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Äspö Hard Rock Laboratory

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Abstract

The Posiva Flow Log, Difference Flow Method (PFL DIFF) uses a flowmeter that incorporates a flow guide and can be used for relatively quick determinations of hydraulic conductivity and hydraulic head in fractures/fractured zones in cored boreholes. This report presents the main principles of the methods as well as the results of measurements carried out in an underground borehole KA2051A01 at the Äspö Hard Rock Laboratory, Sweden, in June 2011.

The flow logging measurements were done with a 1 m test section by moving the measurement tool in 0.1 m steps. This method was used to flow log the entire measurable part of the borehole. The borehole was partially closed during the measurements. Pressure in the borehole was controlled by adjusting flow from the partially closed borehole. The flow measurement was repeated using a two different pressure state in the borehole.

The electrical conductivity (EC) and temperature of borehole water were also measured. The EC measurements were used to study the occurrence of saline water in the borehole.

The outflow from the borehole was measured during the time the borehole was open or partially closed for measurements.

Sammanfattning

Posiva Flow Log, Differensflödesloggning (PFL DIFF) är en snabb metod för bestämning av transmissiviteten och hydraulisk tryckhöjd i borrhålssektioner och sprickor/sprickzoner i kärnborrhål. Denna rapport presenterar huvudprinciperna för metoden och resultat av mätningar utförda i borrhål KA2051A01 inom Äspölaboratoriet, Sverige, i juni 2011.

Flödesmätningarna gjordes med en 1 m lång testsektion som förflyttades successivt i steg om 0,1 m i den mätbara delen av borrhålet. Borrhålet var delvis stängt under mätningarna. Tryck i borrhålet förändrades genom att justera flödet från borrhålet. Flödesmätningarna utfördes i två tryckförhållanden i borrhålet.

Elektrisk konduktivitet (EC) och temperatur på borrhålsvattnet mättes också. EC-mätningarna användes för att studera förekomsten av saltvatten i borrhålet.

Utflödet från borrhålet mättes under tiden detta var öppet eller delvis öppet för mätningarna.

Contents

1 Introduction

The core drilled borehole KA2051A1 at Äspö, Sweden was measured using the Posiva Flow Log, Difference Flow Method (PFL DIFF) which provides a swift, multifaceted characterization of a borehole. The measurements were conducted between June 11 and June 15, 2011. The borehole is located in the Äspö tunnel at the Äspö Hard Rock Laboratory (HRL).

KA2051A1 is 319.84 m long and its inclination at its reference point at –276.61 m.a.s.l. is –34.8° from the horizontal plane. The borehole interval 0–3.14 m is cased and its inner diameter is 80 mm. The interval between c. 3.14 m and 319.84 m is core drilled with a diameter of c. 76 mm. The borehole interval 67.26–119.59 m is grouted.

The location of KA2051A01 at the Äspö tunnel is illustrated in Figure 1-1.

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

This document reports the results acquired by PFL DIFF in borehole KA2051A01. Measurements and results presented in this report were undertaken in the framework of the project TDUP002 towards extending the tunnel system at the Äspö Hard Rock Laboratory (HRL). The measurements were carried out in accordance to SKB's internal controlling document AP TDUP002-11-006. The controlling documents for performing according to this Activity Plan are listed in Table 1-1. The list of the controlling documents excludes the assignment-specific quality plans. Both the Activity Plan and the Method Descriptions are SKB's internal controlling documents. The measurement data and the results were delivered to the SKB site characterization database SICADA and are traceable by the Activity Plan number.

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

Activity Plan	Number	Version
Difference flow logging in borehole KA2051A01 and KA3007A01	AP TDUP002-11-006	1.0

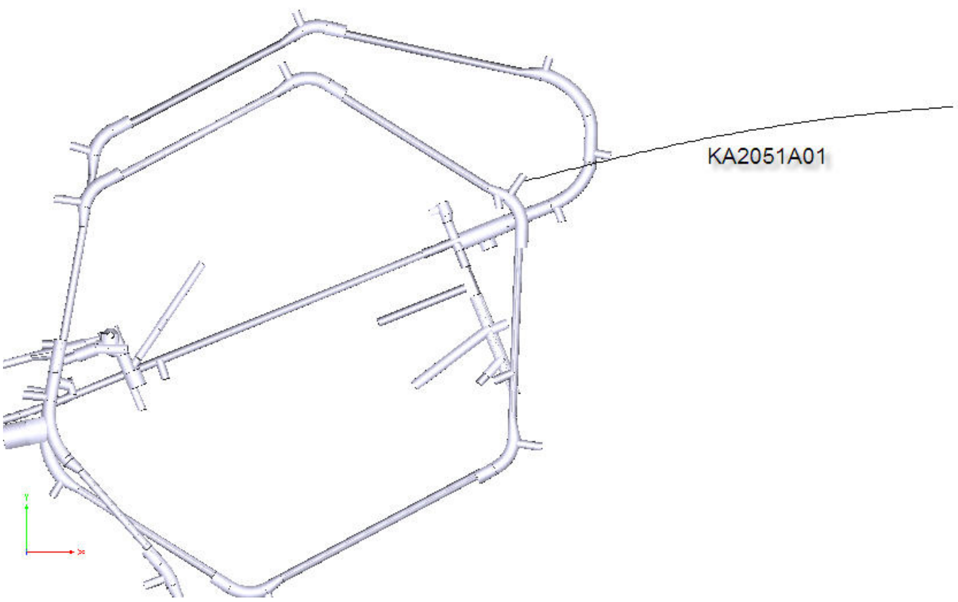

Figure 1-1. Tentative location of boreholes KA2051A01, KA3007A01 and KBTUN in the Äspö tunnel.

2 Objective and scope

The main objective of the PFL DIFF measurements in KA2051A01 was to identify water-conductive sections/fractures suitable for subsequent hydro-geochemical characterisation. Secondly, the measurements aimed at a hydrogeological characterisation, which includes the estimates of the transmissivity of tested sections and detected fractures. Based on the results of these investigations, a more detailed characterisation of flow anomalies along the borehole, e.g., an estimate of the conductive fracture frequency (CFF), may be obtained.

Besides difference flow logging, the measurement programme also included supporting measurements, performed in order to gain a better understanding of the overall hydrogeochemical conditions. These measurements included the electrical conductivity (EC) and the temperature of the borehole fluid as well as the single-point resistance of the borehole wall. The flow measurement and the single-point resistance measurement were used to locate flowing fractures. Furthermore, the flow rate out from the open or partially closed borehole was recorded.

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.

3 Principles of measurement and interpretation

3.1 Measurements

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

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

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

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

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

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

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

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

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

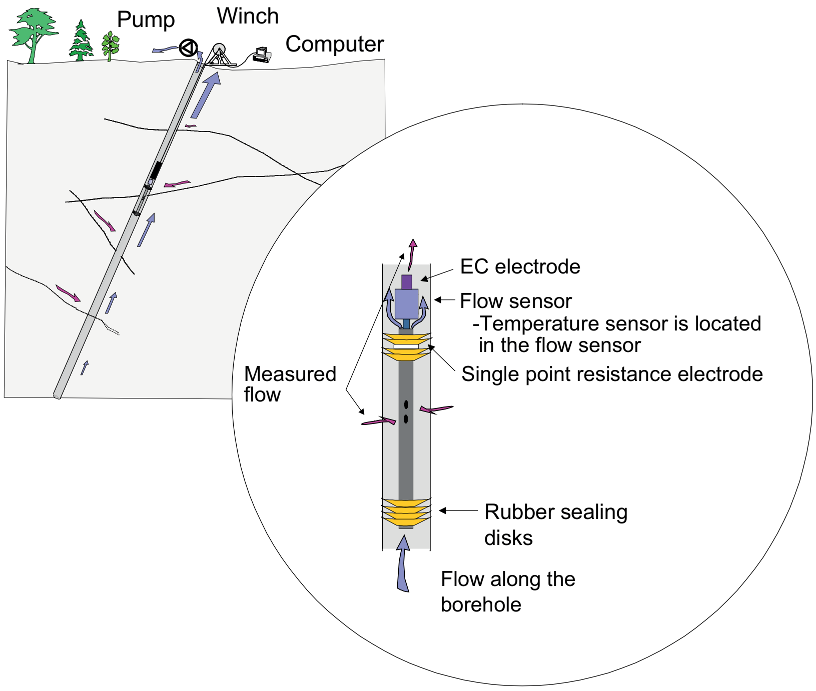

Figure 3-1. *Schematic of the probe used in the PFL DIFF.*

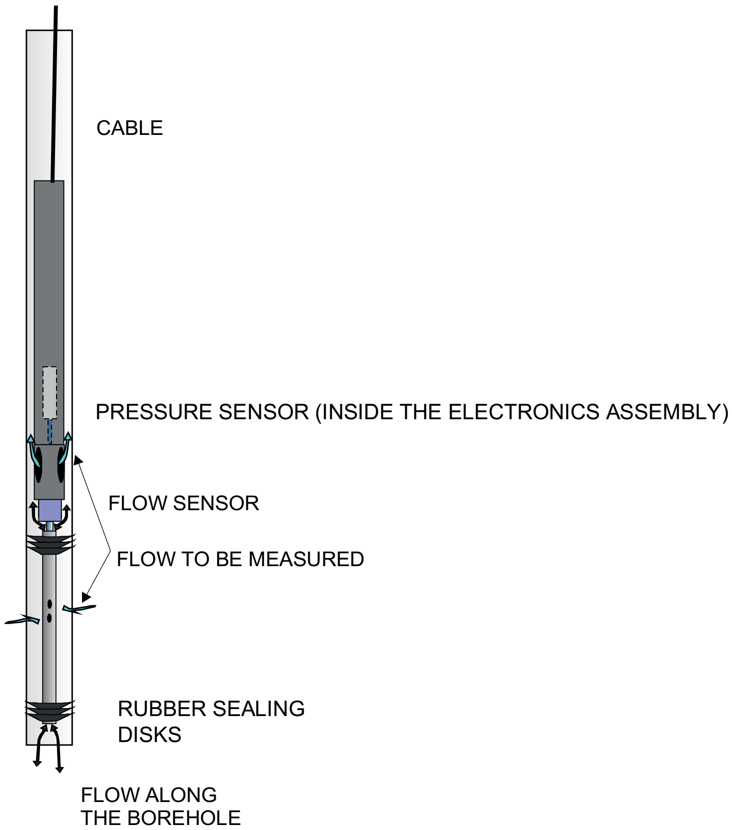

Figure 3-2. *The absolute pressure sensor is located inside the electronics assembly and connected to the borehole water through a tube.*

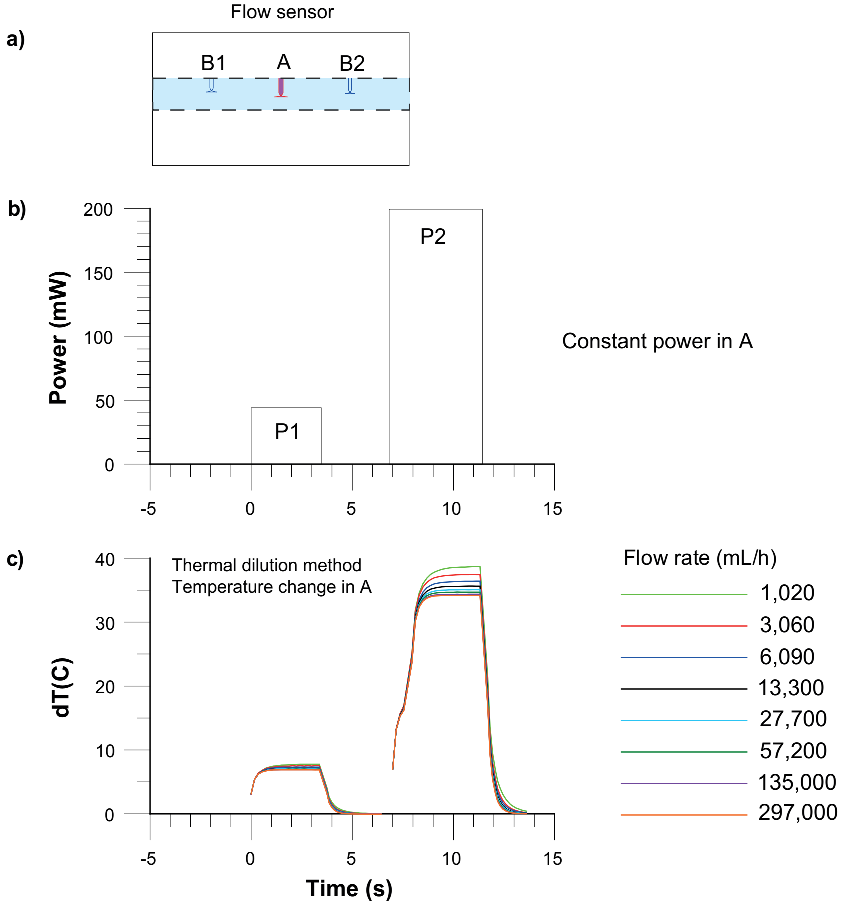

Figure 3-3. *Flow rate measurement.*

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

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

3.2 Interpretation

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

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

where

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

Q is the flow rate into the borehole,

T is the transmissivity of the test section,

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

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

where

r_0 is the radius of the well and

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

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

$$Q_{S0} = T_S \cdot a \cdot (h_S - h_0) \qquad 3\text{-}3$$

$$Q_{S1} = T_S \cdot a \cdot (h_S - h_1) \qquad 3\text{-}4$$

where

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

Q_{S0} and Q_{S1} are the measured flow rates in the test section,

T_S is the transmissivity of the test section and

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

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

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

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

$$h_S = (h_0 - b \cdot h_1)/(1\text{-}b) \qquad 3\text{-}5$$

$$T_S = (1/a)\ (Q_{S0} - Q_{S1})/(h_1 - h_0) \qquad 3\text{-}6$$

where

$b = Q_{S0}/Q_{S1}$

The transmissivity (T_f) and hydraulic head (h_f) of individual fractures can be calculated provided that the flow rates at the individual fractures are known. Similar assumptions to those employed above must be used (a steady-state cylindrical flow regime without skin zones).

$$h_f = (h_0 - b \cdot h_1)/(1\text{-}b) \qquad 3\text{-}7$$

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

where

Q_{f0} and Q_{f1} are the flow rates at a fracture and h_f and T_f are the hydraulic head (far away from borehole) and transmissivity of a fracture, respectively.

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

4 Equipment specification

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

Type of instrument:	PFL DIFF probe
Borehole diameters:	56 mm, 66 mm and 76 mm (or larger)
Length of test section:	The flow guide length can be varied
Method of flow measurement:	Thermal pulse and thermal dilution.
Range and accuracy of measurement:	See Table 4-1.
Additional measurements:	Temperature, Single point resistance, Electrical conductivity of water, Water pressure
Winch:	Mount Sopris Wna 10, 0.55 kW, conductors, Gerhard-Owen cable head.
Depth determination	Based on a digital distance counter.
Logging computer:	PC (Windows 7)
Software	Based on MS Visual Basic
Total power consumption:	1.5–2.5 kW depending on the type of pump employed
Calibration of flow probe:	May 2011 (Probe PFL12)

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

Table 4-1. Range and accuracy of sensors.

Sensor	Range	Accuracy
Flow	30–300,000 mL/h	± 10% curr.value
Temperature (central thermistor)	0–50°C	0.1°C
Temperature difference (between outer thermistors)	–2 – +2°C	0.0001°C
Electrical conductivity of water (EC)	0.02–11 S/m	± 5% curr.value
Single point resistance (SPR)	5–500,000 Ω	± 10% curr.value
Groundwater level sensor	0–0.1 MPa	± 1% full-scale
Air pressure sensor	800–1,060 hPa	± 5 hPa
Absolute pressure sensor	0–20 MPa	± 0.01% full-scale

5 Execution of measurements

5.1 General

The work commission was performed according to Activity Plan AP TDUP002-11-006 following the SKB Method Description 322.011e, Version 2.0 (Method description for Difference Flow Logging). The Activity Plan and the Method Description are both SKB's internal controlling documents. Prior to the measurements, the downhole tools and the measurement cable were disinfected. Time was synchronized to local Swedish time, UTC +2 (Central European Summer Time). The activity schedule of the borehole measurements is presented in Table 5-1. The items and activities in Table 5-1 are the same as in the Activity Plan.

Logging cables, wires, and pipe strings are exposed to stretching when lowered into a vertical or sub-vertical borehole. This will introduce a certain error in defining the position of a test tool connected to the end of a logging cable. A linear length calibration was made based on borehole casing length, on the cable counter and on length marks marked into the measurement cable.

The outflow from the open or partially closed borehole was measured during the measurements.

The dummy logging (Item 7) of the borehole is done in order to assure that the measurement tools do not get stuck in the borehole. The dummy also collects solid material from the borehole wall. The solid material in the dummy is used for evaluation whether it is safe to continue with other logging tools.

The overlapping flow logging (Item 8, Item9 and Item 9 extra) was carried out in the partially closed borehole in a three different difference pressure state with a 1 m section length and in 0.1 m length increments (step length). Different pressure states in the borehole were achieved by adjusting the partially closed borehole outflow. After these measurements the borehole was closed.

The electrical conductivity (EC) and temperature of borehole water (Item 8, Item 9 and Item 9 extra) were measured during flow logging measurements.

The interval between 67.26 and 119.59 m is not representative as properties of the rock because of grouting.

Table 5-1. Flow logging and testing in KA2051A01. Activity schedule.

Item	Activity	Explanation	Date
2	Mobilisation at site	Unpacking the trailer.	2011-06-10
7	Dummy logging	Borehole stability/risk evaluation.	2011-06-10–2011-06-11
8	Overlapping flow logging – partially closed borehole	Section length L_w=1 m. Step length dL=0.1 m. Measurement depth 316.15– 4.45 m. Absolute pressure from 2,730 kPa to 1,000 kPa.	2011-06-11–2011-06-13
9	Overlapping flow logging – partially closed borehole	Section length L_w=1 m. Step length dL=0.1 m. Measurement depth between 316.55–3.45 m. Absolute pressure from 3,180 kPa to 1,670 kPa.	2011-06-13– 2011-06-15
9 extra	Selective overlapping flow logging – partially closed borehole	Section length L_w=1 m. Step length dL=0.1 m. Measurements between 141.18– 34.84 m. Absolute pressure from 2,520 kPa to 1,990 kPa.	2011-06-15
–	Closing of the borehole	–	2011-06-15
10	Demobilisation	Packing the trailer.	2011-06-15–2011-06-16

5.2 Nonconformities

An extra measurement was made (Item 9 extra) because flow rate was over the measurement limit at the 129.8 m fracture. This and other high flowing intervals were re-measured (re-measured intervals were c. 140–128 m, c. 67–60 m and c. 39–35 m). The flow measurement was repeated by adjusting the partially closed borehole outflow to minimum. The borehole leaked still through the rubber cone (installed in to the casing tube) so much that fracture flow at 129.8 m exceeded the measurement limit.

The actual borehole outflow was probably bigger than the manually measured borehole outflow. Manual outflow measurement was difficult to execute because water leaked not only at the rubber cone but also at the connection of extra casing tube.

It was not physically possible to measure approximately 0.95 m of the bottom of the borehole. There was a centralizer in the measurement device, which reduces the measured distance by c. 0.85 m. The rubber sealing disks in the device must also be flipped before the measurement begins. This reduces the measured distance for approximately 0.10 m. It is possible that there were also drill cuttings at the bottom of the borehole.

6 Results

6.1 Length calibration

6.1.1 SPR measurement

An accurate length scale for the measurements is difficult to achieve in long boreholes. The main cause of inaccuracy is the stretching of the logging cable. The stretching depends on the tension on the cable, the magnitude of which in turn depends, among other things, on the inclination of the borehole and the roughness (friction properties) of the borehole wall. The cable tension is larger when the borehole is measured upwards. The cables, especially new cables, may also stretch out permanently.

A linear length calibration was made based on borehole casing length, the cable counter and length marks marked on the measurement cable. The borehole casing length at the upper end of the borehole was detected by single-point resistance (SPR) measurements using the SPR sensor of the PFL DIFF probe. At the end of the borehole measurement length was adjusted using cable length marks.

6.1.2 Estimated error in location of detected fractures

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

1. The point interval in the overlapping mode flow measurements is 0.1 m. This could cause an error of ± 0.05 m.
2. The length of the test section is not exact. The specified section length denotes the distance between the nearest upper and lower rubber sealing disks. Effectively, the section length can be larger. At the upper end of the test section there are four rubber sealing disks. The distance between them is 5 cm. This will cause rounded flow anomalies: a flow may be detected already when a fracture is situated between the upper rubber sealing disks. These phenomena can cause an error of ± 0.05 m when the short step length (0.1 m) is used.
3. The cable stretches under tension. When the probe is lifted upwards at c. 1,000 m the tension can be c. 175 kg. When it is lowered at the same length, the tension can be c. 75 kg. This difference could cause a depth difference of c. 3 m between the measurements at depth of c. 1,000 m. The tension values here are estimates and can vary greatly depending on the device setup and hole properties.
4. The total error in the worst case can be estimated. With a 0.1 m point interval the error would be:

   $E = 0.05\ m + 0.05\ m + d \cdot 0.002$

   where E is the total estimated error and d is the length of the probe shown by the cable counter of the winch. Note that this is only a rough estimate and it is subject to change. It should also be noted that this is only one way of estimating the error. Experience has shown that when holes with length marks have been measured the error has been approximately 1 m at the length of c. 1,000 m.

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

6.2 Electrical conductivity and temperature

6.2.1 Electrical conductivity and temperature of borehole water

The electrical conductivity of the borehole water (borehole EC) was measured during the flow logging measurements. The measurement was performed upwards, see Appendices 2.1 (linear scale) and 2.2 (logarithmic scale).

Borehole EC profile was relatively constant during measurements in different borehole pressure states. Borehole EC was higher at the bottom – c. 140 m of the borehole, average value about 1.1 S/m. At the fracture area c. 140–129 m borehole EC decreases to about 0.85 S/m.

The temperature of the borehole water was measured simultaneously with the EC and flow measurements. The EC values are temperature corrected to 25°C to make them more comparable with other EC measurements (Heikkonen et al. 2002). The temperature plots in Appendix 2.3 have the same length axis as the EC plots in 2.1 and 2.2. There is a small difference in temperature profiles during different measurements.

6.3 Absolute pressure and outflow measurements

Absolute pressure was registered together with the other measurements in Items 8–9 extra. The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. The hydraulic head along the borehole at natural and pumped conditions is determined in the following way. First, the monitored air pressure at the site is subtracted from the measured absolute pressure. The hydraulic head (h) at a certain elevation (z) is calculated according to the following expression:

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

where

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

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

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

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

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

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

A sensor-specific offset of 4.9 kPa is added to absolute pressure results.

The calculated head distributions are presented in Appendices 10.1–10.3. The exact z-coordinates are important in head calculation. A 10 cm error in the z-coordinate means a 10 cm error in the head.

Borehole outflow was measured manually during the measurements. The results are shown in Appendix 10.3. Three different pressure states in the borehole was achieved by adjusting the partially closed borehole outflow. After the measurements the borehole was closed.

6.4 Flow logging

6.4.1 General comments on results

The measuring programme contained several flow logging sequences. The results were plotted on the same diagram with single-point resistance (right hand side), see Appendices 3.1–3.16. SPR has a lower value on a fracture where flow is detected. Many other resistance anomalies result from other fractures and geological features. As the electrode of the SPR tool is located within the upper rubber sealing disks of the probe, the locations of resistance anomalies associated with leaky fractures coincide with the lower end of the flow anomalies.

The flow logging was performed with a 1 m section length and with 0.1 m length increments. The method (overlapping flow logging) gives the length and the thickness of conductive zones with a length resolution of 0.1 m.

The direction of small flows (< 100 mL/h) cannot be detected in the normal overlapping mode (thermal dilution method). Therefore the measurement time was longer (so that the thermal pulse method could be used) at every 1 metre interval. It is common that the flows in open underground boreholes are directed towards the borehole.

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

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

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

The explanations to the tables in Appendices 5.1–5.12 and Appendices 7.1–7.4 are given in Appendix 4.

The interval between 67.26 m and 119.59 m is not representative as properties of the rock because of grouting.

6.4.2 Transmissivity of borehole sections

The entire borehole was flow logged with a 1 m section length and with 0.1 m length increments in a two different pressure states. In the first measurement absolute pressure was from c. 2,730 kPa (head –178 m in RHB 70 scale) to 1,000 kPa head –173 m in RHB 70 scale) and in the second measurement from c. 3,180 kPa (head –137 m in RHB 70 scale) to 1,670 kPa (head –109 m in RHB 70 scale), see appendix 10.2.

Two sets of flow measurements are needed for calculation of transmissivity as described in Section 3, Equation 3-6. In this case the borehole was all the time partially closed in a different outflow and pressure state. Head in the open borehole is the water level at the top of the borehole (–276.61 m in RHB 70 scale).

The results of the flow logging measurements with a 1 m section length are presented in tables, see 5.1–5.12. Only the results with 1 m length increments are used. All borehole sections are shown in Appendices 3.1–3.16. Secup and Seclow in Appendices 5.1–5.12 are the distances along the borehole from the reference level (tunnel wall) to the upper end of the test section and to the lower end of the test section, respectively.

Pressure was measured and calculated as described in Section 6.3. h_{0FW} and h_{1FW} in Appendices 5.1–5.12 represent heads in borehole in different pressure states. The head in the borehole and calculated heads of formations or fractures are given in RHB 70 scale.

The flow rates are positive if the flow direction is from the bedrock into the borehole and vice versa. 128 sections were detected as flow yielding in the first measurement where borehole outflow was the highest. All of the flows were positive.

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

The lower and upper measurement limits of the flow are also presented in the plot (Appendix 6.1) and in the tables (see Appendices 5.1–5.12). There are theoretical and practical lower limits of flow, see Section 6.4.4.

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

The sum of all the detected flows (Q_0) was $5.2 \cdot 10^{-4}$ m^3/s (31 L/min). The average of manually measured outflow from the borehole was approximately 25 L/min during the measurement. The sum of all the detected flows (Q_1) was $3.0 \cdot 10^{-4}$ m^3/s (18 L/min). The manually measured outflow from the borehole was approximately 16 L/min during the measurement.

Sum of detected flows and manually measured flow should normally be equal. The actual borehole outflow was probably bigger than the manually measured borehole outflow. Manual outflow measurement was difficult to execute because water leaked not only at the rubber cone but also at the connection of extra casing tube. On the other hand the sum of the measured flow was uncertain because the measurement limit was exceeded.

6.4.3 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 0.1 m length increments were used for this purpose. The first step in this procedure is to identify the locations of individual flowing fractures and then evaluate their flow rates.

In cases where the fracture distance is less than one metre, it may be difficult to evaluate the flow rate. There are such cases for instance in Appendix 3.5. In these cases a stepwise increase or decrease in the flow data plot equals the flow rate of a specific fracture (filled triangles in the appendices).

The total amount of detected flowing fractures was 152. These fractures were used for transmissivity estimations. Transmissivity of fractures is presented in Appendices 7.1–7.4 and Appendix 8.

Some fracture-specific results were classified to be "uncertain." The basis for this classification is either a minor flow rate (< 30 mL/h) or unclear fracture anomalies. Anomalies are considered unclear if the distance between them is less than 1 m or their nature is unclear because of noise.

Fracture-specific transmissivities were compared with transmissivities of sections in Appendix 9. All fracture-specific transmissivities within each 1 m interval were first summed together to make them comparable with transmissivities of sections. Transmissivities of sections were calculated from the flow rates of 1 m depth increments. The obtained transmissivities are fairly consistent between the two interpretations.

6.4.4 Theoretical and practical measurement limits of flow and transmissivity

The theoretical minimum for measurable flow rate is some 30 mL/h. The upper limit of flow measurement is 300,000 mL/h. As these upper and lower limits are determined by flow calibration, it is assumed that flows can be reliably detected between the upper and lower theoretical limits in favorable borehole conditions.

In practice, the minimum measurable flow rate may be much higher. Borehole conditions may have an influence on the flow base level (i.e. noise level). Noise levels can be evaluated in intervals along the borehole where there are no flowing fractures or other complicating structures, and may vary along a borehole.

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

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

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

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

Pressure of flowing water is released when it enters into the borehole. This may lead to the release of dissolved gas and increase the quantity of gas bubbles entrained in the water. Some fractures may produce more gas than others. Sometimes, when the borehole is being measured upwards, increased noise levels are observed just above certain fractures. The reason for this is assumed to be gas bubbles.

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

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

The practical minimum for measurable flow rate is presented in Appendices 3.1–3.16 using a grey dashed line (Lower limit of flow rate). The practical minimum level of the measurable flow was evaluated using the flow data obtained in the 1 m section length measurements. The limit is an approximation. It is evaluated to obtain a limit below which there may be fractures or structures that remain undetected.

The noise level varied between 30 mL/h and 150 mL/h. It is possible to detect the existence of flow anomalies below the theoretical limit of the thermal dilution method (30 mL/h). The noise line (grey dashed line) was never drawn below 30 mL/h, because the values of flow rate measured below 30 mL/h are uncertain.

In some boreholes the upper limit of flow measurement (300,000 mL/h) may be exceeded. Such fractures or structures hardly remain undetected (as the fractures below the lower limit). There were such fractures detected during this campaign.

The practical minimum for measurable flow rate is also presented in Appendices 5.1–5.12 (Q-lower limit P) and is obtained from the plots in Appendices 3.1–3.16 (Lower limit of flow rate). The practical minimum of measurable transmissivity can be evaluated using Q-lower limit and the assumed head difference at each measurement location, see Appendices 5.1–5.12 (T_D-measl$_{LP}$). The theoretical minimum for measurable transmissivity (T_D-measl$_{LT}$) is evaluated using a Q value of 30 mL/h (the minimum theoretical flow rate using the thermal dilution method). The upper measurement limit for transmissivity can be evaluated using the maximum flow rate (300,000 mL/h) and the assumed head difference as above, see Appendices 5.1–5.12 (T_D-measl$_U$). These transmissivity limits are only qualitative because of the assumptions described in Section 6.4.2.

All three flow limits are plotted with the measured flow rates, see Appendix 6.1.The three transmissivity limits are also presented graphically, see Appendix 6.2.

Similar flow and transmissivity limits are not provided for the fracture-specific results as the limits for these are harder to define. The situation is similar for the upper flow limit. If several high-flowing fractures are positioned closer to one another than a distance of 1 m, the upper flow limit will depend on the sum of these flows, and this must be below 300,000 mL/h.

6.4.5 Sensitivity of transmissivity and the head to the ratio of flow rates

The aim was to measure flow rates in different pressure conditions in the borehole to achieve as large difference in flow rate as possible. Accuracy of interpretation depends among others on the ratio of the measured flow rates (Q_0/Q_1) (Rouhiainen 1996). Unfortunately, closing the borehole good enough was not successful and the measured flow rates remained relatively close to each other. In the situation when the measured flow rates (Q_0 and Q_1) are close to each other the calculated results are uncertain, i.e. small errors in the measured parameters (Q_0 and Q_1, borehole pressure) can cause large errors in final results (hydraulic head, transmissivity).

This can be analysed by taking partial derivatives of the Equations 3-5 and 3-6 with respect to the measured flows Q_0 and Q_1 as well as with respect to the heads h_1 and h_0 (Rouhiainen 1996).

As a simplified example it can be assumed that there is no errors in pressure measurement but the error of the measured flow rates (Q_0 and Q_1) is 10%. It is also assumed that that the errors are in the worst possible direction, positive in Q_0 and negative in Q_1. This probably not a typical case but can demonstrate the problem as a conservative case. The relative errors are:

$$\Delta h_S/h_S = 0.2/(1-b) \qquad 6\text{-}1$$

and

$$\Delta T_S/T_S = 0.1\cdot(b+1)/(b-1) \qquad 6\text{-}2$$

where

Δh_S is the error in hydraulic head,

ΔT_S is the error in transmissivity, and

$b = Q_0/Q_1$.

Relative errors are approximately the same for head and T but their significance is apparently different, Figure 6.1. If Q_0/Q_1 ratio is less than 2–3 hydraulic head hardly carries any relevant information (except possibly that all sections have head larger than –100 m). Transmissivity values could still be useful in spite of large error bars. This is because transmissivity measurement is an order of magnitude-measurement and the results are generally presented in logarithmic scale. Note that the plotter program cannot present error bars in logarithmic scale if they are larger than 100%, as at 120 m and 130 m, Figure 6.1.

If Q_0/Q_1 ratio is less than 2–3 the possibilities to calculate hydraulic head reliably is poor (assuming in this case that the flow direction is the same for Q_0 and Q_1). The error bars are not equal for each point because the ratio Q_0/Q_1 varies. The error approaches infinity when the ratio is close to one.

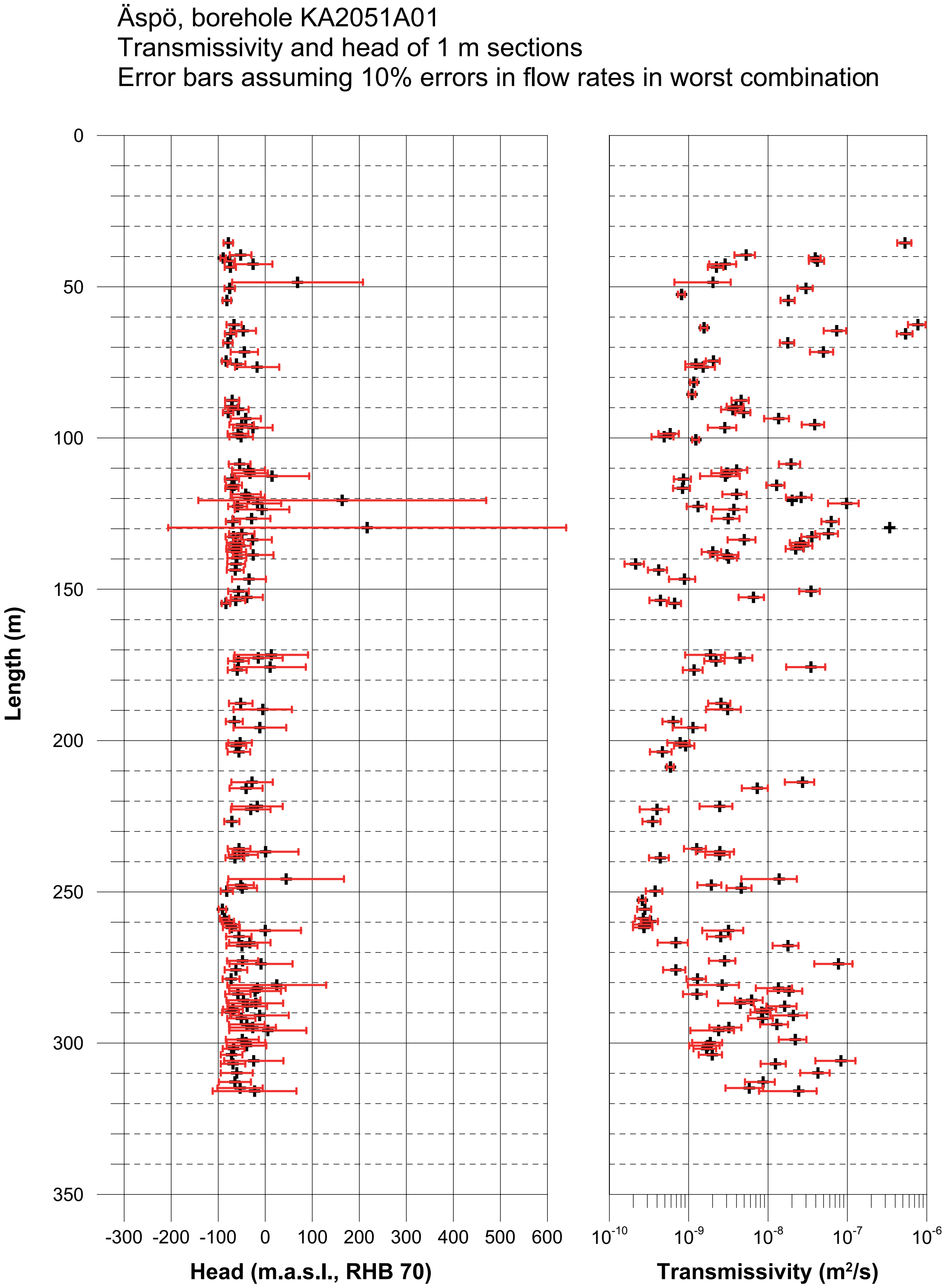

Figure 6-1. *Demonstrative plot of errors of final results depending on the ratio of Q_0/Q_1.*

7 Summary

In this study, the Posiva Flow Log, Difference Flow Method has been used to determine the location and flow rate of flowing fractures or structures in borehole KA2051A01 in the Äspö HRL, Sweden. A 1 m section length with 0.1 m length increments was used in measurements. The borehole was partially closed during the measurements. The whole borehole was measured twice and selected depths of the borehole once with different pressure states by adjusting the partially closed borehole's outflow.

It is possible to interpret transmissivity and hydraulic head of fractures if the borehole is measured in two different pressure conditions. The prerequisites to a reliable interpretation are among others that the measured flow rates are within the limits of measurements and that the ratio of the measured flow rates is large enough when measured at the same depth. These prerequisites were not completely fulfilled for technical reasons for the tight time schedule.

Length calibration was made by using the borehole's lower end as a depth mark, the cable counter and the cable's length marks. The single point resistance was measured simultaneously with the flow measurements, and thus all flow results could be length synchronized by synchronizing the single-point resistance logs.

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

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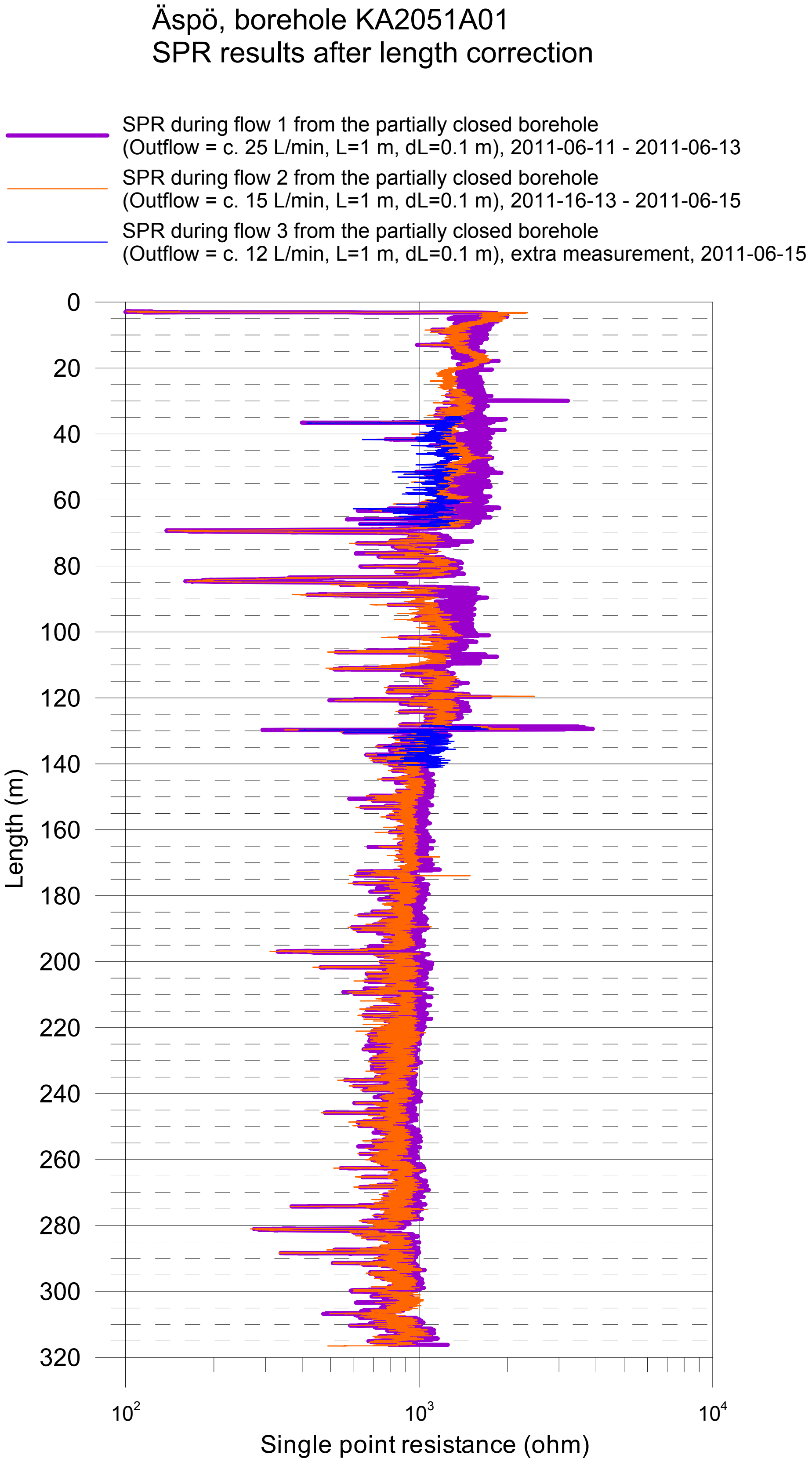
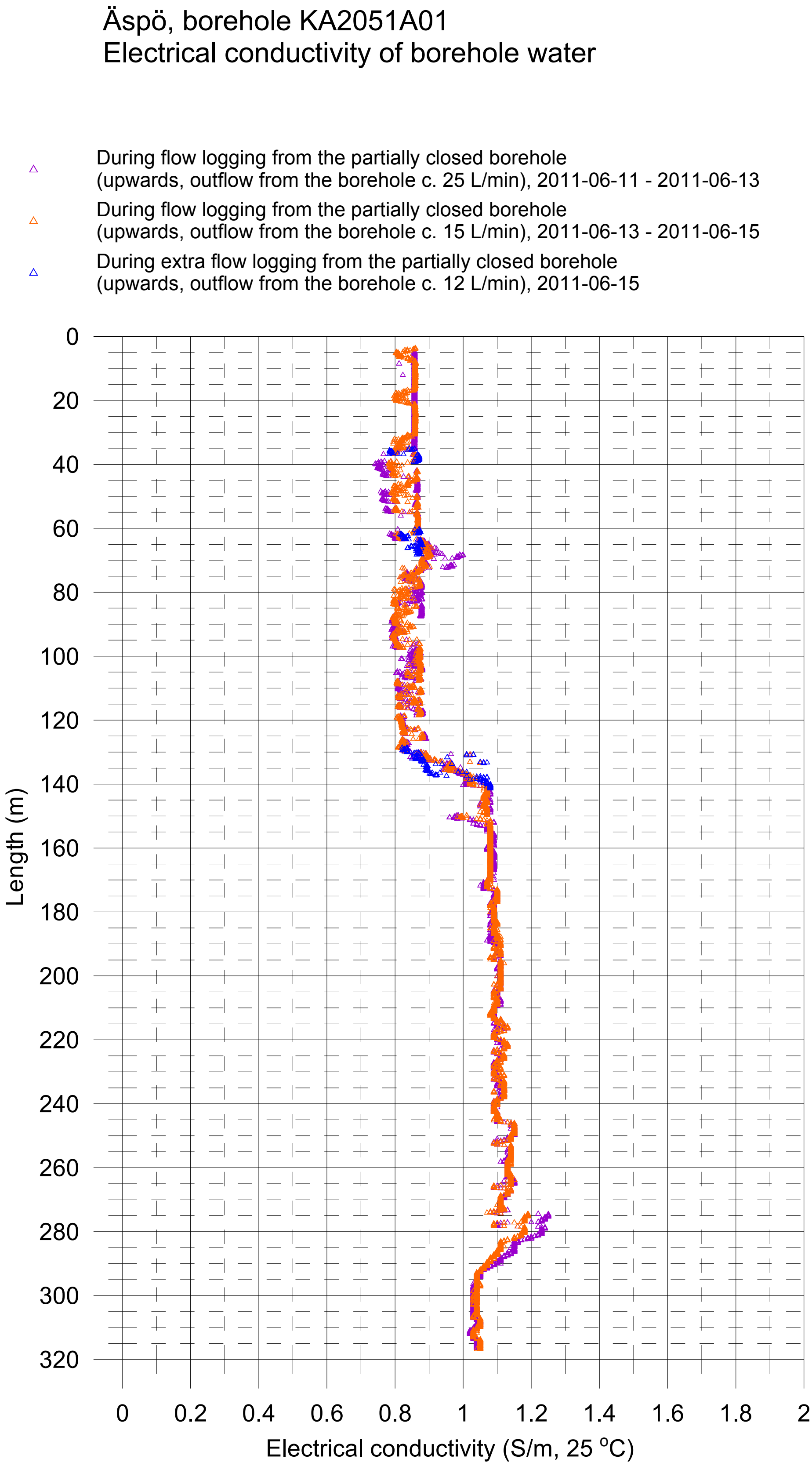
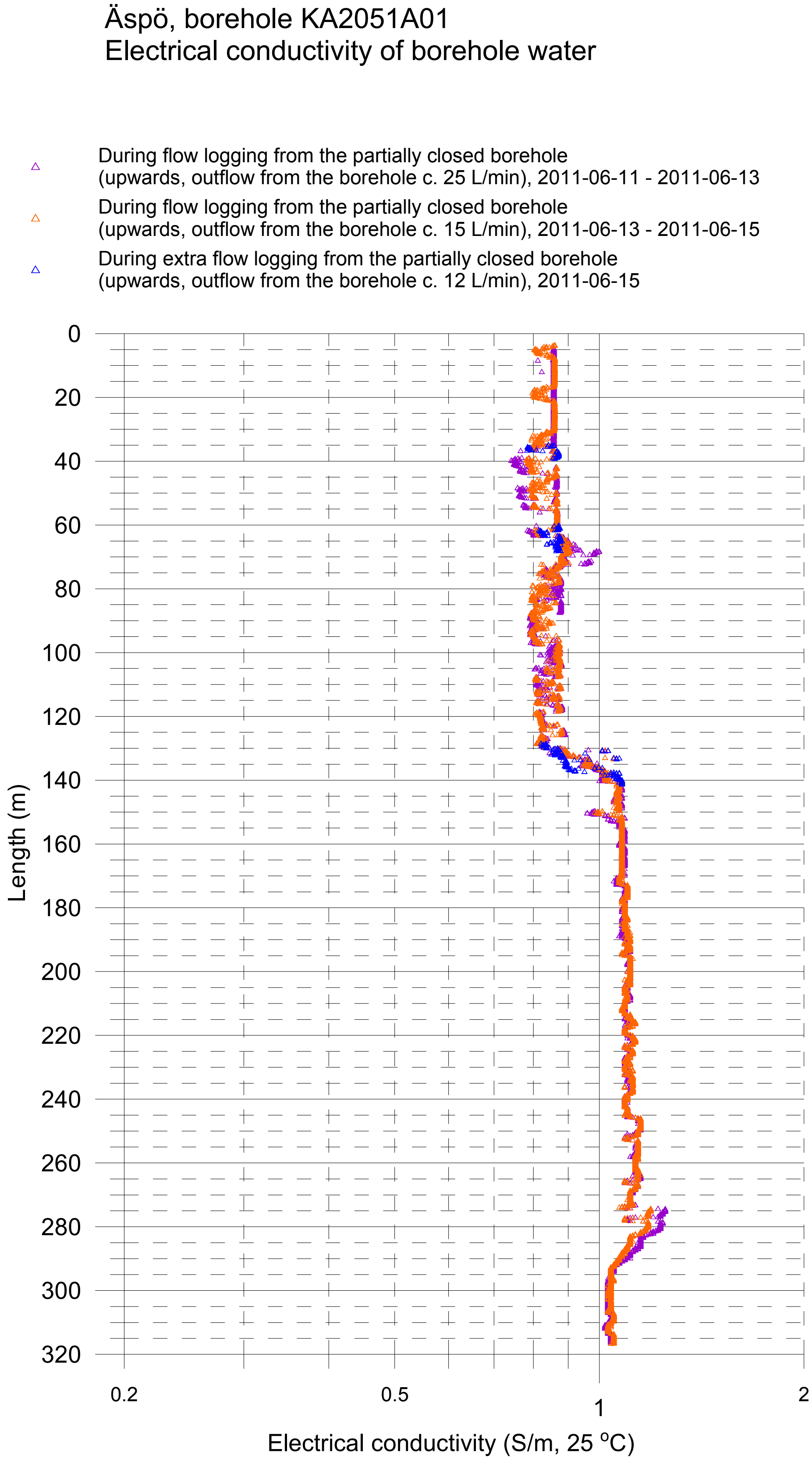
SPR results after length correction



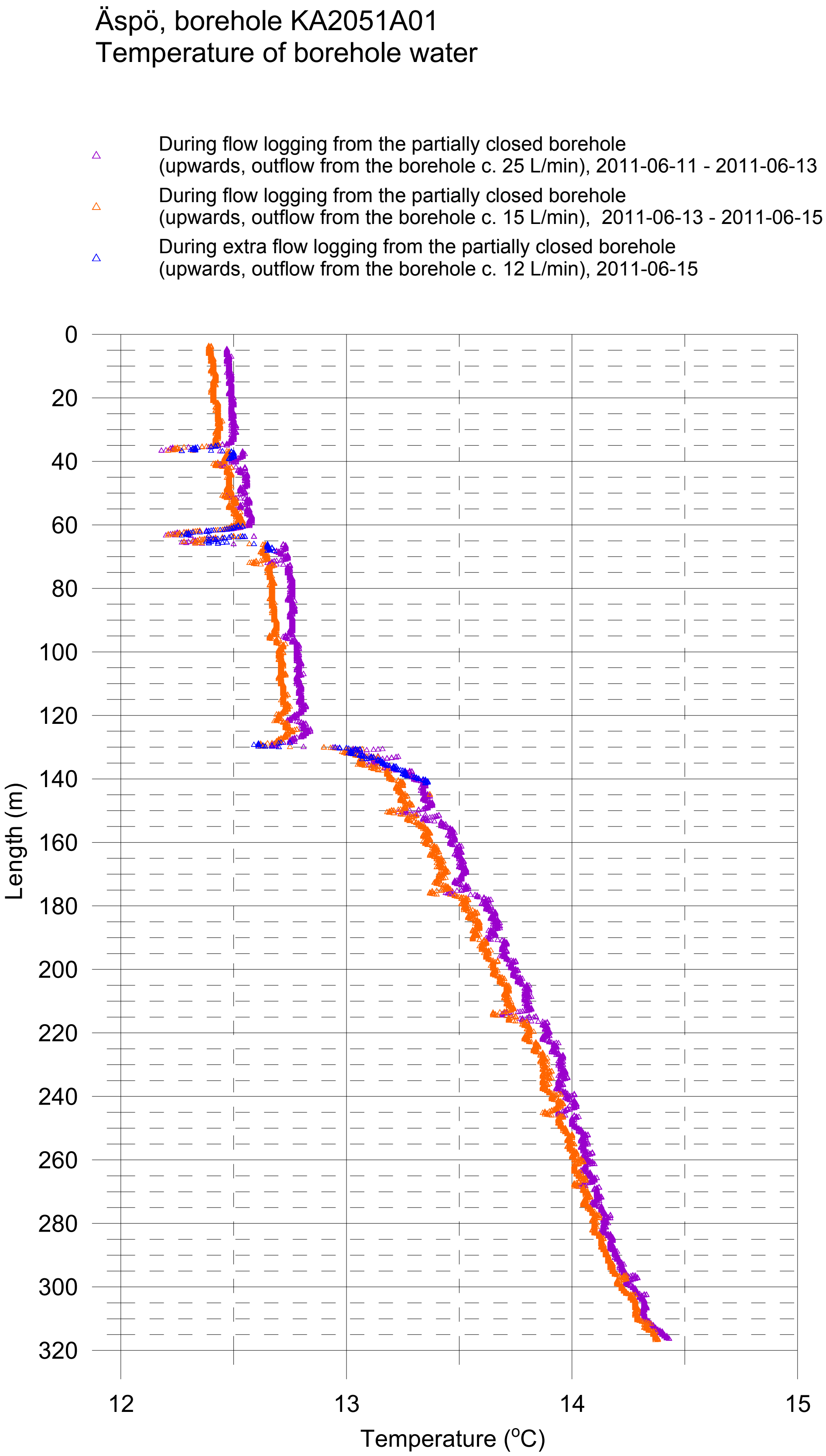
Electrical conductivity of borehole water



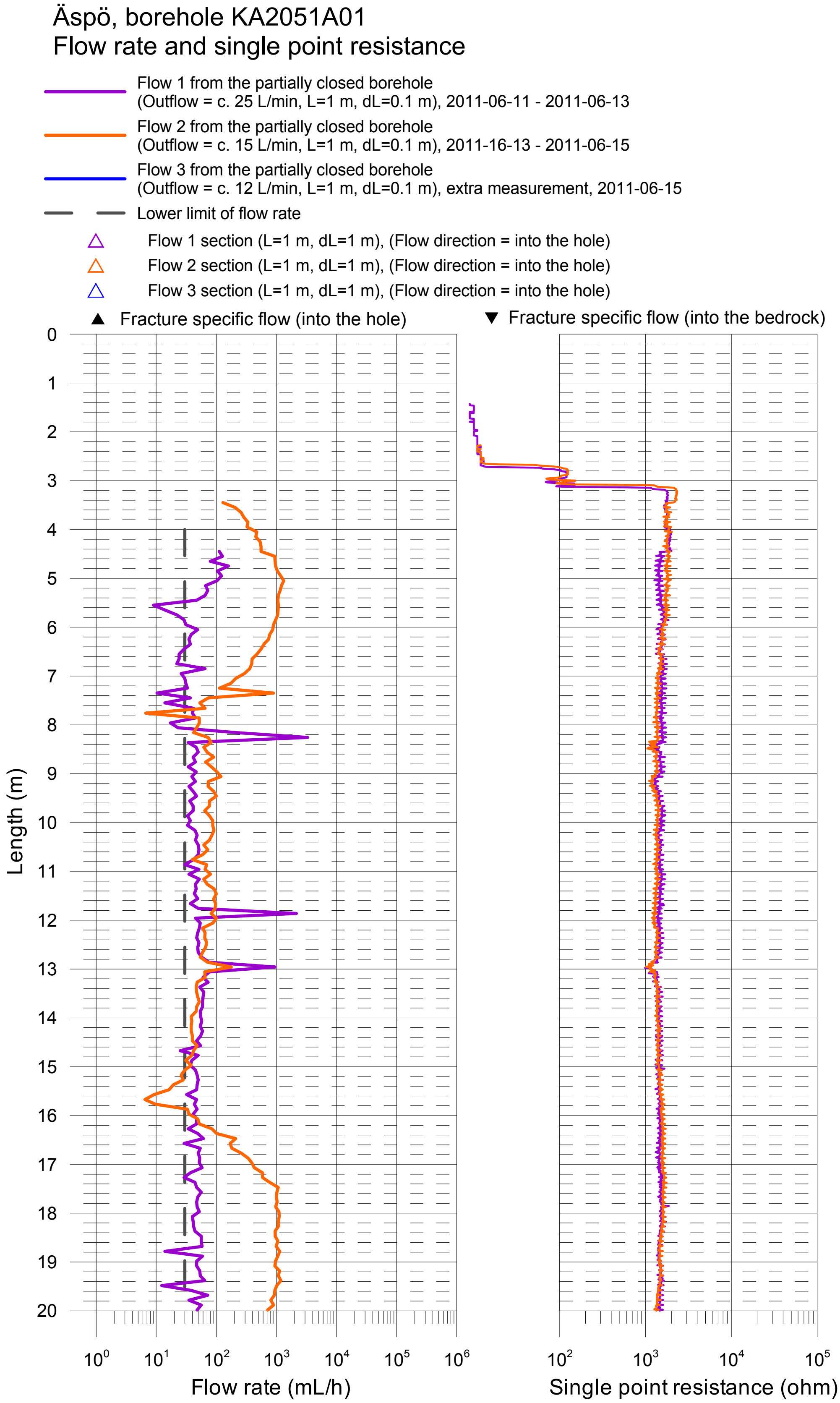
Electrical conductivity of borehole water



Temperature of borehole water



Flow rate and single point resistance



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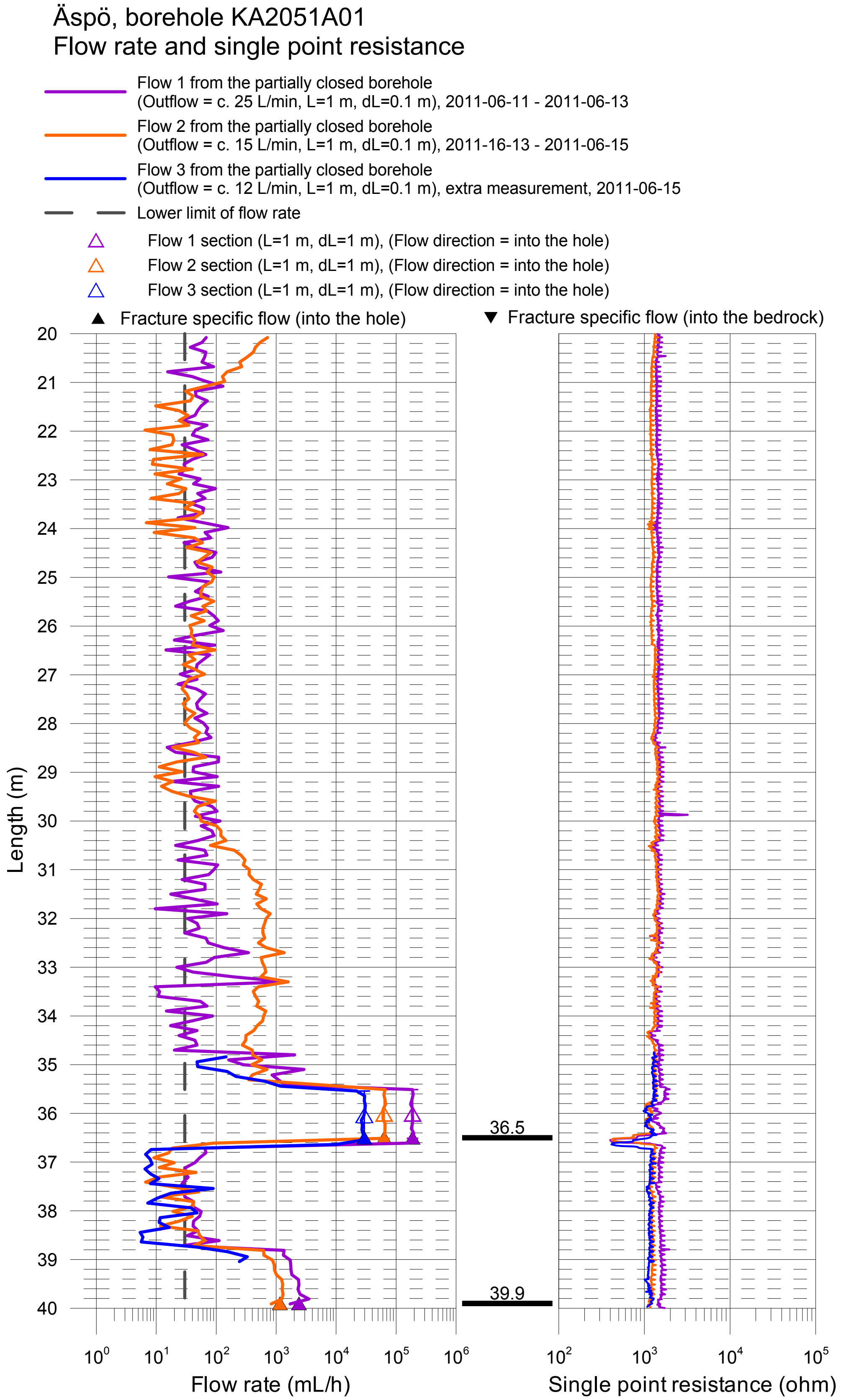

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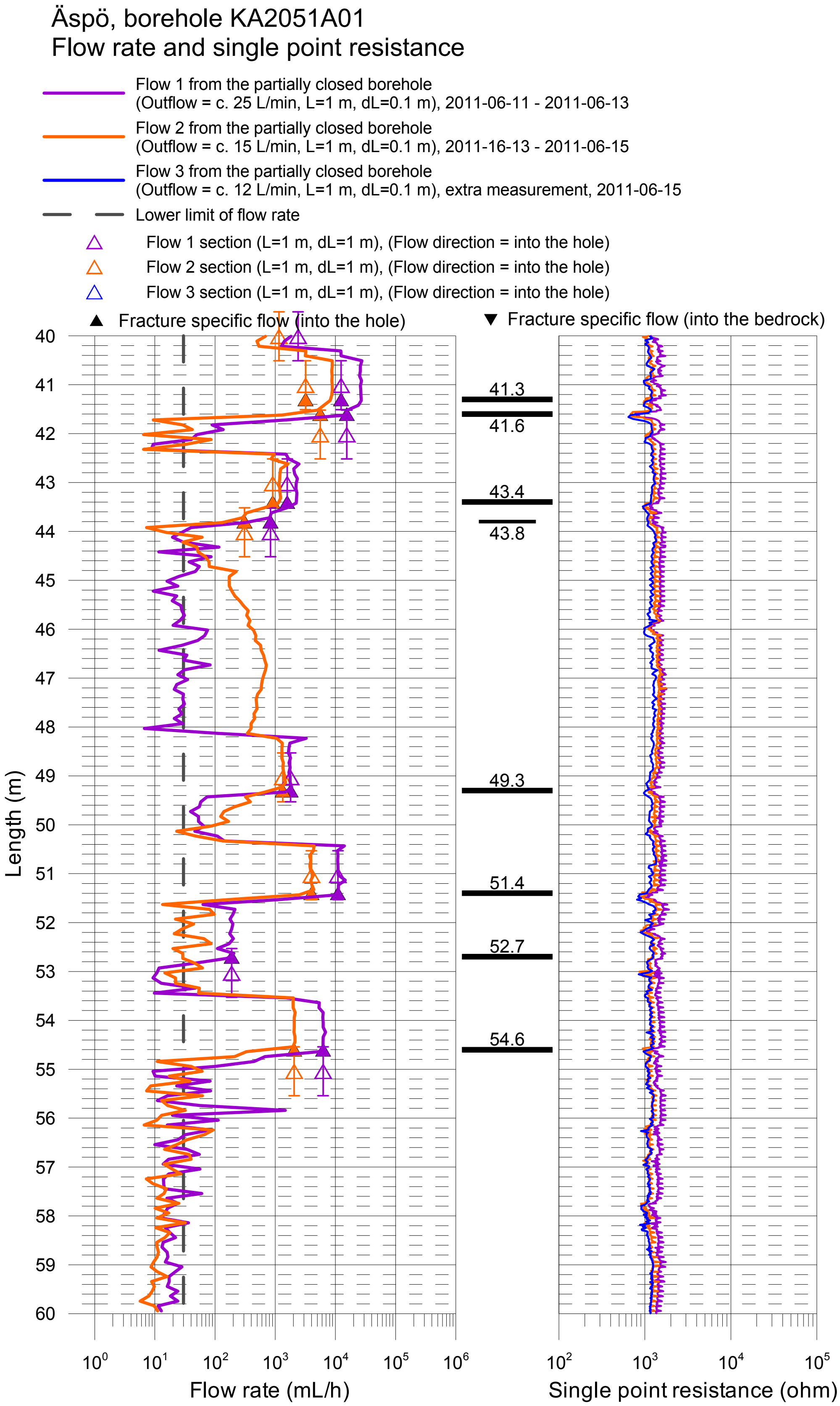

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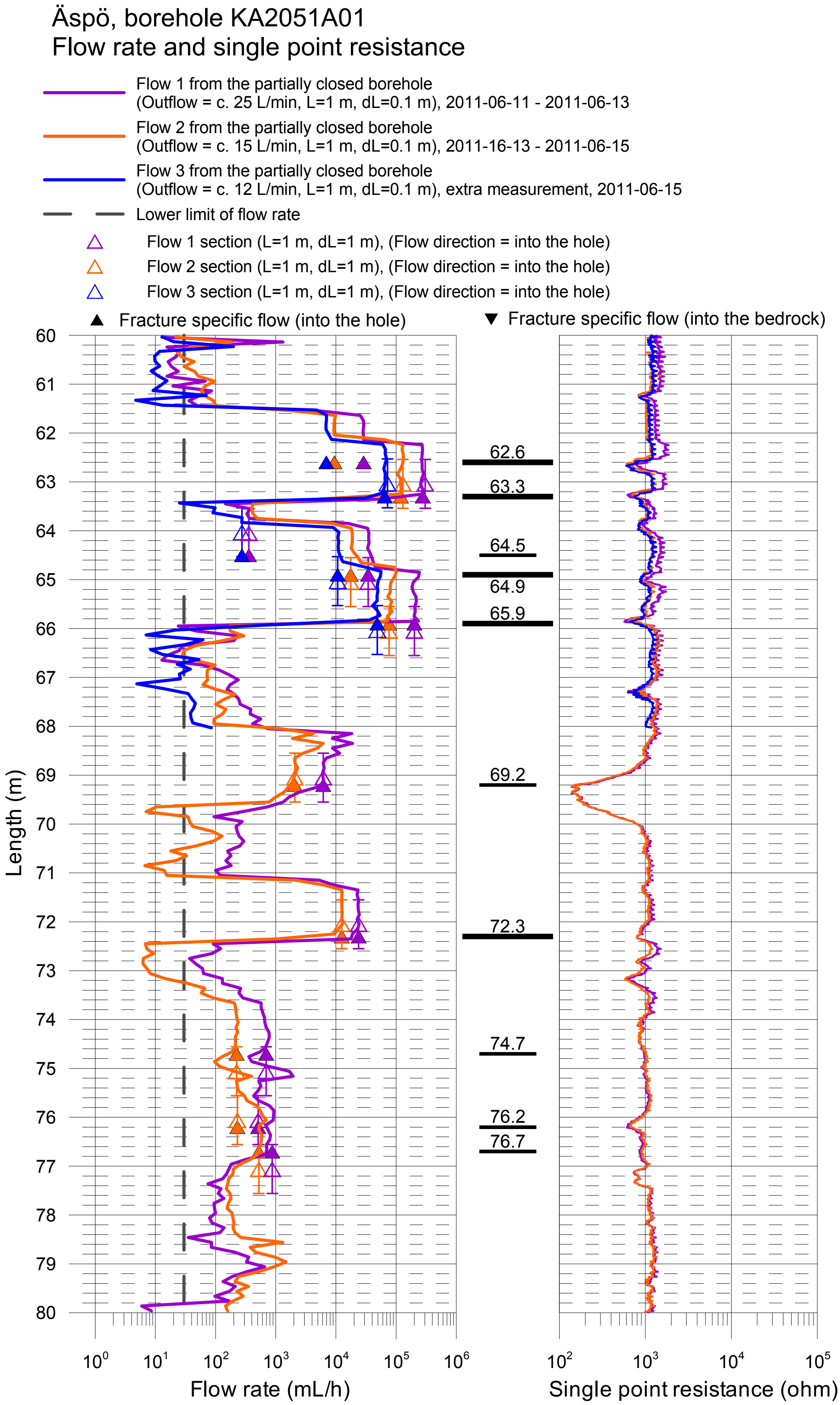

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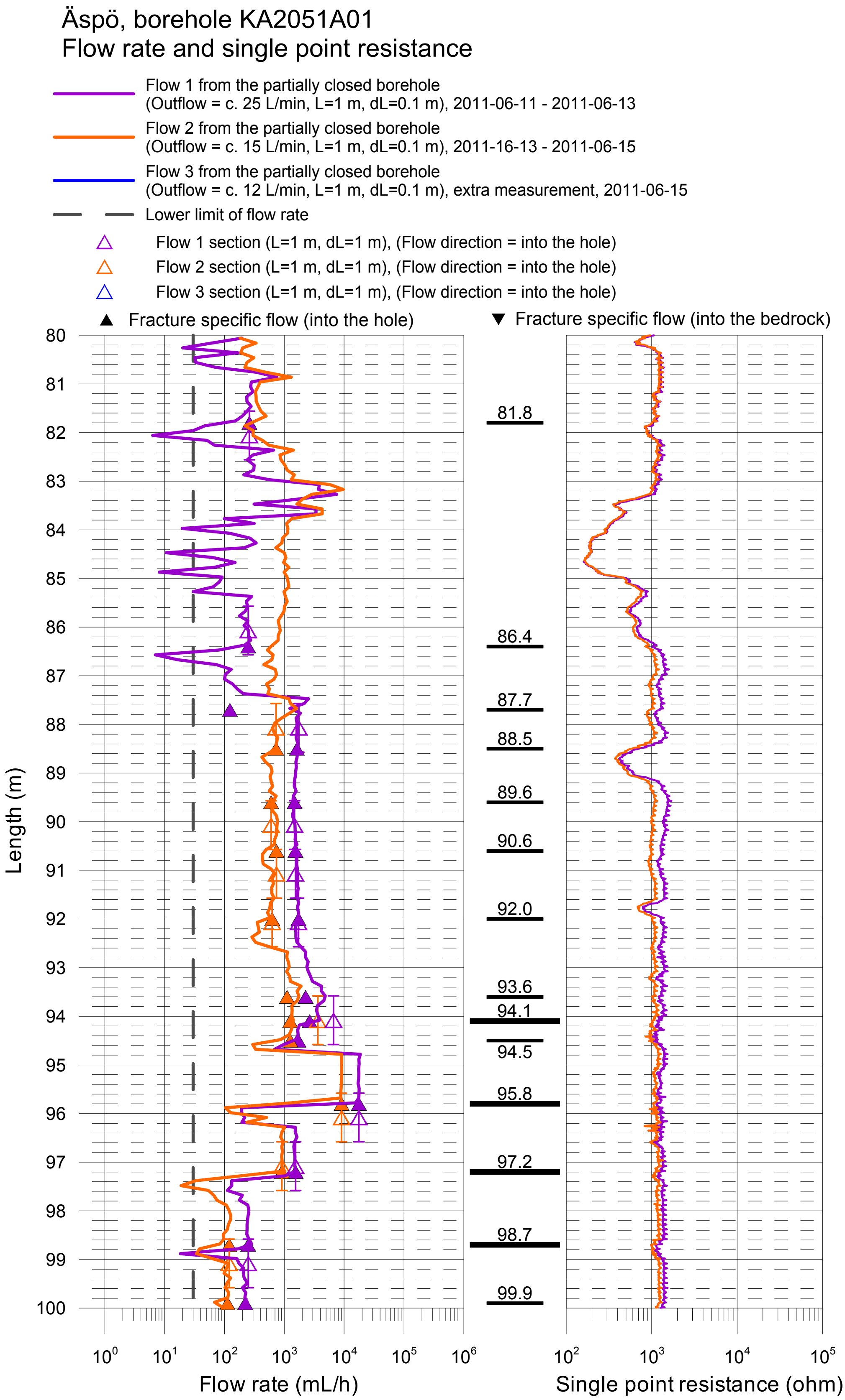

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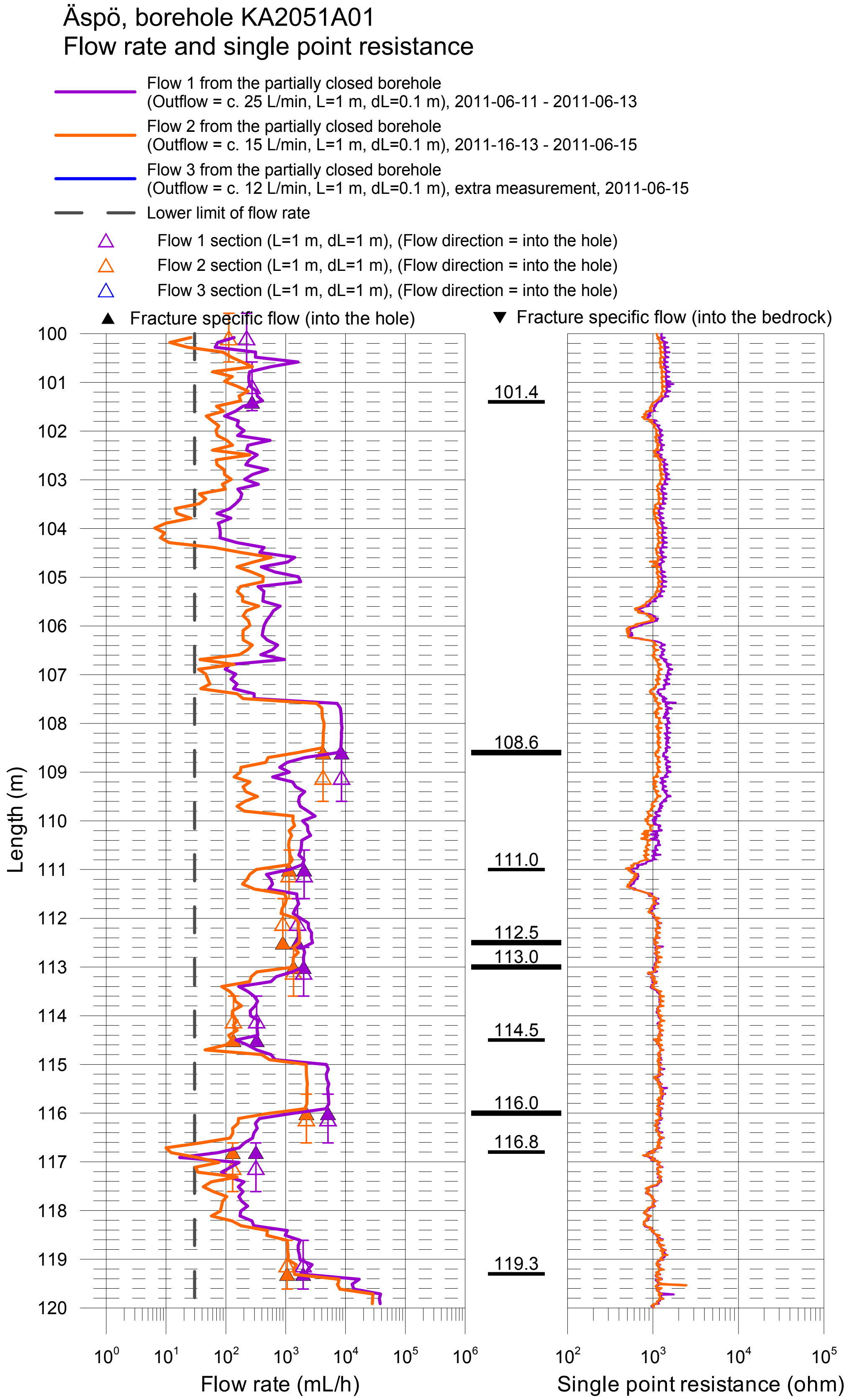

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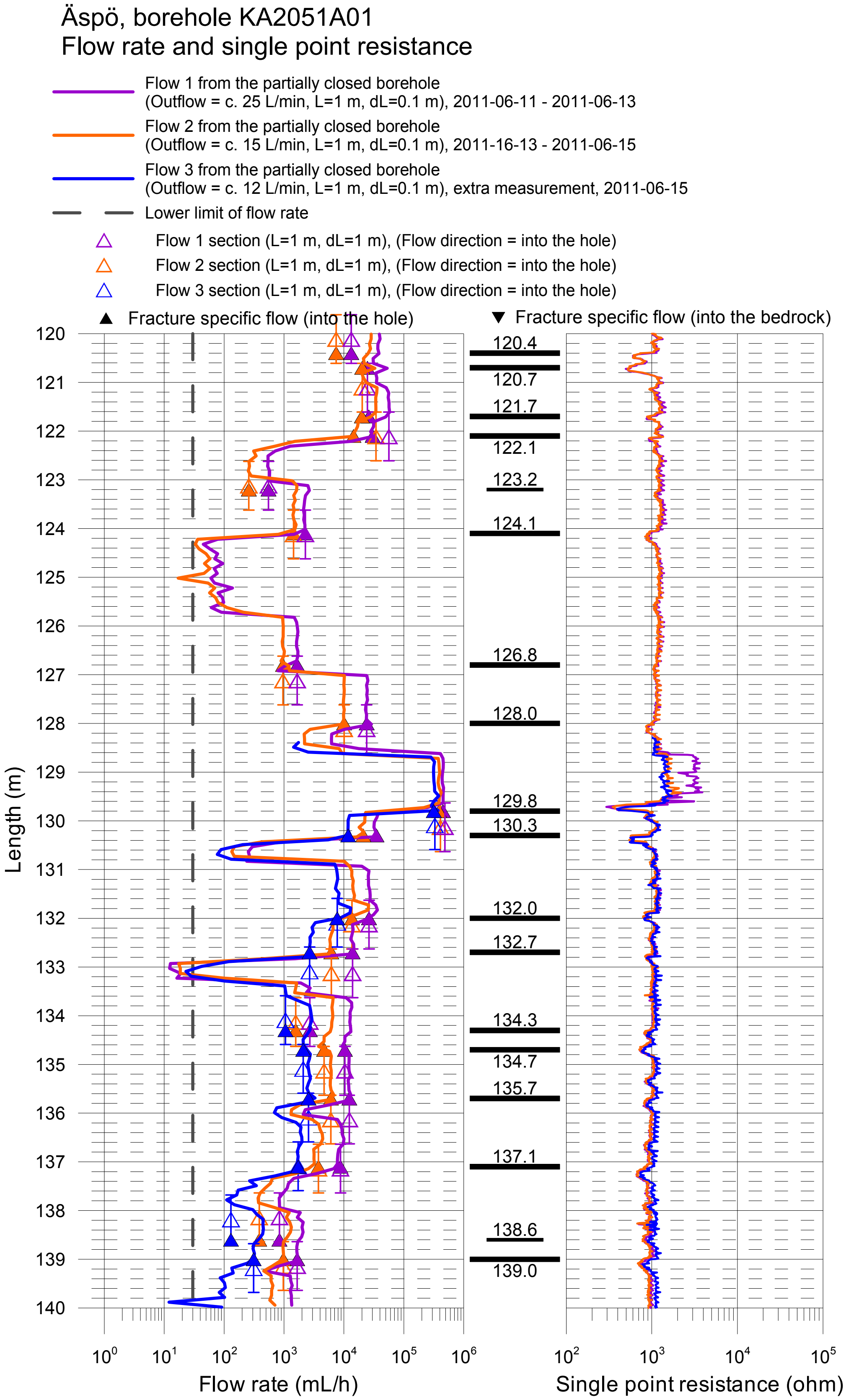

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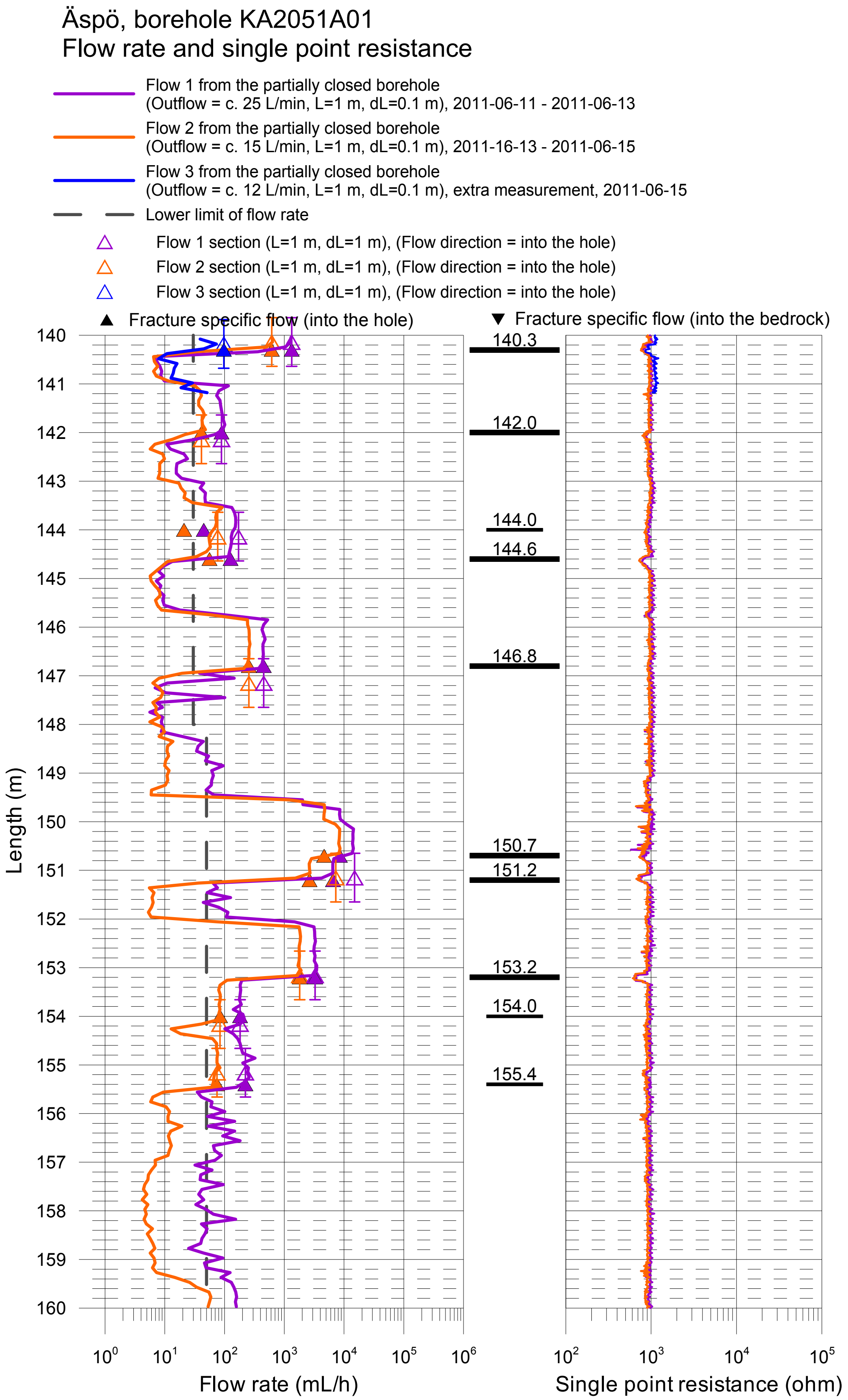

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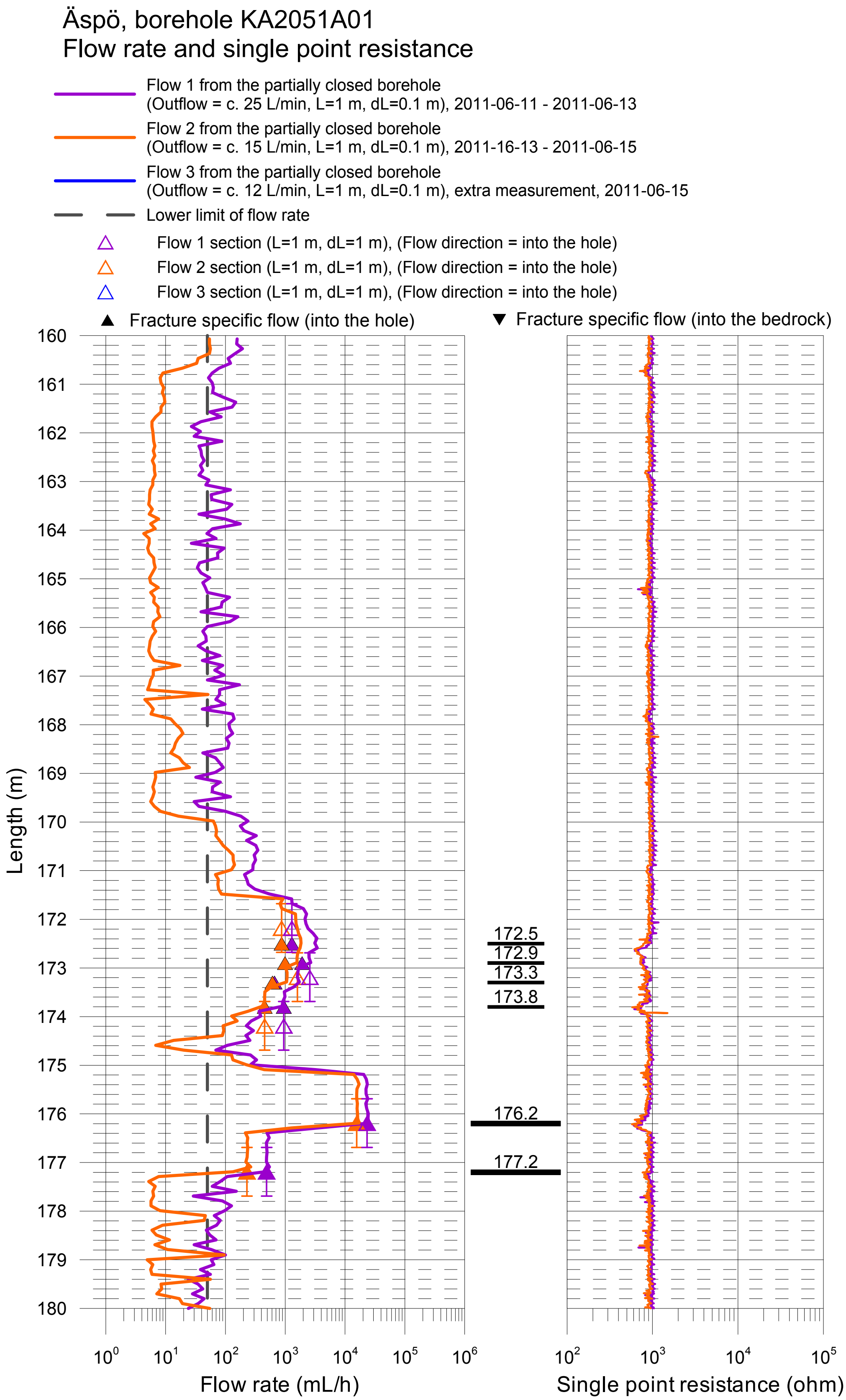

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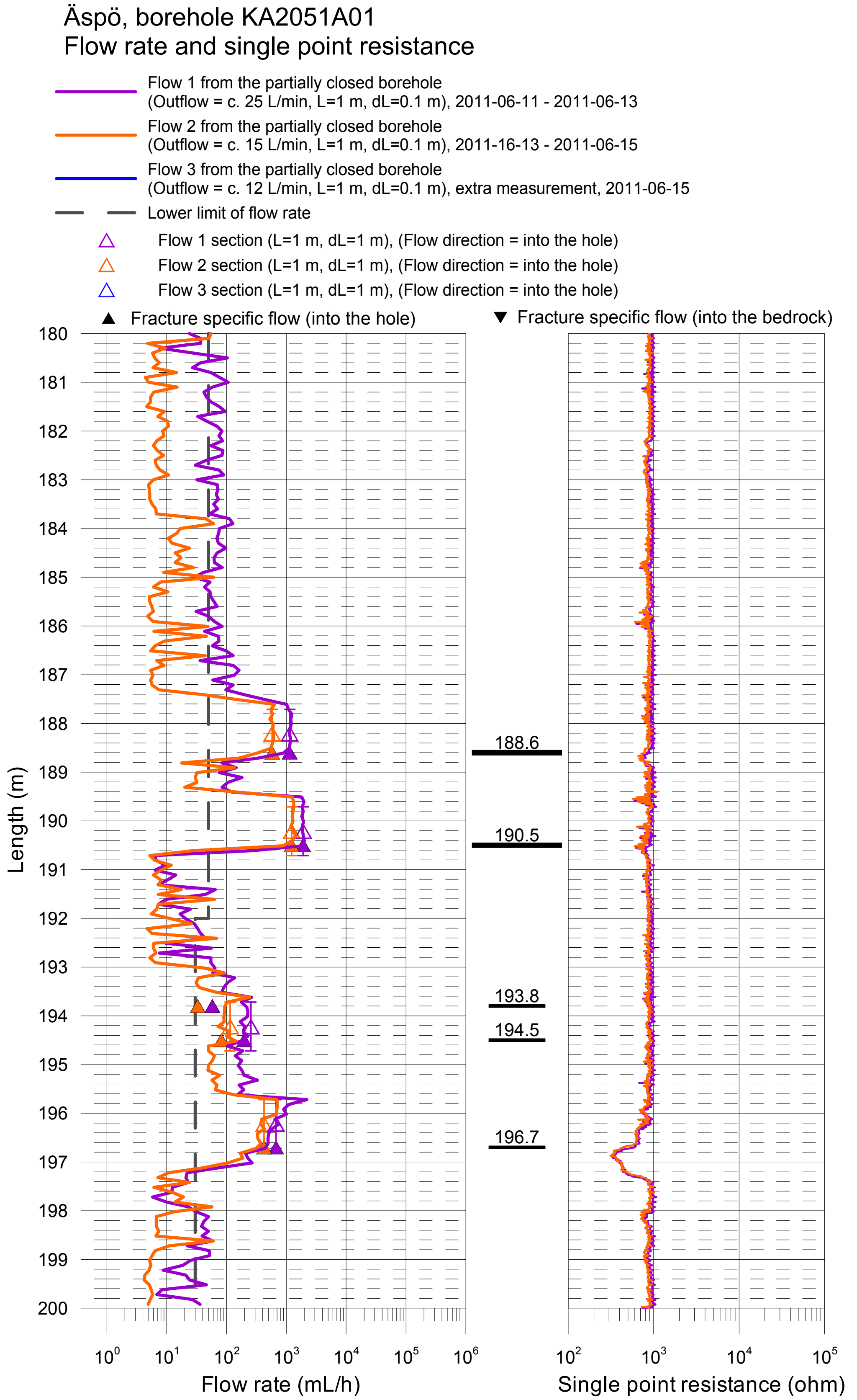

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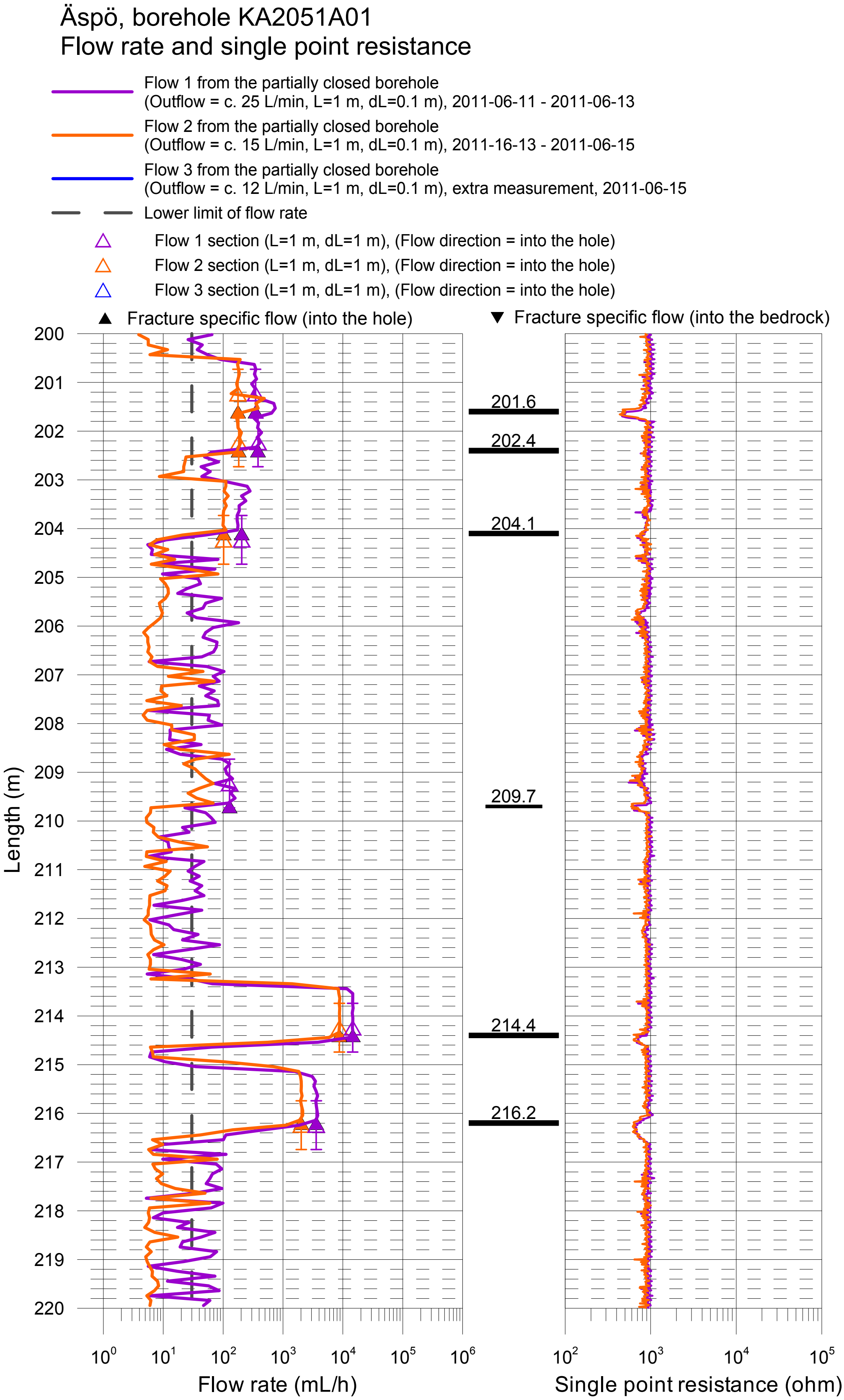

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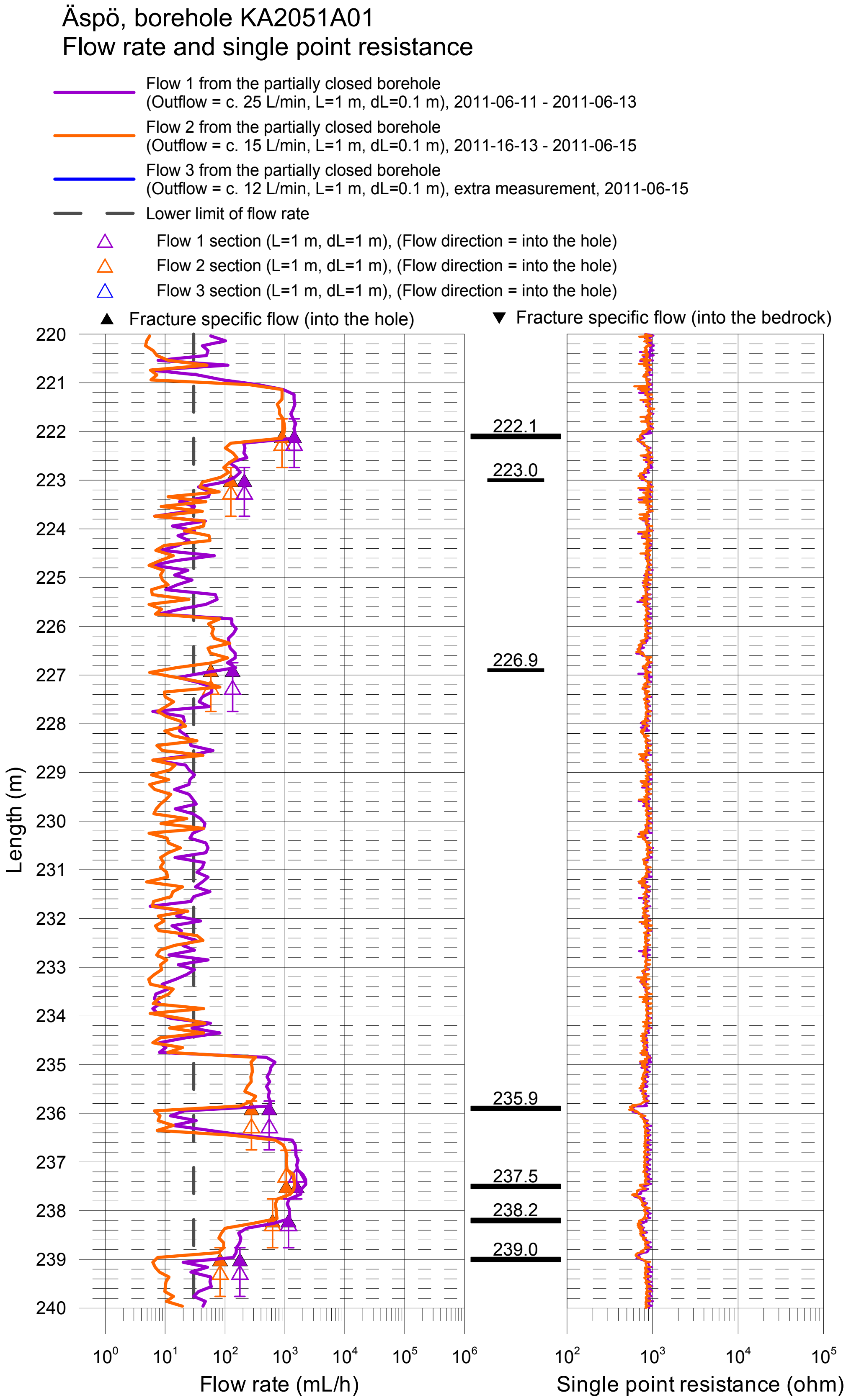
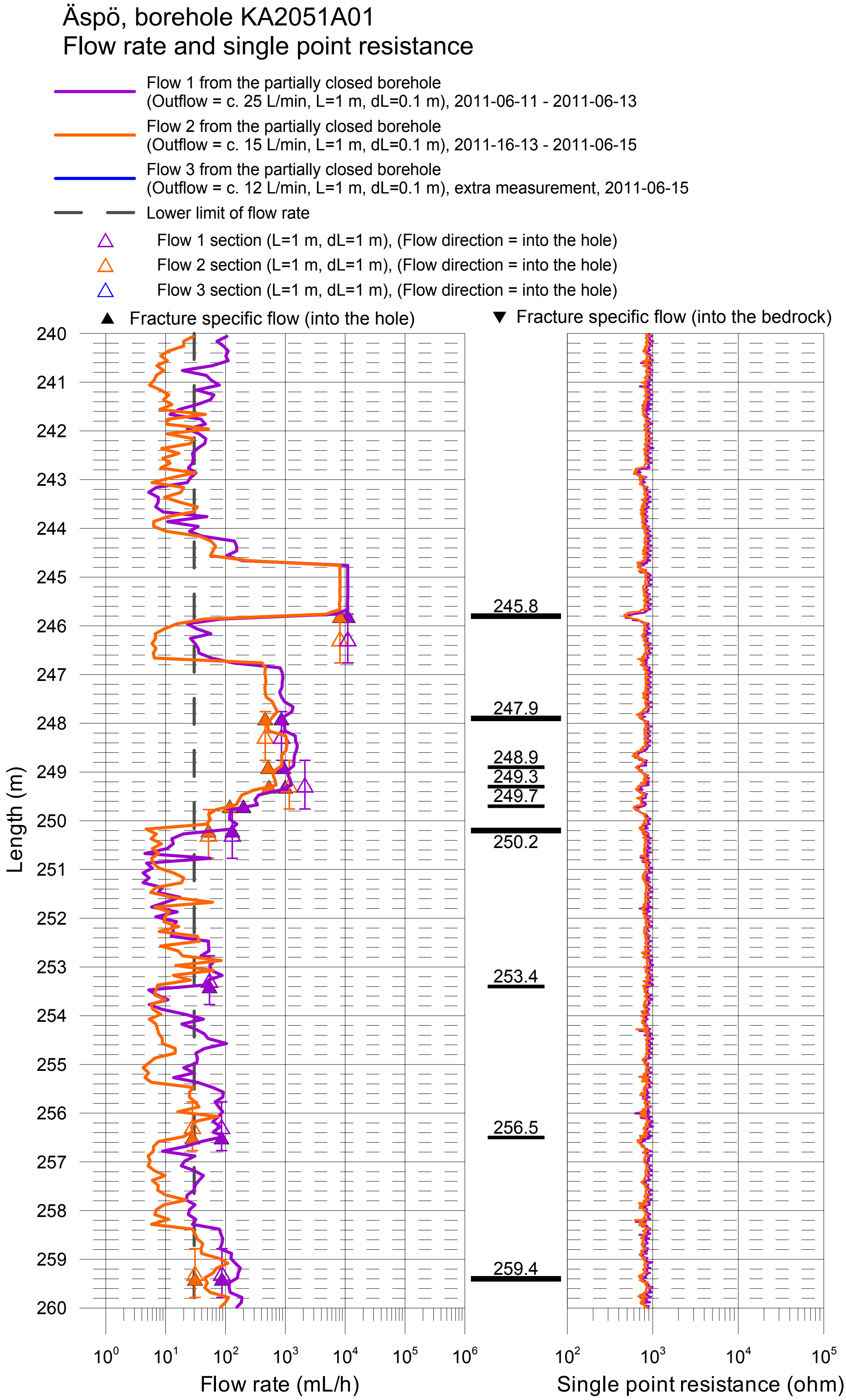


Flow rate and single point resistance



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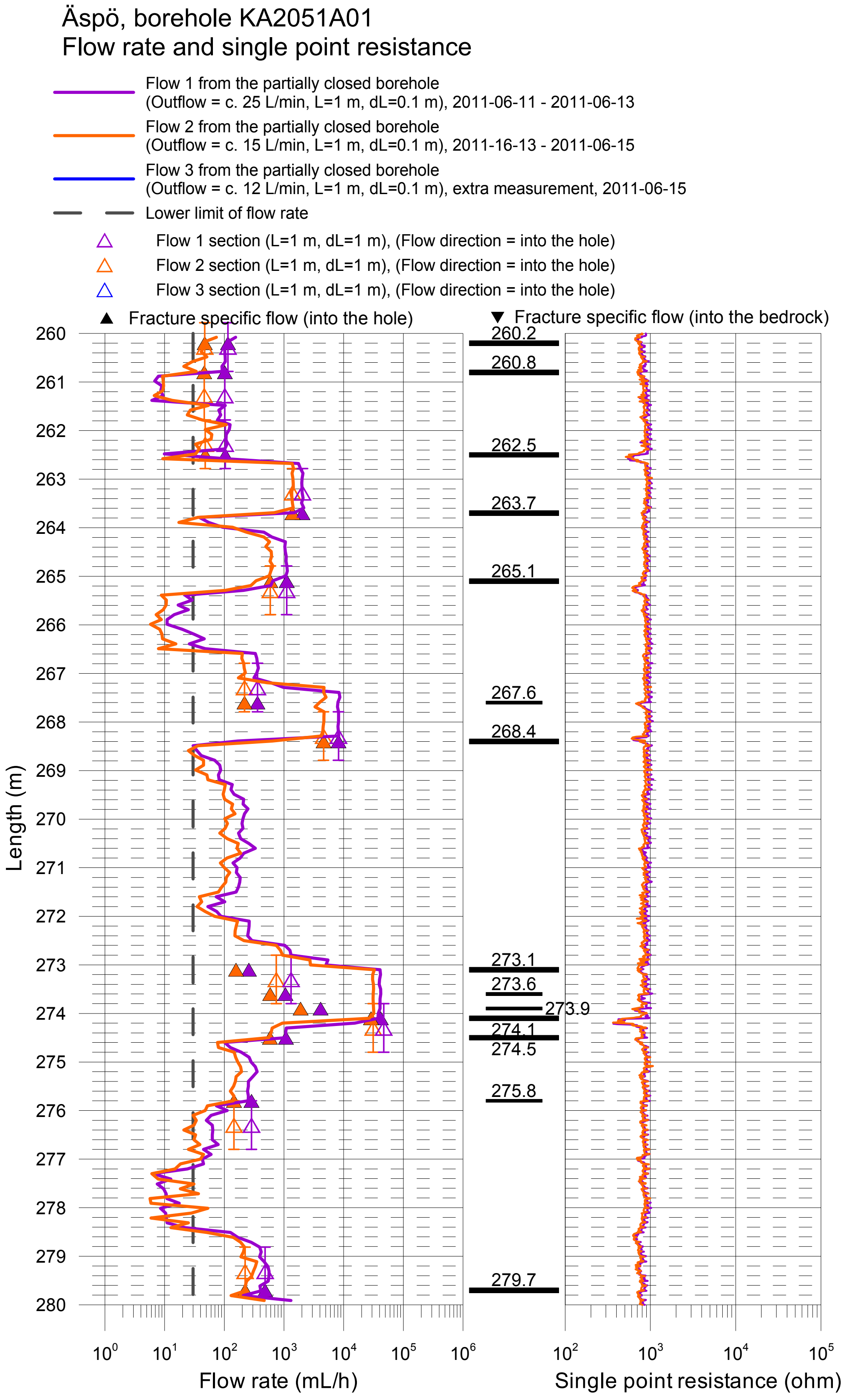
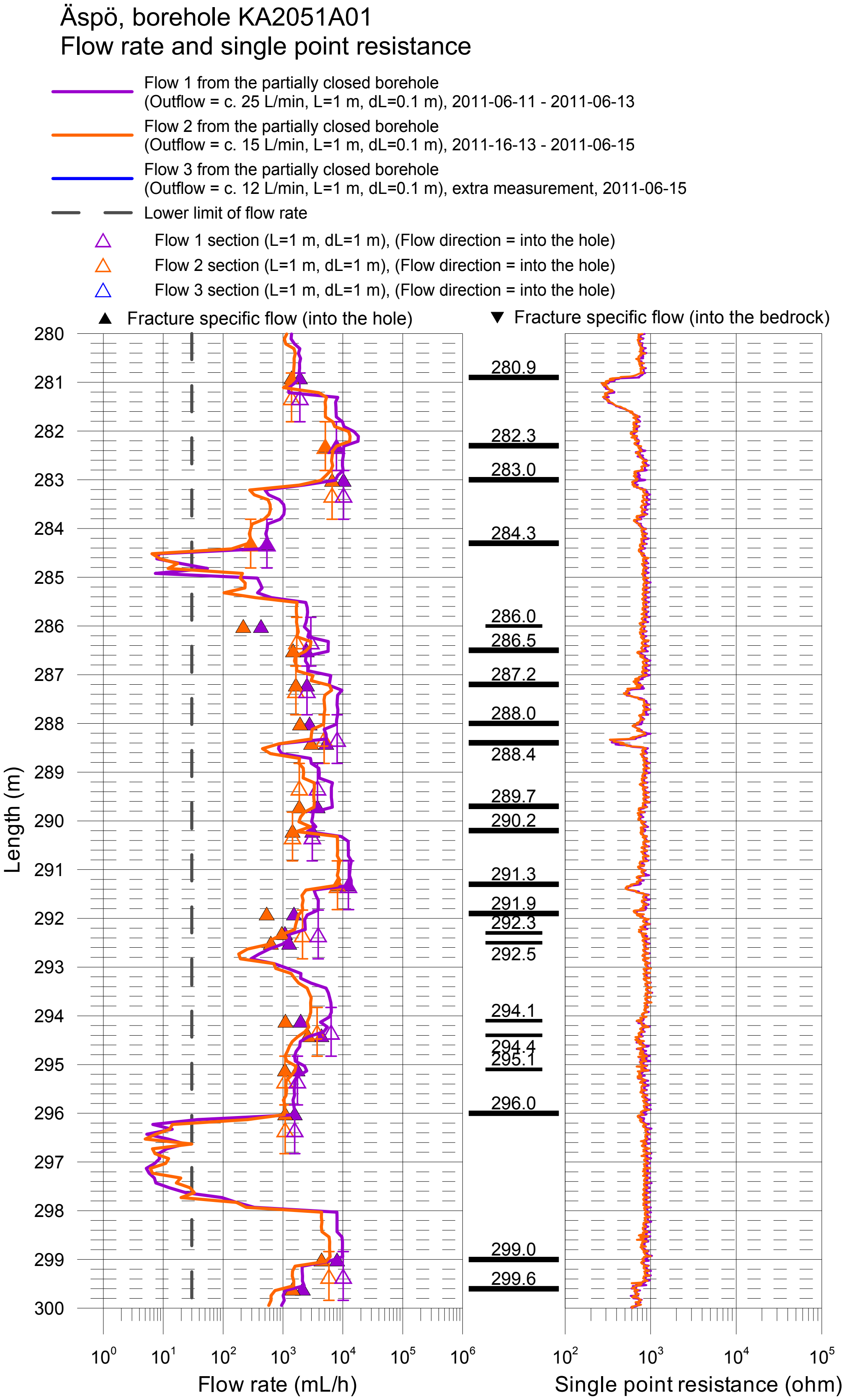


Flow rate and single point resistance



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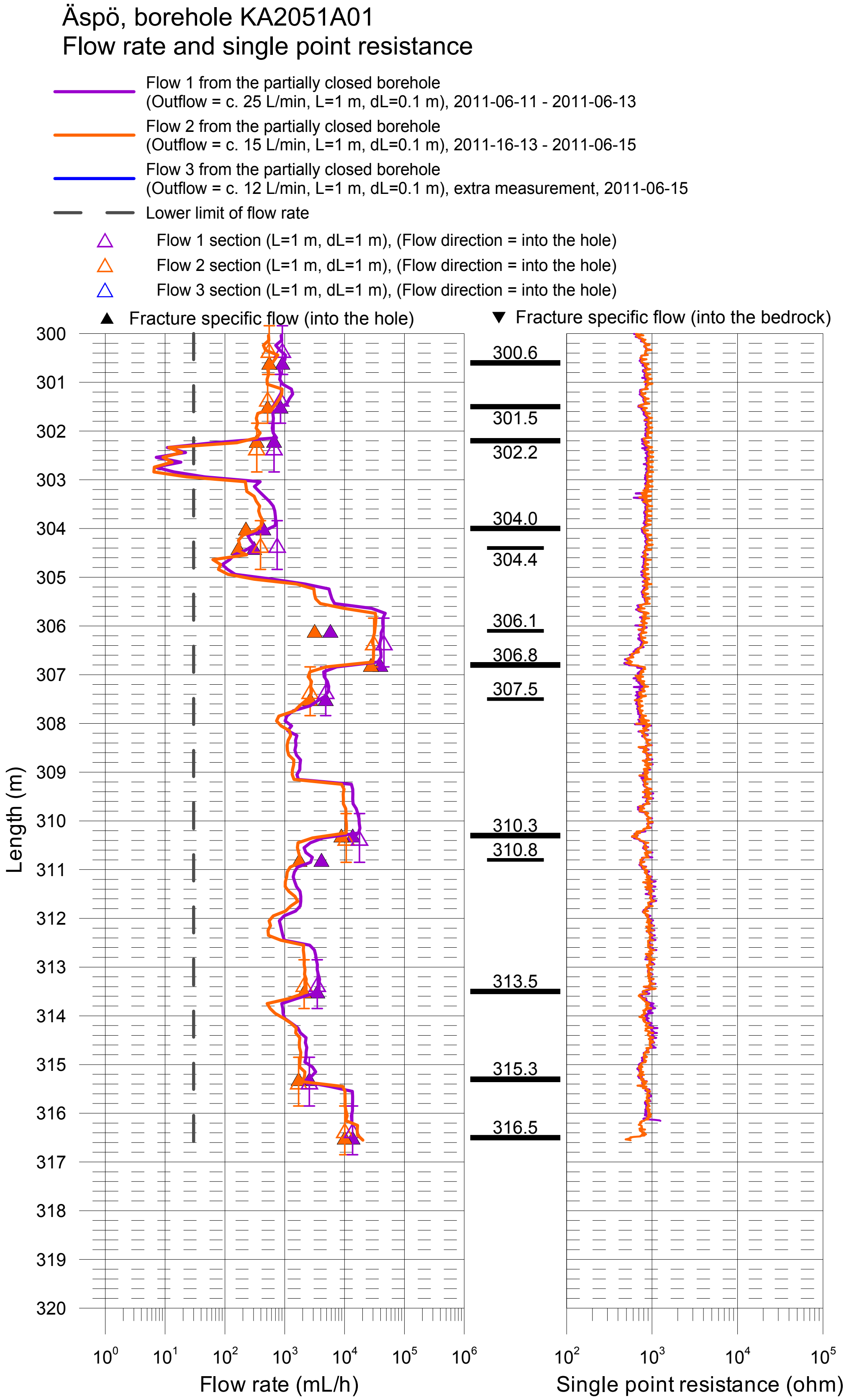


Explanations for the tables in Appendices 5 and 7

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

Appendix 5.1

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KA2051A01	4.45	5.45	1	–	–177.79	–	–110.84	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	5.45	6.45	1	–	–178.21	–	–111.28	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	6.45	7.45	1	–	–178.28	–	–110.79	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	7.45	8.45	1	–	–177.71	–	–110.86	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	8.46	9.46	1	–	–177.37	–	–110.50	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	9.46	10.46	1	–	–177.59	–	–111.15	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	10.46	11.46	1	–	–177.11	–	–110.02	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	11.46	12.46	1	–	–177.10	–	–110.82	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	12.46	13.46	1	–	–177.00	–	–110.88	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	13.47	14.47	1	–	–176.73	–	–110.41	–	–	30	1.2E–10	1.2E–10	1.2E–06	
KA2051A01	14.47	15.47	1	–	–176.72	–	–110.94	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	15.47	16.47	1	–	–177.22	–	–111.61	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	16.47	17.47	1	–	–177.58	–	–111.58	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	17.47	18.47	1	–	–176.07	–	–109.98	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	18.47	19.47	1	–	–176.16	–	–110.42	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	19.48	20.48	1	–	–176.40	–	–110.90	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	20.48	21.48	1	–	–175.30	–	–110.13	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	21.48	22.48	1	–	–176.43	–	–110.65	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	22.48	23.48	1	–	–176.08	–	–110.33	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	23.48	24.48	1	–	–175.91	–	–110.53	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	24.49	25.49	1	–	–176.02	–	–110.74	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	25.49	26.49	1	–	–175.54	–	–110.45	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	26.49	27.49	1	–	–174.67	–	–109.81	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	27.49	28.49	1	–	–174.01	–	–108.93	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	28.49	29.49	1	–	–176.30	–	–111.71	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	29.49	30.49	1	–	–176.93	–	–112.30	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	30.50	31.50	1	–	–176.85	–	–112.35	–	–	30	1.3E–10	1.3E–10	1.3E–06	

Appendix 5.2

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	Comments
KA2051A01	31.50	32.50	1	–	–176.53	–	–111.65	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	32.50	33.50	1	–	–176.57	–	–111.46	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	33.50	34.50	1	–	–175.47	–	–111.37	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	34.50	35.50	1	–	–176.04	–	–111.35	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	35.51	36.51	1	5.22E–05	–175.73	1.75E–05	–111.11	5.3E–07	–78.50	30	1.3E–10	1.3E–10	4.8E–07	
KA2051A01	36.51	37.51	1	–	–175.97	–	–111.70	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	37.51	38.51	1	–	–175.71	–	–111.24	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	38.51	39.51	1	–	–176.22	–	–111.54	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	39.51	40.51	1	6.64E–07	–176.26	3.19E–07	–111.95	5.3E–09	–52.30	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	40.51	41.51	1	3.44E–06	–176.08	8.83E–07	–111.60	3.9E–08	–89.40	30	1.3E–10	1.3E–10	1.2E–06	
KA2051A01	41.52	42.52	1	4.28E–06	–176.66	1.55E–06	–112.16	4.2E–08	–75.50	30	1.3E–10	1.3E–10	1.2E–06	
KA2051A01	42.52	43.52	1	4.39E–07	–176.80	2.52E–07	–112.41	2.9E–09	–25.90	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	43.52	44.52	1	2.31E–07	–176.28	8.56E–08	–111.93	2.2E–09	–74.20	30	1.3E–10	1.3E–10	1.3E–06	*
KA2051A01	44.52	45.52	1	–	–176.43	–	–111.92	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	45.52	46.52	1	–	–176.30	–	–111.95	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	46.53	47.53	1	–	–175.88	–	–111.26	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	47.53	48.53	1	–	–175.69	–	–111.75	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	48.53	49.53	1	5.00E–07	–176.52	3.69E–07	–112.50	2.0E–09	68.70	30	1.3E–10	1.3E–10	1.3E–06	***
KA2051A01	49.53	50.53	1	–	–176.55	–	–112.35	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	50.53	51.53	1	3.06E–06	–176.25	1.11E–06	–112.04	3.0E–08	–75.60	30	1.3E–10	1.3E–10	1.2E–06	
KA2051A01	51.53	52.53	1	–	–176.12	–	–112.48	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	52.53	53.53	1	5.25E–08	–176.29	–	–112.39	8.1E–10	–	30	1.3E–10	1.3E–10	1.3E–06	¤
KA2051A01	53.54	54.54	1	–	–176.37	–	–112.82	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	54.54	55.54	1	1.73E–06	–176.44	5.72E–07	–112.98	1.8E–08	–81.60	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	55.54	56.54	1	–	–176.28	–	–112.89	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	56.54	57.54	1	–	–175.21	–	–111.88	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	57.54	58.54	1	–	–175.39	–	–111.84	–	–	30	1.3E–10	1.3E–10	1.3E–06	
KA2051A01	58.54	59.54	1	–	–175.74	–	–111.96	–	–	30	1.3E–10	1.3E–10	1.3E–06	

Appendix 5.3

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KA2051A01	59.54	60.54	1	–	–175.83	–	–112.80	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	60.54	61.54	1	–	–175.55	–	–112.25	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	61.54	62.54	1	–	–175.61	–	–112.13	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	62.54	63.54	1	8.49E–05	–175.06	3.60E–05	–112.43	7.70E–07	–66.40	30	1.30E–10	1.30E–10	2.50E–08	**
KA2051A01	63.55	64.55	1	9.94E–08	–175.57	–	–112.47	1.60E–9	–	30	1.30E–10	1.30E–10	1.30E–06	*,¤
KA2051A01	64.55	65.55	1	9.53E–06	–175.48	4.89E–06	–112.82	7.30E–08	–46.80	30	1.30E–10	1.30E–10	1.20E–06	
KA2051A01	65.55	66.55	1	5.58E–05	–175.75	2.12E–05	–112.38	5.40E–07	–73.60	30	1.30E–10	1.30E–10	4.30E–07	
KA2051A01	66.55	67.55	1	–	–175.16	–	–111.56	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	67.55	68.55	1	–	–174.90	–	–110.66	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	68.55	69.55	1	1.72E–06	–175.31	5.78E–07	–111.69	1.80E–08	–79.40	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	69.55	70.55	1	–	–175.66	–	–112.74	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	70.55	71.55	1	–	–176.09	–	–112.74	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	71.55	72.55	1	6.64E–06	–176.02	3.47E–06	–113.22	5.00E–08	–44.40	30	1.30E–10	1.30E–10	1.20E–06	
KA2051A01	72.55	73.55	1	–	–175.36	–	–112.51	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	73.56	74.56	1	–	–175.32	–	–112.89	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	74.56	75.56	1	1.93E–07	–176.09	6.22E–08	–113.12	2.10E–09	–83.10	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	75.56	76.56	1	1.42E–07	–175.59	6.39E–08	–112.80	1.20E–09	–61.20	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	76.56	77.56	1	2.43E–07	–174.98	1.45E–07	–111.68	1.50E–09	–17.40	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	77.56	78.56	1	–	–174.82	–	–112.08	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	78.56	79.56	1	–	–175.41	–	–113.30	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	79.56	80.56	1	–	–175.79	–	–113.83	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	80.56	81.56	1	–	–175.53	–	–113.39	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	81.56	82.56	1	7.25E–08	–175.86	–	–113.94	1.20E–09	–	30	1.30E–10	1.30E–10	1.30E–06	*,¤
KA2051A01	82.56	83.56	1	–	–175.37	–	–114.26	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	83.57	84.57	1	–	–176.00	–	–113.99	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	84.57	85.57	1	–	–176.22	–	–114.24	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	85.57	86.57	1	6.92E–08	–176.22	–	–114.01	1.10E–09	–	30	1.30E–10	1.30E–10	1.30E–06	*,¤
KA2051A01	86.57	87.57	1	–	–175.77	–	–113.81	–	–	30	1.30E–10	1.30E–10	1.30E–06	

Appendix 5.4

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KA2051A01	87.57	88.57	1	4.87E–07	–175.44	2.02E–07	–113.90	4.60E–09	–70.30	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	88.57	89.57	1	–	–175.47	–	–113.77	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	89.57	90.57	1	4.14E–07	–175.15	1.67E–07	–113.34	4.00E–09	–71.40	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	90.57	91.57	1	4.28E–07	–175.22	2.05E–07	–113.88	3.60E–09	–57.30	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	91.57	92.57	1	4.81E–07	–175.46	1.74E–07	–113.91	4.90E–09	–78.90	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	92.58	93.58	1	–	–175.69	–	–114.24	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	93.58	94.58	1	1.84E–06	–175.60	1.01E–06	–114.61	1.40E–08	–41.50	30	1.40E–10	1.40E–10	1.30E–06	
KA2051A01	94.58	95.58	1	–	–175.65	–	–114.60	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	95.58	96.58	1	4.92E–06	–175.85	2.51E–06	–114.44	3.90E–08	–50.20	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	96.58	97.58	1	4.31E–07	–175.44	2.53E–07	–113.71	2.90E–09	–26.20	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	97.58	98.58	1	–	–175.96	–	–114.39	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	98.58	99.58	1	6.94E–08	–175.80	3.33E–08	–114.48	5.80E–10	–57.90	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	99.58	100.58	1	6.17E–08	–175.71	3.11E–08	–114.12	4.90E–10	–51.40	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	100.58	101.58	1	7.64E–08	–175.26	–	–113.64	1.20E–09	–	30	1.30E–10	1.30E–10	1.30E–06	*,¤
KA2051A01	101.59	102.59	1	–	–174.94	–	–113.48	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	102.59	103.59	1	–	–174.75	–	–113.68	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	103.59	104.59	1	–	–174.99	–	–113.98	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	104.59	105.59	1	–	–175.01	–	–113.46	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	105.59	106.59	1	–	–175.41	–	–113.57	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	106.59	107.59	1	–	–175.49	–	–113.64	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	107.59	108.59	1	–	–175.2	–	–113.48	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	108.60	109.60	1	2.39E–06	–175.55	1.17E–06	–113.85	2.00E–08	–54.50	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	109.60	110.60	1	–	–175.37	–	–113.73	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	110.60	111.60	1	5.67E–07	–174.97	3.17E–07	–113.51	4.00E–09	–35.70	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	111.60	112.60	1	4.39E–07	–175.23	2.49E–07	–113.51	3.00E–09	–32.50	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	112.60	113.60	1	5.56E–07	–175.27	3.75E–07	–113.62	2.90E–09	14.40	30	1.30E–10	1.30E–10	1.30E–06	***
KA2051A01	113.60	114.60	1	9.08E–08	–175.28	3.72E–08	–113.58	8.60E–10	–70.70	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	114.60	115.60	1	–	–174.98	–	–113.36	–	–	30	1.30E–10	1.30E–10	1.30E–06	

Appendix 5.5

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD-measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KA2051A01	115.61	116.61	1	1.42E–06	–175.63	6.17E–07	–114.00	1.30E–08	–66.50	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	116.61	117.61	1	8.81E–08	–175.23	3.61E–08	–113.74	8.40E–10	–71.00	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	117.61	118.61	1	–	–175.55	–	–113.88	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	118.61	119.61	1	5.44E–07	–175.61	2.94E–07	–114.03	4.00E–09	–41.50	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	119.61	120.61	1	3.69E–06	–175.66	2.06E–06	–113.72	2.60E–08	–35.80	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	120.61	121.61	1	6.89E–06	–175.68	5.64E–06	–114.12	2.00E–08	163.60	30	1.30E–10	1.30E–10	1.20E–06	***
KA2051A01	121.61	122.61	1	1.57E–05	–174.91	9.56E–06	–113.07	9.80E–08	–16.40	30	1.30E–10	1.30E–10	1.10E–06	***
KA2051A01	122.62	123.62	1	1.53E–07	–174.74	7.19E–08	–113.30	1.30E–09	–59.00	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	123.62	124.62	1	6.31E–07	–174.85	4E–07	–113.38	3.70E–09	–6.70	30	1.30E–10	1.30E–10	1.30E–06	***
KA2051A01	124.62	125.62	1	–	–174.73	–	–113.48	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	125.62	126.62	1	–	–174.34	–	–113.57	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	126.62	127.62	1	4.61E–07	–173.87	2.67E–07	–112.96	3.20E–09	–29.00	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	127.62	128.62	1	6.67E–06	–174.20	2.81E–06	–113.12	6.30E–08	–68.70	30	1.40E–10	1.40E–10	1.20E–06	
KA2051A01	128.62	129.62	1	–	–173.12	–	–113.48	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	129.63	130.63	1	1.35E–04	–174.64	1.14E–04	–113.59	3.40E–07	216.70	30	1.40E–10	1.40E–10	8.40E–07	**, ***
KA2051A01	130.63	131.63	1	–	–175.18	–	–114.48	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	131.63	132.63	1	7.31E–06	–175.20	3.78E–06	–114.65	5.80E–08	–49.80	30	1.40E–10	1.40E–10	1.20E–06	
KA2051A01	132.63	133.63	1	3.89E–06	–175.43	1.71E–06	–114.91	3.60E–08	–67.40	30	1.40E–10	1.40E–10	1.30E–06	
KA2051A01	133.63	134.63	1	7.50E–07	–174.84	4.36E–07	–112.92	5.00E–09	–26.90	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	134.63	135.63	1	2.89E–06	–175.47	1.30E–06	–113.90	2.60E–08	–63.70	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	135.63	136.63	1	3.42E–06	–175.28	1.68E–06	–113.53	2.80E–08	–54.00	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	136.64	137.64	1	2.43E–06	–174.73	1.04E–06	–113.20	2.20E–08	–66.90	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	137.64	138.64	1	2.33E–07	–175.24	1.07E–07	–113.59	2.00E–09	–60.80	30	1.30E–10	1.30E–10	1.30E–06	*
KA2051A01	138.64	139.64	1	4.61E–07	–175.63	2.71E–07	–113.83	3.00E–09	–25.70	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	139.64	140.64	1	3.69E–07	–175.61	1.72E–07	–113.99	3.20E–09	–60.30	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	140.64	141.64	1	–	–175.80	–	–114.66	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	141.64	142.64	1	2.47E–08	–176.04	1.14E–08	–114.49	2.10E–10	–61.90	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	142.64	143.64	1	–	–176.66	–	–115.16	–	–	30	1.30E–10	1.30E–10	1.30E–06	

Appendix 5.6

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_{U}$ (m^2/s)	Comments
KA2051A01	143.64	144.64	1	4.75E–08	–176.11	2.14E–08	–114.33	4.20E–10	–63.70	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	144.65	145.65	1	–	–176.14	–	–114.53	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	145.65	146.65	1	–	–176.31	–	–115.00	–	–	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	146.65	147.65	1	1.26E–07	–175.43	7.08E–08	–113.81	8.80E–10	–34.50	30	1.30E–10	1.30E–10	1.30E–06	
KA2051A01	147.65	148.65	1	–	–175.34	–	–114.09	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	148.65	149.65	1	–	–175.49	–	–113.87	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	149.65	150.65	1	–	–176.00	–	–114.56	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	150.65	151.65	1	4.19E–06	–175.95	2.03E–06	–114.55	3.50E–08	–56.90	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	151.66	152.66	1	–	–175.92	–	–114.43	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	152.66	153.66	1	9.08E–07	–176.29	5.03E–07	–115.03	6.60E–09	–39.10	50	1.40E–10	2.20E–10	1.30E–06	
KA2051A01	153.66	154.66	1	5.06E–08	–176.45	2.33E–08	–115.20	4.40E–10	–62.70	50	1.40E–10	2.20E–10	1.40E–06	*
KA2051A01	154.66	155.66	1	6.22E–08	–176.29	2.08E–08	–114.66	6.60E–10	–83.60	50	1.30E–10	2.20E–10	1.30E–06	*
KA2051A01	155.66	156.66	1	–	–176.31	–	–115.04	–	–	50	1.40E–10	2.20E–10	1.40E–06	
KA2051A01	156.66	157.66	1	–	–175.70	–	–114.28	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	157.66	158.66	1	–	–175.71	–	–114.15	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	158.67	159.67	1	–	–175.78	–	–114.64	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	159.67	160.67	1	–	–175.74	–	–114.37	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	160.67	161.67	1	–	–175.79	–	–114.27	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	161.67	162.67	1	–	–175.69	–	–114.37	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	162.67	163.67	1	–	–175.63	–	–114.34	–	–	50	1.40E–10	2.20E–10	1.40E–06	
KA2051A01	163.67	164.67	1	–	–175.46	–	–114.12	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	164.67	165.67	1	–	–175.55	–	–114.24	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	165.68	166.68	1	–	–175.41	–	–114.32	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	166.68	167.68	1	–	–175.05	–	–113.84	–	–	50	1.40E–10	2.20E–10	1.40E–06	
KA2051A01	167.68	168.68	1	–	–175.17	–	–113.93	–	–	50	1.40E–10	2.20E–10	1.40E–06	
KA2051A01	168.68	169.68	1	–	–175.59	–	–114.12	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	169.68	170.68	1	–	–175.51	–	–114.47	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	170.68	171.68	1	–	–175.35	–	–114.01	–	–	50	1.30E–10	2.20E–10	1.30E–06	

Appendix 5.7

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	Comments
KA2051A01	171.68	172.68	1	3.58E–07	–175.36	2.42E–07	–114.10	1.90E–09	12.80	50	1.40E–10	2.20E–10	1.30E–06	*,***
KA2051A01	172.69	173.69	1	7.18E–07	–175.20	4.44E–07	–114.14	4.40E–09	–14.90	50	1.40E–10	2.30E–10	1.30E–06	*,***
KA2051A01	173.69	174.69	1	2.63E–07	–175.14	1.26E–07	–113.68	2.20E–09	–57.10	50	1.30E–10	2.20E–10	1.30E–06	*
KA2051A01	174.69	175.69	1	–	–175.23	–	–113.60	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	175.69	176.69	1	6.5E–06	–175.08	4.36E–06	–114.04	3.50E–08	10.40	50	1.40E–10	2.30E–10	1.30E–06	***
KA2051A01	176.69	177.69	1	1.36E–07	–174.92	6.36E–08	–113.61	1.20E–09	–59.60	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	177.69	178.69	1	–	–174.84	–	–113.53	–	–	50	1.30E–10	2.20E–10	1.30E–06	
KA2051A01	178.69	179.69	1	–	–175.10	–	–114.18	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	179.70	180.70	1	–	–174.95	–	–114.06	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	180.70	181.70	1	–	–175.14	–	–114.03	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	181.70	182.70	1	–	–175.20	–	–114.07	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	182.70	183.70	1	–	–175.11	–	–114.09	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	183.70	184.70	1	–	–175.24	–	–114.28	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	184.70	185.70	1	–	–175.43	–	–114.50	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	185.70	186.70	1	–	–175.34	–	–114.18	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	186.71	187.71	1	–	–175.17	–	–114.33	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	187.71	188.71	1	3.17E–07	–175.05	1.61E–07	–114.62	2.60E–09	–52.30	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	188.71	189.71	1	–	–175.13	–	–114.77	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	189.71	190.71	1	5.31E–07	–175.36	3.42E–07	–114.82	3.10E–09	–5.30	50	1.40E–10	2.30E–10	1.40E–06	***
KA2051A01	190.71	191.71	1	–	–175.16	–	–114.57	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	191.71	192.71	1	–	–175.26	–	–114.66	–	–	50	1.40E–10	2.30E–10	1.40E–06	
KA2051A01	192.71	193.71	1	–	–175.40	–	–114.85	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	193.72	194.72	1	7.08E–08	–175.66	3.19E–08	–115.28	6.40E–10	–65.70	30	1.40E–10	1.40E–10	1.40E–06	*
KA2051A01	194.72	195.72	1	–	–175.42	–	–115.17	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	195.72	196.72	1	1.87E–07	–175.36	1.18E–07	–114.89	1.10E–09	–11.50	30	1.40E–10	1.40E–10	1.40E–06	*,***
KA2051A01	196.72	197.72	1	–	–175.27	–	–114.96	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	197.72	198.72	1	–	–175.59	–	–115.33	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	198.72	199.72	1	–	–176.08	–	–115.97	–	–	30	1.40E–10	1.40E–10	1.40E–06	

Appendix 5.8

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	Comments
KA2051A01	199.72	200.72	1	–	–175.60	–	–115.50	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	200.73	201.73	1	9.67E–08	–176.03	4.92E–08	–115.79	7.80E–10	–53.40	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	201.73	202.73	1	1.06E–07	–176.48	5.06E–08	–116.36	9.10E–10	–61.70	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	202.73	203.73	1	–	–176.44	–	–116.64	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	203.73	204.73	1	5.67E–08	–175.98	2.83E–08	–115.99	4.70E–10	–56.00	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	204.73	205.73	1	–	–176.21	–	–116.47	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	205.73	206.73	1	–	–176.47	–	–116.73	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	206.73	207.73	1	–	–176.22	–	–116.24	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	207.73	208.73	1	–	–175.72	–	–115.83	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	208.73	209.73	1	3.56E–08	–175.61	–	–115.84	5.90E–10	–	30	1.40E–10	1.40E–10	1.40E–06	*,¤
KA2051A01	209.73	210.73	1	–	–175.70	–	–116.01	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	210.73	211.73	1	–	–176.11	–	–116.03	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	211.73	212.73	1	–	–175.94	–	–116.31	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	212.74	213.74	1	–	–176.16	–	–116.45	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	213.74	214.74	1	4.06E–06	–175.83	2.42E–06	–116.33	2.70E–08	–28.10	30	1.40E–10	1.40E–10	1.30E–06	
KA2051A01	214.74	215.74	1	–	–176.31	–	–116.68	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	215.74	216.74	1	1.00E–06	–176.27	5.61E–07	–116.79	7.30E–09	–40.80	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	216.74	217.74	1	–	–176.10	–	–116.50	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	217.74	218.74	1	–	–176.43	–	–116.75	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	218.74	219.74	1	–	–176.49	–	–117.12	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	219.74	220.74	1	–	–176.52	–	–117.20	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	220.74	221.74	1	–	–176.26	–	–116.99	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	221.74	222.74	1	3.97E–07	–176.39	2.49E–07	–117.07	2.50E–09	–16.90	30	1.40E–10	1.40E–10	1.40E–06	***
KA2051A01	222.74	223.74	1	5.86E–08	–176.05	3.47E–08	–116.85	4.00E–10	–30.80	30	1.40E–10	1.40E–10	1.40E–06	*
KA2051A01	223.74	224.74	1	–	–175.96	–	–116.56	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	224.75	225.75	1	–	–175.89	–	–116.47	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	225.75	226.75	1	–	–176.02	–	–116.51	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	226.75	227.75	1	3.72E–08	–175.89	1.61E–08	–116.44	3.50E–10	–71.10	30	1.40E–10	1.40E–10	1.40E–06	*

Appendix 5.9

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD- measl$_U$ (m^2/s)	Comments
KA2051A01	227.75	228.75	1	–	–175.77	–	–116.35	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	228.75	229.75	1	–	–175.70	–	–116.27	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	229.75	230.75	1	–	–175.31	–	–116.25	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	230.75	231.75	1	–	–175.41	–	–116.32	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	231.75	232.75	1	–	–175.34	–	–116.34	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	232.75	233.75	1	–	–175.24	–	–116.00	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	233.75	234.75	1	–	–175.17	–	–115.95	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	234.75	235.75	1	–	–174.92	–	–115.56	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	235.75	236.75	1	1.52E–07	–175.18	7.69E–08	–116.13	1.30E–09	–55.80	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	236.76	237.76	1	4.39E–07	–175.24	2.92E–07	–116.24	2.50E–09	0.70	30	1.40E–10	1.40E–10	1.40E–06	***
KA2051A01	237.76	238.76	1	3.19E–07	–175.45	1.73E–07	–116.41	2.50E–09	–46.40	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	238.76	239.76	1	4.92E–08	–175.53	2.31E–08	–116.55	4.40E–10	–64.50	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	239.76	240.76	1	–	–176.01	–	–117.46	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	240.76	241.76	1	–	–175.92	–	–117.22	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	241.76	242.76	1	–	–175.95	–	–117.67	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	242.76	243.76	1	–	–176.22	–	–118.28	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	243.76	244.76	1	–	–176.18	–	–117.86	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	244.76	245.76	1	–	–176.05	–	–117.38	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	245.76	246.76	1	3.08E–06	–175.78	2.27E–06	–117.62	1.40E–08	44.60	30	1.40E–10	1.40E–10	1.40E–06	***
KA2051A01	246.76	247.76	1	–	–175.83	–	–117.79	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	247.76	248.76	1	2.40E–07	–175.50	1.28E–07	–118.03	1.90E–09	–52.20	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	248.76	249.76	1	5.89E–07	–175.86	3.25E–07	–118.80	4.60E–09	–48.80	30	1.50E–10	1.50E–10	1.40E–06	*
KA2051A01	249.77	250.77	1	3.61E–08	–176.59	1.44E–08	–119.75	3.80E–10	–81.90	30	1.50E–10	1.50E–10	1.50E–06	*
KA2051A01	250.77	251.77	1	–	–176.27	–	–119.42	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	251.77	252.77	1	–	–176.69	–	–119.71	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	252.77	253.77	1	1.50E–08	–176.33	–	–119.28	2.60E–10	–	30	1.50E–10	1.50E–10	1.50E–06	*,¤
KA2051A01	253.77	254.77	1	–	–176.20	–	–118.92	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	254.77	255.77	1	–	–175.74	–	–118.51	–	–	30	1.40E–10	1.40E–10	1.40E–06	

Appendix 5.10

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KA2051A01	255.77	256.77	1	2.39E–08	–175.43	7.78E–09	–118.60	2.80E–10	–91.20	30	1.50E–10	1.50E–10	1.50E–06	*
KA2051A01	256.78	257.78	1	–	–175.56	–	–118.46	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	257.78	258.78	1	–	–175.88	–	–118.74	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	258.78	259.78	1	2.42E–08	–175.85	8.61E–09	–118.47	2.70E–10	–86.70	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	259.78	260.78	1	3.19E–08	–175.45	1.31E–08	–118.80	3.30E–10	–79.60	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	260.78	261.78	1	2.83E–08	–176.08	1.28E–08	–119.37	2.70E–10	–72.80	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	261.78	262.78	1	2.89E–08	–176.90	1.33E–08	–120.47	2.70E–10	–72.10	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	262.78	263.78	1	5.67E–07	–176.70	3.86E–07	–120.38	3.20E–09	0.10	30	1.50E–10	1.50E–10	1.50E–06	***
KA2051A01	263.79	264.79	1	–	–176.55	–	–120.02	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	264.79	265.79	1	3.08E–07	–176.71	1.64E–07	–120.28	2.50E–09	–56.00	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	265.79	266.79	1	–	–176.66	–	–120.49	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	266.79	267.79	1	1E–07	–176.26	6.06E–08	–119.68	6.90E–10	–32.80	30	1.50E–10	1.50E–10	1.50E–06	*
KA2051A01	267.79	268.79	1	2.28E–06	–176.56	1.28E–06	–120.83	1.80E–08	–49.50	30	1.50E–10	1.50E–10	1.40E–06	
KA2051A01	268.79	269.79	1	–	–176.72	–	–120.54	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	269.79	270.79	1	–	–176.63	–	–120.58	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	270.80	271.80	1	–	–176.34	–	–120.27	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	271.80	272.80	1	–	–176.16	–	–120.29	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	272.80	273.80	1	3.66E–07	–176.18	2.07E–07	–120.51	2.80E–09	–48.30	30	1.50E–10	1.50E–10	1.50E–06	*
KA2051A01	273.80	274.80	1	1.31E–05	–176.44	8.69E–06	–120.45	7.70E–08	–9.00	30	1.50E–10	1.50E–10	1.20E–06	***
KA2051A01	274.80	275.80	1	–	–176.05	–	–120.10	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	275.80	276.80	1	7.92E–08	–175.71	4.03E–08	–119.98	6.90E–10	–62.30	30	1.50E–10	1.50E–10	1.50E–06	*
KA2051A01	276.80	277.80	1	–	–176.09	–	–120.21	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	277.81	278.81	1	–	–176.20	–	–120.58	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	278.81	279.81	1	1.34E–07	–175.74	6.19E–08	–120.24	1.30E–09	–72.60	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	279.81	280.81	1	–	–175.89	–	–120.69	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	280.81	281.81	1	5.33E–07	–175.75	3.86E–07	–120.51	2.60E–09	24.40	30	1.50E–10	1.50E–10	1.50E–06	***
KA2051A01	281.81	282.81	1	2.17E–06	–175.78	1.41E–06	–120.47	1.40E–08	–16.60	30	1.50E–10	1.50E–10	1.50E–06	***
KA2051A01	282.81	283.81	1	2.86E–06	–175.24	1.84E–06	–120.36	1.80E–08	–21.60	30	1.50E–10	1.50E–10	1.50E–06	***

Appendix 5.11

Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-measl$_{LT}$ (m^2/s)	TD- measl$_{LP}$ (m^2/s)	TD-measl$_U$ (m^2/s)	Comments
KA2051A01	283.81	284.81	1	1.50E–07	–175.51	8.03E–08	–120.81	1.30E–09	–58.10	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	284.82	285.82	1	–	–175.38	–	–120.65	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	285.82	286.82	1	8.11E–07	–175.53	4.71E–07	–121.37	6.20E–09	–46.20	30	1.50E–10	1.50E–10	1.50E–06	*
KA2051A01	286.82	287.82	1	7E–07	–175.15	4.56E–07	–121.00	4.50E–09	–20.10	30	1.50E–10	1.50E–10	1.50E–06	***
KA2051A01	287.82	288.82	1	2.24E–06	–175.46	1.36E–06	–121.55	1.60E–08	–38.40	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	288.82	289.82	1	1.05E–06	–175.73	5.19E–07	–121.67	9.70E–09	–68.70	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	289.82	290.82	1	8.56E–07	–175.56	4E–07	–121.33	8.30E–09	–73.70	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	290.82	291.82	1	3.44E–06	–175.71	2.26E–06	–119.20	2.10E–08	–12.00	30	1.50E–10	1.50E–10	1.40E–06	***
KA2051A01	291.83	292.83	1	1.08E–06	–175.56	5.88E–07	–119.08	8.50E–09	–50.90	30	1.50E–10	1.50E–10	1.40E–06	*
KA2051A01	292.83	293.83	1	–	–175.65	–	–118.58	–	–	30	1.40E–10	1.40E–10	1.40E–06	
KA2051A01	293.83	294.83	1	1.77E–06	–175.36	1.03E–06	–118.71	1.30E–08	–39.20	30	1.50E–10	1.50E–10	1.40E–06	*
KA2051A01	294.83	295.83	1	4.83E–07	–175.54	3E–07	–119.02	3.20E–09	–26.50	30	1.50E–10	1.50E–10	1.50E–06	*
KA2051A01	295.83	296.83	1	4.36E–07	–175.68	3.03E–07	–120.29	2.40E–09	5.50	30	1.50E–10	1.50E–10	1.50E–06	***
KA2051A01	296.83	297.83	1	–	–175.25	–	–120.56	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	297.83	298.83	1	–	–175.23	–	–121.62	–	–	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	298.84	299.84	1	2.82E–06	–175.21	1.63E–06	–121.74	2.20E–08	–48.70	30	1.50E–10	1.50E–10	1.50E–06	
KA2051A01	299.84	300.84	1	2.54E–07	–175.28	1.53E–07	–122.02	1.90E–09	–41.00	30	1.60E–10	1.60E–10	1.50E–06	
KA2051A01	300.84	301.84	1	2.37E–07	–175.28	1.44E–07	–122.26	1.70E–09	–39.60	30	1.60E–10	1.60E–10	1.60E–06	
KA2051A01	301.84	302.84	1	1.84E–07	–175.45	9.47E–08	–122.93	1.70E–09	–67.30	30	1.60E–10	1.60E–10	1.60E–06	
KA2051A01	302.84	303.84	1	–	–175.04	–	–125.23	–	–	30	1.70E–10	1.70E–10	1.70E–06	
KA2051A01	303.84	304.84	1	2.08E–07	–175.43	1.09E–07	–126.16	2.00E–09	–71.60	30	1.70E–10	1.70E–10	1.70E–06	*
KA2051A01	304.84	305.84	1	–	–175.59	–	–126.14	–	–	30	1.70E–10	1.70E–10	1.70E–06	
KA2051A01	305.84	306.84	1	1.26E–05	–175.58	8.55E–06	–126.67	8.30E–08	–24.60	30	1.70E–10	1.70E–10	1.40E–06	***
KA2051A01	306.84	307.84	1	1.34E–06	–175.51	7.39E–07	–127.34	1.20E–08	–68.60	30	1.70E–10	1.70E–10	1.70E–06	*
KA2051A01	307.85	308.85	1	–	–176.06	–	–128.29	–	–	30	1.70E–10	1.70E–10	1.70E–06	
KA2051A01	308.85	309.85	1	–	–176.15	–	–129.32	–	–	30	1.80E–10	1.80E–10	1.80E–06	
KA2051A01	309.85	310.85	1	4.94E–06	–175.53	2.95E–06	–129.22	4.30E–08	–60.60	30	1.80E–10	1.80E–10	1.70E–06	*
KA2051A01	310.85	311.85	1	–	–175.57	–	–129.38	–	–	30	1.80E–10	1.80E–10	1.80E–06	

Appendix 5.12

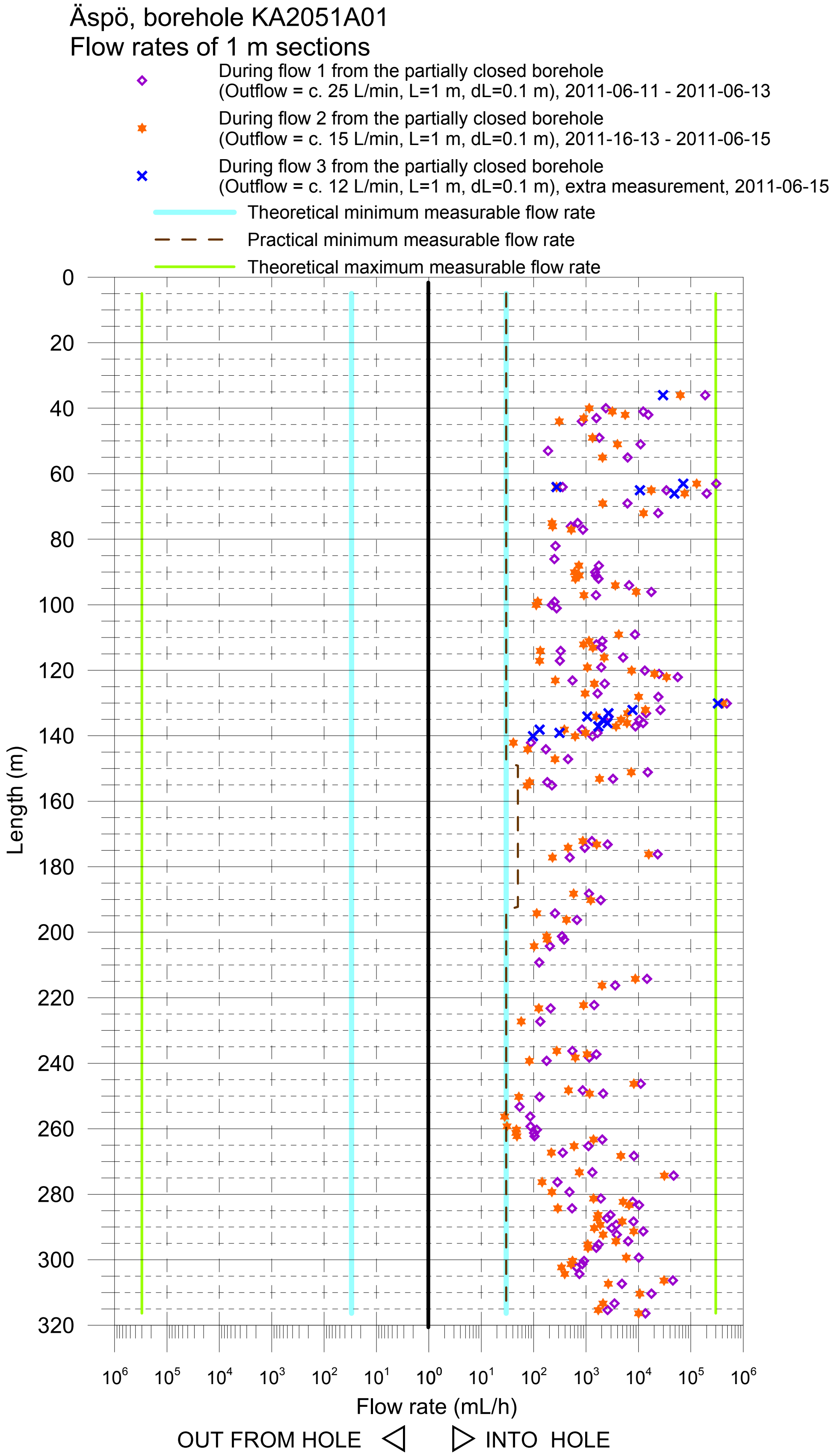
Results of sequential flow logging

Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	TD-$measl_{LT}$ (m^2/s)	TD- $measl_{LP}$ (m^2/s)	TD- $measl_U$ (m^2/s)	Comments
KA2051A01	311.85	312.85	1	–	–175.94	–	–130.96	–	–	30	1.80E–10	1.80E–10	1.80E–06	
KA2051A01	312.85	313.85	1	9.72E–07	–175.78	5.86E–07	–131.62	8.70E–09	–64.60	30	1.90E–10	1.90E–10	1.90E–06	
KA2051A01	313.85	314.85	1	–	–176.15	–	–133.19	–	–	30	1.90E–10	1.90E–10	1.90E–06	
KA2051A01	314.85	315.85	1	7.17E–07	–176.03	4.75E–07	–134.71	5.80E–09	–53.50	30	2.00E–10	2.00E–10	2.00E–06	***
KA2051A01	315.85	316.85	1	3.78E–06	–176.43	2.81E–06	–136.85	2.40E–08	–22.60	30	2.10E–10	2.10E–10	2.00E–06	***

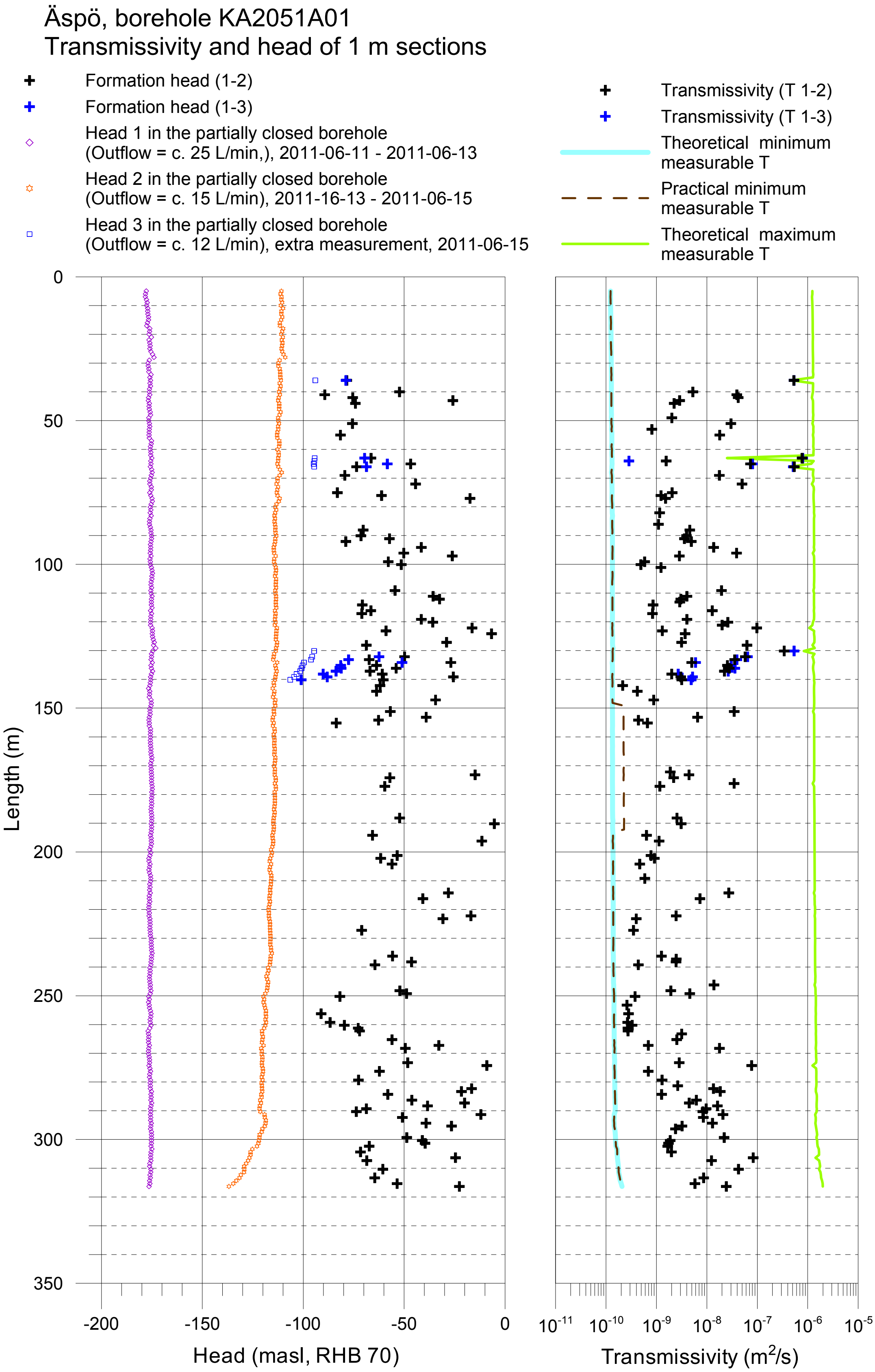
* Uncertain = The flow rate Q_0 and/or Q_1 is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.
** Flow rate Q_0 and/or Q_1 over the measurement limit (300 000 mL/h)
*** T_D and h_i inaccurate because the ratio of Q_0/Q_1 is small
¤ T_D calculation based on assumption that flow rate Q_1 = 0 mL/h

The interval between 67.26 m and 119.59 m is not representative as properties of the rock because of grouting.

Plotted flow rates of 1 m sections



Plotted transmissivity and head of 1 m sections



Appendix 7.1

Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KA2051A01	36.5	1	0.1	5.22E–05	–175.54	1.75E–05	–111.28	5.3E–07	–78.80	
KA2051A01	39.9	1	0.1	6.64E–07	–176.18	3.19E–07	–111.79	5.3E–09	–52.10	
KA2051A01	41.3	1	0.1	3.44E–06	–176.76	8.83E–07	–112.14	3.9E–08	–89.90	
KA2051A01	41.6	1	0.1	4.28E–06	–176.52	1.55E–06	–111.73	4.2E–08	–74.90	
KA2051A01	43.4	1	0.1	4.39E–07	–176.49	2.52E–07	–111.91	2.9E–09	–25.10	
KA2051A01	43.8	1	0.1	2.31E–07	–176.31	8.56E–08	–111.80	2.2E–09	–74.00	*
KA2051A01	49.3	1	0.1	5.00E–07	–176.57	3.69E–07	–112.48	2.0E–09	68.90	***
KA2051A01	51.4	1	0.1	3.06E–06	–176.51	1.11E–06	–112.47	3.0E–08	–76.20	
KA2051A01	52.7	1	0.1	5.25E–08	–176.65	–	–	8.2E–10	–	¤
KA2051A01	54.6	1	0.1	1.73E–06	–176.69	5.72E–07	–112.96	1.8E–08	–81.40	
KA2051A01	62.6	1	0.1	7.97E–06	–175.46	2.63E–06	–112.39	8.4E–08	–81.40	
KA2051A01	63.3	1	0.1	7.69E–05	–175.66	3.33E–05	–112.82	6.9E–07	–64.80	
KA2051A01	64.5	1	0.1	9.94E–08	–175.68	–	–122.77	1.6E–09	–	*, ¤
KA2051A01	64.9	1	0.1	9.53E–06	–175.50	4.89E–06	–112.75	7.3E–08	–46.60	
KA2051A01	65.9	1	0.1	5.58E–05	–175.60	2.12E–05	–112.59	5.4E–07	–74.00	
KA2051A01	69.2	1	0.1	1.72E–06	–175.29	5.78E–07	–111.99	1.8E–08	–79.90	*
KA2051A01	72.3	1	0.1	6.64E–06	–175.85	3.47E–06	–113.06	5.0E–08	–44.20	
KA2051A01	74.7	1	0.1	1.93E–07	–175.49	6.22E–08	–112.54	2.1E–09	–82.50	*
KA2051A01	76.2	1	0.1	1.42E–07	–175.56	6.39E–08	–112.87	1.2E–09	–61.40	*
KA2051A01	76.7	1	0.1	2.43E–07	–175.03	1.45E–07	–112.43	1.5E–09	–19.20	*
KA2051A01	81.8	1	0.1	7.25E–08	–176.03	–	–	1.2E–09	–	*,¤
KA2051A01	86.4	1	0.1	6.92E–08	–175.89	–	–	1.1E–09	–	*,¤
KA2051A01	87.7	1	0.1	3.42E–08	–174.53	–	–	5.4E–10	–	*,¤
KA2051A01	88.5	1	0.1	4.53E–07	–175.49	2.02E–07	–113.82	4.0E–09	–64.20	*
KA2051A01	89.6	1	0.1	4.14E–07	–175.87	1.67E–07	–114.10	4.0E–09	–72.20	*
KA2051A01	90.6	1	0.1	4.28E–07	–175.60	2.05E–07	–114.29	3.6E–09	–57.70	*
KA2051A01	92.0	1	0.1	4.81E–07	–175.65	1.74E–07	–114.04	4.9E–09	–79.00	*
KA2051A01	93.6	1	0.1	6.31E–07	–175.51	3.08E–07	–114.04	5.2E–09	–55.20	*
KA2051A01	94.1	1	0.1	7.33E–07	–175.60	3.47E–07	–114.53	6.3E–09	–59.60	
KA2051A01	94.5	1	0.1	4.81E–07	–175.42	3.50E–07	–113.94	2.1E–09	50.90	*,***
KA2051A01	95.8	1	0.1	4.92E–06	–175.37	2.51E–06	–113.75	3.9E–08	–49.30	
KA2051A01	97.2	1	0.1	4.31E–07	–175.51	2.53E–07	–113.94	2.9E–09	–26.60	
KA2051A01	98.7	1	0.1	6.94E–08	–175.52	3.33E–08	–113.95	5.8E–10	–57.10	
KA2051A01	99.9	1	0.1	6.17E–08	–175.59	3.11E–08	–113.99	4.9E–10	–51.30	*
KA2051A01	101.4	1	0.1	7.64E–08	–175.71	–	–	1.2E–09	–	*,¤
KA2051A01	108.6	1	0.1	2.39E–06	–175.16	1.17E–06	–113.88	2.0E–08	–55.00	
KA2051A01	111.0	1	0.1	5.67E–07	–175.08	3.17E–07	–113.63	4.0E–09	–35.80	*
KA2051A01	112.5	1	0.1	4.39E–07	–175.63	2.49E–07	–113.94	3.0E–09	–32.90	
KA2051A01	113.0	1	0.1	5.56E–07	–175.38	3.75E–07	–113.72	2.9E–09	14.30	***
KA2051A01	114.5	1	0.1	9.08E–08	–175.31	3.72E–08	–113.60	8.6E–10	–70.80	*

Appendix 7.2

Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KA2051A01	116.0	1	0.1	1.42E–06	–175.49	6.17E–07	–113.94	1.3E–08	–66.50	
KA2051A01	116.8	1	0.1	8.81E–08	–175.24	3.61E–08	–113.74	8.4E–10	–71.00	*
KA2051A01	119.3	1	0.1	5.44E–07	–175.85	2.94E–07	–114.28	4.0E–09	–41.80	*
KA2051A01	120.4	1	0.1	3.69E–06	–175.58	2.06E–06	–113.73	2.6E–08	–35.90	
KA2051A01	120.7	1	0.1	6.89E–06	–175.50	5.64E–06	–113.80	2.0E–08	164.50	***
KA2051A01	121.7	1	0.1	7.28E–06	–175.12	5.53E–06	–113.33	2.8E–08	81.90	***
KA2051A01	122.1	1	0.1	8.39E–06	–174.92	4.03E–06	–113.07	7.0E–08	–56.00	
KA2051A01	123.2	1	0.1	1.53E–07	–174.82	7.19E–08	–113.41	1.3E–09	–59.10	*
KA2051A01	124.1	1	0.1	6.31E–07	–174.87	4.00E–07	–113.48	3.7E–09	–7.00	***
KA2051A01	126.8	1	0.1	4.61E–07	–174.16	2.67E–07	–113.14	3.1E–09	–29.00	
KA2051A01	128.0	1	0.1	6.67E–06	–174.59	2.81E–06	–113.37	6.2E–08	–68.90	
KA2051A01	129.8	1	0.1	1.25E–04	–174.70	1.08E–04	–113.83	2.8E–07	268.10	**,***
KA2051A01	130.3	1	0.1	9.69E–06	–175.08	5.86E–06	–114.36	6.2E–08	–21.50	
KA2051A01	132.0	1	0.1	7.31E–06	–175.18	3.78E–06	–114.64	5.8E–08	–49.80	
KA2051A01	132.7	1	0.1	3.89E–06	–174.79	1.71E–06	–114.33	3.6E–08	–66.80	
KA2051A01	134.3	1	0.1	7.50E–07	–175.00	4.36E–07	–113.30	5.0E–09	–27.60	
KA2051A01	134.7	1	0.1	2.89E–06	–175.37	1.30E–06	–113.88	2.6E–08	–63.80	
KA2051A01	135.7	1	0.1	3.42E–06	–175.40	1.68E–06	–113.64	2.8E–08	–54.10	
KA2051A01	137.1	1	0.1	2.43E–06	–174.76	1.04E–06	–113.23	2.2E–08	–67.00	
KA2051A01	138.6	1	0.1	2.33E–07	–175.75	1.07E–07	–114.23	2.0E–09	–61.60	*
KA2051A01	139.0	1	0.1	4.61E–07	–175.66	2.71E–07	–114.04	3.1E–09	–26.10	
KA2051A01	140.3	1	0.1	3.69E–07	–175.65	1.72E–07	–113.92	3.2E–09	–60.20	
KA2051A01	142.0	1	0.1	2.47E–08	–176.02	1.14E–08	–114.60	2.2E–10	–62.10	
KA2051A01	144.0	1	0.1	1.25E–08	–176.06	5.83E–09	–114.43	1.1E–10	–60.50	*
KA2051A01	144.6	1	0.1	3.50E–08	–175.51	1.56E–08	–113.98	3.1E–10	–64.80	
KA2051A01	146.8	1	0.1	1.26E–07	–175.38	7.08E–08	–113.67	8.8E–10	–34.20	
KA2051A01	150.7	1	0.1	2.37E–06	–176.01	1.29E–06	–114.52	1.7E–08	–40.60	
KA2051A01	151.2	1	0.1	1.82E–06	–175.90	7.36E–07	–114.40	1.7E–08	–72.60	
KA2051A01	153.2	1	0.1	9.08E–07	–176.36	5.03E–07	–115.11	6.6E–09	–39.20	
KA2051A01	154.0	1	0.1	5.06E–08	–176.22	2.33E–08	–114.84	4.4E–10	–62.20	*
KA2051A01	155.4	1	0.1	6.22E–08	–176.14	2.08E–08	–114.61	6.7E–10	–83.60	*
KA2051A01	172.5	1	0.1	3.58E–07	–175.30	2.42E–07	–114.06	1.9E–09	12.80	*
KA2051A01	172.9	1	0.1	5.33E–07	–175.20	2.74E–07	–114.10	4.2E–09	–49.30	*
KA2051A01	173.3	1	0.1	1.84E–07	–175.28	1.70E–07	–114.15	2.3E–10	605.30	*,***
KA2051A01	173.8	1	0.1	2.63E–07	–174.75	1.26E–07	–113.71	2.2E–09	–57.50	*
KA2051A01	176.2	1	0.1	6.50E–06	–175.09	4.36E–06	–114.04	3.5E–08	10.40	***
KA2051A01	177.2	1	0.1	1.36E–07	–174.93	6.36E–08	–113.62	1.2E–09	–59.60	
KA2051A01	188.6	1	0.1	3.17E–07	–174.95	1.61E–07	–114.51	2.6E–09	–52.10	
KA2051A01	190.5	1	0.1	5.31E–07	–175.20	3.42E–07	–114.65	3.1E–09	–5.10	***
KA2051A01	193.8	1	0.1	1.61E–08	–175.76	9.17E–09	–115.64	1.1E–10	–36.30	*
KA2051A01	194.5	1	0.1	5.47E–08	–175.64	2.28E–08	–115.25	5.2E–10	–72.20	*
KA2051A01	196.7	1	0.1	1.87E–07	–175.54	1.18E–07	–115.40	1.1E–09	–12.60	*,***

Appendix 7.3

Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KA2051A01	201.6	1	0.1	9.67E–08	–176.08	4.92E–08	–115.98	7.8E–10	–53.80	
KA2051A01	202.4	1	0.1	1.06E–07	–176.35	5.06E–08	–116.38	9.2E–10	–61.80	
KA2051A01	204.1	1	0.1	5.67E–08	–176.25	2.83E–08	–116.28	4.7E–10	–56.30	
KA2051A01	209.7	1	0.1	3.56E–08	–176.10	–	–	5.9E–10	–	*,¤
KA2051A01	214.4	1	0.1	4.06E–06	–176.01	2.42E–06	–116.45	2.7E–08	–28.10	
KA2051A01	216.2	1	0.1	1.00E–06	–176.22	5.61E–07	–116.84	7.3E–09	–40.90	
KA2051A01	222.1	1	0.1	3.97E–07	–176.58	2.49E–07	–117.14	2.5E–09	–16.80	***
KA2051A01	223.0	1	0.1	5.86E–08	–176.15	3.47E–08	–116.90	4.0E–10	–30.80	*
KA2051A01	226.9	1	0.1	3.72E–08	–175.26	1.61E–08	–115.98	3.5E–10	–70.70	*
KA2051A01	235.9	1	0.1	1.52E–07	–175.28	7.69E–08	–116.13	1.3E–09	–55.70	
KA2051A01	237.5	1	0.1	4.39E–07	–174.59	2.92E–07	–115.77	2.5E–09	0.80	***
KA2051A01	238.2	1	0.1	3.19E–07	–175.60	1.73E–07	–116.72	2.5E–09	–46.90	
KA2051A01	239.0	1	0.1	4.92E–08	–175.68	2.31E–08	–116.94	4.4E–10	–65.10	
KA2051A01	245.8	1	0.1	3.08E–06	–175.39	2.27E–06	–117.26	1.4E–08	44.80	***
KA2051A01	247.9	1	0.1	2.40E–07	–175.61	1.28E–07	–118.01	1.9E–09	–52.00	
KA2051A01	248.9	1	0.1	2.58E–07	–175.81	1.44E–07	–118.52	2.0E–09	–46.50	*
KA2051A01	249.3	1	0.1	2.76E–07	–175.87	1.48E–07	–118.81	2.2E–09	–52.60	*
KA2051A01	249.7	1	0.1	5.56E–08	–175.72	3.28E–08	–118.42	3.9E–10	–36.00	*
KA2051A01	250.2	1	0.1	3.61E–08	–176.53	1.44E–08	–119.75	3.8E–10	–81.90	
KA2051A01	253.4	1	0.1	1.50E–08	–176.40	–	–	2.6E–10	–	*,¤
KA2051A01	256.5	1	0.1	2.39E–08	–175.93	7.78E–09	–119.05	2.8E–10	–91.60	*
KA2051A01	259.4	1	0.1	2.42E–08	–175.94	8.61E–09	–118.70	2.7E–10	–87.00	
KA2051A01	260.2	1	0.1	3.19E–08	–175.36	1.31E–08	–118.58	3.3E–10	–79.30	
KA2051A01	260.8	1	0.1	2.83E–08	–176.02	1.28E–08	–119.64	2.7E–10	–73.30	
KA2051A01	262.5	1	0.1	2.89E–08	–177.16	1.33E–08	–120.75	2.7E–10	–72.40	
KA2051A01	263.7	1	0.1	5.67E–07	–177.21	3.86E–07	–121.12	3.2E–09	–1.20	
KA2051A01	265.1	1	0.1	3.08E–07	–176.63	1.64E–07	–120.38	2.5E–09	–56.30	
KA2051A01	267.6	1	0.1	1.00E–07	–174.40	6.06E–08	–118.11	6.9E–10	–31.70	*
KA2051A01	268.4	1	0.1	2.28E–06	–176.60	1.28E–06	–120.84	1.8E–08	–49.40	
KA2051A01	273.1	1	0.1	7.19E–08	–176.53	4.36E–08	–121.07	5.1E–10	–35.70	
KA2051A01	273.6	1	0.1	2.94E–07	–176.42	1.63E–07	–120.61	2.3E–09	–51.10	*
KA2051A01	273.9	1	0.1	1.14E–06	–176.89	5.28E–07	–120.97	1.1E–08	–73.10	*
KA2051A01	274.1	1	0.1	1.16E–05	–176.32	8.00E–06	–120.27	6.4E–08	3.90	***
KA2051A01	274.5	1	0.1	3.00E–07	–176.35	1.62E–07	–120.42	2.5E–09	–55.10	
KA2051A01	275.8	1	0.1	7.92E–08	–176.53	4.03E–08	–120.28	6.8E–10	–62.00	*
KA2051A01	279.7	1	0.1	1.34E–07	–176.16	6.19E–08	–120.89	1.3E–09	–73.50	
KA2051A01	280.9	1	0.1	5.33E–07	–176.21	3.86E–07	–121.24	2.7E–09	22.90	***
KA2051A01	282.3	1	0.1	2.17E–06	–175.81	1.41E–06	–120.52	1.4E–08	–16.70	***
KA2051A01	283.0	1	0.1	2.86E–06	–175.81	1.84E–06	–120.82	1.8E–08	–21.90	***
KA2051A01	284.3	1	0.1	1.50E–07	–175.50	8.03E–08	–120.80	1.3E–09	–58.10	
KA2051A01	286.0	1	0.1	1.19E–07	–175.80	6.03E–08	–121.44	1.1E–09	–66.10	*

Appendix 7.4

Inferred flow anomalies from overlapping flow logging

Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KA2051A01	286.5	1	0.1	6.92E–07	–175.24	4.11E–07	–121.00	5.1E–09	–41.50	
KA2051A01	287.2	1	0.1	7.00E–07	–175.38	4.56E–07	–121.06	4.5E–09	–19.80	***
KA2051A01	288.0	1	0.1	7.72E–07	–175.45	5.36E–07	–121.65	4.3E–09	0.50	***
KA2051A01	288.4	1	0.1	1.47E–06	–175.47	8.22E–07	–121.48	1.2E–08	–52.60	
KA2051A01	289.7	1	0.1	1.05E–06	–175.47	5.19E–07	–121.07	9.7E–09	–67.80	
KA2051A01	290.2	1	0.1	8.56E–07	–175.67	4.00E–07	–121.47	8.3E–09	–73.90	
KA2051A01	291.3	1	0.1	3.44E–06	–175.65	2.26E–06	–119.18	2.1E–08	–12.10	***
KA2051A01	291.9	1	0.1	4.22E–07	–175.60	1.48E–07	–118.92	4.8E–09	–88.20	
KA2051A01	292.3	1	0.1	3.00E–07	–175.57	2.65E–07	–119.09	6.1E–10	312.40	*,***
KA2051A01	292.5	1	0.1	3.53E–07	–175.31	1.74E–07	–118.96	3.1E–09	–63.80	*
KA2051A01	294.1	1	0.1	5.50E–07	–175.54	3.06E–07	–118.92	4.3E–09	–48.20	*
KA2051A01	294.4	1	0.1	1.22E–06	–175.46	7.28E–07	–118.74	8.6E–09	–34.80	*
KA2051A01	295.1	1	0.1	4.83E–07	–175.66	3.00E–07	–119.09	3.2E–09	–26.50	*
KA2051A01	296.0	1	0.1	4.36E–07	–175.79	3.03E–07	–119.79	2.4E–09	7.40	***
KA2051A01	299.0	1	0.1	2.23E–06	–175.20	1.23E–06	–121.63	1.8E–08	–55.70	
KA2051A01	299.6	1	0.1	5.94E–07	–175.24	4.00E–07	–122.09	3.6E–09	–12.80	***
KA2051A01	300.6	1	0.1	2.54E–07	–175.30	1.53E–07	–122.20	1.9E–09	–41.50	
KA2051A01	301.5	1	0.1	2.37E–07	–175.29	1.44E–07	–122.40	1.7E–09	–40.00	
KA2051A01	302.2	1	0.1	1.84E–07	–175.40	9.47E–08	–122.87	1.7E–09	–67.20	
KA2051A01	304.0	1	0.1	1.22E–07	–175.07	6.25E–08	–125.57	1.2E–09	–73.80	
KA2051A01	304.4	1	0.1	8.56E–08	–175.28	4.67E–08	–125.92	7.8E–10	–66.70	*
KA2051A01	306.1	1	0.1	1.61E–06	–175.37	8.81E–07	–126.49	1.5E–08	–67.80	*
KA2051A01	306.8	1	0.1	1.10E–05	–175.66	7.67E–06	–126.84	6.8E–08	–15.50	***
KA2051A01	307.5	1	0.1	1.34E–06	–174.52	7.39E–07	–126.73	1.3E–08	–68.40	*
KA2051A01	310.3	1	0.1	3.81E–06	–175.50	2.46E–06	–129.24	2.9E–08	–44.30	
KA2051A01	310.8	1	0.1	1.14E–06	–175.73	4.89E–07	–129.57	1.4E–08	–94.90	*
KA2051A01	313.5	1	0.1	9.72E–07	–176.11	5.86E–07	–132.22	8.7E–09	–65.60	
KA2051A01	315.3	1	0.1	7.17E–07	–176.03	4.75E–07	–134.64	5.8E–09	–53.30	***
KA2051A01	316.5	1	0.1	3.78E–06	–176.44	2.81E–06	–137.10	2.4E–08	–23.60	***

* Uncertain = The flow rate Q_0 and/or Q_1 is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

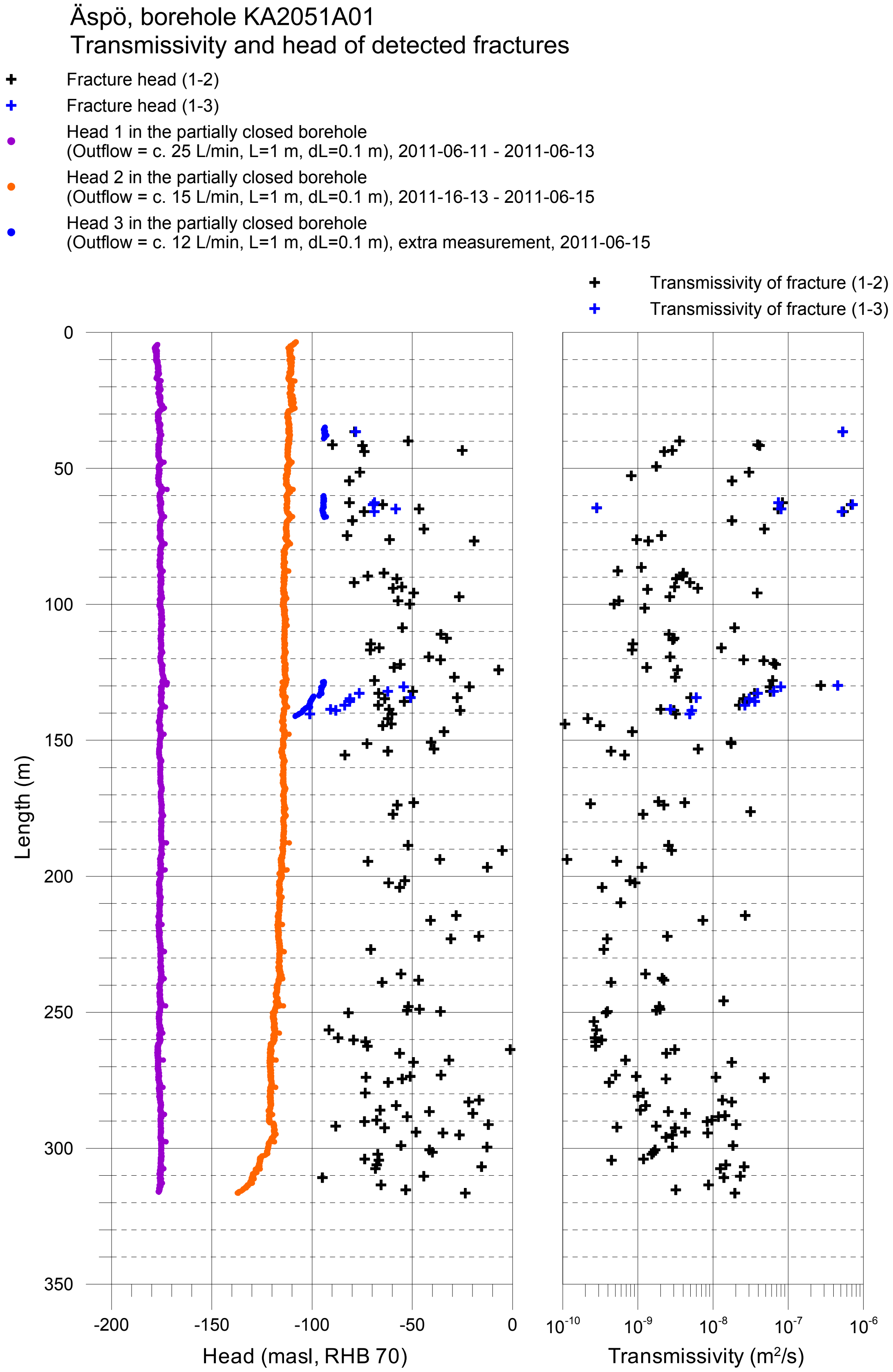
** Flow rate Q_0 and Q_1 over the measurement limit (300 000 mL/h).

*** T_D and h_i inaccurate because the ratio of Q_0/Q_1 is small.

¤ T_D calculation based on assumption that flow rate Q_1 = 0 mL/h.

The interval between 67.26 m and 119.59 m is not representative as properties of the rock because of grouting.

Plotted transmissivity of detected fractures

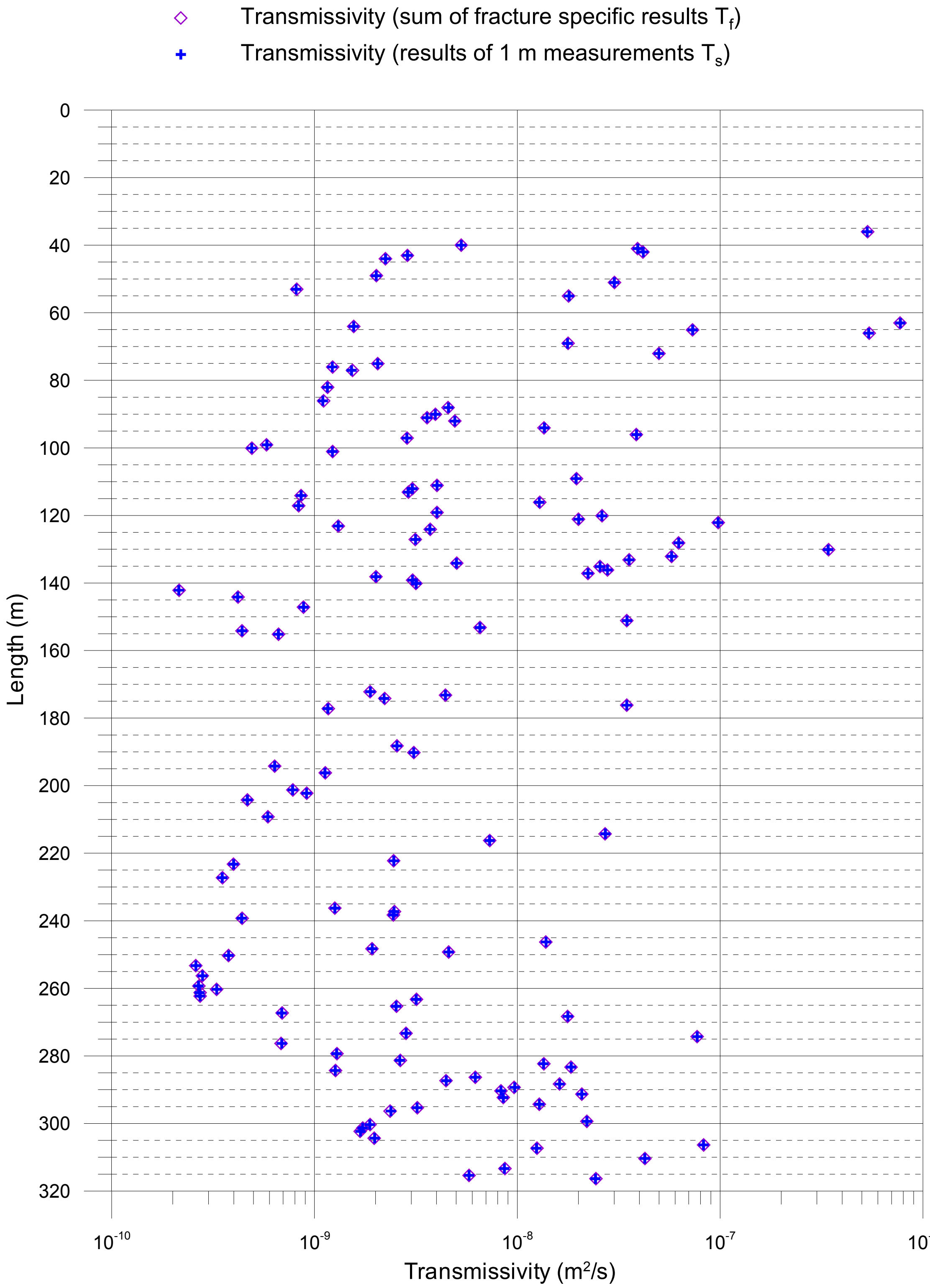


Appendix 9

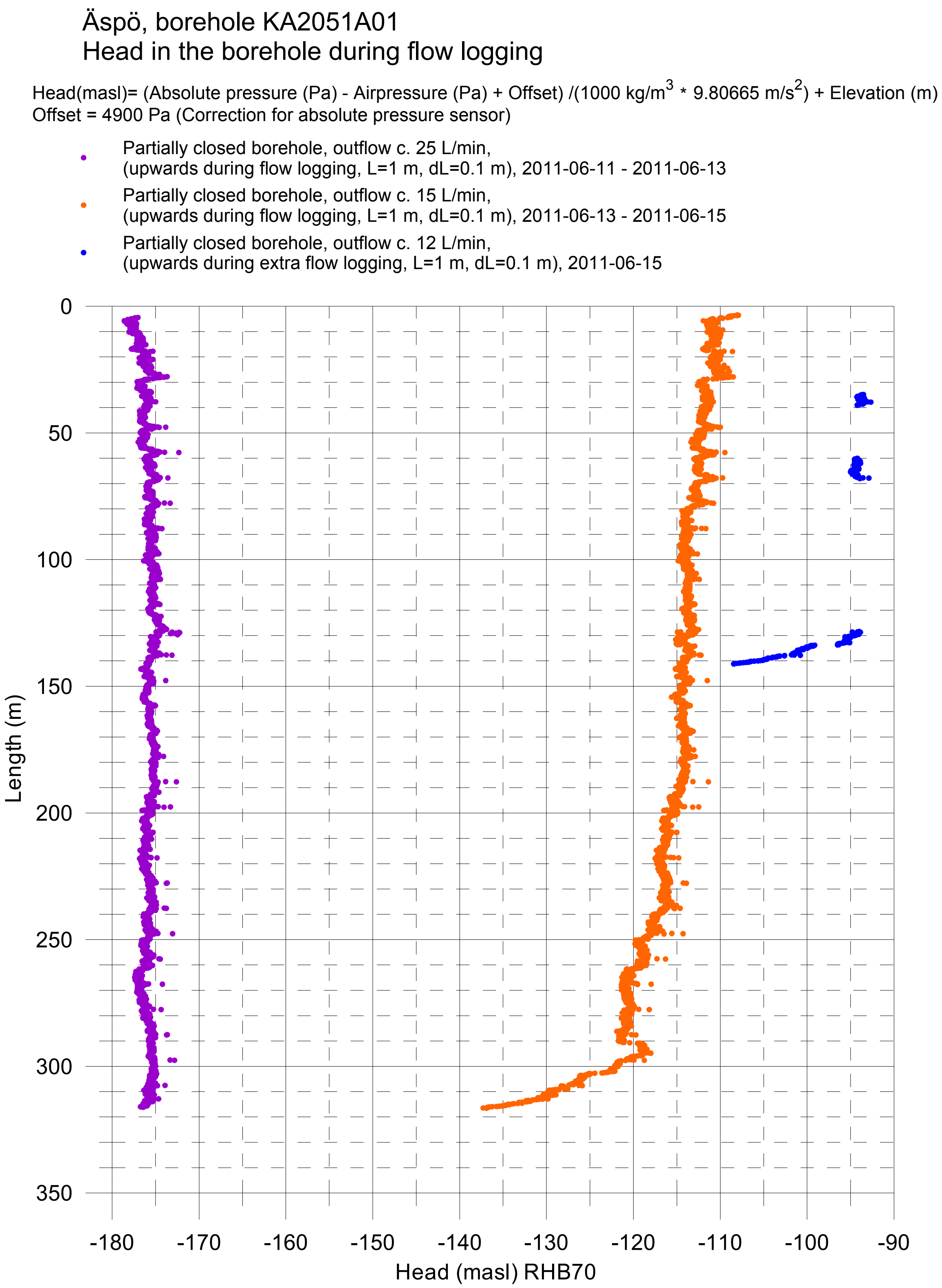
Comparison between section transmissivity and fracture transmissivity

Äspö, borehole KA2051A01

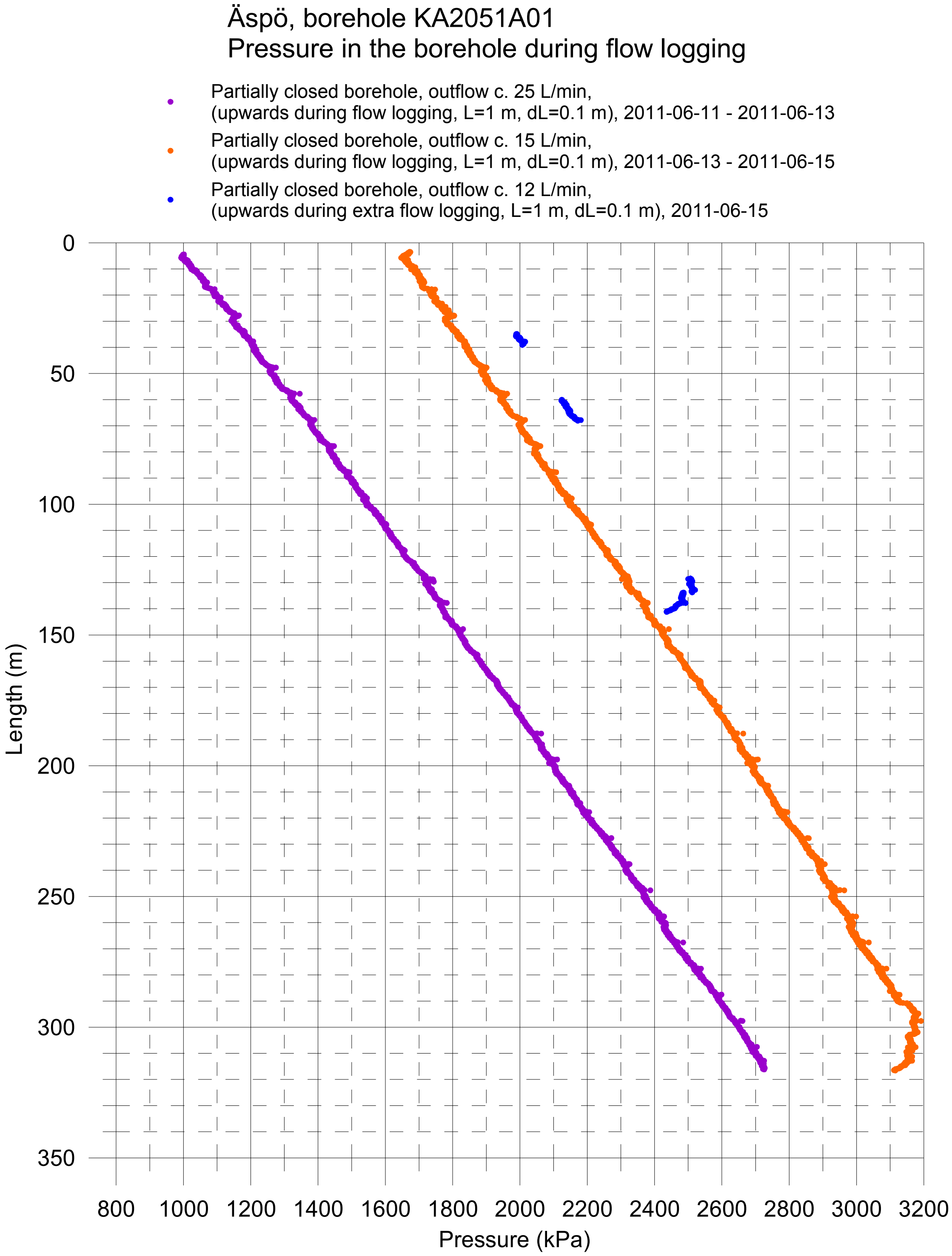
Comparison between section transmissivity and fracture transmissivity



Head in the borehole during flow logging



Pressure in the borehole during flow logging



Borehole pressure and outflow from the borehole