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Site investigation SFR

Difference flow logging in borehole KFR102A

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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 borehole KFR102A at Forsmark, Sweden, in January 2009.

The first flow logging measurements were done with a 5 m test section by moving the measurement tool in 0.5 m steps. This method was used to flow log the entire measurable part of the borehole during natural (un-pumped) as well as pumped conditions. 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 (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 KFR102A i Forsmark, Sverige, i januari 2009.

Flödet till eller från en 5 m lång testsektion (som förflyttades successivt med 0,5 m) mättes i borrhålet under såväl naturliga (icke-pumpade) som pumpade förhållanden. 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 (1 m lång testsektion).

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

Contents

1 Introduction

The core drilled borehole KFR102A at Forsmark, Sweden was measured using the Posiva Flow Log, Difference Flow Method (PFL DIFF) which provides a swift, multifaceted characterization of a borehole. The borehole was measured between January 19–28, 2009.

KFR102A is 600.8 m long and its inclination at the ground level is c. 65° from the horizontal plane. The borehole was drilled using a telescopic drilling technique, where the c. 0 m–70 m interval was percussion drilled, and its inner diameter is 200 mm. A stainless steel support casing has been inserted into this part. The rest of the borehole was core drilled with a diameter of c. 76 mm. A stainless steel guide with an inner diameter of c. 80 mm–195 mm has been placed between c. 67 m and 72 m.

The location of KFR102A at Forsmark is illustrated in Figure 1-1.

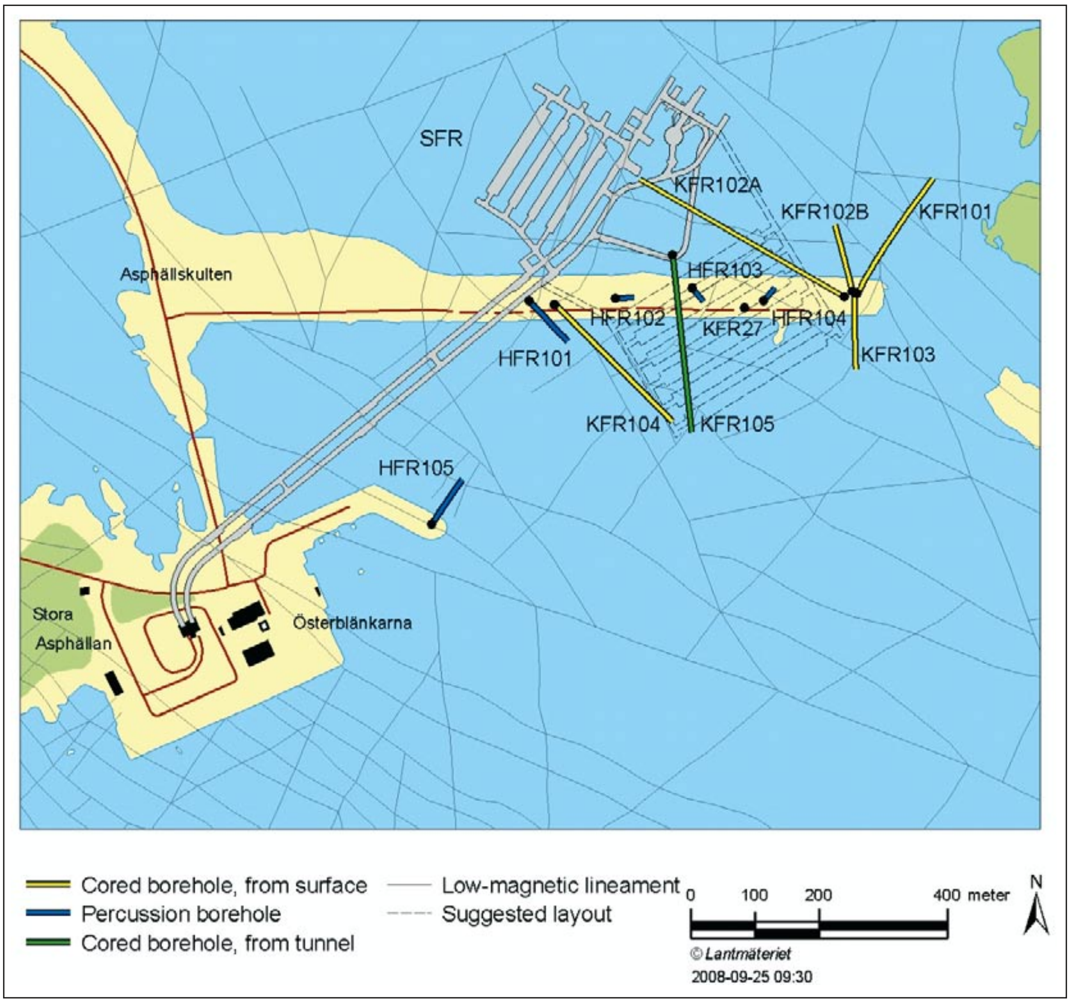

Figure 1-1. Location Map over the SFR facility and the location of the boreholes, including KFR102A.

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 borehole KFR102A. 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-08-030. 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 borehole KFR102A	AP SFR-08-030	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 KFR102A 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 the borehole 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.

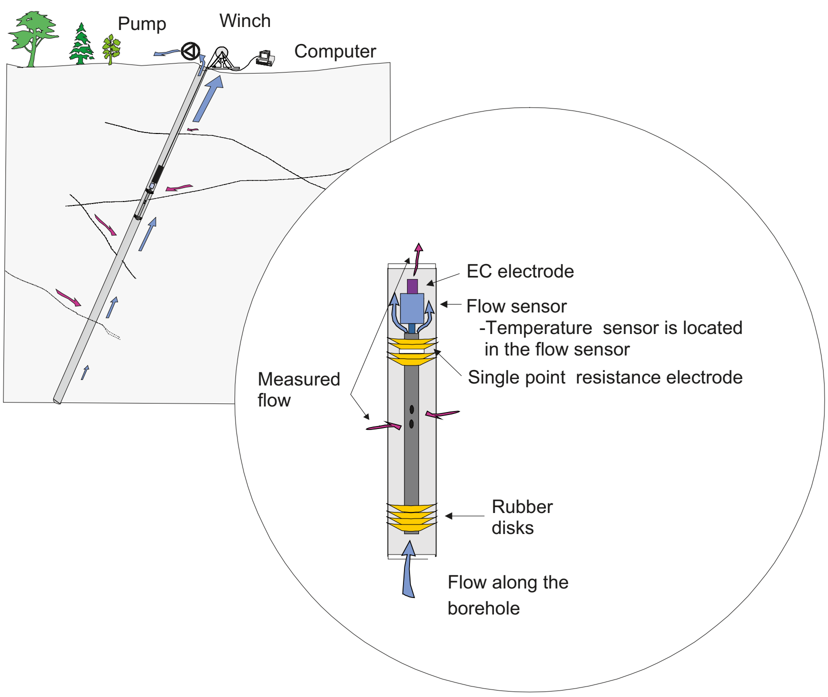

Figure 3-1. *Schematic of the probe used in the PFL DIFF.*

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.

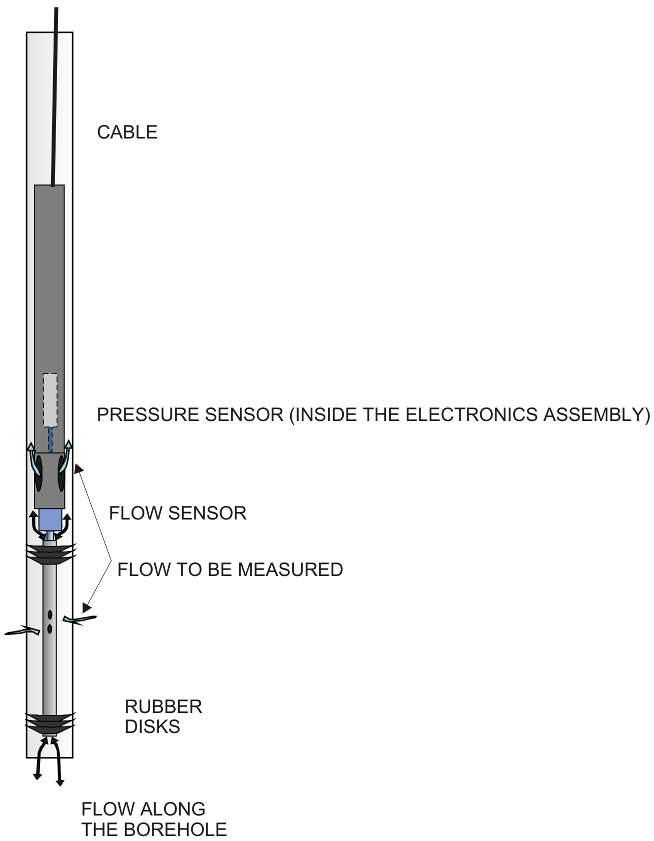

Figure 3-2. *The absolute pressure sensor is located inside the electronics assembly and connected to the borehole water through a tube.*

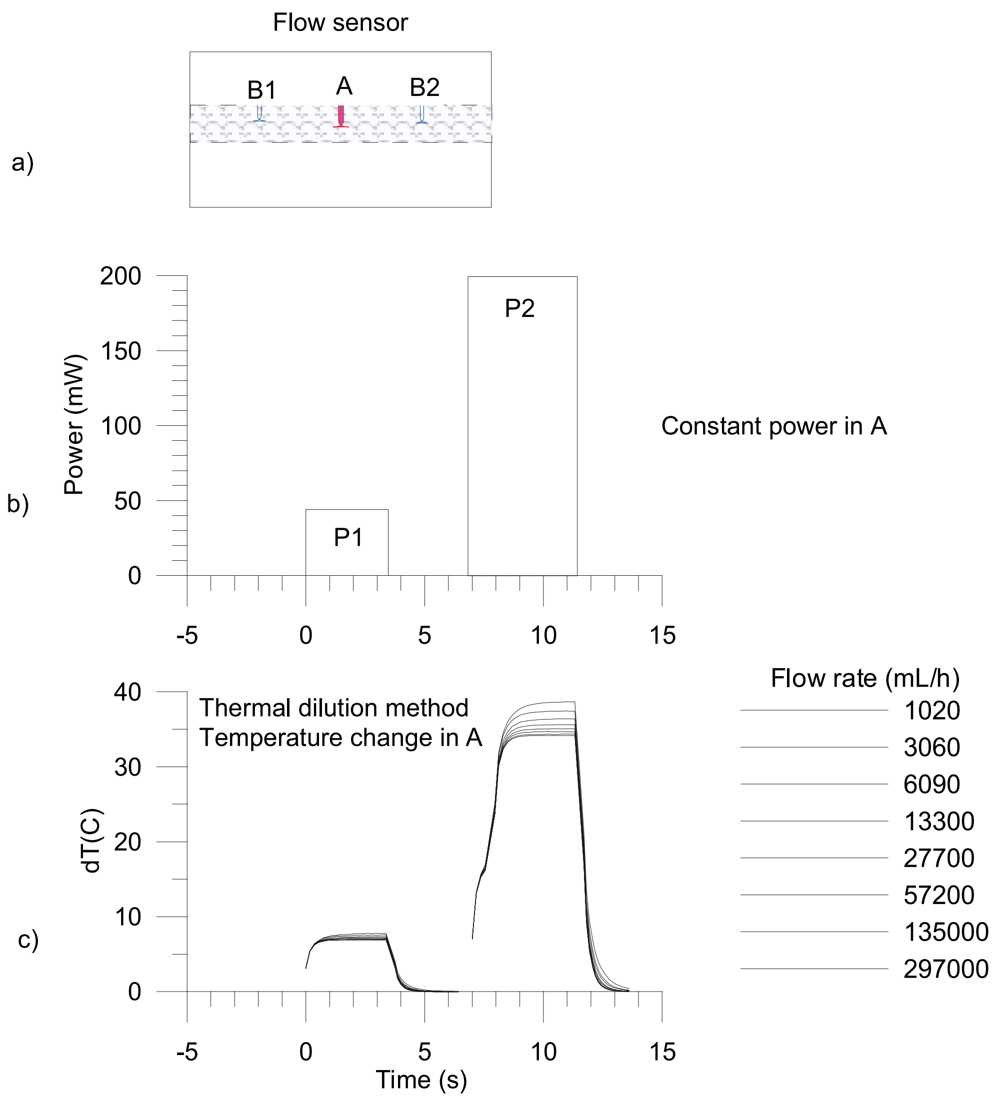

Figure 3-3. *Flow rate measurement.*

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.

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.

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 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:

$a = 2 \cdot \varpi / \ln(R/r_0)$ 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/:

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

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:

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

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 flow probe:	May 2008 (Probe FL8).

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-08-030 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.

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.

Table 5-1. Flow logging and testing in KFR102A. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer.	2009-01-19
8	Dummy logging	Borehole stability/risk evaluation.	2009-01-19
9	Calibration	SKB Caliper and SPR. Logging without the lower rubber sealing disks, no pumping.	2009-01-19–2009-01-20
10	EC- and temp-logging of the borehole fluid	Logging without the lower rubber sealing disks, no pumping.	2009-01-20
11	Combined overlapping/sequential flow logging	Section length L_w = 5 m. Step length dL = 0.5 m, no pumping.	2009-01-21–2009-01-22
12	Overlapping flow logging	Section length L_w = 5 m. Step length dL = 0.5 m, pumping.	2009-01-23–2009-01-24
13/14	Overlapping flow logging and fracture-specific EC-measurements in pre-selected fractures	Section length L_w = 1 m. Step length dL = 0.1 m, pumping. Fracture-specific EC in pre-selected fractures.	2009-01-24–2009-01-26
15	EC- and temp-logging of the borehole fluid	Logging without the lower rubber sealing disks, pumping.	2009-01-27
16	Recovery transient	Measurement of water level and absolute pressure in the borehole after the pumping was stopped.	2009-01-27–2009-01-28
18	Demobilisation	Packing the trailer.	2009-01-28

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 borehole with a 5 m section length and in 0.5 m length increments (step length). The measurements were performed during natural (un-pumped) conditions.

The pumping was started on January 22, 2009. After a 19 hours waiting time (the minimum waiting time was set to 5 hours), overlapping flow logging (Item 12) was conducted using the same section and step lengths as before.

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).

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

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).

5.2 Nonconformities

The dummy got stuck in the borehole at c. 595 m, but was successfully freed. After this a decision was made to not measure from the bottom of the borehole.

During pressure measurement, before overlapping flow logging (Item 12) on January 22nd the groundwater level sensor broke down. The sensor was replaced with SKB's pressure logger, which was in use during the remaining measurements. The absolute pressure data was also used to estimate the water level, see Appendix KFR102A.10.2.

When the borehole was pumped during overlapping flow logging (Item 12) pumping rate had lowered between length c. 175 m–200 m. A decision was made to measure that interval again. During re-measurement the pumping rate lowered again. The effect is most clearly visible in the head curves is Appendix KFR102A.10.1. The original head curve is shown along with the re-measurement. The original curve shows a hump which was reduced to a spike in the re-measurement, see Section 6.4.1. The re-measurement did not affect the planned time schedule.

During fracture-specific EC-measurement (Item 14) at length 251.0 m the measurement stopped due to a data communication error. The location was re-measured as can be seen in Appendix KFR102A.11.1.

It was not physically possible to measure approximately 16.3 m of the bottom of the borehole. There were weights (2) and a centralizer in the measurement device, which reduce the measured distance by c. 3.7 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. It is known that there is rock debris/mud at the bottom of the borehole, as was noticed during dummy logging (Item 8) when the dummy got stuck at c. 595 m.

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, Appendix KFR102A.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 and 13/14 to obtain relative length errors of these measurement sequences.
- All SPR curves could then be synchronized, as can be seen in Appendices KFR102A.1.2–KFR102A.1.18.

The results of the caliper and single-point resistance measurements from all measurements in the entire borehole are presented in Appendix KFR102A.1.1. Three SPR-curves are plotted together with the caliper-data. These measurements correspond to Items 9, 11, 12 and 13/14.

Zoomed results of the caliper and SPR data are presented in Appendices KFR102A.1.2–KFR102A.1.18. The detectability of the length marks is listed in Table 6-1. 10 out of 11 length marks were detected by the caliper tool.

Table 6-1. Detected length marks.

Length marks given by SKB (m)	Length marks detected by caliper	Length marks detected by SPR
100	both	yes
146	both	yes
200	both	yes
249	both	yes
300	both	yes
351	both	yes
400	both	yes
448	both	yes
500	both	yes
550	both	yes
580	none	partially

10 out of 11 length marks were adequately detected in the single-point resistance measurements. The length mark at 580 m was only partially detected. 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 KFR102A.1.2–KFR102A.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. A length correction was also performed at the lower end of the steel guide as can be seen in Appendix KFR102A.1.2.

The magnitude of length correction along the borehole is presented in Appendix KFR102A.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.

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 KFR102A.2.1 (linear scale) and KFR102A.2.2 (logarithmic scale), blue curve.

The EC measurement was repeated during pumping (after a pumping period of approximately five days), see Appendices KFR102A.2.1 and KFR102A.2.2, green curve.

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 Appendix KFR102A.2.3 have the same length axis as the EC results in KFR102A.2.1 and KFR102A.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 Appendix KFR102A.1.19.

6.2.2 Electrical conductivity of fracture-specific water

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 KFR102A.11.1–KFR102A.11.3. The blue symbol represents the conductivity value when the tool was moved and the red symbol is used for the set of stationary measurements. At the length of 199.8 m the tool stopped to measure fracture-specific EC (Appendix KFR102A.11.2), although there is no fracture at that length. There is however a high flowing fracture at 200.9 m, that caused a rounded flow anomaly, which caused this measurement. The anomaly can be seen in Appendices KFR102A.3.7 and KFR102A.3.8.

Lengths to the upper and lower ends of the section, fracture locations and the final EC values for borehole are listed in Table 6-2.

For comparison, the fracture-specific EC and temperature results are also plotted with the EC and temperature results of borehole water, see Appendices KFR102A.2.1–KFR102A.2.3.

Table 6-2. Fracture-specific EC.

Upper end of section (m)	Lower end of section (m)	Measured fractures (m)	EC (S/m) at 25°C
103.94	104.94	104.7	1.06
187.70	188.70	188.4	1.12
200.60	201.60	200.9	1.19
201.40	202.40	201.6, 202.1	1.25
205.35	206.35	206	1.18
251.02	252.02	251.7	1.26
426.54	427.54	427.3	1.15

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 Appendix KFR102A.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/:

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

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 2.6 kPa is added to absolute pressure results.

The calculated head distributions are presented in Appendix KFR102A.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 KFR102A.3.1–KFR102A.3.27. 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.

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 KFR102A.5 and KFR102A.7 are given in Appendix KFR102A.4.

During the measurement of Item 12 there were some pumping problems when the PFL DIFF probe was between c. 175 m–200 m. A re-measurement was performed but there were still some minor, similar pumping problems. On the first measurement, the pumping rate was reduced when the device was above c. 200.5 m, i.e. just above the high flowing 206.0 m fracture. On the re-measurement a spike occurred when the device was at c. 190 m–192.5 m. It is possible that the flow along the borehole was so high that the device interfered it somewhat when the device was located on and above the 206.0 m fracture. The pump probably took air and pumping rate decreased. This caused an increase of groundwater level in the borehole. Once the air bubbles were released the pump started to work properly again. The results from the re-measurement were used in the interpretation. The re-measured part is visible in Appendix KFR102A.10.1. In other appendices the re-measurement has not been singled out. There were no pumping problems during the measurements with a one meter section length.

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 KFR102A.5.1–KFR102A.5.4. Only the results with 5 m length increments are used. All borehole sections are shown in Appendices KFR102A.3.1–KFR102A.3.27. Secup and Seclow in Appendices KFR102A.5.1–KFR102A.5.4 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 KFR102A.5.1–KFR102A.5.4 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} in Appendices KFR102A.5.1–KFR102A.5.4 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 KFR102A.5.1–KFR102A.5.4 (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 at rest, 34 sections were detected as flow yielding, 17 of which had a flow direction from the borehole into the bedrock (negative flow). During pumping, all 42 detected flow yielding sections were directed 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 Appendix KFR102A.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 plot (Appendix KFR102A.6.1) and in the tables (Appendix KFR102A.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 Appendix KFR102A.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 Appendix KFR102A.6.2 and in Appendix KFR102A.5. All the measurement limit values of transmissivity are based on the actual pressure difference in the borehole (h_{0FW} and h_{1FW} in Appendix KFR102A.5).

The sum of all the detected flows without pumping (Q_0) was $-1.99 \cdot 10^{-6}$ m^3/s (–7.2 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. In this case there is apparently flow into the borehole that was not detected by the flowmeter. There may be leaks in the casing tube that could not be properly measured because of the wide diameter of the casing tube. This part of the borehole could possibly explain the unbalance of the summed flow rates.

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 Appendix KFR102A.3.7. 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 Appendix KFR102A.7. The flow direction is evaluated as well. The results of the evaluation are plotted in Appendix KFR102A.3, blue filled triangle.

The total amount of detected flowing fractures was 104, but only 24 of them could be defined without pumping. These 24 fractures could be used for head estimations and all 104 were used for transmissivity estimations. Transmissivity and hydraulic head of fractures are presented in Appendices KFR102A.7 and KFR102A.8.

There is porous rock (conductive zone) between length c. 451 m–458 m. The zone was modeled by 7 fractures, which are 1 m apart from each other. The location can be seen in Appendices KFR102A.3.20 and KFR102A.7.3.

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 1 m or their nature is unclear because of noise.

Fracture-specific transmissivities were compared with transmissivities of sections in Appendix KFR102A.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. The decrease of flow as a function of pumping time can be seen in some fractures. 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.

The sum of the detected flows was smaller than the average pumping rate. This suggests that there could be an undetected leak in the casing tube but above the lower end of it. Pumping problems indicated that there might be pressure drop at the flow probe between c. 188 m–206 m. The transmissivity of these high yielding fractures could be underestimated in this case.

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 KFR102A.3.1–KFR102A.3.27 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 varied between 30 mL/h and 300 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. There was no need for any such additional measurements during this campaign.

The practical minimum for measurable flow rate is also presented in Appendix KFR102A.5 (Q-lower limit P) and is obtained from the plots in Appendix KFR102A.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 Appendix KFR102A.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 Appendix KFR102A.5 (T_D-measl$_U$).

All three flow limits are plotted with the measured flow rates, see Appendix KFR102A.6.1.

The three transmissivity limits are also presented graphically, see Appendix KFR102A.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 1 m, 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 Appendix KFR102A.10.2. Borehole was pumped between January 22 and January 27 with a drawdown of approximately 10 m. The pumping rates were recorded, see Appendix KFR102A.10.2.

The groundwater recovery was measured after the pumping period, between January 27 and 28, see Appendix KFR102A.10.3. The recovery was measured with two sensors, SKB's water level sensor (pressure logger for monitoring water level) and the absolute pressure sensor. The absolute pressure sensor was located at the length of 53.5 m. The head values of both of the sensors were nearly equal at the beginning of the recovery but there was a difference of about 0.5 m between them at the end. The reason for this is not known.

6.5.1 Transmissivity of the entire borehole

(by J-E Ludvigson, Geosigma AB)

The pumping test during difference flow logging in KFR102A 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 SKB water level sensor was analysed, see Appendix KFR102A.10.3.

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.

KFR102A

Steady-state analysis

The final flow rate Q_p during the flow period in KFR102A was c. 22.8 L/min and the drawdown of the water level was $s_p = 9.81$ m by the end of the flow period (Appendix KFR102A.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 6-3. In Dupuit's formula, the ratio R/r_0 is assumed to be 500, cf. Chapter 3. In Moye's formula, the length of the test section L (open borehole interval) is 530.68 m and the borehole diameter $2r_0$ is 0.0758 m. The borehole is cased in the interval 0–70.15 m with an inner diameter of 0.2 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 KFR102A which was used to estimate the transmissivity of the entire borehole. The interpretation of flow regimes is somewhat uncertain in this case due to a fluctuating pressure derivative. The pressure recovery seems to be only slightly affected by wellbore storage during only the first few seconds. Instead, a fracture response is indicated in the beginning. After a transition period, approximate pseudo-radial flow (PRF) seems to occur after c. 5,000 s (c. 1.4 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 $T = 2.4 \cdot 10^{-5}$ m^2/s, a skin factor of –7.49 and a wellbore storage coefficient of $C = 7.4 \cdot 10^{-7}$ m^3/Pa. The value on the latter coefficient, calculated from the simulated effective casing radius of the borehole, is regarded as uncertain in this case. The estimated transmissivity of borehole KFR102A 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 6-3. Estimated transmissivity of borehole KFR102A.

Method	Transmissivity (m^2/s)
Dupuit	$3.8 \cdot 10^{-5}$
Moye	$6.1 \cdot 10^{-5}$
Transient	$2.4 \cdot 10^{-5}$

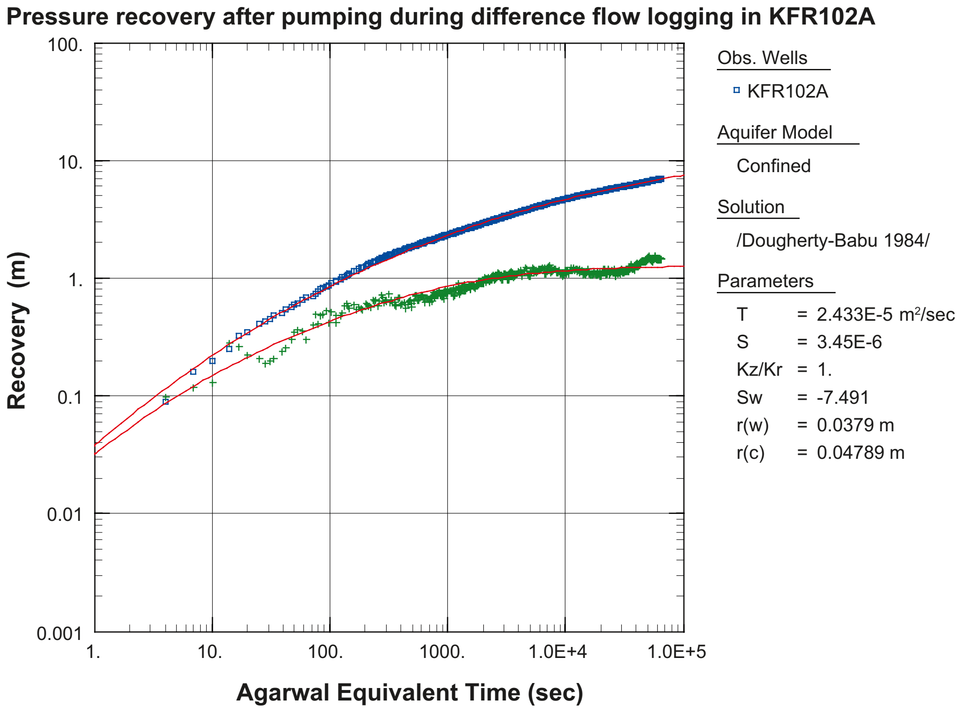

Figure 6-1a. *Log-log plot of the pressure recovery in KFR102A showing the observed pressure recovery of the water level (□) and associated derivative (+) versus Agarwal equivalent time together with simulated best fit curves of the pressure recovery and its derivative (–).*

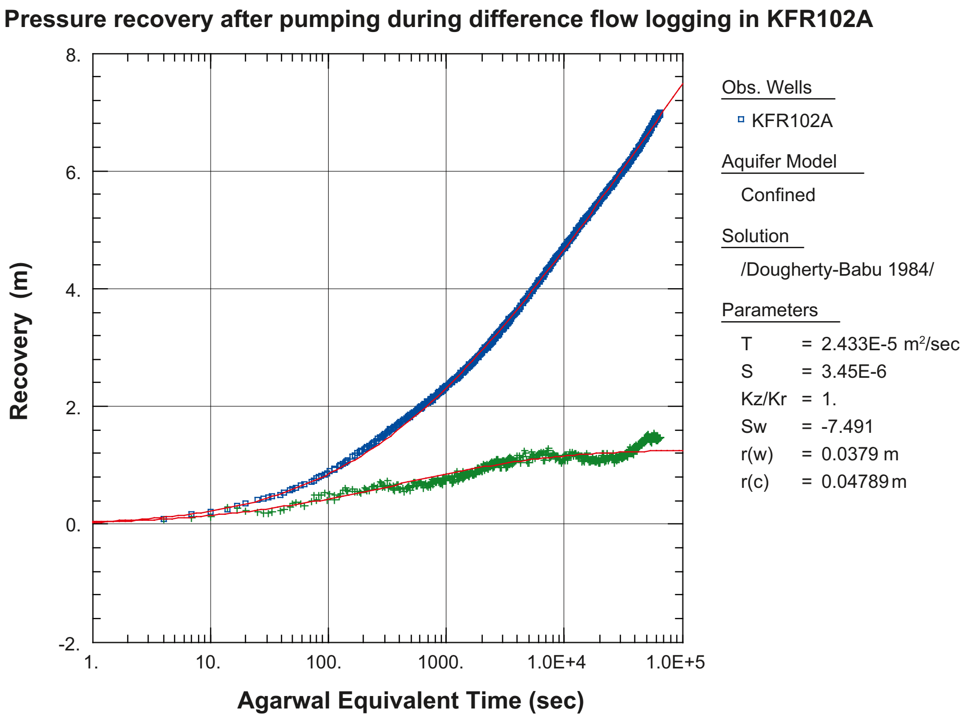

Figure 6-1b. *Lin-log plot of the pressure recovery in KFR102A showing the observed pressure recovery of the water level (□) and associated derivative (+) versus Agarwal equivalent time together with simulated best fit curves of the pressure recovery and its derivative (–).*

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 borehole KFR102A at Forsmark, Sweden. 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.

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.

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

The total amount of detected flowing fractures was 104. Seven of these 104 fractures were used to model the porous zone at c. 451 m–458 m. Transmissivity and hydraulic head were calculated for measured borehole sections. The highest section transmissivity ($3.9 \cdot 10^{-6}$ m^2/s) was detected at length interval 199.11 m–204.11 m. Other high-transmissive sections were found at length intervals 204.15 m–209.15 m and 184.10 m–189.10 m.

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Appendices

Appendices	KFR102A.1.1–KFR102A.1.18	SPR and Caliper results after length correction
Appendix	KFR102A.1.19	Length correction
Appendices	KFR102A.2.1–KFR102A.2.2	Electrical conductivity of borehole water
Appendix	KFR102A.2.3	Temperature of borehole water
Appendices	KFR102A.3.1–KFR102A.3.27	Flow rate, caliper and single point resistance
Appendix	KFR102A.4	Explanations for the tables in Appendices 5 and 7
Appendices	KFR102A.5.1–KFR102A.5.4	Results of sequential flow logging
Appendix	KFR102A.6.1	Plotted flow rates of 5 m sections
Appendix	KFR102A.6.2	Plotted transmissivity and head of 5 m sections
Appendices	KFR102A.7.1–KFR102A.7.3	Inferred flow anomalies from overlapping flow logging
Appendix	KFR102A.8	Plotted transmissivity and head of detected fractures
Appendix	KFR102A.9	Comparison between section transmissivity and fracture transmissivity
Appendix	KFR102A.10.1	Head in the borehole during flow logging
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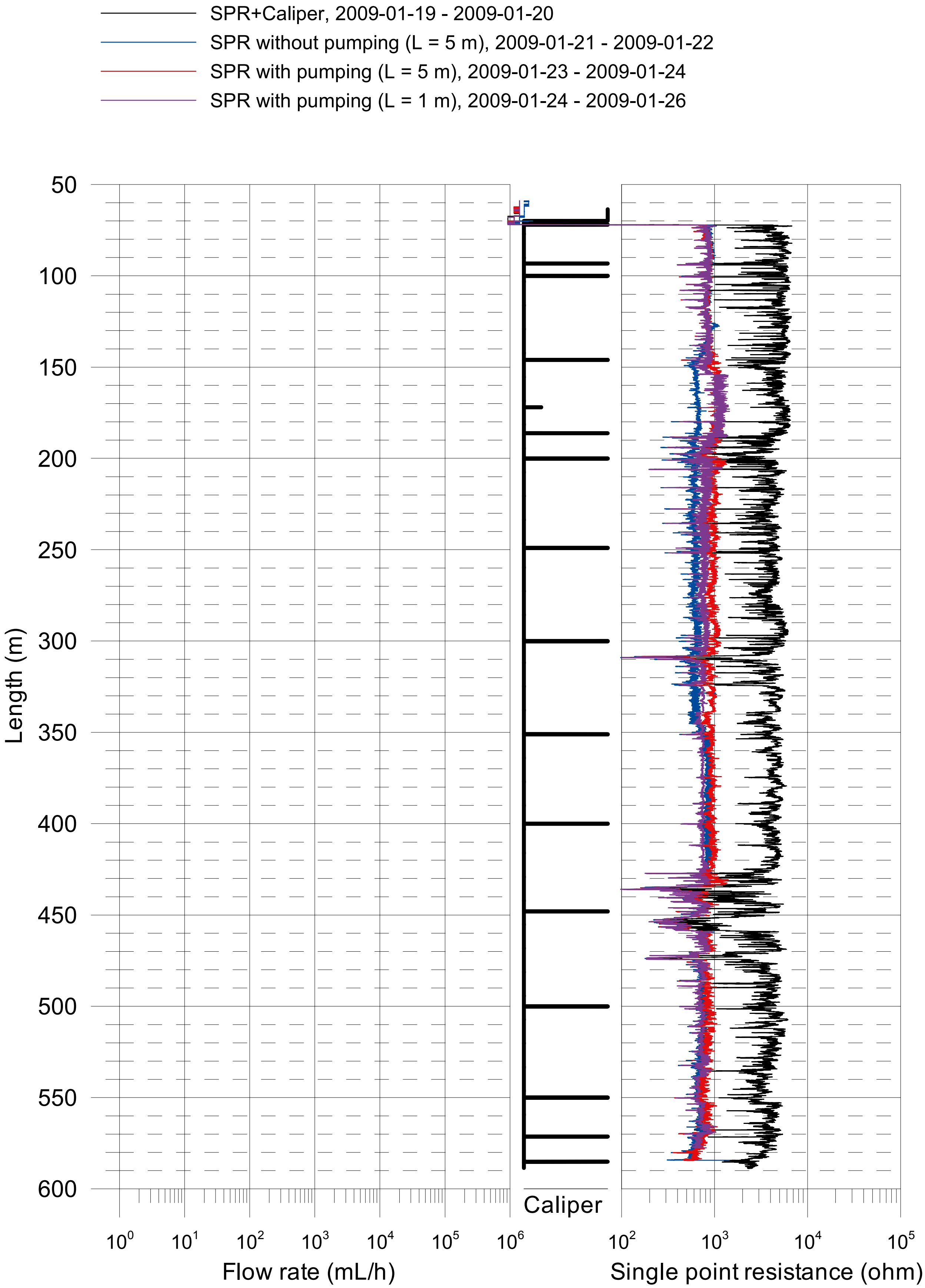
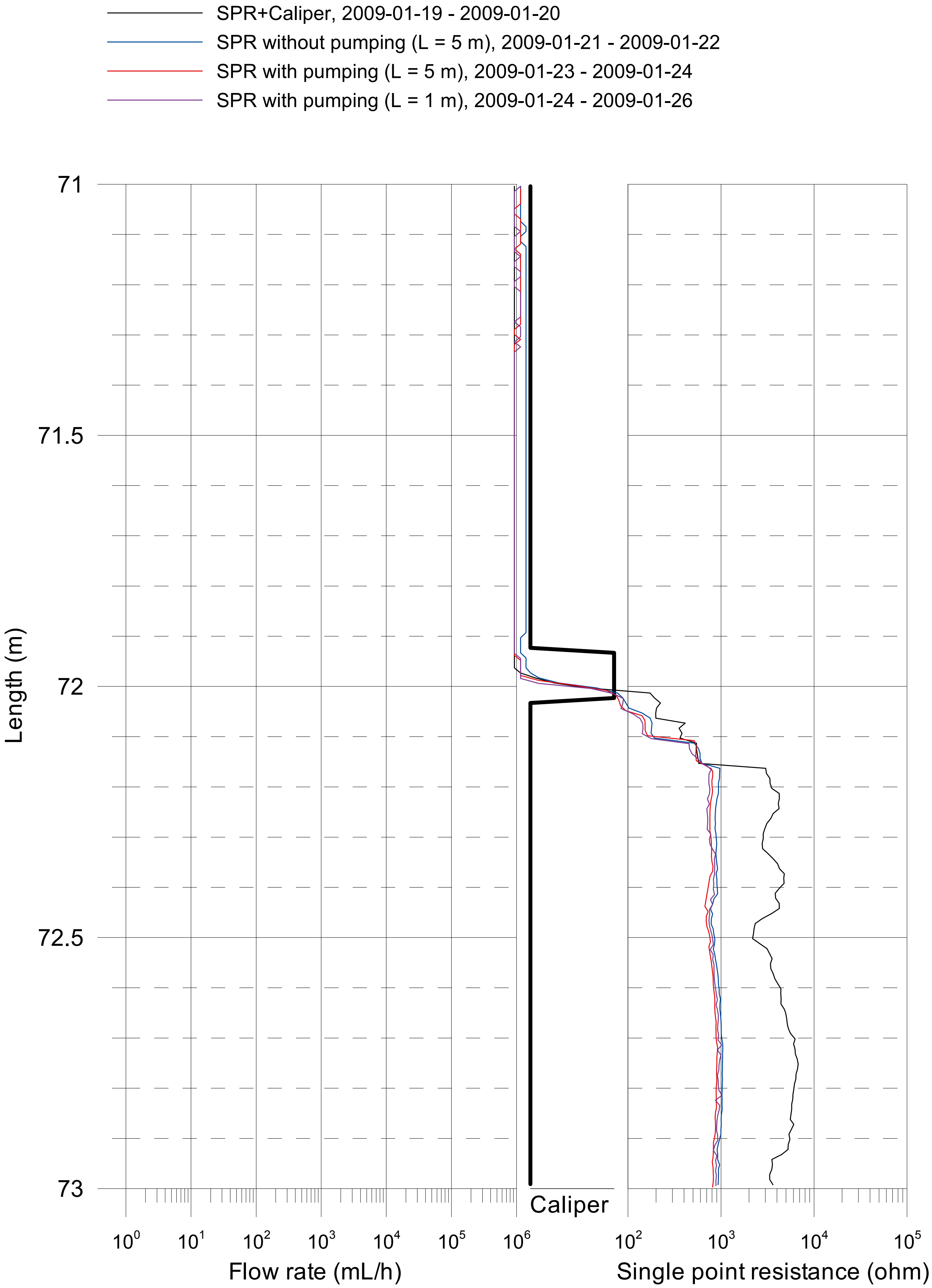
Appendix	KFR102A.10.3	Groundwater recovery after pumping
Appendices	KFR102A.11.1–KFR102A.11.3	Fracture-specific EC results by date

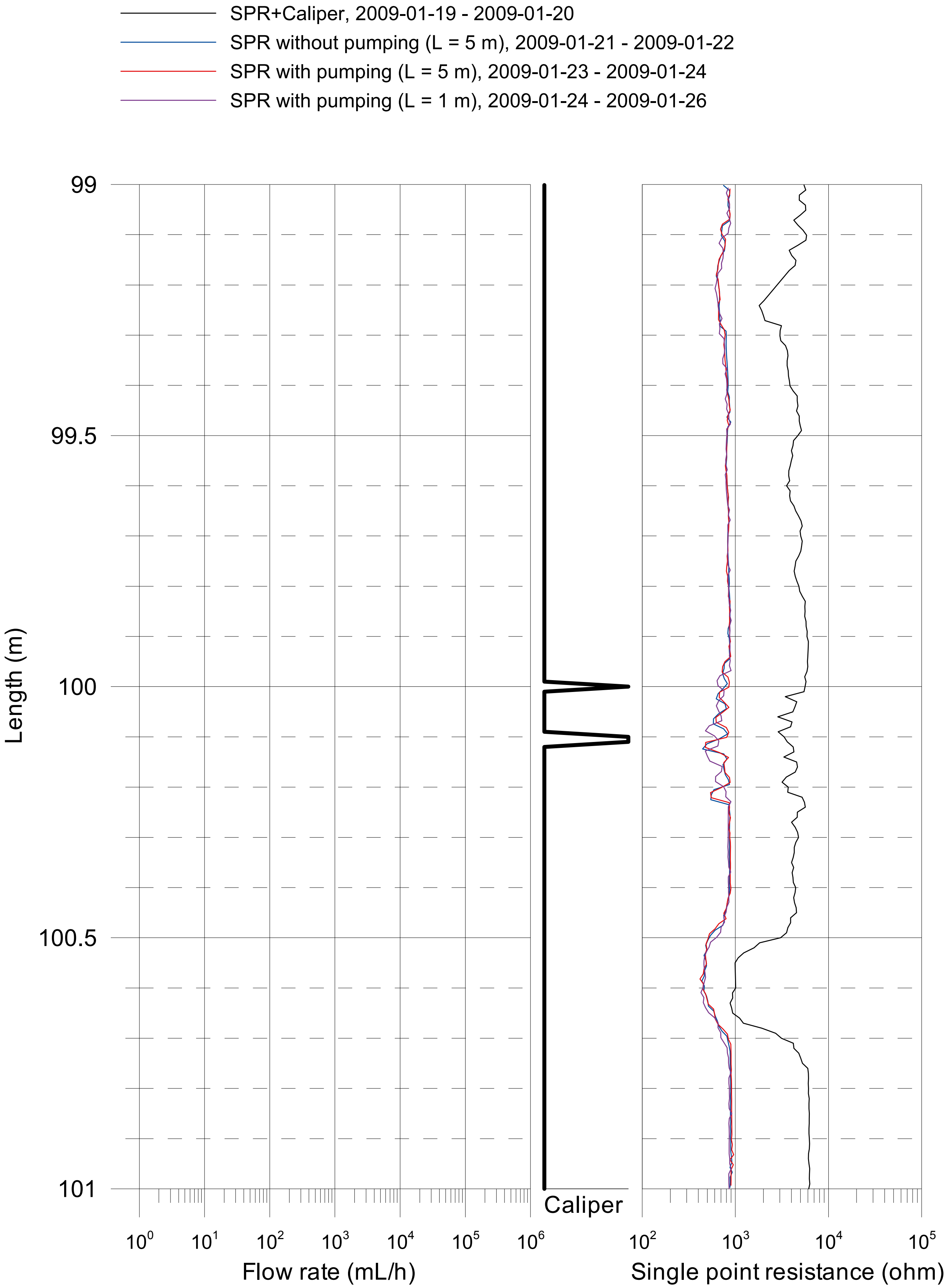
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



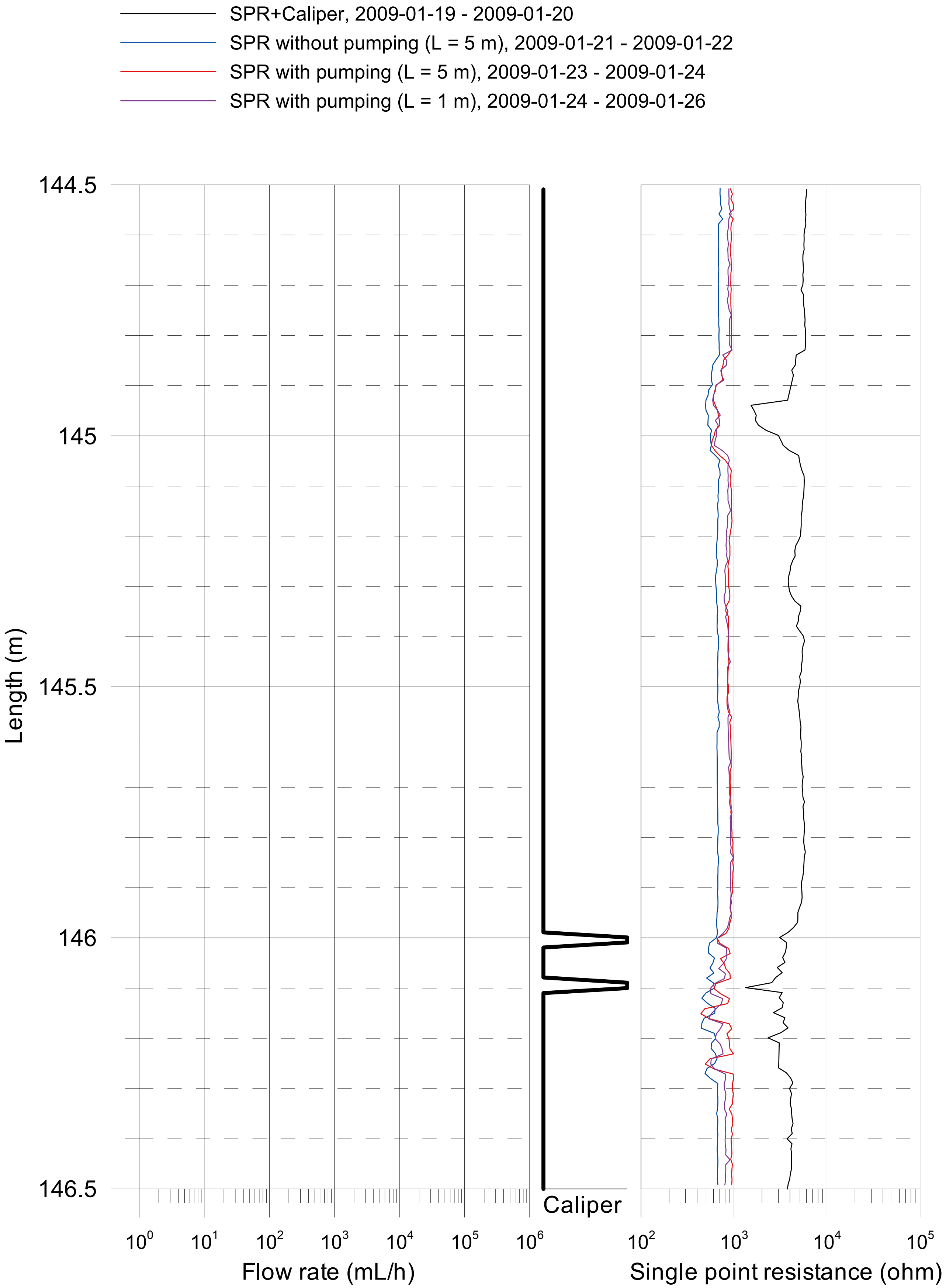
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



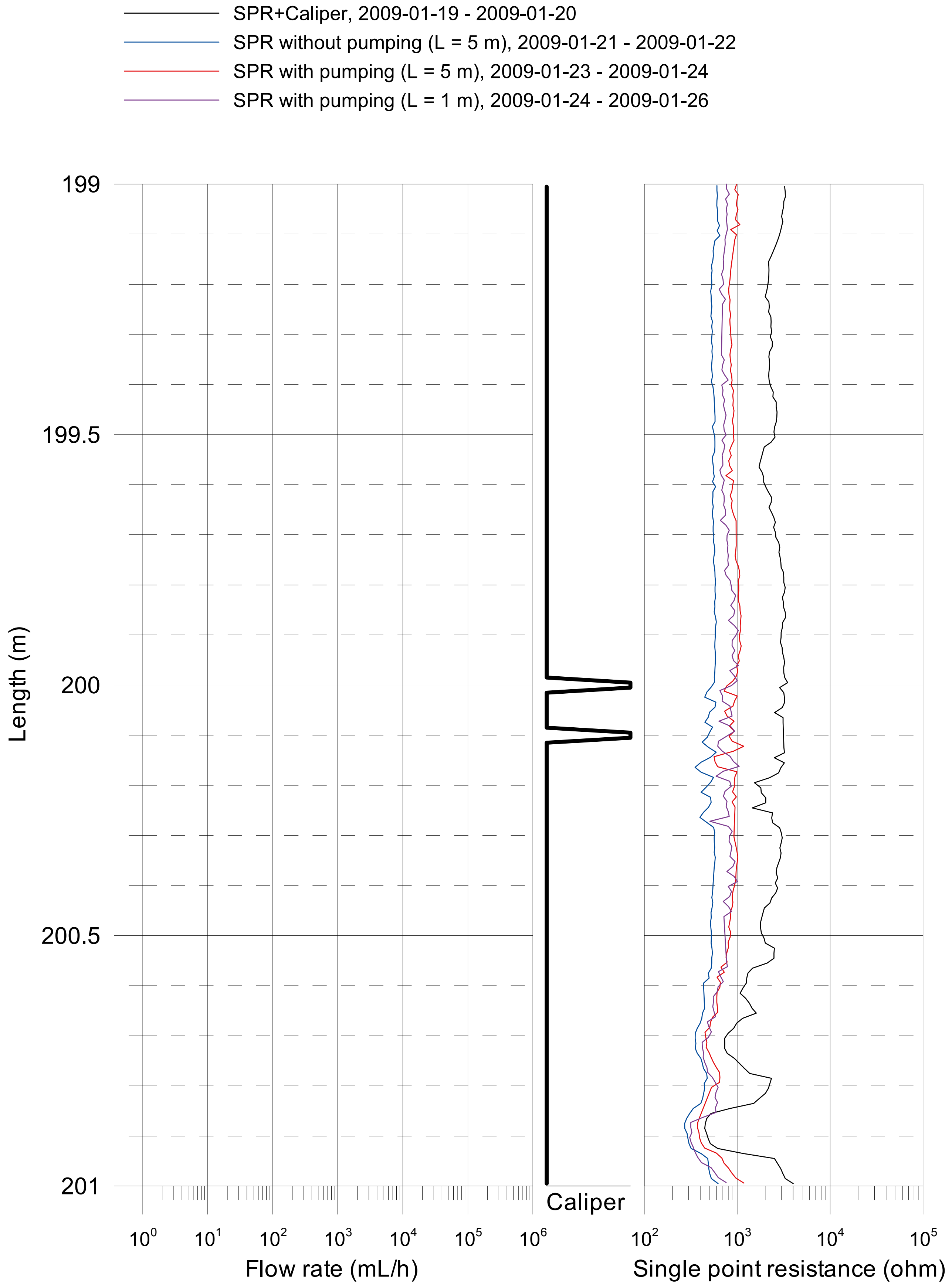
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



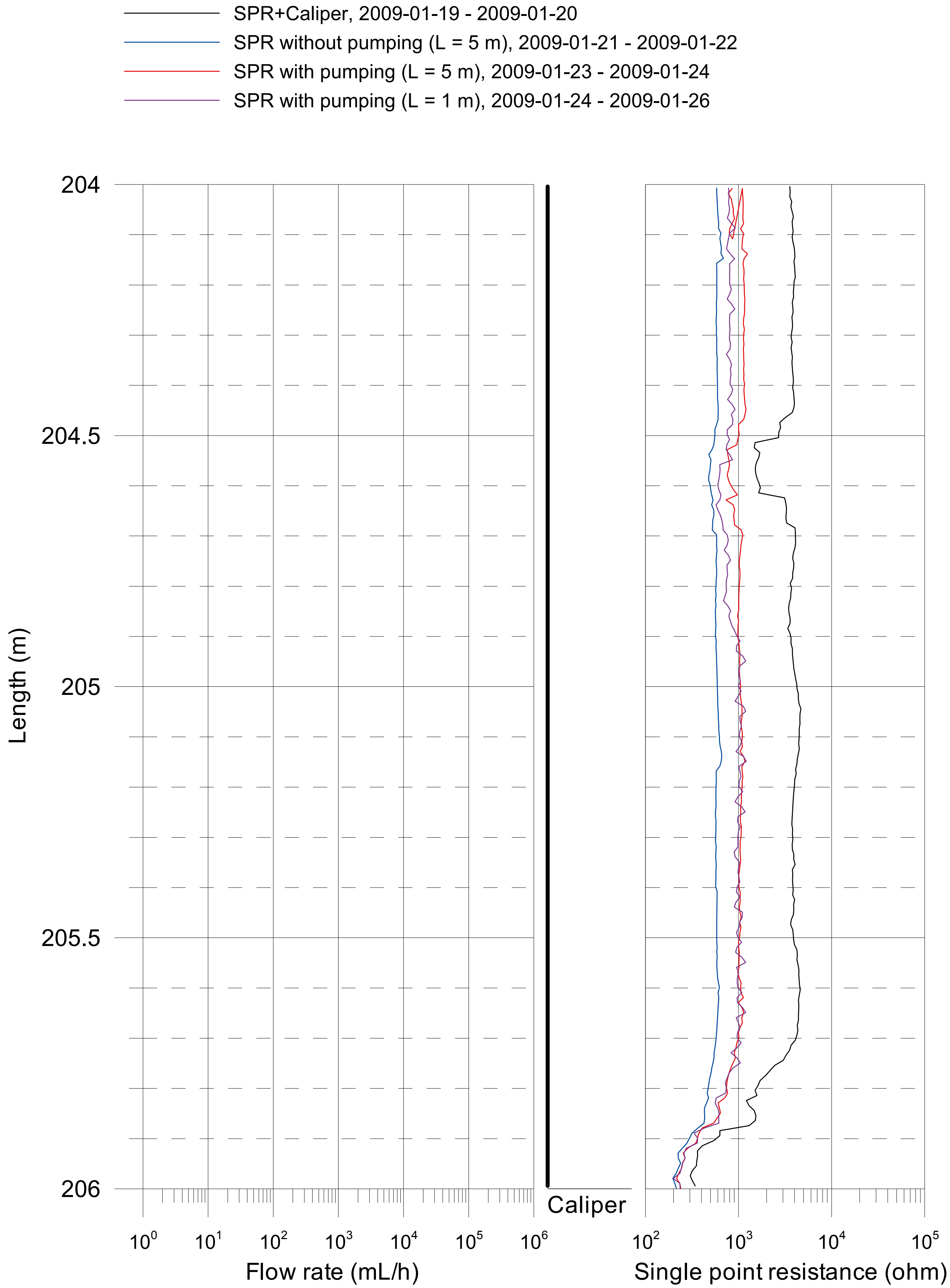
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



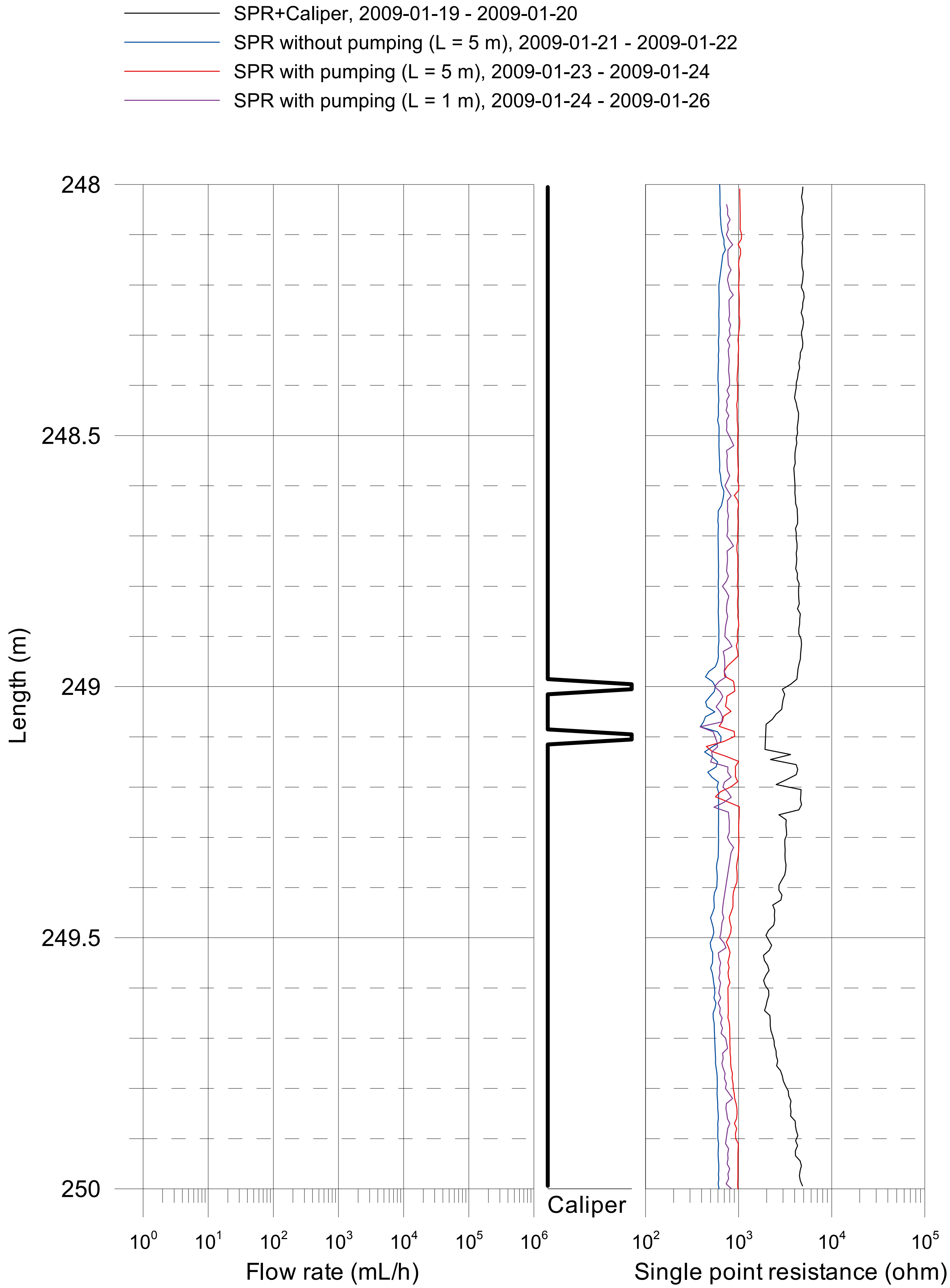
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



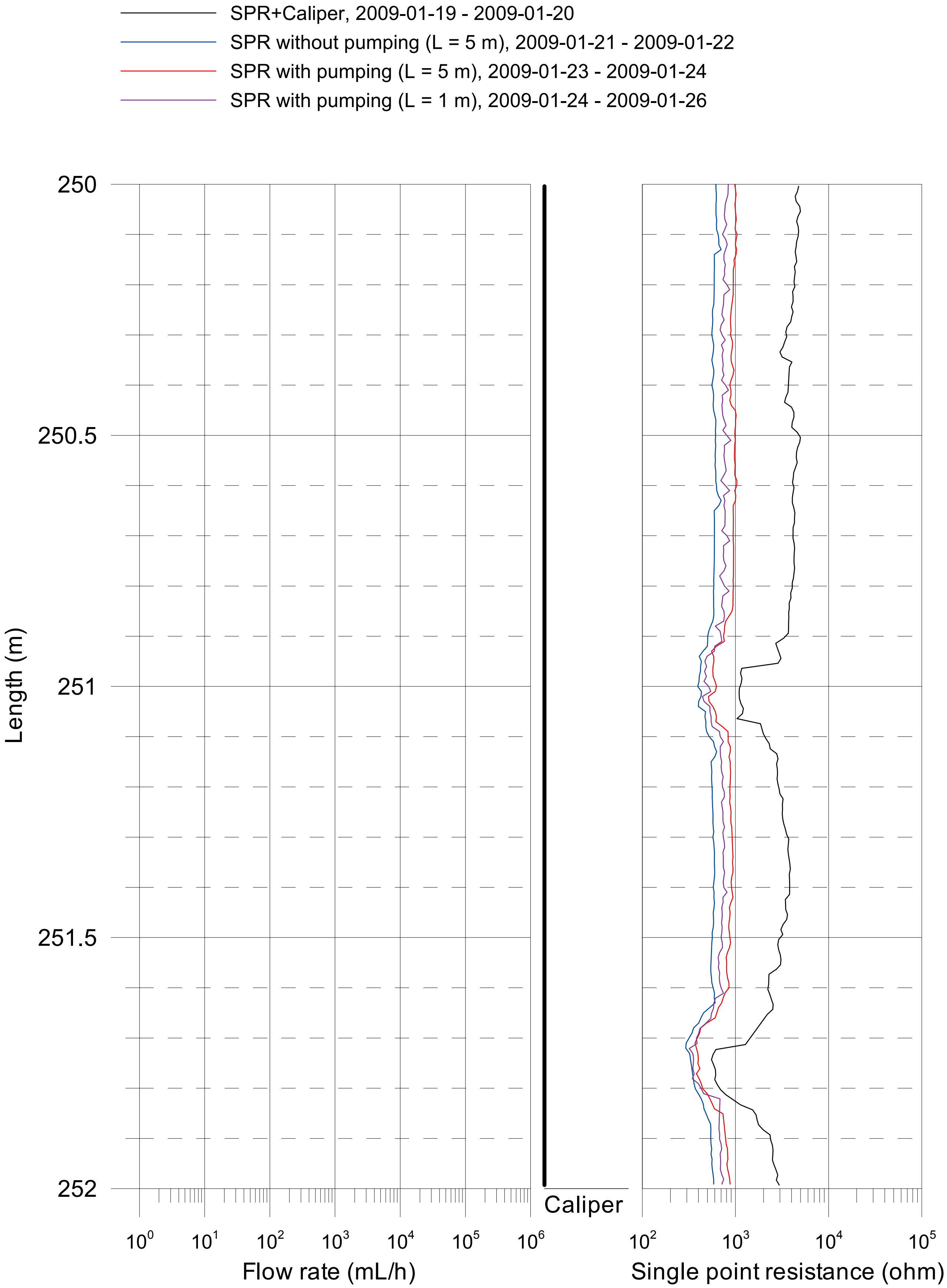
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



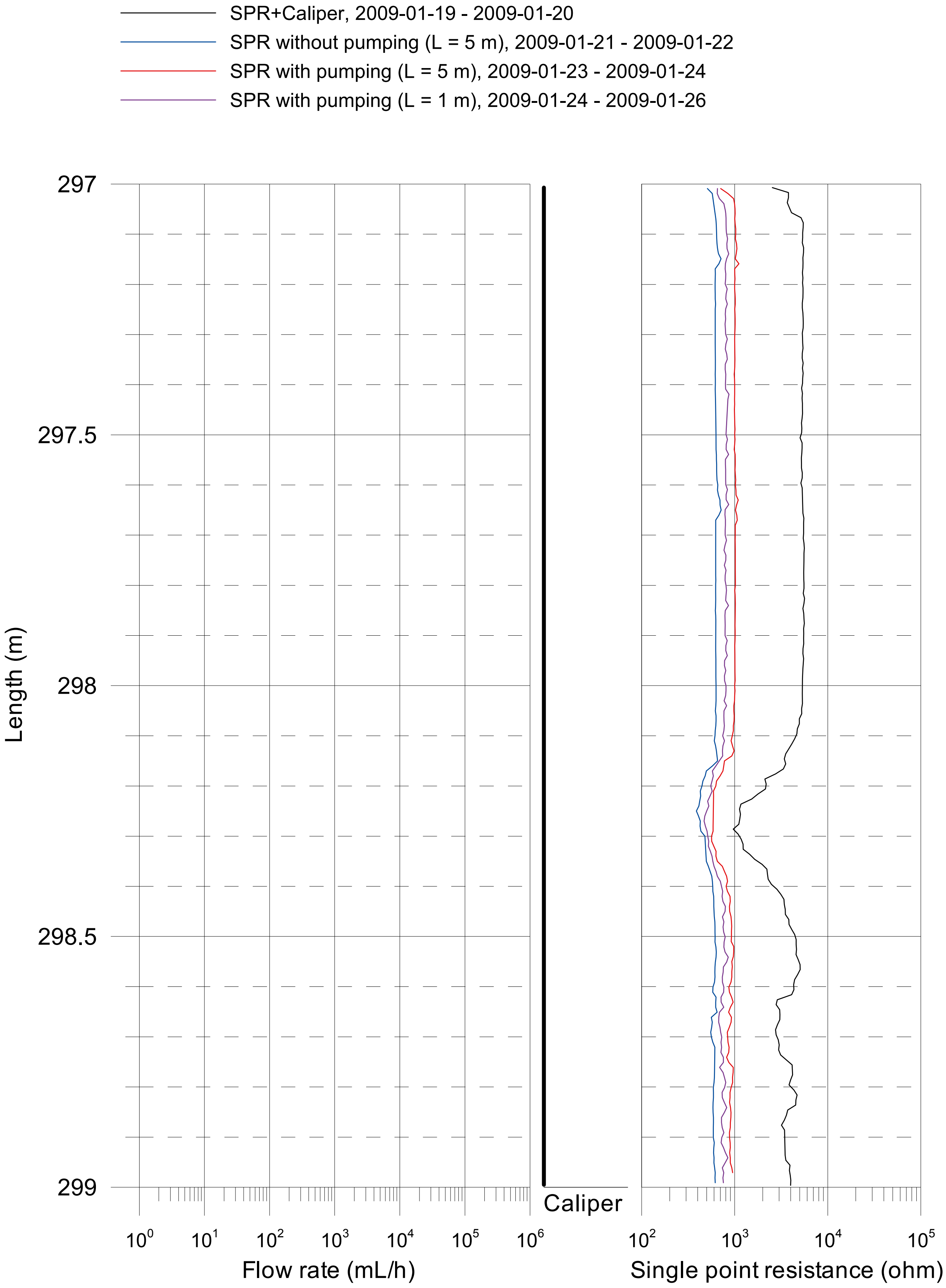
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



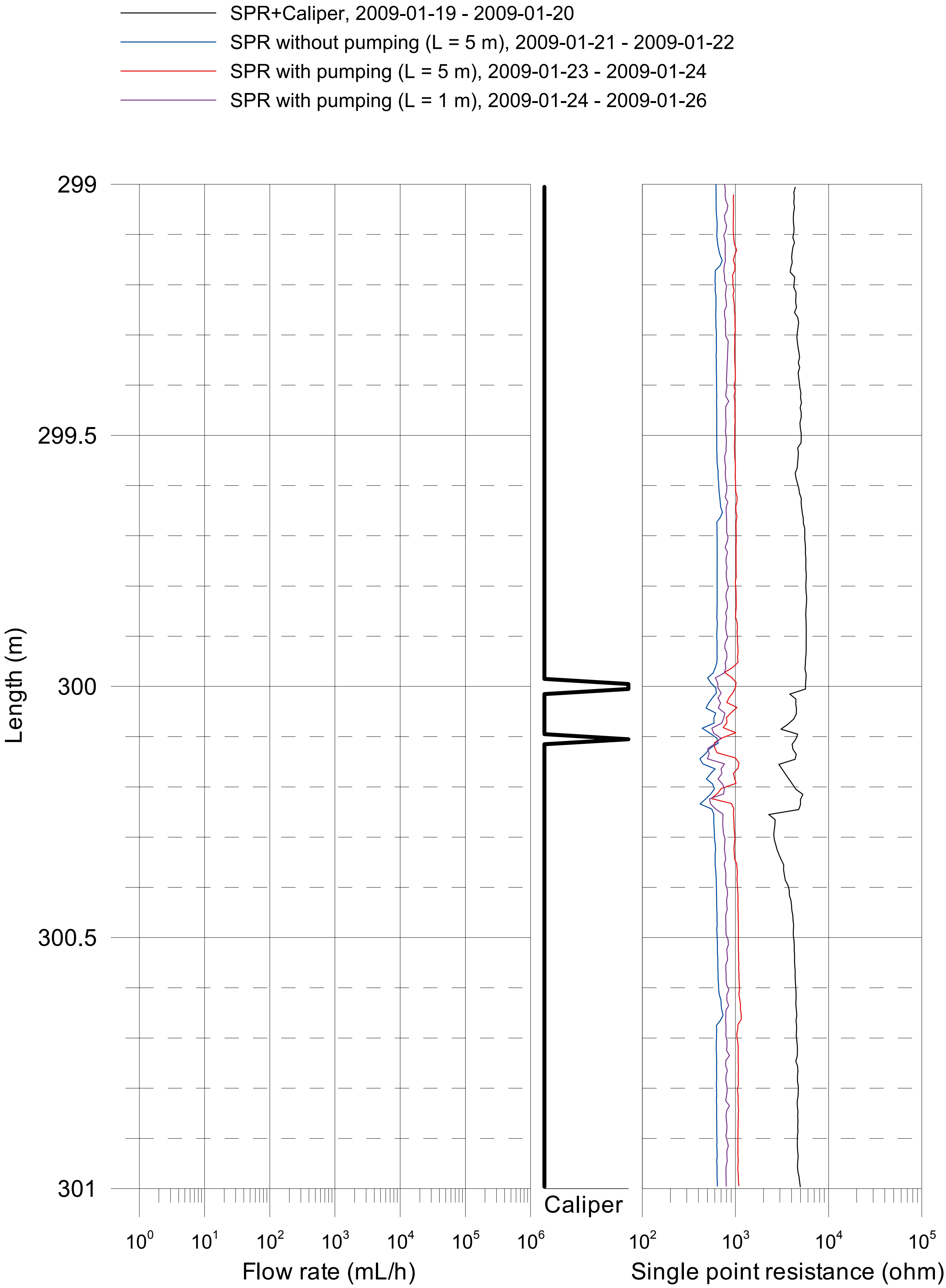
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



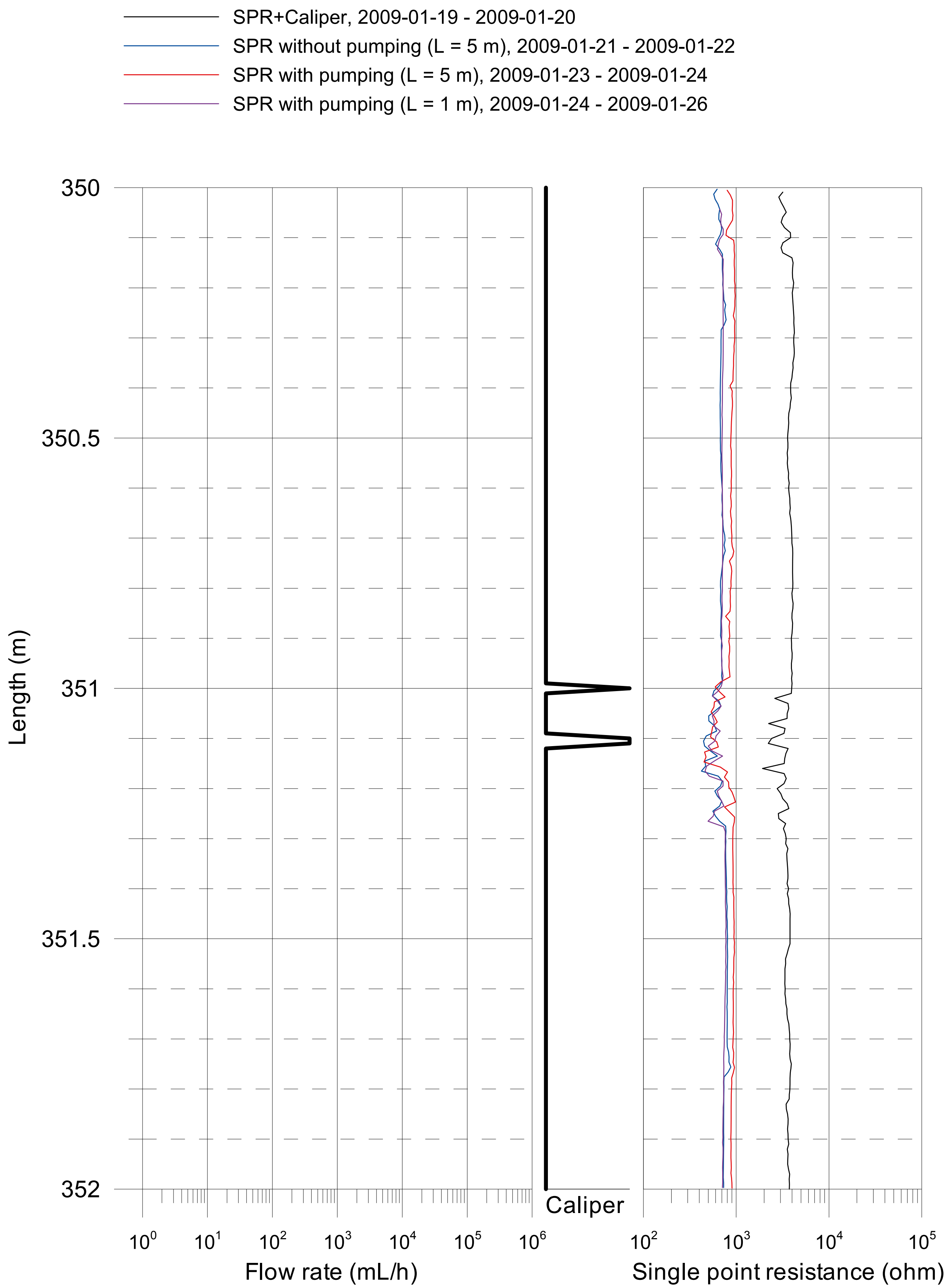
Forsmark, borehole KFR102A
SPR and Caliper results after length correction

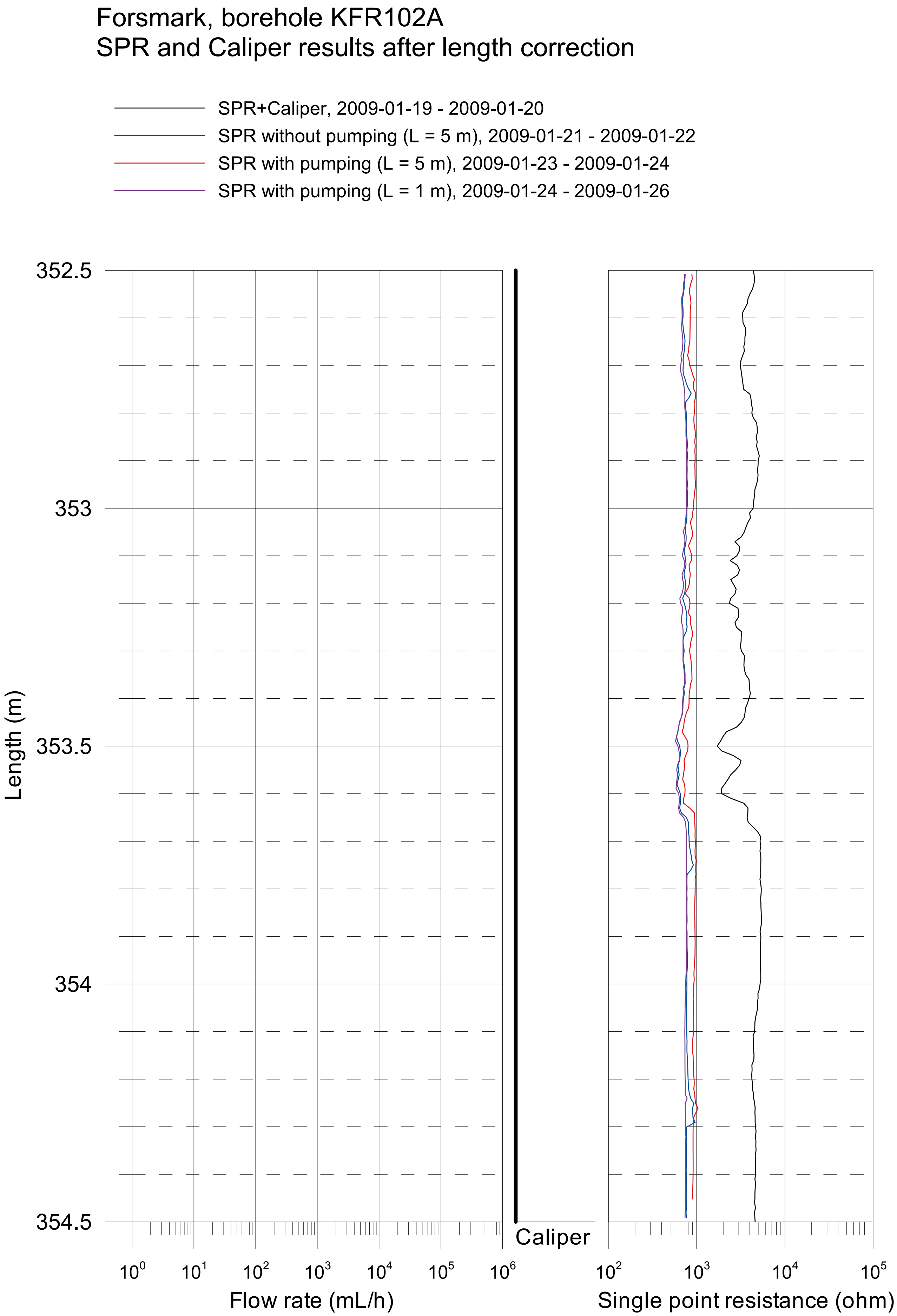


Forsmark, borehole KFR102A
SPR and Caliper results after length correction

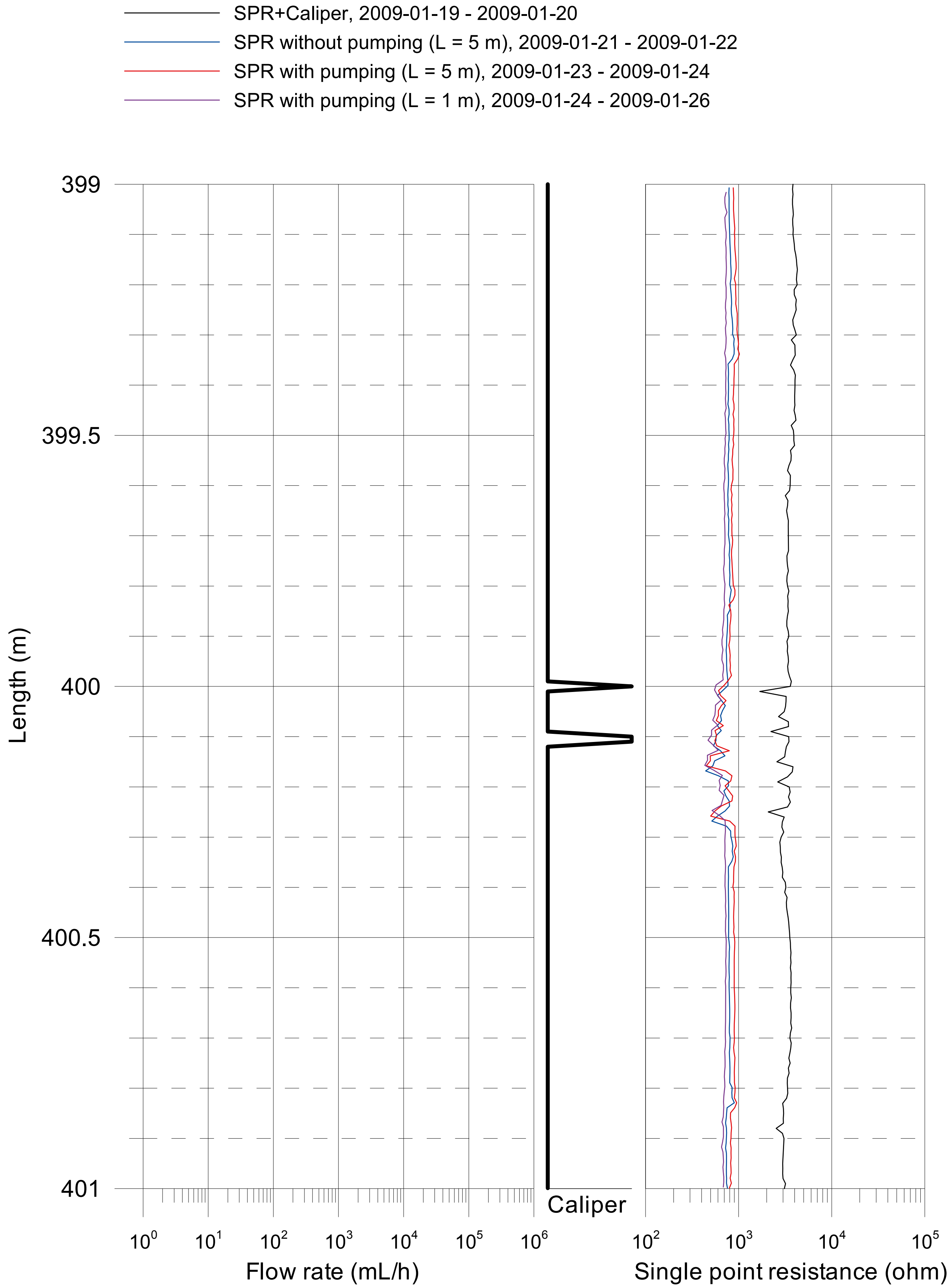


Forsmark, borehole KFR102A
SPR and Caliper results after length correction

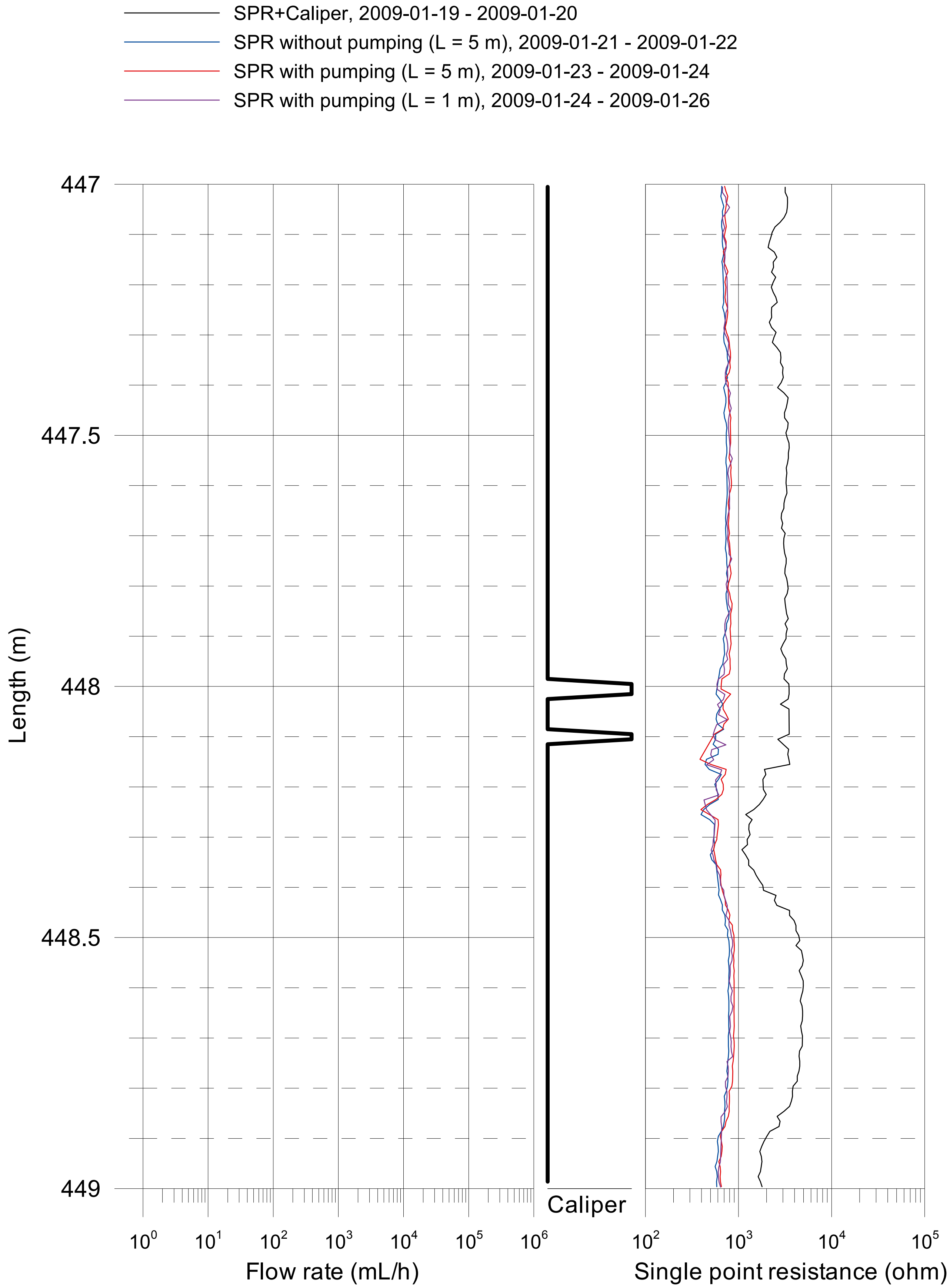



Forsmark, borehole KFR102A
SPR and Caliper results after length correction
SPR+Caliper, 2009-01-19 - 2009-01-20
SPR without pumping (L = 5 m), 2009-01-21 - 2009-01-22
SPR with pumping (L = 5 m), 2009-01-23 - 2009-01-24
SPR with pumping (L = 1 m), 2009-01-24 - 2009-01-26
352.5
353
353.5
354
354.5
Length (m)
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)

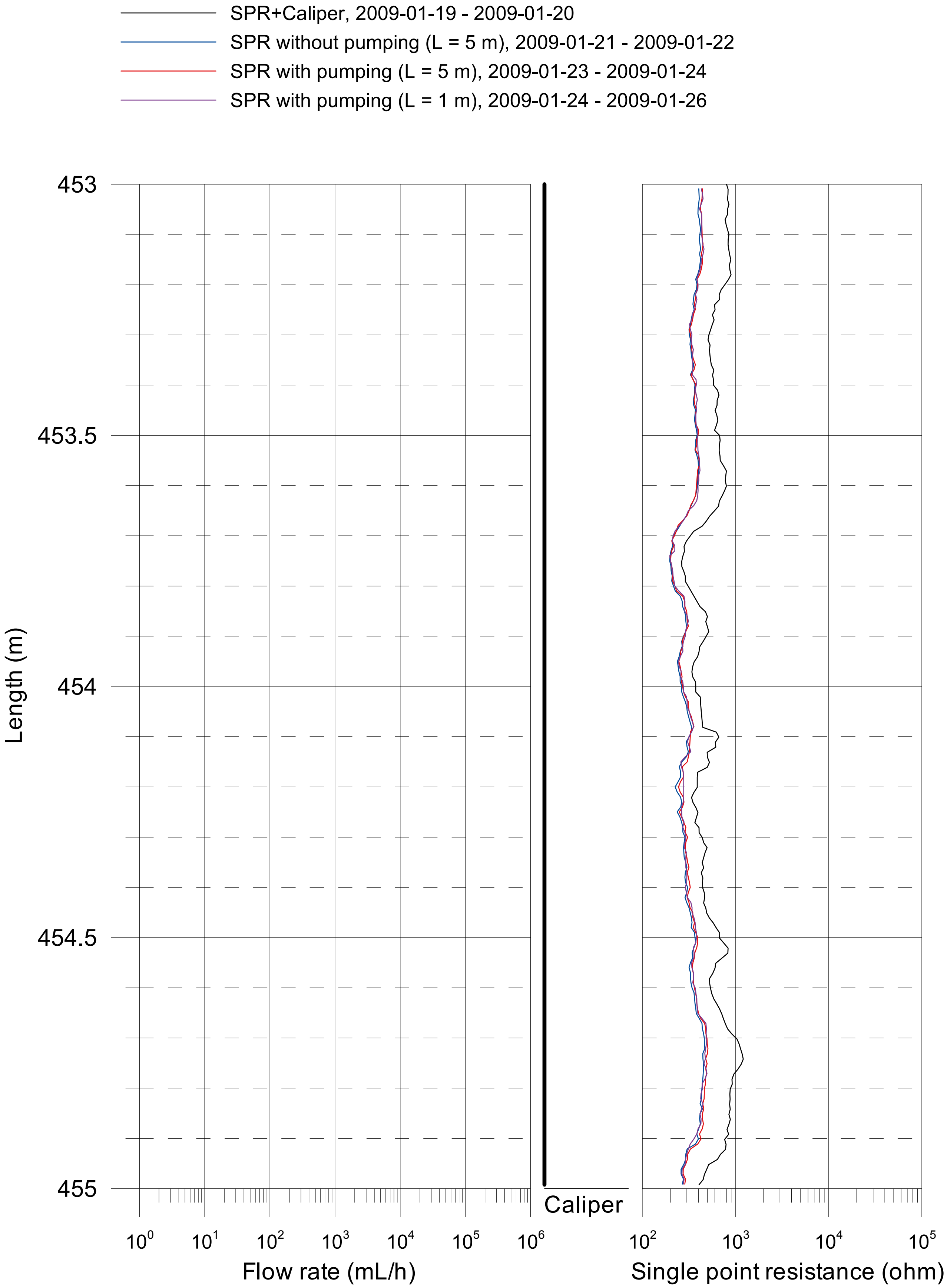
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



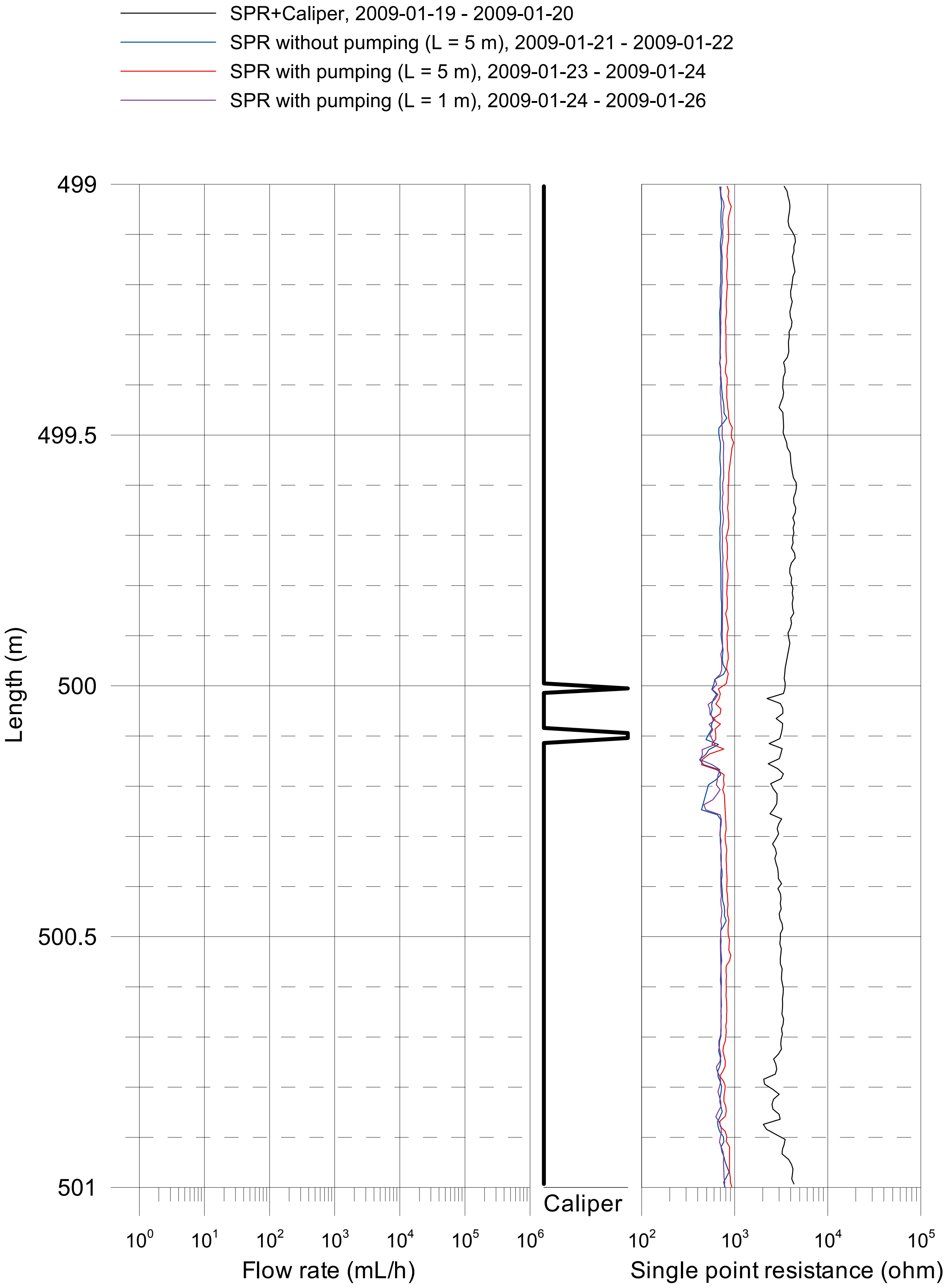
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



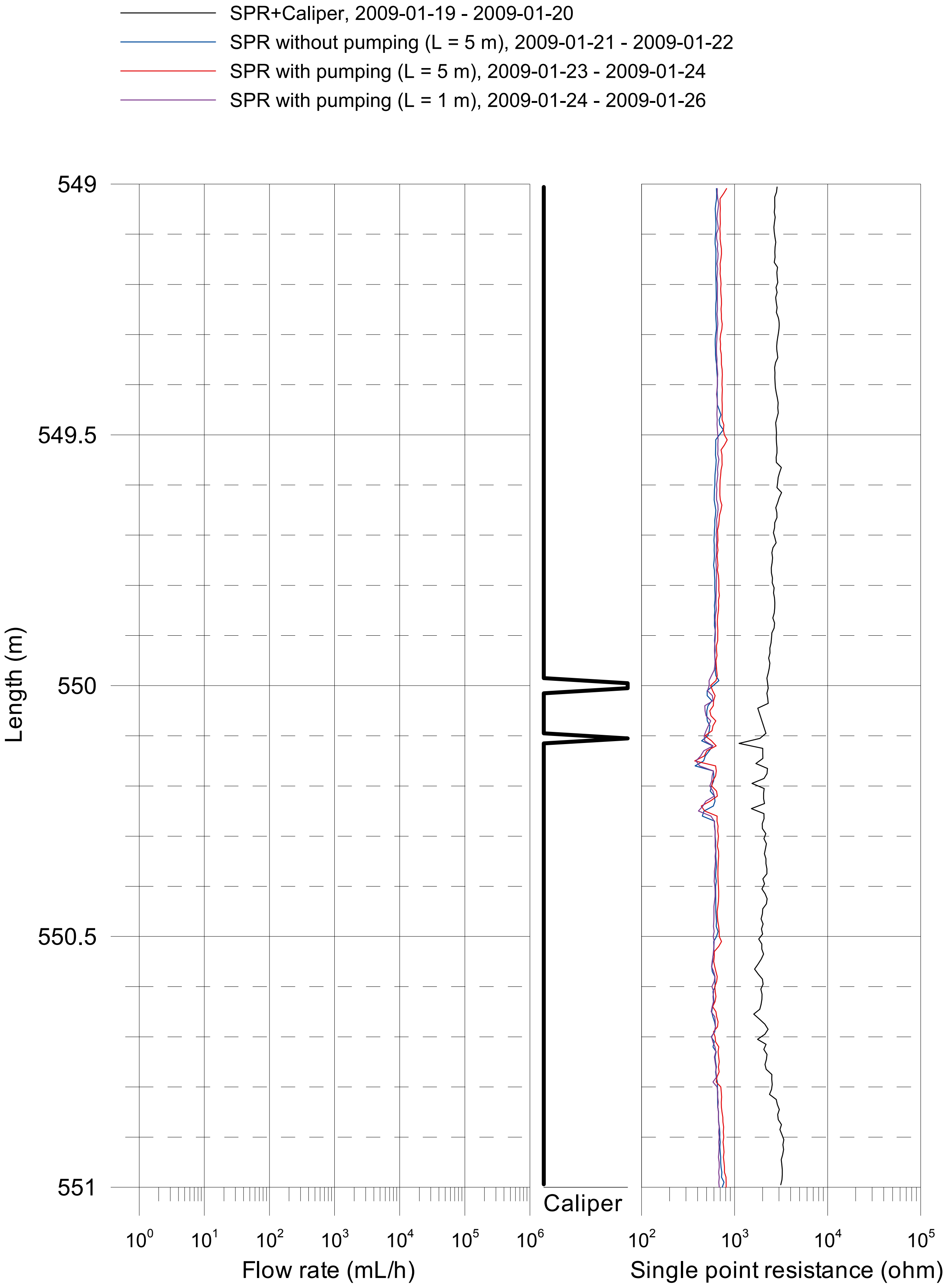
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



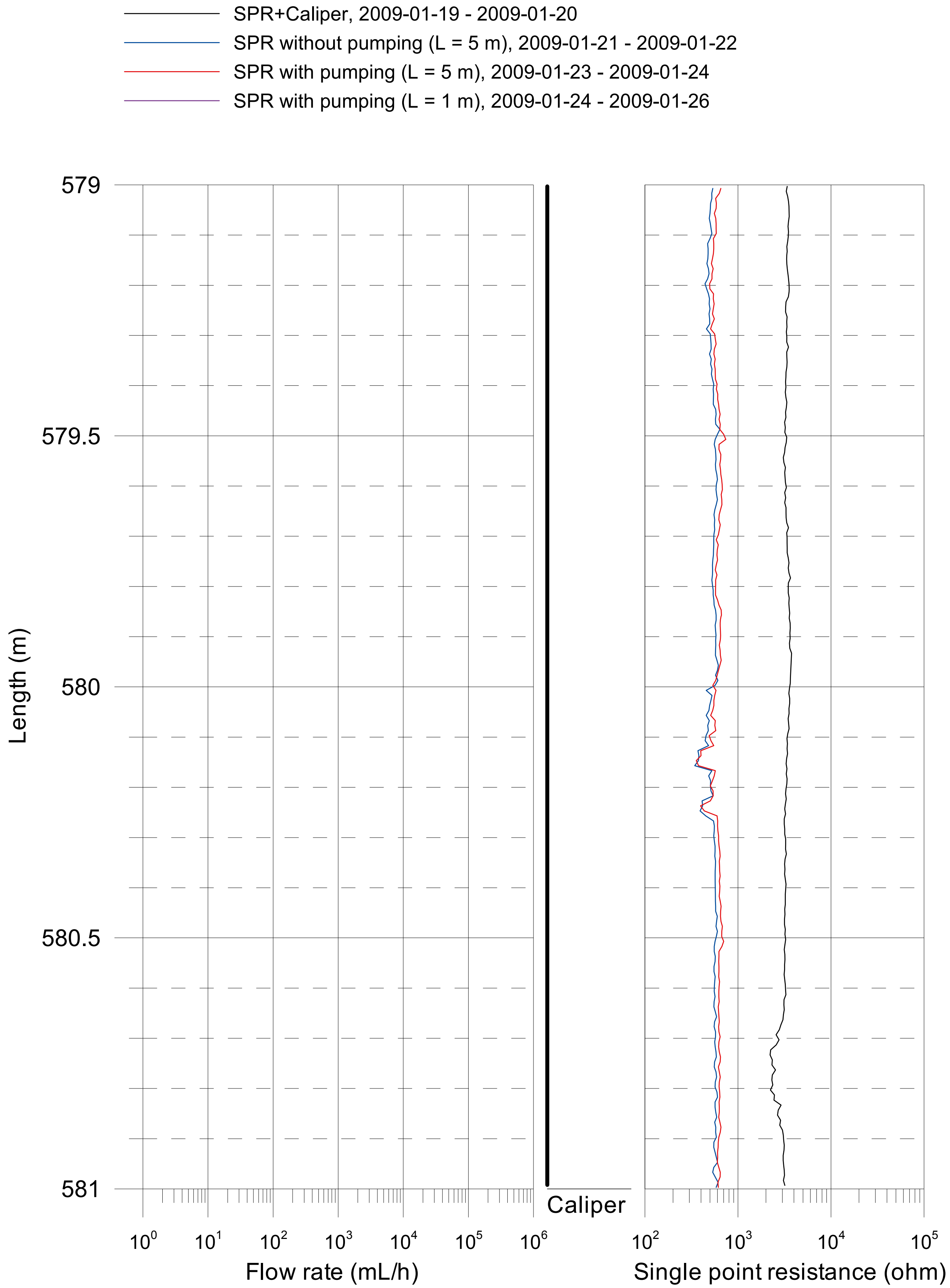
Forsmark, borehole KFR102A
SPR and Caliper results after length correction



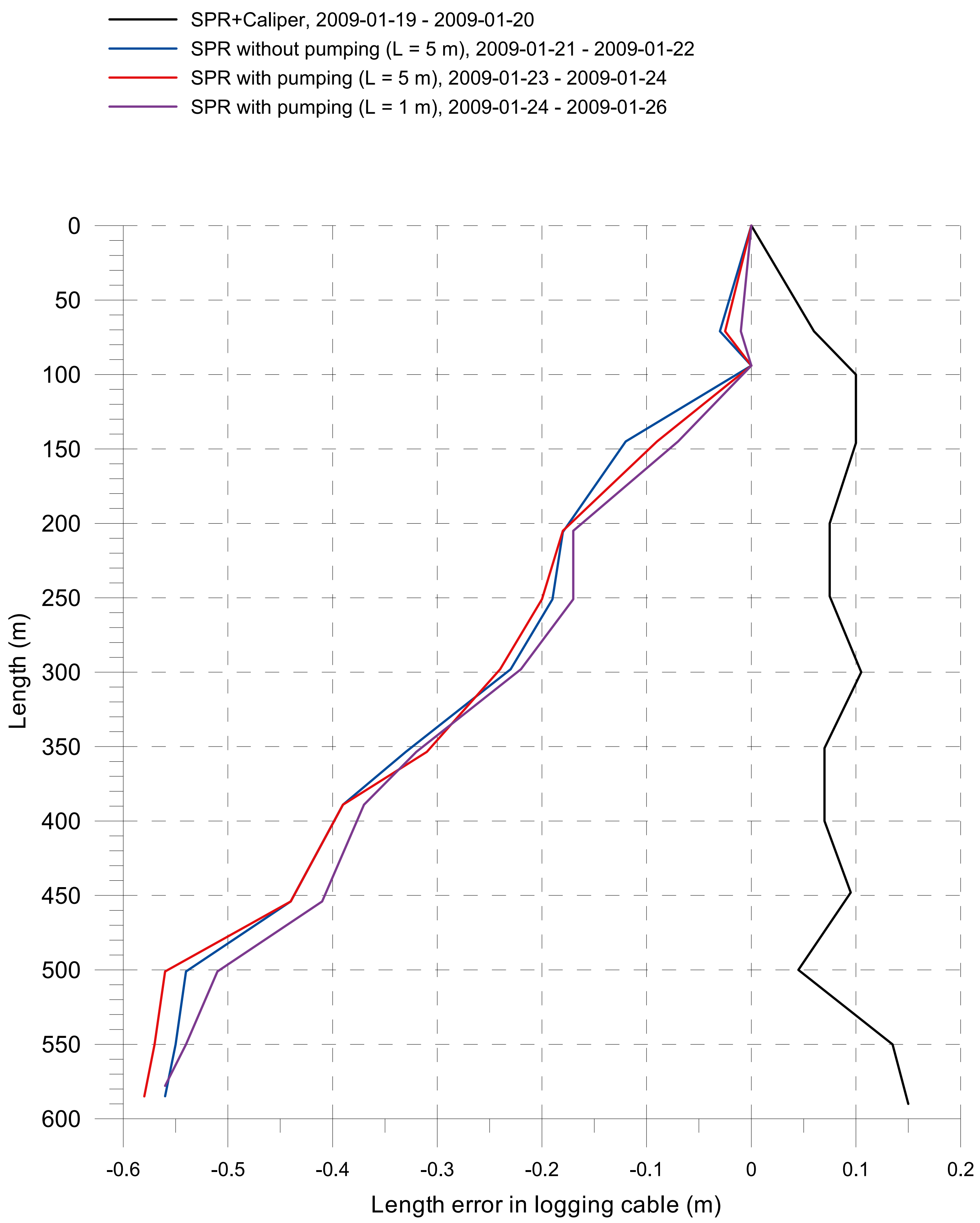
Forsmark, borehole KFR102A
SPR and Caliper results after length correction

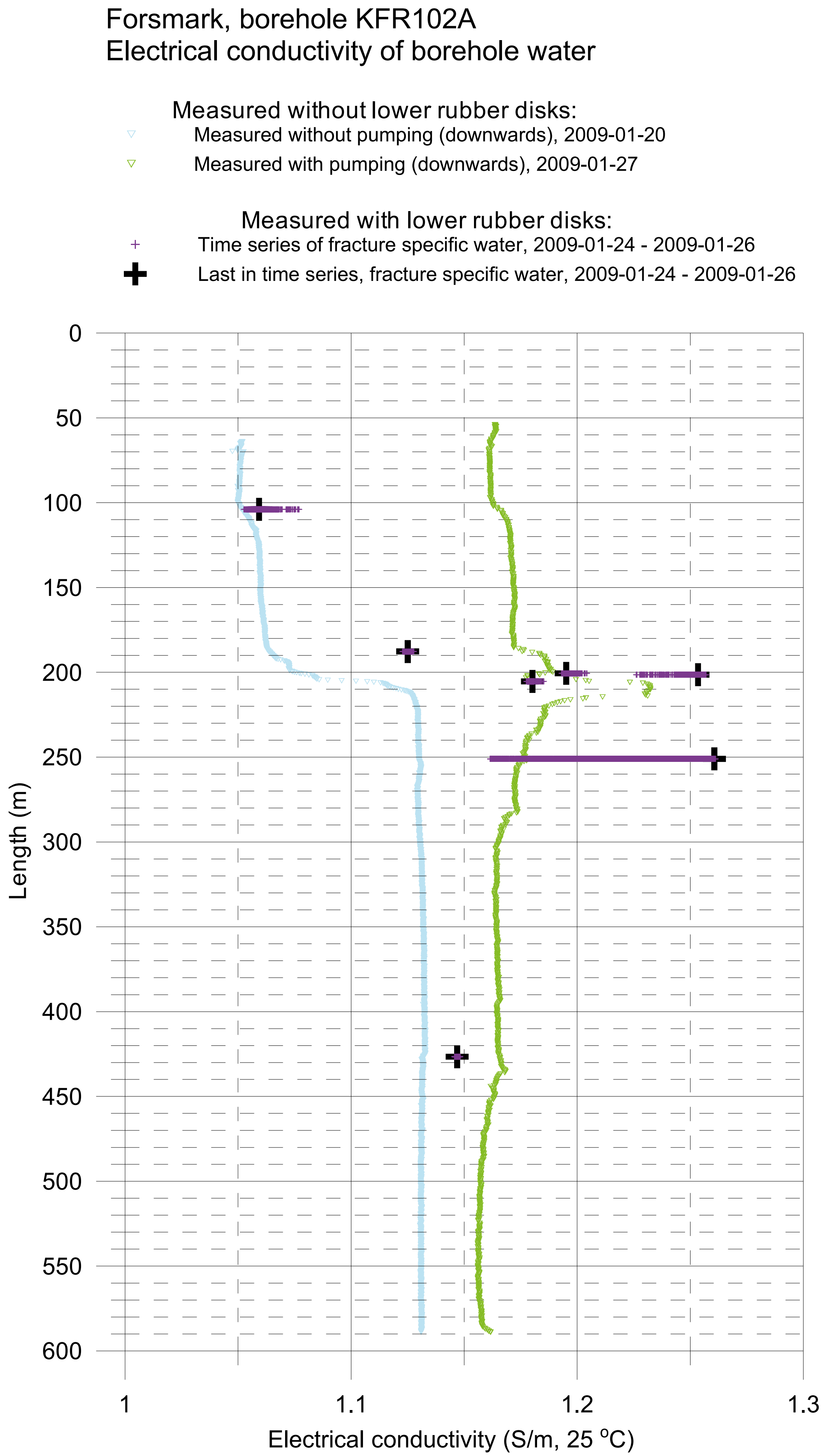


Forsmark, borehole KFR102A
SPR and Caliper results after length correction

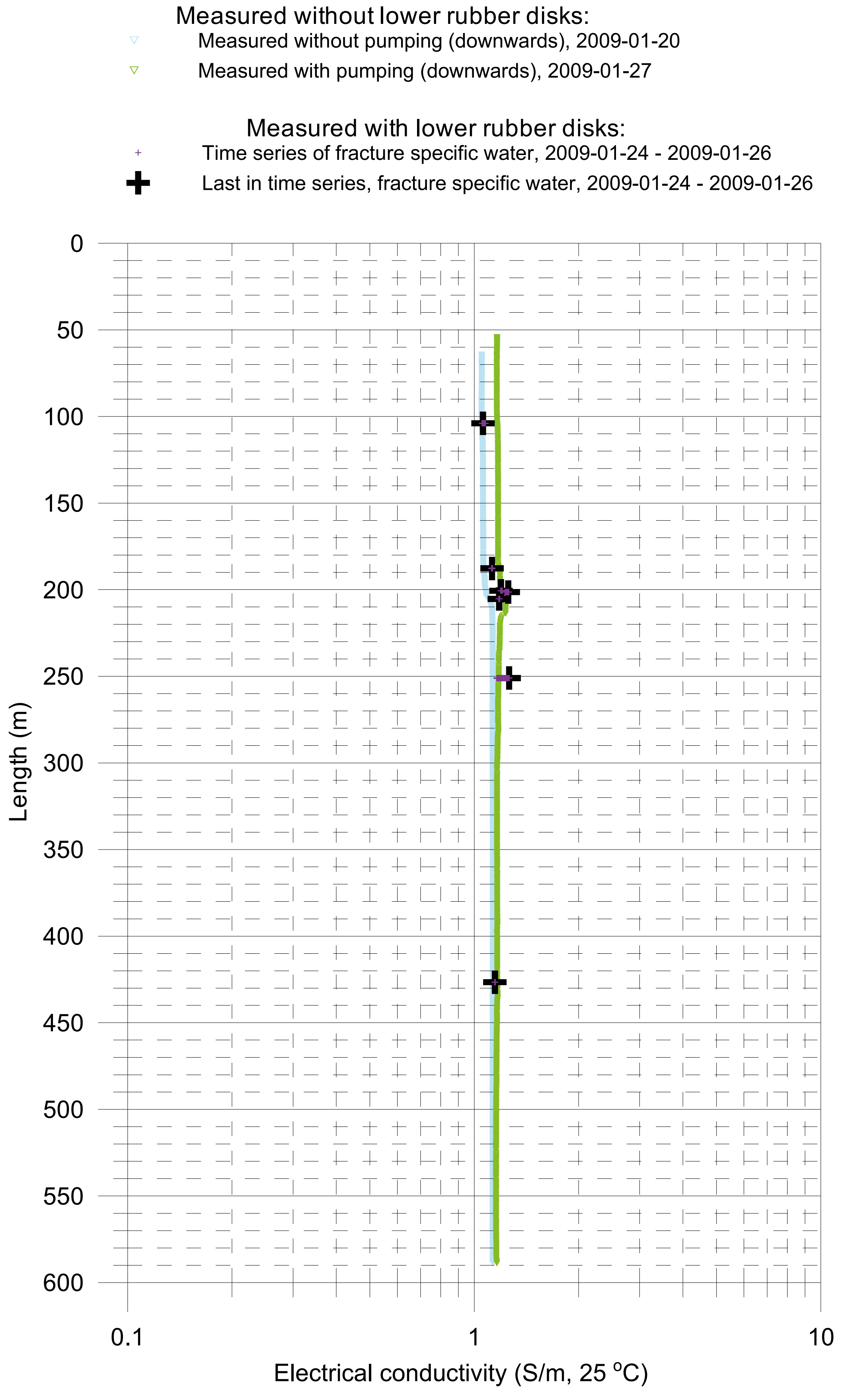


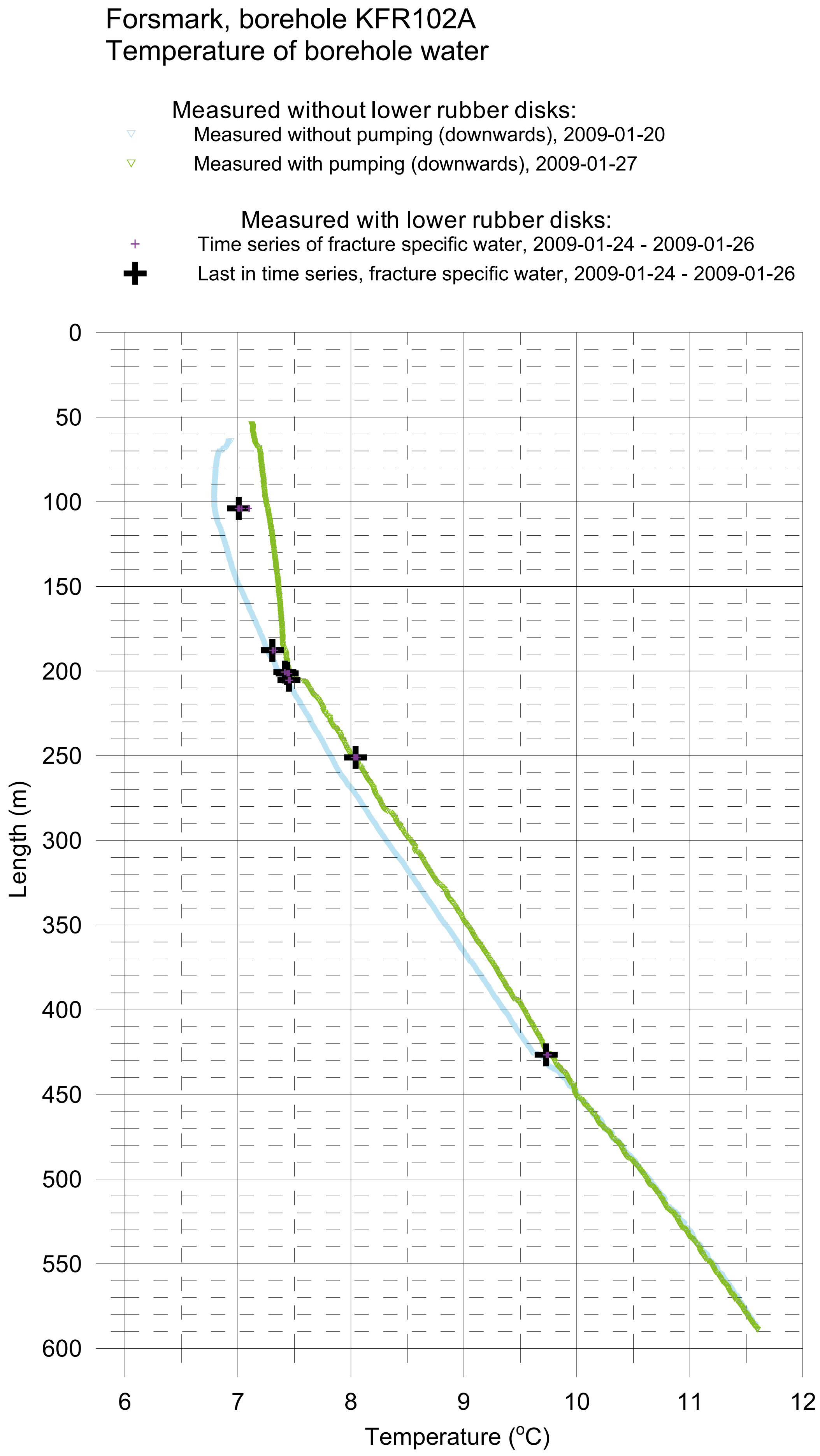
Forsmark, borehole KFR102A
Length correction




Forsmark, borehole KFR102A
Electrical conductivity of borehole water
Measured without lower rubber disks:
Measured without pumping (downwards), 2009-01-20
Measured with pumping (downwards), 2009-01-27
Measured with lower rubber disks:
Time series of fracture specific water, 2009-01-24 - 2009-01-26
Last in time series, fracture specific water, 2009-01-24 - 2009-01-26
0
50
100
150
200
250
300
350
400
450
500
550
600
Length (m)
1
1.1
1.2
1.3
Electrical conductivity (S/m, 25 °C)

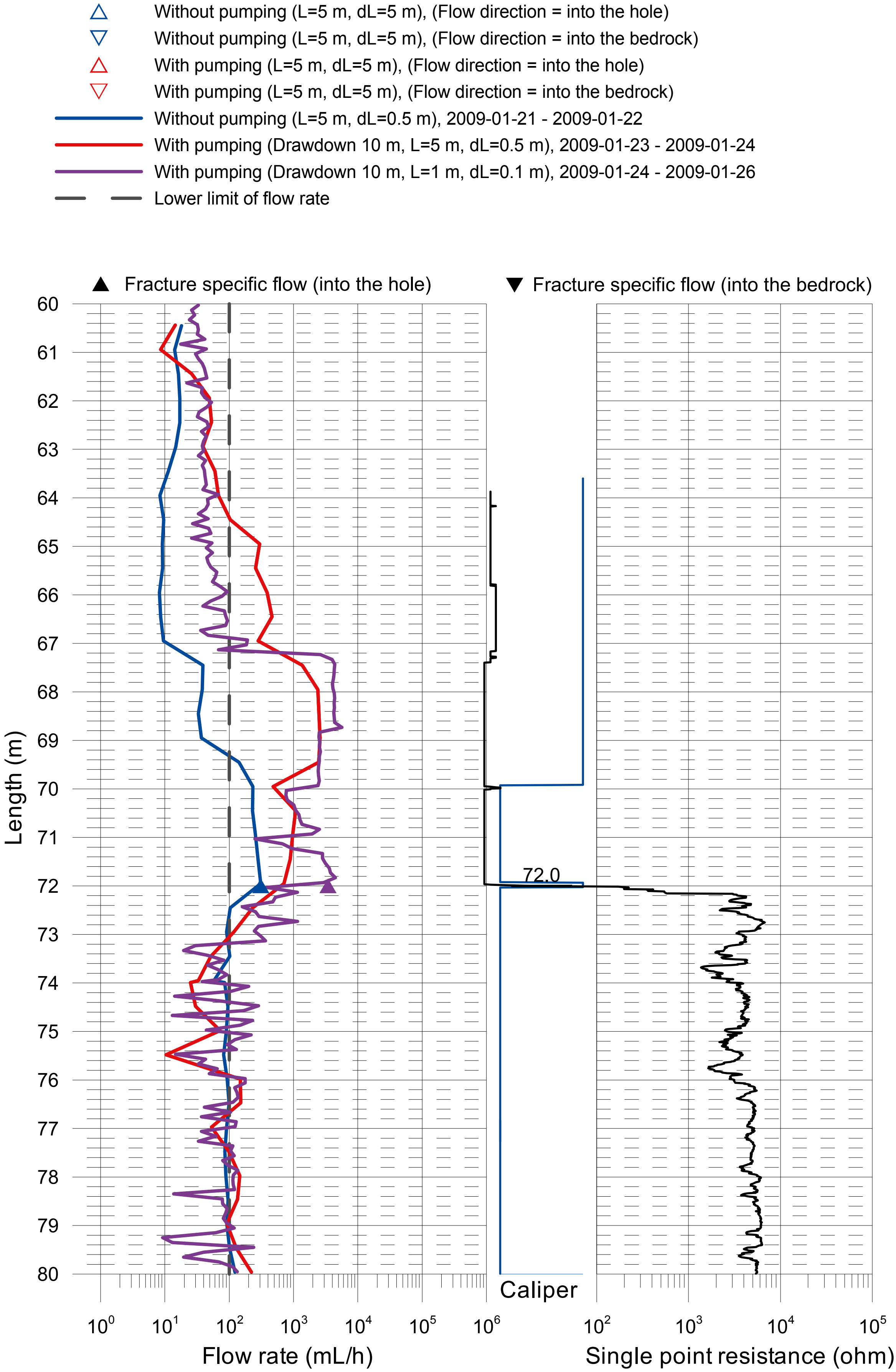
Forsmark, borehole KFR102A
Electrical conductivity of borehole water



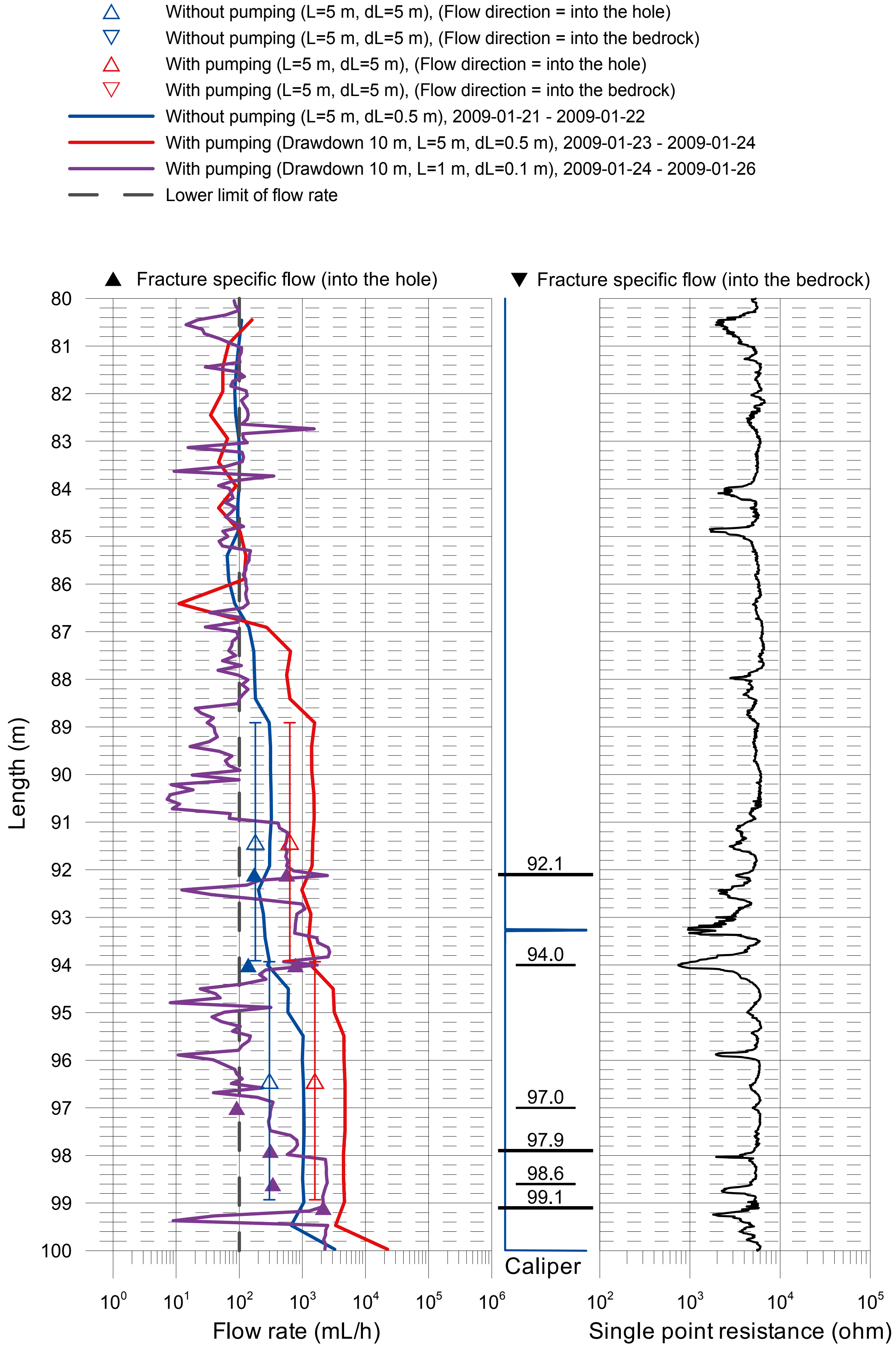


Forsmark, borehole KFR102A
Temperature of borehole water
Measured without lower rubber disks:
Measured without pumping (downwards), 2009-01-20
Measured with pumping (downwards), 2009-01-27
Measured with lower rubber disks:
Time series of fracture specific water, 2009-01-24 - 2009-01-26
Last in time series, fracture specific water, 2009-01-24 - 2009-01-26
0
50
100
150
200
250
300
350
400
450
500
550
600
Length (m)
6
7
8
9
10
11
12
Temperature (°C)

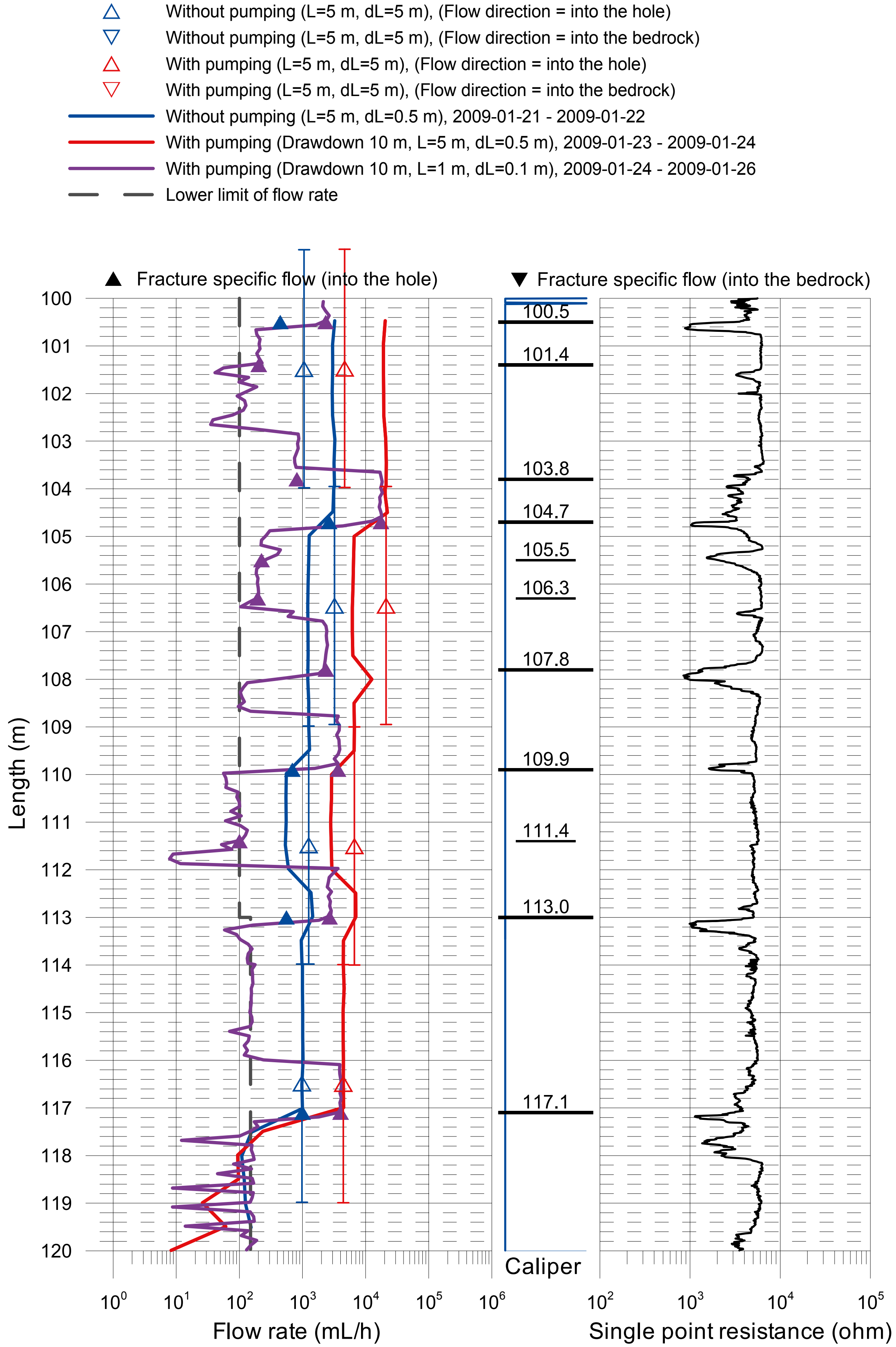
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance



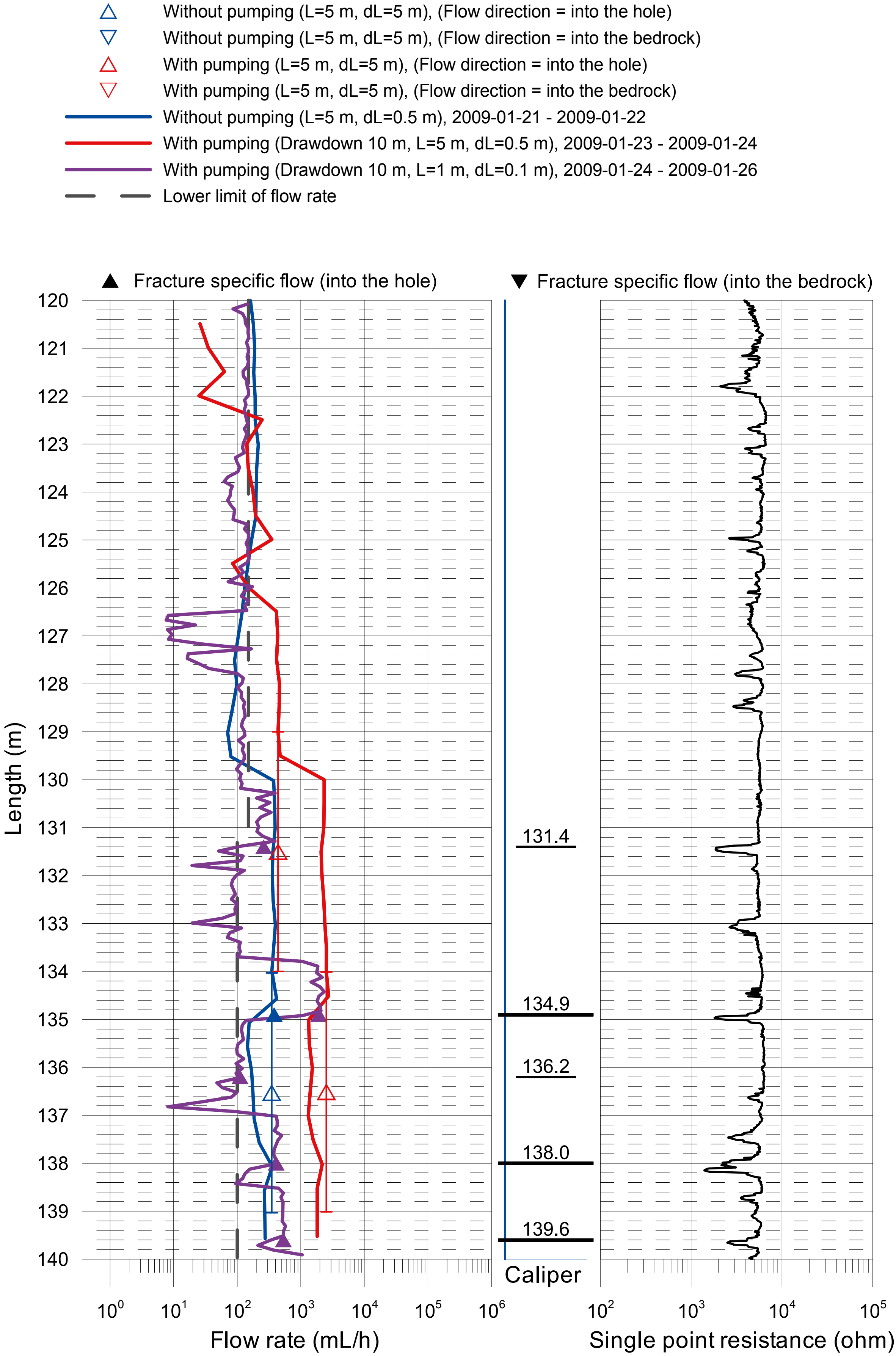
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance



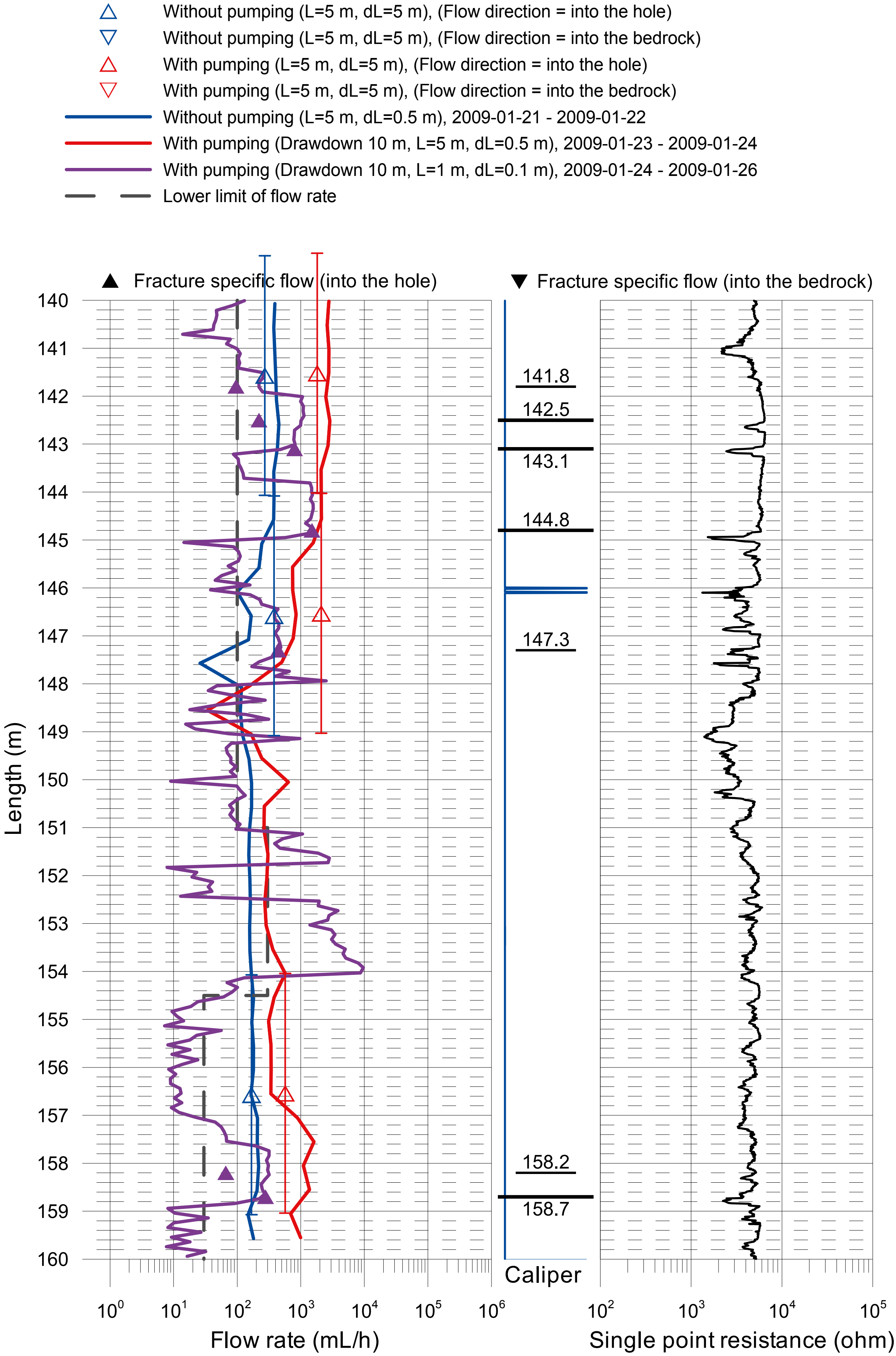
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance

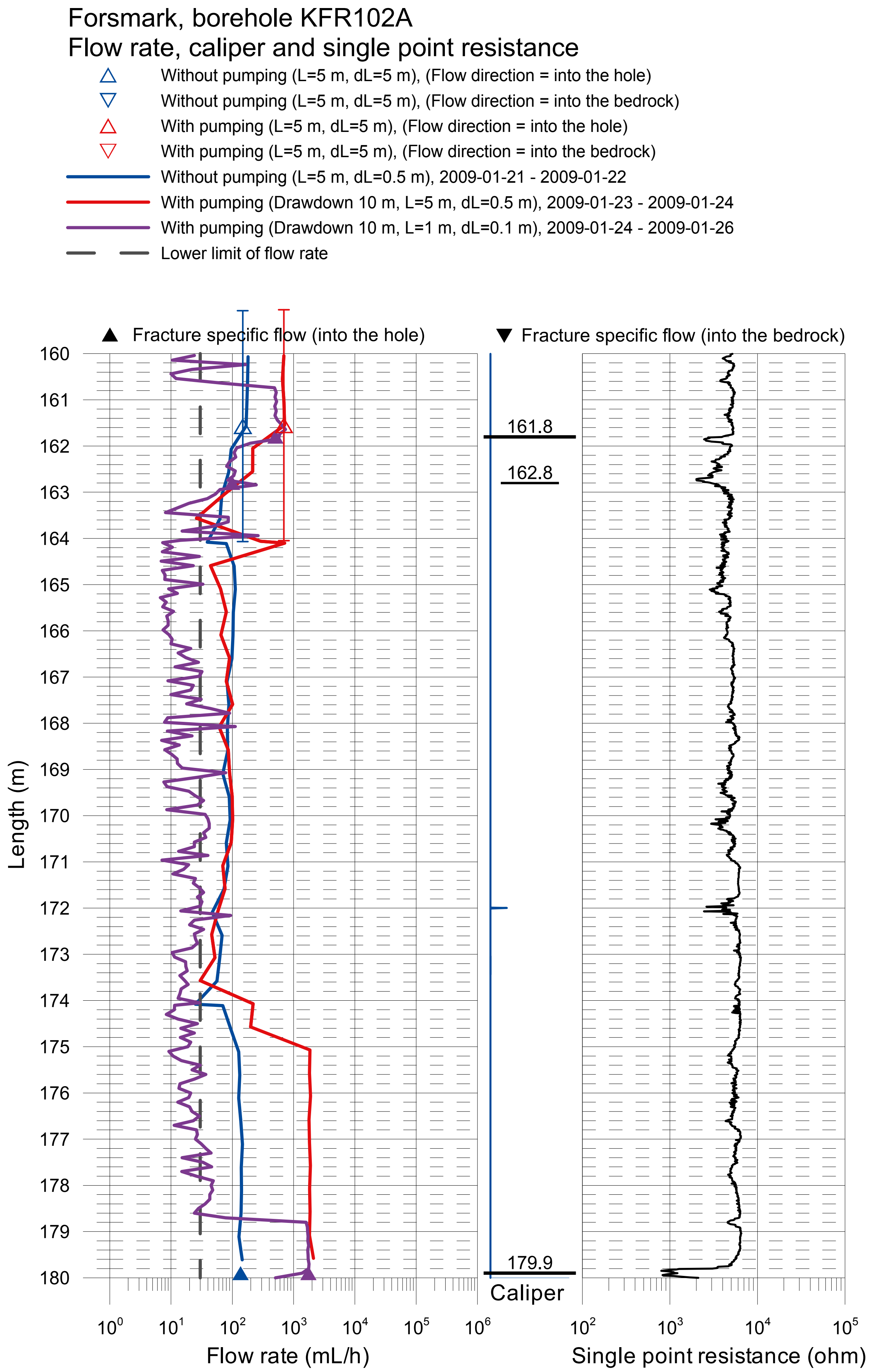


Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance

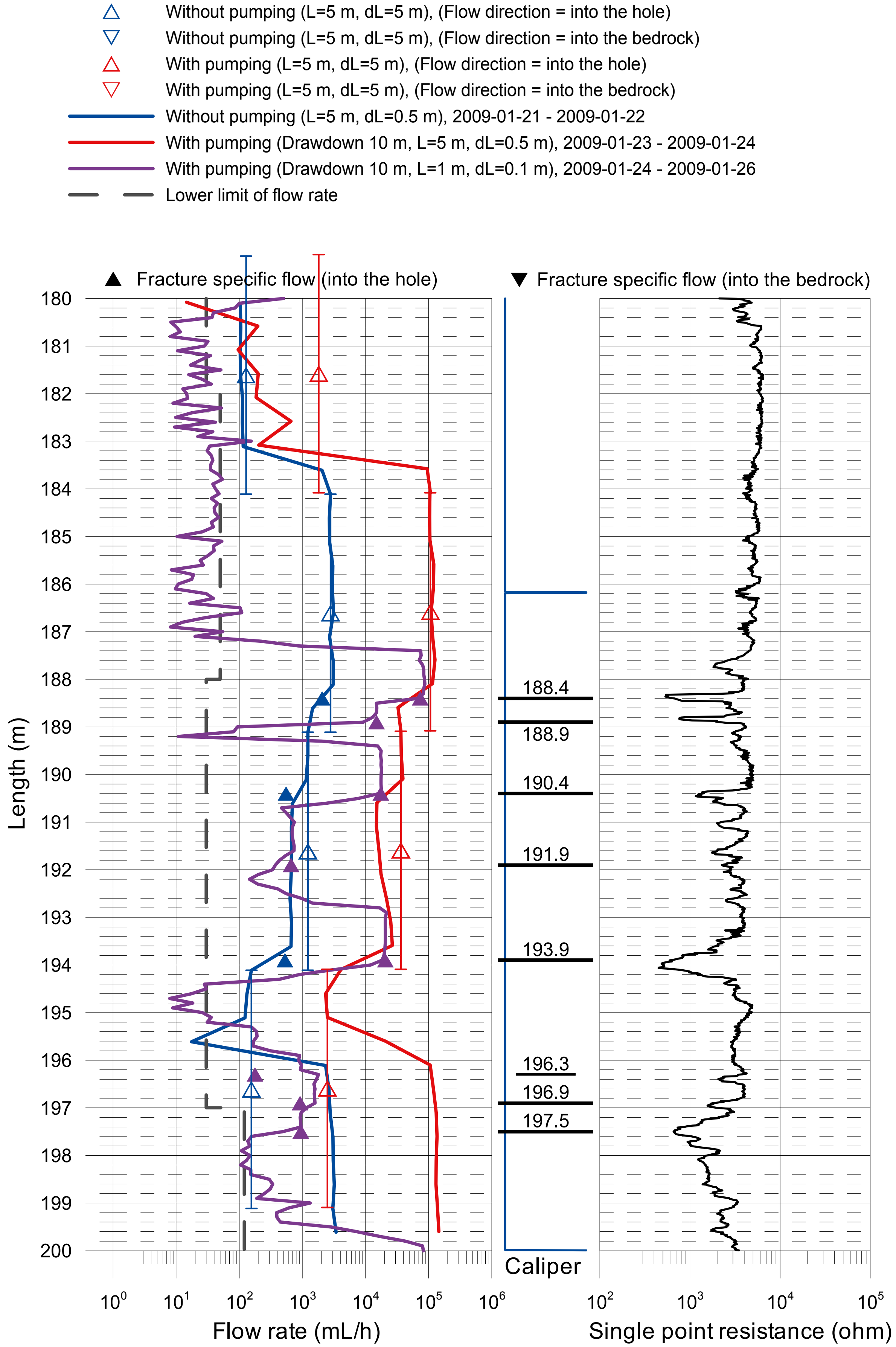


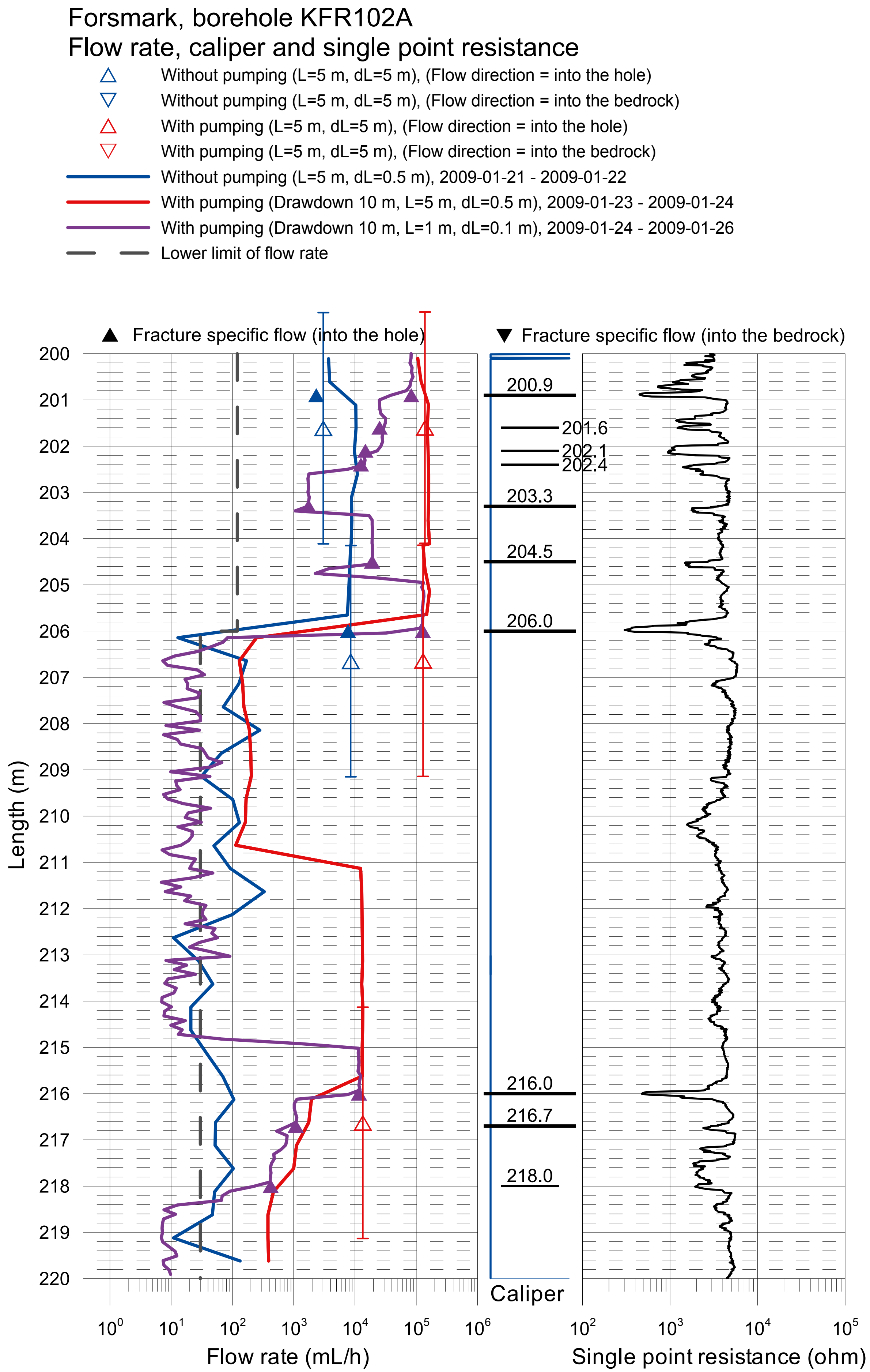
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance



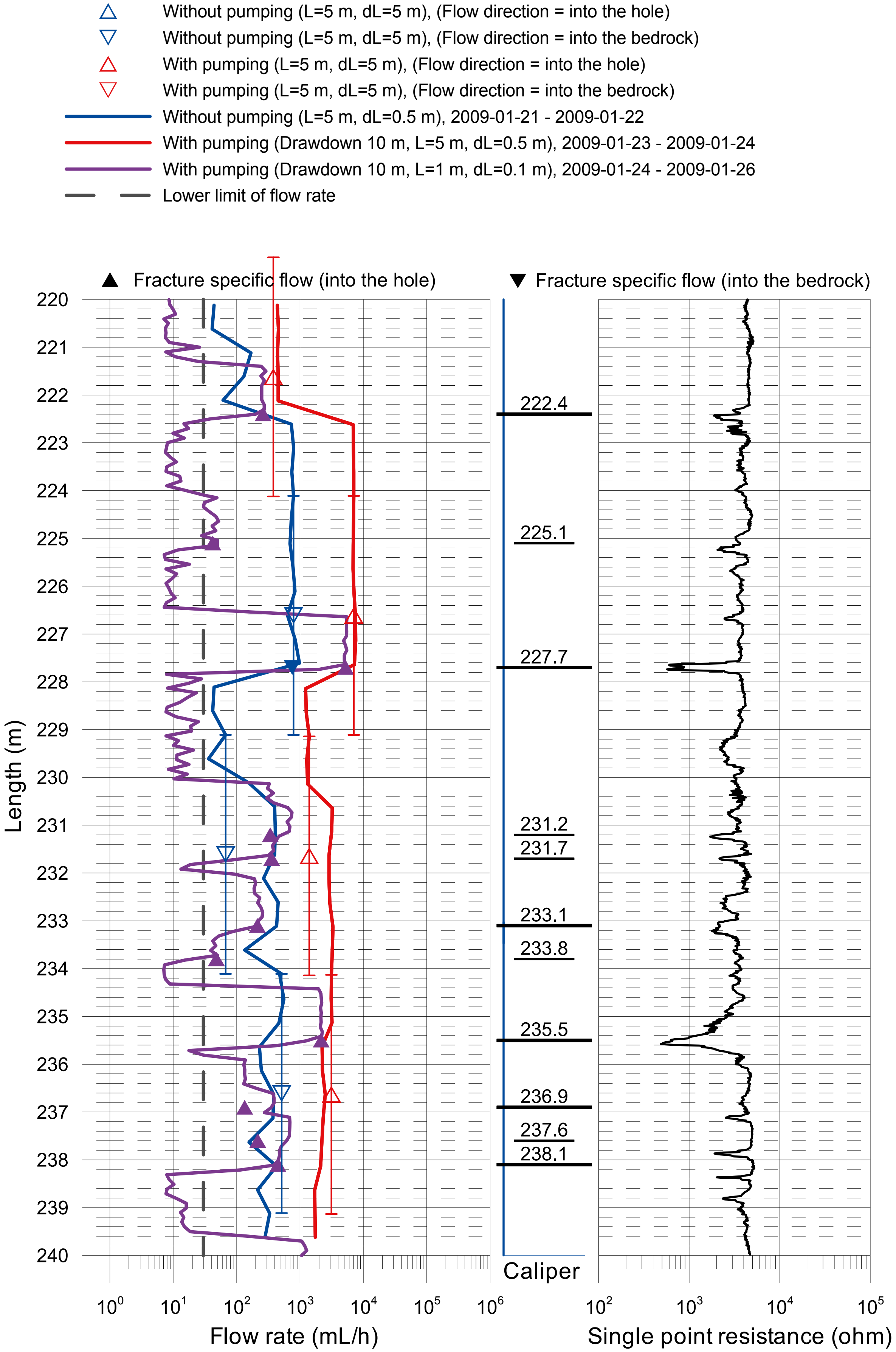

Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
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
161.8
162.8
179.9
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

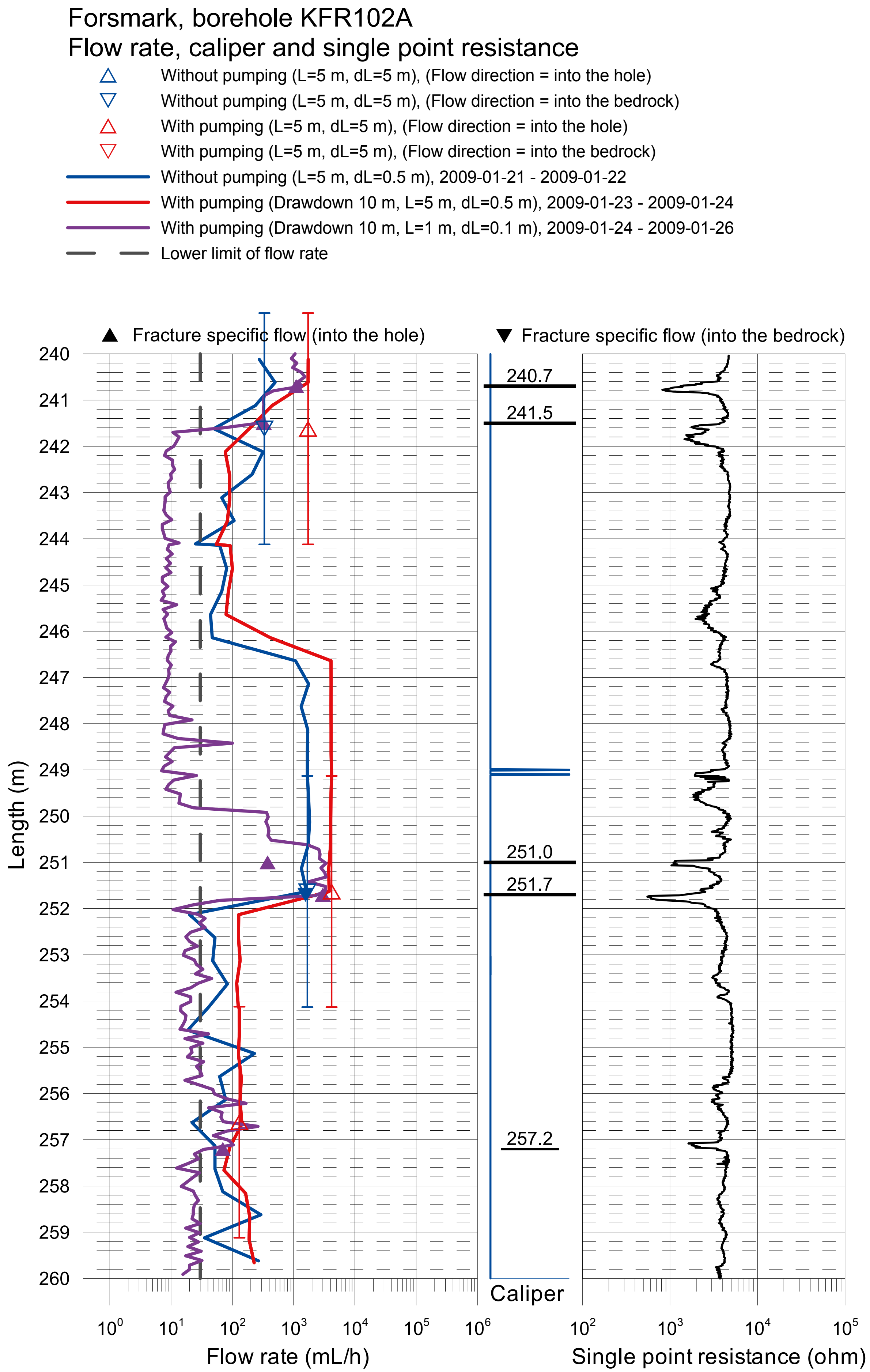
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance



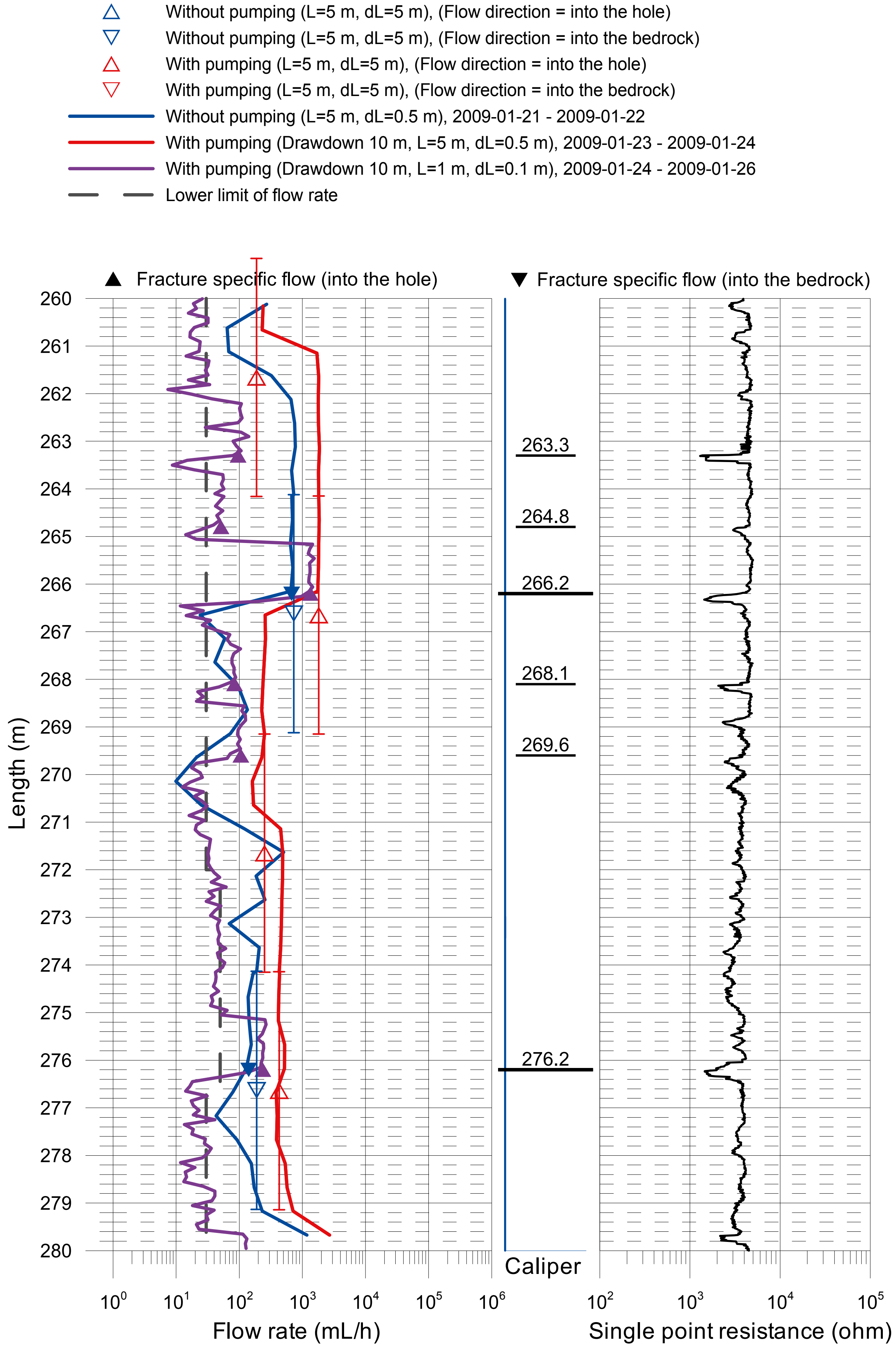

Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
200.9
201.6
202.1
202.4
203.3
204.5
206.0
216.0
216.7
218.0
Caliper
Flow rate (mL/h)
Single point resistance (ohm)

Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance

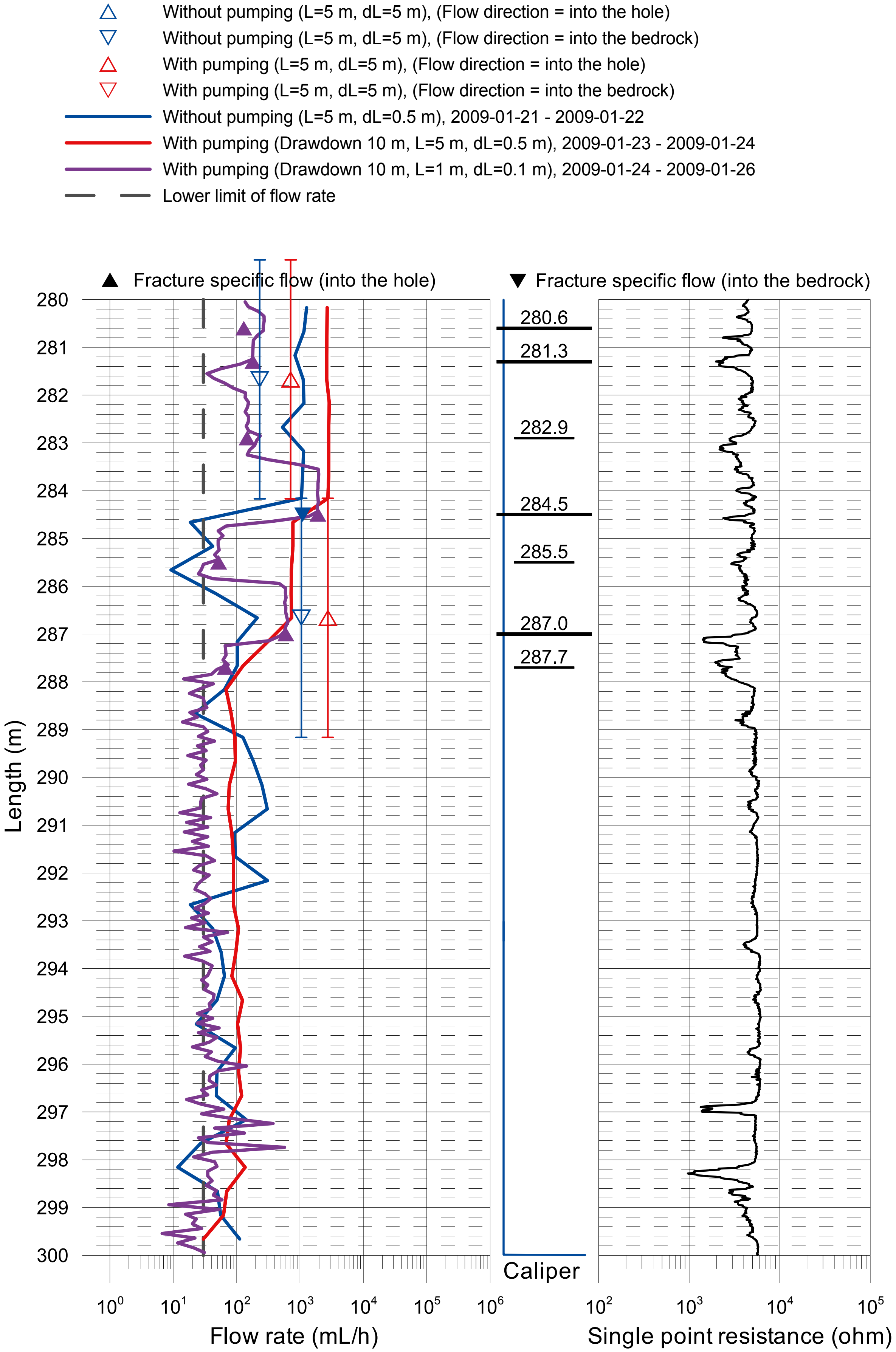


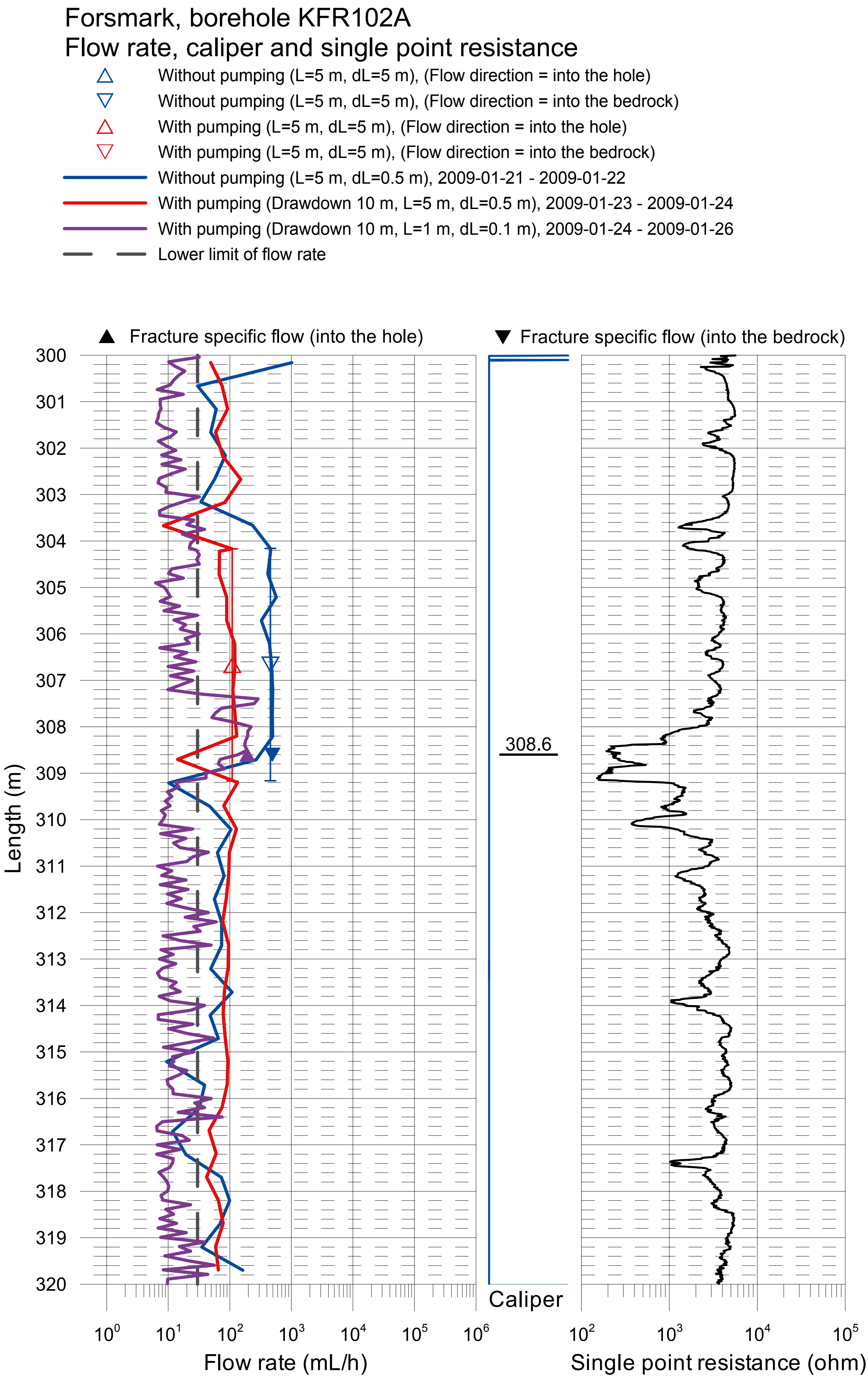

Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
240.7
241.5
251.0
251.7
257.2
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 KFR102A
Flow rate, caliper and single point resistance

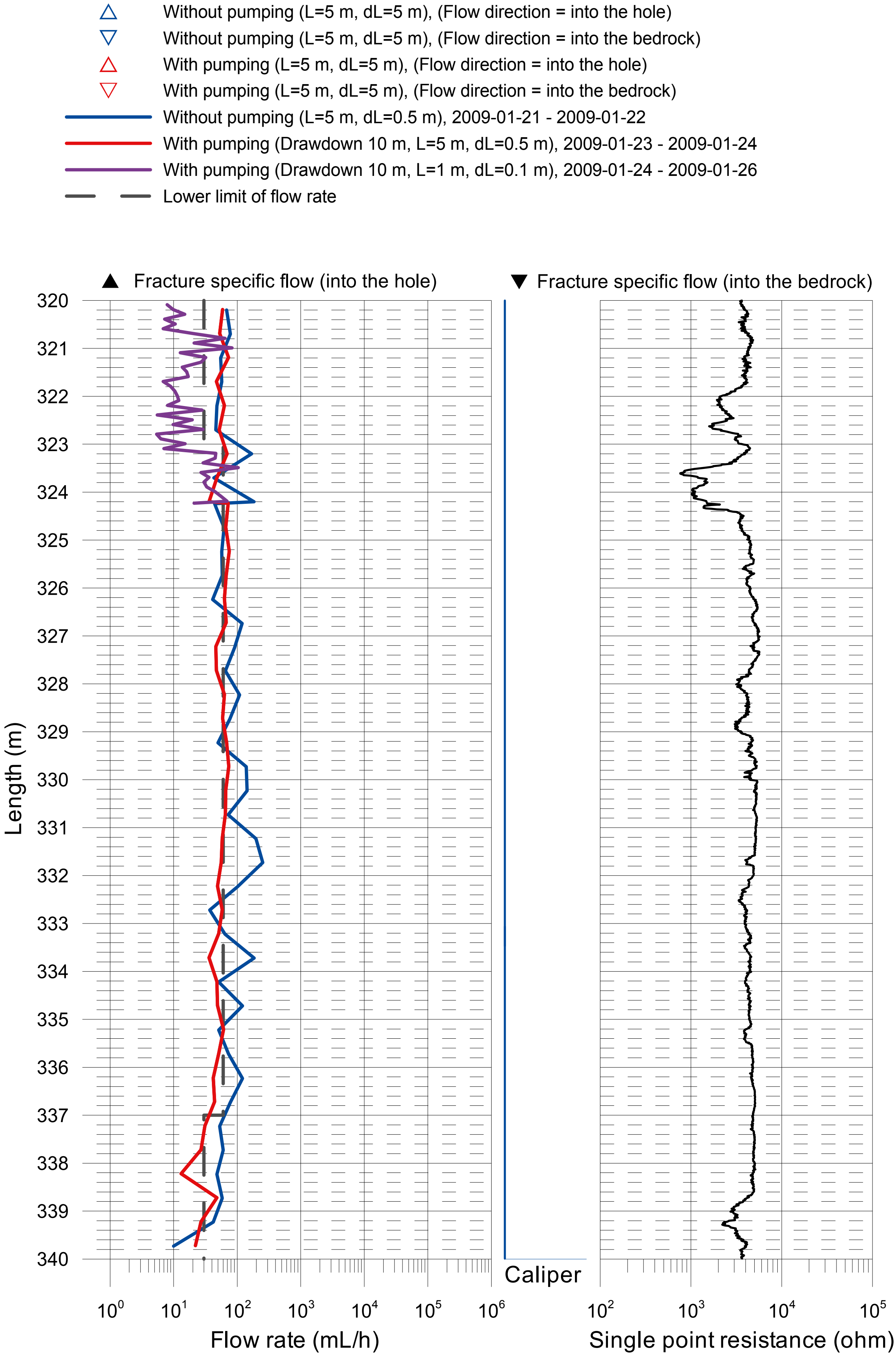


Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance

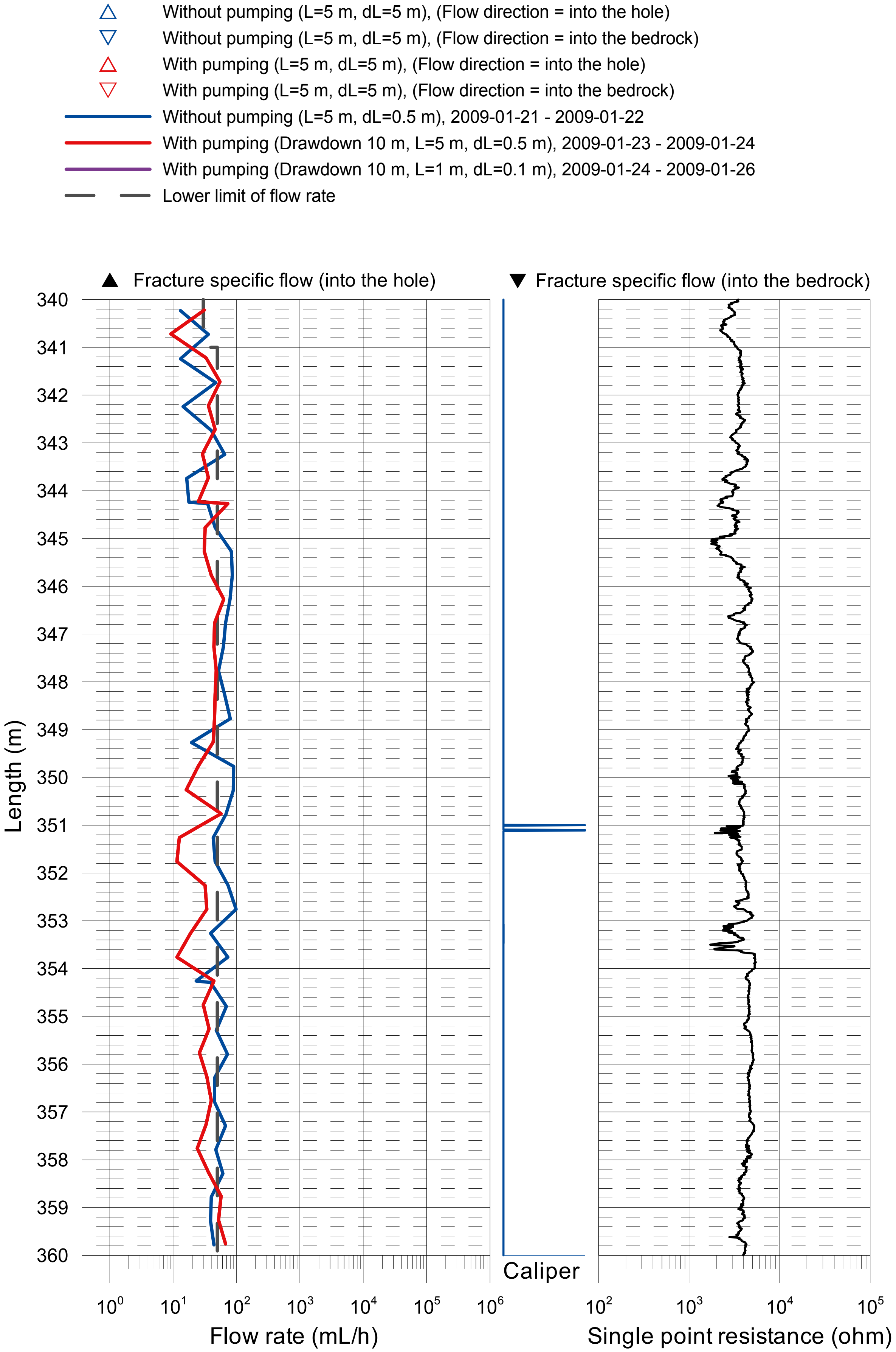


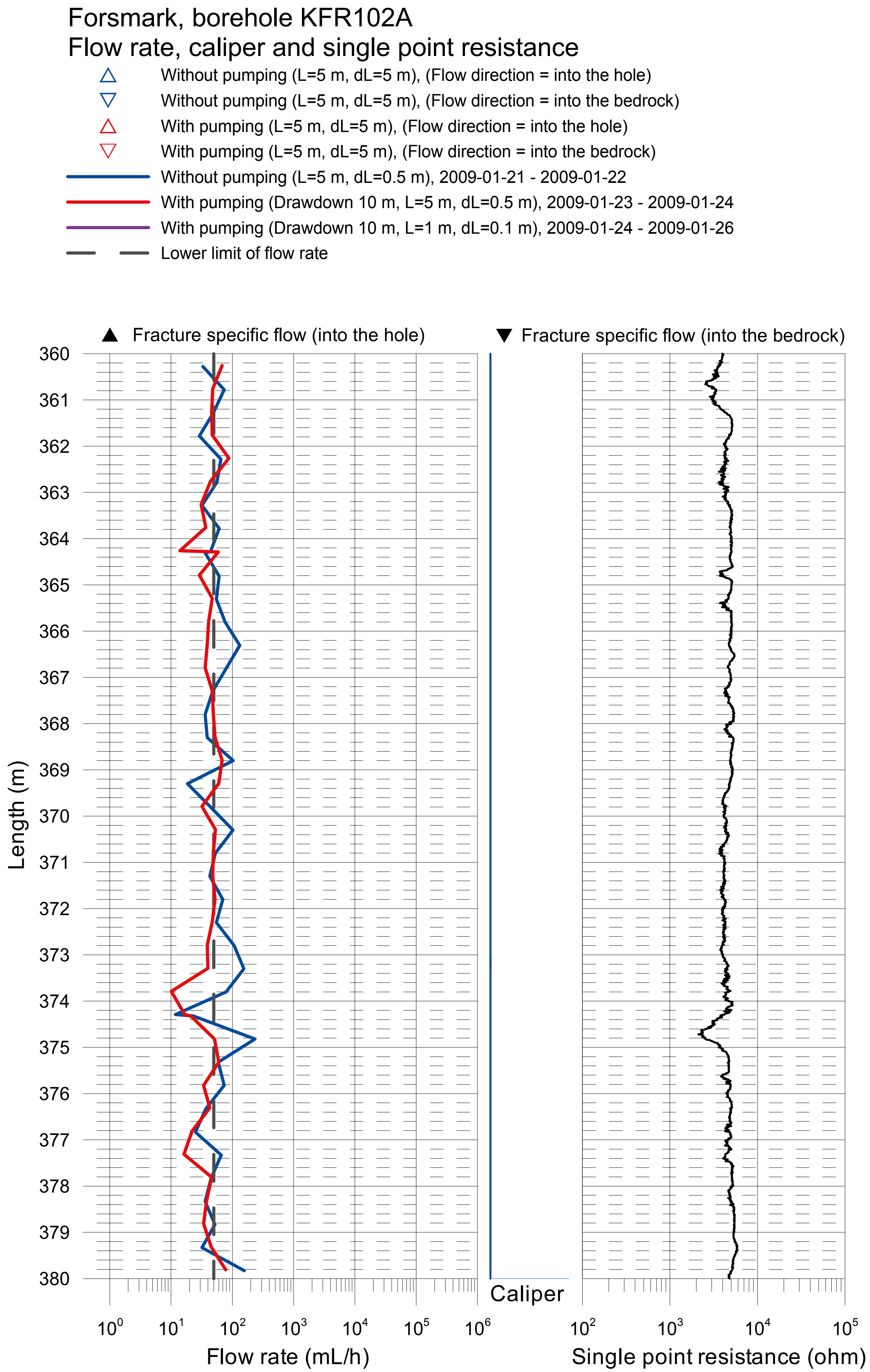

Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
308.6
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 KFR102A
Flow rate, caliper and single point resistance

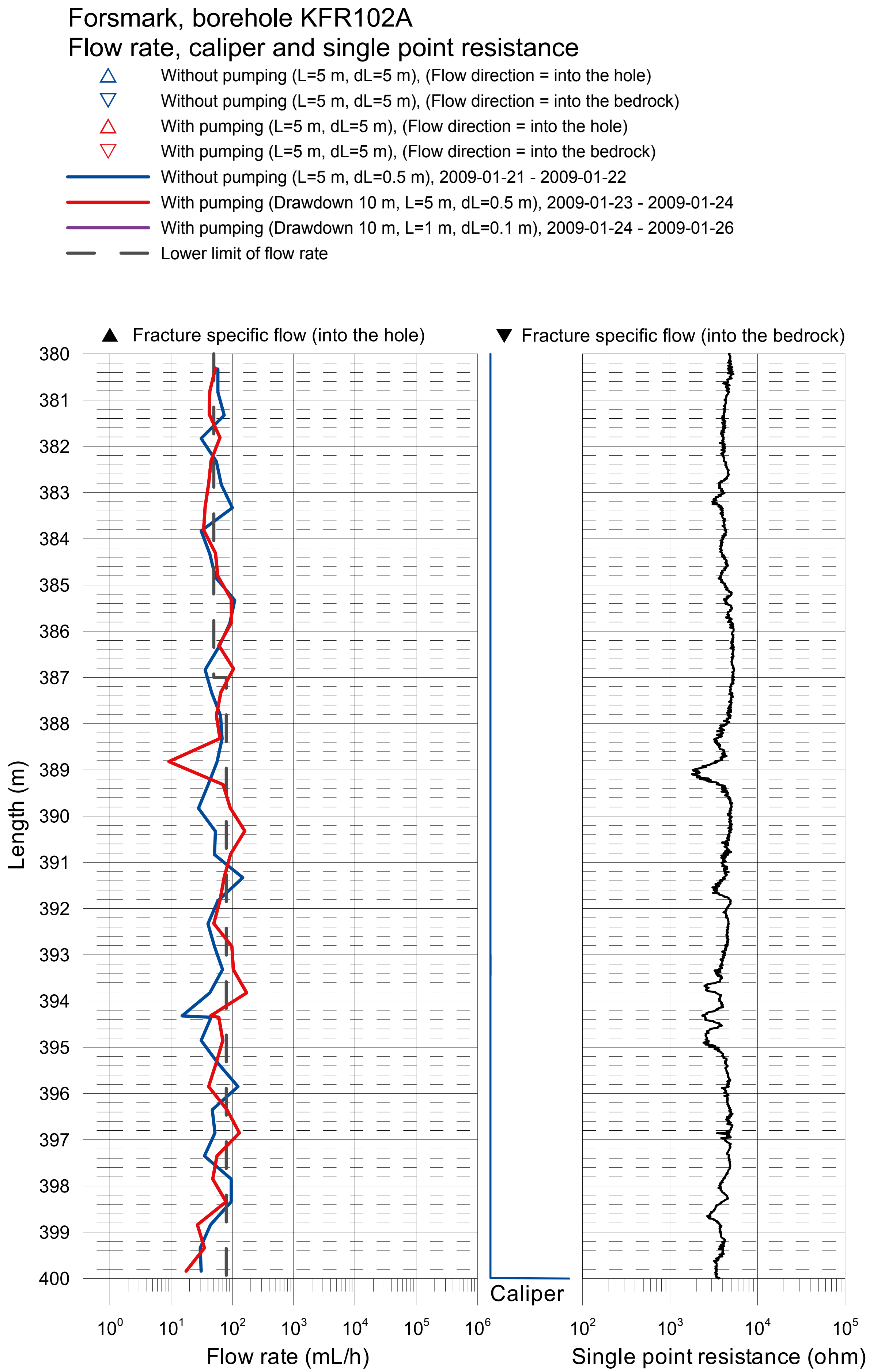


Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance

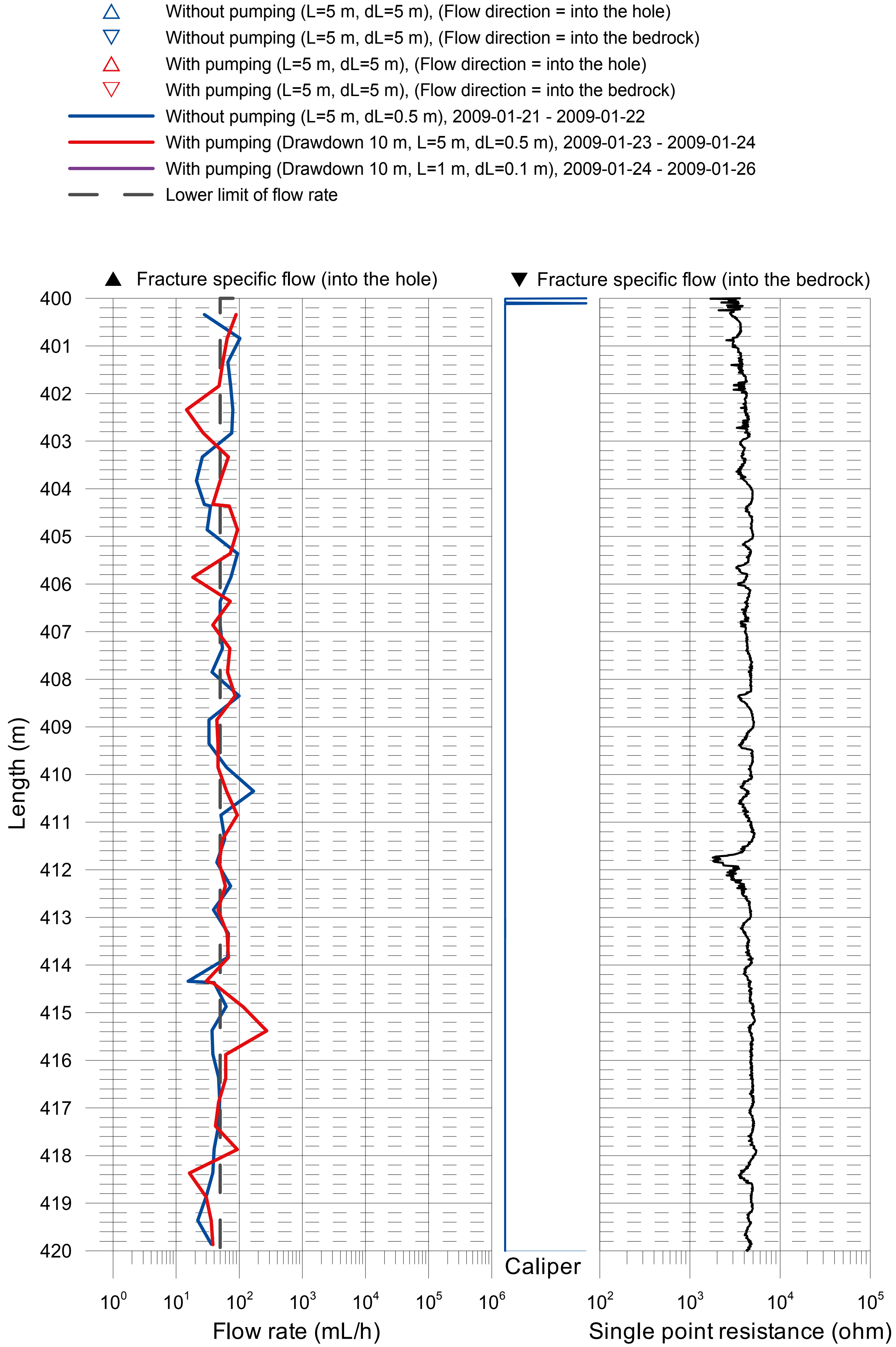




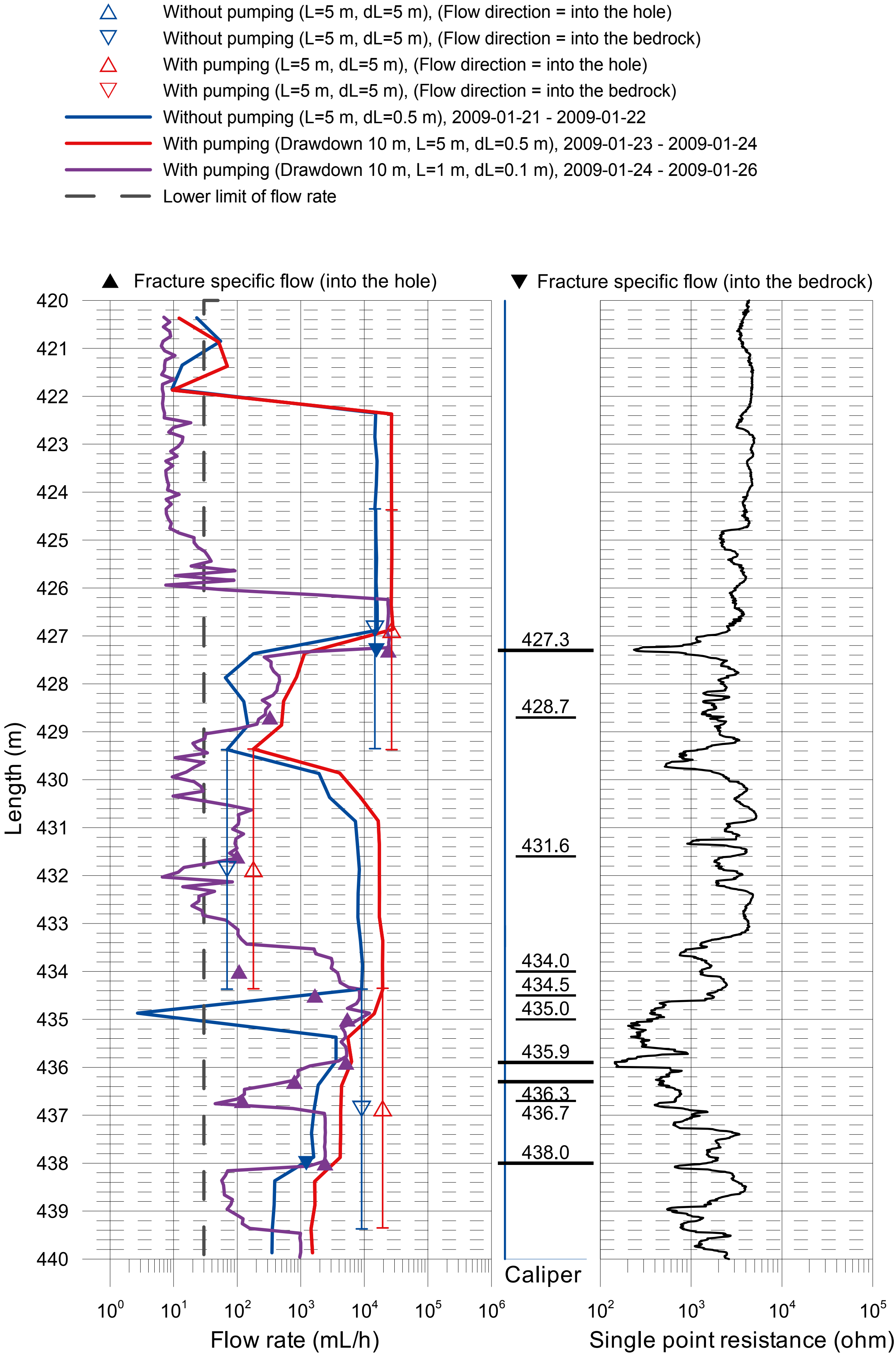
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
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)

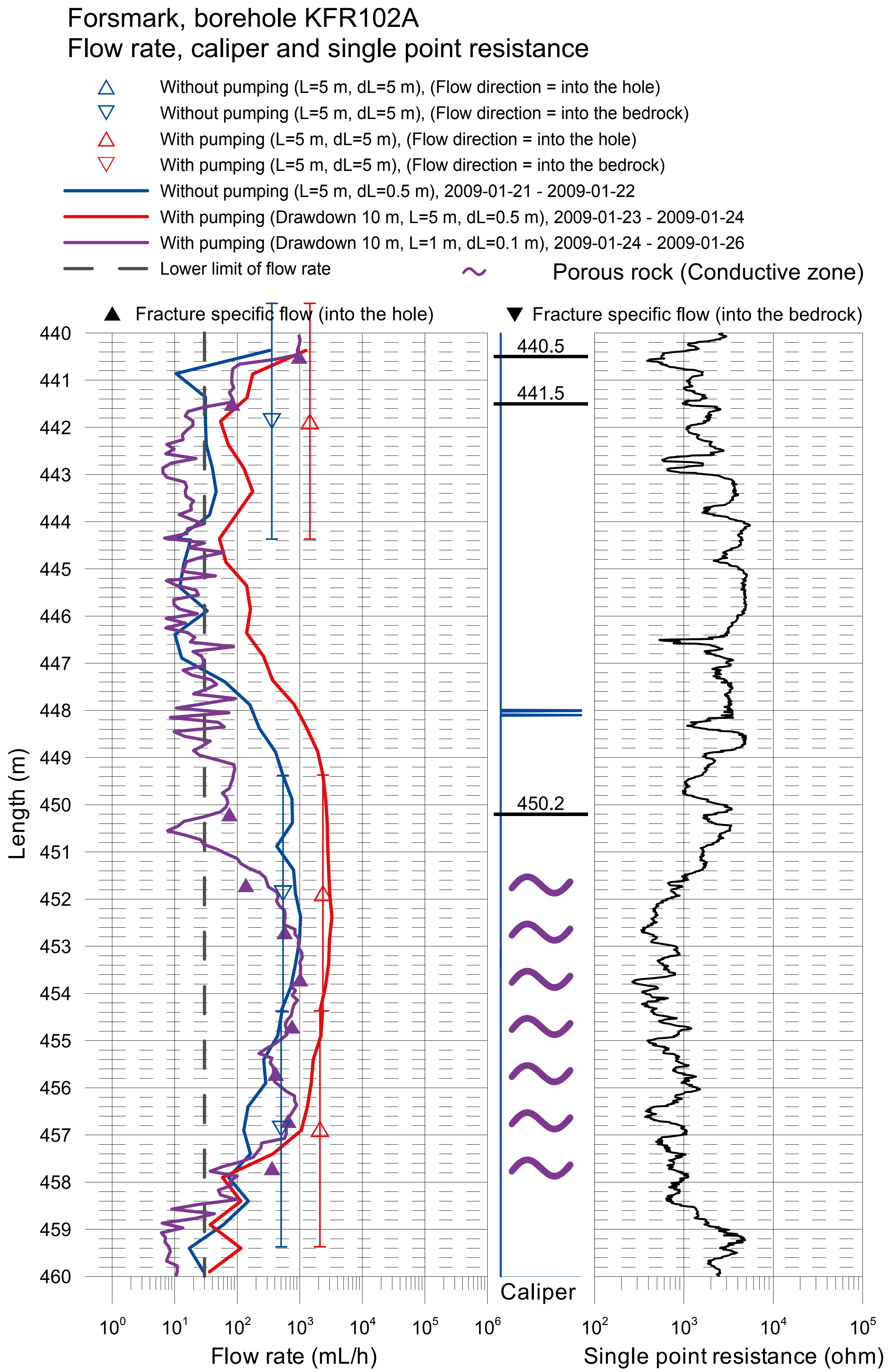

Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
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)

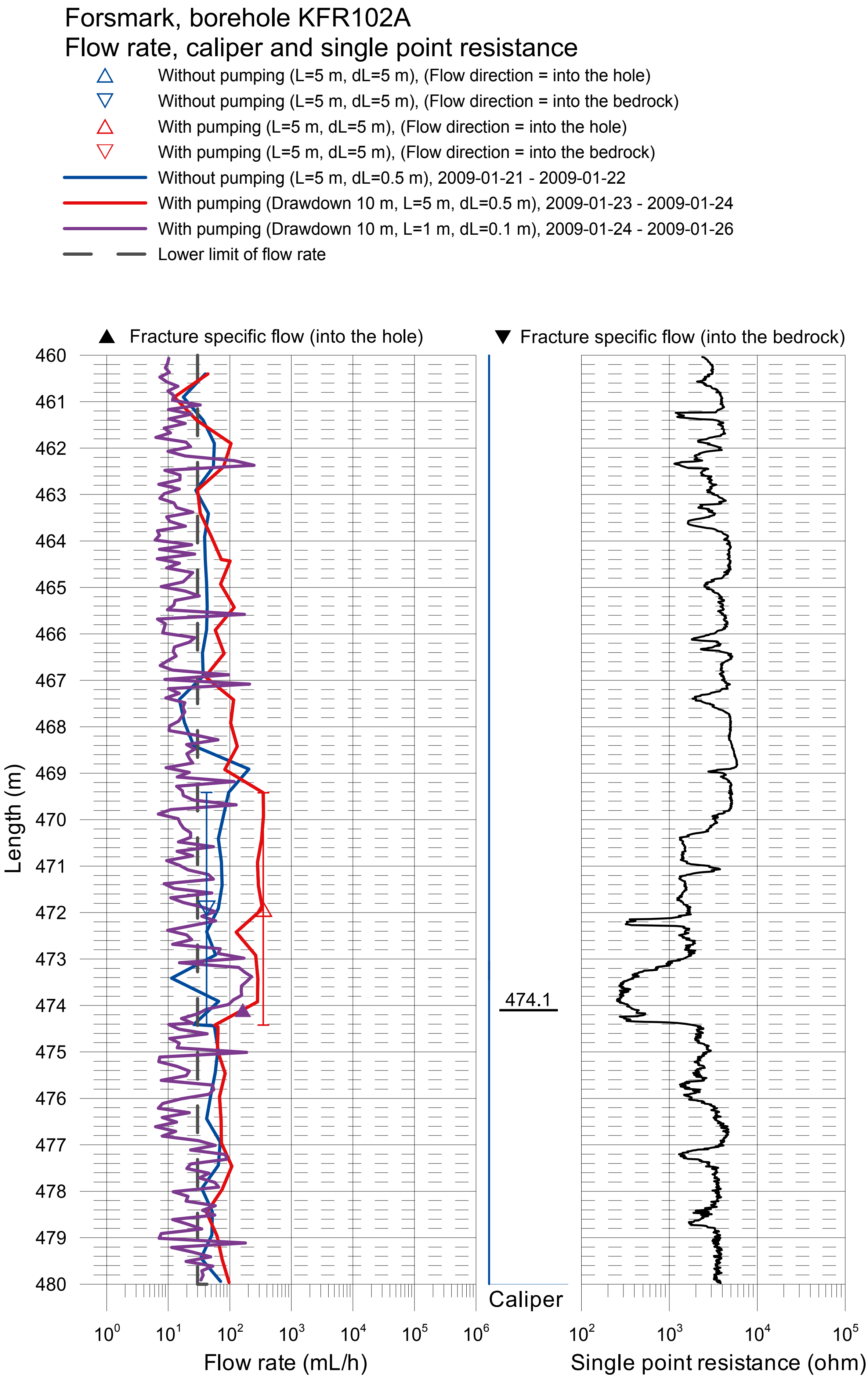
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance



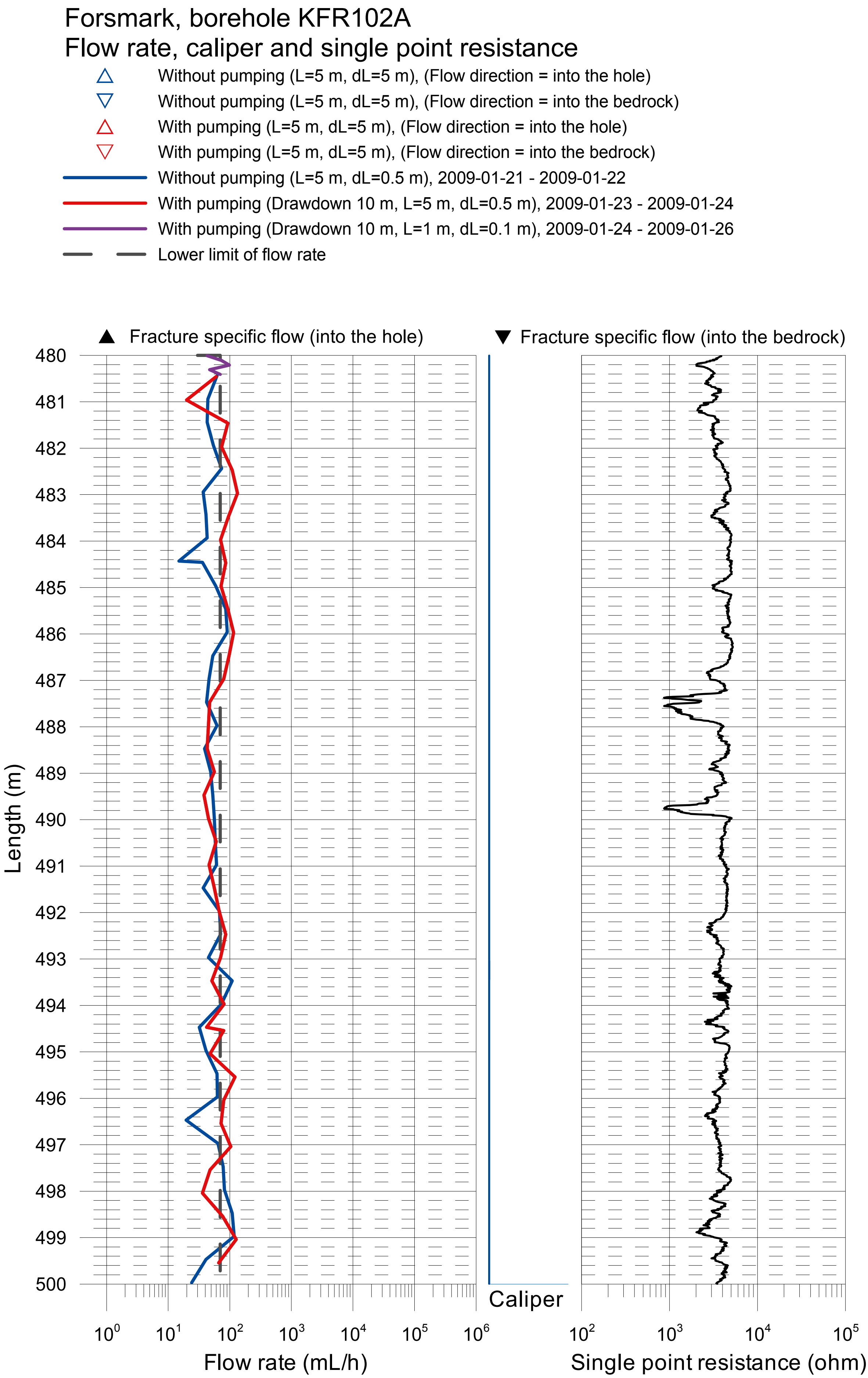
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance



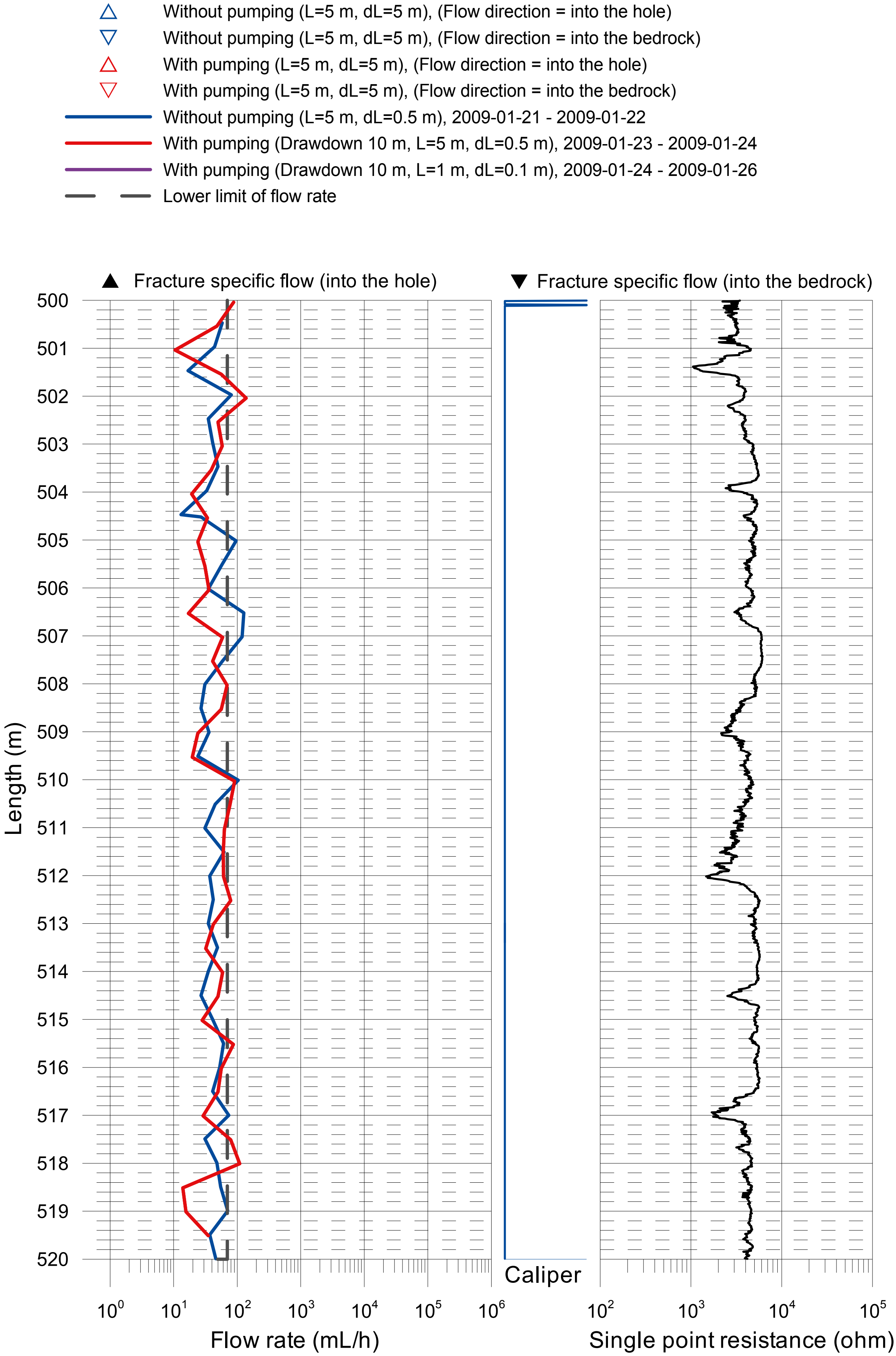

Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate
Porous rock (Conductive zone)
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
440.5
441.5
450.2
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)



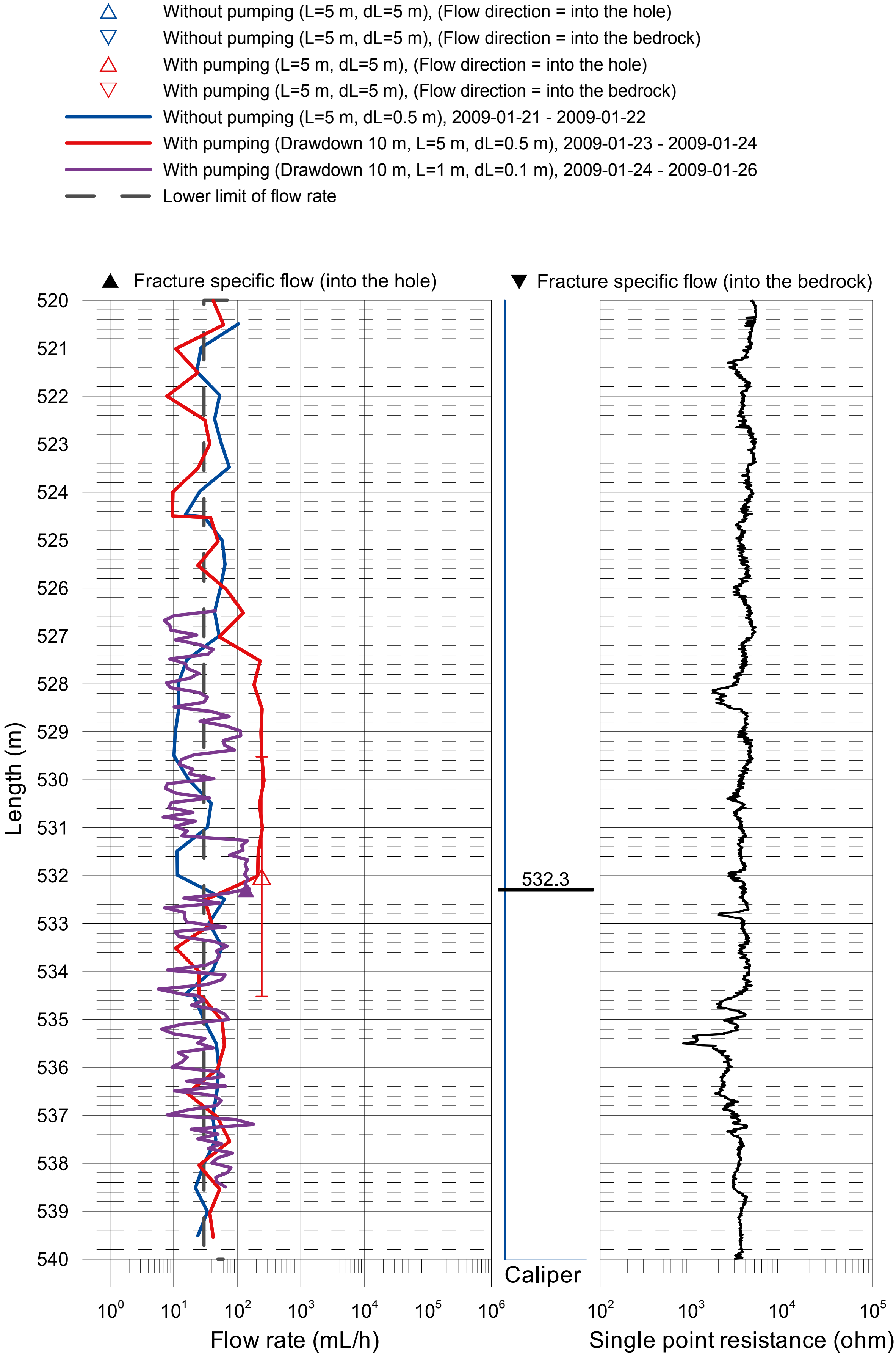
Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance
Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
474.1
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 KFR102A
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), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate
Fracture specific flow (into the hole)
Fracture specific flow (into the bedrock)
Length (m)
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
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 KFR102A
Flow rate, caliper and single point resistance

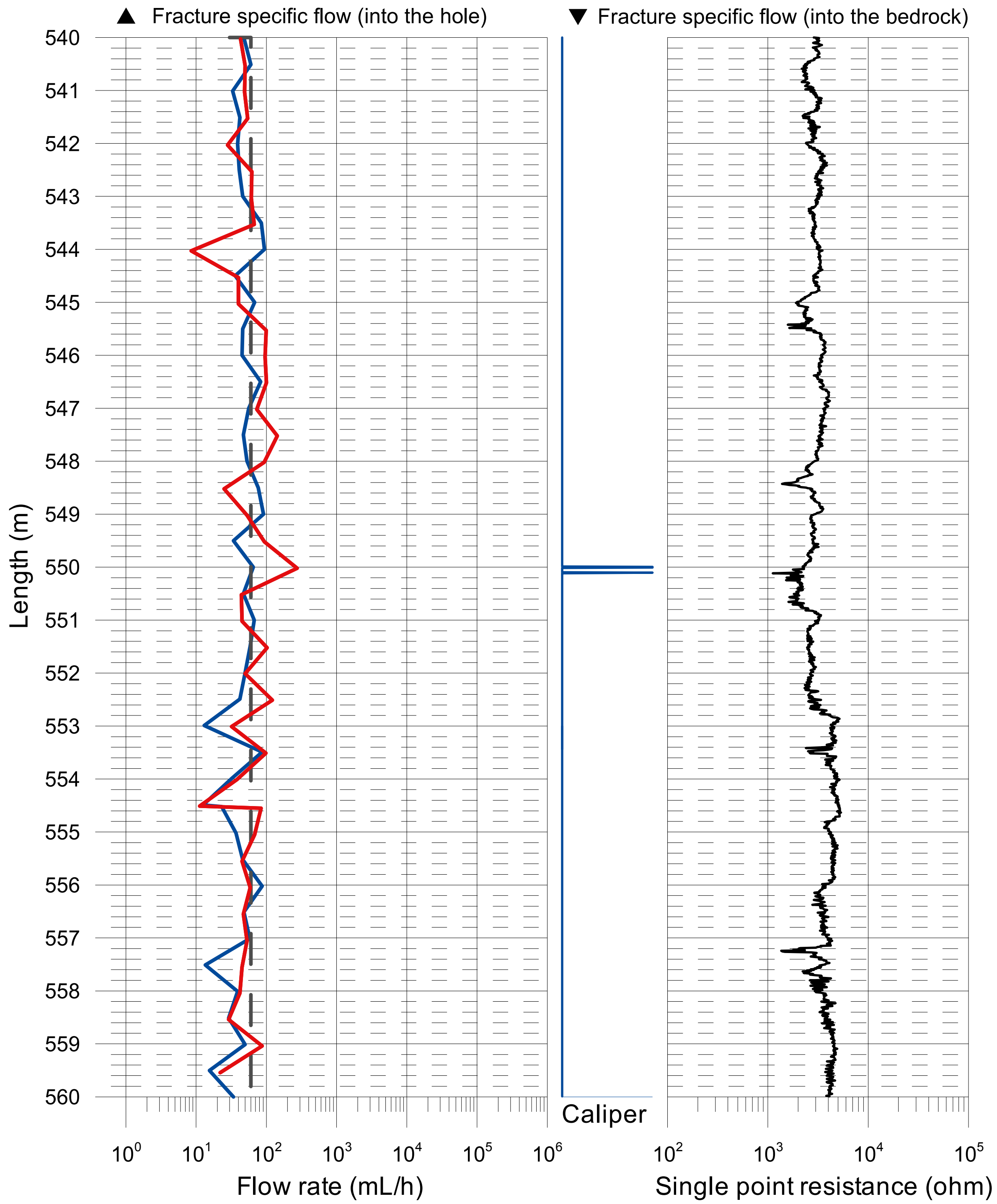


Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance

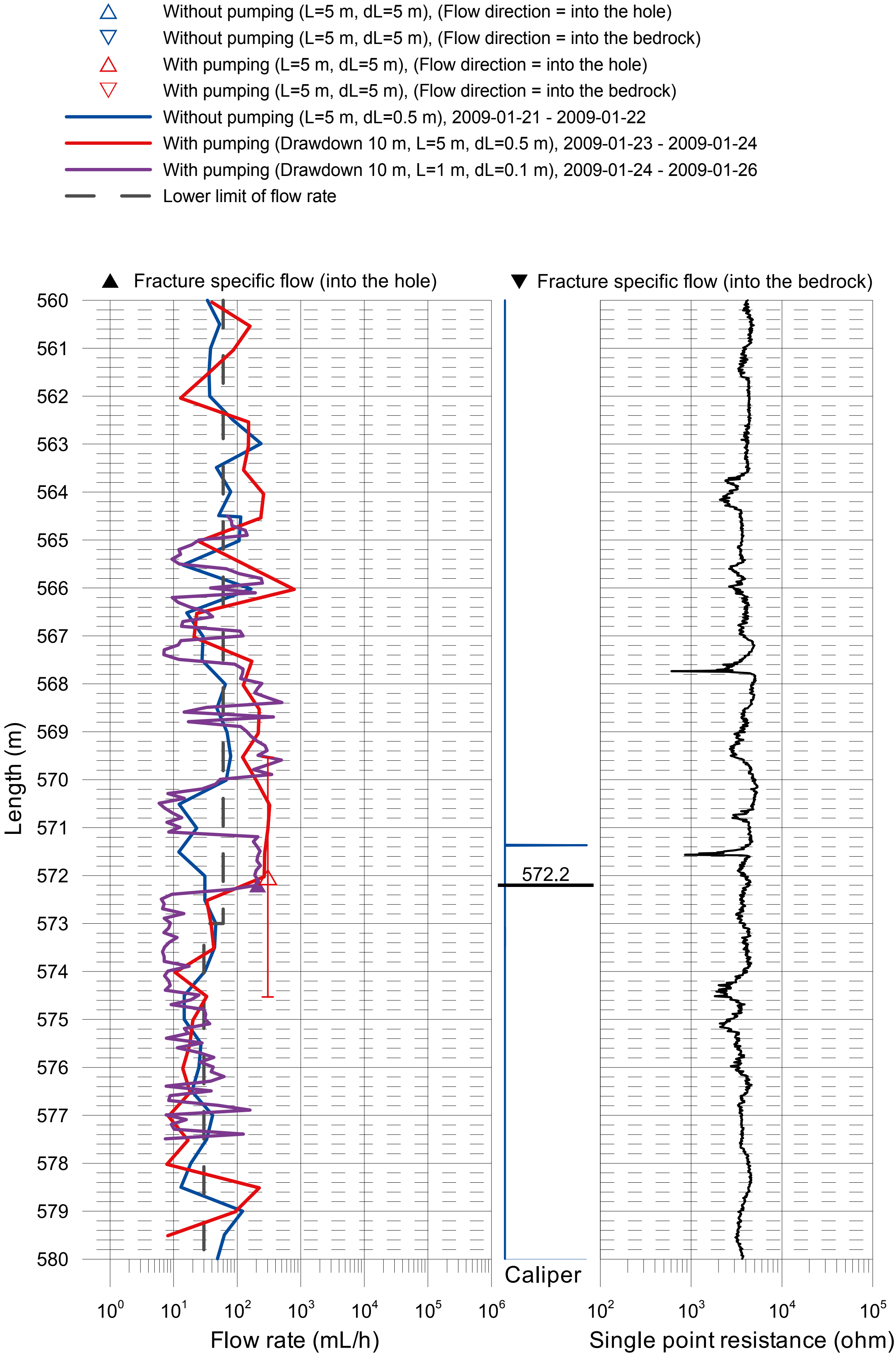


Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance

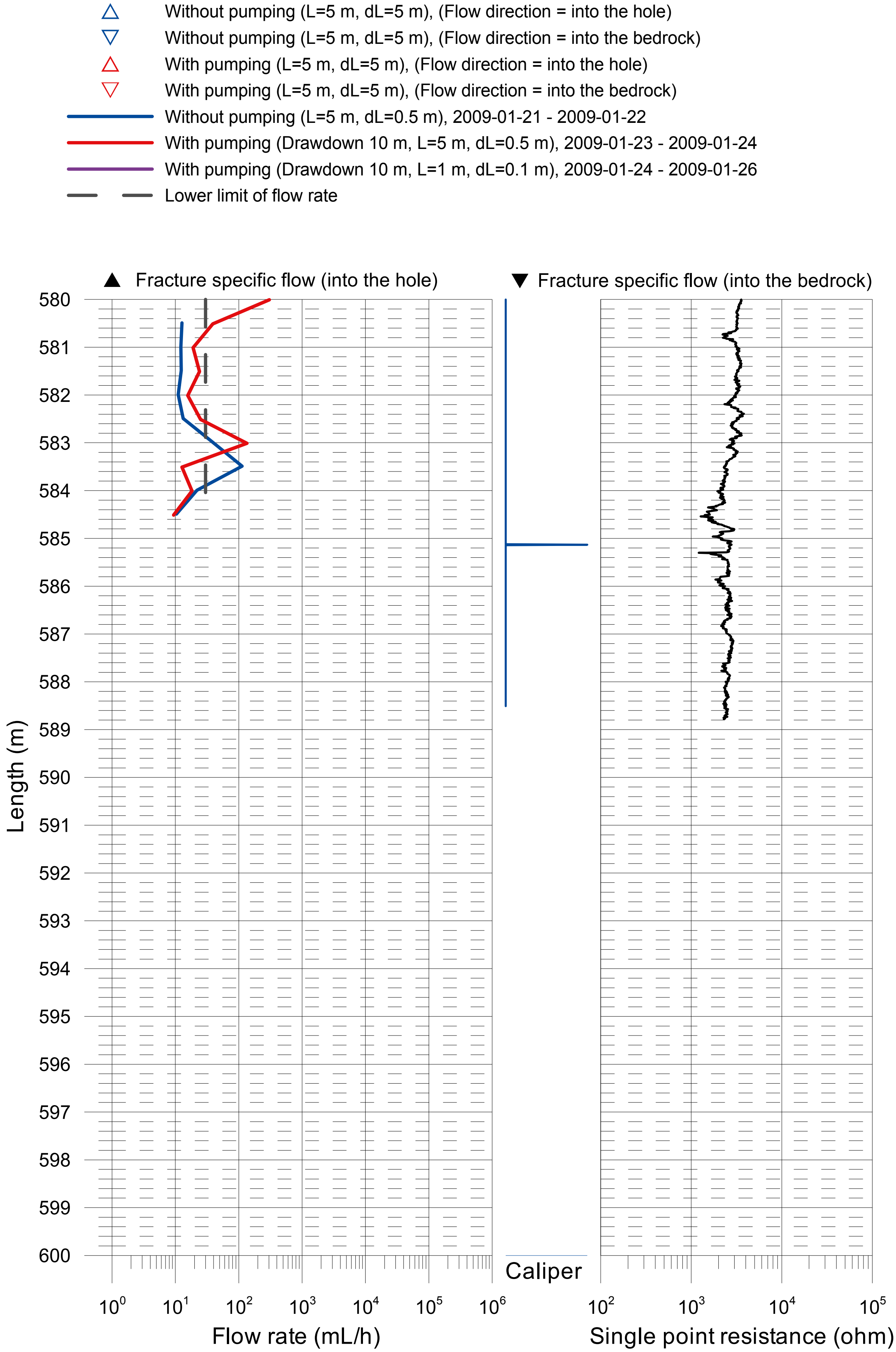
△ Without pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
▽ Without pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
△ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
▽ With pumping (L=5 m, dL=5 m), (Flow direction = into the bedrock)
Without pumping (L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (Drawdown 10 m, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
With pumping (Drawdown 10 m, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Lower limit of flow rate



Forsmark, borehole KFR102A
Flow rate, caliper and single point resistance



Forsmark, borehole KFR102A
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-$measl_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-$measl_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
T-$measl_U$	m^2/s	Estimated upper measurement limit for evaluated T_D. If the estimated T_D equals T_D-measlim, the actual T_D is considered to be equal or less than T_D-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions).

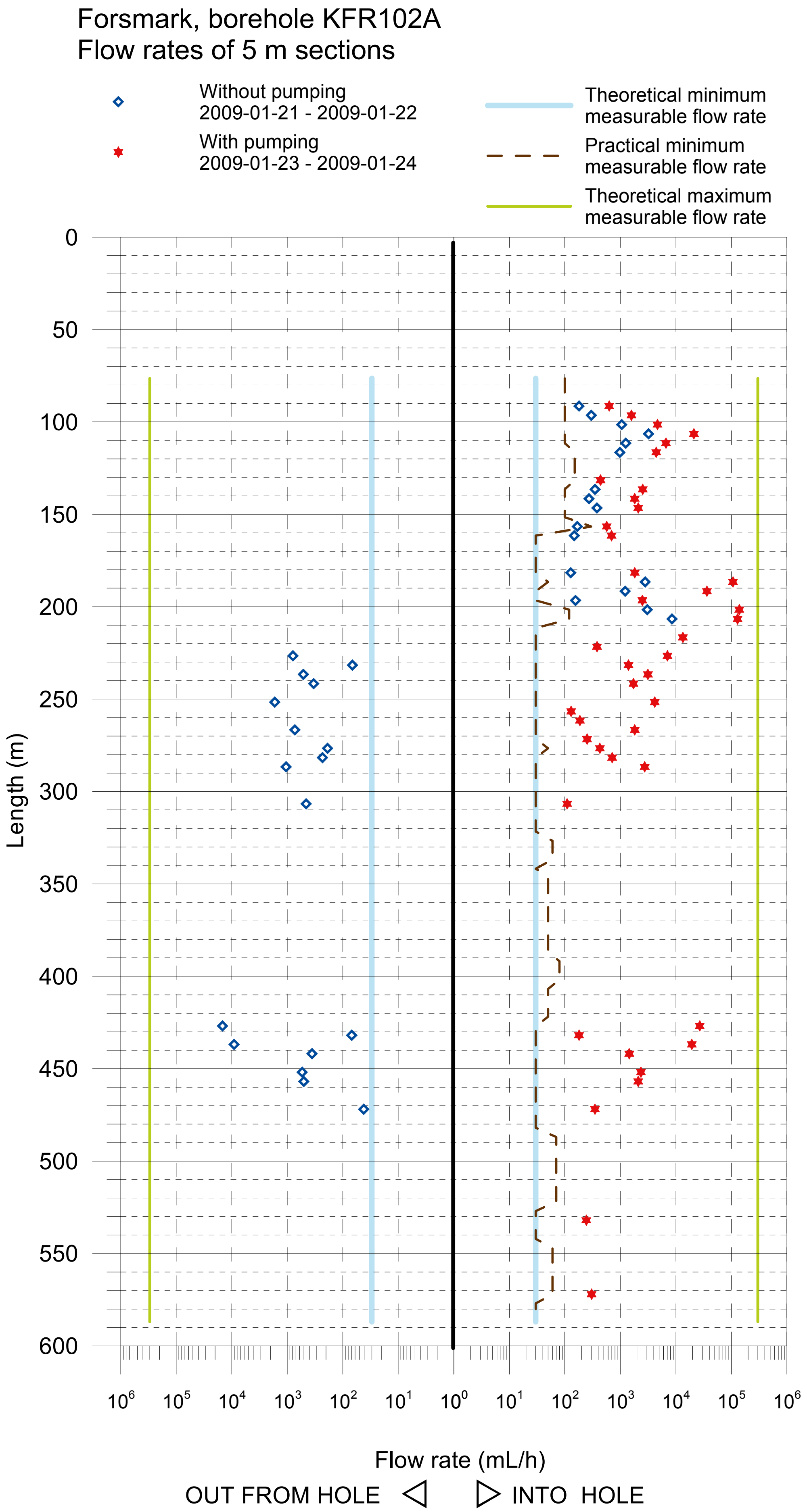
Results of sequential flow logging.

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1 (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
KFR102A	73.95	78.95	5	–	–1.81	–	–11.82	–	–	100	8.2E-10	2.7E-09	8.2E-06	
KFR102A	78.97	83.97	5	–	–1.77	–	–11.75	–	–	100	8.3E-10	2.8E-09	8.3E-06	
KFR102A	83.94	88.94	5	–	–1.74	–	–11.73	–	–	100	8.3E-10	2.8E-09	8.3E-06	
KFR102A	88.91	93.91	5	5.00E-08	–1.73	1.75E-07	–11.72	1.2E-08	2.3	100	8.3E-10	2.8E-09	8.2E-06	
KFR102A	93.93	98.93	5	8.33E-08	–1.69	4.39E-07	–11.69	3.5E-08	0.7	100	8.2E-10	2.7E-09	8.2E-06	
KFR102A	98.98	103.98	5	2.94E-07	–1.67	1.29E-06	–11.65	9.9E-08	1.3	100	8.3E-10	2.8E-09	8.2E-06	
KFR102A	103.95	108.95	5	8.92E-07	–1.66	5.86E-06	–11.61	4.9E-07	0.1	100	8.3E-10	2.8E-09	8.2E-06	
KFR102A	108.99	113.99	5	3.47E-07	–1.63	1.84E-06	–11.58	1.5E-07	0.7	100	8.3E-10	2.8E-09	8.2E-06	
KFR102A	113.99	118.99	5	2.73E-07	–1.60	1.23E-06	–11.55	9.5E-08	1.2	150	8.3E-10	4.1E-09	8.3E-06	
KFR102A	119.00	124.00	5	–	–1.58	–	–11.51	–	–	150	8.3E-10	4.2E-09	8.3E-06	
KFR102A	124.00	129.00	5	–	–1.61	–	–11.49	–	–	150	8.3E-10	4.2E-09	8.3E-06	
KFR102A	129.01	134.01	5	–	–1.61	1.22E-07	–11.48	1.2E-08	–	150	8.4E-10	4.2E-09	8.4E-06	
KFR102A	134.02	139.02	5	9.69E-08	–1.63	7.03E-07	–11.47	6.1E-08	–0.1	100	8.4E-10	2.8E-09	8.4E-06	
KFR102A	139.05	144.05	5	7.56E-08	–1.61	5.03E-07	–11.45	4.3E-08	0.1	100	8.4E-10	2.8E-09	8.4E-06	
KFR102A	144.06	149.06	5	1.05E-07	–1.58	5.83E-07	–11.43	4.8E-08	0.6	100	8.4E-10	2.8E-09	8.4E-06	
KFR102A	149.06	154.06	5	–	–1.53	–	–11.41	–	–	100	8.3E-10	2.8E-09	8.3E-06	
KFR102A	154.06	159.06	5	4.67E-08	–1.49	1.58E-07	–11.37	1.1E-08	2.7	300	8.3E-10	8.3E-09	8.3E-06	
KFR102A	159.06	164.06	5	4.11E-08	–1.45	1.93E-07	–11.35	1.5E-08	1.2	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	164.07	169.07	5	–	–1.41	–	–11.13	–	–	30	8.5E-10	8.5E-10	8.5E-06	
KFR102A	169.09	174.09	5	–	–1.38	–	–9.99	–	–	30	9.6E-10	9.6E-10	9.6E-06	
KFR102A	174.08	179.08	5	–	–1.36	–	–8.98	–	–	30	1.1E-09	1.1E-09	1.1E-05	
KFR102A	179.10	184.10	5	3.56E-08	–1.32	5.06E-07	–9.03	6.0E-08	–0.7	30	1.1E-09	1.1E-09	1.1E-05	
KFR102A	184.10	189.10	5	7.75E-07	–1.30	2.97E-05	–10.68	3.1E-06	–1.1	50	8.8E-10	1.5E-09	8.7E-06	
KFR102A	189.10	194.10	5	3.39E-07	–1.30	1.01E-05	–10.13	1.1E-06	–1.0	30	9.3E-10	9.3E-10	9.3E-06	
KFR102A	194.10	199.10	5	4.33E-08	–1.26	6.92E-07	–9.77	7.5E-08	–0.7	30	9.7E-10	9.7E-10	9.7E-06	
KFR102A	199.11	204.11	5	8.47E-07	–1.25	3.86E-05	–10.87	3.9E-06	–1.0	120	8.6E-10	3.4E-09	8.5E-06	
KFR102A	204.15	209.15	5	2.37E-06	–1.21	3.58E-05	–11.12	3.3E-06	–0.5	120	8.3E-10	3.3E-09	8.1E-06	

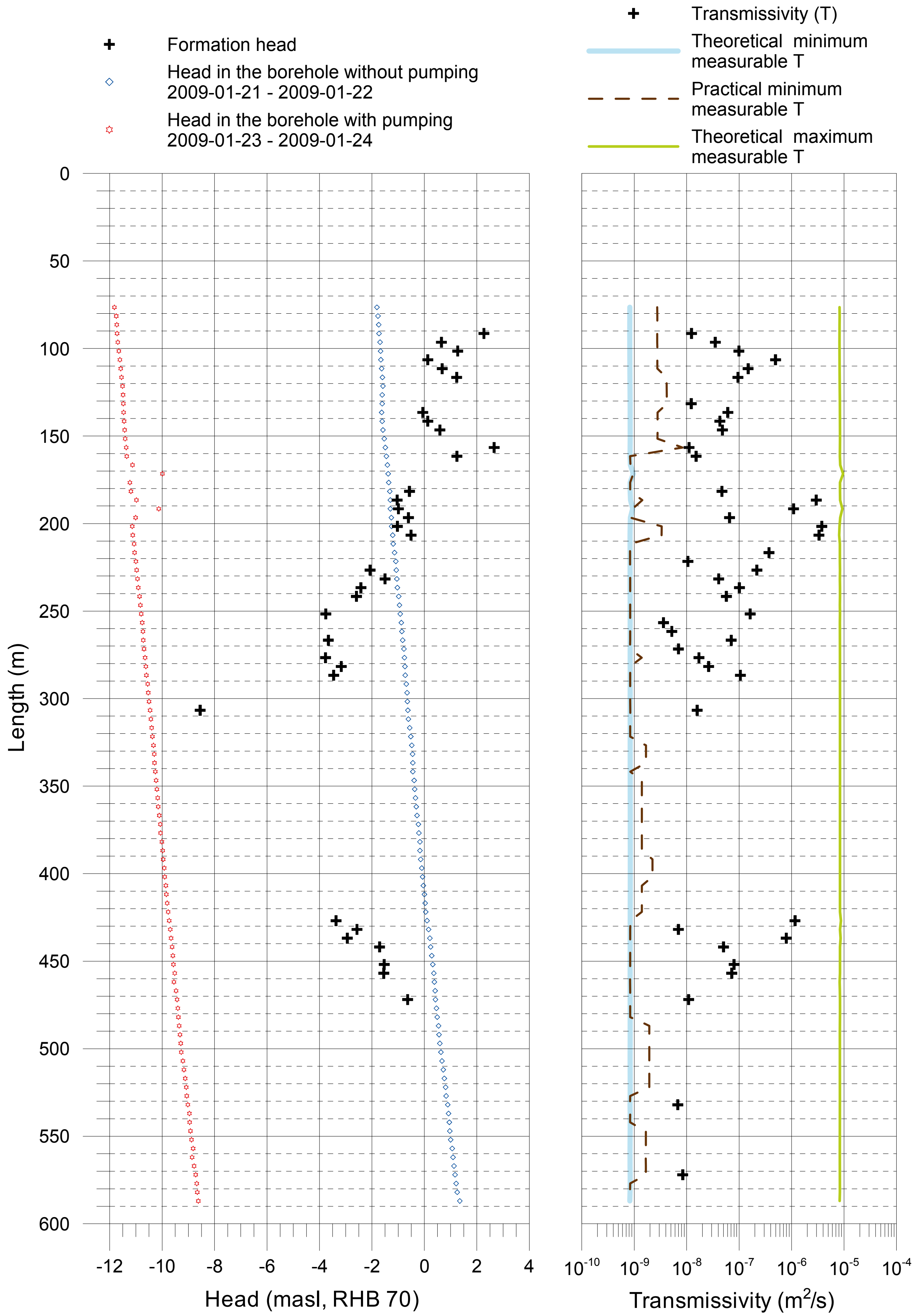
Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1 (m^3/s)	h_{1FW} (masl)	T_D (m^2/s)	h_i (masl)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D- measl$_{LP}$ (m^2/s)	T_D- measl$_U$ (m^2/s)	Comments
KFR102A	209.14	214.14	5	–	–1.19	–	–11.07	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	214.13	219.13	5	–	–1.14	3.72E-06	–11.05	3.7E-07	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	219.12	224.12	5	–	–1.09	1.06E-07	–11.00	1.1E-08	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	224.11	229.11	5	–2.19E-07	–1.07	1.96E-06	–10.97	2.2E-07	–2.1	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	229.13	234.13	5	–1.86E-08	–1.05	3.89E-07	–10.94	4.1E-08	–1.5	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	234.12	239.12	5	–1.43E-07	–1.03	8.69E-07	–10.91	1.0E-07	–2.4	30	8.3E-10	8.3E-10	8.4E-06	
KFR102A	239.12	244.12	5	–9.28E-08	–0.98	4.78E-07	–10.86	5.7E-08	–2.6	30	8.3E-10	8.3E-10	8.4E-06	
KFR102A	244.12	249.12	5	–	–0.95	–	–10.83	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	249.13	254.13	5	–4.67E-07	–0.92	1.16E-06	–10.80	1.6E-07	–3.8	30	8.3E-10	8.3E-10	8.4E-06	
KFR102A	254.13	259.13	5	–	–0.88	3.61E-08	–10.76	3.6E-09	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	259.14	264.14	5	–	–0.86	5.19E-08	–10.73	5.2E-09	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	264.14	269.14	5	–2.03E-07	–0.83	5.06E-07	–10.72	7.1E-08	–3.7	30	8.3E-10	8.3E-10	8.4E-06	
KFR102A	269.15	274.15	5	–	–0.78	6.97E-08	–10.69	7.0E-09	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	274.14	279.14	5	–5.22E-08	–0.76	1.19E-07	–10.65	1.7E-08	–3.8	50	8.3E-10	1.4E-09	8.3E-06	
KFR102A	279.17	284.17	5	–6.44E-08	–0.74	1.98E-07	–10.62	2.6E-08	–3.2	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	284.16	289.16	5	–2.92E-07	–0.73	7.64E-07	–10.60	1.1E-07	–3.5	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	289.16	294.16	5	–	–0.69	–	–10.55	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	294.16	299.16	5	–	–0.66	–	–10.53	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	299.16	304.16	5	–	–0.65	–	–10.50	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	304.17	309.17	5	–1.27E-07	–0.63	3.06E-08	–10.46	1.6E-08	–8.6	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	309.21	314.21	5	–	–0.61	–	–10.43	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	314.20	319.20	5	–	–0.56	–	–10.40	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	319.20	324.20	5	–	–0.52	–	–10.37	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	324.20	329.20	5	–	–0.48	–	–10.33	–	–	60	8.4E-10	1.7E-09	8.4E-06	
KFR102A	329.23	334.23	5	–	–0.45	–	–10.30	–	–	60	8.4E-10	1.7E-09	8.4E-06	
KFR102A	334.22	339.22	5	–	–0.44	–	–10.29	–	–	60	8.4E-10	1.7E-09	8.4E-06	
KFR102A	339.23	344.23	5	–	–0.44	–	–10.26	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	344.24	349.24	5	–	–0.39	–	–10.23	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	349.27	354.27	5	–	–0.37	–	–10.20	–	–	50	8.4E-10	1.4E-09	8.4E-06	

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
KFR102A	354.26	359.26	5	–	–0.34	–	–10.17	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	359.27	364.27	5	–	–0.31	–	–10.15	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	364.27	369.27	5	–	–0.28	–	–10.11	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	369.30	374.30	5	–	–0.23	–	–10.07	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	374.29	379.29	5	–	–0.21	–	–10.06	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	379.32	384.32	5	–	–0.17	–	–10.01	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	384.32	389.32	5	–	–0.17	–	–9.98	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	389.33	394.33	5	–	–0.14	–	–9.96	–	–	80	8.4E-10	2.2E-09	8.4E-06	
KFR102A	394.32	399.32	5	–	–0.10	–	–9.92	–	–	80	8.4E-10	2.2E-09	8.4E-06	
KFR102A	399.34	404.34	5	–	–0.07	–	–9.90	–	–	80	8.4E-10	2.2E-09	8.4E-06	
KFR102A	404.33	409.33	5	–	–0.04	–	–9.86	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	409.35	414.35	5	–	0.00	–	–9.84	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	414.34	419.34	5	–	0.03	–	–9.81	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	419.37	424.37	5	–	0.05	–	–9.77	–	–	50	8.4E-10	1.4E-09	8.4E-06	
KFR102A	424.36	429.36	5	–4.08E-06	0.10	7.47E-06	–9.73	1.2E-06	–3.4	30	8.4E-10	8.4E-10	8.8E-06	
KFR102A	429.37	434.37	5	–1.92E-08	0.16	5.00E-08	–9.69	6.9E-09	–2.6	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	434.36	439.36	5	–2.52E-06	0.21	5.39E-06	–9.66	7.9E-07	–2.9	30	8.4E-10	8.4E-10	8.6E-06	
KFR102A	439.37	444.37	5	–9.94E-08	0.24	4.03E-07	–9.62	5.0E-08	–1.7	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	444.36	449.36	5	–	0.28	–	–9.59	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	449.38	454.38	5	–1.50E-07	0.32	6.53E-07	–9.57	8.0E-08	–1.5	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	454.37	459.37	5	–1.40E-07	0.36	5.83E-07	–9.52	7.2E-08	–1.6	30	8.3E-10	8.3E-10	8.4E-06	
KFR102A	459.40	464.40	5	–	0.38	–	–9.55	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	464.41	469.41	5	–	0.41	–	–9.47	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	469.42	474.42	5	–1.17E-08	0.42	9.69E-08	–9.43	1.1E-08	–0.6	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	474.42	479.42	5	–	0.46	–	–9.40	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	479.45	484.45	5	–	0.49	–	–9.38	–	–	30	8.4E-10	8.4E-10	8.4E-06	
KFR102A	484.45	489.45	5	–	0.54	–	–9.35	–	–	70	8.3E-10	1.9E-09	8.3E-06	
KFR102A	489.47	494.47	5	–	0.56	–	–9.32	–	–	70	8.3E-10	1.9E-09	8.3E-06	
KFR102A	494.47	499.47	5	–	0.59	–	–9.29	–	–	70	8.3E-10	1.9E-09	8.3E-06	

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
KFR102A	499.51	504.51	5	–	0.63	–	–9.27	–	–	70	8.3E-10	1.9E-09	8.3E-06	
KFR102A	504.51	509.51	5	–	0.67	–	–9.21	–	–	70	8.3E-10	1.9E-09	8.3E-06	
KFR102A	509.52	514.52	5	–	0.72	–	–9.17	–	–	70	8.3E-10	1.9E-09	8.3E-06	
KFR102A	514.51	519.51	5	–	0.76	–	–9.12	–	–	70	8.3E-10	1.9E-09	8.3E-06	
KFR102A	519.50	524.50	5	–	0.81	–	–9.08	–	–	70	8.3E-10	1.9E-09	8.3E-06	
KFR102A	524.49	529.49	5	–	0.83	–	–9.06	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	529.51	534.51	5	–	0.89	6.78E-08	–9.02	6.8E-09	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	534.51	539.51	5	–	0.92	–	–8.96	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	539.53	544.53	5	–	0.95	–	–8.95	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	544.52	549.52	5	–	0.97	–	–8.92	–	–	60	8.3E-10	1.7E-09	8.3E-06	
KFR102A	549.51	554.51	5	–	1.00	–	–8.88	–	–	60	8.3E-10	1.7E-09	8.3E-06	
KFR102A	554.52	559.52	5	–	1.06	–	–8.82	–	–	60	8.3E-10	1.7E-09	8.3E-06	
KFR102A	559.52	564.52	5	–	1.09	–	–8.86	–	–	60	8.3E-10	1.7E-09	8.3E-06	
KFR102A	564.52	569.52	5	–	1.13	–	–8.78	–	–	60	8.3E-10	1.7E-09	8.3E-06	
KFR102A	569.52	574.52	5	–	1.17	8.42E-08	–8.72	8.4E-09	–	60	8.3E-10	1.7E-09	8.3E-06	
KFR102A	574.51	579.51	5	–	1.21	–	–8.68	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	579.50	584.50	5	–	1.25	–	–8.66	–	–	30	8.3E-10	8.3E-10	8.3E-06	
KFR102A	584.50	589.50	5	–	1.35	–	–8.62	–	–	30	8.3E-10	8.3E-10	8.3E-06	


Forsmark, borehole KFR102A
Flow rates of 5 m sections
Without pumping
2009-01-21 - 2009-01-22
With pumping
2009-01-23 - 2009-01-24
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
500
550
600
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 KFR102A
Transmissivity and head of 5 m sections



Inferred flow anomalies from overlapping flow logging.

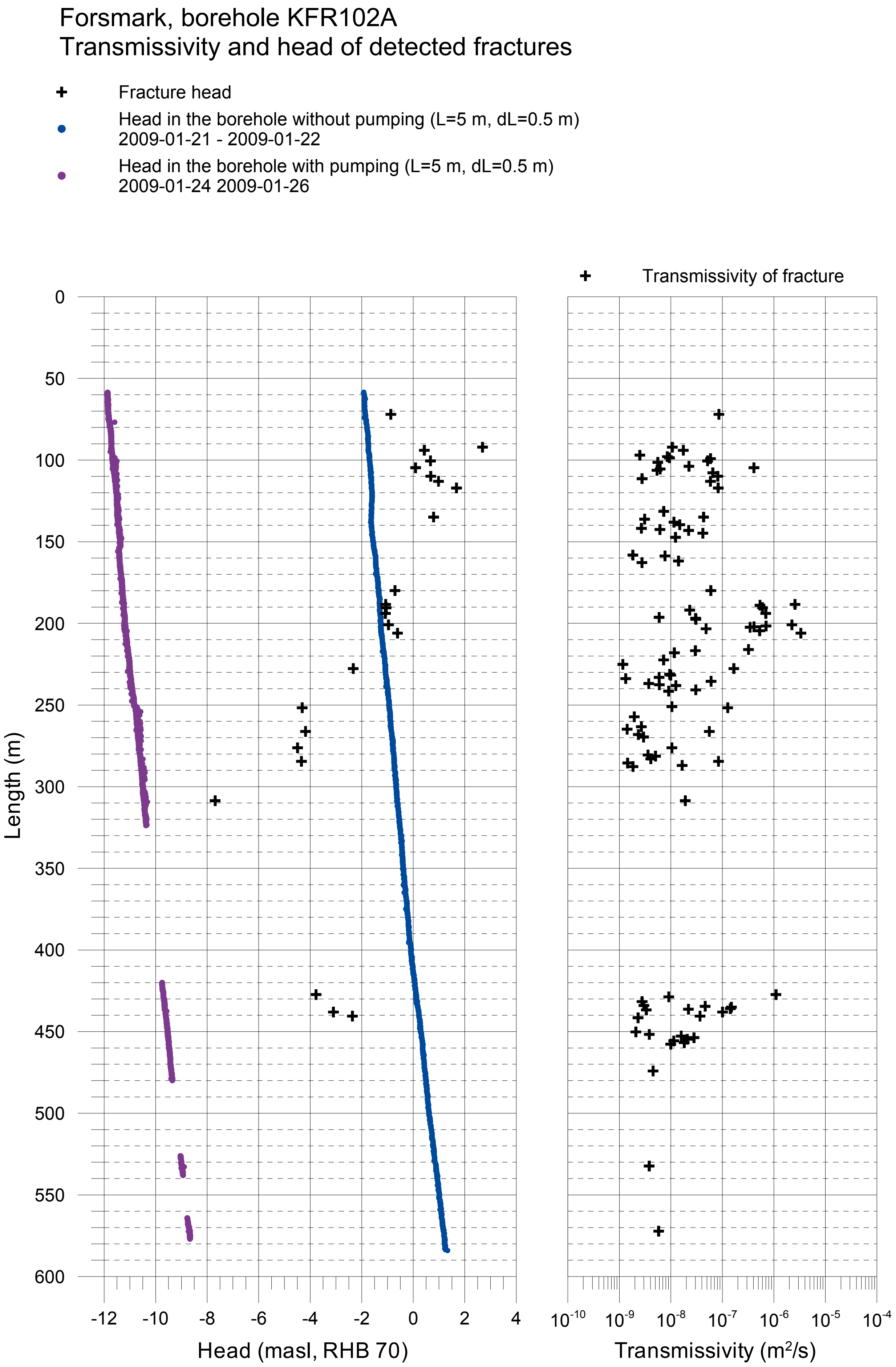
Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1 (m^3/s)	h_{1FW} (masl)	T_D (m^2/s)	h_i (masl)	Comments
KFR102A	72.0	1	0.1	8.58E-08	–1.86	9.53E-07	–11.87	8.6E-08	–0.9	*
KFR102A	92.1	1	0.1	4.81E-08	–1.74	1.56E-07	–11.73	1.1E-08	2.7	
KFR102A	94.0	1	0.1	3.86E-08	–1.75	2.15E-07	–11.73	1.8E-08	0.4	*
KFR102A	97.0	1	0.1	–	–1.70	2.53E-08	–11.69	2.5E-09	–	*
KFR102A	97.9	1	0.1	–	–1.70	8.64E-08	–11.68	8.6E-09	–	
KFR102A	98.6	1	0.1	–	–1.71	9.44E-08	–11.68	9.4E-09	–	*
KFR102A	99.1	1	0.1	–	–1.71	5.94E-07	–11.67	5.9E-08	–	
KFR102A	100.5	1	0.1	1.24E-07	–1.69	6.47E-07	–11.68	5.2E-08	0.7	
KFR102A	101.4	1	0.1	–	–1.68	5.64E-08	–11.66	5.6E-09	–	
KFR102A	103.8	1	0.1	–	–1.67	2.26E-07	–11.62	2.3E-08	–	
KFR102A	104.7	1	0.1	7.31E-07	–1.67	4.86E-06	–11.63	4.1E-07	0.1	
KFR102A	105.5	1	0.1	–	–1.65	6.25E-08	–11.62	6.2E-09	–	*
KFR102A	106.3	1	0.1	–	–1.67	5.42E-08	–11.62	5.4E-09	–	*
KFR102A	107.8	1	0.1	–	–1.64	6.56E-07	–11.60	6.5E-08	–	
KFR102A	109.9	1	0.1	1.92E-07	–1.64	1.01E-06	–11.59	8.2E-08	0.7	
KFR102A	111.4	1	0.1	–	–1.63	2.78E-08	–11.60	2.8E-09	–	*
KFR102A	113.0	1	0.1	1.55E-07	–1.63	7.44E-07	–11.57	5.9E-08	1.0	
KFR102A	117.1	1	0.1	2.78E-07	–1.63	1.11E-06	–11.56	8.3E-08	1.7	
KFR102A	131.4	1	0.1	–	–1.62	7.25E-08	–11.49	7.3E-09	–	*
KFR102A	134.9	1	0.1	1.06E-07	–1.63	5.36E-07	–11.47	4.3E-08	0.8	
KFR102A	136.2	1	0.1	–	–1.63	3.08E-08	–11.47	3.1E-09	–	*
KFR102A	138.0	1	0.1	–	–1.64	1.14E-07	–11.47	1.2E-08	–	
KFR102A	139.6	1	0.1	–	–1.62	1.48E-07	–11.46	1.5E-08	–	
KFR102A	141.8	1	0.1	–	–1.62	2.67E-08	–11.46	2.7E-09	–	*
KFR102A	142.5	1	0.1	–	–1.61	6.11E-08	–11.45	6.1E-09	–	
KFR102A	143.1	1	0.1	–	–1.61	2.21E-07	–11.46	2.2E-08	–	
KFR102A	144.8	1	0.1	–	–1.59	4.17E-07	–11.44	4.2E-08	–	
KFR102A	147.3	1	0.1	–	–1.58	1.22E-07	–11.43	1.2E-08	–	*
KFR102A	158.2	1	0.1	–	–1.48	1.83E-08	–11.38	1.8E-09	–	*
KFR102A	158.7	1	0.1	–	–1.46	7.72E-08	–11.38	7.7E-09	–	
KFR102A	161.8	1	0.1	–	–1.46	1.41E-07	–11.36	1.4E-08	–	
KFR102A	162.8	1	0.1	–	–1.45	2.75E-08	–11.36	2.8E-09	–	*
KFR102A	179.9	1	0.1	3.78E-08	–1.33	4.83E-07	–8.70	6.0E-08	–0.7	
KFR102A	188.4	1	0.1	5.72E-07	–1.29	2.06E-05	–8.97	2.6E-06	–1.1	
KFR102A	188.9	1	0.1	–	–1.30	4.17E-06	–8.98	5.4E-07	–	
KFR102A	190.4	1	0.1	1.53E-07	–1.30	4.86E-06	–9.04	6.0E-07	–1.1	
KFR102A	191.9	1	0.1	–	–1.31	1.84E-07	–9.12	2.3E-08	–	
KFR102A	193.9	1	0.1	1.47E-07	–1.29	5.75E-06	–9.24	7.0E-07	–1.1	
KFR102A	196.3	1	0.1	–	–1.26	4.94E-08	–9.51	5.9E-09	–	*
KFR102A	196.9	1	0.1	–	–1.27	2.54E-07	–9.61	3.0E-08	–	
KFR102A	197.5	1	0.1	–	–1.26	2.62E-07	–9.73	3.1E-08	–	
KFR102A	200.9	1	0.1	6.47E-07	–1.25	2.30E-05	–11.15	2.2E-06	–1.0	
KFR102A	201.6	1	0.1	–	–1.26	7.03E-06	–11.14	7.0E-07	–	*
KFR102A	202.1	1	0.1	–	–1.27	4.11E-06	–11.15	4.1E-07	–	*
KFR102A	202.4	1	0.1	–	–1.26	3.47E-06	–11.15	3.5E-07	–	*

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
KFR102A	203.3	1	0.1	–	–1.25	4.83E-07	–11.15	4.8E-08	–	
KFR102A	204.5	1	0.1	–	–1.24	5.31E-06	–11.14	5.3E-07	–	
KFR102A	206.0	1	0.1	2.14E-06	–1.24	3.56E-05	–11.12	3.4E-06	–0.6	
KFR102A	216.0	1	0.1	–	–1.16	3.22E-06	–11.09	3.2E-07	–	
KFR102A	216.7	1	0.1	–	–1.15	3.00E-07	–11.06	3.0E-08	–	
KFR102A	218.0	1	0.1	–	–1.14	1.17E-07	–11.04	1.2E-08	–	*
KFR102A	222.4	1	0.1	–	–1.11	7.25E-08	–11.02	7.2E-09	–	
KFR102A	225.1	1	0.1	–	–1.09	1.17E-08	–10.99	1.2E-09	–	*
KFR102A	227.7	1	0.1	–2.10E-07	–1.09	1.46E-06	–10.97	1.7E-07	–2.3	
KFR102A	231.2	1	0.1	–	–1.08	9.44E-08	–10.96	9.5E-09	–	*
KFR102A	231.7	1	0.1	–	–1.06	9.92E-08	–10.95	9.9E-09	–	*
KFR102A	233.1	1	0.1	–	–1.04	5.92E-08	–10.95	5.9E-09	–	
KFR102A	233.8	1	0.1	–	–1.05	1.33E-08	–10.94	1.3E-09	–	*
KFR102A	235.5	1	0.1	–	–1.03	6.03E-07	–10.92	6.0E-08	–	
KFR102A	236.9	1	0.1	–	–1.03	3.72E-08	–10.92	3.7E-09	–	
KFR102A	237.6	1	0.1	–	–1.01	6.00E-08	–10.94	6.0E-09	–	*
KFR102A	238.1	1	0.1	–	–1.03	1.25E-07	–10.92	1.3E-08	–	
KFR102A	240.7	1	0.1	–	–0.99	3.06E-07	–10.89	3.1E-08	–	
KFR102A	241.5	1	0.1	–	–0.99	9.06E-08	–10.87	9.1E-09	–	
KFR102A	251.0	1	0.1	–	–0.93	1.05E-07	–10.82	1.1E-08	–	
KFR102A	251.7	1	0.1	–4.33E-07	–0.93	8.33E-07	–10.81	1.3E-07	–4.3	
KFR102A	257.2	1	0.1	–	–0.91	1.94E-08	–10.78	2.0E-09	–	*
KFR102A	263.3	1	0.1	–	–0.87	2.67E-08	–10.74	2.7E-09	–	*
KFR102A	264.8	1	0.1	–	–0.86	1.42E-08	–10.73	1.4E-09	–	*
KFR102A	266.2	1	0.1	–1.88E-07	–0.85	3.72E-07	–10.77	5.6E-08	–4.2	
KFR102A	268.1	1	0.1	–	–0.83	2.33E-08	–10.71	2.3E-09	–	*
KFR102A	269.6	1	0.1	–	–0.81	2.94E-08	–10.70	3.0E-09	–	*
KFR102A	276.2	1	0.1	–3.92E-08	–0.79	6.56E-08	–10.68	1.1E-08	–4.5	
KFR102A	280.6	1	0.1	–	–0.75	3.61E-08	–10.64	3.6E-09	–	
KFR102A	281.3	1	0.1	–	–0.75	5.03E-08	–10.63	5.0E-09	–	
KFR102A	282.9	1	0.1	–	–0.75	4.06E-08	–10.61	4.1E-09	–	*
KFR102A	284.5	1	0.1	–3.06E-07	–0.74	5.33E-07	–10.61	8.4E-08	–4.3	
KFR102A	285.5	1	0.1	–	–0.74	1.44E-08	–10.61	1.5E-09	–	*
KFR102A	287.0	1	0.1	–	–0.73	1.66E-07	–10.60	1.7E-08	–	
KFR102A	287.7	1	0.1	–	–0.71	1.83E-08	–10.59	1.8E-09	–	*
KFR102A	308.6	1	0.1	–1.36E-07	–0.64	5.36E-08	–10.46	1.9E-08	–7.7	*
KFR102A	427.3	1	0.1	–4.31E-06	0.11	6.61E-06	–9.72	1.1E-06	–3.8	
KFR102A	428.7	1	0.1	–	0.12	9.08E-08	–9.73	9.1E-09	–	*
KFR102A	431.6	1	0.1	–	0.16	2.75E-08	–9.71	2.8E-09	–	*
KFR102A	434.0	1	0.1	–	0.16	2.97E-08	–9.67	3.0E-09	–	*
KFR102A	434.5	1	0.1	–	0.18	4.64E-07	–9.69	4.7E-08	–	*
KFR102A	435.0	1	0.1	–	0.17	1.50E-06	–9.70	1.5E-07	–	*
KFR102A	435.9	1	0.1	–	0.19	1.43E-06	–9.69	1.4E-07	–	
KFR102A	436.3	1	0.1	–	0.19	2.19E-07	–9.68	2.2E-08	–	
KFR102A	436.7	1	0.1	–	0.20	3.33E-08	–9.67	3.3E-09	–	*
KFR102A	438.0	1	0.1	–3.39E-07	0.22	6.69E-07	–9.66	1.0E-07	–3.1	
KFR102A	440.5	1	0.1	–9.67E-08	0.23	2.71E-07	–9.63	3.7E-08	–2.4	

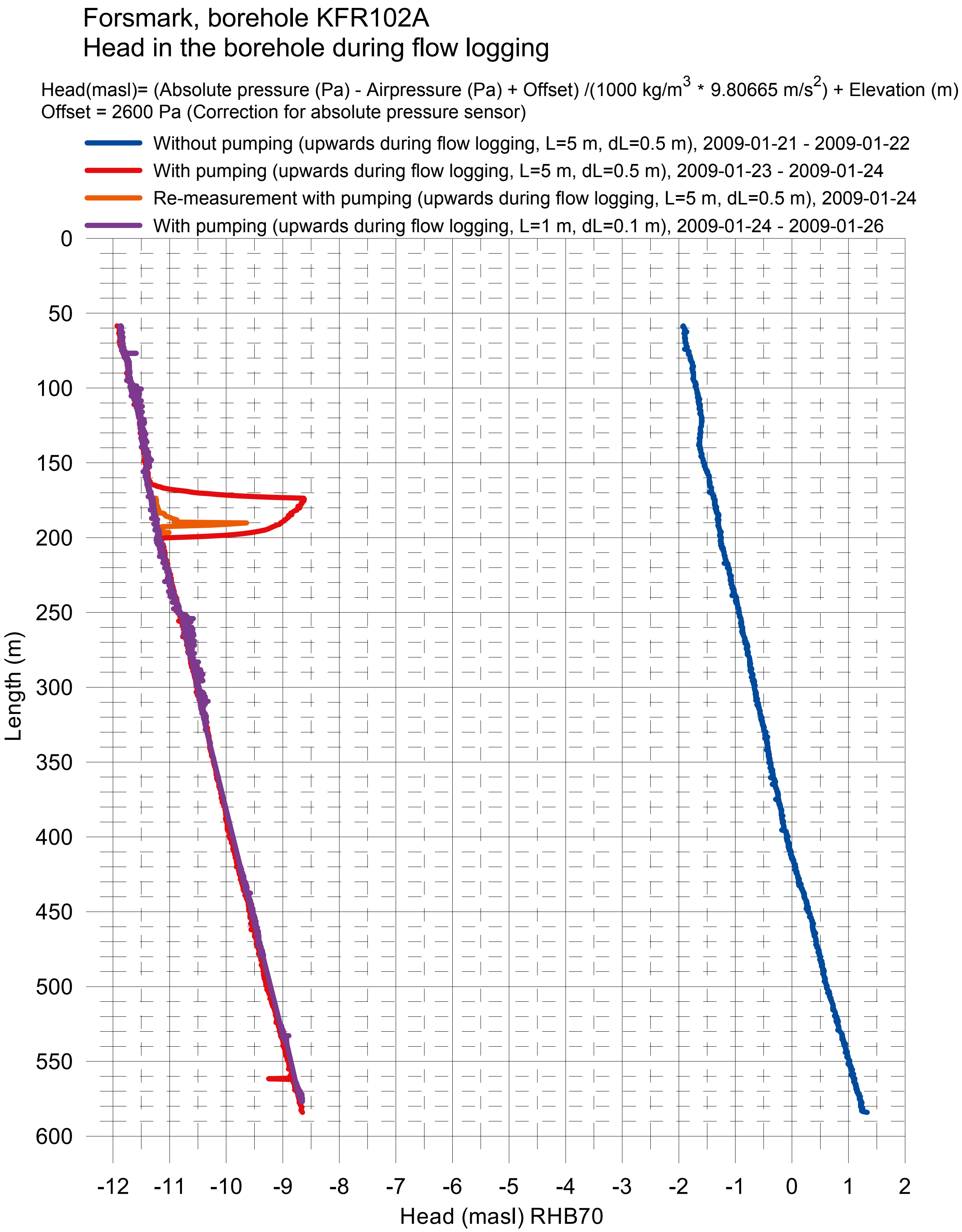
Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (masl)	Q_1 (m^3/s)	h_{1FW} (masl)	T_D (m^2/s)	h_i (masl)	Comments
KFR102A	441.5	1	0.1	–	0.23	2.31E-08	–9.64	2.3E-09	–	
KFR102A	450.2	1	0.1	–	0.30	2.08E-08	–9.58	2.1E-09	–	
KFR102A	451.7	1	0.1	–	0.32	3.81E-08	–9.57	3.8E-09	–	**
KFR102A	452.7	1	0.1	–	0.32	1.59E-07	–9.58	1.6E-08	–	**
KFR102A	453.7	1	0.1	–	0.32	2.81E-07	–9.56	2.8E-08	–	**
KFR102A	454.7	1	0.1	–	0.34	2.09E-07	–9.55	2.1E-08	–	**
KFR102A	455.7	1	0.1	–	0.35	1.14E-07	–9.55	1.1E-08	–	**
KFR102A	456.7	1	0.1	–	0.35	1.82E-07	–9.54	1.8E-08	–	**
KFR102A	457.7	1	0.1	–	0.37	1.00E-07	–9.55	1.0E-08	–	**
KFR102A	474.1	1	0.1	–	0.45	4.53E-08	–9.43	4.5E-09	–	*
KFR102A	532.3	1	0.1	–	0.88	3.81E-08	–9.03	3.8E-09	–	
KFR102A	572.2	1	0.1	–	1.17	5.81E-08	–8.73	5.8E-09	–	

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

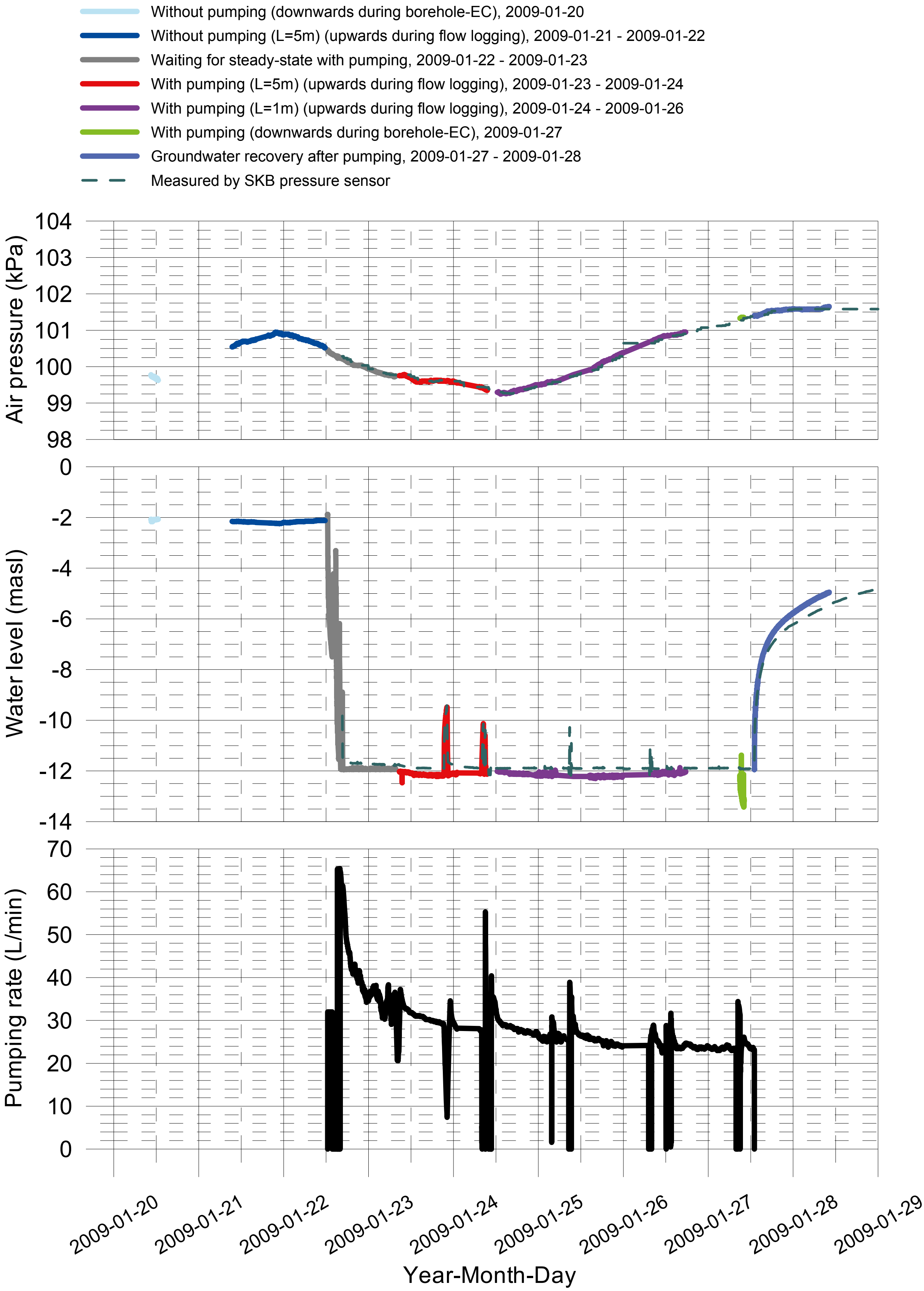
** Porous rock (Conductive zone).


Forsmark, borehole KFR102A
Transmissivity and head of detected fractures
Fracture head
Head in the borehole without pumping (L=5 m, dL=0.5 m)
2009-01-21 - 2009-01-22
Head in the borehole with pumping (L=5 m, dL=0.5 m)
2009-01-24 2009-01-26
Transmissivity of fracture
Length (m)
Head (masl, RHB 70)
Transmissivity (m²/s)

Forsmark, borehole KFR102A
Comparison between section transmissivity and fracture transmissivity

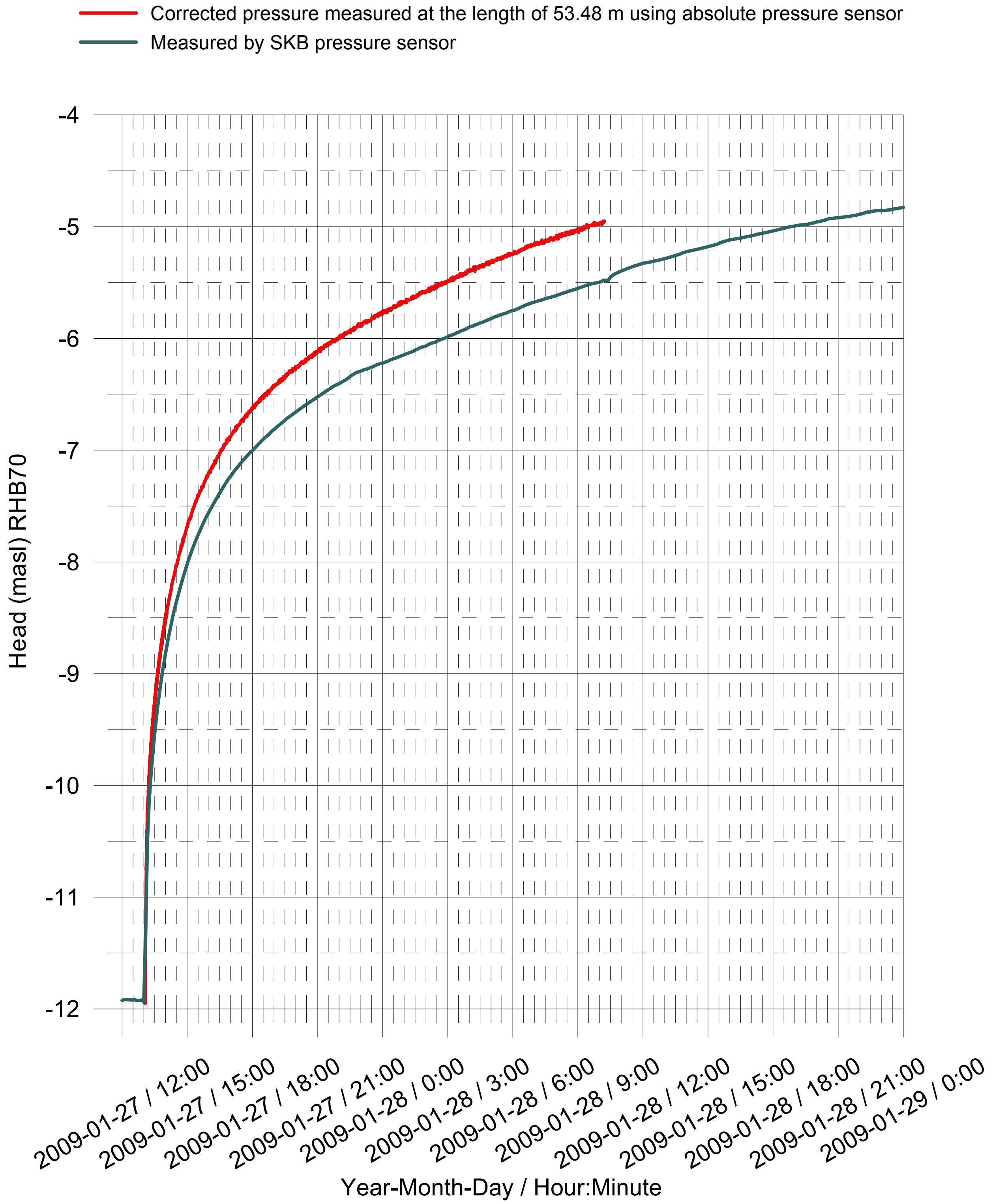

Forsmark, borehole KFR102A
Head in the borehole during flow logging
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m3 * 9.80665 m/s2) + Elevation (m)
Offset = 2600 Pa (Correction for absolute pressure sensor)
Without pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2009-01-21 - 2009-01-22
With pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2009-01-23 - 2009-01-24
Re-measurement with pumping (upwards during flow logging, L=5 m, dL=0.5 m), 2009-01-24
With pumping (upwards during flow logging, L=1 m, dL=0.1 m), 2009-01-24 - 2009-01-26
Length (m)
Head (masl) RHB70
0
50
100
150
200
250
300
350
400
450
500
550
600
-12
-11
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2

Forsmark, borehole KFR102A
Air pressure, water level in the borehole and pumping rate during flow logging

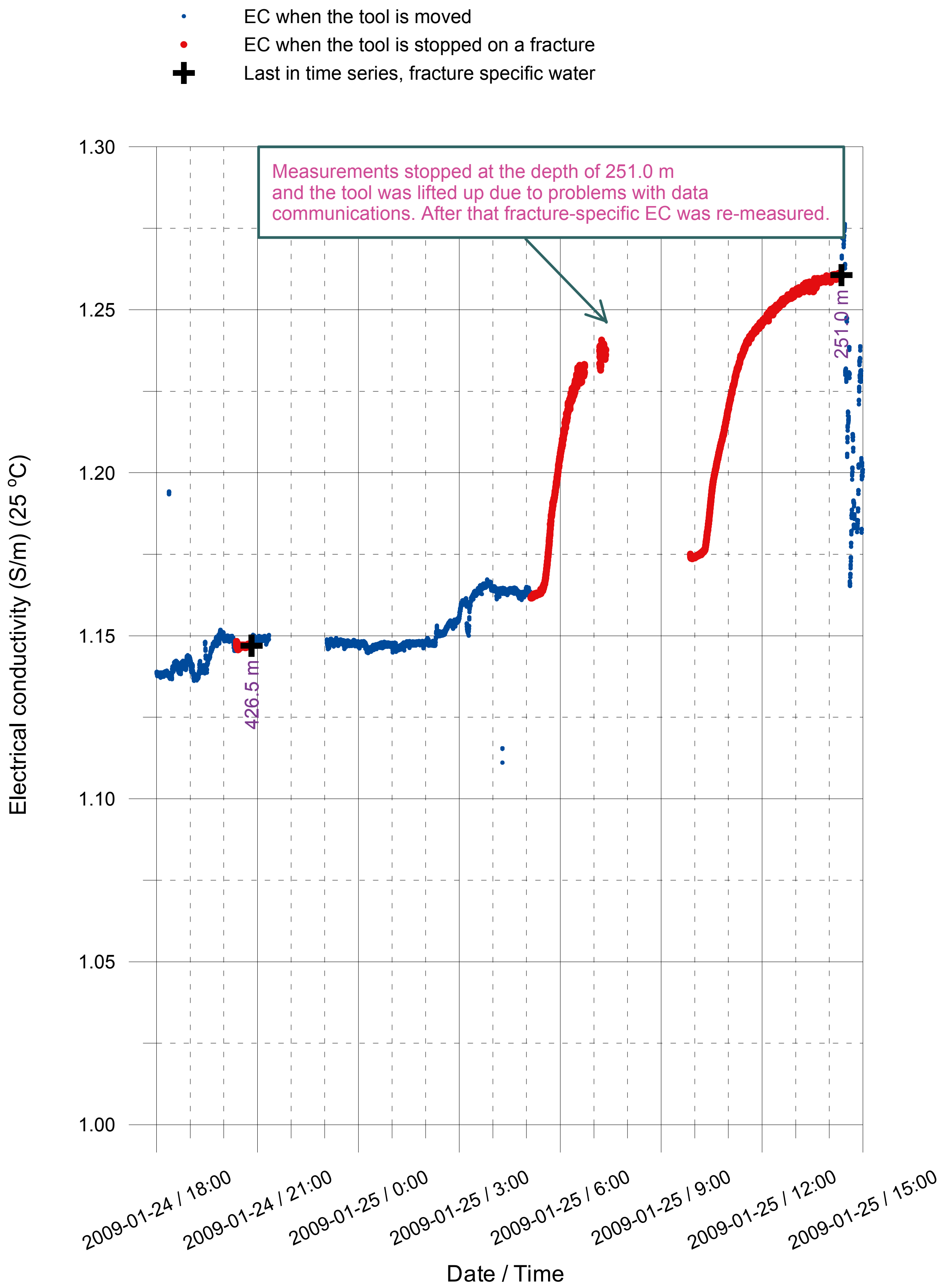


Forsmark, borehole KFR102A
Groundwater recovery after pumping

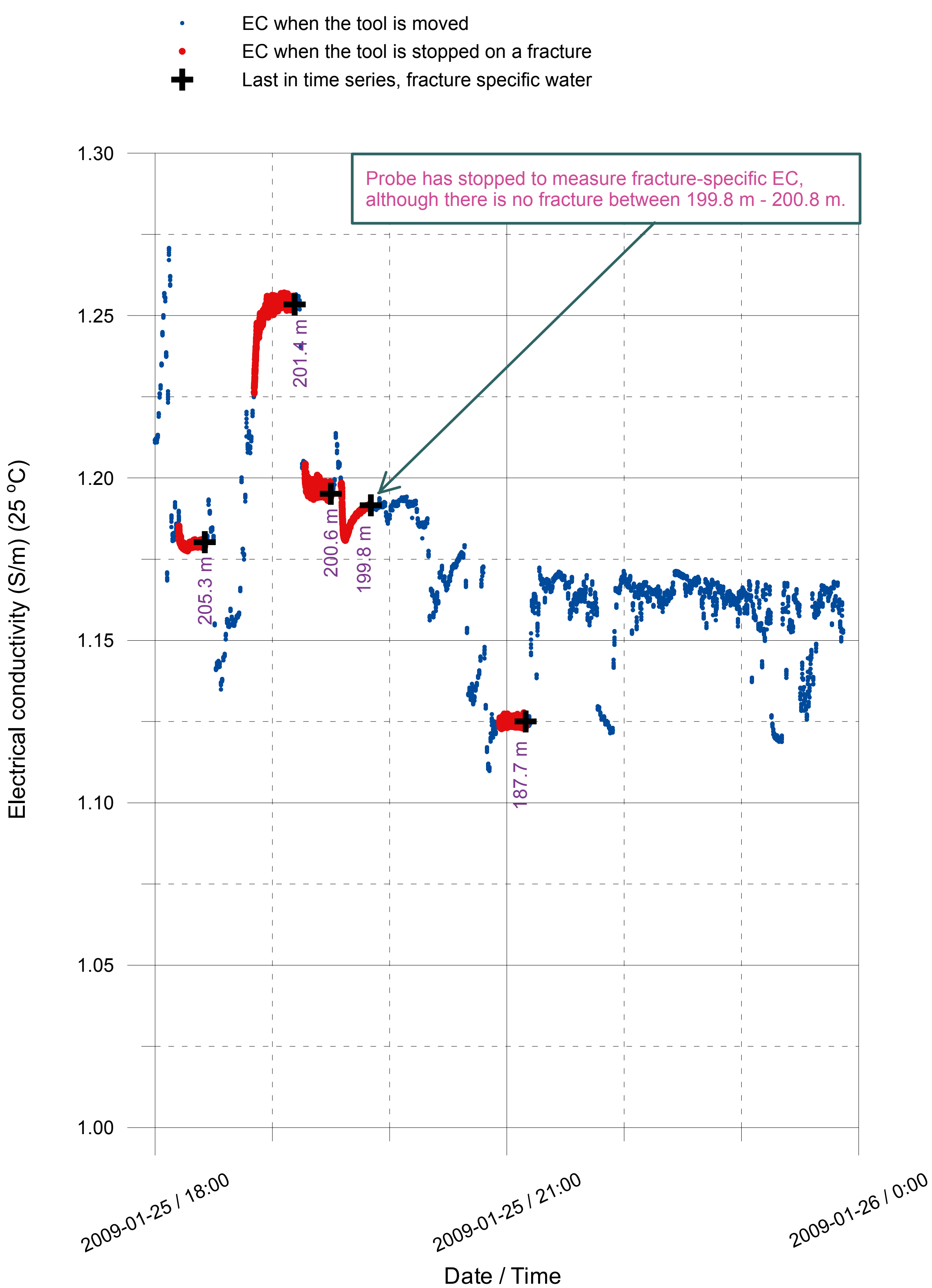
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2600 Pa (Correction for absolute pressure sensor)



Forsmark, borehole KFR102A
Fracture-specific EC results by date



Forsmark, borehole KFR102A
Fracture-specific EC results by date



Forsmark, borehole KFR102A
Fracture-specific EC results by date