P-04-216

Oskarshamn site investigation

Difference flow measurements in borehole KAV04A and KAV04B

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August 2004

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ISSN 1651-4416
SKB P-04-216

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Keywords: Ävrö, Hydrogeology, Hydraulic tests, Difference flow measurements, Transmissivity, Flow logging.

Abstract

Difference flow logging is a swift method for determination of the transmissivity and the hydraulic head in borehole sections and fractures/fracture zones in core drilled boreholes. This report presents the main principles of the method as well as results of measurements carried out in borehole KAV04A and KAV04B at Oskarshamn, Sweden, in June 2004, using Posiva flow log. The primary aim of the measurements was to determine the position and flow rate of flow yielding fractures in borehole KAV04A.

The flow rate into or out of a 5 m long test section was measured in borehole KAV04A between 100.16–994.17 m borehole lengths during pumped conditions. The flow measurements were repeated at the location of the detected flow anomalies using a 1 m long test section, successively transferred with an overlapping of 0.1 m.

Length calibration was made based on length marks milled into the borehole wall at accurately determined positions along the borehole (only in KAV04A). The length marks were detected by caliper measurements and by single point resistance measurements using sensors connected to the flow logging tool.

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

A c 100 m long borehole KAV04B is drilled alongside the borehole KAV04A. The idea of KAV04B is to cover the cased upper part of KAV04A. The flow logging in KAV04B was performed between 19.53–95.93 m borehole lengths under pumped conditions with a 1 m section length and with 0.1 m length increments.

Sammanfattning

Differensflödesloggning är en snabb metod för bestämning av transmissiviteten och hydraulisk head i borrhålssektioner och sprickor/sprickzoner i kärnborrhål. Denna rapport presenterar huvud-principerna för metoden och resultat av mätningar utförda i borrhål KAV04A och KAV04B i Oskarshamn, Sverige, i juni 2004 med Posiva flödesloggningsmetod. Det primära syftet med mätningarna var att bestämma läget och flödet för vattenförande sprickor i borrhål KAV04A.

Flödet till eller från en 5 m lång testsektion mättes i borrhål KAV04A mellan 100.16–994.17 m borrhålslängd under pumpade förhållanden. Flödesmätningarna upprepades vid lägena för de detekterade flödesanomalierna med en 1 m lång testsektion som förflyttades successivt med 0.1 m.

Längdkalibrering gjordes baserad på längdmärkerna som frästs in i borrhålsväggen vid noggrant bestämda positioner längs borrhålet (endast i KAV04A). Längmärkena detekterades med caliper-mätningar och med punktresistansmätningar med hjälp av sensorer anslutna på flödesloggningssonden.

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

Ca 100 m långt borrhål KAV04B finns bredvid KAV04A. Intention med KAV04B är att täcka det rörläggade övre delen av KAV04A. Flödesloggingen under pumpade förhållandena mellan 19.53–95.93 m utfördes med en 1 m lång testsektion som förflyttades successivt med 0.1 m.

Contents

1 Introduction

A general program for site investigations presenting survey methods has been prepared /SKB 2001/, as well as a site-specific program for the investigations in the Simpevarp area /SKB 2002b/. The difference flow logging form part of the site characterization program in the work breakdown structure number 1.1.5.7 of the execution programme /SKB 2002b/. Data and results were delivered to the SKB site characterization database SICADA with field note number Simpevarp 382.

This document reports the results gained by the difference flow logging, which is one of the activities performed within the site investigation at Oskarshamn. The work was carried out in accordance with activity plan AP PS 400-04-35. In table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

Table 1-1. Controlling documents for the performance of the activity.

Activity plan	Number	Version
Difference flow logging in borehole KAV04A	AP PS 400-04-35	0.9
Method descriptions	**Number**	**Version**
Method description for difference flow logging	SKB MD 322.010	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning	SKB MD 600.004	
Instruktion för längdkalibrering vid undersökningar i kärnborrhål	SKB MD 620.010	
Instruktion för analys av injektions- och enhålspumptester	SKB MD 320.004	

The difference flow logging in the core drilled borehole KAV04A at Oskarshamn was conducted between June 7–June 16, 2004. Borehole KAV04A is inclined c 85° from the horizontal direction, c.1004 m long and performed with a telescopic drilling technique. The interval 0–c 100 m is percussion drilled and cased with the inner diameter 200 mm. The interval, c 100–1,004 m, is core drilled with the diameter 76 mm. The location of borehole KAV04A at the drill site within the Oskarshamn area is shown in Figure 1-1.

The difference flow logging in the core drilled borehole KAV04B, which is adjacent to borehole KAV04A, was conducted between June 16–June 18, 2004. Results of measurements carried out in KAV04B are presented in chapter 7 and in Appendices 13–17.

The field work and the subsequent interpretation were conducted by PRG-Tec Oy.

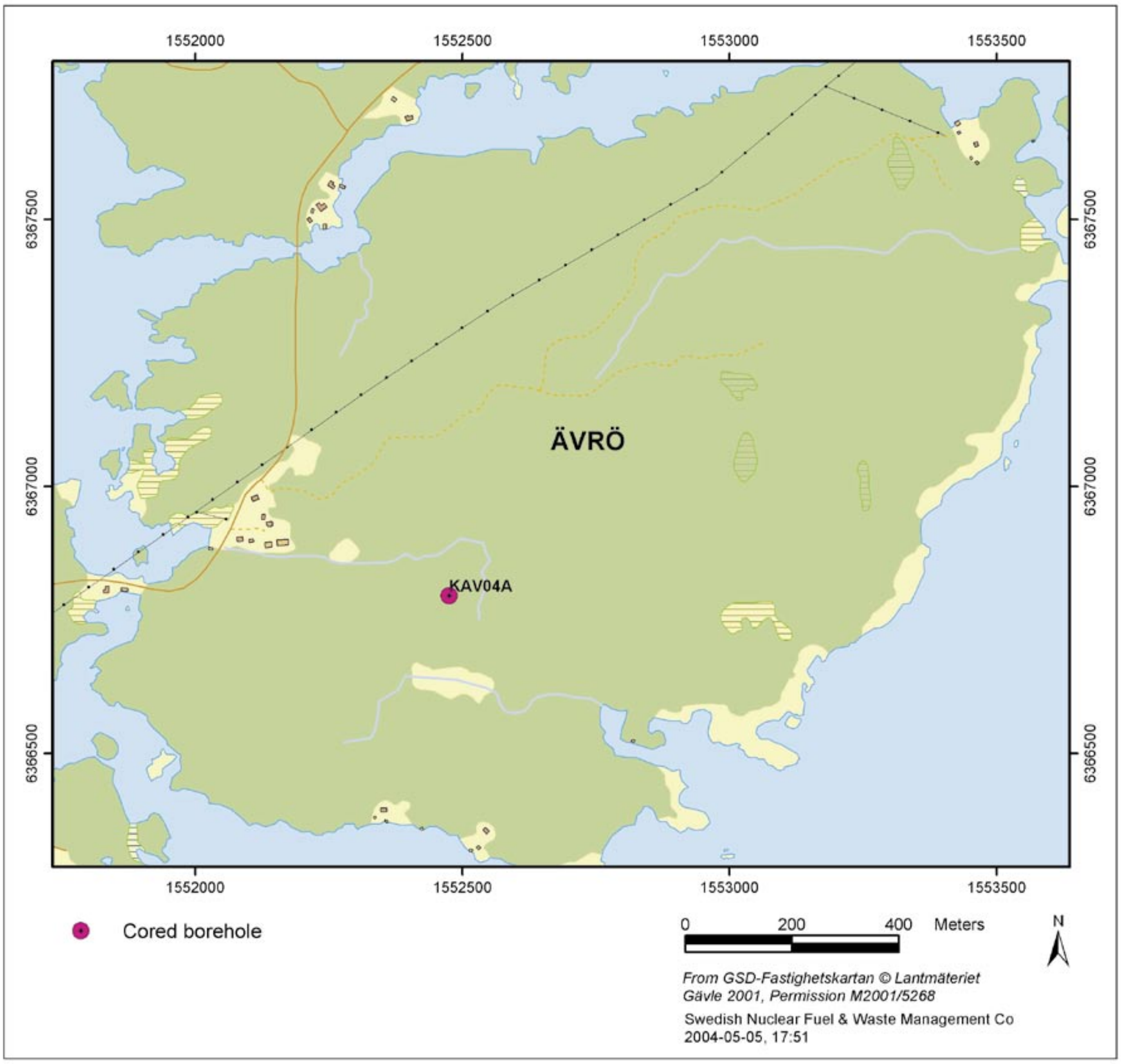

Figure 1-1. *Site map showing the location of borehole KAV04, which is situated on the island of Ävrö. KAV04A and KAV04B are about 1 m apart.*

2 Objective and scope

The main objective of the difference flow logging in KAV04A and in KAV04B was to characterise the rock hydrogeologicaly. Secondly, this would provide a basis for possible groundwater sampling campaigns of water-conductive sections/fractures suitable for subsequent hydro-geochemical characterisation. Based on the results of these investigations, a more detailed characterisation of flow anomalies along the hole, e.g. an estimate of the conductive fracture frequency (CFF), may be obtained.

Besides the difference flow logging, the measuring programme also included supporting measurements, performed for a better understanding of the overall hydrogeochemical conditions. These measurements included single-point resistance of the borehole wall. Furthermore, the recovery of the groundwater level after pumping was registered and interpreted hydraulically.

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

Single point resistance measurements were also combined with caliper (borehole diameter) measurements for detection of length marks milled into the borehole wall at accurately determined positions along the borehole. This procedure was applied for length calibration of all results

3 Principles of measurement and interpretation

3.1 Measurements

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

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

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

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

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

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

All of the above measurements, except electric conductivity (EC) and temperature measurements, were performed in KAV04A.

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

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

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

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

The lower end limits of the thermal dilution and the thermal pulse methods in Table 3-1 are theoretical lowest measurable values. Depending on the borehole conditions these limits may not always prevail. Examples of disturbing conditions are floating drilling debris in the borehole water, gas bubbles in the water and high flow rates (above about 30 L/min) along the borehole. If disturbing conditions are significant, a practical measurement limit is calculated for each set of data.

Table 3-1. Ranges of flow measurement.

Method	Range of measurement (mL/h)
Thermal dilution P1	30–6,000
Thermal dilution P2	600–300,000
Thermal pulse	6–600

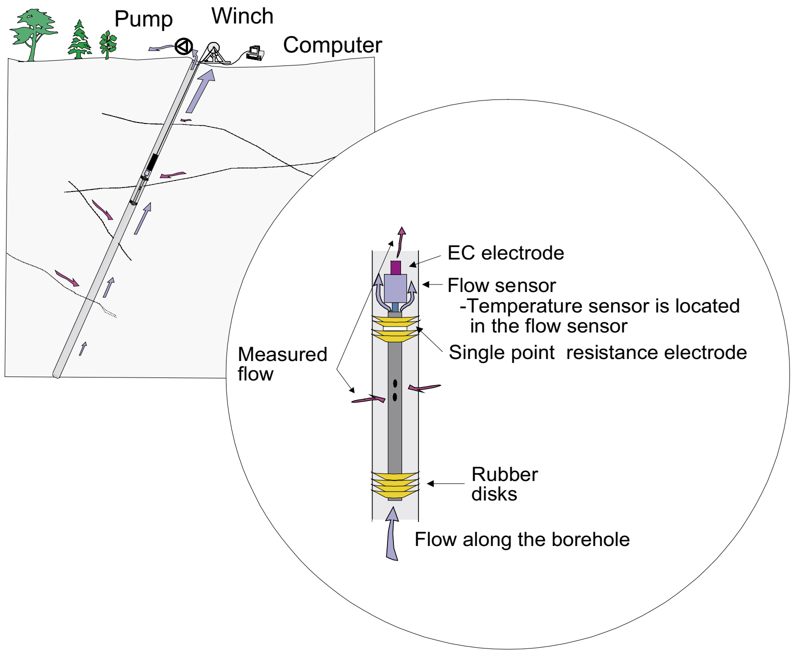

Figure 3-1. *Schematic of the downhole equipment used in the Difference flowmeter.*

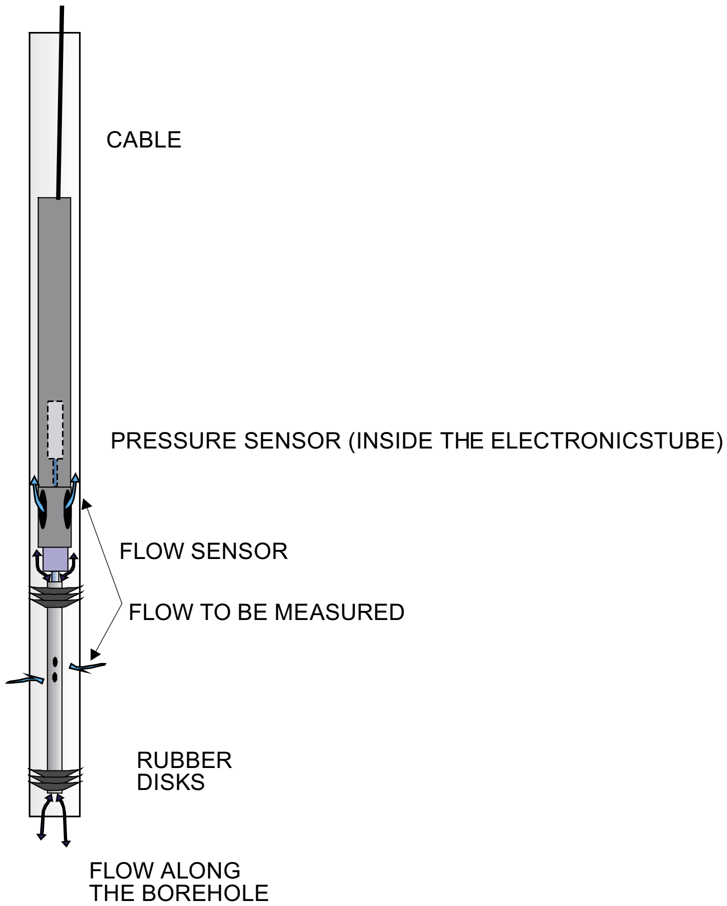

Figure 3-2. *The absolute pressure sensor is located inside the electronics tube and connected through a tube to the borehole water.*

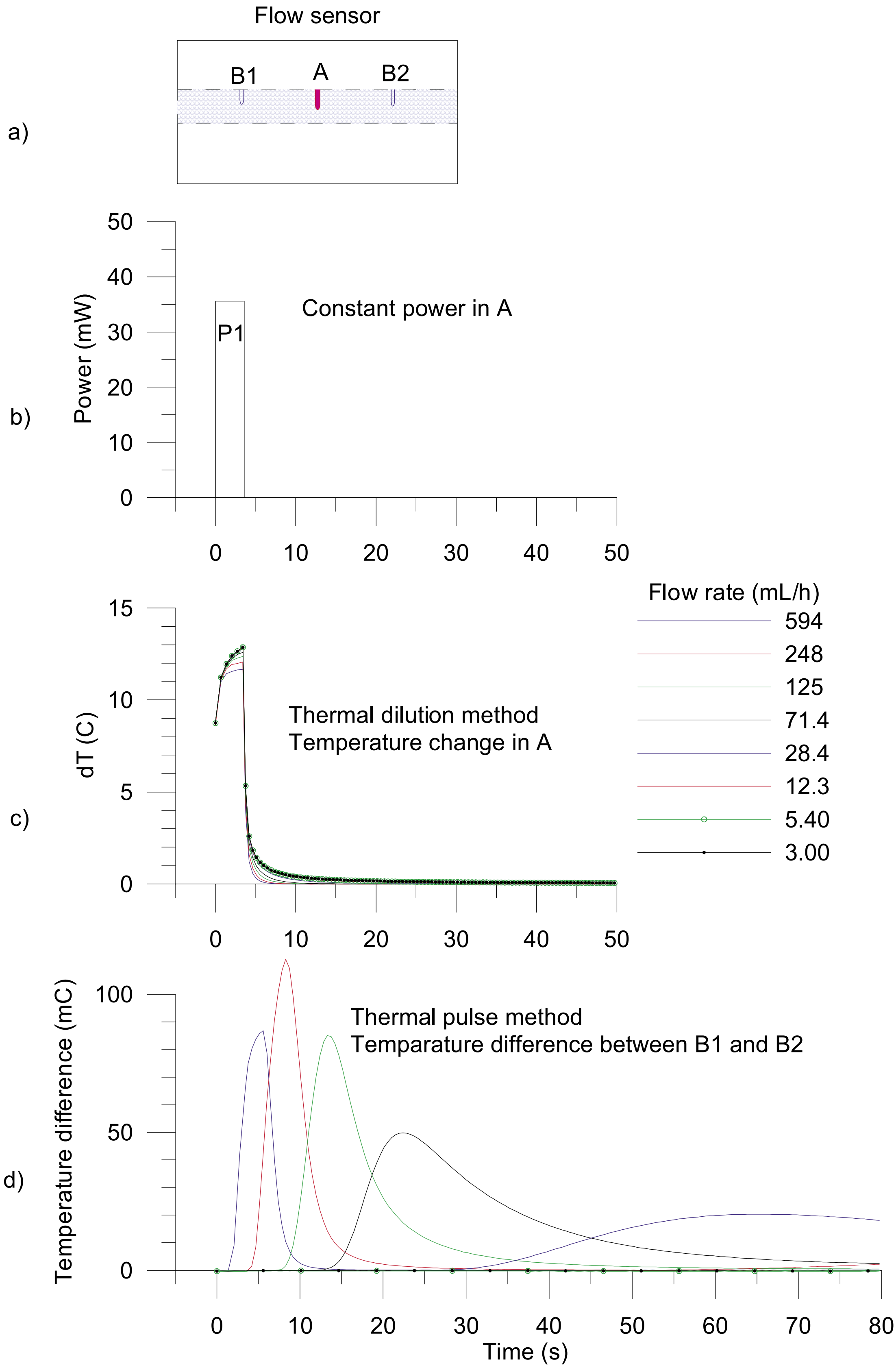

Figure 3-3. *Flow measurement, flow rate < 600 mL/h.*

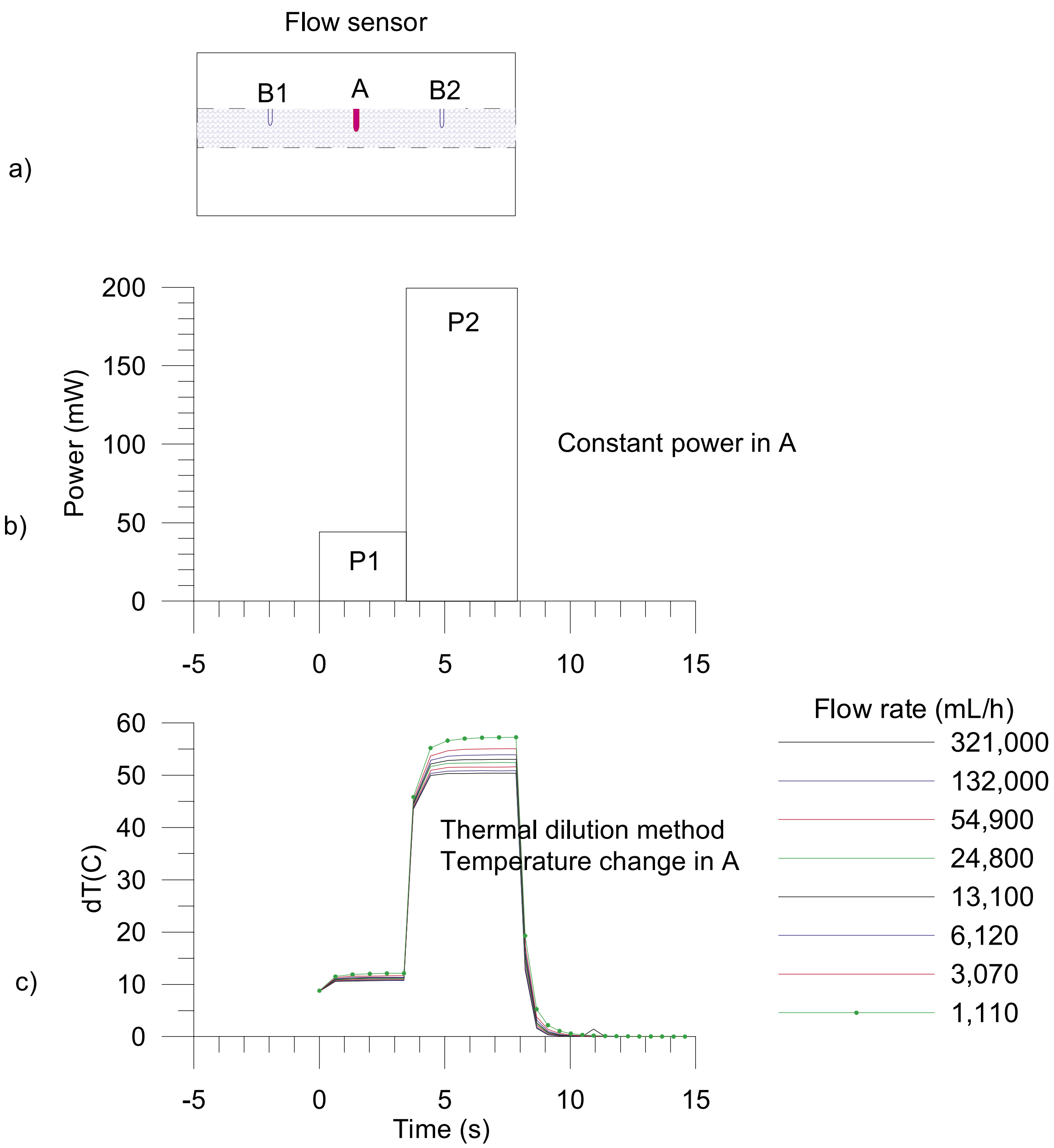

Figure 3-4. *Flow measurement, flow rate > 600 mL/h.*

3.2 Interpretation

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

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

where h is hydraulic head in the vicinity of borehole and $h = h_S$ at the radius of influence (R),

Q is flow rate into the borehole,

T is transmissivity of the test section,

a is a constant depending on the assumed flow geometry. For cylindrical flow, constant a is:

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

where

r_0 is radius of the well and

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

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

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

$$Q_{s2} = T_s \cdot a \cdot (h_s – h_2) \qquad 3\text{-}4$$

where

h_1 and h_2 are the hydraulic heads in the borehole at the test level,

Q_{s1} and Q_{s2} are the measured flows rates in the test section,

T_s is transmissivity of the test section and

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

Since, in general, very little is known of 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 there are no strong pressure gradients along the borehole, except at the ends of the borehole.

The radial distance R to the undisturbed hydraulic head h_S is not known and it 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:

$h_s = (h_1 – b \cdot h_2)/(1–b)$ 3-5

$T_s = (1/a)\ (Q_{s1}–Q_{s2})/(h_2–h_1)$ 3-6

where

$b = Q_{s1}/Q_{s2}$

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

$h_f = (h_1–b\ h_2)/(1–b)$ 3-7

$T_f = (1/a)\ (Q_{f1}–Q_{f2})/(h_2–h_1)$ 3-8

where

Q_{f1} and Q_{f2} are flow rates at a fracture and

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

Since the actual flow geometry and the skin effects are unknown, transmissivity values should be taken as indicating 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 is provided in /Ludvigson et al. 2002/.

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

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

where

s is drawdown and

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

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

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

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

Jacob's approximation can be used for the recovery phase /Marsily, 1986/:

$$s = \frac{Q}{T4\pi} \ln\left(\frac{t_0 + t}{t} \right), \qquad \text{3-11}$$

where

t_0 is the duration of the pumping period and

t is time from the end of the pumping period.

If s is plotted as a function of $\ln\left(\frac{t_0 + t}{t} \right)$ (Horner's diagram), a straight line appears. T can be solved from the slope:

$$T = \frac{Q}{4\pi} \frac{\Delta\left[\ln\left(\frac{t_0 + t}{t} \right) \right]}{\Delta s} \qquad \text{3-12}$$

4 Equipment specifications

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

Type of instrument:	Posiva Flow Log/Difference Flowmeter.
Borehole diameters:	56 mm, 66 mm and 76 mm.
Length of test section:	A variable length flow guide is used.
Method of flow measurement:	Thermal pulse and/or thermal dilution.
Range and accuracy of measurement:	Table 4-1.
Additional measurements:	Temperature, Single point resistance, Electric conductivity of water, Caliper, Water pressure.
Winch:	Mount Sopris Wna 10, 0.55 kW, 220V/50Hz. Steel wire cable 1500 m, four conductors, Gerhard-Owen cable head.
Length determination	Based on the marked cable and on the digital length counter.
Logging computer:	PC, Windows 2000.
Software:	Based on MS Visual Basic.
Total power consumption:	1.5–2.5 kW depending on the pumps.
Calibrated:	April 2004.
Calibration of cable length:	Using length marks in the borehole.

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

Table 4-1. Range and accuracy of sensors.

Sensor	Range	Accuracy
Flow	6–300,000 mL/h	+/– 10% curr.value
Temperature (middle thermistor)	0–50°C	0.1°C
Temperature difference (between outer thermistors)	–2–+ 2°C	0.0001°C
Electric conductivity of water (EC)	0.02–11 S/m	+/– 5% curr.value
Single point resistance	5–500,000 Ω	+/– 10% curr.value
Groundwater level sensor	0–0.1 MPa	+/– 1% fullscale
Absolute pressure sensor	0–20 MPa	+/– 0.01% fullscale

5 Performance

The commission was performed according to Activity Plan AP PS 400-04-35 (SKB internal controlling document) following the SKB Method Description 322.010, Version 1.0 Method description for difference flow logging (SKB internal controlling document).

Prior to the measurements, the downhole tools and the measurement cable were disinfected. Clocks were synchronized to local Swedish time. The activity schedule of the borehole measurements is presented in Table 5-1 for KAV04A and Table 5-2 for KAV04B. The items and activities in Table 5-1 and 5-2 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 e.g. a logging cable. Immediately after completion of the drilling operations in borehole KAV04A, length marks were milled into the borehole wall at certain intervals (normally every 50m) 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 includes two 20 mm wide tracks in the borehole wall. The distance between the marks is 100 mm. The upper track represents the reference level. An inevitable condition for a successful length calibration is that all length marks, or at least the major part of them, are detectable. The Difference flowmeter system uses caliper measurements in combination with single point resistance measurement (SPR) for this purpose, and these measurements were the first to be performed in borehole KAV04A (Item 6 in Table 5-1). These methods also reveal widened parts of the borehole.

Pumping was started on June 10. After 24 hours waiting time, the overlapping flow logging (Item 7) was carried out in the borehole interval 95.16–994.17 m. The section length was 5 m, and the length increment (step length) 5 m.

The overlapping flow logging was then continued in the way that previously measured flow anomalies were re-measured with 1 m section length and 0.1 m step length (Item 8).

After this, the pump was stopped and the recovery of the groundwater level was monitored (Item 9).

**Table 5-1. Flow logging and testing in KAV04A. Activity schedule.
(The item number is retained from the Activity Plan AP PS 400-04-35, SKB internal controlling document)**

Item	Activity	Explanation	Date
6	Length calibration of the downhole tool	Dummy logging (SKB Caliper and SPR). Logging without the lower rubber discs, no pumping	2004-06-09 2004-06-10
7	Overlapping flow logging	Section length L_w = 5 m, Step length dL = 0.5 m at pumping (includes 1 day waiting after beginning of pumping)	2004-06-10 2004-06-13
8	Overlapping flow logging	Section length L_w = 1 m, Step length dL = 0.1 m, at pumping (only in conductive borehole intervals)	2004-06-13 2004-06-15
9	Recovery transient and demobilisation	Measurement of water level and absolute pressure in the borehole after stopping of pumping. Uninstallation of the tool. Packing the trailer.	2004-06-15 2004-06-16
10	Delivery and filling of measured data	Delivering Daily logs, logging reports and raw data files for SKB.	2004-06-16

**Table 5-2. Flow logging in KAV04B. Activity schedule.
(The item number is retained from the Activity Plan AP PS 400-04-35, SKB internal controlling document)**

Item	Activity	Explanation	Date
8	Overlapping flow logging	Section length L_w = 1 m, Step length dL = 0.1 m, at pumping (includes 14 hour waiting after beginning of pumping)	2004-06-16 2004-06-17
9	Recovery transient and demobilisation	Measurement of water level and absolute pressure in the borehole after stopping of pumping. Uninstallation of the tool. Packing the trailer.	2004-06-17 2004-06-18
10	Delivery and filling of measured data	Delivering Daily logs, logging reports and raw data files for SKB.	2004-06-18

6 Results, KAV04A

6.1 Length calibration

6.1.1 Caliper and SPR measurement

Accurate length scale of measurements is difficult to achieve in long boreholes. The main cause of inaccuracy is stretching of the logging cable. The stretching depends on the tension of the cable that in turn depends, among other things, on the inclination of the borehole and on friction of the borehole wall. The cable tension is higher when the borehole is measured upwards. The cables, especially new cables, may also stretch out permanently. In KAV04A the stretching of the cable was relatively high since the measurements were performed from the bottom of the borehole in the upward direction, see Appendix 1.45.

Length marks on the borehole wall can be used to minimise the length errors. The length marks are detected with the SKB caliper tool. The length scale is firstly 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 measurements) with the original caliper/SPR measurement.

The procedure of length correction was the following:

- Caliper+SPR measurement (Item 6) was initially length corrected in relation to the known length marks, Appendix 1.45 black curve. Corrections between the length marks were obtained for each length mark by linear interpolation.
- The SPR curve of Item 6 was then compared with the SPR curves of Items 7 and 8 to obtain relative length errors of these measurement sequences.
- All SPR curves could then be synchronized, as can be seen in Appendices 1.2–1.44.

The results of the caliper and single point resistance measurements from all measurements in the entire borehole are presented in Appendix 1.1. Two SPR-curves are plotted together with the SPR+caliper measurement. These measurements correspond to Items 7 and 8 in Table 5-1.

Caliper tool shows low voltage when the borehole diameter is below 77 mm and high voltage when borehole diameter is over 77 mm.

Zoomed results of caliper and SPR are presented in Appendices 1.2–1.44. The length marks were detected at 110 m, 150 m, 200 m, 250 m, 300 m, 350 m, 400 m, 451 m, 500 m, 550 m, 600 m, 650 m, 700 m, 750 m (only the lower one), 800 m, 846 m, 900 m and at 950 m. In other words, every mark was detected at least partly. They can also be seen in SPR results. However, the anomaly is complicated due to the four rubber disks used at the upper end of the section, two at the each side of the resistance electrode. A selection of length intervals where clear SPR-anomalies were found, are plotted as well.

The aim of the plots in Appendices 1.2–1.44 is to verify the accuracy of the length correction. The curves in these plots represent length corrected results. The same length corrections were applied to the flow- and EC measurements.

The magnitude of length correction along the borehole is presented in Appendix 1.45. The error is negative, due to fact that the stretching extends the logging cable (i.e. the cable is longer than the nominal length marked on the cable).

6.1.2 Estimated error in location of detected fractures

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

1. Point interval in flow measurements is 0.1 m in overlapping mode. This could cause an error +/–0.05 m.
2. The length of the test section is not exact. The specified section length denotes the distance between the nearest upper and lower rubber disks. Effectively, the section length can be larger. At the upper end of the test section there are four rubber disks. The distance between these is 5 cm. This will cause rounded flow anomalies, there may be detected flow already when a fracture is between the upper rubber disks. These phenomena can only be seen with short step length (0.1 m). This could cause an error of +/–0.05 m.
3. Corrections between the length marks can be other than linear. This could cause error +/–0.1 m in the SPR+ caliper measurement (Item 6).
4. SPR curves may be imperfectly synchronized. This could cause error +/– 0.1 m.

In the worst case, the errors of points 1, 2, 3 and 4 are summed up. Then the total estimated error between the length marks would be +/– 0.3 m.

Near the length marks the situation is slightly better. In the worst case, the errors of points 1, 2, and 4 are summed up. Then the total estimated error near the length marks would be +/–0.2 m.

Accurate location is important when different measurements are compared, for instance if the flow logging and borehole TV are compared. In that case the situation may not be as severe as the worst case above since part of the length errors are systematic and the length error is nearly constant in fractures near each other. However, the error of point 1 is of random type.

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

6.2 Pressure measurements

Absolute pressure was registered with the other measurements in Items 7–9. The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered, Appendix 12.2. Hydraulic head along the borehole is determined in the following way. Firstly, the monitored air pressure at the site is subtracted from the measured absolute pressure by the pressure sensor. The hydraulic head (h) at a certain elevation z is then calculated according to the following expression /SKB, 2002/:

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

where

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

p_{abs} is absolute pressure (Pa),

p_b is barometric (air) pressure (Pa),

ρ_{fw} is unit density 1000 kg/m^3

g is standard gravity 9.80065 m/s^2 and

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

An offset of 2.46 kPa is subtracted from all absolute pressure results.

Exact z-coordinates are important in head calculation, 10 cm error in z-coordinate means 10 cm error in head. The calculated head results are presented in a graph in Appendix 12.1. Absolute pressure is registered during flow logging and these measurements were done only at pumped conditions. Therefore the head can be calculated only for pumped conditions. In transmissivity calculations the drawdown of water level was used as the pressure difference, Appendices 3.2 and 4.

6.3 Flow logging

6.3.1 General comments on results

The flow results are presented together with single point resistance (right hand side) and caliper plot (in the middle), see Appendices 2.1–2.45. Single point resistance shows usually low resistance value on a fracture where flow is detected. There are also many other resistance anomalies from other fractures and geological features. The electrode of the Single point resistance tool is located within the upper rubber disks. Thus, the locations of the resistance anomalies of the leaky fractures fit with the lower end of the flow anomalies.

Caliper tool shows low voltage when the borehole diameter is below 77 mm and high voltage when borehole diameter is over 77 mm.

The flow logging was firstly performed with a 5 m section length and with 0.5 m length increments under pumped conditions, see Appendices 2.1–2.45 (red curve). The method (overlapping flow logging) gives the length and the thickness of conductive zones with a length resolution of 0.5 m. To obtain quick results, only the thermal dilution method is used for flow determination.

The test section length determines the width of a flow anomaly of a single fracture in the plots. If the distance between flow yielding fractures is less than the section length, the anomalies will be overlapped, resulting in a stepwise flow anomaly. The overlapping flow logging was therefore repeated in the vicinity of identified flow anomalies using a 1 m long test section and 0.1 m length increments, see Appendices 2.1–2.45 (violet curve).

Detected fractures are shown on the caliper scale with their positions (borehole length). They are interpreted on the basis of the flow curves and represent therefore flowing fractures. A long line represents the location of a leaky fracture; short line denotes that the existence of a leaky fracture is uncertain. A short line is used if the flow rate is less than 30 mL/h or if the flow anomalies are overlapping or if they are unclear because of noise.

The tables in Appendices 9.1–9.4 was used to calculate conductive fracture frequency (CFF). The number of conductive fractures were counted on the same 5 meter sections as in Appendix 6 before. The number of conductive fractures were sorted in six columns depending on their flow rate. The total conductive fracture frequency is presented graphically, see Appendix 10.

6.3.2 Transmissivity of borehole sections

The entire borehole between 95 and 994 m was flow logged with a 5 m section length and with 0.5 m length increments. All the flow logging results presented in this report is derived from measurements with the thermal dilution method.

The results of the measurements with a 5 m section length are presented in tables, see Appendices 6.1–6.6. Only the results with a 5 m length increments are used. Secup presented in Appendices 6.1–6.6 are calculated as the distance along the borehole from the reference level (top of the casing tube) to the upper end of the test section. Seclow is respectively the distance to the lower end of the test section. The same flow rates as in Appendix 6, are also plotted in Appendices 2.1–2.45.

Pressure was measured and calculated as described in Chapter 6.2. Borehole head dh_1 in Appendices 6.1–6.6 represent head determined from measurement with a 5 m section length and head dh_2 in Appendices 7.1–7.3 head at respective fracture level determined from measurement with a 1 m section length. Head in the borehole is given in RHB 70 scale.

The flow result (Q_1) presented in Appendices 6.1–6.6, is determined from measurement with a 5 m section length, and the flow result (Q_2) presented in Appendices 7.1–7.3, is determined from measurement with a 1 m section length. Flow rates are positive if the flow direction is from the bedrock into the borehole and vice versa. During pumping, all 134 detected flows were directed towards the borehole.

The flow data is presented as a plot, see Appendix 3.1. The left hand side of each diagram represents flow from the borehole into the bedrock for the respective test sections, whereas the right hand side represents the opposite. If the measured flow was zero (below the measurement limit), it is not visible in the logarithmic scale of the appendices.

In the plots (Appendix 3.1) and in the tables (Appendix 6), also the lower and upper measurement limits of flow are presented. There are theoretical and practical lower limits of flow, see Chapter 6.3.4.

Hydraulic head and transmissivity (T_S) of borehole sections can be calculated from flow data using the method described in Chapter 3. Because there were no measurements in natural conditions, two assumptions had to be made:

- flow rate without pumping is zero,
- borehole head difference is drawdown.

Hydraulic head of borehole sections could not be calculated because there were no measurements in natural conditions. Transmissivity (see Appendix 3.2 and Appendix 6) is more uncertain than usual because of the additional assumptions above. The head values in Appendix 6 are not used for transmissivity calculations because borehole head without pumping was not measured.

6.3.3 Transmissivity of fractures

An attempt was made to evaluate the magnitude of fracture-specific flow rates. The results for a 1 m section length and for 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 to evaluate their flow rates.

In cases where fracture distance is less than one meter, it may be difficult to evaluate the flow rate. There are such cases for instance in Appendix 2.1. Increase or decrease of flow anomaly at the fracture location (marked with the lines in Appendix 2) is used for determination of flow rate (filled triangles in Appendix 2).

Some fracture-specific results were rated to be "uncertain" results, see Appendices 7.1–7.3. The criterion of "uncertain" was in most cases a minor flow rate (< 30 mL/h). In some cases fracture anomalies were unclear, since the distance between them was less than one meter.

Total amount of detected flowing fractures under pumped conditions was 134. Transmissivity was estimated for these fractures with the same method and the same additional assumptions as for borehole sections. Transmissivity is calculated using pressure difference derived from the water level drawdown. The head values in Appendix 7 are not used for transmissivity calculations because borehole head without pumping was not measured. Fracture-specific transmissivity is presented as a plot (Appendix 4) and in table (Appendix 7).

Fracture-specific transmissivities were compared with transmissivities of borehole sections in Appendix 11. All fracture-specific transmissivities within each 5 m interval were first summed up to make them comparable with measurements with a 5 m section length. The results are, in most cases, consistent between the two types of measurements. The errors caused by the "new" assumptions are not visible in Appendix 11 because the same assumptions were used for the both transmissivity estimates.

6.3.4 Theoretical and practical limits of flow measurements and transmissivity

Theoretical minimum of measurable flow rate in the overlapping results (thermal dilution method only) is about 30 mL/h. The upper limit of flow measurement is 300,000 mL/h. These limits are determined on the basis of flow calibration. It is assumed that flow can be reliably detected between the upper and lower theoretical limits in favourable borehole conditions.

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

There are several known reasons for increased noise in flow:

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

Rough borehole wall always causes high noise not only in flow but also in single point resistance results. Flow curve and SPR curves are typically spiky when borehole wall is rough.

Drilling mud usually increases noise level. Typically this kind of noise is seen both without pumping and with pumping.

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

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

High noise level in flow masks "real" flow that is smaller than the noise. Real flows are totally invisible if they are about ten times smaller than the noise. Real flows are registered correctly if they are about ten times larger than noise. By experience, real flows between 1/10 times noise and 10 times noise are summed up with noise. Therefore noise level could be subtracted from the measured flow to get the real flow. This correction has not been done so far because it is not clear whether it is applicable in each case.

The practical minimum level of measurable flow rate is evaluated and presented in Appendices 2.1–2.45 using grey dashed line (Lower limit of flow rate). Below this line there may be fractures or structures that remain undetected.

Noise level in KAV04A was between 50–200 mL/h. Mostly it was between 100–200 mL/h. A possible reason for noise could be drilling mud in the borehole water.

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 smaller drawdown. In KAV04A there was no need for this kind of extra measurements.

Practical minimum of measurable flow rate is also presented in Appendix 6 (TD-measl_{LP}). It is taken from the plotted curve in Appendix 2 (Lower limit of flow rate). Practical minimum of measurable transmissivity can be evaluated using Q-lower limit and the head difference at each measurement, see Appendix 6. Theoretical minimum measurable transmissivity can also be evaluated using Q value of 30 mL/h (minimum theoretical flow rate with thermal dilution method) instead of Q-lower limit Practical, see Appendix 6 (TD-measl_{LT}).

The upper measurement limit of transmissivity can be evaluated using the maximum flow rate (300,000 mL/h) at the actual head difference as above, see Appendix 6 (TD-measl_{U}).

All three flow limits are also plotted with measured flow rates, see Appendix 3.1. Theoretical minimum and maximum values are 30 mL/h and 300,000 mL/h, respectively.

The three transmissivity limits are also presented graphically, see Appendix 3.2.

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

6.3.5 Transmissivity of the entire borehole

Transmissivity of the entire borehole is evaluated with the three methods described in Chapter 3.

For the Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500.

In the Moye's formula (equation 3-10) length of test section L is 903 m and borehole diameter $2r_0$ is 0.076 m.

Jacob/Horner's approximation for the recovery phase (equation 3-12) is presented in Figure 6-1.

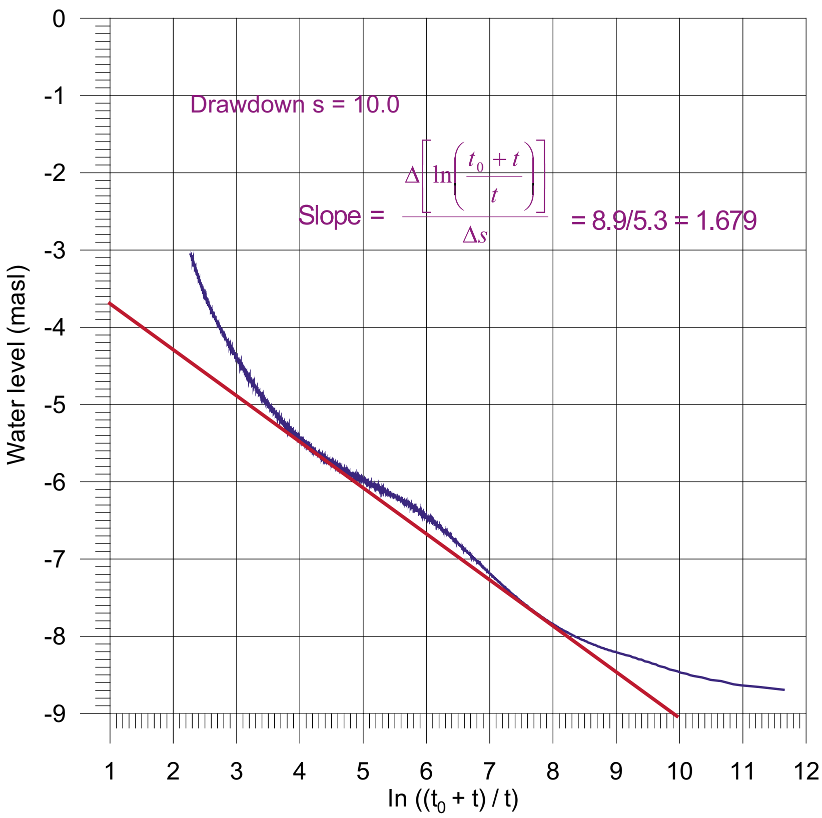

Figure 6-1. *Horner's diagram for the recovery phase.*

The results of the three methods are given in Table 6-1 where the flow was set to Q = 10.6 L/min and drawdown s = 10 m. Moye's approximation gives the highest and Dupuit method the lowest transmissivity. Basic test data is gathered in Appendix 5.

Table 6-1. Transmissivity of the entire borehole.

Method	Transmissivity (m^2/s)
Dupuit	1.75 E-05
Moye	2.92 E-05
Jacob/Horner	2.36 E-05

6.4 Groundwater level and pumping rate

The level of the groundwater table in the borehole during the measurement sequences is presented in Appendix 12.3. The borehole was pumped between June 10 and 15 with a drawdown of about 10.0 meters. Pumping rate was also recorded, see Appendix 12.5.

The groundwater recovery was measured after the pumping period, June 15–16, Appendix 12.4. The recovery was measured with two sensors, using the water level sensor (pressure sensor for monitoring water level) and the absolute pressure sensor located in the flowmeter tool at the borehole length of 975.54 m.

7 Results, KAV04B

The overlapping flow logging was performed between 19.53–95.93 m borehole lengths under pumped conditions with a 1 m section length and with 0.1 m length increments, see Appendix 13.1–13.4. Because the borehole is relatively short, there was no need for length correction.

Total amount of detected flowing fractures under pumped conditions was 54. All these fractures were used for transmissivity estimations. Transmissivity of fractures are presented in Appendices 14 and 16. The same assumptions were used as explained in chapter 6.3.2.

Transmissivity of the entire borehole is evaluated with the three methods described in Chapter 3.

For the Dupuit's formula (equation 3-9) R/r_0 is chosen to be 500.

In the Moye's formula (equation 3-10) length of test section L is 84 m and borehole diameter $2r_0$ is 0.076 m.

Jacob/Horner's approximation for the recovery phase (equation 3-12) is presented in Figure 7-1.

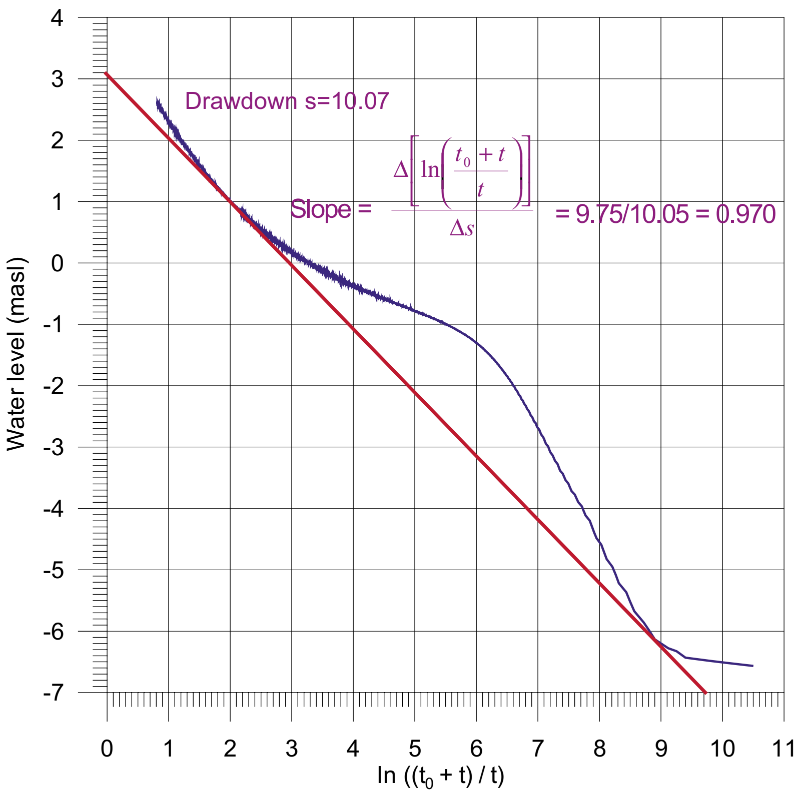

Figure 7-1. *Horner's diagram for the recovery phase.*

The results of the three methods are given in Table 7-2 where the flow was set to Q = 23.38 L/min and drawdown s = 10.07 m. Moye's approximation gives the highest and Jacob/Horner method the lowest transmissivity. Basic test data is gathered in Appendix 15.

Table 7-2. Transmissivity of the entire borehole.

Method	Transmissivity (m^2/s)
Dupuit	3.83 E-05
Moye	4.93 E-05
Jacob/Horner	3.01 E-05

Noise level in KAV04B was between 30–200 mL/h. Mostly it was even below 30 mL/h, i.e. below the theoretical limit of thermal dilution method. However, the noise line (grey dashed line, Appendix 13) was never drawn below 30 mL/h.

The level of the groundwater table in the borehole during the measurement is presented in Appendix 17.3. The borehole was pumped between June 16 and 17 with a drawdown of about 10.1 meters. Pumping rate was also recorded, see Appendix 17.5.

The groundwater recovery was measured after the pumping period, June 17–18, Appendix 17.4. The recovery was measured with two sensors, using the water level sensor (pressure sensor for monitoring water level) and the absolute pressure sensor located in the flowmeter tool at the borehole length of 19.09 m.

Hydraulic head along the borehole is presented in Appendix 17.1. Air pressure during flow logging was also registered, Appendix 17.2.

8 Summary

In this study, the Posiva Flow Log/Difference Flow method has been used to determine the location and flow rate of flowing fractures or structures in boreholes KAV04A and KAV04B at Oskarshamn. Measurements were carried out under pumped conditions. With borehole KAV04A a 5 m section length with 0.5 m length increments was used firstly. The measurements were repeated using 1 m section length with 0.1 m length increments over the flow anomalies. The borehole KAV04B was measured using 1 m section length with 0.1 m length increments.

Length calibration in KAV04A was made using the length marks on the borehole wall. The length marks were detected by caliper and in single point resistance logging. The latter method was also performed simultaneously with the flow measurements, and thus all flow results could be length calibrated by synchronising the single point resistance logs. Because of short length of the borehole, length calibration was not made in KAV04B.

The total amount of detected flowing fractures in KAV04A was 134. Transmissivity was estimated for borehole sections and fractures. The highest transmissivity was detected in a fracture at the length of 714.3 m. High-transmissive fractures were also found at 257.0 m, 714.5 m and 756.1 m. Below 894.4 m no flowing fractures were identified.

The total amount of detected flowing fractures in KAV04B was 54. Hydraulic head was estimated from water level drawdown and transmissivity was calculated for all fractures. The highest transmissivity was detected in a fracture at the length of 51.3 m.

Transmissivity of entire borehole KAV04A was smaller than entire borehole KAV04B.

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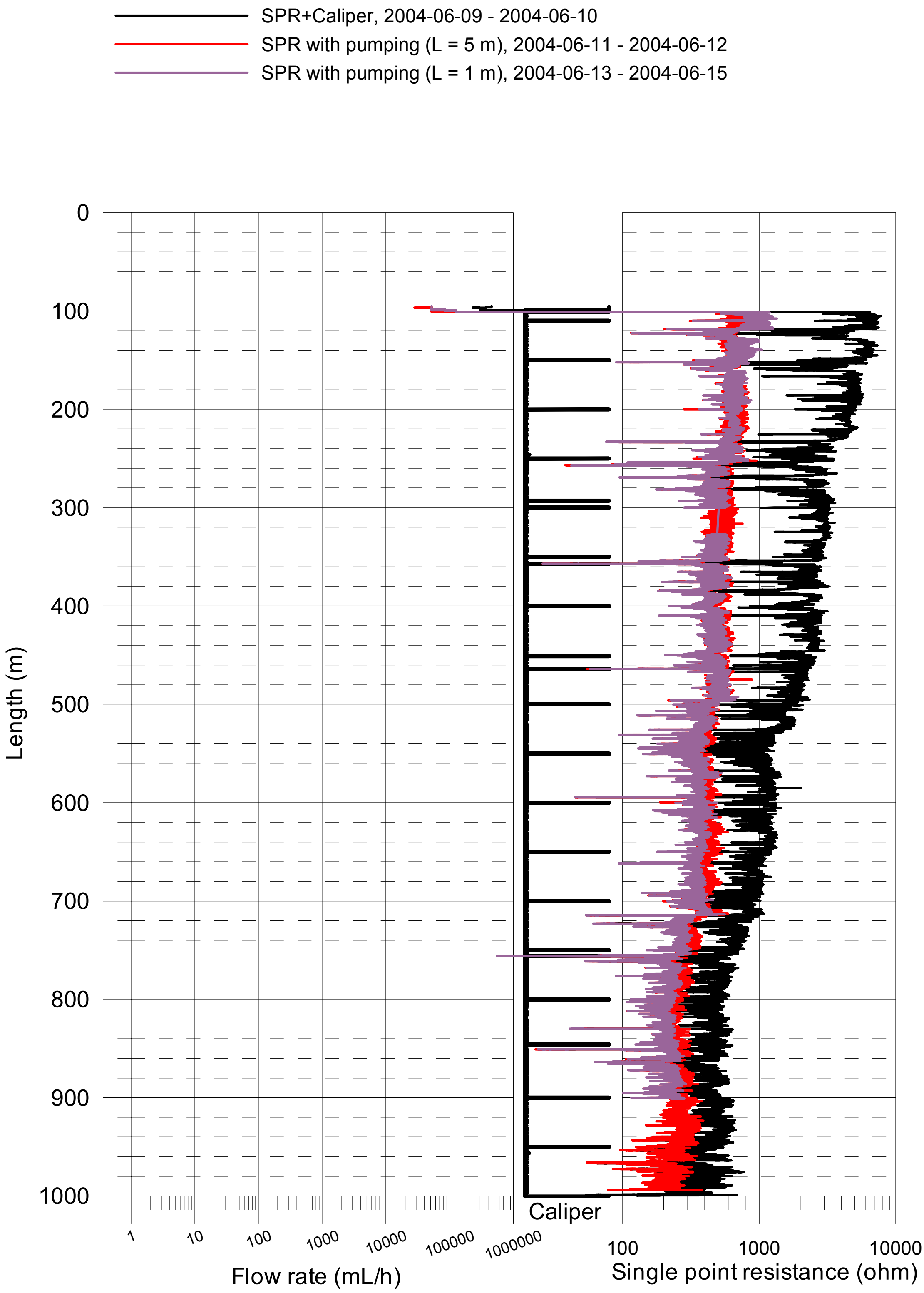
Appendices

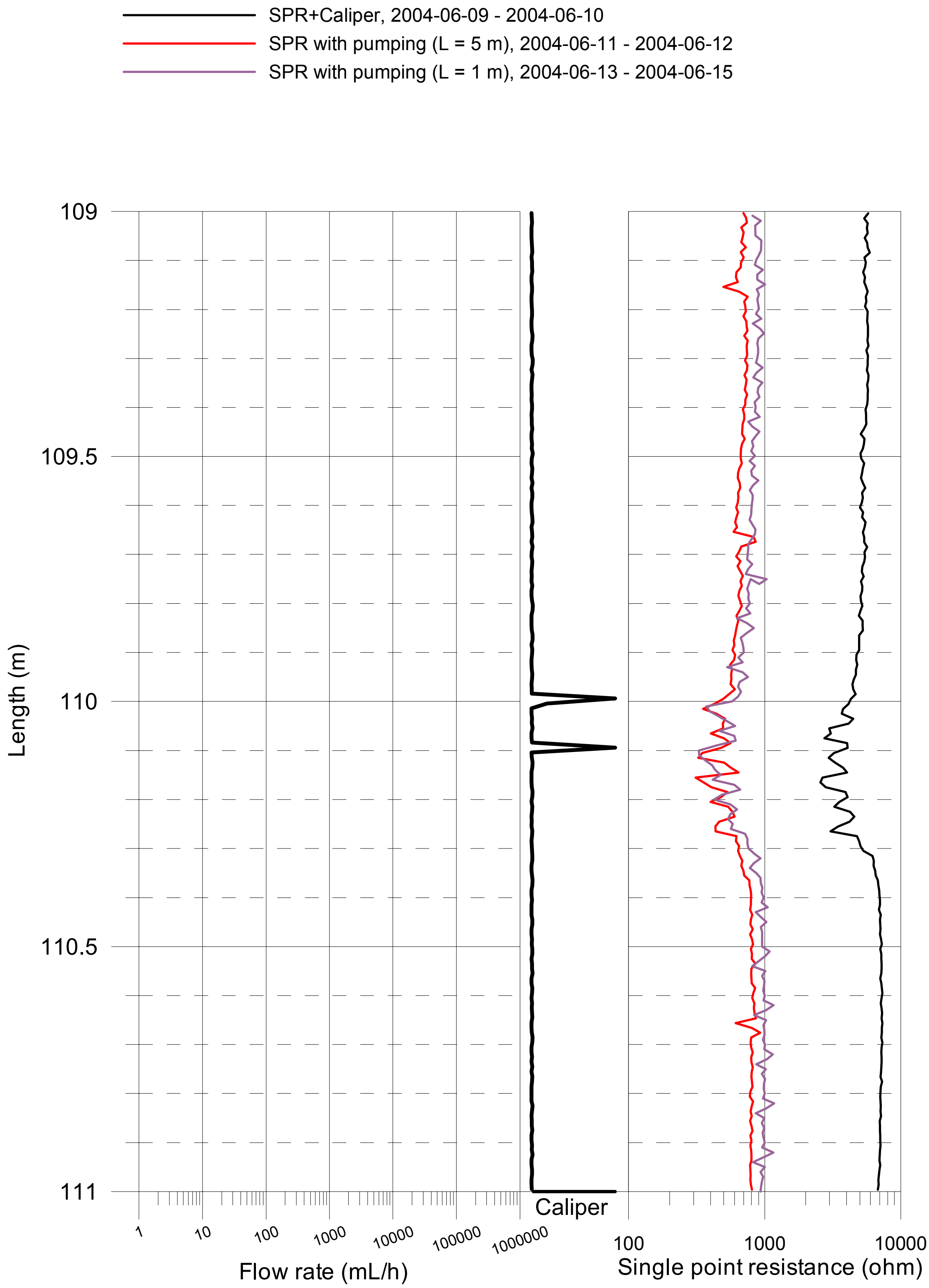
KAV04A

KAV04B

Ävrö, KAV04A
SPR and Caliper results after length correction

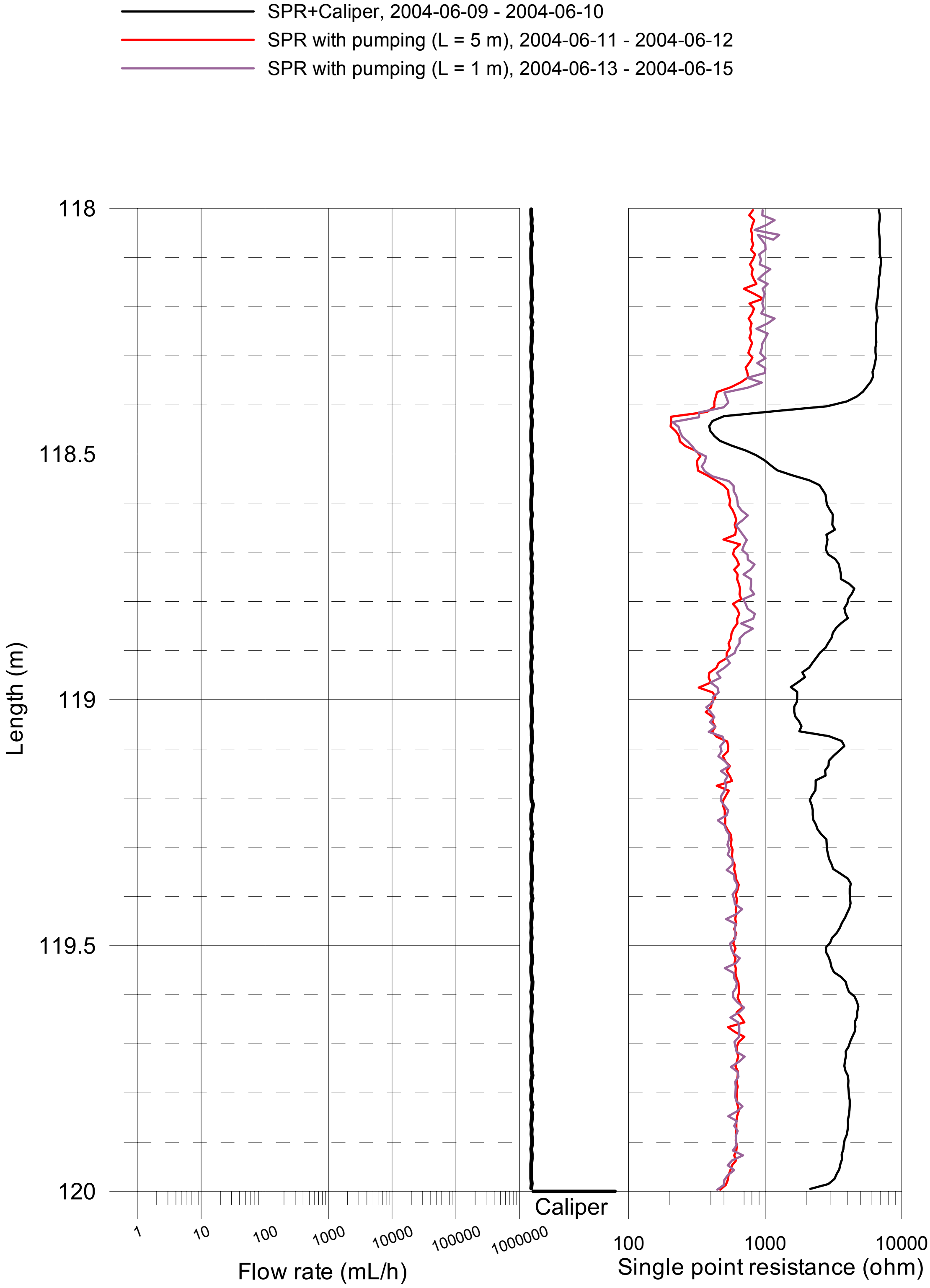


Ävrö, KAV04A
SPR and Caliper results after length correction



Appendix 1.3

Ävrö, KAV04A
SPR and Caliper results after length correction



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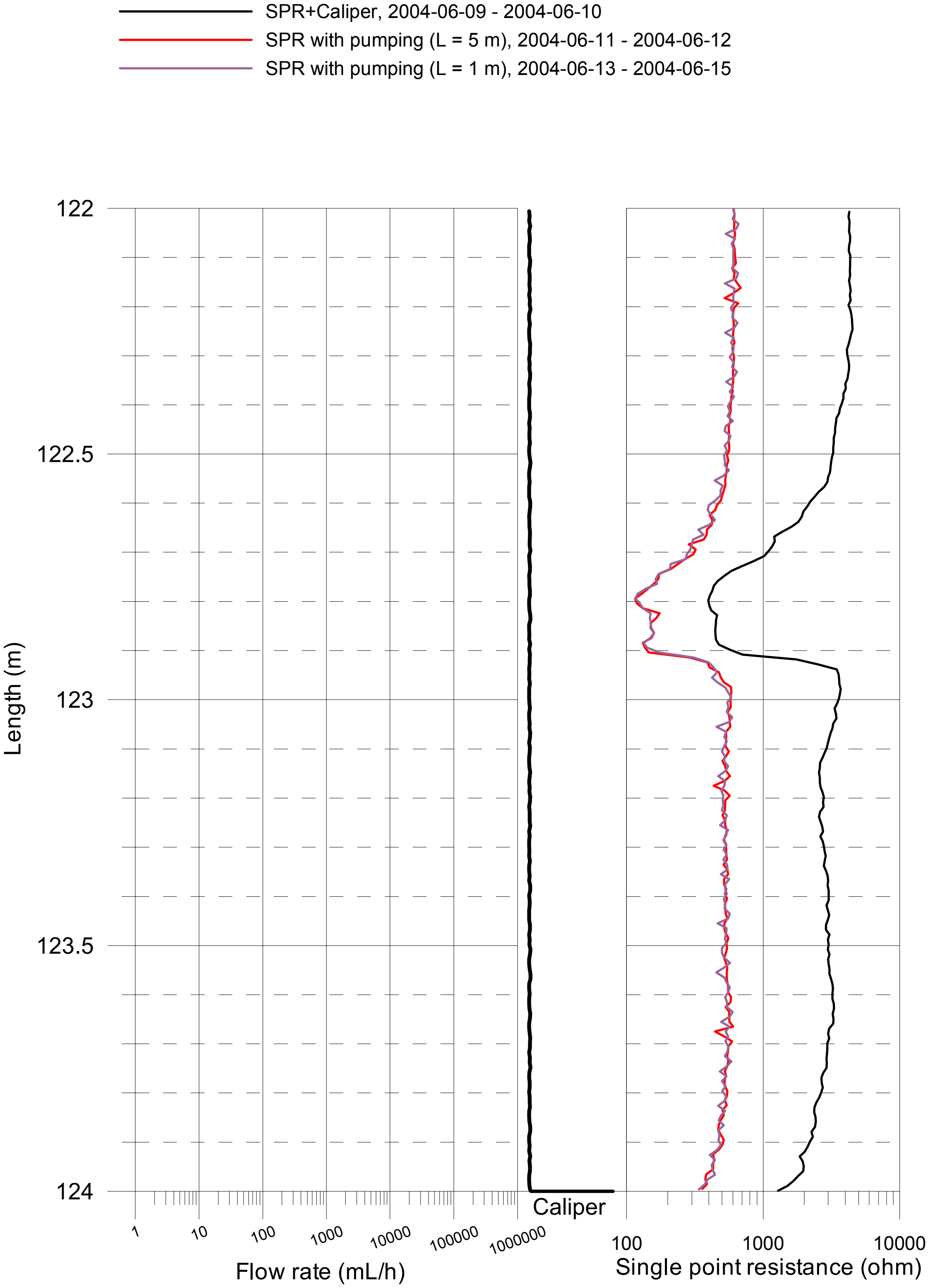
SPR and Caliper results after length correction



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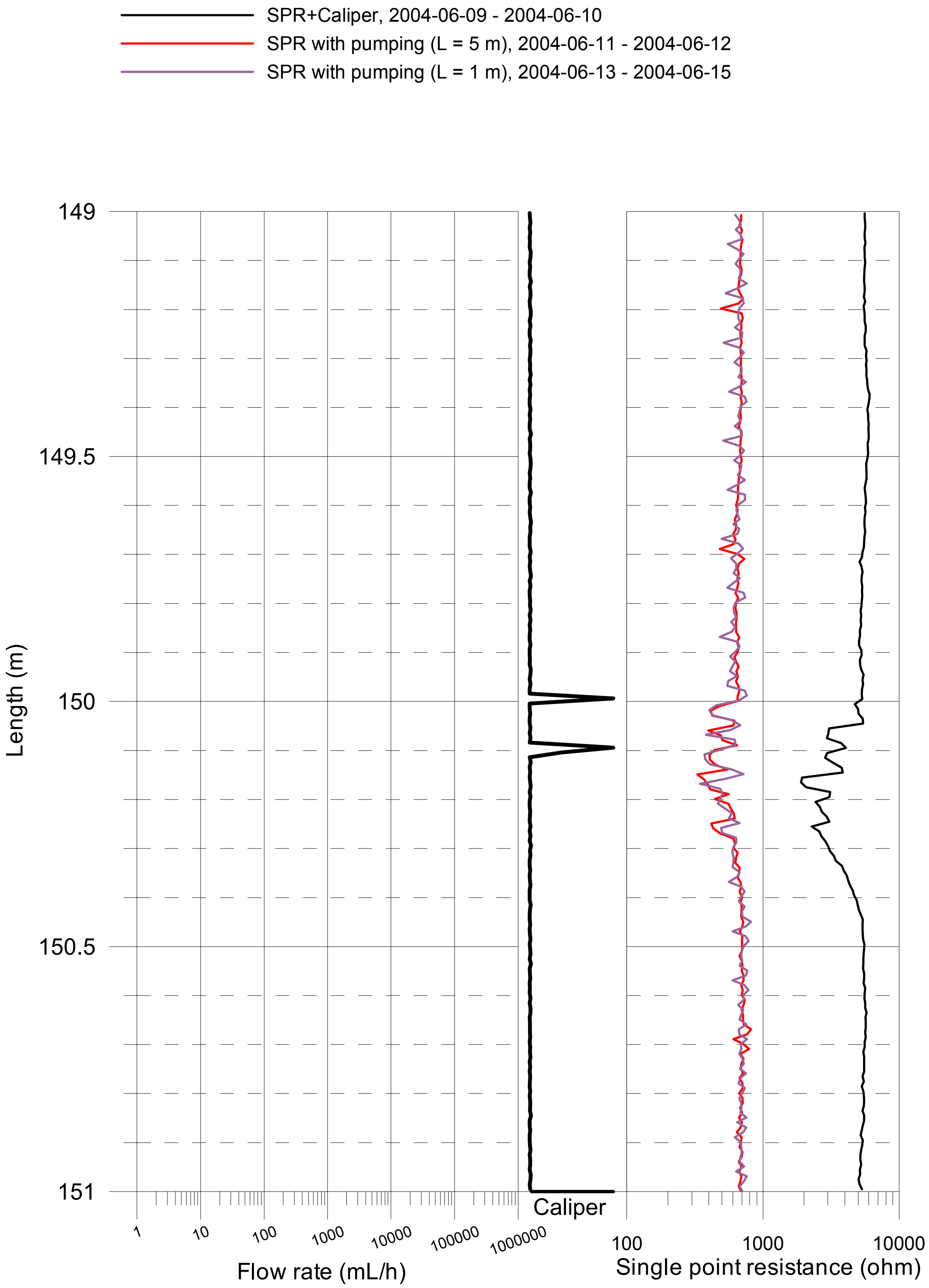
SPR and Caliper results after length correction



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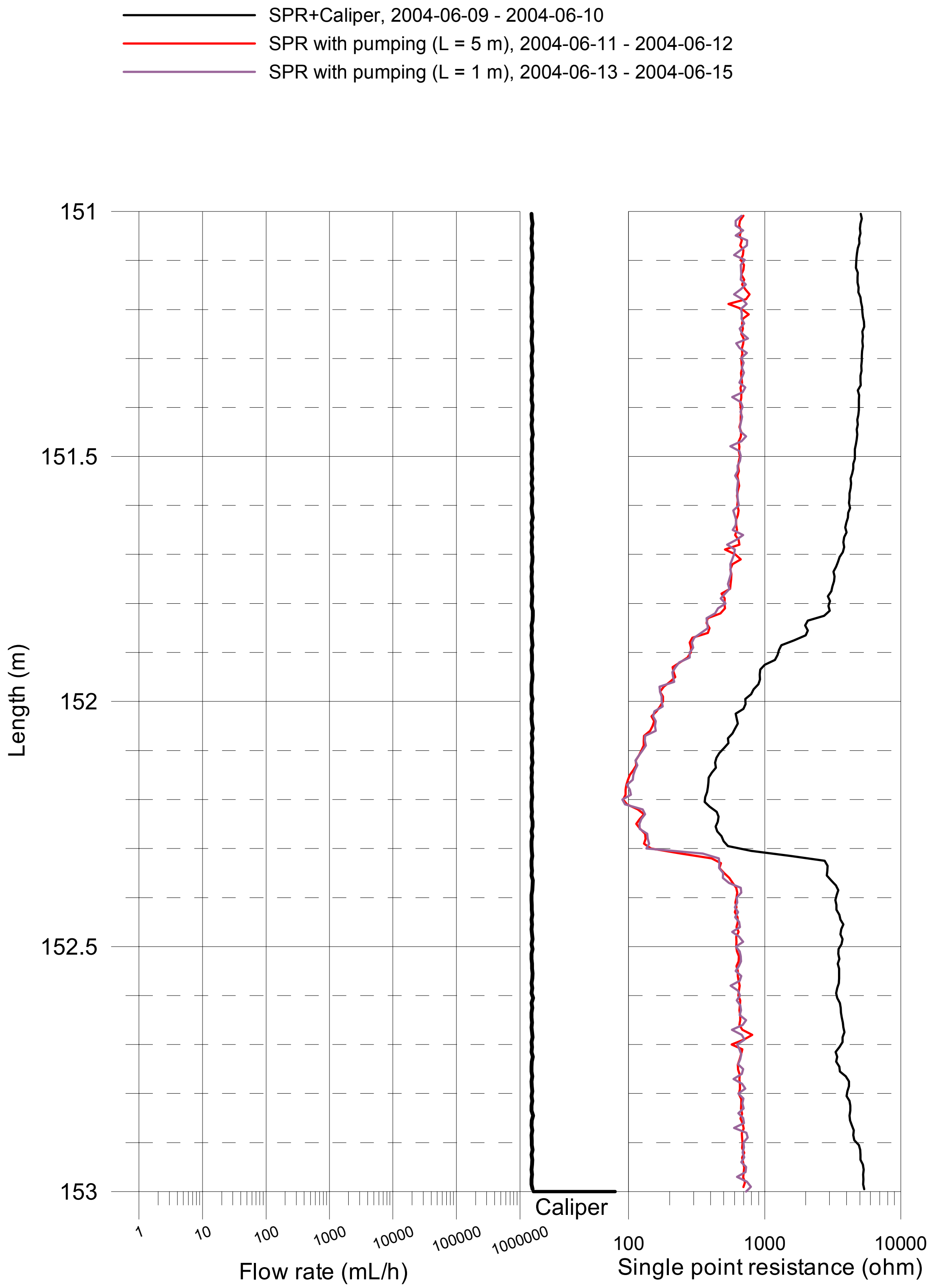

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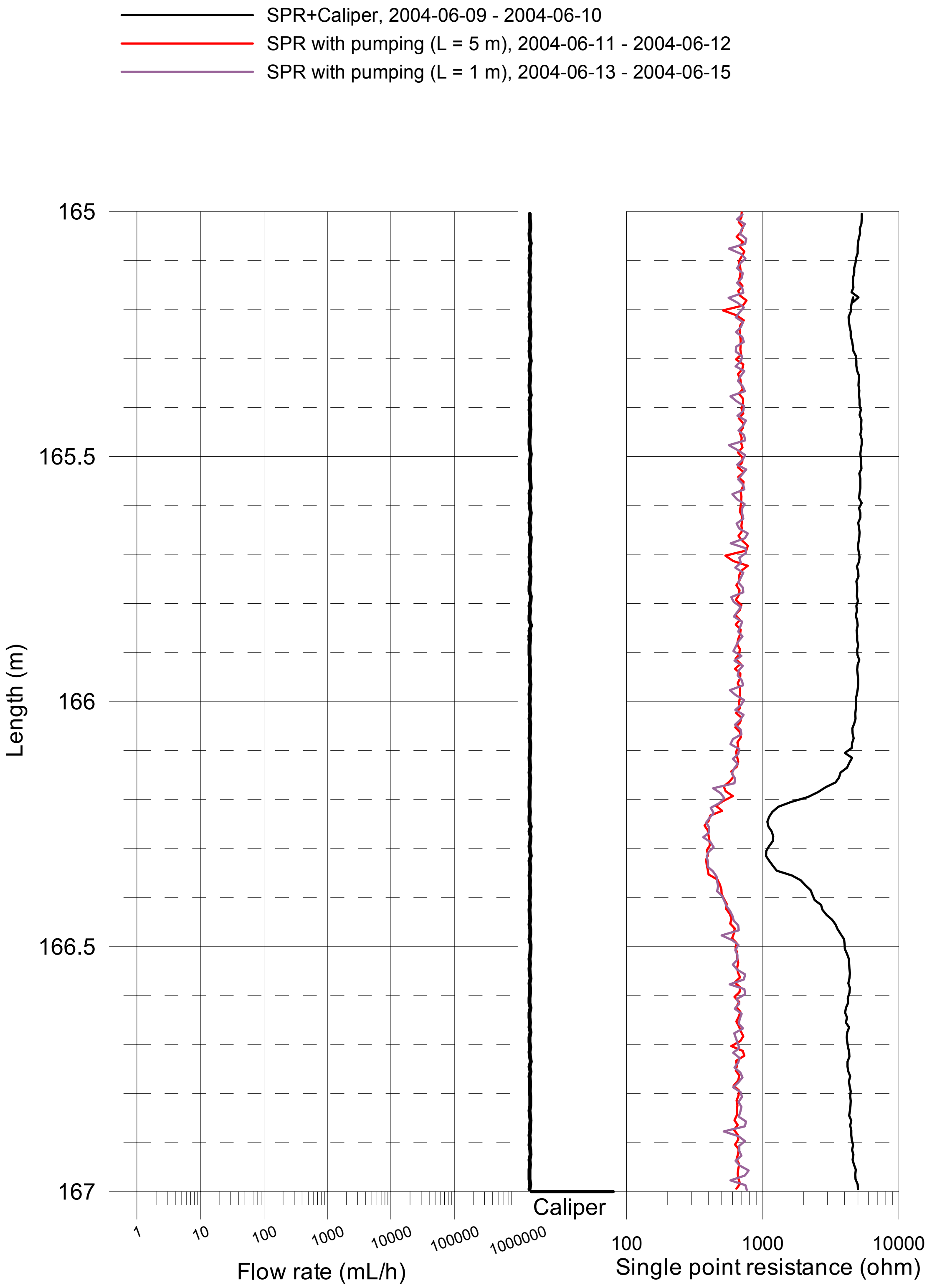

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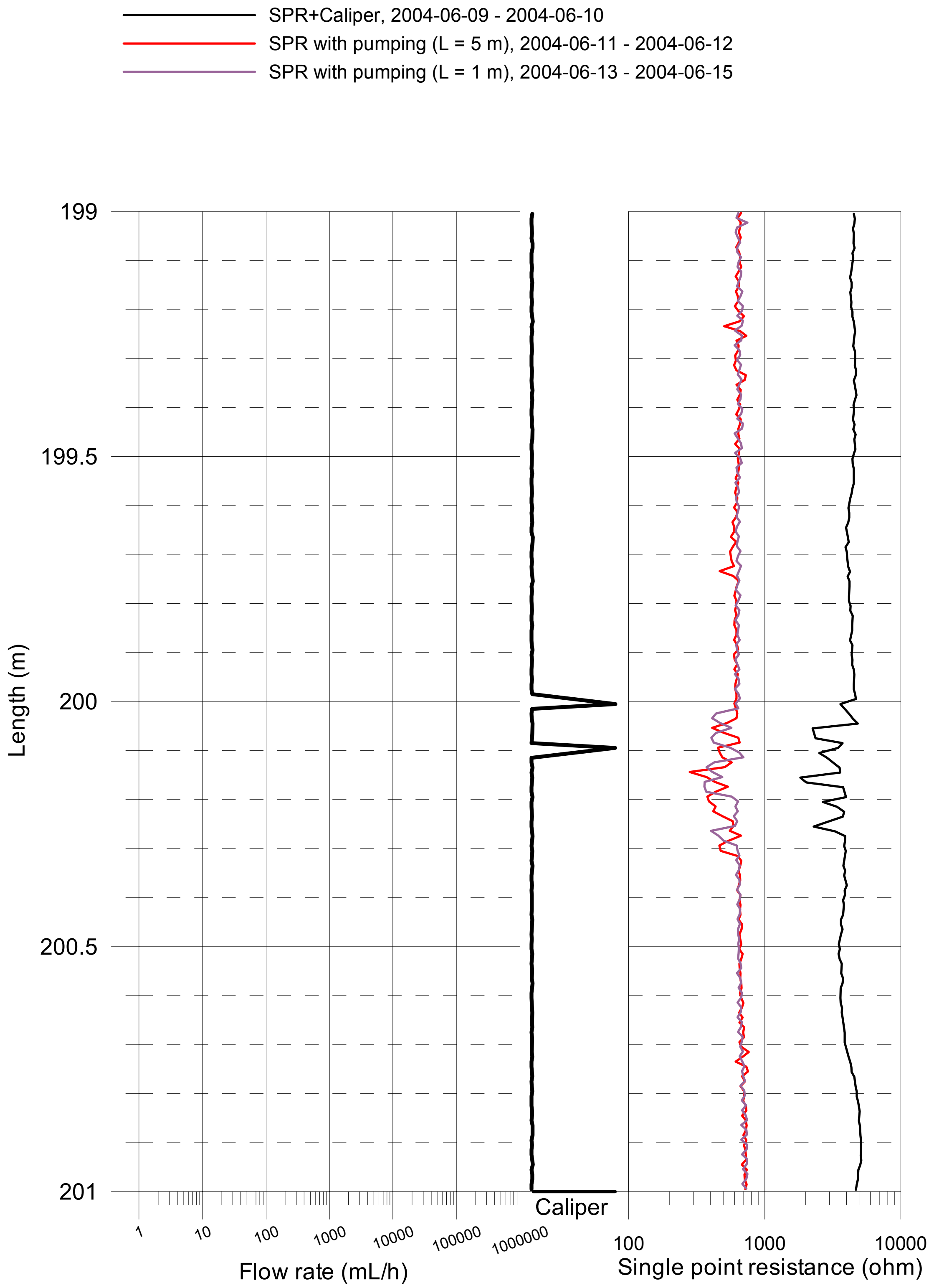
SPR and Caliper results after length correction



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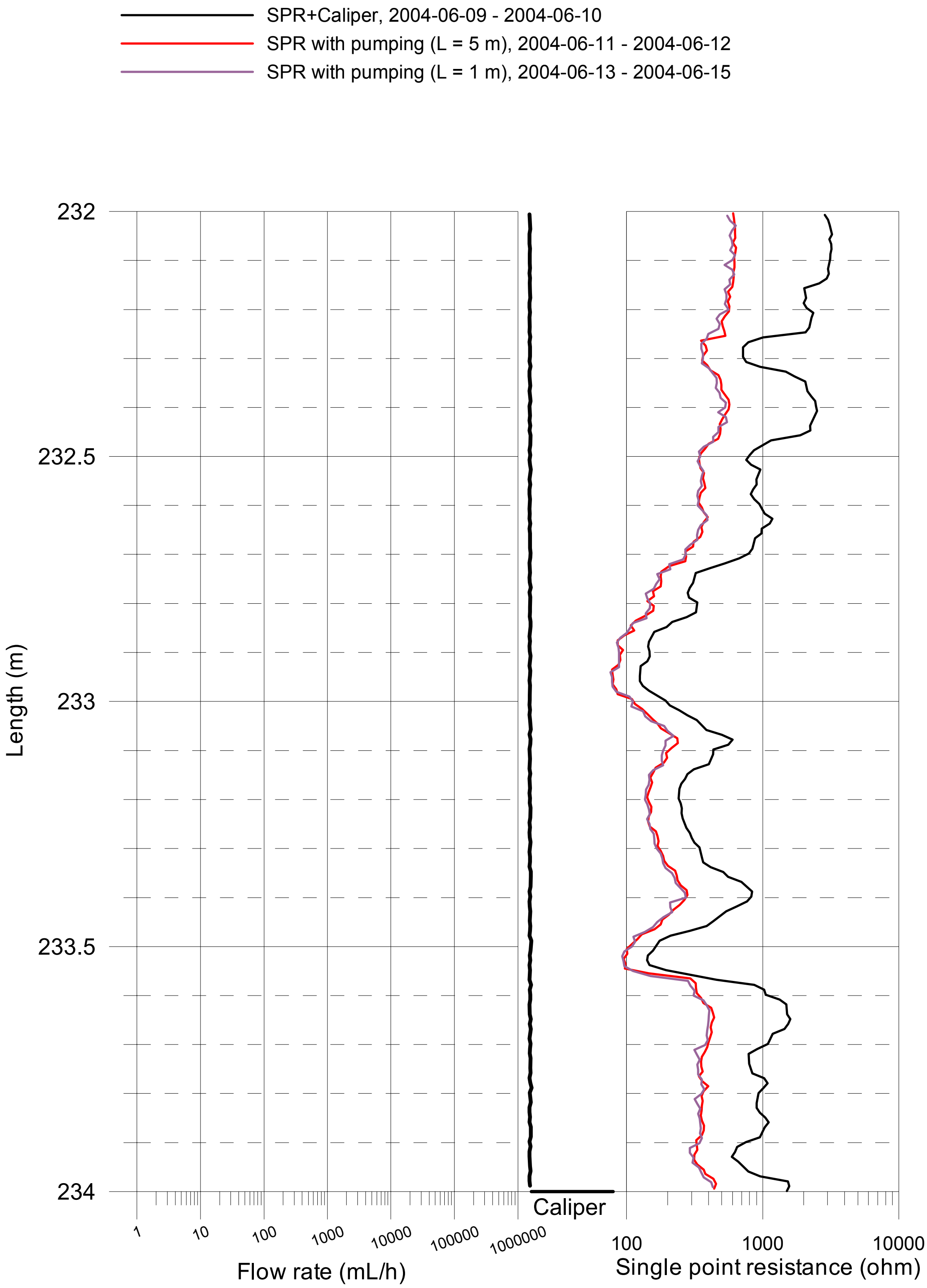
SPR and Caliper results after length correction



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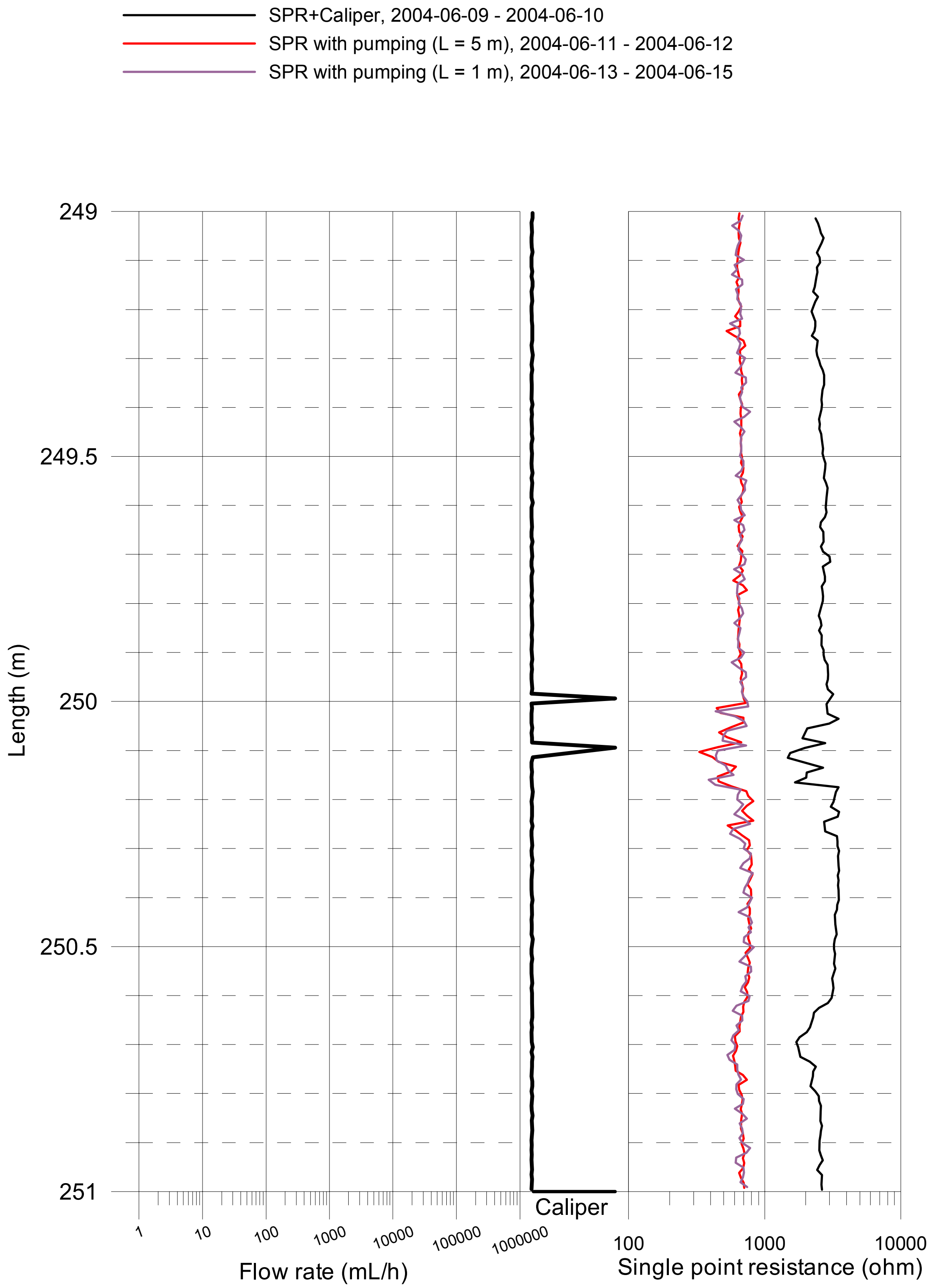

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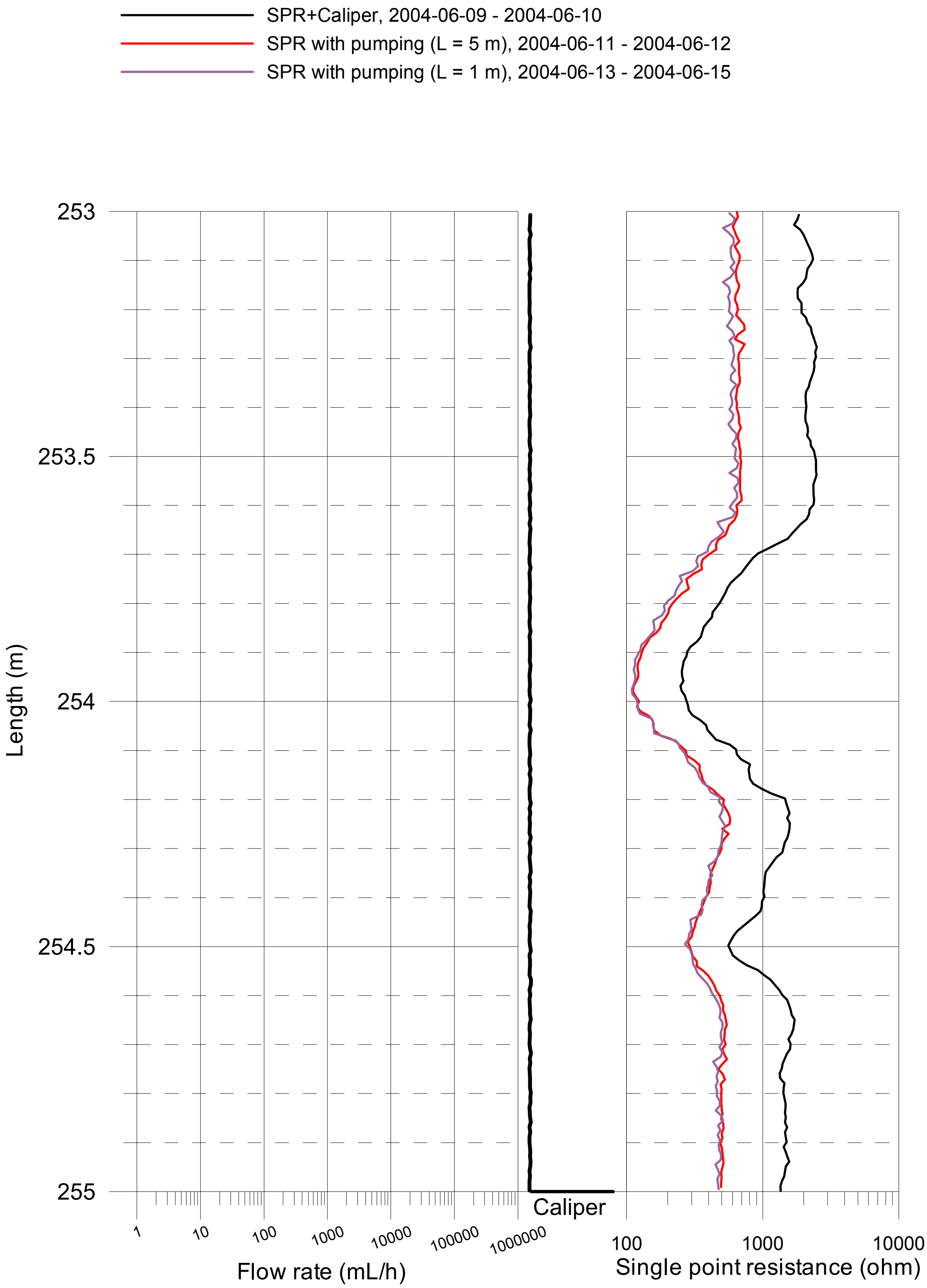
SPR and Caliper results after length correction



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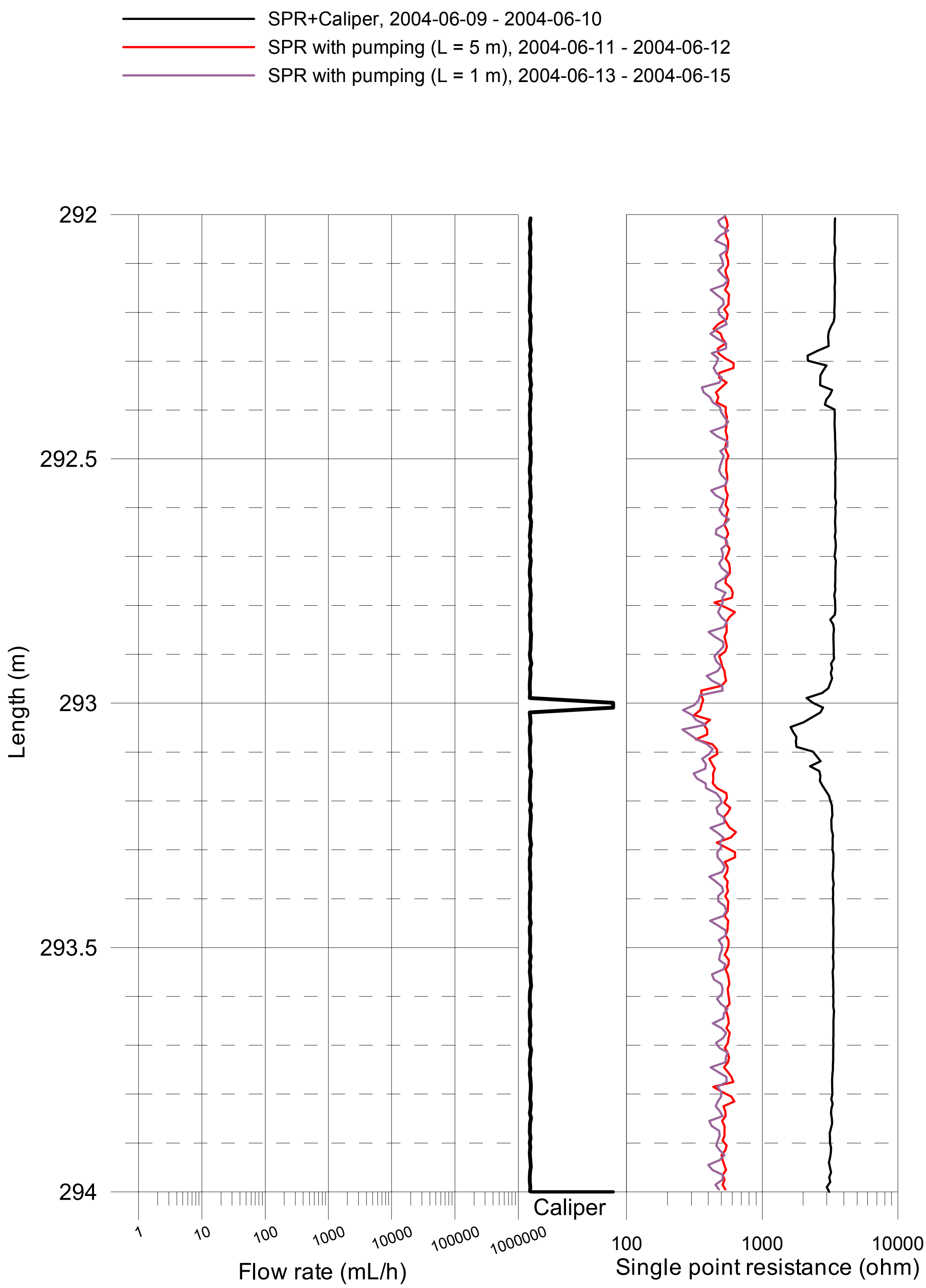
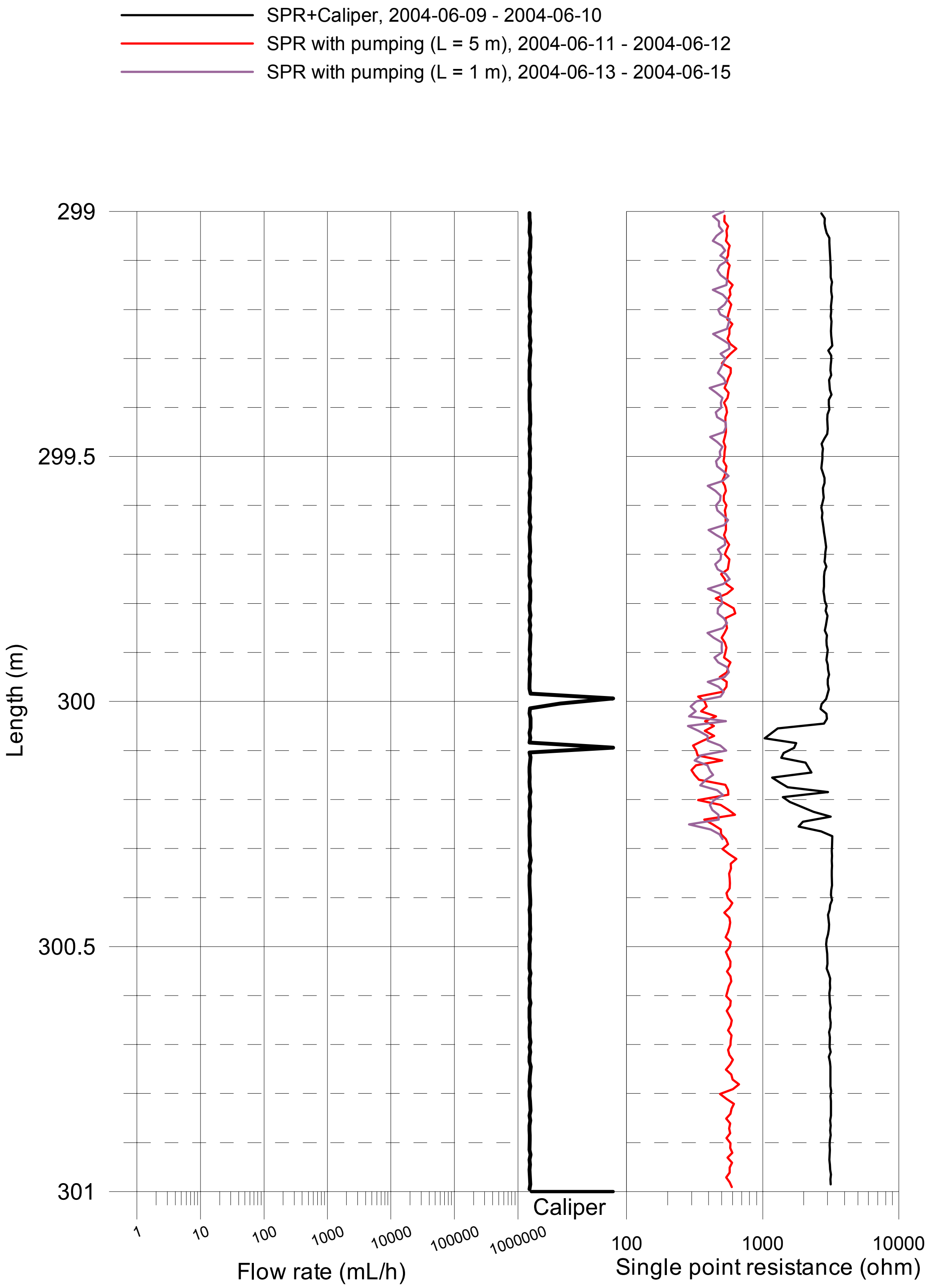
SPR and Caliper results after length correction



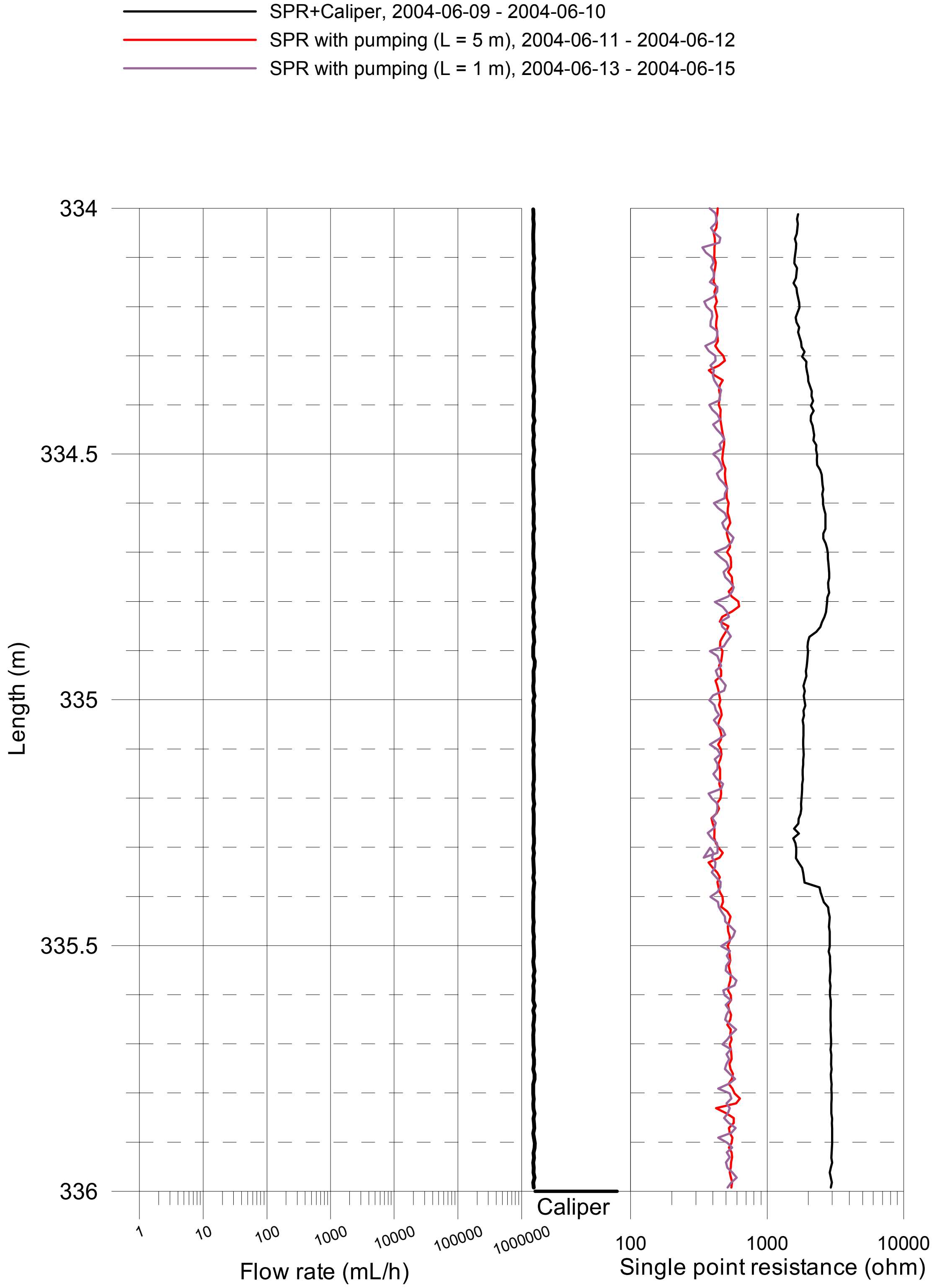
Appendix 1.13

Ävrö, KAV04A
SPR and Caliper results after length correction



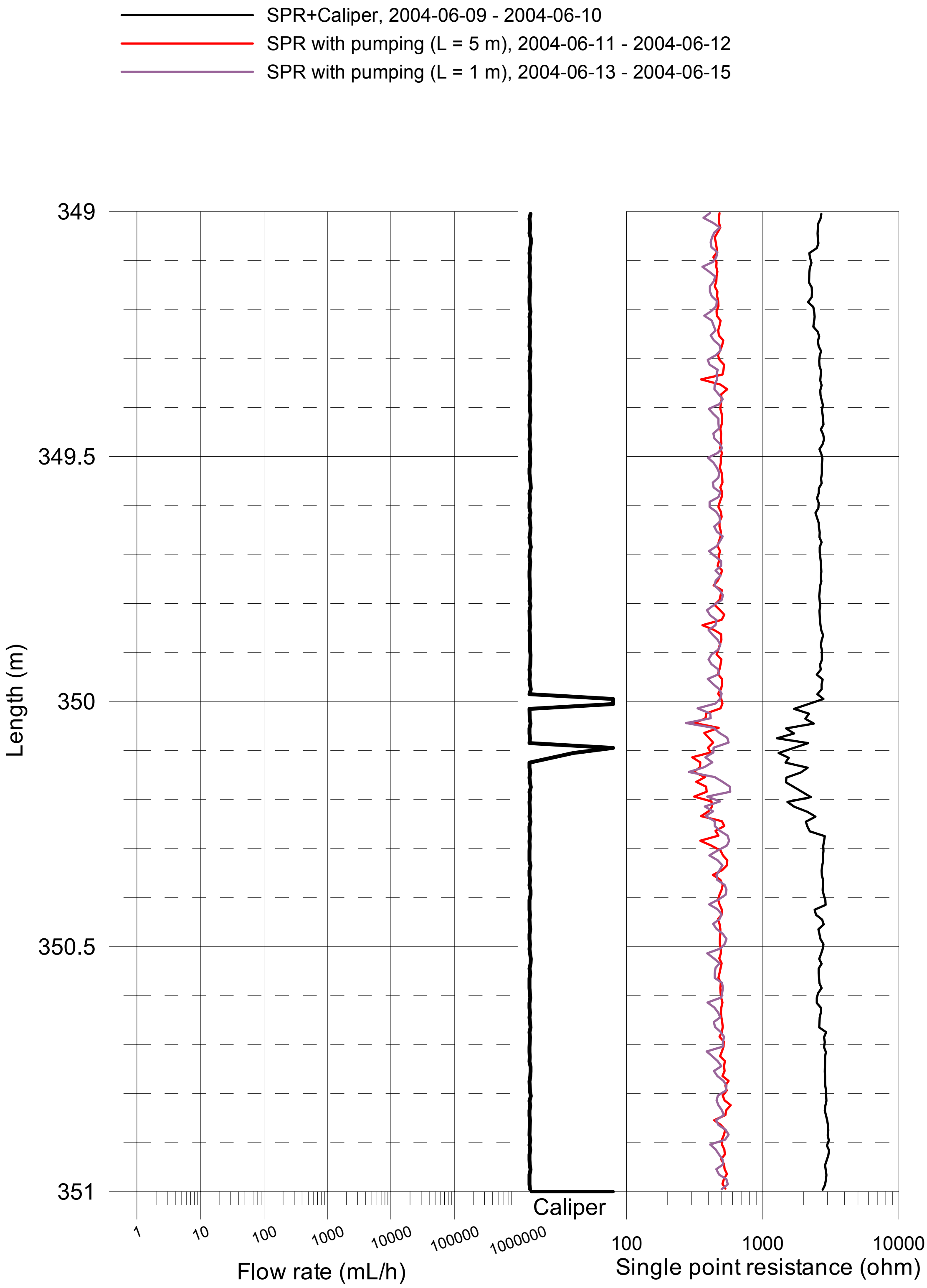
Appendix 1.14

Ävrö, KAV04A
SPR and Caliper results after length correction



Appendix 1.15

Ävrö, KAV04A
SPR and Caliper results after length correction



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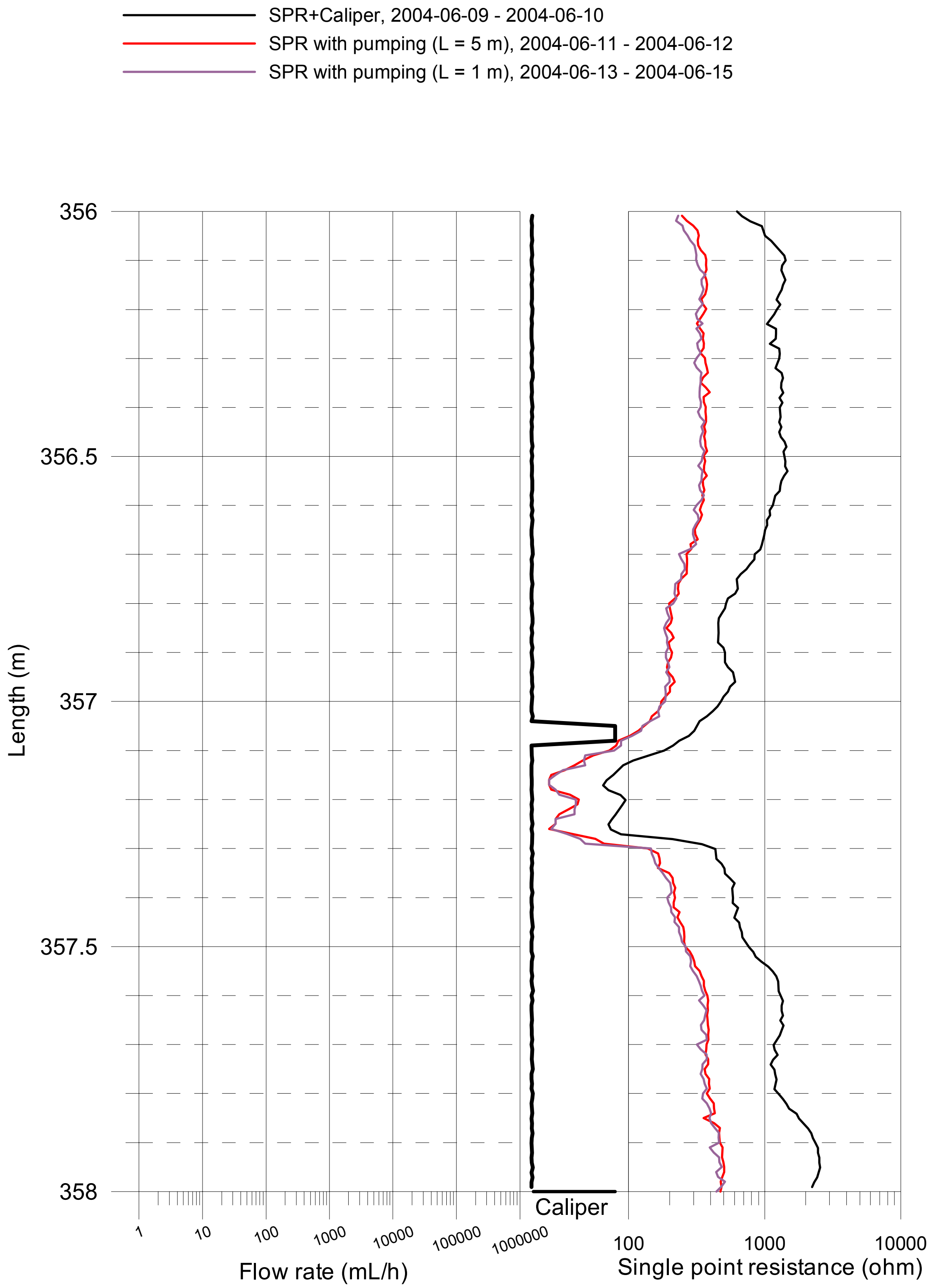
SPR and Caliper results after length correction



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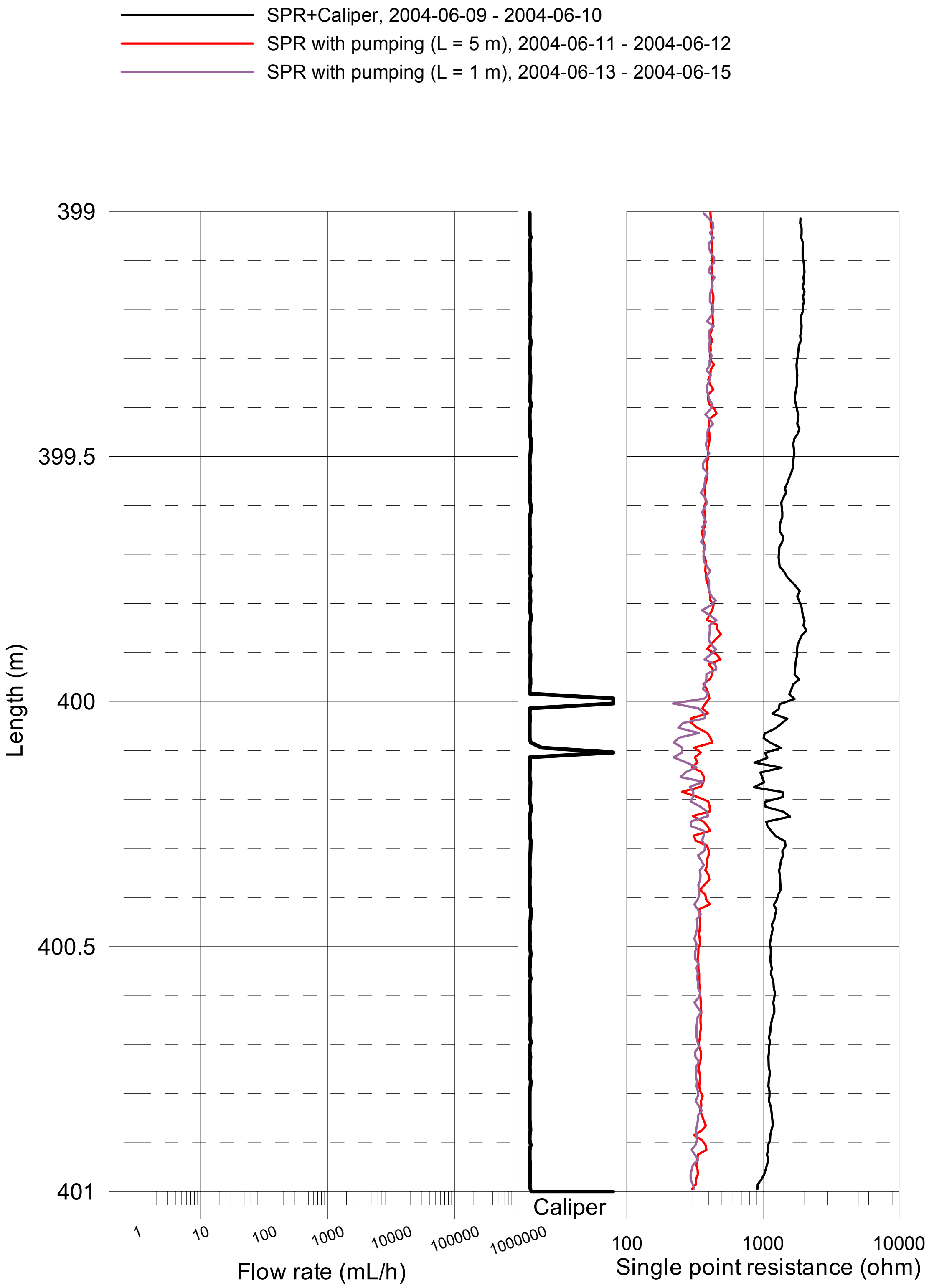
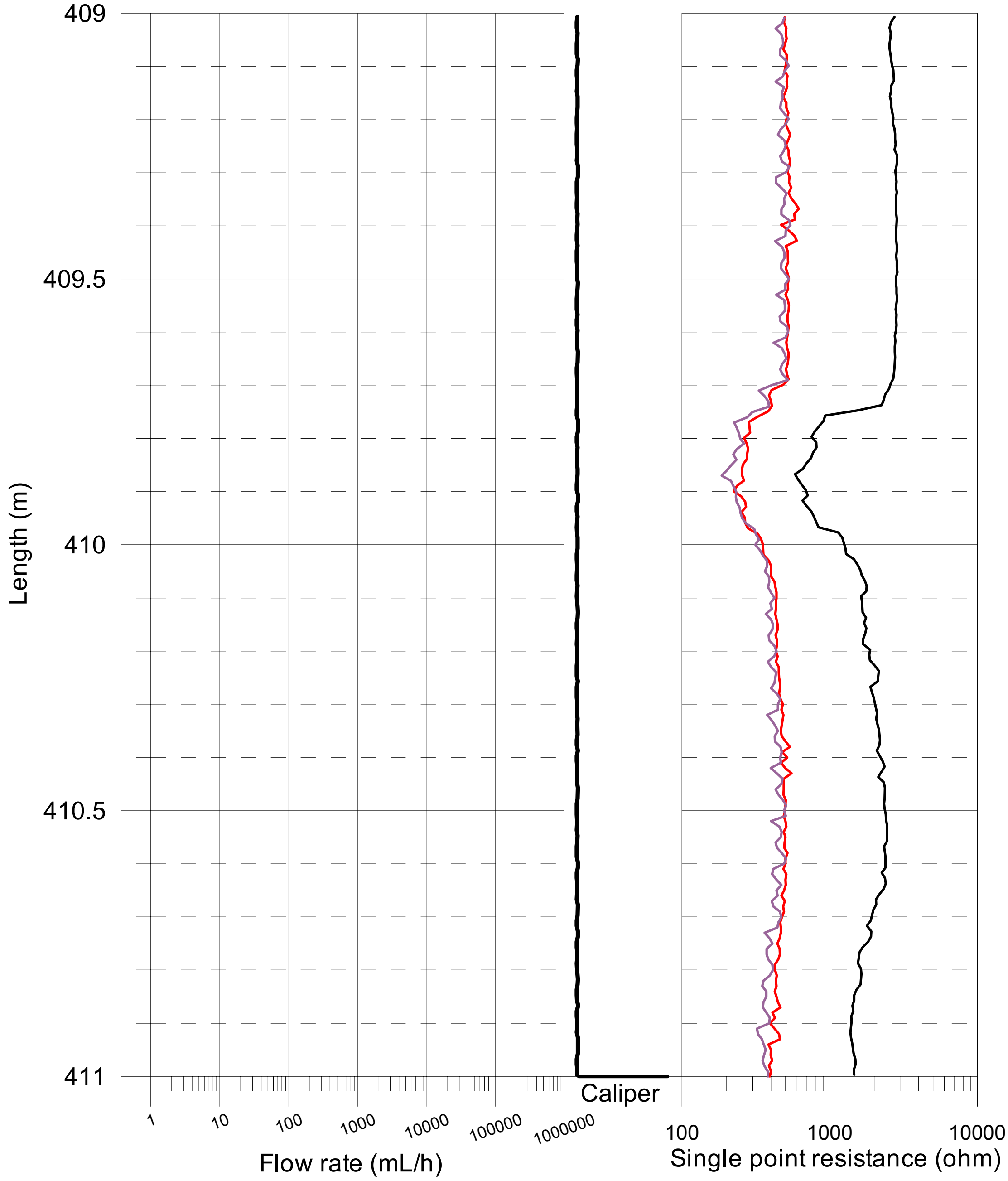
SPR and Caliper results after length correction



Ävrö, KAV04A
SPR and Caliper results after length correction

SPR+Caliper, 2004-06-09 - 2004-06-10
SPR with pumping (L = 5 m), 2004-06-11 - 2004-06-12
SPR with pumping (L = 1 m), 2004-06-13 - 2004-06-15



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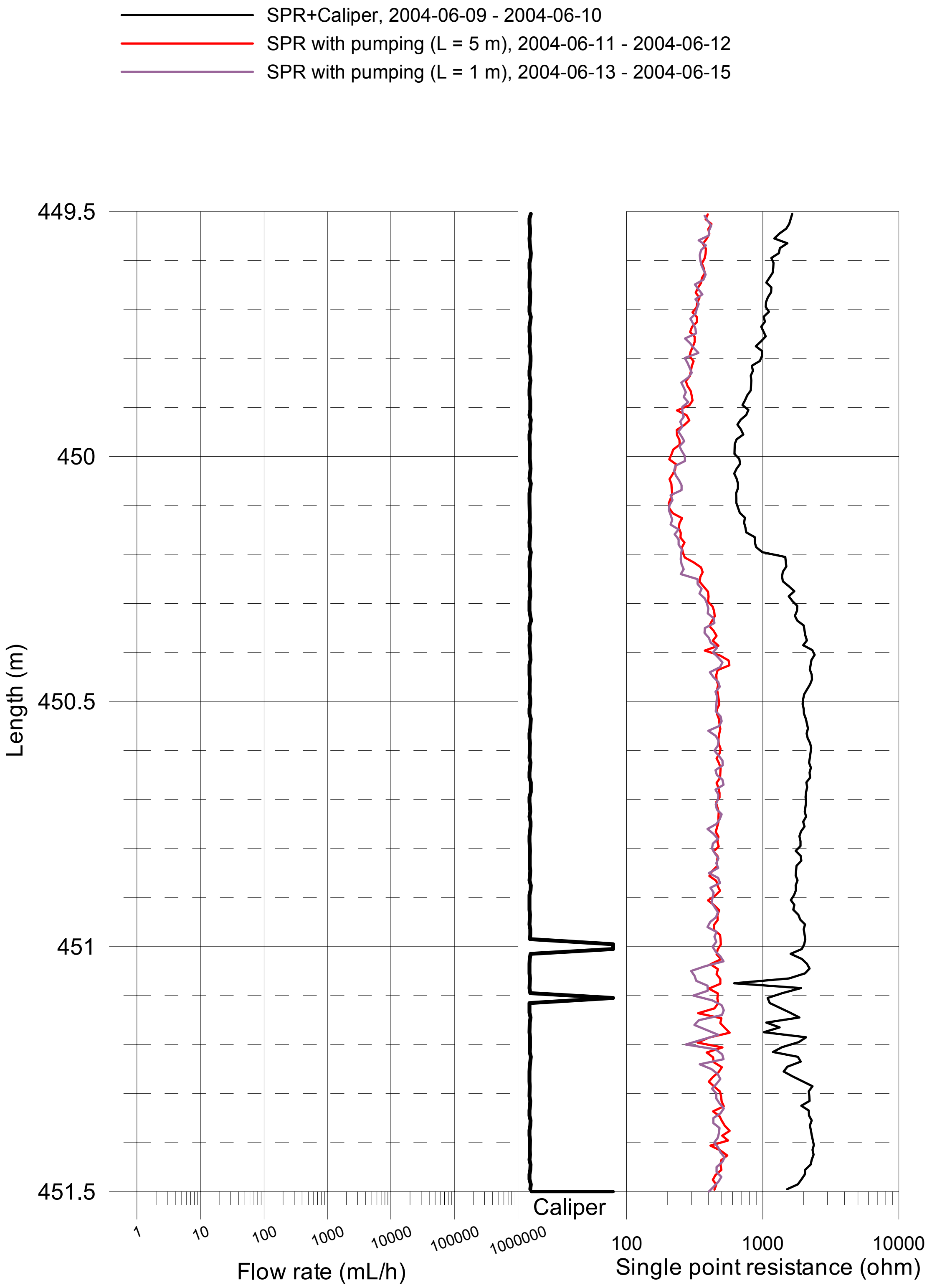
SPR and Caliper results after length correction



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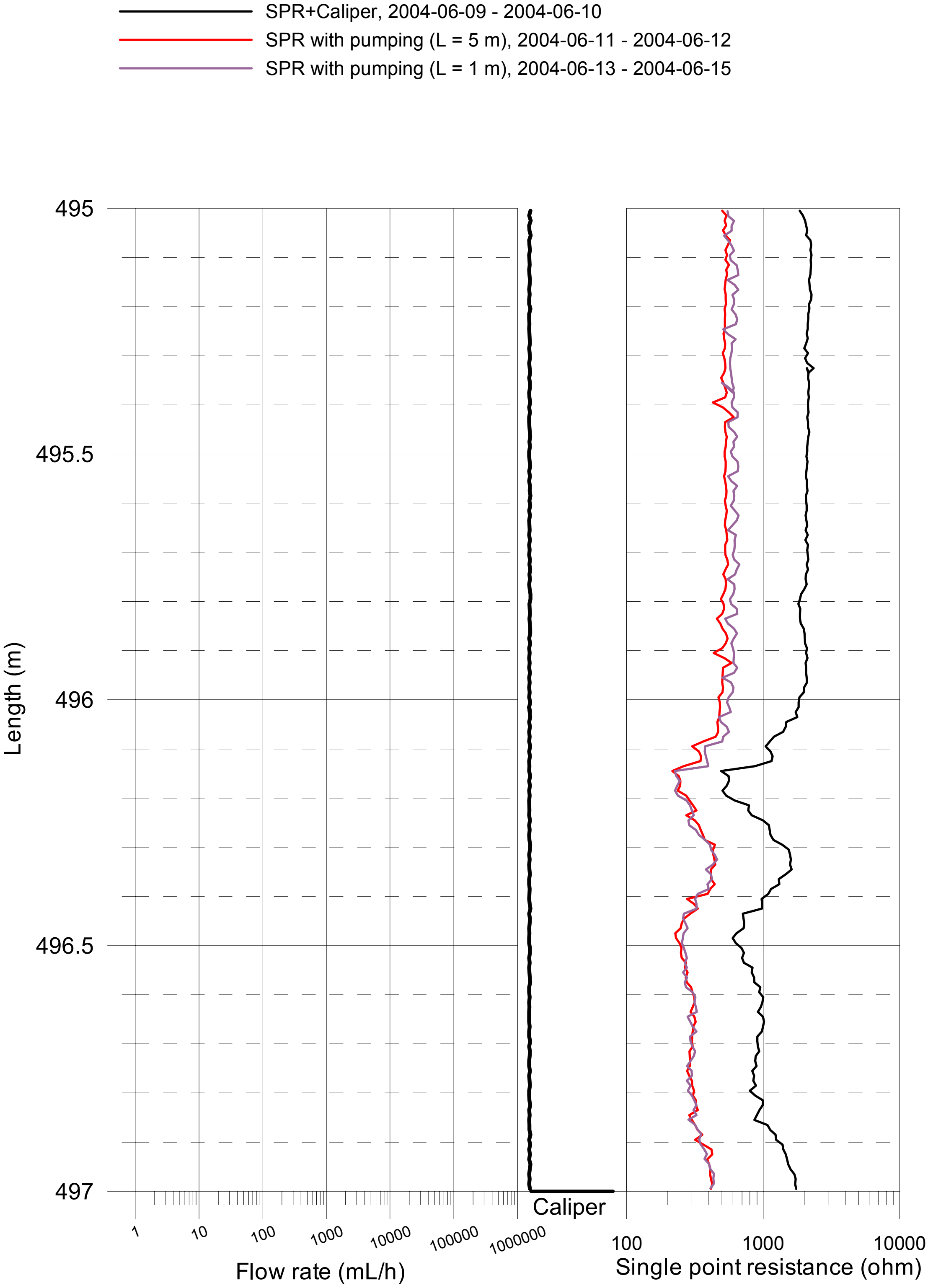
SPR and Caliper results after length correction



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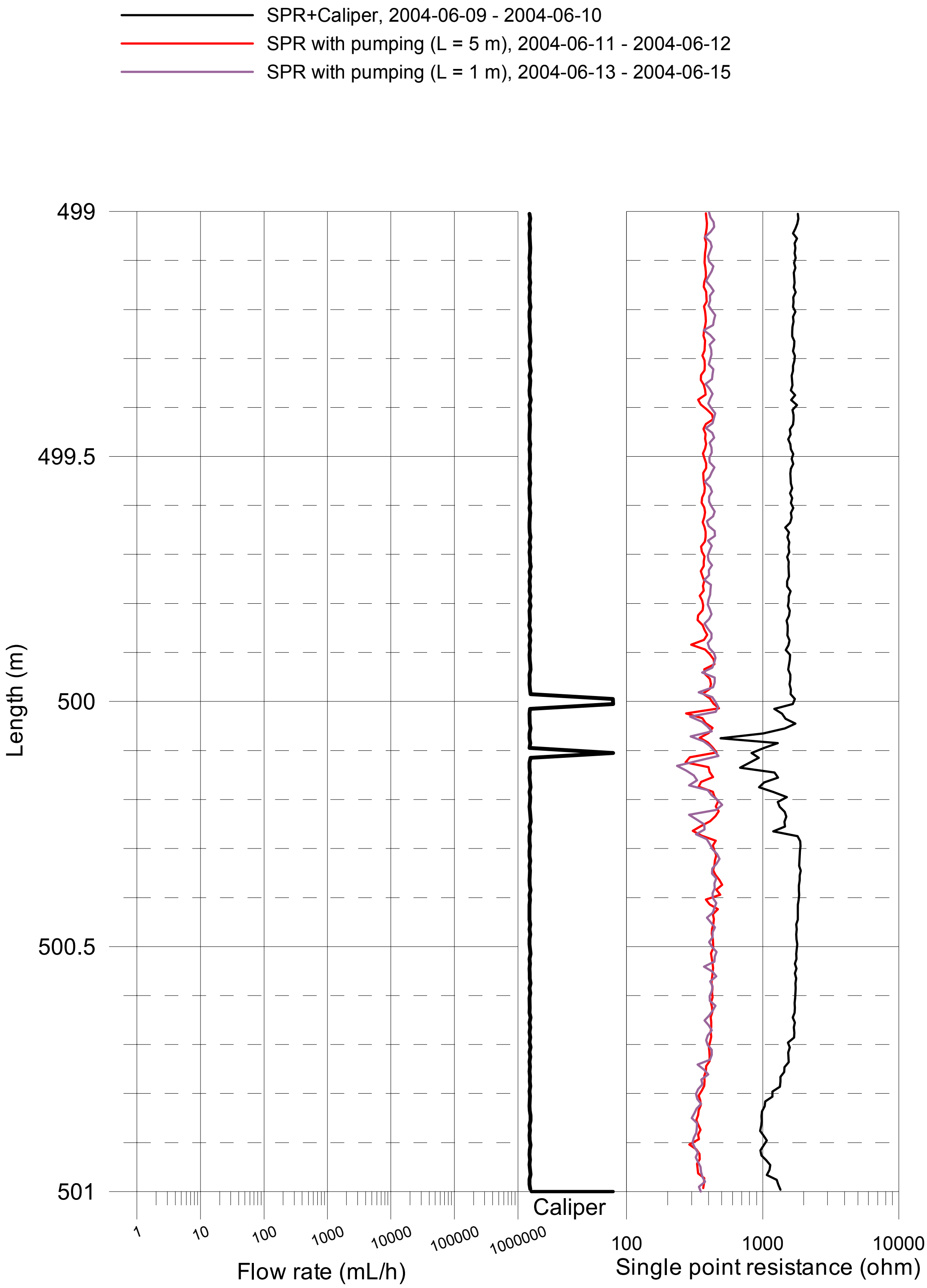
SPR and Caliper results after length correction



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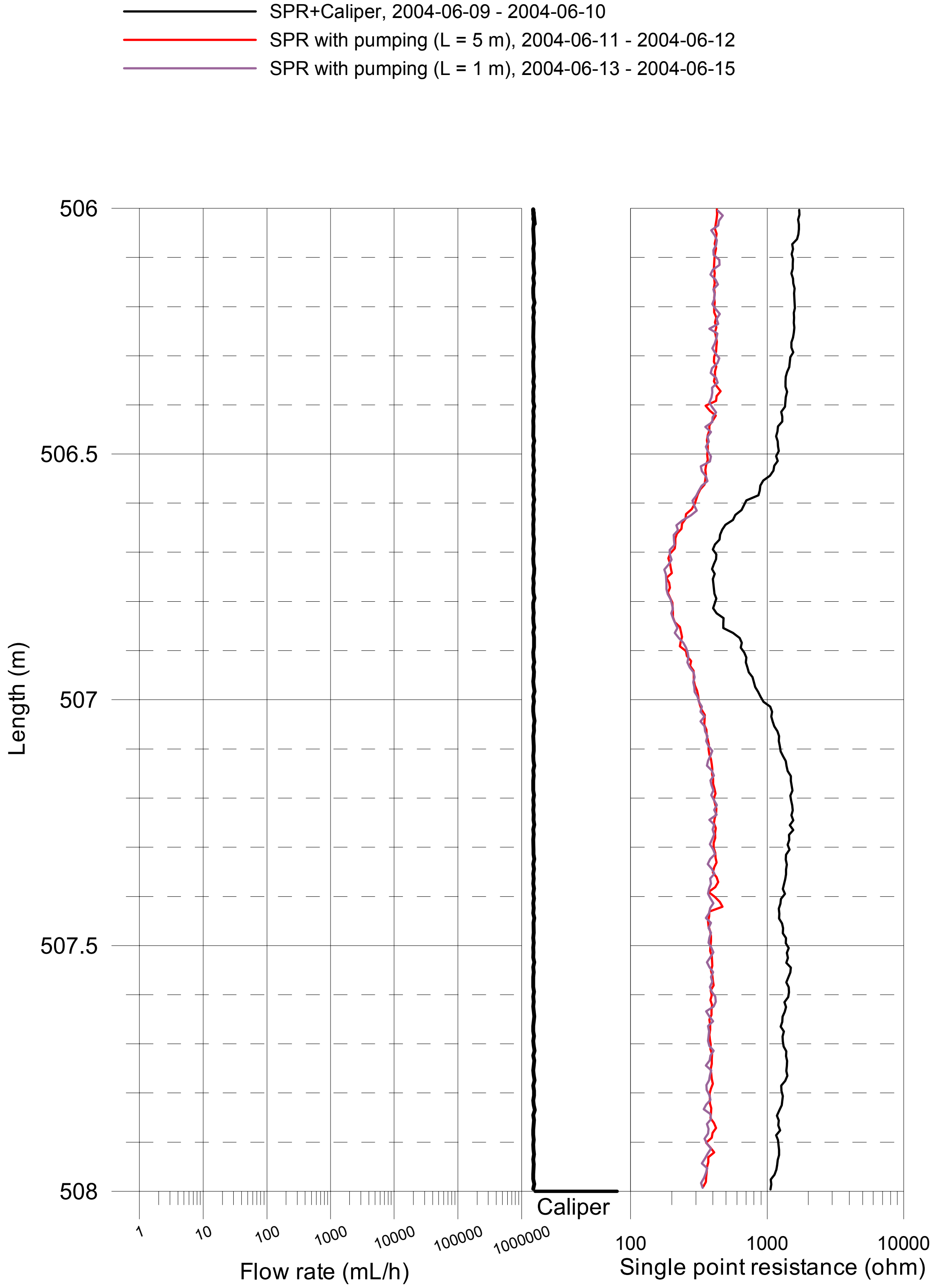

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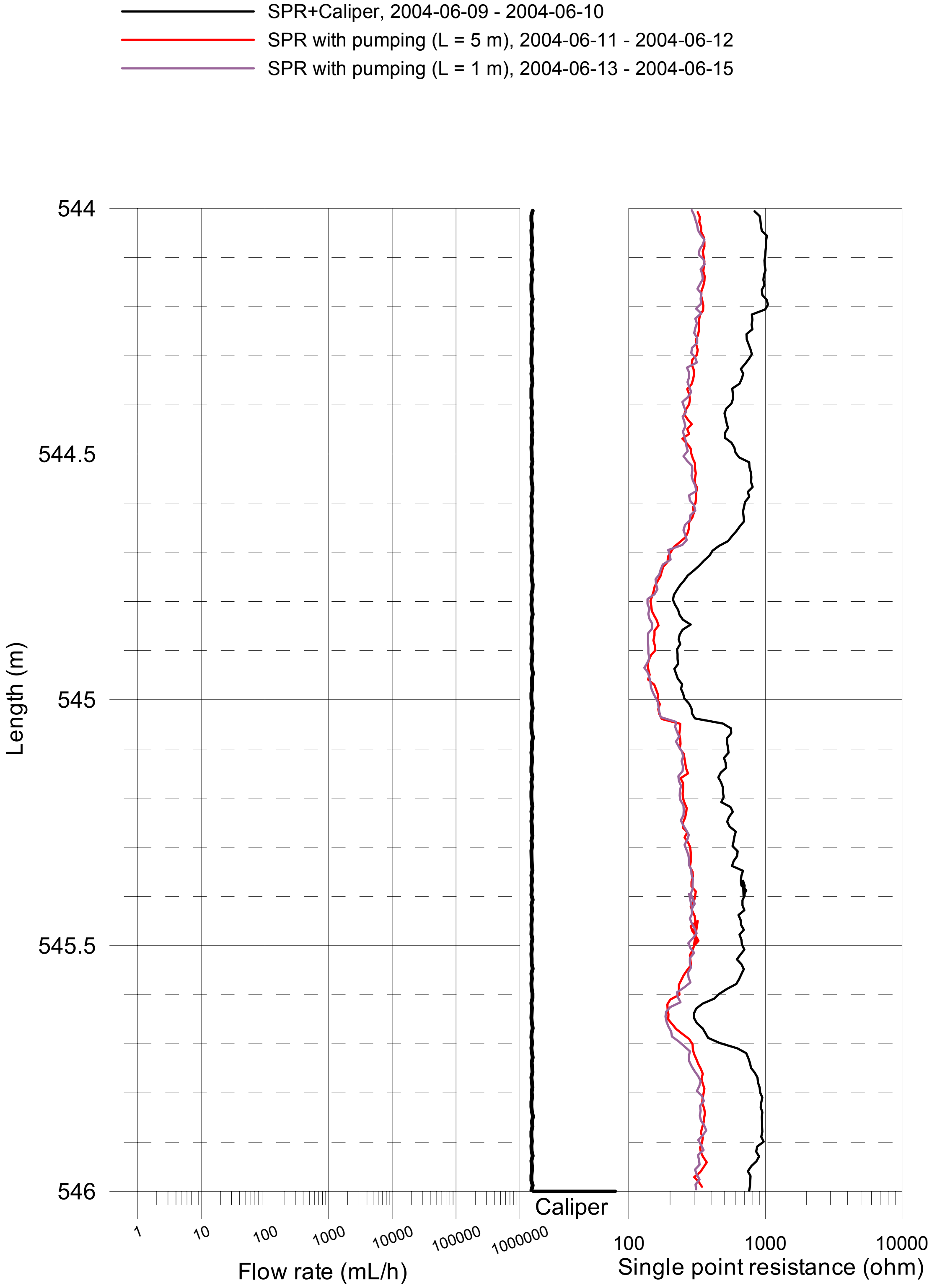

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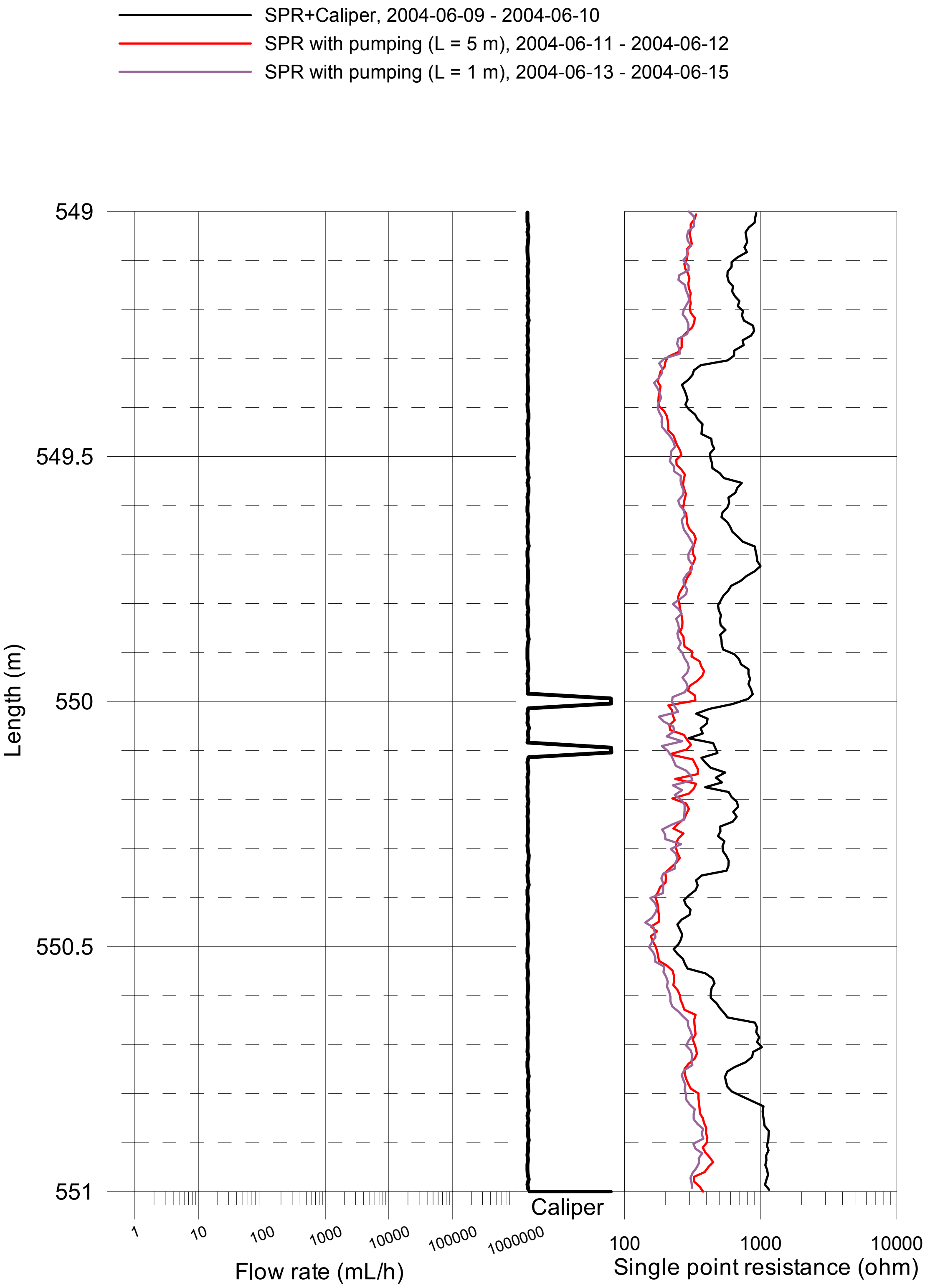
SPR and Caliper results after length correction



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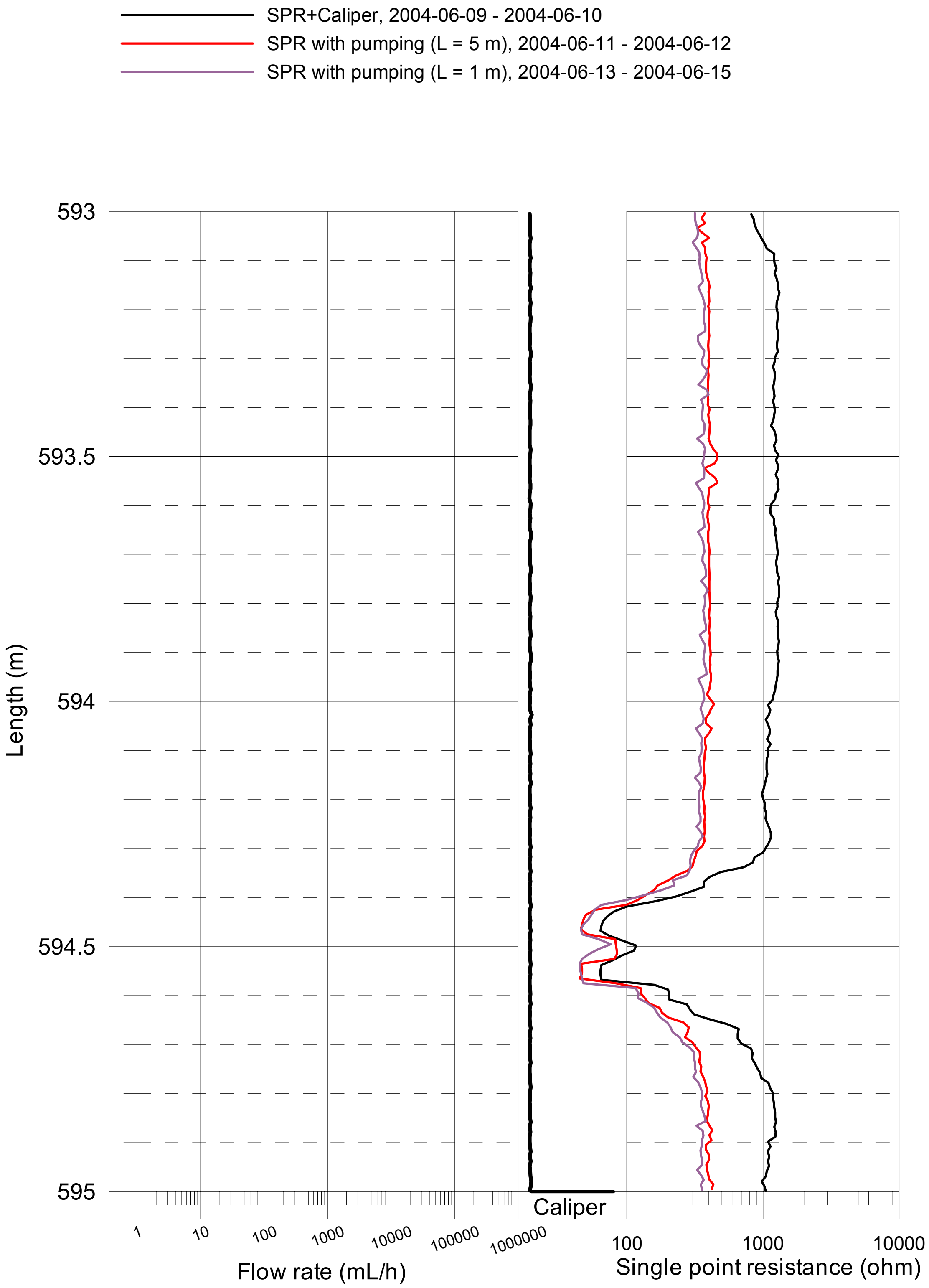
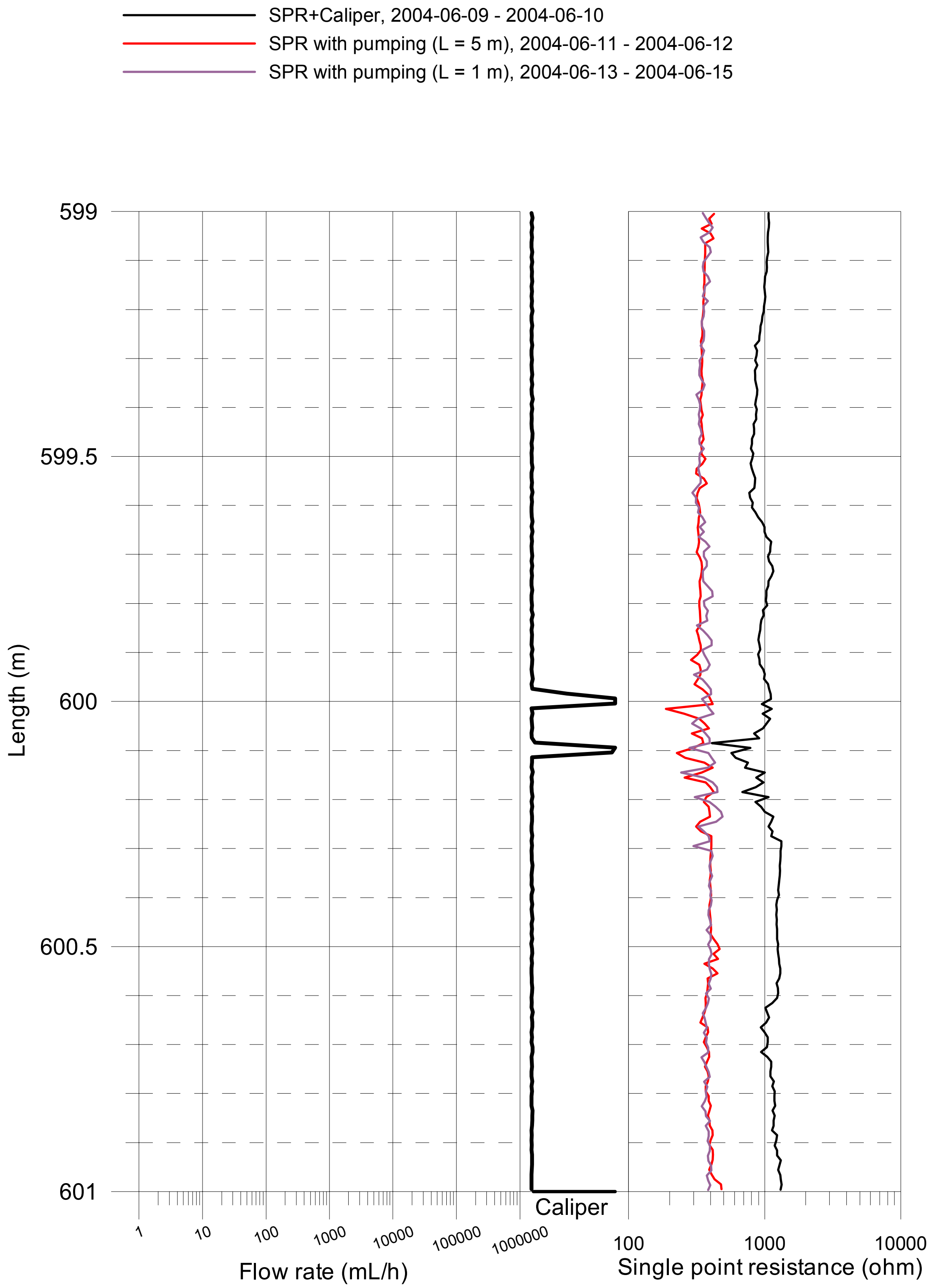
SPR and Caliper results after length correction



Appendix 1.26

Ävrö, KAV04A
SPR and Caliper results after length correction



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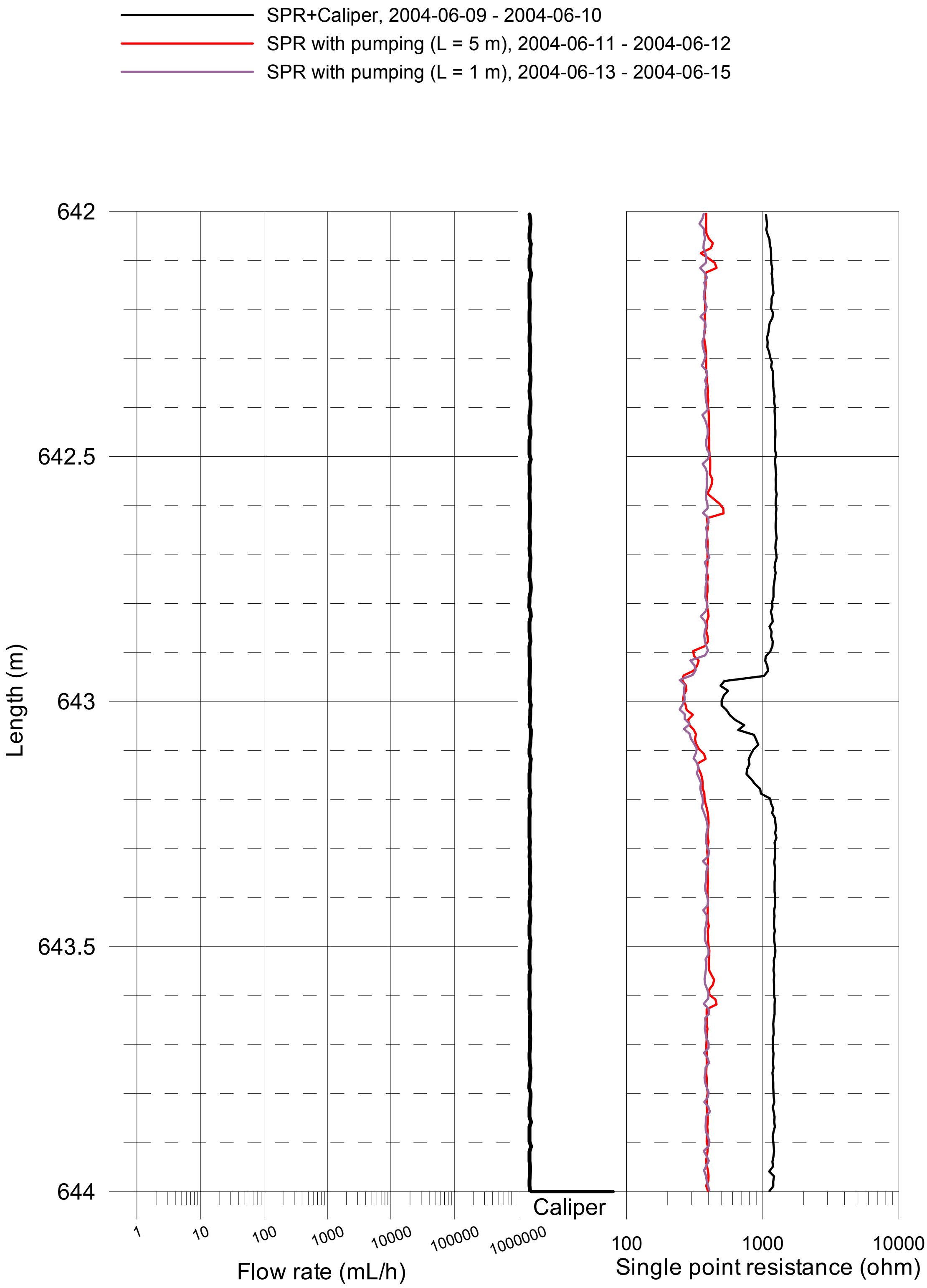
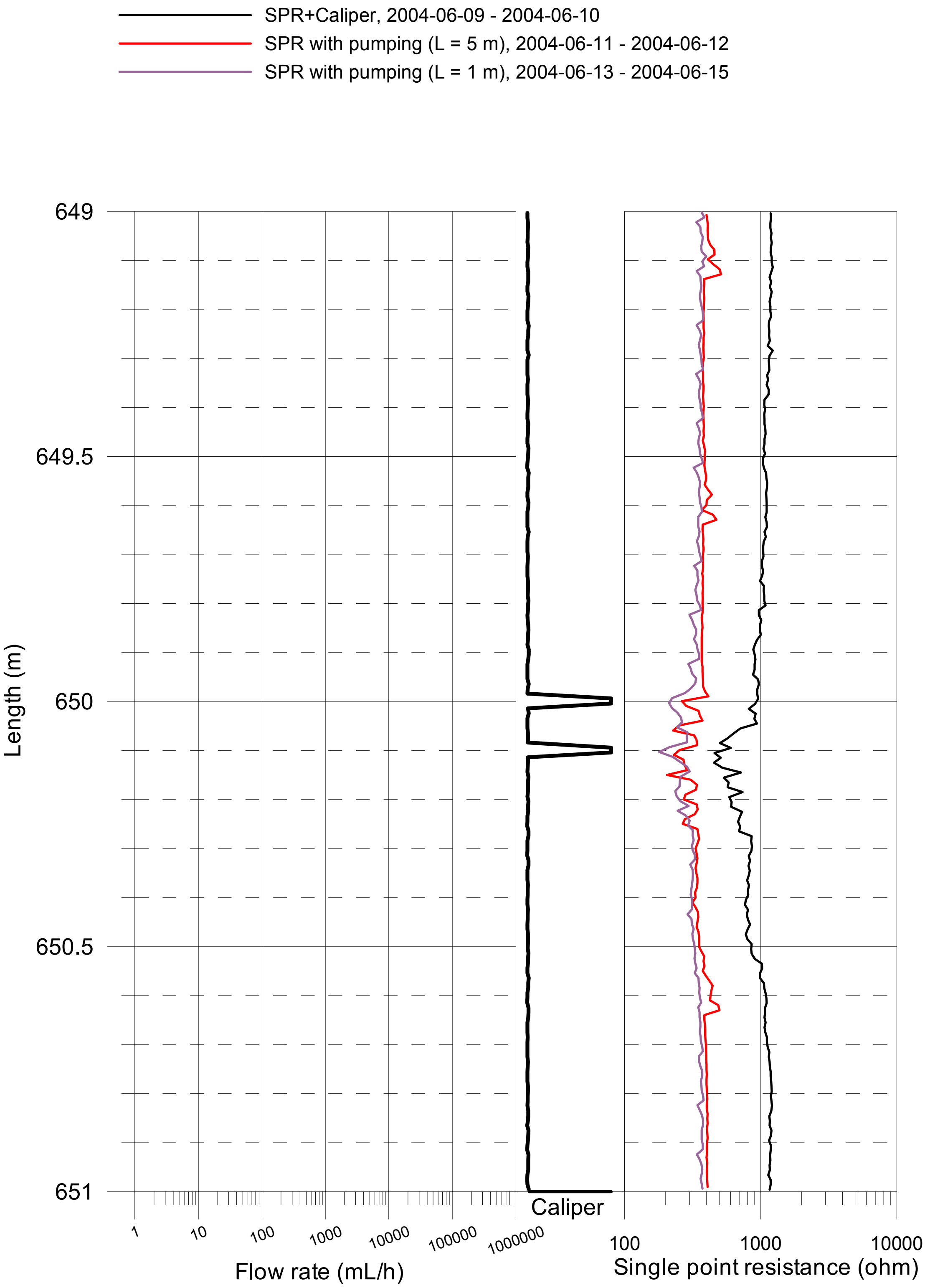
SPR and Caliper results after length correction

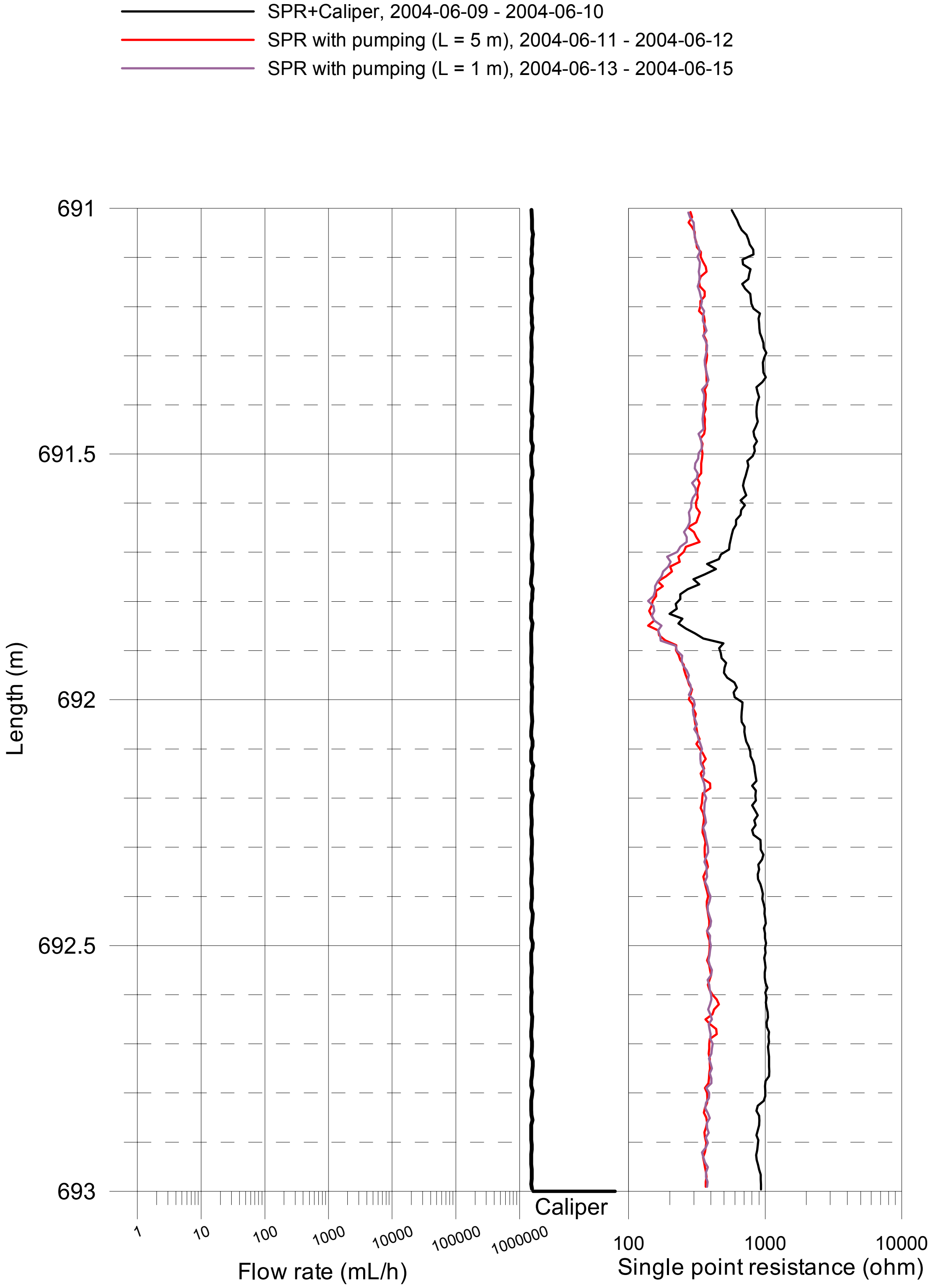


Appendix 1.28

Ävrö, KAV04A
SPR and Caliper results after length correction

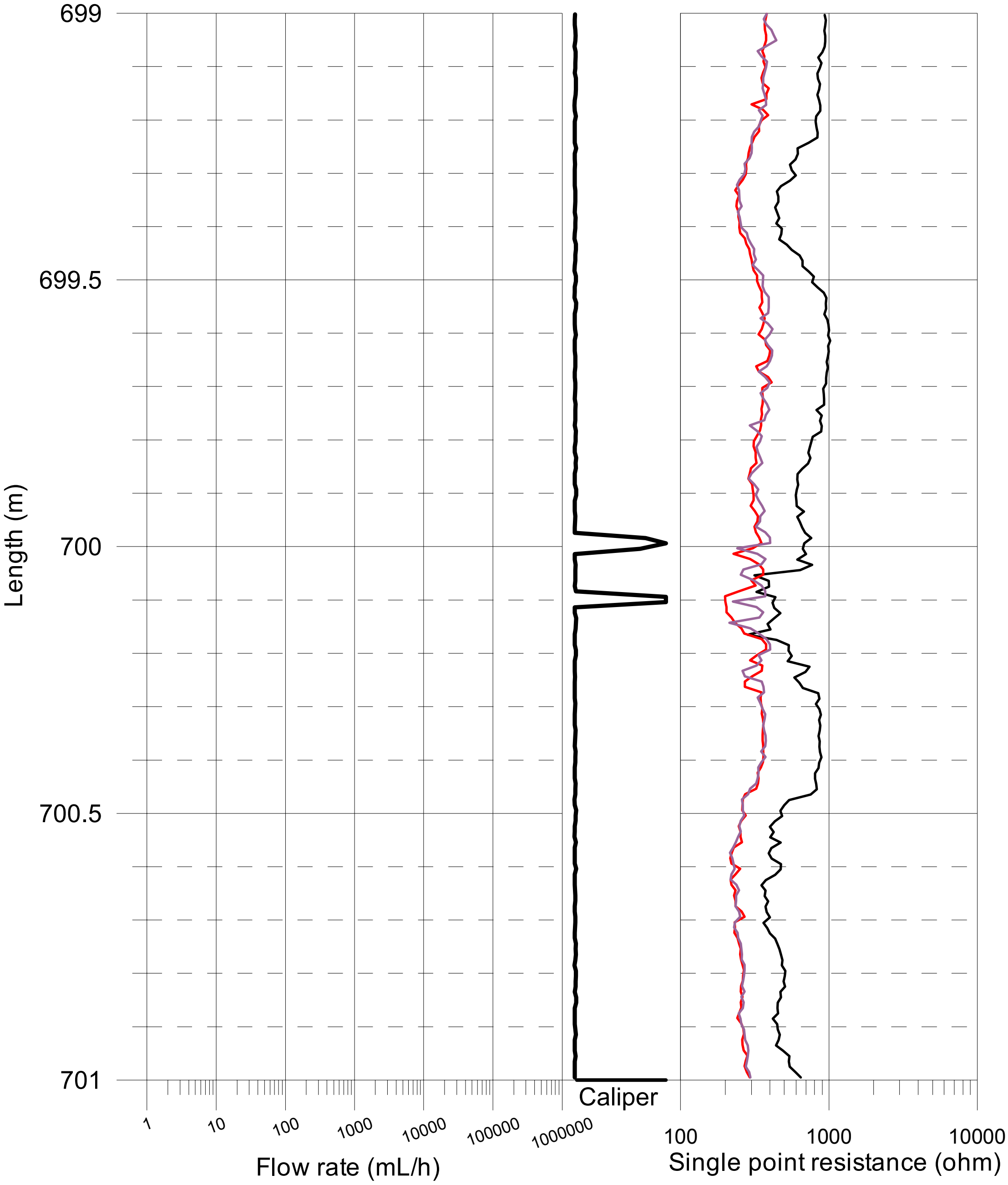


Ävrö, KAV04A
SPR and Caliper results after length correction

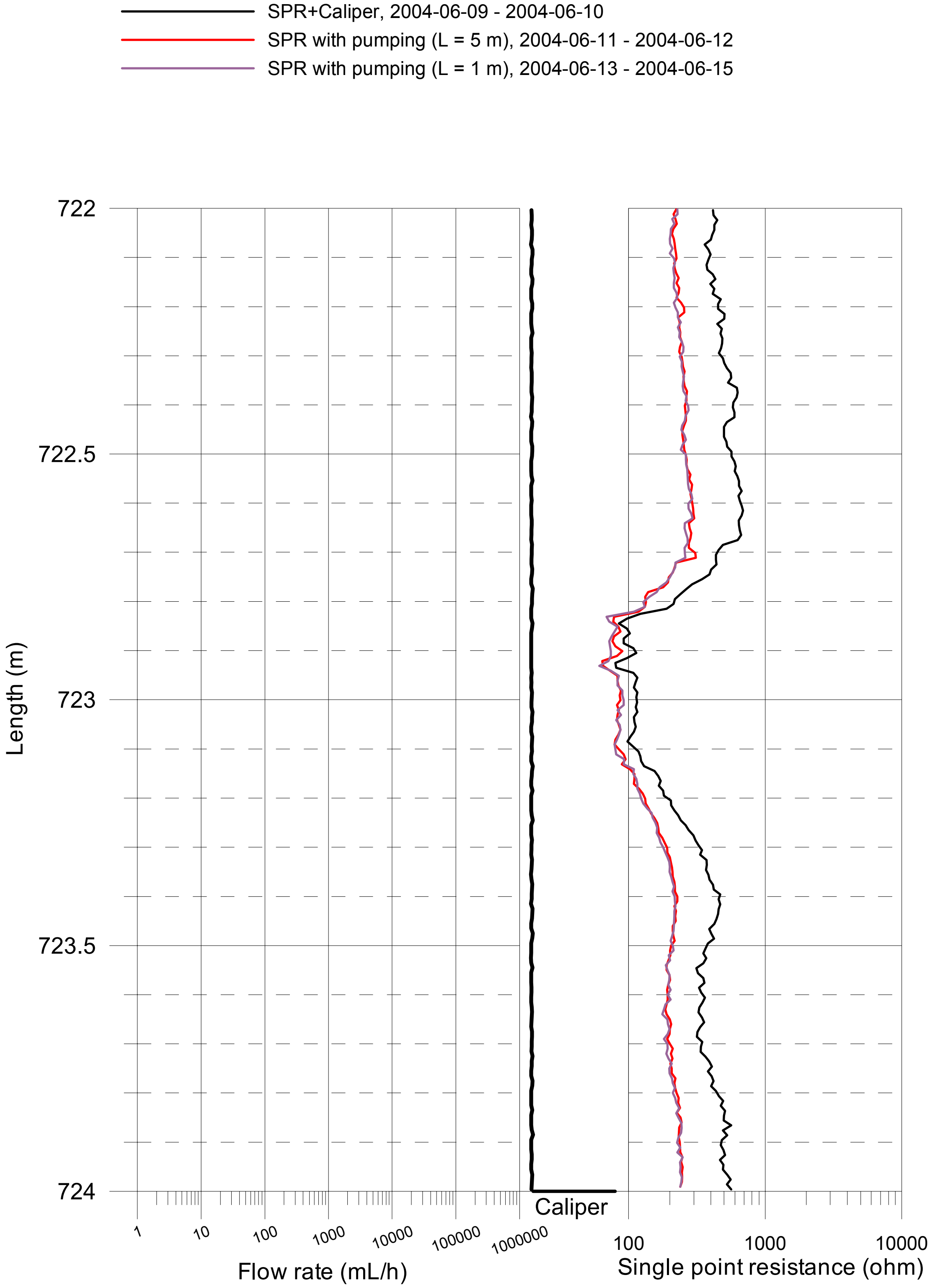


Ävrö, KAV04A
SPR and Caliper results after length correction

SPR+Caliper, 2004-06-09 - 2004-06-10
SPR with pumping (L = 5 m), 2004-06-11 - 2004-06-12
SPR with pumping (L = 1 m), 2004-06-13 - 2004-06-15

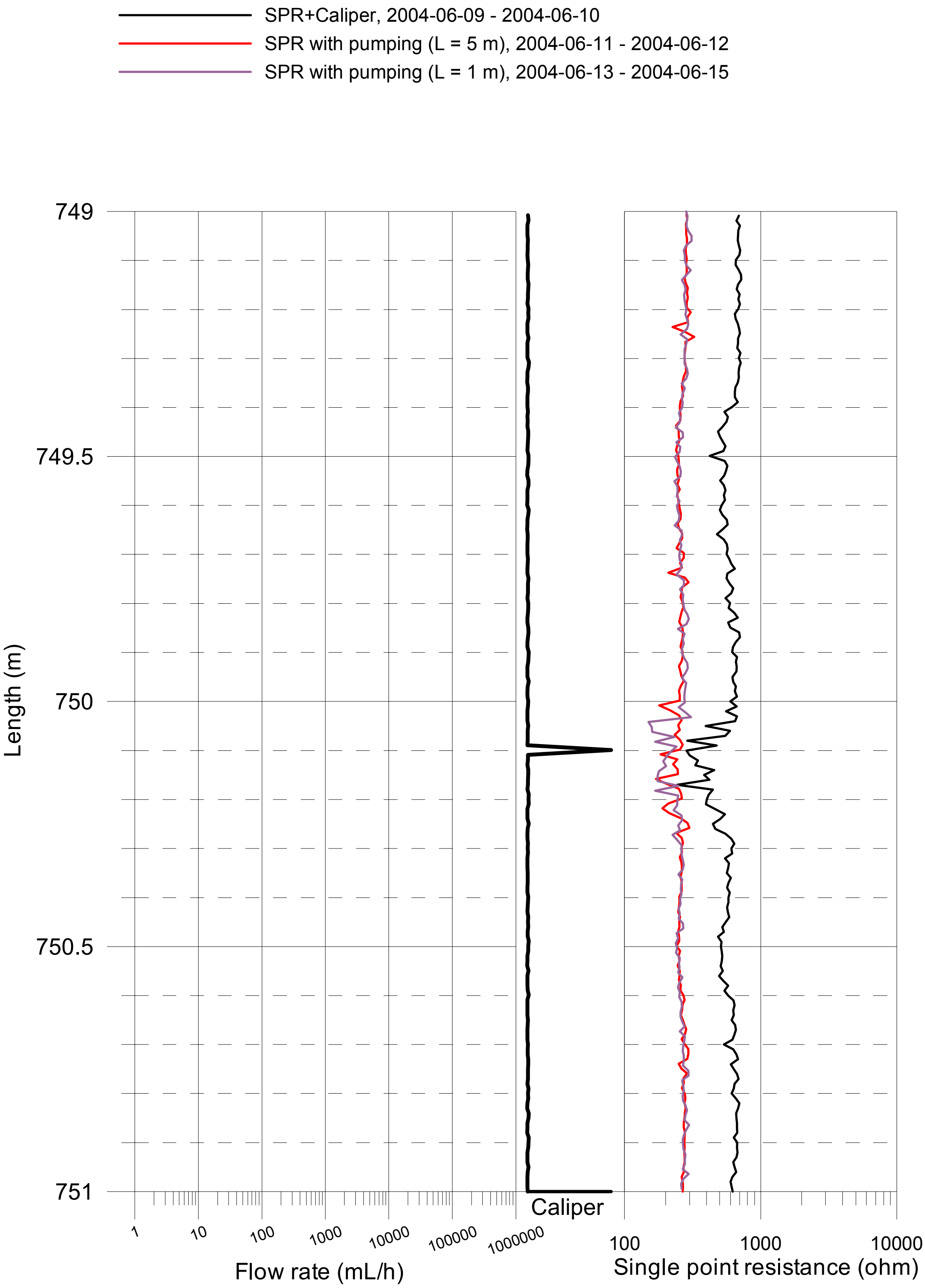


Ävrö, KAV04A
SPR and Caliper results after length correction



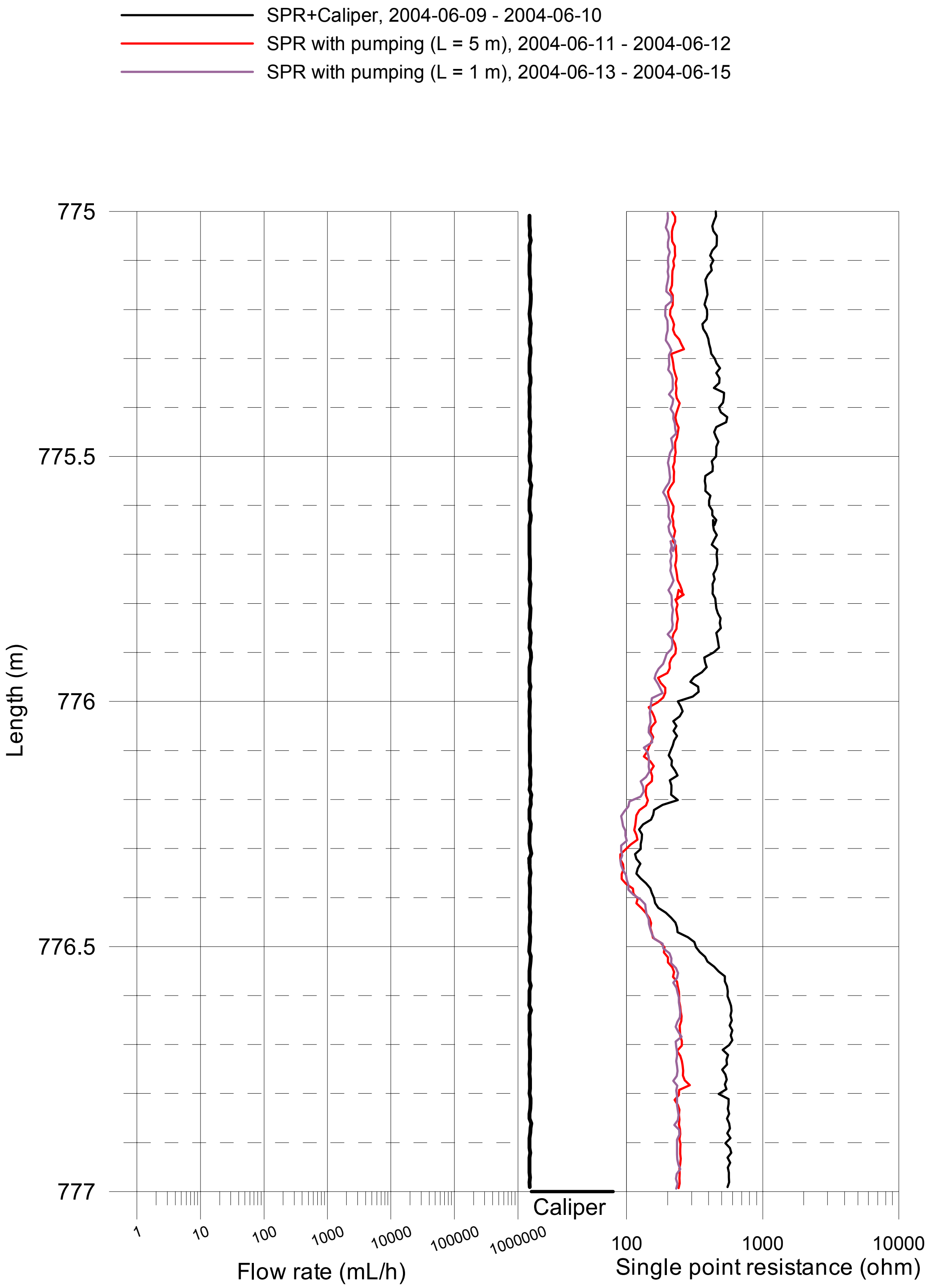
Appendix 1.32

Ävrö, KAV04A
SPR and Caliper results after length correction



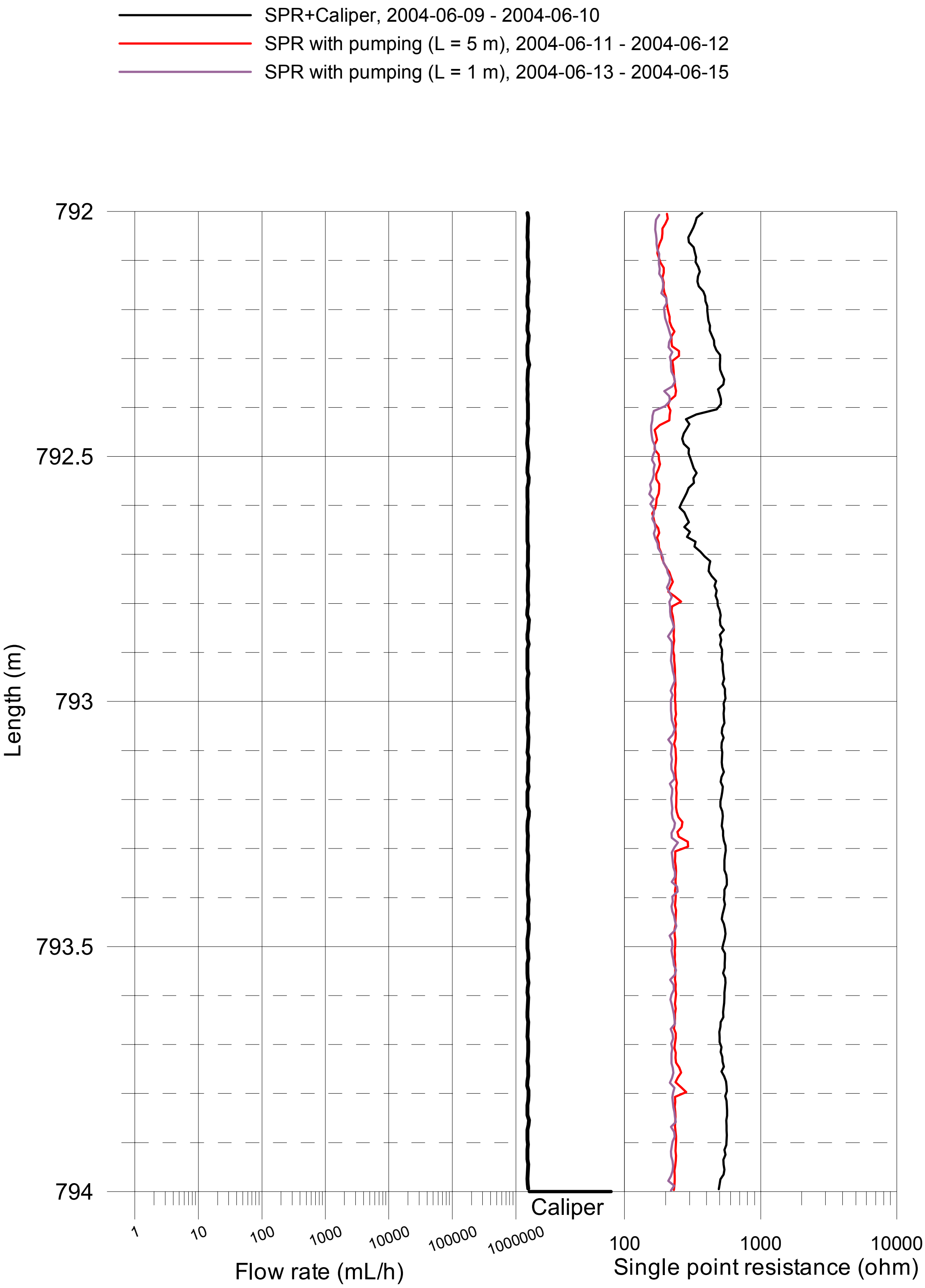
Appendix 1.33

Ävrö, KAV04A
SPR and Caliper results after length correction

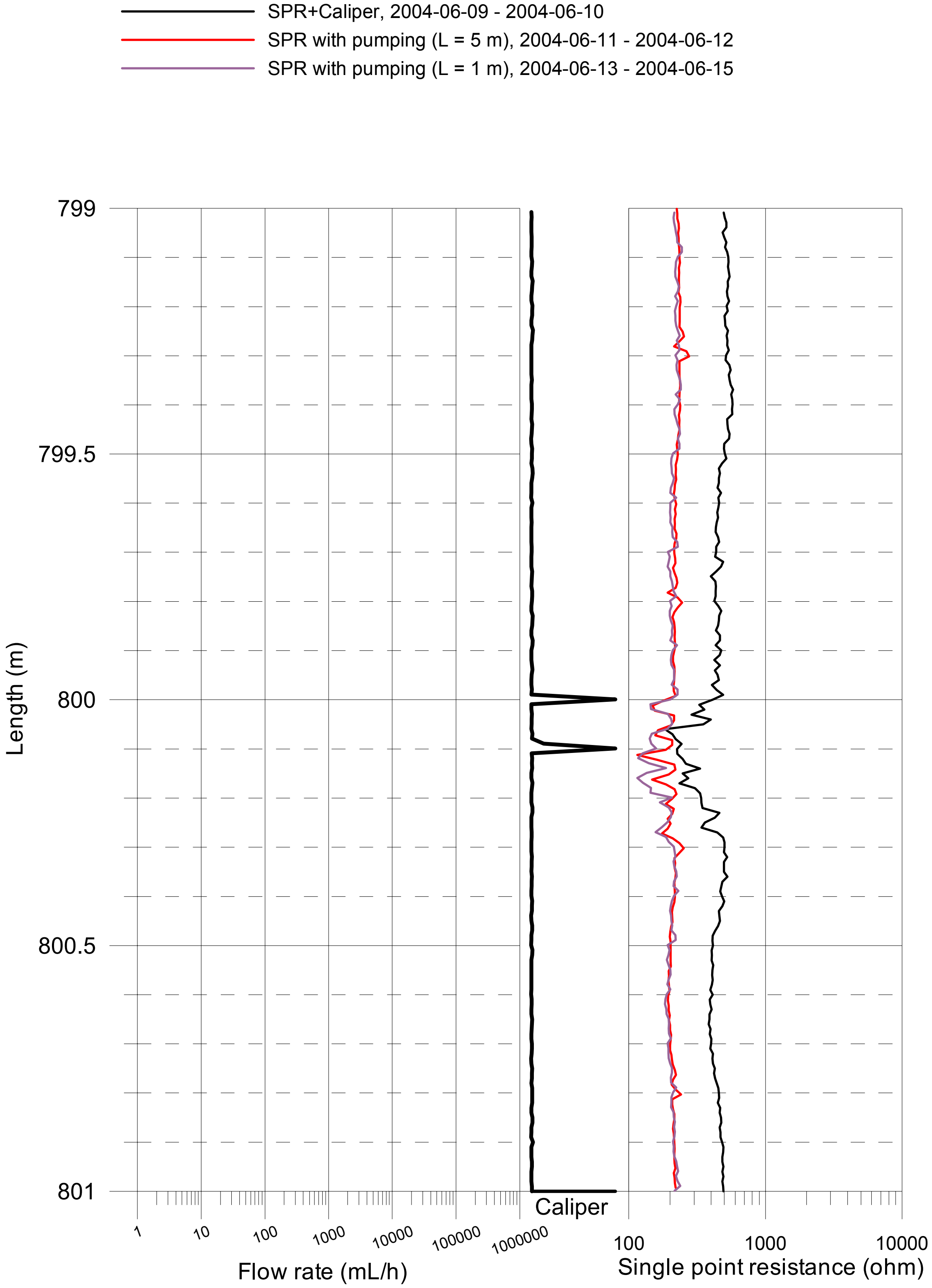


Appendix 1.34

Ävrö, KAV04A
SPR and Caliper results after length correction

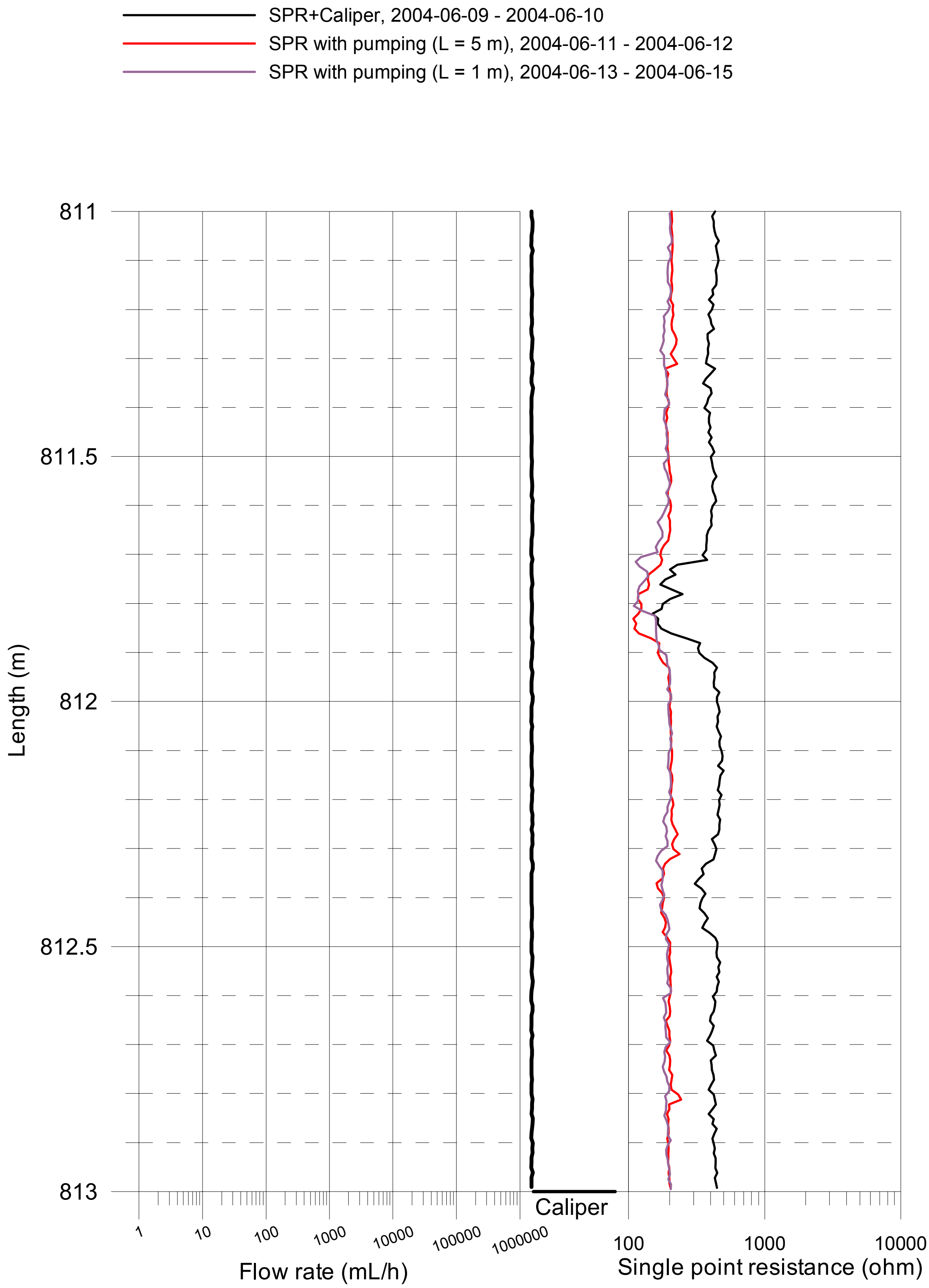


Ävrö, KAV04A
SPR and Caliper results after length correction

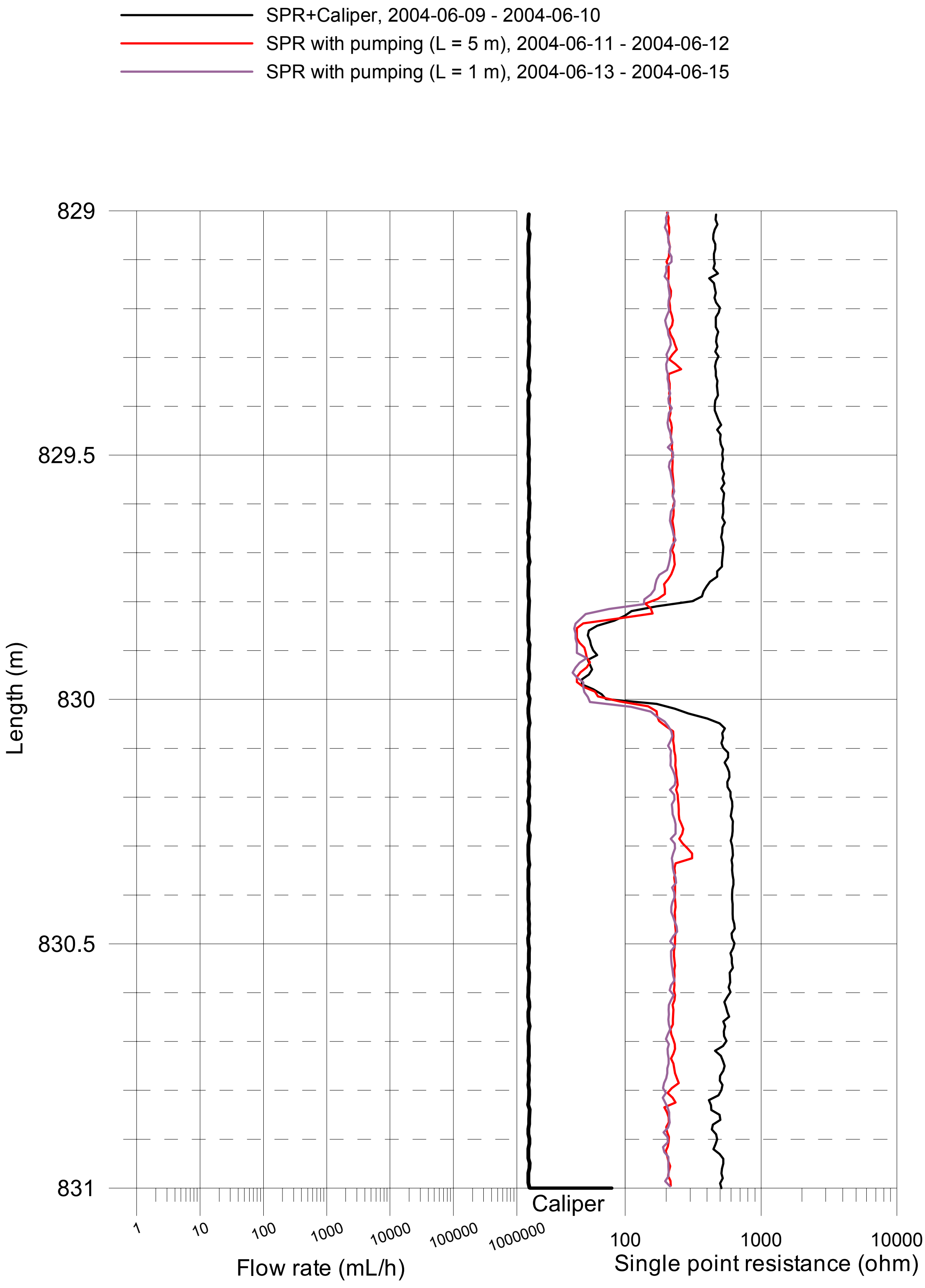


Appendix 1.36

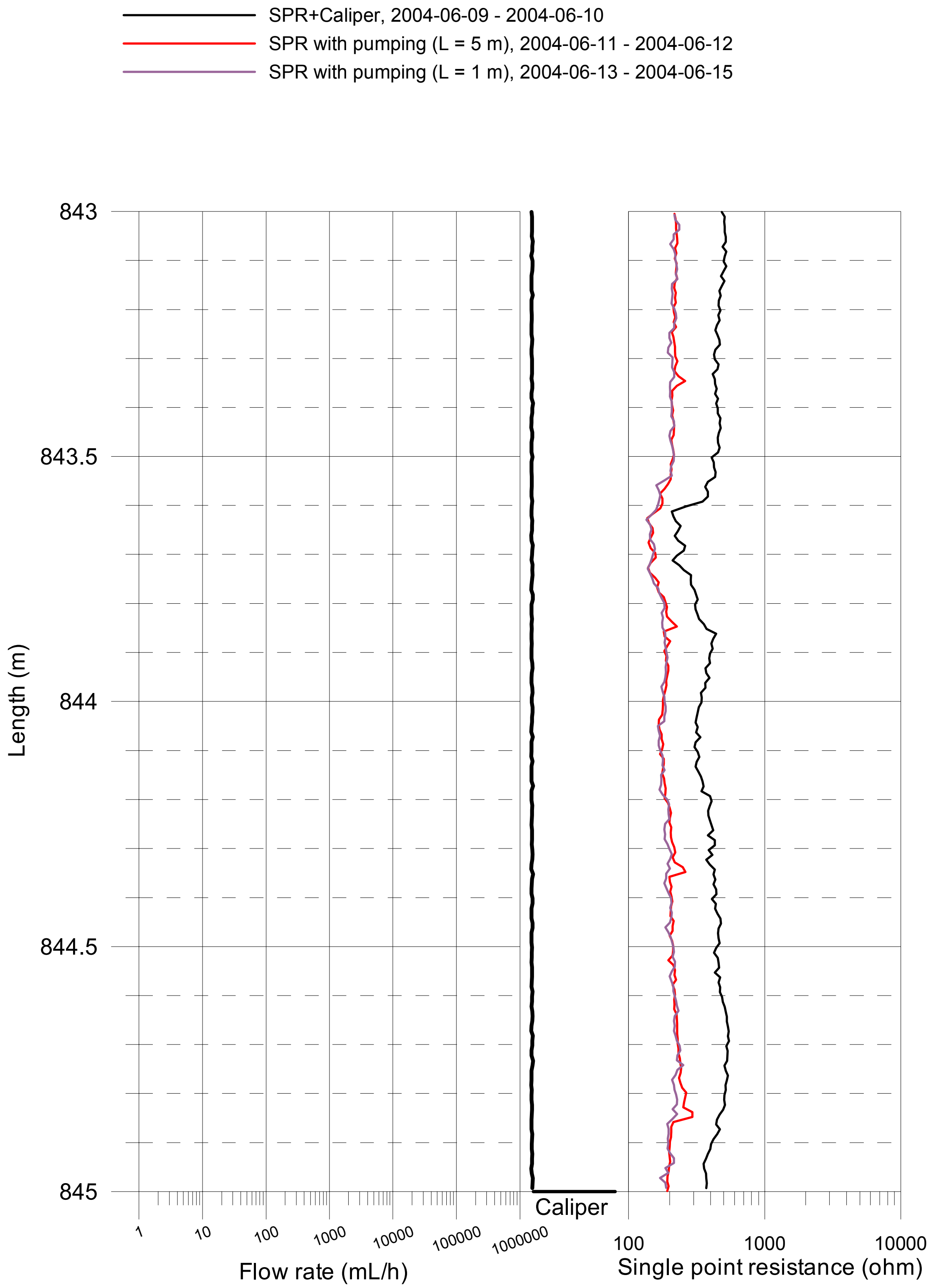
Ävrö, KAV04A
SPR and Caliper results after length correction



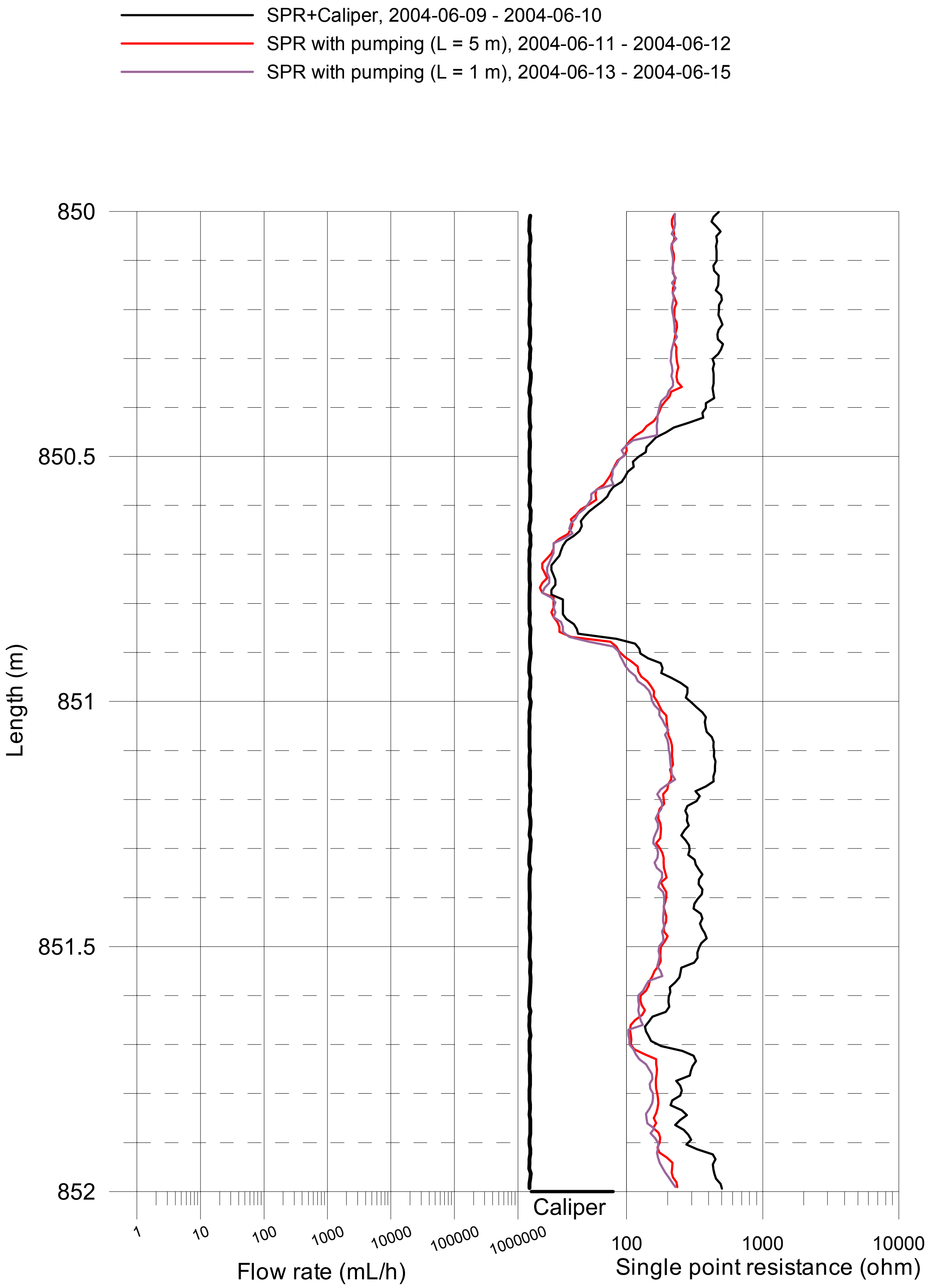
Ävrö, KAV04A
SPR and Caliper results after length correction



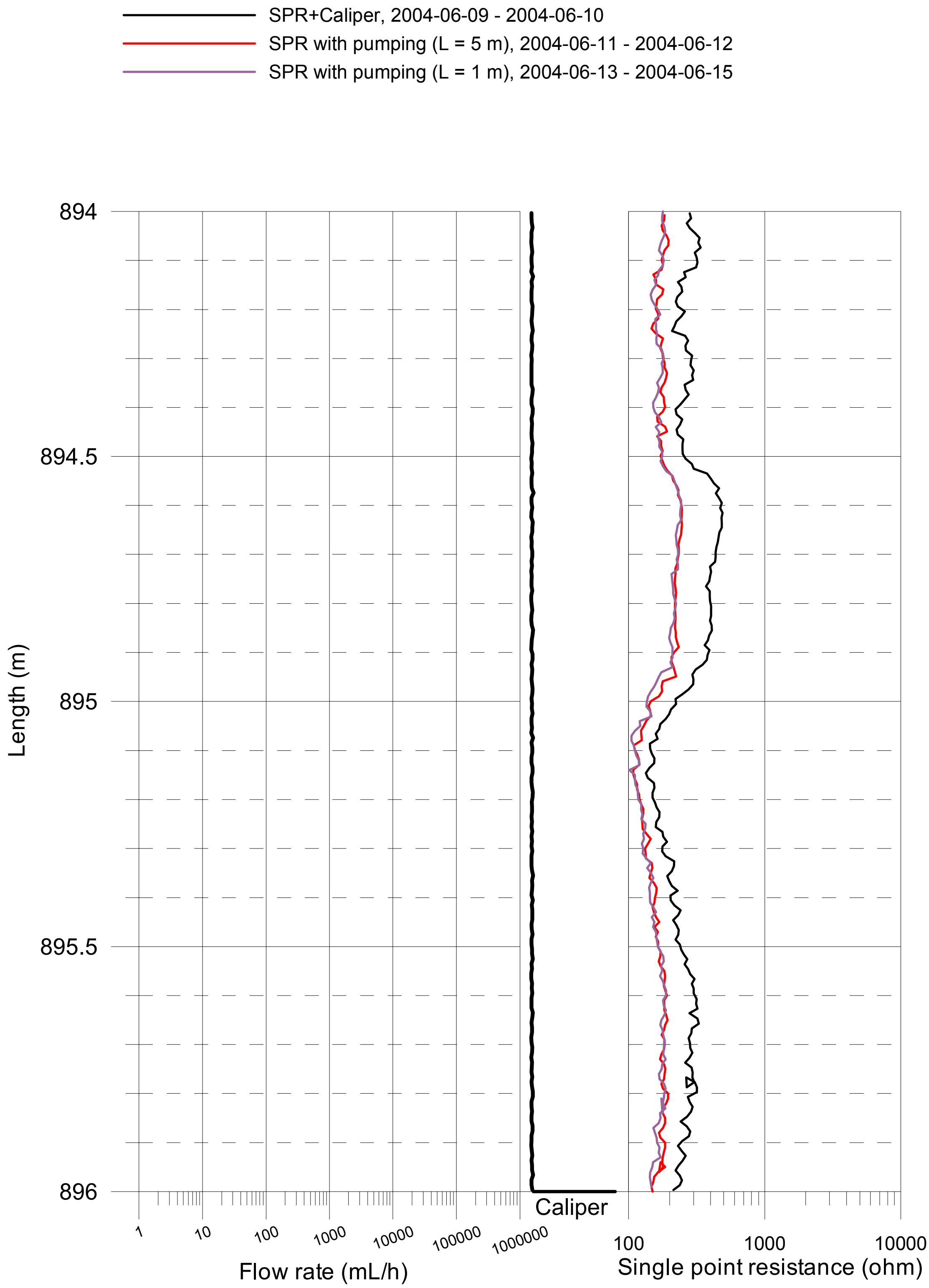
Ävrö, KAV04A
SPR and Caliper results after length correction



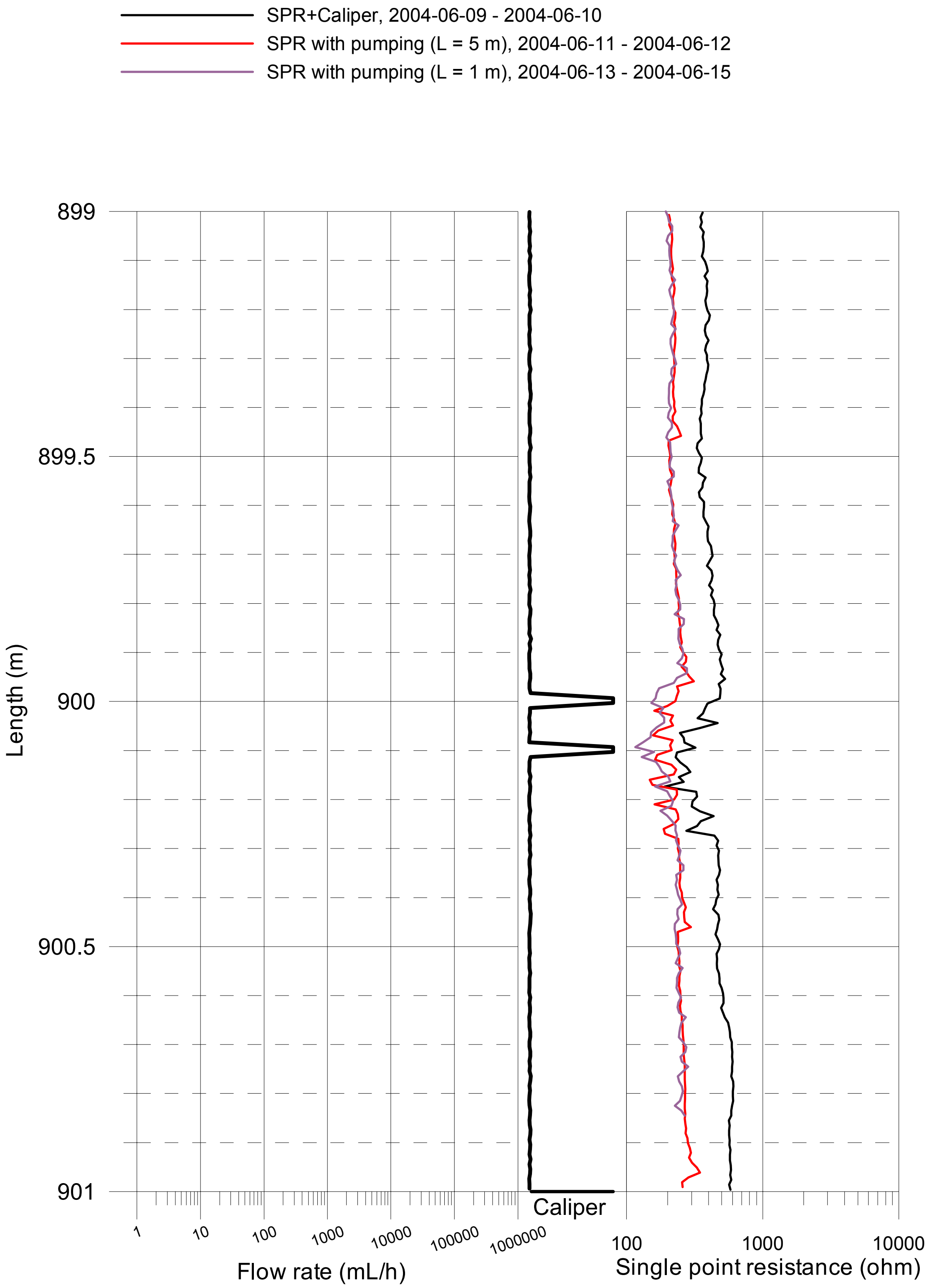
Ävrö, KAV04A
SPR and Caliper results after length correction



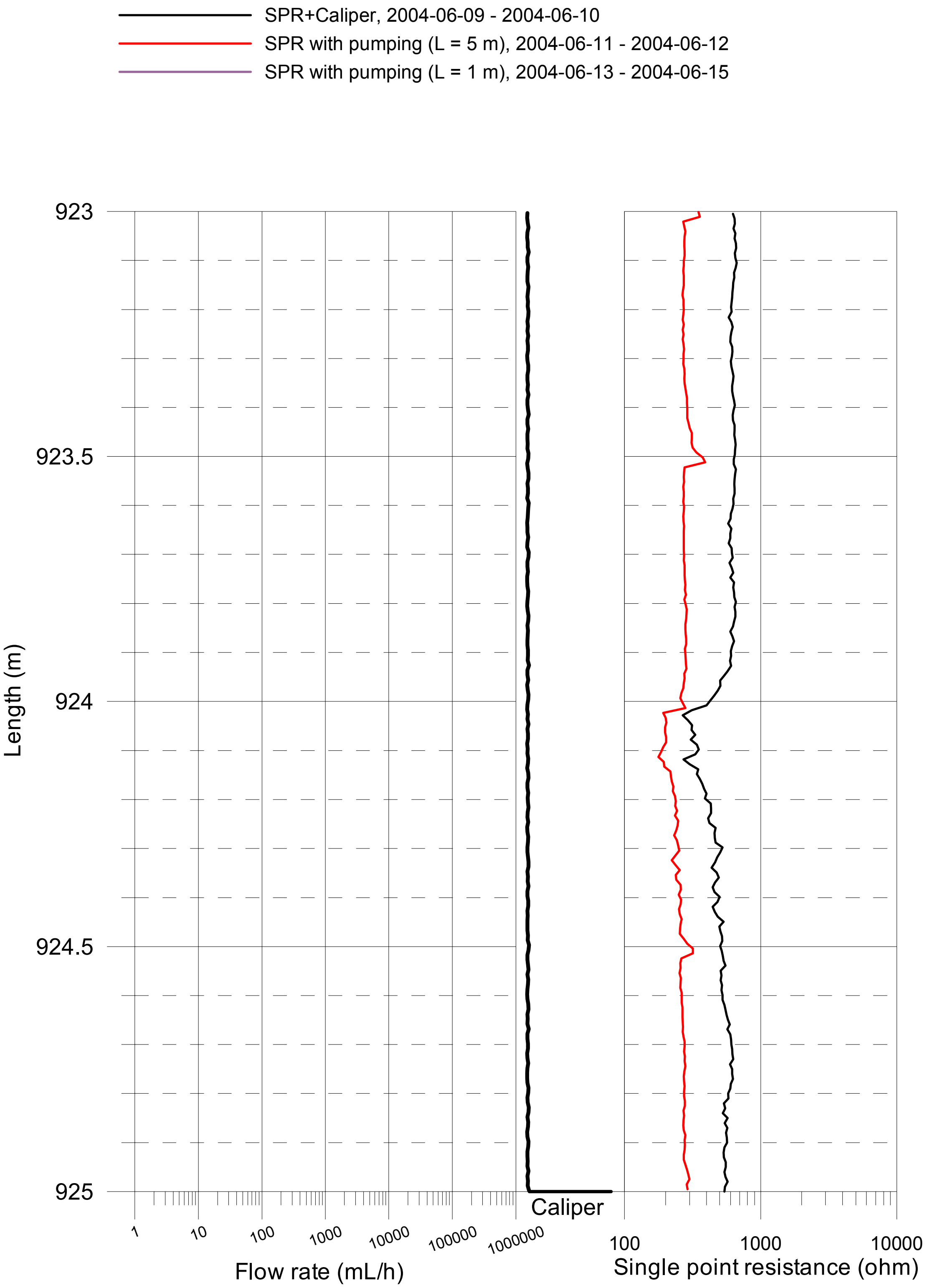
Ävrö, KAV04A
SPR and Caliper results after length correction



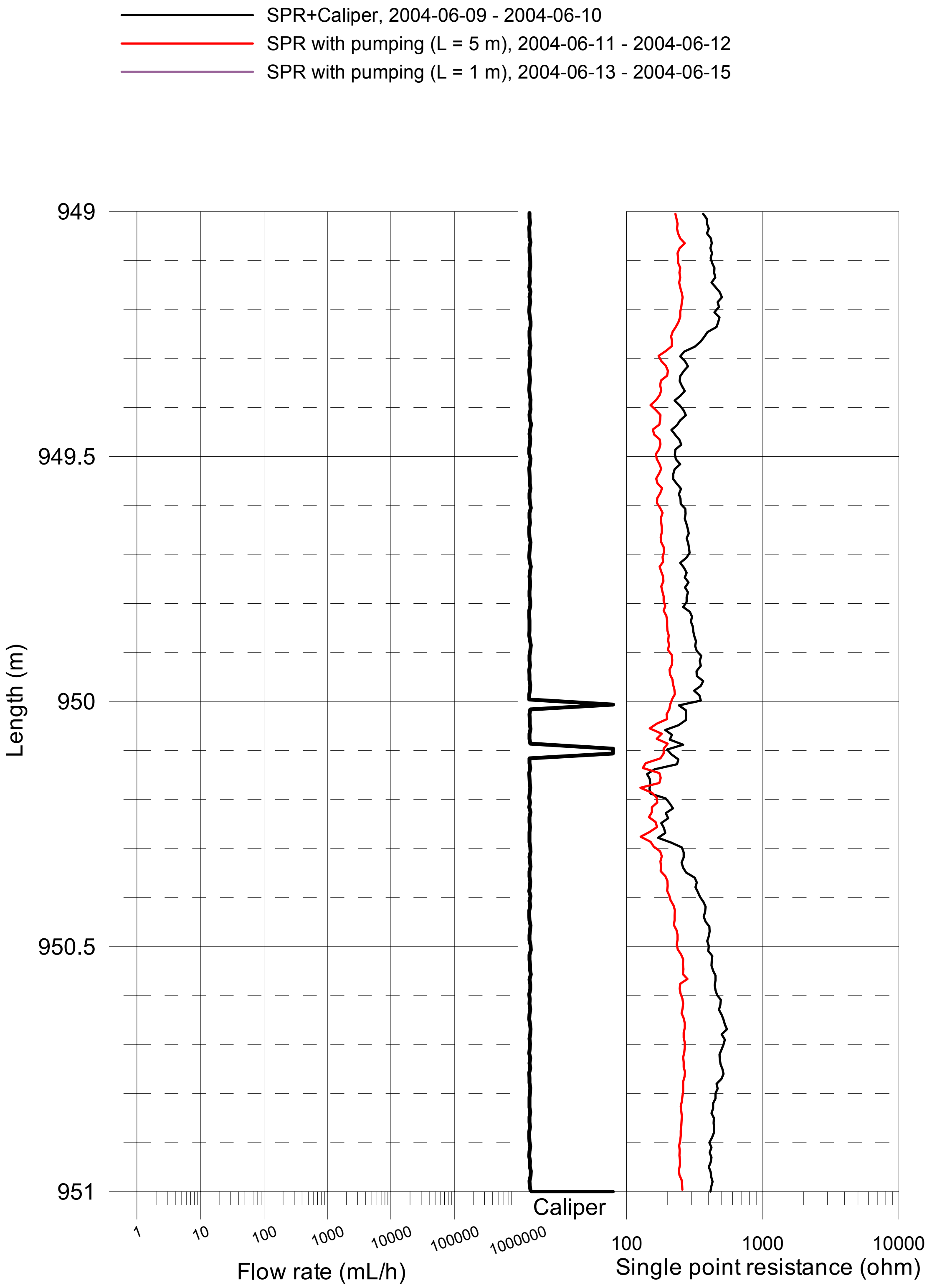
Ävrö, KAV04A
SPR and Caliper results after length correction



Ävrö, KAV04A
SPR and Caliper results after length correction

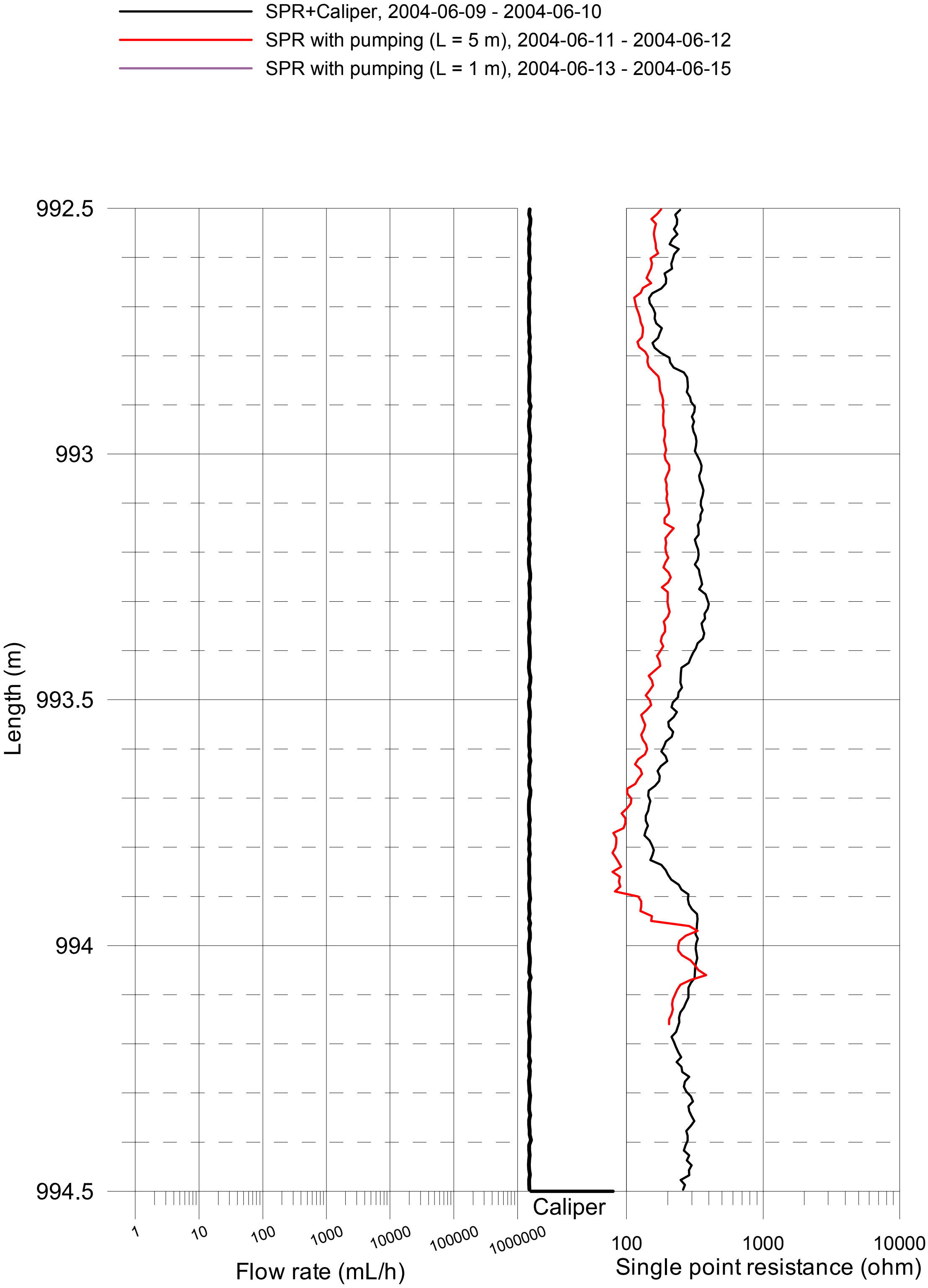


Ävrö, KAV04A
SPR and Caliper results after length correction



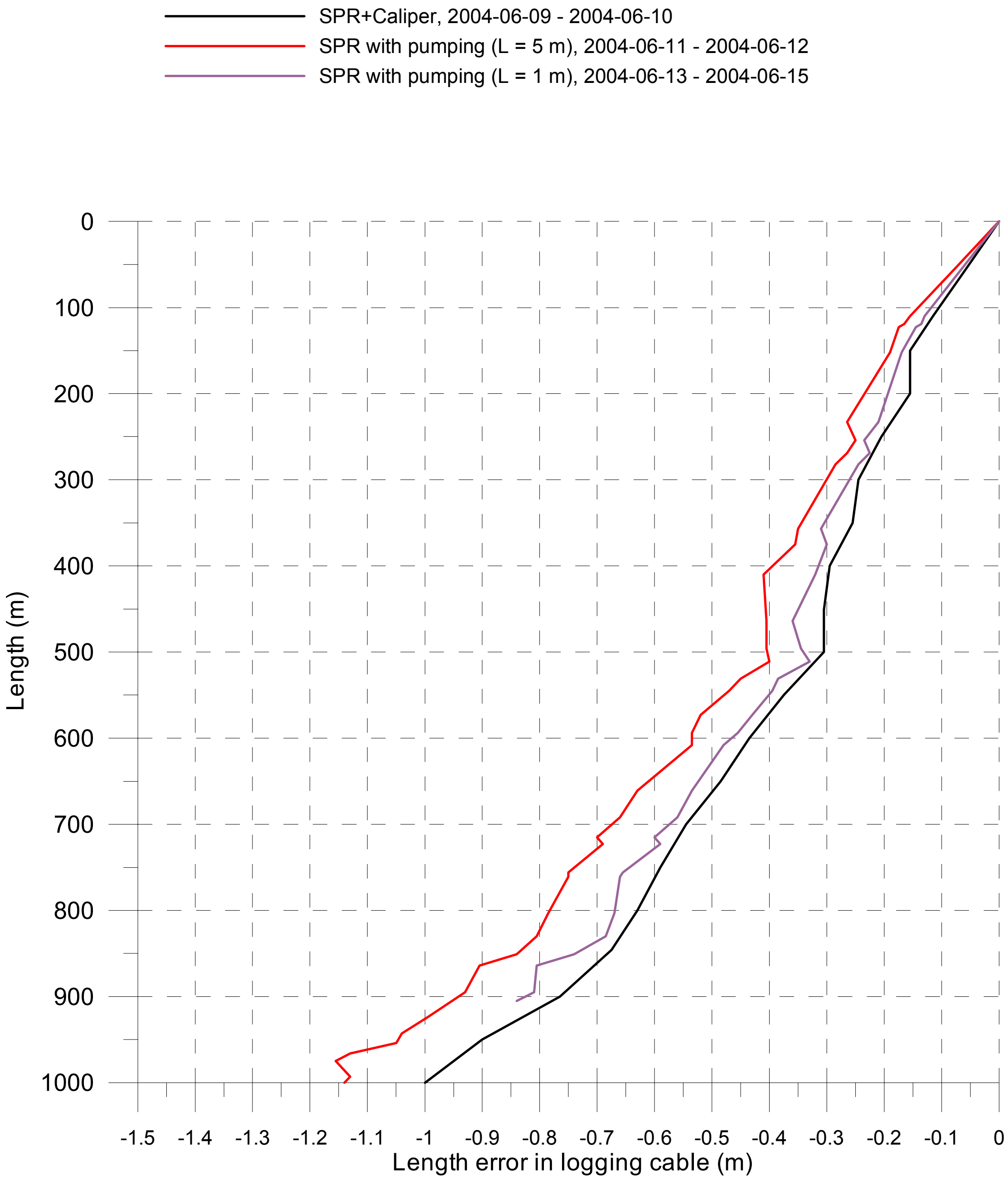
Appendix 1.44

Ävrö, KAV04A
SPR and Caliper results after length correction

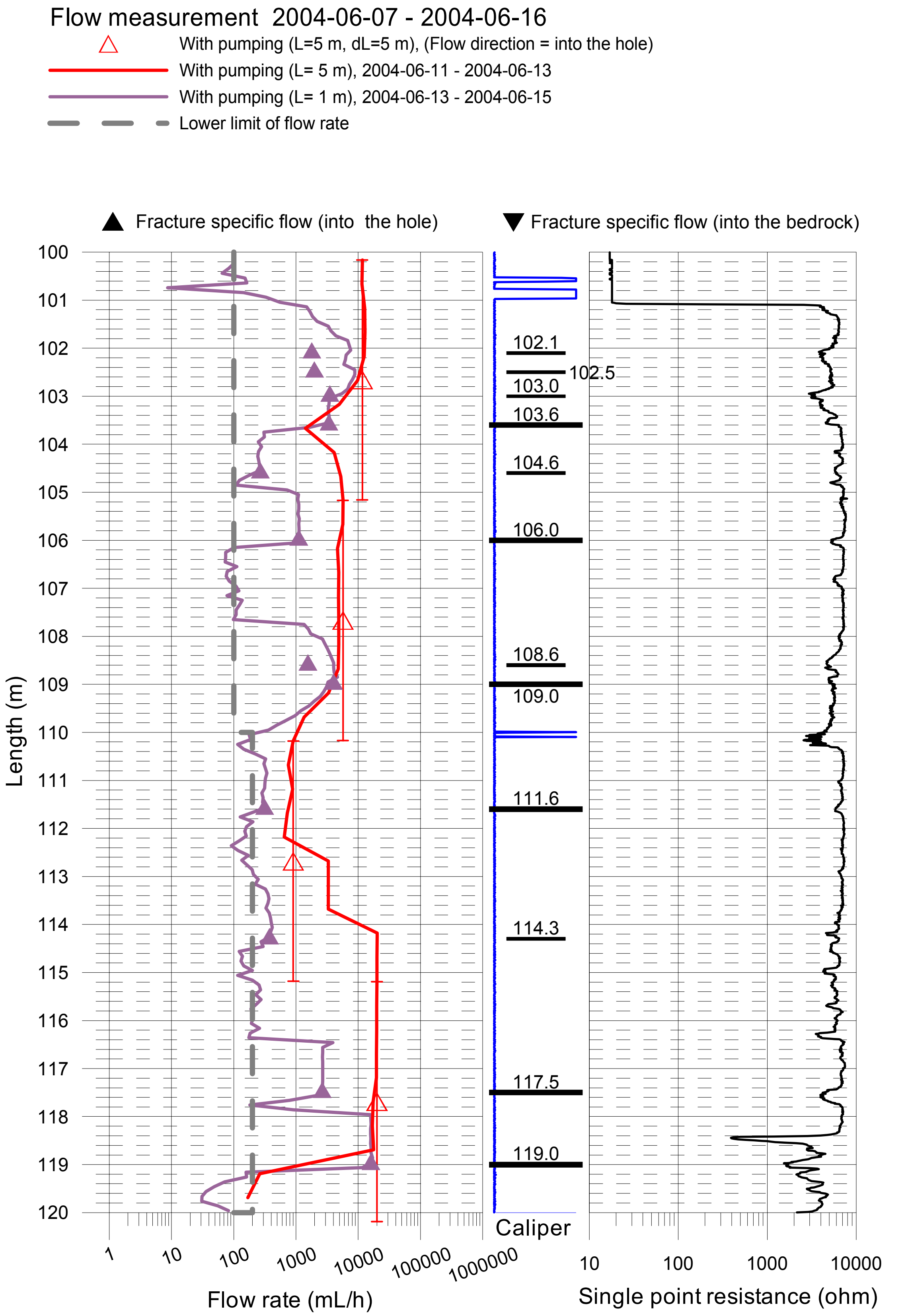


Appendix 1.45

SPR used with

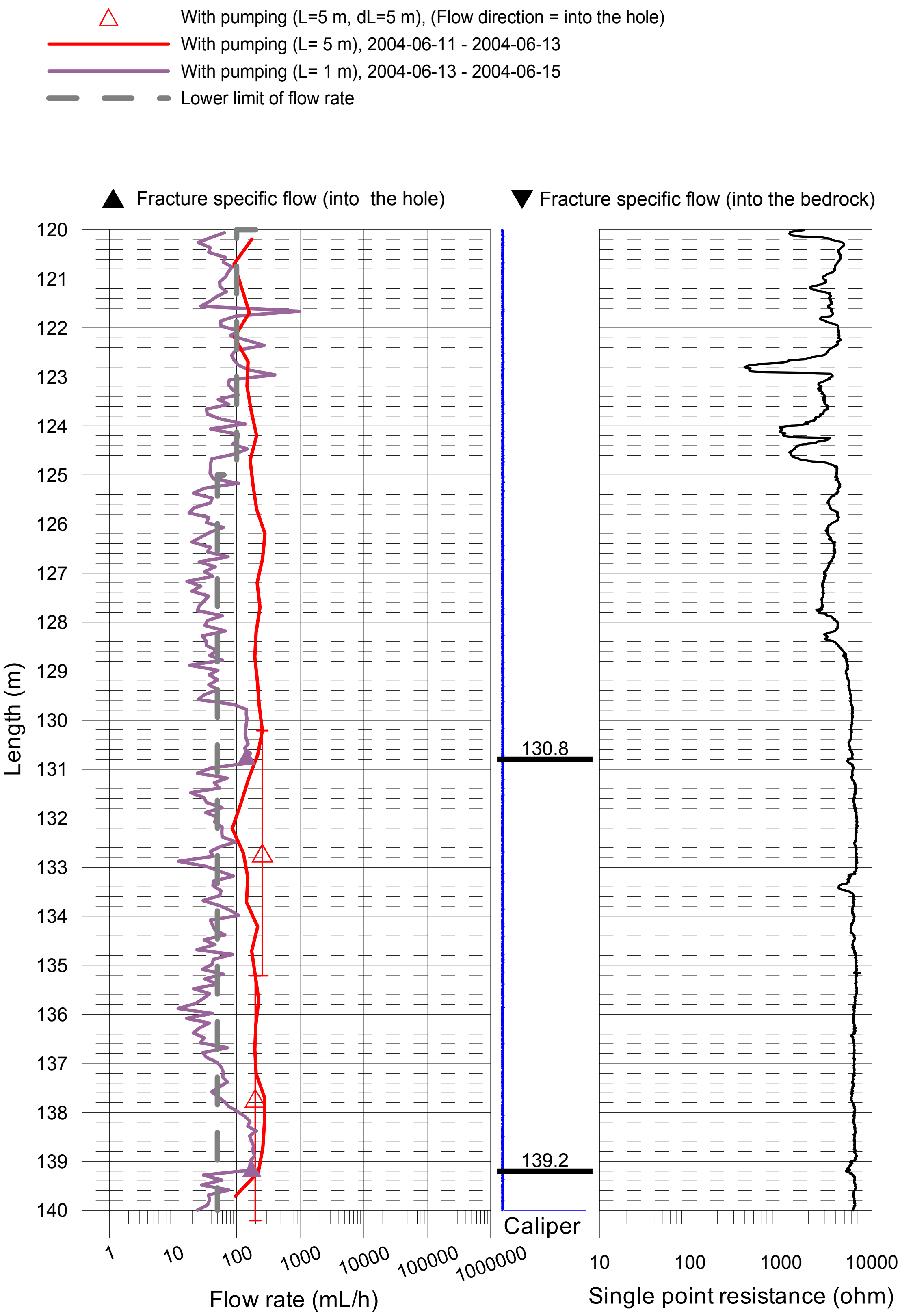


Ävrö, Borehole KAV04A



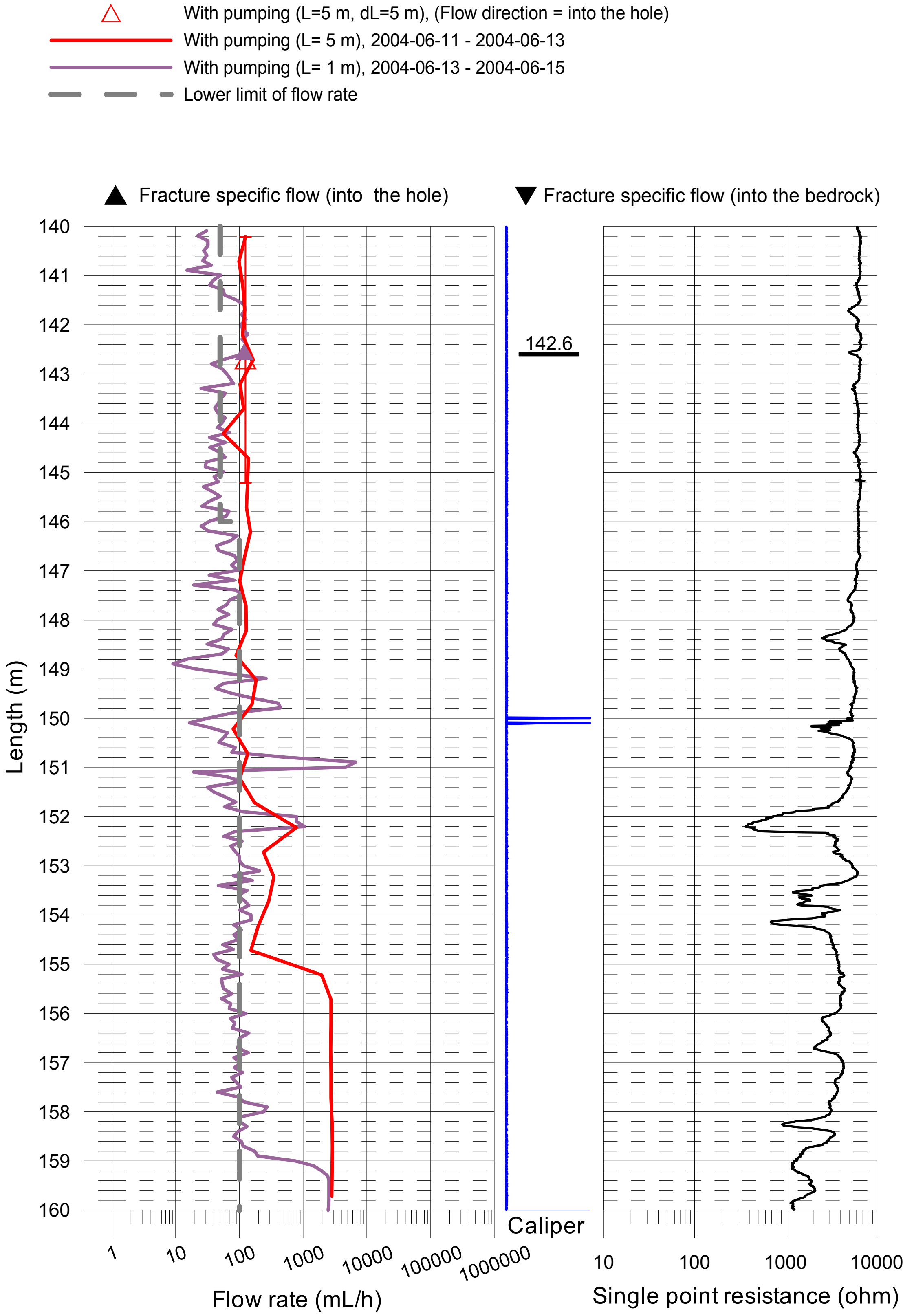
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



Ävrö, Borehole KAV04A

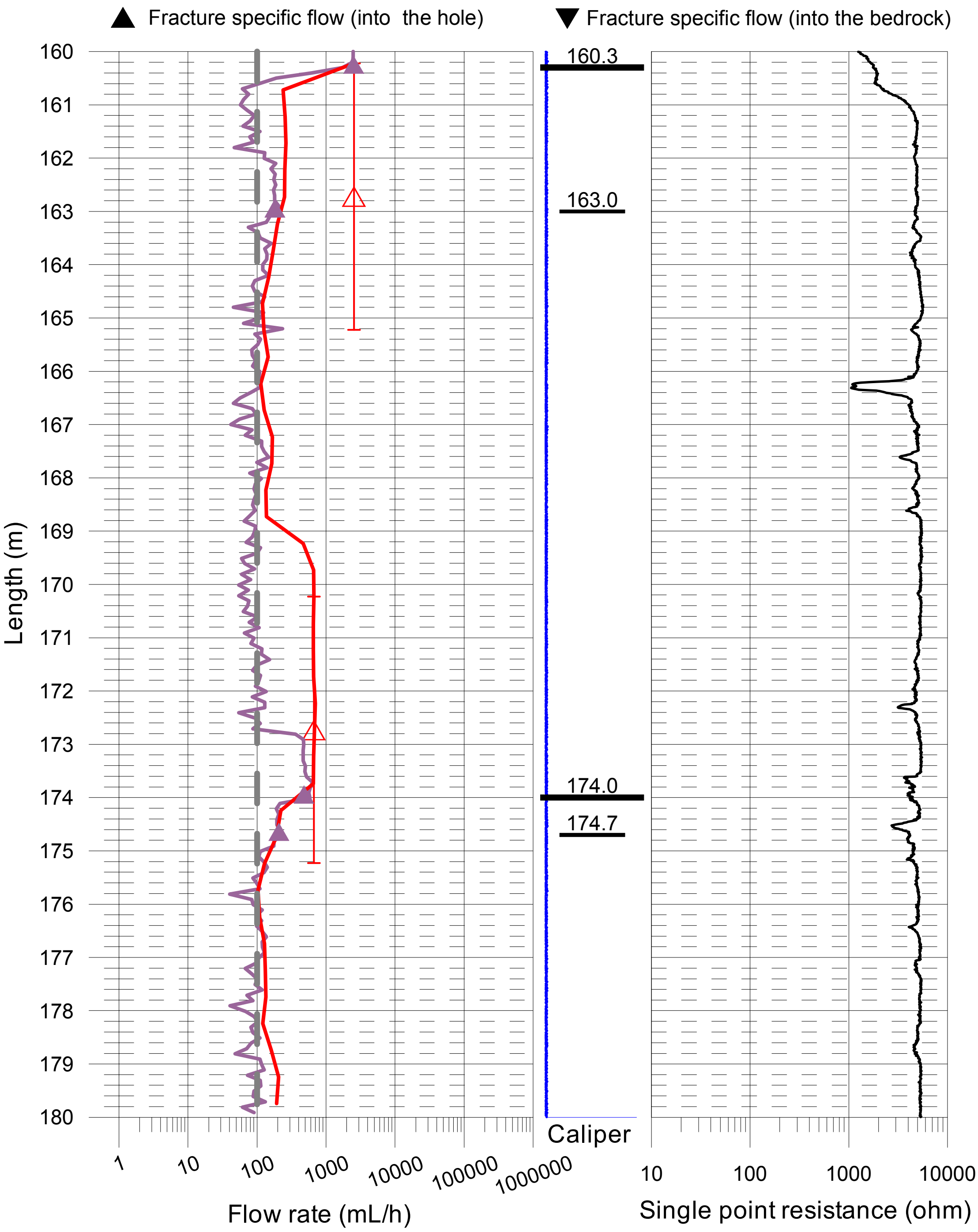
Flow measurement 2004-06-07 - 2004-06-16



Ävrö, Borehole KAV04A

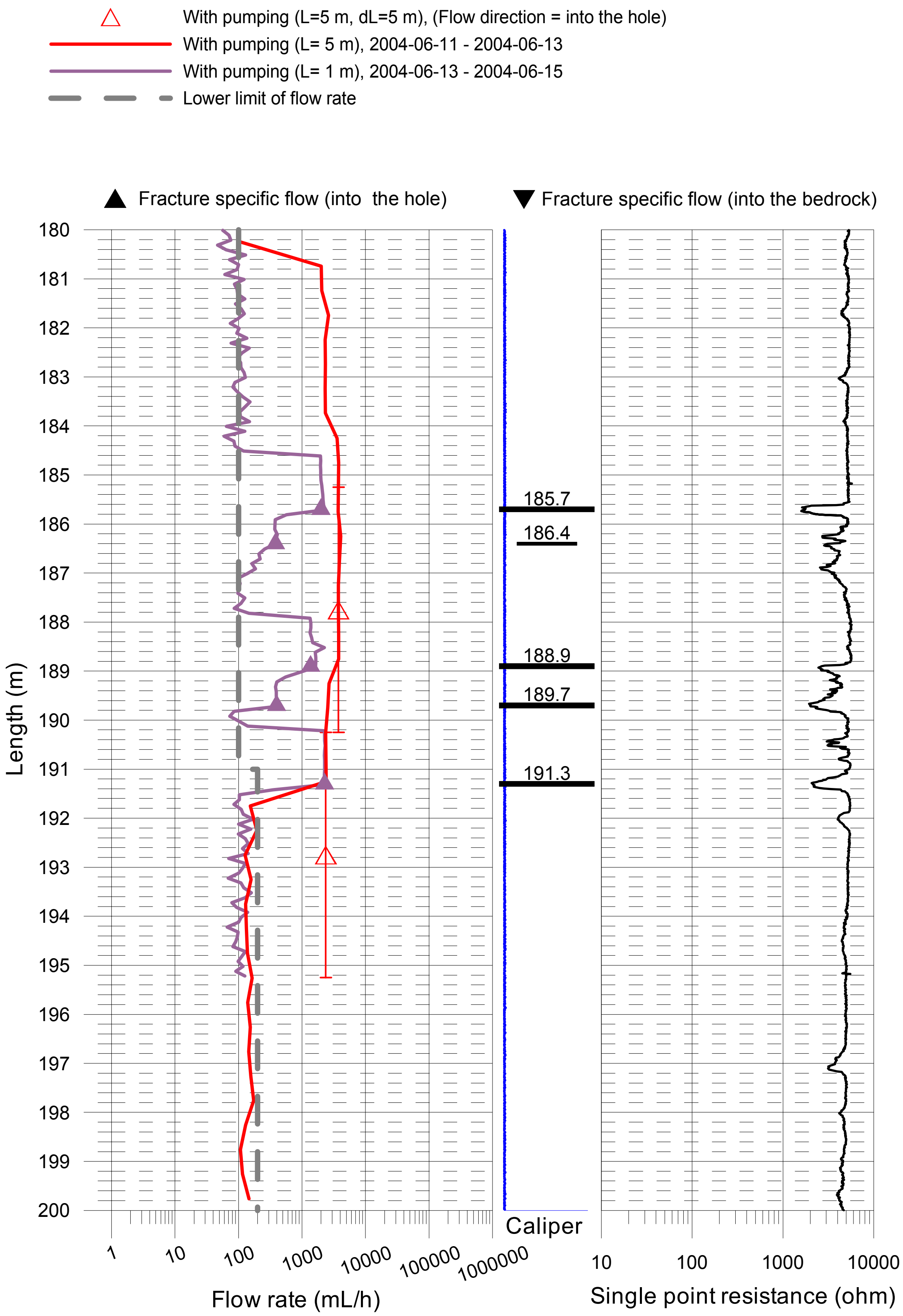
Flow measurement 2004-06-07 - 2004-06-16

△ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L= 5 m), 2004-06-11 - 2004-06-13
With pumping (L= 1 m), 2004-06-13 - 2004-06-15
Lower limit of flow rate



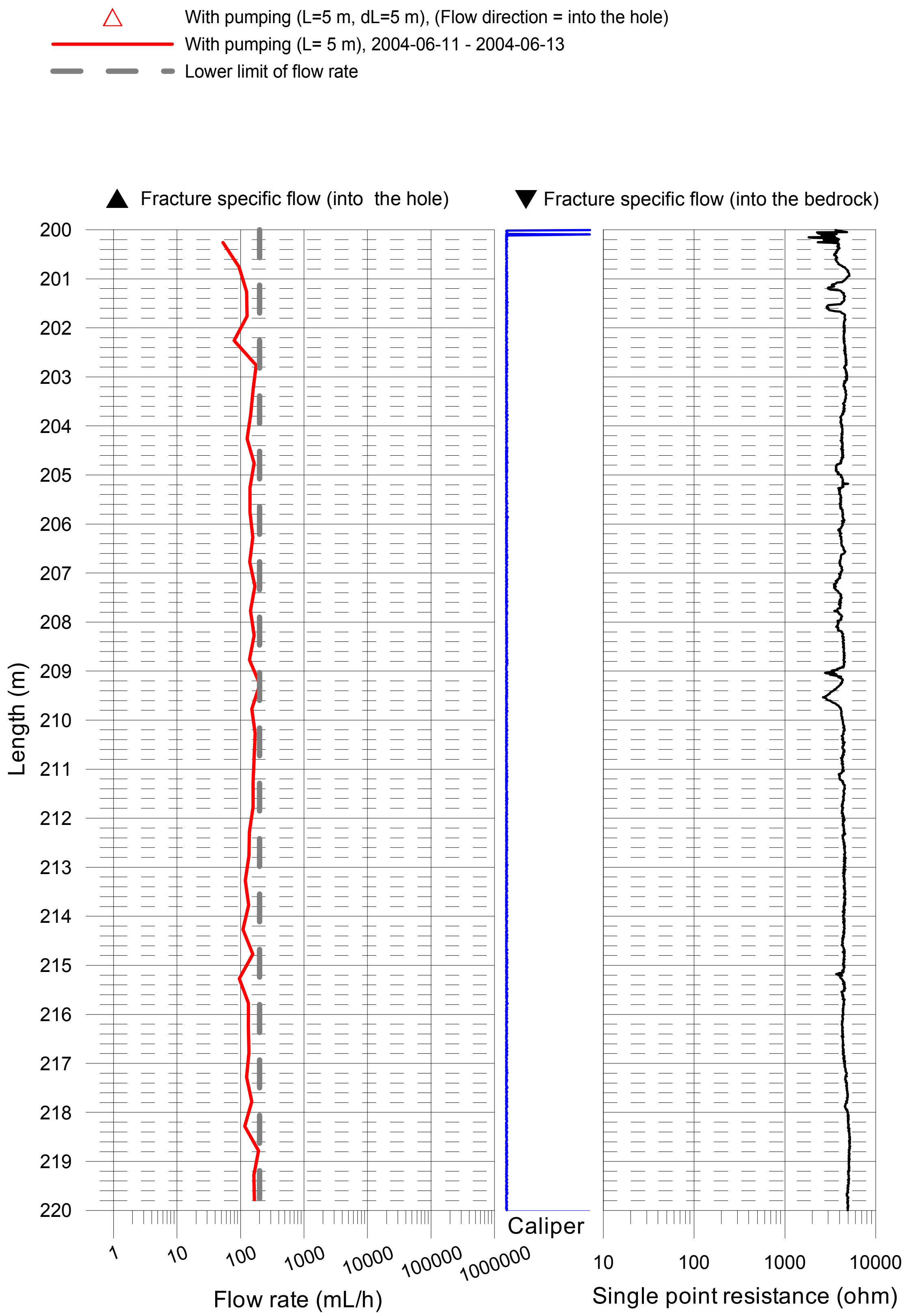
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

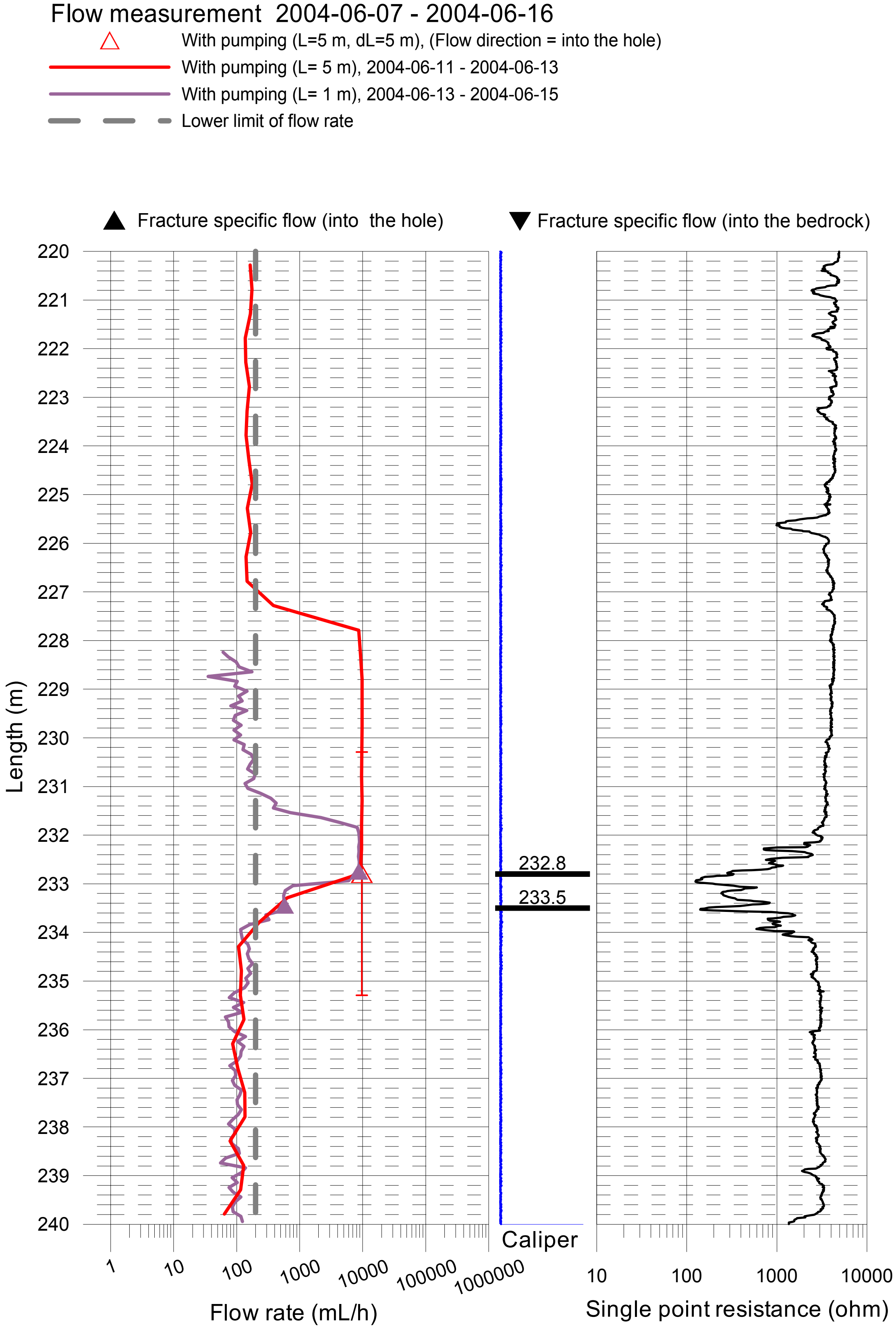


Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



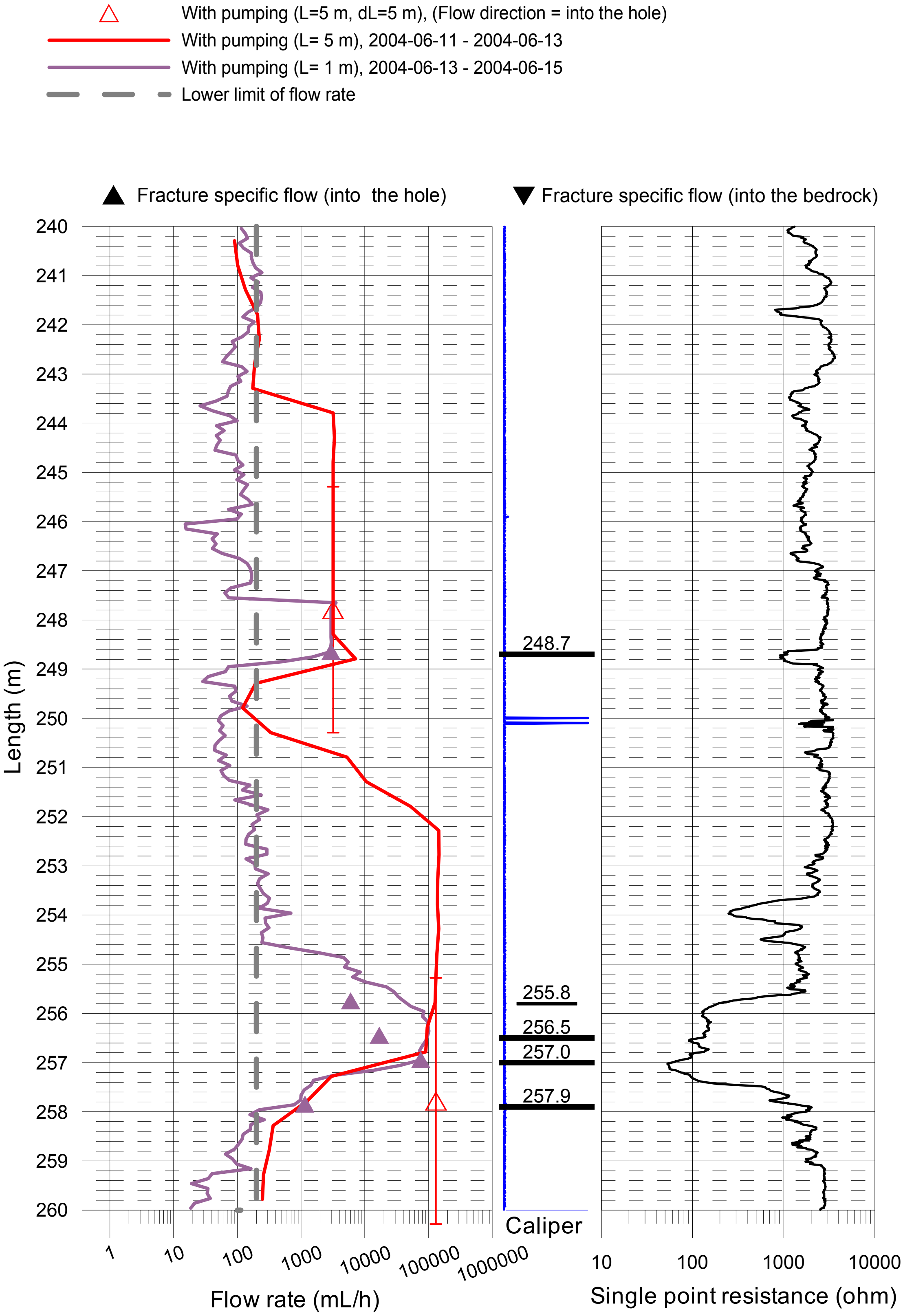
Ävrö, Borehole KAV04A



Appendix 2.8

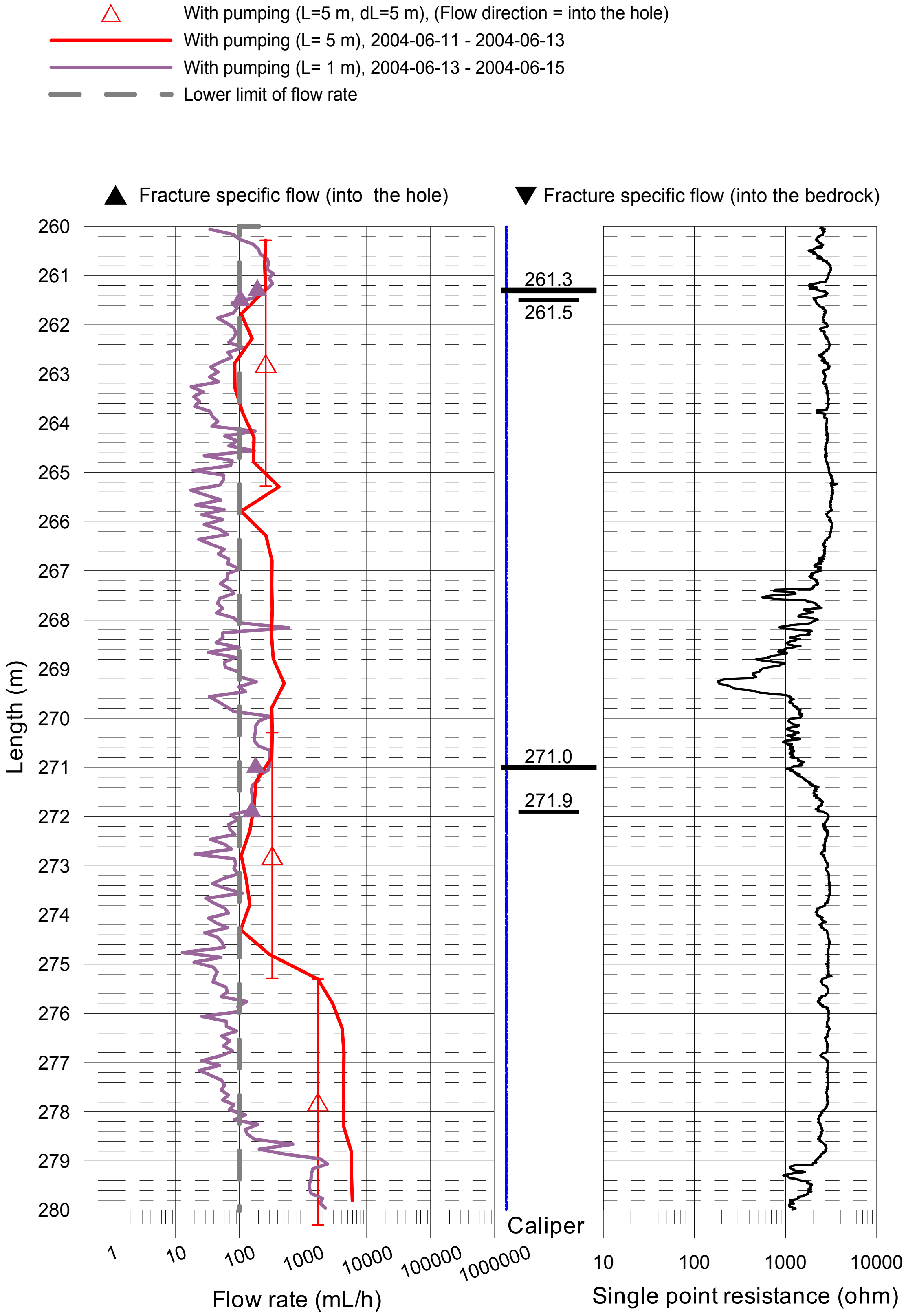
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

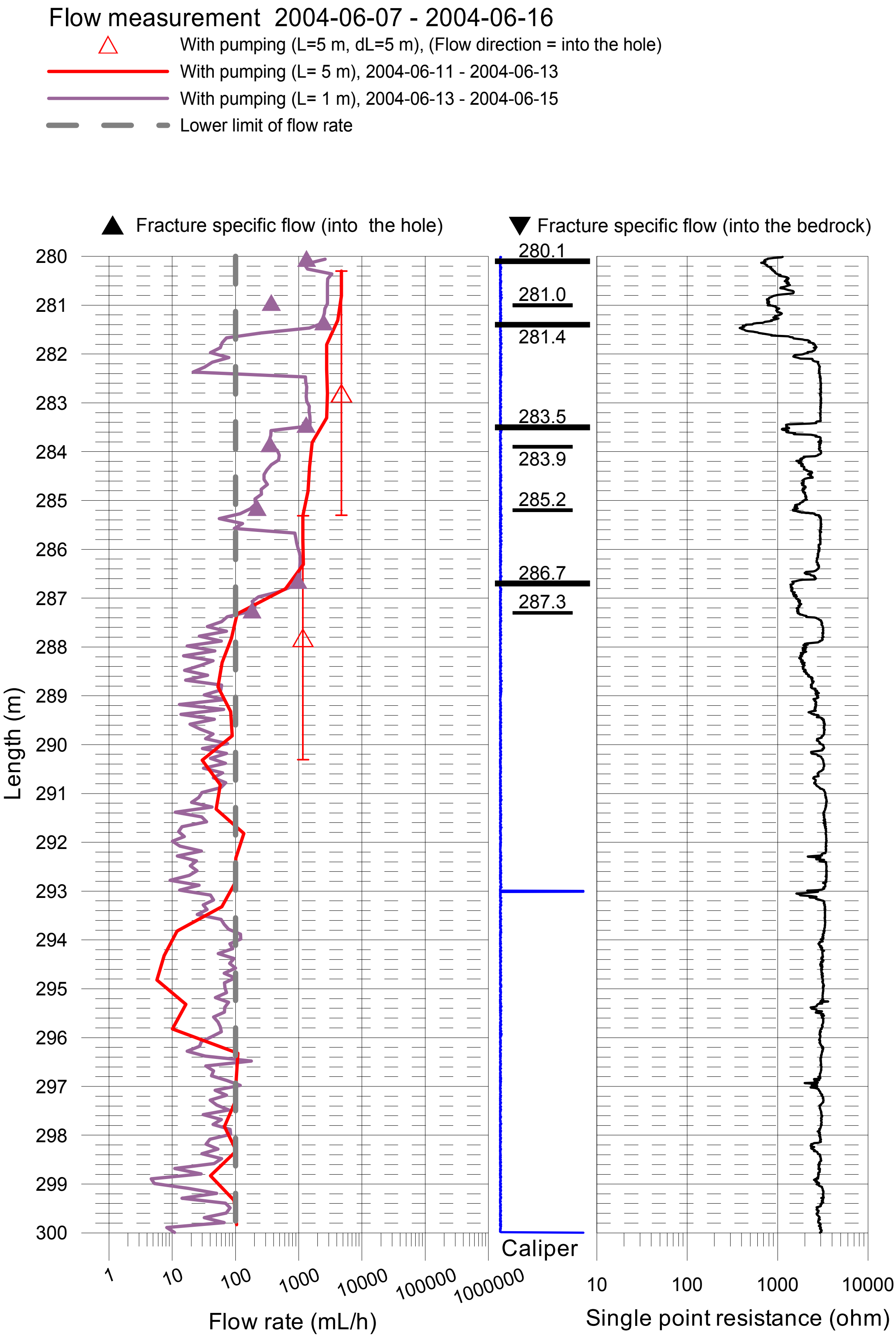


Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

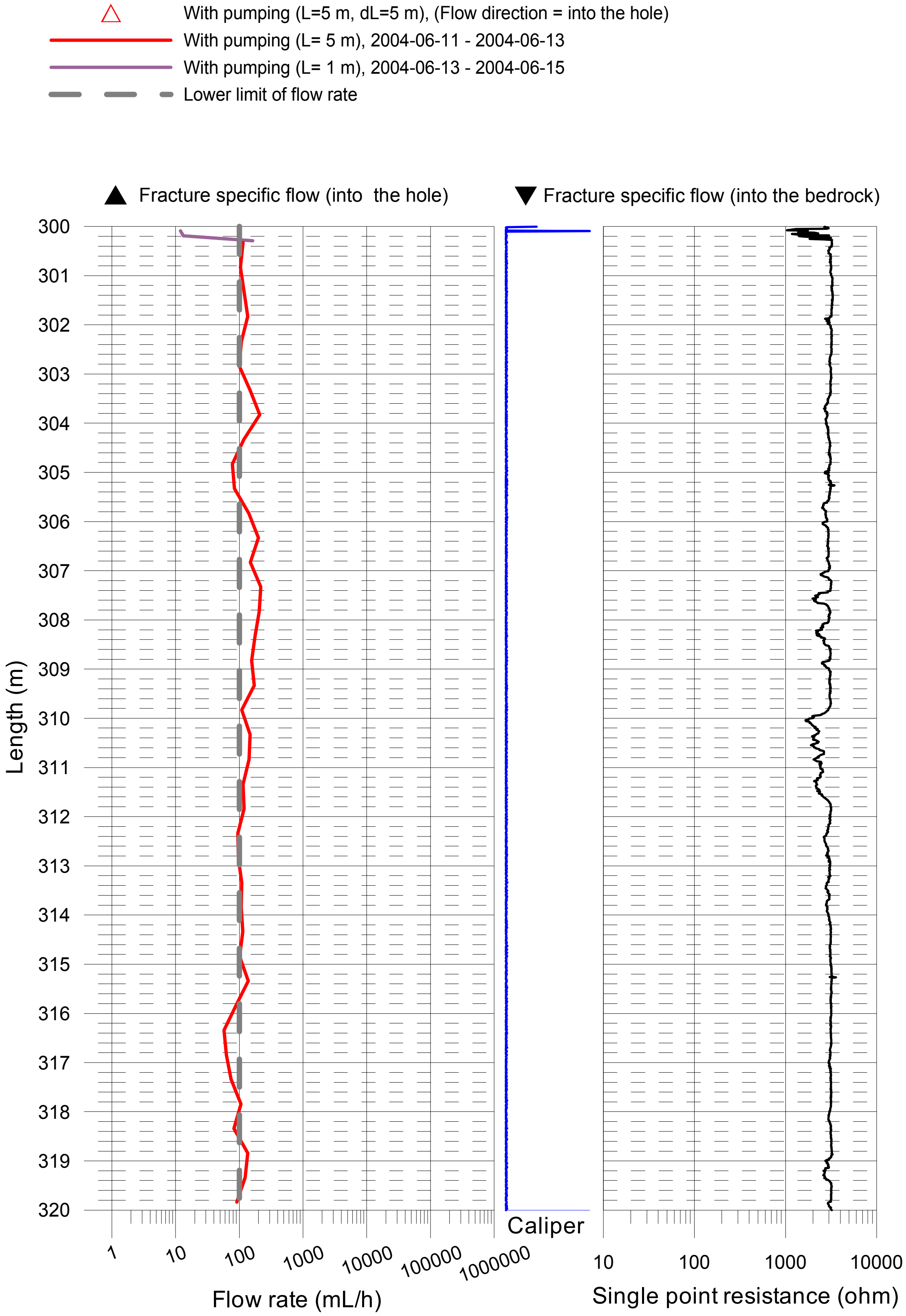


Ävrö, Borehole KAV04A



Ävrö, Borehole KAV04A

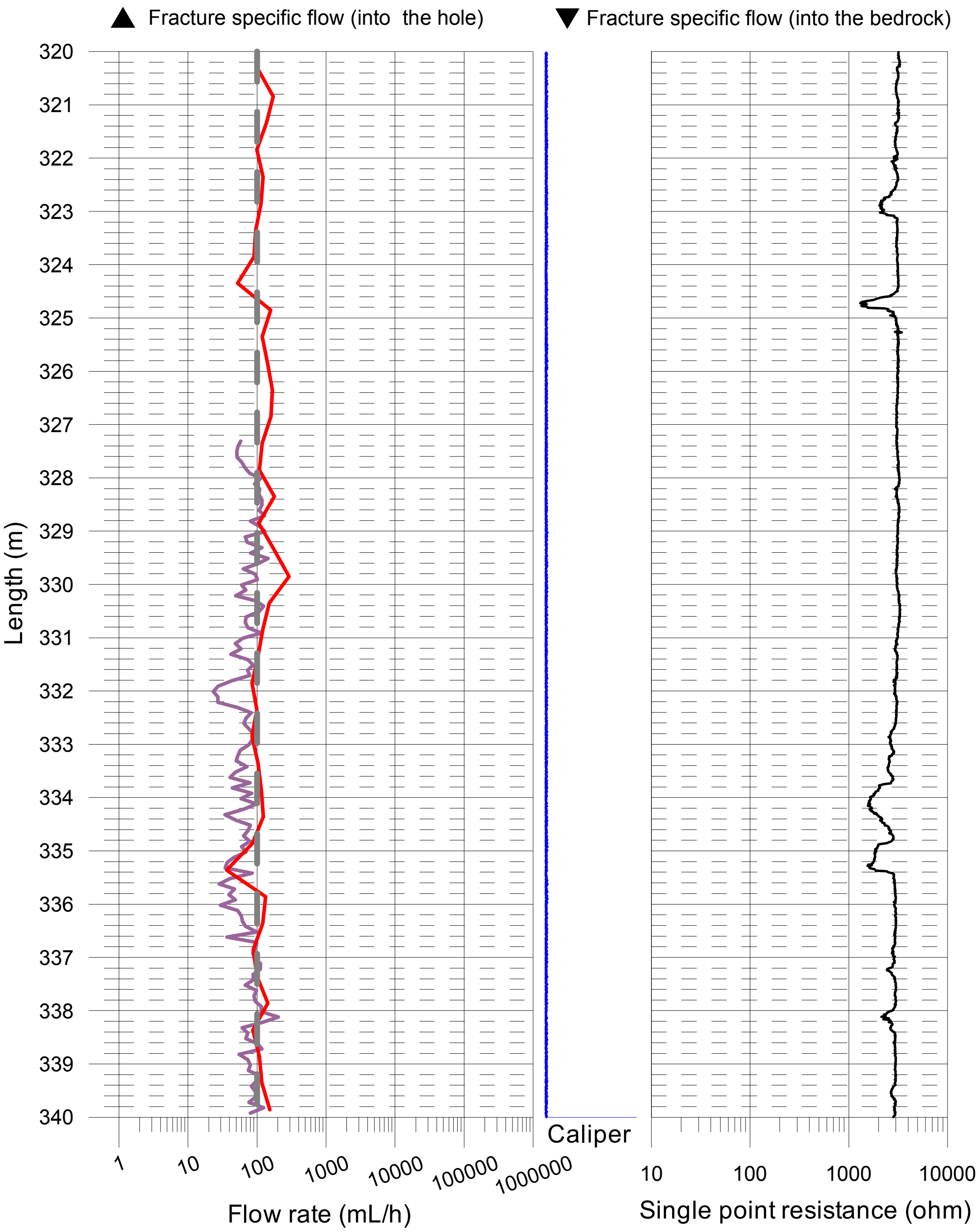
Flow measurement 2004-06-07 - 2004-06-16



Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

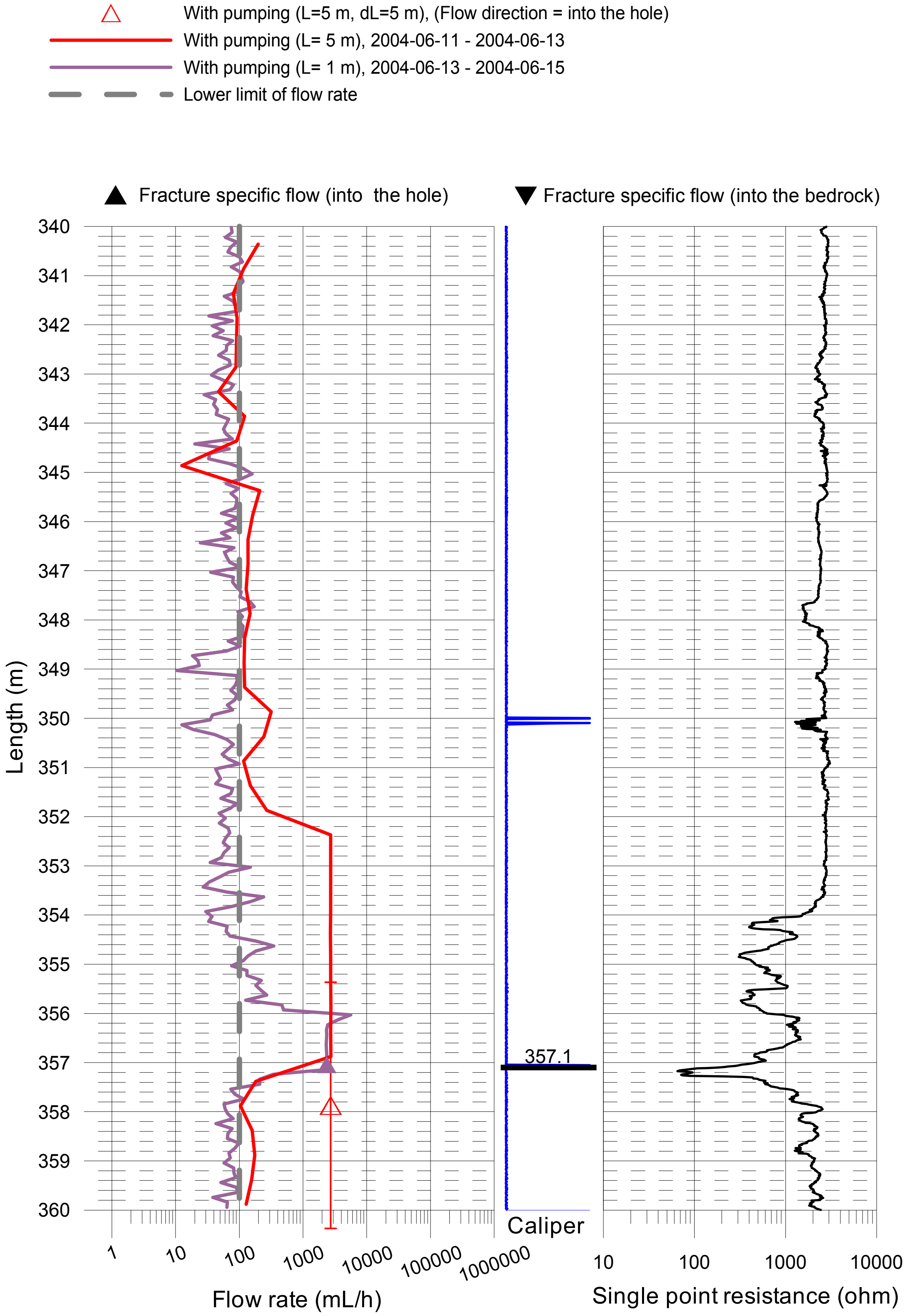
With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)
With pumping (L= 5 m), 2004-06-11 - 2004-06-13
With pumping (L= 1 m), 2004-06-13 - 2004-06-15
Lower limit of flow rate



Appendix 2.13

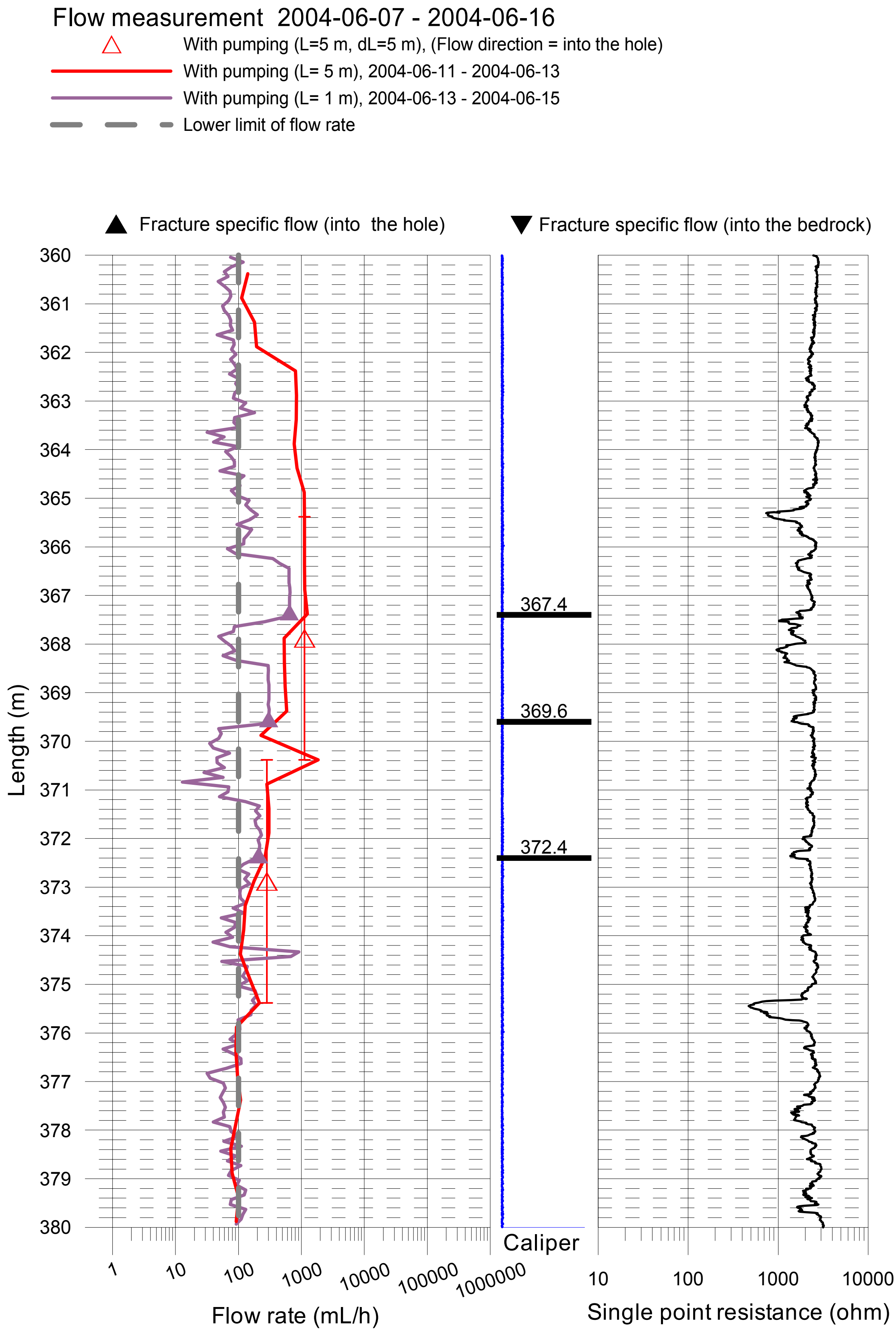
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



Appendix 2.14

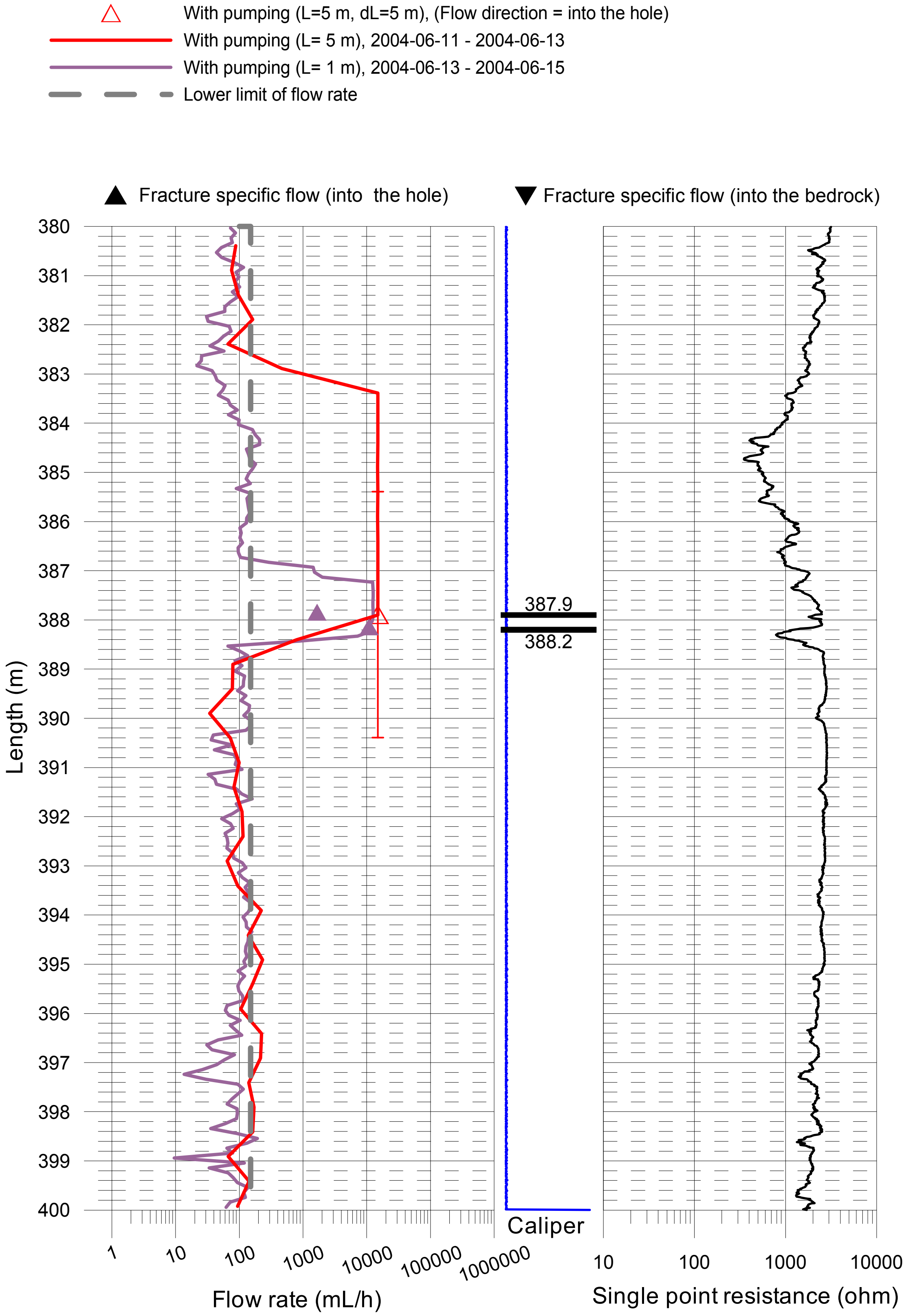
Ävrö, Borehole KAV04A



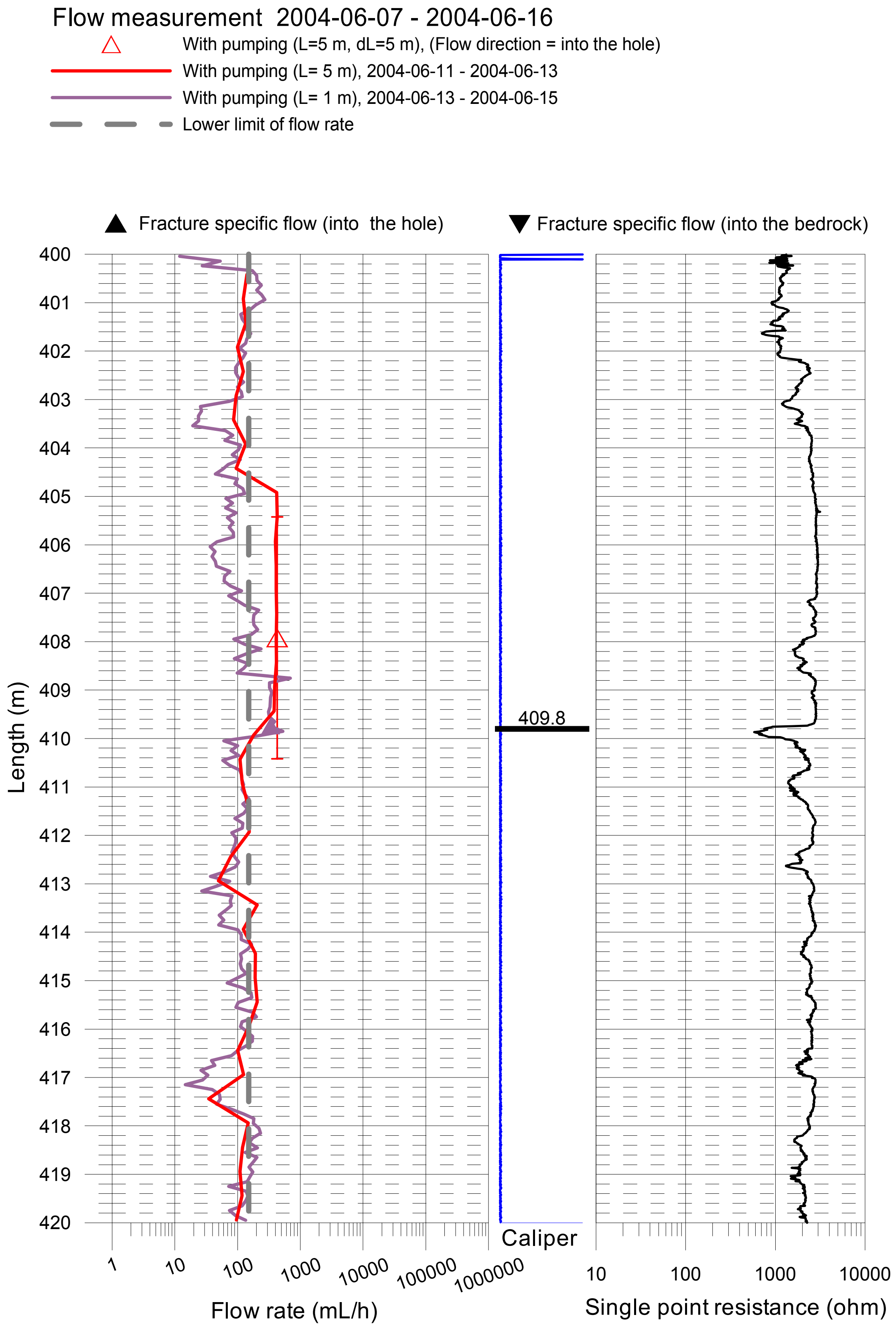
Appendix 2.15

Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

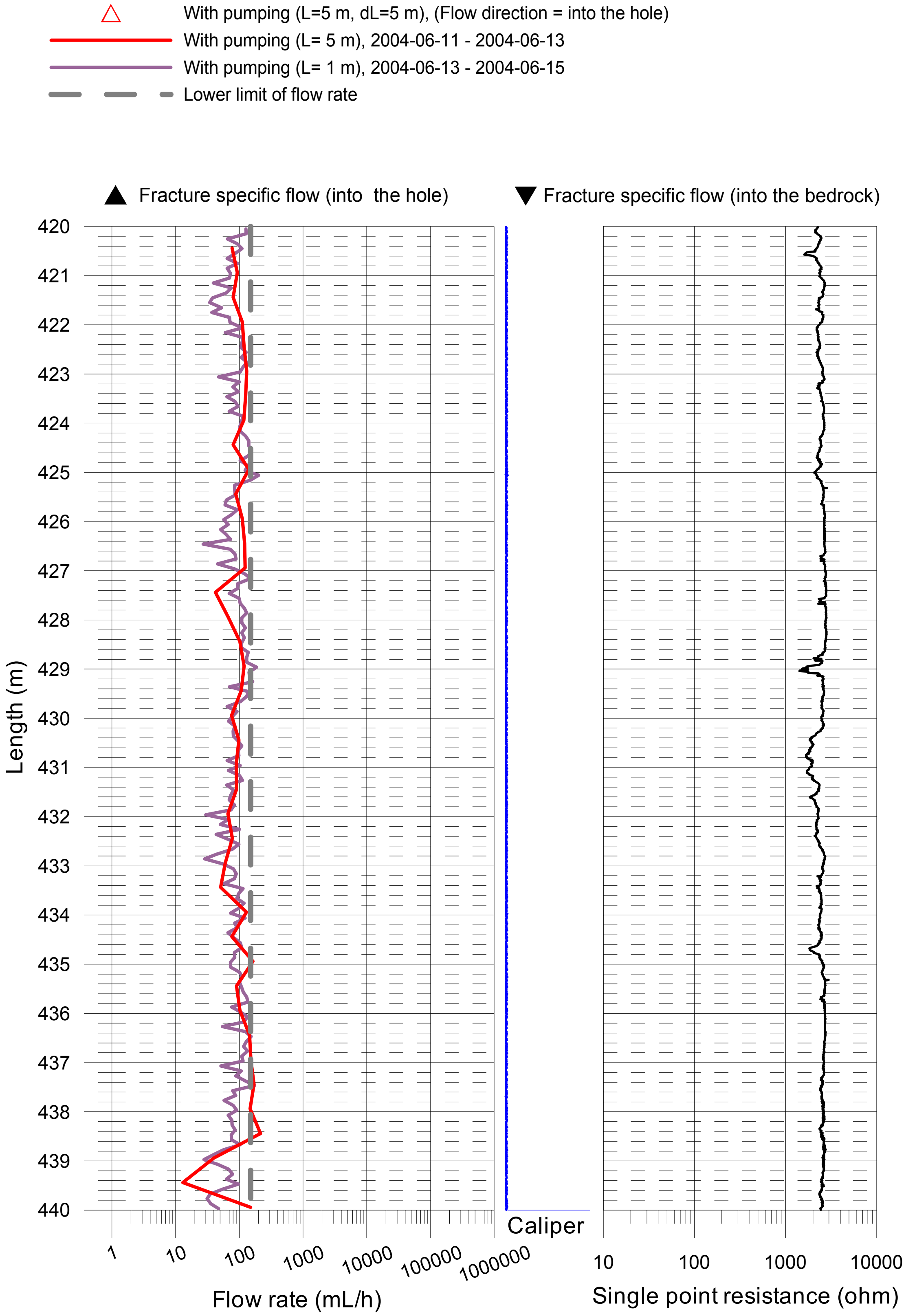


Ävrö, Borehole KAV04A



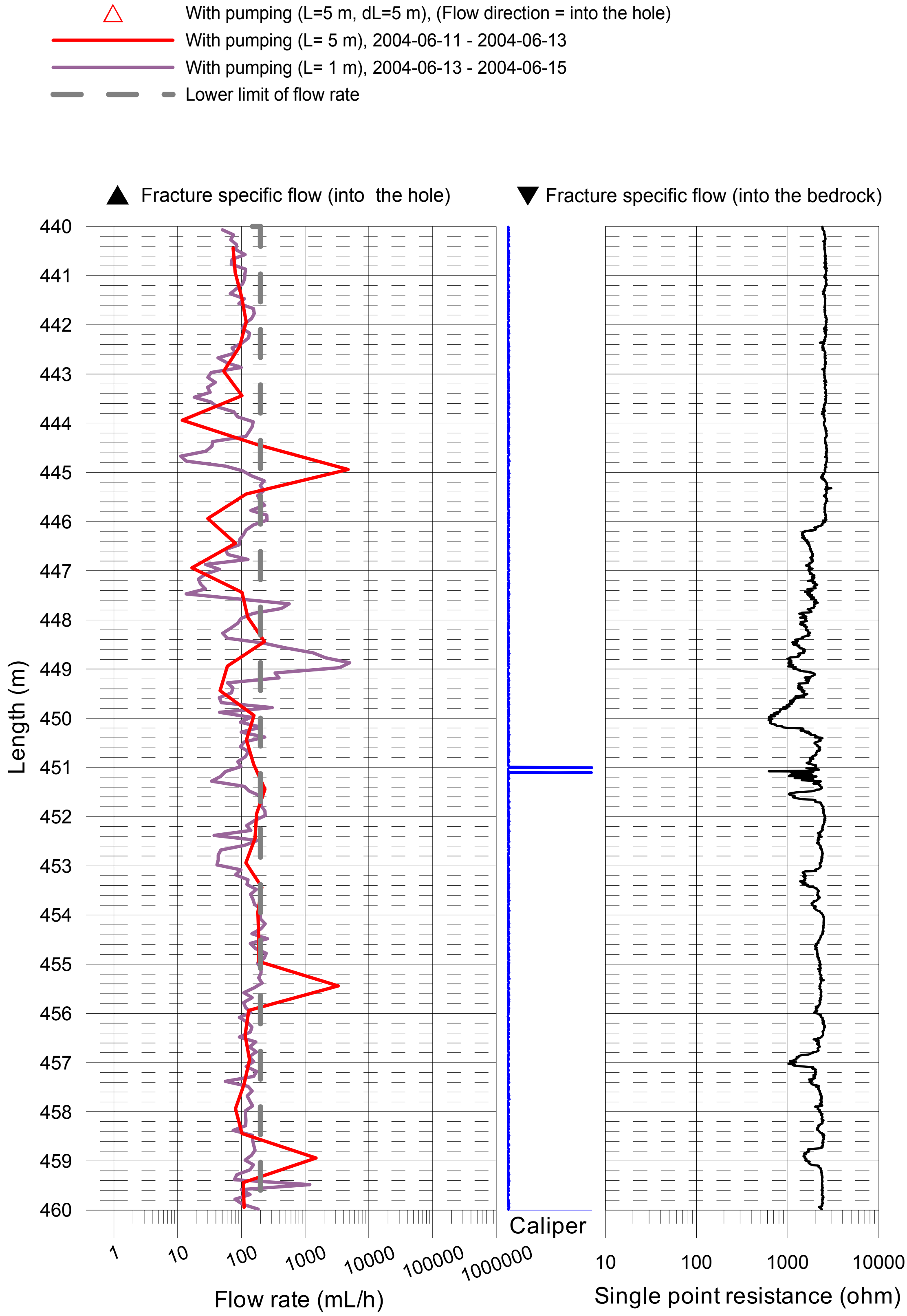
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



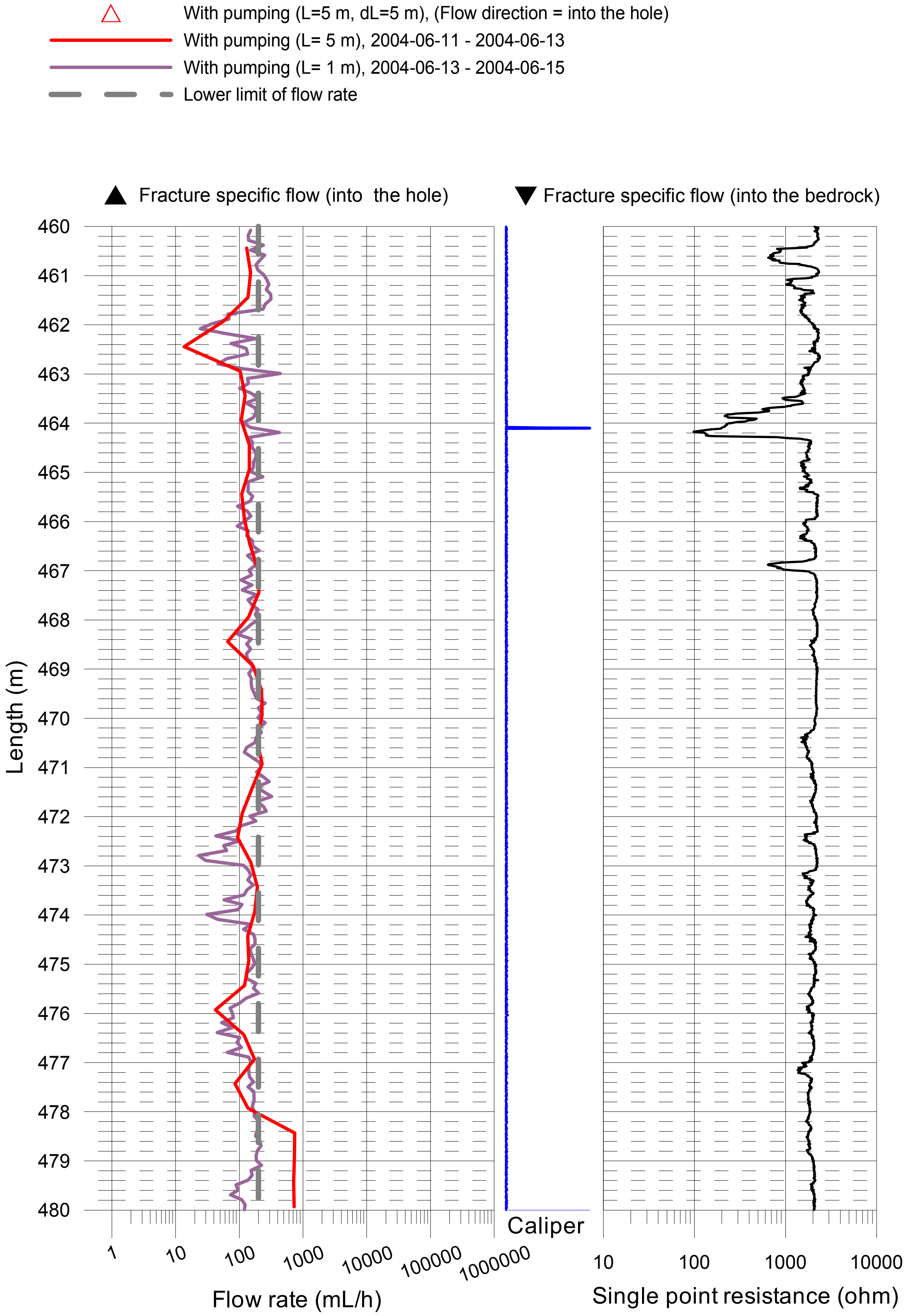
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

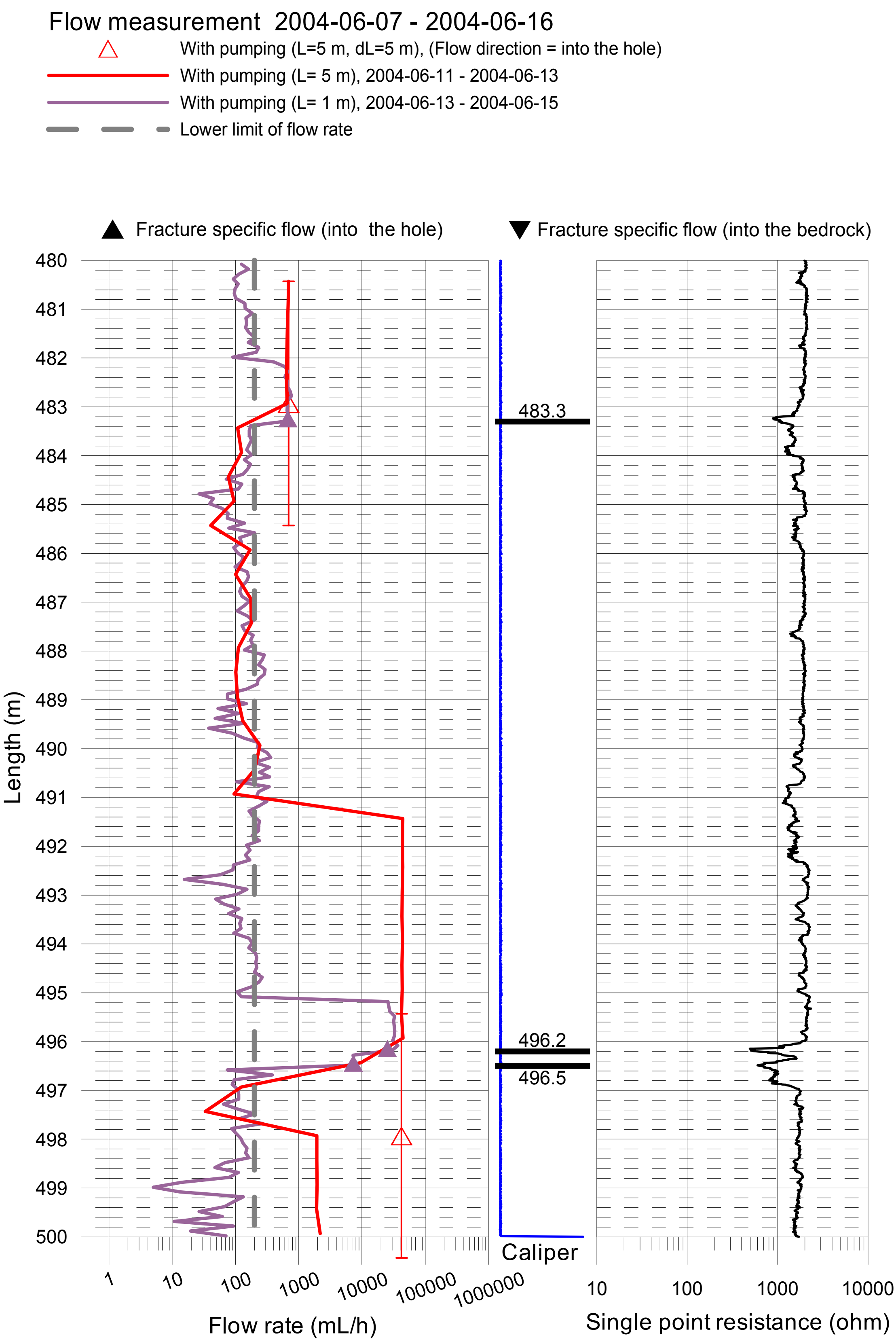


Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



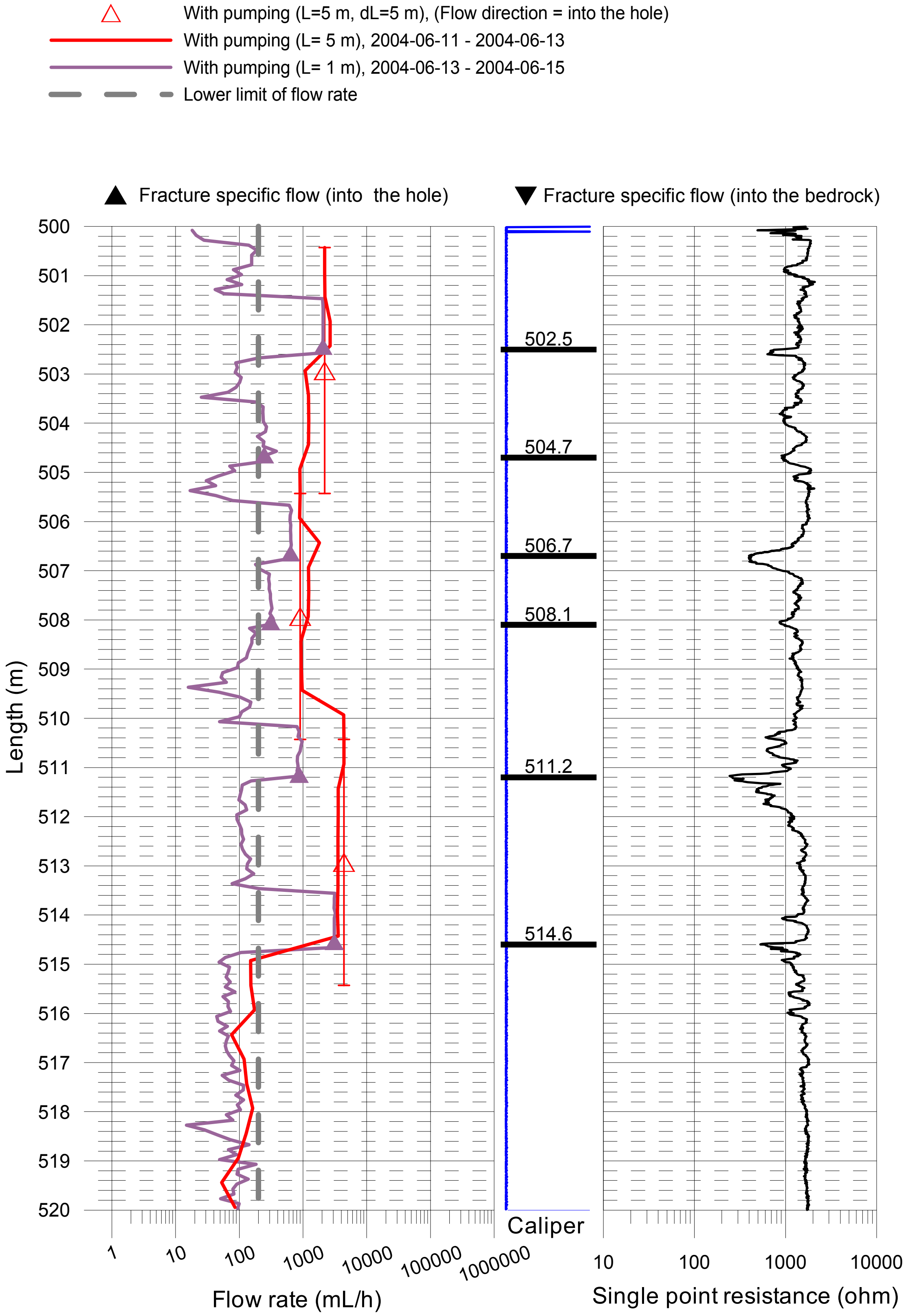
Ävrö, Borehole KAV04A



Appendix 2.21

Ävrö, Borehole KAV04A

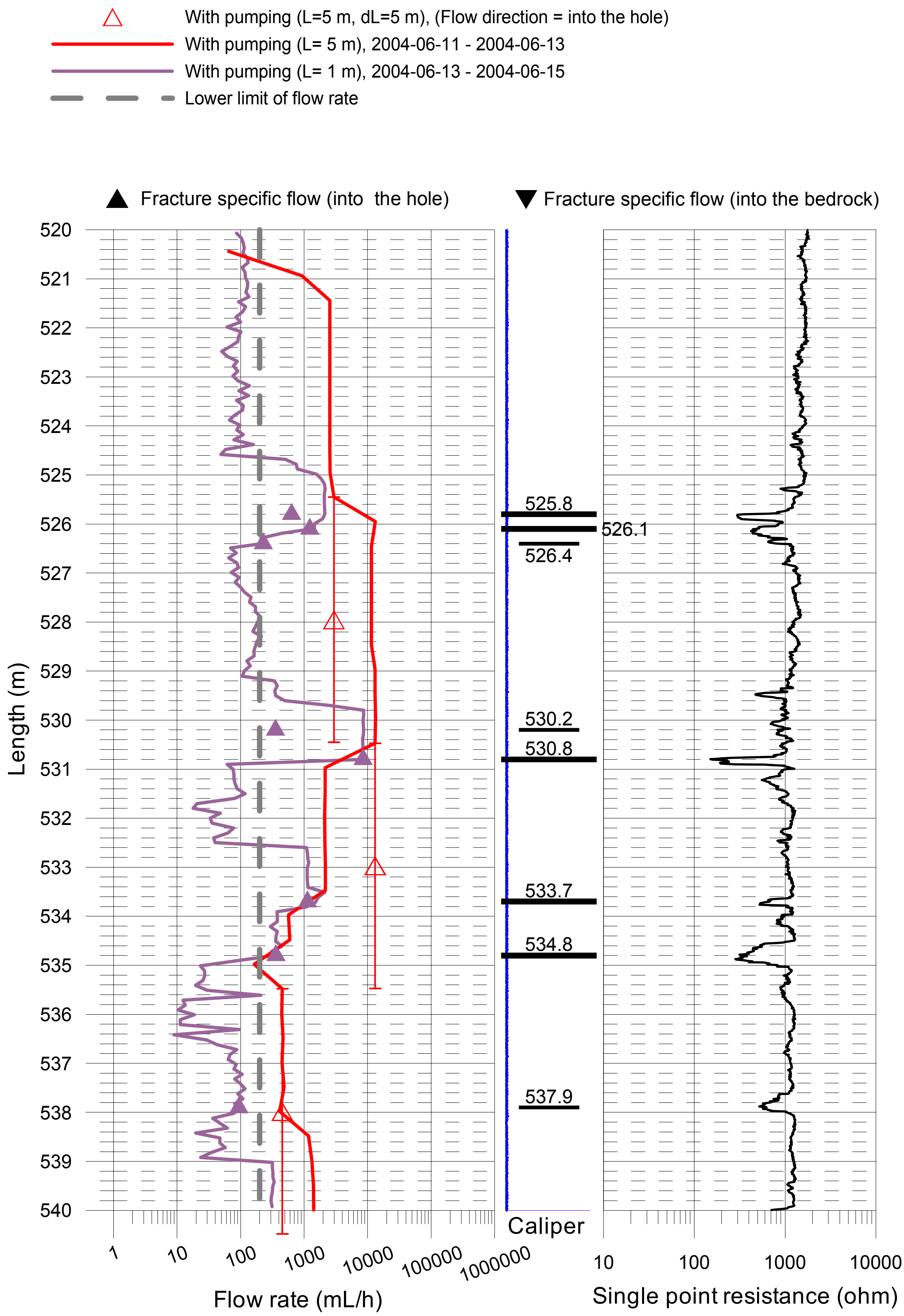
Flow measurement 2004-06-07 - 2004-06-16



Appendix 2.22

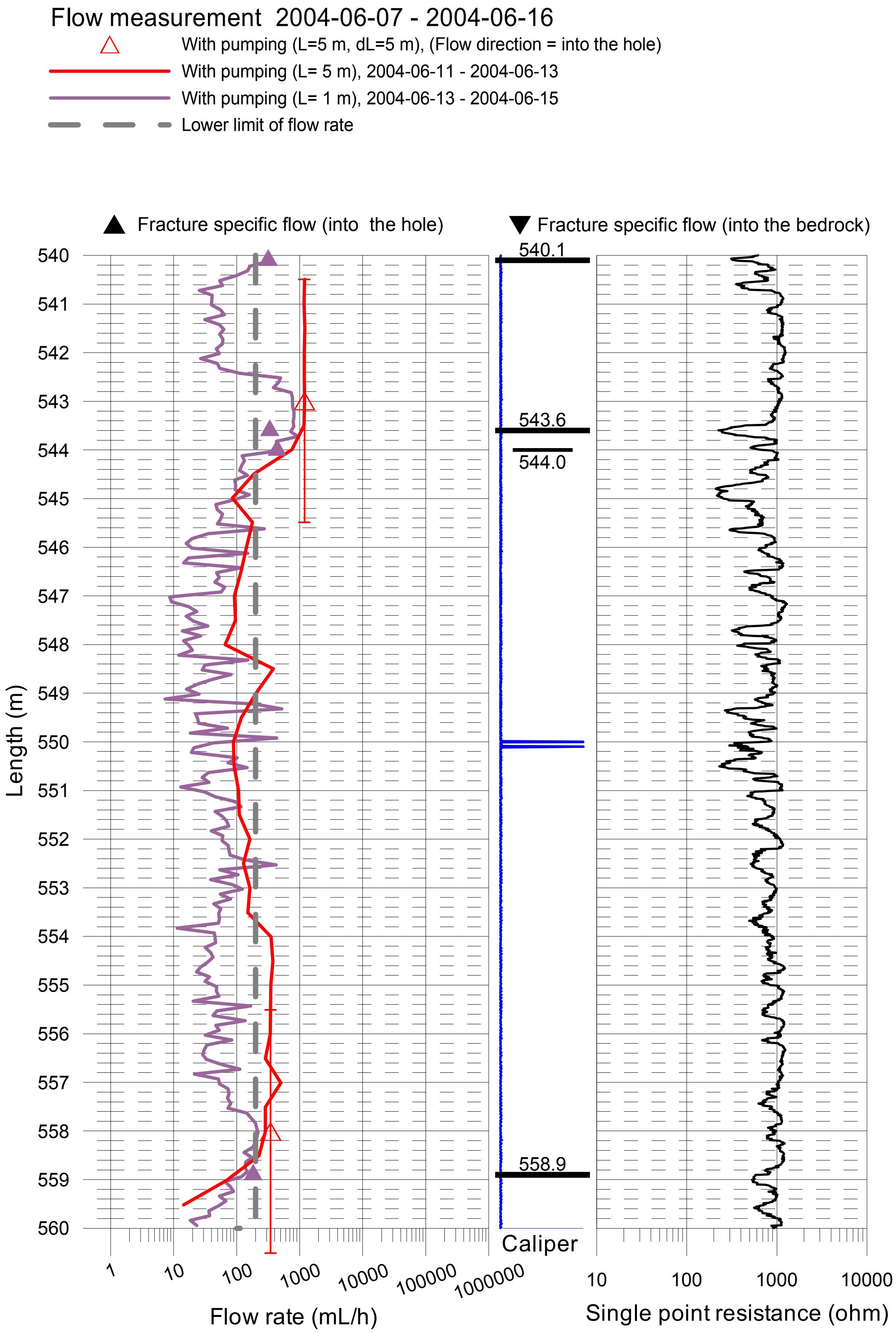
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



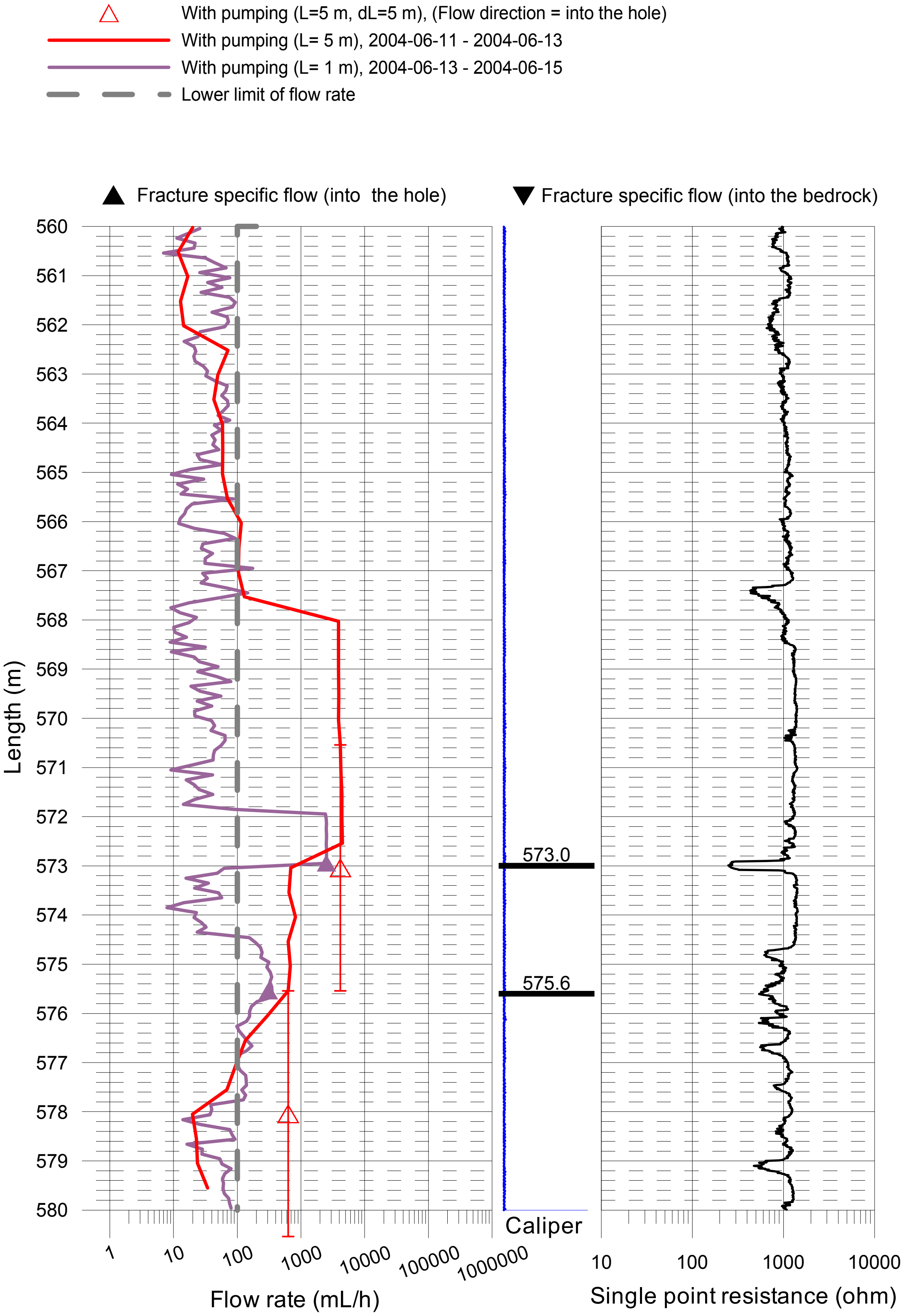
Appendix 2.23

Ävrö, Borehole KAV04A

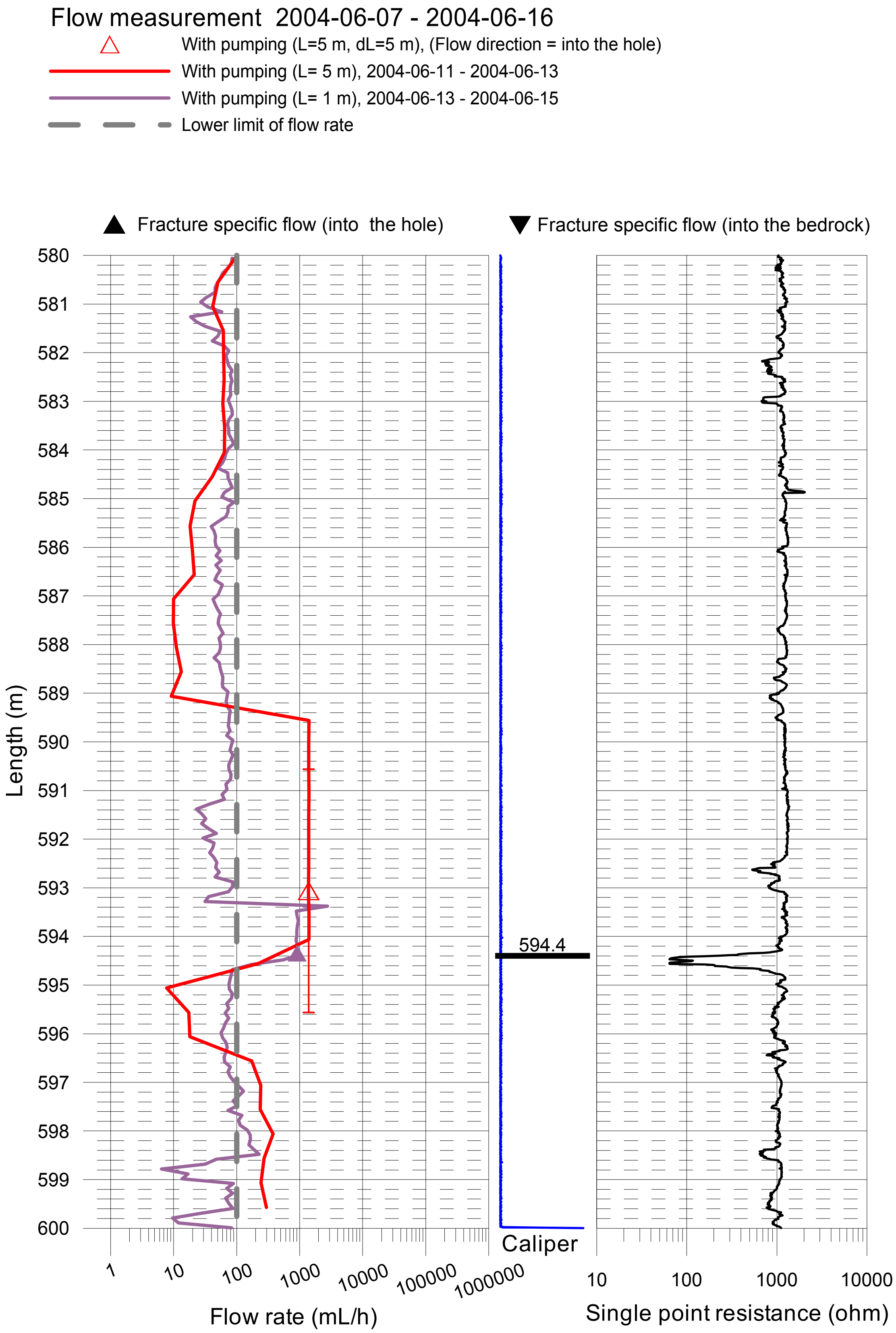


Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



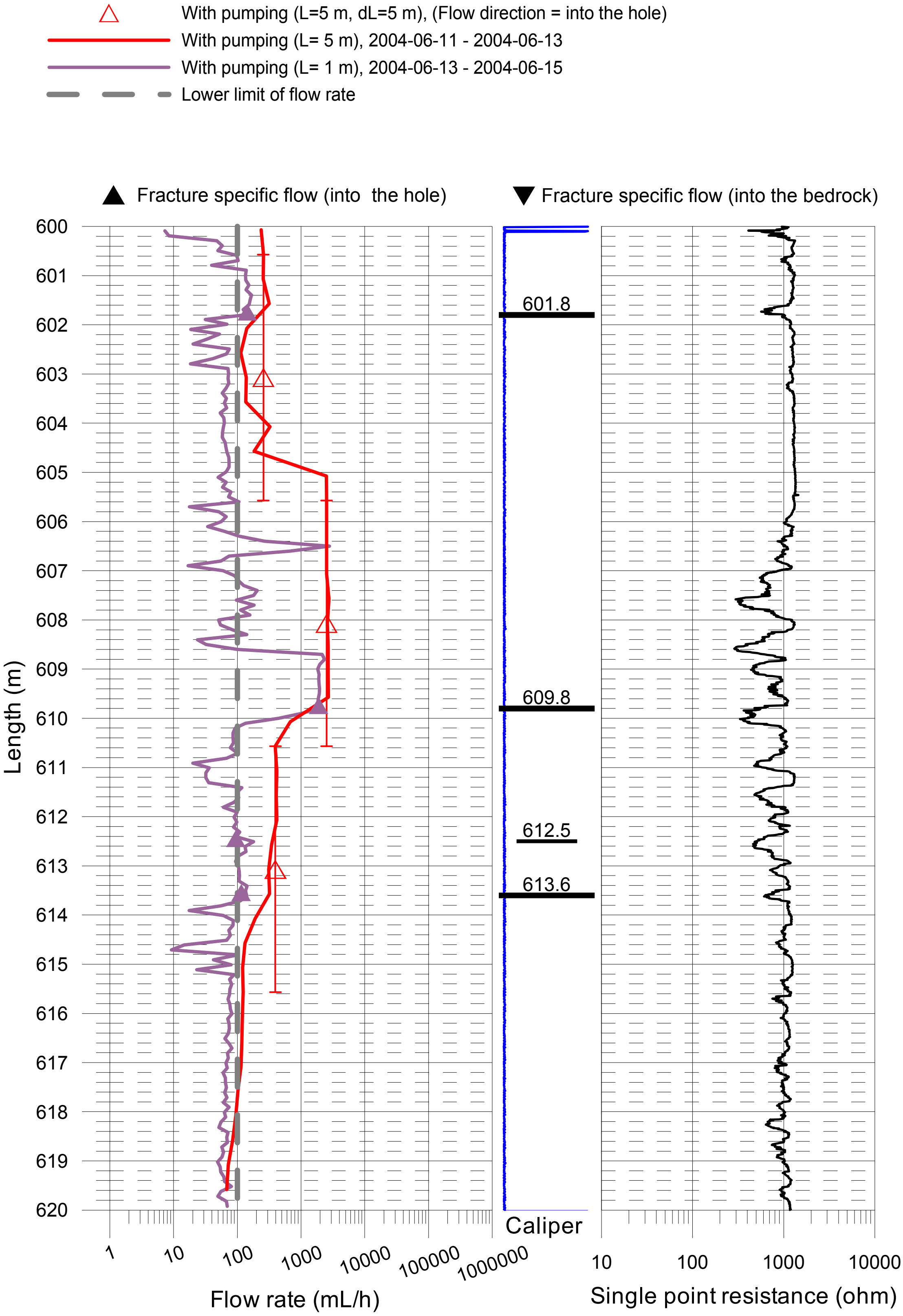
Ävrö, Borehole KAV04A



Appendix 2.26

Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



Ävrö, Borehole KAV04A

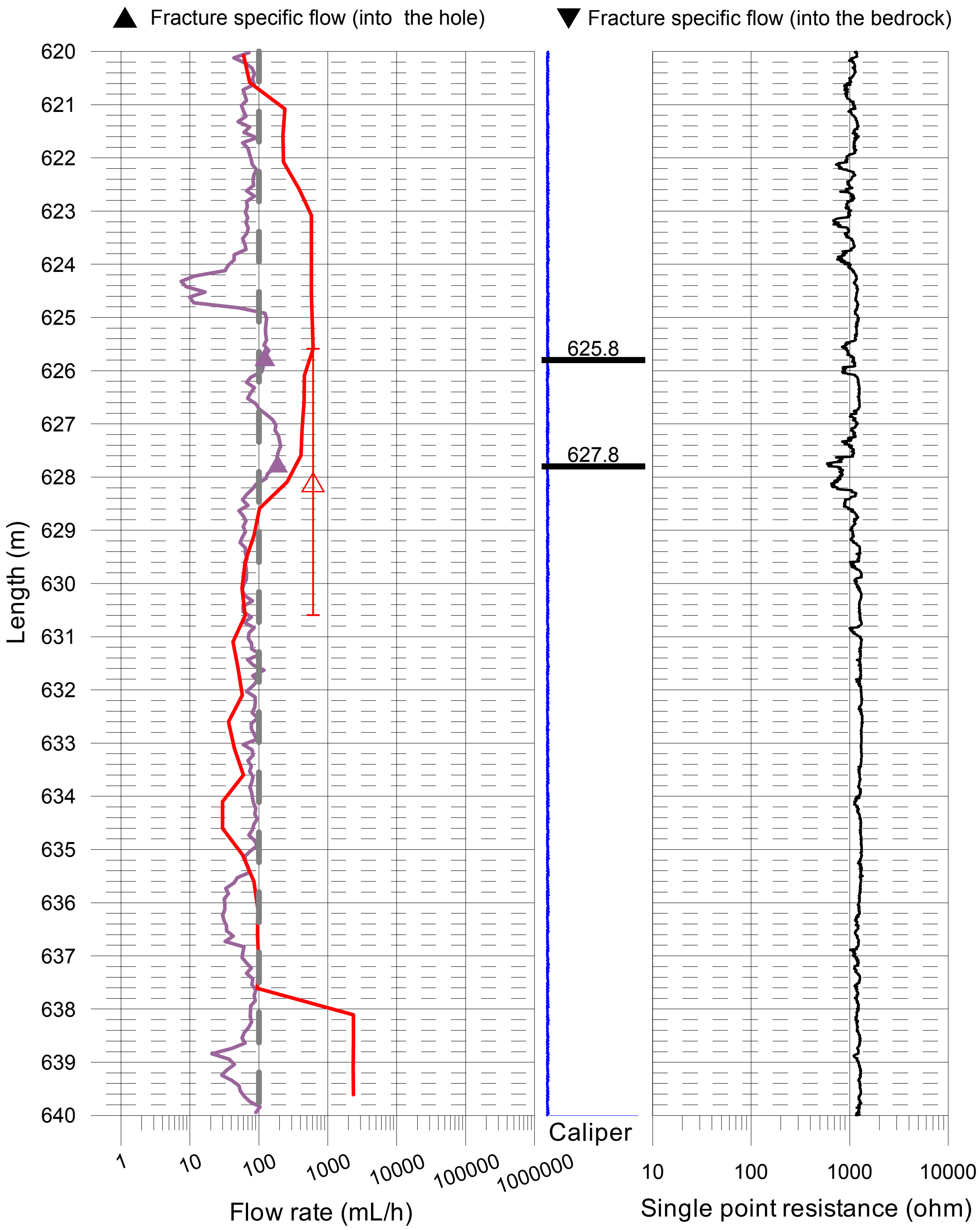
Flow measurement 2004-06-07 - 2004-06-16

△ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)

With pumping (L= 5 m), 2004-06-11 - 2004-06-13

With pumping (L= 1 m), 2004-06-13 - 2004-06-15

Lower limit of flow rate



Ävrö, Borehole KAV04A

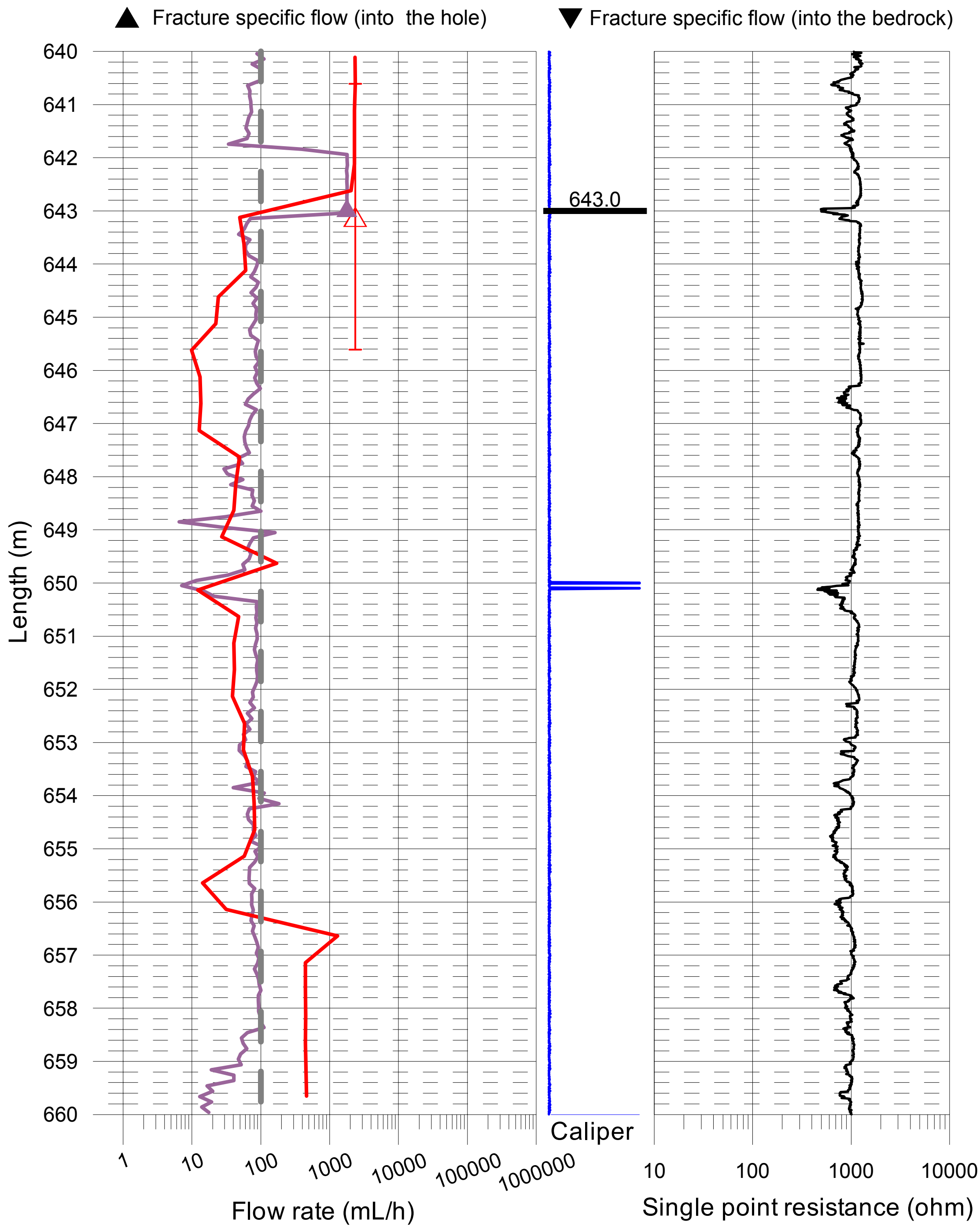
Flow measurement 2004-06-07 - 2004-06-16

△ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)

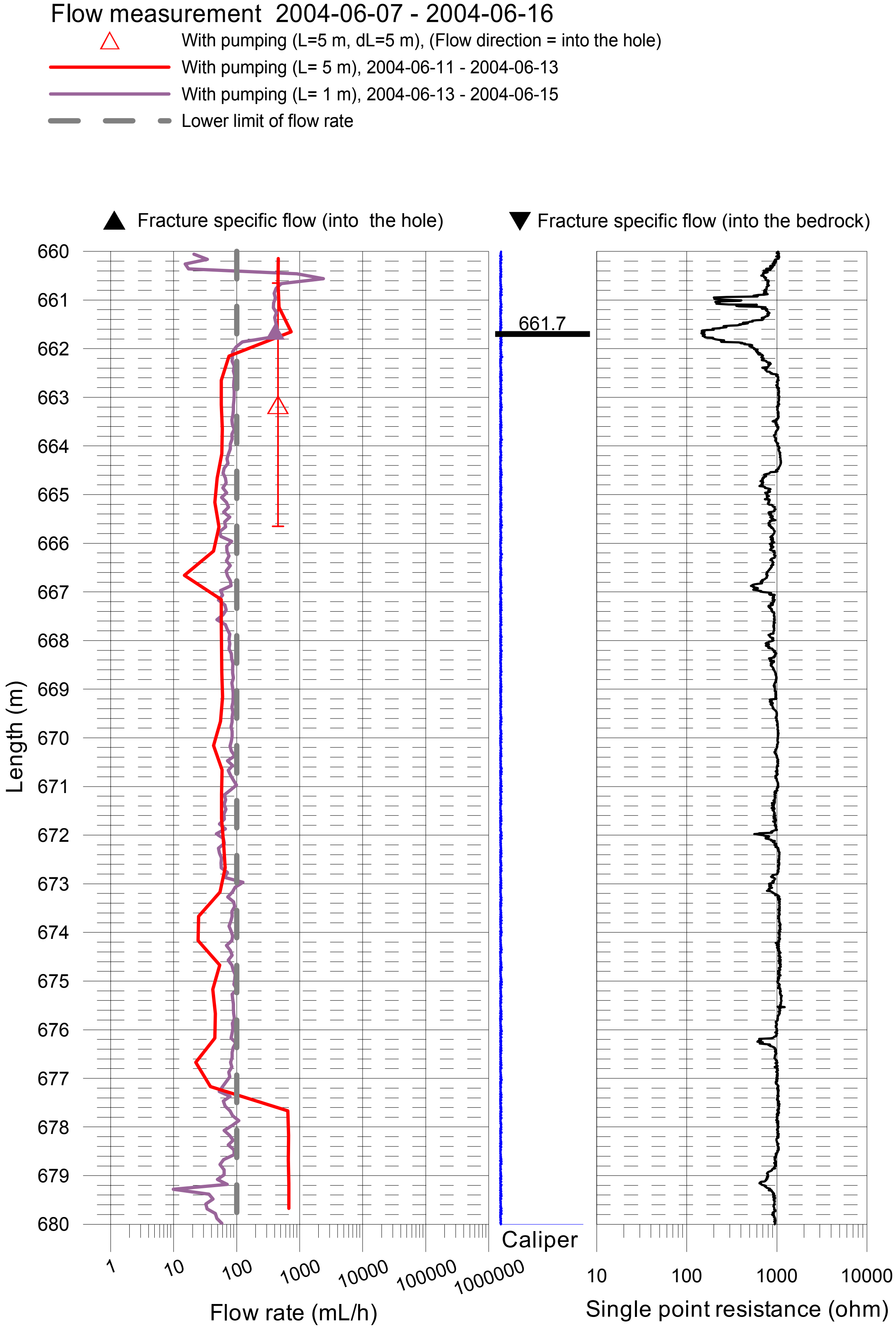
With pumping (L= 5 m), 2004-06-11 - 2004-06-13

With pumping (L= 1 m), 2004-06-13 - 2004-06-15

Lower limit of flow rate

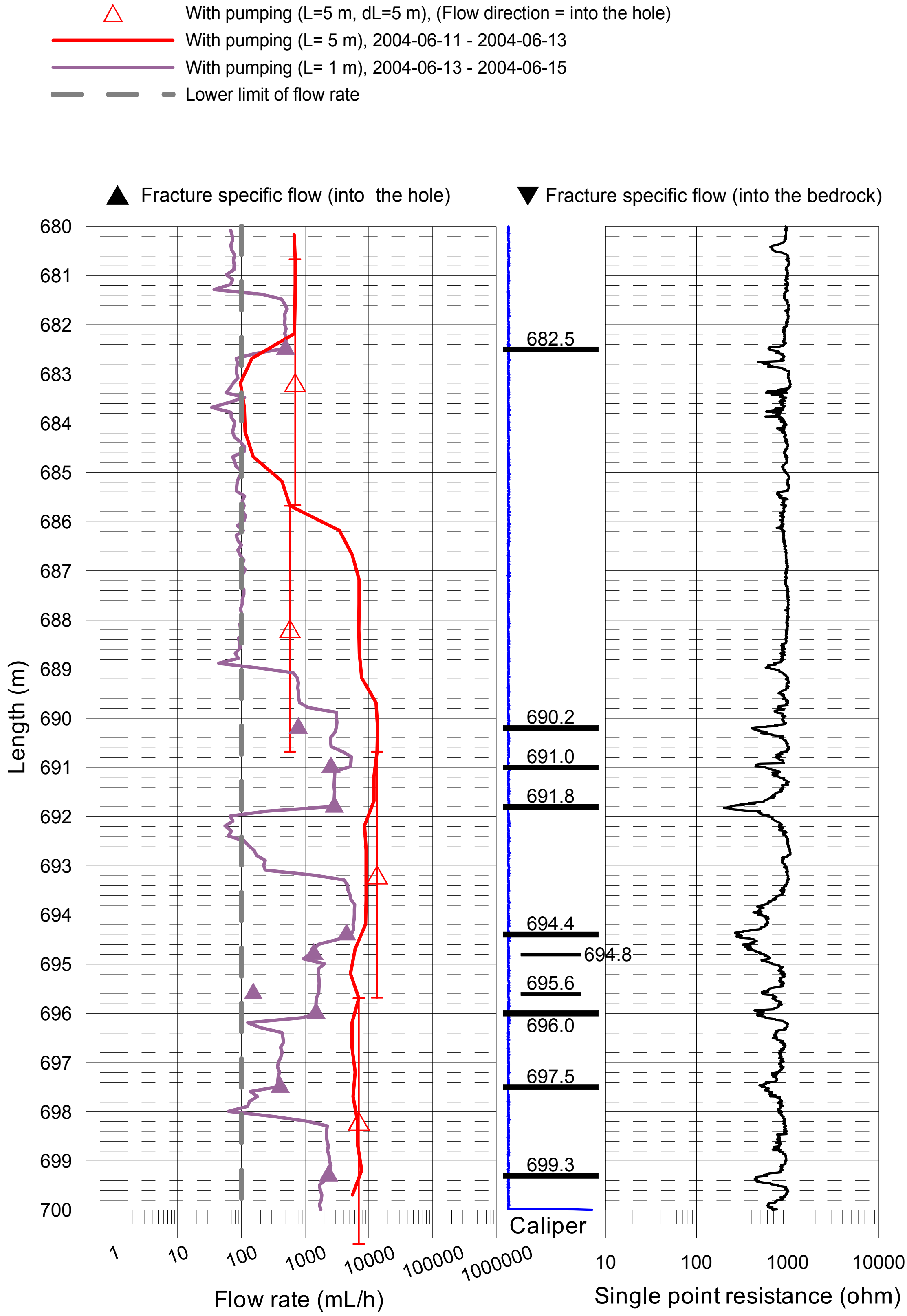


Ävrö, Borehole KAV04A



Ävrö, Borehole KAV04A

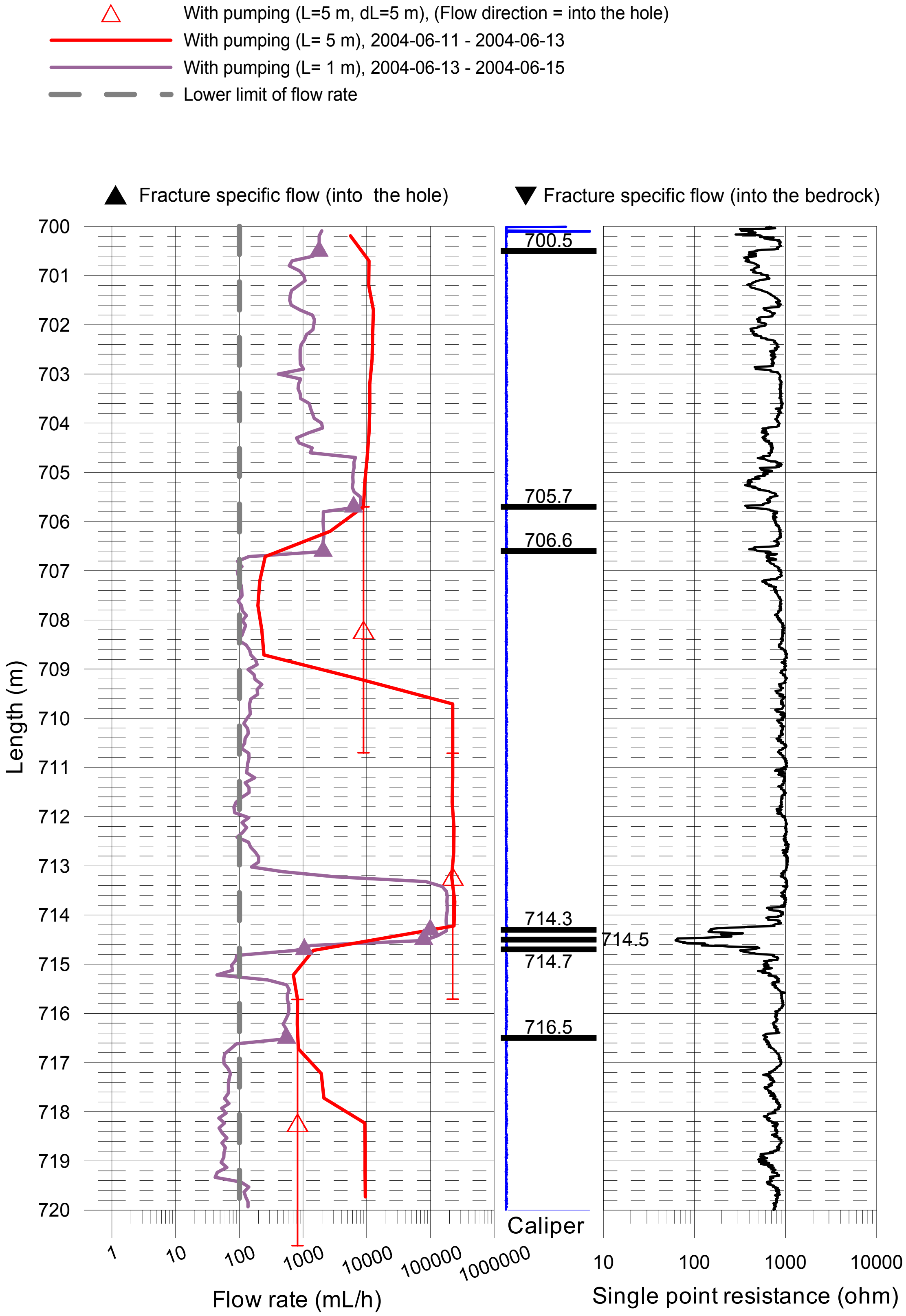
Flow measurement 2004-06-07 - 2004-06-16



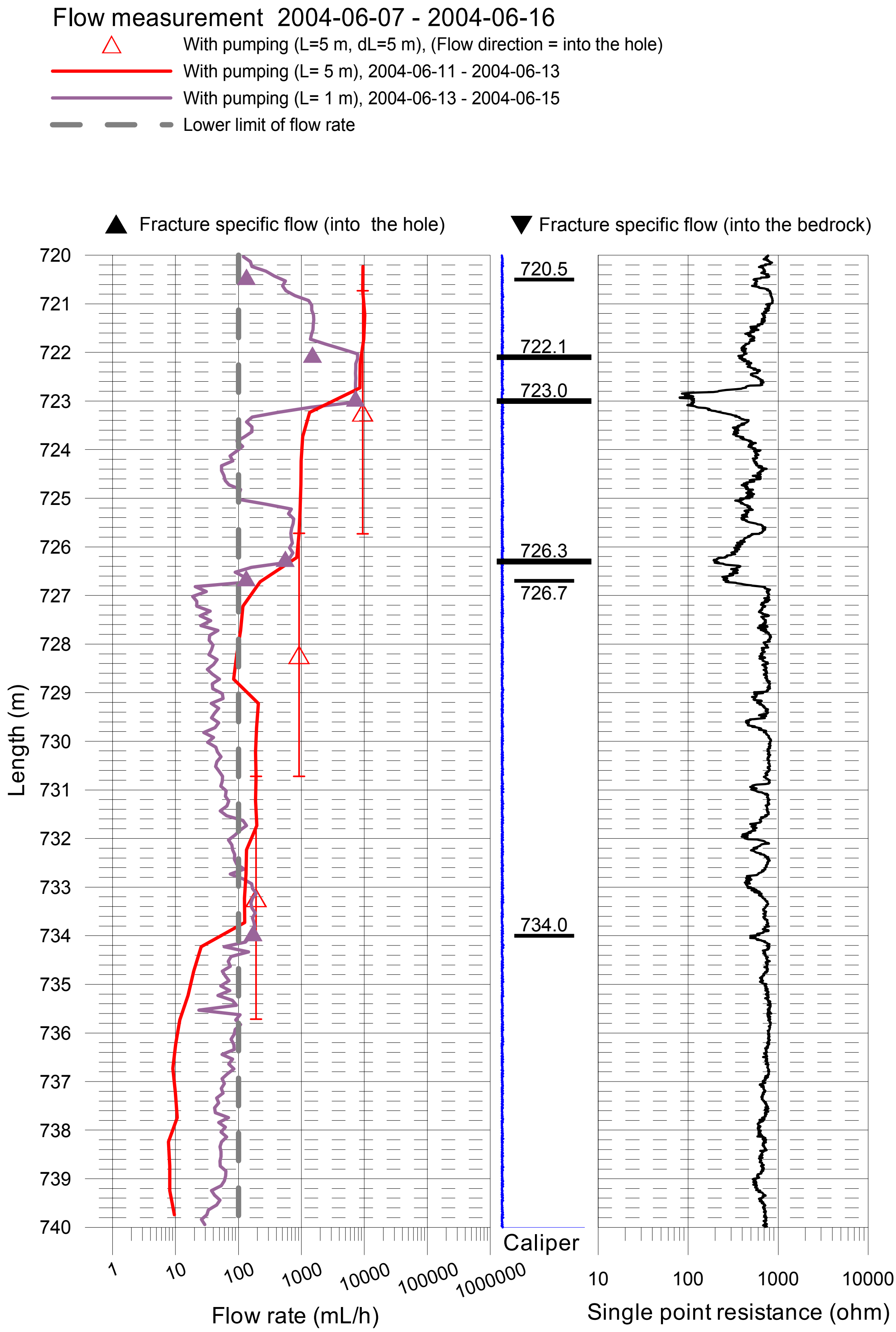
Appendix 2.31

Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

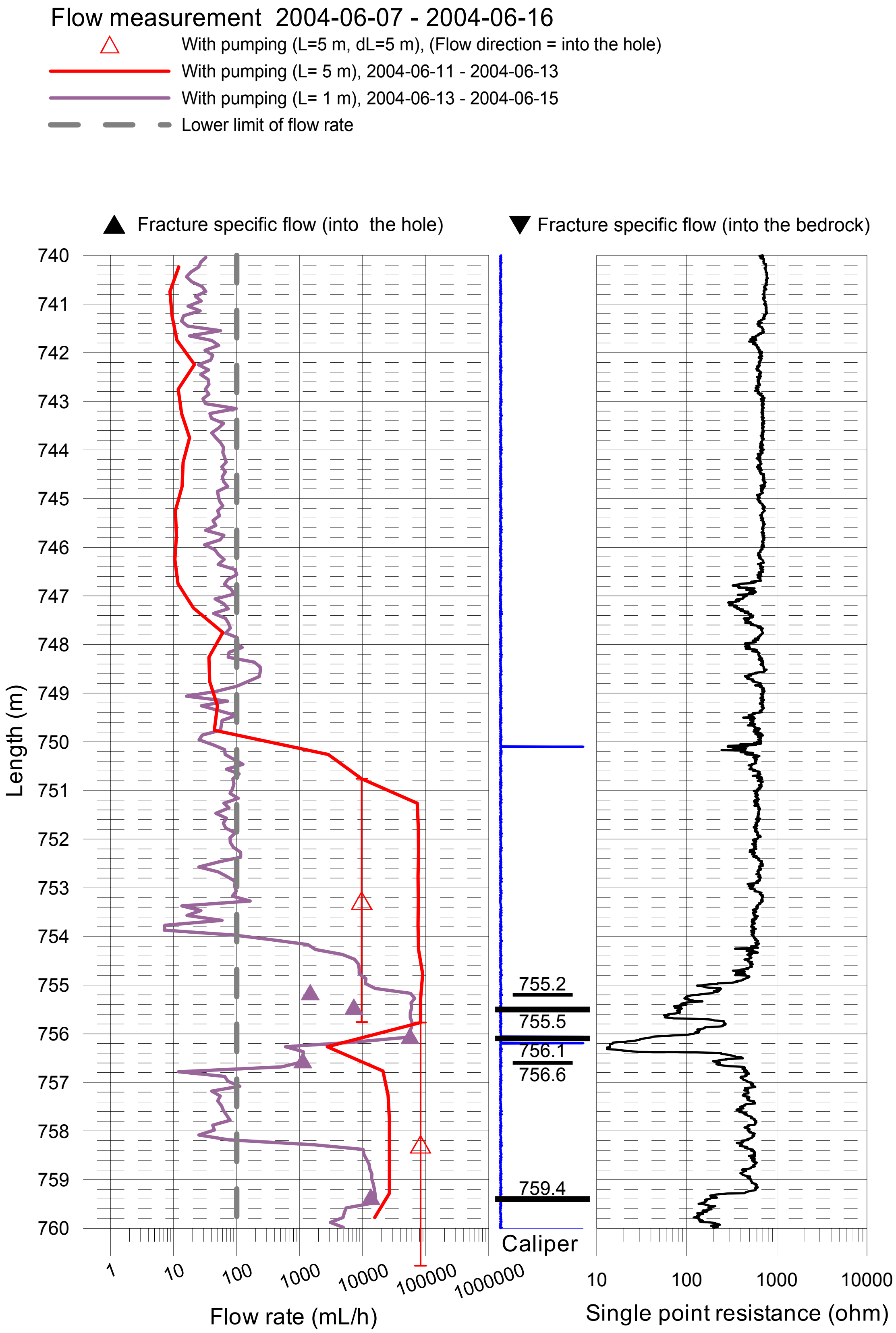


Ävrö, Borehole KAV04A



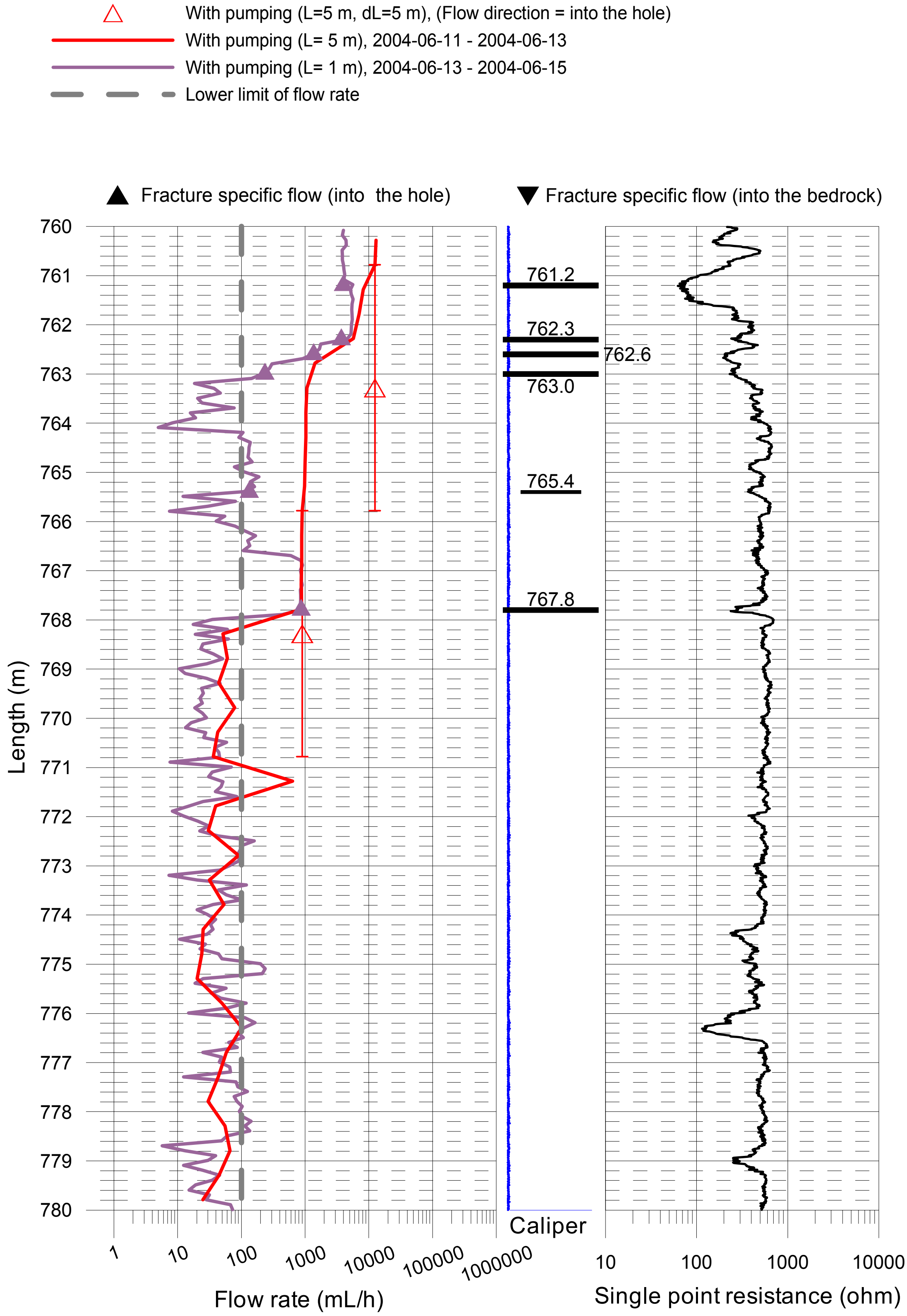
Appendix 2.33

Ävrö, Borehole KAV04A



Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



Ävrö, Borehole KAV04A

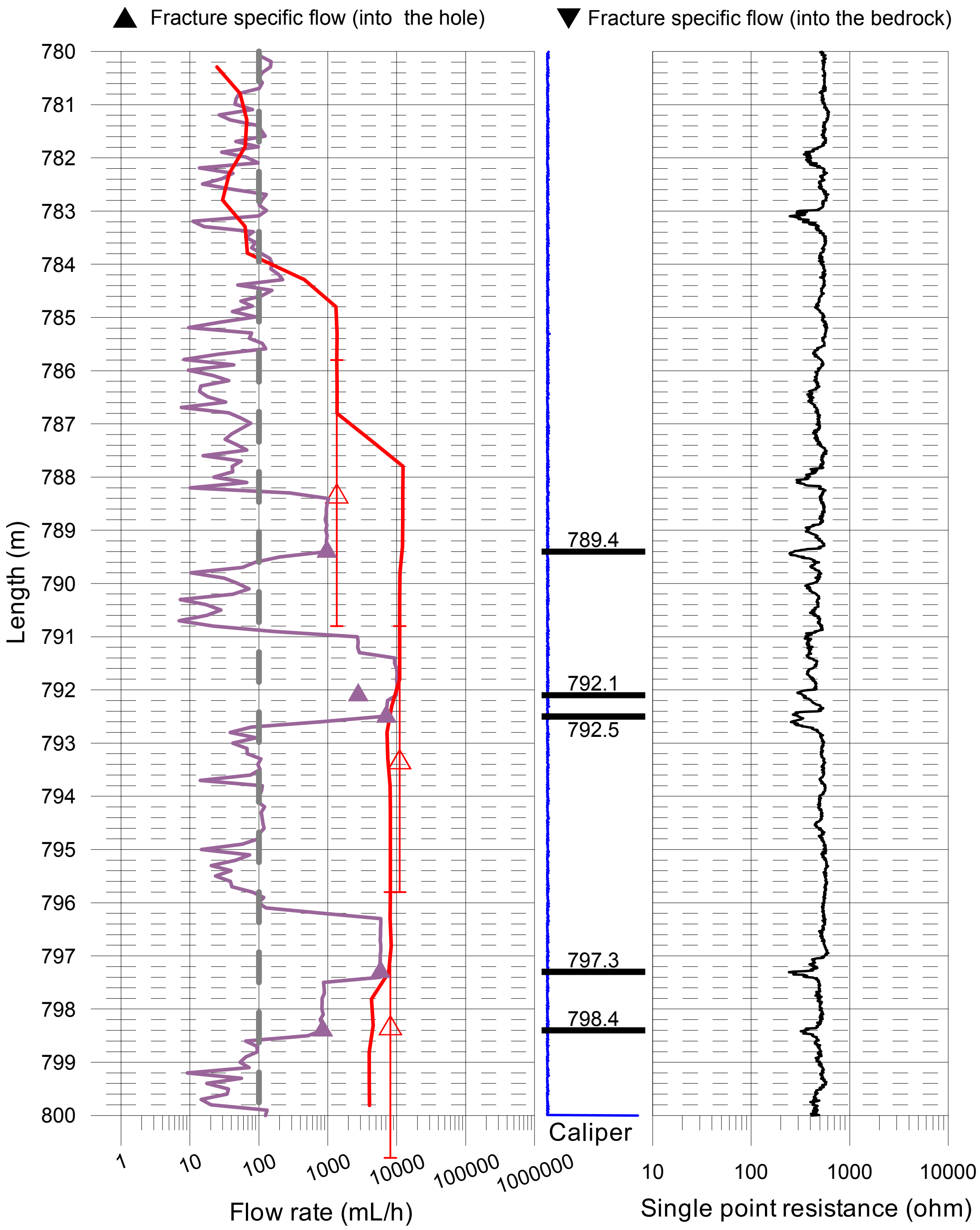
Flow measurement 2004-06-07 - 2004-06-16

△ With pumping (L=5 m, dL=5 m), (Flow direction = into the hole)

With pumping (L= 5 m), 2004-06-11 - 2004-06-13

With pumping (L= 1 m), 2004-06-13 - 2004-06-15

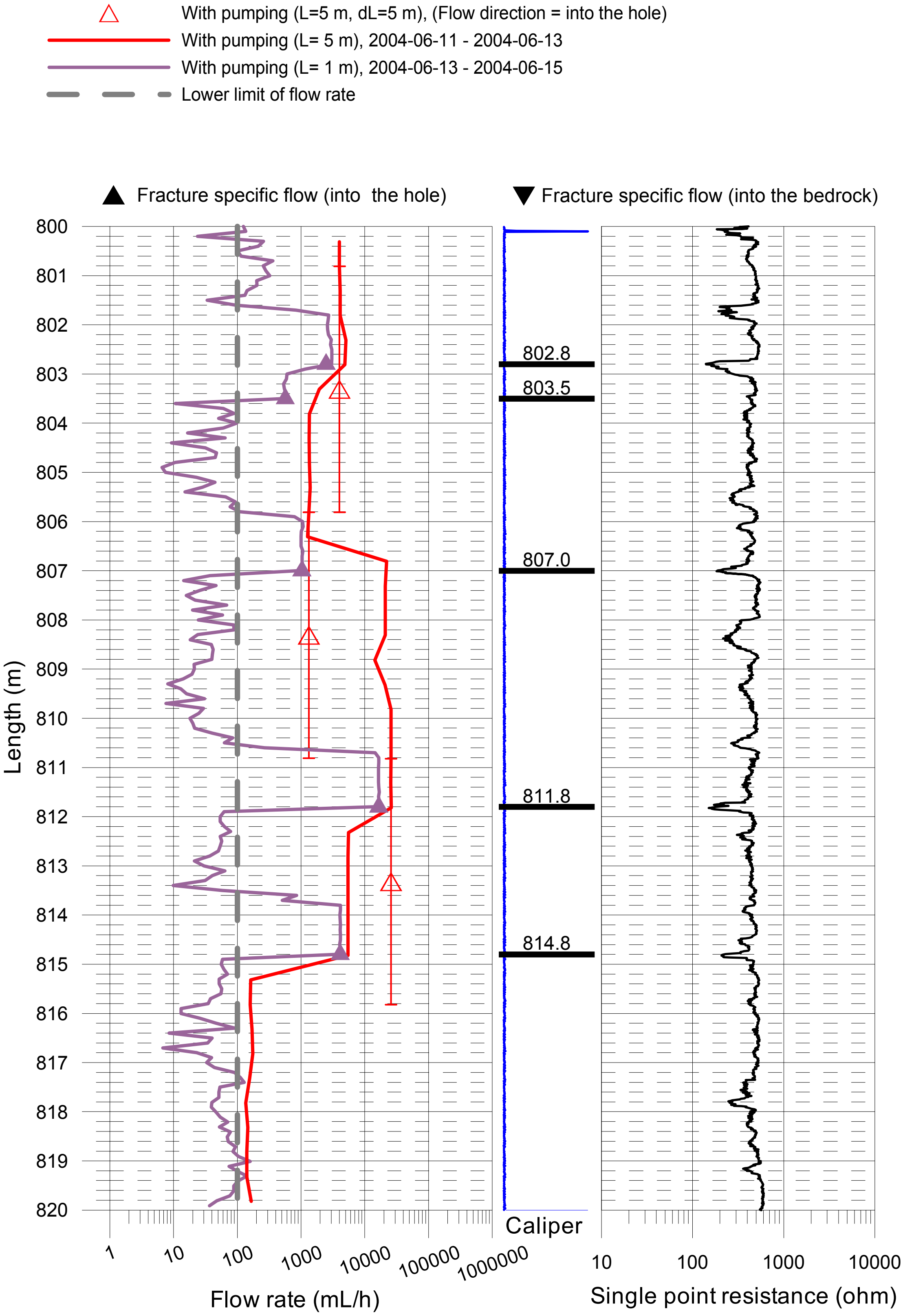
Lower limit of flow rate



Appendix 2.36

Ävrö, Borehole KAV04A

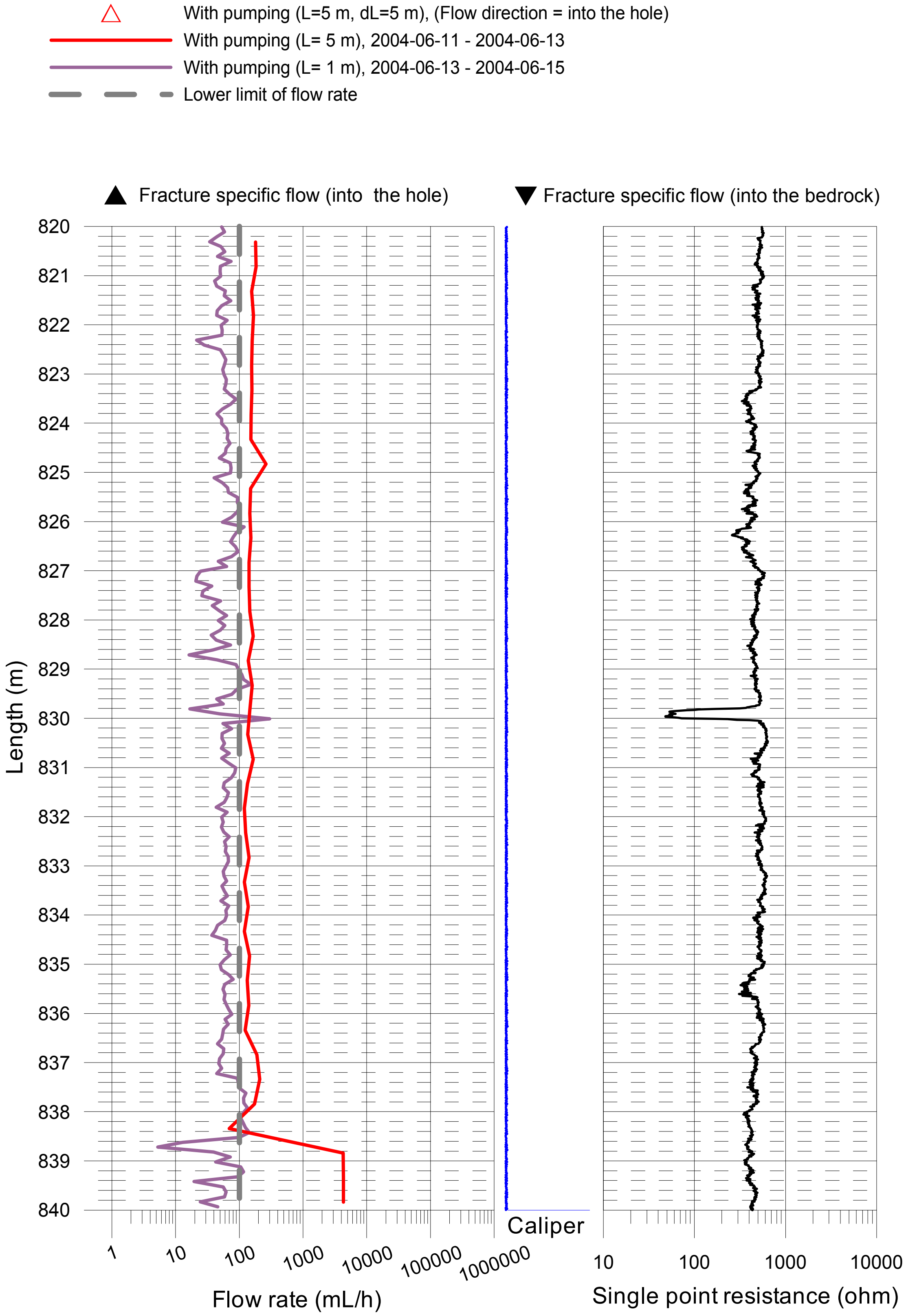
Flow measurement 2004-06-07 - 2004-06-16



Appendix 2.37

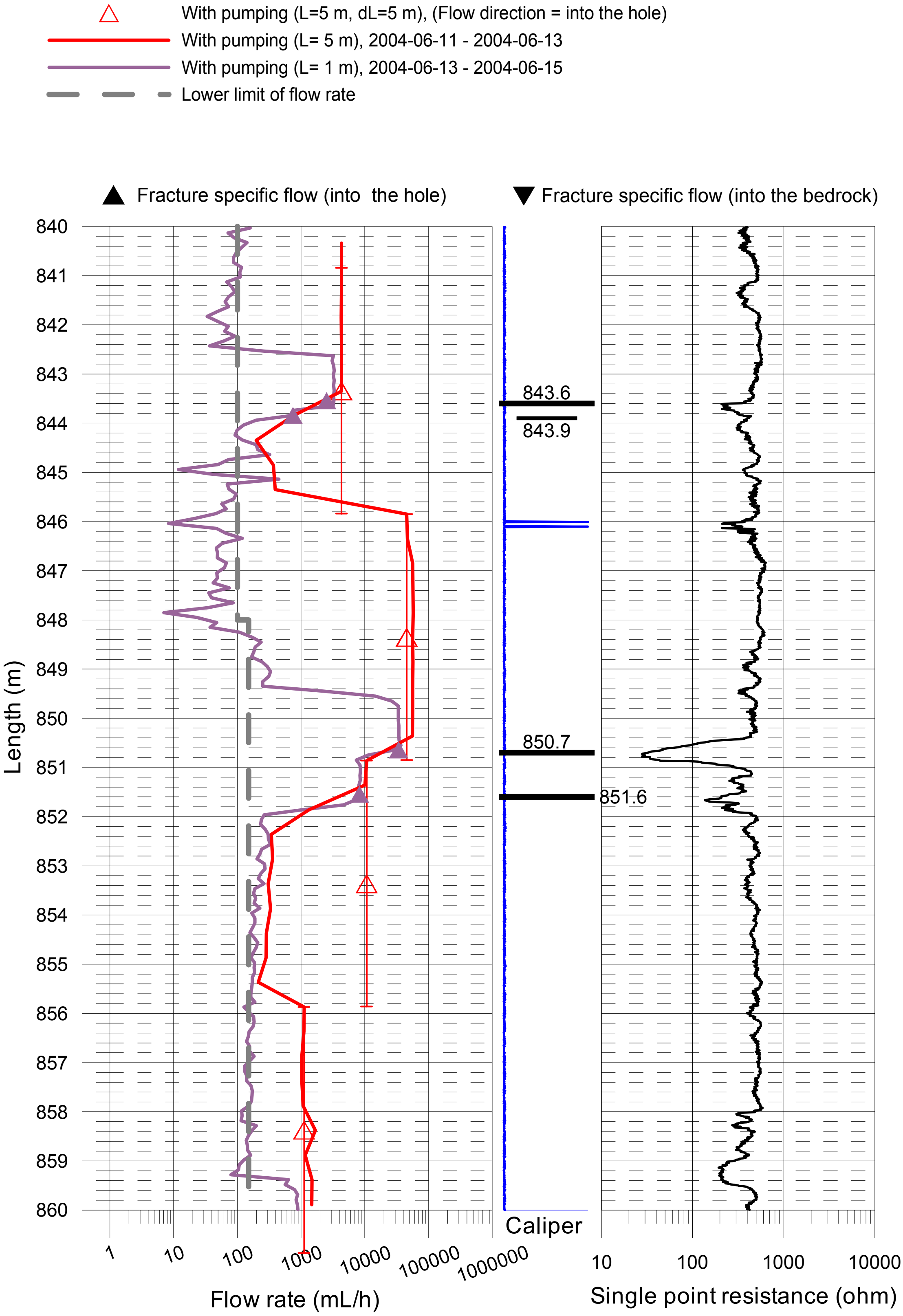
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

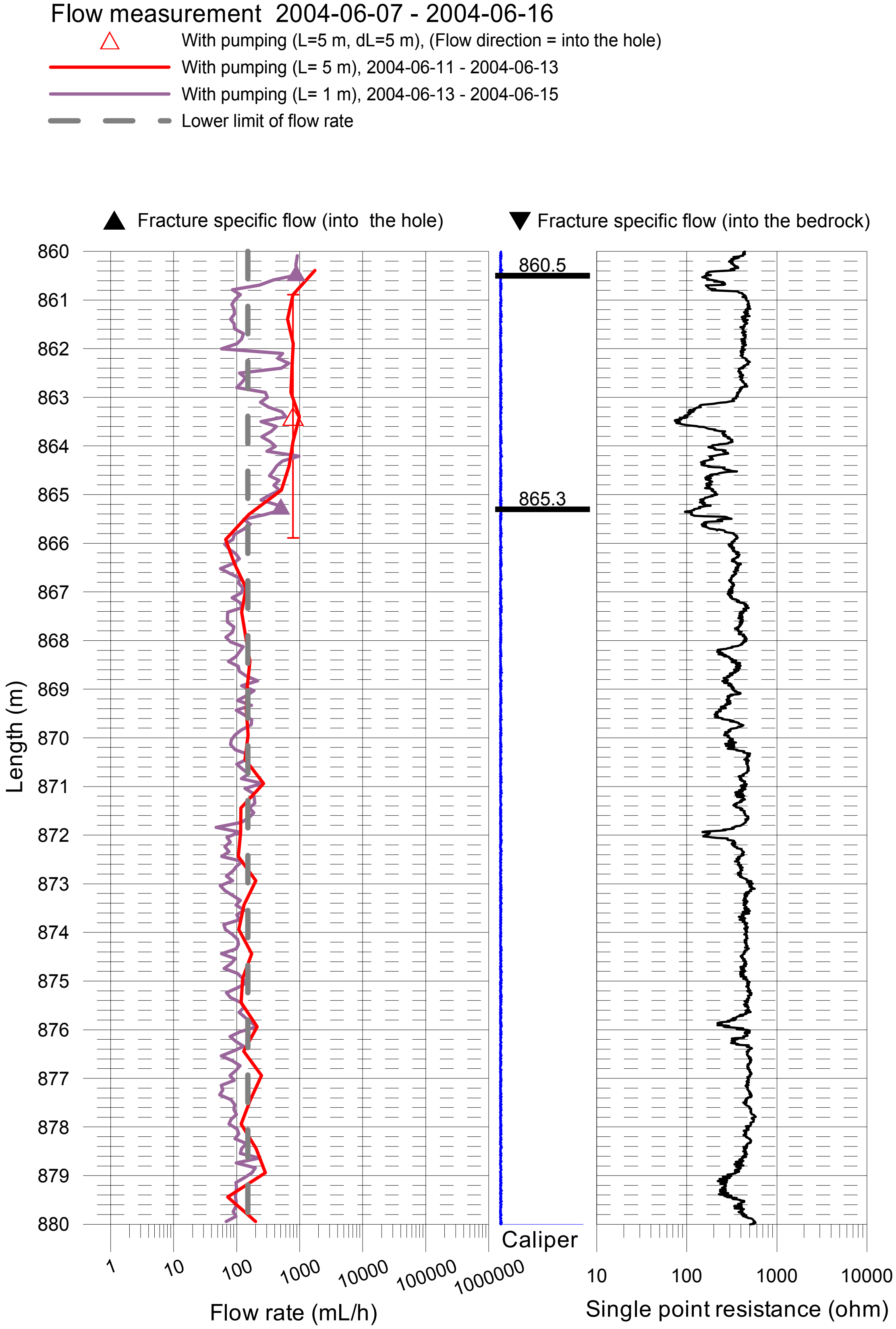


Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

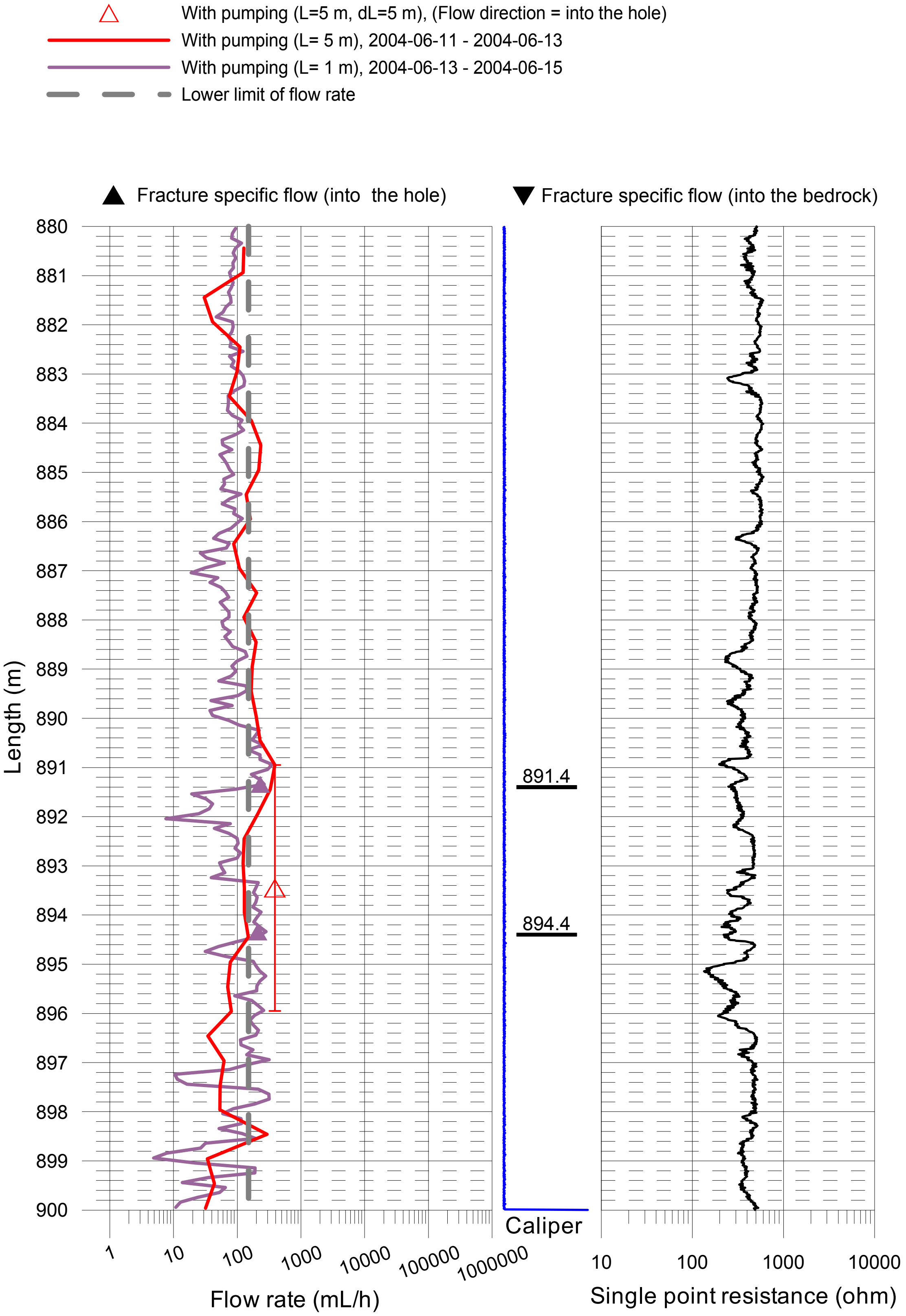


Ävrö, Borehole KAV04A



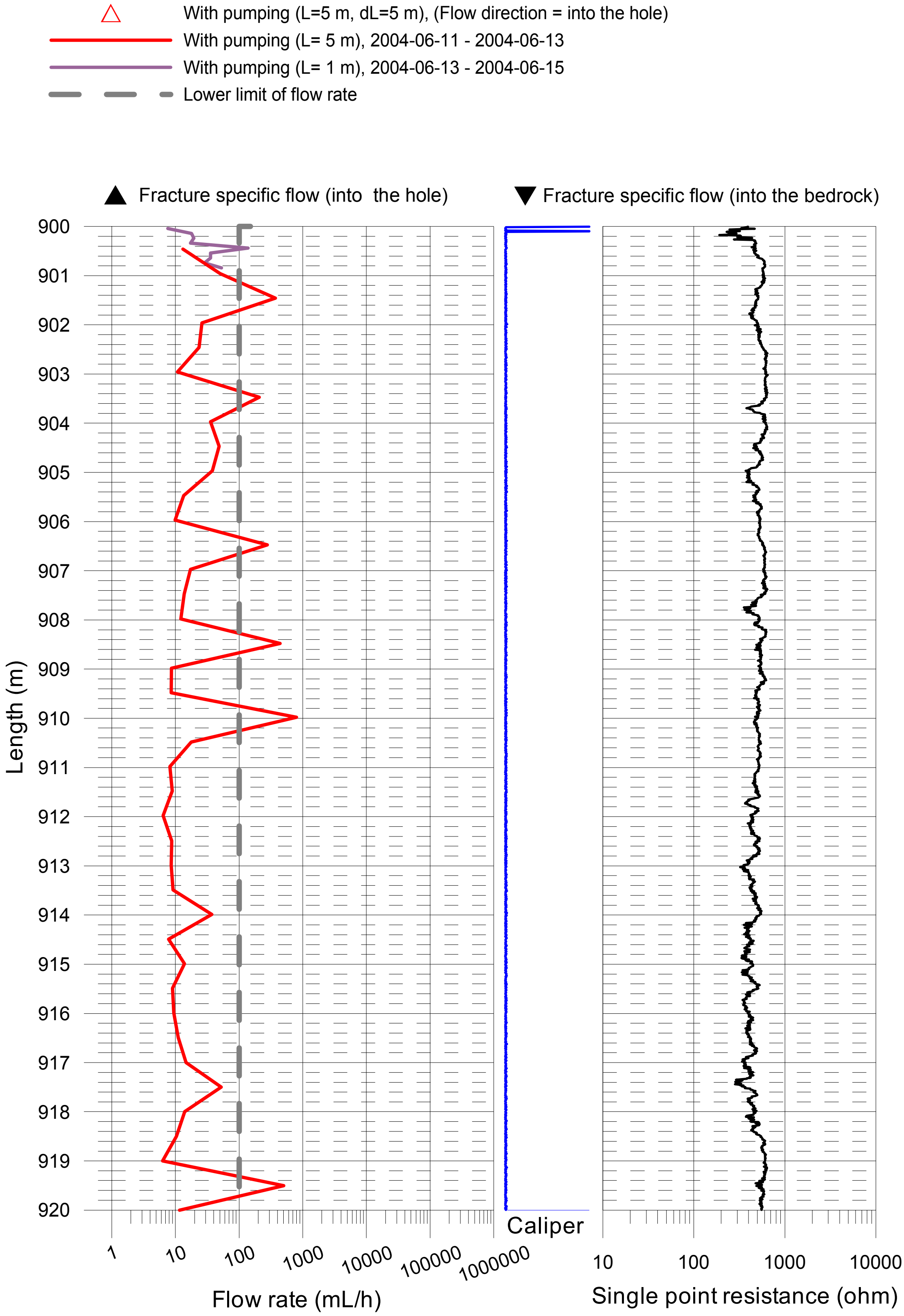
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



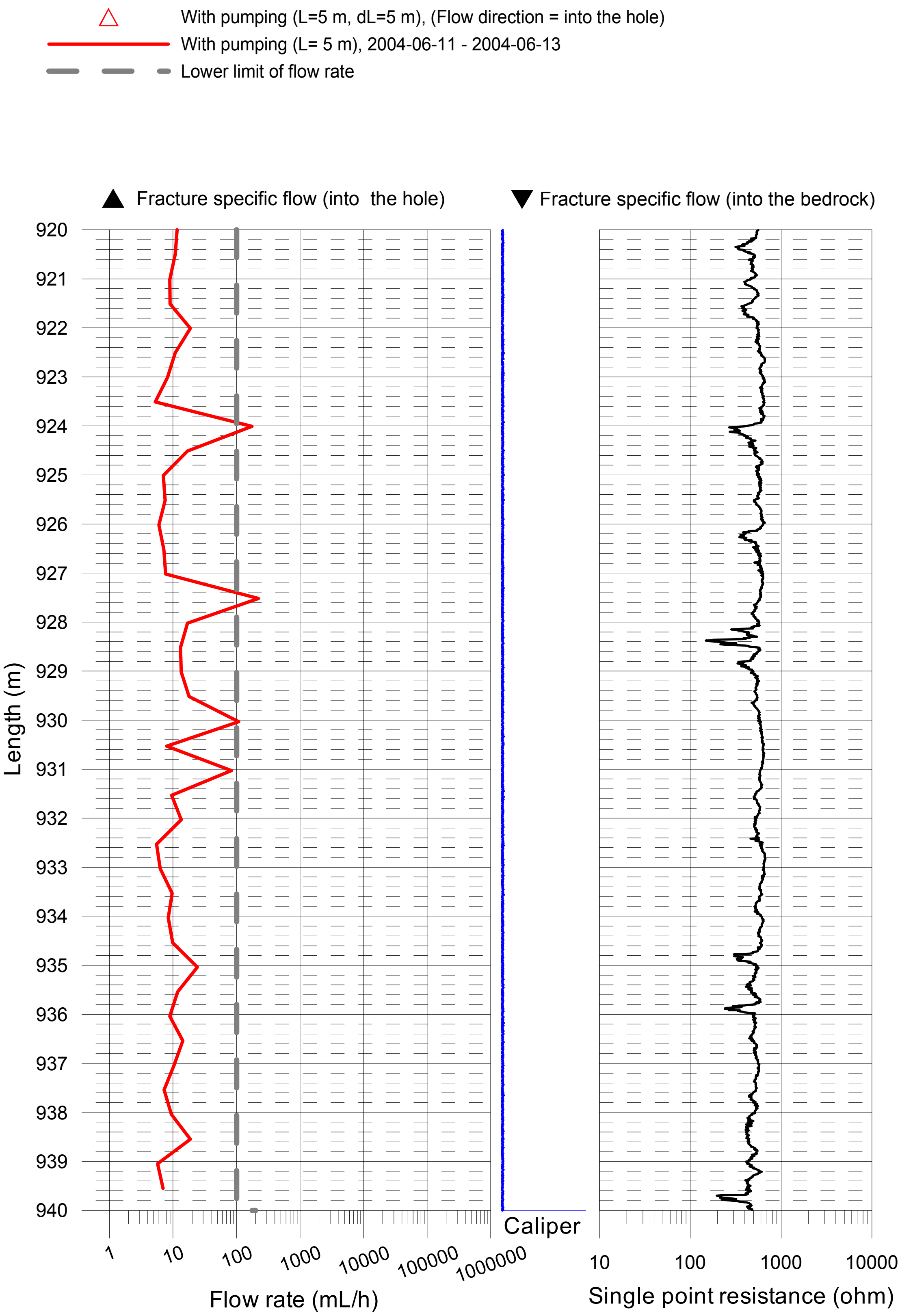
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



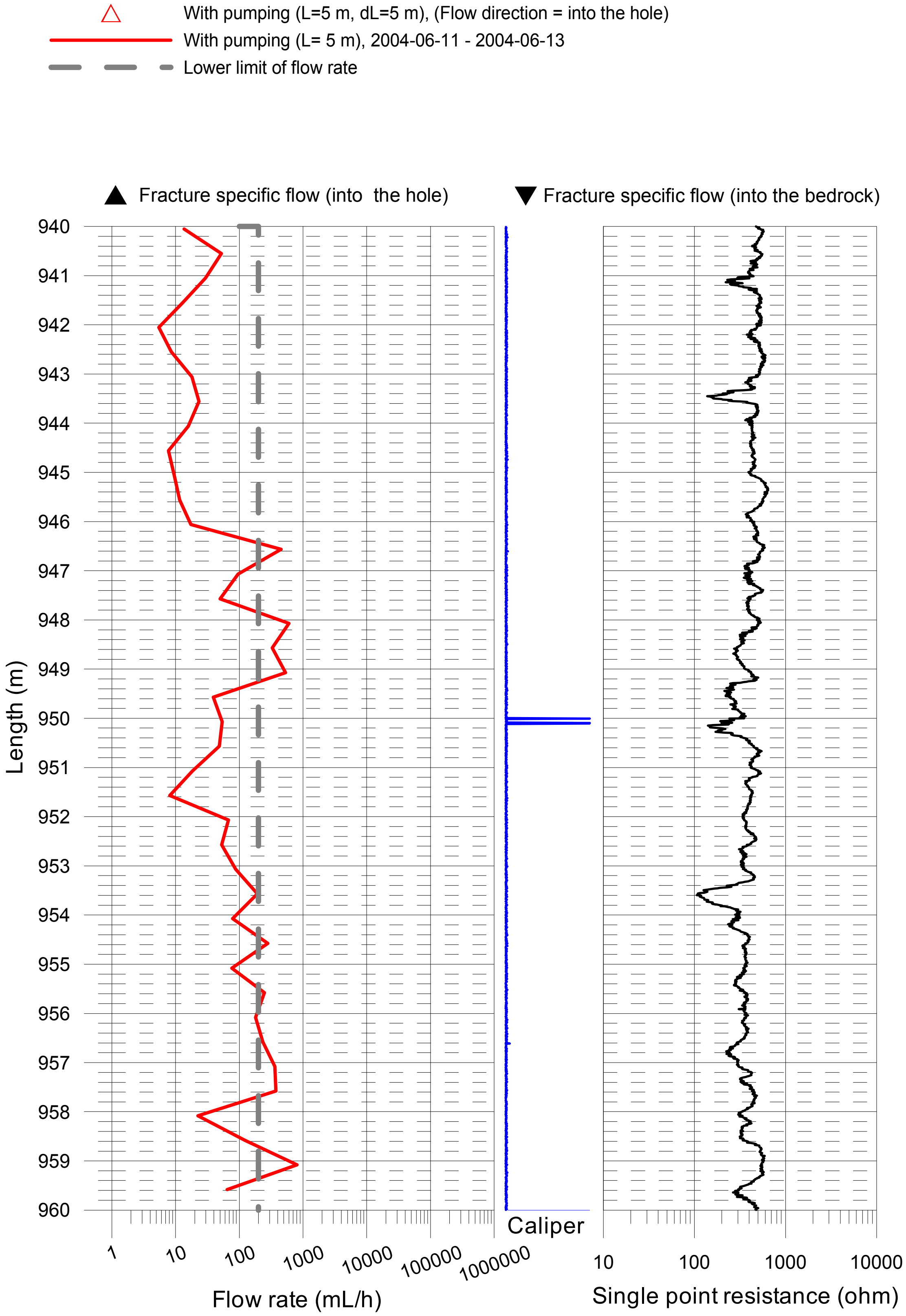
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



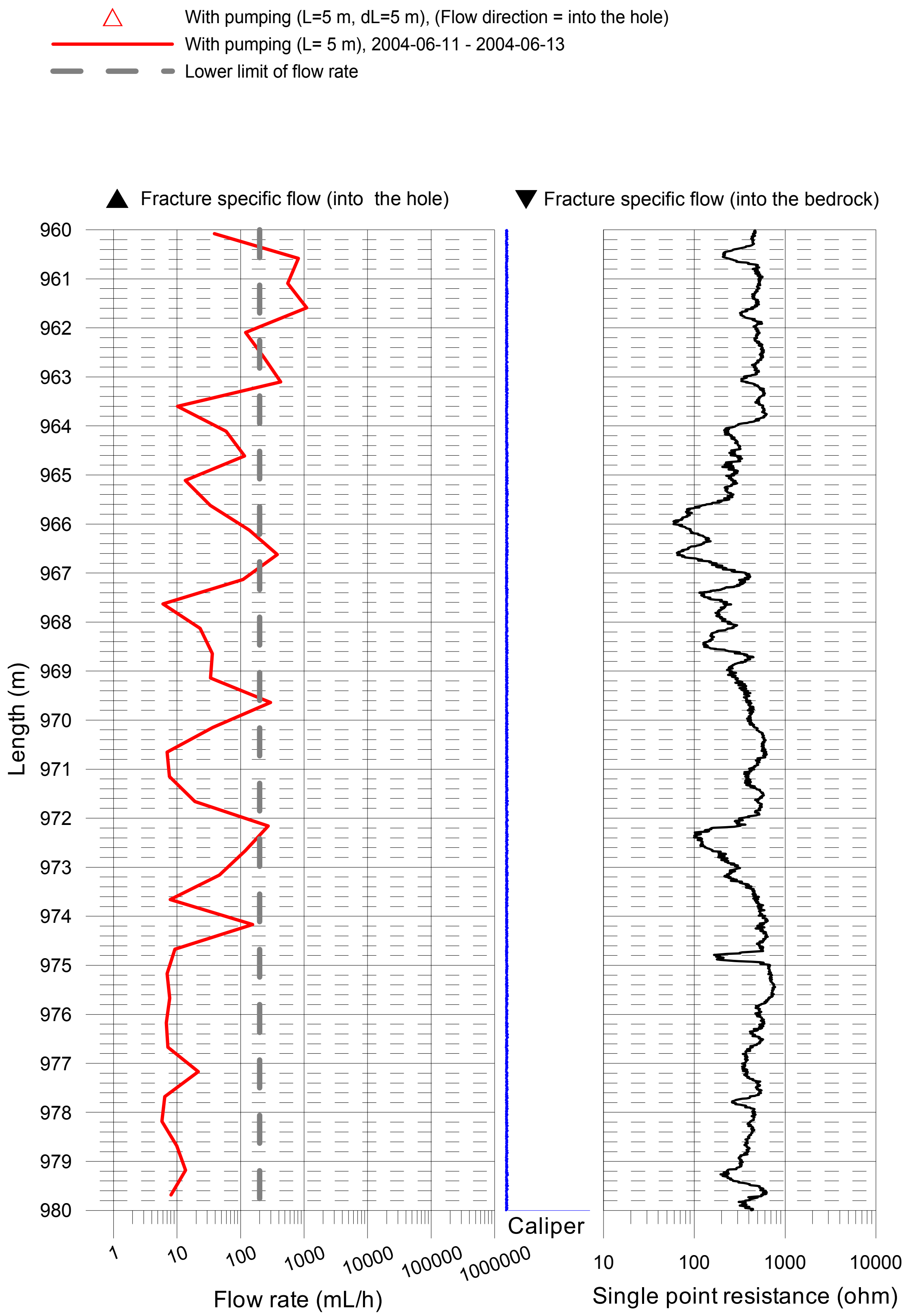
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16



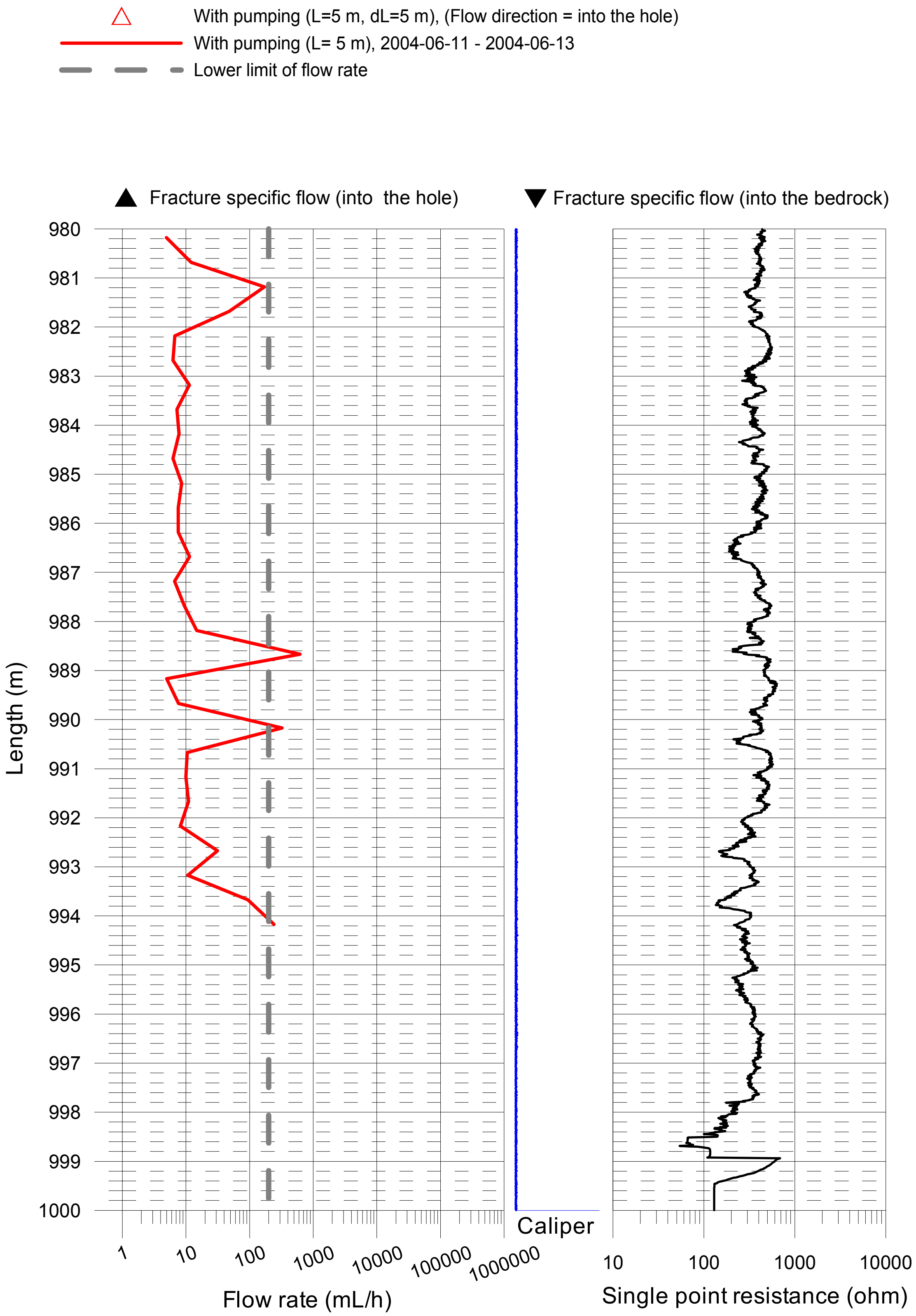
Ävrö, Borehole KAV04A

Flow measurement 2004-06-07 - 2004-06-16

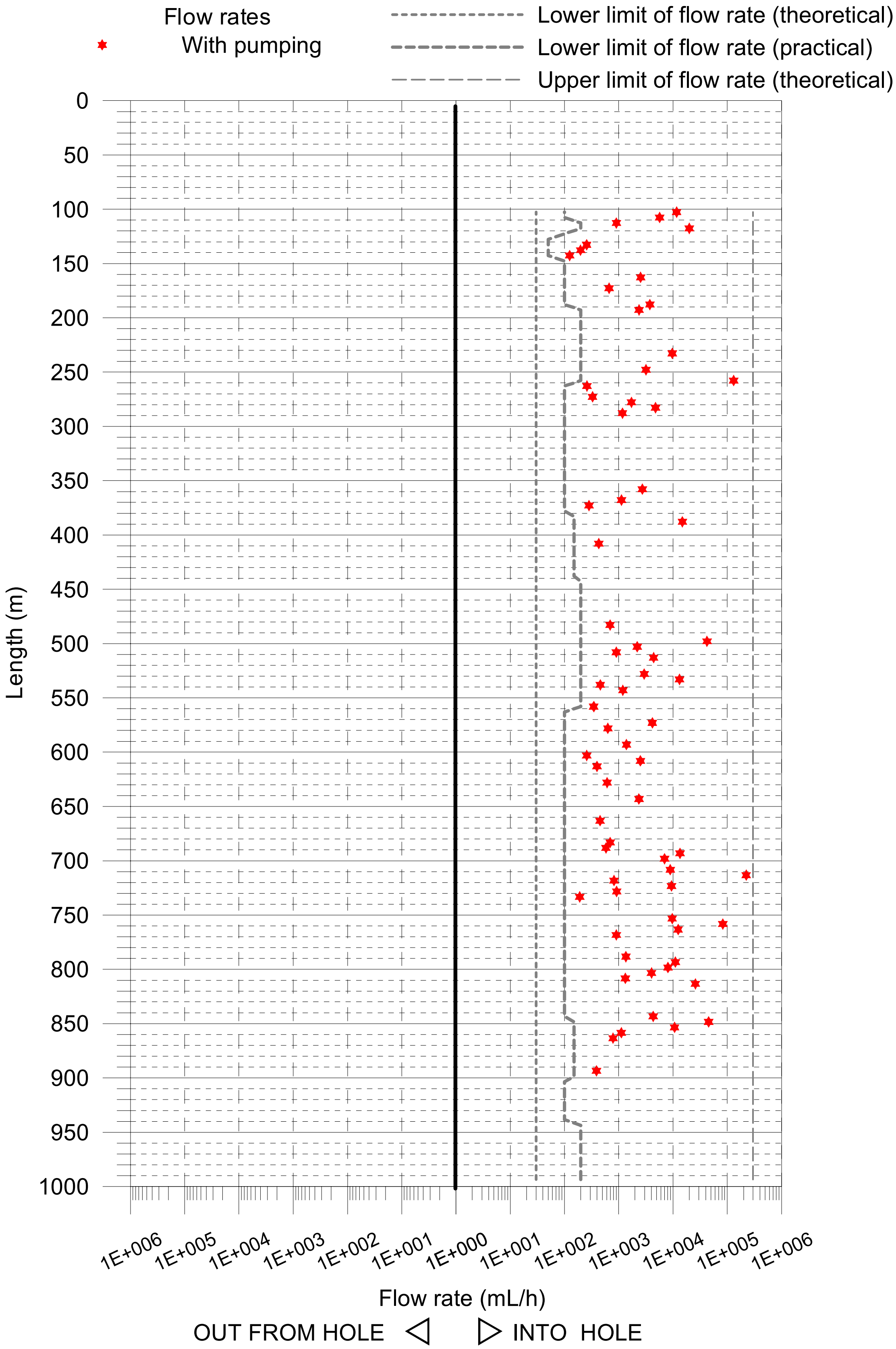


Ävrö, Borehole KAV04A

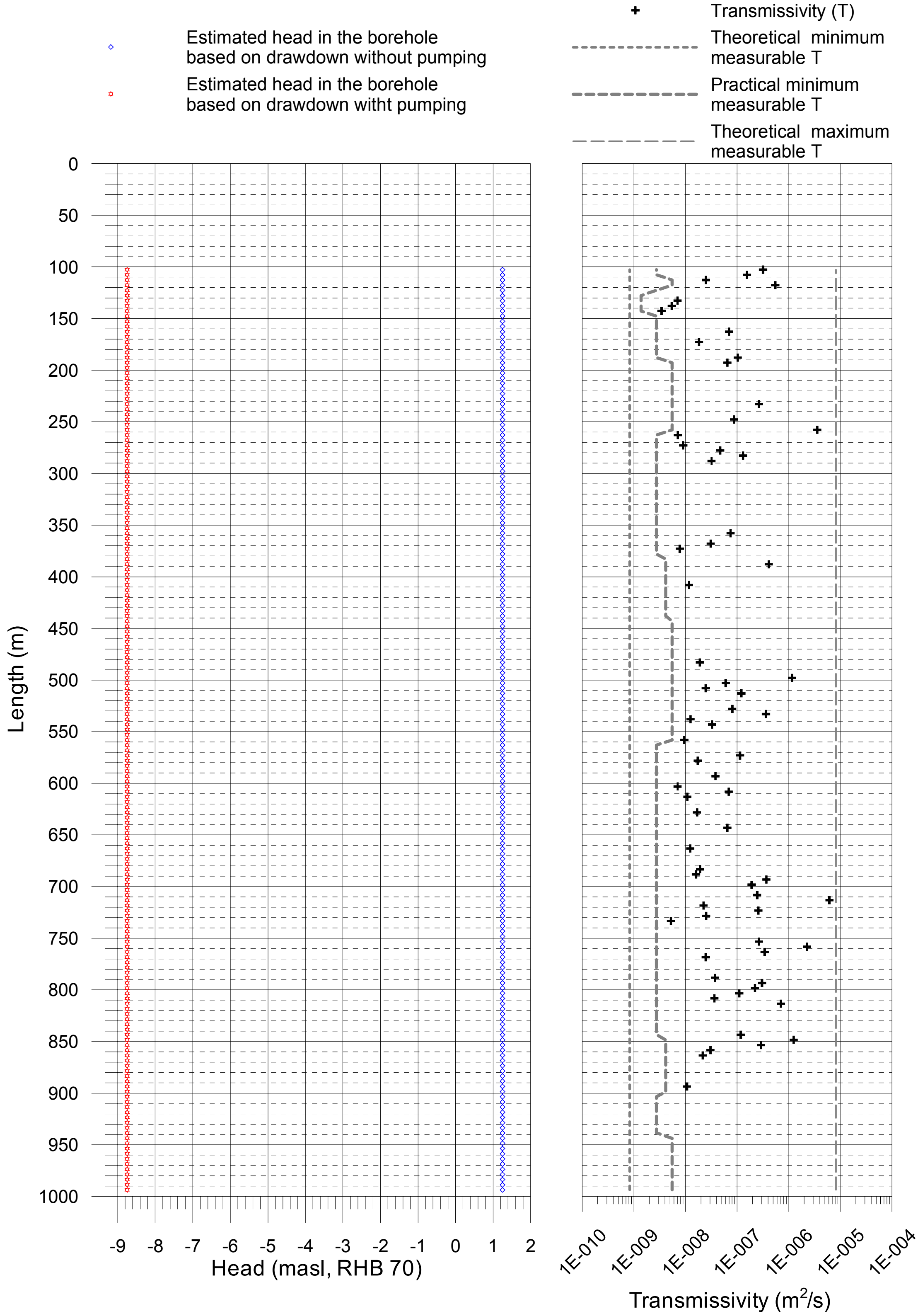
Flow measurement 2004-06-07 - 2004-06-16



Forsmark, Borehole KAV04A
Difference flow measurement 2004-06-07 - 2004-06-16
Length of section 5 m, depth increment 5 m

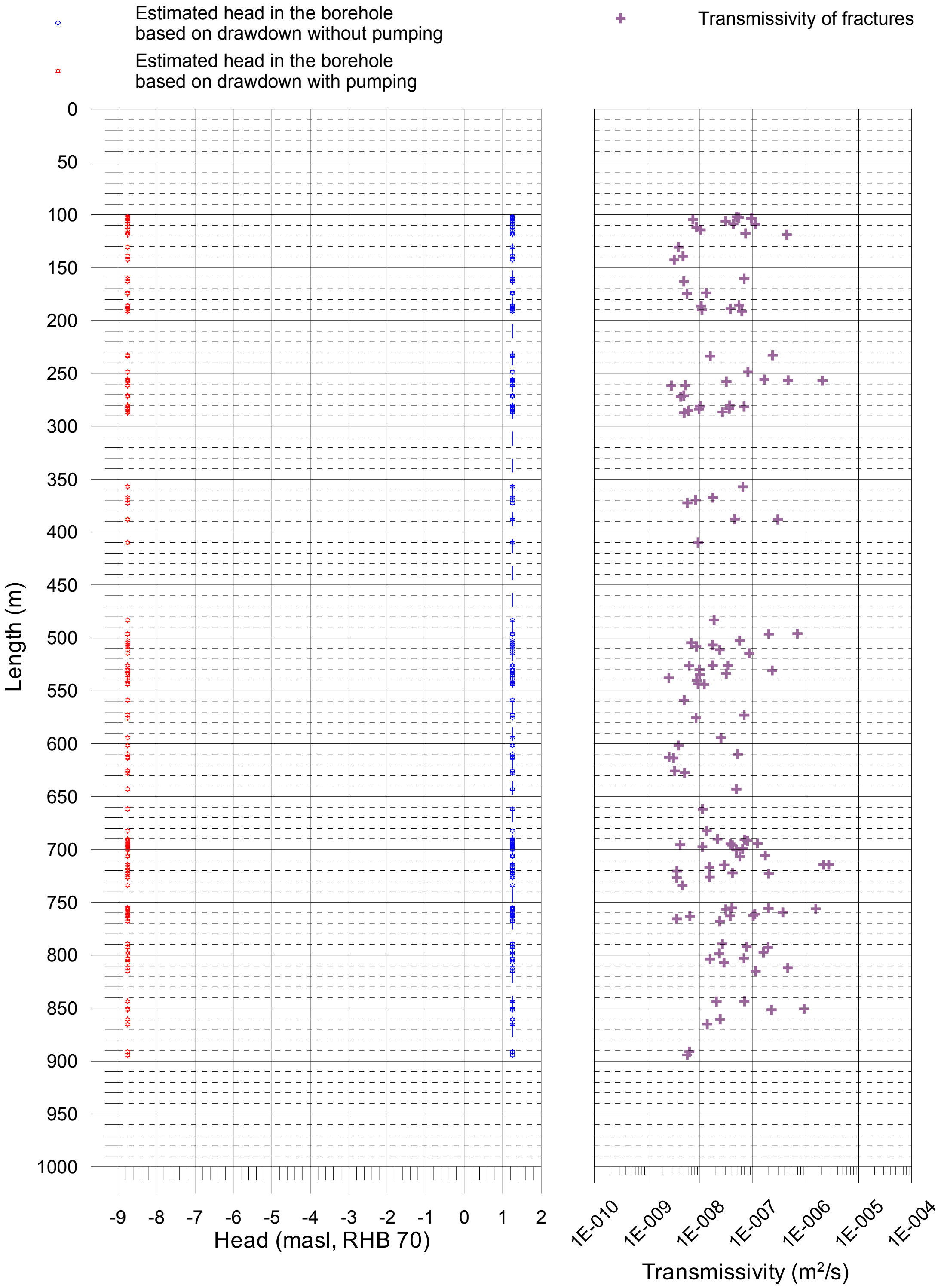


ÄVRÖ, Borehole KAV04A
Difference flow measurement
Length of section 5 m, length increment 5 m



Appendix 4

ÄVRÖ, Borehole KAV04A
Difference flow measurement
Fracture-specific results



Appendix 5

5. PFL-DIFFERENCE FLOW LOGGING - Basic test data													
Borehole	**Logged interval**		**Test**	**Date of**	**Time of**	**Date of**	**Time of**	**Date of**	**Time of**	L_w	**dL**	Q_{p1}	Q_{p2}
ID	Secup	Seclow	**type**	**test, start**	**test, start**	**flowl., start**	**flowl., start**	**test, stop**	**test, stop**				
	(m)	(m)	(1-6)	YYYYMMDD	hh:mm	YYYYMMDD	hh:mm	YYYYMMDD	hh:mm	(m)	(m)	(m^3/s)	(m^3/s)
KAV04A	**100.16**	**994.17**	**5A**	**20040610**	**12:29**	**20040611**	**12:29**	**20040615**	**23:50**	**5**	**5**	**1.77E-4**	

5. PFL-DIFFERENCE	FLOW LOGGING -	Basic test data									
t_{p1}	t_{p2}	t_{F1}	t_{F2}	h_0	h_1	h_2	s_1	s_2	**T**	Reference	Comments
									Entire hole		
(s)	(s)	(s)	(s)	(m)	(m)	(m)	(m)	(m)	(m2/s)	(-)	(-)
472860		**54300**		**1.25**	**-8.75**		**-10**		**1.75E-5**		

Appendix 6.1

DIFFERENCE FLOW LOGGING -Sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q_1 (m^3/s)	dh_1 (m)	TD (m^2/s)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	ECw_1 (S/m)	Tew_1 (C)	Comments
KAV04A	991.17	996.17	5	0.00E+00	4.65	-	8.24E-10	5.49E-09	8.24E-06	3.16	22.17	
KAV04A	986.18	991.18	5	0.00E+00	4.58	-	8.24E-10	5.49E-09	8.24E-06	3.16	22.17	
KAV04A	981.18	986.18	5	0.00E+00	4.52	-	8.24E-10	5.49E-09	8.24E-06	3.14	22.10	
KAV04A	976.17	981.17	5	0.00E+00	4.45	-	8.24E-10	5.49E-09	8.24E-06	3.14	21.99	
KAV04A	971.15	976.15	5	0.00E+00	4.38	-	8.24E-10	5.49E-09	8.24E-06	3.16	21.84	
KAV04A	966.12	971.12	5	0.00E+00	4.32	-	8.24E-10	5.49E-09	8.24E-06	3.17	21.76	
KAV04A	961.09	966.09	5	0.00E+00	4.23	-	8.24E-10	5.49E-09	8.24E-06	3.18	21.66	
KAV04A	956.08	961.08	5	0.00E+00	4.19	-	8.24E-10	5.49E-09	8.24E-06	3.19	21.59	
KAV04A	951.07	956.07	5	0.00E+00	4.10	-	8.24E-10	5.49E-09	8.24E-06	3.27	21.50	
KAV04A	946.06	951.06	5	0.00E+00	4.02	-	8.24E-10	5.49E-09	8.24E-06	3.23	21.45	
KAV04A	941.05	946.05	5	0.00E+00	3.92	-	8.24E-10	5.49E-09	8.24E-06	3.24	21.40	
KAV04A	936.04	941.04	5	0.00E+00	3.83	-	8.24E-10	2.75E-09	8.24E-06	3.27	21.28	
KAV04A	931.03	936.03	5	0.00E+00	3.78	-	8.24E-10	2.75E-09	8.24E-06	3.29	21.20	
KAV04A	926.02	931.02	5	0.00E+00	3.72	-	8.24E-10	2.75E-09	8.24E-06	3.32	21.09	
KAV04A	921.01	926.01	5	0.00E+00	3.61	-	8.24E-10	2.75E-09	8.24E-06	3.35	21.01	
KAV04A	915.99	920.99	5	0.00E+00	3.53	-	8.24E-10	2.75E-09	8.24E-06	3.38	20.95	
KAV04A	910.98	915.98	5	0.00E+00	3.45	-	8.24E-10	2.75E-09	8.24E-06	3.42	20.83	
KAV04A	905.97	910.97	5	0.00E+00	3.38	-	8.24E-10	2.75E-09	8.24E-06	3.45	20.76	
KAV04A	900.96	905.96	5	0.00E+00	3.30	-	8.24E-10	2.75E-09	8.24E-06	3.49	20.72	
KAV04A	895.96	900.96	5	0.00E+00	3.24	-	8.24E-10	4.12E-09	8.24E-06	3.54	20.58	
KAV04A	890.95	895.95	5	1.08E-07	3.14	1.07E-08	8.24E-10	4.12E-09	8.24E-06	3.58	20.46	
KAV04A	885.95	890.95	5	0.00E+00	3.04	-	8.24E-10	4.12E-09	8.24E-06	3.62	20.39	
KAV04A	880.94	885.94	5	0.00E+00	2.93	-	8.24E-10	4.12E-09	8.24E-06	3.65	20.30	
KAV04A	875.94	880.94	5	0.00E+00	2.85	-	8.24E-10	4.12E-09	8.24E-06	3.66	20.25	
KAV04A	870.94	875.94	5	0.00E+00	2.74	-	8.24E-10	4.12E-09	8.24E-06	3.63	20.13	
KAV04A	865.92	870.92	5	0.00E+00	2.65	-	8.24E-10	4.12E-09	8.24E-06	3.63	20.13	
KAV04A	860.89	865.89	5	2.19E-07	2.61	2.16E-08	8.24E-10	4.12E-09	8.24E-06	3.63	20.13	
KAV04A	855.87	860.87	5	3.09E-07	2.57	3.06E-08	8.24E-10	4.12E-09	8.24E-06	3.75	19.89	
KAV04A	850.86	855.86	5	2.97E-06	2.47	2.93E-07	8.24E-10	4.12E-09	8.24E-06	3.56	19.84	
KAV04A	845.85	850.85	5	1.26E-05	2.39	1.25E-06	8.24E-10	4.12E-09	8.24E-06	3.78	19.79	

Appendix 6.2

DIFFERENCE FLOW LOGGING -Sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q_1 (m^3/s)	dh_1 (m)	TD (m^2/s)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	ECw_1 (S/m)	Tew_1 (C)	Comments
KAV04A	840.84	845.84	5	1.20E-06	2.24	1.18E-07	8.24E-10	2.75E-09	8.24E-06	3.87	19.75	
KAV04A	835.84	840.84	5	0.00E+00	2.11	-	8.24E-10	2.75E-09	8.24E-06	4.29	19.71	
KAV04A	830.83	835.83	5	0.00E+00	2.02	-	8.24E-10	2.75E-09	8.24E-06	4.31	19.66	
KAV04A	825.83	830.83	5	0.00E+00	1.92	-	8.24E-10	2.75E-09	8.24E-06	4.31	19.59	
KAV04A	820.82	825.82	5	0.00E+00	1.82	-	8.24E-10	2.75E-09	8.24E-06	4.34	19.54	
KAV04A	815.82	820.82	5	0.00E+00	1.73	-	8.24E-10	2.75E-09	8.24E-06	4.34	19.46	
KAV04A	810.82	815.82	5	7.17E-06	1.60	7.10E-07	8.24E-10	2.75E-09	8.24E-06	3.88	19.36	
KAV04A	805.81	810.81	5	3.68E-07	1.50	3.64E-08	8.24E-10	2.75E-09	8.24E-06	3.97	19.29	
KAV04A	800.81	805.81	5	1.12E-06	1.41	1.10E-07	8.24E-10	2.75E-09	8.24E-06	3.93	19.23	
KAV04A	795.8	800.80	5	2.25E-06	1.34	2.22E-07	8.24E-10	2.75E-09	8.24E-06	3.86	19.17	
KAV04A	790.8	795.80	5	3.07E-06	1.20	3.04E-07	8.24E-10	2.75E-09	8.24E-06	3.86	19.10	
KAV04A	785.8	790.80	5	3.76E-07	1.11	3.72E-08	8.24E-10	2.75E-09	8.24E-06	3.90	19.03	
KAV04A	780.79	785.79	5	0.00E+00	1.02	-	8.24E-10	2.75E-09	8.24E-06	4.05	19.00	
KAV04A	775.79	780.79	5	0.00E+00	0.89	-	8.24E-10	2.75E-09	8.24E-06	4.06	18.93	
KAV04A	770.78	775.78	5	0.00E+00	0.77	-	8.24E-10	2.75E-09	8.24E-06	4.07	18.87	
KAV04A	765.78	770.78	5	2.51E-07	0.69	2.48E-08	8.24E-10	2.75E-09	8.24E-06	3.97	18.79	
KAV04A	760.78	765.78	5	3.46E-06	0.61	3.42E-07	8.24E-10	2.75E-09	8.24E-06	3.83	18.70	
KAV04A	755.77	760.77	5	2.30E-05	0.53	2.27E-06	8.24E-10	2.75E-09	8.24E-06	3.60	18.51	
KAV04A	750.76	755.76	5	2.68E-06	0.45	2.65E-07	8.24E-10	2.75E-09	8.24E-06	3.66	18.50	
KAV04A	745.75	750.75	5	0.00E+00	0.37	-	8.24E-10	2.75E-09	8.24E-06	3.66	18.50	
KAV04A	740.74	745.74	5	0.00E+00	0.24	-	8.24E-10	2.75E-09	8.24E-06	3.73	18.49	
KAV04A	735.73	740.73	5	0.00E+00	0.16	-	8.24E-10	2.75E-09	8.24E-06	3.72	18.45	
KAV04A	730.72	735.72	5	5.31E-08	0.05	5.25E-09	8.24E-10	2.75E-09	8.24E-06	3.70	18.39	
KAV04A	725.72	730.72	5	2.54E-07	-0.03	2.52E-08	8.24E-10	2.75E-09	8.24E-06	3.65	18.33	
KAV04A	720.73	725.73	5	2.61E-06	-0.12	2.58E-07	8.24E-10	2.75E-09	8.24E-06	3.65	18.33	
KAV04A	715.72	720.72	5	2.28E-07	-0.21	2.25E-08	8.24E-10	2.75E-09	8.24E-06	3.64	18.20	
KAV04A	710.71	715.71	5	6.22E-05	-0.29	6.15E-06	8.24E-10	2.75E-09	8.24E-06	2.86	17.92	
KAV04A	705.7	710.70	5	2.48E-06	-0.35	2.46E-07	8.24E-10	2.75E-09	8.24E-06	2.81	17.90	
KAV04A	700.7	705.70	5	0.00E+00	-0.45	-	8.24E-10	2.75E-09	8.24E-06	2.81	17.88	
KAV04A	695.69	700.69	5	1.94E-06	-0.49	1.92E-07	8.24E-10	2.75E-09	8.24E-06	2.82	17.86	
KAV04A	690.68	695.68	5	3.74E-06	-0.58	3.70E-07	8.24E-10	2.75E-09	8.24E-06	2.83	17.82	

Appendix 6.3

DIFFERENCE FLOW LOGGING -Sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q_1 (m^3/s)	dh_1 (m)	TD (m^2/s)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	ECw_1 (S/m)	Tew_1 (C)	Comments
KAV04A	685.68	690.68	5	1.61E-07	-0.64	1.60E-08	8.24E-10	2.75E-09	8.24E-06	3.01	17.81	
KAV04A	680.67	685.67	5	1.93E-07	-0.72	1.91E-08	8.24E-10	2.75E-09	8.24E-06	2.98	17.80	
KAV04A	675.67	680.67	5	0.00E+00	-0.82	-	8.24E-10	2.75E-09	8.24E-06	3.09	17.80	
KAV04A	670.66	675.66	5	0.00E+00	-0.94	-	8.24E-10	2.75E-09	8.24E-06	3.08	17.75	
KAV04A	665.66	670.66	5	0.00E+00	-0.99	-	8.24E-10	2.75E-09	8.24E-06	3.07	17.74	
KAV04A	660.65	665.65	5	1.26E-07	-1.03	1.24E-08	8.24E-10	2.75E-09	8.24E-06	3.03	17.69	
KAV04A	655.64	660.64	5	0.00E+00	-1.07	-	8.24E-10	2.75E-09	8.24E-06	3.07	17.66	
KAV04A	650.63	655.63	5	0.00E+00	-1.14	-	8.24E-10	2.75E-09	8.24E-06	3.07	17.64	
KAV04A	645.62	650.62	5	0.00E+00	-1.23	-	8.24E-10	2.75E-09	8.24E-06	3.08	17.58	
KAV04A	640.61	645.61	5	6.54E-07	-1.36	6.47E-08	8.24E-10	2.75E-09	8.24E-06	2.89	17.51	
KAV04A	635.6	640.60	5	0.00E+00	-1.41	-	8.24E-10	2.75E-09	8.24E-06	3.10	17.49	
KAV04A	630.6	635.60	5	0.00E+00	-1.44	-	8.24E-10	2.75E-09	8.24E-06	3.09	17.44	
KAV04A	625.59	630.59	5	1.70E-07	-1.46	1.68E-08	8.24E-10	2.75E-09	8.24E-06	2.99	17.37	
KAV04A	620.58	625.58	5	0.00E+00	-1.55	-	8.24E-10	2.75E-09	8.24E-06	3.06	17.31	
KAV04A	615.57	620.57	5	0.00E+00	-1.66	-	8.24E-10	2.75E-09	8.24E-06	3.10	17.26	
KAV04A	610.57	615.57	5	1.10E-07	-1.76	1.09E-08	8.24E-10	2.75E-09	8.24E-06	3.10	17.26	
KAV04A	605.57	610.57	5	6.98E-07	-1.79	6.91E-08	8.24E-10	2.75E-09	8.24E-06	3.08	17.19	
KAV04A	600.57	605.57	5	7.14E-08	-1.85	7.06E-09	8.24E-10	2.75E-09	8.24E-06	2.87	17.09	
KAV04A	595.56	600.56	5	0.00E+00	-1.91	-	8.24E-10	2.75E-09	8.24E-06	3.08	17.02	
KAV04A	590.56	595.56	5	3.86E-07	-2.04	3.81E-08	8.24E-10	2.75E-09	8.24E-06	2.89	16.94	
KAV04A	585.56	590.56	5	0.00E+00	-2.13	-	8.24E-10	2.75E-09	8.24E-06	2.89	16.94	
KAV04A	580.55	585.55	5	0.00E+00	-2.17	-	8.24E-10	2.75E-09	8.24E-06	3.09	16.88	
KAV04A	575.54	580.54	5	1.75E-07	-2.23	1.73E-08	8.24E-10	2.75E-09	8.24E-06	2.99	16.80	
KAV04A	570.54	575.54	5	1.16E-06	-2.26	1.14E-07	8.24E-10	2.75E-09	8.24E-06	2.83	16.67	
KAV04A	565.53	570.53	5	0.00E+00	-2.32	-	8.24E-10	2.75E-09	8.24E-06	3.08	16.67	
KAV04A	560.52	565.52	5	0.00E+00	-2.45	-	8.24E-10	2.75E-09	8.24E-06	3.06	16.62	
KAV04A	555.51	560.51	5	9.61E-08	-2.52	9.51E-09	8.24E-10	5.49E-09	8.24E-06	3.03	16.54	
KAV04A	550.5	555.50	5	0.00E+00	-2.57	-	8.24E-10	5.49E-09	8.24E-06	3.07	16.48	
KAV04A	545.49	550.49	5	0.00E+00	-2.61	-	8.24E-10	5.49E-09	8.24E-06	3.07	16.41	
KAV04A	540.49	545.49	5	3.31E-07	-2.71	3.27E-08	8.24E-10	5.49E-09	8.24E-06	2.90	16.32	
KAV04A	535.48	540.48	5	1.27E-07	-2.77	1.25E-08	8.24E-10	5.49E-09	8.24E-06	3.01	16.27	

DIFFERENCE FLOW LOGGING -Sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q_1 (m^3/s)	dh_1 (m)	TD (m^2/s)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	ECw_1 (S/m)	Tew_1 (C)	Comments
KAV04A	530.47	535.47	5	3.66E-06	-2.88	3.35E-07	8.24E-10	5.49E-09	8.24E-06	2.65	16.05	
KAV04A	525.45	530.45	5	8.19E-07	-2.96	8.10E-08	8.24E-10	5.49E-09	8.24E-06	2.77	16.03	
KAV04A	520.44	525.44	5	0.00E+00	-2.98	-	8.24E-10	5.49E-09	8.24E-06	2.99	16.03	
KAV04A	515.43	520.43	5	0.00E+00	-3.02	-	8.24E-10	5.49E-09	8.24E-06	3.03	15.99	
KAV04A	510.43	515.43	5	1.22E-06	-3.10	1.21E-07	8.24E-10	5.49E-09	8.24E-06	2.66	15.85	
KAV04A	505.43	510.43	5	2.51E-07	-3.19	2.48E-08	8.24E-10	5.49E-09	8.24E-06	2.66	15.85	
KAV04A	500.43	505.43	5	6.10E-07	-3.26	6.03E-08	8.24E-10	5.49E-09	8.24E-06	2.71	15.73	
KAV04A	495.43	500.43	5	1.18E-05	-3.31	1.17E-06	8.24E-10	5.49E-09	8.24E-06	2.19	15.27	
KAV04A	490.43	495.43	5	0.00E+00	-3.37	-	8.24E-10	5.49E-09	8.24E-06	2.93	15.55	
KAV04A	485.43	490.43	5	0.00E+00	-3.42	-	8.24E-10	5.49E-09	8.24E-06	2.80	15.49	
KAV04A	480.43	485.43	5	1.92E-07	-3.55	1.90E-08	8.24E-10	5.49E-09	8.24E-06	2.62	15.43	
KAV04A	475.43	480.43	5	0.00E+00	-3.60	-	8.24E-10	5.49E-09	8.24E-06	2.81	15.39	
KAV04A	470.43	475.43	5	0.00E+00	-3.61	-	8.24E-10	5.49E-09	8.24E-06	2.83	15.33	
KAV04A	465.44	470.44	5	0.00E+00	-3.68	-	8.24E-10	5.49E-09	8.24E-06	2.83	15.33	
KAV04A	460.44	465.44	5	0.00E+00	-3.83	-	8.24E-10	5.49E-09	8.24E-06	2.76	15.29	
KAV04A	455.44	460.44	5	0.00E+00	-3.88	-	8.24E-10	5.49E-09	8.24E-06	2.80	15.22	
KAV04A	450.44	455.44	5	0.00E+00	-3.91	-	8.24E-10	5.49E-09	8.24E-06	2.40	15.16	
KAV04A	445.44	450.44	5	0.00E+00	-3.96	-	8.24E-10	5.49E-09	8.24E-06	2.85	15.11	
KAV04A	440.44	445.44	5	0.00E+00	-4.06	-	8.24E-10	5.49E-09	8.24E-06	2.81	15.05	
KAV04A	435.44	440.44	5	0.00E+00	-4.08	-	8.24E-10	4.12E-09	8.24E-06	2.84	14.98	
KAV04A	430.44	435.44	5	0.00E+00	-4.14	-	8.24E-10	4.12E-09	8.24E-06	2.83	14.93	
KAV04A	425.44	430.44	5	0.00E+00	-4.25	-	8.24E-10	4.12E-09	8.24E-06	2.73	14.86	
KAV04A	420.44	425.44	5	0.00E+00	-4.30	-	8.24E-10	4.12E-09	8.24E-06	2.80	14.80	
KAV04A	415.44	420.44	5	0.00E+00	-4.34	-	8.24E-10	4.12E-09	8.24E-06	2.81	14.73	
KAV04A	410.43	415.43	5	0.00E+00	-4.41	-	8.24E-10	4.12E-09	8.24E-06	2.80	14.61	
KAV04A	405.42	410.42	5	1.19E-07	-4.49	1.18E-08	8.24E-10	4.12E-09	8.24E-06	2.72	14.53	
KAV04A	400.42	405.42	5	0.00E+00	-4.58	-	8.24E-10	4.12E-09	8.24E-06	2.80	14.48	
KAV04A	395.41	400.41	5	0.00E+00	-4.61	-	8.24E-10	4.12E-09	8.24E-06	2.83	14.38	
KAV04A	390.4	395.40	5	0.00E+00	-4.69	-	8.24E-10	4.12E-09	8.24E-06	2.82	14.34	
KAV04A	385.39	390.39	5	4.15E-06	-4.77	4.10E-07	8.24E-10	4.12E-09	8.24E-06	2.25	14.10	
KAV04A	380.39	385.39	5	0.00E+00	-4.83	-	8.24E-10	4.12E-09	8.24E-06	2.79	14.18	

Appendix 6.5

DIFFERENCE FLOW LOGGING -Sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q_1 (m^3/s)	dh_1 (m)	TD (m^2/s)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	ECw_1 (S/m)	Tew_1 (C)	Comments
KAV04A	375.38	380.38	5	0.00E+00	-4.86	-	8.24E-10	2.75E-09	8.24E-06	2.73	14.12	
KAV04A	370.38	375.38	5	7.86E-08	-4.98	7.78E-09	8.24E-10	2.75E-09	8.24E-06	2.55	14.04	
KAV04A	365.38	370.38	5	3.12E-07	-5.04	3.09E-08	8.24E-10	2.75E-09	8.24E-06	2.63	13.96	
KAV04A	360.38	365.38	5	0.00E+00	-5.07	-	8.24E-10	2.75E-09	8.24E-06	2.81	13.91	
KAV04A	355.37	360.37	5	7.56E-07	-5.13	7.47E-08	8.24E-10	2.75E-09	8.24E-06	2.43	13.78	
KAV04A	350.37	355.37	5	0.00E+00	-5.23	-	8.24E-10	2.75E-09	8.24E-06	2.69	13.77	
KAV04A	345.37	350.37	5	0.00E+00	-5.26	-	8.24E-10	2.75E-09	8.24E-06	2.80	13.71	
KAV04A	340.36	345.36	5	0.00E+00	-5.32	-	8.24E-10	2.75E-09	8.24E-06	2.79	13.66	
KAV04A	335.36	340.36	5	0.00E+00	-5.39	-	8.24E-10	2.75E-09	8.24E-06	2.72	13.60	
KAV04A	330.35	335.35	5	0.00E+00	-5.47	-	8.24E-10	2.75E-09	8.24E-06	2.81	13.55	
KAV04A	325.35	330.35	5	0.00E+00	-5.49	-	8.24E-10	2.75E-09	8.24E-06	2.80	13.49	
KAV04A	320.34	325.34	5	0.00E+00	-5.56	-	8.24E-10	2.75E-09	8.24E-06	2.78	13.41	
KAV04A	315.34	320.34	5	0.00E+00	-5.65	-	8.24E-10	2.75E-09	8.24E-06	2.79	13.35	
KAV04A	310.33	315.33	5	0.00E+00	-5.70	-	8.24E-10	2.75E-09	8.24E-06	2.78	13.28	
KAV04A	305.33	310.33	5	0.00E+00	-5.75	-	8.24E-10	2.75E-09	8.24E-06	2.73	13.23	
KAV04A	300.33	305.33	5	0.00E+00	-5.81	-	8.24E-10	2.75E-09	8.24E-06	2.75	13.17	
KAV04A	295.32	300.32	5	0.00E+00	-5.89	-	8.24E-10	2.75E-09	8.24E-06	2.81	13.09	
KAV04A	290.32	295.32	5	0.00E+00	-6.01	-	8.24E-10	2.75E-09	8.24E-06	2.82	13.03	
KAV04A	285.31	290.31	5	3.25E-07	-6.04	3.21E-08	8.24E-10	2.75E-09	8.24E-06	2.50	12.95	
KAV04A	280.3	285.30	5	1.32E-06	-6.08	1.31E-07	8.24E-10	2.75E-09	8.24E-06	2.26	12.79	
KAV04A	275.3	280.30	5	4.76E-07	-6.16	4.71E-08	8.24E-10	2.75E-09	8.24E-06	2.41	12.79	
KAV04A	270.29	275.29	5	9.14E-08	-6.25	9.04E-09	8.24E-10	2.75E-09	8.24E-06	2.66	12.75	
KAV04A	265.29	270.29	5	0.00E+00	-6.28	-	8.24E-10	2.75E-09	8.24E-06	2.79	12.69	
KAV04A	260.28	265.28	5	7.22E-08	-6.32	7.14E-09	8.24E-10	2.75E-09	8.24E-06	2.75	12.62	
KAV04A	255.28	260.28	5	3.64E-05	-6.39	3.60E-06	8.24E-10	5.49E-09	8.24E-06	1.82	11.91	
KAV04A	250.29	255.29	5	0.00E+00	-6.48	-	8.24E-10	5.49E-09	8.24E-06	1.82	11.91	
KAV04A	245.29	250.29	5	8.83E-07	-6.53	8.73E-08	8.24E-10	5.49E-09	8.24E-06	2.24	12.12	
KAV04A	240.29	245.29	5	0.00E+00	-6.57	-	8.24E-10	5.49E-09	8.24E-06	1.96	12.07	
KAV04A	235.29	240.29	5	0.00E+00	-6.63	-	8.24E-10	5.49E-09	8.24E-06	2.43	12.08	
KAV04A	230.29	235.29	5	2.70E-06	-6.69	2.67E-07	8.24E-10	5.49E-09	8.24E-06	1.72	11.90	
KAV04A	225.28	230.28	5	0.00E+00	-6.78	-	8.24E-10	5.49E-09	8.24E-06	2.45	11.96	

Appendix 6.6

DIFFERENCE FLOW LOGGING -Sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	Lw (m)	Q_1 (m^3/s)	dh_1 (m)	TD (m^2/s)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	ECw_1 (S/m)	Tew_1 (C)	Comments
KAV04A	220.28	225.28	5	0.00E+00	-6.86	-	8.24E-10	5.49E-09	8.24E-06	2.40	11.93	
KAV04A	215.27	220.27	5	0.00E+00	-6.90	-	8.24E-10	5.49E-09	8.24E-06	2.45	11.85	
KAV04A	210.27	215.27	5	0.00E+00	-6.92	-	8.24E-10	5.49E-09	8.24E-06	2.44	11.81	
KAV04A	205.26	210.26	5	0.00E+00	-6.99	-	8.24E-10	5.49E-09	8.24E-06	2.39	11.77	
KAV04A	200.26	205.26	5	0.00E+00	-7.09	-	8.24E-10	5.49E-09	8.24E-06	2.39	11.71	
KAV04A	195.26	200.26	5	0.00E+00	-7.14	-	8.24E-10	5.49E-09	8.24E-06	2.47	11.66	
KAV04A	190.25	195.25	5	6.59E-07	-7.17	6.52E-08	8.24E-10	5.49E-09	8.24E-06	1.93	11.57	
KAV04A	185.25	190.25	5	1.04E-06	-7.21	1.03E-07	8.24E-10	2.75E-09	8.24E-06	1.75	11.48	
KAV04A	180.24	185.24	5	0.00E+00	-7.26	-	8.24E-10	2.75E-09	8.24E-06	2.37	11.48	
KAV04A	175.24	180.24	5	0.00E+00	-7.34	-	8.24E-10	2.75E-09	8.24E-06	2.33	11.45	
KAV04A	170.23	175.23	5	1.85E-07	-7.39	1.83E-08	8.24E-10	2.75E-09	8.24E-06	2.22	11.38	
KAV04A	165.23	170.23	5	0.00E+00	-7.43	-	8.24E-10	2.75E-09	8.24E-06	2.44	11.34	
KAV04A	160.22	165.22	5	7.04E-07	-7.48	6.97E-08	8.24E-10	2.75E-09	8.24E-06	1.88	11.27	
KAV04A	155.22	160.22	5	0.00E+00	-7.51	-	8.24E-10	2.75E-09	8.24E-06	1.93	11.17	
KAV04A	150.22	155.22	5	0.00E+00	-7.57	-	8.24E-10	2.75E-09	8.24E-06	1.93	11.17	
KAV04A	145.21	150.21	5	0.00E+00	-7.64	-	8.24E-10	2.75E-09	8.24E-06	2.40	11.12	
KAV04A	140.21	145.21	5	3.47E-08	-7.74	3.43E-09	8.24E-10	1.37E-09	8.24E-06	2.33	11.07	
KAV04A	135.21	140.21	5	5.50E-08	-7.79	5.4E-09	8.24E-10	1.37E-09	8.24E-06	2.31	11.01	
KAV04A	130.21	135.21	5	7.11E-08	-7.82	7.03E-09	8.24E-10	1.37E-09	8.24E-06	2.31	11.01	
KAV04A	125.2	130.20	5	0.00E+00	-7.87	-	8.24E-10	1.37E-09	8.24E-06	2.38	10.90	
KAV04A	120.19	125.19	5	0.00E+00	-7.92	-	8.24E-10	2.75E-09	8.24E-06	2.42	10.84	
KAV04A	115.19	120.19	5	5.55E-06	-7.96	5.49E-07	8.24E-10	5.49E-09	8.24E-06	1.51	10.57	
KAV04A	110.18	115.18	5	2.52E-07	-8.01	2.49E-08	8.24E-10	5.49E-09	8.24E-06	2.30	10.66	
KAV04A	105.17	110.17	5	1.58E-06	-8.05	1.56E-07	8.24E-10	2.75E-09	8.24E-06	1.46	10.53	
KAV04A	100.16	105.16	5	3.23E-06	-8.16	3.20E-07	8.24E-10	2.75E-09	8.24E-06	1.45	10.40	

Appendix 7.1

PFL - DIFFERENCE FLOW LOGGING - Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_W (m)	d_L (m)	Q_2 (m^3/s)	dh_2 (m)	TD (m^2/s)	Comments
KAV04A	102.1	1.0	0.1	5.00E-07	-8.12	4.95E-08	Uncertain
KAV04A	102.5	1.0	0.1	5.50E-07	-8.13	5.44E-08	Uncertain
KAV04A	103.0	1.0	0.1	9.72E-07	-8.12	9.62E-08	Uncertain
KAV04A	103.6	1.0	0.1	9.42E-07	-8.12	9.32E-08	
KAV04A	104.6	1.0	0.1	7.44E-08	-8.13	7.36E-09	Uncertain
KAV04A	106.0	1.0	0.1	3.09E-07	-8.07	3.05E-08	
KAV04A	108.6	1.0	0.1	4.33E-07	-8.02	4.29E-08	Uncertain
KAV04A	109.0	1.0	0.1	1.12E-06	-8.02	1.11E-07	
KAV04A	111.6	1.0	0.1	8.69E-08	-7.99	8.60E-09	
KAV04A	114.3	1.0	0.1	1.04E-07	-7.99	1.03E-08	Uncertain
KAV04A	117.5	1.0	0.1	7.35E-07	-7.97	7.27E-08	
KAV04A	119.0	1.0	0.1	4.44E-06	-7.93	4.40E-07	
KAV04A	130.8	1.0	0.1	4.00E-08	-7.83	3.96E-09	
KAV04A	139.2	1.0	0.1	4.83E-08	-7.74	4.78E-09	
KAV04A	142.6	1.0	0.1	3.31E-08	-7.67	3.27E-09	Uncertain
KAV04A	160.3	1.0	0.1	6.96E-07	-7.49	6.88E-08	
KAV04A	163.0	1.0	0.1	5.03E-08	-7.43	4.97E-09	Uncertain
KAV04A	174.0	1.0	0.1	1.33E-07	-7.30	1.31E-08	
KAV04A	174.7	1.0	0.1	5.75E-08	-7.29	5.69E-09	Uncertain
KAV04A	185.7	1.0	0.1	5.54E-07	-7.18	5.48E-08	
KAV04A	186.4	1.0	0.1	1.06E-07	-7.19	1.05E-08	Uncertain
KAV04A	188.9	1.0	0.1	3.81E-07	-7.18	3.77E-08	
KAV04A	189.7	1.0	0.1	1.10E-07	-7.17	1.09E-08	
KAV04A	191.3	1.0	0.1	6.31E-07	-7.12	6.24E-08	
KAV04A	232.8	1.0	0.1	2.40E-06	-6.63	2.38E-07	
KAV04A	233.5	1.0	0.1	1.59E-07	-6.63	1.57E-08	
KAV04A	248.7	1.0	0.1	8.20E-07	-6.48	8.11E-08	
KAV04A	255.8	1.0	0.1	1.66E-06	-6.39	1.64E-07	Uncertain
KAV04A	256.5	1.0	0.1	4.68E-06	-6.40	4.63E-07	
KAV04A	257.0	1.0	0.1	2.09E-05	-6.39	2.07E-06	
KAV04A	257.9	1.0	0.1	3.19E-07	-6.39	3.16E-08	
KAV04A	261.3	1.0	0.1	5.33E-08	-6.30	5.28E-09	Uncertain
KAV04A	261.5	1.0	0.1	2.92E-08	-6.30	2.88E-09	
KAV04A	271.0	1.0	0.1	5.03E-08	-6.18	4.97E-09	
KAV04A	271.9	1.0	0.1	4.39E-08	-6.16	4.34E-09	Uncertain
KAV04A	280.1	1.0	0.1	3.70E-07	-6.04	3.66E-08	
KAV04A	281.0	1.0	0.1	1.02E-07	-6.03	1.01E-08	Uncertain
KAV04A	281.4	1.0	0.1	6.89E-07	-6.02	6.82E-08	
KAV04A	283.5	1.0	0.1	3.64E-07	-6.01	3.60E-08	
KAV04A	283.9	1.0	0.1	9.72E-08	-6.01	9.62E-09	Uncertain
KAV04A	285.2	1.0	0.1	6.11E-08	-6.02	6.04E-09	Uncertain
KAV04A	286.7	1.0	0.1	2.70E-07	-6.01	2.67E-08	
KAV04A	287.3	1.0	0.1	5.08E-08	-6.00	5.03E-09	Uncertain
KAV04A	357.1	1.0	0.1	6.55E-07	-5.07	6.48E-08	
KAV04A	367.4	1.0	0.1	1.79E-07	-4.94	1.77E-08	
KAV04A	369.6	1.0	0.1	8.39E-08	-4.92	8.30E-09	
KAV04A	372.4	1.0	0.1	5.83E-08	-4.84	5.77E-09	

Appendix 7.2

PFL - DIFFERENCE FLOW LOGGING - Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_w (m)	d_L (m)	Q_2 (m^3/s)	dh_2 (m)	TD (m^2/s)	Comments
KAV04A	387.9	1.0	0.1	4.60E-07	-4.65	4.55E-08	
KAV04A	388.2	1.0	0.1	3.02E-06	-4.63	2.98E-07	
KAV04A	409.8	1.0	0.1	9.31E-08	-4.32	9.20E-09	
KAV04A	483.3	1.0	0.1	1.87E-07	-3.39	1.85E-08	
KAV04A	496.2	1.0	0.1	7.00E-06	-3.21	6.93E-07	
KAV04A	496.5	1.0	0.1	2.03E-06	-3.19	2.00E-07	
KAV04A	502.5	1.0	0.1	5.71E-07	-3.11	5.65E-08	
KAV04A	504.7	1.0	0.1	6.86E-08	-3.08	6.79E-09	
KAV04A	506.7	1.0	0.1	1.77E-07	-3.04	1.75E-08	
KAV04A	508.1	1.0	0.1	8.67E-08	-2.99	8.57E-09	
KAV04A	511.2	1.0	0.1	2.40E-07	-2.97	2.37E-08	
KAV04A	514.6	1.0	0.1	8.58E-07	-2.96	8.49E-08	
KAV04A	525.8	1.0	0.1	1.76E-07	-2.78	1.74E-08	
KAV04A	526.1	1.0	0.1	3.42E-07	-2.78	3.38E-08	
KAV04A	526.4	1.0	0.1	6.33E-08	-2.77	6.26E-09	Uncertain
KAV04A	530.2	1.0	0.1	9.89E-08	-2.72	9.78E-09	Uncertain
KAV04A	530.8	1.0	0.1	2.35E-06	-2.72	2.33E-07	
KAV04A	533.7	1.0	0.1	3.15E-07	-2.71	3.12E-08	
KAV04A	534.8	1.0	0.1	1.00E-07	-2.69	9.89E-09	
KAV04A	537.9	1.0	0.1	2.61E-08	-2.61	2.58E-09	Uncertain
KAV04A	540.1	1.0	0.1	8.81E-08	-2.59	8.71E-09	
KAV04A	543.6	1.0	0.1	9.33E-08	-2.58	9.23E-09	
KAV04A	544.0	1.0	0.1	1.22E-07	-2.58	1.21E-08	Uncertain
KAV04A	558.9	1.0	0.1	5.08E-08	-2.27	5.03E-09	
KAV04A	573.0	1.0	0.1	6.96E-07	-2.11	6.88E-08	
KAV04A	575.6	1.0	0.1	8.56E-08	-2.11	8.46E-09	
KAV04A	594.4	1.0	0.1	2.53E-07	-1.83	2.50E-08	
KAV04A	601.8	1.0	0.1	4.00E-08	-1.69	3.96E-09	
KAV04A	609.8	1.0	0.1	5.25E-07	-1.60	5.19E-08	
KAV04A	612.5	1.0	0.1	2.64E-08	-1.53	2.61E-09	Uncertain
KAV04A	613.6	1.0	0.1	3.19E-08	-1.51	3.16E-09	
KAV04A	625.8	1.0	0.1	3.39E-08	-1.33	3.35E-09	
KAV04A	627.8	1.0	0.1	5.19E-08	-1.32	5.14E-09	
KAV04A	643.0	1.0	0.1	4.95E-07	-1.15	4.90E-08	
KAV04A	661.7	1.0	0.1	1.13E-07	-0.84	1.12E-08	
KAV04A	682.5	1.0	0.1	1.37E-07	-0.51	1.35E-08	
KAV04A	690.2	1.0	0.1	2.18E-07	-0.44	2.16E-08	
KAV04A	691.0	1.0	0.1	7.08E-07	-0.43	7.00E-08	
KAV04A	691.8	1.0	0.1	7.99E-07	-0.42	7.91E-08	
KAV04A	694.4	1.0	0.1	1.24E-06	-0.35	1.23E-07	
KAV04A	694.8	1.0	0.1	3.81E-07	-0.35	3.77E-08	Uncertain
KAV04A	695.6	1.0	0.1	4.28E-08	-0.30	4.23E-09	Uncertain
KAV04A	696.0	1.0	0.1	4.13E-07	-0.30	4.08E-08	
KAV04A	697.5	1.0	0.1	1.13E-07	-0.27	1.12E-08	
KAV04A	699.3	1.0	0.1	6.49E-07	-0.23	6.42E-08	
KAV04A	700.5	1.0	0.1	4.96E-07	-0.24	4.91E-08	
KAV04A	705.7	1.0	0.1	1.73E-06	-0.22	1.71E-07	
KAV04A	706.6	1.0	0.1	5.75E-07	-0.21	5.69E-08	

Appendix 7.3

PFL - DIFFERENCE FLOW LOGGING - Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_W (m)	d_L (m)	Q_2 (m^3/s)	dh_2 (m)	TD (m^2/s)	Comments
KAV04A	714.3	1.0	0.1	2.77E-05	-0.05	2.74E-06	
KAV04A	714.5	1.0	0.1	2.19E-05	-0.05	2.16E-06	
KAV04A	714.7	1.0	0.1	2.92E-07	-0.04	2.89E-08	
KAV04A	716.5	1.0	0.1	1.54E-07	-0.03	1.52E-08	
KAV04A	720.5	1.0	0.1	3.72E-08	0.02	3.68E-09	Uncertain
KAV04A	722.1	1.0	0.1	4.15E-07	0.06	4.11E-08	
KAV04A	723.0	1.0	0.1	2.02E-06	0.10	1.99E-07	
KAV04A	726.3	1.0	0.1	1.54E-07	0.20	1.53E-08	
KAV04A	726.7	1.0	0.1	3.69E-08	0.20	3.65E-09	Uncertain
KAV04A	734.0	1.0	0.1	4.75E-08	0.27	4.70E-09	Uncertain
KAV04A	755.2	1.0	0.1	4.09E-07	0.69	4.04E-08	Uncertain
KAV04A	755.5	1.0	0.1	2.00E-06	0.72	1.98E-07	
KAV04A	756.1	1.0	0.1	1.57E-05	0.72	1.55E-06	
KAV04A	756.6	1.0	0.1	3.11E-07	0.73	3.07E-08	Uncertain
KAV04A	759.4	1.0	0.1	3.73E-06	0.77	3.69E-07	
KAV04A	761.2	1.0	0.1	1.10E-06	0.79	1.09E-07	
KAV04A	762.3	1.0	0.1	1.03E-06	0.81	1.02E-07	
KAV04A	762.6	1.0	0.1	3.78E-07	0.81	3.74E-08	
KAV04A	763.0	1.0	0.1	6.53E-08	0.82	6.46E-09	
KAV04A	765.4	1.0	0.1	3.69E-08	0.85	3.65E-09	Uncertain
KAV04A	767.8	1.0	0.1	2.41E-07	0.91	2.39E-08	
KAV04A	789.4	1.0	0.1	2.69E-07	1.39	2.66E-08	
KAV04A	792.1	1.0	0.1	7.68E-07	1.43	7.60E-08	
KAV04A	792.5	1.0	0.1	1.97E-06	1.43	1.95E-07	
KAV04A	797.3	1.0	0.1	1.62E-06	1.50	1.60E-07	
KAV04A	798.4	1.0	0.1	2.34E-07	1.51	2.31E-08	
KAV04A	802.8	1.0	0.1	6.86E-07	1.64	6.78E-08	
KAV04A	803.5	1.0	0.1	1.57E-07	1.65	1.56E-08	
KAV04A	807.0	1.0	0.1	2.88E-07	1.78	2.85E-08	
KAV04A	811.8	1.0	0.1	4.61E-06	1.87	4.56E-07	
KAV04A	814.8	1.0	0.1	1.15E-06	1.89	1.13E-07	
KAV04A	843.6	1.0	0.1	7.01E-07	2.48	6.94E-08	
KAV04A	843.9	1.0	0.1	2.08E-07	2.49	2.05E-08	Uncertain
KAV04A	850.7	1.0	0.1	9.40E-06	2.67	9.29E-07	
KAV04A	851.6	1.0	0.1	2.29E-06	2.67	2.26E-07	
KAV04A	860.5	1.0	0.1	2.44E-07	2.84	2.42E-08	
KAV04A	865.3	1.0	0.1	1.39E-07	2.93	1.37E-08	
KAV04A	891.4	1.0	0.1	6.39E-08	3.41	6.32E-09	Uncertain
KAV04A	894.4	1.0	0.1	5.81E-08	3.47	5.74E-09	Uncertain

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
Lw	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Qp1	m3/s	Flow rate at surface by the end of the first pumping period of the flow logging
Qp2	m3/s	Flow rate at surface by the end of the second pumping period of the flow logging
tp1	s	Duration of the first pumping period
tp2	s	Duration of the second pumping period
tF1	s	Duration of the first recovery period
tF2	s	Duration of the second recovery period
h0	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.
h1	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.
h2	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.
s1	m	Drawdown of the water level in the borehole during first pumping period. Difference between the actual hydraulic head and the initial head (s1= h1-h0)
s2	m	Drawdown of the water level in the borehole during second pumping period. Difference between the actual hydraulic head and the initial head (s2=h2-h0)
T	m2/s	Transmissivity of the entire borehole
Q0	m3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with h=h0 in the open borehole
Q1	m3/s	Measured flow rate through the test section or flow anomaly during the first pumping period
Q2	m3/s	Measured flow rate through the test section or flow anomaly during the second pumping period
dh0	m	Corrected initial hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid before pumping
dh1	m	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period
dh2	m	Corrected hydraulic head difference along the hole due to e.g. varying salinity conditions of the borehole fluid during the second pumping period
ECw	S/m	Measured electric conductivity of the borehole fluid in the test section during difference flow logging
Tew	o C	Measured borehole fluid temperature in the test section during difference flow logging
ECf	S/m	Measured fracture-specific electric conductivity of the fluid in flow anomaly during difference flow logging
Tef	o C	Measured fracture-specific fluid temperature in flow anomaly during difference flow logging
TD	m2/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$_{LT}$	m2/s	Estimated theoretical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-
T-meas$_{lLP}$	m2/s	Estimated practical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-
T-meas$_{lU}$	m2/s	Estimated upper measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
hi	m	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

Appendix 9.1

Calculation of conductive fracture frequency

SecUp (m)	SecLow (m)	Number of Fractures, Total	Number of Fractures 10–100 (ml/h)	Number of Fractures 100–1,000 (ml/h)	Number of Fractures 1,000–10,000 (ml/h)	Number of Fractures 10,000–100,000 (ml/h)	Number of Fractures 100,000–1,000,000 (ml/h)
991.17	996.17	0	0	0	0	0	0
986.18	991.18	0	0	0	0	0	0
981.18	986.18	0	0	0	0	0	0
976.17	981.17	0	0	0	0	0	0
971.15	976.15	0	0	0	0	0	0
966.12	971.12	0	0	0	0	0	0
961.09	966.09	0	0	0	0	0	0
956.08	961.08	0	0	0	0	0	0
951.07	956.07	0	0	0	0	0	0
946.06	951.06	0	0	0	0	0	0
941.05	946.05	0	0	0	0	0	0
936.04	941.04	0	0	0	0	0	0
931.03	936.03	0	0	0	0	0	0
926.02	931.02	0	0	0	0	0	0
921.01	926.01	0	0	0	0	0	0
915.99	920.99	0	0	0	0	0	0
910.98	915.98	0	0	0	0	0	0
905.97	910.97	0	0	0	0	0	0
900.96	905.96	0	0	0	0	0	0
895.96	900.96	0	0	0	0	0	0
890.95	895.95	2	0	2	0	0	0
885.95	890.95	0	0	0	0	0	0
880.94	885.94	0	0	0	0	0	0
875.94	880.94	0	0	0	0	0	0
870.94	875.94	0	0	0	0	0	0
865.92	870.92	0	0	0	0	0	0
860.89	865.89	1	0	1	0	0	0
855.87	860.87	1	0	1	0	0	0
850.86	855.86	1	0	0	1	0	0
845.85	850.85	1	0	0	0	1	0
840.84	845.84	2	0	1	1	0	0
835.84	840.84	0	0	0	0	0	0
830.83	835.83	0	0	0	0	0	0
825.83	830.83	0	0	0	0	0	0
820.82	825.82	0	0	0	0	0	0
815.82	820.82	0	0	0	0	0	0
810.82	815.82	2	0	0	1	1	0
805.81	810.81	1	0	0	1	0	0
800.81	805.81	2	0	1	1	0	0
795.8	800.8	2	0	1	1	0	0
790.8	795.8	2	0	0	2	0	0
785.8	790.8	1	0	1	0	0	0
780.79	785.79	0	0	0	0	0	0
775.79	780.79	0	0	0	0	0	0
770.78	775.78	0	0	0	0	0	0
765.78	770.78	1	0	1	0	0	0

Appendix 9.2

Calculation of conductive fracture frequency

SecUp (m)	SecLow (m)	Number of Fractures, Total	Number of Fractures 10–100 (ml/h)	Number of Fractures 100–1,000 (ml/h)	Number of Fractures 1,000–10,000 (ml/h)	Number of Fractures 10,000–100,000 (ml/h)	Number of Fractures 100,000–1,000,000 (ml/h)
760.78	765.78	5	0	2	3	0	0
755.77	760.77	3	0	0	1	2	0
750.76	755.76	2	0	0	2	0	0
745.75	750.75	0	0	0	0	0	0
740.74	745.74	0	0	0	0	0	0
735.73	740.73	0	0	0	0	0	0
730.72	735.72	1	0	1	0	0	0
725.72	730.72	2	0	2	0	0	0
720.73	725.73	2	0	0	2	0	0
715.72	720.72	2	0	2	0	0	0
710.71	715.71	3	0	0	1	2	0
705.7	710.7	2	0	0	2	0	0
700.7	705.7	0	0	0	0	0	0
695.69	700.69	4	0	1	3	0	0
690.68	695.68	5	0	1	4	0	0
685.68	690.68	1	0	1	0	0	0
680.67	685.67	1	0	1	0	0	0
675.67	680.67	0	0	0	0	0	0
670.66	675.66	0	0	0	0	0	0
665.66	670.66	0	0	0	0	0	0
660.65	665.65	1	0	1	0	0	0
655.64	660.64	0	0	0	0	0	0
650.63	655.63	0	0	0	0	0	0
645.62	650.62	0	0	0	0	0	0
640.61	645.61	1	0	0	1	0	0
635.6	640.6	0	0	0	0	0	0
630.6	635.6	0	0	0	0	0	0
625.59	630.59	2	0	2	0	0	0
620.58	625.58	0	0	0	0	0	0
615.57	620.57	0	0	0	0	0	0
610.57	615.57	2	1	1	0	0	0
605.57	610.57	1	0	0	1	0	0
600.57	605.57	1	0	1	0	0	0
595.56	600.56	0	0	0	0	0	0
590.56	595.56	1	0	1	0	0	0
585.56	590.56	0	0	0	0	0	0
580.55	585.55	0	0	0	0	0	0
575.54	580.54	1	0	1	0	0	0
570.54	575.54	1	0	0	1	0	0
565.53	570.53	0	0	0	0	0	0
560.52	565.52	0	0	0	0	0	0
555.51	560.51	1	0	1	0	0	0
550.5	555.5	0	0	0	0	0	0
545.49	550.49	0	0	0	0	0	0
540.49	545.49	2	0	2	0	0	0

Appendix 9.3

Calculation of conductive fracture frequency

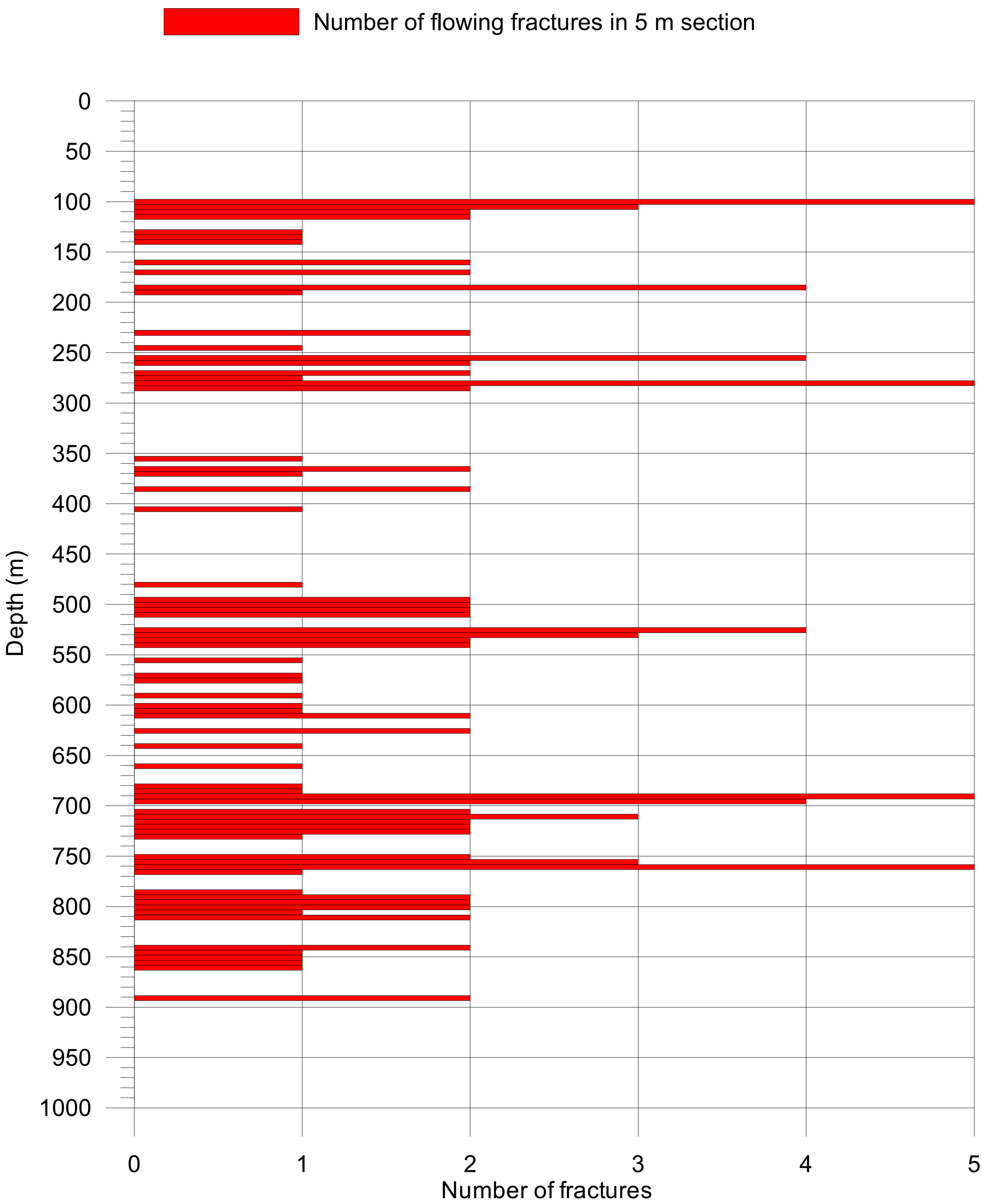
SecUp (m)	SecLow (m)	Number of Fractures, Total	Number of Fractures 10–100 (ml/h)	Number of Fractures 100–1,000 (ml/h)	Number of Fractures 1,000–10,000 (ml/h)	Number of Fractures 10,000–100,000 (ml/h)	Number of Fractures 100,000–1,000,000 (ml/h)
535.48	540.48	2	1	1	0	0	0
530.47	535.47	3	0	1	2	0	0
525.45	530.45	4	0	3	1	0	0
520.44	525.44	0	0	0	0	0	0
515.43	520.43	0	0	0	0	0	0
510.43	515.43	2	0	1	1	0	0
505.43	510.43	2	0	2	0	0	0
500.43	505.43	2	0	1	1	0	0
495.43	500.43	2	0	0	1	1	0
490.43	495.43	0	0	0	0	0	0
485.43	490.43	0	0	0	0	0	0
480.43	485.43	1	0	1	0	0	0
475.43	480.43	0	0	0	0	0	0
470.43	475.43	0	0	0	0	0	0
465.44	470.44	0	0	0	0	0	0
460.44	465.44	0	0	0	0	0	0
455.44	460.44	0	0	0	0	0	0
450.44	455.44	0	0	0	0	0	0
445.44	450.44	0	0	0	0	0	0
440.44	445.44	0	0	0	0	0	0
435.44	440.44	0	0	0	0	0	0
430.44	435.44	0	0	0	0	0	0
425.44	430.44	0	0	0	0	0	0
420.44	425.44	0	0	0	0	0	0
415.44	420.44	0	0	0	0	0	0
410.43	415.43	0	0	0	0	0	0
405.42	410.42	1	0	1	0	0	0
400.42	405.42	0	0	0	0	0	0
395.41	400.41	0	0	0	0	0	0
390.4	395.4	0	0	0	0	0	0
385.39	390.39	2	0	0	1	1	0
380.39	385.39	0	0	0	0	0	0
375.38	380.38	0	0	0	0	0	0
370.38	375.38	1	0	1	0	0	0
365.38	370.38	2	0	2	0	0	0
360.38	365.38	0	0	0	0	0	0
355.37	360.37	1	0	0	1	0	0
350.37	355.37	0	0	0	0	0	0
345.37	350.37	0	0	0	0	0	0
340.36	345.36	0	0	0	0	0	0
335.36	340.36	0	0	0	0	0	0
330.35	335.35	0	0	0	0	0	0
325.35	330.35	0	0	0	0	0	0
320.34	325.34	0	0	0	0	0	0
315.34	320.34	0	0	0	0	0	0
310.33	315.33	0	0	0	0	0	0

Appendix 9.4

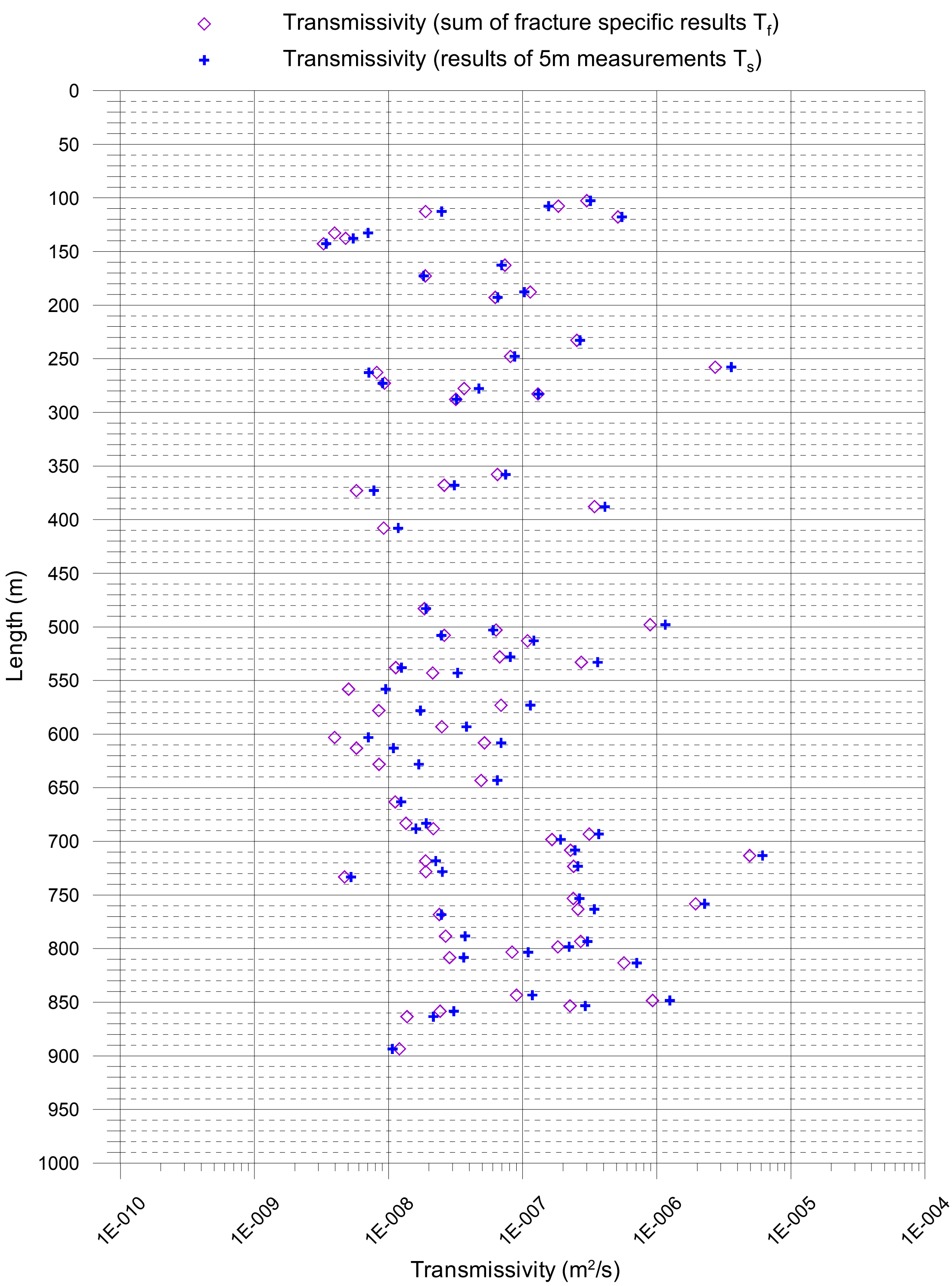
Calculation of conductive fracture frequency

SecUp (m)	SecLow (m)	Number of Fractures, Total	Number of Fractures 10–100 (ml/h)	Number of Fractures 100–1,000 (ml/h)	Number of Fractures 1,000–10,000 (ml/h)	Number of Fractures 10,000–100,000 (ml/h)	Number of Fractures 100,000–1,000,000 (ml/h)
305.33	310.33	0	0	0	0	0	0
300.33	305.33	0	0	0	0	0	0
295.32	300.32	0	0	0	0	0	0
290.32	295.32	0	0	0	0	0	0
285.31	290.31	2	0	2	0	0	0
280.3	285.3	5	0	3	2	0	0
275.3	280.3	1	0	0	1	0	0
270.29	275.29	2	0	2	0	0	0
265.29	270.29	0	0	0	0	0	0
260.28	265.28	2	0	2	0	0	0
255.28	260.28	4	0	0	2	2	0
250.29	255.29	0	0	0	0	0	0
245.29	250.29	1	0	0	1	0	0
240.29	245.29	0	0	0	0	0	0
235.29	240.29	0	0	0	0	0	0
230.29	235.29	2	0	1	1	0	0
225.28	230.28	0	0	0	0	0	0
220.28	225.28	0	0	0	0	0	0
215.27	220.27	0	0	0	0	0	0
210.27	215.27	0	0	0	0	0	0
205.26	210.26	0	0	0	0	0	0
200.26	205.26	0	0	0	0	0	0
195.26	200.26	0	0	0	0	0	0
190.25	195.25	1	0	0	1	0	0
185.25	190.25	4	0	2	2	0	0
180.24	185.24	0	0	0	0	0	0
175.24	180.24	0	0	0	0	0	0
170.23	175.23	2	0	2	0	0	0
165.23	170.23	0	0	0	0	0	0
160.22	165.22	2	0	1	1	0	0
155.22	160.22	0	0	0	0	0	0
150.22	155.22	0	0	0	0	0	0
145.21	150.21	0	0	0	0	0	0
140.21	145.21	1	0	1	0	0	0
135.21	140.21	1	0	1	0	0	0
130.21	135.21	1	0	1	0	0	0
125.2	130.2	0	0	0	0	0	0
120.19	125.19	0	0	0	0	0	0
115.19	120.19	2	0	0	1	1	0
110.18	115.18	2	0	2	0	0	0
105.17	110.17	3	0	0	3	0	0
100.16	105.16	5	0	1	4	0	0

Simpevarp, Borehole KAV04A
Calculation of conductive fracture frequency

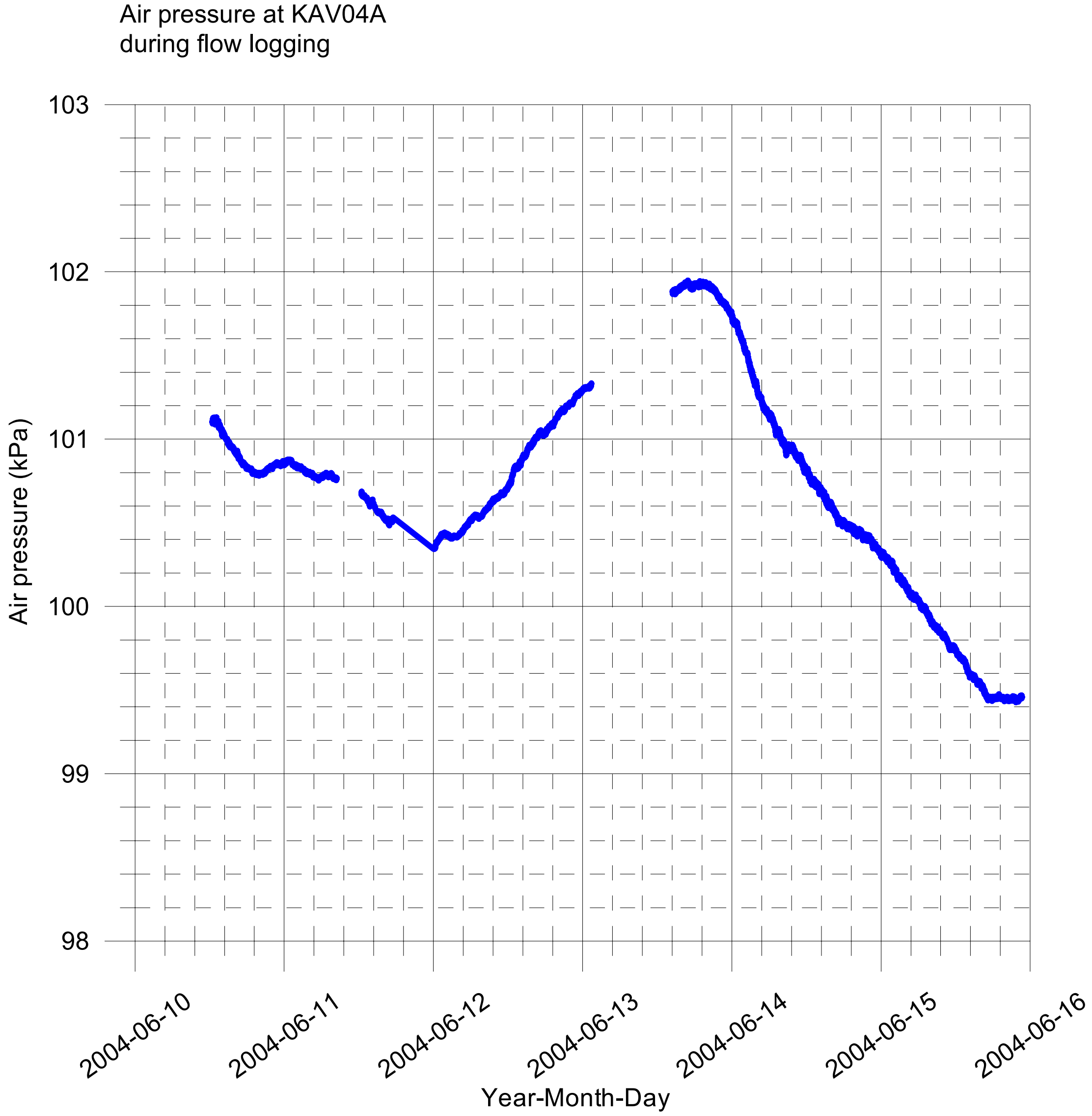


Forsmark, Borehole KAV04A
Comparison of transmissivity of borehole sections (5m) and fracture transmissivities



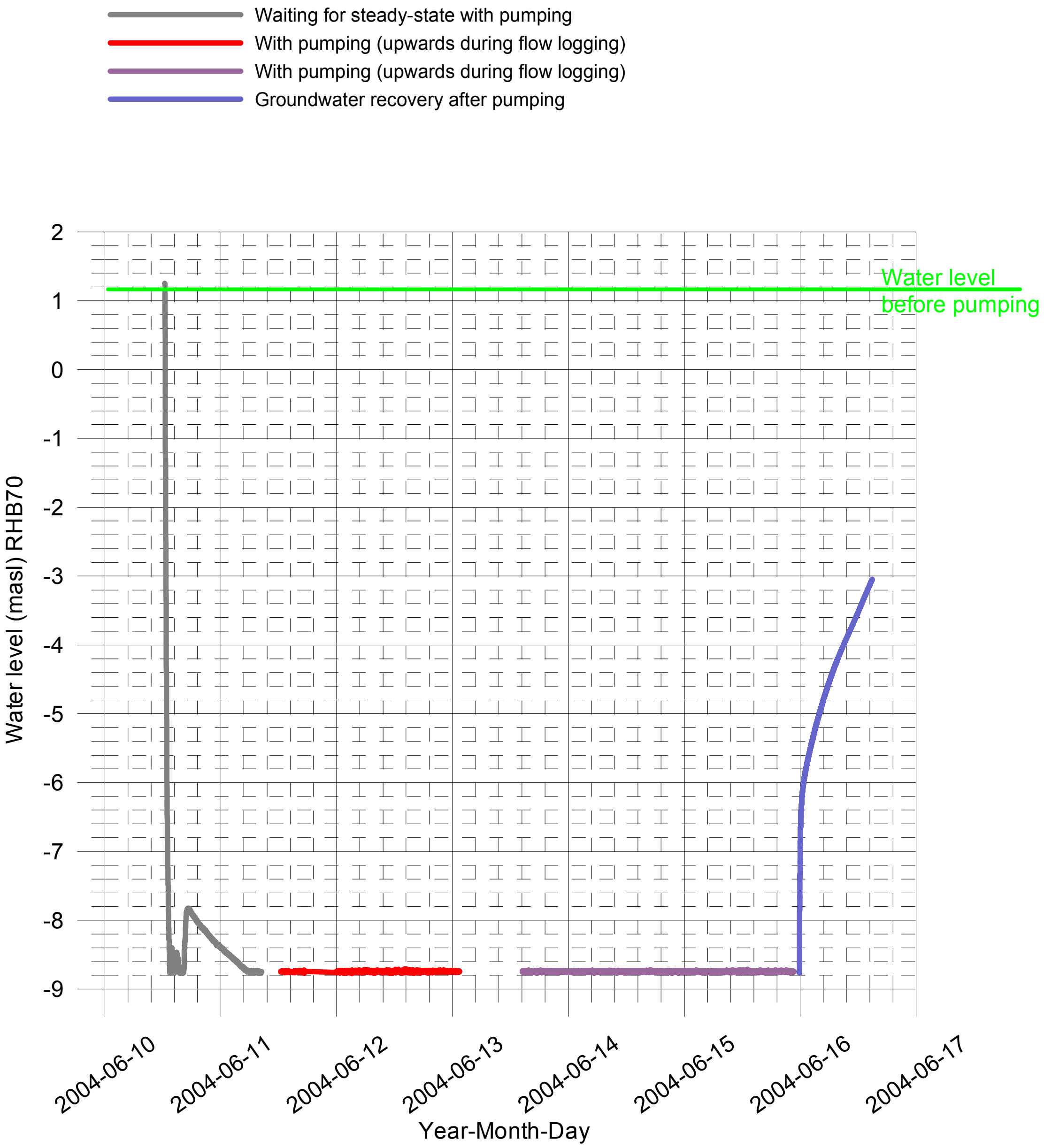
Head during flow logging in borehole KAV04A

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



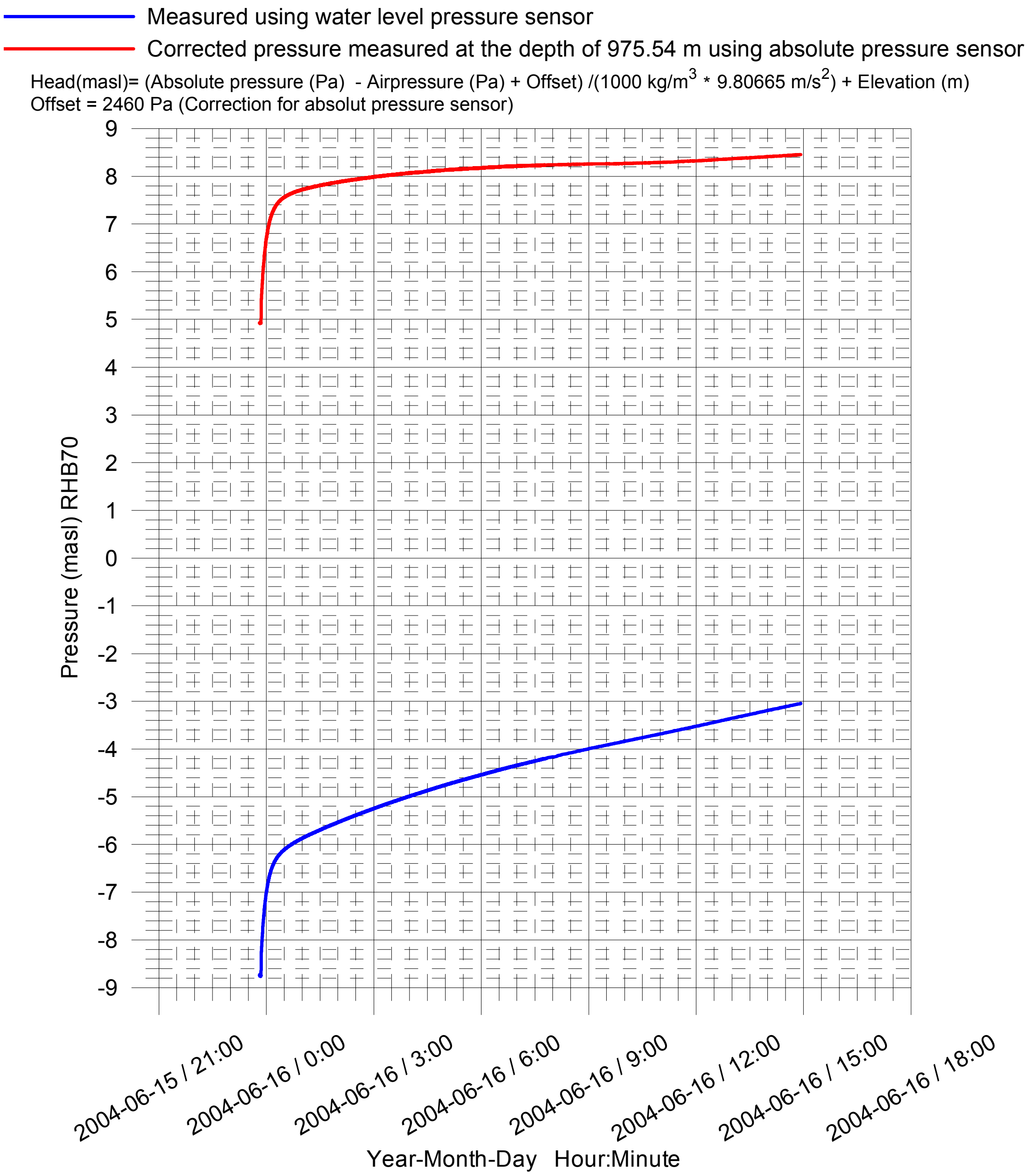
Air pressure at KAV04A
during flow logging
Air pressure (kPa)
103
102
101
100
99
98
2004-06-10
2004-06-11
2004-06-12
2004-06-13
2004-06-14
2004-06-15
2004-06-16
Year-Month-Day

Water level during difference flow logging
Borehole KAV04A, Ävrö

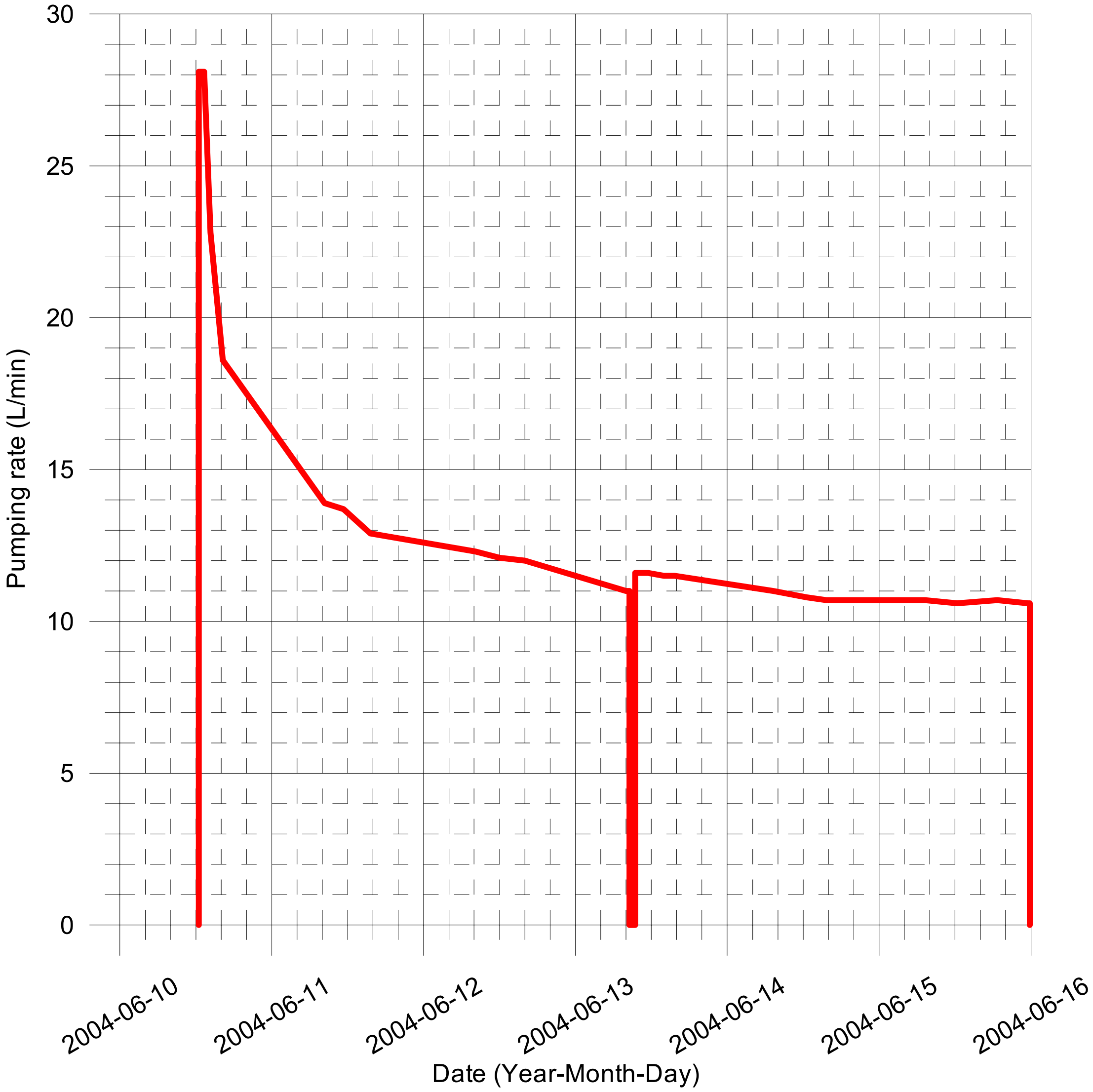


Appendix 12.4

Groundwater recovery after pumping

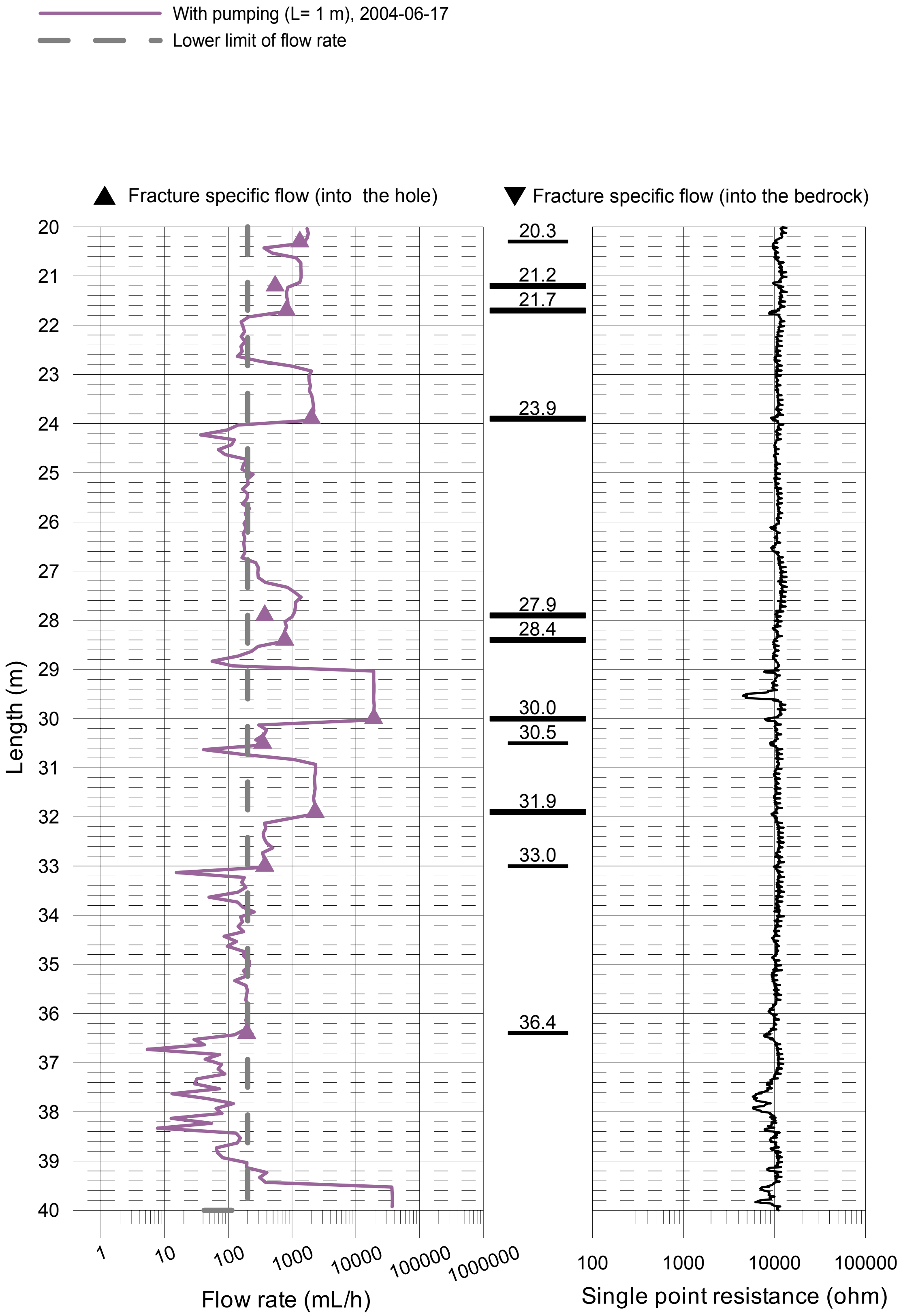


Pumping rate during flow logging
Ävrö, borehole KAV04A



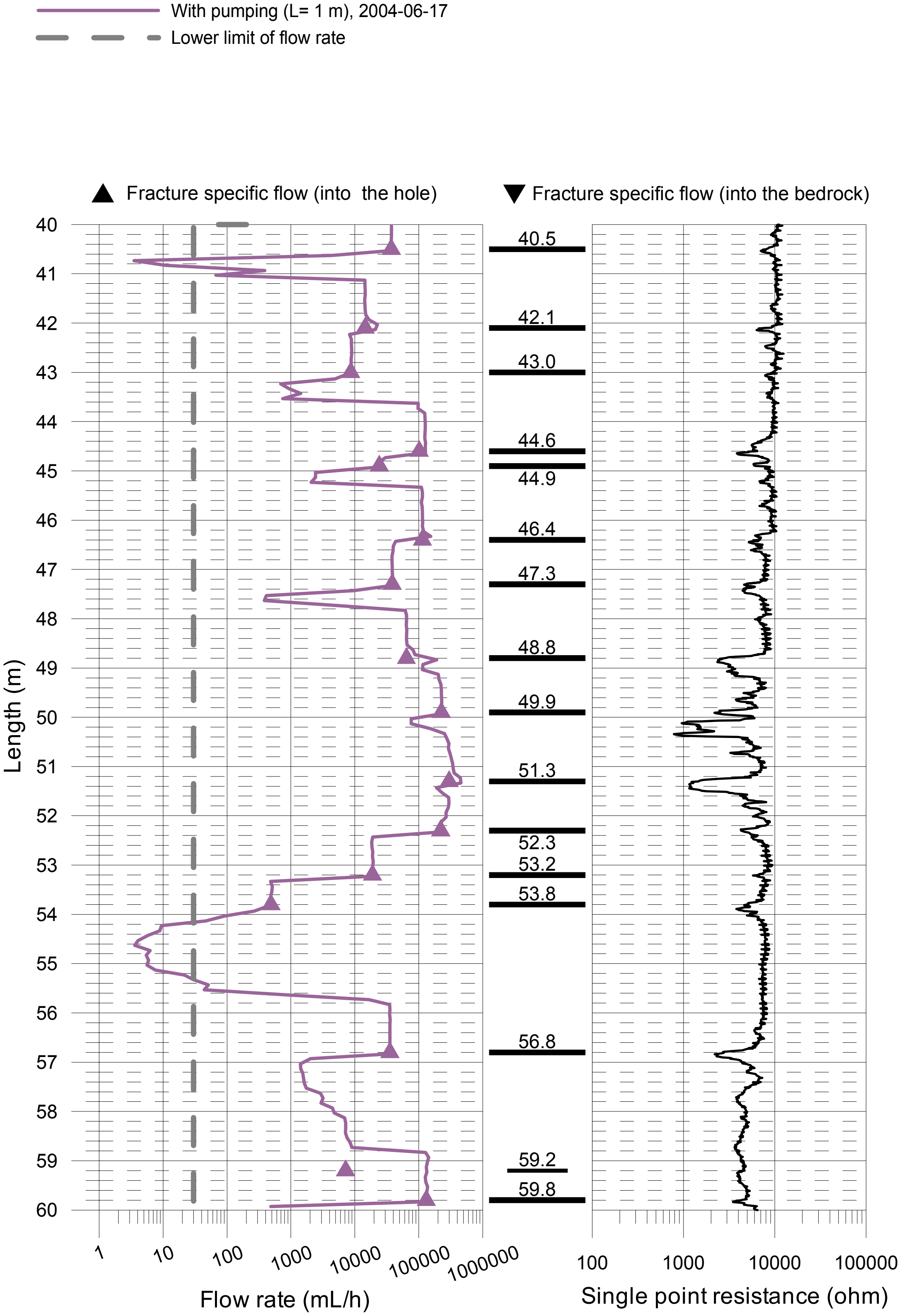
Ävrö, Borehole KAV04B

Flow measurement 2004-06-16 - 2004-06-18



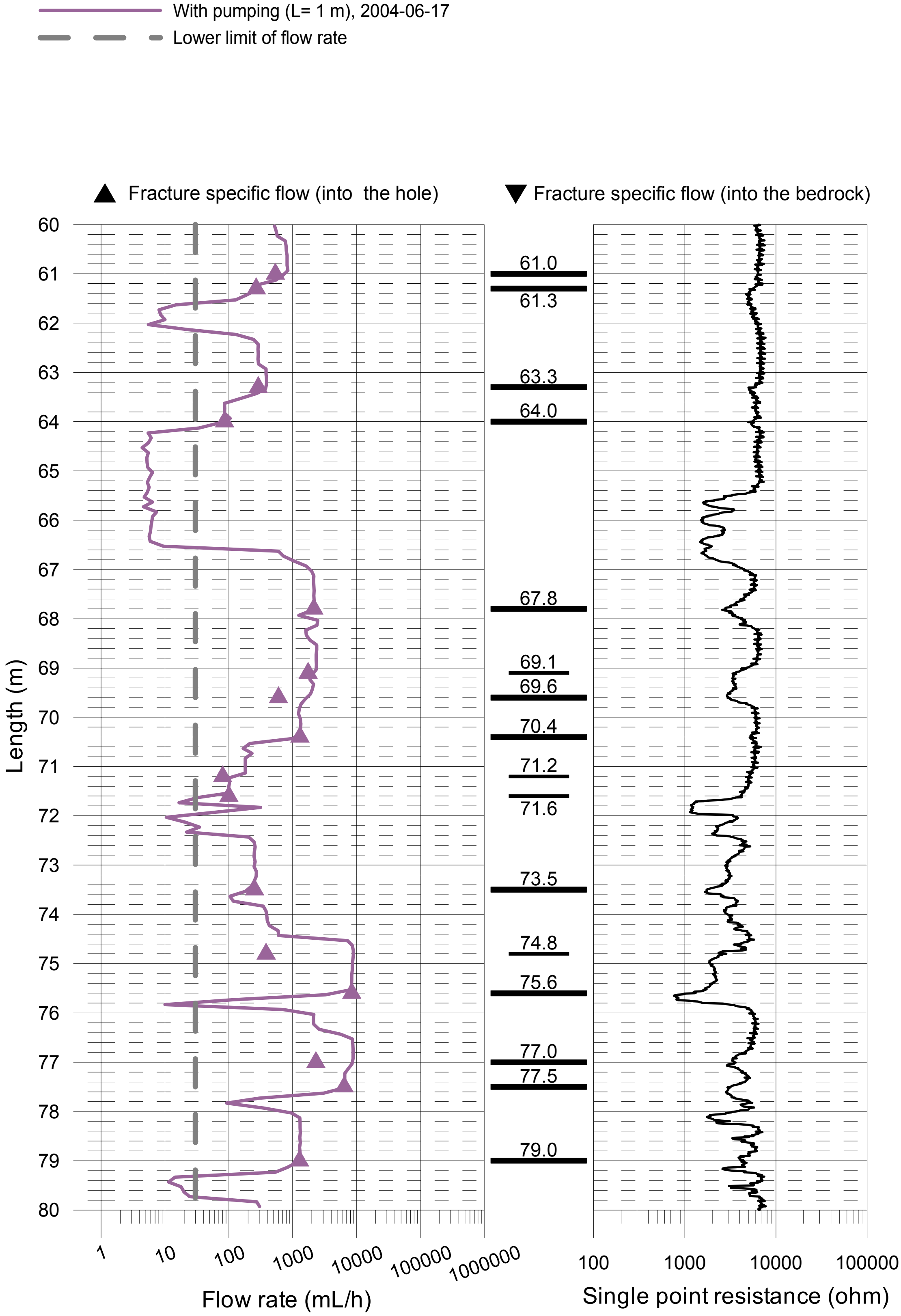
Ävrö, Borehole KAV04B

Flow measurement 2004-06-16 - 2004-06-18

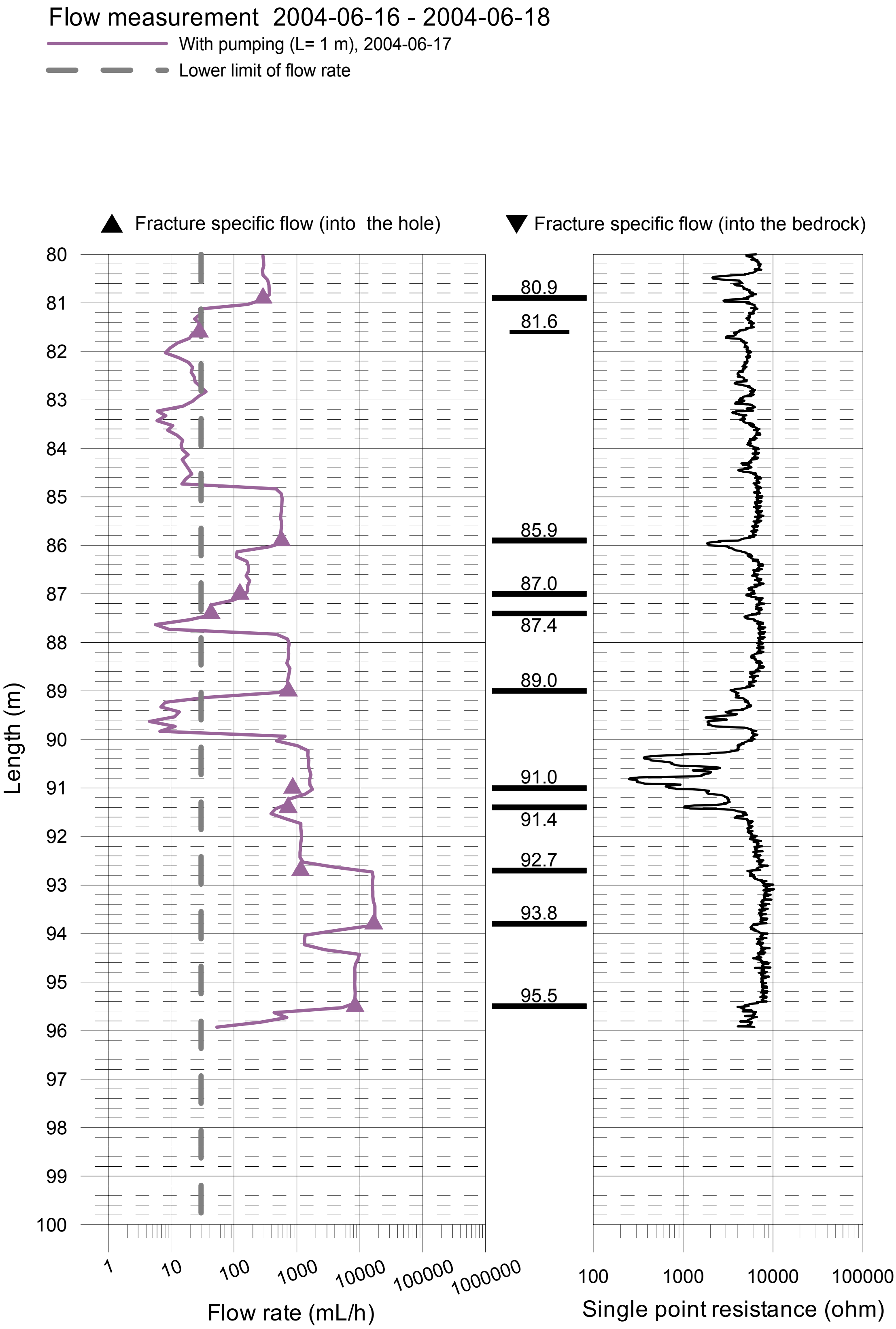


Ävrö, Borehole KAV04B

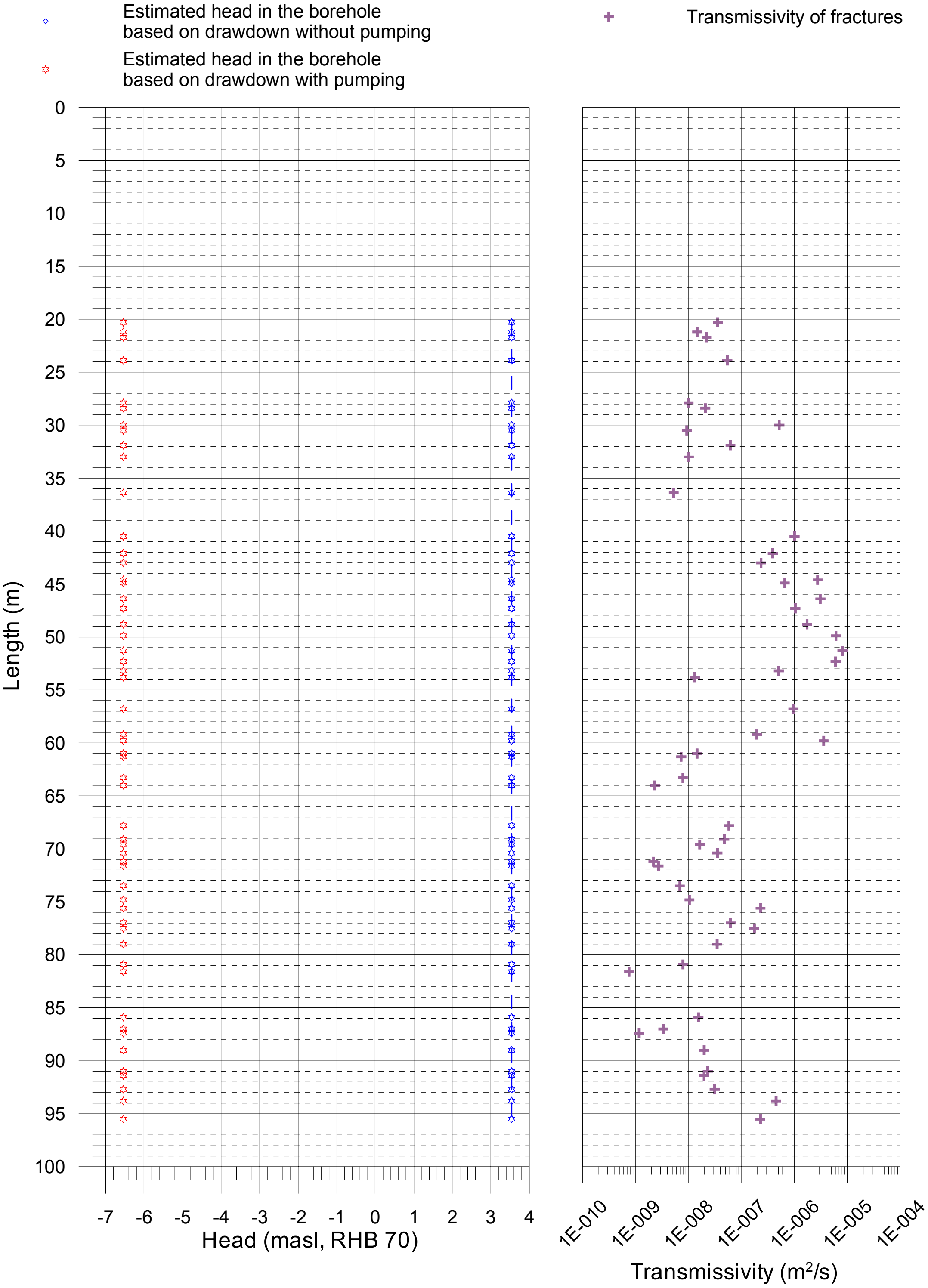
Flow measurement 2004-06-16 - 2004-06-18



Ävrö, Borehole KAV04B



ÄVRÖ, Borehole KAV04B
Difference flow measurement
Fracture-specific results



5. PFL-DIFFERENCE FLOW LOGGING - Basic test data													
Borehole	**Logged interval**		**Test**	**Date of**	**Time of**	**Date of**	**Time of**	**Date of**	**Time of**	**L_w**	**dL**	**Q_{p1}**	**Q_{p2}**
ID	Secup	Seclow	**type**	**test, start**	**test, start**	**flowl., start**	**flowl., start**	**test, stop**	**test, stop**				
	(m)	(m)	(1-6)	YYYYMMDD	hh:mm	YYYYMMDD	hh:mm	YYYYMMDD	hh:mm	(m)	(m)	(m^3/s)	(m^3/s)
KAV04B	**19.53**	**95.93**	**5B**	**20040616**	**17:19**	**20040617**	**07:42**	**20040617**	**13:53**	**1**	**0.1**	**3.9E-4**	

5. PFL-DIFFERENCE	FLOW LOGGING -	Basic test data									
t_{p1}	**t_{p2}**	**t_{F1}**	**t_{F2}**	**h_0**	**h_1**	**h_2**	**s_1**	**s_2**	**T**	Reference	Comments
									Entire hole		
(s)	(s)	(s)	(s)	(m)	(m)	(m)	(m)	(m)	(m2/s)	(-)	(-)
74040		**58680**		**3.52**	**-6.55**		**-10.07**		**3.83E-5**		

Appendix 16.1

PFL - DIFFERENCE FLOW LOGGING - Inferred flow anomalies from overlapping flow logging

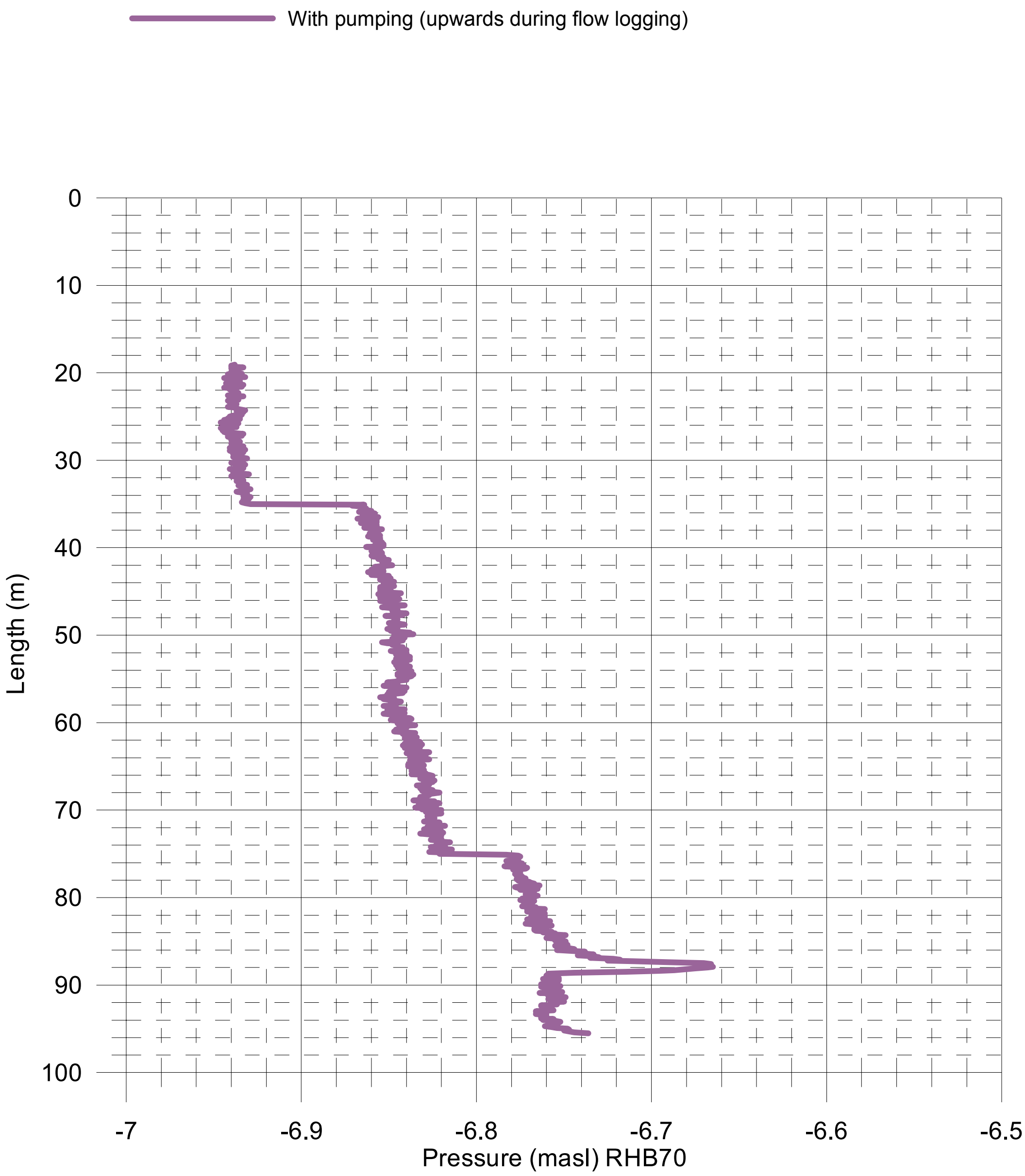
Borehole ID	Length to flow anom. L (m)	L_W (m)	d_L (m)	Q_2 (m^3/s)	dh_2 (m)	TD (m^2/s)	Comments
KAV04B	20.3	1.0	0.1	3.67E-07	-6.87	3.60E-08	Uncertain
KAV04B	21.2	1.0	0.1	1.50E-07	-6.87	1.47E-08	
KAV04B	21.7	1.0	0.1	2.28E-07	-6.87	2.24E-08	
KAV04B	23.9	1.0	0.1	5.58E-07	-6.86	5.47E-08	
KAV04B	27.9	1.0	0.1	1.03E-07	-6.84	1.01E-08	
KAV04B	28.4	1.0	0.1	2.13E-07	-6.84	2.09E-08	
KAV04B	30.0	1.0	0.1	5.31E-06	-6.84	5.21E-07	
KAV04B	30.5	1.0	0.1	9.56E-08	-6.83	9.38E-09	Uncertain
KAV04B	31.9	1.0	0.1	6.36E-07	-6.83	6.24E-08	
KAV04B	33.0	1.0	0.1	1.04E-07	-6.82	1.02E-08	Uncertain
KAV04B	36.4	1.0	0.1	5.39E-08	-6.74	5.29E-09	Uncertain
KAV04B	40.5	1.0	0.1	1.03E-05	-6.72	1.01E-06	
KAV04B	42.1	1.0	0.1	4.01E-06	-6.72	3.94E-07	
KAV04B	43.0	1.0	0.1	2.40E-06	-6.71	2.35E-07	
KAV04B	44.6	1.0	0.1	2.83E-05	-6.71	2.77E-06	
KAV04B	44.9	1.0	0.1	6.72E-06	-6.7	6.59E-07	
KAV04B	46.4	1.0	0.1	3.17E-05	-6.7	3.11E-06	
KAV04B	47.3	1.0	0.1	1.06E-05	-6.69	1.04E-06	
KAV04B	48.8	1.0	0.1	1.78E-05	-6.68	1.75E-06	
KAV04B	49.9	1.0	0.1	6.26E-05	-6.67	6.14E-06	
KAV04B	51.3	1.0	0.1	8.30E-05	-6.68	8.14E-06	
KAV04B	52.3	1.0	0.1	6.12E-05	-6.67	6.01E-06	
KAV04B	53.2	1.0	0.1	5.22E-06	-6.67	5.12E-07	
KAV04B	53.8	1.0	0.1	1.35E-07	-6.66	1.32E-08	
KAV04B	56.8	1.0	0.1	9.83E-06	-6.66	9.65E-07	
KAV04B	59.2	1.0	0.1	1.99E-06	-6.65	1.95E-07	Uncertain
KAV04B	59.8	1.0	0.1	3.65E-05	-6.65	3.58E-06	
KAV04B	61.0	1.0	0.1	1.49E-07	-6.65	1.46E-08	
KAV04B	61.3	1.0	0.1	7.47E-08	-6.64	7.33E-09	
KAV04B	63.3	1.0	0.1	8.03E-08	-6.64	7.88E-09	
KAV04B	64.0	1.0	0.1	2.39E-08	-6.63	2.34E-09	
KAV04B	67.8	1.0	0.1	5.98E-07	-6.62	5.87E-08	
KAV04B	69.1	1.0	0.1	4.86E-07	-6.61	4.76E-08	Uncertain
KAV04B	69.6	1.0	0.1	1.68E-07	-6.6	1.64E-08	
KAV04B	70.4	1.0	0.1	3.62E-07	-6.6	3.55E-08	
KAV04B	71.2	1.0	0.1	2.22E-08	-6.6	2.18E-09	Uncertain
KAV04B	71.6	1.0	0.1	2.78E-08	-6.6	2.73E-09	Uncertain
KAV04B	73.5	1.0	0.1	7.03E-08	-6.59	6.90E-09	
KAV04B	74.8	1.0	0.1	1.07E-07	-6.59	1.05E-08	Uncertain
KAV04B	75.6	1.0	0.1	2.34E-06	-6.54	2.30E-07	
KAV04B	77.0	1.0	0.1	6.43E-07	-6.53	6.31E-08	
KAV04B	77.5	1.0	0.1	1.78E-06	-6.53	1.75E-07	
KAV04B	79.0	1.0	0.1	3.56E-07	-6.51	3.49E-08	
KAV04B	80.9	1.0	0.1	8.06E-08	-6.51	7.90E-09	
KAV04B	81.6	1.0	0.1	7.78E-09	-6.51	7.63E-10	Uncertain
KAV04B	85.9	1.0	0.1	1.58E-07	-6.48	1.55E-08	
KAV04B	87.0	1.0	0.1	3.44E-08	-6.45	3.38E-09	

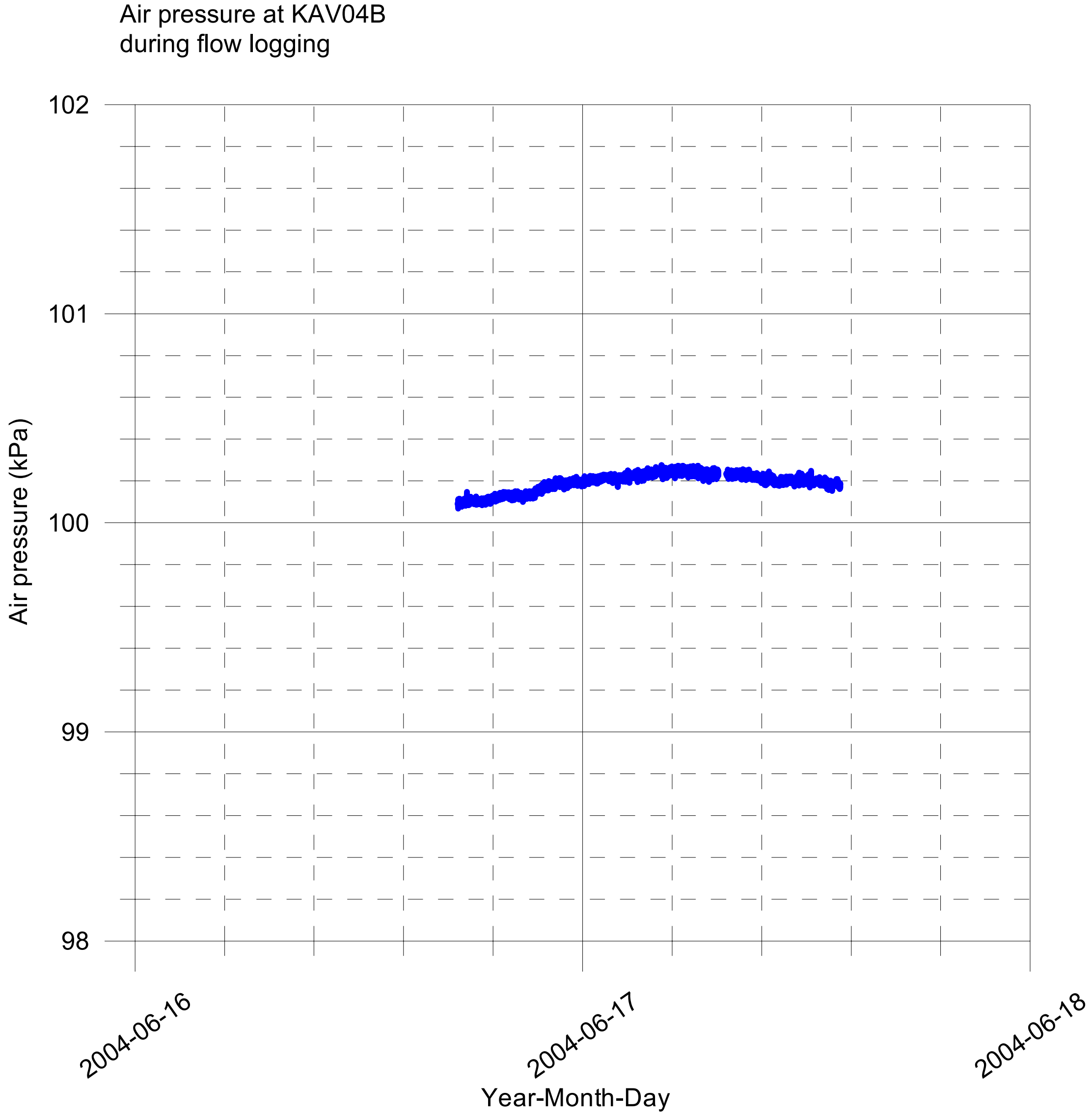
PFL - DIFFERENCE FLOW LOGGING - Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_W (m)	d_L (m)	Q_2 (m^3/s)	dh_2 (m)	TD (m^2/s)	Comments
KAV04B	87.4	1.0	0.1	1.19E-08	-6.42	1.17E-09	
KAV04B	89.0	1.0	0.1	2.03E-07	-6.48	1.99E-08	
KAV04B	91.0	1.0	0.1	2.38E-07	-6.47	2.33E-08	
KAV04B	91.4	1.0	0.1	2.01E-07	-6.47	1.98E-08	
KAV04B	92.7	1.0	0.1	3.19E-07	-6.47	3.13E-08	
KAV04B	93.8	1.0	0.1	4.62E-06	-6.47	4.53E-07	
KAV04B	95.5	1.0	0.1	2.32E-06	-6.47	2.28E-07	

Head during flow logging in borehole KAV04B

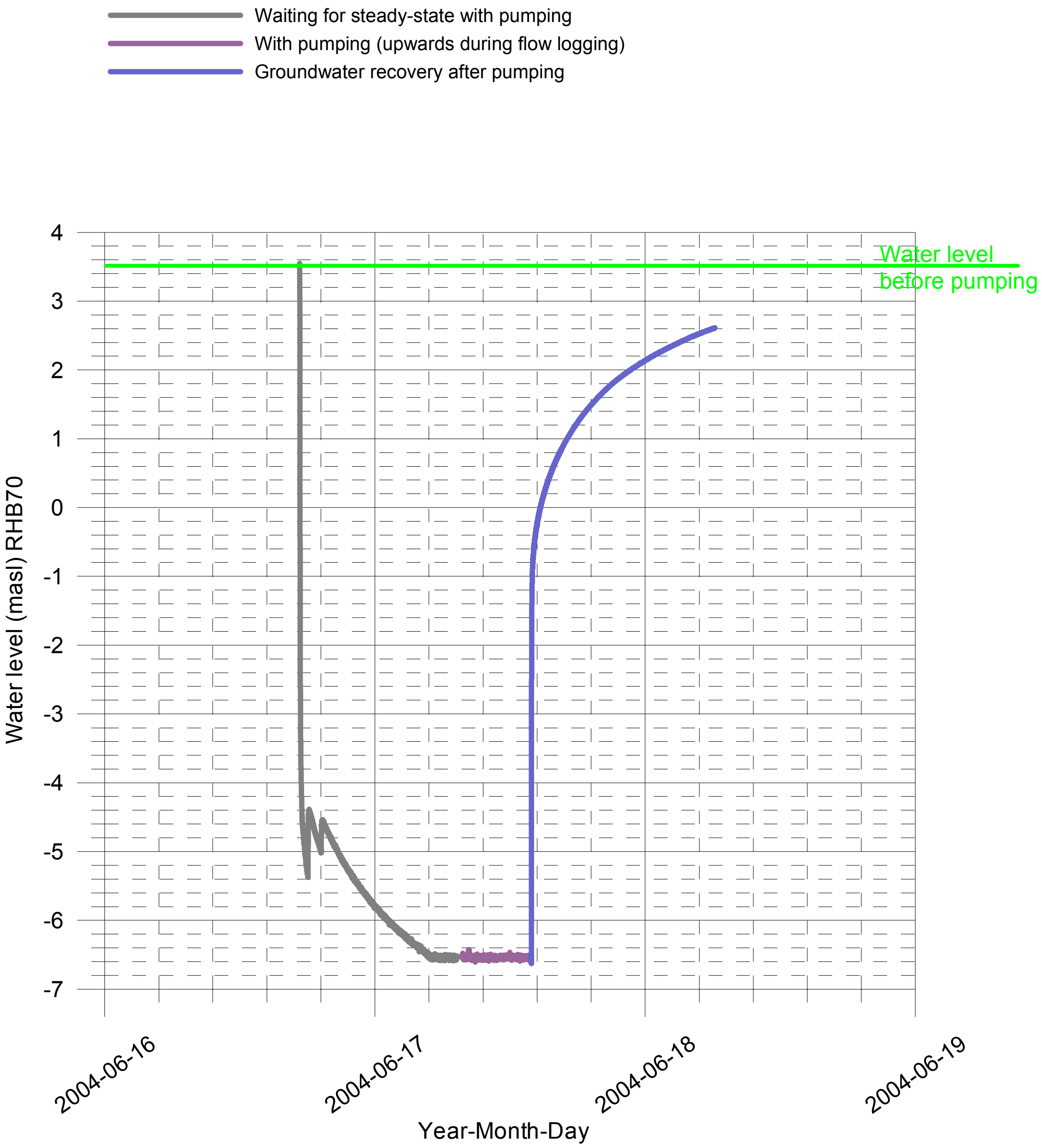
Head(masl)= (Absolute pressure (Pa) - Airpressure (Pa) + Offset) /(1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = 2460 Pa (Correction for absolut pressure sensor)




Air pressure at KAV04B
during flow logging
102
101
100
99
98
Air pressure (kPa)
2004-06-16
2004-06-17
2004-06-18
Year-Month-Day

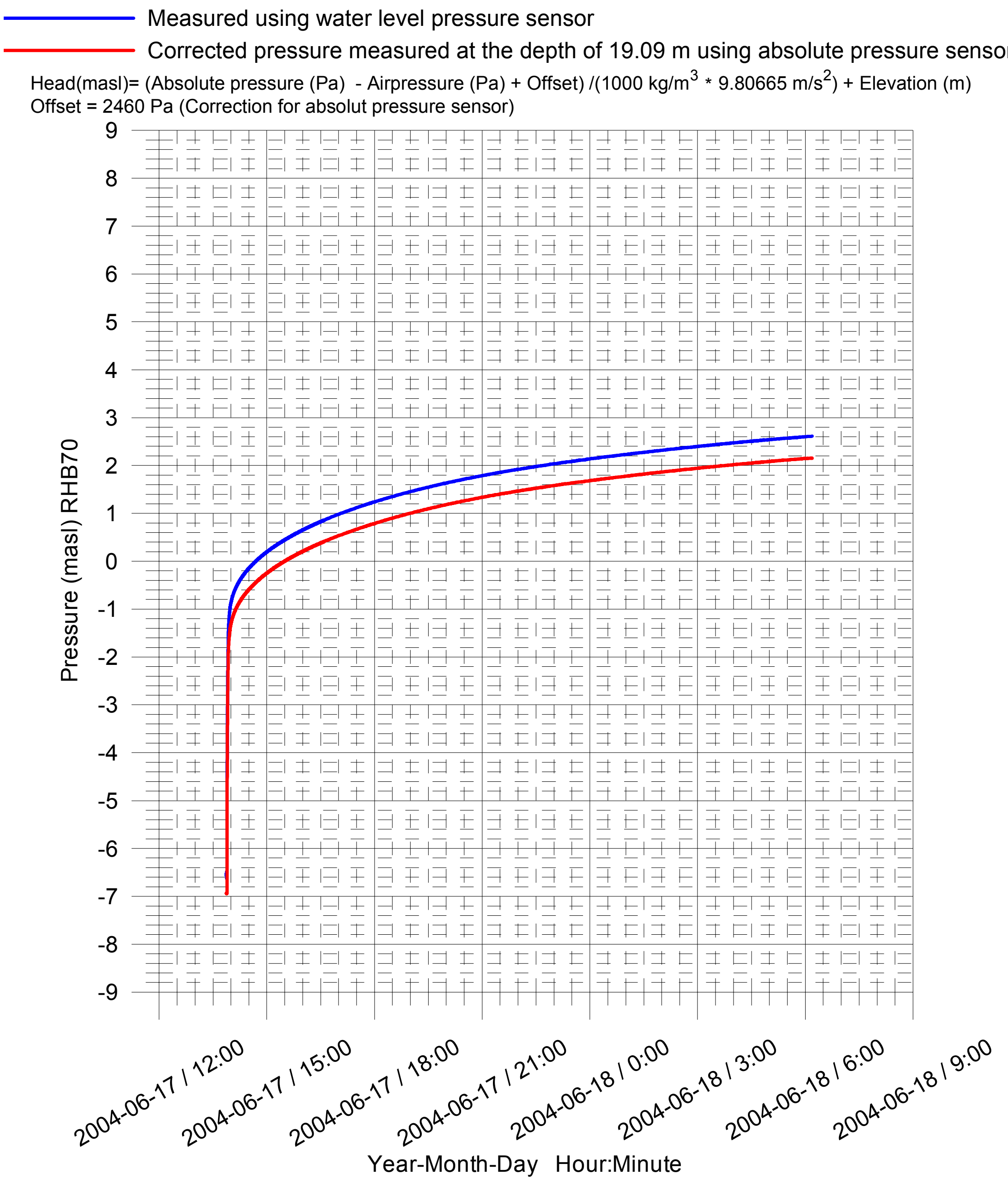
Appendix 17.3

Water level during difference flow logging
Borehole KAV04B, Ävrö

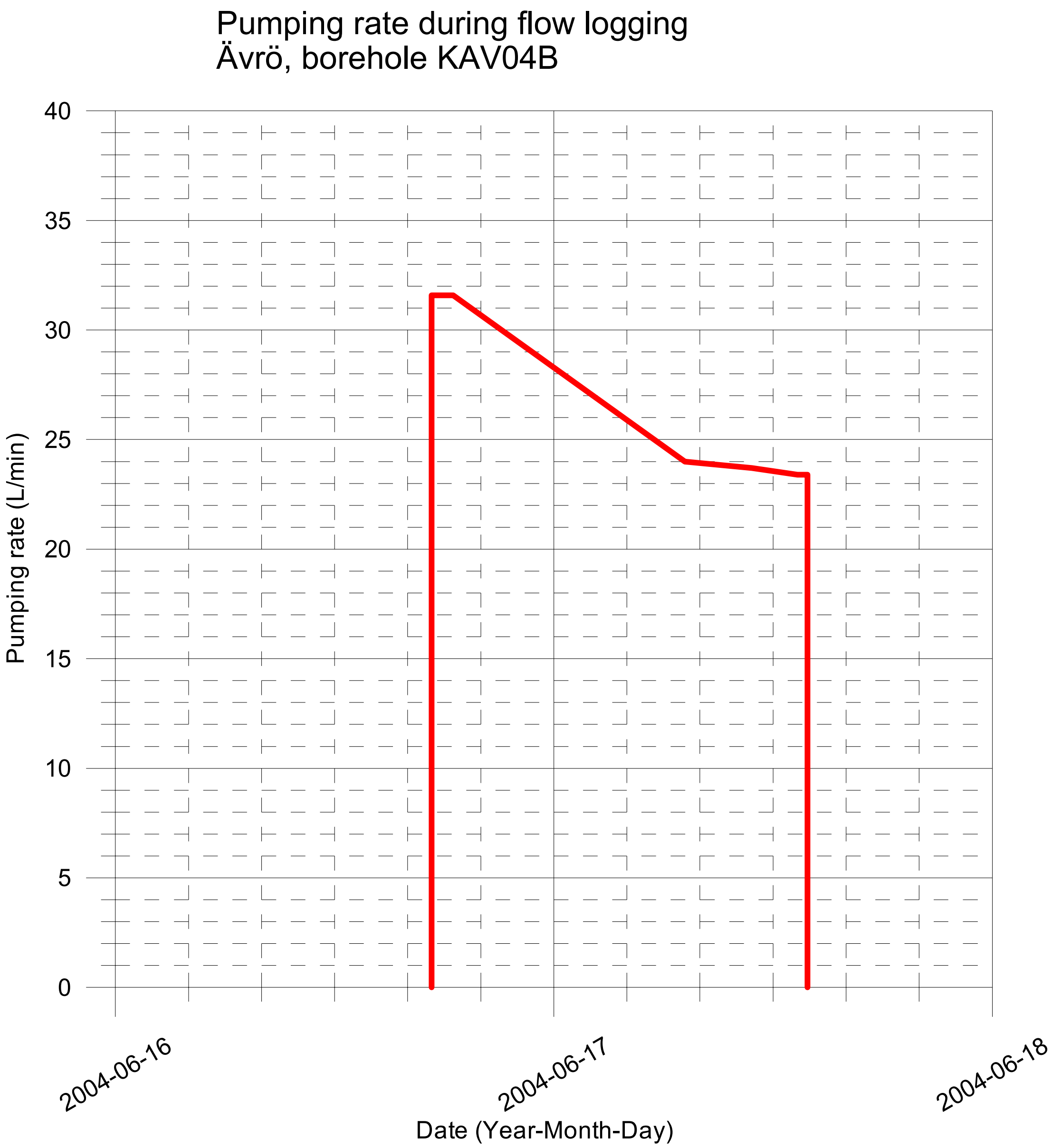


Appendix 17.4

Groundwater recovery after pumping



Appendix 17.5



Appendix 18.1

Calculation of conductive fracture frequency

SecUp (m)	SecLow (m)	Number Of Fractures, Total	Number Of Fractures 10–100 (ml/h)	Number Of Fractures 100–1,000 (ml/h)	Number Of Fractures 1,000–10,000 (ml/h)	Number Of Fractures 10,000–100,000 (ml/h)	Number Of Fractures 100,000–1,000,000 (ml/h)
20	25	4	0	2	2	0	0
25	30	2	0	2	0	0	0
30	35	4	0	2	1	1	0
35	40	1	0	1	0	0	0
40	45	5	0	0	1	3	1
45	50	4	0	0	0	2	2
50	55	4	0	1	0	1	2
55	60	3	0	0	1	1	1
60	65	4	1	3	0	0	0
65	70	3	0	1	2	0	0
70	75	5	1	2	1	0	0
75	80	4	0	0	4	0	0
80	85	2	1	1	0	0	0
85	90	4	1	3	0	0	0
90	95	4	0	2	1	1	0
95	100	1	0	0	1	0	0

Appendix 18.2

Simpevarp, Borehole KAV04B
Calculation of conductive fracture frequency