution absolute pressure sensor was used to measure the absolute 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. The EC of fracture-specific water was measured only in borehole KFR104 (1 m test section) for a selection of fractures.

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

Sammanfattning

Posiva Flow Log, Differensflödesloggning (PFL DIFF) är en snabb metod för bestämning av transmissiviteten och hydraulisk tryckhöjd i borrhålssektioner och sprickor/sprickzoner i kärnborrhål. Denna rapport presenterar huvudprinciperna för metoden och resultat av mätningar utförda i borrhål KFR104 och KFR27 i Forsmark, Sverige, i november 2008.

Flödet till eller från en 5 m lång testsektion (som förflyttades successivt med 0,5 m) mättes i borrhålet KFR104 under såväl naturliga (icke-pumpade) som pumpade förhållanden. Bara den förlängda delen av KFR27 mättes. Flödesmätningarna upprepades under pumpade förhållande med en 1 m lång testsektion som förflyttades successivt i steg om 0,1 m vid lägena för de detekterade flödesanomalierna.

Längdkalibrering gjordes med hjälp av de längdmärken som finns infrästa vid noggrant bestämda positioner längs borrhålet. Längdmärkena detekterades med caliper och punktresistansmätningar (SPR) med hjälp av sensorer anslutna på PFL DIFF sonden.

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

Elektrisk konduktivitet (EC) och temperatur på borrhålsvattnet mättes också. EC-mätningarna användes för att studera förekomsten av saltvatten i borrhålet under såväl naturliga som pumpade förhållanden. EC mättes även i ett antal utvalda sprickor i borrhål KFR104 (1 m lång testsektion).

Återhämtningen av grundvattennivån mättes efter att pumpningen i respektive hål avslutades.

Contents

1 Introduction

The core drilled boreholes KFR104 and KFR27 at Forsmark, Sweden were measured using the Posiva Flow Log, Difference Flow Method (PFL DIFF) which provides a swift, multifaceted characterization of a borehole. Borehole KFR104 was measured between November 12–21, 2008 and borehole KFR27 was measured between November 15–16 and November 21–27, 2008. The upper part of borehole KFR27 had already been measured in July 2008 /Pekkanen et al. 2008/. The extended part below c. 140 m was measured during this campaign.

KFR104 is 454.6 m long and its inclination at the ground level is 54 ° from the horizontal plane. The borehole was drilled using a telescopic drilling technique, where the c. 0–9 m interval was percussion drilled, and its inner diameter is 130 mm, whereas the rest of the borehole was core drilled with the diameter 76 mm. A stainless steel support casing with an inner diameter of 77 mm has been placed within the percussion drilled part.

Borehole KFR27 is 501.6 m long and its inclination at the ground level is c. 89 °. The borehole interval through the soil, c. 12 m, is cased with an inner diameter of 77 mm. The part of the borehole above 148 m is core drilled with the diameter c. 77 mm. The part of the borehole below 148 m is core drilled with the diameter c. 76 mm.

The locations of KFR104 and KFR27 at Forsmark are illustrated in Figure 1-1.

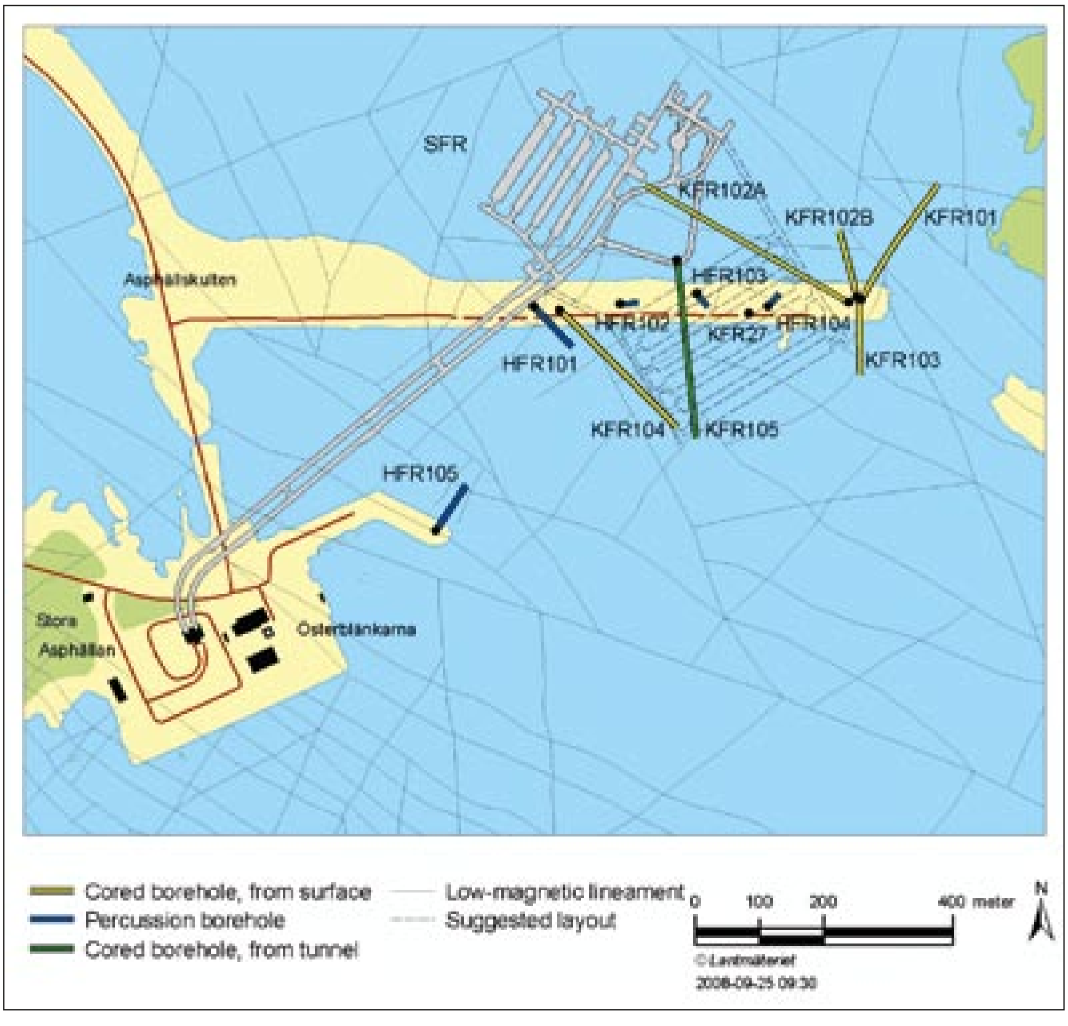


Figure 1-1. *Location Map over the SFR facility and the location of the boreholes, including KFR104 and KFR27.*

The field work and the subsequent data interpretation were conducted by PRG-Tec Oy as Posiva Oy's subcontractor. PFL DIFF has previously been employed in Posiva's site characterisation programme in Finland as well as at the Äspö Hard Rock Laboratory at Simpevarp, Sweden. The commissions at the latter site included measurements in the 1,700 m long cored borehole KLX02 at Laxemar together with a methodology study /Ludvigson et al.2002/. PFL DIFF has also been employed in SKB's site characterisation programme at Laxemar and Forsmark.

This document reports the results acquired by PFL DIFF in boreholes KFR104 and KFR27. The measurements were carried out as a part of a project named "Projekt SFR-utbyggnad" and in accordance to SKB's internal controlling document AP SFR-08-025. The controlling documents for performing according to this Activity Plan are listed in Table 1-1. The list of the controlling documents excludes the assignment-specific quality plans. Both the Activity Plan and the Method Descriptions are SKB's internal controlling documents. The measurement data and the results were delivered to the SKB site characterization database SICADA and are traceable by the Activity Plan number.

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

Activity Plan	Number	Version
Difference flow logging in boreholes KFR104 and KFR27	AP SFR-08-025	1.0
Method Descriptions	**Number**	**Version**
Method Description for Difference Flow Logging	SKB MD 322.010e	2.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	1.0
Instruction for length calibration in investigation of core boreholes	SKB MD 620.010e	2.0
Instruktion för analys av injektions- och enhålspumptester	SKB MD 320.004	2.0

2 Objective and scope

The main objective of the PFL DIFF measurements in KFR104 and KFR27 was to identify water-conductive sections/fractures suitable for subsequent hydro-geochemical characterisation. Secondly, the measurements aimed at a hydrogeological characterisation, which includes the inspection of the prevailing water flow balance in the borehole and the hydraulic properties (transmissivity and undisturbed hydraulic head) of the tested sections. 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 measurement programme also included supporting measurements, performed in order to gain a better understanding of the overall hydrogeochemical conditions. These measurements included the electrical conductivity (EC) and the temperature of the borehole fluid as well as the single-point resistance of the borehole wall. The electrical conductivity of a number of selected high-transmissive fractures (the electrical conductivity of the water in the fractures) in borehole KFR104 was also measured. Furthermore, the recovery of the groundwater level after pumping the borehole was registered.

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

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

3 Principles of measurement and interpretation

3.1 Measurements

Unlike conventional borehole flowmeters which measure the total cumulative flow rate along a borehole, PFL DIFF probe measures the flow rate into or out of defined borehole sections. The advantage that follows from measuring the flow rate in isolated sections is improved detection of incremental changes of flow along the borehole. As these are generally very small, they can easily be missed when using conventional flowmeters.

Rubber sealing disks located at the top and bottom of the probe are used to isolate the flow of water in the test section from the flow in the rest of the borehole, see Figure 3-1. Flow inside the test section is directed through the flow sensor. Flow along the borehole is directed around the test section by means of a bypass pipe and is discharged at either the upper or lower end of the probe. The entire structure is called the flow guide.

Generally two separate measurements with two different section lengths (e.g. 5 m and 1 m) are used. The 5 m setup is usually used first to obtain a general picture of the flow anomalies. It is also good for measuring larger (less than 5 m in length) fractured zones. The 1 m section setup can separate anomalies which are close to each other. There are also many other advantages to using different section lengths.

Flow rates into or out of the test section are monitored using thermistors, which track both the dilution (cooling) of a thermal pulse and its transfer by the moving water /Öhberg and Rouhiainen 2000, 11–13/. The thermal dilution method is used in measuring flow rates because it is faster than the thermal pulse method, and the latter is used only to determine flow direction within a given time frame. Both methods are used simultaneously at each measurement location.

In addition to incremental changes in flow, the PFL DIFF probe can also be used to measure:

- The electrical conductivity (EC) of both borehole water and fracture-specific water. The electrode used in EC measurements is located at the top of the flow sensor, see Figure 3-1.
- The single point resistance (SPR) of the borehole wall (grounding resistance). The electrode used for SPR measurements is located between the uppermost rubber sealing disks, see Figure 3-1, and is used for the high-resolution depth determination of fractures and geological structures.
- The prevailing water pressure profile in the borehole. Located inside the watertight electronics assembly, the pressure sensor transducer is connected to the borehole water through a tube, see Figure 3-2.
- The temperature of the water in the borehole. The temperature sensor is part of the flow sensor, see Figure 3-1.

The principles behind PFL DIFF flow measurements are shown in Figure 3-3. The flow sensor consists of three thermistors (Figure 3-3 a). The central thermistor, A, is used both as a heating element and to register temperature changes (Figures 3-3 b and c). The side thermistors, B1 and B2, serve as detectors of the moving thermal pulse caused by the heating of A.

Flow rate is measured by monitoring heat transients after constant power heating in thermistor A. The measurement begins by constant power (P_1) heating. After the power is cut off the flow rate is measured by monitoring transient thermal dilution (Figure 3-3 c). If the measured flow rate exceeds a certain limit, another constant power heating (P_2) period is started after which the flow rate is re-measured from the following heat transient.

Flows are measured when the probe is at rest. After transferring the probe to a new position, a waiting period (which can be adjusted according to the prevailing circumstances) is allowed to elapse before the heat pulse (Figure 3-3 b) is applied. The measurement period after the constant-power thermal pulse (normally 100 s each time the probe has moved a distance equal to the test section length and 10 s in every other location) can also be adjusted. The longer (100 s) measurement time is used to allow the direction of even the smallest measurable flows to be visible.

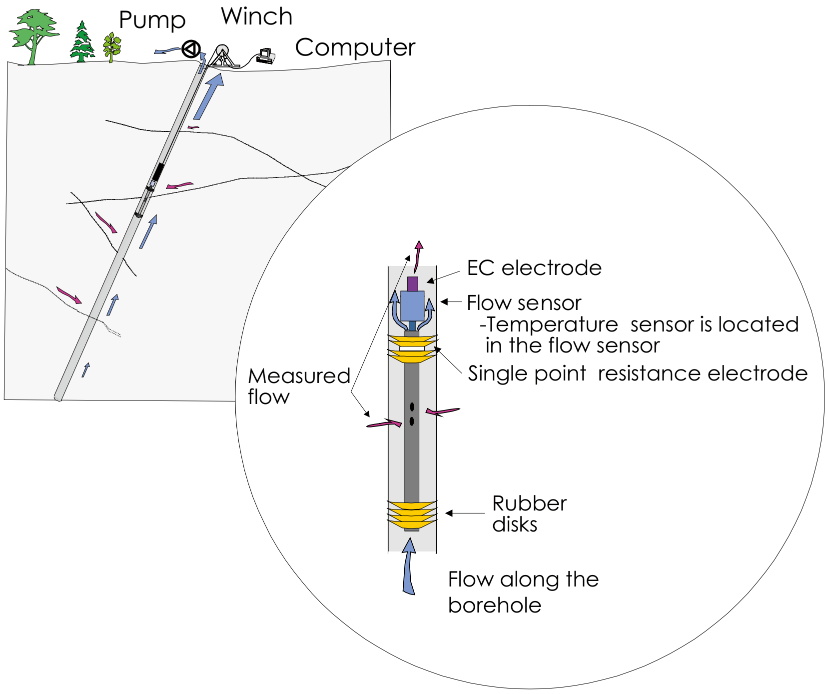


Figure 3-1. *Schematic of the probe used in the PFL DIFF.*

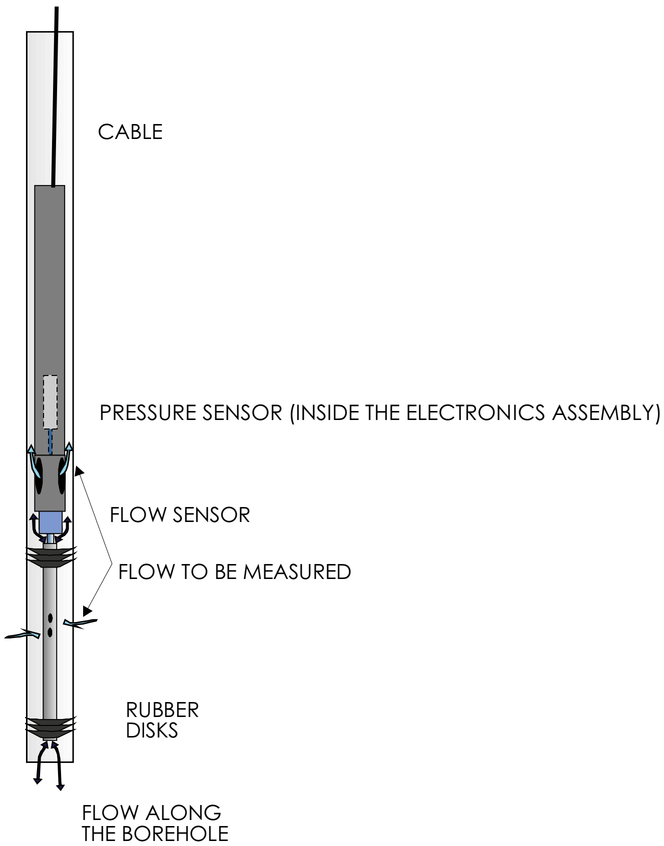


Figure 3-2. *The absolute pressure sensor is located inside the electronics assembly and connected to the borehole water through a tube.*

The flow rate measurement range is 30 mL/h – 300,000 mL/h. The lower limit of measurement for the thermal dilution method is the theoretical lowest measurable value. Depending on conditions in the borehole, these flow limits may not always prevail. Examples of possible disturbances are drilling debris entrained in the borehole water, bubbles of gas in the water and high flow rates (some 30 L/min, i.e., 1,800 000 mL/h or more) along the borehole. If the disturbances encountered are significant, limits on practical measurements are calculated for each set of data.

The device depth reference point in the PFL DIFF is situated at the upper end of the test section.

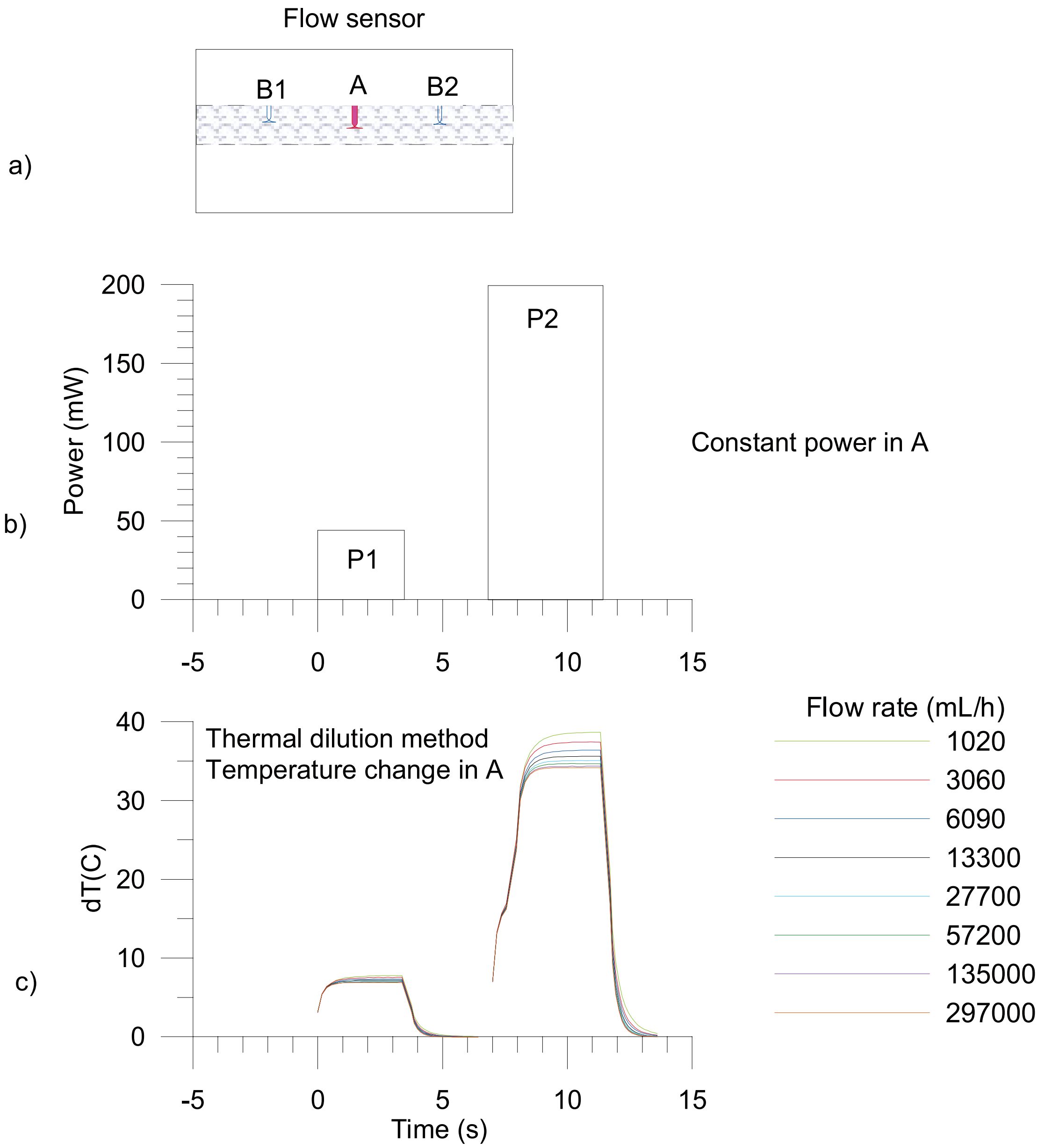


Figure 3-3. *Flow rate measurement.*

3.2 Interpretation

The interpretation of data is based on Thiem's or Dupuit's formula, which describes a steady state and two-dimensional radial flow into the borehole /Marsily G 1986/:

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

where h is the hydraulic head in the vicinity of the borehole and $h = h_S$ 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 pumping is felt.

If measurements of flow rate are carried out using two levels of hydraulic head in the borehole, i.e. natural and pump-induced heads, then the undisturbed (natural) hydraulic head and the transmissivity of the borehole sections tested can be calculated. Equation 3-1 can be reformulated in the following two ways:

$Q_{s0} = T_s \cdot a \cdot (h_s - h_0)$ 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 levels, 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.

In general, since very little is known about the flow geometry, cylindrical flow without skin zones is assumed. Cylindrical flow geometry is also justified because the borehole is at a constant head, and no strong pressure gradients along the borehole exist 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

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

The transmissivity (T_f) and hydraulic head (h_f) of individual fractures can be calculated provided that the flow rates at the individual fractures are known. Similar assumptions to those employed above must 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 transmissivity of a fracture, respectively.

Since the actual flow geometry and any skin effects are unknown, transmissivity values should only be considered as an indication of the prevailing 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 geometry. A discussion of potential uncertainties in the calculation of transmissivity and hydraulic head can be found in /Ludvigson et al. 2002/.

The transmissivity of the entire borehole can be evaluated in several ways using the data from the flow period and recovery period. 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 (m) and Q is the pumping rate at the end of the flow period (m^3/s)

In Moye's formula /Moye 1967/ it is assumed the steady-state flow is cylindrical near the borehole (to a distance r = L/2, where L is the length of the test section) and spherical further away from the borehole:

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

where L is length of the test section (m), in this case the water filled uncased part of the borehole and r_0 is the diameter of the borehole (m).

The transient recovery period is evaluated according to SKB MD 320.004 (SKB internal controlling document).

4 Equipment specification

In the PFL DIFF method, the flow of groundwater into or out of a borehole section is monitored using a flow guide which employs rubber sealing disks to isolate any such flow from the flow of water along the borehole. This flow guide defines the test section being measured without altering the hydraulic head. Groundwater flowing into or out of the test section is guided to the flow sensor, and flow is measured using the thermal pulse and thermal dilution methods. Measured values are transferred to a computer in digital form.

Type of instrument:	PFL DIFF probe.
Borehole diameters:	56 mm, 66 mm and 76 mm (or larger).
Length of test section:	The flow guide length can be varied.
Method of flow measurement:	Thermal pulse and thermal dilution.
Range and accuracy of measurement:	See Table 4-1.
Additional measurements:	Temperature, Single point resistance, Electrical conductivity of water, Water pressure.
Winch:	Mount Sopris Wna 10, 0.55 kW, conductors, Gerhard-Owen cable head.
Depth determination;	Based on a digital distance counter.
Logging computer:	PC (Windows XP).
Software;	Based on MS Visual Basic.
Total power consumption:	1.5–2.5 kW depending on the type of pump employed.
Calibration of FL sensor:	October 2008 (Probe FL7).

The range and accuracy of the sensors used is shown in Table 4-1.

Table 4-1. Range and accuracy of sensors.

Sensor	Range	Accuracy
Flow	30 – 300,000 mL/h	± 10% curr.value
Temperature (central 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 (SPR)	5 – 500,000 Ω	± 10% curr.value
Groundwater level sensor	0 – 0.1 MPa	± 1% full-scale
Air pressure sensor	800 – 1,060 hPa	± 5 hPa
Absolute pressure sensor	0 – 20 MPa	± 0.01% full-scale

5 Execution of measurements

5.1 General

The work commission was performed according to Activity Plan AP SFR-08-025 following the SKB Method Description 322.010e, Version 2.0 (Method description for Difference Flow Logging), see Table 1-1. The Activity Plan and the Method Description are both SKB's internal controlling documents. Prior to the measurements, the downhole tools and the measurement cable were disinfected. Time was synchronized to local Swedish time. The activity schedule of the borehole measurements is presented in Table 5-1. The items and activities in Table 5-1 are the same as in the Activity Plan. The boreholes were measured in the order KFR104 and KFR27.

Logging cables, wires, and pipe strings are exposed to stretching when lowered into a vertical or sub-vertical borehole. This will introduce a certain error in defining the position of a test tool connected to the end of a logging cable. Immediately after completion of the drilling operations, length marks were milled into the borehole wall at certain intervals to be used for length calibration of various logging tools. By using the known positions of the length marks, logging cables etc can be calibrated in order to obtain an accurate length correction of the testing tool. Each length mark consists of two 20 mm wide tracks in the borehole wall. The distance between the tracks is 100 mm. The upper track defines a reference level.

The dummy logging (Item 8) of the borehole is done in order to assure that the measurement tools do not get stuck in the borehole. The dummy also collects solid material from the borehole wall. The solid material in the dummy is used for evaluation whether it is safe to continue with other logging tools.

Caliper measurements were used in combination with single-point resistance measurements for detection of length marks (Item 9). These methods also reveal parts of the borehole widened for some reason (fracture zones, breakouts etc). The length calibration was performed before any other measurements were started.

The electrical conductivity (EC) and temperature of borehole water (Item 10) during natural (un-pumped) conditions were measured before flow logging.

The combined overlapping/sequential flow logging (Item 11) was carried out in the boreholes with a 5 m section length and in 0.5 m length increments (step length). The measurements were performed during natural (un-pumped) conditions.

The pumping of borehole KFR104 was started on November 15, 2008. After a 3 hours waiting time (the minimum waiting time was set to 3 hours), overlapping flow logging (Item 12) was conducted using the same section and step lengths as before. In KFR27 the pumping was started on November 23, 2008. The waiting time after which the measurements (Item 12) were started was 4 h.

The overlapping flow logging was continued by re-measuring previously detected flow anomalies with a 1 m section length and a 0.1 m step length (Item 13). Borehole KFR104 was only measured partially, see Section 5.2.

The fracture specific EC of water from some selected fractures (Item 14) was performed in conjunction with Item 13, in borehole KFR104.

The EC of borehole water (Item 15) was logged while the measured borehole was still pumped. After this, the pump was stopped and the recovery of the groundwater level was monitored (Item 16).

Some extra measurements were also performed, see Section 5.2.

Table 5-1. Flow logging and testing in KFR104 and KFR27. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site (KFR104)	Unpacking the trailer.	2008-11-12
8	Dummy logging (KFR104)	Borehole stability/risk evaluation.	2008-11-12
9	Calibration (KFR104)	SKB Caliper and SPR. Logging without the lower rubber sealing disks, no pumping.	2008-11-12 – 2008-11-13
10	EC- and temp-logging of the borehole fluid (KFR104)	Logging without the lower rubber sealing disks, no pumping.	2008-11-13 – 2008-11-14
11	Combined overlapping/sequential flow logging (KFR104)	Section length L_w=5 m. Step length dL=0.5 m, no pumping.	2008-11-14 – 2008-11-15
12	Overlapping flow logging (KFR104)	Section length L_w=5 m. Step length dL=0.5 m, pumping.	2008-11-15 – 2008-11-16
8	Dummy logging (KFR27)	Borehole stability/risk evaluation.	2008-11-15 – 2008-11-16
13 / 14	Overlapping flow logging and fracture-specific EC-measurements in pre-selected fractures (KFR104)	Section length L_w=1 m. Step length dL=0.1 m, pumping. Fracture-specific EC in pre-selected fractures.	2008-11-17 – 2008-11-19
13 Extra	Overlapping flow logging (KFR104)	Section length L_w=1 m. Step length dL=0.1 m, pumping.	2008-11-19 – 2008-11-20
15	EC- and temp-logging of the borehole fluid (KFR104)	Logging without the lower rubber sealing disks, pumping.	2008-11-20
16	Recovery transient (KFR104)	Measurement of water level and absolute pressure in the borehole after the pumping was stopped.	2008-11-20 – 2008-11-21
18 & 2	Demobilisation at KFR104 and mobilisation at KFR27	Packing the trailer. Moving to KFR27. Unpacking the trailer.	2008-11-21
8	Dummy logging (KFR27)	Borehole stability/risk evaluation.	2008-11-21
9	Calibration (KFR27)	SKB Caliper and SPR. Logging without the lower rubber sealing disks, no pumping.	2008-11-21
10	EC- and temp-logging of the borehole fluid (KFR27)	Logging without the lower rubber sealing disks, no pumping.	2008-11-22
11	Combined overlapping/sequential flow logging (KFR27)	Section length L_w=5 m. Step length dL=0.5 m, no pumping.	2008-11-22 – 2008-11-23
12	Overlapping flow logging (KFR27)	Section length L_w=5 m. Step length dL=0.5 m, pumping.	2008-11-23 – 2008-11-24
13 Extra	Overlapping flow logging (KFR27)	Section length L_w=1 m. Step length dL=0.1 m, pumping.	2008-11-24 – 2008-11-26
15	EC- and temp-logging of the borehole fluid (KFR27)	Logging without the lower rubber sealing disks, pumping.	2008-11-26
16	Recovery transient (KFR27)	Measurement of water level and absolute pressure in the borehole after the pumping was stopped.	2008-11-26 – 2008-11-27
18	Demobilisation (KFR27)	Packing the trailer.	2008-11-27

5.2 Nonconformities

Nonconformities in KFR104:

During dummy logging (Item 8) the dummy got stuck at c. 270 m and when overlapping flow logging with pumping (Item 12) was measured, the probe got stuck at c. 260 m. After the probe got stuck, a decision was made to not measure in or below the crushed problem zone (c. 260 m).

The pump stopped during automatic Item 12 measurements at night. This can be seen clearly (as a “hump”) in the head and water level curves in Appendices KFR104.10.1 and KFR104.10.2. The pump also restarted automatically, but between c. 283 m – 315 m the water level was not constant. A decision was made not to measure the interval again, because of the crushed zone.

After Items 13/14 a decision was made to lower the drawdown to 16 m and measure Item 13 Extra, because some of the flows with pumping were negative (from borehole into the bedrock) and the differences between flows in pumped conditions and natural conditions were quite small.

It was not physically possible to measure approximately 16.4 m of the bottom of the borehole. There were weights (3) and a centralizer in the measurement device, which reduce the measured distance by c. 5.1 m. The rubber sealing disks in the device must also be flipped before the measurement begins. This reduces the measured distance for approximately 10 cm. In addition, drill cuttings had been detected in BIPS imaging below 441.90 m.

Nonconformities in KFR27:

After overlapping flow logging with 5 m section length (Item 12) it was noticed that many of the flow anomalies in this borehole were in close proximity to one another. Because of this, a more detailed measurement with a 1 m section length was warranted (Item 13 Extra).

Approximately 6 m of the bottom of the borehole was not measured. It was not physically possible to measure approximately 3.7 m + 0.1 m of the bottom of the borehole, because there were weights (2) and a centralizer in the measurement device and the rubber sealing disks had to be flipped. It is also possible that there is rock debris at the bottom of the borehole.

6 Results

6.1 Length calibration

6.1.1 Caliper and SPR measurement

An accurate length scale for the measurements is difficult to achieve in long boreholes. The main cause of inaccuracy is the stretching of the logging cable. The stretching depends on the tension on the cable, the magnitude of which in turn depends, among other things, on the inclination of the borehole and the roughness (friction properties) of the borehole wall. The cable tension is larger 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 minimize the length errors. The length marks are initially detected with the SKB caliper tool. The length scale is first corrected according to the length marks. Single-point resistance is recorded simultaneously with the caliper logging. All flow measurement sequences can then be length corrected by synchronising the SPR results (SPR is recorded during all the measurements except borehole EC measurements) with the original caliper/ SPR-measurement.

The procedure of the length correction was as follows:

- The caliper/SPR-measurements (Item 9) were initially length corrected in relation to the known length marks, Appendices KFR104.1.21 and KFR27.1.19, black curve. Corrections between the length marks were obtained by linear interpolation.
- The SPR curve of Item 9 was then compared with the SPR curves of Items 11, 12, 13, 13 Extra and 14 to obtain relative length errors of these measurement sequences.
- All SPR curves could then be synchronized, as can be seen in Appendices KFR104.1.2 – KFR104.1.20 and KFR27.1.2 – KFR27.1.18.

The results of the caliper and single-point resistance measurements from all measurements in the entire borehole are presented in Appendices KFR104.1.1 and KFR27.1.1. Four SPR-curves from KFR104 are plotted together with the caliper-data. These measurements correspond to Items 9, 11, 12, 13 Extra and 13/14. Three SPR-curves from KFR27 are plotted together with the caliper-data. These measurements correspond to Items 9, 11, 12 and 13 Extra.

Zoomed results of the caliper and SPR data are presented in Appendices KFR104.1.2 – KFR104.1.20 and KFR27.1.2 – KFR27.1.18. The detectability of the length marks in borehole KFR104 is listed in Table 6-1 and KFR27 in Table 6-2. All the length marks were at least partially detected by the caliper tool in KFR104 and 6 out of 10 in KFR27.

All the length marks were detected in the single-point resistance measurements. The SPR-anomaly is complicated due to the four rubber sealing disks used at the upper end of the section, two at each side of the resistance electrode, but it is often possible to successfully detect the length marks even if the caliper tool has not found the marks.

The aim of the plots in Appendices KFR104.1.2 – KFR104.1.20 and KFR27.1.2 – KFR27.1.18 is to verify the accuracy of the length correction. The curves in these plots represent length corrected results. These appendices also illustrate a few locations where SPR anomalies that could be used to help in determining the location of the measurement tool in the borehole were found.

The magnitude of length correction along the borehole is presented in Appendices KFR104.1.21 and KFR27.1.19. The negative values of the error represent the situation where the logging cable has been extended, i.e., the cable is longer than the nominal length marked on it.

Table 6-1. Detected length marks, KFR104.

Length marks given by SKB (m)	Length marks detected by caliper	Length marks detected by SPR
49	both	yes
100	both	yes
149	both	yes
200	both	yes
250	both	yes
300	both	yes
353	both	yes
400	both	yes
435	both	yes

Table 6-2. Detected length marks, KFR27.

Length marks given by SKB (m)	Length marks detected by caliper	Length marks detected by SPR
48	none	yes
102	both	yes
150	both	yes
201	both	yes
249	both	yes
300	none	yes
358	only lower	yes
399	only lower	yes
450	none	yes
484	none	yes

6.1.2 Estimated error in location of detected fractures

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

1. The point interval in the overlapping mode flow measurements is 0.1 m. This could cause an error of ± 0.05 m.
2. The length of the test section is not exact. The specified section length denotes the distance between the nearest upper and lower rubber sealing disks. Effectively, the section length can be larger. At the upper end of the test section there are four rubber sealing disks. The distance between them is 5 cm. This will cause rounded flow anomalies: a flow may be detected already when a fracture is situated between the upper rubber sealing disks. These phenomena can cause an error of ± 0.05 m when the short step length (0.1 m) is used.
3. Corrections between the length marks can be other than linear. This could cause an error of ± 0.1 m in the caliper/SPR-measurement.
4. SPR curves may be imperfectly synchronized. This could cause an error of ± 0.1 m.

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

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

Knowing the location accurately is important when different measurements are compared, for instance flow logging and borehole TV. In 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.

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

6.2 Electrical conductivity and temperature

6.2.1 Electrical conductivity and temperature of borehole water

The electrical conductivity of the borehole water was initially measured when the borehole was at rest, i.e., at natural, un-pumped conditions. The measurement was performed downwards, see Appendices KFR104.2.1, KFR27.2.1 (linear scale), KFR104.2.2 and KFR27.2.2 (logarithmic scale), blue curve.

The EC measurement was repeated during pumping (after a pumping period of approximately five days in KFR104 and three days in KFR27), see Appendices KFR104.2.1, KFR104.2.2, KFR27.2.1 and KFR27.2.2, green curve.

In KFR27 the electrical conductivity measurement indicated that there was fresh water in the borehole at around c. 400 m in natural conditions. This result was confirmed by internal checks.

The temperature of the borehole water was measured simultaneously with the EC measurements. The EC values are temperature corrected to 25°C to make them more comparable with other EC measurements /Heikkonen et al.2002/. The temperature results in Appendices KFR104.2.3 and KFR27.2.3 have the same length axis as the EC results in KFR104.2.1, KFR104.2.2, KFR27.2.1 and KFR27.2.2.

The length calibration of the borehole electrical conductivity measurements is not as accurate as in other measurements, because single-point resistance is not registered. The length correction of the SPR/caliper-measurement was applied to the borehole EC measurements, black curve in Appendices KFR104.1.21 and KFR27.1.19.

6.2.2 Electrical conductivity of fracture-specific water

Electrical conductivity of fracture-specific water measurements were made only in borehole KFR104.

The flow direction is always from the fractures into the borehole if the borehole is pumped with a sufficiently large drawdown. This enables the determination of electrical conductivity from fracture-specific water. Both electrical conductivity and temperature of flowing water from the fractures were measured.

The fractures detected in the flow measurements can be measured for electrical conductivity later. These fracture-specific measurements begin near the fracture which has been chosen for inspection. The tool is first moved stepwise closer to the fracture until the detected flow is larger than a predetermined limit. At this point the tool is stopped. The measurement is continued at the given position allowing the fracture-specific water to enter the section. The waiting time for the EC measurement can be automatically calculated from the measured flow rate. The aim is to flush the water volume within the test section sufficiently to gain accurate results. The measuring computer is programmed so that the water in the test section will be replaced approximately three times over. After the set of stationary measurements, the tool is once again moved stepwise past the fracture. The electrical conductivity is also measured during the stepwise movement before and after the set of stationary measurements.

The test section in these measurements was 1 m long and the tool was moved in 0.1 m steps. The water volume in a 1 m long test section is 3.6 L. The results are presented in Appendices KFR104.11.1 – KFR104.11.2. The blue symbol represents the conductivity value when the tool was moved and the red symbol is used for the set of stationary measurements.

Lengths to the upper and lower ends of the section, fracture locations and the final EC values for borehole KFR104 are listed in Table 6-3.

For comparison, the fracture-specific EC and temperature results are also plotted with the EC and temperature results of borehole water, see Appendices KFR104.2.1 – KFR104.2.3.

Table 6-3. Fracture-specific EC, KFR104.

Upper end of section (m)	Lower end of section (m)	Measured fractures (m)	EC (S/m) at 25°C
49.51	50.51	50.1	0.93
64.00	65.00	64.6	0.93
72.80	73.80	73.5	0.94
90.50	91.50	91.2	0.95

6.3 Pressure measurements

Absolute pressure was registered together with the other measurements in Items 11 – 14 and 16. The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered separately, see Appendices KFR104.10.2 and KFR27.10.2. The hydraulic head along the borehole at natural and pumped conditions is determined in the following way. First, the monitored air pressure at the site is subtracted from the measured absolute pressure. The hydraulic head (h) at a certain elevation (z) is calculated according to the following expression /Nordqvist 2001/:

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

where

h is the hydraulic head (masl) according to the RHB 70 reference system,

p_{abs} is the absolute pressure (Pa),

p_b is the barometric (air) pressure (Pa),

ρ_{fw} is the unit density, 1,000 kg/m^3

g is the standard gravity, 9.80665 m/s^2 and

z is the elevation of measurement (masl) according to the RHB 70 reference system.

A sensor-specific offset of –1.97 kPa is added to absolute pressure results.

The calculated head distributions are presented in Appendices KFR104.10.1 and KFR27.10.1. The exact z-coordinates are important in head calculation. A 10 cm error in the z-coordinate means a 10 cm error in the head.

6.4 Flow logging

6.4.1 General comments on results

The measuring programme contained several flow logging sequences. They were gathered on the same diagram with single-point resistance (right hand side) and caliper plots (in the middle), see Appendices KFR104.3.1–KFR104.3.22 and KFR27.3.1–KFR27.3.21. SPR has a lower value on a fracture where flow is detected. Many other resistance anomalies result from other fractures and geological features. As the electrode of the SPR tool is located within the upper rubber sealing disks of the probe, the locations of resistance anomalies associated with leaky fractures coincide with the lower end of the flow anomalies.

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

The flow logging was first performed with a 5 m section length and with 0.5 m length increments. The method (overlapping flow logging) gives the length and the thickness of conductive zones with a length resolution of 0.5 m.

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

In these measurements some negative (into the bedrock) flows were detected during pumping in both boreholes. In KFR104 an extra measurement was performed using a larger drawdown, but because of the crushed zone the entire borehole was not measured completely with this drawdown. In KFR27 all the pumped state measurements were conducted using the same drawdown.

The test section length determines the width of a flow anomaly of a single fracture. If the distance between flow yielding fractures is less than the section length, the anomalies will overlap, resulting in a stepwise flow data plot. The overlapping flow logging was repeated in the vicinity of identified flow anomalies using a 1 m long test section and 0.1 m length increments.

The positions (borehole length) of the detected fractures are shown on the caliper scale. 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 or the flow anomalies are overlapping or unclear because of noise.

The coloured triangles show the magnitude and direction of the measured flows. The triangles have the same colour than the corresponding curves.

The explanations to the tables in Appendices KFR104.5 , KFR104.7, KFR27.5 and KFR27.7 are given in Appendices KFR104.4 and KFR27.4.

6.4.2 Transmissivity and hydraulic head of borehole sections

The boreholes were flow logged with a 5 m section length and with 0.5 m length increments both in un-pumped and pumped conditions.

The results of the measurements with a 5 m section length are presented in tables, see Appendices KFR104.5.1–KFR104.5.3 and KFR27.5.1–KFR27.5.3. Only the results with 5 m length increments are used in borehole KFR27 and results with 5 m and 1 m length increments are used in KFR104. The flow results from the 1 m section length measurements have been summed within each 5 m interval in order to find the section flow. All borehole sections are shown in Appendices KFR104.3.1–KFR104.3.22 and KFR27.3.1–KFR27.3.21. Secup and Seclow in Appendices KFR104.5.1–KFR104.5.3 and KFR27.5.1–KFR27.5.3 are the distances along the borehole from the reference level (top of the casing tube) to the upper end of the test section and to the lower end of the test section, respectively. The Secup and Seclow values for the two sequences (measurements in un-pumped and pumped conditions) are not exactly identical, due to a minor difference in the cable stretching. The difference between these two sequences was small. Secup and Seclow given in Appendices KFR104.5.1–KFR104.5.3 and KFR27.5.1–KFR27.5.3 are calculated as the average of these two values.

Pressure was measured and calculated as described in Section 6.3. h_{0FW} and h_{1FW}/h_{2FW} in Appendices KFR104.5.1–KFR104.5.3 and KFR27.5.1–KFR27.5.3 represent heads determined without and with pumping, respectively. The head in the borehole and calculated heads of borehole sections are given in RHB 70 scale.

The flow results in Appendices KFR104.5.1–KFR104.5.3 (Q_0, Q_1 and Q_2) and KFR27.5.1–KFR27.5.3 (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.

With the borehole KFR104 at rest, 43 sections were detected as flow yielding, 34 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping in borehole KFR104, 44 sections were detected as flow yielding, 38 of which had a flow direction towards the borehole (positive flow) and six of the detected flows had a flow direction from the borehole into the bedrock. 34 of the positive flows were measured with the 1 m section length and 16 m drawdown.

Without pumping in the borehole KFR27, 29 sections were detected as flow yielding, 27 of which had a flow direction from the borehole into the bedrock (negative flow).
During pumping 31 sections were detected as flow yielding, 27 of which had a flow direction towards the borehole (positive flow).

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

The flow data is presented as a plot, see Appendices KFR104.6.1 and KFR27.6.1. The left-hand plot in each diagram represents flow from the borehole into the bedrock for the respective test sections, while the right-hand plot represents flow from the bedrock into the borehole. If flow could not be detected (zero flow), no corresponding point will be visible on the logarithmic plots in the appendices.

The lower and upper measurement limits of the flow are also presented in the plots (Appendices KFR104.6.1 and KFR27.6.1) and in the tables (Appendices KFR104.5 and KFR27.5). There are theoretical and practical lower limits of flow, see Section 6.4.4.

The hydraulic head and transmissivity (T_D) of borehole sections can be calculated from the flow data using the method described in Chapter 3. The results are illustrated in Appendices KFR104.6.2 and KFR27.6.2. The hydraulic head of sections is presented in the plots if none of the two flow values at the same length is equal to zero. Transmissivity is presented if none or just one of the flows is equal to zero.

The measurement limits of transmissivity are also shown in Appendices KFR104.6.2, KFR27.6.2 and in Appendices KFR104.5 and KFR27.5. All the measurement limit values of transmissivity are based on the actual pressure difference in the borehole (h_{0FW} and h_{1FW}/ h_{2FW} in Appendices KFR104.5 and KFR27.5).

In borehole KFR104 the sum of all the detected flows without pumping (Q_0) was $-2.98 \cdot 10^{-6}$ m^3/s (–10.7 L/h). This sum should normally be zero if all the flows in the borehole are not disturbed by noise or other external factors, 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. There may be leaks from the bedrock into the borehole between the lengths 9 m (end of the casing tube) and 19 m that could not be properly measured, see Appendix KFR104.3.1. This part of the borehole could possibly explain the unbalance of the summed flow rates.

As the top part of KFR27 was not measured, the flow sum was not calculated.

The weights and a centralizer in the measurement device and drill debris in the borehole prohibit measuring the borehole all the way to the bottom and it is always possible that there are also flows in this area.

6.4.3 Transmissivity and hydraulic head of fractures

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

In cases where the fracture distance is less than one metre, it may be difficult to evaluate the flow rate. There are such cases for instance in Appendices KFR104.3.3 and KFR27.3.12. In these cases a stepwise increase or decrease in the flow data plot equals the flow rate of a specific fracture (filled triangles in the appendices).

Since the 1 m long measurement section was not used during un-pumped conditions, the results for the 5 m section were used instead. The fracture locations are important when evaluating the flow rate in un-pumped conditions. The fracture locations are known on the basis of the 1 m section measurements. It is not a problem to evaluate the flow rate during un-pumped conditions when the distance between flowing fractures is more than 5 m. The evaluation may, however, be problematic when the distance between fractures is less than 5 m. In this case an increase or decrease of a flow anomaly at the fracture location determines the flow rate. However, this evaluation is used conservatively, i.e., only in the clearest of cases, and no flow value is usually evaluated during un-pumped conditions at densely fractured parts of bedrock. If the flow for a specific fracture cannot be determined conclusively, the flow rate is marked with "–" and the value 0 is used in the transmissivity calculation, see Appendices KFR104.7 and KFR27.7. The flow direction is evaluated as well. The results of the evaluation are plotted in Appendices KFR104.3 and KFR27.3, blue filled triangle.

The total amount of detected flowing fractures in borehole KFR104 was 92, but only 33 of them could be defined without pumping. These 33 fractures could be used for head estimations and all 92 were used for transmissivity estimations. As there were no 1 m section length measurements below 240 m, the fractures below 240 m were interpreted using the 5 m section length results. The results for the 293.6 m fracture are uncertain (fracture transmissivity and head were not calculated), because the pump had stopped during the 5 m section length measurements and the drillhole conditions were changing, see Section 5.2. In these measurements the total amount of detected flowing fractures in borehole KFR27 was 76, but only 22 of them could be defined without pumping. These 22 fractures could be used for head estimations and all 76 were used for transmissivity estimations.

Transmissivities were not calculated for the fractures above the 143.3 m fracture, because the natural state (no pumping) PFL DIFF measurements for these fractures were conducted before the borehole was extended and are therefore not applicable. The results for the 231 m and 234.1 m fractures were not used for transmissivity calculations because the pumped flows were directed towards the bedrock and the flow rates were higher than the corresponding section flow in the 5 m natural state measurements. This is unusual and it should not happen if hydraulic background conditions and fracture properties remain the same. Fracture aperture at the borehole wall is critical and the result could possibly be explained by a wider fracture aperture during pumping.

Transmissivity and hydraulic head of fractures are presented in Appendices KFR104.7, KFR104.8, KFR27.7 and KFR27.8.

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

Fracture-specific transmissivities were compared with transmissivities of sections in Appendices KFR104.9 and KFR27.9. All fracture-specific transmissivities within each 5 m interval were first summed together to make them comparable with measurements with a 5 m section length. The results are fairly consistent between the two types of measurements. There is some inconsistency in the transmissivities between 419.50 m–429.48 m in KFR27. This is most likely caused by the inaccuracy in the fracture location, see Section 6.1.2. The decrease of flow as a function of pumping time can be seen in some fractures (in KFR27). The 1 m section measurements were carried out later than the 5 m section measurements and therefore flow rate and transmissivity can be smaller in the 1 m section measurement results.

6.4.4 Theoretical and practical measurement limits of flow and transmissivity

The theoretical minimum for measurable flow rate in overlapping measurements is some 30 mL/h. The upper limit of flow measurement is 300,000 mL/h. As these upper and lower limits are determined by flow calibration, it is assumed that flows 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 have an influence on the flow base level (i.e. noise level). Noise levels can be evaluated in intervals along the borehole where there are no flowing fractures or other complicating structures, and may vary along a borehole.

There are several known reasons for increased noise in the flow:

1) Roughness of the borehole wall
2) Solid particles such as clay or drilling debris in the water
3) Gas bubbles entrained in the water
4) High flow rate along the borehole

Roughness in the borehole wall always results in high levels of noise, not only in the flow results, but also in the SPR results. The flow curve and SPR curves are typically spiky when the borehole wall is rough.

Drilling debris usually increases noise levels. This kind of noise is typical for both natural (un-pumped) and pumped conditions.

Pumping results in lower pressure in the borehole water and in the water in fractures located near the borehole. This may lead to the release of dissolved gas and increase the quantity of gas bubbles entrained in the water. Some fractures may produce more gas than others. Sometimes, when the borehole is being measured upwards, increased noise levels are observed just above certain fractures. The reason for this is assumed to be gas bubbles.

The effect of a high flow rate along the borehole can often be seen above fractures with a high flow. Any minor leakage in the seal provided by the lower rubber sealing disks will appear in the measurement as increased levels of noise.

A high level of noise in a flow will mask the "real" flow if this is smaller than the noise. Real flows are registered correctly if they are about ten times larger than the noise but are totally invisible if they are some ten times smaller than the noise. Experience indicates that real flows between one-tenth of the noise level and 10 times the noise level are summed with the noise. Noise levels could therefore be subtracted from measured flows to get real flows. This correction has not yet been carried out because the cases to which it is applicable are unclear.

The practical minimum for measurable flow rate is presented in Appendices KFR104.3.1 – KFR104.3.22 and KFR27.3.1 – KFR27.3.21 using a grey dashed line (Lower limit of flow rate). The practical minimum level of the measurable flow is always evaluated in pumped conditions since this measurement is the most important for transmissivity calculations. The limit is an approximation. It is evaluated to obtain a limit below which there may be fractures or structures that remain undetected.

The noise level in KFR104 varied between 30 mL/h and 300 mL/h and in KFR27 between 30 mL/h and 2,000 mL/h. It is possible to detect the existence of flow anomalies below the theoretical limit of the thermal dilution method (30 mL/h). The noise line (grey dashed line) was never drawn below 30 mL/h, because the values of flow rate measured below 30 mL/h are uncertain.

In some boreholes the upper limit of flow measurement (300,000 mL/h) may be exceeded. Such fractures or structures hardly remain undetected (as the fractures below the lower limit). High flow fractures can be measured separately at a smaller drawdown. The measurement limit was not exceeded in the 5 m or 1 m measurements and therefore no re-measurements were needed.

The practical minimum for measurable flow rate is also presented in Appendices KFR104.5 and KFR27.5 (Q-lower limit P) and is obtained from the plots in Appendices KFR104.3 and KFR27.3 (Lower limit of flow rate). The practical minimum of measurable transmissivity can be evaluated using Q-lower limit and the actual head difference at each measurement location, see Appendices KFR104.5 and KFR27.5 (T_D-measl$_{LP}$). The theoretical minimum for measurable transmissivity (T_D-measl$_{LT}$) is evaluated using a Q value of 30 mL/h (the minimum theoretical flow rate using the thermal dilution method). The upper measurement limit for transmissivity can be evaluated using the maximum flow rate (300,000 mL/h) and the actual head difference as above, see Appendices KFR104.5 and KFR27.5 (T_D-measl$_U$).

All three flow limits are plotted with the measured flow rates, see Appendices KFR104.6.1 and KFR27.6.1. 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 KFR104.6.2 and KFR27.6.2.

Similar flow and transmissivity limits are not provided for the fracture-specific results as the limits for these are harder to define. The situation is similar for the upper flow limit. If several high-flowing fractures are positioned closer to one another than a distance of one metre, the upper flow limit will depend on the sum of these flows, and this must be below 300,000 mL/h.

6.5 Groundwater level and pumping rate

The level of the groundwater table in the borehole during the measurement sequences is presented in Appendices KFR104.10.2 and KFR27.10.2.

Borehole KFR104 was pumped between November 15 and November 20. The drawdown was approximately 5 m except during the additional measurement (Item 13 Extra) and borehole-EC (Item 15) where a drawdown of approximately 16 m was used.

Borehole KFR27 was pumped between November 23 and November 26 with a drawdown of approximately 5 metres.

The pumping rates were recorded, see Appendices KFR104.10.2 and KFR27.10.2.

The groundwater recovery of KFR104 was measured after the pumping period, between November 20 and 21, see Appendix KFR104.10.3. Recovery of KFR27 was measured after the pumping period, between November 26 and 27, see Appendix KFR27.10.3. The recovery was measured in both boreholes with two sensors, the water level sensor (pressure sensor for monitoring water level) and the absolute pressure sensor. The absolute pressure sensor was located at the length of 34.7 m in borehole KFR104 and at the length of 23.8 m in borehole KFR27.

6.5.1 Transmissivity of the entire borehole

(by J-E Ludvigson, Geosigma AB)

The pumping test during difference flow logging and its subsequent recovery period is utilized to evaluate the transmissivity of the entire borehole. From the flow period the transmissivity is estimated by two steady-state methods together with transient analysis of the recovery period as described in Chapter 3. Only the pressure recovery measured by the water level sensor was analysed. The pressure recovery measured by the deeper sensor was similar, see Appendix KFR104.10.3 and KFR27.10.3 respectively.

Transient analysis is done on the pressure recovery period after the pumping in accordance with the methodology specified in SKB MD 320.004 (SKB internal controlling document). Briefly, it specifies that the transient analysis of the pressure recovery should be made versus Agarwal equivalent time in log-log and semi-log plots including the pressure derivative. The storativity S was estimated from an empirical relationship between T and S described in the MD above. Furthermore, the skin factor and the borehole storage coefficient C should also be estimated. If the transmissivity changes during the test, e.g. due to hydraulic boundaries or intersecting hydraulic structures with deviating transmissivity, the estimated hydraulic properties (and radius of influence) should be based on the early response before any effects of hydraulic boundaries are observed.

KFR104

Steady-state analysis

The final flow rate Q_p during the flow period in KFR104 was c. 7.2 L/min and the drawdown of the water level was s_p = 16.53 m by the end of the flow period (Appendix KFR104.10.2). The steady-state transmissivity calculated with Dupuit's formula (Equation 3-9) and Moye's equation (Equation 3-10), respectively is shown in Table 6-5. In Dupuit's formula, the ratio R/r_0 is assumed to be 500, c.f. Chapter 3. In Moye's formula, the length of the test section L (open borehole interval) is 445.84 m and the borehole diameter $2r_0$ is 0.0758 m. The borehole is cased in the interval 0–8.73 m with an inner diameter of 0.0770 m.

Transient analysis

Figures 6-1a and b shows log-log and semi-log plots respectively of the transient pressure recovery of the water level during the pumping test in KFR104 which was used to estimate the transmissivity of the entire borehole. The pressure recovery seems to be dominated by wellbore storage during the first c. 100 s. However, the initial pressure response is fast and it is not clear if this effect is real or due to uncertainties in the early data curve. After a rather long transition period, pseudo-radial flow (PRF) occurs after c. 20,000 s (c. 5.5 h), cf Figure 6-1a.

From the transient response during the recovery period test parameters were estimated for an assumed storativity value (calculated from the empirical relationship between T and S). The best fit simulation yields a transmissivity $T = 6.2 \cdot 10^{-6}$ m²/s, a skin factor of –4.9 and a wellbore storage coefficient of $C = 4.1 \cdot 10^{-7}$ m³/Pa. The latter coefficient is calculated from the simulated effective casing radius of the borehole. The estimated transmissivity of borehole KFR104 according to the three methods described above is given in Table 6-5. The transient transmissivity T_T was selected as the most representative for the borehole.

Table 6-4. Estimated transmissivity of borehole KFR104.

Method	Transmissivity (m^2/s)
Dupuit	$7.2 \cdot 10^{-6}$
Moye	$1.1 \cdot 10^{-5}$
Transient	$6.2 \cdot 10^{-6}$

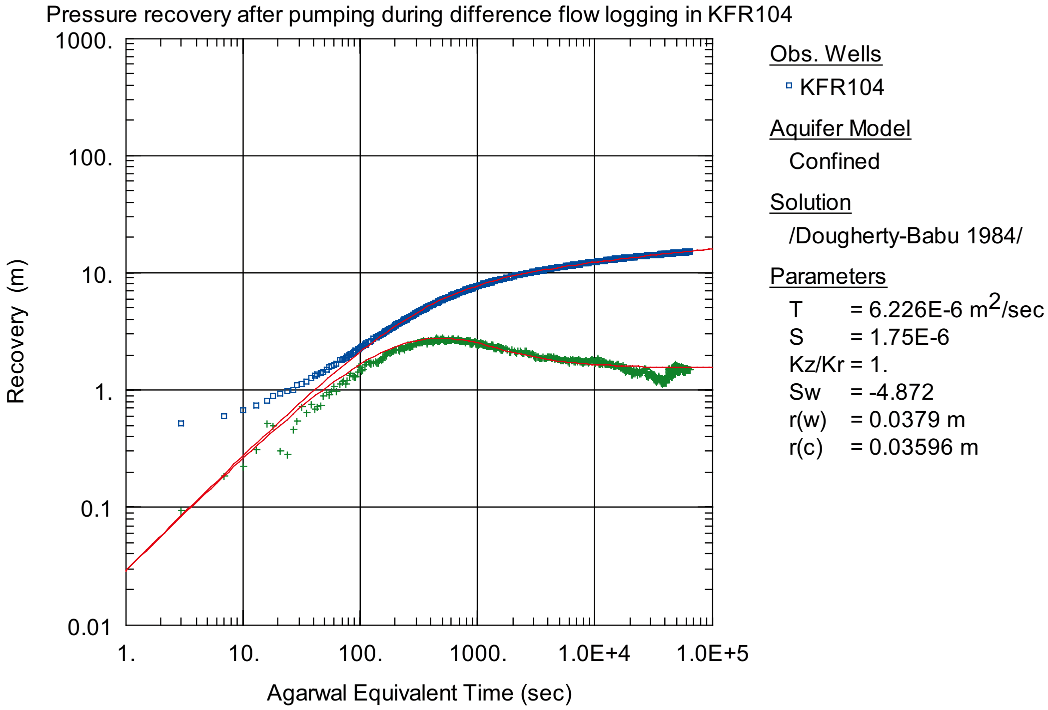


Figure 6-1a. *Log-log plot of the pressure recovery in KFR104 showing the observed pressure recovery of the water level (□) and associated derivative (+) versus Agarwal equivalent time together with simulated best fit curves of the pressure recovery and its derivative (-).*

KFR27

Steady-state analysis

The final flow rate Q_p during the flow period in KFR27 was c. 11.4 L/min and the drawdown of the water level was s_p = 5.07 m by the end of the flow period (Appendix KFR27.10.2). The steady-state transmissivity calculated with Dupuit's formula (Equation 3-9) and Moye's equation (Equation 3-10), respectively is shown in Table 6-5. In Dupuit's formula, the ratio R/r_0 is assumed to be 500, c.f. Chapter 3. The total borehole length of KFR27 is 501.64 m. In Moye's formula (Equation 3-10) the length of the test section L (open borehole interval) is 489.73 m and the borehole diameter $2r_0$ is 0.0758 m. The borehole is cased in the interval 0–11.91 m with an inner diameter of 0.0770 m.

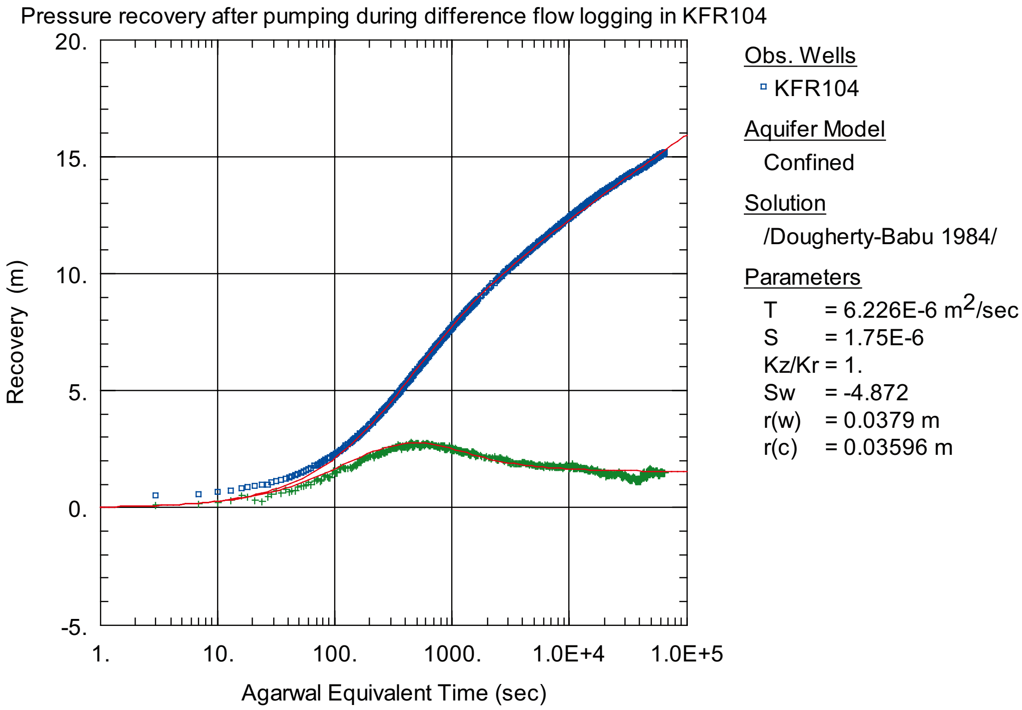


Figure 6-1b. *Lin-log plot of the pressure recovery in KFR104 showing the observed pressure recovery of the water level (□) and associated derivative (+) versus Agarwal equivalent time together with simulated best fit curves of the pressure recovery and its derivative (-).*

Transient analysis

Figures 6-2a and b respectively shows log-log and semi-log plots of the transient pressure recovery of the water level during the pumping test in KFR27 from which the transmissivity of the entire borehole was estimated. The pressure recovery period indicates a fracture response (strongly negative skin factor) transitioning to pseudo-radial flow (PRF) after c. 5,000 s (c. 1.4 h). By the end of the recovery period, an apparent no-flow hydraulic boundary is indicated, cf Figure 6-2a. However, it may also be interpreted as non-significant pressure fluctuations.

From the transient response during the recovery period, test parameters were estimated for an assumed storativity value (calculated from the empirical relationship between T and S). The best fit simulation yields a transmissivity $T = 2.1 \cdot 10^{-5}$ m²/s, a skin factor = –7.8 and a fixed wellbore storage coefficient of $C = 4.7 \cdot 10^{-7}$ m³/Pa corresponding to the inner casing diameter.

The estimated transmissivity of borehole KFR27 according to the three methods described above are given in Table 6-6. The transient transmissivity T_T was selected as the most representative for the borehole.

Table 6-5. Estimated transmissivity of borehole KFR27.

Method	Transmissivity (m²/s)
Dupuit	$3.7 \cdot 10^{-5}$
Moye	$5.8 \cdot 10^{-5}$
Transient	$2.1 \cdot 10^{-5}$

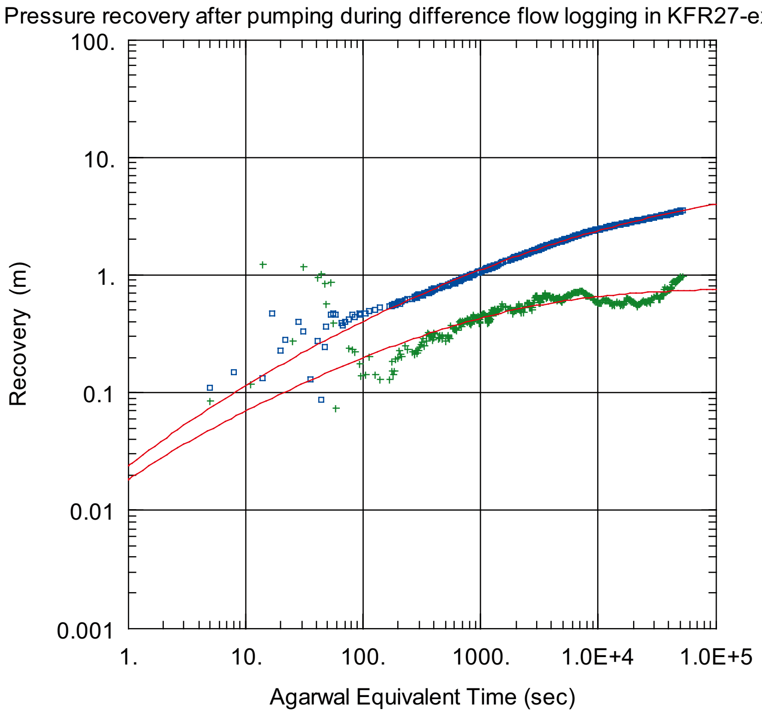


Figure 6-2a. *Log-log plot of the pressure recovery in KFR27 showing the observed pressure recovery of the water level (□) and associated derivative (+) versus Agarwal equivalent time together with simulated best fit curves of the pressure recovery and its derivative (-).*

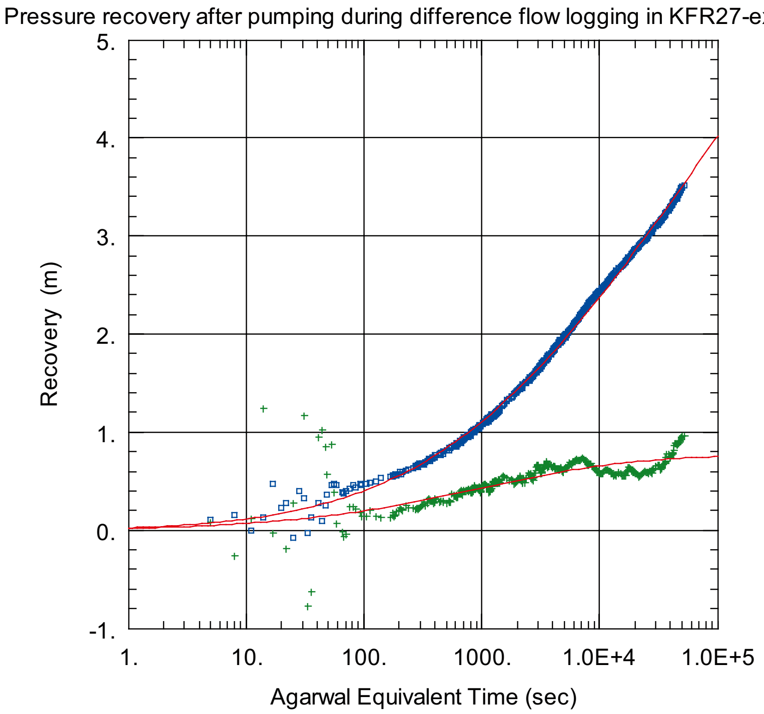


Figure 6-2b. *Lin-log plot of the pressure recovery in KFR27 showing the observed pressure recovery of the water level (□) and associated derivative (+) versus Agarwal equivalent time together with simulated best fit curves of the pressure recovery and its derivative (-).*

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 KFR104 and KFR27 at Forsmark, Sweden. The upper part of borehole KFR27 had already been measured in July 2008 /Pekkanen et al. 2008/. The extended part below c. 140 m was measured during this campaign.

Measurements were carried out both when the borehole was at rest and during pumping. A 5 m section length with 0.5 m length increments was used initially. The detected flow anomalies were re-measured with a 1 m section and a 0.1 m measurement interval except in borehole KFR104 where such measurements were not conducted below c. 240 m. The reason being that the 5 m section length device got stuck in the borehole during the measurements and further measurements were deemed too risky.

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

The distribution of saline water along the borehole was logged by electrical conductivity and temperature measurements of the borehole water. In addition, the electrical conductivity of fracture-specific water was measured in selected flowing fractures in KFR104.

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

Transmissivity and hydraulic head were calculated for measured borehole sections. The highest section transmissivity in KFR104 ($2.7 \cdot 10^{-6}$ m^2/s) was detected at length interval 60.30 m–65.30 m and in KFR27 ($6.1 \cdot 10^{-6}$ m^2/s) at length interval 189.42 m–194.42 m. Other high-transmissive sections were found in KFR104 at length intervals 70.32 m–75.32 m and 205.41 m–210.41 m and in KFR27 at length intervals 349.50 m–354.50 m and 424.48 m–429.48 m.

The total amount of detected flowing fractures in these measurements was 92 in KFR104 and 76 in KFR27.

References

Dougherty D E and Babu D K, 1984. Flow to a partially penetrating well in a double-porosity reservoir, Water Resour. Res, 20 (8), 1116–1122.

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

Ludvigson J-E, Hansson K and Rouhiainen P, 2002. Methodology study of Posiva difference flow meter in borehole KLX02 at Laxemar. SKB Rapport R-01-52.

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

Moye D G, 1967. Diamond drilling for foundation exploration. Civil Eng. Trans., Inst. Eng. Australia, 95–100.

Nordqvist R, 2001. Grundvattentryck – Inventering och utarbetande av rekommendationer för det geovetenskapliga undersökningsprogrammet. Djupförvarsteknik. SKB TD-03-01, Svensk Kärnbränslehantering AB.

Pekkanen J Pöllänen J and Väisäsvaara J, 2008. Site investigation SFR. Difference flow logging in boreholes KFR101 and KFR27. SKB P-08-98, Svensk Kärnbränslehantering AB.

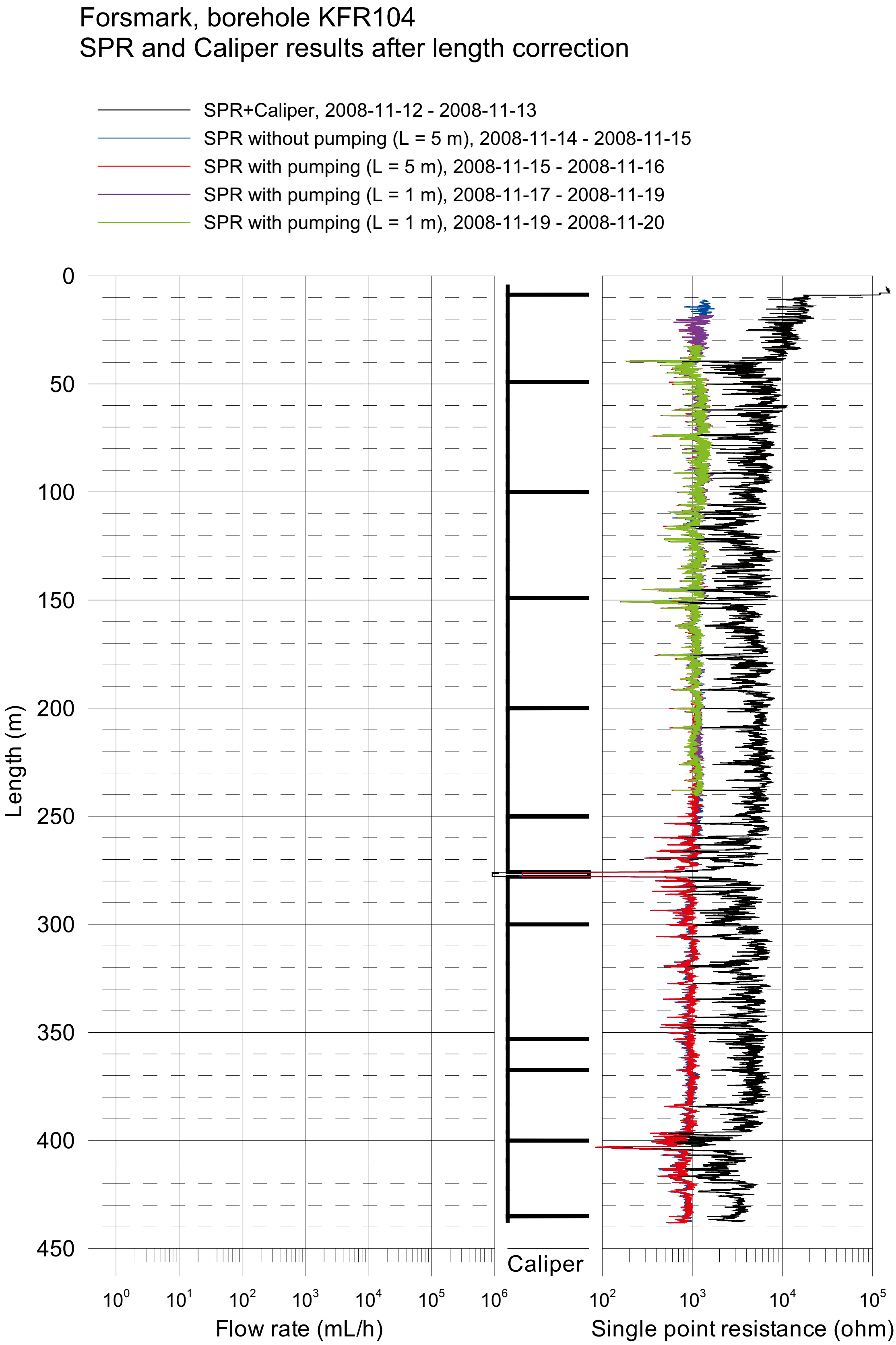
Öhberg A and Rouhiainen P, 2000. Posiva Groundwater Flow Measuring Techniques. Posiva 2000-12.

Appendices KFR104

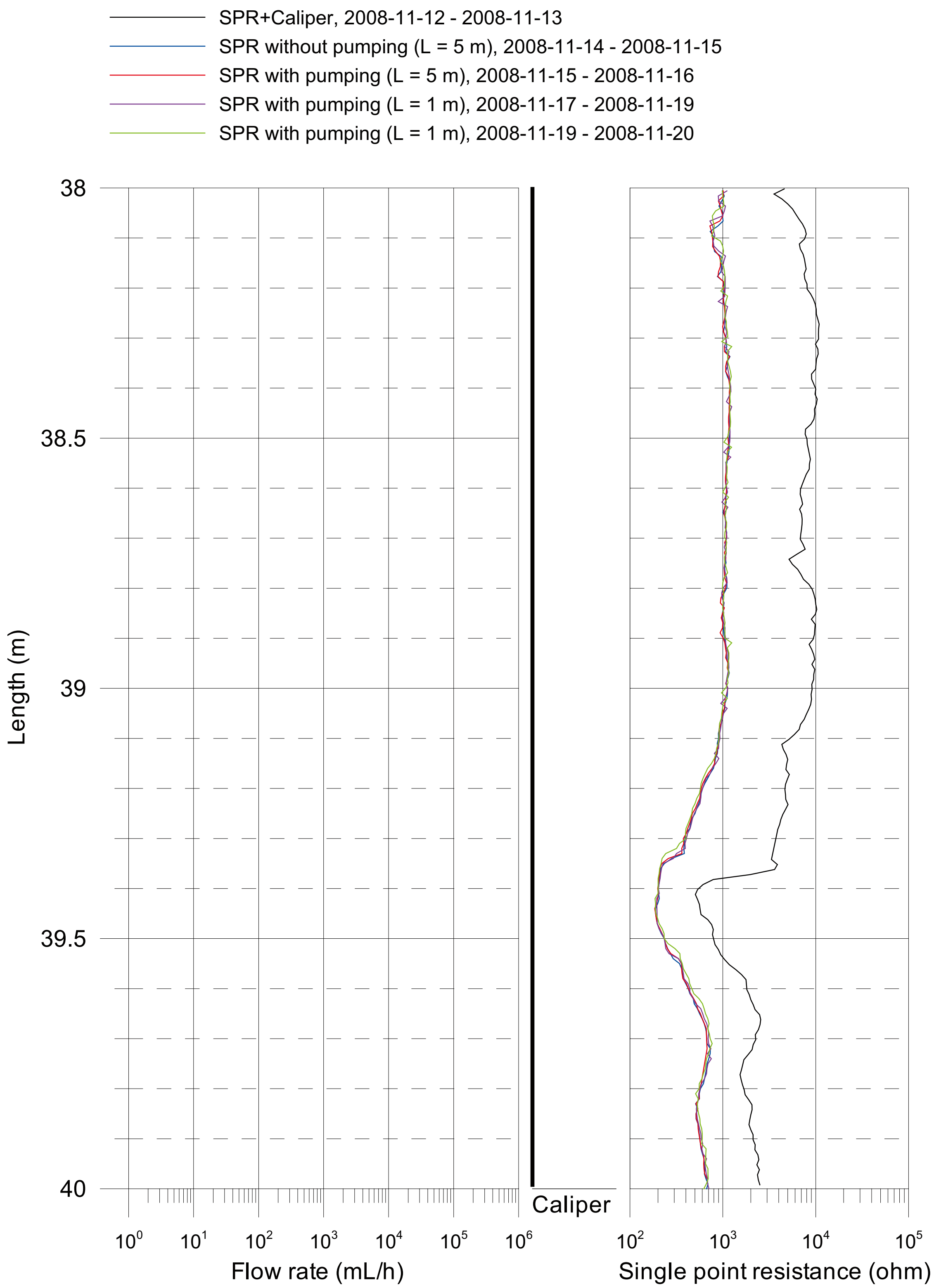
Appendices	KFR104.1.1–KFR104.1.20	SPR and Caliper results after length correction
Appendix	KFR104.1.21	Length correction
Appendices	KFR104.2.1–KFR104.2.2	Electrical conductivity of borehole water
Appendix	KFR104.2.3	Temperature of borehole water
Appendices	KFR104.3.1–KFR104.3.22	Flow rate, caliper and single point resistance
Appendix	KFR104.4	Explanations for the tables in Appendices 5 and 7
Appendices	KFR104.5.1–5.3	Results of sequential flow logging
Appendix	KFR104.6.1	Plotted flow rates of 5 m sections
Appendix	KFR104.6.2	Plotted transmissivity and head of 5 m sections
Appendices	KFR104.7.1–KFR104.7.3	Inferred flow anomalies from overlapping flow logging
Appendix	KFR104.8	Plotted transmissivity and head of detected fractures
Appendix	KFR104.9	Comparison between section transmissivity and fracture transmissivity
Appendix	KFR104.10.1	Head in the borehole during flow logging
Appendix	KFR104.10.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	KFR104.10.3	Groundwater recovery after pumping
Appendices	KFR104.11.1–KFR104.11.2	Fracture-specific EC results by date

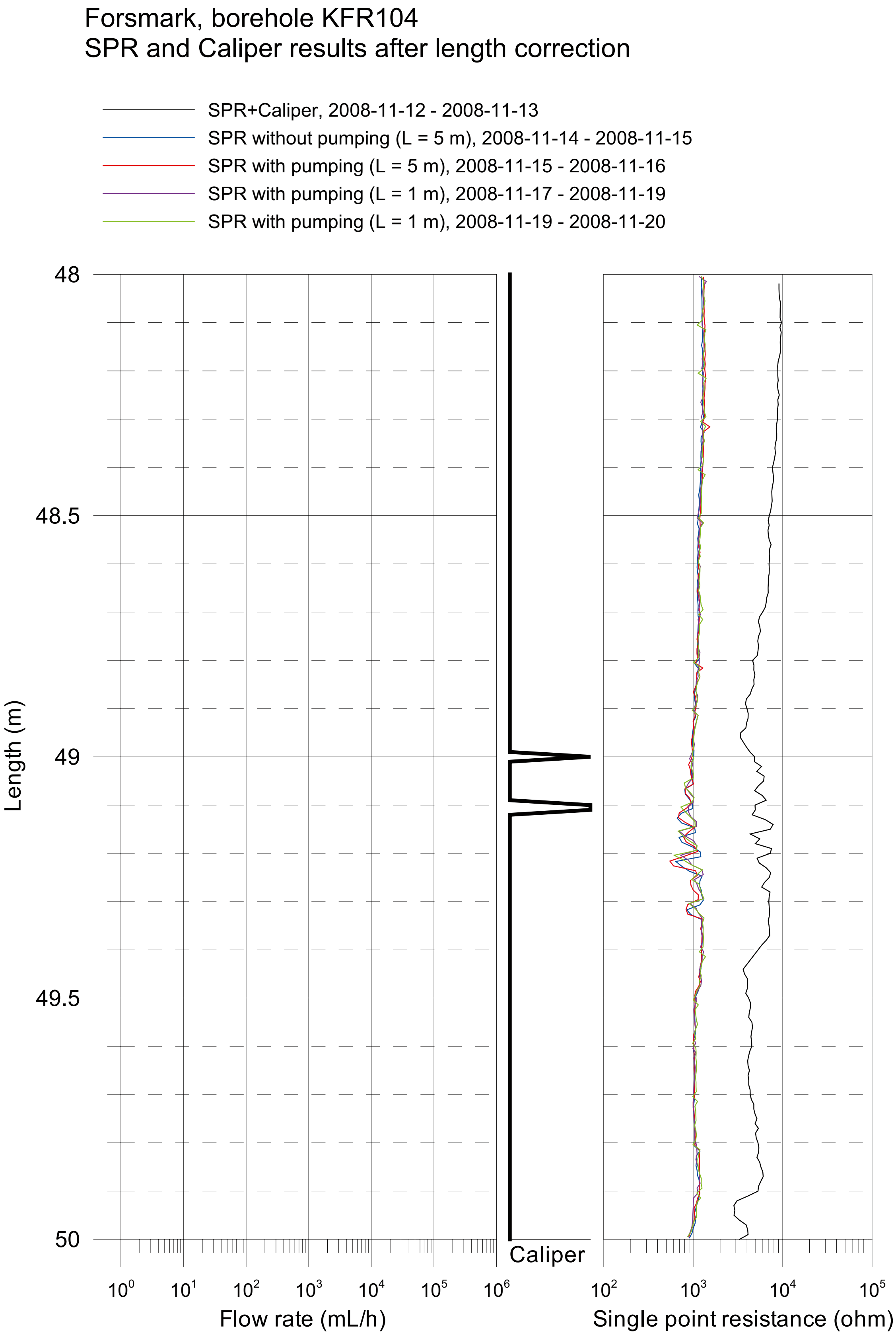
Appendices KFR27

Appendices	KFR27.1.1–KFR27.1.18	SPR and Caliper results after length correction
Appendix	KFR27.1.1.19	Length correction
Appendices	KFR27.2.1–KFR27.2.2	Electrical conductivity of borehole water
Appendix	KFR27.2.3	Temperature of borehole water
Appendices	KFR27.3.1–KFR27.3.21	Flow rate, caliper and Single point resistance
Appendix	KFR27.4	Explanations for the tables in Appendices 5 and 7
Appendices	KFR27.5.1–KFR27.5.3	Results of sequential flow logging
Appendix	KFR27.6.1	Plotted flow rates of 5 m sections
Appendix	KFR27.6.2	Plotted transmissivity and head of 5 m sections
Appendices	KFR27.7.1–KFR27.7.2	Inferred flow anomalies from overlapping flow logging
Appendix	KFR27.8	Plotted transmissivity and head of detected fractures
Appendix	KFR27.9	Comparison between section transmissivity and fracture transmissivity
Appendix	KFR27.10.1	Head in the borehole during flow logging
Appendix	KFR27.10.2	Air pressure, water level in the borehole and pumping rate during flow logging
Appendix	KFR27.10.3	Groundwater recovery after pumping

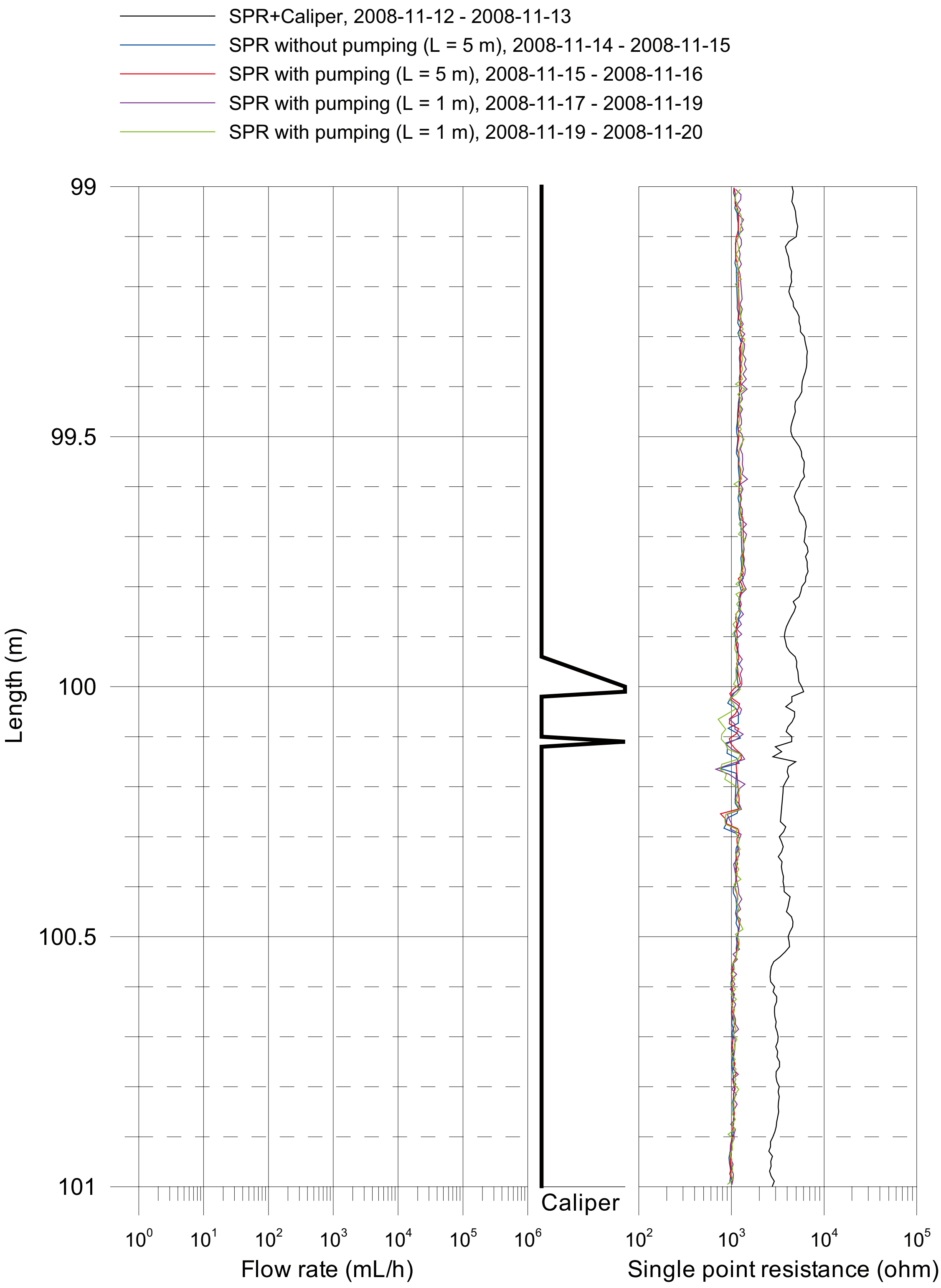

Forsmark, borehole KFR104
SPR and Caliper results after length correction
SPR+Caliper, 2008-11-12 - 2008-11-13
SPR without pumping (L = 5 m), 2008-11-14 - 2008-11-15
SPR with pumping (L = 5 m), 2008-11-15 - 2008-11-16
SPR with pumping (L = 1 m), 2008-11-17 - 2008-11-19
SPR with pumping (L = 1 m), 2008-11-19 - 2008-11-20
Length (m)
0
50
100
150
200
250
300
350
400
450
Caliper
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
10^2
10^3
10^4
10^5
Single point resistance (ohm)

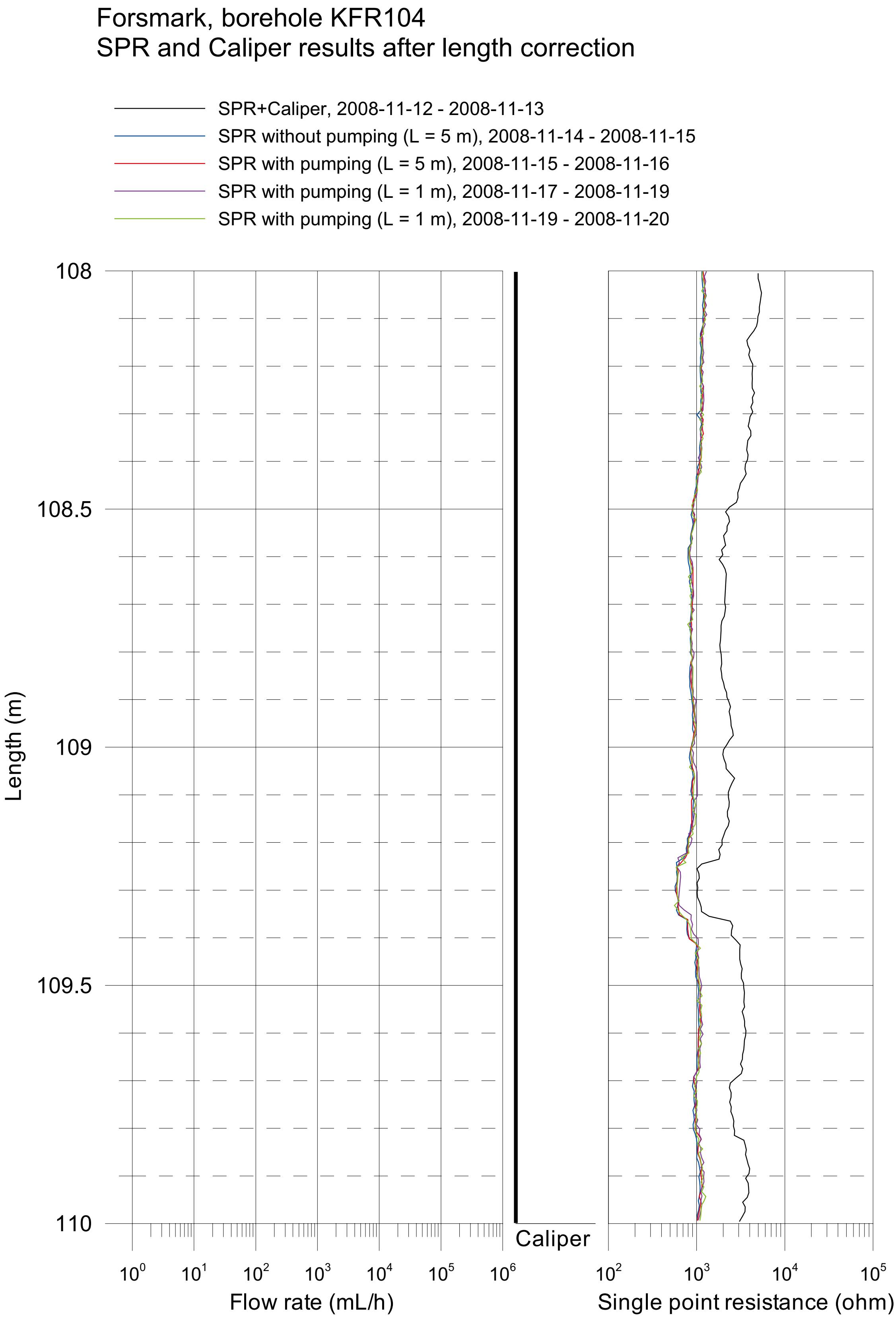
Forsmark, borehole KFR104
SPR and Caliper results after length correction



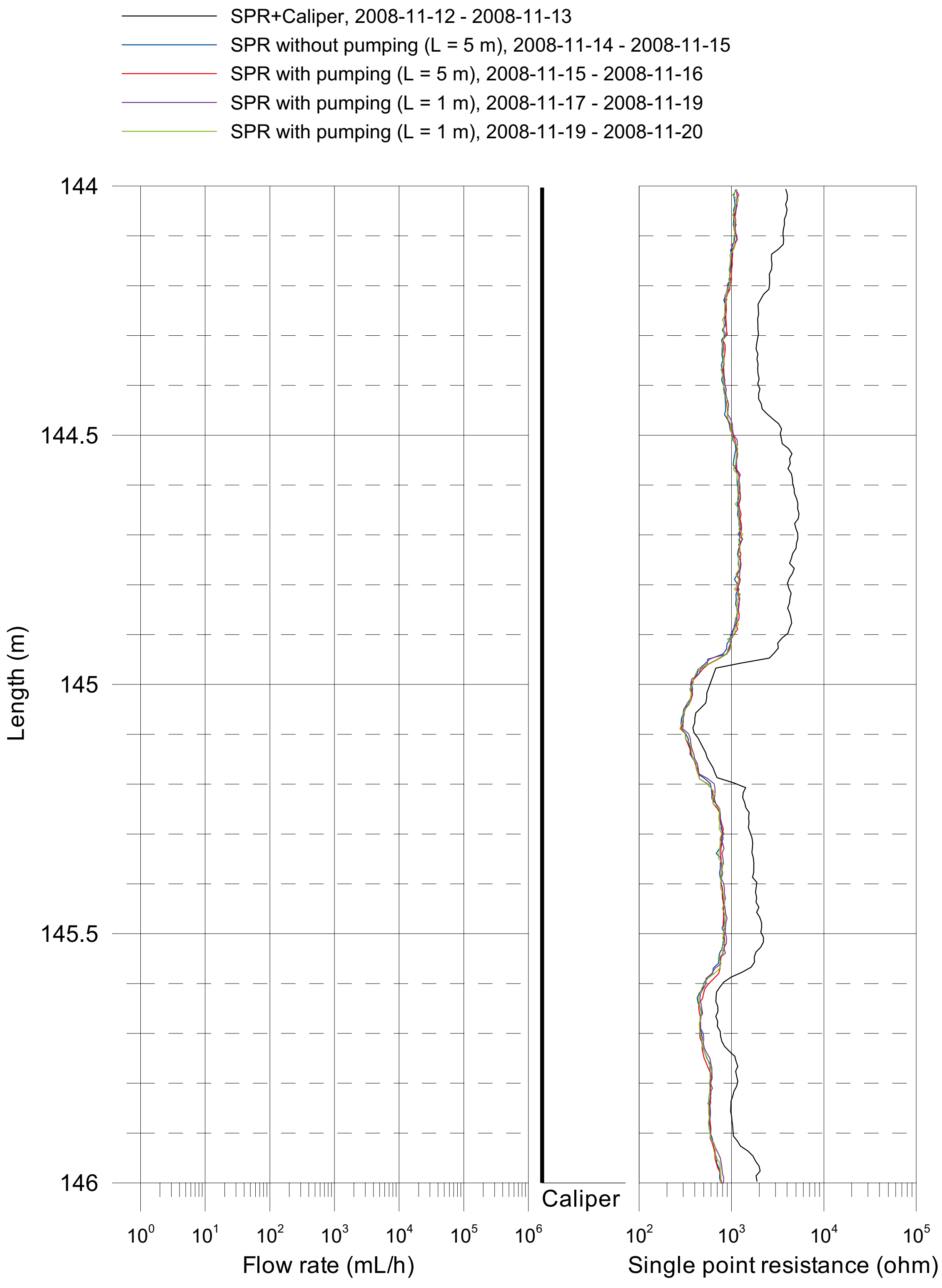

Forsmark, borehole KFR104
SPR and Caliper results after length correction
SPR+Caliper, 2008-11-12 - 2008-11-13
SPR without pumping (L = 5 m), 2008-11-14 - 2008-11-15
SPR with pumping (L = 5 m), 2008-11-15 - 2008-11-16
SPR with pumping (L = 1 m), 2008-11-17 - 2008-11-19
SPR with pumping (L = 1 m), 2008-11-19 - 2008-11-20
Length (m)
48
48.5
49
49.5
50
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

Forsmark, borehole KFR104
SPR and Caliper results after length correction

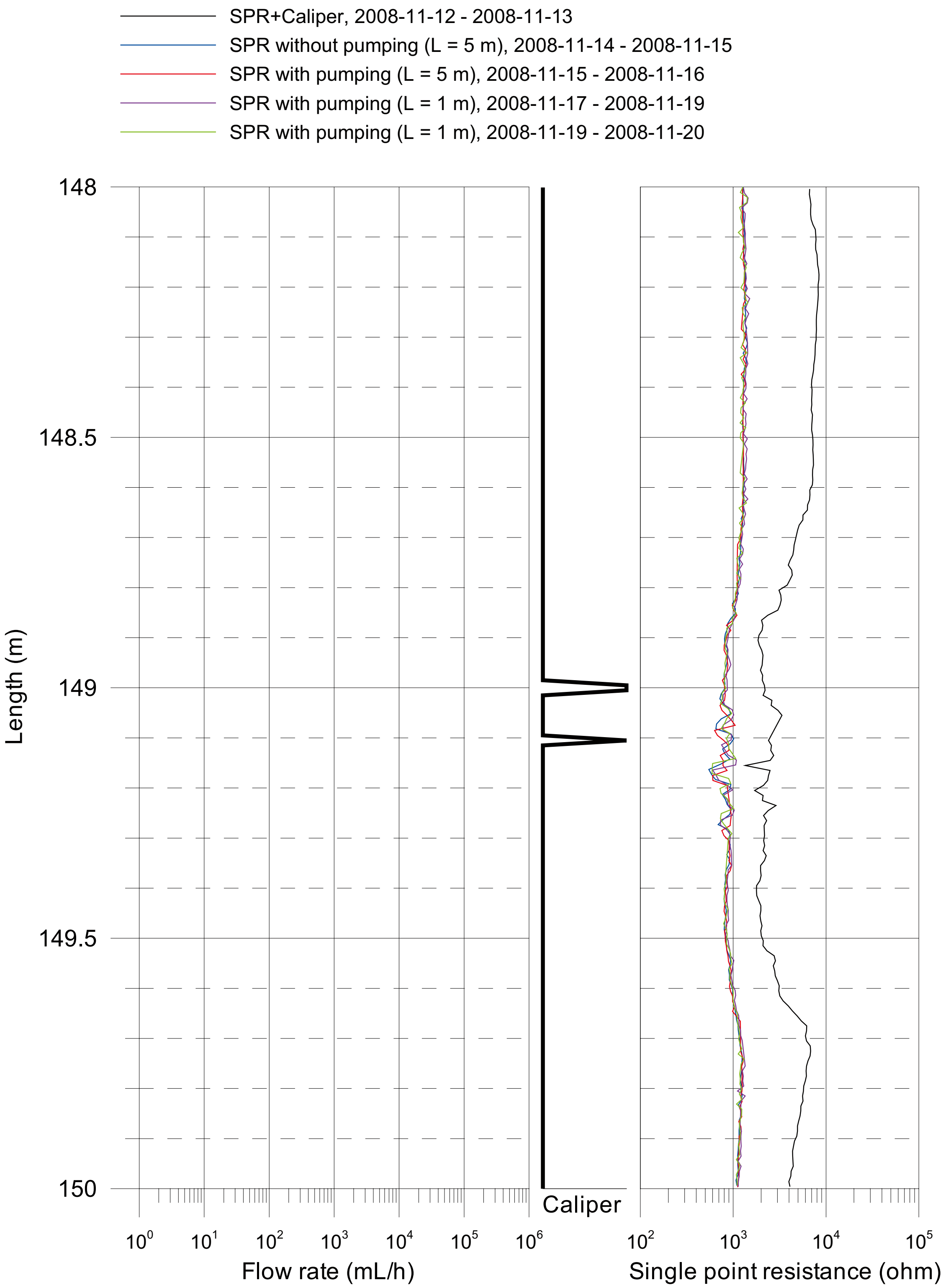



Forsmark, borehole KFR104
SPR and Caliper results after length correction
SPR+Caliper, 2008-11-12 - 2008-11-13
SPR without pumping (L = 5 m), 2008-11-14 - 2008-11-15
SPR with pumping (L = 5 m), 2008-11-15 - 2008-11-16
SPR with pumping (L = 1 m), 2008-11-17 - 2008-11-19
SPR with pumping (L = 1 m), 2008-11-19 - 2008-11-20
Length (m)
108
108.5
109
109.5
110
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

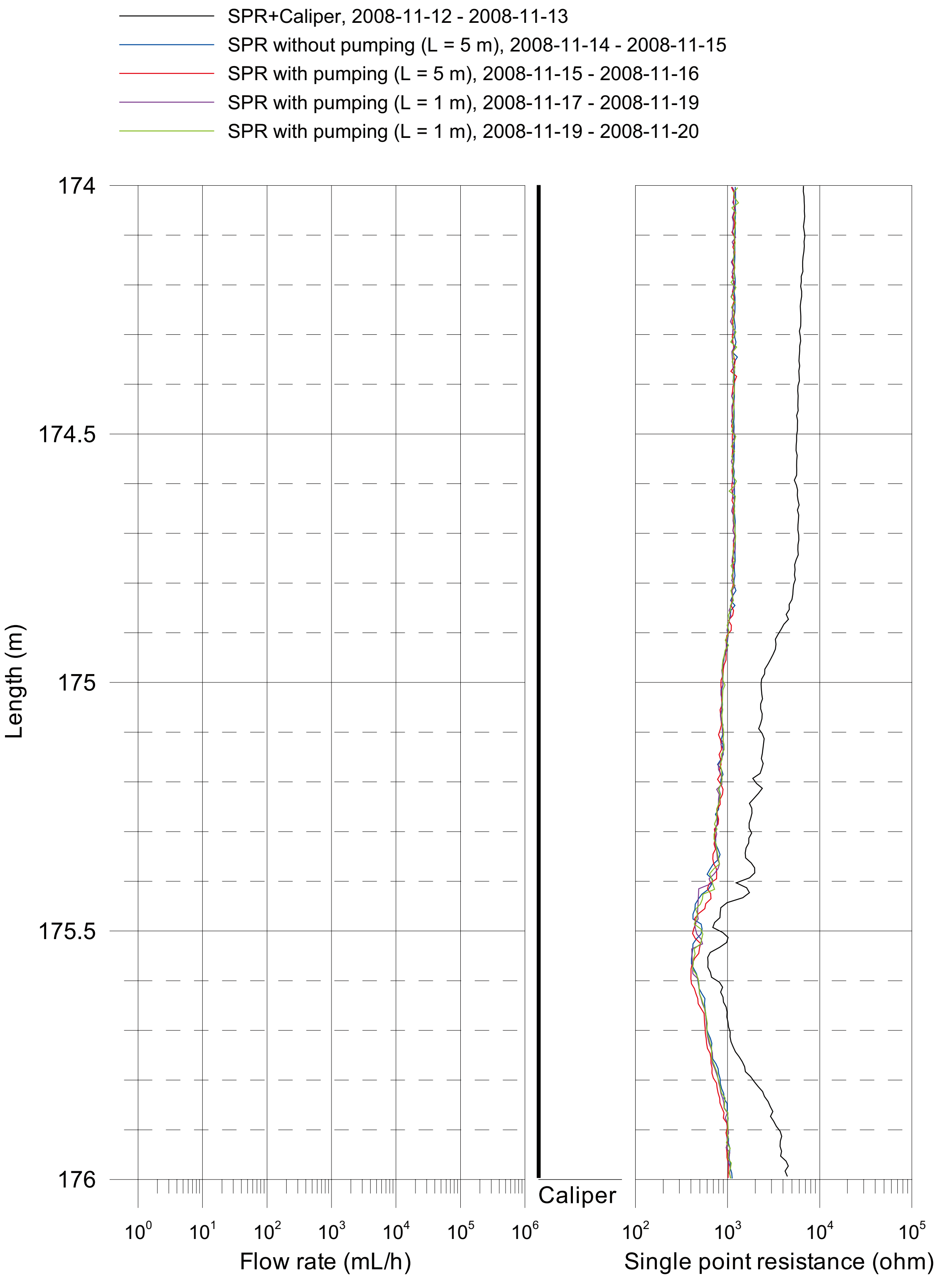
Forsmark, borehole KFR104
SPR and Caliper results after length correction



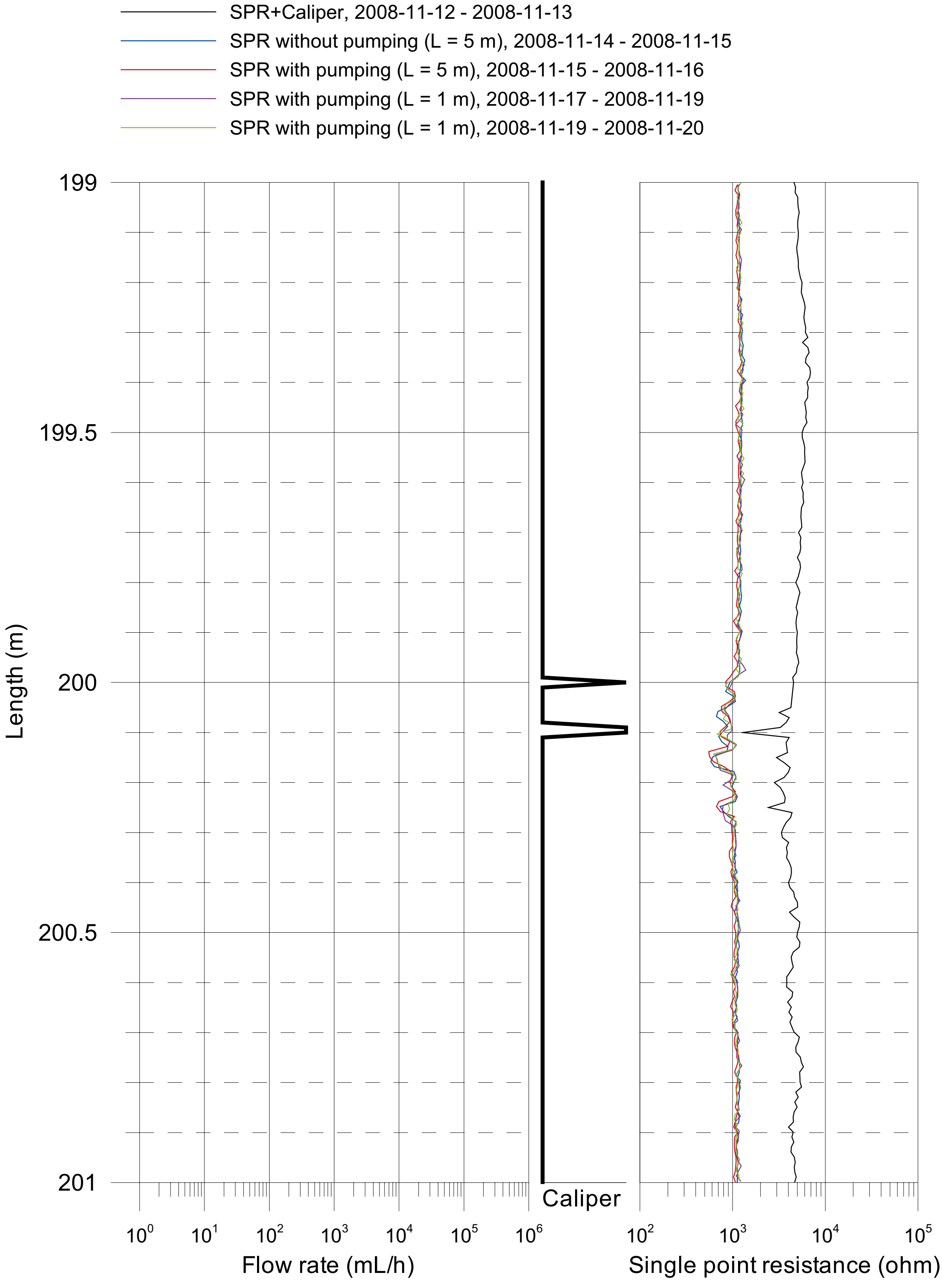
Forsmark, borehole KFR104
SPR and Caliper results after length correction



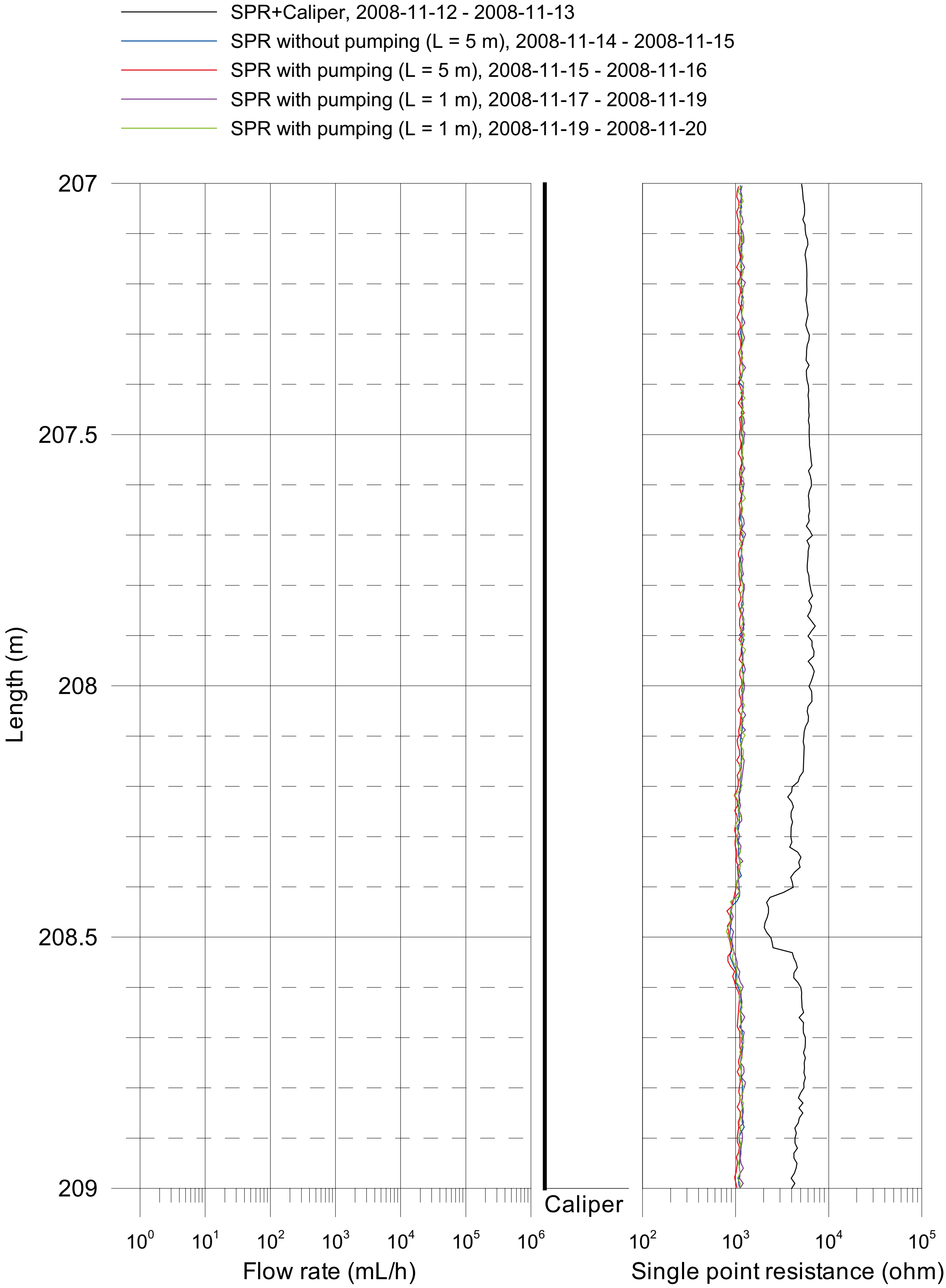
Forsmark, borehole KFR104
SPR and Caliper results after length correction



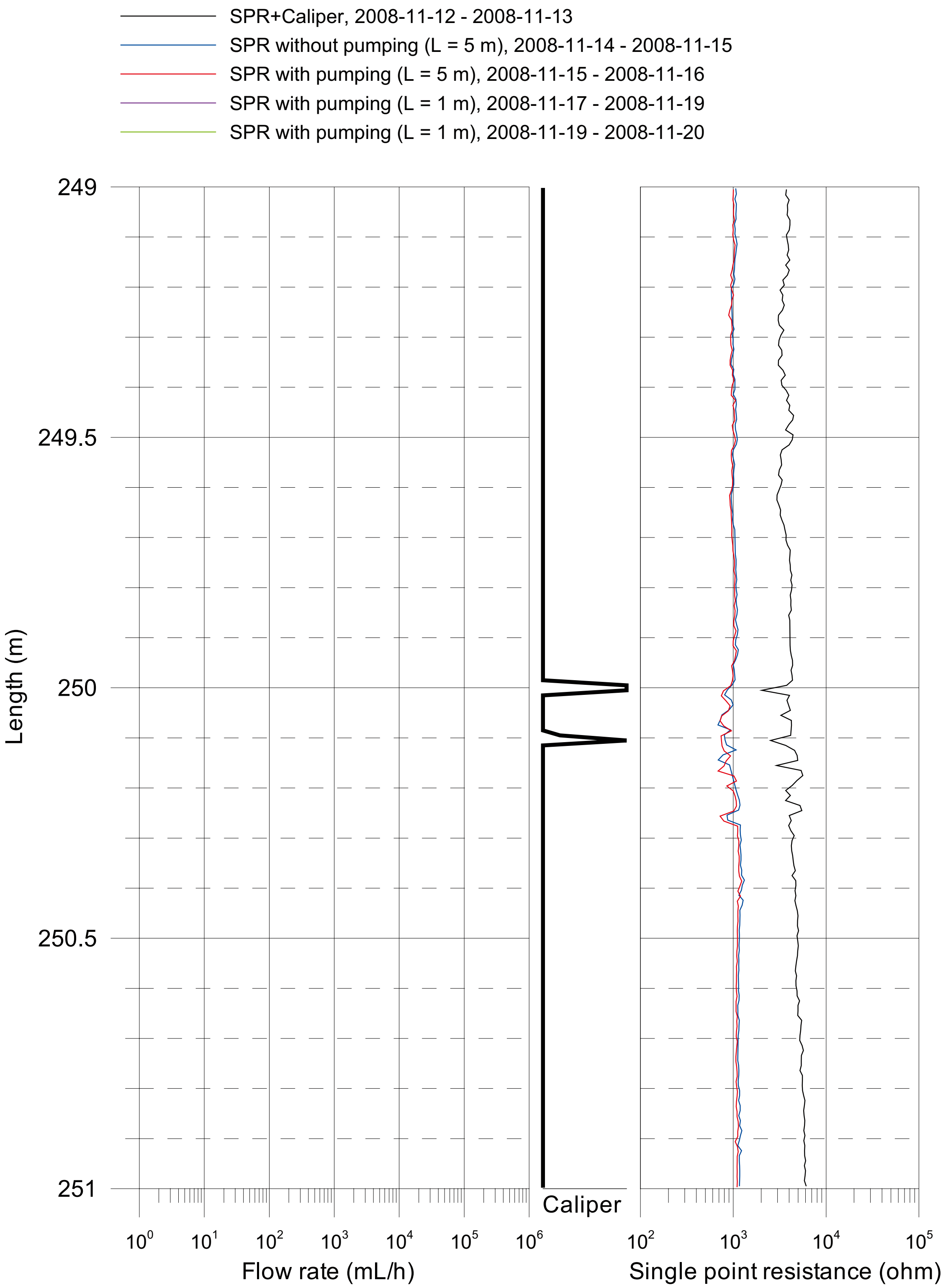
Forsmark, borehole KFR104
SPR and Caliper results after length correction



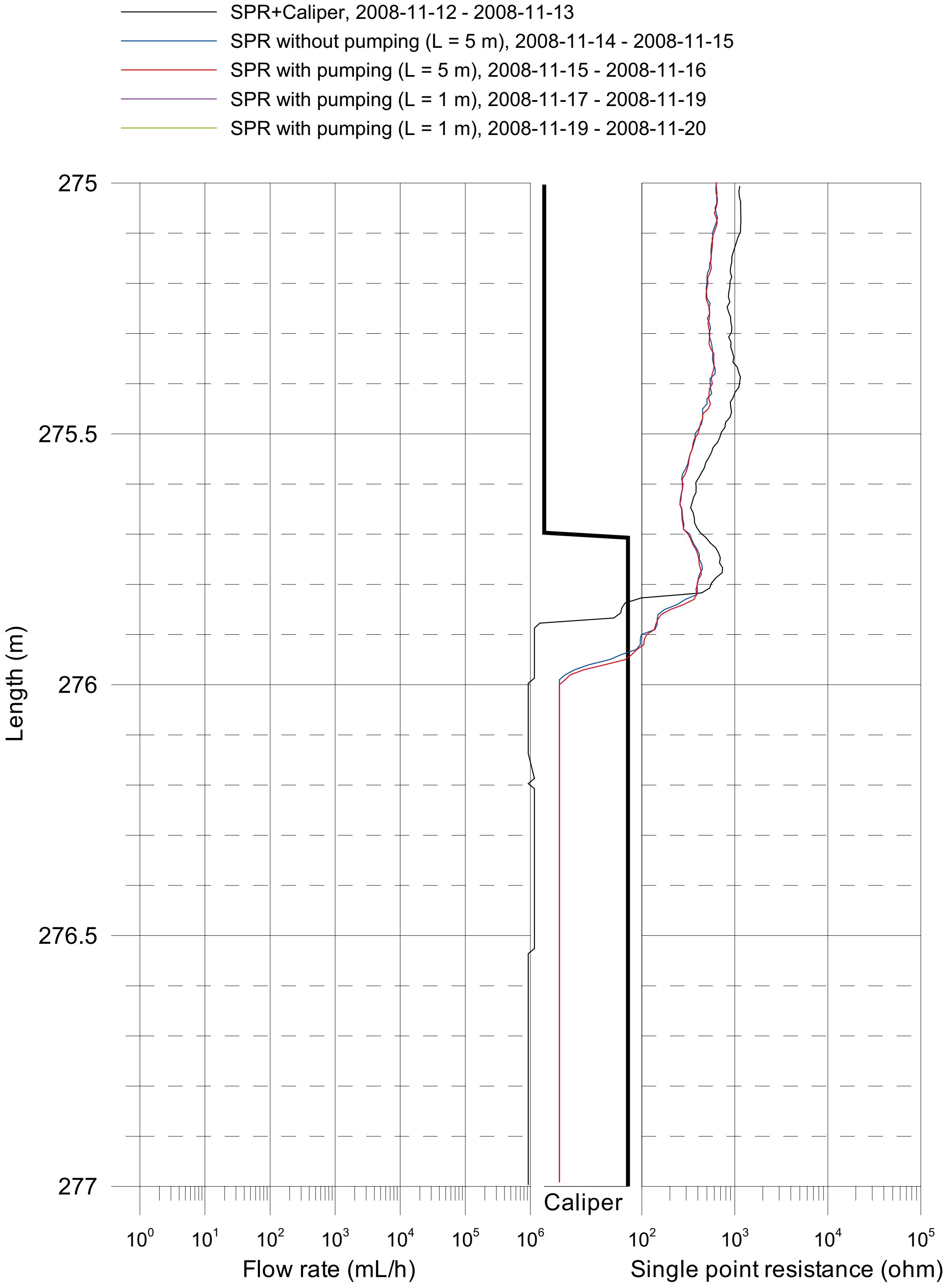
Forsmark, borehole KFR104
SPR and Caliper results after length correction



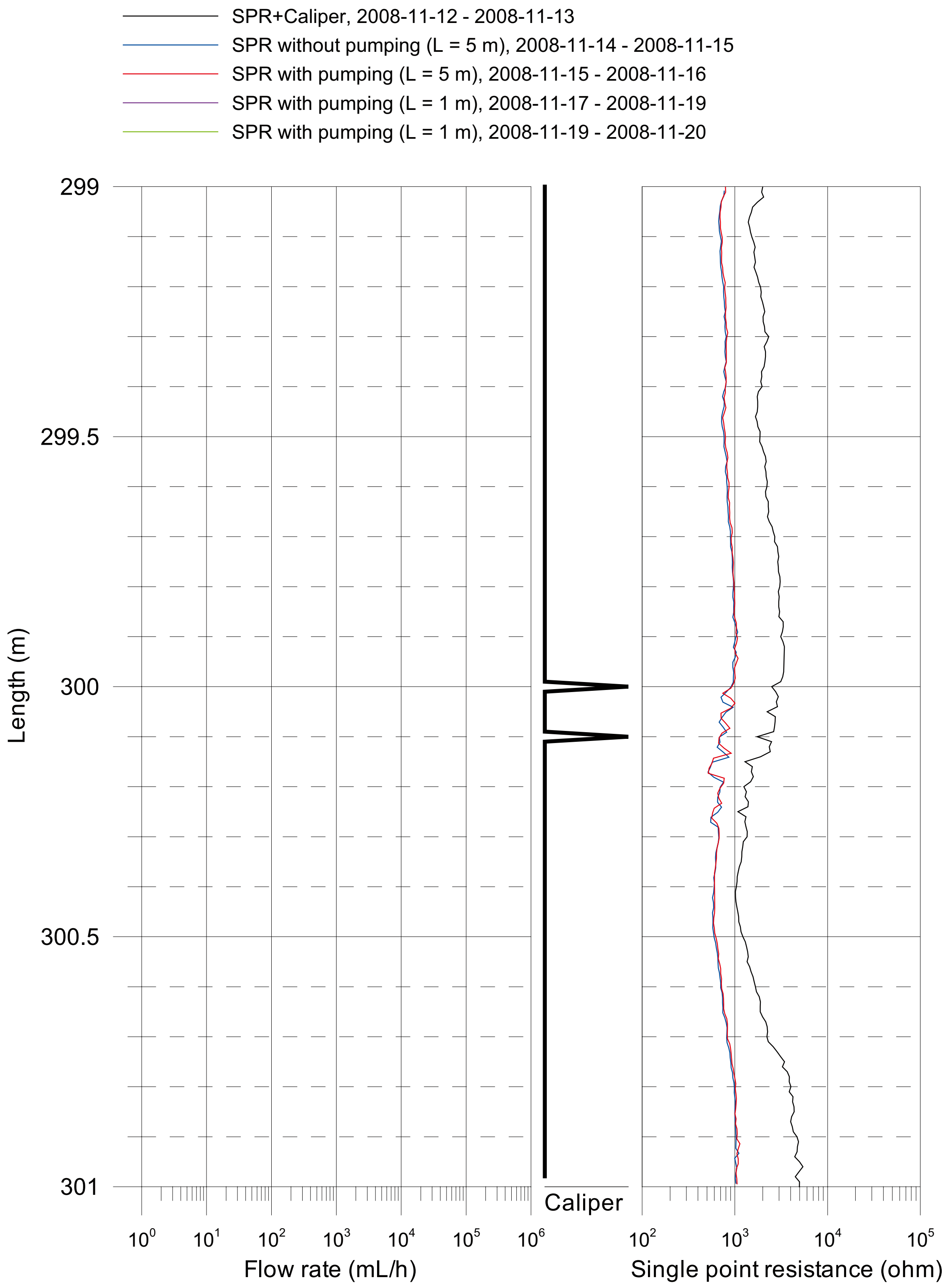
Forsmark, borehole KFR104
SPR and Caliper results after length correction



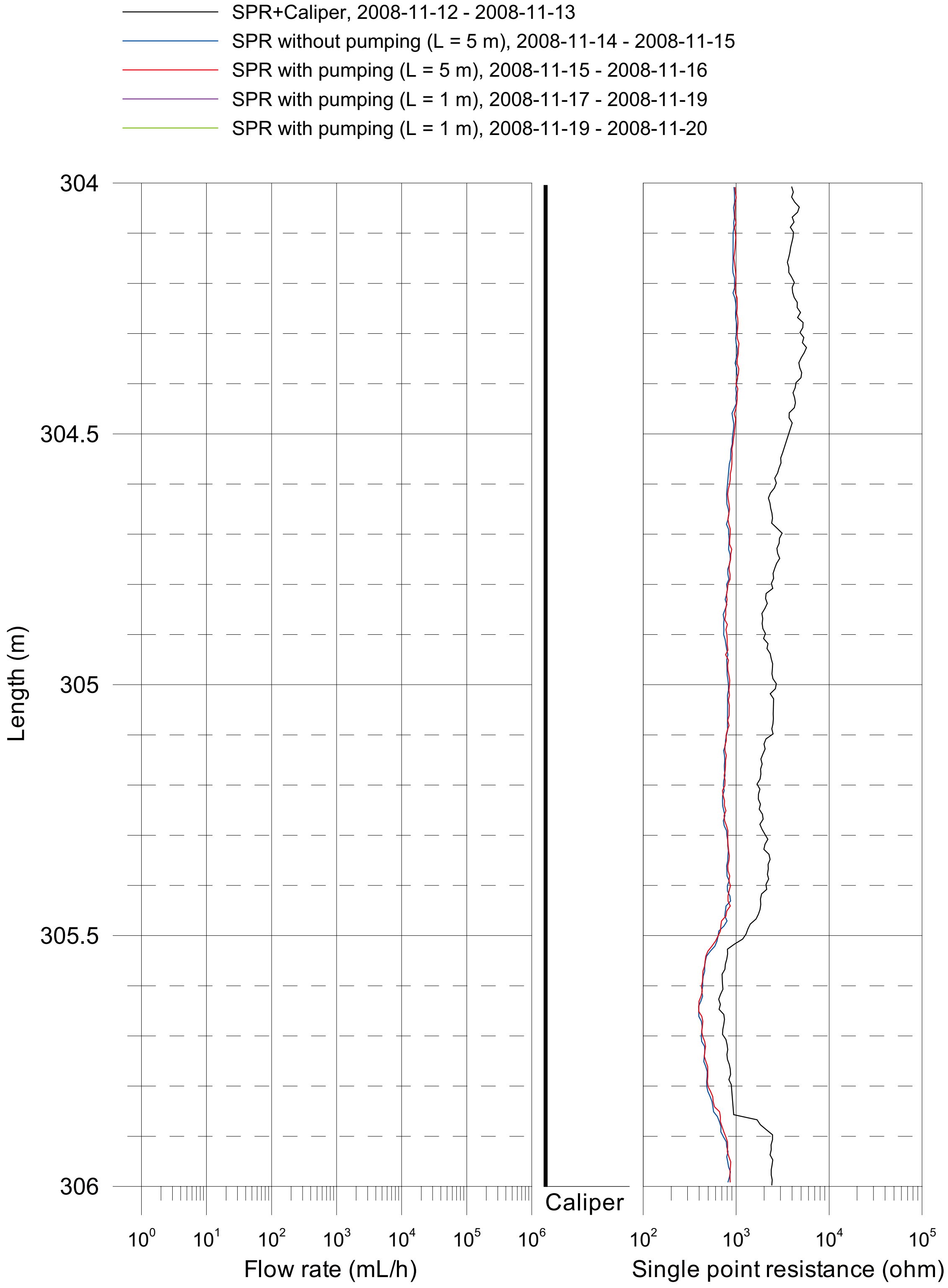
Forsmark, borehole KFR104
SPR and Caliper results after length correction



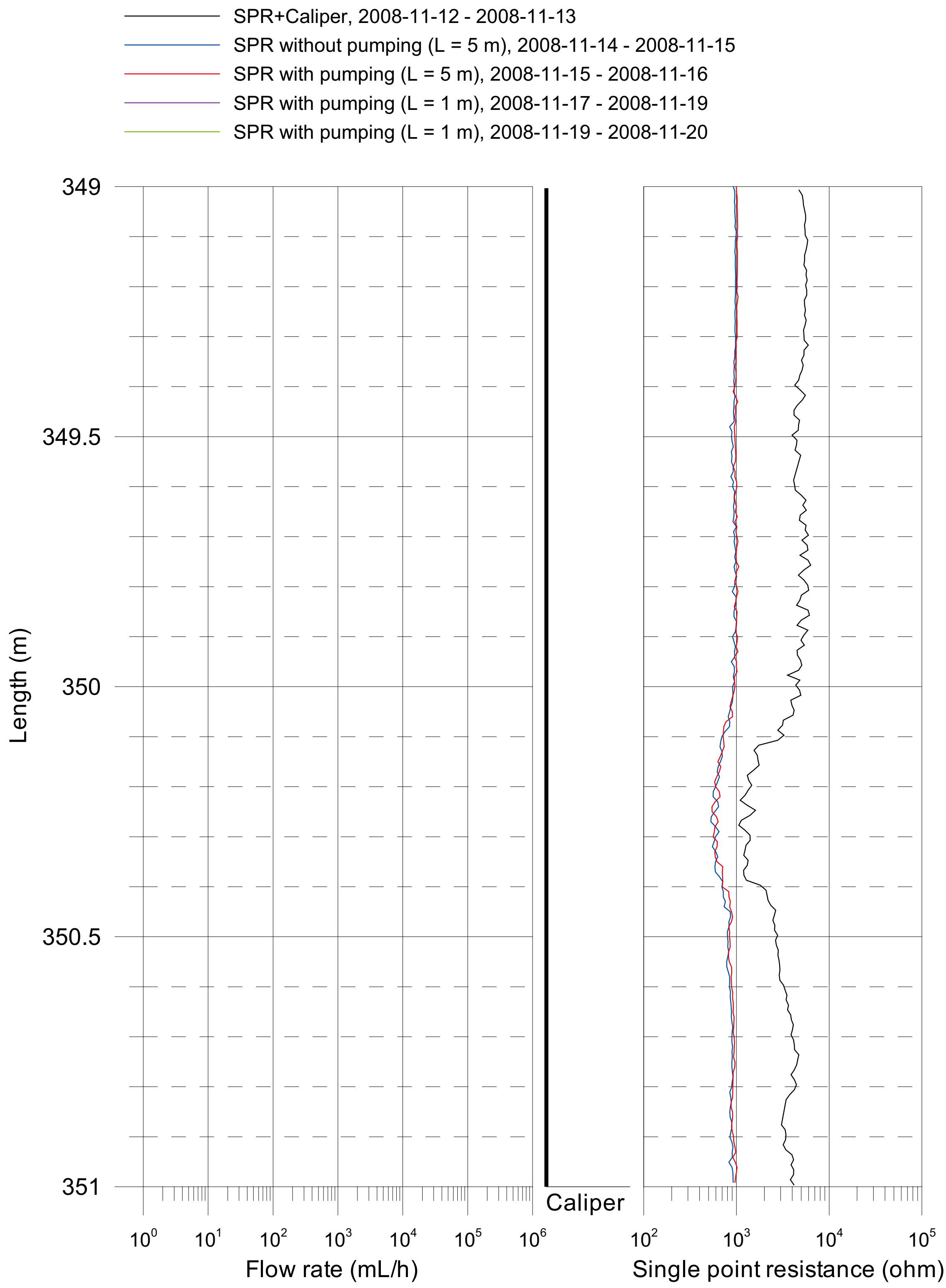
Forsmark, borehole KFR104
SPR and Caliper results after length correction



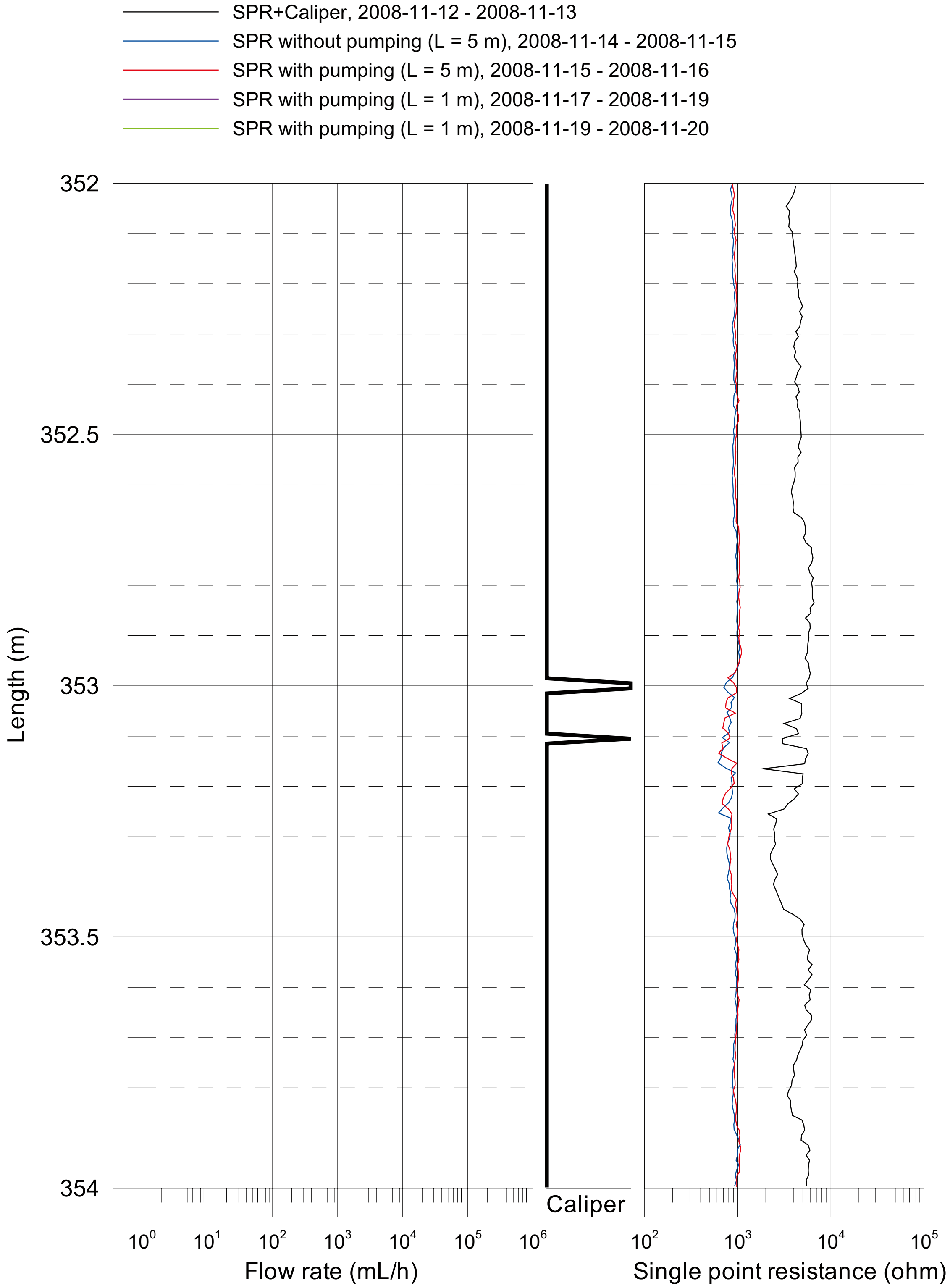
Forsmark, borehole KFR104
SPR and Caliper results after length correction



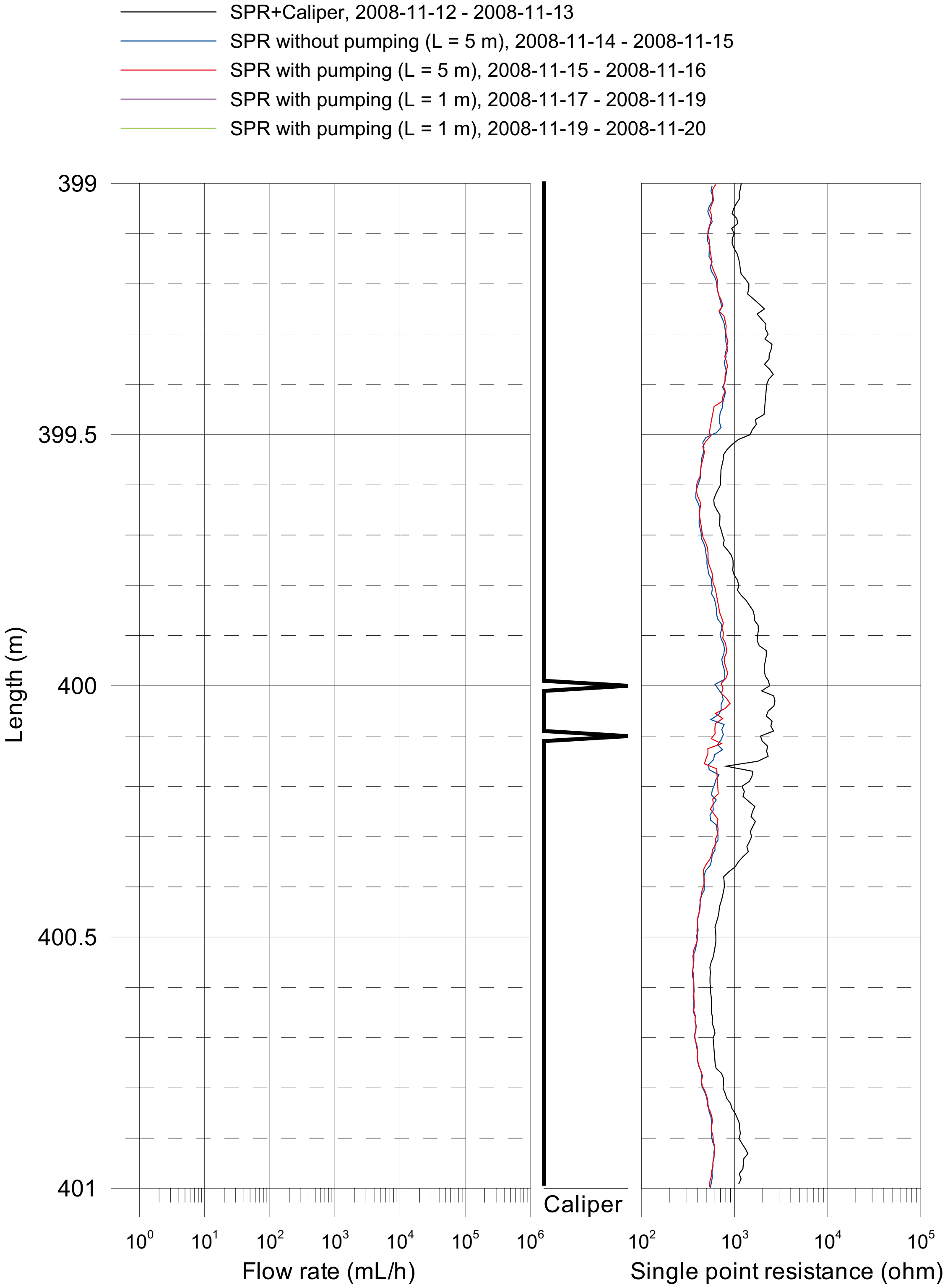
Forsmark, borehole KFR104
SPR and Caliper results after length correction



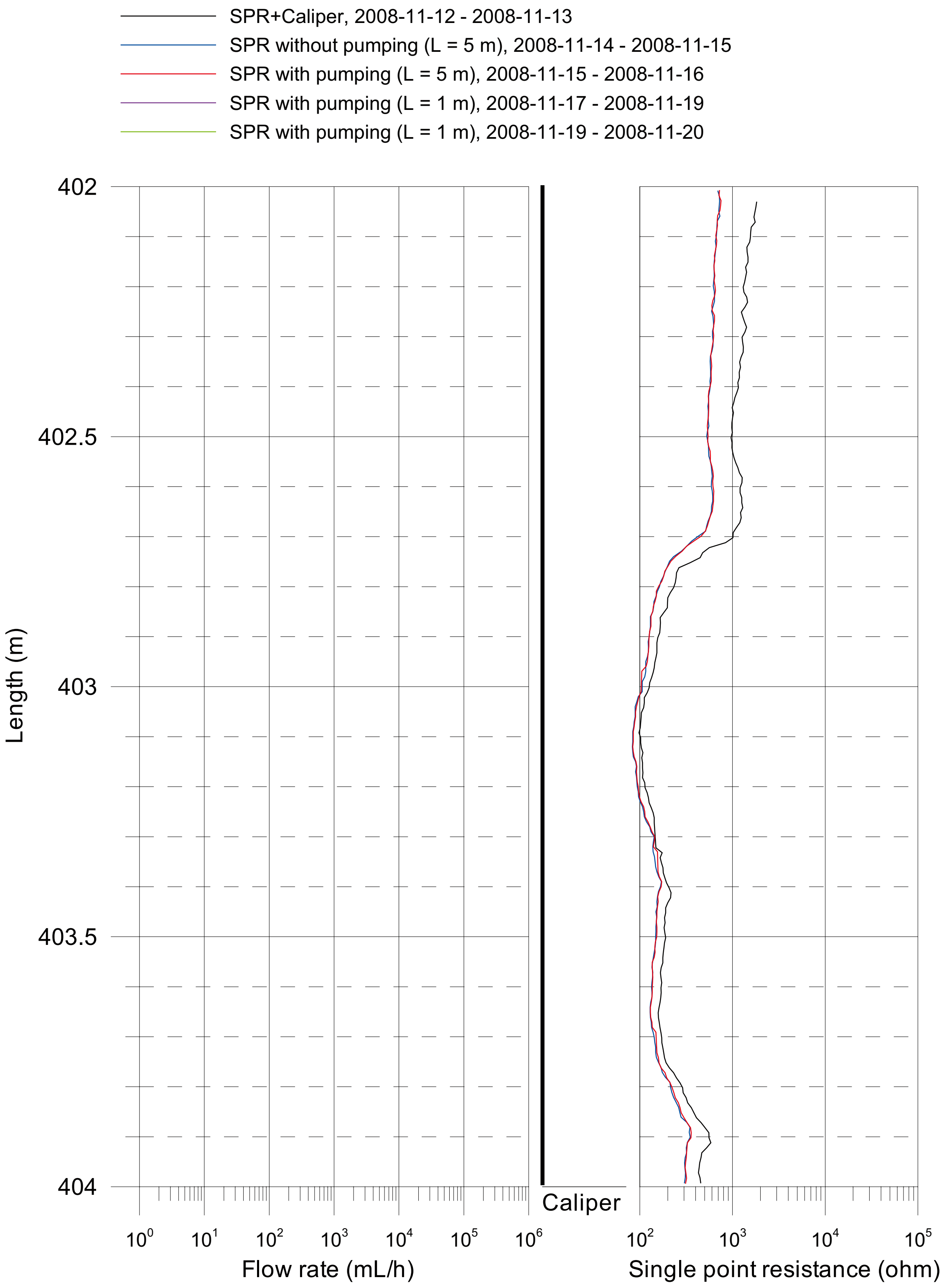
Forsmark, borehole KFR104
SPR and Caliper results after length correction



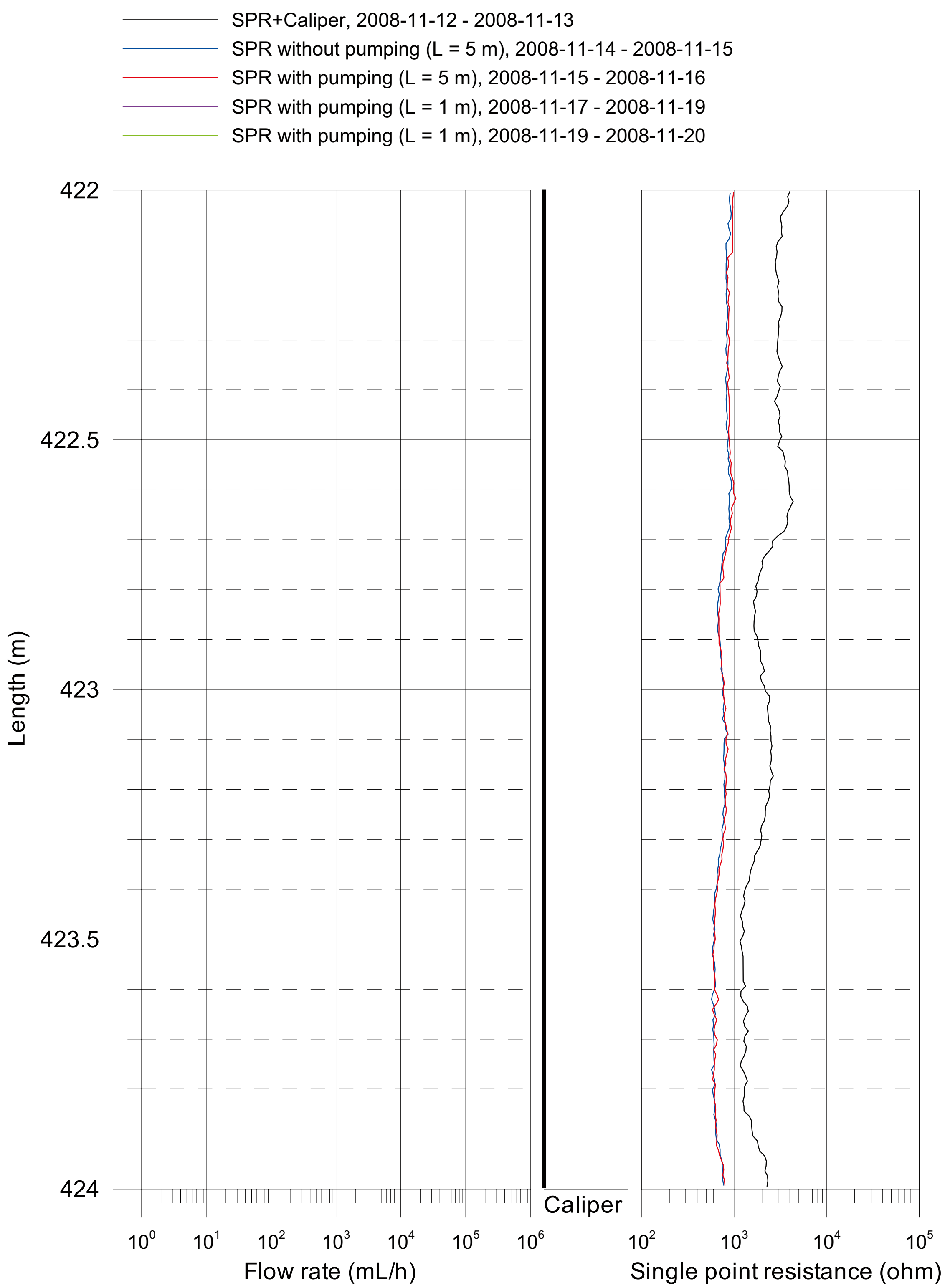
Forsmark, borehole KFR104
SPR and Caliper results after length correction



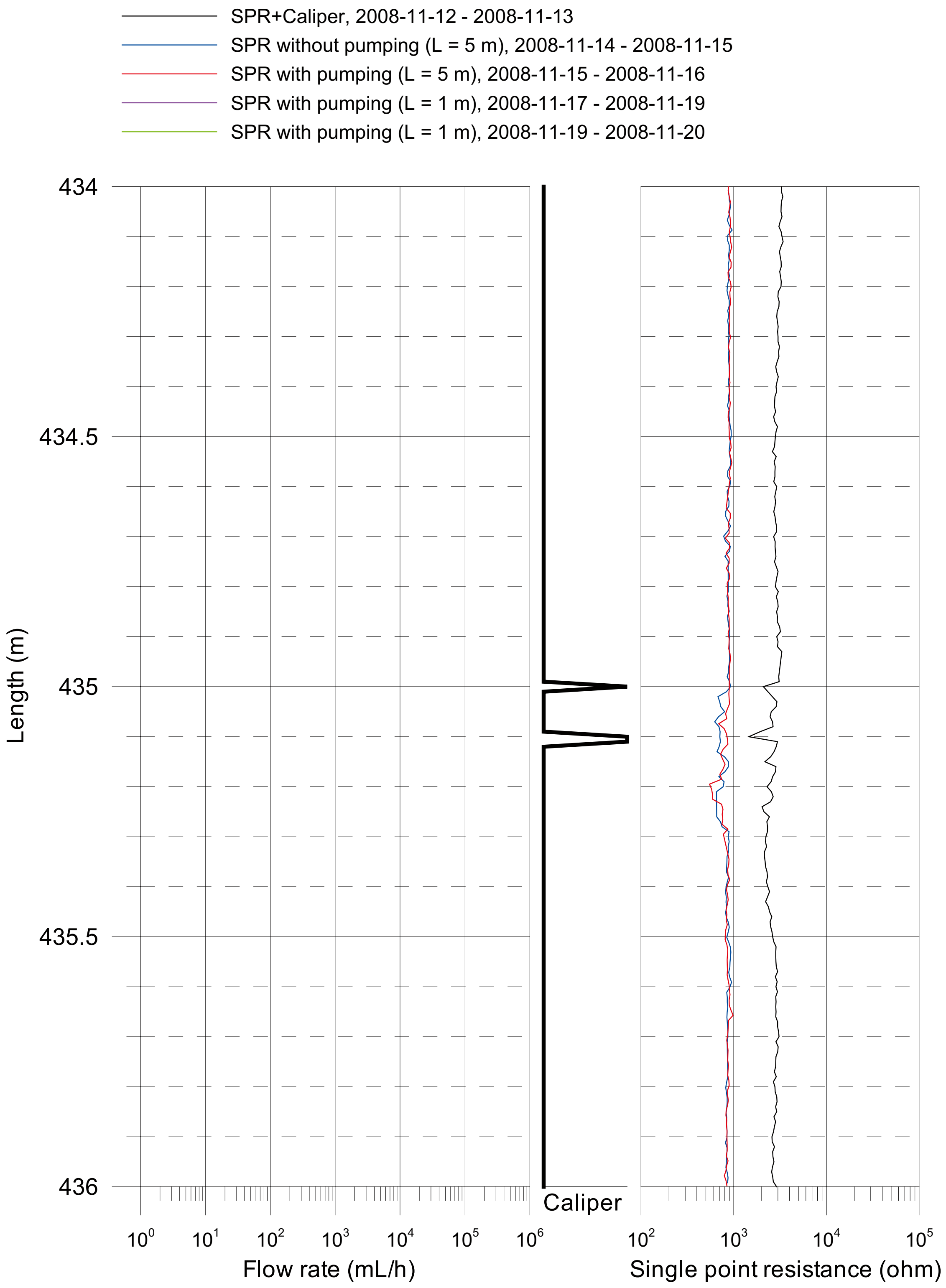
Forsmark, borehole KFR104
SPR and Caliper results after length correction



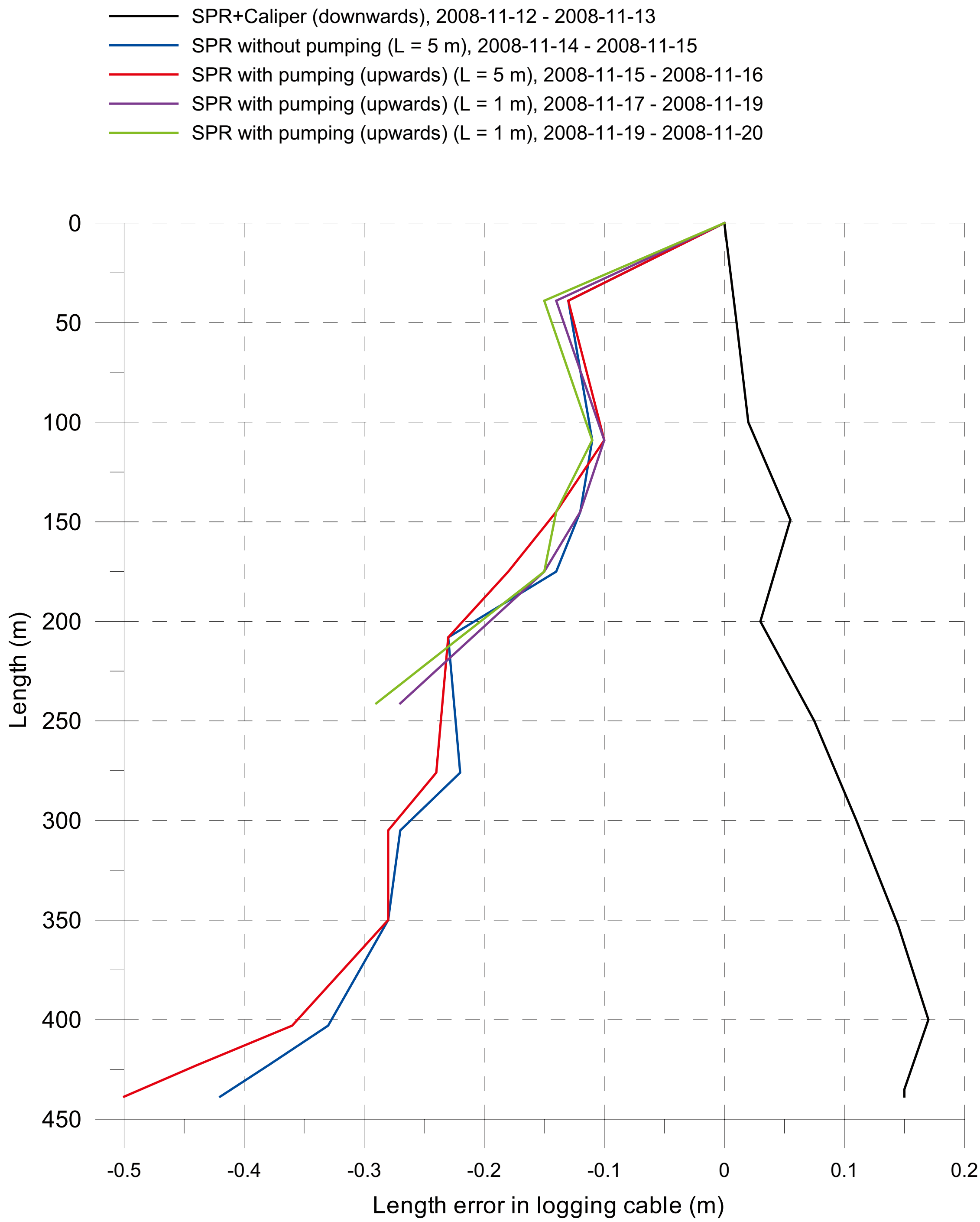
Forsmark, borehole KFR104
SPR and Caliper results after length correction



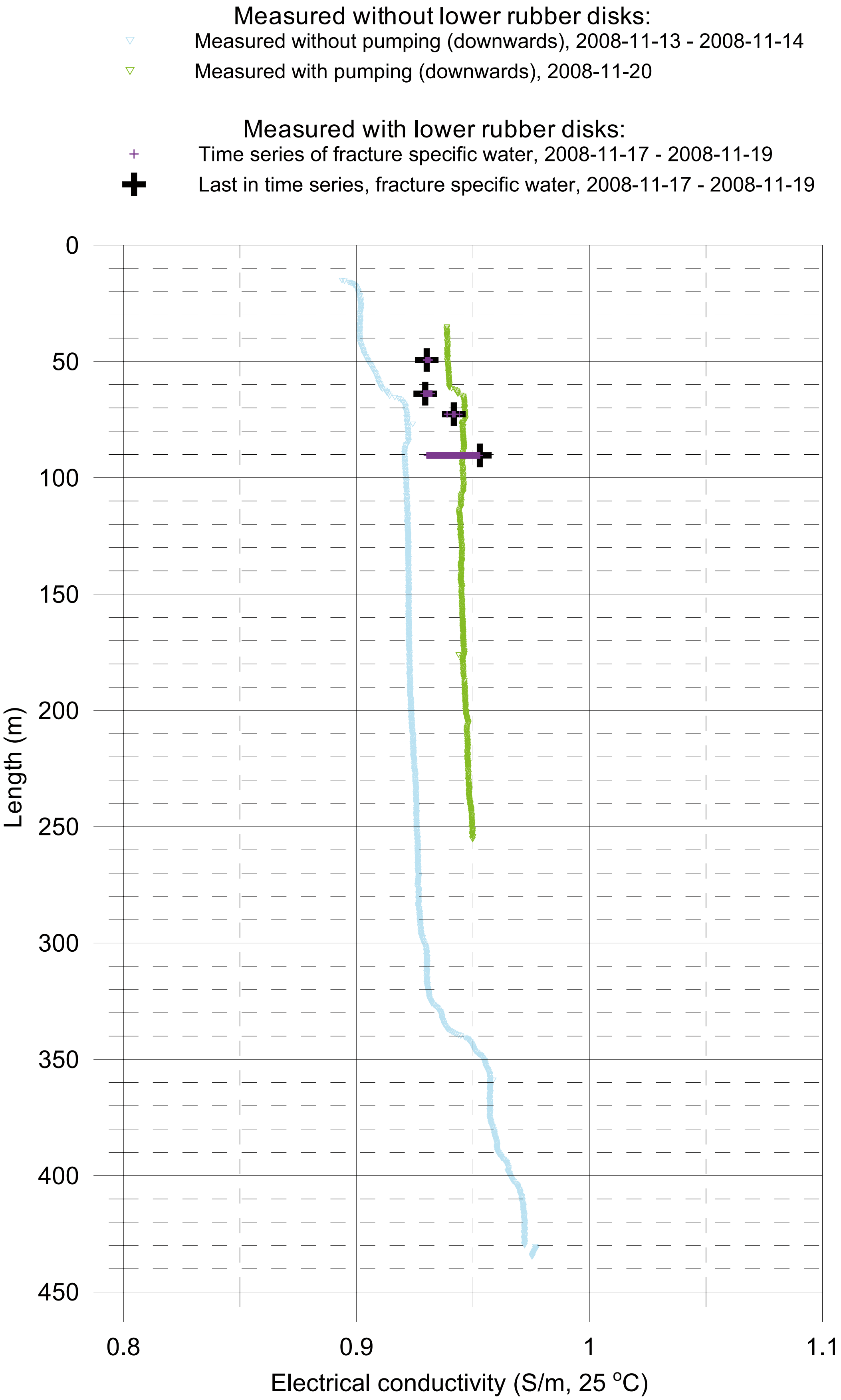
Forsmark, borehole KFR104
SPR and Caliper results after length correction

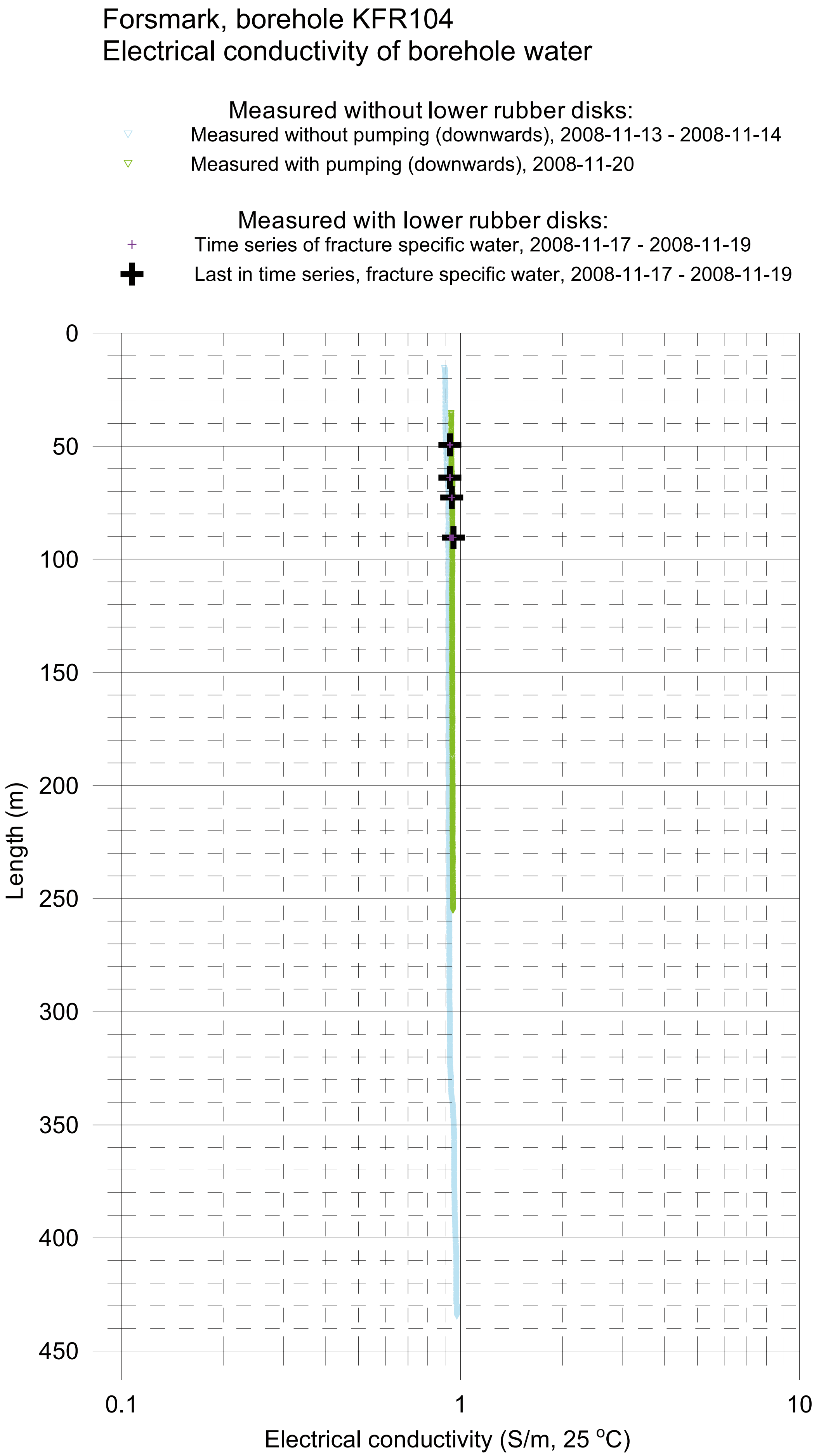


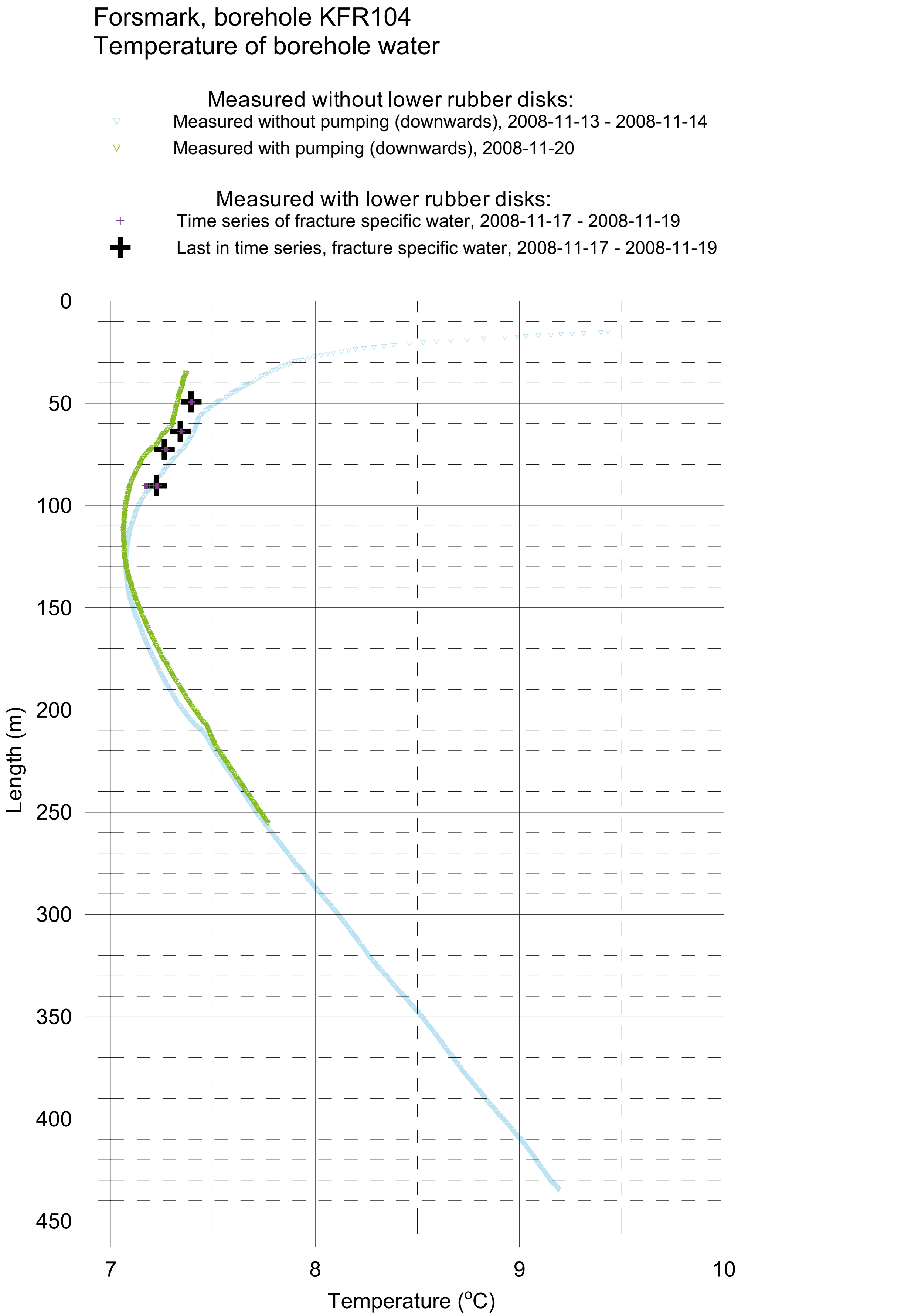
Forsmark, borehole KFR104
Length correction

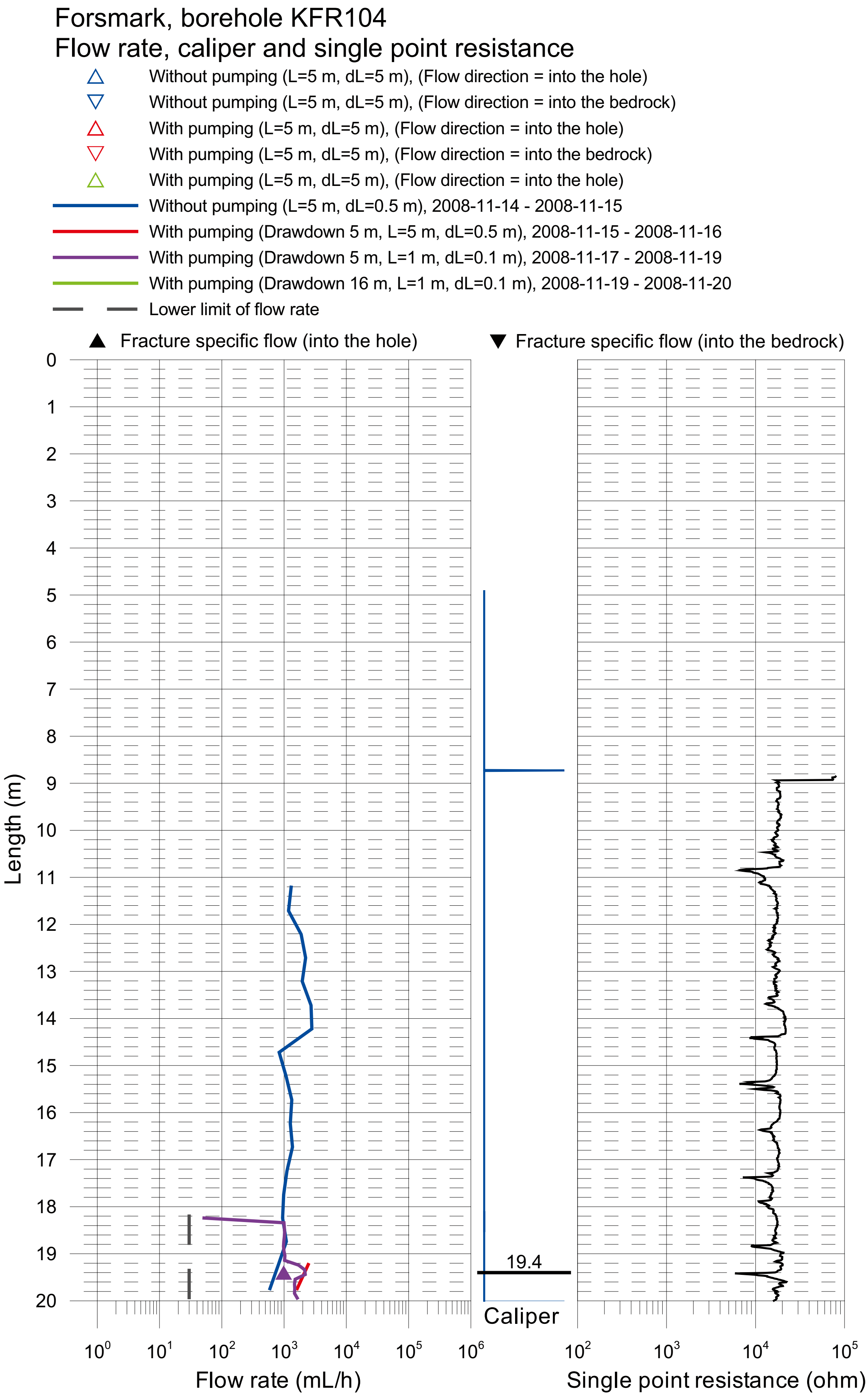


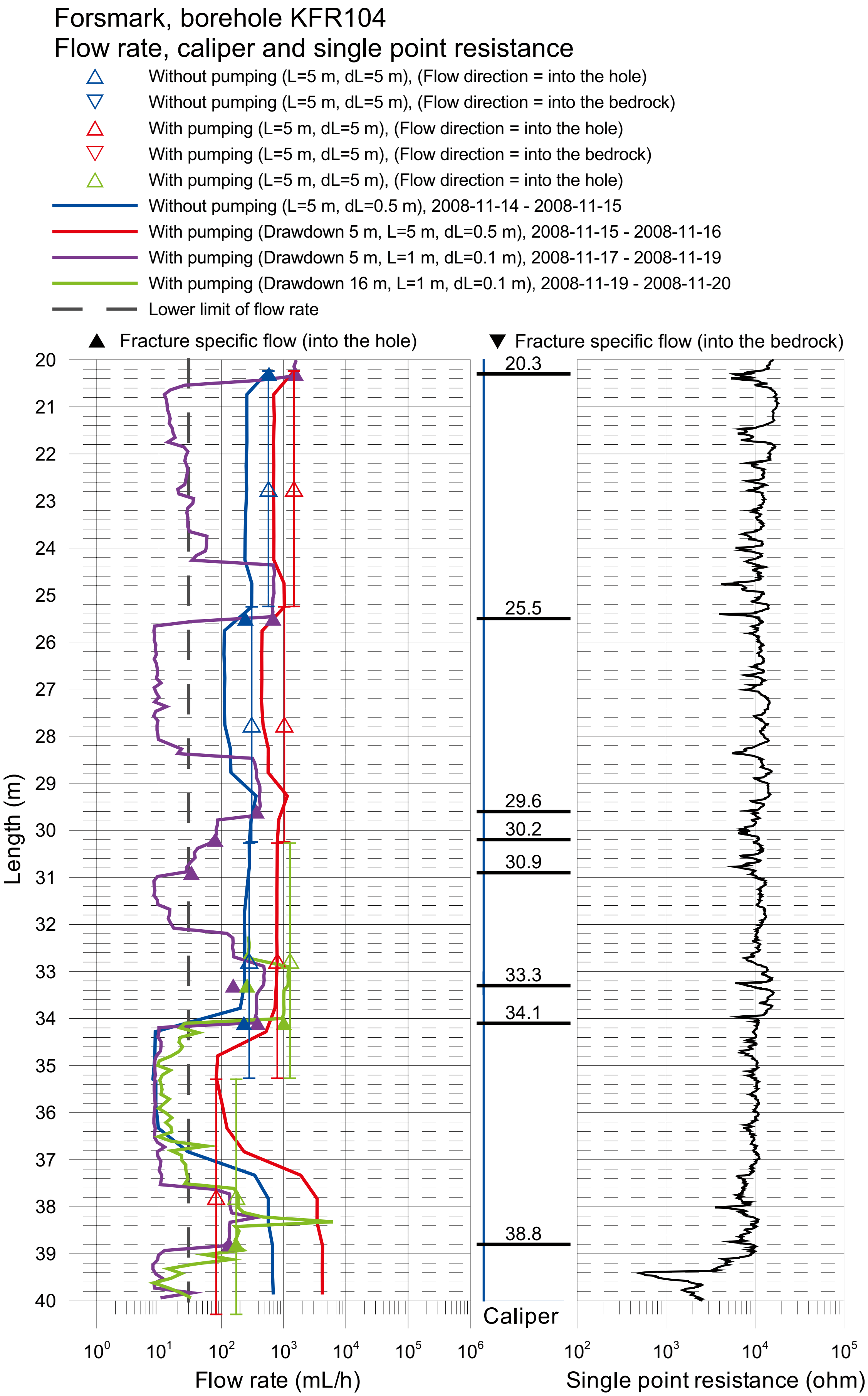
Forsmark, borehole KFR104
Electrical conductivity of borehole water



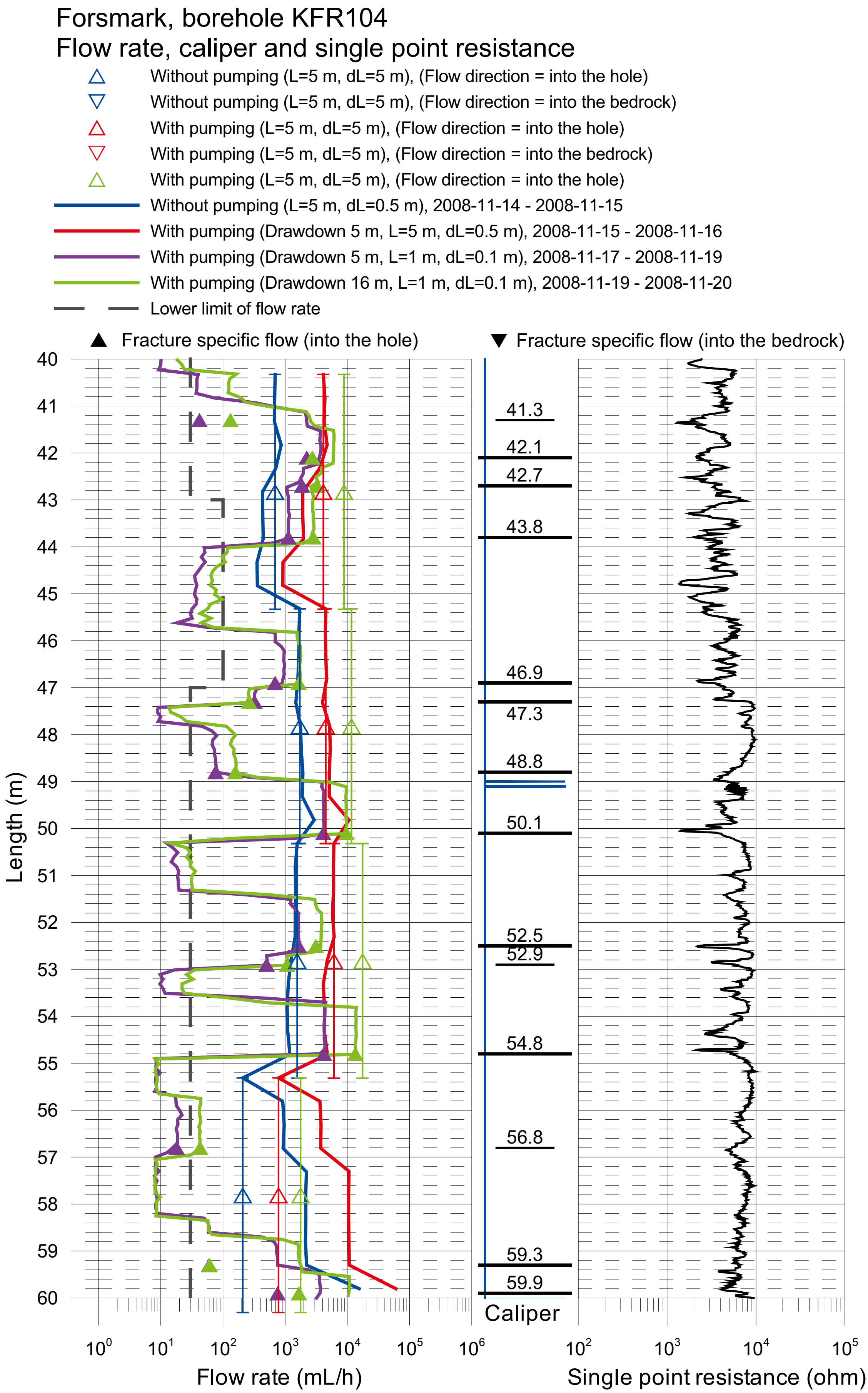

Forsmark, borehole KFR104
Electrical conductivity of borehole water
Measured without lower rubber disks:
Measured without pumping (downwards), 2008-11-13 - 2008-11-14
Measured with pumping (downwards), 2008-11-20
Measured with lower rubber disks:
Time series of fracture specific water, 2008-11-17 - 2008-11-19
Last in time series, fracture specific water, 2008-11-17 - 2008-11-19
Length (m)
0
50
100
150
200
250
300
350
400
450
0.1
1
10
Electrical conductivity (S/m, 25 ^{o}C)

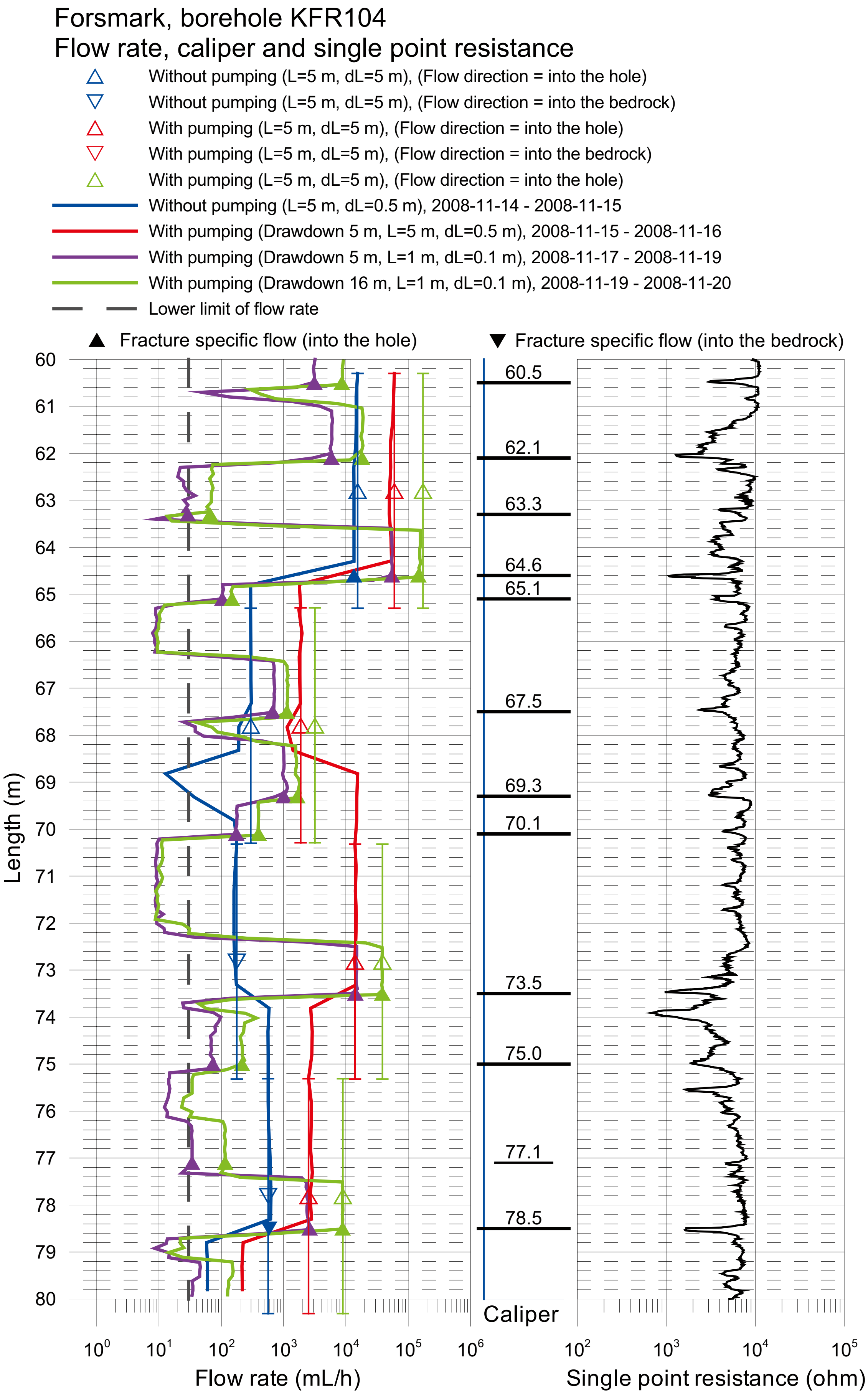

Forsmark, borehole KFR104
Temperature of borehole water
Measured without lower rubber disks:
Measured without pumping (downwards), 2008-11-13 - 2008-11-14
Measured with pumping (downwards), 2008-11-20
Measured with lower rubber disks:
Time series of fracture specific water, 2008-11-17 - 2008-11-19
Last in time series, fracture specific water, 2008-11-17 - 2008-11-19
0
50
100
150
200
250
300
350
400
450
Length (m)
7
8
9
10
Temperature (°C)

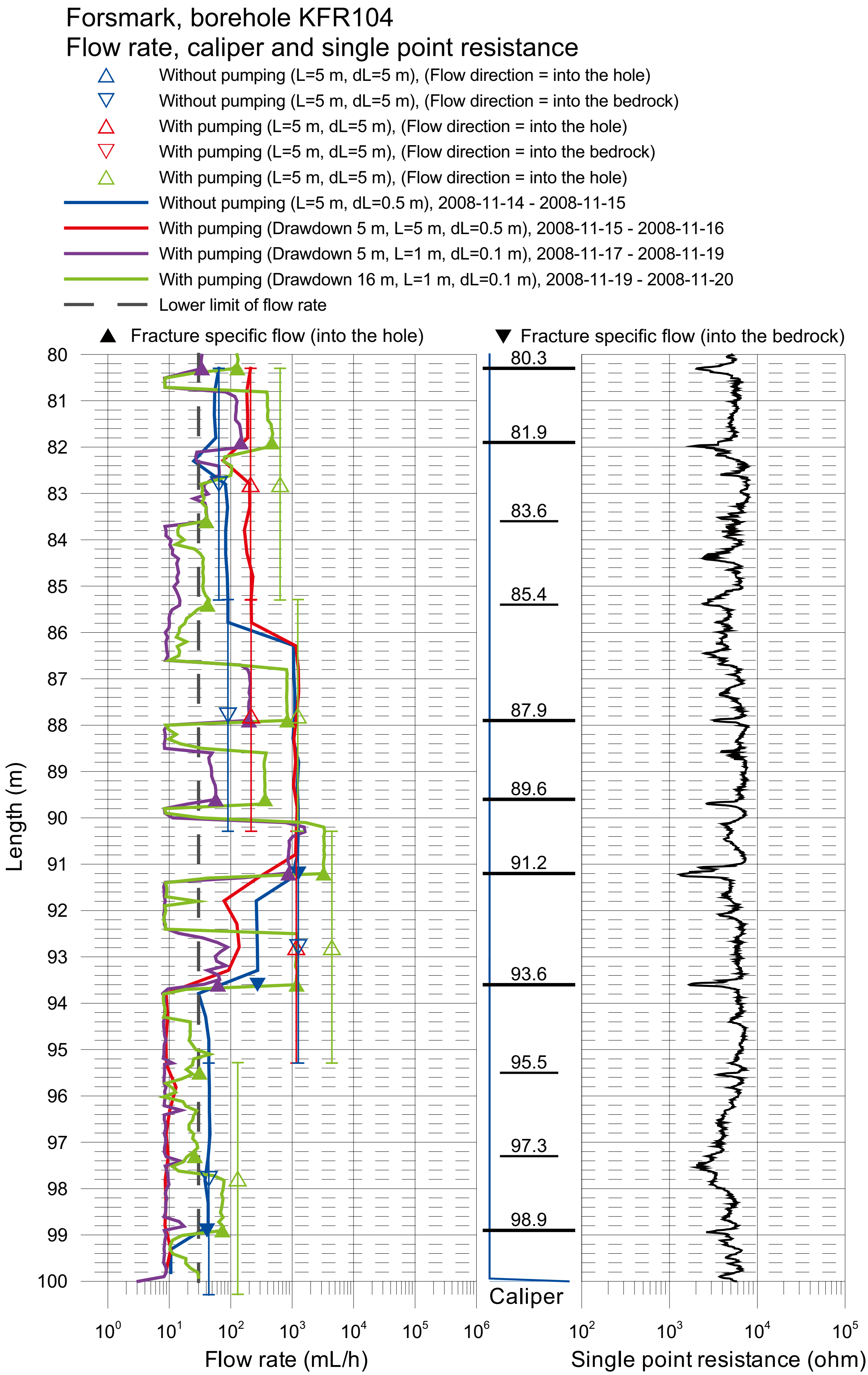

Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
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
19.4
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)



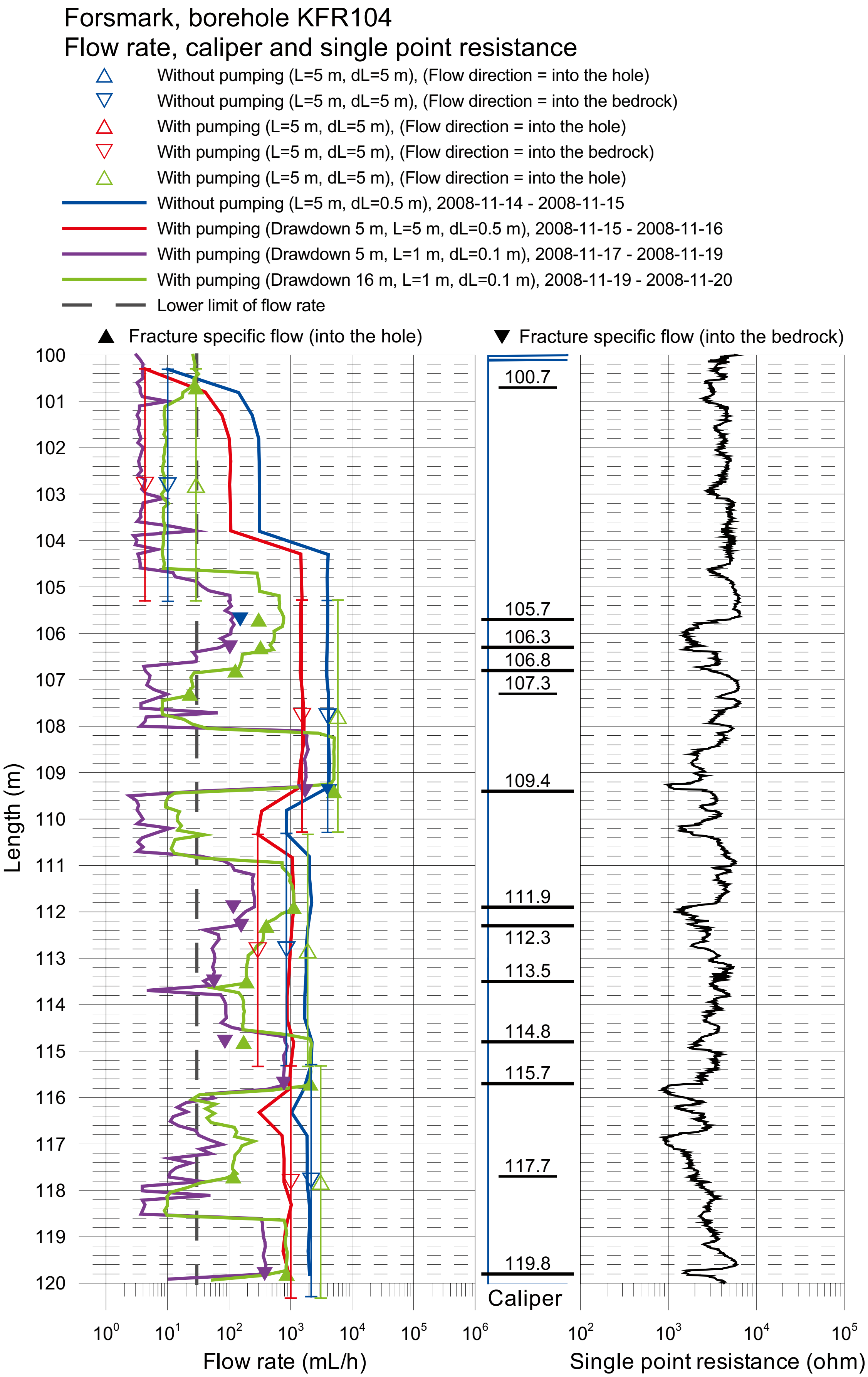
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
20.3
25.5
29.6
30.2
30.9
33.3
34.1
38.8
Caliper
Flow rate (mL/h)
Single point resistance (ohm)


Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
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
41.3
42.1
42.7
43.8
46.9
47.3
48.8
50.1
52.5
52.9
54.8
56.8
59.3
59.9
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

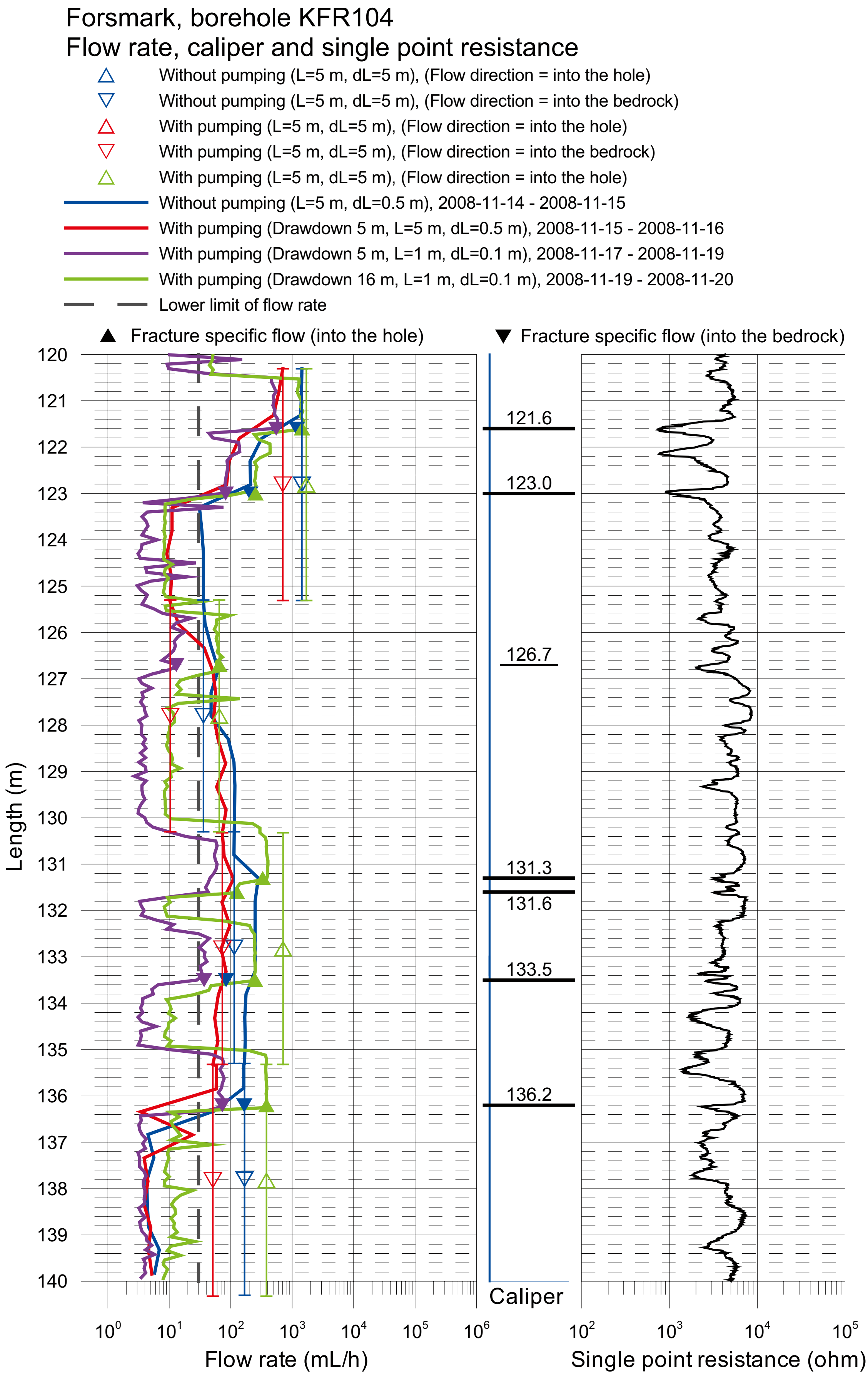

Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
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
60.5
62.1
63.3
64.6
65.1
67.5
69.3
70.1
73.5
75.0
77.1
78.5
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)



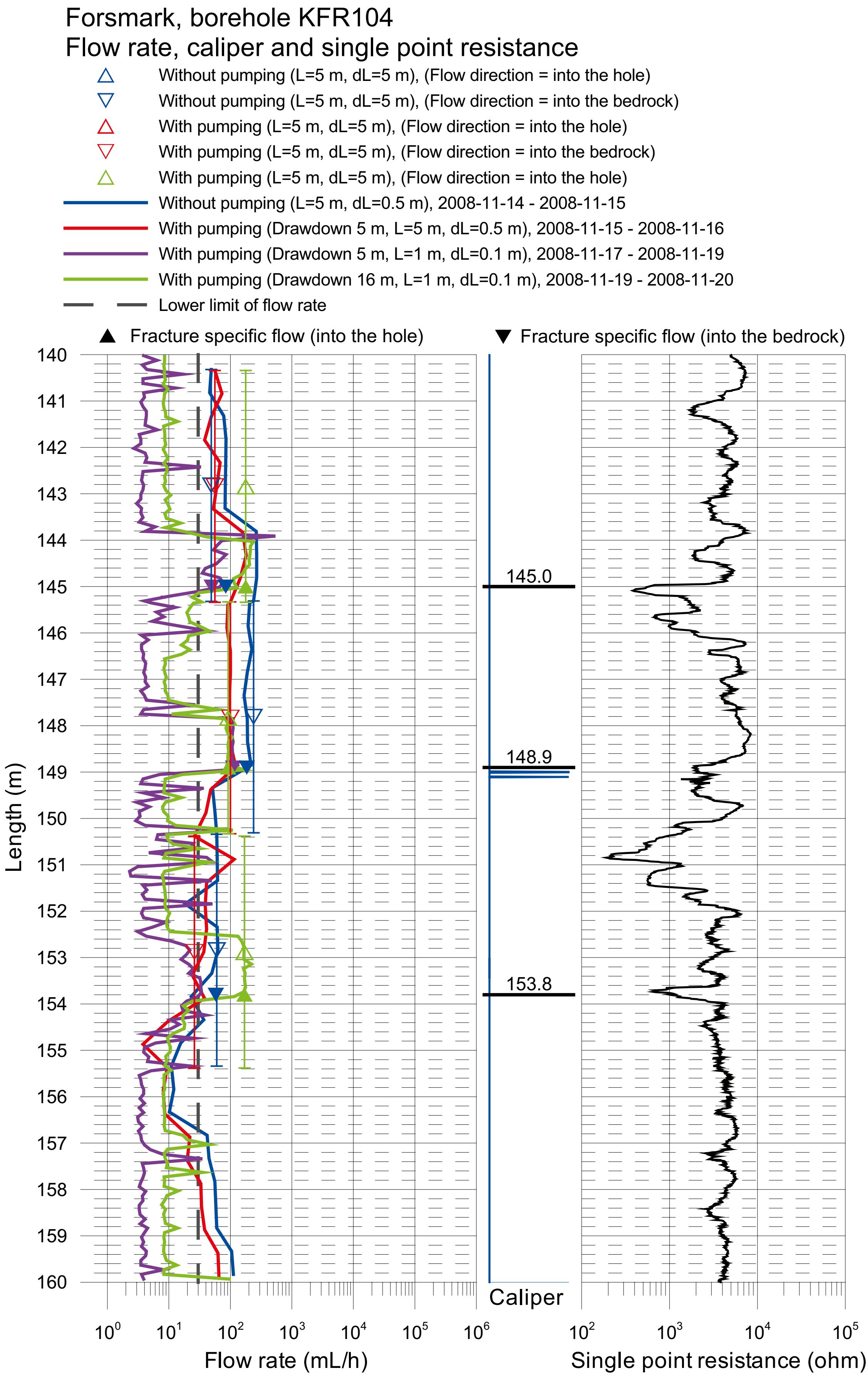
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
80.3
81.9
83.6
85.4
87.9
89.6
91.2
93.6
95.5
97.3
98.9
Caliper
Flow rate (mL/h)
Single point resistance (ohm)



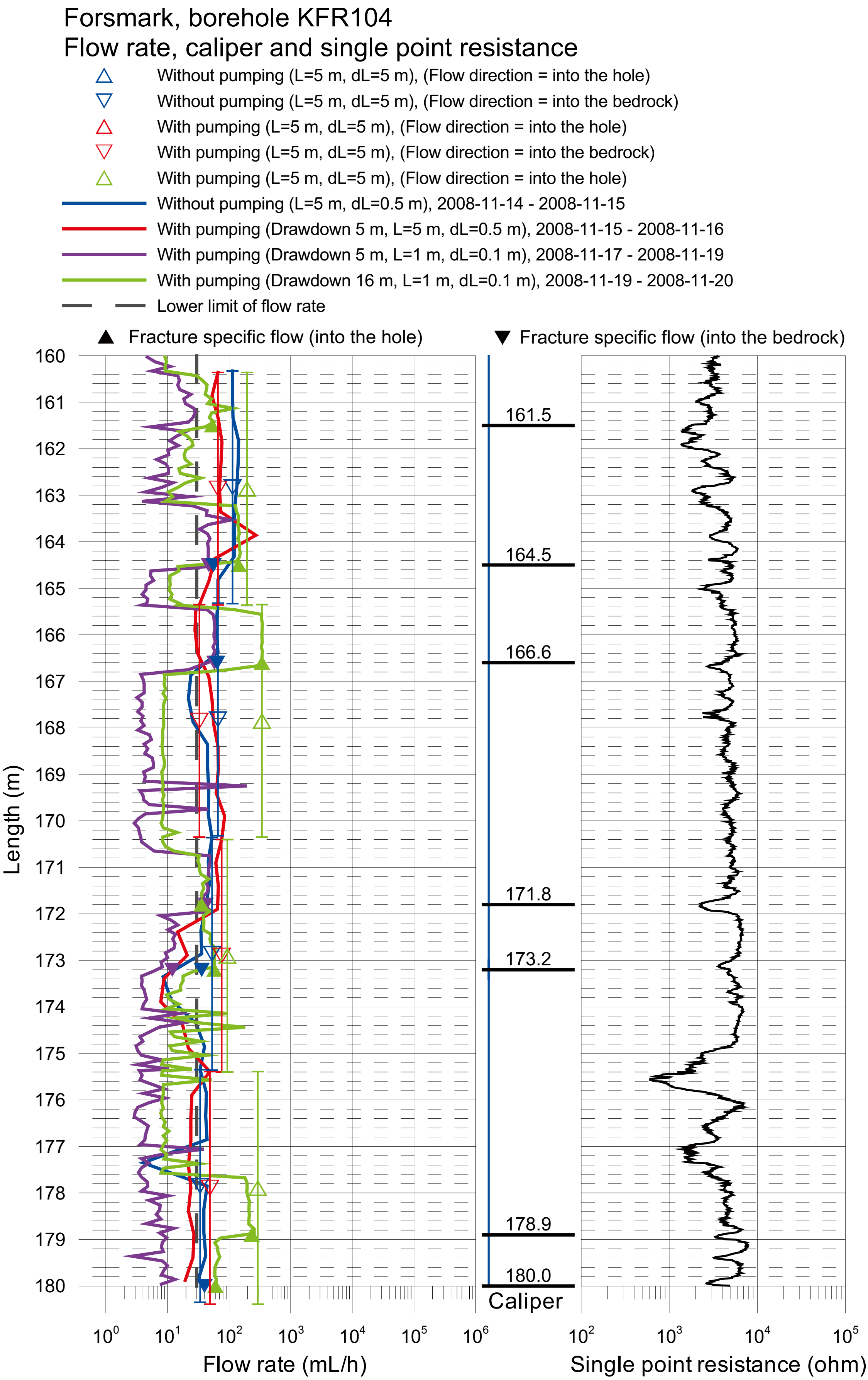
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
100.7
105.7
106.3
106.8
107.3
109.4
111.9
112.3
113.5
114.8
115.7
117.7
119.8
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)



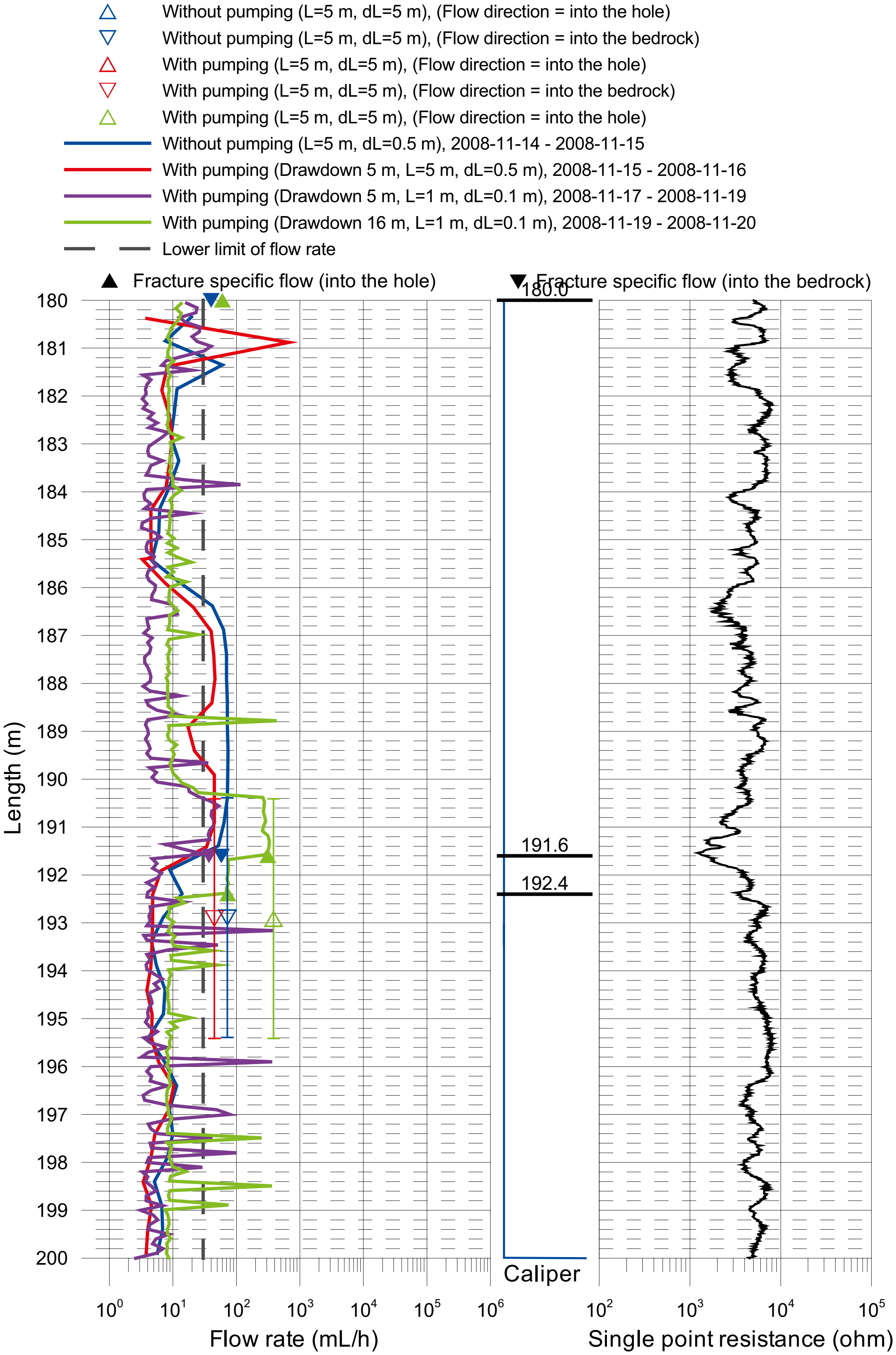
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
121.6
123.0
126.7
131.3
131.6
133.5
136.2
Caliper
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
10^2
10^3
10^4
10^5
Single point resistance (ohm)



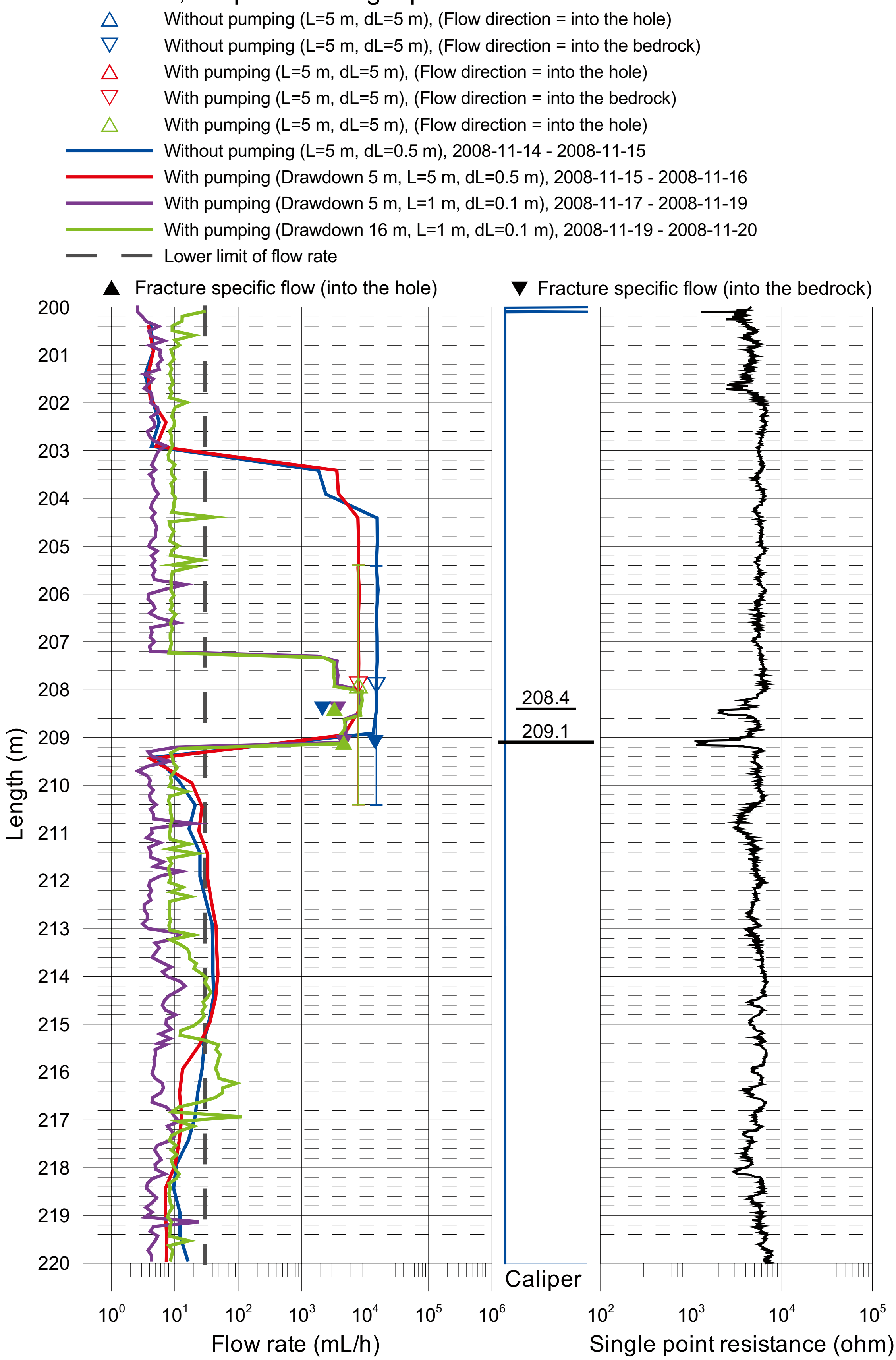
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
145.0
148.9
153.8
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

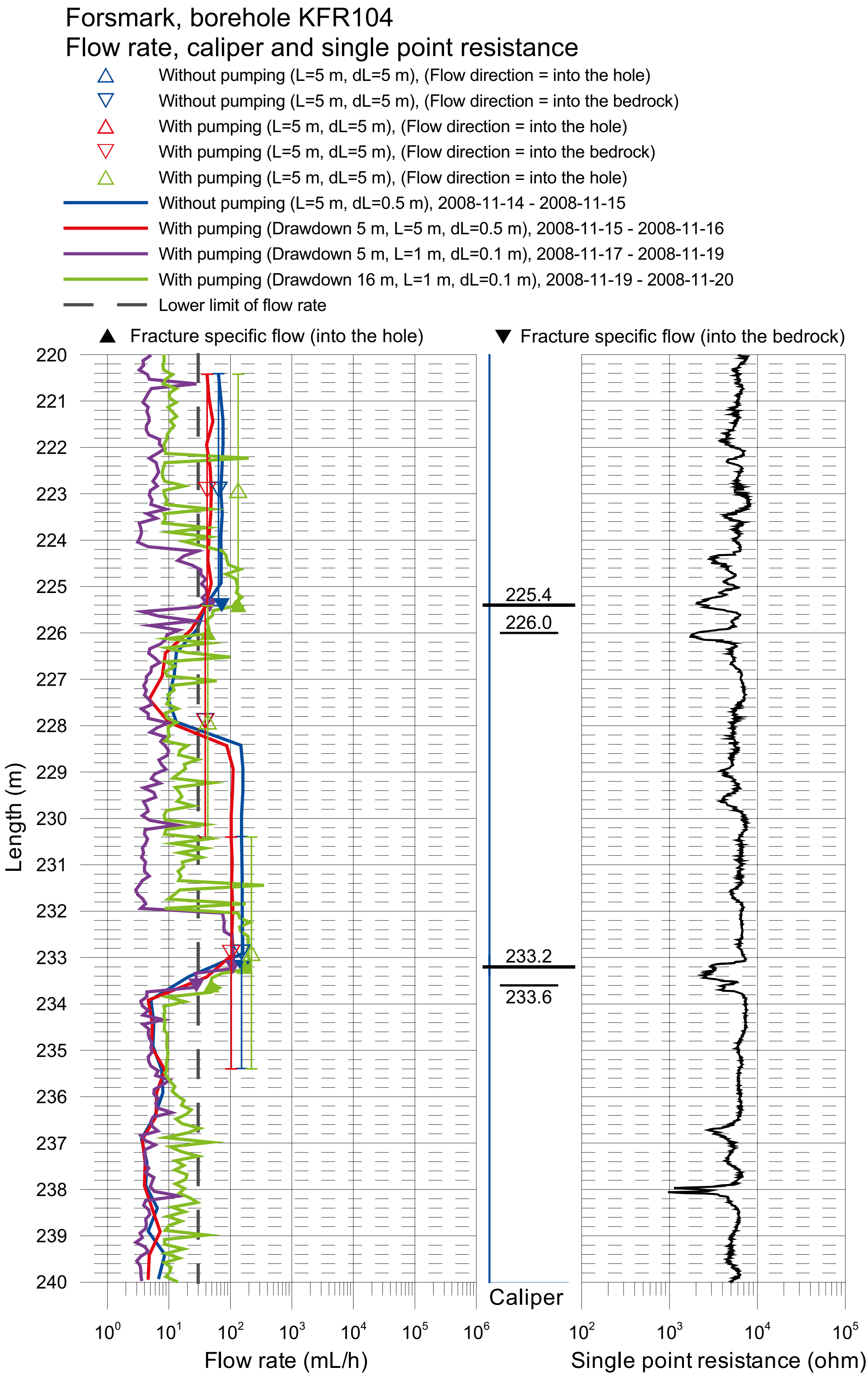

Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
161.5
164.5
166.6
171.8
173.2
178.9
180.0
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

Forsmark, borehole KFR104
Flow rate, caliper and single point resistance

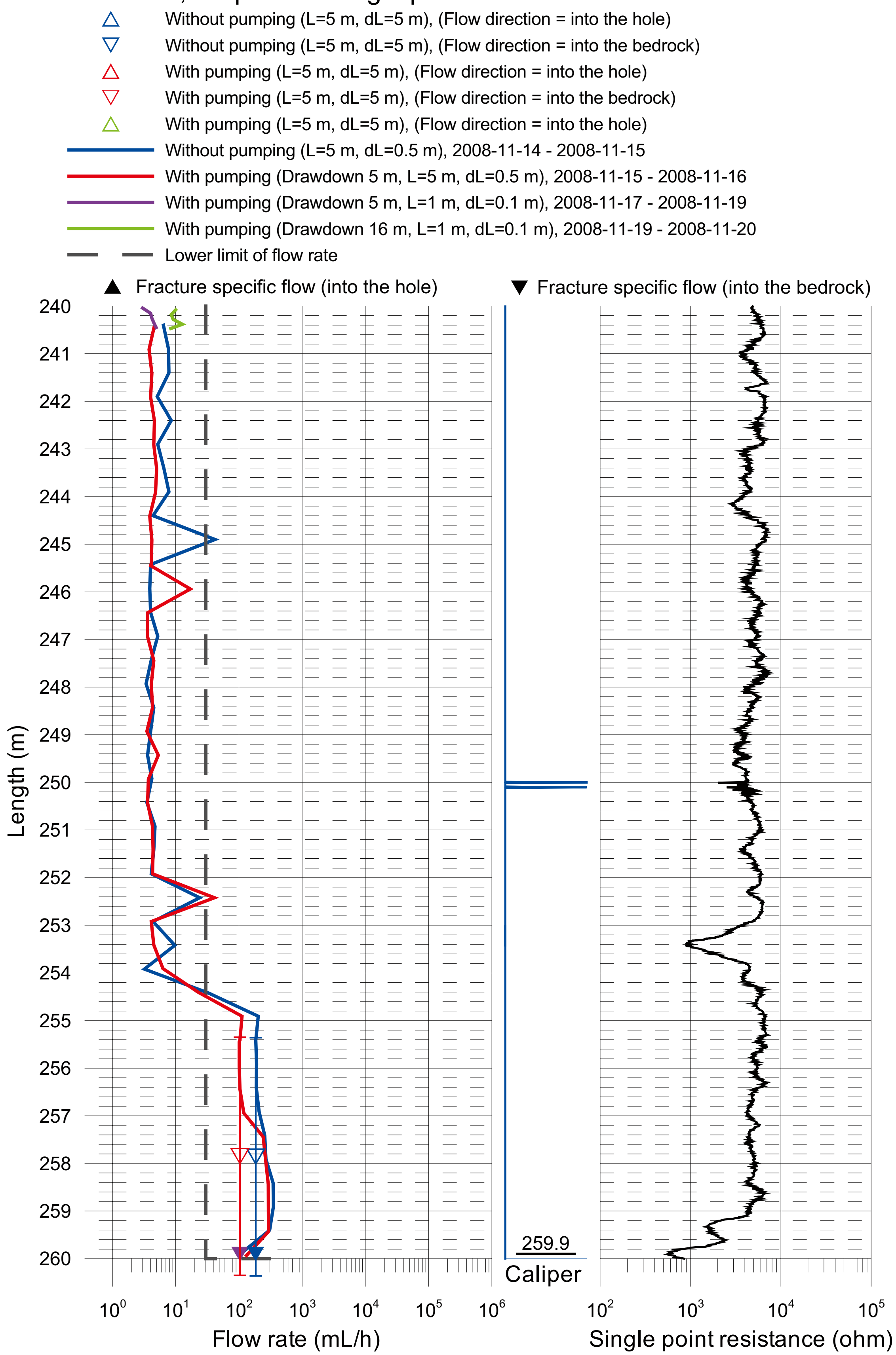


Forsmark, borehole KFR104
Flow rate, caliper and single point resistance

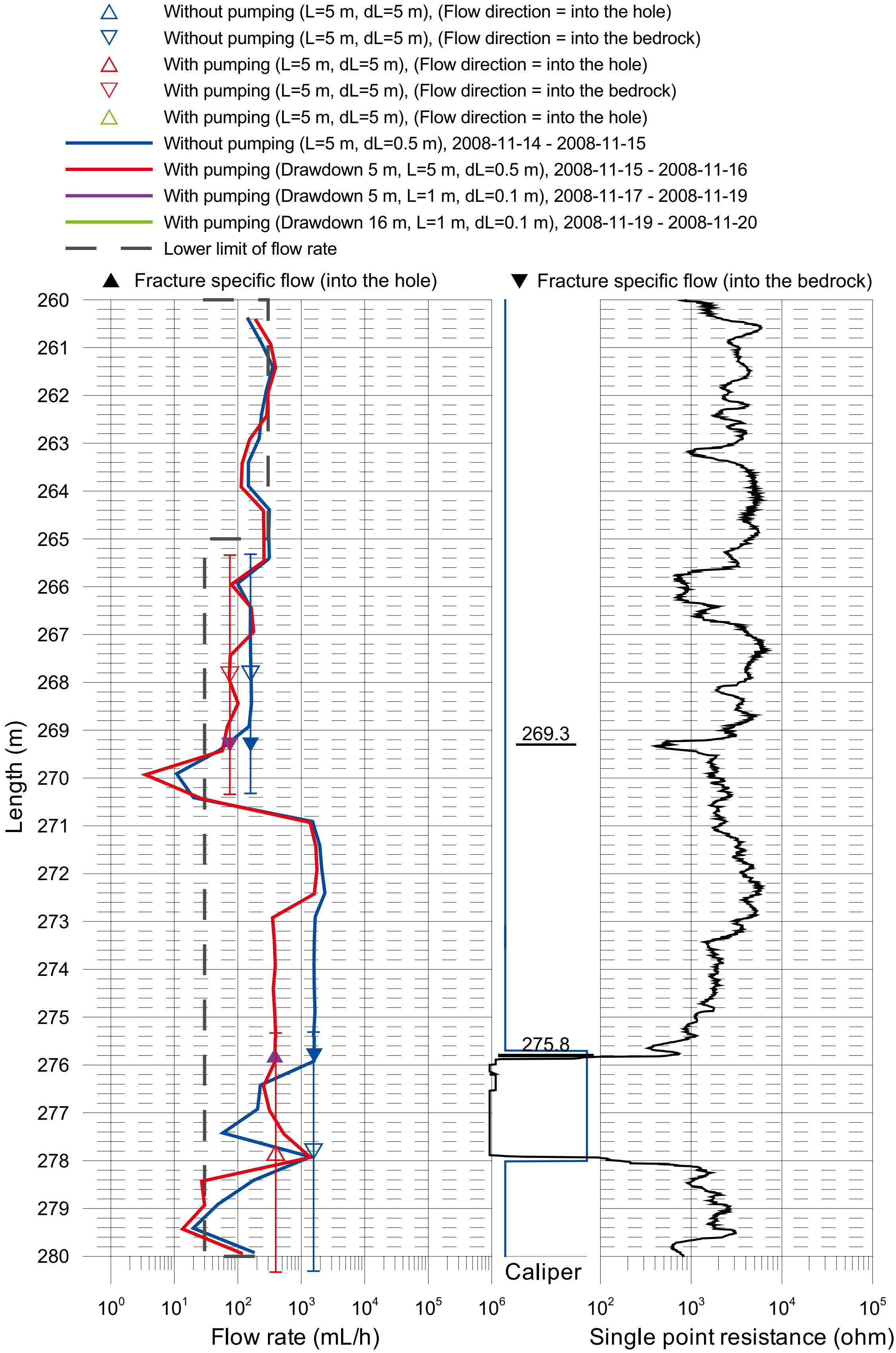



Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
225.4
226.0
233.2
233.6
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

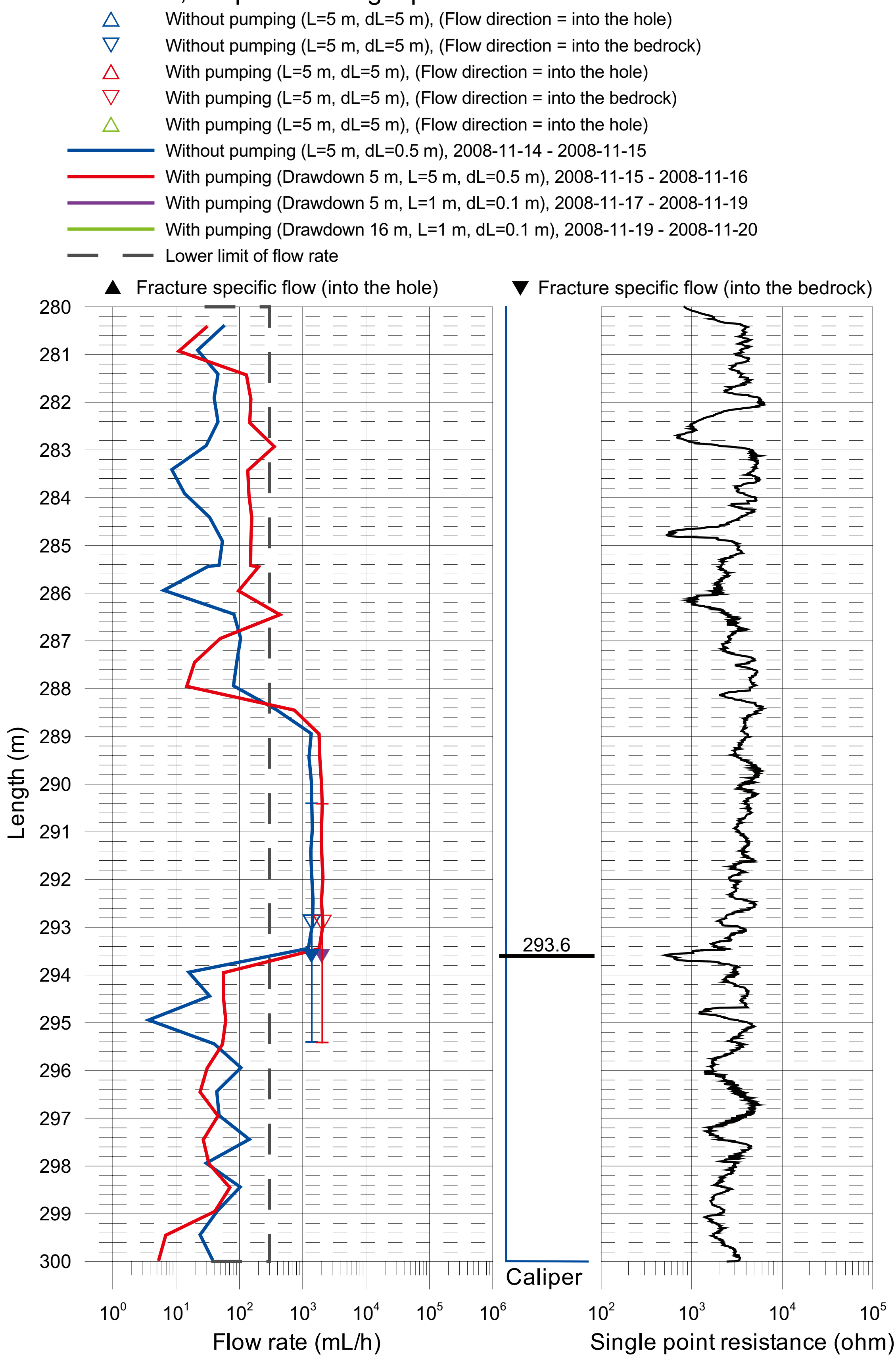
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance



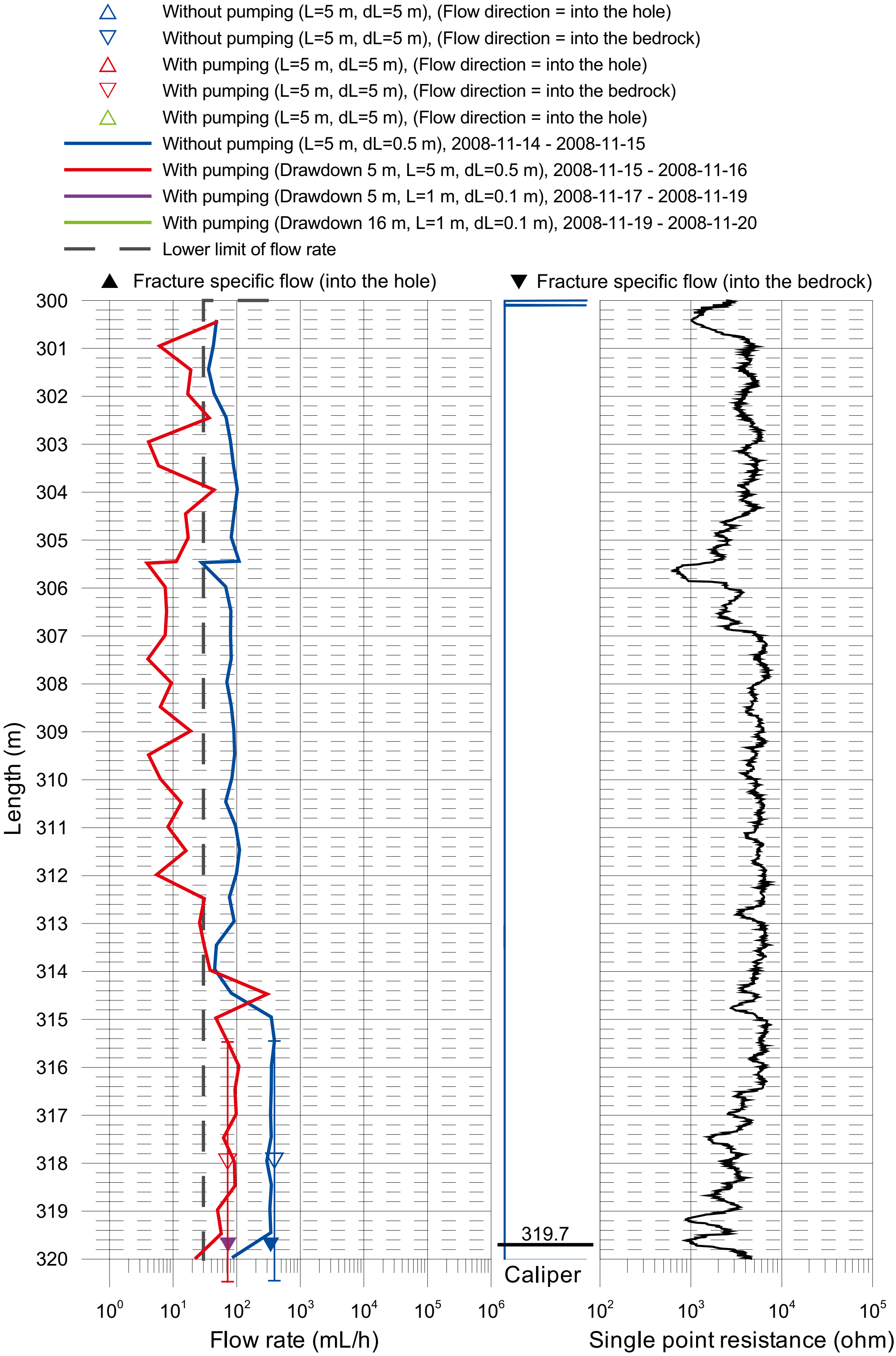
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance

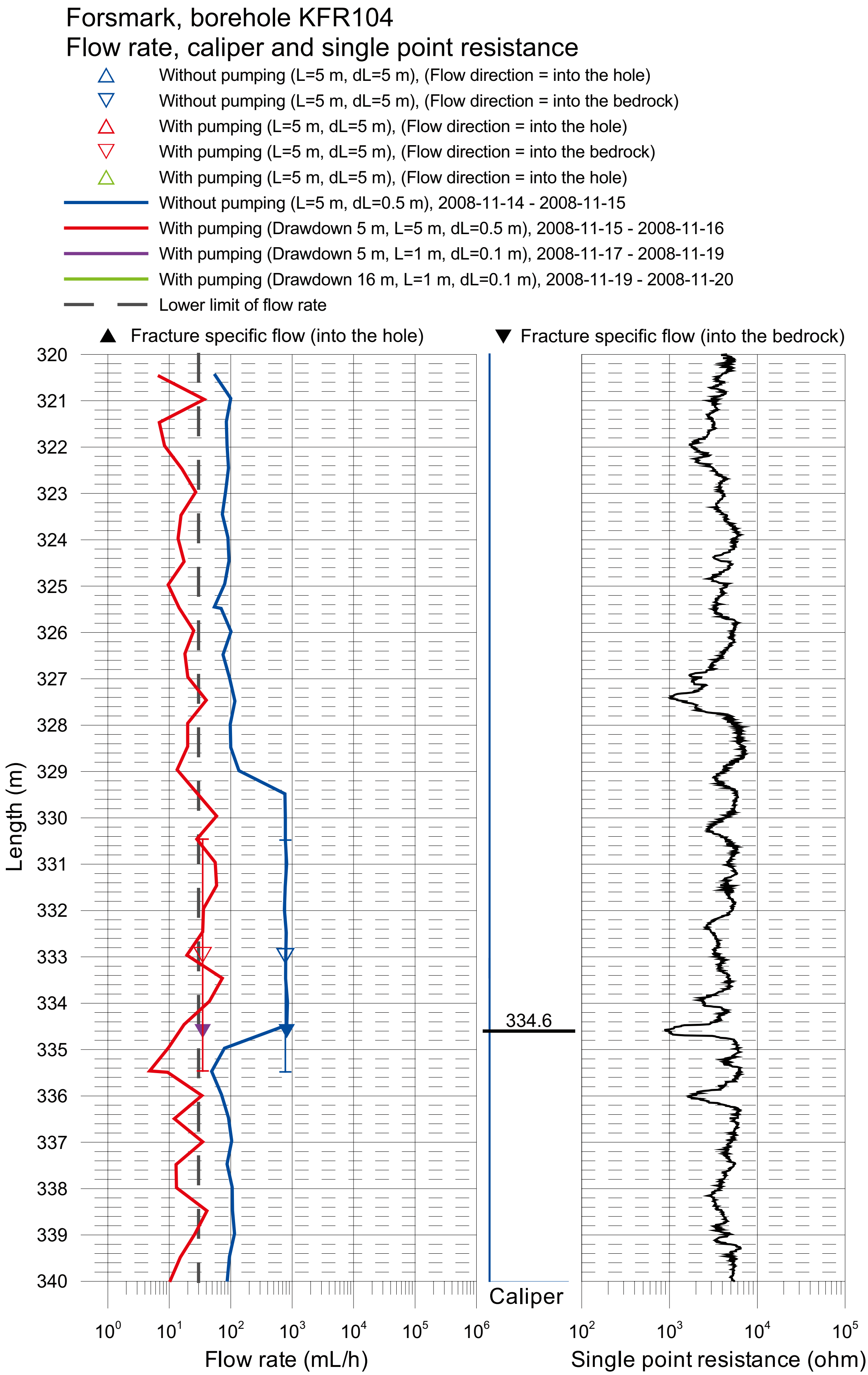


Forsmark, borehole KFR104
Flow rate, caliper and single point resistance

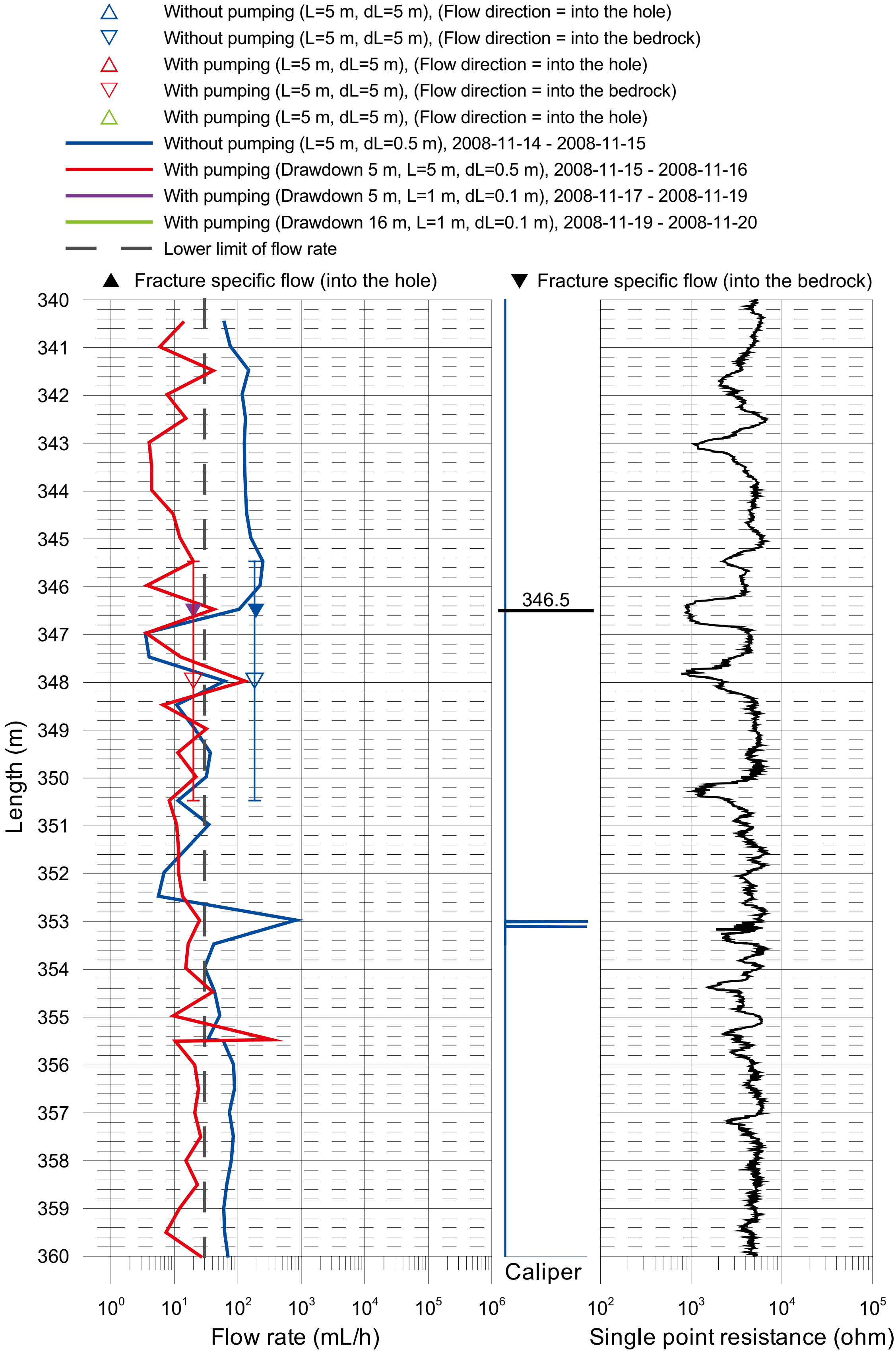


Forsmark, borehole KFR104
Flow rate, caliper and single point resistance

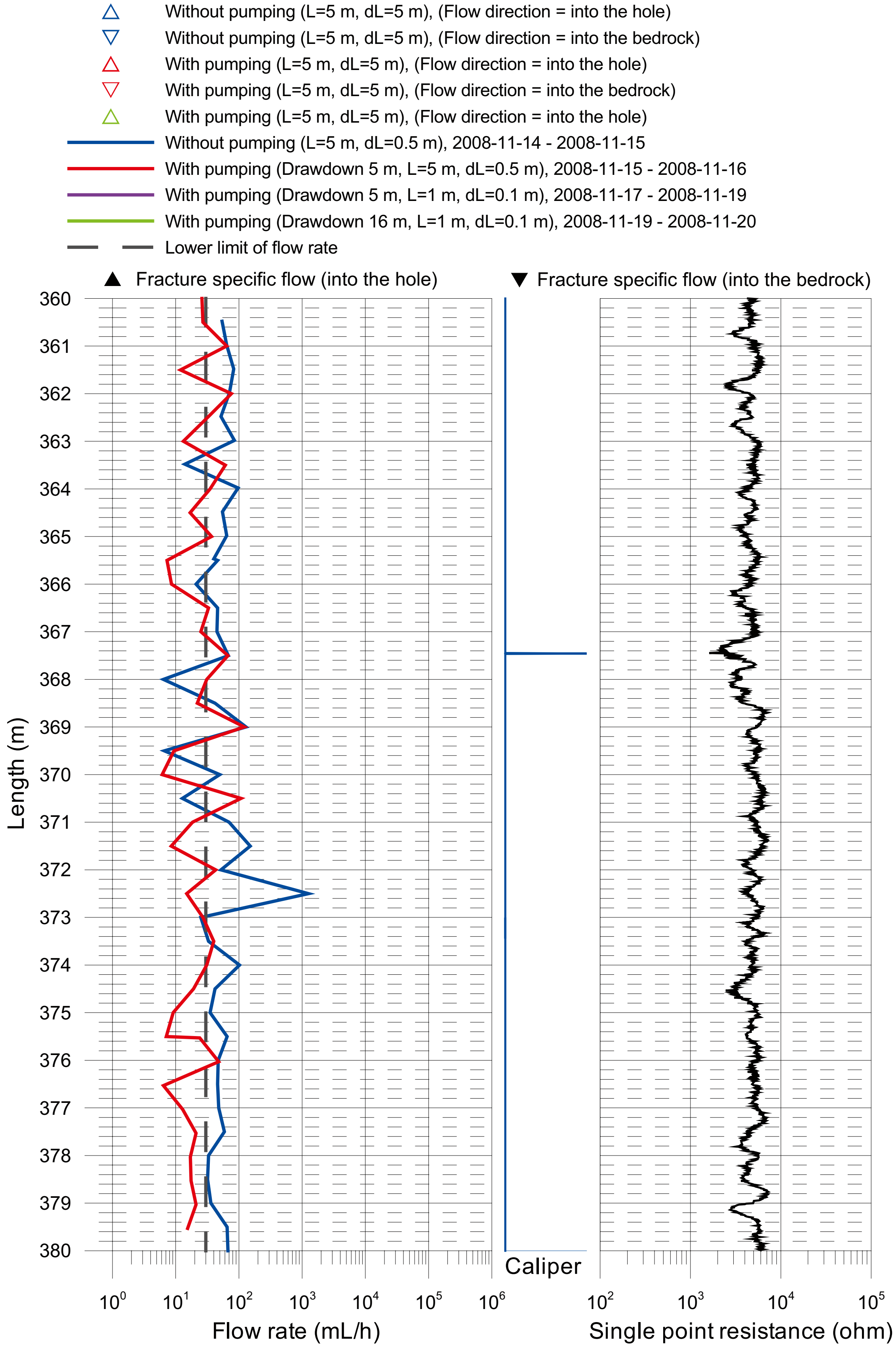



Forsmark, borehole KFR104
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-11-14 - 2008-11-15
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-15 - 2008-11-16
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-17 - 2008-11-19
With pumping (Drawdown 16 m, L=1 m, dL=0.1 m), 2008-11-19 - 2008-11-20
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
334.6
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

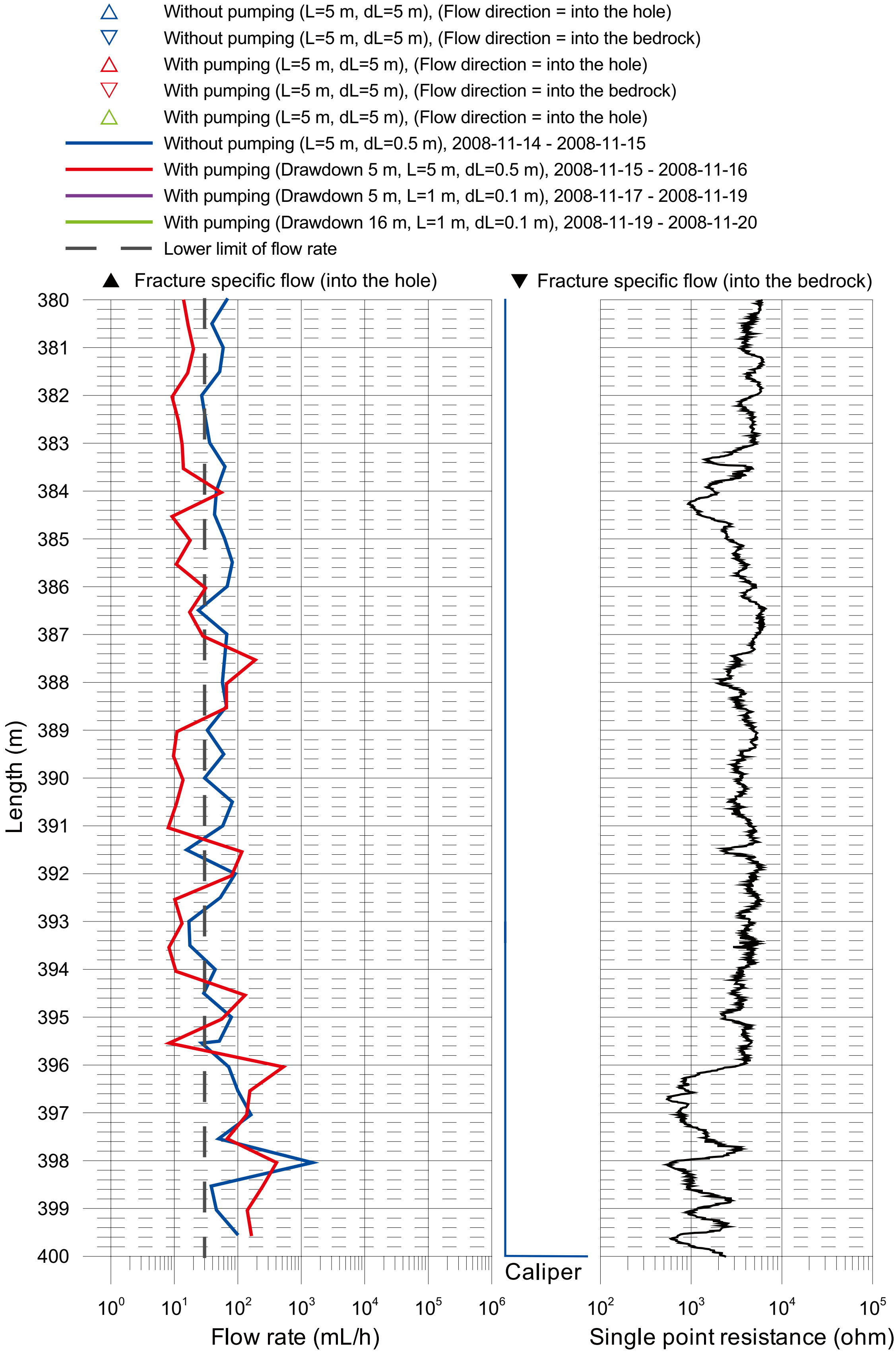
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance



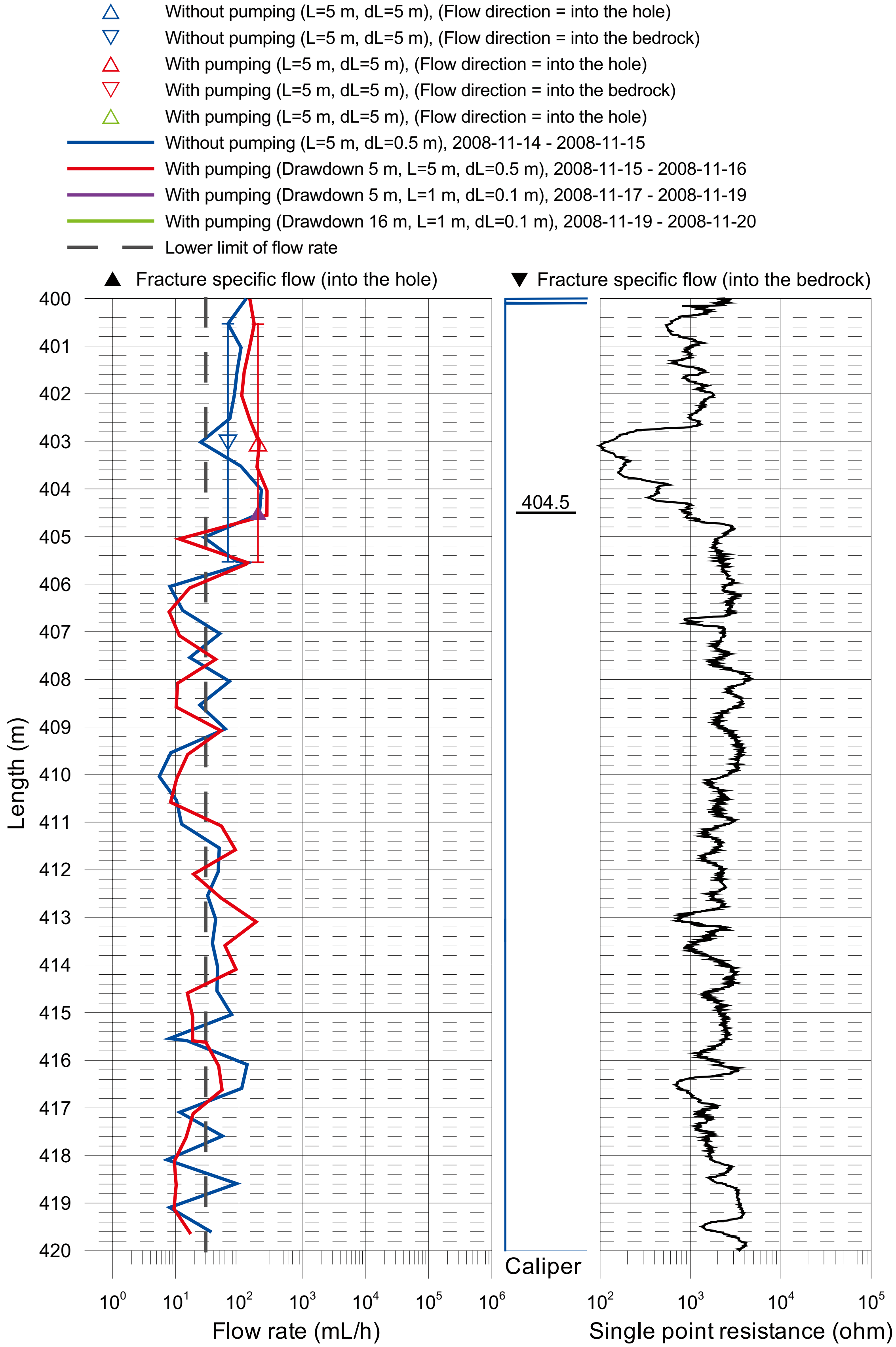
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance



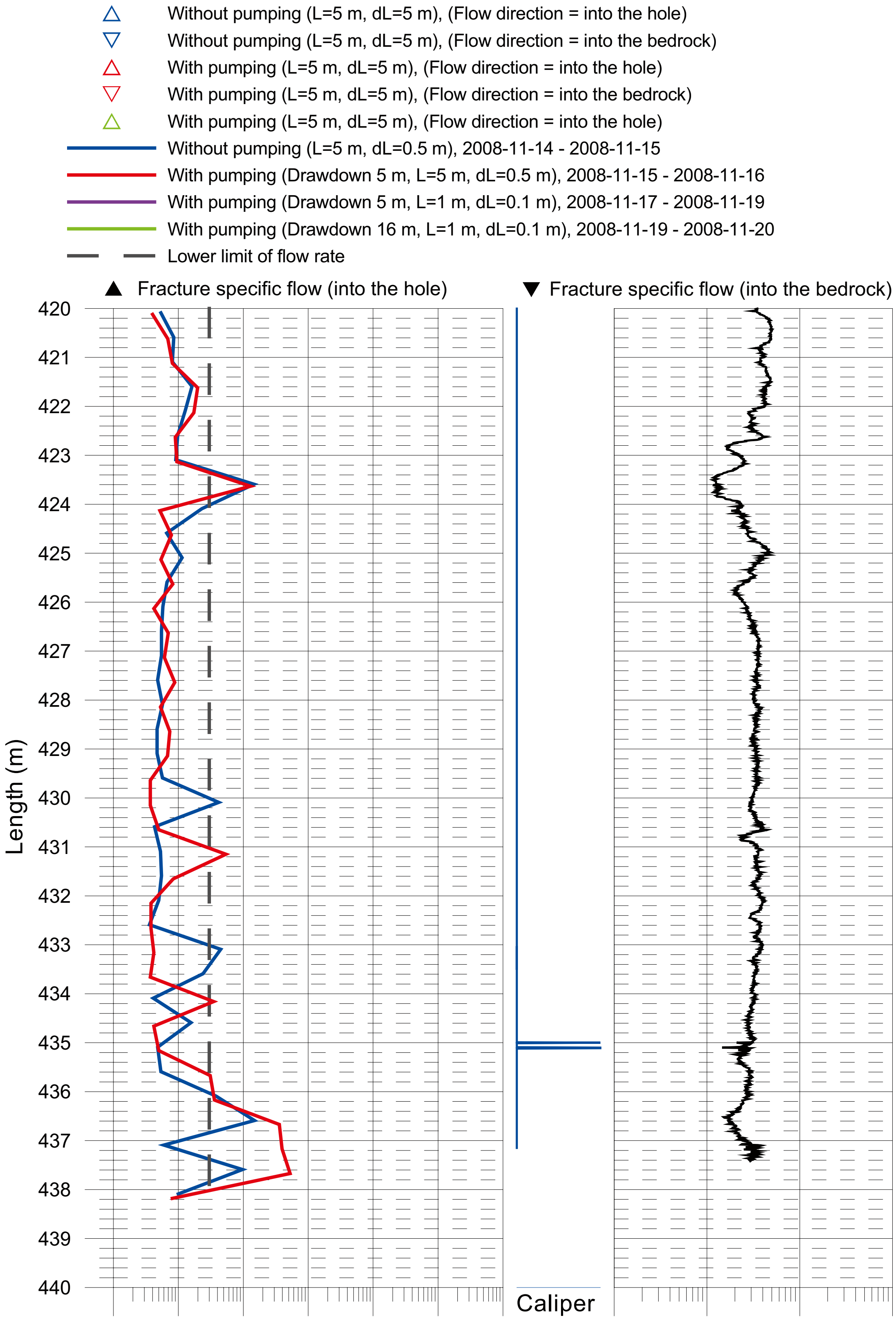
Forsmark, borehole KFR104
Flow rate, caliper and single point resistance



Forsmark, borehole KFR104
Flow rate, caliper and single point resistance



Forsmark, borehole KFR104
Flow rate, caliper and single point resistance



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).

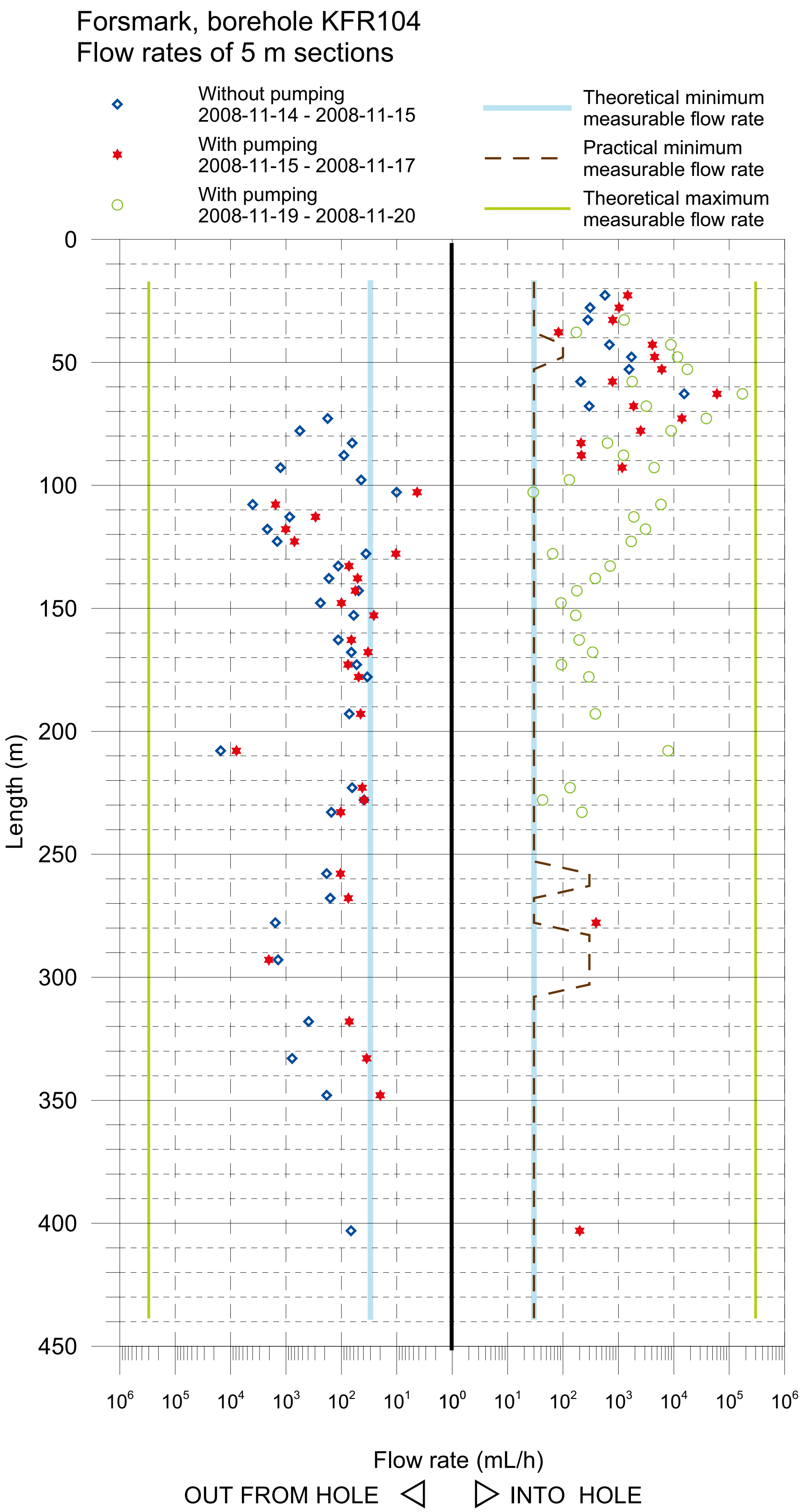
Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1/Q_2 (m^3/s)	h_{1FW}/h_{2FW} (masl)	T_D (m^2/s)	h_i (masl)	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
KFR104	20.24	25.24	5	1.59E-07	–4.30	4.08E-07	–9.20	5.0E-08	–1.2	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	25.25	30.25	5	8.56E-08	–4.30	2.86E-07	–9.24	4.0E-08	–2.2	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	30.27	35.27	5	7.81E-08	–4.31	3.53E-07	–20.53	1.7E-08	0.3	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	35.29	40.29	5	–	–4.31	4.83E-08	–20.53	2.9E-09	–	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	40.33	45.33	5	1.91E-07	–4.29	2.45E-06	–20.50	1.4E-07	–2.9	100	5.1E-10	1.7E-09	5.1E-06	**
KFR104	45.32	50.32	5	4.78E-07	–4.26	3.24E-06	–20.48	1.7E-07	–1.5	100	5.1E-10	1.7E-09	5.1E-06	**
KFR104	50.32	55.32	5	4.33E-07	–4.25	4.89E-06	–20.47	2.7E-07	–2.7	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	55.31	60.31	5	5.78E-08	–4.23	4.93E-07	–20.46	2.7E-08	–2.1	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	60.30	65.30	5	4.28E-06	–4.22	4.80E-05	–20.45	2.7E-06	–2.6	30	5.1E-10	5.1E-10	4.8E-06	**
KFR104	65.30	70.30	5	8.25E-08	–4.20	8.85E-07	–20.43	4.9E-08	–2.5	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	70.32	75.32	5	–4.92E-08	–4.18	1.07E-05	–20.39	6.6E-07	–4.3	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	75.31	80.31	5	–1.56E-07	–4.15	2.49E-06	–20.37	1.6E-07	–5.1	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	80.30	85.30	5	–1.78E-08	–4.12	1.77E-07	–20.37	1.2E-08	–5.6	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	85.29	90.29	5	–2.50E-08	–4.11	3.43E-07	–20.30	2.3E-08	–5.2	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	90.29	95.29	5	–3.50E-07	–4.08	1.23E-06	–20.33	9.6E-08	–7.7	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	95.29	100.29	5	–1.22E-08	–4.06	3.61E-08	–20.27	3.0E-09	–8.2	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	100.31	105.31	5	–2.81E-09	–4.03	8.06E-09	–20.21	6.6E-10	–8.2	30	5.1E-10	5.1E-10	5.1E-06	*, **
KFR104	105.29	110.29	5	–1.11E-06	–4.00	1.63E-06	–20.21	1.7E-07	–10.6	30	5.1E-10	5.1E-10	5.2E-06	**
KFR104	110.32	115.32	5	–2.38E-07	–3.98	5.28E-07	–20.21	4.7E-08	–9.0	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	115.31	120.31	5	–6.03E-07	–3.97	8.56E-07	–20.18	8.9E-08	–10.7	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	120.31	125.31	5	–4.00E-07	–3.94	4.73E-07	–20.17	5.3E-08	–11.4	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	125.30	130.30	5	–1.00E-08	–3.93	1.81E-08	–20.13	1.7E-09	–9.7	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	130.31	135.31	5	–3.17E-08	–3.92	1.97E-07	–20.10	1.4E-08	–6.2	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	135.31	140.31	5	–4.67E-08	–3.90	1.06E-07	–20.11	9.3E-09	–8.9	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	140.33	145.33	5	–1.36E-08	–3.89	4.94E-08	–20.07	3.9E-09	–7.4	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	145.32	150.32	5	–6.64E-08	–3.85	2.56E-08	–20.04	5.6E-09	–15.5	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	150.36	155.36	5	–1.67E-08	–3.83	4.72E-08	–20.00	3.9E-09	–8.1	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	155.36	160.36	5	–	–3.81	-	–19.96	-	–	30	5.1E-10	5.1E-10	5.1E-06	**

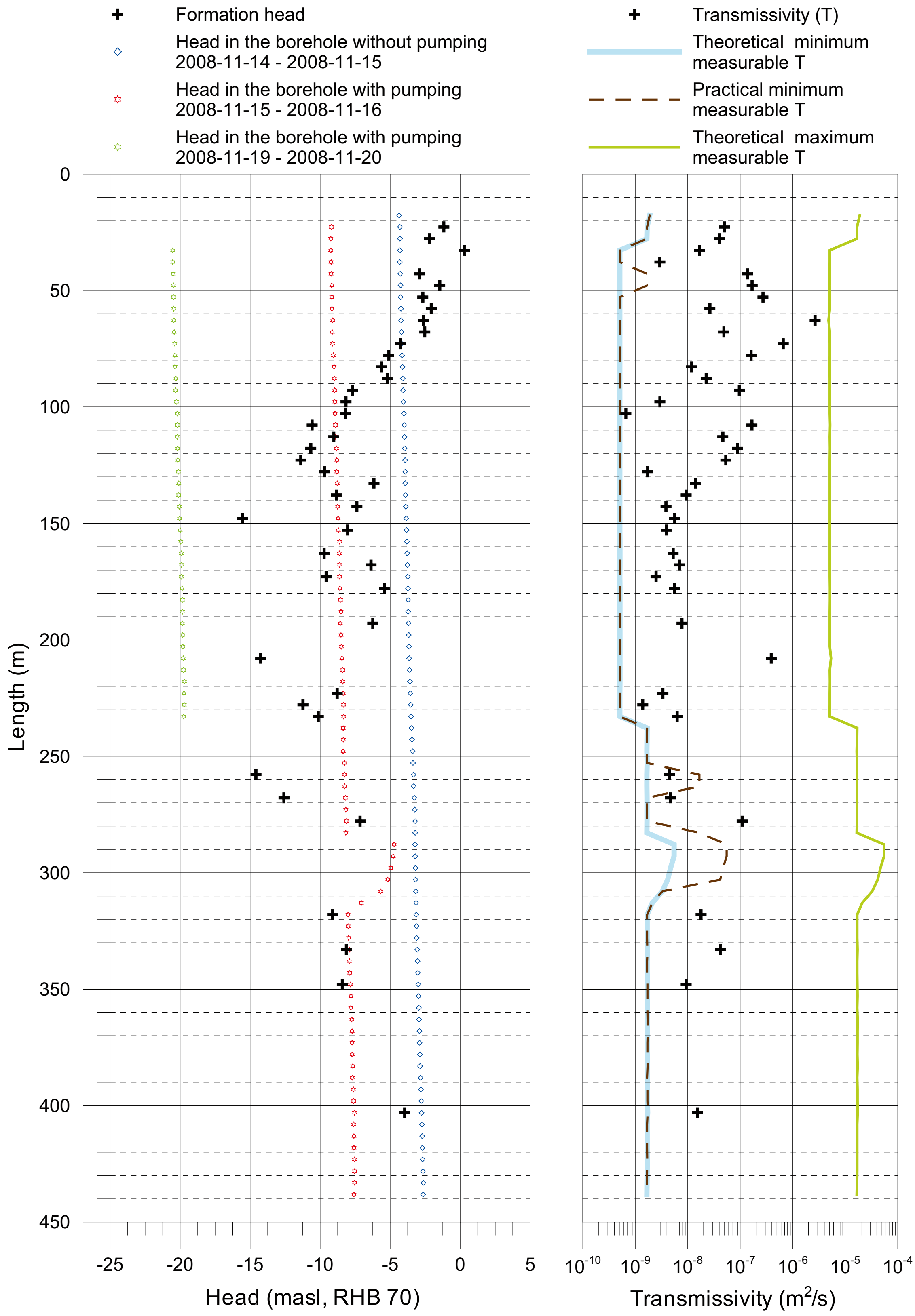
Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1/Q_2 (m^3/s)	h_{1FW}/h_{2FW} (masl)	T_D (m^2/s)	h_i (masl)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	Comments
KFR104	160.35	165.35	5	–3.17E-08	–3.78	5.44E-08	–19.92	5.3E-09	–9.7	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	165.34	170.34	5	–1.83E-08	–3.77	9.53E-08	–19.91	7.0E-09	–6.4	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	170.38	175.38	5	–1.47E-08	–3.74	2.61E-08	–19.92	2.5E-09	–9.6	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	175.37	180.37	5	–9.44E-09	–3.73	8.14E-08	–19.86	5.6E-09	–5.4	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	180.37	185.37	5	–	–3.72	–	–19.84	–	–	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	185.37	190.37	5	–	–3.71	–	–19.84	–	–	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	190.40	195.40	5	–2.00E-08	–3.69	1.07E-07	–19.85	7.8E-09	–6.2	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	195.41	200.41	5	–	–3.67	–	–19.82	–	–	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	200.41	205.41	5	–	–3.65	–	–19.81	–	–	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	205.41	210.41	5	–4.19E-06	–3.64	2.19E-06	–19.78	3.9E-07	–14.3	30	5.1E-10	5.1E-10	5.4E-06	**
KFR104	210.43	215.43	5	–	–3.61	–	–19.77	–	–	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	215.42	220.42	5	–	–3.59	–	–19.70	–	–	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	220.42	225.42	5	–1.78E-08	–3.56	3.72E-08	–19.73	3.4E-09	–8.8	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	225.41	230.41	5	–1.08E-08	–3.53	1.19E-08	–19.71	1.4E-09	–11.2	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	230.40	235.40	5	–4.22E-08	–3.50	6.11E-08	–19.75	6.3E-09	–10.1	30	5.1E-10	5.1E-10	5.1E-06	**
KFR104	235.39	240.39	5	–	–3.47	–	–8.36	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	240.37	245.37	5	–	–3.44	–	–8.35	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	245.36	250.36	5	–	–3.40	–	–8.36	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	250.38	255.38	5	–	–3.37	–	–8.27	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	255.36	260.36	5	–5.14E-08	–3.33	–2.89E-08	–8.26	4.5E-09	–14.6	300	1.7E-09	1.7E-08	1.7E-05	
KFR104	260.36	265.36	5	–	–3.32	–	–8.25	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR104	265.33	270.33	5	–4.42E-08	–3.28	–2.08E-08	–8.20	4.7E-09	–12.6	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	270.35	275.35	5	–	–3.25	–	–8.17	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	275.32	280.32	5	–4.33E-07	–3.22	1.10E-07	–8.14	1.1E-07	–7.2	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	280.35	285.35	5	–	–3.22	–	–8.17	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR104	285.36	290.36	5	–	–3.22	–	–4.72	–	–	300	5.5E-09	5.5E-08	5.5E-05	
KFR104	290.41	295.41	5	–3.86E-07	–3.21	–5.67E-07	–4.79	–	–	300	5.5E-09	5.5E-08	5.5E-05	***
KFR104	295.42	300.42	5	–	–3.20	–	–4.95	–	–	300	4.7E-09	4.7E-08	4.7E-05	
KFR104	300.44	305.44	5	–	–3.19	–	–5.17	–	–	300	4.2E-09	4.2E-08	4.2E-05	

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1/Q_2 (m^3/s)	h_{1FW}/h_{2FW} (masl)	T_D (m^2/s)	h_i (masl)	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
KFR104	305.45	310.45	5	–	–3.17	–	–5.68	–	–	30	3.3E-09	3.3E-09	3.3E-05	
KFR104	310.47	315.47	5	–	–3.15	–	–7.06	–	–	30	2.1E-09	2.1E-09	2.1E-05	
KFR104	315.46	320.46	5	–1.09E-07	–3.13	–2.00E-08	–8.01	1.8E-08	–9.1	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	320.46	325.46	5	–	–3.11	–	–8.00	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	325.46	330.46	5	–	–3.10	–	–7.97	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	330.47	335.47	5	–2.15E-07	–3.06	–9.72E-09	–7.90	4.2E-08	–8.1	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	335.47	340.47	5	–	–3.04	–	–7.91	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	340.48	345.48	5	–	–3.02	–	–7.89	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	345.47	350.47	5	–5.11E-08	–2.99	–5.53E-09	–7.83	9.3E-09	–8.4	30	1.7E-09	1.7E-09	1.7E-05	*
KFR104	350.47	355.47	5	–	–2.97	–	–7.80	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	355.47	360.47	5	–	–2.95	–	–7.81	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	360.49	365.49	5	–	–2.94	–	–7.74	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	365.49	370.49	5	–	–2.91	–	–7.72	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	370.50	375.50	5	–	–2.90	–	–7.72	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	375.50	380.50	5	–	–2.87	–	–7.72	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	380.52	385.52	5	–	–2.87	–	–7.67	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	385.51	390.51	5	–	–2.83	–	–7.71	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	390.52	395.52	5	–	–2.81	–	–7.63	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	395.52	400.52	5	–	–2.79	–	–7.61	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	400.54	405.54	5	–1.86E-08	–2.76	5.56E-08	–7.55	1.5E-08	–4.0	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	405.55	410.55	5	–	–2.73	–	–7.61	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	410.56	415.56	5	–	–2.72	–	–7.59	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	415.58	420.58	5	–	–2.70	–	–7.59	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	420.61	425.61	5	–	–2.69	–	–7.55	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	425.61	430.61	5	–	–2.66	–	–7.54	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	430.62	435.62	5	–	–2.63	–	–7.54	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR104	435.63	440.63	5	–	–2.64	–	–7.59	–	–	30	1.7E-09	1.7E-09	1.7E-05	

* Flow rate Q_0 and/or Q_1/Q_2 below 30 mL/h,
** Values calculated from the 1 m measurement with 16 m drawdown,
*** Uncertain result , pump had stopped during measurement


Forsmark, borehole KFR104
Flow rates of 5 m sections
Without pumping
2008-11-14 - 2008-11-15
With pumping
2008-11-15 - 2008-11-17
With pumping
2008-11-19 - 2008-11-20
Theoretical minimum measurable flow rate
Practical minimum measurable flow rate
Theoretical maximum measurable flow rate
Length (m)
0
50
100
150
200
250
300
350
400
450
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

Forsmark, borehole KFR104
Transmissivity and head of 5 m sections



Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1/Q_2 (m^3/s)	h_{1FW}/h_{2FW} (masl)	T_D (m^2/s)	h_i (masl)	Comments
KFR104	19.4	1	0.1	–	–4.33	2.74E-07	–9.22	5.6E-08	–	
KFR104	20.3	1	0.1	1.62E-07	–4.33	4.33E-07	–9.23	5.5E-08	–1.4	
KFR104	25.5	1	0.1	6.81E-08	–4.31	1.89E-07	–9.26	2.4E-08	–1.5	
KFR104	29.6	1	0.1	–	–4.31	1.02E-07	–9.26	2.0E-08	–	
KFR104	30.2	1	0.1	–	–4.31	2.22E-08	–9.24	4.5E-09	–	
KFR104	30.9	1	0.1	–	–4.31	9.17E-09	–9.27	1.8E-09	–	
KFR104	33.3	1	0.1	–	–4.31	7.22E-08	–20.52	4.4E-09	–	**
KFR104	34.1	1	0.1	6.42E-08	–4.31	2.81E-07	–20.50	1.3E-08	0.5	**
KFR104	38.8	1	0.1	–	–4.32	4.83E-08	–20.51	3.0E-09	–	**
KFR104	41.3	1	0.1	–	–4.32	3.67E-08	–20.51	2.2E-09	–	*,**
KFR104	42.1	1	0.1	–	–4.30	7.61E-07	–20.52	4.6E-08	–	**
KFR104	42.7	1	0.1	–	–4.30	9.06E-07	–20.52	5.5E-08	–	**
KFR104	43.8	1	0.1	–	–4.29	7.86E-07	–20.51	4.8E-08	–	**
KFR104	46.9	1	0.1	–	–4.28	4.58E-07	–20.50	2.8E-08	–	**
KFR104	47.3	1	0.1	–	–4.28	7.31E-08	–20.52	4.5E-09	–	**
KFR104	48.8	1	0.1	–	–4.27	4.39E-08	–20.50	2.7E-09	–	**
KFR104	50.1	1	0.1	–	–4.27	2.67E-06	–20.51	1.6E-07	–	**
KFR104	52.5	1	0.1	–	–4.26	8.64E-07	–20.46	5.3E-08	–	**
KFR104	52.9	1	0.1	–	–4.26	3.00E-07	–20.48	1.8E-08	–	*,**
KFR104	54.8	1	0.1	–	–4.26	3.72E-06	–20.52	2.3E-07	–	**
KFR104	56.8	1	0.1	–	–4.28	1.19E-08	–20.48	7.3E-10	–	*,**
KFR104	59.3	1	0.1	–	–4.24	1.69E-08	–20.45	1.0E-09	–	**
KFR104	59.9	1	0.1	–	–4.24	4.64E-07	–20.44	2.8E-08	–	**
KFR104	60.5	1	0.1	–	–4.24	2.39E-06	–20.46	1.5E-07	–	**
KFR104	62.1	1	0.1	–	–4.23	5.06E-06	–20.42	3.1E-07	–	**
KFR104	63.3	1	0.1	–	–4.23	1.83E-08	–20.42	1.1E-09	–	**
KFR104	64.6	1	0.1	3.75E-06	–4.22	4.06E-05	–20.43	2.3E-06	–2.6	**
KFR104	65.1	1	0.1	–	–4.22	4.11E-08	–20.43	2.5E-09	–	**
KFR104	67.5	1	0.1	–	–4.21	3.14E-07	–20.41	1.9E-08	–	**
KFR104	69.3	1	0.1	–	–4.20	4.61E-07	–20.41	2.8E-08	–	**
KFR104	70.1	1	0.1	–	–4.20	1.10E-07	–20.39	6.7E-09	–	**
KFR104	73.5	1	0.1	–	–4.18	1.07E-05	–20.41	6.5E-07	–	**
KFR104	75.0	1	0.1	–	–4.18	5.97E-08	–20.39	3.6E-09	–	**
KFR104	77.1	1	0.1	–	–4.17	3.19E-08	–20.37	2.0E-09	–	*,**
KFR104	78.5	1	0.1	–1.63E-07	–4.16	2.46E-06	–20.36	1.6E-07	–5.2	**
KFR104	80.3	1	0.1	–	–4.14	3.56E-08	–20.35	2.2E-09	–	**
KFR104	81.9	1	0.1	–	–4.13	1.30E-07	–20.35	7.9E-09	–	**
KFR104	83.6	1	0.1	–	–4.13	1.11E-08	–20.36	6.8E-10	–	*,**
KFR104	85.4	1	0.1	–	–4.12	1.17E-08	–20.33	7.1E-10	–	*,**

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1/Q_2 (m^3/s)	h_{1FW}/h_{2FW} (masl)	T_D (m^2/s)	h_i (masl)	Comments
KFR104	87.9	1	0.1	–	–4.12	2.31E-07	–20.32	1.4E-08	–	**
KFR104	89.6	1	0.1	–	–4.10	1.00E-07	–20.30	6.1E-09	–	**
KFR104	91.2	1	0.1	–3.50E-07	–4.09	9.03E-07	–20.31	7.6E-08	–8.6	**
KFR104	93.6	1	0.1	–7.58E-08	–4.09	3.28E-07	–20.30	2.5E-08	–7.1	**
KFR104	95.5	1	0.1	–	–4.08	8.61E-09	–20.27	5.3E-10	–	*,**
KFR104	97.3	1	0.1	–	–4.06	7.22E-09	–20.28	4.4E-10	–	*,**
KFR104	98.9	1	0.1	–1.14E-08	–4.06	2.03E-08	–20.24	1.9E-09	–9.9	**
KFR104	100.7	1	0.1	–	–4.06	8.06E-09	–20.24	4.9E-10	–	*,**
KFR104	105.7	1	0.1	–4.22E-08	–4.02	8.42E-08	–20.22	7.7E-09	–9.4	**
KFR104	106.3	1	0.1	–	–4.02	9.06E-08	–20.21	5.5E-09	–	**
KFR104	106.8	1	0.1	–	–4.02	3.53E-08	–20.22	2.2E-09	–	**
KFR104	107.3	1	0.1	–	–4.02	6.39E-09	–20.21	3.9E-10	–	*,**
KFR104	109.4	1	0.1	–1.17E-06	–4.00	1.41E-06	–20.19	1.6E-07	–11.3	**
KFR104	111.9	1	0.1	–	–4.00	3.14E-07	–20.21	1.9E-08	–	**
KFR104	112.3	1	0.1	–	–3.99	1.12E-07	–20.19	6.8E-09	–	**
KFR104	113.5	1	0.1	–	–3.99	5.36E-08	–20.18	3.3E-09	–	**
KFR104	114.8	1	0.1	–	–3.98	4.81E-08	–20.16	2.9E-09	–	**
KFR104	115.7	1	0.1	–	–3.98	5.83E-07	–20.19	3.6E-08	–	**
KFR104	117.7	1	0.1	–	–3.98	3.25E-08	–20.16	2.0E-09	–	*,**
KFR104	119.8	1	0.1	–	–3.96	2.40E-07	–20.16	1.5E-08	–	**
KFR104	121.6	1	0.1	–3.31E-07	–3.96	4.03E-07	–20.16	4.5E-08	–11.3	**
KFR104	123.0	1	0.1	–5.78E-08	–3.95	7.03E-08	–20.14	7.8E-09	–11.3	**
KFR104	126.7	1	0.1	–	–3.94	1.81E-08	–20.13	1.1E-09	–	*,**
KFR104	131.3	1	0.1	–	–3.93	9.25E-08	–20.15	5.6E-09	–	**
KFR104	131.6	1	0.1	–	–3.93	3.50E-08	–20.13	2.1E-09	–	**
KFR104	133.5	1	0.1	–2.33E-08	–3.93	6.94E-08	–20.12	5.7E-09	–8.0	**
KFR104	136.2	1	0.1	–4.61E-08	–3.92	1.06E-07	–20.05	9.3E-09	–8.8	**
KFR104	145.0	1	0.1	–2.33E-08	–3.89	4.94E-08	–20.06	4.5E-09	–9.1	**
KFR104	148.9	1	0.1	–5.14E-08	–3.86	2.56E-08	–20.02	4.7E-09	–14.7	**
KFR104	153.8	1	0.1	–1.61E-08	–3.84	4.72E-08	–20.00	3.9E-09	–8.0	**
KFR104	161.5	1	0.1	–	–3.80	1.47E-08	–19.98	9.0E-10	–	**
KFR104	164.5	1	0.1	–1.56E-08	–3.79	3.97E-08	–19.95	3.4E-09	–8.3	**
KFR104	166.6	1	0.1	–1.78E-08	–3.79	9.53E-08	–19.99	6.9E-09	–6.3	**
KFR104	171.8	1	0.1	–	–3.76	1.00E-08	–19.92	6.1E-10	–	**
KFR104	173.2	1	0.1	–1.00E-08	–3.75	1.61E-08	–19.94	1.6E-09	–10.0	**
KFR104	178.9	1	0.1	–	–3.74	6.47E-08	–19.87	4.0E-09	–	**
KFR104	180.0	1	0.1	–1.11E-08	–3.74	1.67E-08	–19.87	1.7E-09	–10.2	**
KFR104	191.6	1	0.1	–1.61E-08	–3.70	8.67E-08	–19.83	6.3E-09	–6.2	**
KFR104	192.4	1	0.1	–	–3.70	2.03E-08	–19.86	1.2E-09	–	**
KFR104	208.4	1	0.1	–5.92E-07	–3.65	9.08E-07	–19.76	9.2E-08	–10.0	*,**

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1/Q_2 (m^3/s)	h_{1FW}/h_{2FW} (masl)	T_D (m^2/s)	h_i (masl)	Comments
KFR104	209.1	1	0.1	–4.03E-06	–3.65	1.28E-06	–19.76	3.3E-07	–15.9	**
KFR104	225.4	1	0.1	–2.00E-08	–3.56	3.72E-08	–19.72	3.5E-09	–9.2	**
KFR104	226.0	1	0.1	–	–3.55	1.19E-08	–19.70	7.3E-10	–	*,**
KFR104	233.2	1	0.1	–4.39E-08	–3.52	4.75E-08	–19.68	5.6E-09	–11.3	**
KFR104	233.6	1	0.1	–	–3.52	1.36E-08	–19.72	8.3E-10	–	*,**
KFR104	259.9	1	0.1	–5.11E-08	–3.34	–2.86E-08	–8.25	4.5E-09	–14.5	*, #
KFR104	269.3	1	0.1	–4.42E-08	–3.28	–2.08E-08	–8.17	4.7E-09	–12.5	*, #
KFR104	275.8	1	0.1	–4.44E-07	–3.26	1.06E-07	–8.14	1.1E-07	–7.2	#
KFR104	293.6	1	0.1	–3.81E-07	–3.22	–5.56E-07	–4.81	–	–	***, #
KFR104	319.7	1	0.1	–9.50E-08	–3.14	–2.03E-08	–8.01	1.5E-08	–9.3	#
KFR104	334.6	1	0.1	–2.26E-07	–3.07	–9.72E-09	–7.94	4.4E-08	–8.2	#
KFR104	346.5	1	0.1	–5.36E-08	–3.01	–5.53E-09	–7.86	9.8E-09	–8.4	#
KFR104	404.5	1	0.1	–	–2.76	5.56E-08	–7.58	1.1E-08	–	*, #

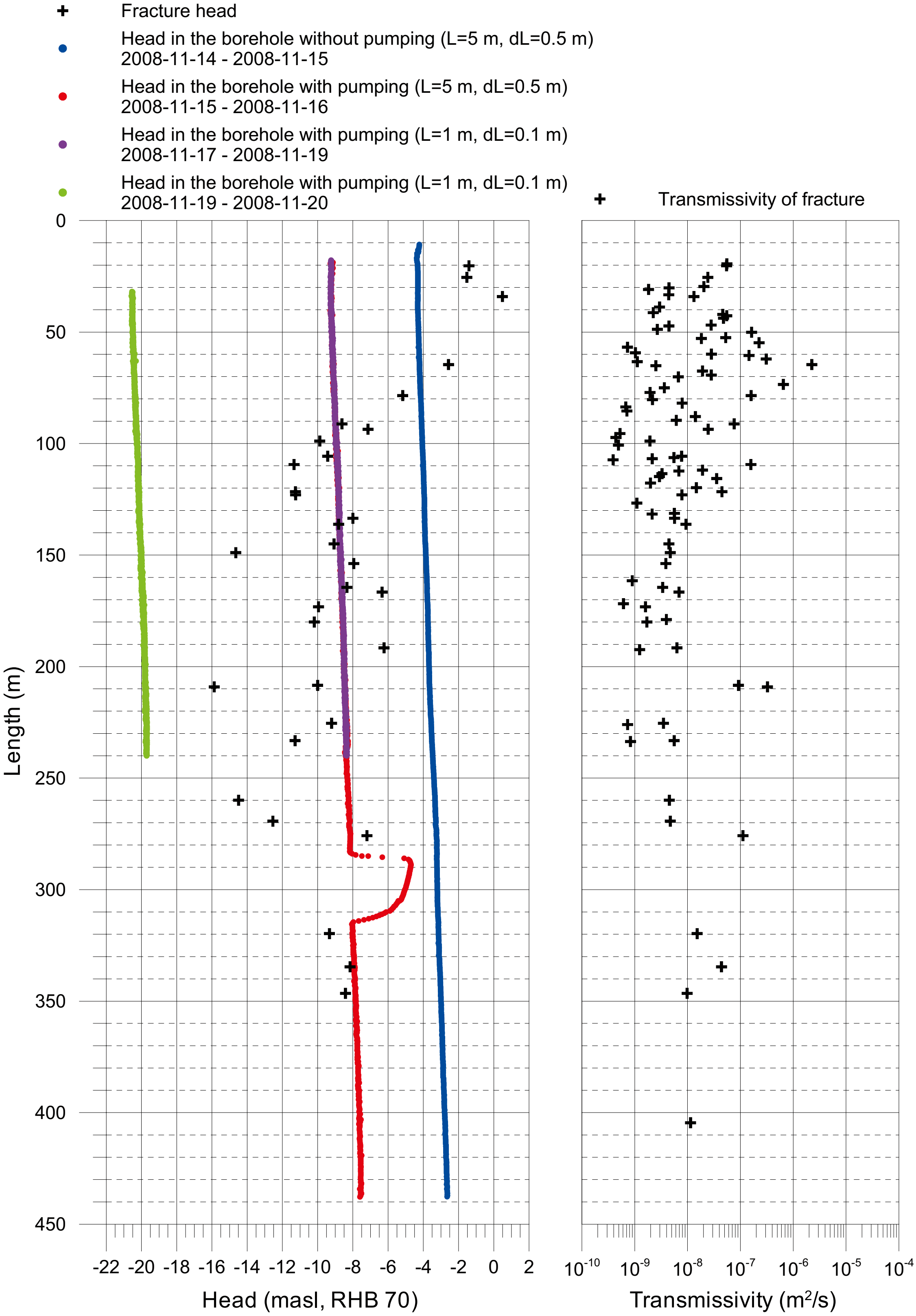
* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

** Value is from measurement with 16 m drawdown.

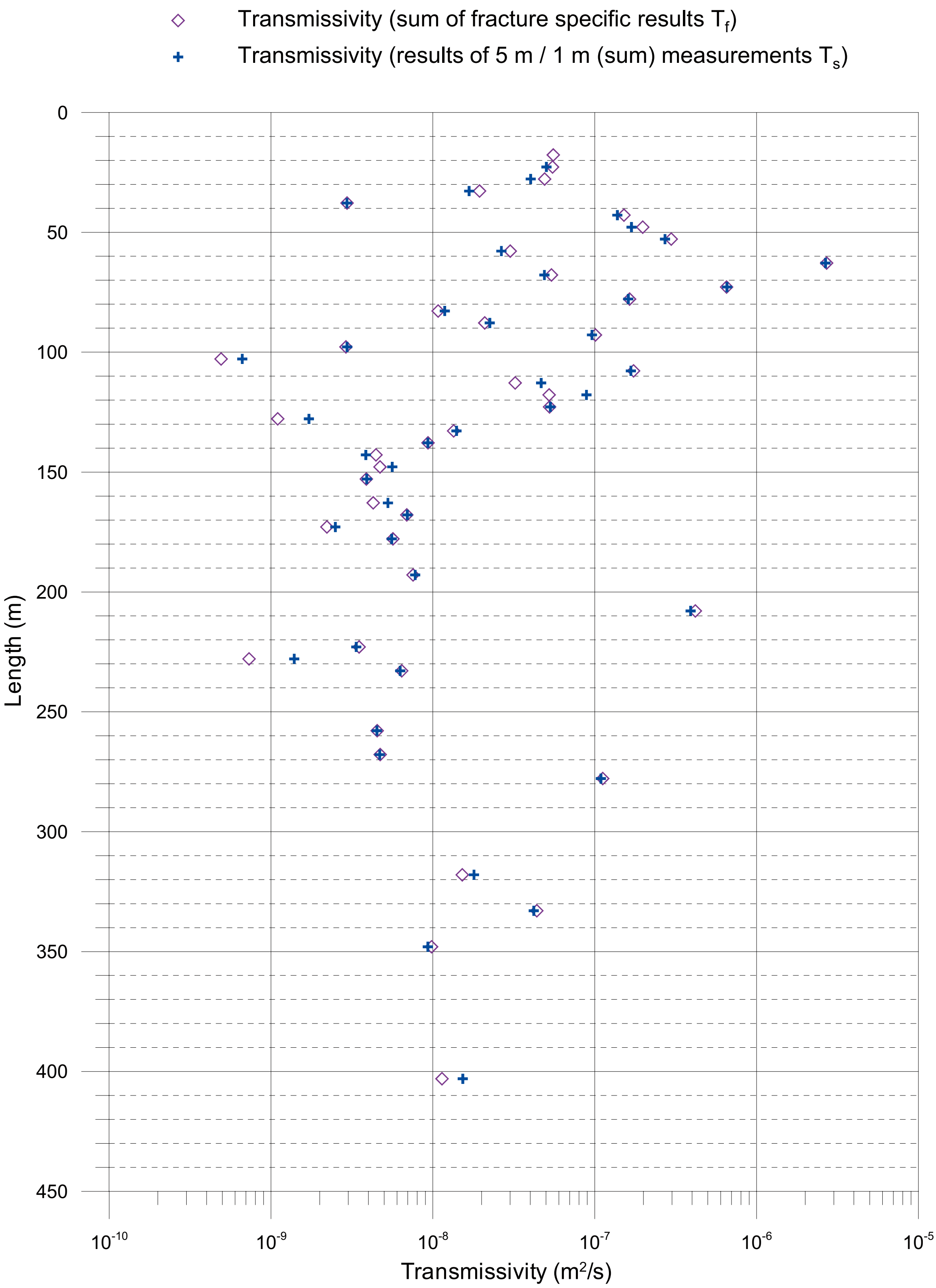
*** Uncertain result, pump had stopped during measurement.

The results for the pumped conditions are from the 5 m section length measurements.

Forsmark, borehole KFR104
Transmissivity and head of detected fractures

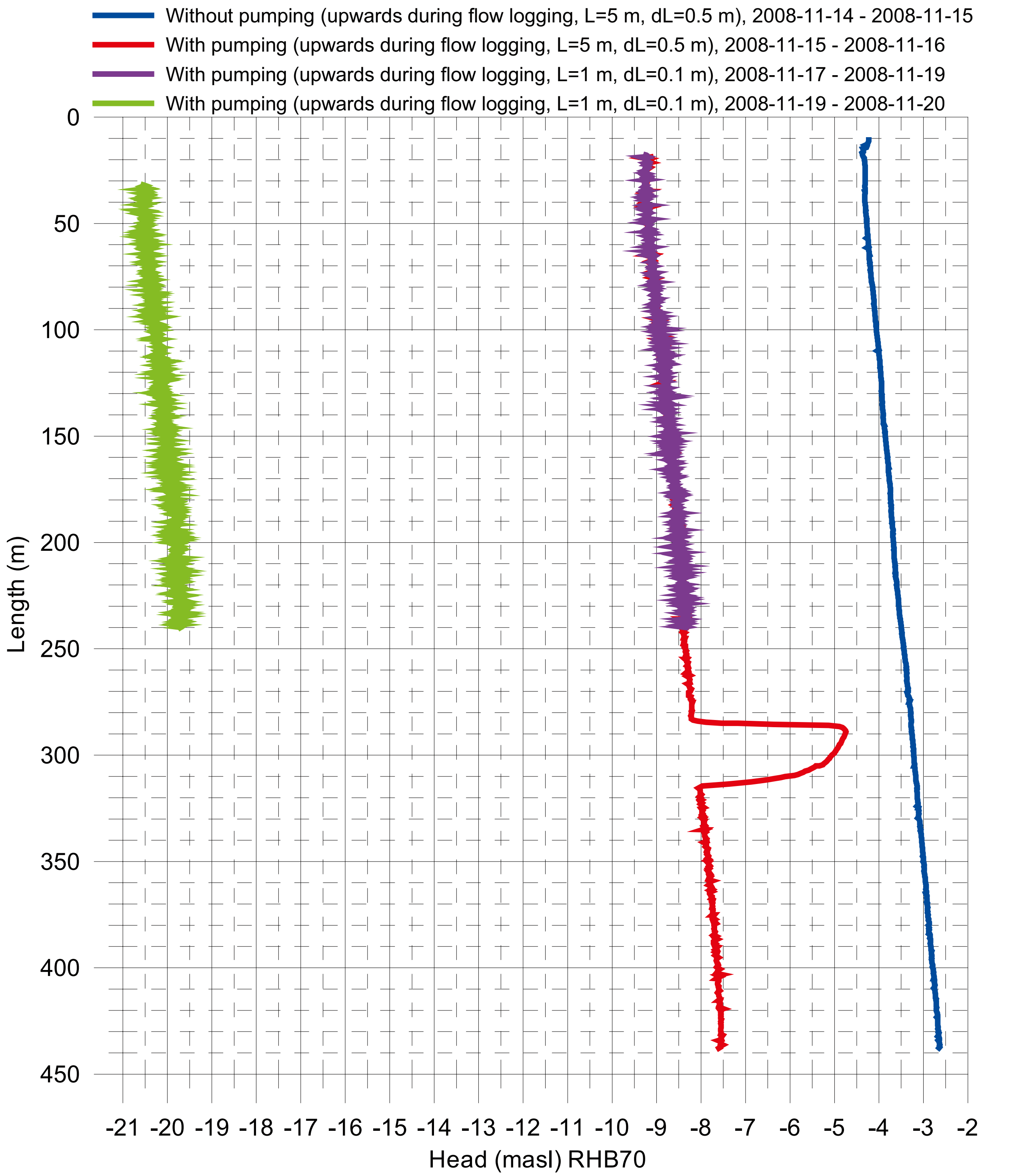


Forsmark, borehole KFR104
Comparison between section transmissivity and fracture transmissivity

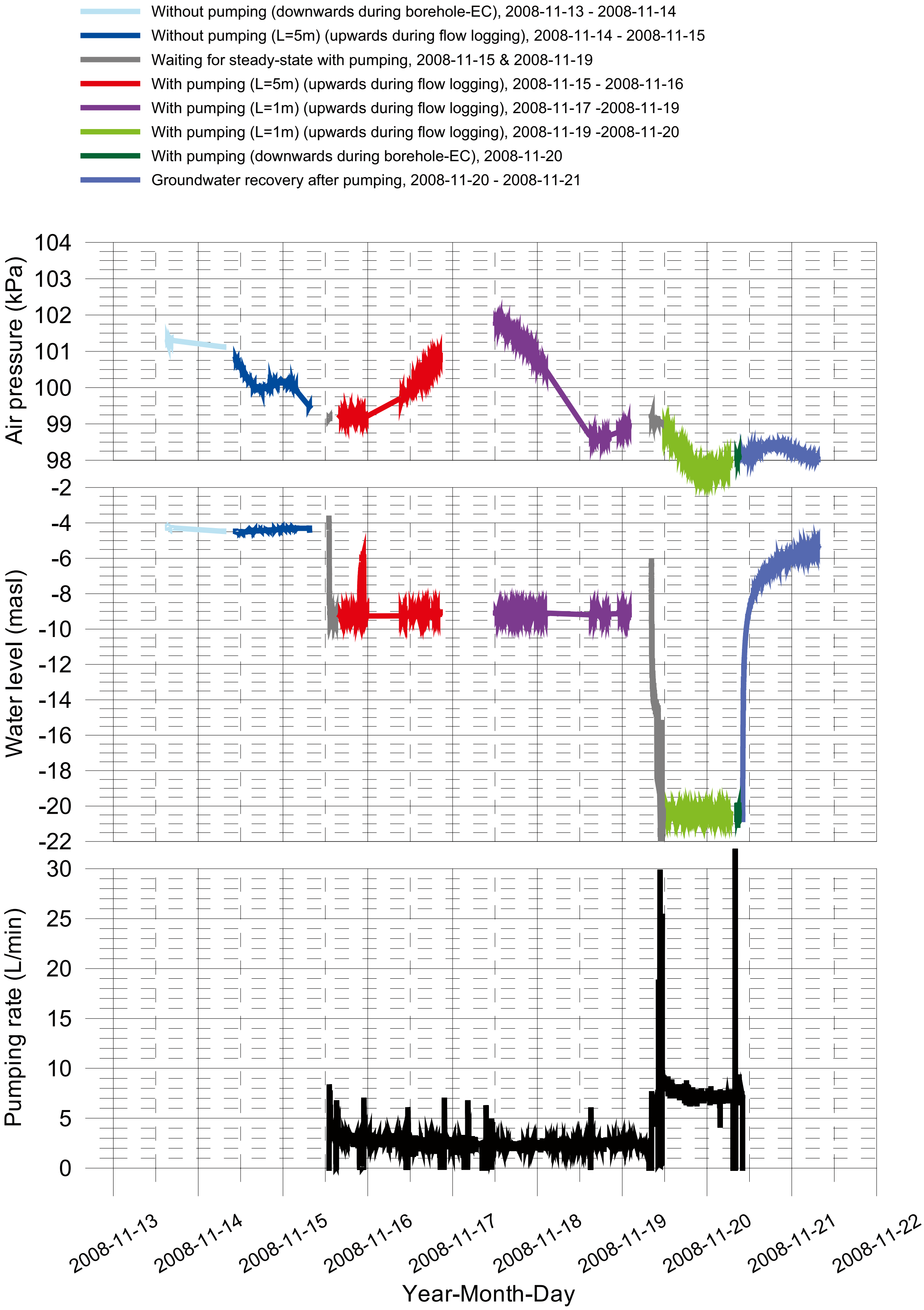


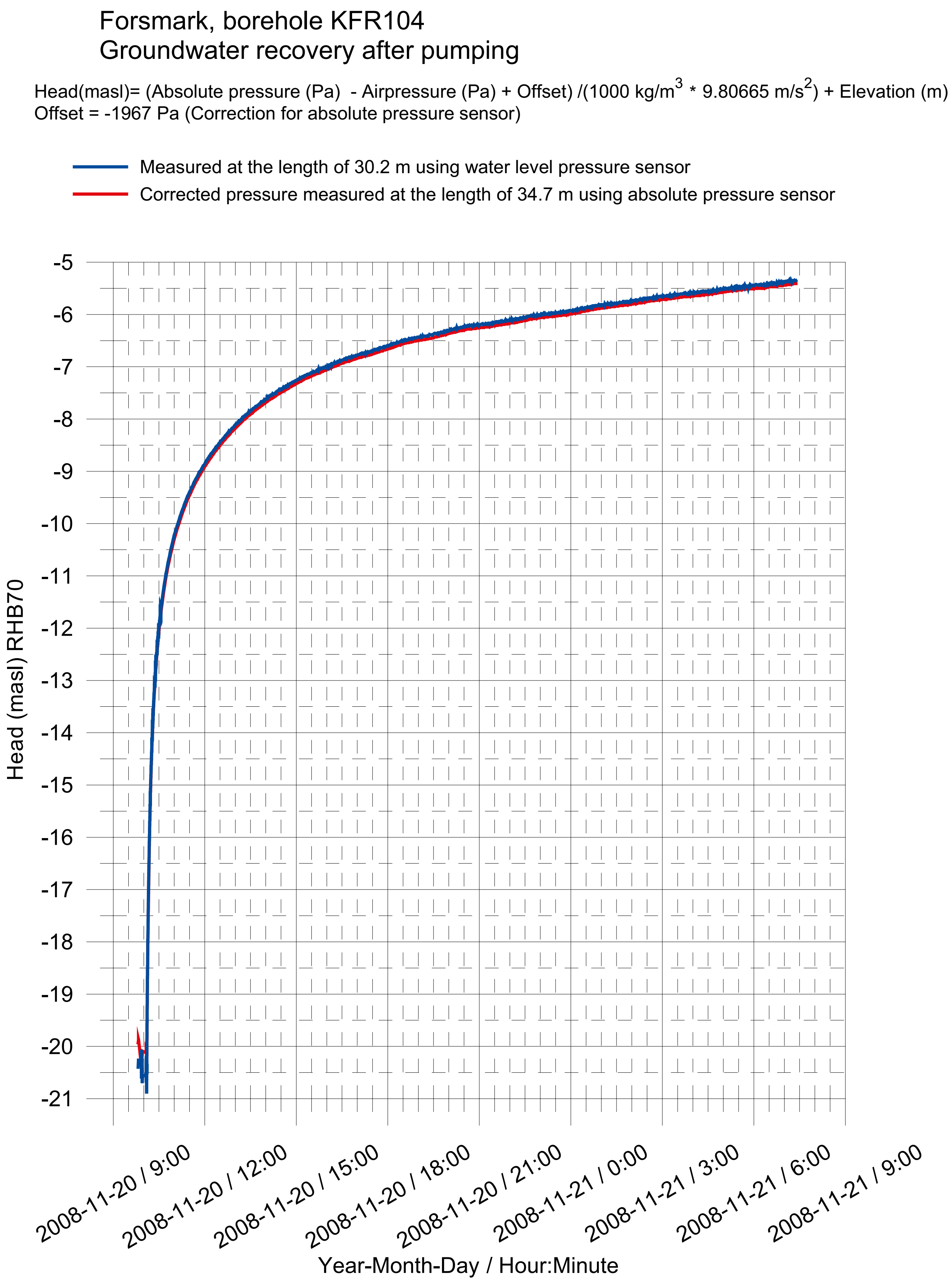
Forsmark, borehole KFR104
Head in the borehole during flow logging

Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = -1967 Pa (Correction for absolute pressure sensor)

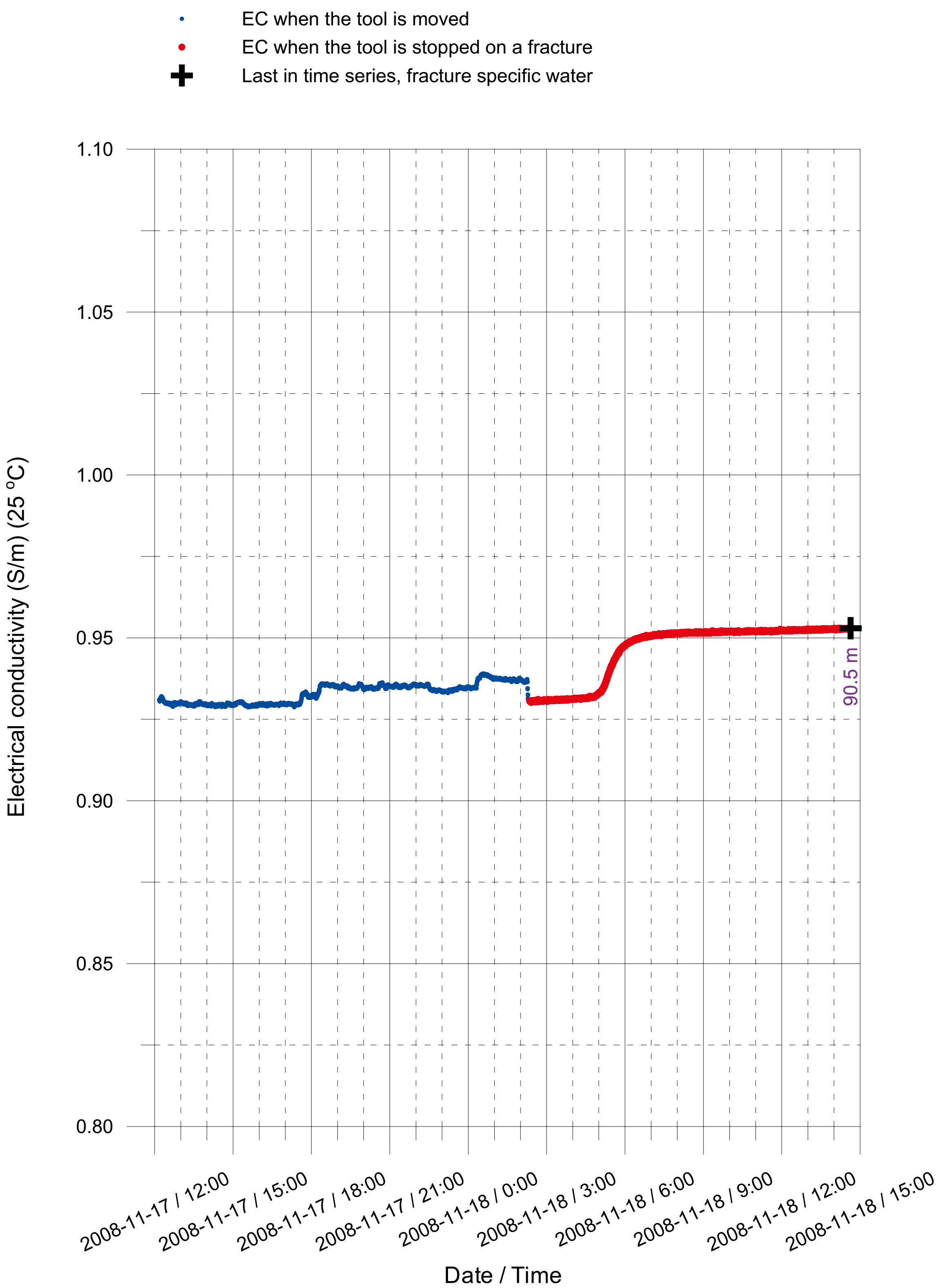


Forsmark, borehole KFR104
Air pressure, water level in the borehole and pumping rate during flow logging

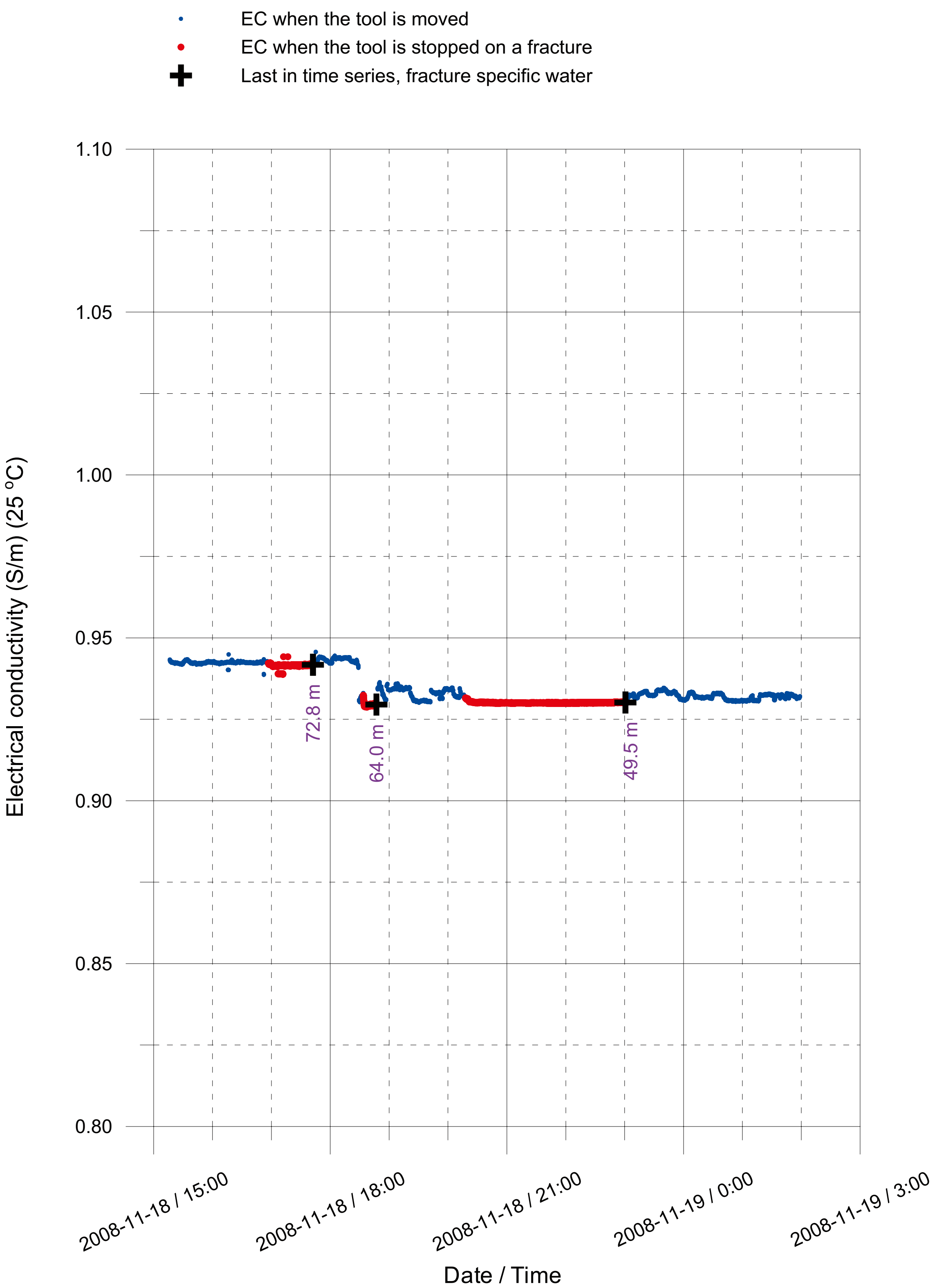



Forsmark, borehole KFR104
Groundwater recovery after pumping
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = -1967 Pa (Correction for absolute pressure sensor)
Measured at the length of 30.2 m using water level pressure sensor
Corrected pressure measured at the length of 34.7 m using absolute pressure sensor
Head (masl) RHB70
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
-21
2008-11-20 / 9:00
2008-11-20 / 12:00
2008-11-20 / 15:00
2008-11-20 / 18:00
2008-11-20 / 21:00
2008-11-21 / 0:00
2008-11-21 / 3:00
2008-11-21 / 6:00
2008-11-21 / 9:00
Year-Month-Day / Hour:Minute

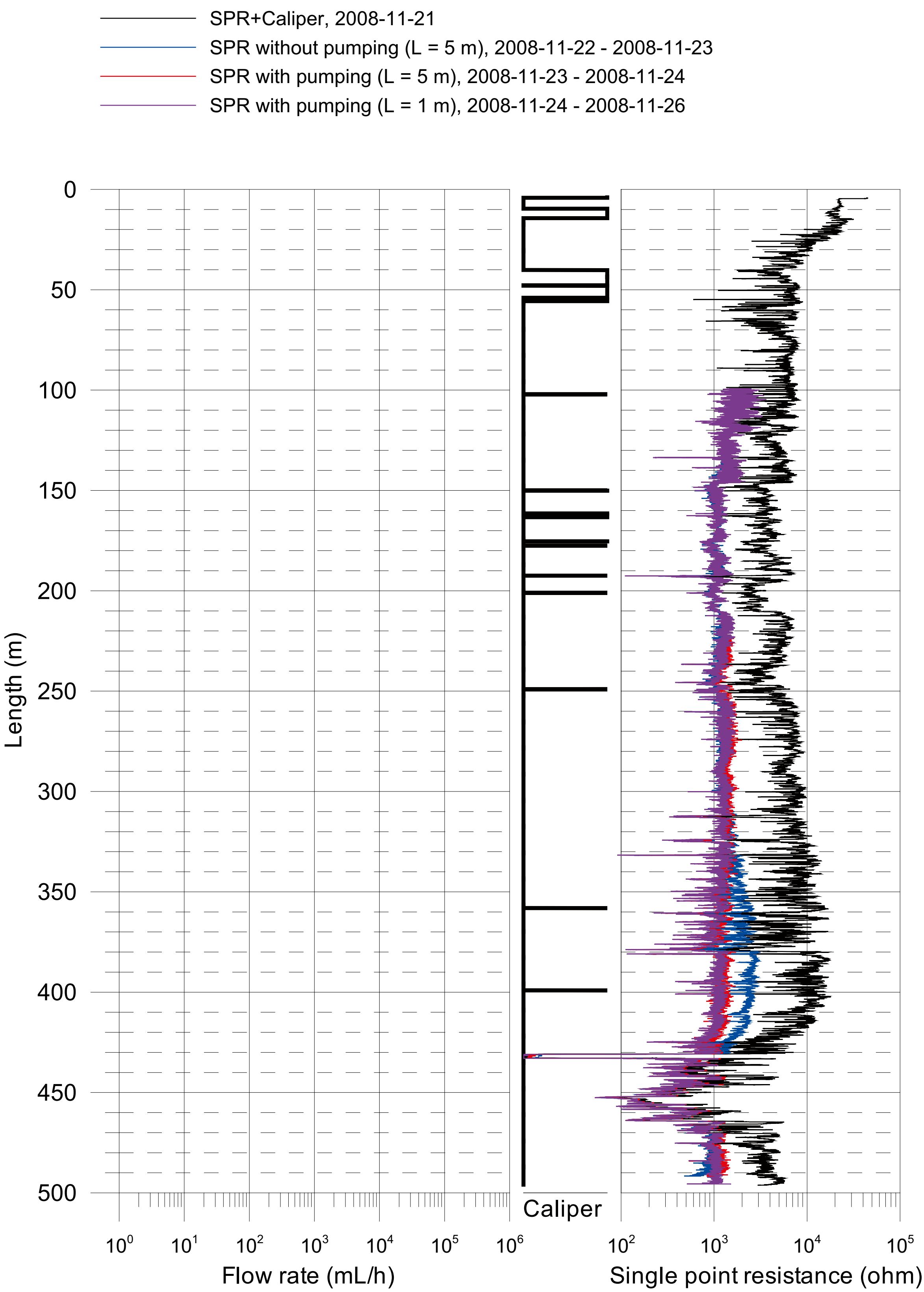
Forsmark, borehole KFR104
Fracture-specific EC results by date



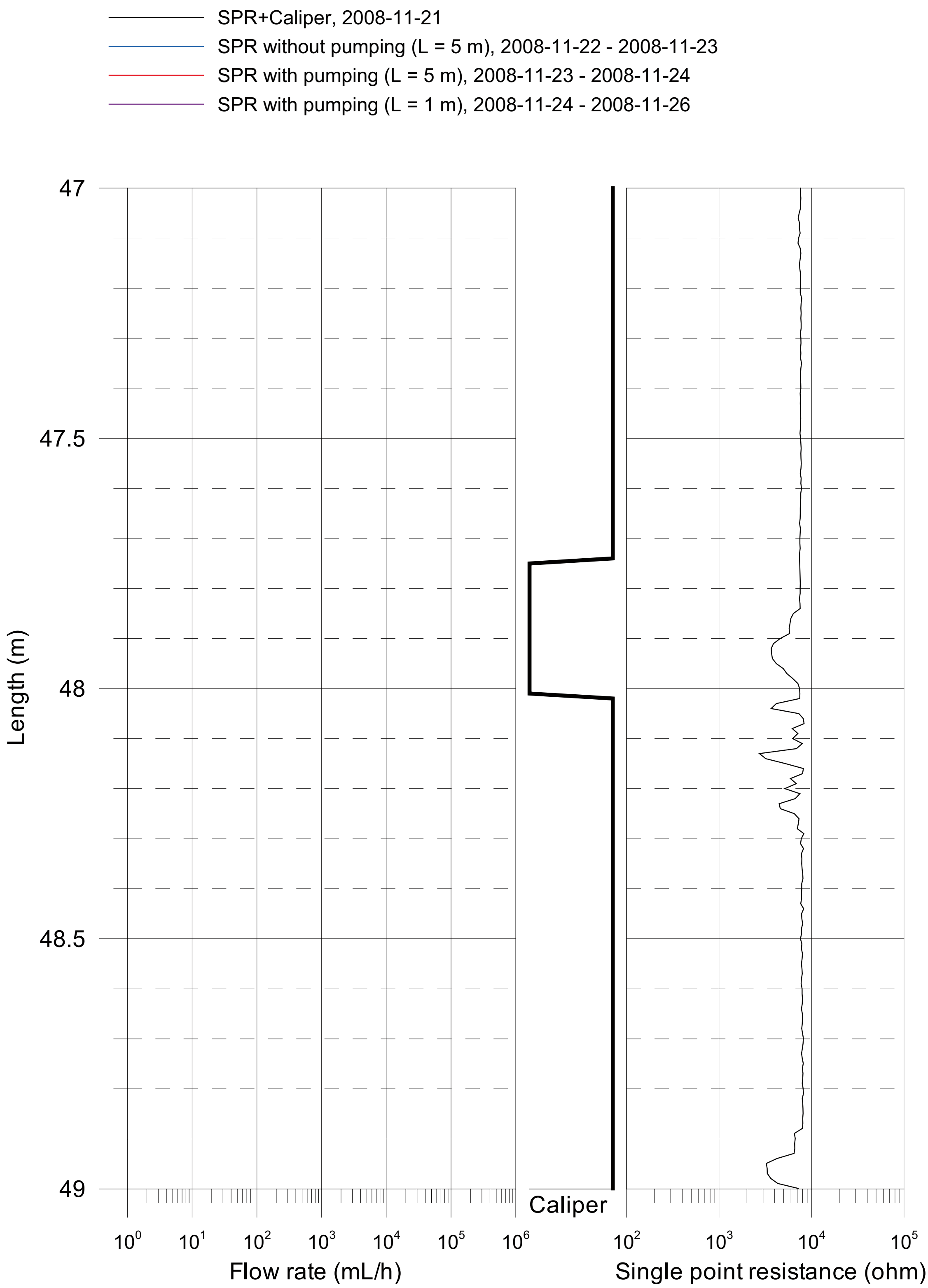
Forsmark, borehole KFR104
Fracture-specific EC results by date



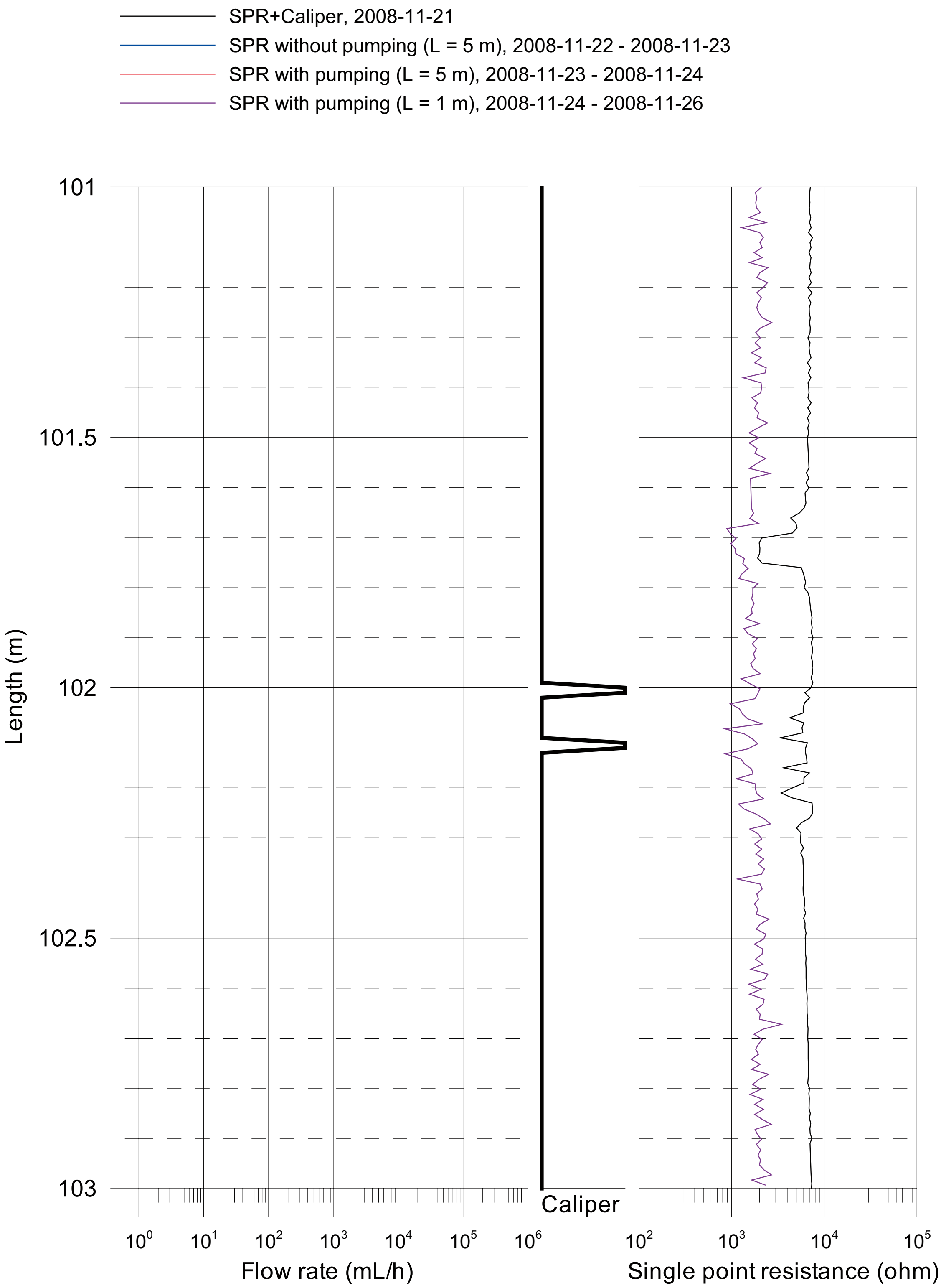
Forsmark, borehole KFR27
SPR and Caliper results after length correction



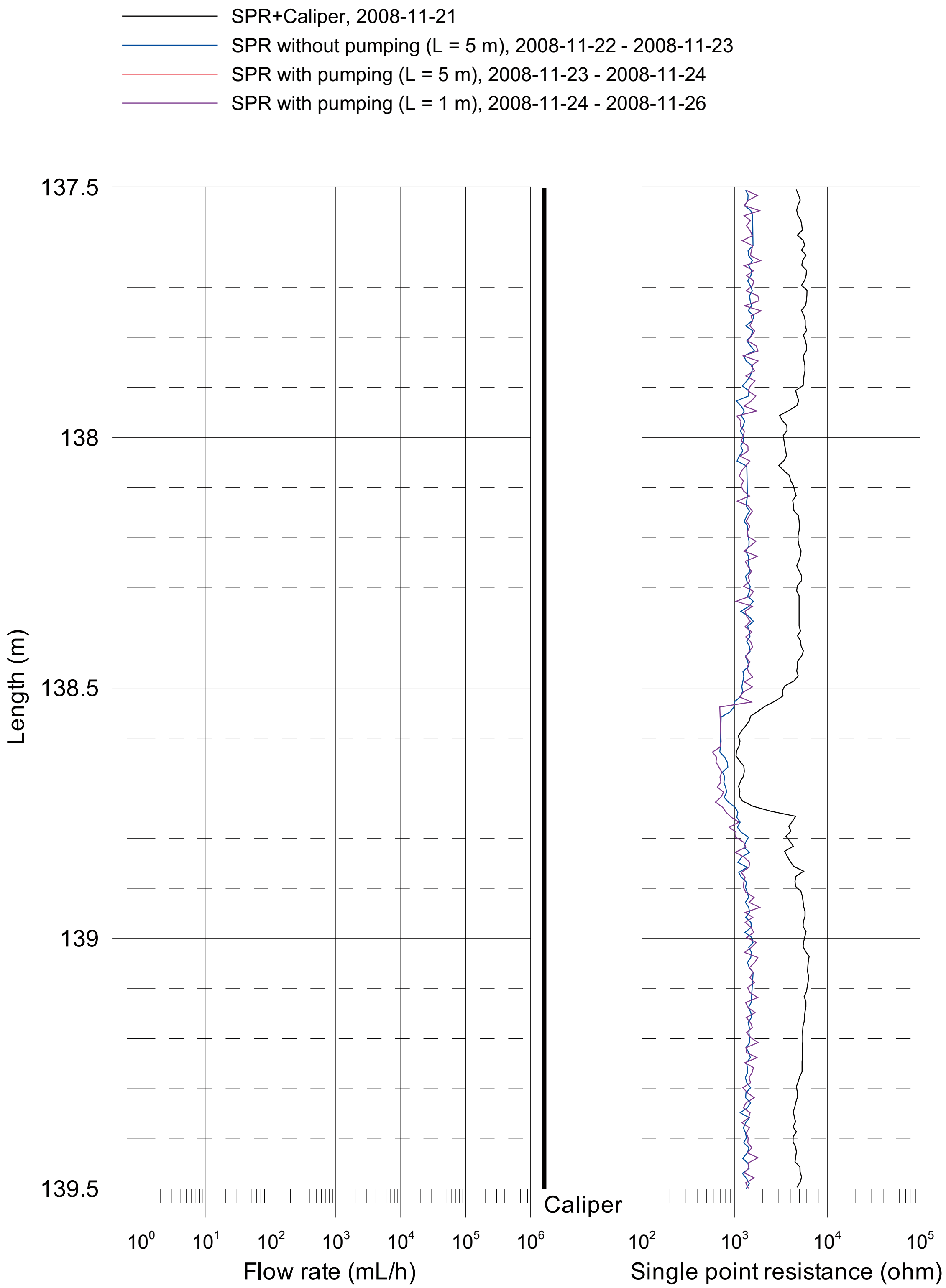
Forsmark, borehole KFR27
SPR and Caliper results after length correction

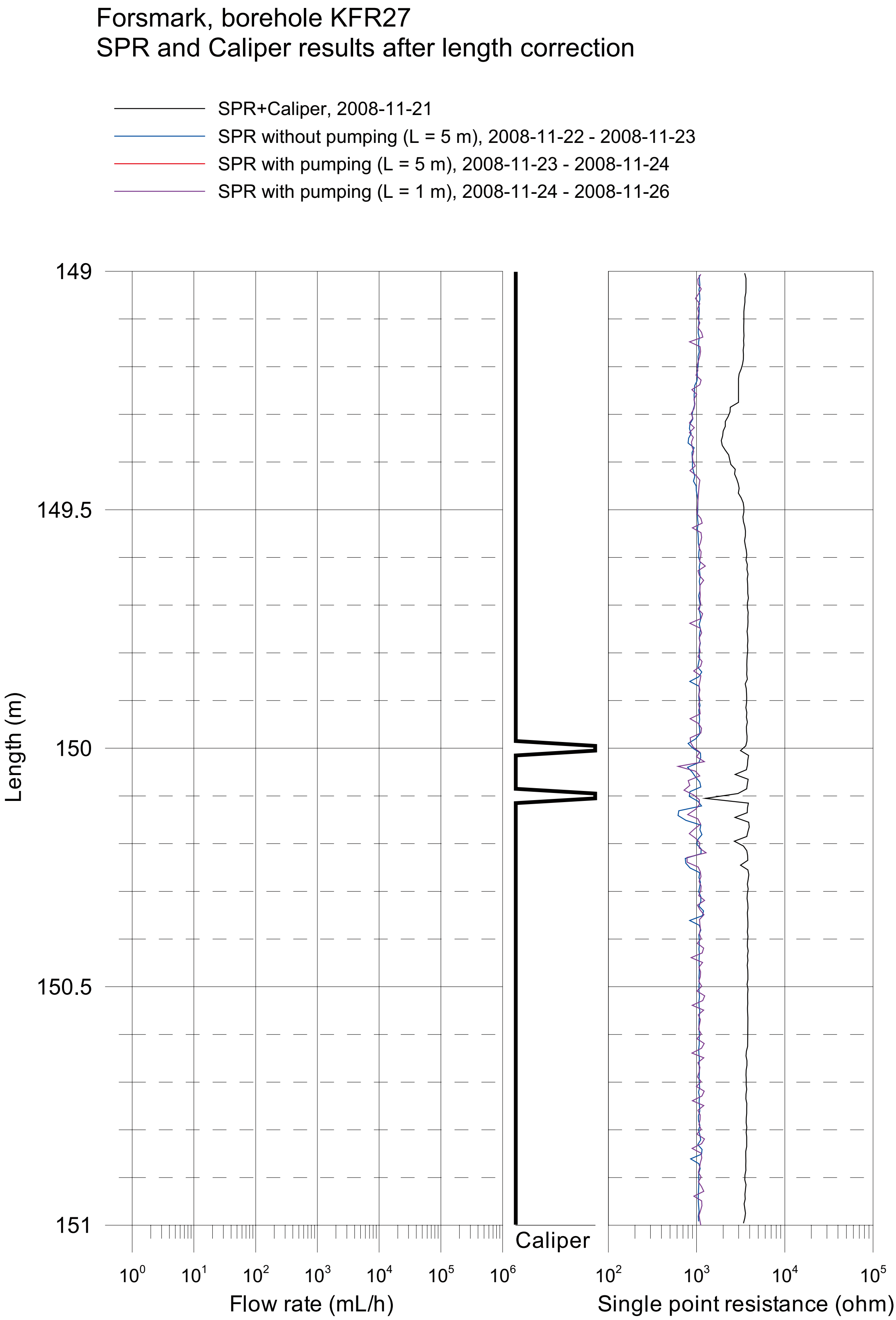


Forsmark, borehole KFR27
SPR and Caliper results after length correction

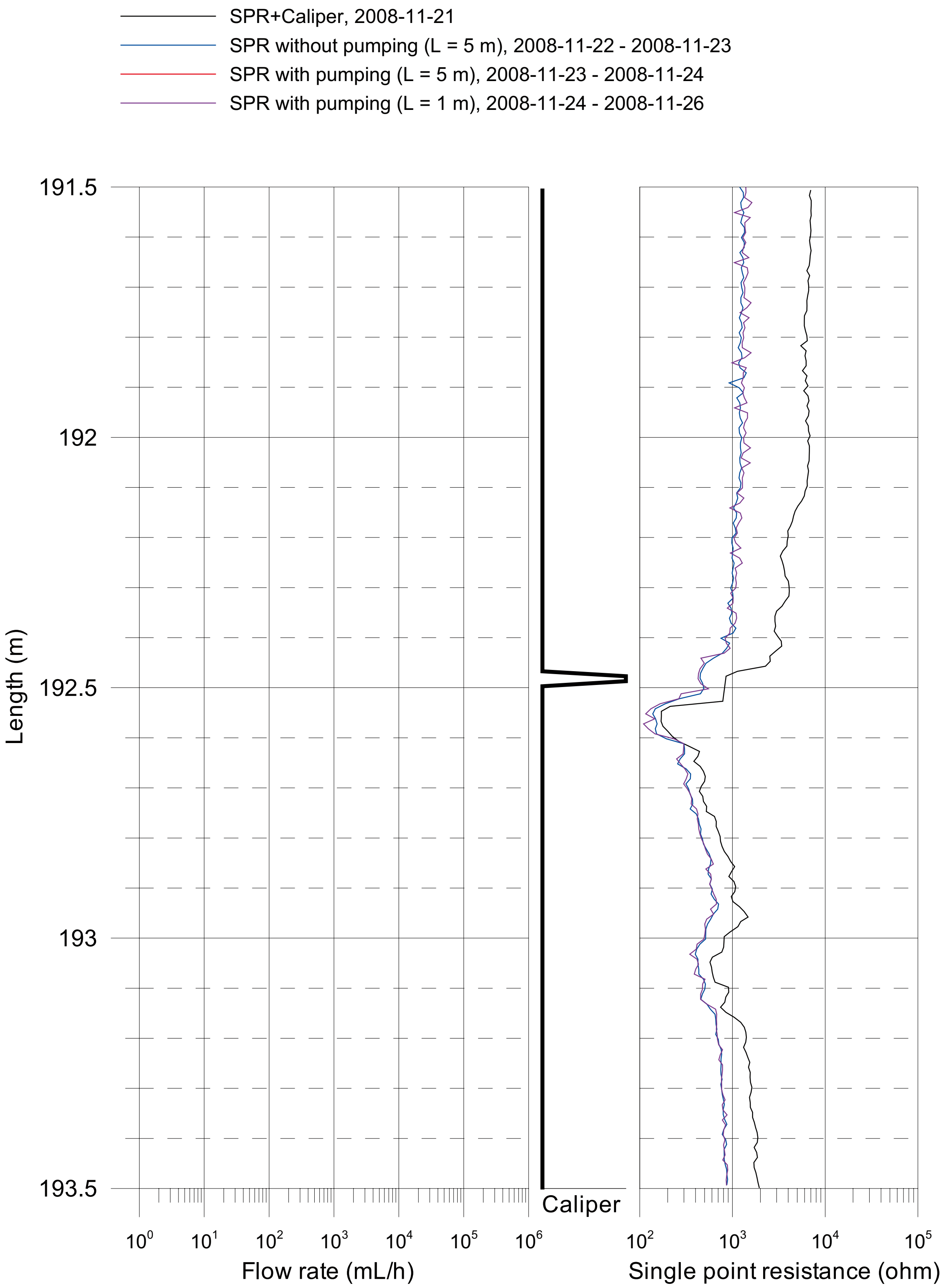


Forsmark, borehole KFR27
SPR and Caliper results after length correction

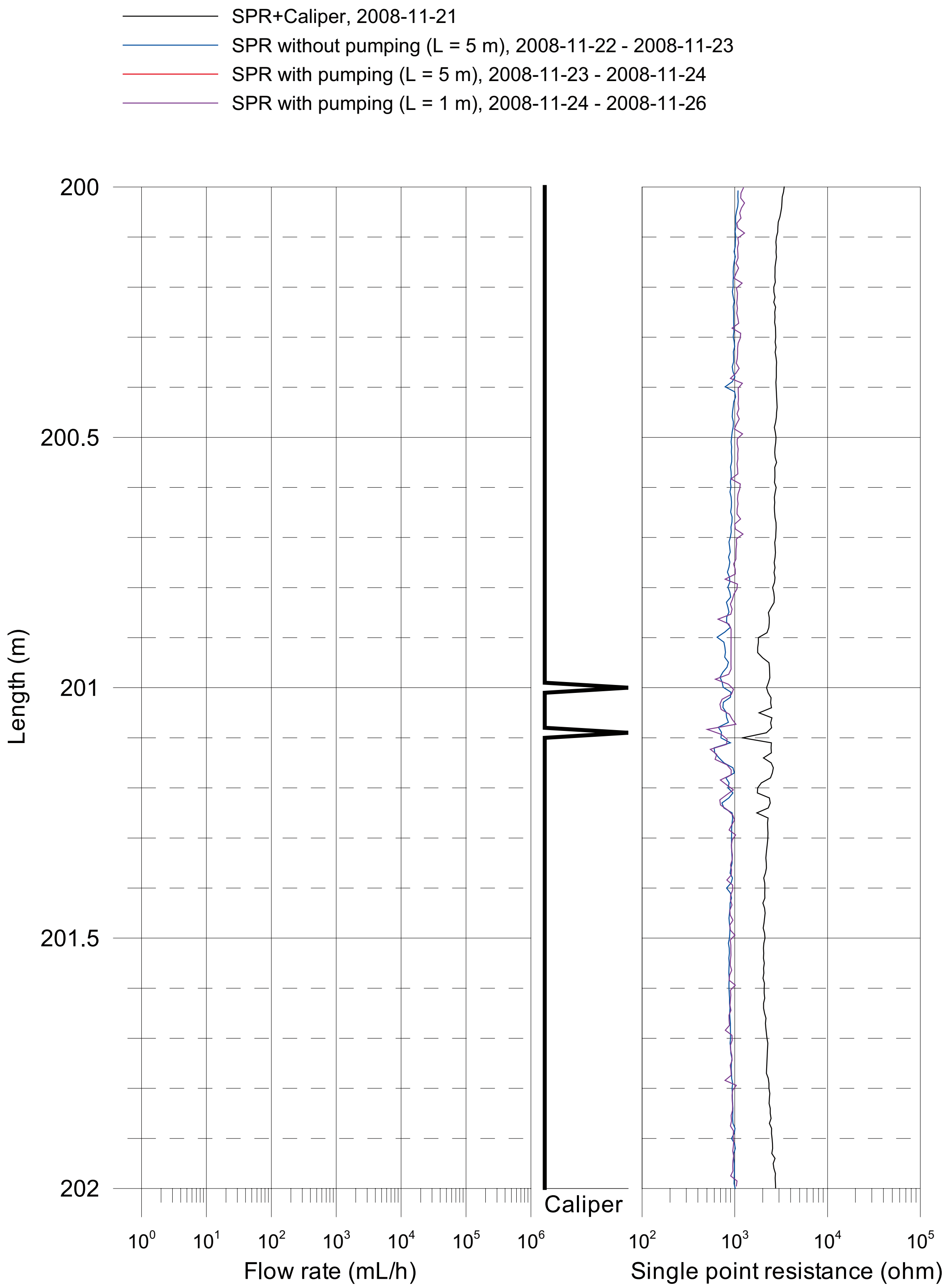



Forsmark, borehole KFR27
SPR and Caliper results after length correction
SPR+Caliper, 2008-11-21
SPR without pumping (L = 5 m), 2008-11-22 - 2008-11-23
SPR with pumping (L = 5 m), 2008-11-23 - 2008-11-24
SPR with pumping (L = 1 m), 2008-11-24 - 2008-11-26
149
149.5
150
150.5
151
Length (m)
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

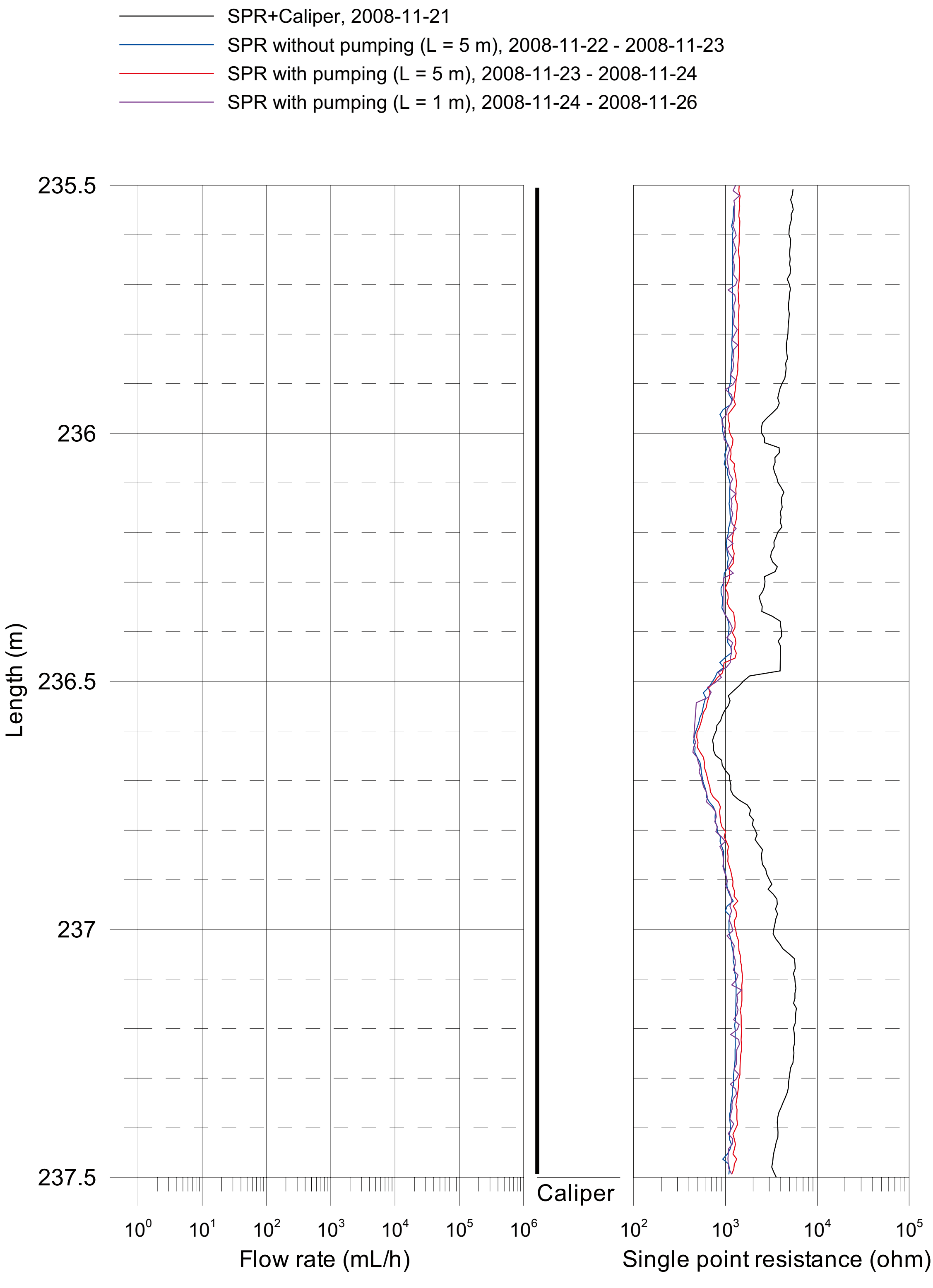
Forsmark, borehole KFR27
SPR and Caliper results after length correction



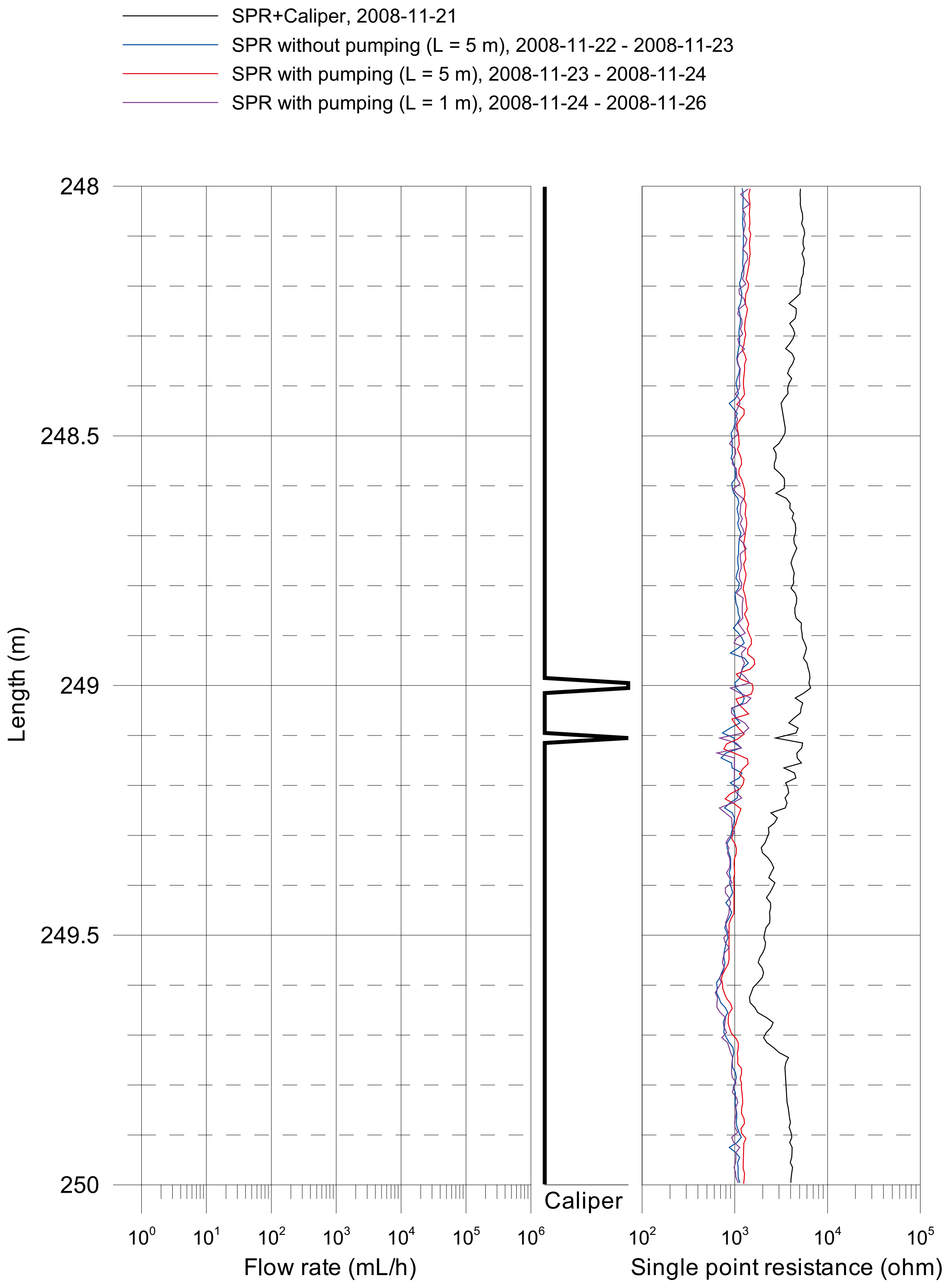
Forsmark, borehole KFR27
SPR and Caliper results after length correction



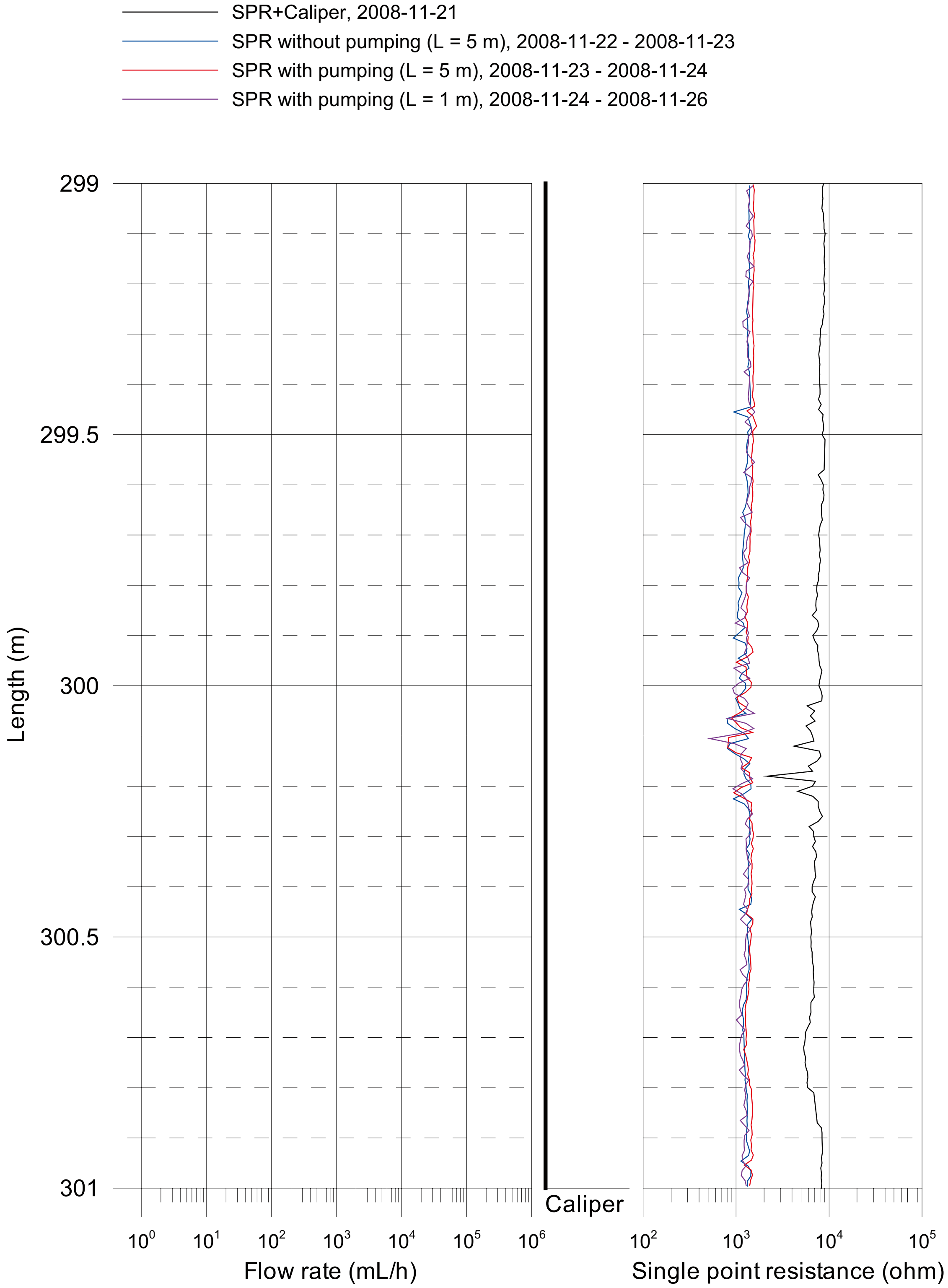
Forsmark, borehole KFR27
SPR and Caliper results after length correction



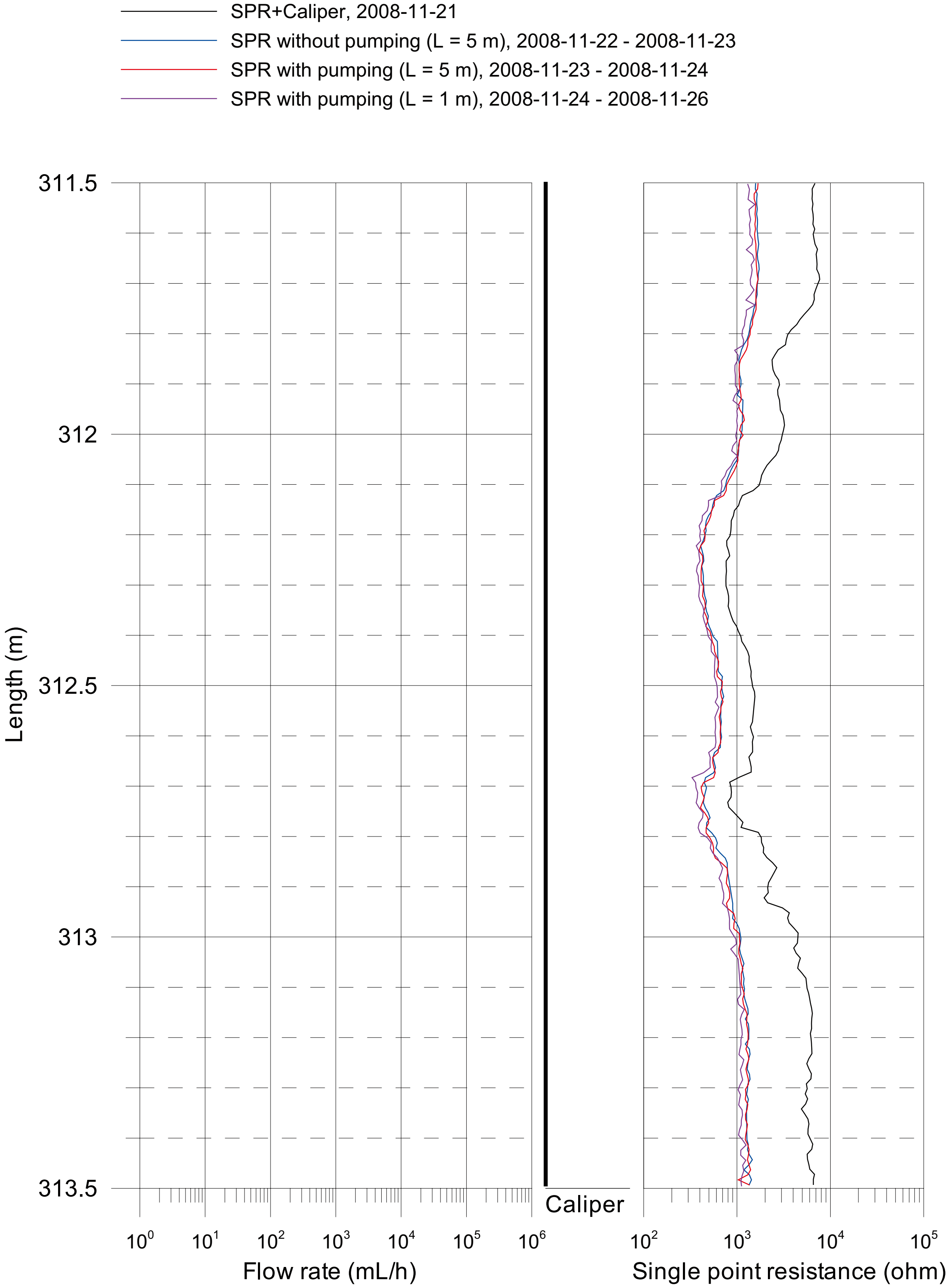
Forsmark, borehole KFR27
SPR and Caliper results after length correction

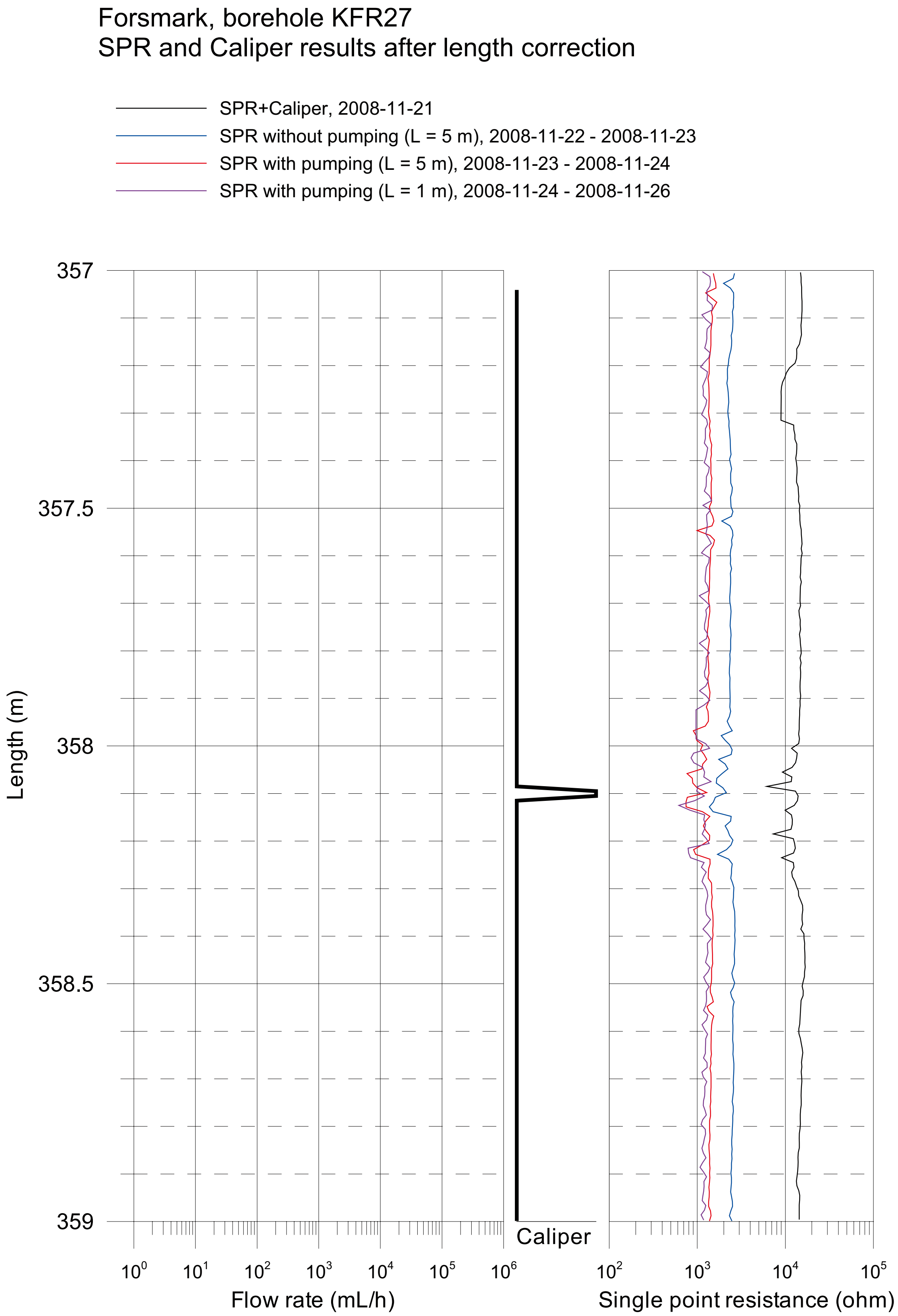


Forsmark, borehole KFR27
SPR and Caliper results after length correction

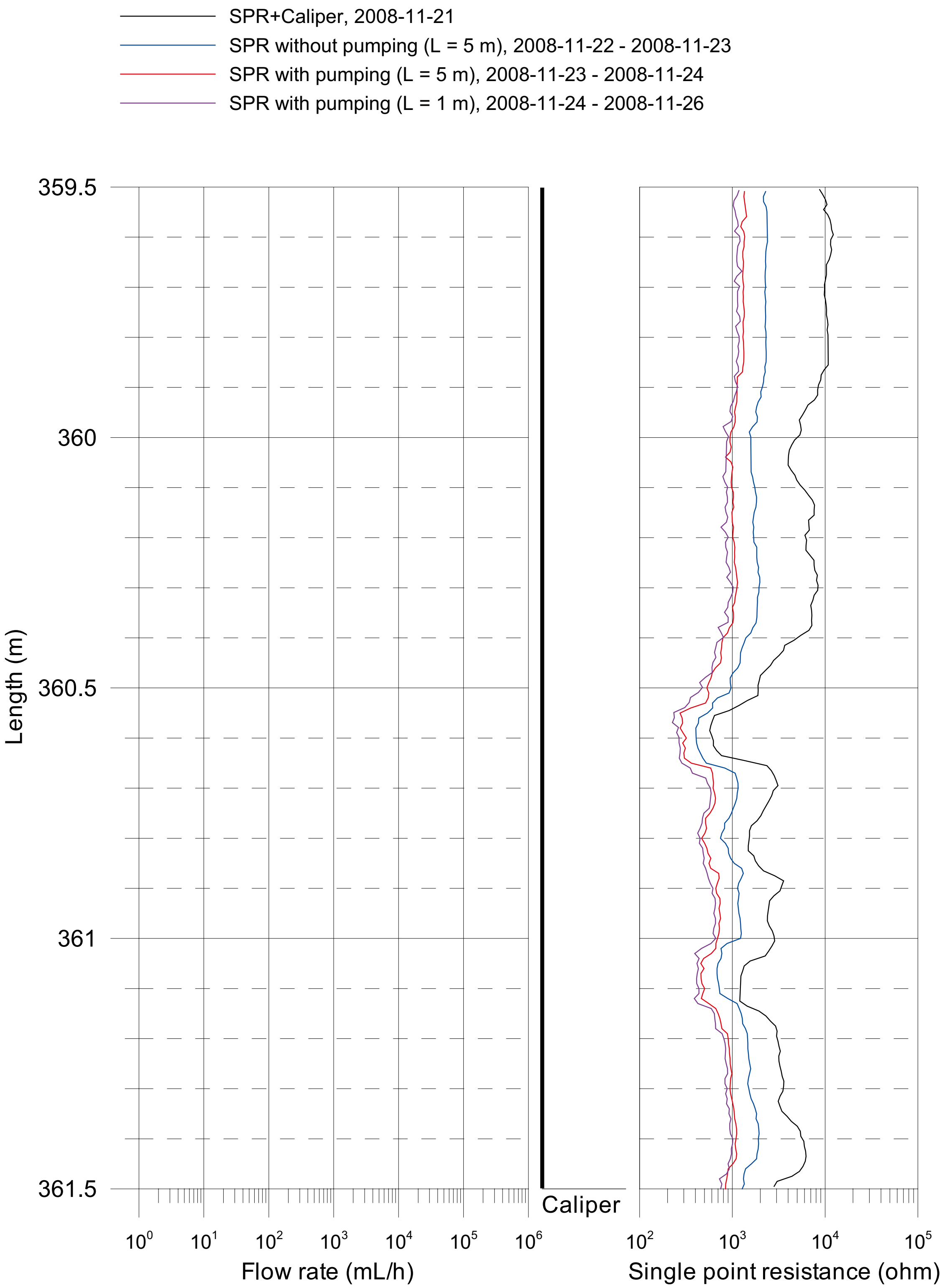


Forsmark, borehole KFR27
SPR and Caliper results after length correction

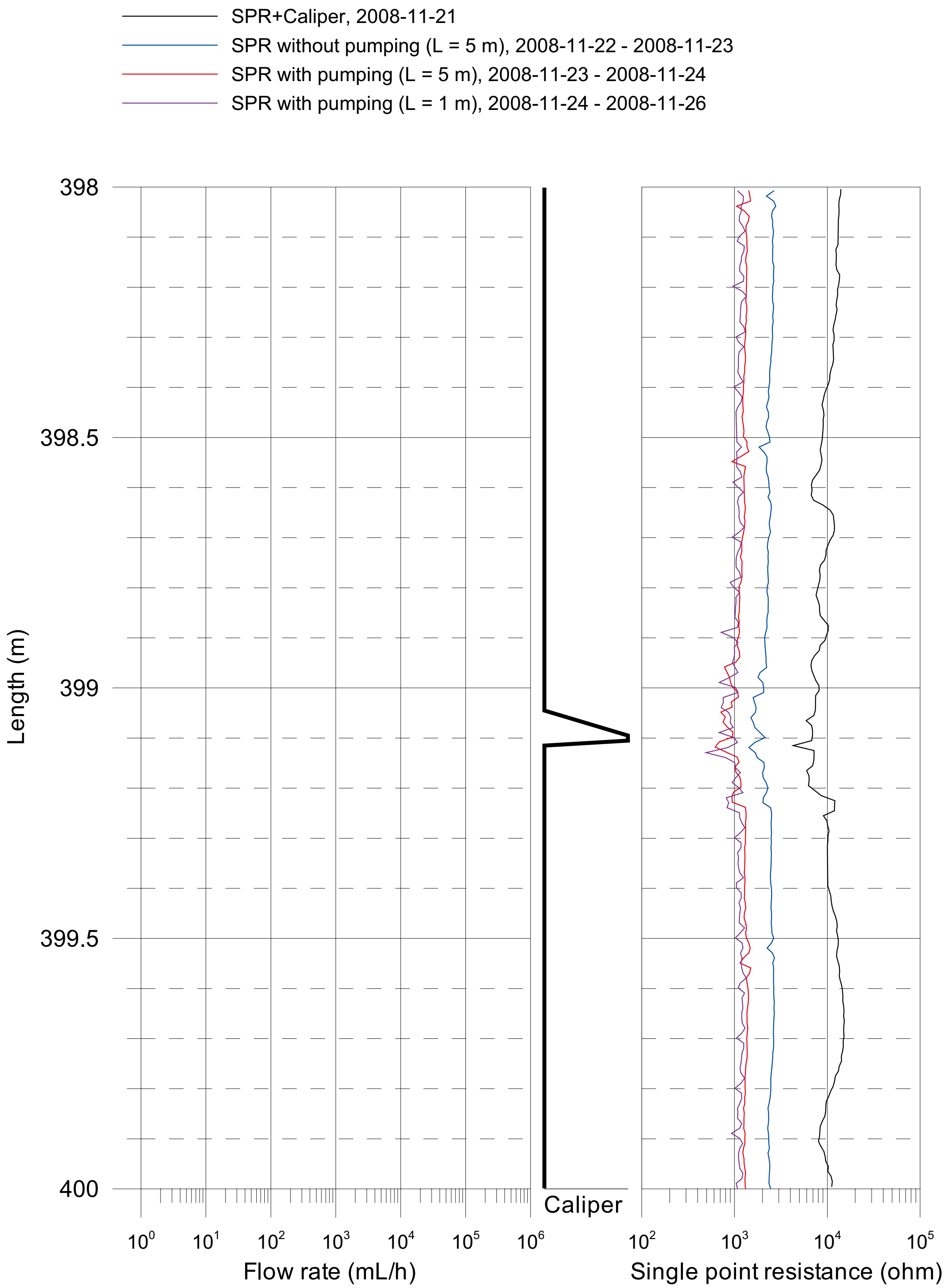



Forsmark, borehole KFR27
SPR and Caliper results after length correction
SPR+Caliper, 2008-11-21
SPR without pumping (L = 5 m), 2008-11-22 - 2008-11-23
SPR with pumping (L = 5 m), 2008-11-23 - 2008-11-24
SPR with pumping (L = 1 m), 2008-11-24 - 2008-11-26
Length (m)
357
357.5
358
358.5
359
Caliper
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
10^2
10^3
10^4
10^5
Single point resistance (ohm)

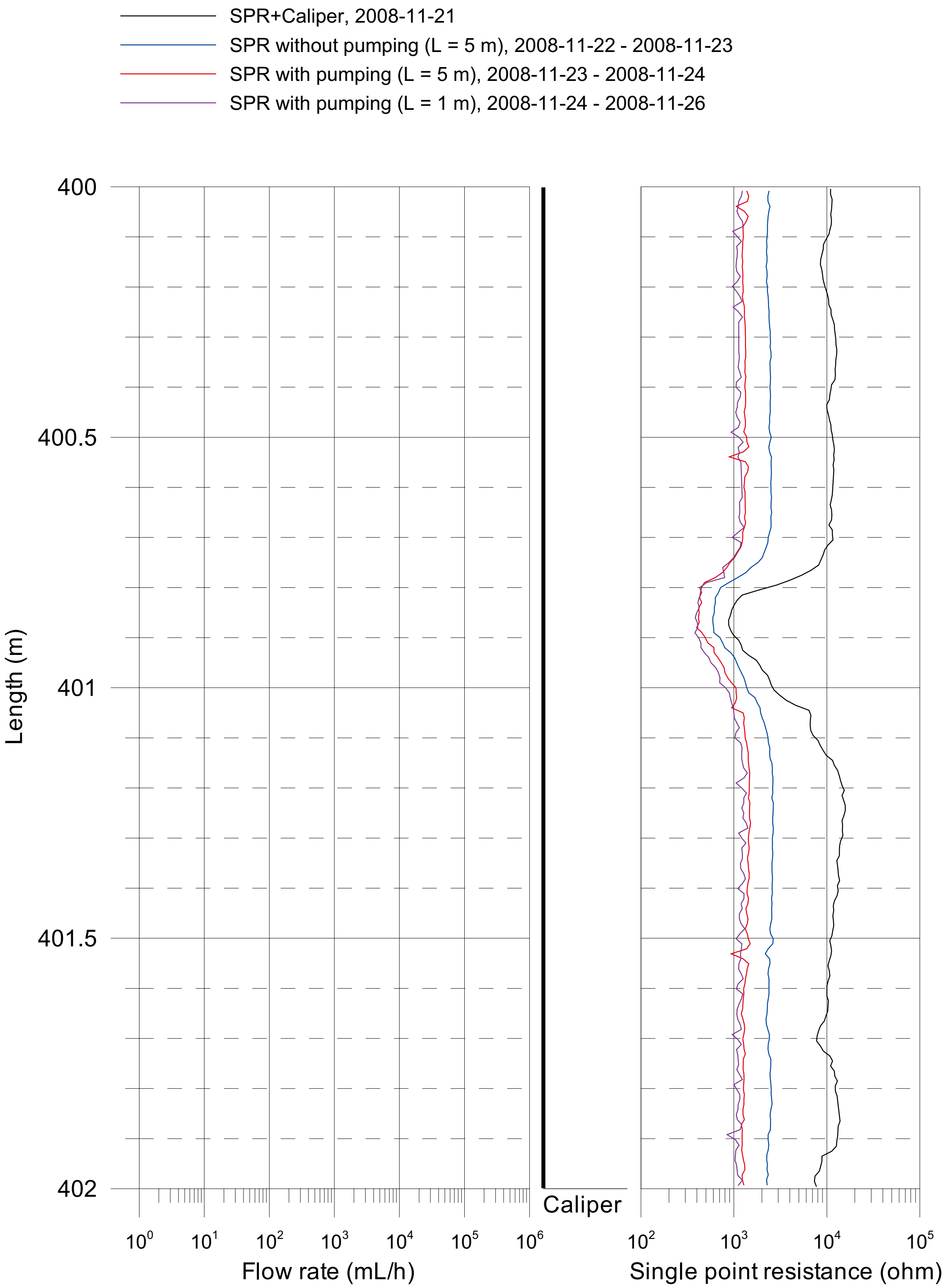
Forsmark, borehole KFR27
SPR and Caliper results after length correction



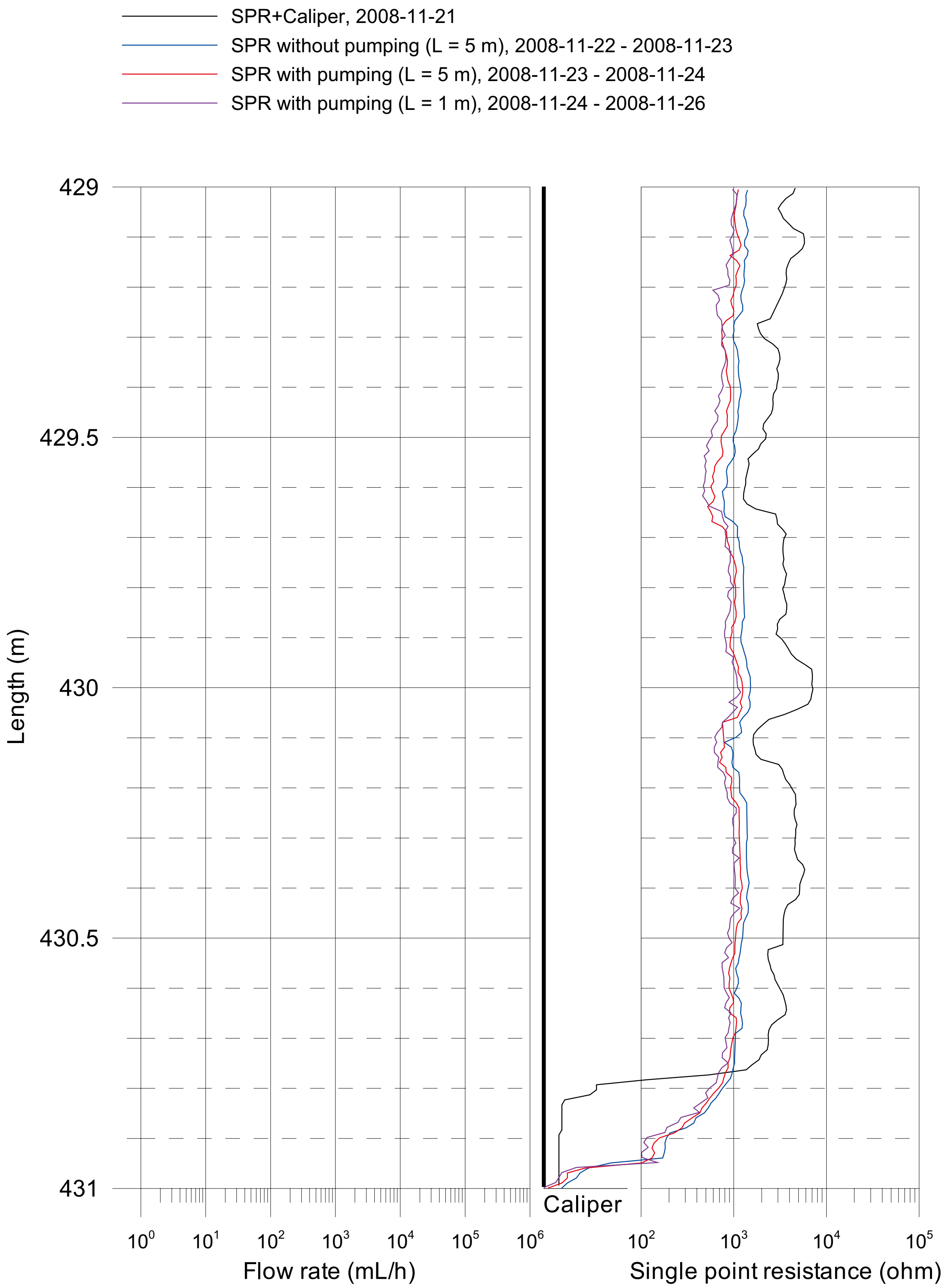
Forsmark, borehole KFR27
SPR and Caliper results after length correction



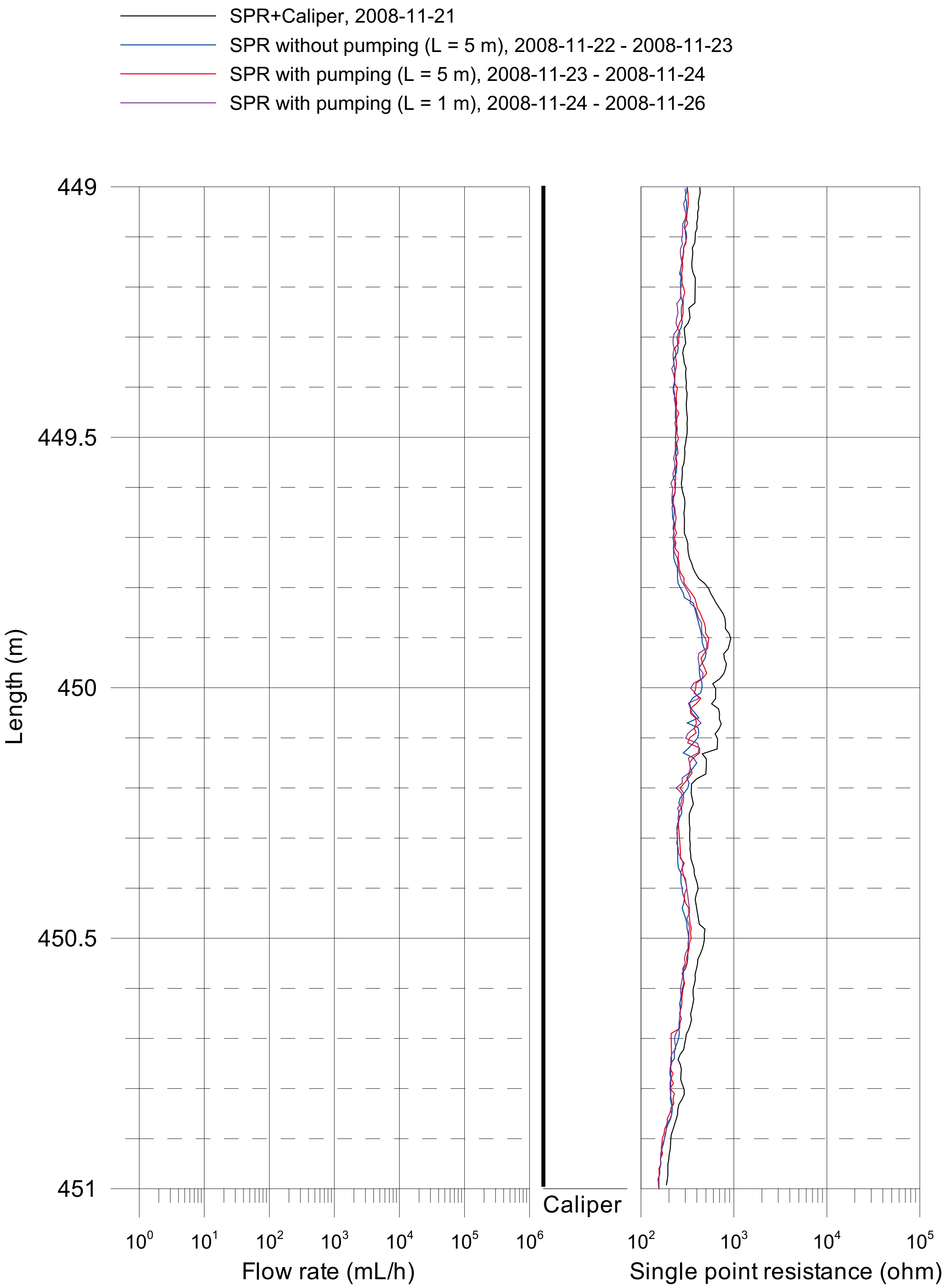
Forsmark, borehole KFR27
SPR and Caliper results after length correction



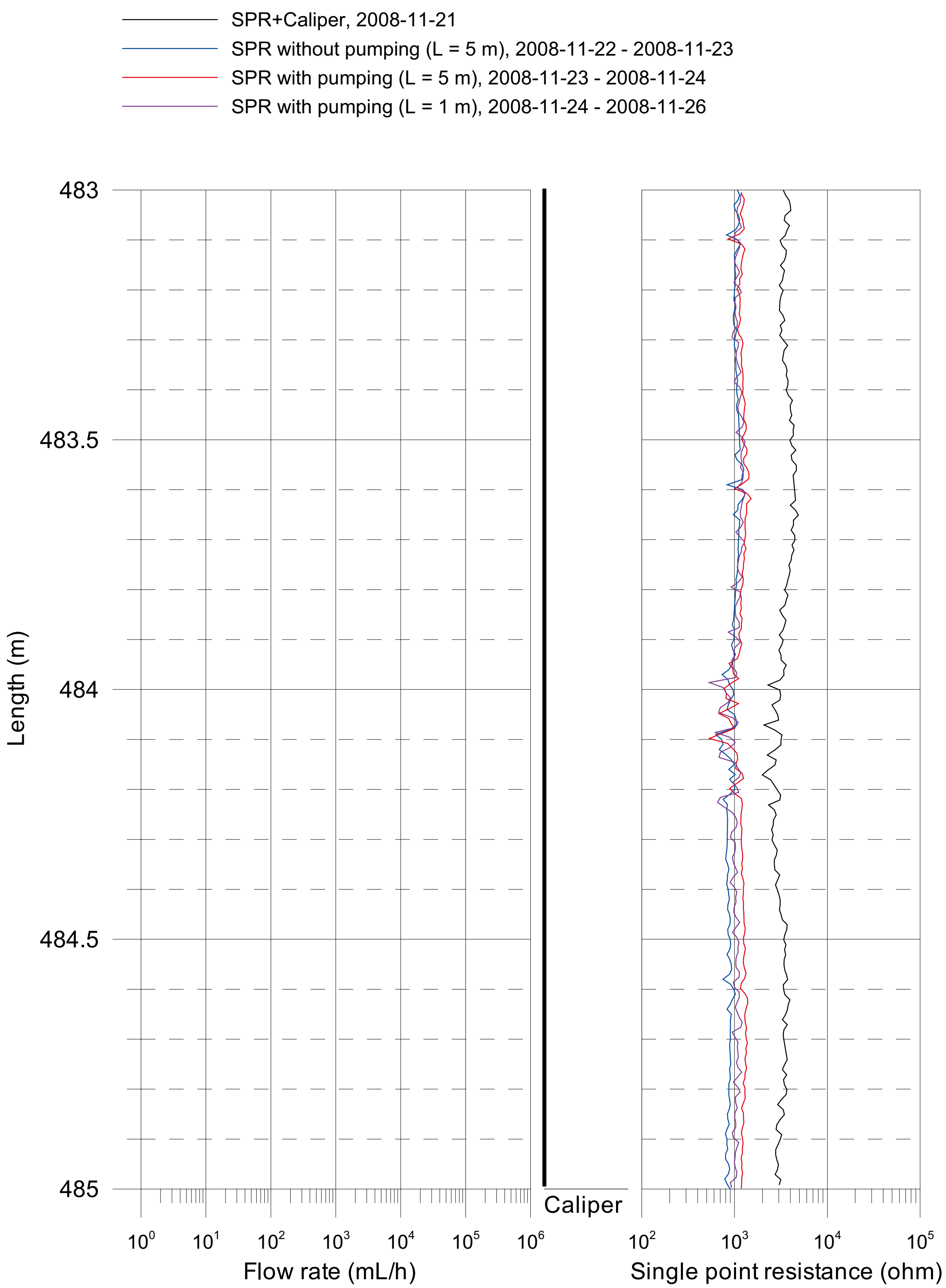
Forsmark, borehole KFR27
SPR and Caliper results after length correction

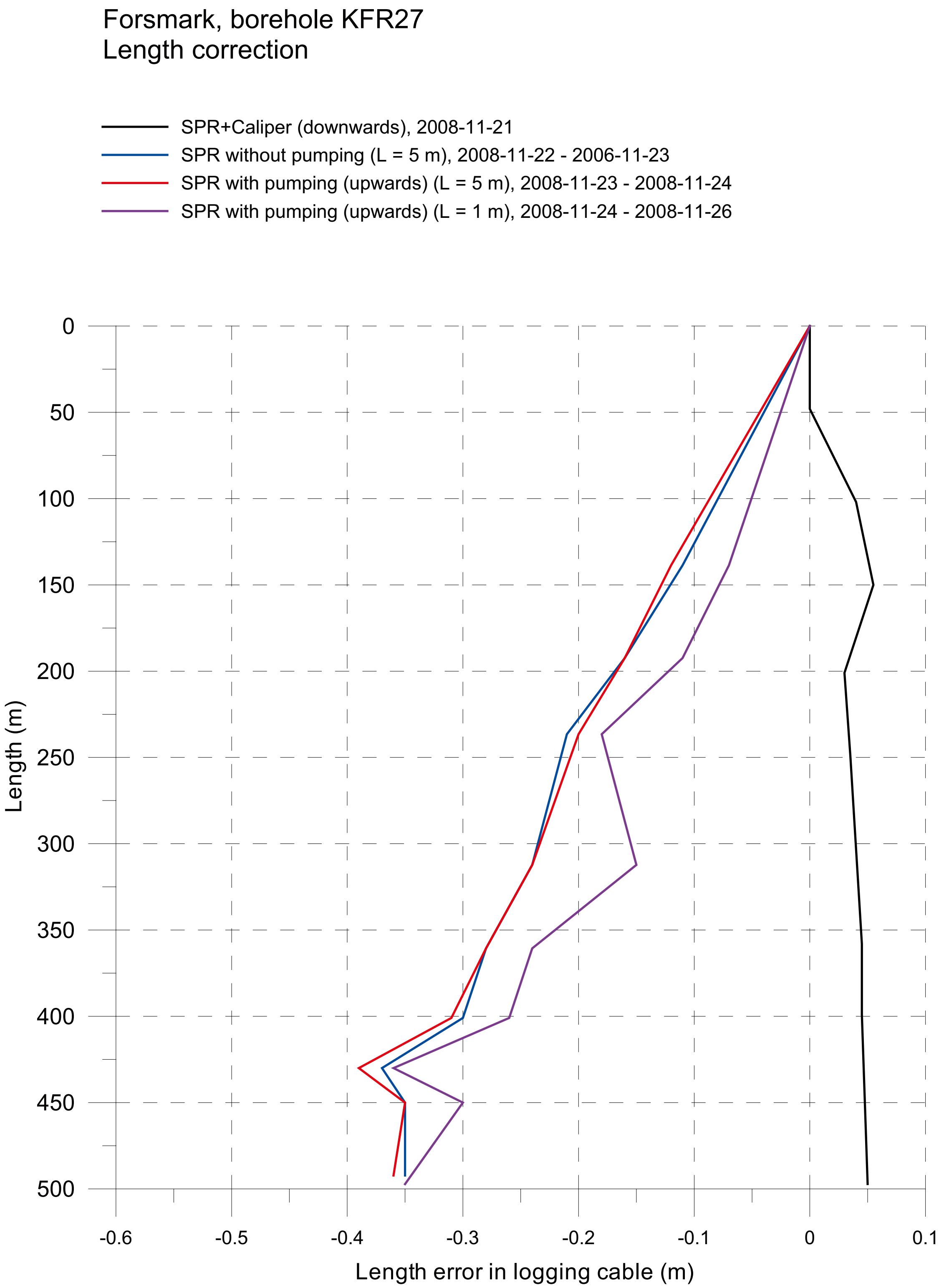


Forsmark, borehole KFR27
SPR and Caliper results after length correction

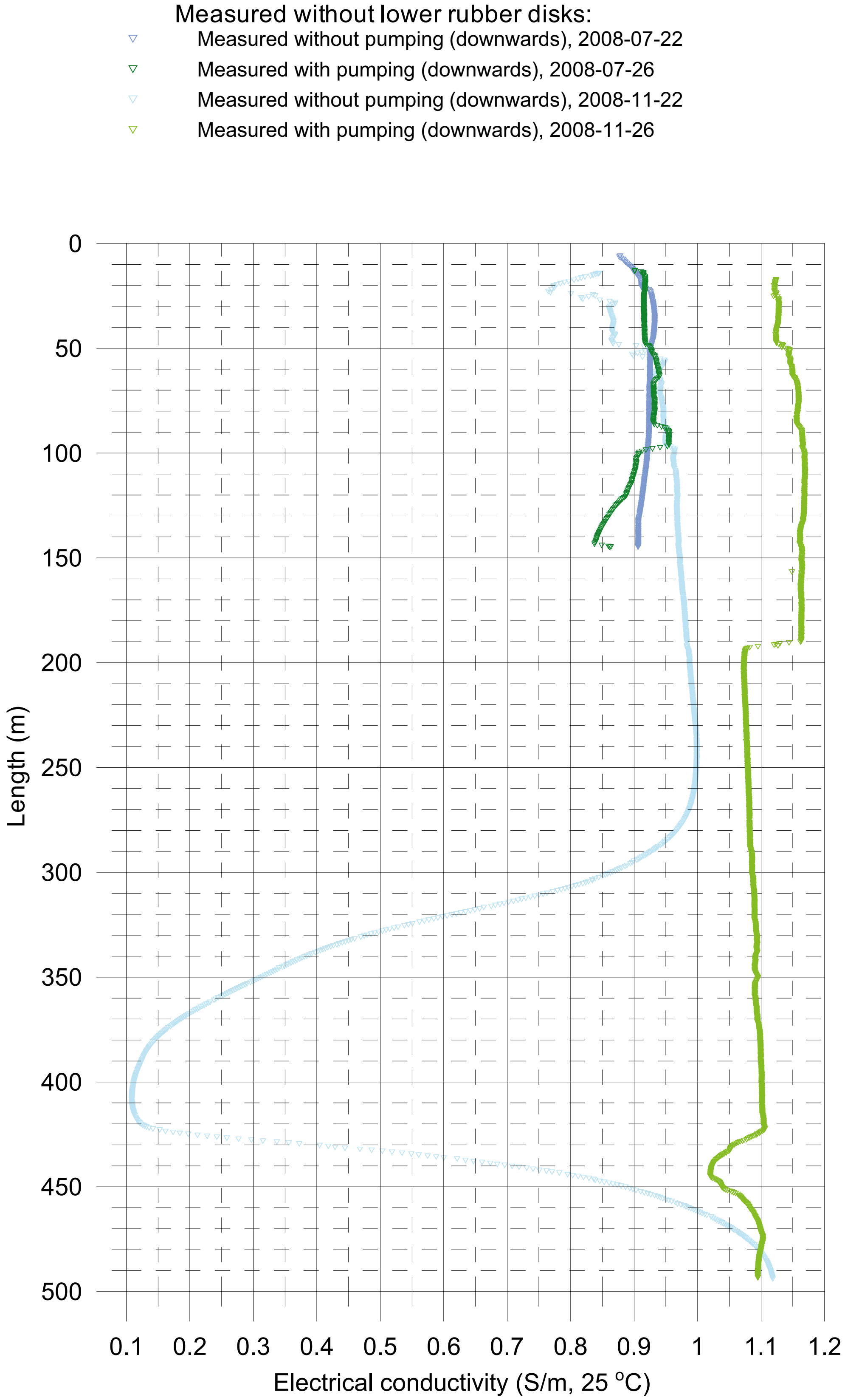


Forsmark, borehole KFR27
SPR and Caliper results after length correction

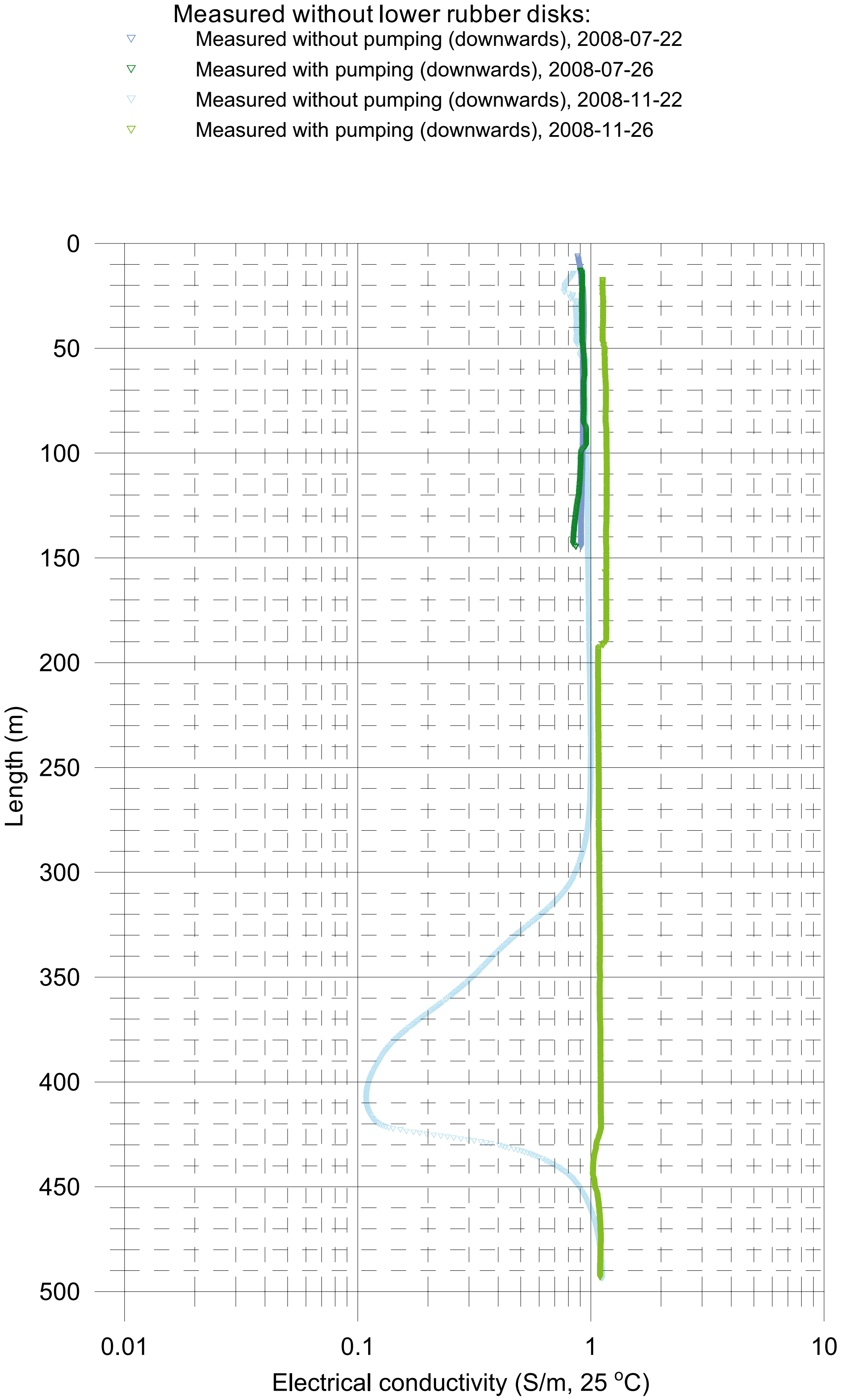



Forsmark, borehole KFR27
Length correction
SPR+Caliper (downwards), 2008-11-21
SPR without pumping (L = 5 m), 2008-11-22 - 2006-11-23
SPR with pumping (upwards) (L = 5 m), 2008-11-23 - 2008-11-24
SPR with pumping (upwards) (L = 1 m), 2008-11-24 - 2008-11-26
Length (m)
0
50
100
150
200
250
300
350
400
450
500
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0
0.1
Length error in logging cable (m)

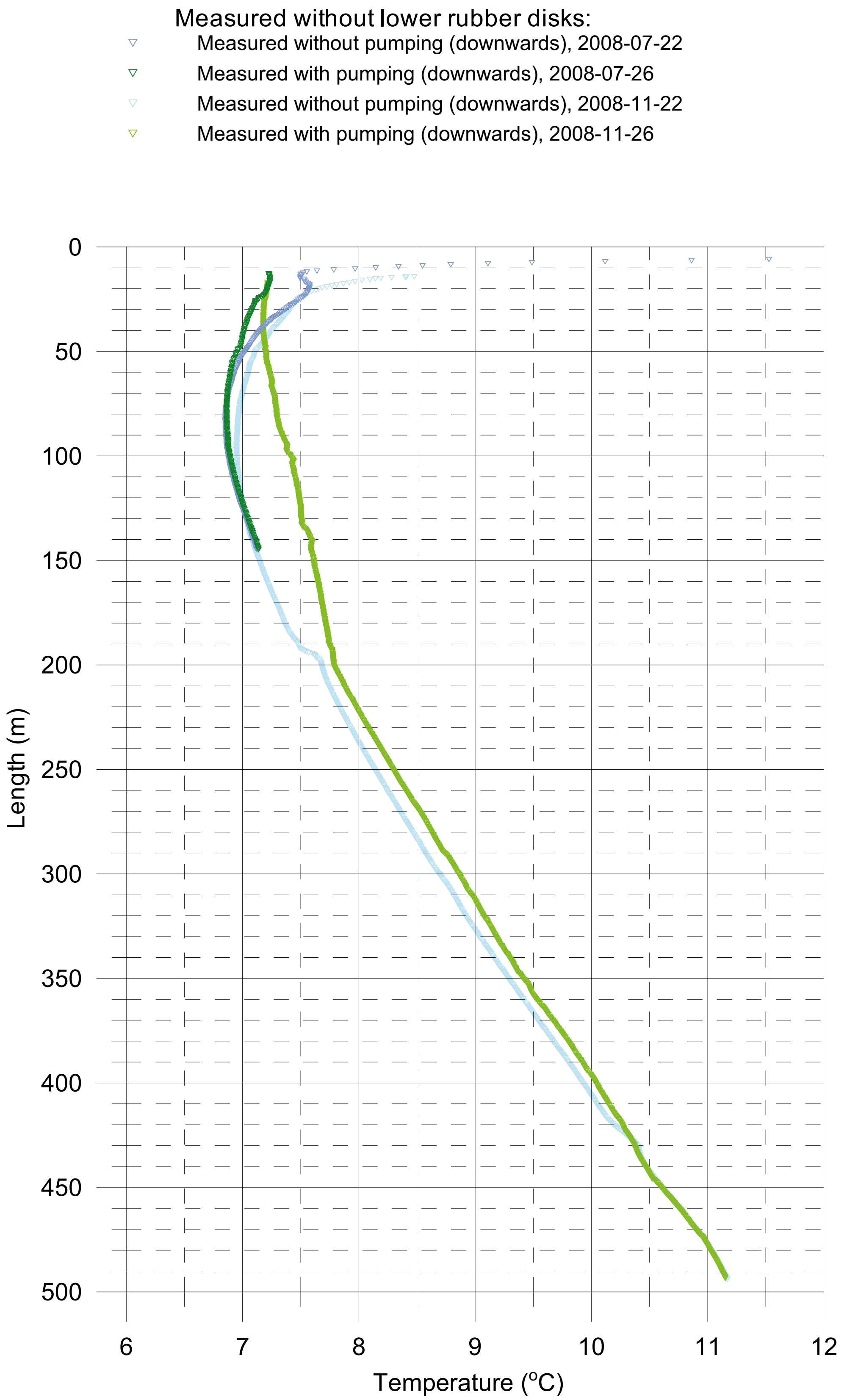
Forsmark, borehole KFR27
Electrical conductivity of borehole water

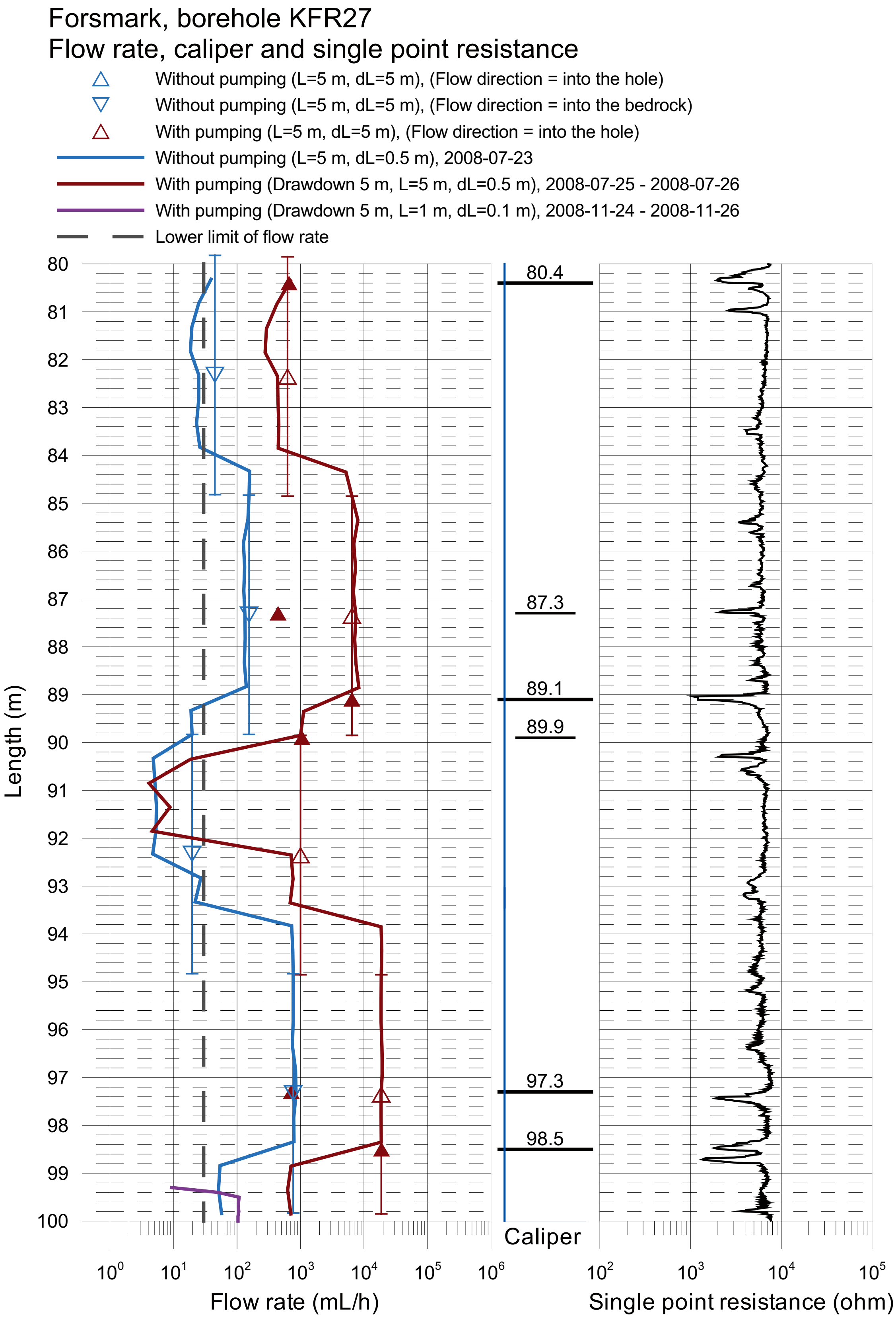


Forsmark, borehole KFR27
Electrical conductivity of borehole water

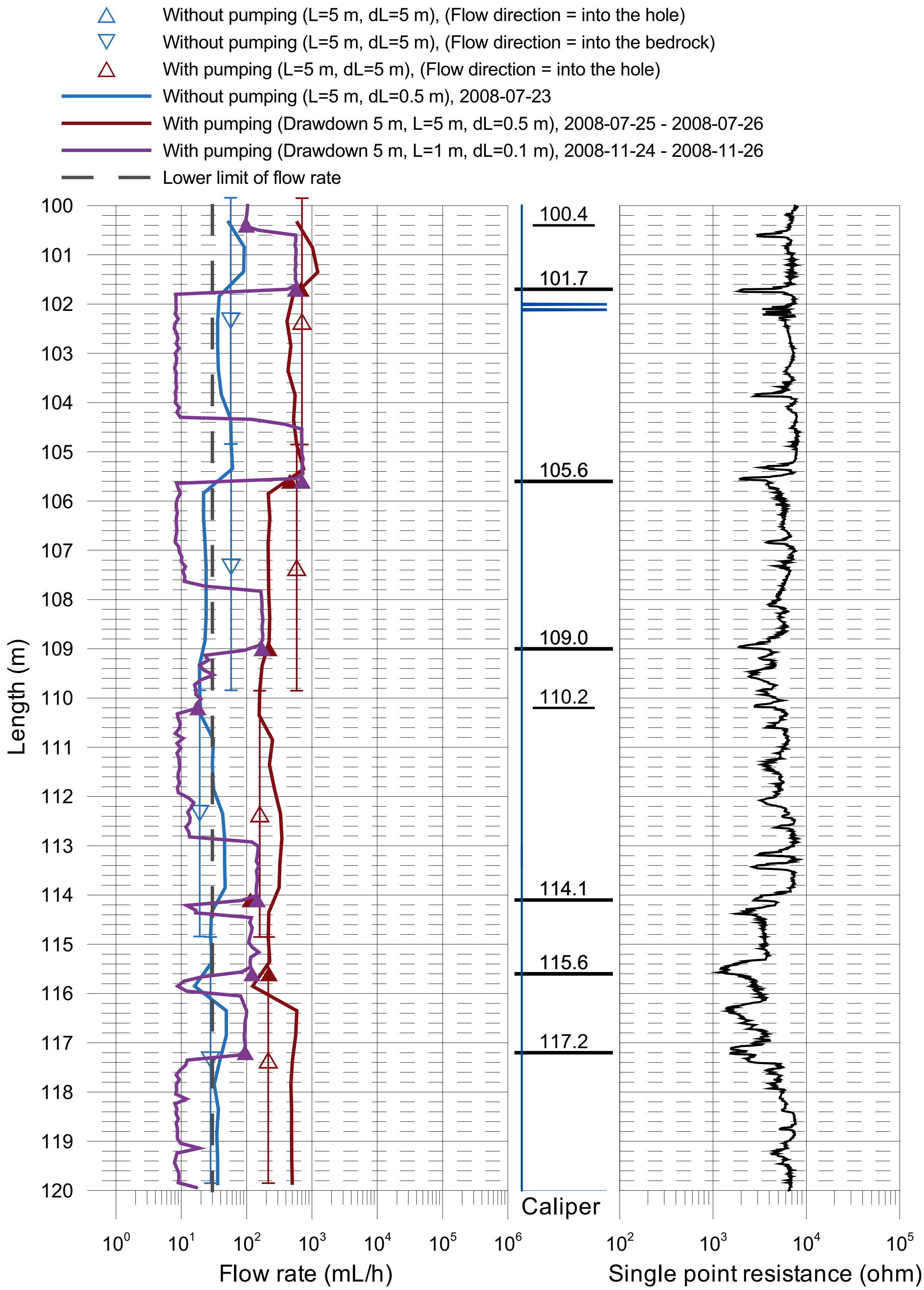


Forsmark, borehole KFR27
Temperature of borehole water

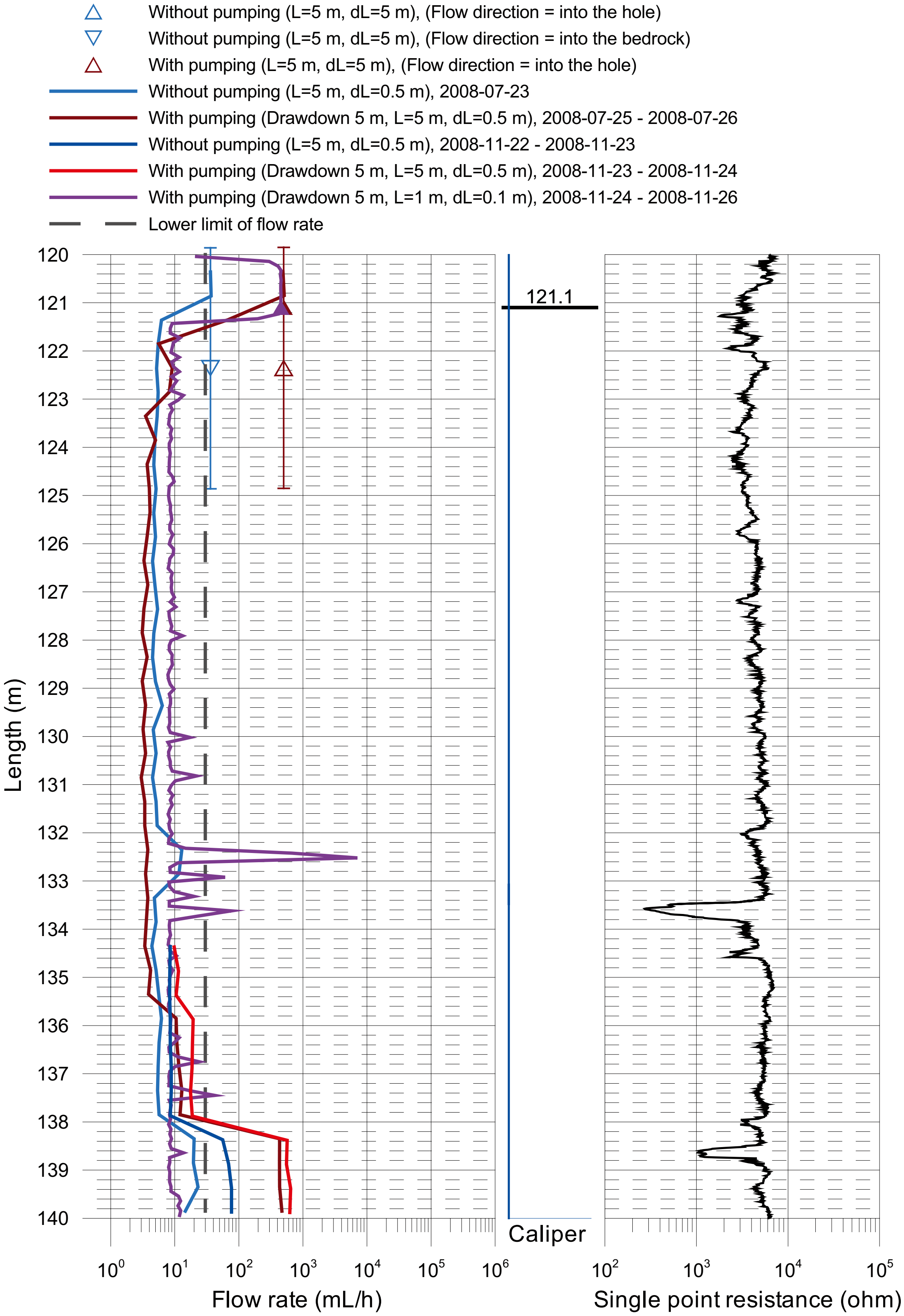


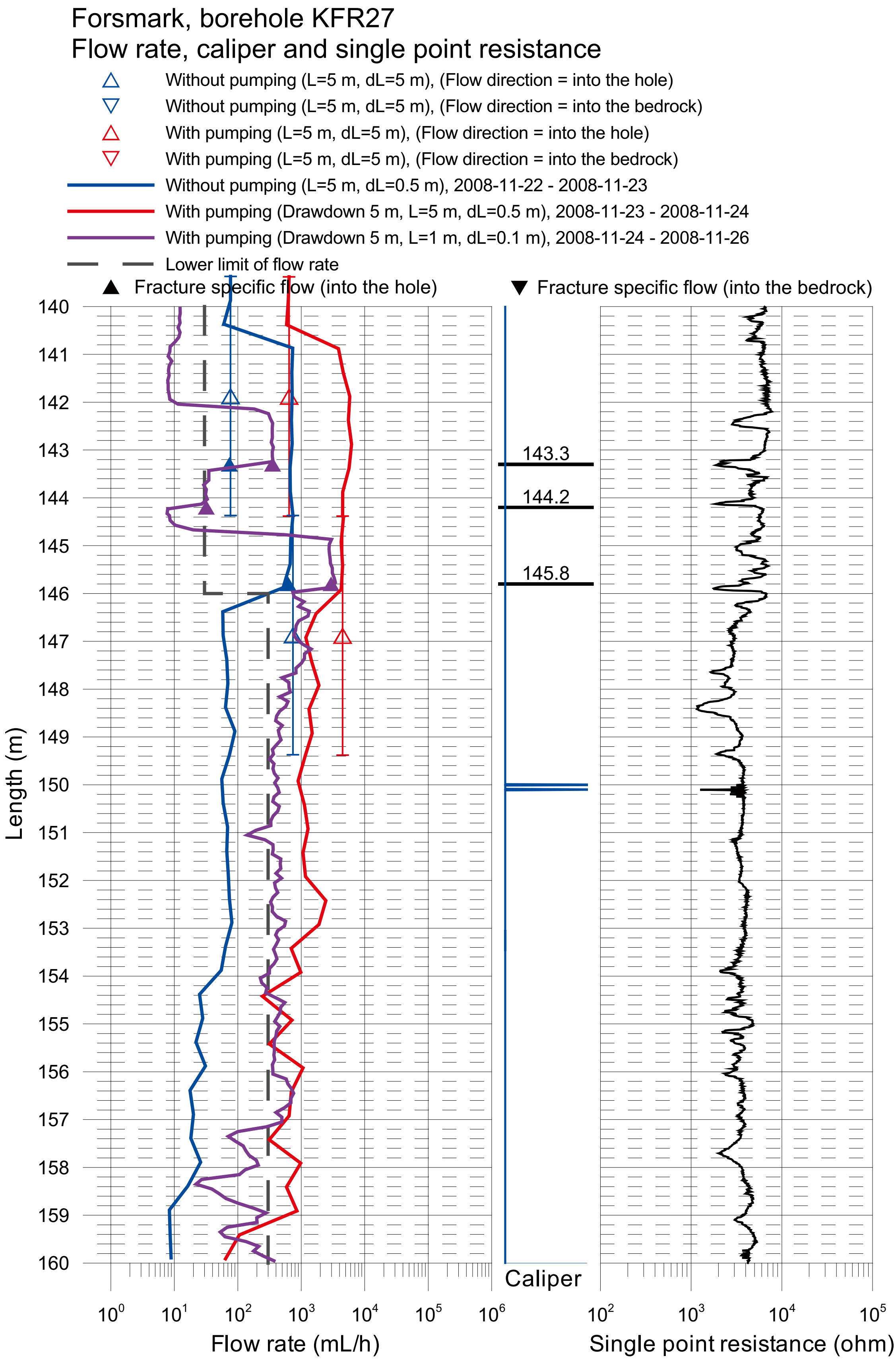

Forsmark, borehole KFR27
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=0.5 m), 2008-07-23
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-07-25 - 2008-07-26
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-24 - 2008-11-26
Lower limit of flow rate
Length (m)
80.4
87.3
89.1
89.9
97.3
98.5
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

Forsmark, borehole KFR27
Flow rate, caliper and single point resistance

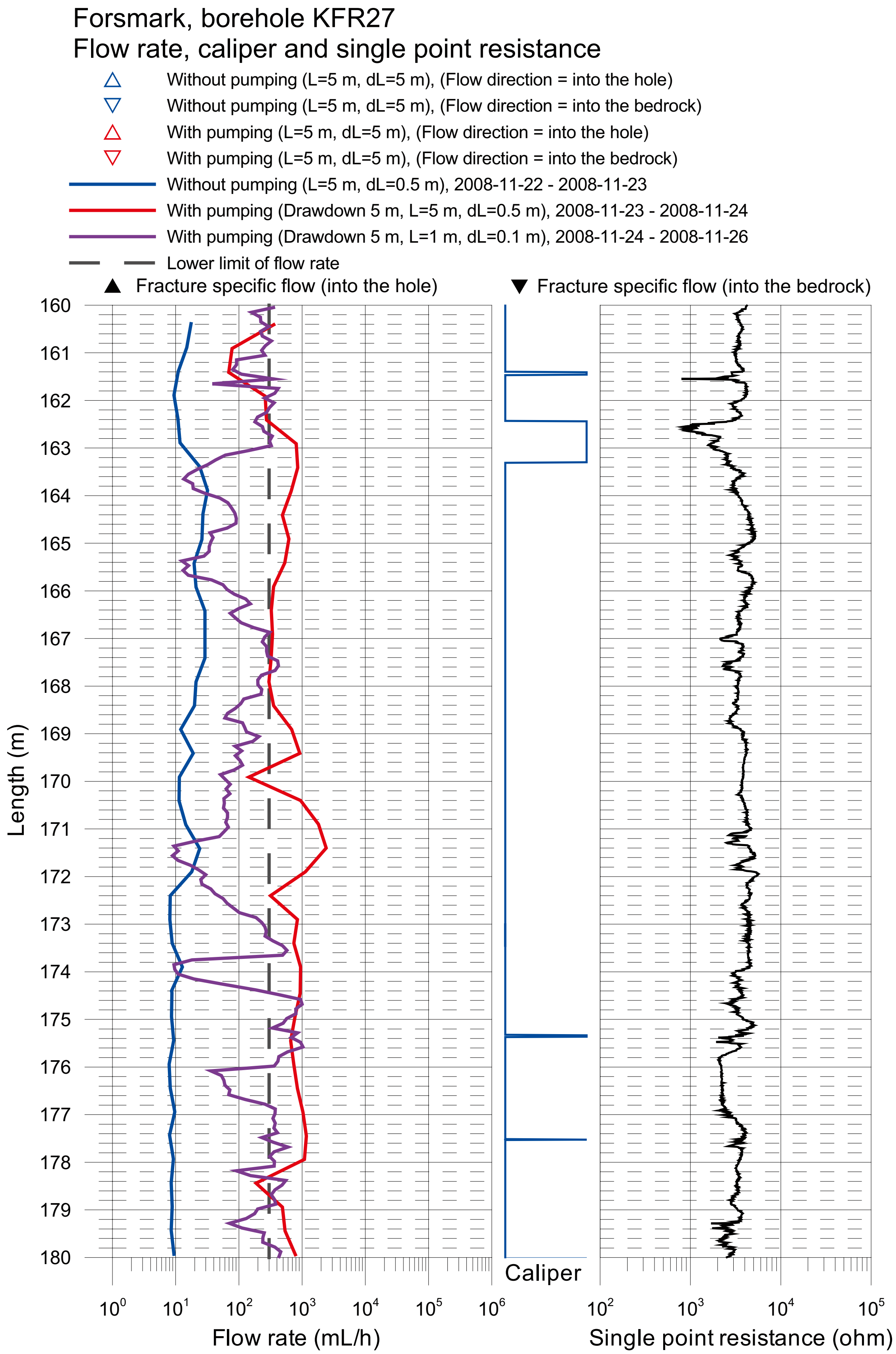


Forsmark, borehole KFR27
Flow rate, caliper and single point resistance

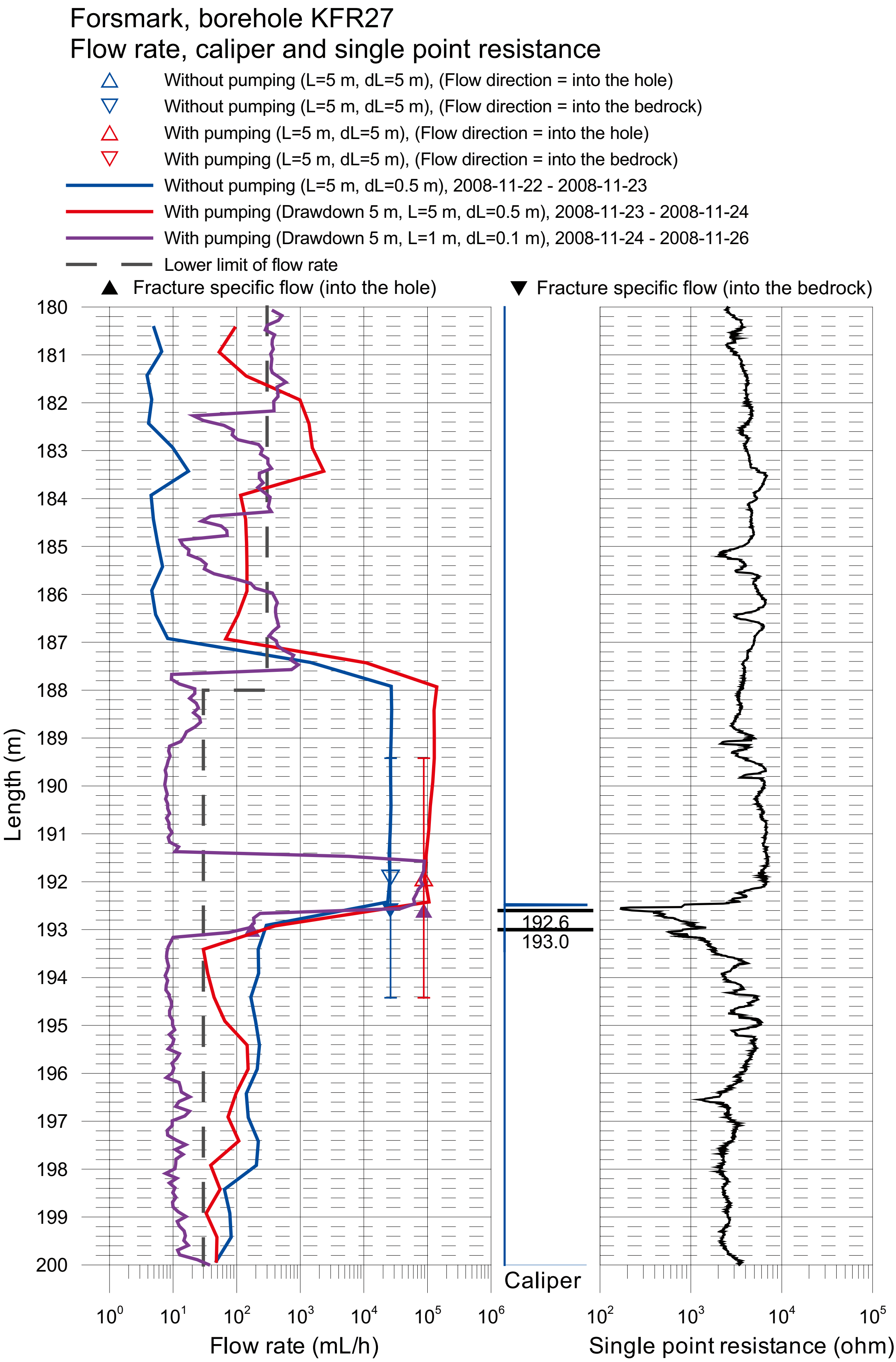




Forsmark, borehole KFR27
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2008-11-22 - 2008-11-23
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-23 - 2008-11-24
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-24 - 2008-11-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
143.3
144.2
145.8
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

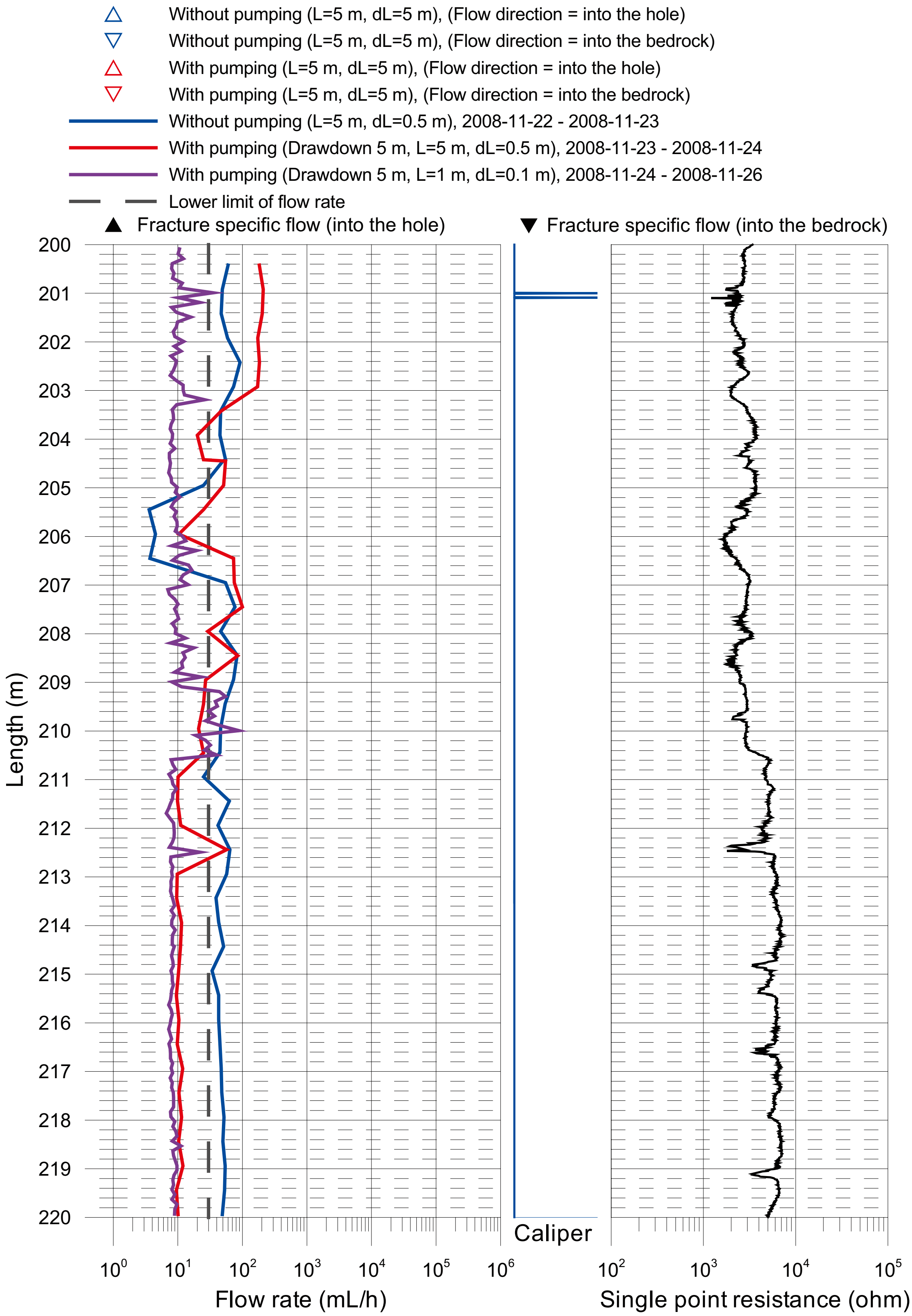


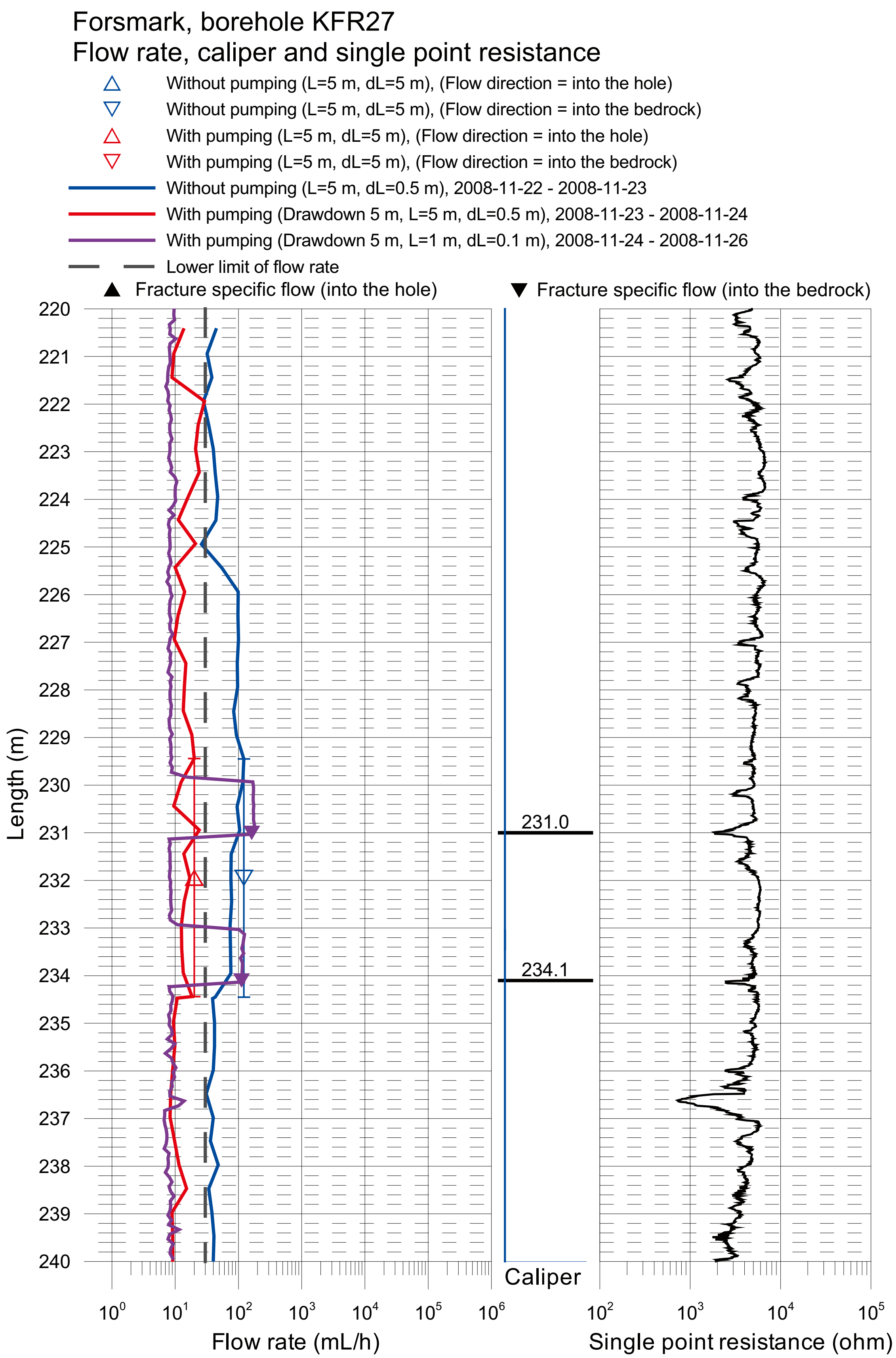
Forsmark, borehole KFR27
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2008-11-22 - 2008-11-23
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-23 - 2008-11-24
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-24 - 2008-11-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)



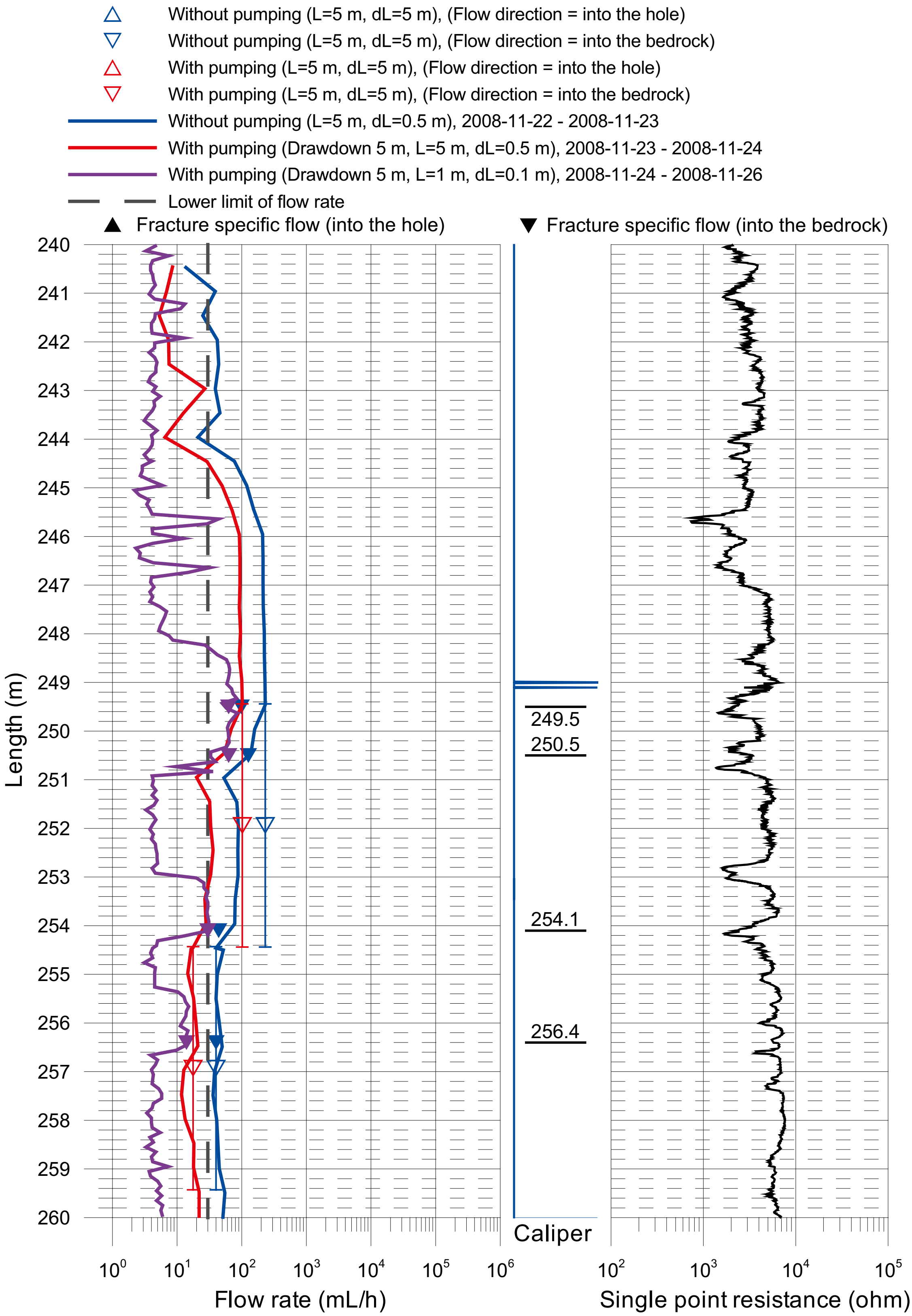
Forsmark, borehole KFR27
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2008-11-22 - 2008-11-23
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-23 - 2008-11-24
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-24 - 2008-11-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
192.6
193.0
Caliper
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
10^2
10^3
10^4
10^5
Single point resistance (ohm)

Forsmark, borehole KFR27
Flow rate, caliper and single point resistance

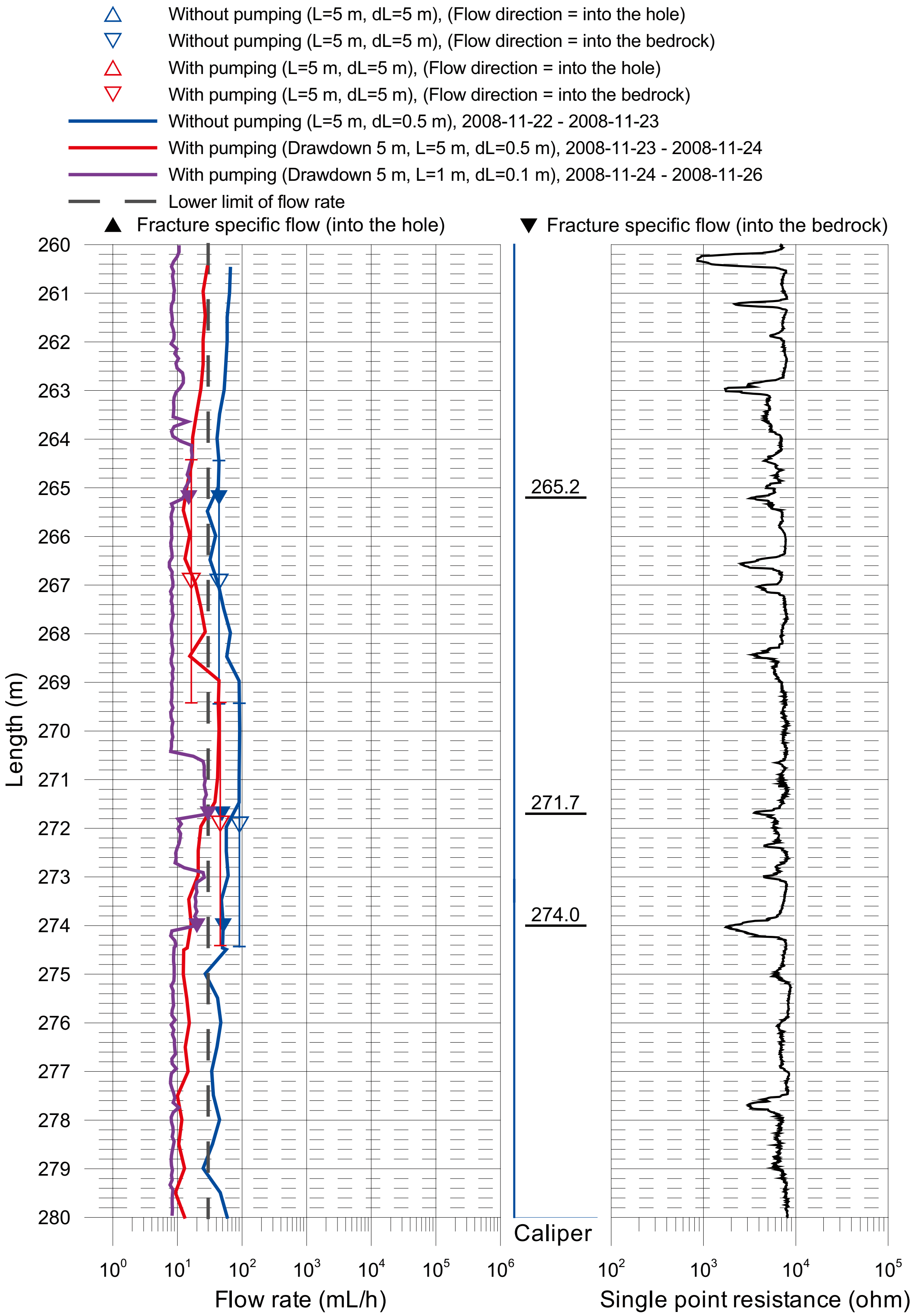



Forsmark, borehole KFR27
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2008-11-22 - 2008-11-23
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-23 - 2008-11-24
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-24 - 2008-11-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
231.0
234.1
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

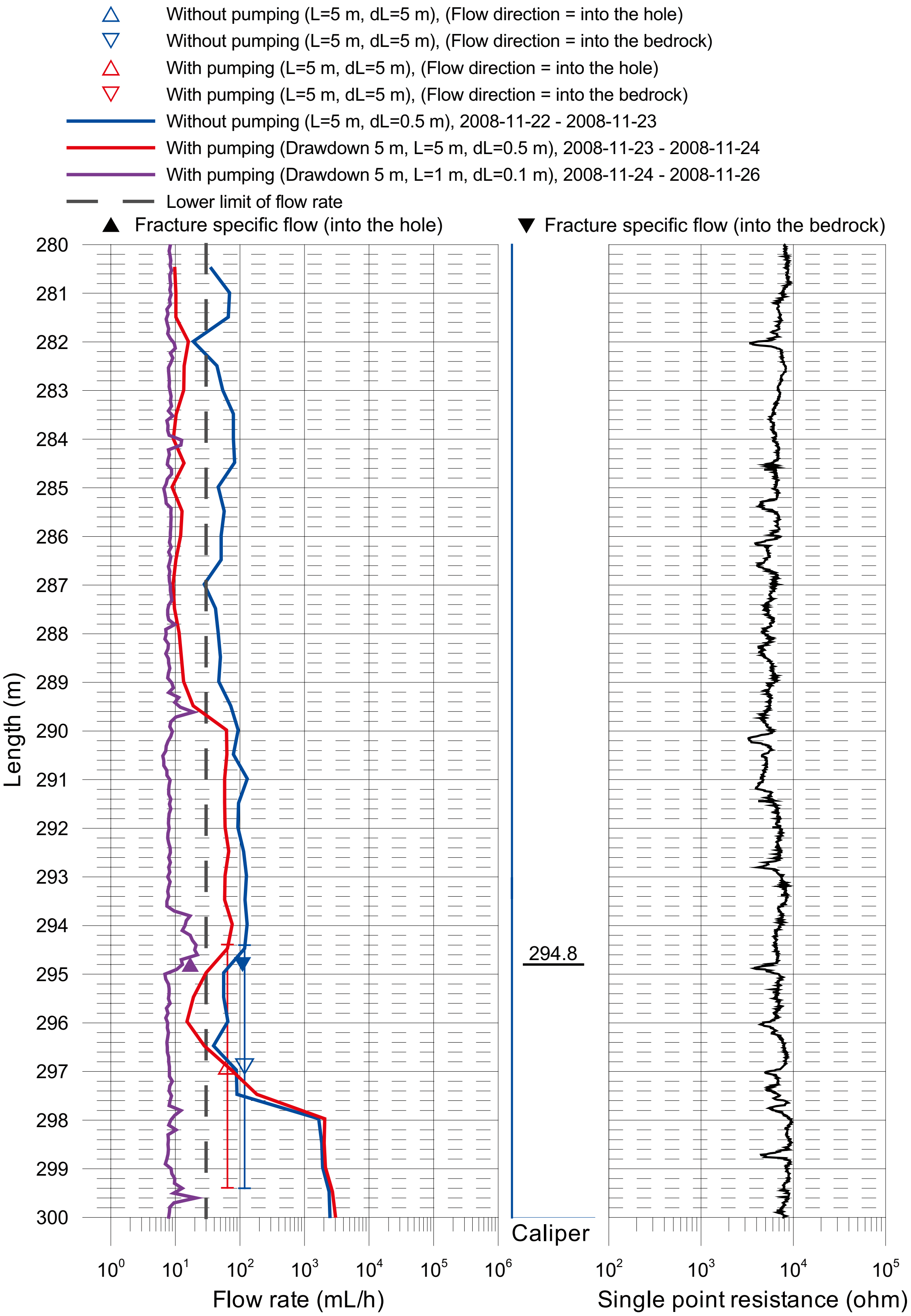
Forsmark, borehole KFR27
Flow rate, caliper and single point resistance



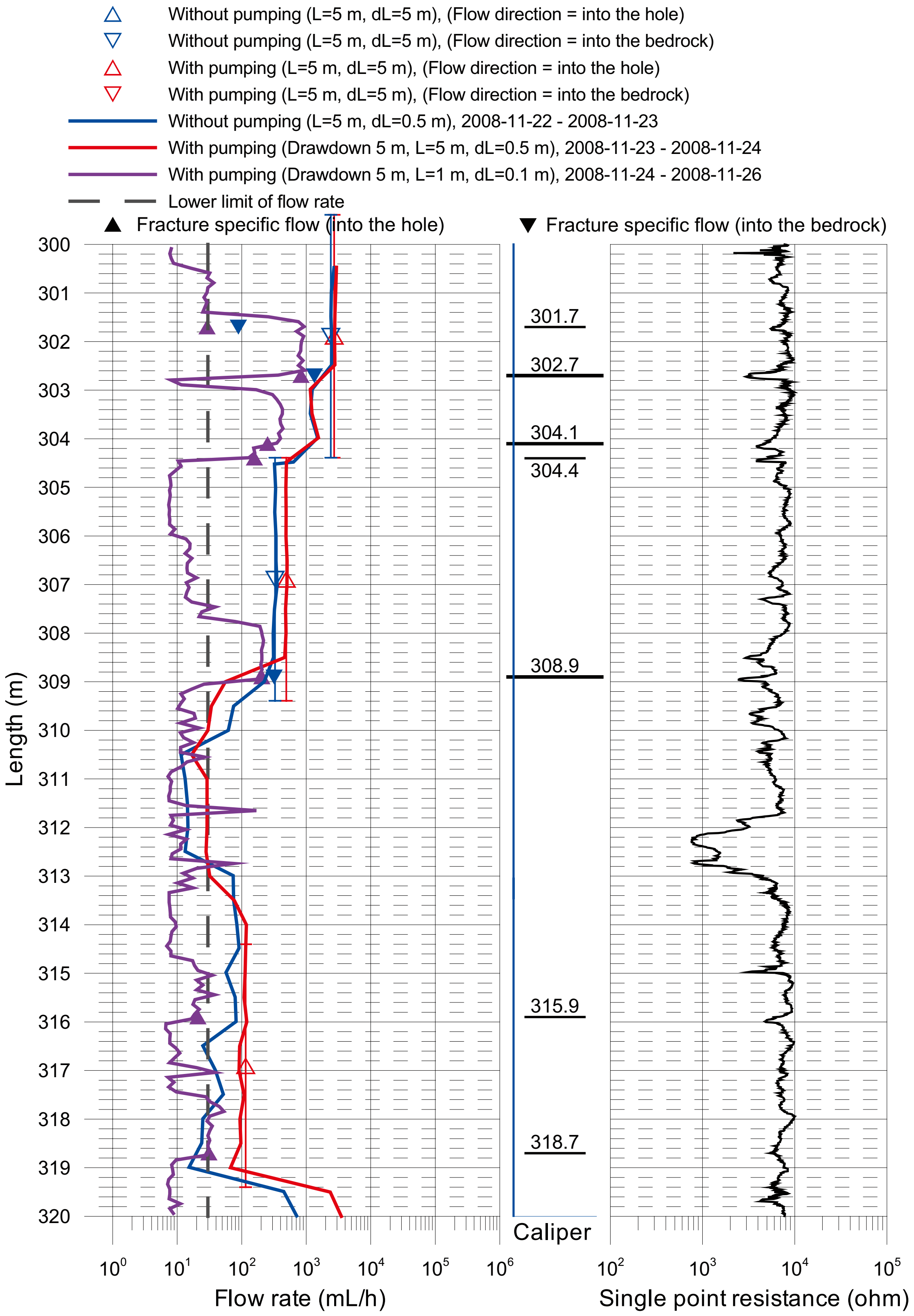
Forsmark, borehole KFR27
Flow rate, caliper and single point resistance

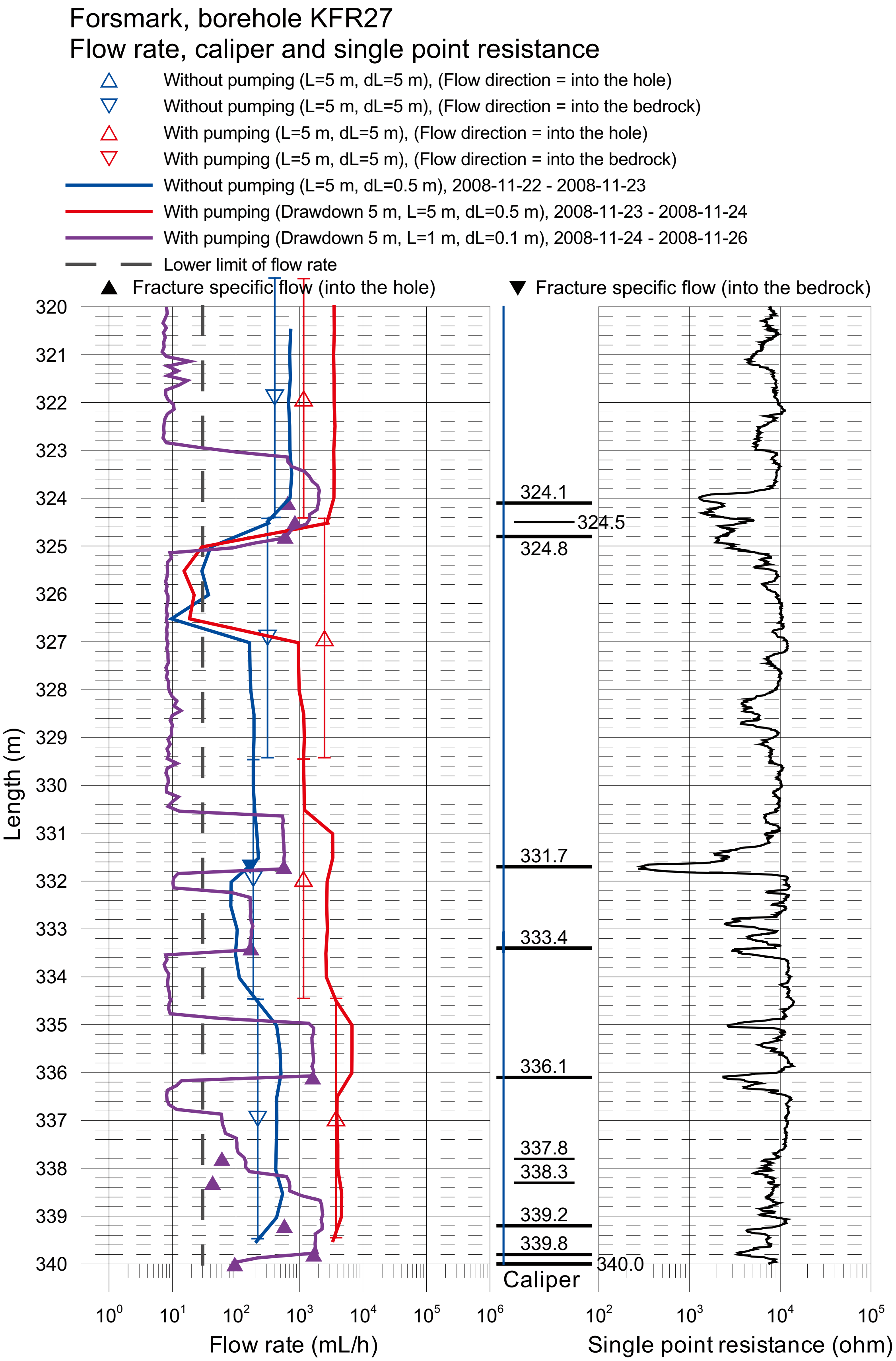


Forsmark, borehole KFR27
Flow rate, caliper and single point resistance



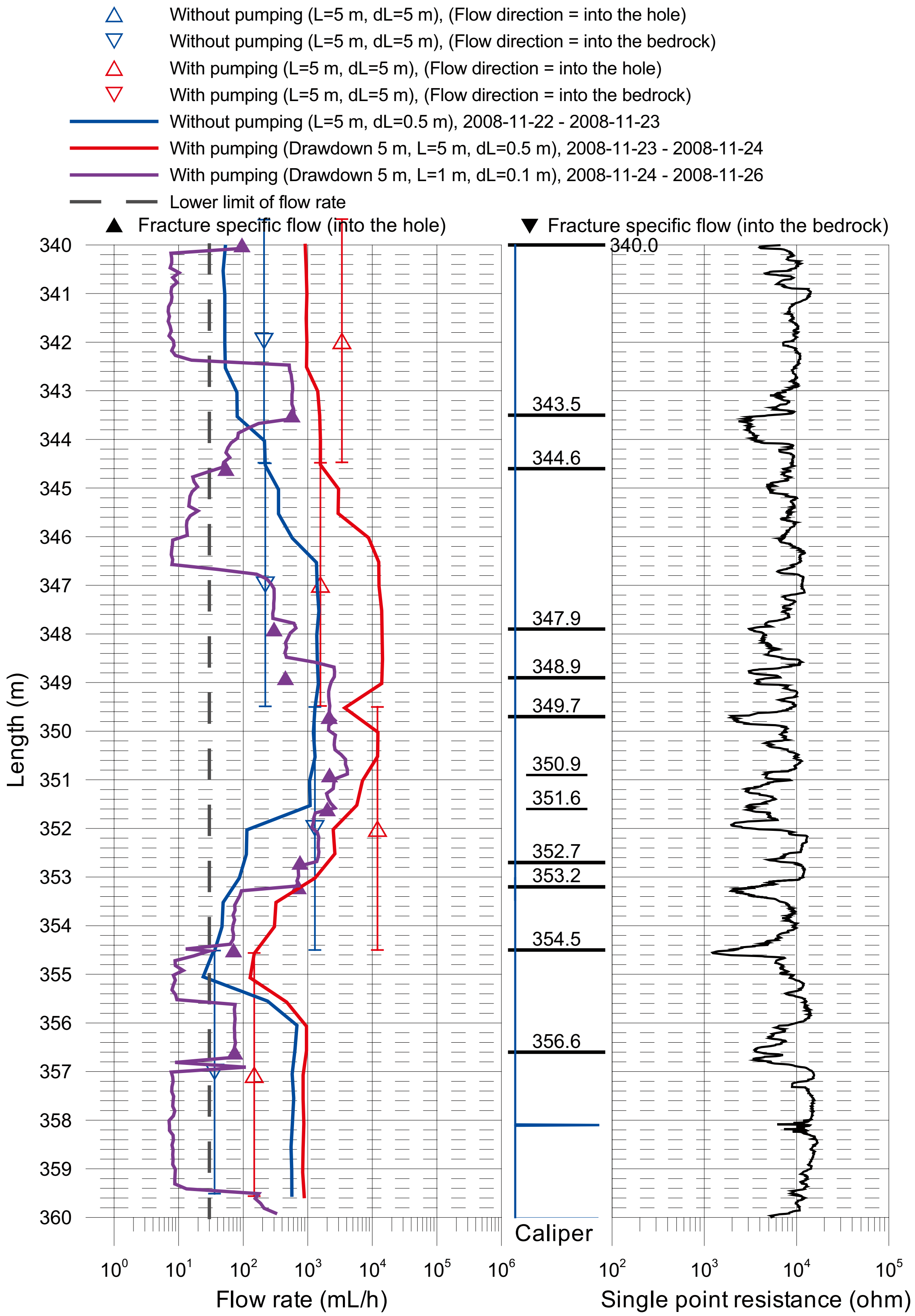
Forsmark, borehole KFR27
Flow rate, caliper and single point resistance



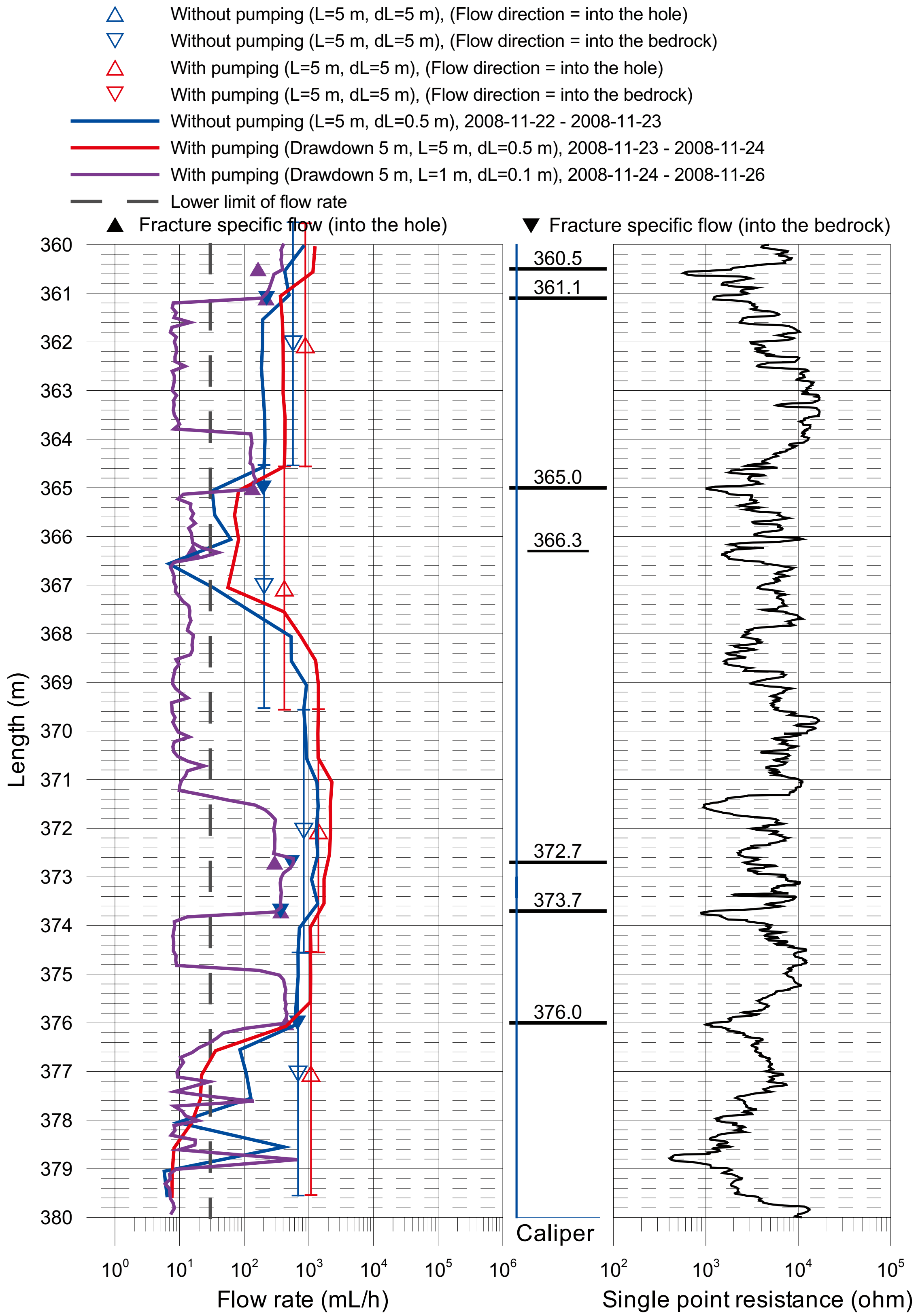


Forsmark, borehole KFR27
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2008-11-22 - 2008-11-23
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-23 - 2008-11-24
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-24 - 2008-11-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
324.1
324.5
324.8
331.7
333.4
336.1
337.8
338.3
339.2
339.8
340.0
Caliper
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^2 10^3 10^4 10^5
Single point resistance (ohm)

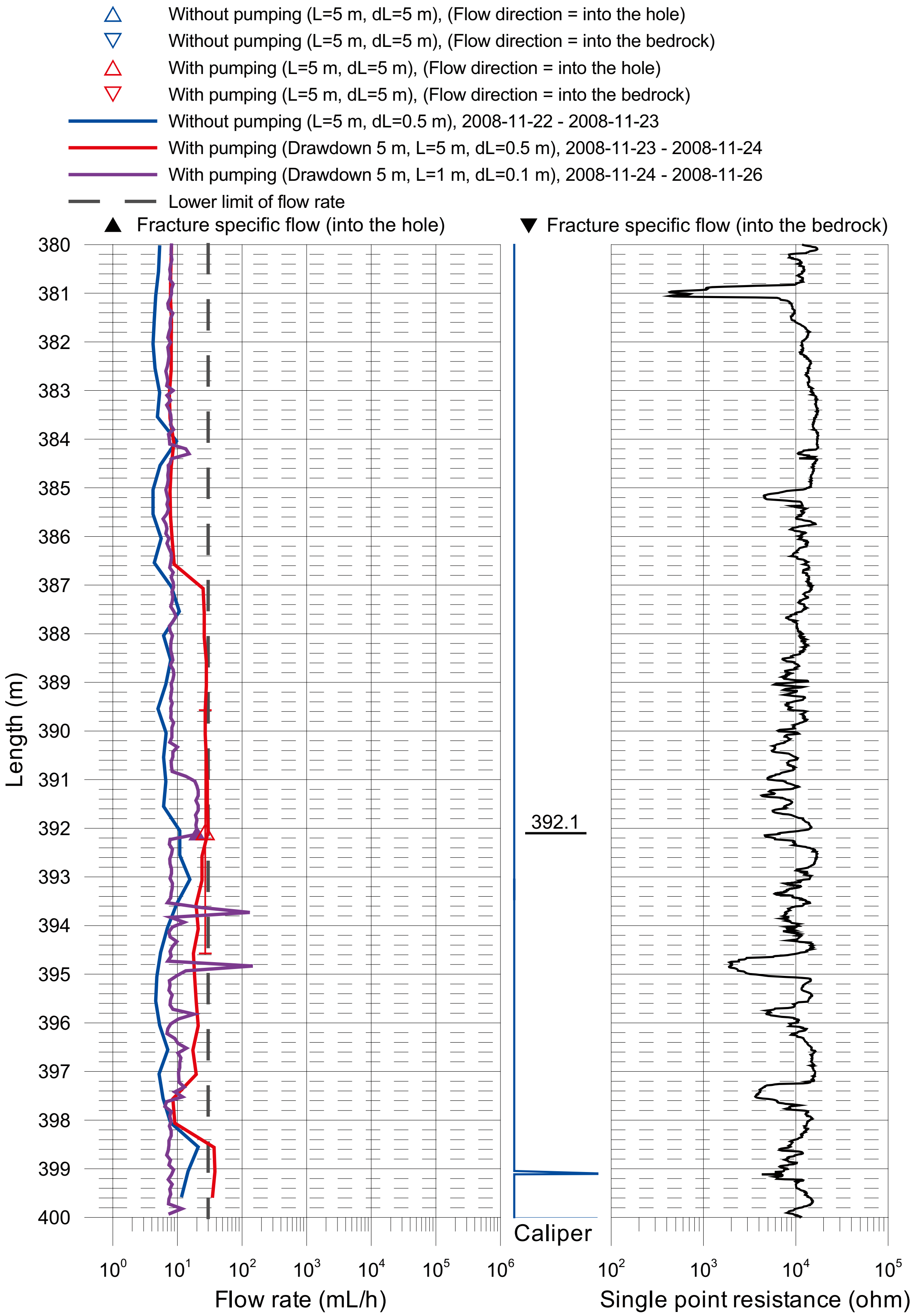
Forsmark, borehole KFR27
Flow rate, caliper and single point resistance



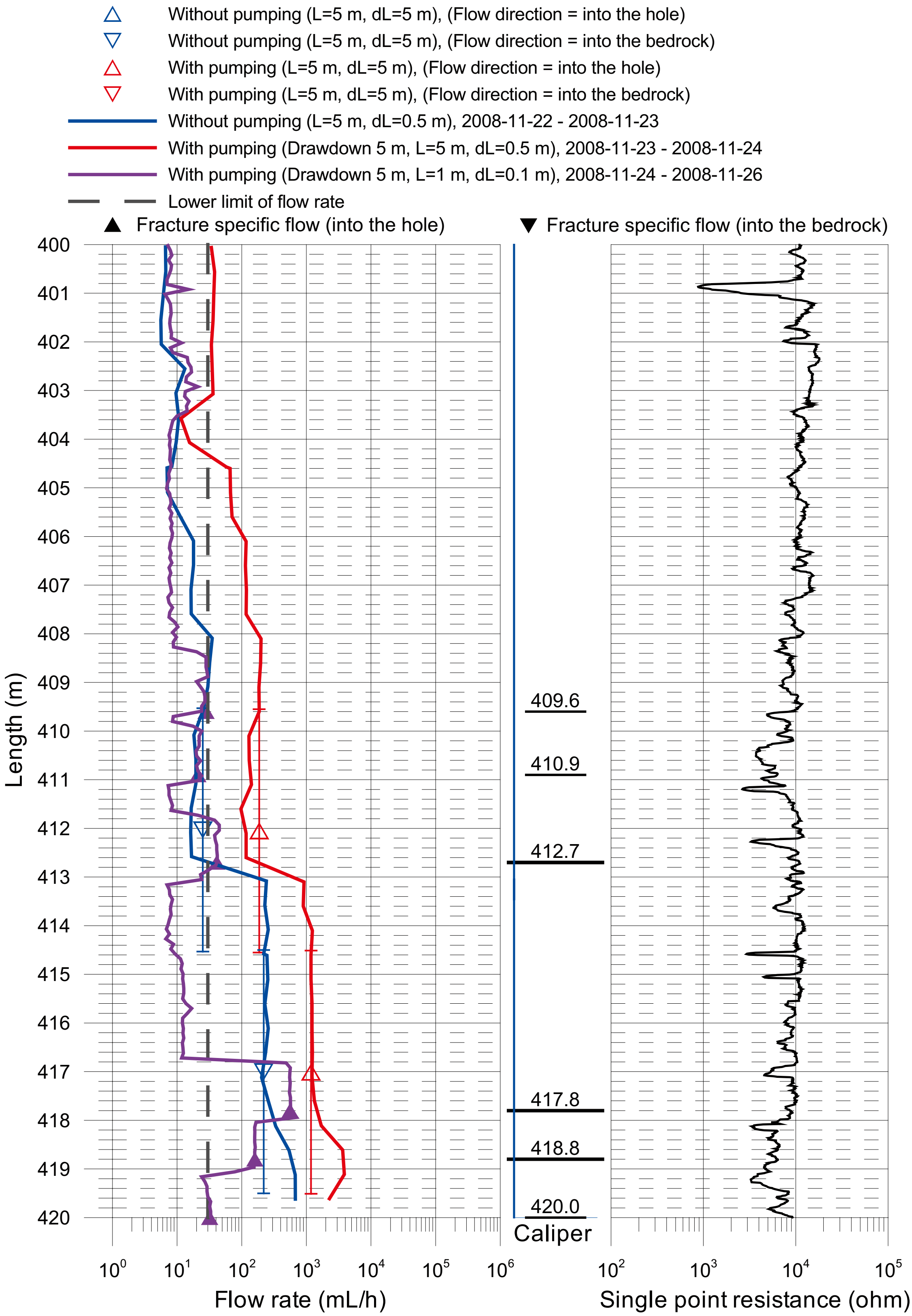
Forsmark, borehole KFR27
Flow rate, caliper and single point resistance



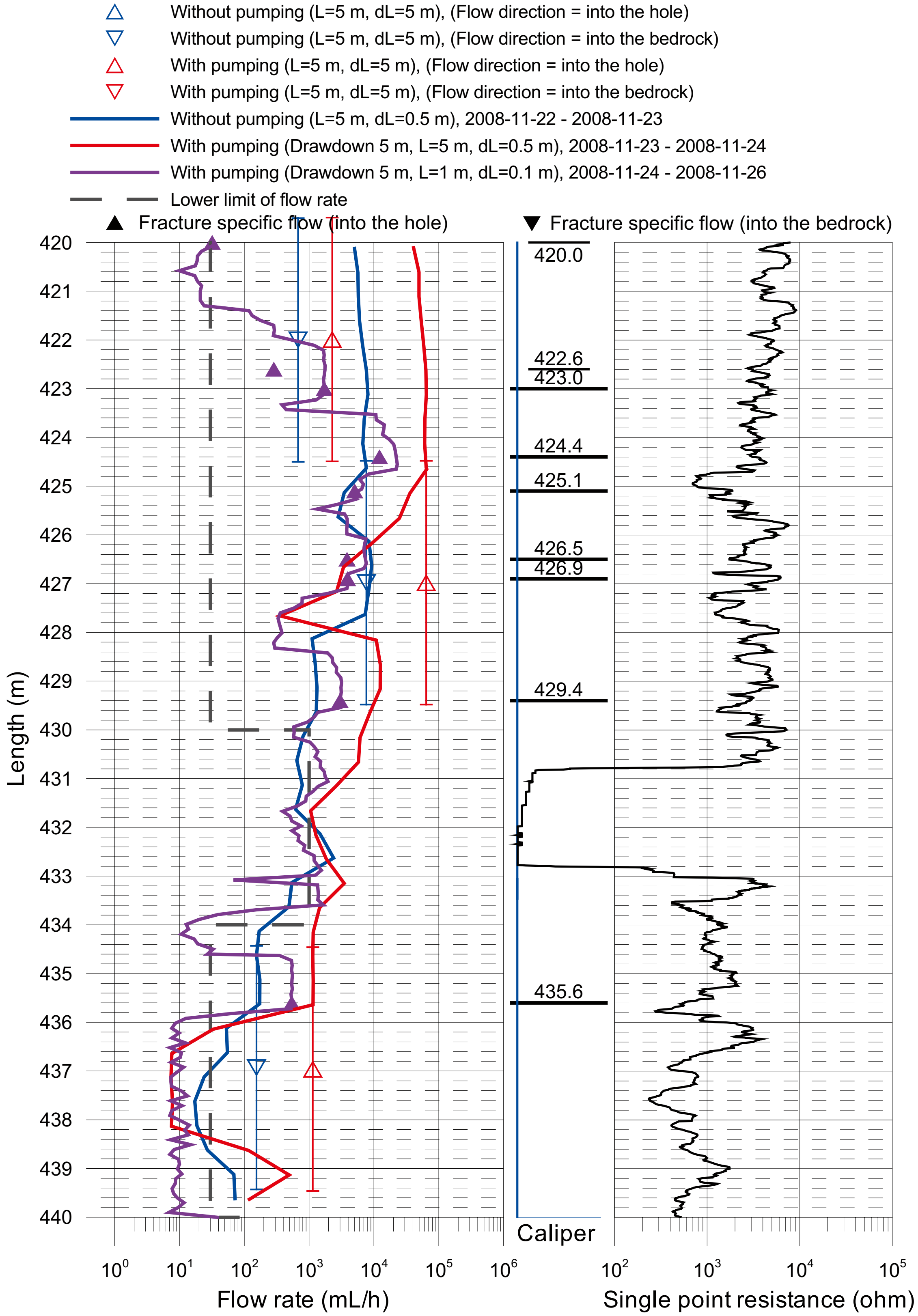
Forsmark, borehole KFR27
Flow rate, caliper and single point resistance

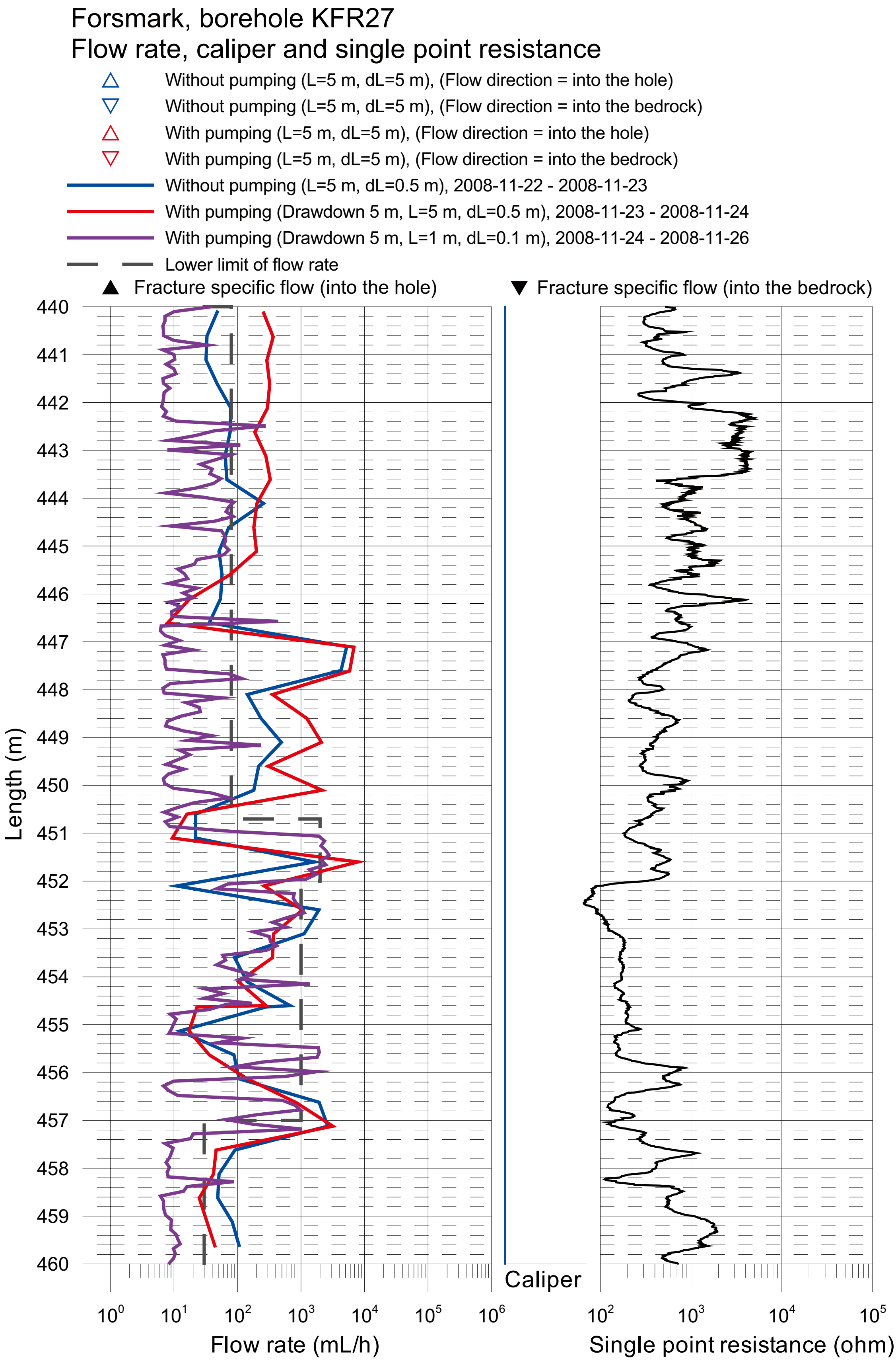


Forsmark, borehole KFR27
Flow rate, caliper and single point resistance

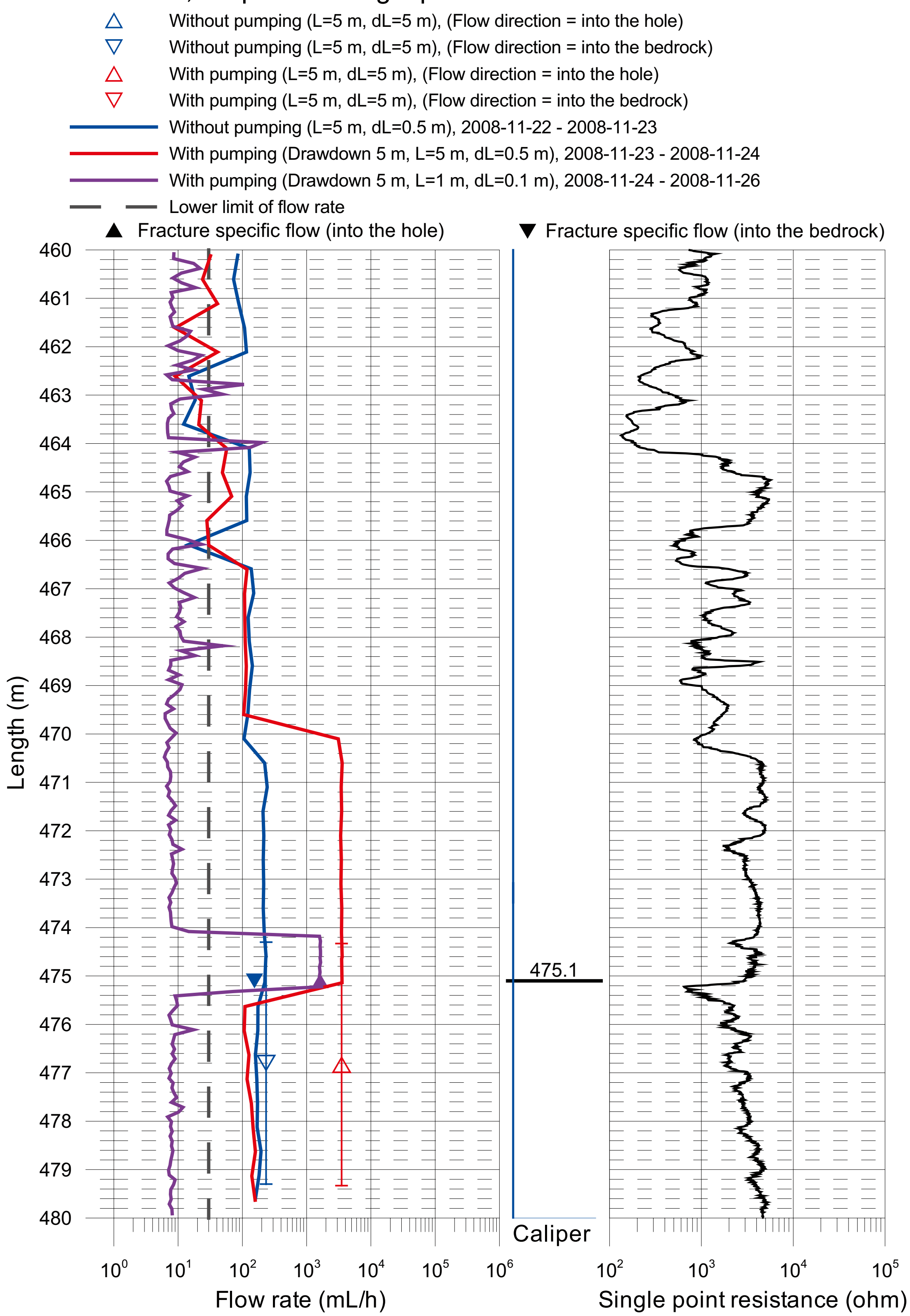


Forsmark, borehole KFR27
Flow rate, caliper and single point resistance

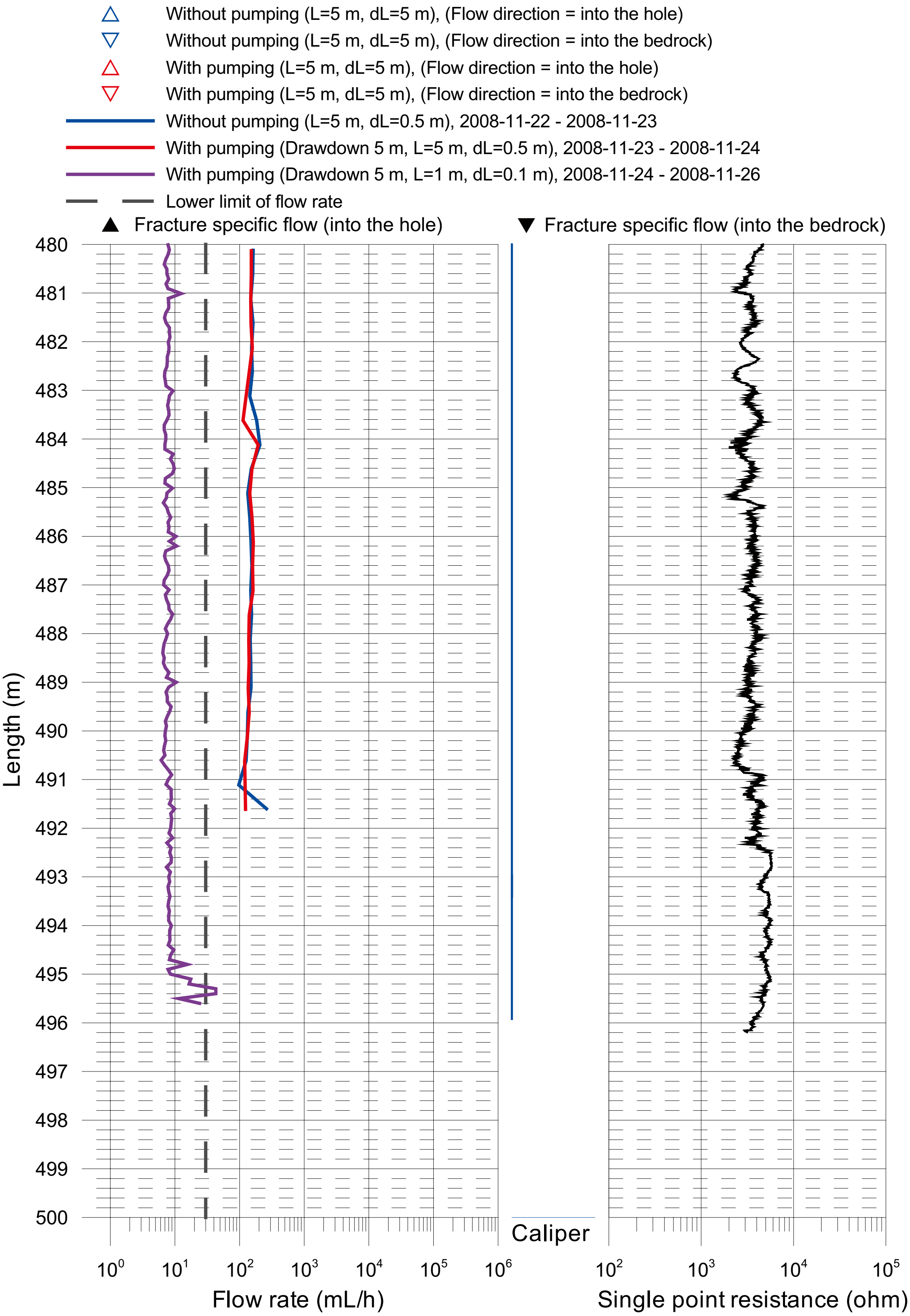



Forsmark, borehole KFR27
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2008-11-22 - 2008-11-23
With pumping (Drawdown 5 m, L=5 m, dL=0.5 m), 2008-11-23 - 2008-11-24
With pumping (Drawdown 5 m, L=1 m, dL=0.1 m), 2008-11-24 - 2008-11-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Flow rate (mL/h)
Caliper
10^2
10^3
10^4
10^5
Single point resistance (ohm)

Forsmark, borehole KFR27
Flow rate, caliper and single point resistance



Forsmark, borehole KFR27
Flow rate, caliper and single point resistance



Explanations

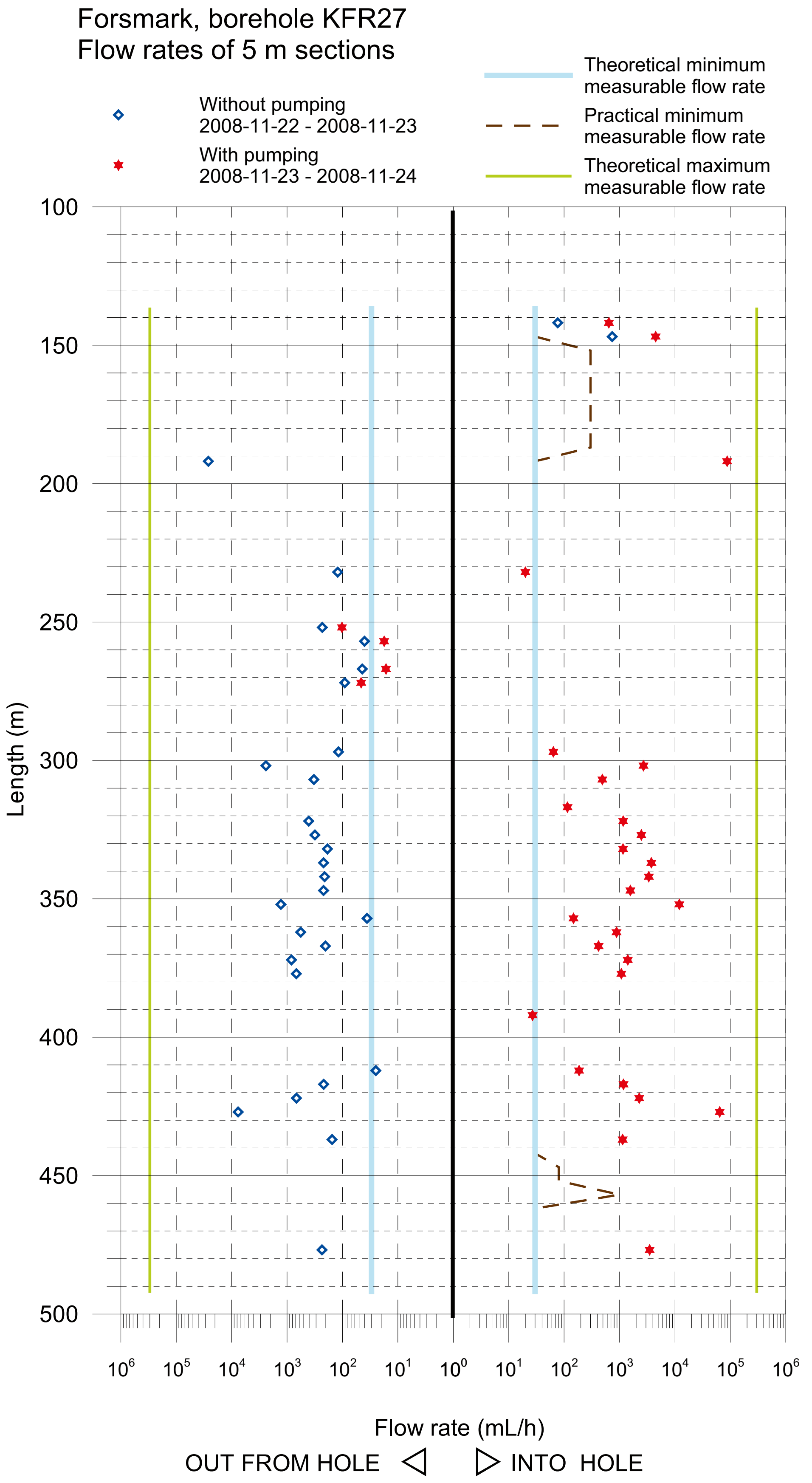
Header	Unit	Explanations
Borehole		ID for borehole.
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L).
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L).
L	m	Corrected length along borehole based 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).

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1 (m^3/s)	h_{1FW} (masl)	T_D (m^2/s)	h_i (masl)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D- measl$_{LP}$ (m^2/s)	T_D- measl$_U$ (m^2/s)	Comments
KFR27	134.37	139.37	5	–	–1.03	–	–5.94	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	139.38	144.38	5	2.14E-08	–1.01	1.78E-07	–5.92	3.2E-08	–0.3	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	144.38	149.38	5	2.06E-07	–1.00	1.25E-06	–5.88	2.1E-07	0.0	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	149.40	154.40	5	–	–0.98	–	–5.85	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR27	154.40	159.40	5	–	–0.96	–	–5.84	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR27	159.40	164.40	5	–	–0.91	–	–5.79	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR27	164.40	169.40	5	–	–0.88	–	–5.74	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR27	169.41	174.41	5	–	–0.85	–	–5.71	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR27	174.43	179.43	5	–	–0.82	–	–5.66	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR27	179.44	184.44	5	–	–0.78	–	–5.65	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR27	184.43	189.43	5	–	–0.70	–	–5.63	–	–	300	1.7E-09	1.7E-08	1.7E-05	
KFR27	189.42	194.42	5	–7.31E-06	–0.68	2.43E-05	–5.78	6.1E-06	–1.9	30	1.6E-09	1.6E-09	1.8E-05	
KFR27	194.41	199.41	5	–	–0.69	–	–5.52	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	199.42	204.42	5	–	–0.67	–	–5.48	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	204.42	209.42	5	–	–0.64	–	–5.46	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	209.45	214.45	5	–	–0.60	–	–5.44	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	214.44	219.44	5	–	–0.56	–	–5.40	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	219.44	224.44	5	–	–0.55	–	–5.38	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	224.44	229.44	5	–	–0.52	–	–5.36	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	229.45	234.45	5	–3.39E-08	–0.51	5.56E-09	–5.31	8.1E-09	–4.6	30	1.7E-09	1.7E-09	1.7E-05	*
KFR27	234.45	239.45	5	–	–0.46	–	–5.31	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	239.46	244.46	5	–	–0.42	–	–5.27	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	244.45	249.45	5	–	–0.40	–	–5.22	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	249.44	254.44	5	–6.42E-08	–0.38	–2.83E-08	–5.19	7.3E-09	–9.0	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	254.43	259.43	5	–1.11E-08	–0.35	–4.92E-09	–5.16	1.3E-09	–9.0	30	1.7E-09	1.7E-09	1.7E-05	*
KFR27	259.45	264.45	5	–	–0.31	–	–5.11	–	–	30	1.7E-09	1.7E-09	1.7E-05	

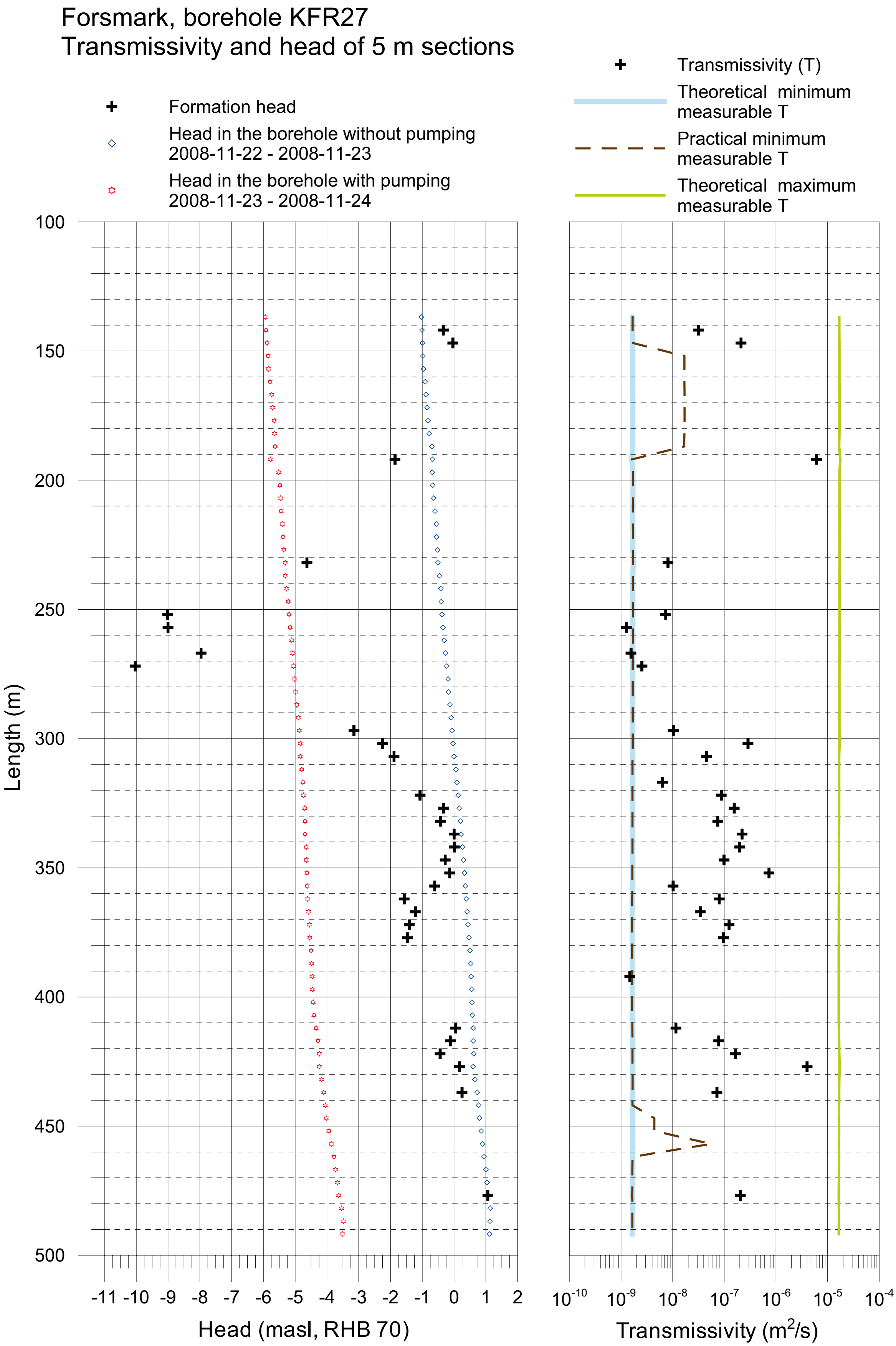
Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1 (m^3/s)	h_{1FW} (masl)	T_D (m^2/s)	h_i (masl)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D- measl$_{LP}$ (m^2/s)	T_D- measl$_U$ (m^2/s)	Comments
KFR27	264.43	269.43	5	–1.22E-08	–0.27	–4.56E-09	–5.08	1.6E-09	–8.0	30	1.7E-09	1.7E-09	1.7E-05	*
KFR27	269.42	274.42	5	–2.53E-08	–0.23	–1.28E-08	–5.05	2.5E-09	–10.0	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	274.42	279.42	5	–	–0.19	–	–5.02	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	279.44	284.44	5	–	–0.18	–	–4.99	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	284.42	289.42	5	–	–0.13	–	–4.95	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	289.41	294.41	5	–	–0.09	–	–4.90	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	294.40	299.40	5	–3.28E-08	–0.06	1.78E-08	–4.87	1.0E-08	–3.2	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	299.39	304.39	5	–6.69E-07	–0.03	7.53E-07	–4.84	2.9E-07	–2.3	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	304.39	309.39	5	–9.11E-08	0.00	1.36E-07	–4.84	4.6E-08	–1.9	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	309.41	314.41	5	–	0.06	–	–4.79	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	314.40	319.40	5	–	0.09	3.19E-08	–4.76	6.4E-09	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	319.41	324.41	5	–1.13E-07	0.13	3.24E-07	–4.74	8.7E-08	–1.1	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	324.42	329.42	5	–8.75E-08	0.16	6.89E-07	–4.70	1.6E-07	–0.3	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	329.46	334.46	5	–5.19E-08	0.20	3.22E-07	–4.69	7.5E-08	–0.4	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	334.46	339.46	5	–6.11E-08	0.22	1.04E-06	–4.69	2.2E-07	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	339.48	344.48	5	–5.83E-08	0.26	9.39E-07	–4.65	2.0E-07	0.0	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	344.49	349.49	5	–6.11E-08	0.30	4.36E-07	–4.65	9.9E-08	–0.3	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	349.50	354.50	5	–3.58E-07	0.33	3.33E-06	–4.63	7.4E-07	–0.1	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	354.54	359.54	5	–1.00E-08	0.35	4.11E-08	–4.62	1.0E-08	–0.6	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	359.55	364.55	5	–1.58E-07	0.38	2.45E-07	–4.61	8.0E-08	–1.6	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	364.55	369.55	5	–5.64E-08	0.41	1.16E-07	–4.58	3.4E-08	–1.2	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	369.56	374.56	5	–2.31E-07	0.44	3.92E-07	–4.55	1.2E-07	–1.4	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	374.55	379.55	5	–1.89E-07	0.47	3.00E-07	–4.54	9.7E-08	–1.5	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	379.56	384.56	5	–	0.50	–	–4.50	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	384.56	389.56	5	–	0.52	–	–4.48	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	389.56	394.56	5	–	0.54	7.50E-09	–4.46	1.5E-09	–	30	1.7E-09	1.7E-09	1.7E-05	*
KFR27	394.56	399.56	5	–	0.55	–	–4.46	–	–	30	1.7E-09	1.7E-09	1.7E-05	

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1 (m^3/s)	h_{1FW} (masl)	T_D (m^2/s)	h_i (masl)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D- measl$_{LP}$ (m^2/s)	T_D- measl$_U$ (m^2/s)	Comments
KFR27	399.56	404.56	5	–	0.56	–	–4.43	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	404.55	409.55	5	–	0.57	–	–4.41	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	409.54	414.54	5	–6.94E-09	0.60	5.17E-08	–4.34	1.2E-08	0.1	30	1.7E-09	1.7E-09	1.7E-05	*
KFR27	414.51	419.51	5	–6.08E-08	0.60	3.28E-07	–4.28	7.8E-08	–0.1	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	419.50	424.50	5	–1.88E-07	0.62	6.31E-07	–4.24	1.6E-07	–0.4	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	424.48	429.48	5	–2.12E-06	0.60	1.79E-05	–4.24	4.0E-06	0.2	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	429.47	434.47	5	–	0.65	–	–4.17	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	434.45	439.45	5	–4.28E-08	0.73	3.17E-07	–4.10	7.2E-08	0.3	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	439.42	444.42	5	–	0.77	–	–4.05	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	444.40	449.40	5	–	0.80	–	–4.02	–	–	80	1.7E-09	4.4E-09	1.7E-05	
KFR27	449.38	454.38	5	–	0.85	–	–3.94	–	–	80	1.7E-09	4.4E-09	1.7E-05	
KFR27	454.38	459.38	5	–	0.90	–	–3.86	–	–	1,000	1.7E-09	5.5E-08	1.7E-05	
KFR27	459.36	464.36	5	–	0.94	–	–3.78	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	464.33	469.33	5	–	1.00	–	–3.73	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	469.31	474.31	5	–	1.04	–	–3.67	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	474.32	479.32	5	–6.50E-08	1.08	9.72E-07	–3.63	2.1E-07	1.1	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	479.30	484.30	5	–	1.14	–	–3.54	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	484.28	489.28	5	–	1.13	–	–3.48	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFR27	489.26	494.26	5	–	1.12	–	–3.51	–	–	30	1.7E-09	1.7E-09	1.7E-05	

* Flow rate Q_0 and/or Q_1 below 30 mL/h



Forsmark, borehole KFR27
Flow rates of 5 m sections
Without pumping
2008-11-22 - 2008-11-23
With pumping
2008-11-23 - 2008-11-24
Theoretical minimum measurable flow rate
Practical minimum measurable flow rate
Theoretical maximum measurable flow rate
Length (m)
100
150
200
250
300
350
400
450
500
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


Forsmark, borehole KFR27
Transmissivity and head of 5 m sections
Formation head
Head in the borehole without pumping
2008-11-22 - 2008-11-23
Head in the borehole with pumping
2008-11-23 - 2008-11-24
Transmissivity (T)
Theoretical minimum measurable T
Practical minimum measurable T
Theoretical maximum measurable T
Length (m)
100
150
200
250
300
350
400
450
500
-11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2
Head (masl, RHB 70)
10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4}
Transmissivity (m^2/s)

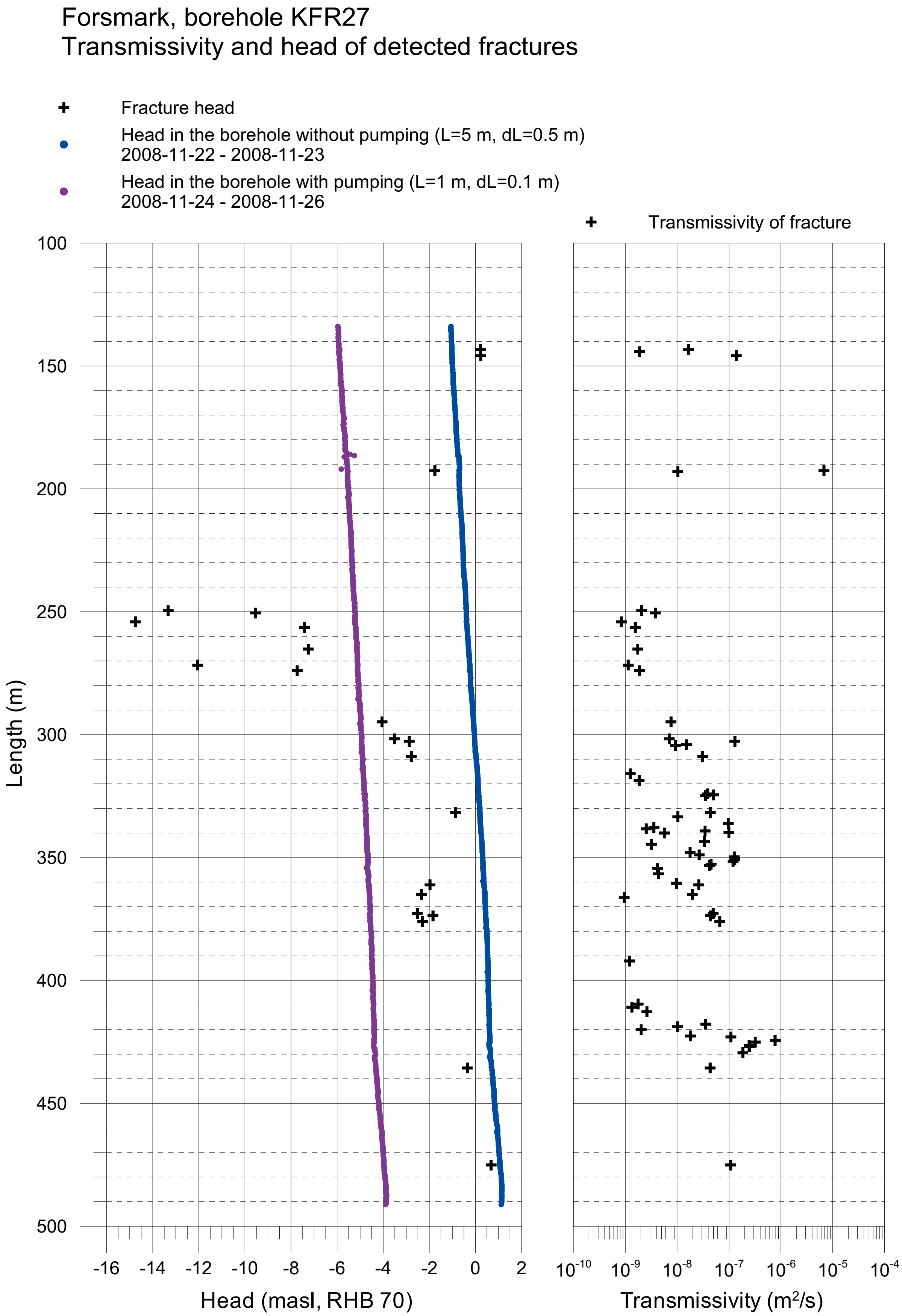
Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m³/s)	h_{0FW} (masl)	Q_1 (m³/s)	h_{1FW} (masl)	T_D (m²/s)	h_i (masl)	Comments
KFR27	100.4	1	0.1	–	–	2.75E-08	–5.93	–	–	*
KFR27	101.7	1	0.1	–	–	1.57E-07	–5.92	–	–	
KFR27	105.6	1	0.1	–	–	1.96E-07	–5.89	–	–	
KFR27	109.0	1	0.1	–	–	4.81E-08	–5.89	–	–	
KFR27	110.2	1	0.1	–	–	5.00E-09	–5.86	–	–	*
KFR27	114.1	1	0.1	–	–	4.03E-08	–5.85	–	–	
KFR27	115.6	1	0.1	–	–	3.36E-08	–5.82	–	–	
KFR27	117.2	1	0.1	–	–	2.64E-08	–5.84	–	–	
KFR27	121.1	1	0.1	–	–	1.26E-07	–5.77	–	–	
KFR27	143.3	1	0.1	2.06E-08	–1.02	9.78E-08	–5.66	1.7E-08	0.2	
KFR27	144.2	1	0.1	–	–1.02	8.89E-09	–5.67	1.9E-09	–	
KFR27	145.8	1	0.1	1.73E-07	–1.01	8.22E-07	–5.65	1.4E-07	0.2	
KFR27	192.6	1	0.1	–7.22E-06	–0.71	2.43E-05	–5.31	6.8E-06	–1.8	
KFR27	193.0	1	0.1	–	–0.70	4.78E-08	–5.31	1.0E-08	–	
KFR27	231.0	1	0.1	–	–0.53	–4.50E-08	–5.11	–	–	**
KFR27	234.1	1	0.1	–	–0.50	–3.11E-08	–5.06	–	–	**
KFR27	249.5	1	0.1	–2.72E-08	–0.39	–1.75E-08	–5.01	2.1E-09	–13.3	*
KFR27	250.5	1	0.1	–3.53E-08	–0.39	–1.75E-08	–5.00	3.8E-09	–9.5	*
KFR27	254.1	1	0.1	–1.22E-08	–0.39	–8.33E-09	–4.96	8.4E-10	–14.8	*
KFR27	256.4	1	0.1	–1.11E-08	–0.36	–3.89E-09	–4.95	1.6E-09	–7.4	*
KFR27	265.2	1	0.1	–1.22E-08	–0.30	–4.17E-09	–4.88	1.7E-09	–7.3	*
KFR27	271.7	1	0.1	–1.36E-08	–0.24	–8.33E-09	–4.82	1.1E-09	–12.1	*
KFR27	274.0	1	0.1	–1.42E-08	–0.26	–5.56E-09	–4.80	1.9E-09	–7.7	*
KFR27	294.8	1	0.1	–3.06E-08	–0.08	4.72E-09	–4.66	7.6E-09	–4.1	*
KFR27	301.7	1	0.1	–2.47E-08	–0.04	8.06E-09	–4.64	7.1E-09	–3.5	*
KFR27	302.7	1	0.1	–3.72E-07	–0.03	2.30E-07	–4.63	1.3E-07	–2.9	
KFR27	304.1	1	0.1	–	–0.03	7.00E-08	–4.63	1.5E-08	–	
KFR27	304.4	1	0.1	–	–0.02	4.36E-08	–4.63	9.4E-09	–	*
KFR27	308.9	1	0.1	–8.83E-08	0.03	5.69E-08	–4.59	3.1E-08	–2.8	
KFR27	315.9	1	0.1	–	0.09	5.83E-09	–4.52	1.3E-09	–	*
KFR27	318.7	1	0.1	–	0.11	8.61E-09	–4.50	1.9E-09	–	*
KFR27	324.1	1	0.1	–	0.14	1.81E-07	–4.48	3.9E-08	–	
KFR27	324.5	1	0.1	–	0.14	2.35E-07	–4.49	5.0E-08	–	*
KFR27	324.8	1	0.1	–	0.14	1.65E-07	–4.47	3.5E-08	–	
KFR27	331.7	1	0.1	–4.64E-08	0.19	1.58E-07	–4.42	4.4E-08	–0.9	
KFR27	333.4	1	0.1	–	0.20	4.78E-08	–4.41	1.0E-08	–	
KFR27	336.1	1	0.1	–	0.21	4.50E-07	–4.39	9.7E-08	–	
KFR27	337.8	1	0.1	–	0.23	1.67E-08	–4.39	3.6E-09	–	*
KFR27	338.3	1	0.1	–	0.23	1.19E-08	–4.42	2.5E-09	–	*

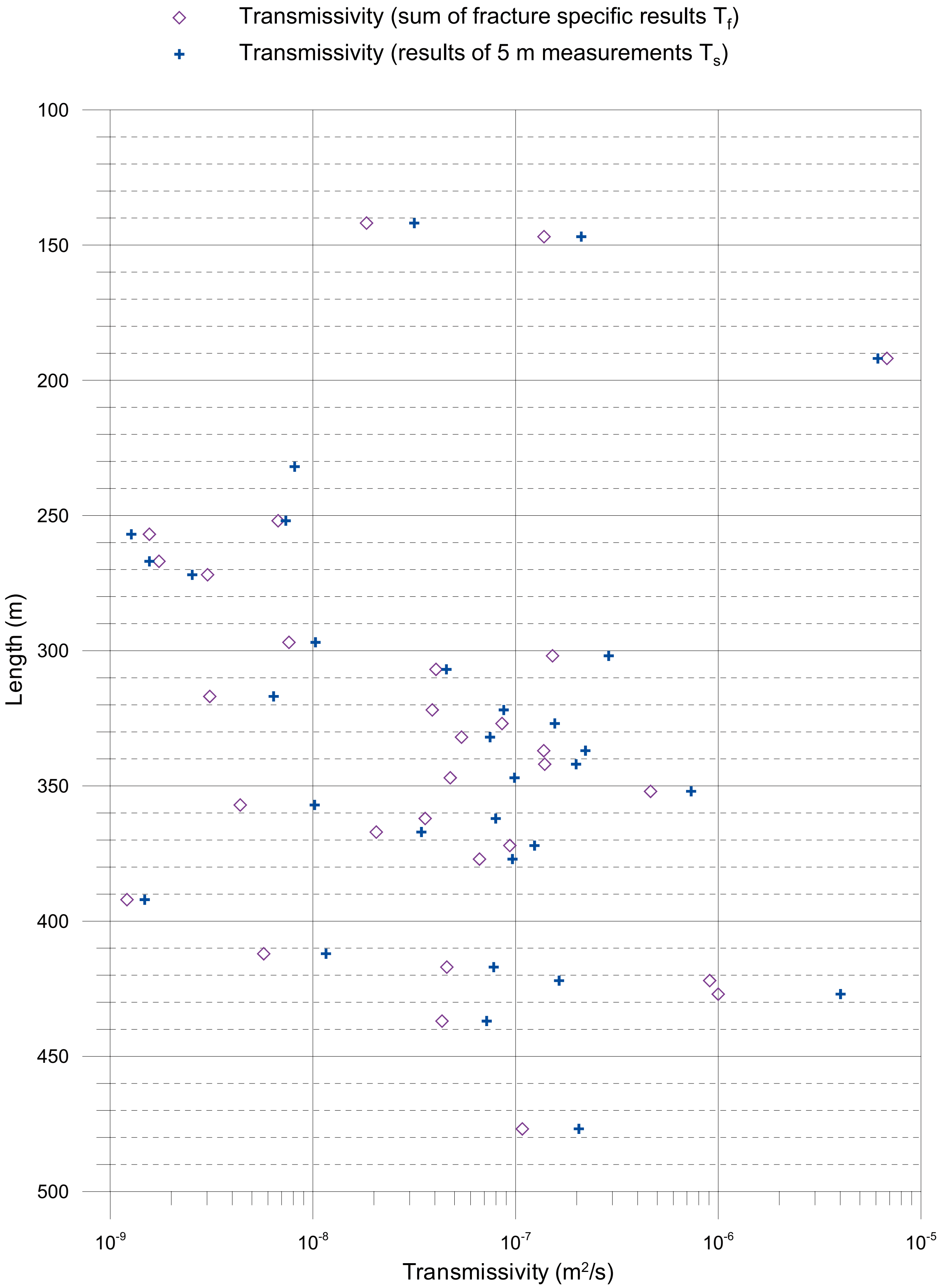
Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1 (m^3/s)	h_{1FW} (masl)	T_D (m^2/s)	h_i (masl)	Comments
KFR27	339.2	1	0.1	–	0.23	1.61E-07	–4.38	3.5E-08	–	
KFR27	339.8	1	0.1	–	0.24	4.67E-07	–4.39	1.0E-07	–	
KFR27	340.0	1	0.1	–	0.24	2.67E-08	–4.39	5.7E-09	–	
KFR27	343.5	1	0.1	–	0.28	1.58E-07	–4.35	3.4E-08	–	
KFR27	344.6	1	0.1	–	0.28	1.50E-08	–4.35	3.2E-09	–	
KFR27	347.9	1	0.1	–	0.30	8.33E-08	–4.34	1.8E-08	–	
KFR27	348.9	1	0.1	–	0.31	1.25E-07	–4.33	2.7E-08	–	
KFR27	349.7	1	0.1	–	0.31	5.94E-07	–4.31	1.3E-07	–	
KFR27	350.9	1	0.1	–	0.32	6.06E-07	–4.32	1.3E-07	–	*
KFR27	351.6	1	0.1	–	0.32	5.58E-07	–4.30	1.2E-07	–	*
KFR27	352.7	1	0.1	–	0.33	2.11E-07	–4.30	4.5E-08	–	
KFR27	353.2	1	0.1	–	0.33	1.97E-07	–4.30	4.2E-08	–	
KFR27	354.5	1	0.1	–	0.34	1.97E-08	–4.29	4.2E-09	–	
KFR27	356.6	1	0.1	–	0.35	2.06E-08	–4.29	4.4E-09	–	
KFR27	360.5	1	0.1	–	0.37	4.56E-08	–4.27	9.7E-09	–	
KFR27	361.1	1	0.1	–6.17E-08	0.37	6.06E-08	–4.26	2.6E-08	–2.0	
KFR27	365.0	1	0.1	–5.44E-08	0.41	3.69E-08	–4.20	2.0E-08	–2.3	
KFR27	366.3	1	0.1	–	0.41	4.44E-09	–4.19	9.6E-10	–	*
KFR27	372.7	1	0.1	–1.49E-07	0.45	8.19E-08	–4.15	5.0E-08	–2.5	
KFR27	373.7	1	0.1	–1.01E-07	0.44	1.02E-07	–4.14	4.4E-08	–1.8	
KFR27	376.0	1	0.1	–1.85E-07	0.46	1.22E-07	–4.11	6.6E-08	–2.3	
KFR27	392.1	1	0.1	–	0.54	5.56E-09	–4.02	1.2E-09	–	*
KFR27	409.6	1	0.1	–	0.59	7.78E-09	–3.76	1.8E-09	–	*
KFR27	410.9	1	0.1	–	0.58	5.83E-09	–3.72	1.3E-09	–	*
KFR27	412.7	1	0.1	–	0.59	1.14E-08	–3.72	2.6E-09	–	
KFR27	417.8	1	0.1	–	0.60	1.55E-07	–3.71	3.6E-08	–	
KFR27	418.8	1	0.1	–	0.60	4.44E-08	–3.72	1.0E-08	–	
KFR27	420.0	1	0.1	–	0.61	8.89E-09	–3.73	2.0E-09	–	*
KFR27	422.6	1	0.1	–	0.63	7.94E-08	–3.71	1.8E-08	–	*
KFR27	423.0	1	0.1	–	0.63	4.78E-07	–3.69	1.1E-07	–	
KFR27	424.4	1	0.1	–	0.63	3.39E-06	–3.69	7.8E-07	–	
KFR27	425.1	1	0.1	–	0.63	1.41E-06	–3.70	3.2E-07	–	
KFR27	426.5	1	0.1	–	0.60	1.07E-06	–3.72	2.5E-07	–	
KFR27	426.9	1	0.1	–	0.60	1.09E-06	–3.71	2.5E-07	–	
KFR27	429.4	1	0.1	–	0.66	8.31E-07	–3.79	1.9E-07	–	
KFR27	435.6	1	0.1	–4.58E-08	0.70	1.50E-07	–3.77	4.3E-08	–0.4	
KFR27	475.1	1	0.1	–4.28E-08	1.07	4.50E-07	–3.43	1.1E-07	0.7	

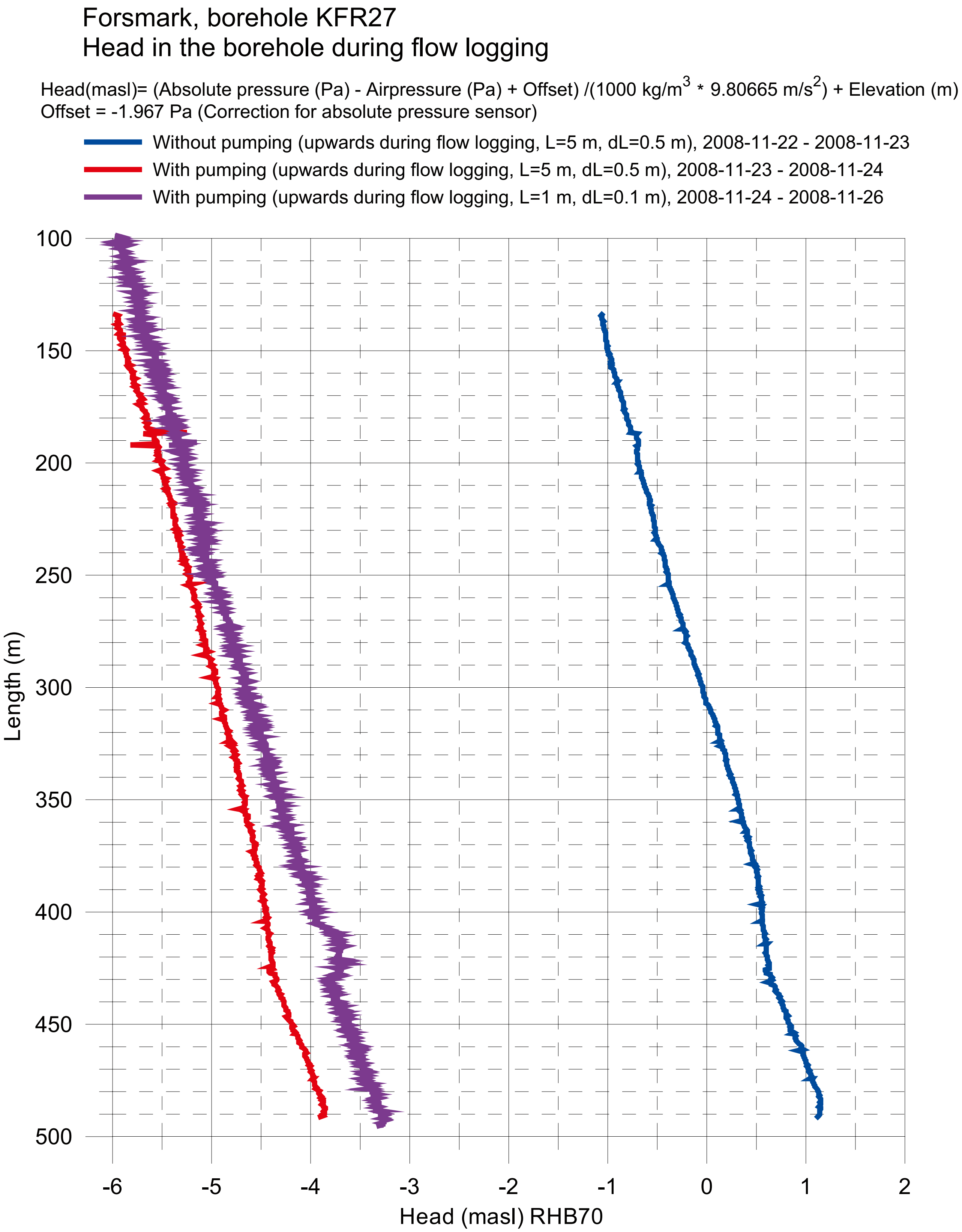
* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

** With pumping flow direction is into the bedrock (L=1 m) and rate is higher than before pumping.


Forsmark, borehole KFR27
Transmissivity and head of detected fractures
Fracture head
Head in the borehole without pumping (L=5 m, dL=0.5 m)
2008-11-22 - 2008-11-23
Head in the borehole with pumping (L=1 m, dL=0.1 m)
2008-11-24 - 2008-11-26
Transmissivity of fracture
Length (m)
100
150
200
250
300
350
400
450
500
-16 -14 -12 -10 -8 -6 -4 -2 0 2
Head (masl, RHB 70)
10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4}
Transmissivity (m^2/s)

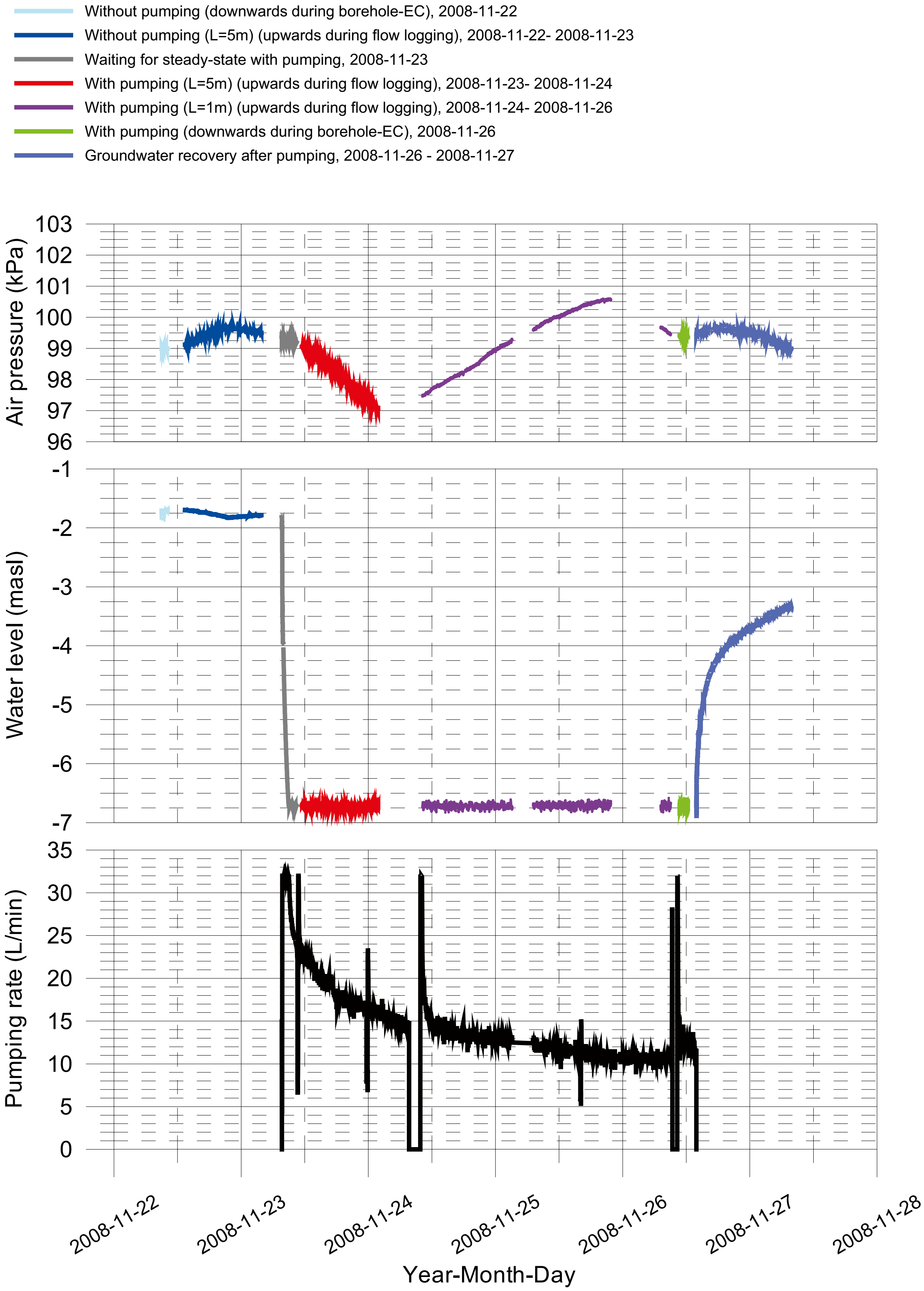
Forsmark, borehole KFR27
Comparison between section transmissivity and fracture transmissivity





Forsmark, borehole KFR27
Head in the borehole during flow logging
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = -1.967 Pa (Correction for absolute pressure sensor)
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2008-11-22 - 2008-11-23
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2008-11-23 - 2008-11-24
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2008-11-24 - 2008-11-26
Length (m)
100
150
200
250
300
350
400
450
500
-6
-5
-4
-3
-2
-1
0
1
2
Head (masl) RHB70

Forsmark, borehole KFR27
Air pressure, water level in the borehole and pumping rate during flow logging



Forsmark, borehole KFR27
Groundwater recovery after pumping

Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = -1.967 Pa (Correction for absolute pressure sensor)