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Forsmark site investigations

Difference flow logging in boreholes KFM14, KFM15, KFM16, KFM20, KFM21, KFM22 and KFM23

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Abstract

This report presents the main principles of the methods as well as the results of measurements carried out in boreholes KFM14, KFM15, KFM16, KFM20, KFM21, KFM22 and KFM23 at Forsmark, Sweden, in November and December 2018.

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 of fractures/fracture zones in boreholes.

The first flow logging measurements were carried out with a 5 m test section by moving the measurement tool in 0.5 m steps. This method was used to flow log the entire measurable part of the boreholes both while the borehole was not pumped and while water level in the measured borehole was lowered by pumping water out of the borehole. The flow measurements in pumped conditions were repeated using a 1 m long test section, with 0.1 m steps.

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

The flow along the borehole was measured below the casing tube during undisturbed conditions to detect possible leakage of the casing tube.

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 in unpumped as well as in pumped conditions. The EC of fracture-specific water was measured (1 m test section) at selected fractures.

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

Sammanfattning

Denna rapport presenterar huvudprinciperna för metoden och resultat av mätningar utförda i borrhål KFM14, KFM15, KFM16, KFM20, KFM21, KFM22 och KFM23 i Forsmark, Sverige, i november och december 2018.

Posiva Flow Log, Differensflödesloggning (*PFL DIFF*) är en snabb metod för bestämning av transmissiviteten och hydraulisk tryckhöjd i borrhålssektioner och sprickor/sprickzoner i kärnborrhål.

Flödet till eller från en 5 m lång testsektion (*som successivt förflyttades med 0,5 m*) mättes i borrhålet under såväl naturliga förhållanden som vid pumpning. Flödesmätningarna upprepades under pumpning med en 1 m lång testsektion som successivt förflyttades i steg om 0,1 m.

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

Mätning av flödet längs borrhålet gjordes nedanför foderröret under naturliga betingelser för att detektera läckage av foderröret.

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

Återhämtningen av grundvattennivån mättes efter att pumpningen i borrhålet avslutats.

Contents

1 Introduction

The core drilled boreholes KFM14, KFM15, KFM16, KFM20, KFM21, KFM22, and KFM23 at Forsmark, Sweden were measured using the Posiva Flow Log, Difference Flow Method (PFL DIFF) which provides a swift, multifaceted characterization of a borehole. The measurement campaign was conducted October 31–December 10, 2018.

The boreholes are shallow with quite short casing tubes. Lengths of boreholes varies from ca. 60 m to 102 m. Boreholes are equipped with casing tubes which are 77.5 mm in diameter. Borehole diameter is 76.3 mm. Casing tube lengths have been adjusted to penetrate soil cover above bedrock, longest casing tube being 8.4 m long. Technical data of boreholes have been presented in Table 1-1.

Table 1-1. *Technical data of the measured boreholes.*

Borehole ID	Length (m)	Inclination (degrees)	Z coordinate of top of the casing (masl)	Length of casing tube (m)
KFM14	60.18	−85.33	1.97	5.91
KFM15	62.30	−83.83	3.47	7.48
KFM16	60.35	−59.47	1.50	4.42
KFM20	60.50	−85.37	2.80	2.33
KFM21	101.60	−70.93	2.62	5.81
KFM22	60.26	−85.50	2.75	8.40
KFM23	100.64	−72.88	2.27	4.60

The locations of measured boreholes at Forsmark are illustrated in Figure 1-1.

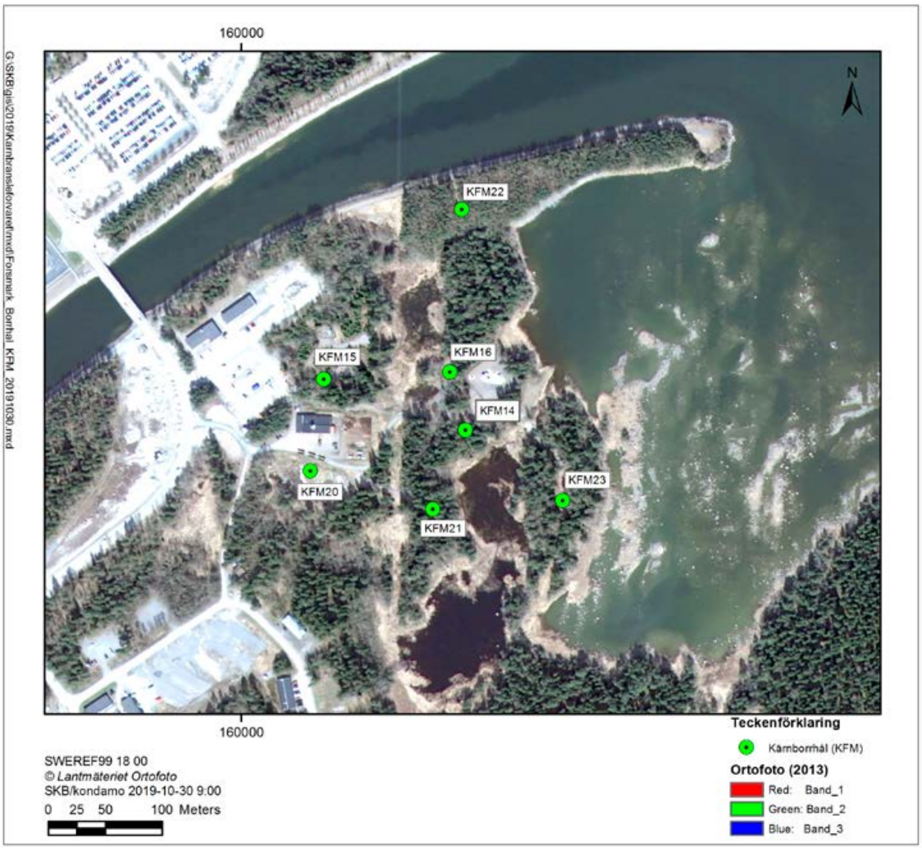


Figure 1-1. *Locations of the boreholes in Forsmark (from AP SFK-18-026).*

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

This document reports the results acquired by PFL DIFF method. The measurements were carried out to investigate the near-surface bedrock in Forsmark as instructed in SKB's internal controlling document AP SFK-18-026. 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 1-2. SKB's internal controlling documents for the activities concerning this report.

Activity Plan	Number	Version
Difference flow logging in boreholes KFM14-16 and KFM20-23	AP SFK-18-026	1.0
Method Descriptions	**Number**	**Version**
Method Description for Difference Flow Logging	SKB MD 322.010e	2.0
Instructions for cleaning borehole equipment and certain surface equipment	SKB MD 600.004e	1.0
Instruction for length calibration in investigation of core boreholes	SKB MD 620.010e	2.0

2 Objective and scope

The main objective of the PFL DIFF measurements in boreholes was to identify water-conductive sections/fractures. Secondly, the measurements aimed at a hydro-geological characterisation, which includes the inspection of the prevailing water flow balance in the borehole and the hydraulic properties (*transmissivity and undisturbed hydraulic head*) of the tested sections. Based on the results of these investigations, a more detailed characterisation of flow anomalies along the borehole, e.g. an estimate of the conductive fracture frequency (*CFF*), may be obtained.

Besides difference flow logging, the measurement programme also included supporting measurements, performed in order to gain a better understanding of the overall hydro-geochemical conditions. These measurements included the electrical conductivity (*EC*) and the temperature of the borehole fluid as well as the single-point resistance of the borehole wall. The electrical conductivity of a number of selected high-transmissive fractures (*the electrical conductivity of the water in the fractures*) in the borehole was also measured. Furthermore, the recovery of the groundwater level after pumping the borehole was registered.

To measure the absolute pressure along the borehole, a high-resolution pressure sensor was used, and pressure measurement was carried out simultaneous as the flow measurements. The results are used for the calculation of the hydraulic head along the borehole.

The flow along the borehole was measured below the casing tube in undisturbed conditions (*without pumping*) to detect possible leakages of the casing tube.

3 Principles of measurement and interpretation

3.1 Measurements

Unlike conventional borehole flowmeters, which measure the total cumulative flow rate along a borehole, the 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 flows are generally very small, they can easily be missed when using conventional flowmeters. Technical illustrations of the PFL DIFF probe are presented in Figure 3-1.

Rubber sealing disks located at the top and bottom of the PFL DIFF probe are used to isolate the flow of water in the test section from the flow in the rest of the borehole, see Figure 3-2. 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. A schematic representing a cross-section of the PFL DIFF probe's structure is presented in Figure 3-3. It should be noted that, depending on pressure difference between a fracture and a borehole, the direction of the measured flow can be from the bedrock into the borehole as the magenta coloured arrows represent in Figure 3-2 and Figure 3-3, or from the borehole into the bedrock in which case the arrowheads in Figure 3-2 and Figure 3-3 would be inverted. The same applies to flow along the hole as well, as it can go either upwards or downwards depending on the prevailing conditions in a borehole at a certain depth.

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*) fracture zones. The 1 m section setup can separate anomalies which are close to each other. Different section lengths can also confirm that a flow anomaly is real and not caused for instance by leakage of the rubber discs.

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). The thermal dilution method is used in measuring flow rates because it is faster than the thermal pulse method, where the latter is used only to determine flow direction within a given time frame. Both methods are used simultaneously at each measurement location.

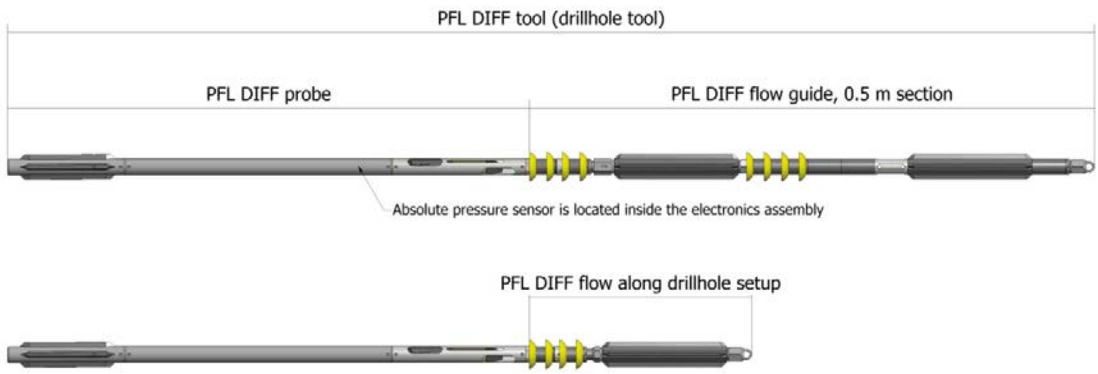


Figure 3-1. *Technical illustration of the PFL DIFF probe in different setups.*

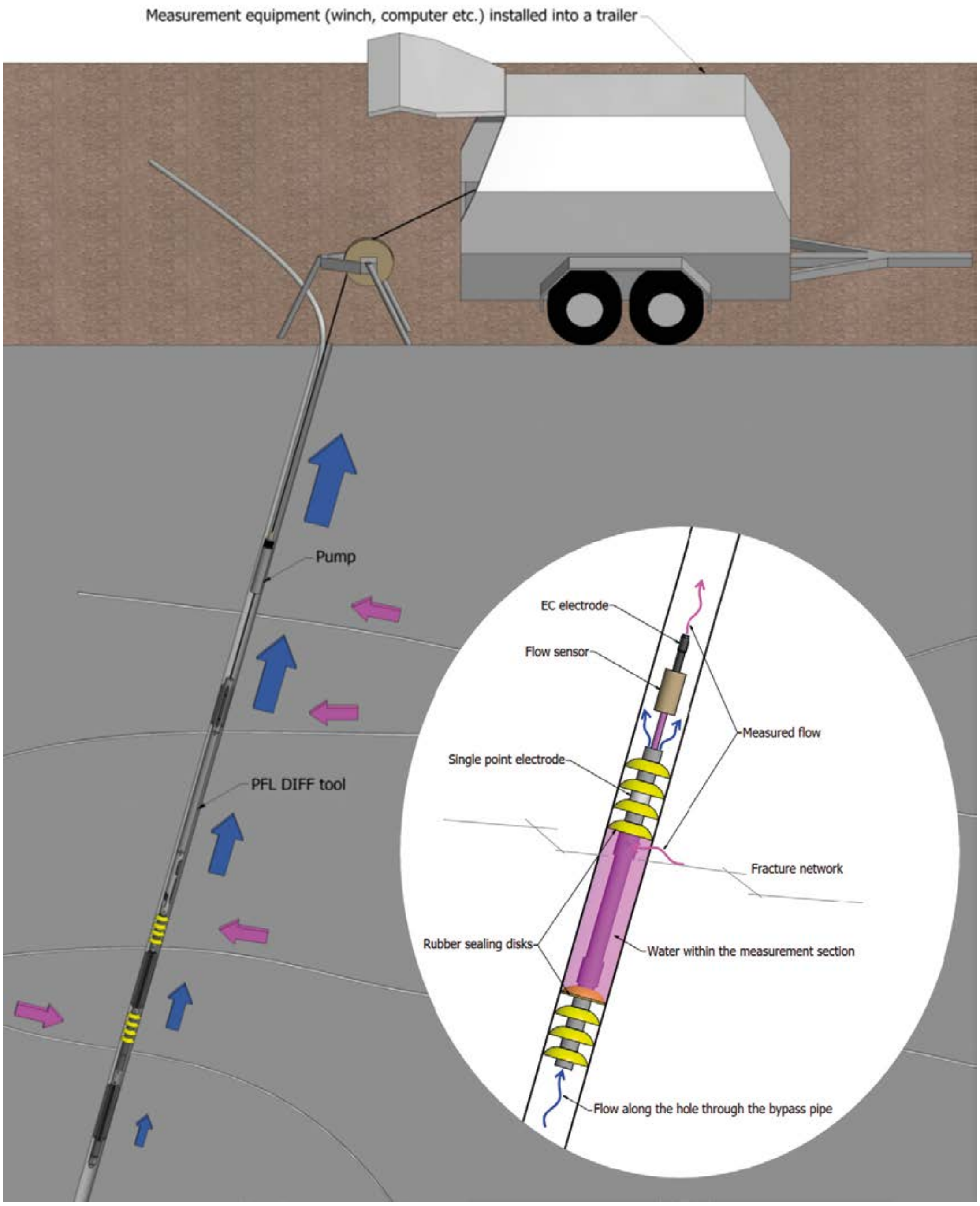


Figure 3-2. *Schematic of the probe used in the PFL DIFF.*

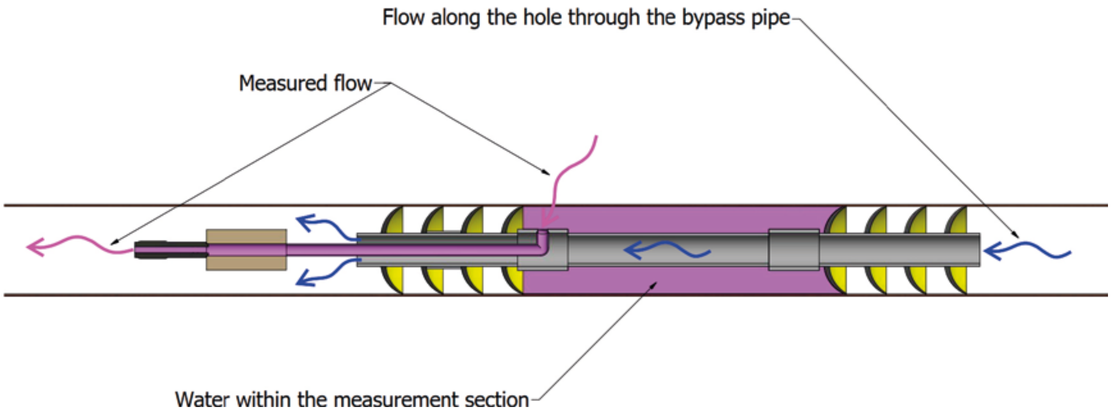


Figure 3-3. *The absolute pressure sensor is located inside the electronics assembly and connected to the section through a tube.*

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 (*Figure 3-2*).
- The single point resistance (*SPR*) of the borehole wall (*grounding resistance*). The SPR electrode is located between the uppermost rubber sealing discs (*Figure 3-2*), and is used for the high-resolution depth determination of fractures and geological structures.
- The ambient water pressure profile in the borehole. Located inside the watertight electronics assembly, the pressure sensor transducer is connected to the measurement section through a tube.
- The temperature of the water in the borehole. The temperature sensor is part of the flow sensor (*Figure 3-2*).

The principles behind PFL DIFF flow measurements are shown in Figure 3-4. The flow sensor consists of three thermistors (*Figure 3-4a*). The central thermistor, A, is used both as a heating element and to register temperature changes (*Figure 3-4b and c*). The side thermistors, B1 and B2, serve as detectors of the moving thermal pulse caused by the heating of thermistor A.

Flow rate is measured by monitoring heat transients after constant power (*P1*) heating in thermistor A. After the power is cut off the flow rate is determined by monitoring transient thermal dilution (*Figure 3-4c*). If the flow rate exceeds a certain limit, 1 200 mL/h, another constant power heating (*P2*) period is started after which the thermal transient is monitored and flow rate determined based on that.

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 3-4b*) 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.

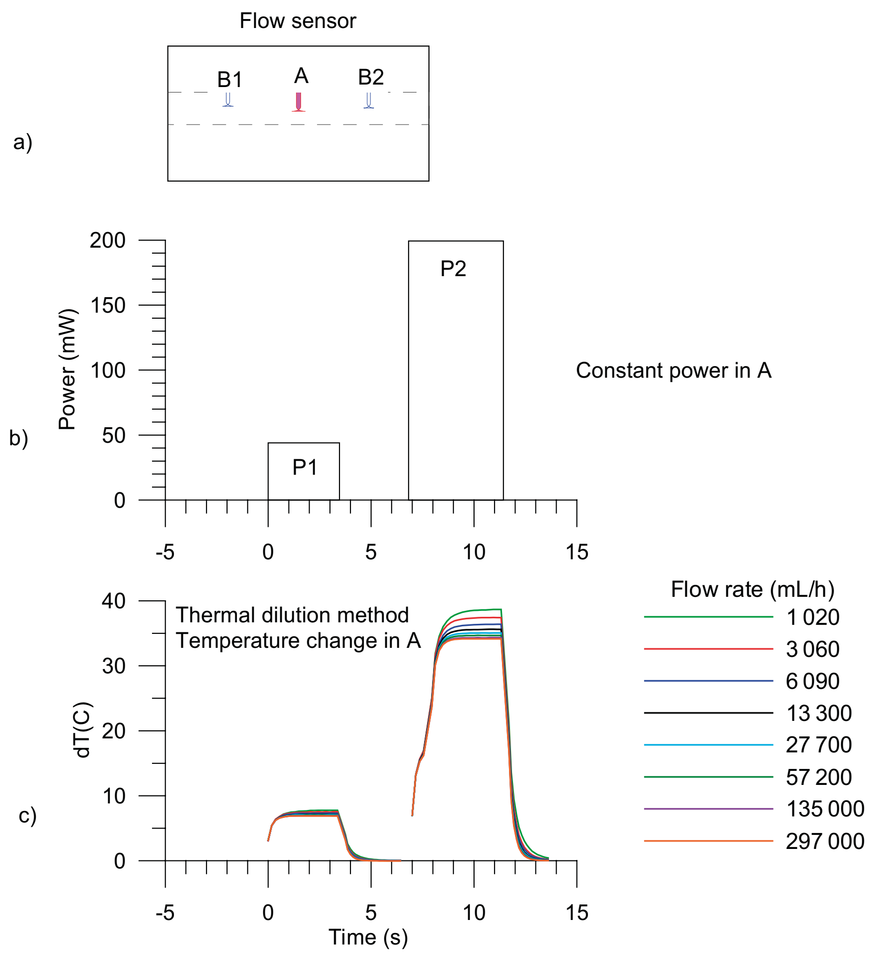


***Figure 3-4.** Flow rate measurement.*

The measurement range for flow rate is 30 mL/h–300 000 mL/h in general. The PFL DIFF probes have been calibrated for flow range from 6 mL/h to 300 000 mL/h in laboratory but usually conditions at field raise the lower limit to around 30 mL/h. Therefore, in some cases flow rates below 30 mL/h can be measured. On the other hand, lower limit of 30 mL/h cannot be assured in all borehole conditions. Examples of possible sources for disturbances are drilling debris entrained in the borehole water, bubbles of gas in the water and very high flow rates along the borehole (*some 30 L/min, i.e., 1 800 000 mL/h or more*). In case of significant disturbances, the practical measurement limits are calculated separately for each set of data. Measurement range of 30–300 000 mL/h has been determined based on experience and it is valid in most of cases, but exceptions exist.

3.2 Interpretation

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

$$h_s - h = \frac{Q}{T \cdot a} \qquad \text{3-1}$$

where

h is the hydraulic head in the borehole (at borehole radius r_0),

h_S is the hydraulic head at the radius of influence (R),

Q is the flow rate into the borehole,

T is the transmissivity of the test section, The constant a depends on the assumed flow geometry. For cylindrical flow, the constant a is:

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

where

r_0 is the radius of the borehole and

R is the radius of influence, i.e., distance to a constant head boundary.

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

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

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

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 section, i.e. head when the section flow is zero.

In general, since very little is known about the flow geometry, cylindrical flow without skin effect is assumed. The measurements are conducted in steady state conditions and therefore no skin effect can be assumed and the calculated transmissivity is determined based on the smallest conductivity in the fracture network where the water flow is coming from or going to. Basically, in case of positive skin the calculated transmissivity represents only the transmissivity close to the borehole and transmissivity of the fracture or fracture network further away from the borehole wall cannot be estimated. Cylindrical flow geometry is 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 therefore be assumed. In this case, a value of 500 for the quotient R/r_0 is selected. This corresponds a radius of influence of 19 m when the diameter of the borehole is 76 mm.

The hydraulic head h_s and the PFL transmissivity $T_{PFL,s}$ in the test section can be deduced from equation 3-5 and 3-6:

$$h_s = \frac{h_0 - bh_1}{1 - b} \quad 3\text{-}5$$

$$T_{PFL,s} = \frac{1}{a}\frac{Q_{s0} - Q_{s1}}{h_1 - h_0}, \quad 3\text{-}6$$

where $b = Qs_0/Qs_1$

The PFL transmissivity ($T_{PFL,f}$) 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*).

$$h_f = \frac{h_0 - bh_1}{1 - b} \quad 3\text{-}7$$

$$T_f = \frac{1}{a}\frac{Q_{f0} - Q_{f1}}{h_1 - h_0}, \quad 3\text{-}8$$

where

Q_{f0} and Q_{f1} are the flow rates at a fracture and h_f and T_f are the hydraulic head (*head when fracture flow is zero*) 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. (2000).

The assumed constant radius of influence used in the formula of transmissivity, leads to uncertainty in determination of the transmissivity. The assumption of constant radius of influence (*R=19 m*) leads to definition of PFL transmissivity which is practically DQ/Dh, i.e. the specific capacity ($T_{PFL} \approx DQ/Dh$). Finally, elevated noise level may affect the flow measurements and decrease the resolution of the flow measurements. This may affect determination of the transmissivity values in low-conducting sections, in which the increased noise level could mask smaller flow anomalies. In this report transmissivity refers to transmissivity calculated by Thiem's formula with above mentioned assumptions unless otherwise stated.

Transmissivity of the entire borehole can be evaluated in several ways using data of the pumping phase. The assumption above (*cylindrical and steady state flow*) leads to Thiems's formula (de Marsily 1986):

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

where

s is drawdown and

Q is the pumping rate at the end if the pumping phase

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

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

where

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

4 Equipment specification

With 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 discs 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, air pressure
Winch:	Mount Sopris Wna 10, 0.55 kW, conductors, Gearhart-Owen cable head.
Depth determination:	Based on a digital distance counter at winch.
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:	March 2018 (Probe FL13).

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 to +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 was carried out according to Activity Plan AP SFK-18-026 following the SKB Method Description 322.010e, Version 2.0 (*Method description for Difference Flow Logging; Table 1-1).* Time was synchronized to local Swedish time. The activity schedules of the borehole measurements are presented in Table 5-1, Table 5-2, Table 5-3, Table 5-4, Table 5-5, Table 5-6 and Table 5-7. The items and activities in the tables are the same as in the Activity Plan. The planned measurement program is described below.

The dummy logging (*Item 4*) of the borehole was done in order to minimize the risk that the measurement tools 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 electrical conductivity (*EC*) and temperature of borehole water (*Item 5*) during undisturbed conditions were measured before flow logging.

The flow along the borehole (*Item 6*) was measured below the casing tube to observe leakages from the casing. Measurement was conducted during undisturbed conditions. Casing tubes in these boreholes were 76 mm in diameter, which enabled measurement of flow along a casing tube similarly as along borehole. In most of the boreholes flow along the lower part of the casing tube was measured.

The flow logging during undisturbed conditions (*Item 7*) was carried out in the borehole with a 5 m section length and in 0.5 m length increments (*step length*).

The pumping was started after flow logging in undisturbed conditions. After 12 hours of pumping flow logging with pumping (*Item 8*) was conducted using the same section and step lengths as Item 7.

The flow logging was continued with a 1 m section length and a 0.1 m step length (*Item 9*). The fracture specific EC of the water from some selected fractures (*Item 9*) was performed in conjunction with flow logging with a 1 m section length.

The EC of borehole water (*Item 10*) was logged while the measured borehole was still pumped. After the pumping, the recovery of the groundwater level was monitored (*Item 11*).

Additional measurements were conducted and these are listed as extra activities in the tables.

Table 5-1. Flow logging and testing in KFM14. Activity schedule.

Item	Activity	Explanation	Date
4	Dummy logging	Borehole stability/risk evaluation.	2018-11-23
5	EC and temperature of borehole water	Logging without the lower rubber discs, no pumping.	2018-11-24
6	Flow along the borehole	Flow along the borehole below the casing tube (length 6.5 m) without the lower rubber discs, no pumping.	2018-11-25
6 extra 1	Flow along the borehole	Flow along the borehole at the casing tube (length 5.4 m) without the lower rubber discs, no pumping. Control measurement to verify the result from flow along the borehole measurement conducted at the length of 6.5 m.	2018-11-25
7	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping.	2018-11-24
7 extra 1	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, no pumping. Borehole length intervals of c. 14.3–28.4 m and 50.3–56.8 m were measured in natural conditions using shorter section length for more detailed results.	2018-11-25
8	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 4 m.	2018-11-26
8 extra 1	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 1 m. Depth of the pump had to be changed.	2018-11-26
8 extra 2	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-11-26
9	Flow logging and fracture-EC with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 3 m.	2018-11-27 to 2018-11-28
9 extra 1	Flow logging and fracture-EC with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 3 m. Fracture-specific EC measurement at fracture at 27.5 m.	2018-11-28
9 extra 2	Flow logging with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 1.5 m. Borehole length intervals of c. 29.8–36.3 m and 50.3–55.3 were measured with smaller drawdown.	2018-11-28
9 extra 3	Flow logging with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 1.5 m. Depth of the pump had to be changed.	2018-11-28
9 extra 4	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-11-28
9 extra 5	Flow logging with pumping	Water level measurement while waiting for steady state with pumping. Depth of the pump had to be changed.	2018-11-26 to 2018-11-27
10	EC and temperature of borehole water with pumping	Logging without the lower rubber discs, with pumping. Drawdown = 3 m.	2018-11-28
11	Transient registration of recovery	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued by SKB.	2018-11-28 to 2018-11-29

Table 5-2. Flow logging and testing in KFM15. Activity schedule.

Item	Activity	Explanation	Date
4	Dummy logging	Borehole stability/risk evaluation.	2018-11-10 to 2018-11-11
5	EC and temperature of borehole water	Logging without the lower rubber discs, no pumping.	2018-11-11
6	Flow along the borehole	Flow along the borehole below the casing tube (length 9.3 m) without the lower rubber discs, no pumping.	2018-11-12
6 extra 1	Flow along the borehole	Flow along the borehole at the casing tube (length 6.3 m) without the lower rubber discs, no pumping. Assuring that uncertain flow anomaly starting at the length of c. 4 m was not a real leakage at the casing tube.	2018-11-12
7	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping.	2018-11-11 to 2018-11-12
7 extra 1	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping. Water level probe was removed from borehole and flow logging was conducted up to the water level.	2018-11-12
8	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 5 m.	2018-11-14
8 extra 1	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 2.5 m. Depth of pump had to be changed therefore water level measurement before flow logging was conducted as another measurement event.	2018-11-14
8 extra 2	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-11-14
9	Flow logging and fracture-EC with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 5 m.	2018-11-14 to 2018-11-16
9 extra 1	Flow logging with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 2.5 m. Depth of pump had to be changed therefore water level measurement before flow logging was conducted as another measurement event.	2018-11-16
9 extra 2	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-11-16
6 extra 2	Flow along the borehole	Flow along the borehole at the bottom of the borehole (length 55.4 m) without the lower rubber discs, with pumping Drawdown = 5 m. To find an explanation for unbalance between the pumping rate and the sum of detected flow while pumping. No flows were detected at the bottom part of the borehole (below the length of 55.4 m).	2018-11-16
6 extra 3	Flow along the borehole	Flow along the borehole below the casing tube (length 11.5 m) without the lower rubber discs, with pumping Drawdown = 5 m. To find out reason for unbalance of pumping rate and sum of detected flow while pump-ing. A leak at the joint of casing tube and borehole was observed.	2018-11-16
10	EC and temperature of borehole water with pumping	Logging without the lower rubber discs, with pumping. Drawdown = 5 m.	2018-11-16
11	Transient registration of recovery	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued between by SKB.	2018-11-16 to 2018-11-17

Table 5-3. Flow logging and testing in KFM16. Activity schedule.

Item	Activity	Explanation	Date
4	Dummy logging	Borehole stability/risk evaluation.	2018-10-30
5	EC and temperature of borehole water	Logging without the lower rubber discs, no pumping.	2018-10-31
6	Flow along the borehole	Flow along the borehole below the casing tube (length 6.2 m) without the lower rubber discs, no pumping.	2018-11-01
7	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping.	2018-10-31
8	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 5 m.	2018-11-02
8 extra 1	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 2.5 m. Depth of the pump had to be changed.	2018-11-02
8 extra 2	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-11-02
9	Flow logging and fracture-specific EC with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 5 m.	2018-11-02 to 2018-11-03
9 extra 1	Flow logging with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 2.5 m. Depth of the pump had to be changed.	2018-11-03
9 extra 2	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-11-03
10	EC and temperature of borehole water with pumping	Logging without the lower rubber discs, with pumping. Drawdown = 5 m.	2018-11-03
11	Transient registration of recovery	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued by SKB.	2018-11-03 to 2018-11-04

Table 5-4. Flow logging and testing in KFM20. Activity schedule.

Item	Activity	Explanation	Date
4	Dummy logging	Borehole stability/risk evaluation.	2018-12-04 to 2018-12-05
5	EC and temperature of borehole water	Logging without the lower rubber discs, no pumping.	2018-12-05
6	Flow along the borehole	Flow along the borehole below the casing tube (length 2.8 m) without the lower rubber discs, no pumping.	2018-12-06
7	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping.	2018-12-05
7 extra 1	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping. Water level probe was removed from borehole and flow logging was conducted up to the water level.	2018-12-06
7 extra 2	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, no pumping. Entire length of the borehole was measured in natural conditions using shorter section length for more detailed results.	2018-12-06
7 extra 3	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, no pumping. Water level probe was removed from borehole and flow logging was conducted up to the water level.	2018-12-07
8	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 3 m.	2018-12-08
8 extra 1	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 1.5 m. Depth of the pump had to be changed.	2018-12-08
8 extra 2	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-12-08
8 extra 3	Flow logging without	Water level measurement while waiting for steady state with pumping. Depth of the pump had to be changed.	2018-12-07 to 2018-12-08
9	Flow logging and fracture-EC with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 3 m.	2018-12-08 to 2018-12-09
9 extra 1	Flow logging with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 1.5 m. Borehole length intervals of c. 6.5–8.5 m and 22.5–28.5 were measured with smaller drawdown.	2018-12-09
9 extra 2	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-12-09
10	EC and temperature of borehole water with pumping	Logging without the lower rubber discs, with pumping. Drawdown = 3 m.	2018-12-09
11	Transient registration of recovery	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued by SKB.	2018-12-09 to 2018-12-10

Table 5-5. Flow logging and testing in KFM21. Activity schedule.

Item	Activity	Explanation	Date
4	Dummy logging	Borehole stability/risk evaluation.	2018-11-29
5	EC and temperature of borehole water	Logging without the lower rubber discs, no pumping.	2018-11-30
6	Flow along the borehole	Flow along the borehole below the casing tube (length 6.2 m) without the lower rubber discs, no pumping.	2018-12-01
6 extra 1	Flow along the borehole	Flow along the borehole at the casing tube (length 5.4 m) without the lower rubber discs, no pumping. Control measurement to verify the result from flow along the borehole measurement conducted at the length of 6.2 m.	2018-12-01
7	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping.	2018-11-30
7 extra 1	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping. Water level probe was removed from the borehole and flow logging was conducted up to the water level.	2018-11-30
7 extra 2	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, no pumping. Borehole was measured in natural conditions using shorter section length for more detailed results.	2018-11-30 to 2018-12-01
7 extra 3	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, no pumping. Water level probe was removed from the bore-hole and flow logging without pumping (shorter section length in use) was conducted up to the water level.	2018-12-01
8	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 1.5 m.	2018-12-02
8 extra 1	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-12-02
8 extra 2	Flow logging with pumping	Water level measurement while waiting for steady state with pumping. Depth of the pump had to be changed.	2018-12-01 to 2018-12-02
9	Flow logging and fracture-EC with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 1.5 m.	2018-12-02 to 2018-12-03
9 extra 1	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, without pumping during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-12-03
10	EC and temperature of borehole water with pumping	Logging without the lower rubber discs, with pumping. Drawdown = 1.5 m.	2018-12-03
11	Transient registration of recovery	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued by SKB.	2018-12-03 to 2018-12-04

Table 5-6. Flow logging and testing in KFM22. Activity schedule.

Item	Activity	Explanation	Date
4	Dummy logging	Borehole stability/risk evaluation.	2018-11-17 to 2018-11-18
5	EC and temperature of borehole water	Logging without the lower rubber discs, no pumping.	2018-11-18
6	Flow along the borehole	Flow along the borehole below the casing tube (length 9.3 m) without the lower rubber discs, no pumping.	2018-11-19
7	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m, no pumping.	2018-11-18
7 extra 1	Flow logging without pumping	Section length L_w = 1 m, step length dL = 0.1 m, no pumping. Entire length of the borehole was measured in natural conditions using shorter section length for comparative purposes.	2018-11-18 to 2018-11-19
8	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 3 m.	2018-11-20
8 extra 1	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, with pumping. Drawdown = 2 m. Depth of the pump had to be changed.	2018-11-20
9	Flow logging and fracture-EC with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 3 m.	2018-11-20
9 extra 1	Flow logging with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 2 m. Depth of the pump had to be changed.	2018-11-21
9 extra 2	Flow logging with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 1 m. Borehole length interval of 25.6–45.1 m was measured with smaller drawdown.	2018-11-21
10	EC and temperature of borehole water with pumping	Logging without the lower rubber discs, with pumping. Drawdown = 3 m.	2018-11-21
11	Transient registration of recovery	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued by SKB.	2018-11-21 to 2018-11-22

Table 5-7. Flow logging and testing in KFM23. Activity schedule.

Item	Activity	Explanation	Date
4	Dummy logging	Borehole stability/risk evaluation.	2018-11-04
5	EC and temperature of borehole water	Logging without the lower rubber discs, no pumping.	2018-11-05
6	Flow along the borehole	Flow along the borehole below the casing tube (length 7.3 m) without the lower rubber discs, no pumping.	2018-11-05 to 2018-11-06
7	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m,	2018-11-05
7 extra 1	Flow logging without pumping	Section length L_w = 5 m, step length dL = 0.5 m. Water level probe was removed from borehole and flow logging was conducted up to the water level.	2018-11-05
8	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m. Drawdown = 1.1 m.	2018-11-08
8 extra 1	Flow logging with pumping	Section length L_w = 5 m, step length dL = 0.5 m, without pumping, during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-11-08
8 extra 2	Flow logging with pumping	Water level measurement while waiting for steady state with pumping. Length of the pump had to be changed therefore water level measurement before flow logging was conducted as another measurement event.	2018-11-06 to 2018-11-07
9	Flow logging and fracture-EC with pumping	Section length L_w = 1 m, step length dL = 0.1 m, with pumping. Drawdown = 1.1 m.	2018-11-08 to 2018-11-09
9 extra 1	Flow logging with pumping	Section length L_w = 1 m, step length dL = 0.1 m, without pumping, during recovery. Pump was removed from borehole and flow logging was conducted up to the water level. Water level was in transition.	2018-11-09
10	EC and temperature of borehole water with pumping	Logging without the lower rubber discs, with pumping. Drawdown = 1.1 m.	2018-11-09
11	Transient registration of recovery	Measurement of water level and absolute pressure in the borehole after the pumping was stopped. The measurement was continued by SKB.	2018-11-09 to 2018-11-10

5.2 Nonconformities

Activity plan specifies target drawdown of 10 m during pumping. Just before starting the measurements the target drawdown was changed to 5 m. Change was done in order to enable flow logging in the upper part of the borehole while pumping was ongoing. Usually a 10 m drawdown does not affect flow logging as casing tubes are long enough in order to prevent water level reaching the borehole. Drawdown of 5 m was considered sufficient from data processing point of view.

Even though target drawdown was decreased, it was not possible to continue flow logging all the way up to casing pipe while the pumping was on. Nevertheless flow logging was continued with even smaller drawdown or by removing pump from the borehole and flow logging while water level rose. Interpretation of transmissivity and head assume steady state conditions therefore measurement results obtained while pressure conditions are not stabile cannot be evaluated similarly than measurement results that were obtained during stabile drawdown. Results obtained during unstable pressure conditions and interpretations based on those are presented in result plots and tables with different colours than other measurement and comments have been added.

5 m drawdown was no achieved at all of the boreholes due to high borehole pumping yield. Casing pipe diameter is 77.5 mm which dictates how large pump can be used in a borehole. Grundfos MP1 submersible pump which has maximum pumping capacity of c. 30 l/min was used. Obtained drawdowns and pumping yields at boreholes are presented in Section 6.6.

High flow rates that required special attention were observed at boreholes KFM14, KFM20, KFM22. The length intervals in which flow rates were close to upper measurement limit were re-measured with smaller drawdown to achieve flow rate clearly within measurement limits. The reported upper measurement limit of 300 000 ml/h is absolute upper limit which cannot be exceeded. Nevertheless even smaller flows (*100 000 mL/h–300 000 mL/h*) can cause flow friction in flow sensor. Therefore flow measurements have been repeated with smaller drawdown even if upper limit has not been exceeded.

It was not physically possible to measure approximately 3.9 m from the bottom of the borehole. There are weights and a centralizer in the measurement device, which reduce the measured distance by c. 3.4 m. The rubber sealing discs in the device must also be flipped before the measurement begins. This reduces the measured distance for approximately 50 cm. It is possible that there were also fallen rocks and debris at the bottom of the borehole.

Nonconformities mentioned above concern all measured boreholes. Borehole specific nonconformities have been mentioned below.

KFM14

An additional flow along the borehole measurement was conducted at the length of c. 5.4 m, at the casing tube to verify the result obtained from the initial flow along the borehole measurement. The results from the additional time series measurement are presented in Appendix A KFM14.2.5 and based on the measurement there is no flow along the casing tube while pumping was not on. The measurement is presented as Item 6 extra 1 in Table 5-1.

Length intervals of c. 14.3–28.4 m and 50.3–56.8 m were flow logged without pumping using shorter 1 m measurement section and 0.1 m measurement interval. The measurement results are labelled as Extra 1 in graphs presented in the appendices (*e.g. Appendix A KFM14.2.1*). The measurement was conducted to distinguish individual fracture flows from flow anomalies obtained in Flow 1 measurement (*5 m section length*) and to extend the measurement under natural conditions to cover the bottom of the borehole in more detail as far as possible. However, the results from the Flow 1 measurement have been used in the interpretations primarily and the results from Extra 1 measurement have been used only if additional information has been gained over the Flow 1 measurement. The measurement is presented as Item 7 extra 1 in Table 5-1.

In order to extend the flow logging measurements under pumped conditions to the casing tube, immersion depth of the submersible pump had to be reduced. The borehole length interval of c. 6.8–10.3 m was then flow logged under pumped conditions using a smaller drawdown. Drawdown of 1 m was used in measurement conducted with 5 m section length and drawdown of 1.5 m in measurement conducted with 1 m section length. Different drawdown was used during the subsequent 1 m section length measurement to save time (*the measurement was conducted directly after Extra 2 measurement*). The difference between drawdowns had no impact on the transmissivity results, however it should be noted that the flow rate results are not directly comparable. These measurements are presented as Item 8 extra 1 (*5 m section length*) and Item 9 extra 3 (*1 m section length*) in Table 5-1. One flowing fracture (*fracture at 7.9 m*) was detected within the measured length interval (*see Appendix A KFM14.2.1*). Because flow logging measurement could not reach the casing tube even with the smaller drawdown, the pump was lifted from the borehole and measurement was continued further during groundwater recovery (i.e. groundwater level was in transition during the measurement). Note that water level sensor was not used in these measurements. The measurements conducted during groundwater recovery are presented as Item 8 extra 2 (*5 m section length*) and Item 9 extra 4 (*1 m section length*) in Table 5-1.

Fracture-specific EC measurement at fracture at 27.5 m was left out of the initial Flow 3 measurement because fracture flow was below the predefined measurement limit. The measurement was conducted afterwards. The measurement is presented as Item 9 extra 1 in Table 5-1.

The borehole length intervals of c. 30–36 m and 50–55 m were re-flow logged under pumped conditions using a smaller drawdown of 1.5 m. A smaller drawdown was used because the measured flow rate was near or exceeded the upper measurement limit (*300 000 mL/h*) at fractures at 35.0 m and 53.3 m in Flow 3 measurement with 3 m drawdown (*see Appendix A KFM14.2.2 to A KFM14.2.3*). The re-measurement is labelled as Extra 2 in graphs presented in the appendices (*e.g. Appendix A KFM14.2.1*). The measurement is presented as Item 9 extra 2 in Table 5-1.

KFM15

Additional flow along the borehole measurements were performed with and without pumping. Flow along the borehole without pumping was measured at the length of 6.3 m at the casing tube to assure that uncertain flow anomaly starting at the length of c. 4.3 m was not a real leak at the casing tube. This measurement is presented as Item 6 extra 1 in Table 5-2. Flow along the borehole with pumping was conducted at the lengths of 11.5 m and 55.4 m in order to seek an explanation for unbalance between the pumping rate and the sum of detected flow while pumping. These measurements are presented as Item 6 extra 2 and Item 6 extra 3 in Table 5-2.

At the uppermost parts of the borehole, water level probe was removed from the borehole and flow logging without pumping was conducted from c. 6.4 m to c. 3.8 m up to the water level. This measurement is presented as Item 7 extra 1 (*5 m section length*). In order to extend the flow logging measurements under pumped conditions to the upper parts of the borehole, immersion depth of the submersible pump had to be reduced. The borehole length interval of c. 8–11.5 m was then flow logged under pumped conditions using a smaller drawdown (*2.5 m*). These measurements are presented as Item 8 extra 1 (*5 m section length*) and Item 9 extra 1 (*1 m section length*) in Table 5-2. While conducting the measurements in the uppermost parts of the borehole, the submersible pump had to be completely removed from the borehole and flow logging was conducted up to the casing tube during groundwater recovery, while water level was in transition. The borehole length interval during recovery measurements was c. 5.5–8 m. The recovery measurements are presented as Item 8 extra 2 (*5 m section length*) and Item 9 extra 2 (*1 m section length*) in Table 5-2.

KFM16

In order to extend the flow logging measurements under pumped conditions to the upper parts of the borehole, immersion depth of the submersible pump had to be reduced. The borehole length interval of c. 7.4–10.8 m was flow logged under pumped conditions using a smaller drawdown (*2.5 m*). These measurements are presented as Item 8 extra 1 (*5 m section length*) and Item 9 extra 1 (*1 m section length*) in Table 5-3. In the uppermost parts of the borehole measurements, the submersible pump had to be completely removed from the borehole and flow logging was conducted up to the casing tube during groundwater recovery, while water level was in transition. The borehole length interval during recovery measurements was c. 4.4–7.4 m. These recovery measurements are presented as Item 8 extra 2 (*5 m section length*) and Item 9 extra 2 (*1 m section length*) in Table 5-3.

KFM20

The entire length of the borehole KFM20 was flow logged without pumping using a 1 m measurement section and a 0.1 m measurement interval. The measurement results are labelled as Extra 1 in graphs presented in the appendices. The measurement was conducted to distinguish individual fracture flows from the flow anomalies obtained in Flow 1 measurement (*5 m section length*) and to extend the measurement under natural conditions to cover the bottom of the borehole in more detail as far as possible. The results from Extra 1 measurement have completely replaced Flow 1 measurement results in fracture-specific interpretations. The measurement is presented as Item 7 extra 2 in Table 5-4.

In order to reach the casing tube under natural conditions, water level sensor was removed from the borehole and flow logging was continued upwards. Length interval of c. 2.9–5.9 was measured using 5 m measurement section and length interval of c. 2.7–5.2 m was measured using 1 m measurement section. Differences in measured length intervals are due to different measurement steps used with different section lengths (*i.e. 0.1 m measurement step with 1 m measurement section and 0.5 m measurement step with 5 m measurement section*). These measurements are presented as Item 7 extra 1 (5 m section length) and Item 7 extra 3 (*1 m section length*) in Table 5-4.

In order to extend the flow logging measurements under pumped conditions towards the casing tube, immersion depth of the submersible pump had to be reduced and flow logging under pumped conditions using a smaller drawdown was then continued upwards. The borehole length interval of c. 6.5–9.5 m was measured with 1.5 m drawdown using 5 m section length. The result is presented as Item 8 extra 1 in Table 5-4. The borehole length interval of c. 6.5–8.5 m was measured with 1.5 m drawdown using 1 m section length. The result is presented as Item 9 extra 1 in Table 5-4.

Because flow logging measurement under pumped conditions could not reach the casing tube even with smaller drawdown, the pump was lifted from the borehole and measurement was continued further during groundwater recovery (*i.e. groundwater level was in transition during the measurement*). Length interval of c. 3.9–6.5 was measured using 5 m measurement section and length interval of c. 4.0–6.5 m was measured using 1 m measurement section. Differences in measured length intervals are due to different measurement steps used with different section lengths (*i.e. 0.1 m measurement step with 1 m measurement section and 0.5 m measurement step with 5 m measurement section*). Note that water level sensor was not used in these measurements. Also note that the casing tube could not be reached even with the pump completely removed from the borehole. However, SP measurement was still continued upwards since SPR electrode is physically located below the flow sensor and therefore making it to possible to measure slightly higher (*wetted contact remains in the SPR electrode even after the flow measurement is no longer possible as the flow sensors are not anymore in the water*). One flowing fracture (*fracture at 6.0 m*) was detected within the measured length interval (*see Appendix D KFM20.2.1*). The measurements conducted during groundwater recovery are presented as Item 8 extra 2 (*5 m section length*) and Item 9 extra 2 (*1 m section length*) in Table 5-4.

Drawdown had to be adjusted and depth of the submersible pump was changed prior to starting Flow 2 measurement and therefore flow logging was conducted as another measurement event. The measurement data containing water level measurement while waiting for steady state with pumping is presented in Appendix D KFM20.9.2. The measurement is presented as Item 8 extra 3 in Table 5-4.

The borehole length interval of c. 22.5–28.5 m was re-flow logged under pumped conditions using a smaller drawdown of 1.5 m. Smaller drawdown was used because measured flow rate was near the upper measurement limit (*300 000 mL/h*) at fracture at 26.6 m in Flow 3 measurement with 3 m drawdown (*see Appendix D KFM20.2.2*). The measurement results are labelled as Extra 2 in graphs presented in the appendices. The measurement is presented as Item 9 extra 1 in Table 5-4.

KFM21

An additional flow along the borehole measurement was conducted at the length of c. 5.4 m, at the casing tube to verify the result obtained from the initial flow along the borehole measurement. The results from the additional time series measurement are presented in Appendix E KFM21.2.7. The measurement is presented as Item 6 extra 1 in Table 5-5.

The entire length of the borehole KFM21 was flow logged without pumping using a 1 m measurement section and a 0.1 m measurement interval. The measurement results are labelled as Extra 1 in graphs presented in the appendices. The measurement was conducted to distinguish individual fracture flows from the flow anomalies obtained in Flow 1 measurement (*5 m section length*) and to extend the measurement under natural conditions to cover the bottom of the borehole in more detail as far as possible. The results from Extra 1 measurement have completely replaced Flow 1 measurement results in fracture-specific interpretations. The measurement is presented as Item 7 extra 2 in Table 5-5.

In order to reach the casing tube under natural conditions, water level sensor was removed from the borehole and flow logging was continued upwards. Length interval of c. 3.5–6.5 was measured using 5 m measurement section and length interval of c. 4.0–6.5 m was measured using 1 m measurement section. Differences in measured length intervals are due to different measurement steps used with different section lengths (*i.e. 0.1 m measurement step with 1 m measurement section and 0.5 m measurement step with 5 m measurement section*). These measurements are presented as Item 7 extra 1 (*5 m section length*) and Item 7 extra 3 (*1 m section length*) in Table 5-5.

Drawdown had to be adjusted and depth of the submersible pump was changed between Flow 2 and Flow 3 measurements and therefore flow logging was conducted as another measurement event. The measurement data containing water level measurement while waiting for steady state with pumping is presented in Appendix E KFM21.9.2. The measurement is presented as Item 8 extra 2 in Table 5-5.

Because flow logging measurement under pumped conditions could not reach the casing tube although the achieved drawdown was small, the pump was lifted from the borehole and measurement was continued further during groundwater recovery (*i.e. groundwater level was in transition during the measurement*). Length interval of c. 3.9–7.4 was measured using 5 m measurement section and length interval of c. 4.0–7.5 m was measured using 1 m measurement section. Differences in measured length intervals are due to different measurement steps used with different section lengths (*i.e. 0.1 m measurement step with 1 m measurement section and 0.5 m measurement step with 5 m measurement section*). Note that water level sensor was not used in these measurements. One flowing fracture (fracture at 6.8 m) was detected within the measured length interval (*see Appendix D KFM20.2.1*). The measurements conducted during groundwater recovery are presented as Item 8 extra 1 (*5 m section length*) and Item 9 extra 1 (*1 m section length*) in Table 5-5.

KFM22

The entire length of the borehole KFM22 was flow logged without pumping using 1 m measurement section and 0.1 m measurement interval (*Extra 1 measurement*). The measurement was conducted to evaluate the advantages gained in using a shorter section length compared to 5 m section length measurement (*Flow 1*). Shorter section length resulted in better resolution data and clarified some previously uncertain parts of the Flow 1 measurement. However, water level in the borehole was unstable during the measurement, the maximum difference being c. 12 cm between the start and the finish. Even a small change in borehole water level can have a considerable impact on fracture flows and therefore the measurement results have not been used in further calculations. The measurement results are nevertheless presented in graphs in the appendices for comparative purposes. The measurement is presented as Item 7 extra 1 in Table 5-6.

In order to extend the flow logging measurements under pumped conditions to the casing tube, immersion depth of the submersible pump had to be reduced. The borehole length interval of c. 7.5–10.5 m was then flow logged under pumped conditions using a smaller drawdown (*2 m*). One flowing fracture (*fracture at 8.4 m*) was detected within the measured length interval (*see Appendix F KFM22.2.1*). These measurements are presented as Item 8 extra 1 (*5 m section length*) and Item 9 extra 1 (*1 m section length*) in Table 5-6.

The borehole length interval of 25.6–45.1 m was re-flow logged under pumped conditions using a smaller drawdown of 1 m. Smaller drawdown was used because measured flow rate was near the upper measurement limit (*300 000 mL/h*) at fracture at 33.3 m and exceeded the upper measurement limit at fracture at 40.8 m in Flow 3 measurement with 3 m drawdown (*see Appendix F KFM22.2.2 to F KFM22.2.3*). The measurement results are labelled as Extra 2 in graphs presented in the appendices. The measurement is presented as Item 9 extra 2 in Table 5-6.

KFM23

At the uppermost parts of the borehole, water level probe was removed from the borehole and flow logging without pumping was conducted from c. 7.3 m to c. 2.8 m up to the water level. This measurement is presented as Item 7 extra 1 (*5 m section length*) in Table 5-7. In order to extend the flow logging measurements under pumped conditions to the upper parts of the borehole, the submersible pump had to be completely removed from the borehole and flow logging was conducted up to the casing tube during groundwater recovery, while water level was in transition. The measured borehole length interval during recovery measurements was c. 3.3–6.4 m. These recovery measurements are presented as Item 8 extra 1 (*5 m section length*) and Item 9 extra 1 (*1 m section length*) in Table 5-7. Depth of the submersible pump had to be changed between measurements made in pumped conditions (*5 m section and 1 m section*). Therefore water level measurement before flow logging was conducted as another measurement event presented as Item 8 extra 2 in Table 5-7.

6 Results

Measurement results are presented mostly in Appendices. The numbering of appendices is the same for all boreholes therefore the appendices are referenced by denoting as X KFM##.m.n. in which X denotes the appendix, ## denotes the borehole number and m and n are detailing numbers of appendices presenting certain measurement results. At the end of appendices there might be additional plots that are numbered similarly but they are borehole specific plots representing special cases.

6.1 Length calibration

An accurate length scale for the measurements is difficult to achieve in long boreholes. The main cause of inaccuracy is the stretching of the logging cable. The stretching depends on the tension on the cable, the magnitude of which in turn depends, among other things, on the inclination of the borehole and the roughness (*friction properties*) of the borehole wall. The cable tension is larger when the borehole is measured upwards. The cables, especially new cables, may also stretch out permanently. Length marks at the cable have been set to tensioned (*c. 100 kg*) cable in order to simulate cable stretching during measurement.

6.1.1 SPR measurement

All flow logging sequences can be length matched by synchronising the SPR results (SPR is recorded during all the measurements except borehole EC measurements) with other resistivity measurements. In this measurement campaign reference data for SPR was no available. Length determination is based on cable marks in the measurement cable. In practice the first flow logging was set as a reference measurement and subsequent measurements were length matched to it if needed.

6.1.2 Estimated error in location of detected fractures

Despite the length calibration described above, there can still be errors due to the following reasons.

1. Stretching of the cable is most likely different during measurement than while cable marks have been set (*calibration tension c. 100 kg*). Based on experience 1 000 m of measurement cable stretches about 3 m when tension is increased from 75 kg to 175 kg. Based on this estimated length error in positioning the PFL DIFF probe in 100 m long borehole while cable tension varies from 50 kg to 150 kg is ±0.15 m at most.
2. The point interval in the overlapping mode flow measurements is 0.1 m. This could cause an error of ±0.05 m. This error is random.
3. The length of the test section is not exact. The specified section length denotes the distance between the nearest upper and lower rubber sealing discs. Effectively, the section length can be larger. At the upper end of the test section there are four rubber sealing discs. 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 discs. These phenomena can cause an error of ±0.05 m when the short step length (*0.1 m*) is used.

In worst case scenario, the errors from sources 1, 2 and 3 are summed and the total estimated error would be ± 0.25 m. Note, that error given above is an estimation based on experience and observations from earlier measurements and it is not guaranteed to hold in all conditions.

Knowing the location accurately is important when different measurements are compared, for instance flow logging and borehole TV. In that case, the situation may not be as severe as the case above, since some of the length errors are systematic and the error is nearly constant in fractures that are close to each other.

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 EC of the borehole water is initially measured when the borehole is at rest, i.e., at undisturbed conditions. The measurement was repeated during pumping (*after a pumping period of three to six days*). Measurements were performed downwards in order to avoid mixing of the borehole water before the measurement. Electrical conductivity measurement results have been presented in Appendices A–G KFM##.2.1 in linear EC scale and in Appendices A–G KFM##2.2 in logarithmic EC scale.

The temperature of the borehole water was measured simultaneously with the EC measurements. The EC values are temperature corrected to 25 °C to make them more comparable with other EC measurements (Heikkonen et al. 2002). The temperature results are presented in Appendices A–G KFM##.2.3

The length calibration of the borehole EC measurements is not as accurate as in other measurements, because SPR is not registered. The length correction is linear and based on the nearest tape marks on the cable at start and end depth.

6.2.2 Electrical conductivity of fracture-specific water

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

Fracture specific EC measurements were conducted using 1 m section length to minimize the time required to adequately flush the measurement section and obtain representative EC measurement from the fracture water. The target fractures for the EC measurement can be selected based on flow logging with 5 m section length which is conducted before flow logging with 1 m section length. Flow rate limit can be set so that PFL DIFF probe stops at fractures in which flow rate is larger than the limit to measure fracture specific EC. The EC measurement procedure is fully automated so that probe is stopped at fracture when predetermined conditions are met and after the water volume in the measurement section has changed three times EC measurement is stopped and overlapping measurement is continued. Volume of the 1 m section length is 3.6 litres.

The results are presented in Appendices A–G, KFM##.10.n. The blue symbol represents the conductivity value when the tool was moved and the red symbol is used for the set of stationary measurements. For comparison, the fracture-specific EC and temperature results are also plotted with the EC and temperature results of borehole water in Appendices A–G, A–G KFM##.1.1, A–G KFM##.1.2 and A–G KFM##.1.3. Locations of PFL DIFF probe during fracture specific EC measurements are presented in Appendices A–G KFM##.2.n.

KFM14

Fracture-specific EC measurement was to be conducted in seven fractures in KFM14 which were chosen based on Flow 2 measurement results. These were fractures at 19.0 m, 22.9 m, 24.3 m, 27.5 m, 35.0 m, 46.6 m and 53.3 m. One extra fracture (*fracture at 54.6 m*) was also included in practice due to automated measurement process and predefined measurement limits. The results are presented in Table 6-1.

Table 6-1. KFM14 fracture specific EC.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	Flow (mL/h)	EC (S/m) at 25 °C
18.63	19.63	19.0	60500	0.54
22.52	23.52	22.9	46900	0.61
23.92	24.92	24.3	27100	0.65
27.14	28.14	27.5	6880	0.65
34.63	35.63	35.0	207000*	0.68
46.21	47.21	46.6	9440	0.76
52.99	53.99	53.3	274000*	0.71
54.27	55.27	54.6	22100	0.68

* Given flow rate is the actual flow rate measured during the fracture-specific EC measurement (Flow3). Note that the flow rate for fractures at 35.0 m and 53.3 m differ from those presented in Appendix A KFM14.6 where more representative values from Extra 2 measurement were selected for interpretations (see Section 6.4.3 for details).

KFM15

Fracture-specific EC measurement was conducted in five fractures in KFM15 which were chosen based on Flow 2 measurement results. These were fractures at 16.1 m, 21.9 m, 32.6 m, 42.0 m and 52.3 m. These results are presented in Table 6-3.

Note that due to 1 m section length used in the measurement and due to close distance between two fractures at the length of 16.1 m, the presented fracture-specific EC and flow rate result at 16.1 m is a combination from two fractures (*Fractures at 16.1 m and 16.4 m remained in the measurement section while fracture-specific EC measurement was conducted*). Given flow rate to fractures 16.1 m and 16.4 m in Table 6-3 is the sum of these two fractures.

Table 6-2. KFM15 fracture specific EC.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	Flow (mL/h)	EC (S/m) at 25 °C
15.53	16.53	16.1 and 16.4	4160*	0.15
21.55	22.55	21.9	3180	0.21
32.17	33.17	32.6	5020	0.65
41.59	42.59	42.0	6890	0.27
51.90	52.90	52.3	465	0.36

* Given flow rate is the sum of fractures within the measurement section during the actual measurement (Flow 3).

KFM16

Fracture-specific EC measurement was to be conducted with fractures exceeding a predefined flow rate of 10000 mL/h. A predefined flow rate limit for fracture-specific EC measurements was chosen based on Flow 2 measurement results. Ten fracture-specific EC measurements were measured, at fractures at 11.7 m, 18.7 m, 19.2 m, 20.6 m, 21.8 m, 28.4 m, 39.9 m, 49.3 m, 51.2 m and 53.2 m. One extra fracture-specific EC measurement was measured at fracture at 52.1 m due to an automated measurement process. The results are presented in Table 6-3.

Note that due to 1 m section length used in the measurement and due to close distance between some of the measured fractures, some of the presented fracture-specific EC and flow rate results are a combination from multiple fractures. This was the case at fracture at 11.7 m where two fractures remained in the measurement section (*fractures at 11.7 m and 12.1 m*) and at fracture at 49.3 m where two fractures remained in the measurement section (*fractures at 49.3 m and 49.8 m*).

Table 6-3. KFM16 fracture specific EC.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	Flow (mL/h)	EC (S/m) at 25 °C
11.36	12.36	11.7 and 12.1	19150*	0.75
18.05	19.05	18.7	55800	0.66
18.86	19.86	19.2	60900	0.54
20.27	21.27	20.6	14400	0.63
21.57	22.57	21.8	58700	0.63
28.08	29.08	28.4	26900	0.54
39.62	40.62	39.9	38400	0.51
49.03	50.03	49.3 and 49.8	73720*	0.61
50.83	51.83	51.2	13300	0.68
52.03	53.03	52.1	9460	0.70
52.83	53.83	53.2	51300	0.69

* Given flow rate is the sum of fractures within the measurement section during the actual measurement (Flow 3).

KFM20

Fracture-specific EC measurement was conducted at fractures exceeding a predefined flow rate of 10000 mL/h. The limit for fracture-specific EC measurements was chosen based on Flow 2 measurement results. Fracture-specific EC measurement was conducted at four fractures in KFM20. These were fractures at 20.1 m, 25.6 m, 26.6 m and 30.2 m. The results are presented in Table 6-4.

Note that due to 1 m section length used in the measurement and due to close distance between some of the measured fractures, one of the presented fracture-specific EC and flow rate results is a combination from multiple fractures. This was the case at fracture at 20.1 m where two fractures remained in the measurement section (*fractures at 19.8 m and 20.1 m*). Also note that the given flow rates in Table 6-3 may differ from those presented in Appendix D KFM20.6. See Table 6-4 and Section 6.4.3 for more detailed information.

Table 6-4. KFM20 fracture specific EC.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	Flow (mL/h)	EC (S/m) at 25 °C
19.74	20.74	19.8 and 20.1	19380*	0.10
25.55	26.55	25.6	97400	0.11
26.36	27.36	26.6	149000**	0.10
29.87	30.87	30.2	16400	0.12

* Given flow rate is the sum of fractures within the measurement section during the actual measurement (Flow 3).

** Note that flow rate for fracture at 26.6 differs from that presented in Appendix D KFM20.6 where more representative value from Extra 2 measurement were selected for interpretations (see Section 6.4.3 for details).

KFM21

Fracture-specific EC measurement was to be conducted overall in 13 fractures in KFM21 which were chosen based on Flow 2 measurement results. These were fractures at 6.8 m, 8.9 m, 10.3 m, 23.7 m, 24.6 m, 26.9 m, 34.8 m, 46.9 m, 48.8 m, 52.8 m, 57.0 m, 61.8 m and 71.5 m. One fracture-specific EC measurement at fracture at 6.8 m was measured without pumping, during groundwater recovery. The results are presented in Table 6-5.

Note that due to 1 m section length used in the measurement and due to close distance between some of the measured fractures, some of the presented fracture-specific EC and flow rate results are a combination from multiple fractures. This was the case at fracture at 24.6 m where two fractures remained in the measurement section (*fractures at 24.6 m and 25.0 m*), at fracture at 34.8 m where two fractures remained in the measurement section (*fractures at 34.8 m and 35.2 m*) and at fracture at 57.0 m, where also two fractures remained in the measurement section (*fractures at 57.0 m and 57.5 m*). Also note that the given flow rates in Table 6-5 may differ from those presented in Appendix E KFM21.6.1 to E KFM21.6.2. See Table 6-5 and Section 6.4.3 for more detailed information.

Table 6-5. KFM21 fracture specific EC.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	Flow (mL/h)	EC (S/m) at 25 °C
6.46	7.46	6.8	138 000*	0.40*
8.56	9.56	8.9	126 000	0.55
9.96	10.96	10.3	87 300	0.49
23.48	24.48	23.7	187 000	0.25
24.28	25.28	24.6 and 25.0	42 876**	0.27
26.56	27.56	26.9	37 500	0.35
34.47	35.47	34.8 and 35.2	140 974**	0.37
46.52	47.52	46.9	9 760	0.44
48.52	49.52	48.8	9 020	0.44
52.42	53.42	52.8	24 900	0.45
56.6	57.6	57.0 and 57.5	26 680**	0.45
61.51	62.51	61.8	9 930	0.50
71.03	72.03	71.5	55 400	0.59

* Flow and EC values for fracture at 6.8 m are from the measurement made without pumping, during groundwater recovery. The upper part of the borehole could not be measured while pumping (while the pump remained in the borehole).

** Given flow rate is the sum of fractures within the measurement section during the actual measurement (Flow 3).

KFM22

Fracture-specific EC measurement was to be conducted in four fractures in KFM22 which were chosen based on Flow 2 measurement results. These were fractures at 21.0 m, 31.7 m, 33.3 m and 40.8 m. One extra fracture-specific EC measurement (*at fracture at 40.2 m*) was also measured due to automated measurement process and predefined measurement limits. The results are presented in Table 6-6.

Note that due to 1 m section length used in the measurement and due to close distance between some of the measured fractures, some of the presented fracture-specific EC and flow rate results are a combination from multiple fractures. This was the case at fracture at 33.3 m where three fractures remained in the measurement section (*fractures at 33.3 m, 33.6 m and 33.8 m*), at fracture at 40.2 m where two fractures remained in the measurement section (*fractures at 40.2 m and 40.5 m*) and at fracture at 40.8 m where two fractures remained in the measurement section (*fractures at 40.8 m and 41.3 m*). Also note that the given flow rates in Table 6-6 may differ from those presented in Appendix F KFM22.6. See Table 6-6 and Section 6.4.3 for more detailed information.

Table 6-6. KFM22 fracture specific EC.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	Flow (mL/h)	EC (S/m) at 25 °C
20.72	21.72	21.0	58 700	0.73
31.31	32.31	31.7	20 700	0.92
33.01	34.01	33.3, 33.6 and 33.8	131 000*	0.91
39.71	40.71	40.2 and 40.5	69 900*	0.94
40.51	41.51	40.8 and 41.3	308 000*	0.95

* Given flow rate is the sum of fractures within the measurement section during the actual measurement (Flow 3). Note that flow rate for fractures at 33.3 m and 40.8 m differ from those presented in Appendix F KFM22.6 where more representative values from Extra 2 measurement were selected for interpretations (see Section 6.4.3 for details).

KFM23

Fracture-specific EC measurement was to be conducted at fractures exceeding a predefined flow rate of 10 000 mL/h. A predefined flow rate limit for fracture-specific EC measurements was chosen based on Flow 2 measurement results. Fracture-specific EC measurements were measured at 12 fractures: 23.6 m, 27.1 m, 31.3 m, 39.0 m, 42.0 m, 49.1 m, 60.6 m, 63.2 m, 64.4 m. 65.2 m, 75.1 m and 75.9 m. Additionally, one fracture-specific EC measurement was decided to be measured at fracture at 86.1 m where measured flow rate was 1 800 mL/h. The results are presented in Table 6-7.

Note that due to 1 m section length used in the measurement and due to close distance between some of the measured fractures, two of the presented fracture-specific EC and flow rate results are a combination from multiple fractures. This was the case at fracture at 42.0 m where two fractures remained in the measurement section (fractures at 42.0 m and 42.3 m) and at fracture at 65.2 m where two fractures remained in the measurement section (fractures at 65.2 m and 65.6 m).

Table 6-7. KFM23 fracture specific EC.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	Flow (mL/h)	EC (S/m) at 25 °C
23.25	24.25	23.6	43 100	0.43
26.75	27.75	27.1	63 500	0.409
30.96	31.96	31.3	23 900	0.535
38.66	39.66	39	64 300	0.773
41.57	42.57	42.0 and 42.3	50 114*	0.742
48.77	49.77	49.1	26 600	0.694
60.27	61.27	60.6	27 800	0.703
62.78	63.78	63.2	20 500	0.701
64.06	65.06	64.4	26 700	0.724
64.86	65.86	65.2 and 65.6	117 620*	0.708
74.75	75.75	75.1	56 800	0.726
75.56	76.56	75.9	100 000	0.716
85.65	86.65	86.1	1 800	0.916

* Given flow rate is the sum of fractures within the measurement section during the actual measurement (Flow 3).

6.3 Pressure measurements

Absolute pressure was registered together with the other measurements in Items 7–9. The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered separately (*Appendices A–G KFM##.9.2*). The hydraulic head along the borehole at undisturbed and pumped conditions is determined in the following way. First, the monitored air pressure at the site is subtracted from the measured absolute pressure. The hydraulic head (h) at a certain elevation (*z*) is calculated according to the following expression (Nordqvist 2001):

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

where

h is the hydraulic head metre above sea level (masl) according to the RH2000 reference system,

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

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

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

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

z is the elevation of measurement (masl) according to the RH2000 reference system.

The calculated head distributions are presented in Appendices A–G KFM##.9.1. Exact z-coordinates are important in hydraulic head calculation as an error in the z-coordinate leads to an equal error in the calculated head.

6.4 Flow logging

6.4.1 General comments on results

The measuring programme contained several flow logging sequences, which are numbered as Flow 1 (*flow flogging without pumping with a 5 m section length, Q_0 in tables*), Flow 2 (*flow logging with pumping with a 5 m section length, Q_1 in section flow table*) and Flow 3 (*flow logging with pumping with a 1 m section length, Q_1 in fracture flow table*). They are shown on the same diagram with the SPR (*right hand side; Appendices A–G KFM##.2.1 to A–G KFM##.2.n*). The SPR usually has a lower value over fractures 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 discs of the probe, the locations of resistance anomalies associated with leaking fractures coincide with the lower end of the flow anomalies. The exact position of the SPR electrode is 5 cm higher than upper end of the measurement section (*the lowest rubber disc at upper end on section*). The reference length for both SPR and flow measurement is distance between borehole 0 m length and upper end of measurement section. This has been taken into account when processing the data.

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

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

The test section length determines the width of a flow anomaly of a single fracture. If the distance between flow yielding fractures is less than 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 position (*borehole length*) of the detected fractures is shown on the middle scale in Appendices A–G KFM##.2. They are interpreted on the basis of the flow curves and therefore represent flowing fractures. A long line represents the location of a leaking fracture; a short line denotes that the existence of a leaking fracture is uncertain. The short line is used when the flow rate is less than 30 mL/h or if determination of flow rate is uncertain due to overlapping flow anomalies or because of noise (*see section 6.4.4).*

The coloured triangles show the magnitude and direction (*from borehole into bedrock or from bedrock into borehole*) of the measured flows. The triangles have the same colour as the corresponding curves.

The explanations to the tables in Appendices A–G KFM##.4 and A–G KFM##.6 are given in Appendices A–G KFM##.3.

KFM14

Results from the flow along the borehole measurements without pumping, alongside with air pressure and water level, are presented in Appendix A KFM14.2.4 and A KFM14.2.5. Time series measurements were conducted at the length of c. 6.5 m, just below the percussion drilled part of the borehole where the casing tube is installed and at the length of c. 5.4 m at the casing tube. Measured flow fluctuated primarily between c. 20–100 mL/h upwards at the length of c. 6.5 m (*see Appendix A KFM14.2.4*) and between c. 10–100 mL/h downwards at the length of c. 5.4 m (*see Appendix A KFM14.2.5*). Water level in the borehole stabilised by the end of the measurements at both borehole lengths, but some fluctuation was still noticeable. Regardless of the fluctuation in the measured flow rate, no trend was observed during the measurements and it can be concluded that no leak in the borehole-casing tube joint exists based on the measurement results.

The flow along the borehole measurement results coincide with the ones obtained from flow logging without pumping measurement (*Flow 1*) and the measurement conducted during groundwater recovery with 1 m section as no flowing fractures above the fracture at 7.9 m were detected (*see Appendix A KFM14.2.1*).

KFM15

Flow along the borehole without pumping measured at the length of 9.3 m, just below the percussion drilled part of the borehole where the casing tube is installed, was about 370 mL/h downwards. The measurement result matched well with the one from flow logging without pumping (Q_0) as the sum of fracture flows below the length of 9.3 m was 371 mL/h into the bedrock. The only flow into the borehole was found at the length of 8.0 m, at the joint of casing tube and borehole, where fracture flow rate (Q_1) was 480 mL/h. Flow along the borehole was also measured at the length of 6.3 m at the casing tube without pumping, where no flow was detected, thus assuring that the uncertain flow anomaly starting at the length of c. 4.3 m (*see Appendix B 15.2.1*) was not a real leak at the casing tube. Additionally, flow along the borehole was measured at the lengths of 11.5 m and 55.4 m while pumping took place to investigate a reason for unbalance between the pumping rate and the sum of detected flows. Based on the measurement results, there seems to be a leak at the joint of casing tube and borehole. Bottom part of the borehole, below the length of 55.4 m, had no detectable flows within the measuring range. The results from the flow along the borehole measurements, with and without pumping, as well as air pressure and water level during the measurements, are presented in Appendix B KFM15.2.4 to B KFM15.2.7.

KFM16

Result from the flow along the borehole measurement without pumping, alongside with air pressure and water level, is presented in Appendix C KFM16.2.4. Time series measurement was conducted at the length of 6.2 m, just below the percussion drilled part of the borehole where the casing tube is installed. Measured flow was close to zero (*average of ten last flow measurements was 16 mL/h upwards*), i.e. the casing tube or its seams, joint of casing tube and borehole, had no detectable leak within the measuring range.

KFM20

Result from the flow along the borehole measurement without pumping, alongside with air pressure and water level, is presented in Appendix D KFM20.2.4. Time series measurement was conducted at the length of c. 2.8 m, below the percussion drilled part of the borehole where the casing tube is installed. Measured flow fluctuated between c. 50 mL/h and c. 100 mL/h downwards. Note that water level data is not available because the top of the PFL DIFF probe was already above the groundwater level during the measurement therefore prohibiting the use of the water level sensor. Therefore the impact of possible variation in groundwater level cannot be estimated.

The flow along the borehole measurement result differs with the one obtained from flow logging without pumping measurement (*Flow 1*) as the measured flow along the borehole at the length of c. 2.8 m was close to zero and the sum of fracture flows below the length of 2.8 m was 28 096 mL/h into the bedrock. The flow along the borehole measurement indicates that there is no leakage at the joint of the casing tube during un-pumped conditions. Based on this assumption and other measurement results, missing flows into the hole in un-pumped conditions could be located at the unmeasured bottom part of the borehole.

KFM21

Results from the flow along the borehole measurements without pumping, alongside with air pressure and water level, are presented in Appendix E KFM21.2.6 and Appendix E KFM21.2.7. Time series measurements were conducted at the length of c. 6.2 m, just below the percussion drilled part of the borehole where the casing tube is installed and at the length of c. 5.4 m at the casing tube. Measured flow fluctuated primarily between c. 20–300 mL/h upwards at the length of c. 6.2 m (*see Appendix E KFM21.2.6*) and between c. 30–300 mL/h upwards at the length of c. 5.4 m (*see Appendix E KFM21.2.7*). Water level in the borehole was stable at both borehole lengths. Regardless of the fluctuation in the measured flow rate, no trend was observed during the measurements and it can be concluded that no leak in the borehole-casing tube joint exists based on the measurement results.

The flow along the borehole measurement results coincide with the ones obtained from flow logging without pumping measurement (*Flow 1*) and the measurement conducted during groundwater recovery with 1 m section as no flowing fractures above the fracture at 6.8 m were detected (*see Appendix E KFM21.2.1*).

KFM22

Result from the flow along the borehole measurement without pumping, alongside with air pressure and water level, is presented in Appendix F KFM22.2.4. Time series measurement was conducted at the length of 9.3 m, just below the percussion drilled part of the borehole where the casing tube is installed. Measured flow fluctuated between c. 100 mL/h and c. 500 mL/h upwards, towards the outflowing fracture at the length of 8.4 m (*see Appendix F KFM22.2.1*). Water level variation in the borehole during the measurement was c. 2–3 cm which could be an explaining factor for the fluctuation of the measured flow rate, especially when considering the highly transmissive fractures present in the borehole. Regardless of the fluctuation in the measured flow rate, no trend was observed during the measurement and the measurement was discontinued after c. 4 h of monitoring.

The flow along the borehole measurement result coincides with the one obtained from flow logging without pumping measurement (*Flow 1*) as the direction of the measured flow was upwards, towards the outflowing fracture detected at 8.4 m. However, the pressure conditions in the borehole (*water level*) were not exactly the same between the Flow 1 measurement and the flow along the borehole measurement (*see Appendix F KFM22.2.4 and Appendix F KFM22.9.2*) therefore making it difficult to compare the flow rate directly to the interpreted fracture-specific flow for the fracture at 8.4 m. Nevertheless there seems to be a leak at joint of casing tube and borehole at the length of 8.4 m.

KFM23

Result from the flow along the borehole measurement without pumping, alongside with air pressure and water level, is presented in Appendix G KFM23.2.6. Time series measurement was conducted at the length of 7.3 m, just below the percussion drilled part of the borehole where the casing tube is installed. Measured flow was c. 27 000 mL/h, upwards in the borehole. The measurement result is in line with flow logging without pumping, as below the length of 7.3 m only flows into the borehole were found in un-pumped conditions. The sum of fracture flows without pumping below the length of 7.3 m was 34 721 mL/h. There is a difference between sum of fracture flows and flow along the borehole at length of 7.3 m but flow rate along the borehole changed during the measurement. Therefore it is difficult to say if the borehole pressure conditions were the same during both measurements. The reason for change in measured flow rate along the borehole was possibly the variation of the borehole water level (*maximum of c. 2 cm*) during the measurement. Water level during the measurement was quite stable, but even a small change in a borehole water level can have an impact on the measured flow rate. Nevertheless there seems to be a leak at joint of casing tube and borehole at the length of 4.8 m.

6.4.2 Transmissivity and hydraulic head of borehole sections

The borehole was flow logged with a 5 m section length and with 0.5 m length increments both in undisturbed conditions and during pumping.

The results of the measurements with 5 m section length are presented in tables (*Appendices A–G KFM##.4*). All flowing borehole sections are shown in Appendices A–G KFM##.2. Secup and Seclow in Appendices A–G KFM##.4 are the distances along the borehole from the reference level (*top of the casing tube*) to the upper end of the test section and to the lower end of the test section, respectively. The Secup and Seclow values for the two sequences (*measurements in undisturbed conditions and during pumping*) are not exactly identical, due to a minor difference in the cable stretching. The difference between these two sequences was small. Secup and Seclow given in Appendices A–G KFM##.4.n are calculated as the average of these two values.

The total conductive fracture frequency (CFF) is presented graphically (*Appendices A–G KFM##.5.4*).

Pressure was measured and hydraulic head calculated as described in Section 6.3. h_{0FW} and h_{1FW} in Appendices A–G KFM##.4 represent heads determined without and with pumping, respectively. The head in the borehole and calculated heads of borehole sections are given in RH2000 scale.

The flow results in Appendices A–G KFM##.4 (*Q_0 and Q_1*), representing the flow rates derived from measurements during undisturbed conditions and under pumping, are presented side by side to make comparison easier. Flow rates are positive if the flow direction is from the bedrock into the borehole and vice versa.

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

The flow data is presented as a plot (*Appendices A–G KFM##.5.1*). 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 (*Appendices A–G KFM##.5.1*) and in the tables (*Appendices A–G KFM##.4*). There are theoretical and practical lower limits of flow (*Section 6.4.4*).

The hydraulic head and transmissivity (T_D) of borehole sections can be calculated from the flow data using the method described in Chapter 3. The results are illustrated in Appendices A–G KFM##.5.2. The hydraulic head of sections is presented in the plots if none of the two flow values at the same length is equal to zero. Transmissivity is presented if none or just one of the flows is equal to zero.

The measurement limits of transmissivity are also shown in Appendices A–G KFM##.5.2 and in Appendices A–G KFM##.4. All the measurement limit values of transmissivity are based on the actual pressure difference in the borehole (*h_{0FW} and h_{1FW} in Appendices A–G KFM##.4*).

KFM14

The sum of all the detected flows in un-pumped conditions (Q_0) was 7.61×10^{-7} m^3/s (*2 738 mL/h*). More flows into the borehole than into the bedrock were detected. This sum should be zero. Sum of the absolute flow rates was 4.52×10^{-6} m^3/s, leaving the unbalance between inflows and outflows (*c. 17 %*) higher than the given ± 10 % accuracy of the flow measurement. The reason for the off-balance is not fully clear. There could be more flows into the bedrock in the unmeasured bottom part of the borehole which could explain the difference. Another contributing factor could be the variation of the groundwater level (*maximum of c. 1.5 cm*) during the measurement. Even a small change in a borehole water level can have a considerable impact on fracture-specific flows if there are highly transmissive fractures present in a borehole, which is the case in KFM14 (*i.e. the fractures at 35.0 m and 53.3 m, see Appendix A KFM14.6*).

The sum of measured section flows in pumped conditions (Q_1) was 2.82×10^{-4} m^3/s (*1 014 665 mL/h*). Pumping rate during the measurement with 4 m drawdown was c. 31 L/min (*1 920 000 mL/h*) on average (*c. 29 L/min at the start and c. 33 L/min in the end of the measurement*).

The pumping rate was significantly higher than the sum of measured section flows (Q_1). However in KFM14 the sum of section flows, as such, cannot be compared directly to the pumping yield. Two of the interpreted section flows are based on flows measured with smaller drawdowns: the uppermost section at 6.81 m (*Secup*) was measured with 1 m drawdown and the section at 54.31 m (*Secup*) with 3 m drawdown (*Flow 3*). The flow rate and hydraulic head obtained in Flow 3 measurement were used in interpretation of the section at 54.31 m (*Secup*), because no detailed Flow 2 measurement data from the corresponding borehole length was available; although the actual measurement range does not increase using a shorter measurement section, a shorter section length enables better measurement resolution. E.g. using a 1 m measurement section it is possible to distinguish flowing fractures individually if the distance between measured fractures is one meter or more. Using a 5 m measurement section the distance must be five meters or more, correspondingly. Also if the longer measurement section includes multiple fractures and if one of the fractures yields significantly higher flow rate over the others, all minor fractures can easily go unnoticed. However, more important factor considering the off-balance is that the measured flow rate of c. 606 000 mL/h from the section at 49.31 m (*Secup*) significantly exceeded the upper measurement limit of the PFL DIFF probe. Due to friction loss in the PFL DIFF probe's flow guide, the actual flow rate would most probably have been higher than the measured flow rate. As said, the reported flow rate should be considered only as very conservative estimate of the actual flow rate. Also, as flow logging measurement passes the flowing borehole section relatively quickly, perfect steady-state conditions cannot be reached during normal measurement if the section has significant influence on a borehole flow system. An example of the described conditions can be seen at the section 49.31 m (*Secup*) where high yield causes a pressure increase of c. 24 kPa in the measurement section (see Appendix A KFM14.9.1). Also the measured pumping rate increased notably as soon as the PFL DIFF probe had passed the high yielding borehole section (*i.e. the fracture at 53.3 m*), see Appendix A KFM14.11.2. Based on the previous, it can be assumed that the actual transmissivity value for the section at 49.11 m (*Secup*) would probably be higher than the one reported here.

Note that given length for the section measured with 4 m drawdown (*10.31 m, Secup*) is 4 m (*see Appendix A KFM14.4*). The physical length of the measurement section was 5 m but the interpreted section length is based on the actual measurement points within the last interpreted section which resulted in a shorter section length. The last three measurement points covered only one flowing fracture (*the fracture at 11.6 m*) and therefore no special procedure in defining the section flow (Q_1) had to be applied.

The previous applies to the section measured with 1 m drawdown (*6.81 m, Secup*) as well. The given section length of 3.5 m is defined by the actual measured points (*although the physical length of the measurement section was again 5 m*). The actual physical length of the measurement section covered more flowing fractures than the section length used in calculations. Therefore the presented section flow (Q_1) was defined by subtracting the measured flow from borehole length of 8.33 m (*when only the fracture at 11.6 m was within the measurement section*) from the measured flow from borehole length of 7.83 m (*when the fractures at 7.9 m and 11.6 m were both within the measurement section*).

KFM15

The sum of all the detected flows in un-pumped conditions (Q_0) was 3.00×10^{-8} m^3/s (*108 mL/h*) including flow out of the borehole at the joint of casing tube and borehole. Flow into the borehole was detected at the joint of casing tube and borehole at the length of 8.0 m. In this case the measured inflows and outflows were not fully balanced as the sum of the absolute flow rates was 2.36×10^{-7} m^3/s, leaving the unbalance between inflows and outflows slightly higher than the given ± 10 % accuracy of the flow measurement. The upper part of the borehole could not be measured with pumping (Q_1), while the pump remained in the borehole). Measurements made at the upper part of the borehole, length interval 5.86 m–8.36 m, during groundwater recovery immediately after the pumping was stopped, were unreliable; a steady state was not reached and therefore sections above 8.36 m (*Secup*) are not presented (Q_1). While pumping was on and a drawdown of c. 5 m was created, the sum of detected flows was 6.67×10^{-6} m^3/s (*24 013 mL/h*). Pumping rate during the measurement was c. 10.8 L/min (*650 100 mL/h*). Pumping rate was clearly higher than the sum of detected flows. However, the results are reasonable when considering the leak at the joint of casing tube and borehole.

During pumping, flow direction in all nine flow yielding sections was into the borehole (*upwards*). Note that given length for the section measured with 2.5 m drawdown (*8.36 m, Secup*) is 4.5 m (*see Appendix B KFM15.4*). The physical length of the measurement section was 5 m but the interpreted section length is based on the actual measurement points within the last interpreted section which resulted in a shorter section length.

Note that given length for the uppermost section measured (*5.86 m, Secup*) is 2.5 m (*see Appendix B KFM15.4*). The physical length of the measurement section was 5 m but the interpreted section length is based on the actual measurement points during recovery within the last interpreted section which resulted in a shorter section length. The previous applies to the section measured with 2.5 m drawdown where given length for the section measured (*8.36 m, Secup*) is 4.5 m. The given section length of 4.5 m is defined by the actual measured points (*although the physical length of the measurement section was again 5 m*) during pumping within the last interpreted section which resulted in a shorter section length.

KFM16

The sum of all the detected flows in un-pumped conditions (*Q_0*) was 4.83×10^{-7} m^3/s (*1 738 mL/h*). More flows into the borehole than into the bedrock were detected. This sum should be zero. In this case inflows and outflows were not fully balanced as the sum of the absolute flow rates was 8.52×10^{-7} m^3/s (*3 068 mL/h*), leaving the unbalance between inflows and outflows higher than ± 10 % accuracy of the flow measurement. The reason for off-balance might be that there could be more flows in to the bedrock at the unmeasured bottom part of the borehole. Another reason could be the variation of the borehole water level (*maximum of c. 3 cm*) during the flow logging. Water level during un-pumped conditions was quite steady, but even a small change in a borehole water level can have an impact on fracture-specific flows which may explain the off-balance.

While pumping was on and drawdown of c. 5 m was created, the sum of detected flows were 1.17×10^{-4} m^3/s (*420 783 mL/h*). Pumping rate during the measurement was c. 9.5 L/min (*570 000 mL/h*). The pumping rate was higher than the sum of measured section flows (Q_1), more than ± 10 % accuracy of the flow measurement. However in KFM16 the sum of section flows, as such, cannot be compared directly to the pumping yield. Firstly, the uppermost section at 4.44 m (*Secup*) covering upper part of the borehole could not be measured in pumped conditions as the pump had to be lifted from the borehole in order to reach the uppermost lengths with the PFL DIFF probe. Flow logging was conducted up to the water level while water level was in transition. Secondly, next section starting at the length of 7.44 m (*Secup*) was measured with smaller drawdown of 2.5 m as the pump had to be lifted upwards so that the section would be possible to measure. Finally, flow rate at section lengths of 13.97 m (*Secup*), 18.97 m (*Secup*), and 49.00 m (*Secup*) caused pressure to rise in the measurement section while pumping was on. Pressure increase of c. 4 kPa at the sections at 13.97 m (*Secup*) and 49.00 m (*Secup*) was measured. In addition, a slight increase in section pressure was also noticed at the section at 18.98 m (*Secup*). Measured flow rates at these lengths were high enough to cause friction loss in the PFL DIFF probe's flow guide and therefore actual flow rates for these three sections would probably be higher than the measured flow rates. These lengths were checked in more detail to make sure correct head and flow values were used in interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*Appendix C KFM16.11.1 to C KFM16.11.3*).

Note that given length for the uppermost section measured during recovery (*4.44 m, Secup*) is 3.0 m, next section measured with 2.5 m drawdown (*7.44 m, Secup*) is 3.5 m and the subsequent section measured with 5 m drawdown at (*10.94 m, Secup*) is 3.0 m (*see Appendix C KFM16.4*). The physical length of the measurement section was 5 m but the interpreted section length is based on the actual measurement points within the last interpreted section in all of these cases resulting shorter section lengths. As in pumped conditions, with 2.5 m and with 5 m drawdown, the physical length of the measurement sections covered more flowing fractures than the section length used in calculations, the presented section flows, at 7.44 m (*Secup*) and at 10.94 m (*Secup*), were defined by subtracting the influence of fracture-specific flows that were left out of the presented section lengths.

KFM20

The sum of all the detected flows in un-pumped conditions (Q_0) was -7.80×10^{-6} m^3/s (*−28 096 mL/h*). More flows into the bedrock than into the borehole were detected. This sum should be zero. In this case the measured inflows and outflows were not balanced, the sum of the absolute flow rates was 9.89×10^{-6} m^3/s, leaving the unbalance between inflows and outflows much higher than the given ± 10 % accuracy of the flow measurement. The reason for the off-balance might be that there could be more flows into the hole in the unmeasured bottom part of the borehole. Water level of the borehole was steady during the flow logging indicating that the measurements were conducted in stable conditions.

The sum of measured section flows in pumped conditions (*Q_1*) was 7.0×10^{-5} m^3/s (*253 886 mL/h*). Pumping rate during the measurement with 3 m drawdown was c. 27 L/min (*1 620 000 mL/h*) on average (*c. 28.3 L/min at the start and c. 25.9 L/min in the end of the measurement*). Pumping rate during the measurement with 1.5 m drawdown was c. 8 L/min (*480 000 mL/h*) on average.

The pumping rate was significantly higher than the sum of measured section flows (*Q_1*). However in KFM20 the sum of section flows, as such, cannot be compared directly to the pumping yield because upper part of the borehole could not be measured in pumped conditions, as the pump had to be lifted from the borehole in order to reach the uppermost lengths with the PFL DIFF probe. Also, the measured flow rate of c. 187 660 mL/h from the section at 23.45 m (*Secup*) was close to exceed the upper measurement limit of the PFL DIFF probe causing pressure to rise in the measurement section while pumping was on. Pressure increase of c. 9 kPa at the section at 23.45 m (*Secup*) was measured. Measured flow rate was high enough to cause friction loss in the PFL DIFF probe's flow guide and therefore actual flow rate for the section at 23.45 m (*Secup*) would probably be higher than the measured flow rate. This section length was checked in more detail to make sure correct head and flow values were used in interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*Appendix D KFM20.11*). The occurrences described above could partly explain the off-balance between the sum of section flows and the measured pumping rate. Also, because the joint of the casing tube could not be measured in pumped conditions, it is possible that some of the missing section flows could leak at the joint of casing tube and borehole. Finally, there could be more flows into the hole in the unmeasured bottom part of the borehole.

Note that given length for the section measured with 3 m drawdown (*9.45 m, Secup*) is 4 m (*see Appendix D KFM20.4*). The physical length of the measurement section was 5 m but the interpreted section length is based on the actual measurement points within the last interpreted section which resulted in a shorter section length. As the physical length of the measurement section covered more flowing fractures than the section length used in calculations, the presented section flow (Q_1) under discussion was defined by subtracting interpreted fracture-specific flow for fracture at 13.9 m from the uppermost measurement point available from measurement Flow 2 (*flow measurement point from borehole length of c. 13.45 m*).

The previous applies to the section measured with 1.5 m drawdown (*6.45 m, Secup*) as well. The given section length of 3.0 m is defined by the actual measured points (*although the physical length of the measurement section was again 5 m*). However, interpreted section flow at the length of 6.45 m (*Secup*) is not presented as the result is so unclear, that the sector flow cannot be determined. The flow rate varies considerably between different measuring points. Therefore measured flow rates during 1.5 m drawdown are not representative.

The previous applies also for the uppermost section measured during recovery (*3.94 m, Secup*) as well. The given section length of 2.5 m is defined by the actual measured points (*although the physical length of the measurement section was again 5 m*). In this case the last two measurement points covered only one flowing fracture (*at 6.0 m*) and therefore no special procedure in defining the section flow (Q_1) had to be applied.

Finally, to get more accurate results at the bottom part of the borehole, values for for the section flow (Q_0) and head (h_{0FW}) at 53.50 m (*Secup*) without pumping are from the Extra 1 measurement. Respectively, values for for the section flow (Q_1) and head (h_{1FW}) at 53.50 m (*Secup*) with pumping are from the Flow 3 measurement.

KFM21

The sum of all the detected flows in un-pumped conditions (Q_0) was -2.12×10^{-8} m^3/s (*−79 mL/h*). Slightly more flows into the bedrock than into the borehole were detected. In this case the measured inflows and outflows were well balanced as the sum of the absolute flow rates was 1.01×10^{-5} m^3/s (36 372 mL/h).

The sum of measured section flows in pumped conditions (Q_1) was 1.64×10^{-4} m^3/s (*590 836 mL/h*). Pumping rate during the measurement with 1.5 m drawdown was 31.2 L/min (*1 872 000 mL/h*) on average (*c. 31.5 L/min at the start and c. 30.2 L/min in the end of the measurement*).

The pumping rate was significantly higher than the sum of measured section flows (Q_1). However in KFM21 the sum of section flows, as such, cannot be compared directly to the pumping yield. The upper part of the borehole could not be measured with pumping (Q_1), while the pump remained in the borehole). Measurements at the upper part of the borehole, length interval c. 4.0 m–7.5 m, were made during groundwater recovery immediately after the pumping was stopped. The uppermost section at 3.95 m (*Secup*) of the interpreted section flow (Q_1), where one high flowing fracture was detected, is based on flows measured during groundwater recovery. It should also be noted, that flow rate at section lengths at 7.45 m (*Secup*), 9.45 m (*Secup*), and 34.50 m (*Secup*) caused pressure to rise in the measurement section while pumping was on. Pressure increase of c. 4 kPa at the section at 7.45 m (*Secup*) and 34.50 m (*Secup*) was measured. A slight increase in section pressure was also noticed at the section at 9.45 m (*Secup*). Measured flow rates at these lengths were high enough to cause friction loss in the PFL DIFF probe's flow guide and therefore actual flow rates for these three sections would probably be higher than the measured flow rates. These lengths were checked in more detail to make sure correct head and flow values were used in interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*Appendix E KFM21.11.1 to E KFM21.11.2*).

Note that given length for the uppermost section measured during groundwater recovery (*3.95 m, Secup*) is 3.5 m (*see Appendix E KFM21.4*). The physical length of the measurement section was 5 m but the interpreted section length is based on the actual measurement points within the last interpreted section which resulted in a shorter section length.

The previous applies to the section measured with 1.5 m drawdown (*7.45 m, Secup*) as well. The given section length of 2.0 m is defined by the actual measured points (*although the physical length of the measurement section was again 5 m).* The actual physical length of the measurement section covered more flowing fractures than the section length used in calculations. Therefore the presented section flow (Q_1) was defined by subtracting the measured flow from borehole length of 9.45 from the measured flow from borehole length of 7.45 m (*leaving only the fracture flow at 8.9 m within the 2 m measurement section*).

KFM22

The sum of all the detected flows in un-pumped conditions (Q_0) was 4.48×10^{-7} m^3/s (*1 612 mL/h*). More flows into the borehole than into the bedrock were detected. This sum should be zero. In this case the measured inflows and outflows were not fully balanced, the sum of the absolute flow rates was 7.39×10^{-7} m^3/s, leaving the unbalance between inflows and outflows higher than the given ± 10 % accuracy of the flow measurement. The reason for the off-balance might be that there could be more flows into the bedrock in the unmeasured bottom part of the borehole. Another reason could be the variation of the borehole water level (*maximum of c. 4 cm*) during the flow logging. Even a small change in a borehole water level can have a considerable impact on fracture-specific flows if there are highly transmissive fractures present in a borehole, which is the case in KFM22 (*e.g. the fractures at 33.0 m and 40.5 m, see Appendix F KFM22.6*). Flow out of the borehole was detected at the joint of casing tube and borehole at the length of 8.4 m.

The sum of measured section flows in pumped conditions (Q_1) was 1.41×10^{-4} m^3/s (*507 018 mL/h*). Pumping rate during the measurement with 3 m drawdown was c. 32 L/min (*1 920 000 mL/h*) on average (*c. 33 L/min at the start and c. 31 L/min in the end of the measurement*). Pumping rate during the measurement with 2 m drawdown was c. 20 L/min (1 200 000 mL/h) on average.

The pumping rate was significantly higher than the sum of measured section flows (Q_1). However in KFM22 the sum of section flows, as such, cannot be compared directly to the pumping yield. Firstly, the uppermost section at 7.60 m (*Secup*) covering the leak at the joint of casing tube and borehole was measured with smaller drawdown of 2 m. Secondly, the measured flow rate of c. 299 000 mL/h from the section at 38.64 m (*Secup*) practically exceeded the upper measurement limit of the PFL DIFF probe. Due to friction loss in the PFL DIFF probe's flow guide, the actual flow rate would have probably been higher than the measured flow rate. Also, as the flow logging measurement passes the flowing borehole section relatively quickly, perfect steady-state conditions cannot be reached during normal measurement if a section has significant influence on a borehole flow system. A clear example of the described conditions can be seen at the section 38.64 m (*Secup*) as the measured pumping rate drops dramatically from c. 33 L/min to c. 11 L/min (*see Appendix F KFM22.11.2*) when the PFL DIFF probe remained on the high yielding fractured zone (*included in the section were fractures at 40.2 m, 40.5 m and 40.8 m*). As soon as the PFL DIFF probe had passed the high yielding fractured zone, pumping rate normalised to c. 32 L/min. Therefore it can be assumed that the actual transmissivity value for the section at 38.64 m (*Secup*) would probably be higher than the one reported here. The occurrences described above could explain the off-balance between the sum of section flows and the measured pumping rate.

Note that given length for the section measured with 3 m drawdown (*10.60 m, Secup*) is 3 m (*see Appendix F KFM22.4*). The physical length of the measurement section was 5 m but the interpreted section length is based on the actual measurement points within the last interpreted section which resulted in a shorter section length. As the physical length of the measurement section covered more flowing fractures than the section length used in calculations, the presented section flow (Q_1) under discussion was defined by subtracting interpreted fracture-specific flow for fracture at 15.4 m from the uppermost measurement point available from measurement Flow 2 (*flow measurement point from borehole length of 10.60 m*).

The previous applies to the section measured with 2 m drawdown (*7.60 m, Secup*) as well. The given section length of 3 m is defined by the actual measured points (*although the physical length of the measurement section was again 5 m*). However, the last two measurement points covered only one flowing fracture (*leak at the joint of casing tube and borehole at 8.4 m*) and therefore no special procedure in defining the section flow (Q_1) had to be applied.

KFM23

The sum of all the detected flows in un-pumped conditions (Q_0) was 3.60×10^{-6} m^3/s (*12 972 mL/h*) including flow out of the borehole at the joint of casing tube and borehole. More flows into the borehole than into the bedrock were detected. This sum should be zero. In this case the measured inflows and outflows were not fully balanced, the sum of the absolute flow rates was 1.57×10^{-5} m^3/s, leaving the unbalance between inflows and outflows higher than the given ± 10 % accuracy of the flow measurement.

The sum of measured section flows in pumped conditions (Q_1) was 1.97×10^{-4} m^3/s (*709 654 mL/h*). Pumping rate during the measurement with 1.1 m drawdown was c. 27 L/min (*1 620 000 mL/h*) on average.

In KFM23 the sum of section flows, as such, cannot be compared directly to the pumping yield. Pumping rate was clearly higher than sum of detected flow which is reasonable as joint of the casing tube and borehole was leaking. The leak at lower end of casing tube could not be measured in pumped conditions as the pump had to be lifted from the borehole in order to reach the length of lower end of casing tube with the PFL DIFF probe. The measurement at uppermost section at 3.33 m (*Secup*) was conducted up to the water level while water level was in transition. It should also be noted, that flow rate at section lengths at 38.36 m (*Secup*), 63.40 m (*Secup*), and 73.41 m (*Secup*) caused pressure to rise in the measurement section while pumping was on. Pressure increase of c. 3 kPa at the sections at 63.40 m (*Secup*) and 73.41 m (*Secup*) was measured. A slight increase in section pressure was also noticed at the section at 38.36 m (*Secup*). Measured flow rates at these lengths were high enough to cause friction loss in the PFL DIFF probe's flow guide and therefore actual flow rates for these three sections would probably be higher than the measured flow rates. These lengths were checked in more detail to make sure correct head and flow values were used in interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*Appendix G KFM23.11.1 to G KFM23.11.3*).

6.4.3 Transmissivity and hydraulic head of fractures

An attempt was made to evaluate the magnitude of fracture-specific flow rates. The first step in this procedure is to identify the locations of individual flowing fractures and then evaluate their flow rates. This is done based on flow logging with 1 m section length in pumped conditions. In cases where the fracture distance is less than one metre, it may be difficult to evaluate the flow rate. 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 A–G KFM##.2).*

The measurement program included flow logging with 5 m section length in undisturbed conditions and flow loggings with 1 m and 5 m section lengths in pumped conditions. In pumped conditions fracture flows were interpreted based on results from flow logging with 1 m section length. In unpumped conditions determining flows of individual fractures can be more difficult as measurement section is longer and possible cover multiple fractures at the same time. This was taken into account during the measurement and if the fracture flows were difficult to interpret based on the measurement an extra measurement was conducted with 1 m section length. These results were used together to interpret flows in unpumped conditions. If the flow for a specific fracture cannot be determined conclusively in unpumped conditions, the flow rate is marked with "–" and the value 0 is used in the transmissivity calculation (*Appendices A–G KFM##.6*). The flow direction is evaluated as well. The results of the evaluation are plotted in Appendices A–G KFM##.2, blue filled triangle.

Fracture-specific transmissivities were compared with transmissivities of sections in Appendices A–G KFM##.8. All fracture-specific transmissivities within each 5 m interval were first summed together to make them comparable with measurements with a 5 m section length. The results are fairly consistent between the two types of measurements. The decrease of flow as a function of pumping time can sometimes be seen in some fractures (*storage effect*). The 1 m section measurements were carried out after the 5 m section measurements and therefore flow rate and transmissivity can be smaller in the 1 m section measurement results.

KFM14

The total amount of detected fractures was 17, of which ten were detected also without pumping.

The sum of fracture flows during pumping of the borehole was 1.21×10^{-4} m^3/s (*434 653 mL/h*). Pumping rate during the measurement with 3 m drawdown was c. 28.5 L/min (*1 710 000 mL/h*) on average (*c. 30 L/min at the start and c. 27 L/min in the end of the measurement*). In order to extend the flow logging measurement to the casing tube, depth of the submersible pump had to be the reduced. Therefore the fracture at the length of 7.9 m was measured with smaller drawdown (*1.5 m*). Pumping rate during the measurement of the upper part of the borehole with 1.5 m drawdown was c. 13 L/min (*780 000 mL/h*) on average.

In KFM14 the sum of fracture flows, as such, cannot be compared directly to the pumping yield because presented flow rates (*and heads*) for fractures at 35.0 m and 53.3 m are interpreted from Extra 2 measurement. Extra 2 measurement was conducted with smaller drawdown (*1 m*) compared to Flow 3 measurement to which other interpreted fracture flow interpretations are based on. For fractures at 35.0 m and 53.3 m results from Flow 3 measurement were unusable or at least would probably yield inaccurate results since measured flow rates were near or above the upper measurement limit of the PFL DIFF probe causing friction loss in the PFL DIFF probe's flow guide. Therefore actual flow rates for the two fractures would probably be higher than the measured flow rates. It should also be taken into account that, despite using smaller drawdown, a pressure rise of c. 4 kPa at the fracture at 53.3 m was measured. A slight increase (*c. 2 kPa*) in section pressure at the fracture at 35.0 m was also noticed. Regardless, the results from Extra 2 measurement were considered as more representative than the results from corresponding lengths from Flow 3 measurement. The borehole lengths were checked in more detail to make sure that correct head and flow values were used in the interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*see Appendix A KFM14.11.1 and A KFM14.11.2).* However, as the flow logging measurement passes a flowing fracture relatively quickly, perfect steady-state conditions cannot be reached during normal measurement if the fracture has a significant influence to a borehole flow system. Therefore it can be assumed that actual transmissivities for fractures at 35.0 and 53.3 m would probably be higher than the ones reported here. Pumping rate during the measurement covering the fractures at 35.0 m and 53.3 m with 1.5 m drawdown was c. 11 L/min (*660 000 mL/h*) on average.

KFM15

The total amount of detected fractures was 24, of which only three were detected also without pumping, including flow rate at the joint of casing tube and borehole, which could not be measured in pumped conditions. The sum of fracture flows without pumping (Q_0) was 3.00×10^{-8} m^3/s (*108 mL/h*). More flows into the borehole than into the bedrock were detected. This sum should normally be zero if the flows in the borehole are not disturbed by noise or other external factors, the borehole is not pumped, the water level is constant, the salinity distribution in the borehole is stabilized and the fractures are at steady state pressure. In this case the measured inflows and outflows were not fully balanced, the sum of the absolute flow rates was 2.36×10^{-7} m^3/s (*851 mL/h*), and the difference (*13 %*) is close to the given accuracy of the PFL DIFF probe's flow measurement (*±10 % curr. value*). The sum of fracture flows was 6.89×10^{-6} m^3/s (*24 787 mL/h*) while pumping was on and drawdown of c. 5 m was created. Pumping rate during the measurement was c. 8.1 L/min (*486 600 mL/h*). Pumping rate was clearly higher than the sum of detected flows. However, the results are reasonable when considering the leak at the joint of the casing tube and borehole and assuming missing fracture flows were coming from the joint. Furthermore, the fractures at 9.8 m and 10.5 m were measured using a smaller drawdown of 2.5 m, as measurement during larger drawdown could not be conducted at the top of the borehole. Measurements made at the upper part of the borehole, length interval c. 5.5 m–8.3 m, during groundwater recovery immediately after the pumping was stopped, were unreliable; a steady state was not reached and therefore fracture flow at 8.0 m (Q_l) is not presented (Q_l).

KFM16

The total amount of detected fractures was 25, of which 9 were detected also without pumping. The sum of fracture-specific flows was 1.22×10^{-6} m^3/s (*438 872 mL/h*) while pumping was on and drawdown of c. 5 m was created. Pumping rate during the measurement was c. 9.1 L/min (*546 000 mL/h*). In KFM16 the sum of fracture-specific flows, as such, cannot be compared directly to the pumping yield because upper part of the borehole could not be measured in pumped conditions, as the pump had to be lifted from the borehole in order to reach the uppermost lengths with the PFL DIFF probe. Fracture-specific flow (Q_l) at the length of 10.2 m was measured was measured with smaller drawdown of 2.5 m as the pump was lifted upwards and fracture-specific flow (Q_l) at the length of 7.4 m was measured during recovery right after pumping was stopped. Also, flows at length interval c. 17 m–22 m, fracture at the length of 39.9 m and length interval c. 48 m–53 m caused pressure to increase in the measurement section while pumping was on. At these lengths flow rates were high enough to cause friction loss in the PFL DIFF probe's flow guide and therefore actual flow rates would probably be higher than the measured flow rates. The magnitude of pressure increase was about 3 kPa at most. These lengths were checked in more detail to make sure correct head and flow values were used in interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*Appendix C KFM16.11.1 to C KFM16.11.3*). Highest detected fracture-specific flow during pumping (*at fracture at 49.1 m*) was 1.99×10^{-5} m^3/s (*71 500 mL/h*) which was clearly below the upper measurement limit.

KFM20

The total amount of detected fractures was 26, of which 19 were detected also without pumping. The sum of fracture flows during pumping of the borehole was 6.66×10^{-5} m^3/s (*239 457 mL/h*). Pumping rate during the measurement with 3 m drawdown was c. 24.1 L/min (*1 440 000 mL/h*) on average (*c. 25.8 L/min at the start and c. 23.3 L/min in the end of the measurement*).

In order to extend the flow logging measurement to the upper parts of the borehole, depth of the submersible pump had first to be reduced, and finally the pump had to be lifted entirely from the borehole in order to reach the uppermost lengths with the PFL DIFF probe. Therefore in KFM20 the sum of fracture-specific flows, as such, cannot be directly compared to the pumping yield because the upper part of the borehole could not be measured in steady pumped conditions as the rest of the borehole was measured. Fracture-specific flow (Q_l) at the length of 6.0 m was measured during groundwater recovery right after pumping was stopped. Also, flows at the length interval c. 24 m–27 m caused pressure to increase in the measurement section while pumping was on. Therefore presented flow rate (*and head*) for fracture at 26.6 m is interpreted from Extra 2 measurement. Extra 2 measurement was conducted with smaller drawdown (*1.5 m*) compared to Flow 3 measurement to which other interpreted fracture flows are based on. For fracture at 26.6 m results from Flow 3 measurement were unusable or at least would probably yield inaccurate results since measured flow rates were near the upper measurement limit of the PFL DIFF probe causing friction loss in the PFL DIFF probe's flow guide and therefore fracture flow would probably be higher in reality. It should also be taken into account that, despite using smaller drawdown, a pressure rise of c. 1 kPa at the fracture at 26.6 m was measured. A slight increase in section pressure at the fractures at 24.8 m and 25.6 m was also noticed. These lengths were checked in more detail to make sure that correct head and flow values were used in the interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*see Appendix D KFM20.11*). Pumping rate during the measurement with 1.5 m drawdown was c. 4.8 L/min (*288 000 mL/h*) on average. Also it should be noted that the joint of casing tube and borehole could not be measured and it is possible that during pumped conditions there could be undetected flows.

KFM21

The total amount of detected fractures was 60, of which 32 were detected also without pumping. The fracture frequency is quite high as 60 fractures were detected between borehole lengths from 6.8 m to 94.2 m.

The sum of fracture flows during pumping of the borehole was 2.17×10^{-4} m^3/s (*780 514 mL/h*). Pumping rate during the measurement with 1.5 m drawdown was c. 31.0 L/min (*1 860 000 mL/h*) on average (*c. 33.2 L/min at the start and c. 27.7 L/min in the end of the measurement*). In order to extend the flow logging measurement to the upper parts of the borehole, depth of the submersible pump had first to be reduced, and finally the pump had to be lifted entirely from the borehole in order to reach the uppermost lengths with the PFL DIFF probe. Therefore in KFM21 the sum of fracture-specific flows, as such, cannot be directly compared to the pumping yield because the upper part of the borehole could not be measured in steady pumped conditions as the rest of the borehole was measured. Fracture-specific flow (Q_1) at the length of 6.8 m was measured during groundwater recovery right after pumping was stopped. Also, flows at fractures 8.9 m, 10.3 m and 34.8 m caused pressure to rise in the measurement section while pumping was on. Measured flow rates at these lengths were high enough to cause friction loss in the PFL DIFF probe's flow guide and therefore actual flow rates for the three fractures would probably be higher than the measured flow rates. The magnitude of pressure increase was 4 kPa at the most. These lengths were checked in more detail to make sure correct head and flow values were used in interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*Appendix E KFM21.11.1 to E KFM21.11.2*). The two highest flow rates detected during pumping were 3.8×10^{-5} m^3/s (*140 040 mL/h*) at the length of 34.8 m and 3.50×10^{-5} m^3/s (*126 000 mL/h*) at the length of 8.9 m which both are clearly below the upper measurement limit. It is also noted that a high flow rate was measured during groundwater recovery, fracture flow of 3.83×10^{-5} m^3/s (*137 880 mL/h*) was measured at the length of 6.8 m. It indicates that there would be a very high flow rate during pumping, if it could have been measured.

KFM22

The total amount of detected fractures was 24, of which six were detected also without pumping. The detected leak at the joint of casing tube and borehole is presented as a fracture at the length of 8.4 m.

The sum of fracture flows during pumping of the borehole was 9.54×10^{-5} m^3/s (*343 407 mL/h*). Pumping rate during the measurement with 3 m drawdown was c. 33 L/min (*1 980 000 mL/h*) on average. In order to extend the flow logging measurement to the casing tube, depth of the submersible pump had to be the reduced. Therefore the leak at the joint of casing tube and borehole at the length of 8.4 m was measured with smaller drawdown (*2 m*). Pumping rate during the measurement with 2 m drawdown was c. 20 L/min (*1 200 000 mL/h*) on average.

In KFM22 the sum of fracture flows, as such, cannot be compared directly to the pumping yield because presented flow rates (*and heads*) for fractures at 33.3 m and 40.8 m are interpreted from Extra 2 measurement. Extra 2 measurement was conducted with smaller drawdown (*1 m*) compared to Flow 3 measurement to which other interpreted fracture flows are based on. For fractures at 33.3 m and 40.8 m results from Flow 3 measurement were unusable or at least would probably yield inaccurate results since measured flow rates were near or above the upper measurement limit of the PFL DIFF probe causing friction loss in the PFL DIFF probe's flow guide and therefore flow rates for the two fractures would probably be higher in reality. It should also be taken into account that, despite using smaller drawdown, a pressure rise of c. 3 kPa at the fracture at 40.8 m was measured. A slight increase in section pressure at the fracture at 33.3 m was also noticed. These lengths were checked in more detail to make sure that correct head and flow values were used in the interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*see Appendix F KFM22.11.2 to F KFM22.11.3*). However, as the flow logging measurement passes a flowing fracture relatively quickly, a perfect steady-state conditions cannot be reached during normal measurement if a fracture has a significant influence to a borehole flow system. A clear example of the described conditions can be seen at the fracture at 40.8 m where, even with reduced drawdown, a dramatic drop in pumped yield (*from c. 11 L/min to c. 5 L/min*) was noticed when the PFL DIFF probe remained on the fracture (*see Appendix F KFM22.11.3*). As soon as the PFL DIFF probe had passed the high yielding fractured zone (*including also fractures at 40.2 m, and 40.5 m*), pumping rate was again normalised to c. 11 L/min. Therefore it can be assumed that actual transmissivity for the fracture at 40.8 m would probably be higher than the one reported here. Pumping rate during rest of the measurement with 1 m drawdown was c. 11 L/min (*660 000 mL/h*) on average.

KFM23

The total amount of detected fractures was 54, of which 27 were detected also without pumping. A leak at joint of casing tube and borehole is presented as a fracture at the length of 4.8 m. The fracture frequency is quite high as 53 fractures were detected between borehole lengths from 8.6 m to 86.1 m. This complicated to define fracture flows in un-pumped conditions in fractures that were close to each other. Due to this missing flow value in un-pumped conditions does not necessarily mean that flow rate was below detection limit.

The sum of fracture flows during pumping of the borehole was 2.25×10^{-4} m^3/s (*810 244 mL/h*). Pumping rate during the measurement was c. 27 L/min (*1 620 000 mL/h*). The sum of fracture-specific flows, as such, cannot be compared directly to the pumping yield because upper part of the borehole could not be measured in pumped conditions, as the pump had to be lifted from the borehole in order to reach the uppermost lengths with the PFL DIFF probe. Also, flows at fractures 39.0 m, 42.0 m, 65.2 m and 75.9 m caused pressure to rise in the measurement section while pumping was on. Measured flow rates at these lengths were high enough to cause friction loss in the PFL DIFF probe's flow guide and therefore actual flow rates for the four fractures would probably be higher than the measured flow rates. The magnitude of pressure increase was 3 kPa at the most. These lengths were checked in more detail to make sure correct head and flow values were used in interpretation. Flow rate and borehole head were plotted together to see the effect of pressure increase (*Appendix G KFM23.11.1 to G KFM23.11.3*). The two highest flow rates detected during pumping were 2.78×10^{-5} m^3/s (*100 000 mL/h*) at the length of 75.9 m and 3.03×10^{-5} m^3/s (*109 000 mL/h*) at the length of 65.2 m which both are clearly below the upper measurement limit.

6.4.4 Theoretical and practical measurement limits of flow and transmissivity

The theoretical minimum for measurable flow rate in overlapping measurements is some 30 mL/h. The upper limit of flow measurement is 300 000 mL/h. As these upper and lower limits are determined by flow calibration, it is assumed that flows can be reliably detected between the upper and lower theoretical limits in favourable 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 no flowing fractures or other complicating structures are lacking, 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.
5) Mixing of waters with different salinity within the test section.

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 increase noise levels. This kind of noise is typical for both undisturbed conditions and under pumping.

Pumping results in lower water pressure in the borehole and in fractures located near the borehole. This may lead to the release of dissolved gas and increase the quantity of gas bubbles entrained in the water. Some fractures may produce more gas than others. Sometimes, when the borehole is being measured upwards, increased noise levels are observed just above certain fractures. One of the reasons 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 and while borehole wall is assumed to be rough. The rubber sealing discs hold the pressure that high flow causes well but if there are leakages between rubber discs and borehole wall high flows along borehole cause increased noise level.

Another reason for increased noise level could be that when the PFL DIFF probe passes a fracture, there still might be less saline water within the test section from other parts of the borehole. When waters with different salinity mix, it might cause high noise level to the flow rate results.

The practical minimum for measurable flow rate is presented in Appendices A–G KFM##.2 using a grey dashed line (*Lower limit of flow rate*). The practical minimum level of the measurable flow is always evaluated in pumped conditions since this measurement is the most important for transmissivity calculations. The limit is an approximation. It is evaluated to obtain a limit below which there may be fractures or structures that remain undetected.

The noise level in these measurements was 30 mL/h. In many cases even smaller flows were successfully detected. 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.

There were some cases when flow rate was close to upper measurement limit and high flow rate caused pressure elevation in the measurement section. In these cases flows were measured with decreased drawdown in order to obtain more representative flow rate value.

The practical minimum for measurable flow rate is also presented in Appendices A–G KFM##.4 (Q-lower limit P) and is obtained from the plots in Appendices A–G KFM##.2 (*Lower limit of flow rate*). The practical minimum of transmissivity can be evaluated using Q-lower limit and the actual head difference at each measurement location (*Appendices A–G KFM##.4* T_D*-measl*$_{LP}$). The theoretical minimum for transmissivity (T_D-measl$_{LT}$) is evaluated using a Q value of 30 mL/h. The upper limit for transmissivity can be evaluated using the maximum flow rate (300 000 mL/h) and the actual head difference as above (*Appendices A–G KFM##.4* T_D*-measl*$_U$). In cases when upper limit of measured flow rate has been passed flow measurement is repeated with smaller drawdown to obtain flow rate within the limits therefore upper limit for transmissivity is never exceeded.

All three flow limits are plotted with the measured flow rates (*Appendices A–G KFM##.5.1*).

The three transmissivity limits are also presented graphically (*Appendices A–G KFM##.5.2*).

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 hydraulic head to the errors in flow and pressure measurements

Transmissivity and hydraulic head results have been presented in tables and plots without assuming any errors related to measured values. Nevertheless possible errors in flow and pressure measurement affects the transmissivity and hydraulic head. Possible error in flow measurement is ± 10 % of the measured value and ± 2 kPa in pressure measurement. Errors in transmissivity and hydraulic head have been evaluated assuming largest possible error that can occur within these errors in flow and pressure measurements. The error limits for transmissivity and hydraulic head have been plotted in Appendices A–G KFM##.5.3. and A–G KFM##.7.2.

6.5 Transmissivity of the entire borehole

The flow period of the pumping during difference flow logging is utilized to evaluate the transmissivity of the entire borehole. This is done with two steady-state methods described in Chapter 3. The results of analysis is presented in Table 6-8.

Table 6-8. Evaluated transmissivities for entire boreholes.

BoreholeID	Pumping yield (L/min)	Drawdown (m)	Borehole length (m)	T_M (m²/s)	T_D (m²/s)
KFM14	33	4	54.27	1.66×10^{-4}	1.36×10^{-4}
KFM15	10.8	5	54.82	4.34×10^{-5}	3.56×10^{-5}
KFM16	9.5	5	55.93	3.83×10^{-5}	3.13×10^{-5}
KFM20	25.9	3	58.17	1.75×10^{-4}	1.42×10^{-4}
KFM21	30.2	1.5	95.79	4.35×10^{-4}	3.32×10^{-4}
KFM22	31	3	51.86	2.06×10^{-4}	1.70×10^{-4}
KFM23	27	1.1	96.04	5.30×10^{-4}	4.05×10^{-4}

In Dupuit's formula (Equation 3-9), R/r_0 is assumed to be 500, Q is pumping rate and s is drawdown by the end of the flow period (Appendices A–G KFM##.9.2). In Moye's formula (Equation 3-10) the borehole length means uncased part of the borehole.

6.6 Groundwater level and pumping rate

The level of the groundwater table in the boreholes during the measurement sequences is presented in Appendices A–G KFM##.9.2. The groundwater recovery was measured after the pumping period. Right after stopping the pumping PFL equipment remained in the borehole to measure the transient of the water level immediately after pump was stopped. After couple of hours water level measurement was continued with SKB's water level sensor and PFL equipment was moved to next borehole in the measurement program. Water level measurement results during the recovery are presented in Appendices A–G KFM##.9.3.

7 Summary

In this study, the Posiva Flow Log, Difference Flow Method has been used to determine the location and flow rate of flowing fractures or structures in boreholes KFM14, KFM15, KFM16, KFM20, KFM21, KFM22, KFM23 and KFM23 at Forsmark, Sweden. Measurements were carried out both when the borehole was at rest and during pumping. A 5 m section length with 0.5 m length increments was used initially. The borehole was also measured with a 1 m section and a 0.1 m measurement interval.

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

A casing tube leakage was measured with flow along the borehole method just below the casing tube in undisturbed conditions. The diameter of the casing pipes was 77.5 mm therefore it was also possible to measure flow along the casing pipe in case it was needed.

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

Fracture frequency was quite high and in some cases it was difficult to distinguish individual fractures especially in natural conditions. In some cases flows were measured both with 5 m section length and 1 m section length in natural conditions to obtain fracture specific flow rate values. High flow values were also detected and many of these were re-measured with smaller drawdown in order to obtain more representative flow value. In general noise level in flow measurements was low (*< 30 mL/h*) therefore all flows higher than 30 mL/h were most likely detected.

High flows caused also high pumping yields. Drawdown of 5 m was obtained only in two boreholes (*KFM15 and KFM16*) due to limited capacity of submersible pump that could fit into the boreholes. The smallest drawdown was obtained in borehole KFM23 in which drawdown of 1.1 m was obtained with pumping rate of 27 L/min. Measurement results obtained even with 1.1 m drawdown are considered reliable. In some of the boreholes high flow rates were detected at the joint of casing pipe and borehole. Most probably these are not bedrock fractures but they have been taken into account in fracture and section specific tables and results with remarks denoting that the flow is from joint of casing pipe and borehole.

Fracture specific electrical conductivity measurements were conducted at 59 fractures in total. In some cases individual fractures were so close to each other that multiple fractures were within the measurement section while electrical conductivity was measured. In these cases the EC value does not represent water coming from only one fracture. The highest measured electrical conductivity value was 0.95 S/m.

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.com/publications.

de Marsily G, 1986. Quantitative hydrogeology, groundwater hydrology for engineers. Orlando, FL: Academic Press.

Heikkonen J, Heikkinen E, Mäntynen M, 2002. Pohjaveden sähkönjohtavuuden lämpötilakorjauksen matemaattinen mallinnus synteettisten vesinäytteiden mittauksista (Mathematical modelling of temperature adjustment algorithm for groundwater electrical conductivity on basis of synthetic water sample analysis). Posiva Working Report 2002-10, Posiva Oy, Finland. (In Finnish.)

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

Moye D G, 1967. Diamond drilling for foundation exploration. Civil Engineering Transactions, Institute of Engineers (Australia), April, 95–100.

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

Öhberg A, Rouhiainen P, 2000. Posiva groundwater flow measuring techniques. Posiva 2000-12, Posiva Oy, Finland.

Appendices

Appendix A

KFM14.1.1–KFM14.1.2	Electrical conductivity of borehole water
KFM14.1.3	Temperature of borehole water
KFM14.2.1–KFM14.2.3	Flow rate and single point resistance
KFM14.2.4	Vertical flow along the borehole at 6.3 m
KFM14.2.5	Vertical flow along the borehole at 5.2 m
KFM14.3	Explanations for the tables in Appendices
KFM14.4	Results of section flows
KFM14.5.1	Plotted flow rates of 5 m sections
KFM14.5.2	Plotted transmissivity and head of 5 m sections
KFM14.5.3	Transmissivity and head of 5 m sections with calculated error limits
KFM14.5.4	Conductive fracture frequency
KFM14.6	Inferred fracture flow anomalies from flow logging
KFM14.7.1	Plotted transmissivity and head of detected fractures
KFM14.7.2	Transmissivity and head of detected fractures with calculated error limits.
KFM14.8	Comparison between section transmissivity and fracture transmissivity
KFM14.9.1	Head in the borehole during flow logging
KFM14.9.2	Air pressure, water level in the borehole and pumping rate during flow logging
KFM14.9.3	Groundwater recovery after pumping
KFM14.10.1–KFM14.10.3	Fracture-specific EC results by date
KFM14.11.1–KFM14.11.2	Flow rate, single point resistance and head in the borehole during flow logging

Appendix B

KFM15.1.1–KFM15.1.2	Electrical conductivity of borehole water
KFM15.1.3	Temperature of borehole water
KFM15.2.1–KFM15.2.3	Flow rate and single point resistance
KFM15.2.4–KFM15.2.7	Vertical flow along the borehole at 6.0 m, 9.0 m, 11.2 m and 55.1 m
KFM15.3	Explanations for the tables in Appendices
KFM15.4	Results of section flows
KFM15.5.1	Plotted flow rates of 5 m sections
KFM15.5.2	Plotted transmissivity and head of 5 m sections
KFM15.5.3	Transmissivity and head of 5 m sections with calculated error limits
KFM15.5.4	Conductive fracture frequency
KFM15.6	Inferred fracture flow anomalies from flow logging
KFM15.7.1	Plotted transmissivity and head of detected fractures
KFM15.7.2	Transmissivity and head of detected fractures with calculated error limits.

KFM15.8	Comparison between section transmissivity and fracture transmissivity
KFM15.9.1	Head in the borehole during flow logging
KFM15.9.2	Air pressure, water level in the borehole and pumping rate during flow logging
KFM15.9.3	Groundwater recovery after pumping
KFM15.10.1–KFM15.10.5	Fracture-specific EC results by date

Appendix C

KFM16.1.1–KFM16.1.2	Electrical conductivity of borehole water
KFM16.1.3	Temperature of borehole water
KFM16.2.1–KFM16.2.3	Flow rate and single point resistance
KFM16.2.4	Vertical flow along the borehole at 6.2 m
KFM16.3	Explanations for the tables in Appendices
KFM16.4	Results of section flows
KFM16.5.1	Plotted flow rates of 5 m sections
KFM16.5.2	Plotted transmissivity and head of 5 m sections
KFM16.5.3	Transmissivity and head of 5 m sections with calculated error limits
KFM16.5.4	Conductive fracture frequency
KFM16.6	Inferred fracture flow anomalies from flow logging
KFM16.7.1	Plotted transmissivity and head of detected fractures
KFM16.7.2	Transmissivity and head of detected fractures with calculated error limits.
KFM16.8	Comparison between section transmissivity and fracture transmissivity
KFM16.9.1	Head in the borehole during flow logging
KFM16.9.2	Air pressure, water level in the borehole and pumping rate during flow logging
KFM16.9.3	Groundwater recovery after pumping
KFM16.10.1–KFM16.10.3	Fracture-specific EC results by date
KFM16.11.1–KFM16.11.3	Flow rate, single point resistance and head in the borehole during flow logging

Appendix D

KFM20.1.1–KFM20.1.2	Electrical conductivity of borehole water
KFM20.1.3	Temperature of borehole water
KFM20.2.1–KFM20.2.3	Flow rate and single point resistance
KFM20.2.4	Vertical flow along the borehole at 2.8 m
KFM20.3	Explanations for the tables in Appendices
KFM20.4	Results of section flows
KFM20.5.1	Plotted flow rates of 5 m sections
KFM20.5.2	Plotted transmissivity and head of 5 m sections
KFM20.5.3	Transmissivity and head of 5 m sections with calculated error limits
KFM20.5.4	Conductive fracture frequency

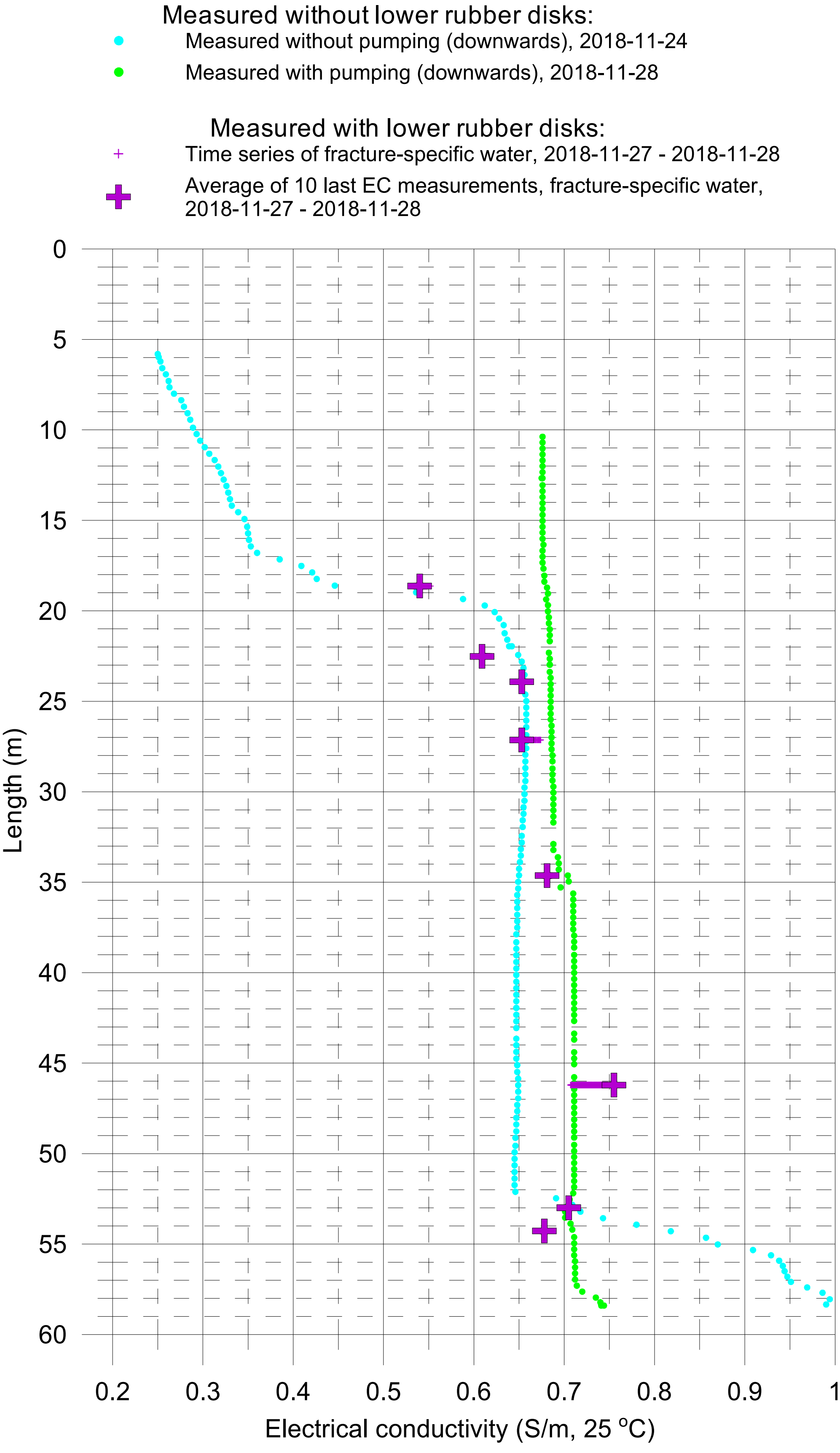
Appendix E

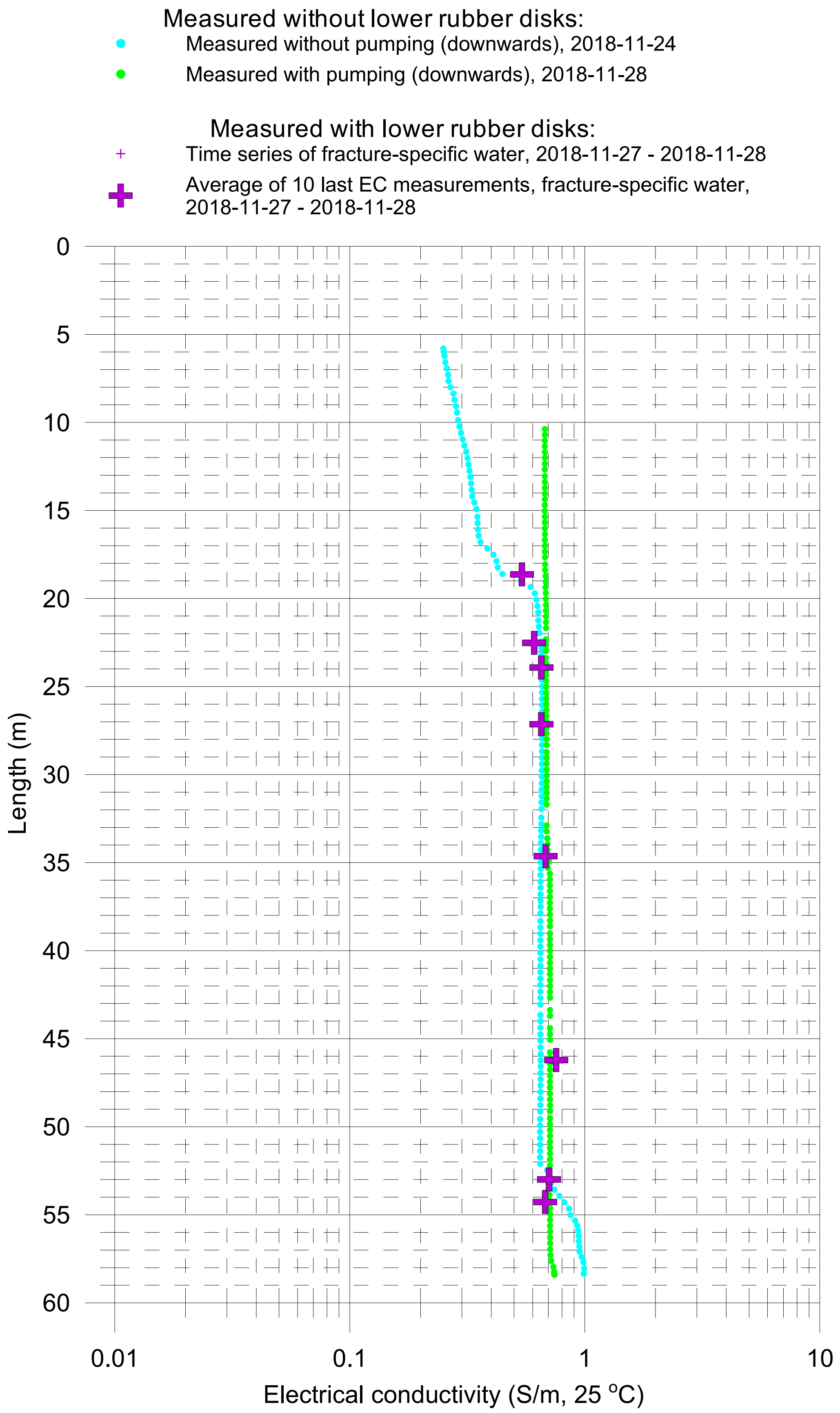
Appendix F

Appendix G

Appendix A

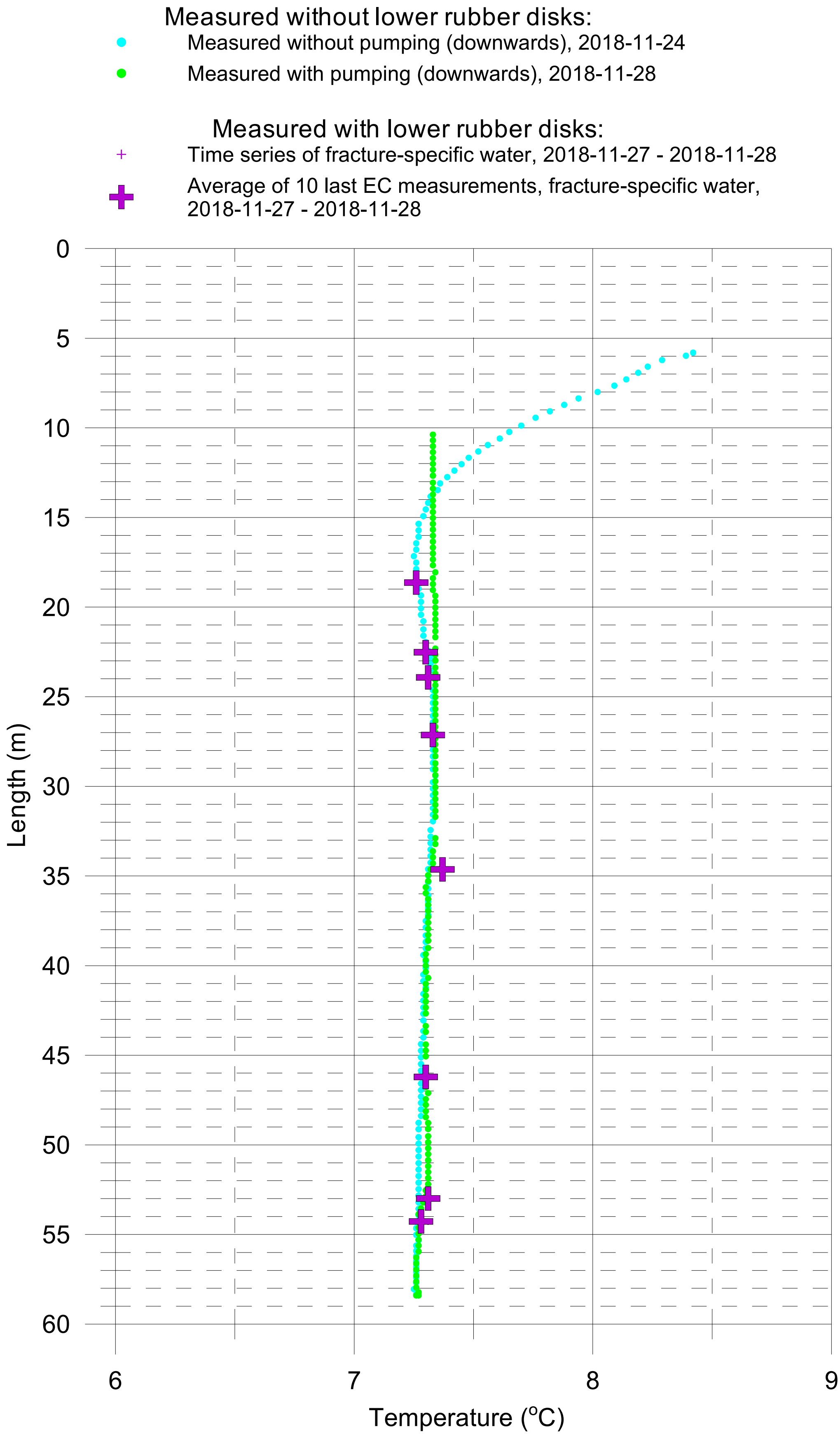
KFM14.1.1–KFM14.1.2 Electrical conductivity of borehole water



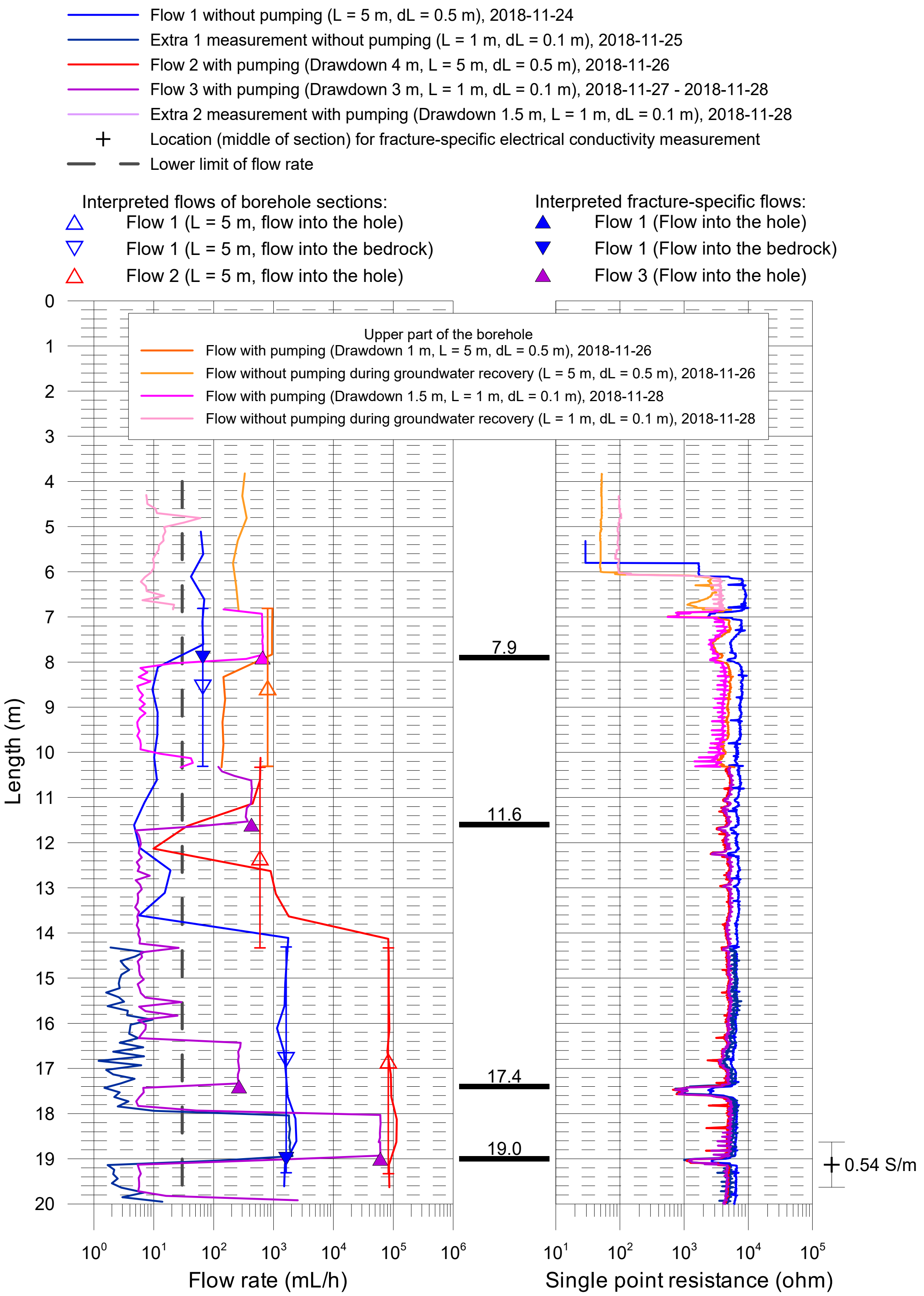


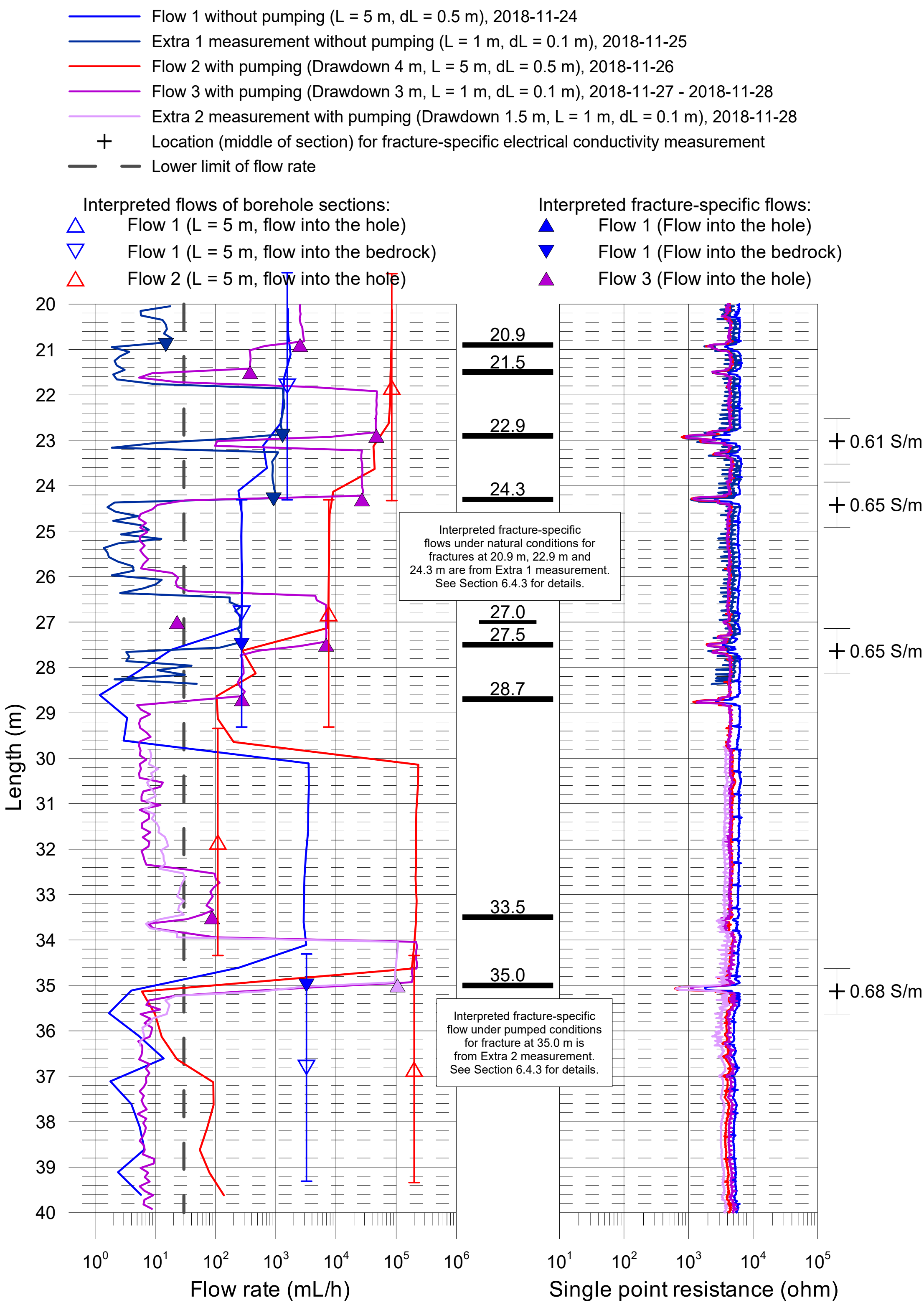
Measured without lower rubber disks:
Measured without pumping (downwards), 2018-11-24
Measured with pumping (downwards), 2018-11-28
Measured with lower rubber disks:
Time series of fracture-specific water, 2018-11-27 - 2018-11-28
Average of 10 last EC measurements, fracture-specific water, 2018-11-27 - 2018-11-28
Length (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
0.01
0.1
1
10
Electrical conductivity (S/m, 25 °C)

KFM14.1.3 Temperature of borehole water

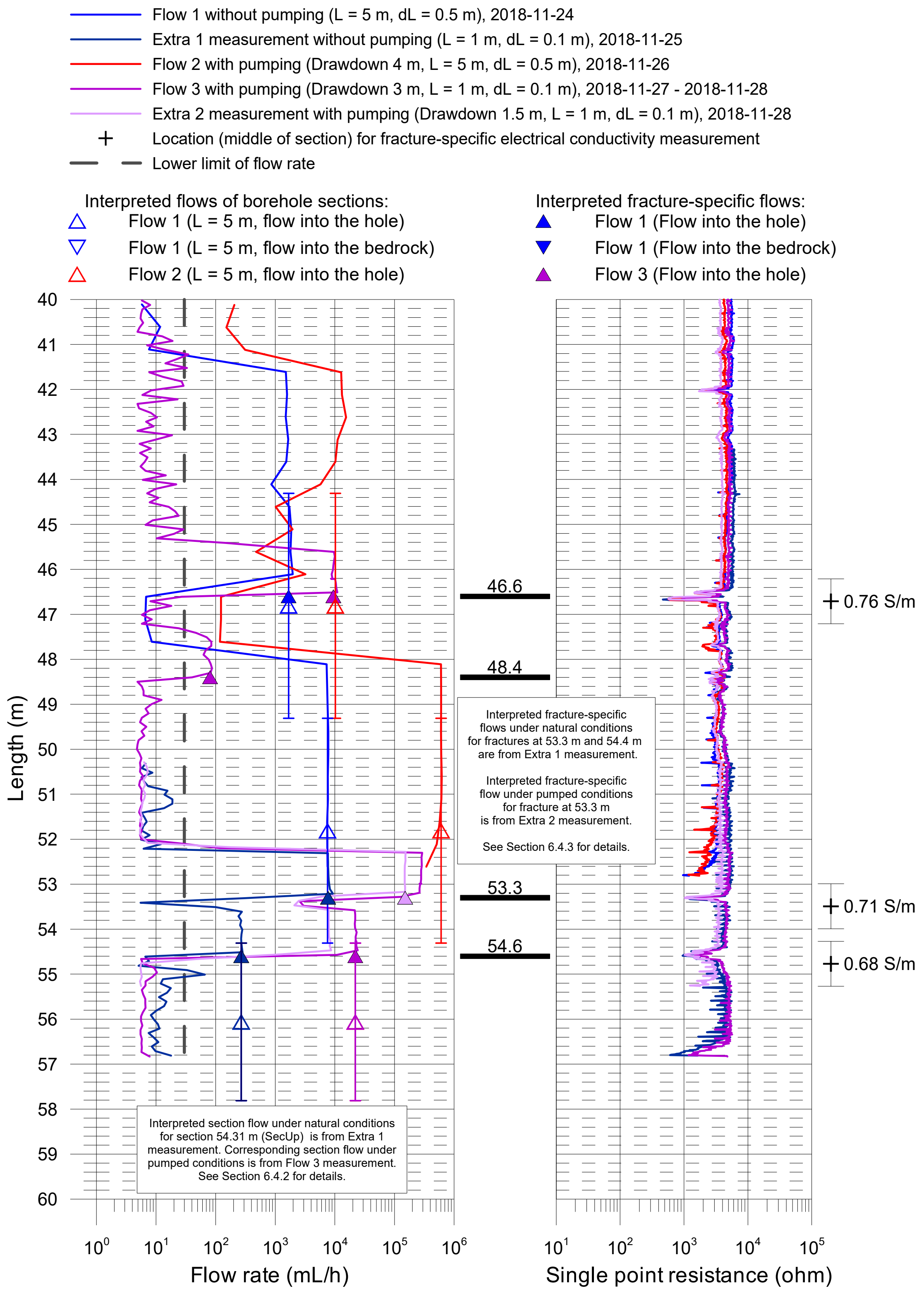


KFM14.2.1– KFM14.2.3 Flow rate and single point resistance



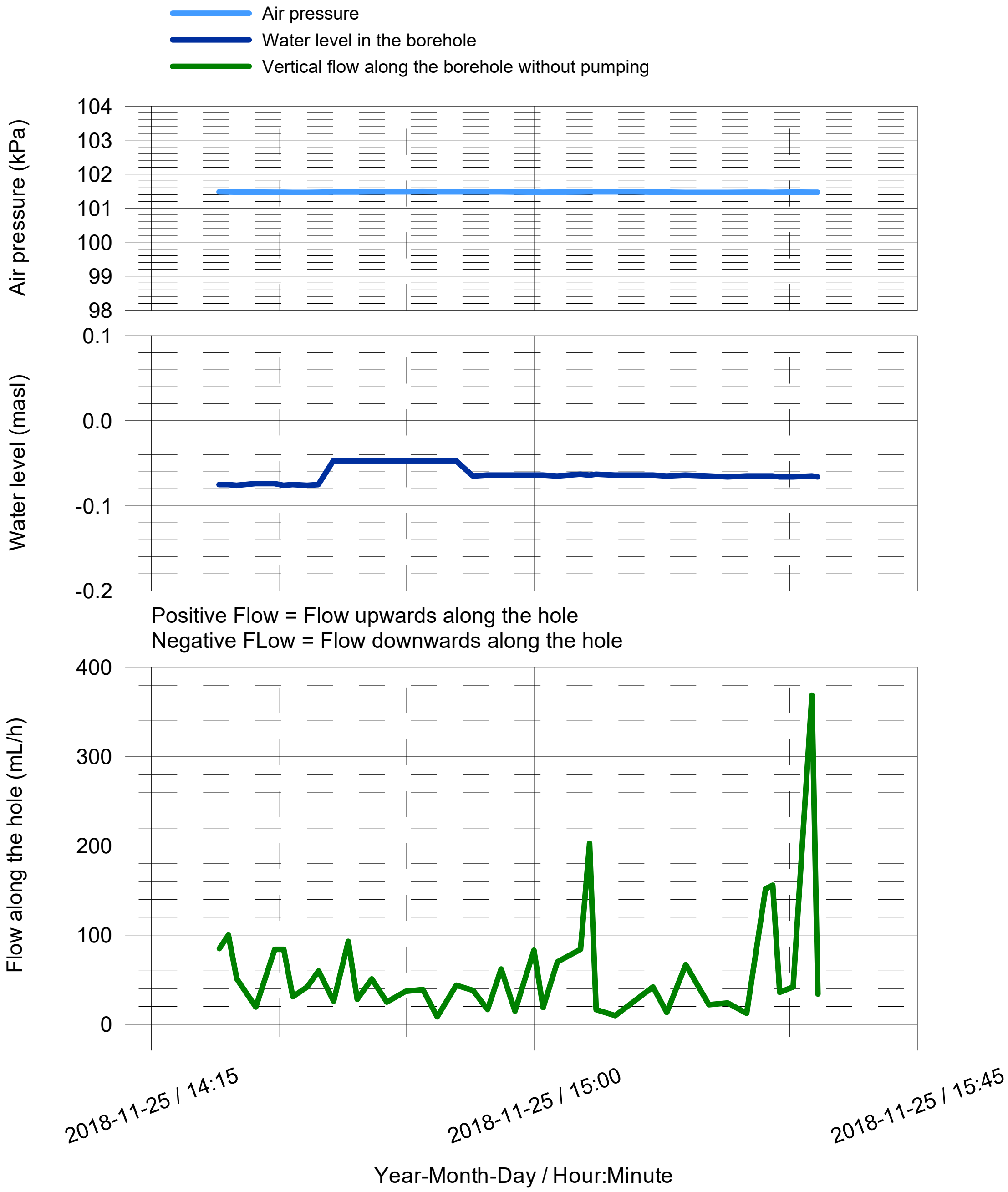


Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-24
Extra 1 measurement without pumping (L = 1 m, dL = 0.1 m), 2018-11-25
Flow 2 with pumping (Drawdown 4 m, L = 5 m, dL = 0.5 m), 2018-11-26
Flow 3 with pumping (Drawdown 3 m, L = 1 m, dL = 0.1 m), 2018-11-27 - 2018-11-28
Extra 2 measurement with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-11-28
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
20.9
21.5
22.9
24.3
27.0
27.5
28.7
33.5
35.0
Interpreted fracture-specific flows under natural conditions for fractures at 20.9 m, 22.9 m and 24.3 m are from Extra 1 measurement. See Section 6.4.3 for details.
Interpreted fracture-specific flow under pumped conditions for fracture at 35.0 m is from Extra 2 measurement. See Section 6.4.3 for details.
0.61 S/m
0.65 S/m
0.65 S/m
0.68 S/m
Flow rate (mL/h)
Single point resistance (ohm)

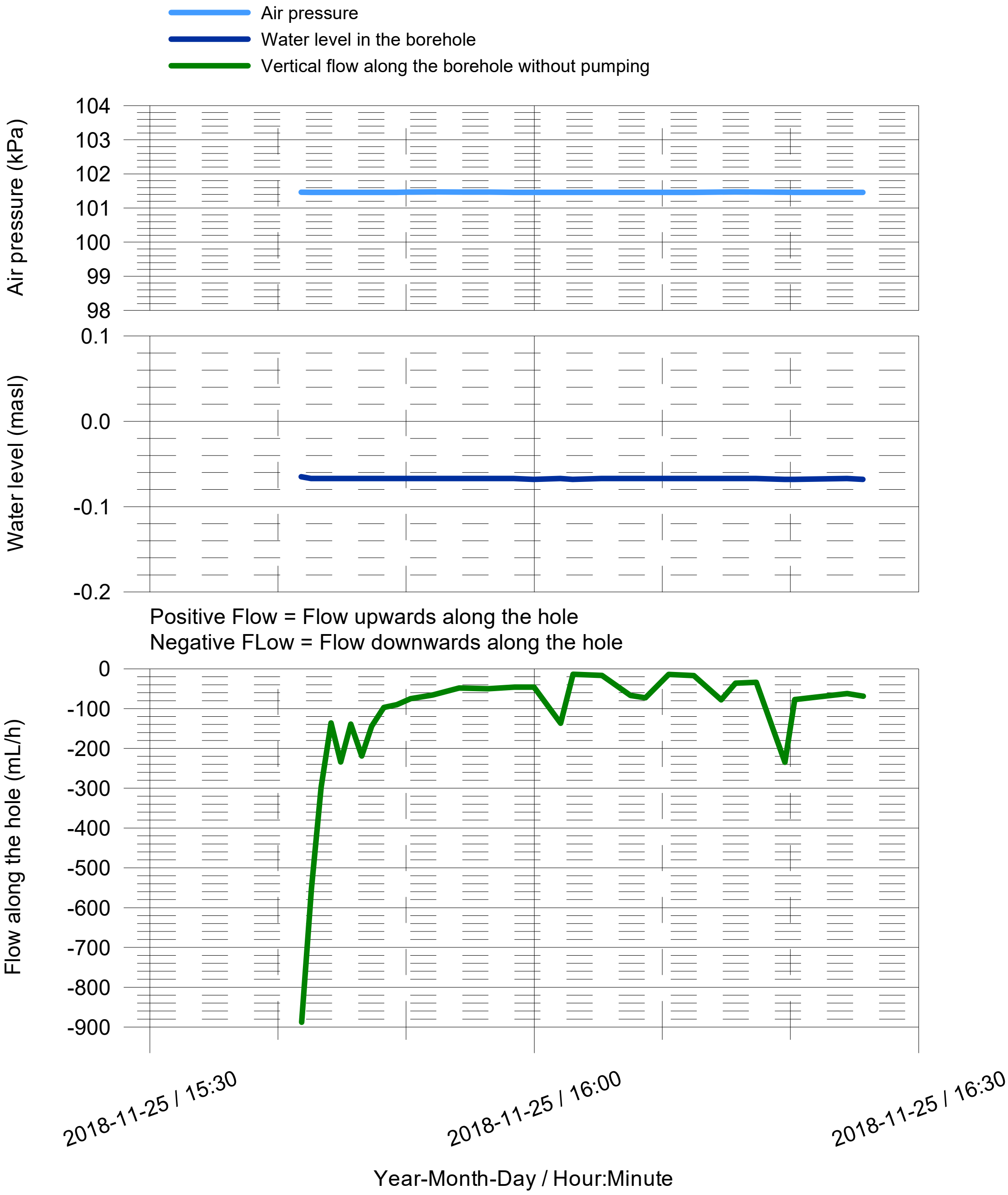


Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-24
Extra 1 measurement without pumping (L = 1 m, dL = 0.1 m), 2018-11-25
Flow 2 with pumping (Drawdown 4 m, L = 5 m, dL = 0.5 m), 2018-11-26
Flow 3 with pumping (Drawdown 3 m, L = 1 m, dL = 0.1 m), 2018-11-27 - 2018-11-28
Extra 2 measurement with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-11-28
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
46.6
48.4
53.3
54.6
Interpreted fracture-specific flows under natural conditions for fractures at 53.3 m and 54.4 m are from Extra 1 measurement.
Interpreted fracture-specific flow under pumped conditions for fracture at 53.3 m is from Extra 2 measurement.
See Section 6.4.3 for details.
Interpreted section flow under natural conditions for section 54.31 m (SecUp) is from Extra 1 measurement. Corresponding section flow under pumped conditions is from Flow 3 measurement. See Section 6.4.2 for details.
0.76 S/m
0.71 S/m
0.68 S/m
Flow rate (mL/h)
Single point resistance (ohm)

KFM14.2.4 Vertical flow along the borehole at 6.3 m



KFM14.2.5 Vertical flow along the borehole at 5.2 m



KFM14.3 Explanations for the tables in Appendices

Header	Unit	Explanations
Borehole ID		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)
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with h=h0 in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid before pumping
h_{1FW}	m.a.s.l.	Corrected hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period
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.
Q-lower limit P	mL/h	Practical lower measurement limit for flow rate.
T-$measl_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-$measl_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-$meas_{lU}$	m^2/s	Estimated upper measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

KFM14.4 Results of section flows

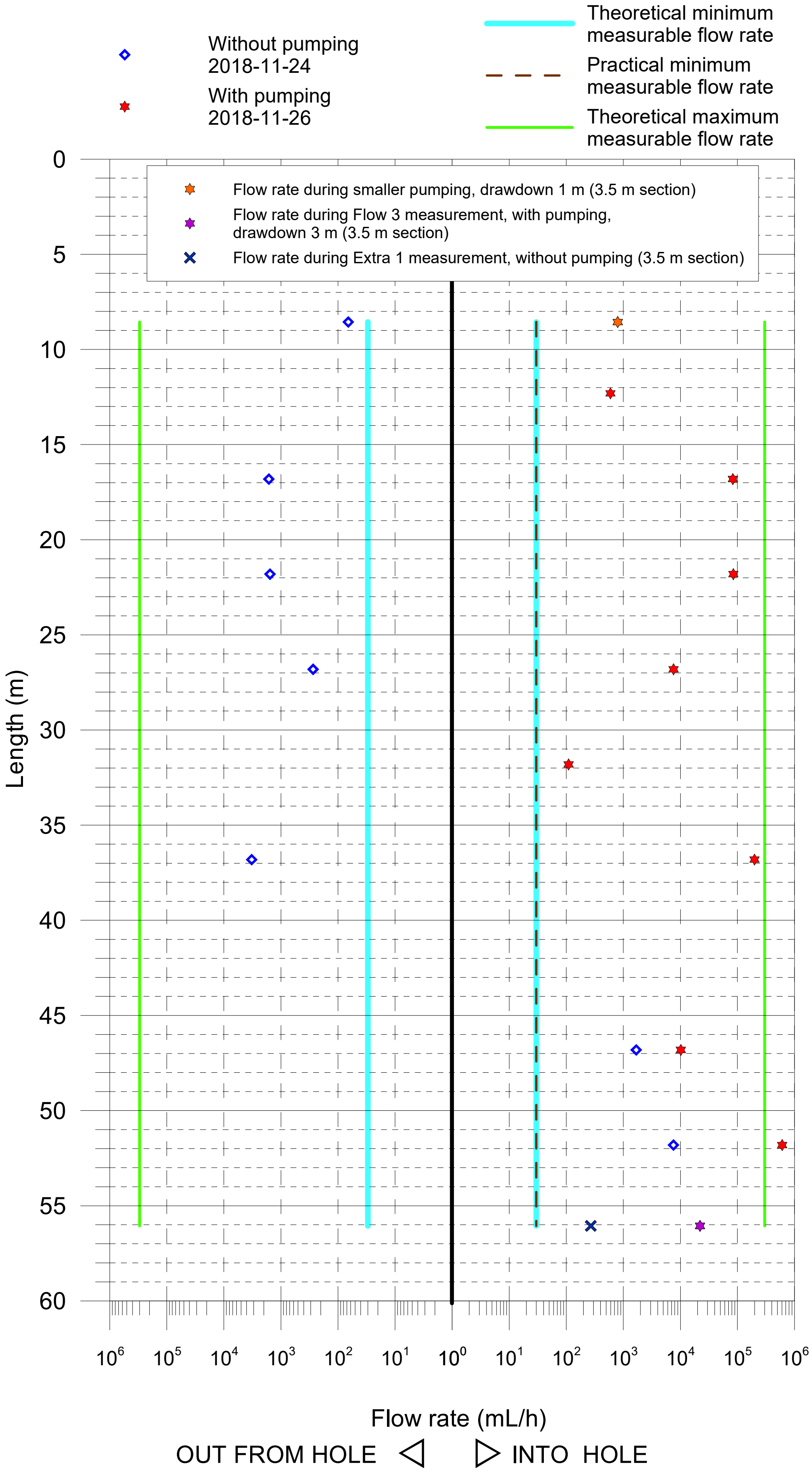
Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	T_D-$measl_{LT}$ (m^2/s)	T_D-$measl_{LP}$ (m^2/s)	T_D-$measl_U$ (m^2/s)	Comments
KFM14	6.81	10.31	3.5	−1.83E-08	−0.01	2.22E-07	−1.58	1.5E-07	−0.1	30	5.3E-09	5.3E-09	5.3E-05	*
KFM14	10.31	14.31	4	–	0.01	1.65E-07	−4.00	4.1E-08	–	30	2.1E-09	2.1E-09	2.1E-05	
KFM14	14.31	19.31	5	−4.53E-07	0.00	2.31E-05	−3.87	6.0E-06	−0.1	30	2.1E-09	2.1E-09	2.1E-05	
KFM14	19.31	24.31	5	−4.31E-07	0.04	2.35E-05	−3.86	6.1E-06	0.0	30	2.1E-09	2.1E-09	2.1E-05	
KFM14	24.31	29.31	5	−7.56E-08	0.03	2.11E-06	−3.98	5.4E-07	−0.1	30	2.1E-09	2.1E-09	2.1E-05	
KFM14	29.31	34.31	5	–	0.05	3.06E-08	−3.91	7.6E-09	–	30	2.1E-09	2.1E-09	2.1E-05	
KFM14	34.31	39.31	5	−9.03E-07	0.04	5.53E-05	−2.85	1.9E-05	0.0	30	2.9E-09	2.9E-09	2.9E-05	**
KFM14	39.31	44.31	5	–	0.04	–	−3.90	–	–	30	2.1E-09	2.1E-09	2.1E-05	
KFM14	44.31	49.31	5	4.67E-07	0.05	2.83E-06	−3.81	6.1E-07	0.8	30	2.1E-09	2.1E-09	2.1E-05	
KFM14	49.31	54.31	5	2.10E-06	0.02	1.68E-04	−1.39	1.2E-04	0.0	30	5.8E-09	5.8E-09	5.7E-05	**
KFM14	54.31	57.81	3.5	7.47E-08	0.06	6.14E-06	−2.81	2.1E-06	0.1	30	2.9E-09	2.9E-09	2.9E-05	***

* Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made with smaller pumping (drawdown 1 m). The upper part of the borehole could not be measured during larger drawdown.

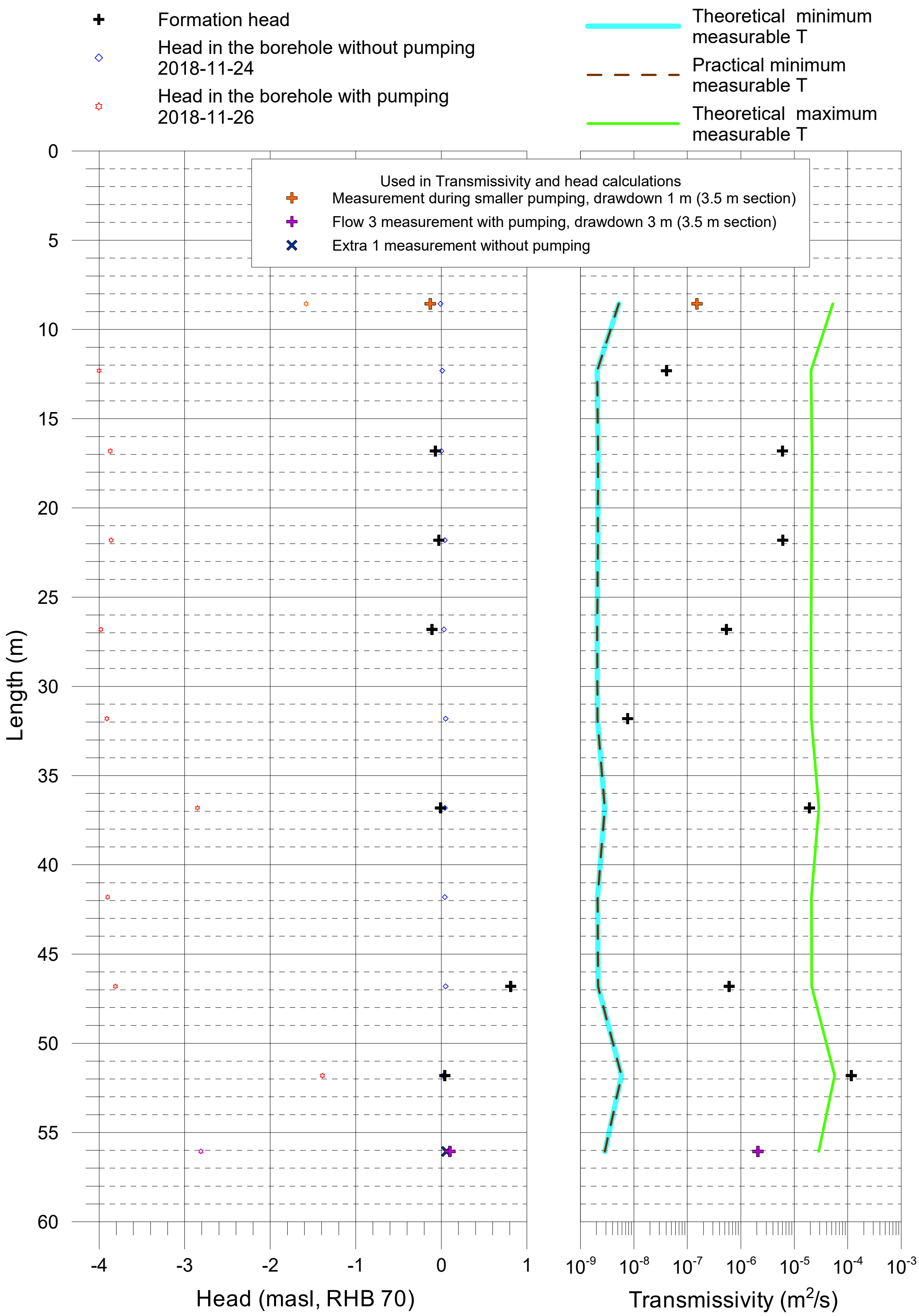
** Measured flow rate is near or exceeds the upper measurement limit. Due to friction loss in the PFL DIFF probe's flow guide, the actual flow rate would probably be higher than the measured flow rate.

*** Values for Flow (Q_0) and Head (h_{0FW}) are from Extra 1 measurement. Values for Flow (Q_1) and Head (h_{1FW}) are from the Flow 3 measurement.

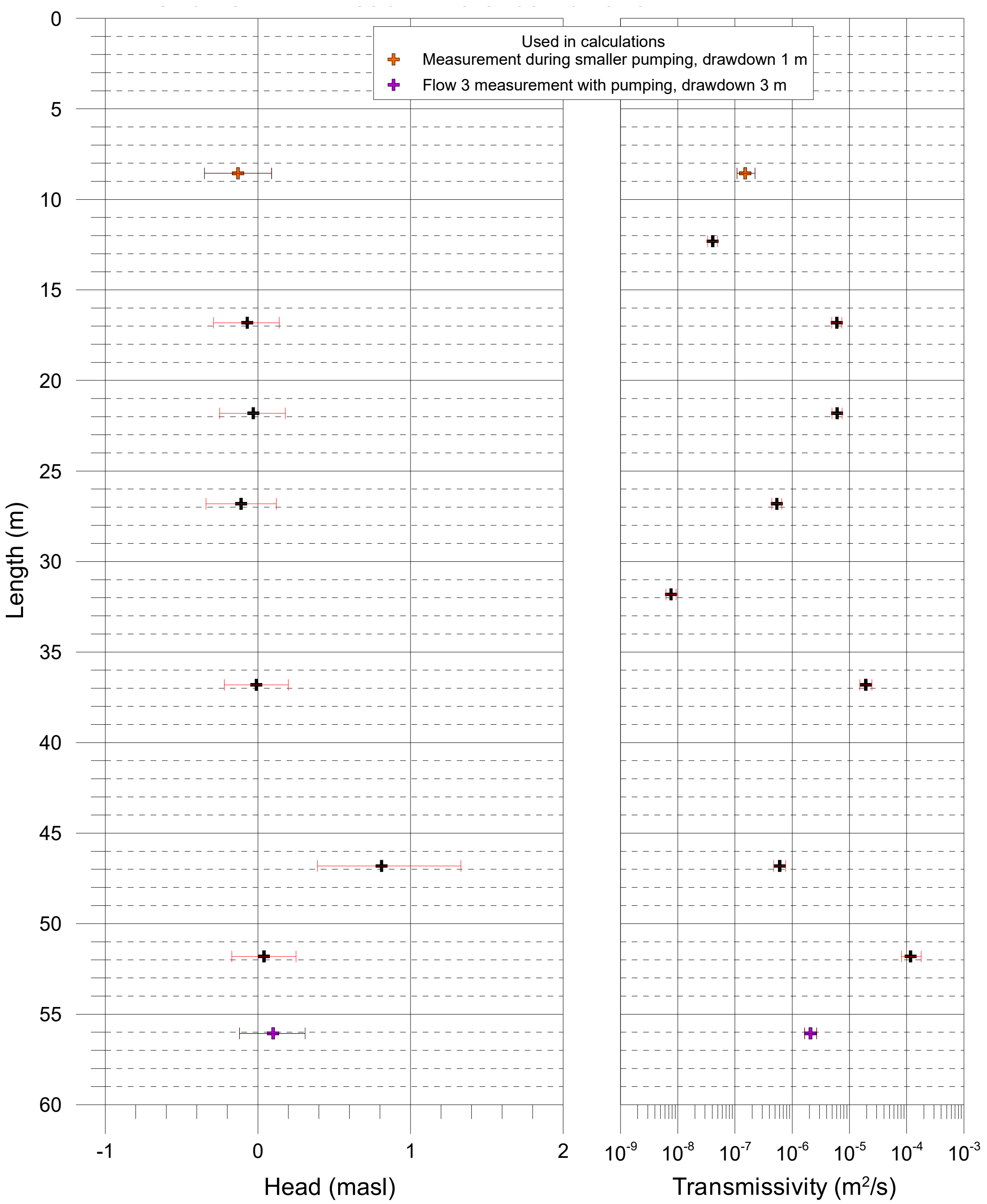
KFM14.5.1 Plotted flow rates of 5 m sections



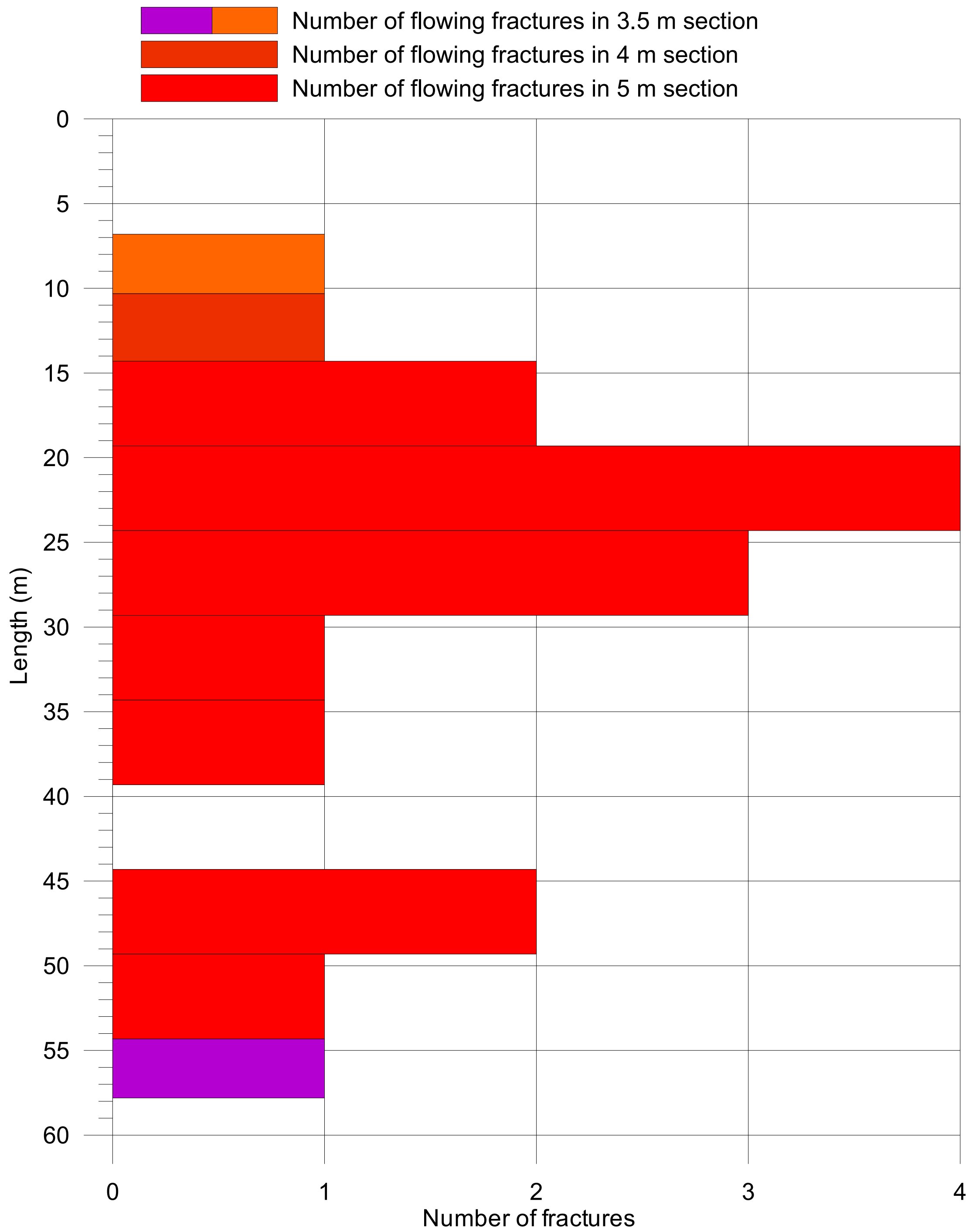
KFM14.5.2 Plotted transmissivity and head of 5 m sections



KFM14.5.3 Transmissivity and head of 5 m sections with calculated error limits



KFM14.5.4 Conductive fracture frequency



KFM14.6 Inferred fracture flow anomalies from 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
KFM14	7.9	1	0.1	−1.83E-08	0.00	1.82E-07	−1.51	1.3E-07	−0.1	**
KFM14	11.6	1	0.1	–	0.02	1.19E-07	−3.05	3.8E-08	–	
KFM14	17.4	1	0.1	–	0.02	7.33E-08	−3.01	2.4E-08	–	
KFM14	19.0	1	0.1	−4.53E-07	0.05	1.68E-05	−2.94	5.7E-06	0.0	
KFM14	20.9	1	0.1	−4.17E-09	−0.02	7.06E-07	−2.98	2.4E-07	0.0	****
KFM14	21.5	1	0.1	–	0.03	1.05E-07	−2.98	3.4E-08	–	
KFM14	22.9	1	0.1	−3.61E-07	−0.03	1.30E-05	−2.93	4.6E-06	−0.1	****
KFM14	24.3	1	0.1	−2.57E-07	−0.03	7.53E-06	−2.95	2.6E-06	−0.1	****
KFM14	27.0	1	0.1	–	0.03	6.39E-09	−2.97	2.1E-09	–	*
KFM14	27.5	1	0.1	−7.56E-08	0.03	1.91E-06	−2.98	6.5E-07	−0.1	
KFM14	28.7	1	0.1	–	0.04	7.67E-08	−2.98	2.5E-08	–	
KFM14	33.5	1	0.1	–	0.04	2.44E-08	−2.78	8.6E-09	–	
KFM14	35.0	1	0.1	−9.03E-07	0.03	2.94E-05	−1.25	2.4E-05	0.0	***
KFM14	46.6	1	0.1	4.67E-07	0.03	2.62E-06	−2.89	7.3E-07	0.7	
KFM14	48.4	1	0.1	–	0.03	2.25E-08	−2.88	7.7E-09	–	
KFM14	53.3	1	0.1	2.14E-06	0.08	4.19E-05	−0.90	4.0E-05	0.1	***,****
KFM14	54.6	1	0.1	7.47E-08	0.07	6.14E-06	−2.81	2.1E-06	0.1	****

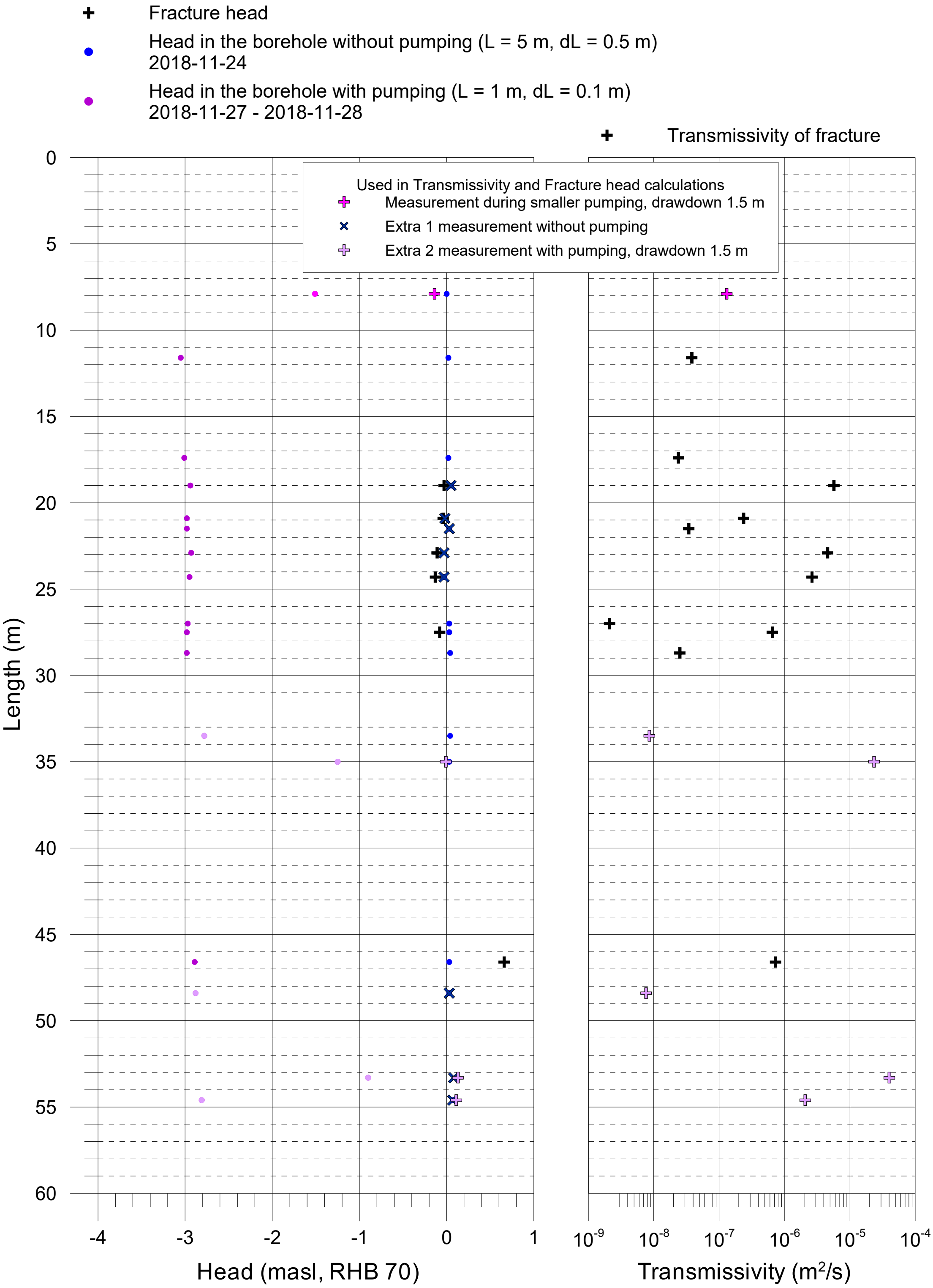
* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

** Values for Flow (Q1) and Head (h1FW) are from the measurement made with smaller pumping (drawdown 1 m). The upper part of the borehole could not be measured during larger drawdown.

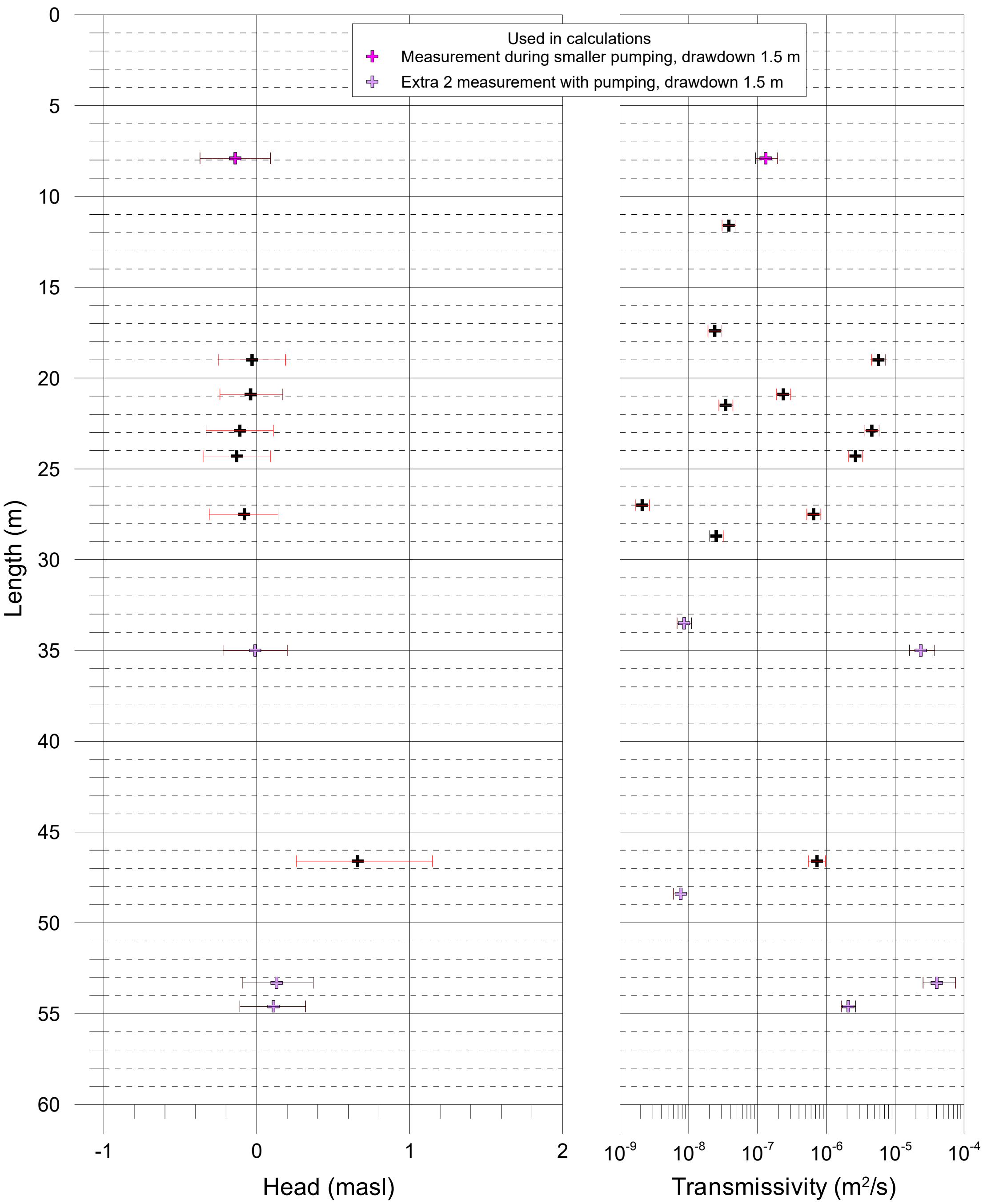
*** Values for Flow (Q1) and Head (h1FW) are from the measurement made with smaller pumping (drawdown 1.5 m) due to exceeding of the upper measurement limit during 3 m drawdown in Flow 3 measurement.

**** Values for Flow (Q0) and Head (h0FW) are from Extra 1 measurement.

KFM14.7.1 Plotted transmissivity and head of detected fractures



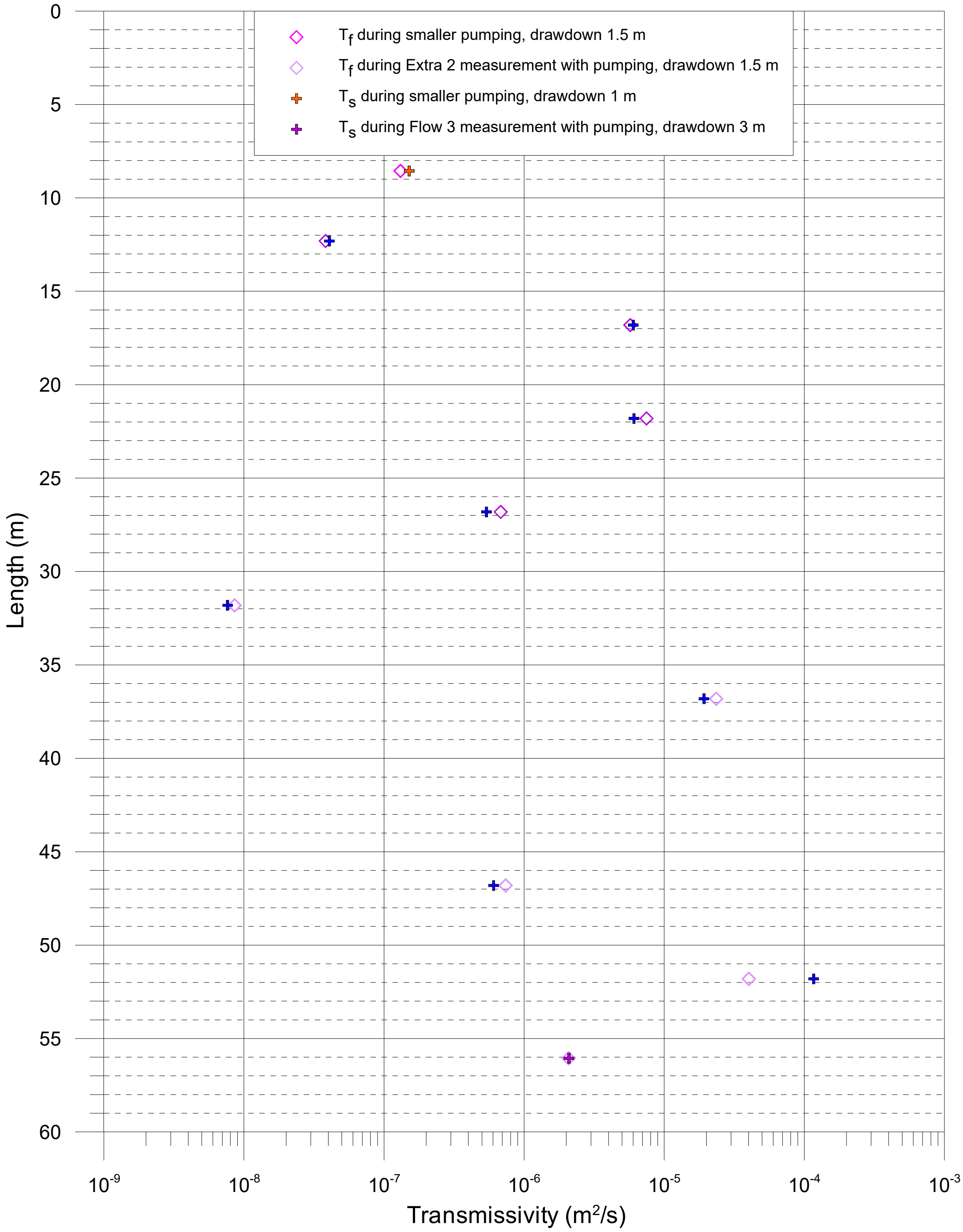
KFM14.7.2 Transmissivity and head of detected fractures with calculated error limits



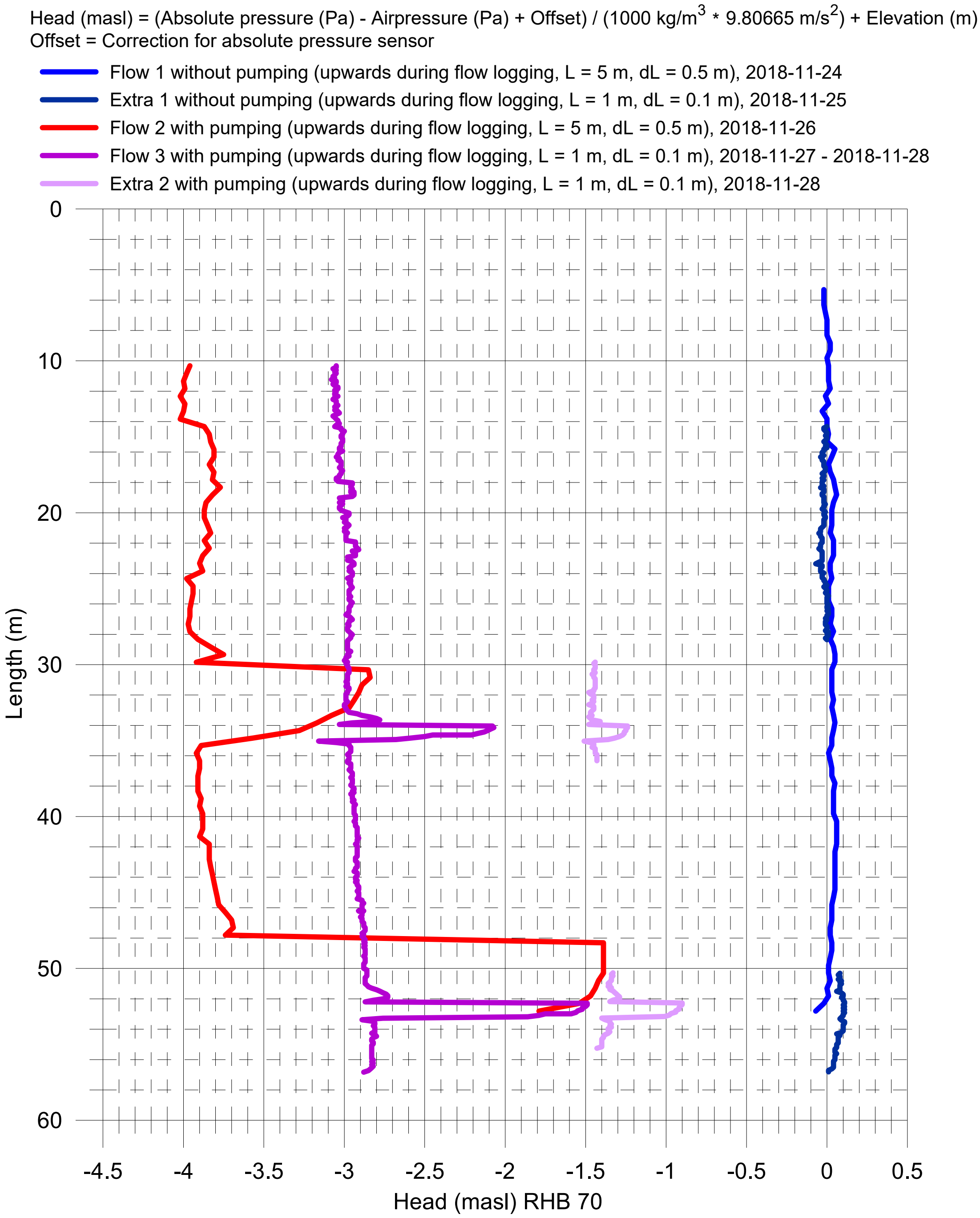
KFM14.8 Comparison between section transmissivity and fracture transmissivity

◇ Transmissivity (sum of fracture-specific results T_f)

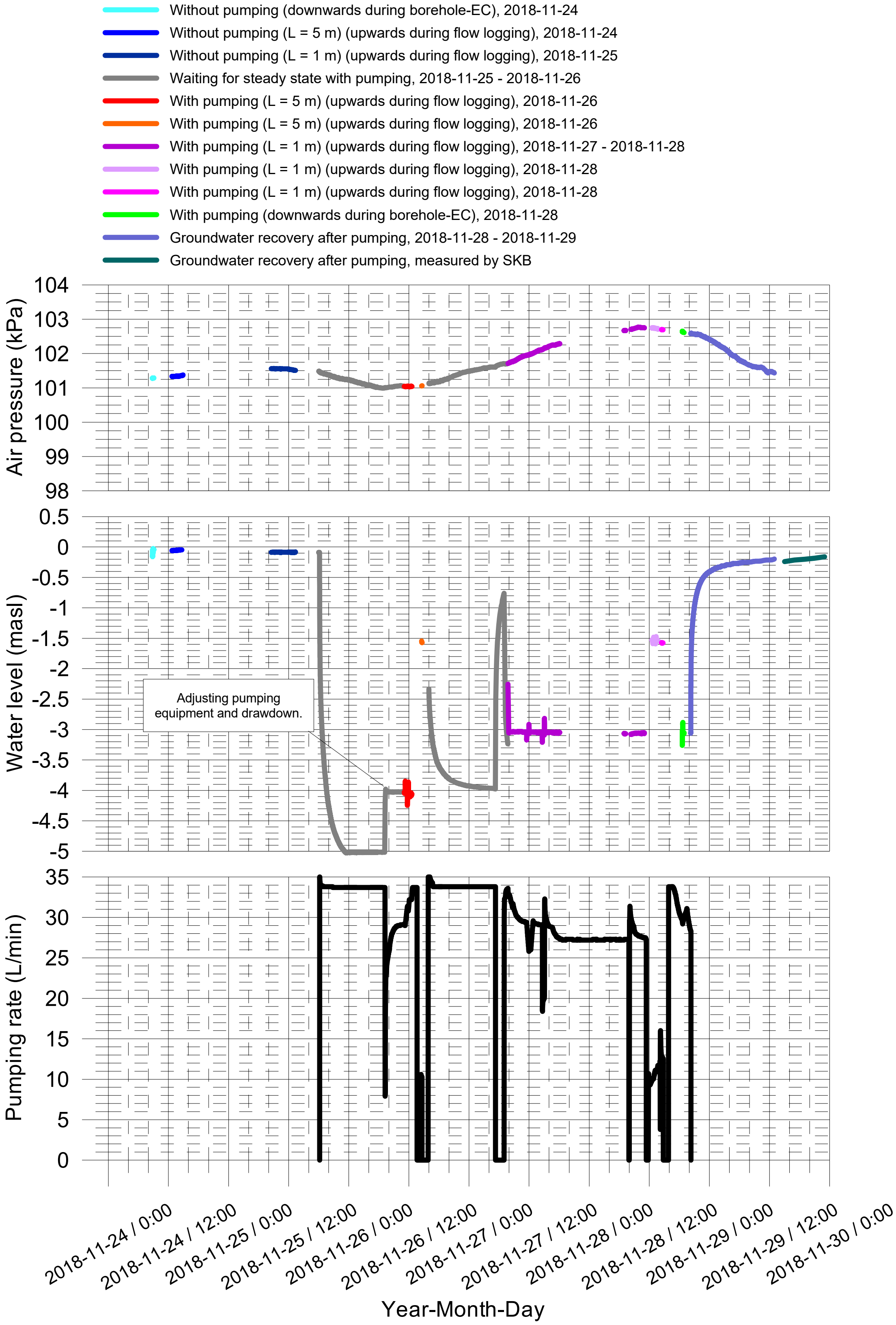
+ Transmissivity (results of 5 m measurements T_s)



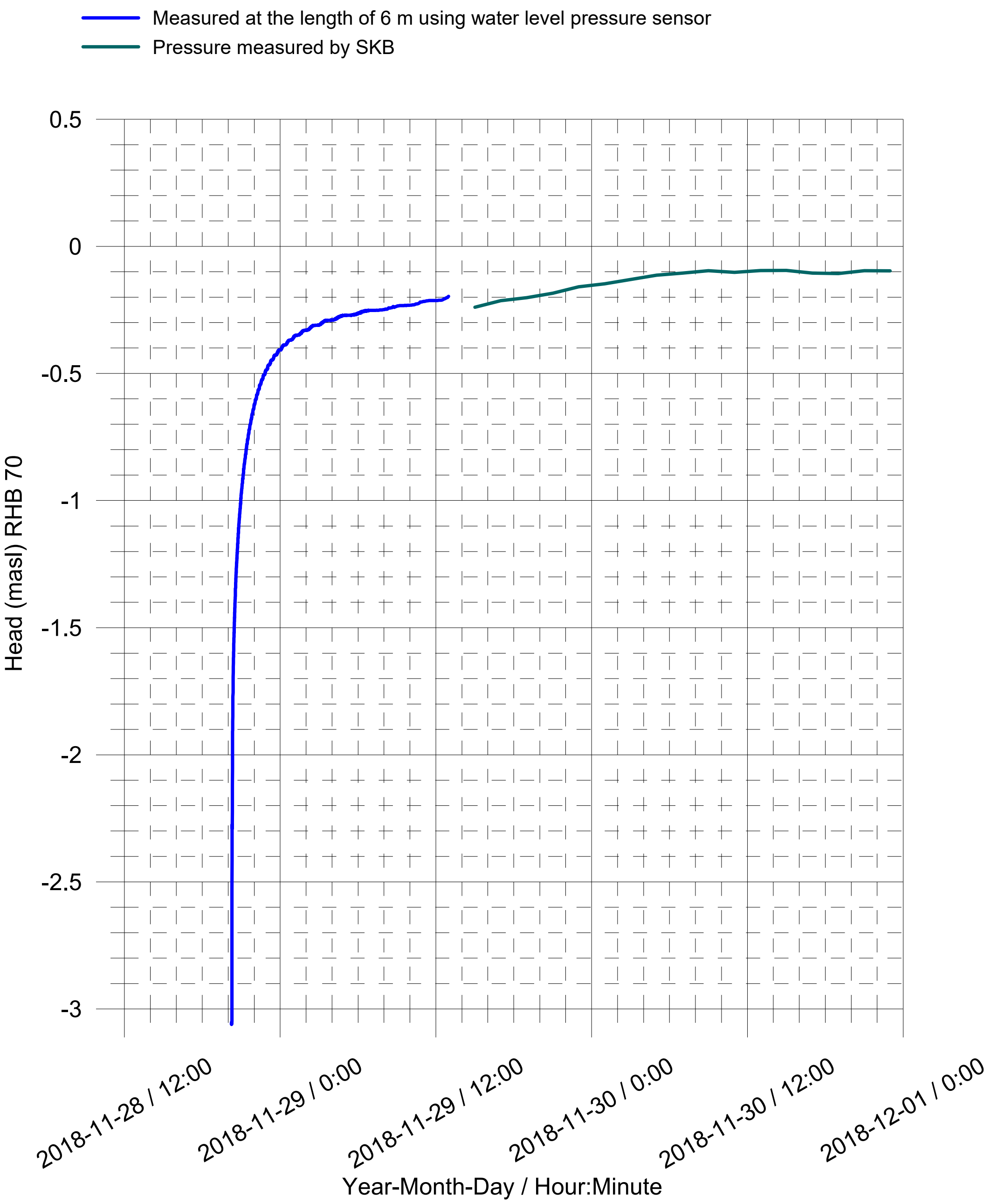
KFM14.9.1 Head in the borehole during flow logging



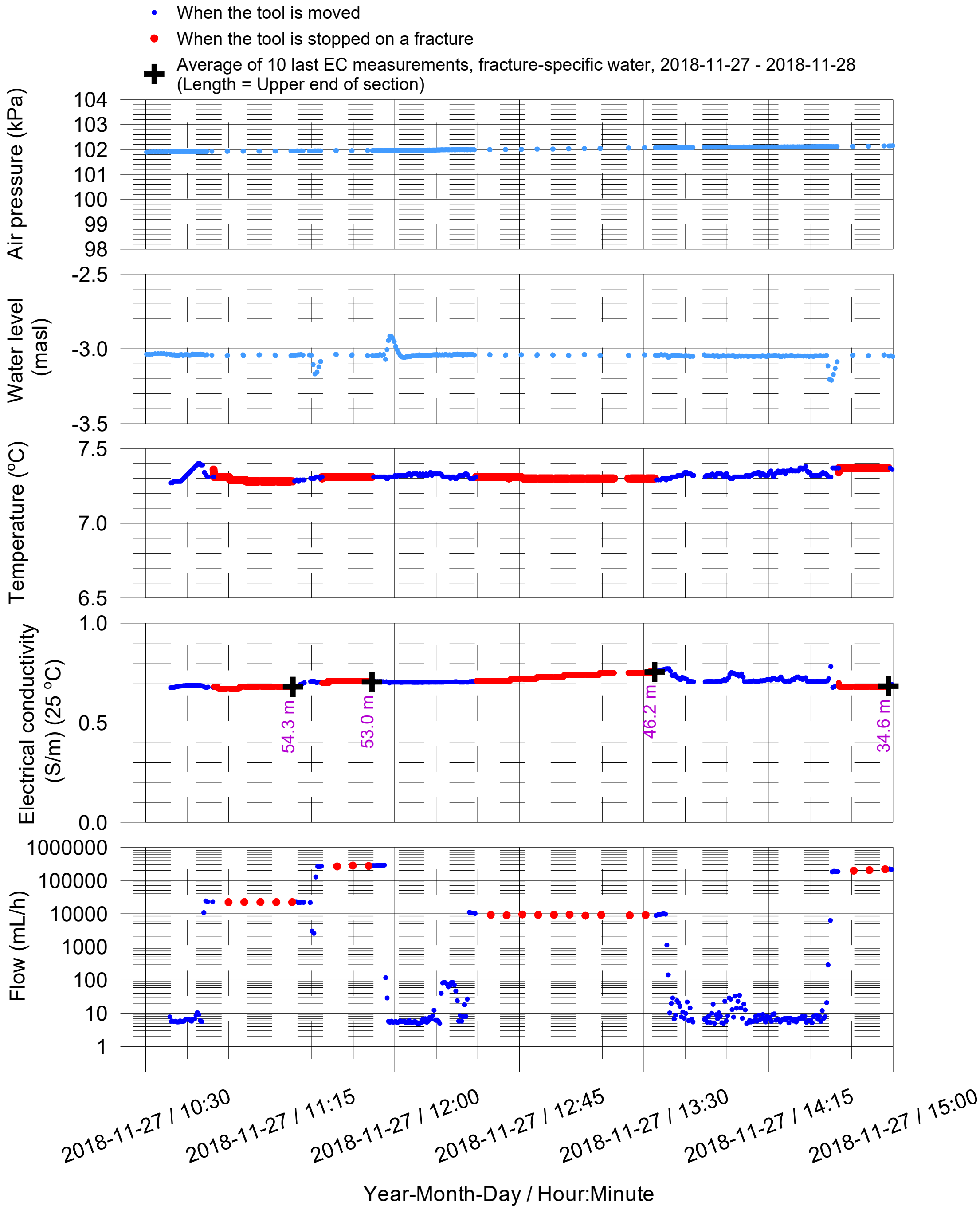
KFM14.9.2 Air pressure, water level in the borehole and pumping rate during flow logging

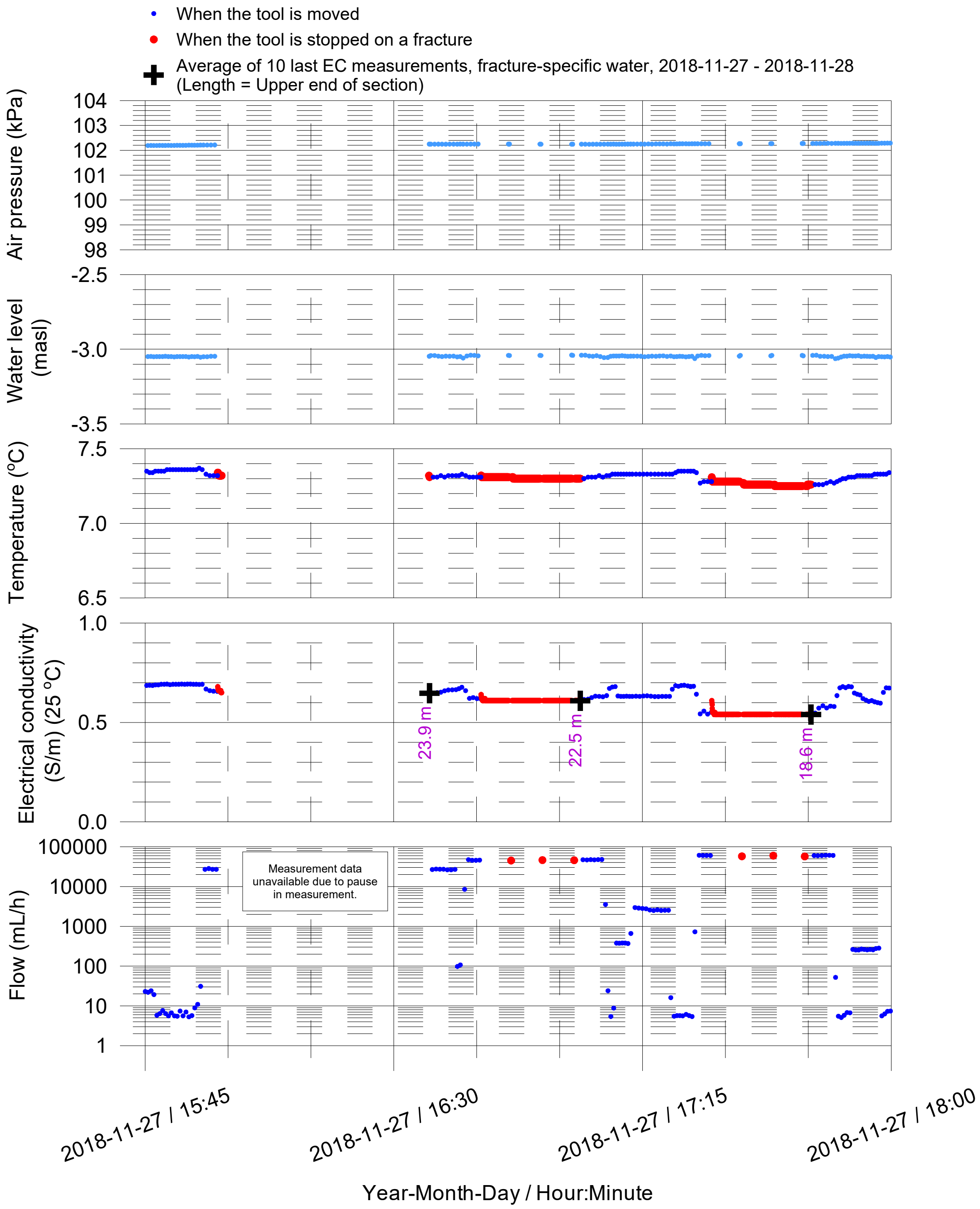


KFM14.9.3 Groundwater recovery after pumping

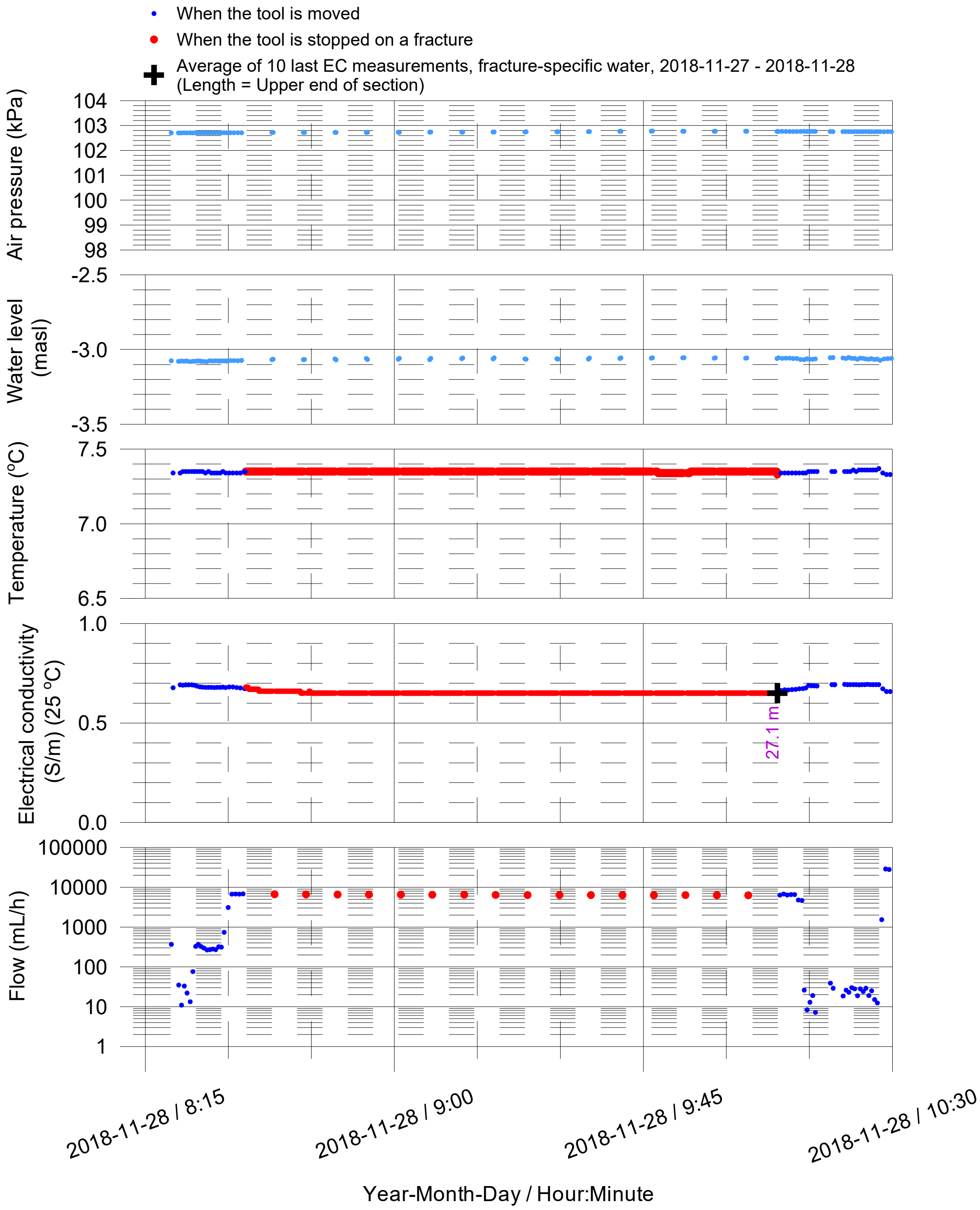


KFM14.10.1–KFM14.10.3 Fracture-specific EC results by date



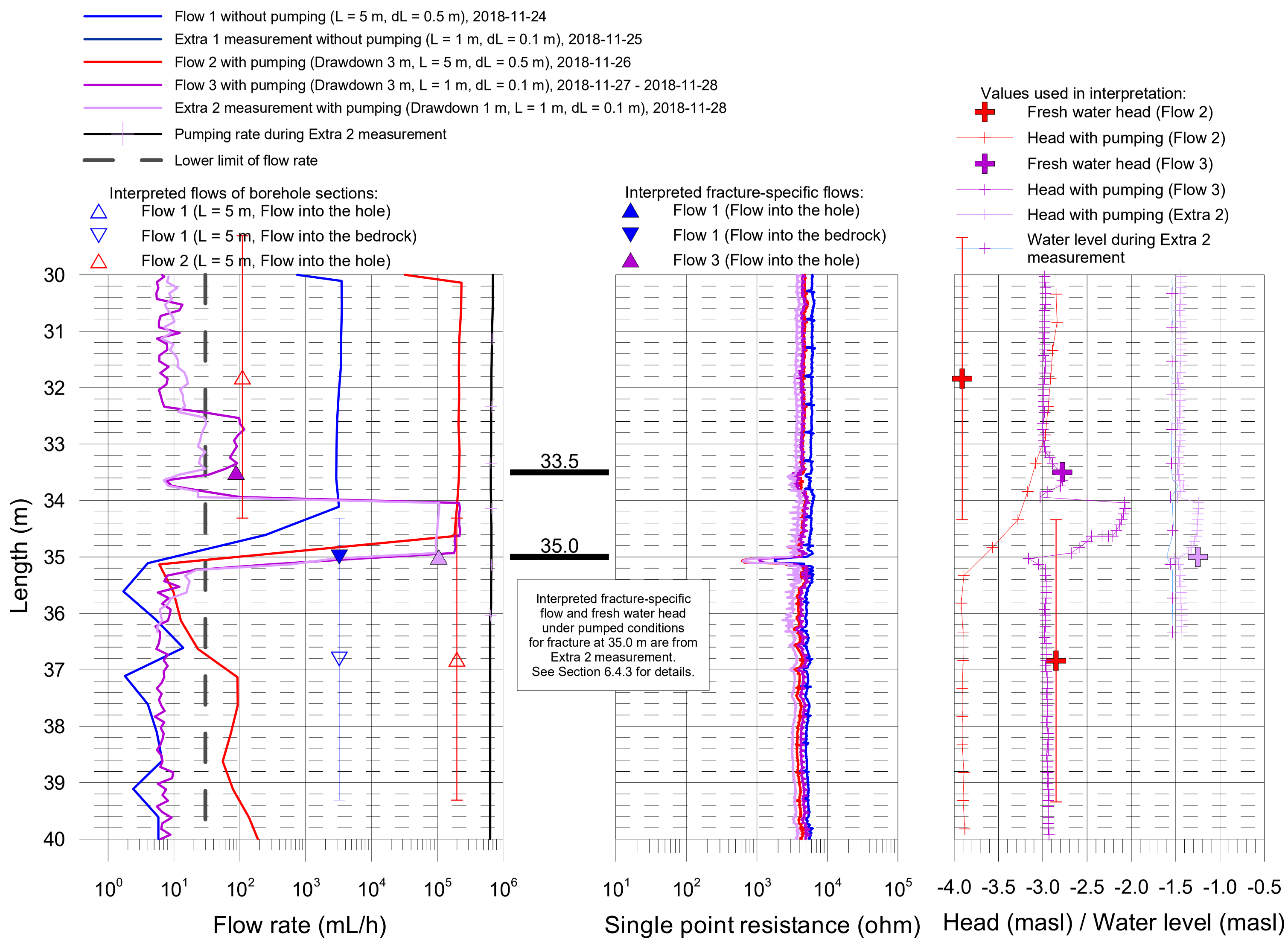


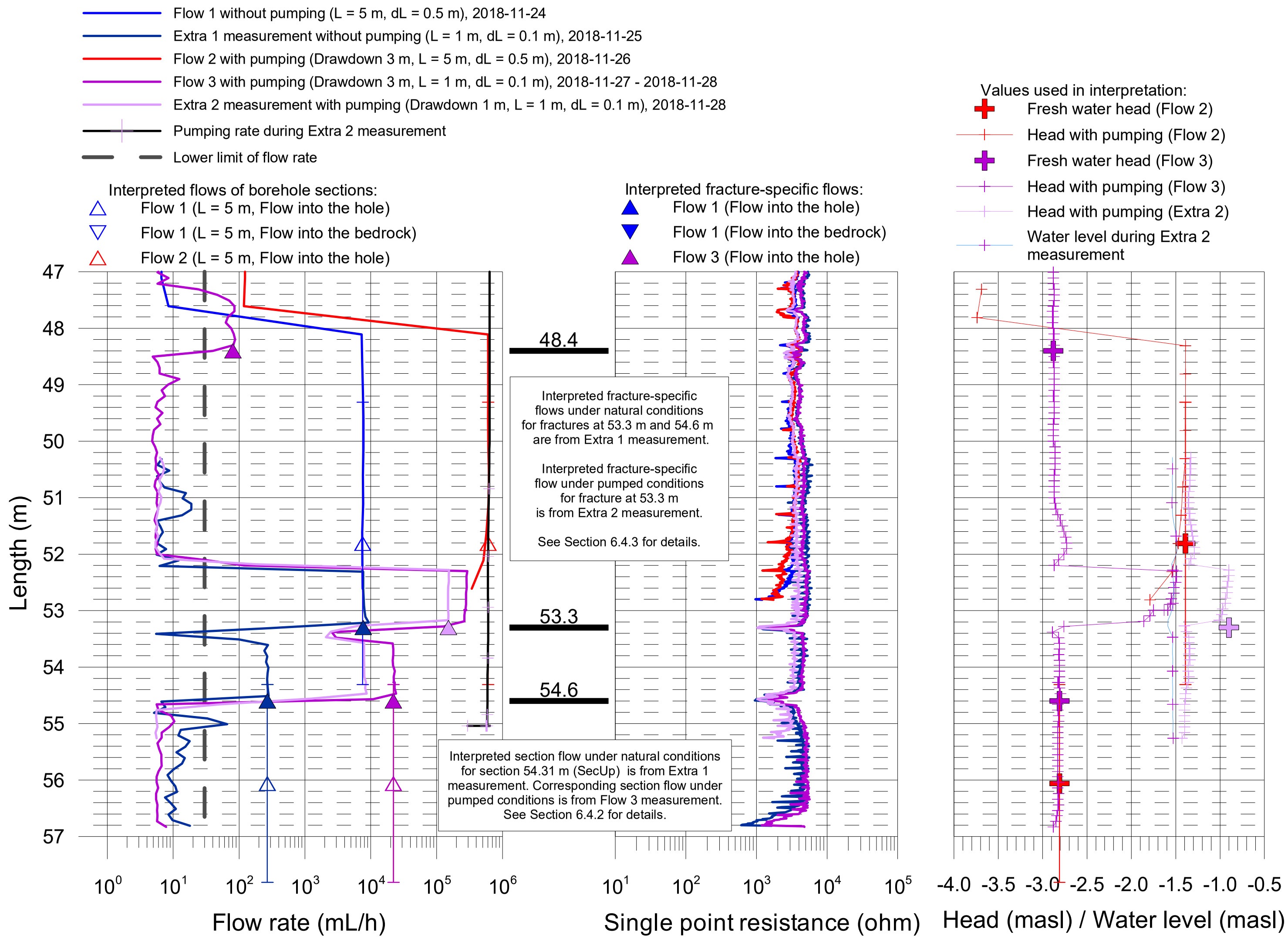
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-27 - 2018-11-28 (Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-2.5
-3.0
-3.5
Temperature (°C)
7.5
7.0
6.5
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
23.9 m
22.5 m
18.6 m
Flow (mL/h)
100000
10000
1000
100
10
1
Measurement data unavailable due to pause in measurement.
2018-11-27 / 15:45
2018-11-27 / 16:30
2018-11-27 / 17:15
2018-11-27 / 18:00
Year-Month-Day / Hour:Minute



When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-27 - 2018-11-28
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level
(masl)
-2.5
-3.0
-3.5
Temperature (ºC)
7.5
7.0
6.5
Electrical conductivity
(S/m) (25 ºC)
1.0
0.5
0.0
27.1 m
Flow (mL/h)
100000
10000
1000
100
10
1
2018-11-28 / 8:15
2018-11-28 / 9:00
2018-11-28 / 9:45
2018-11-28 / 10:30
Year-Month-Day / Hour:Minute

KFM14.11.1–KFM14.11.2 Flow rate, single point resistance and head in the borehole during flow logging

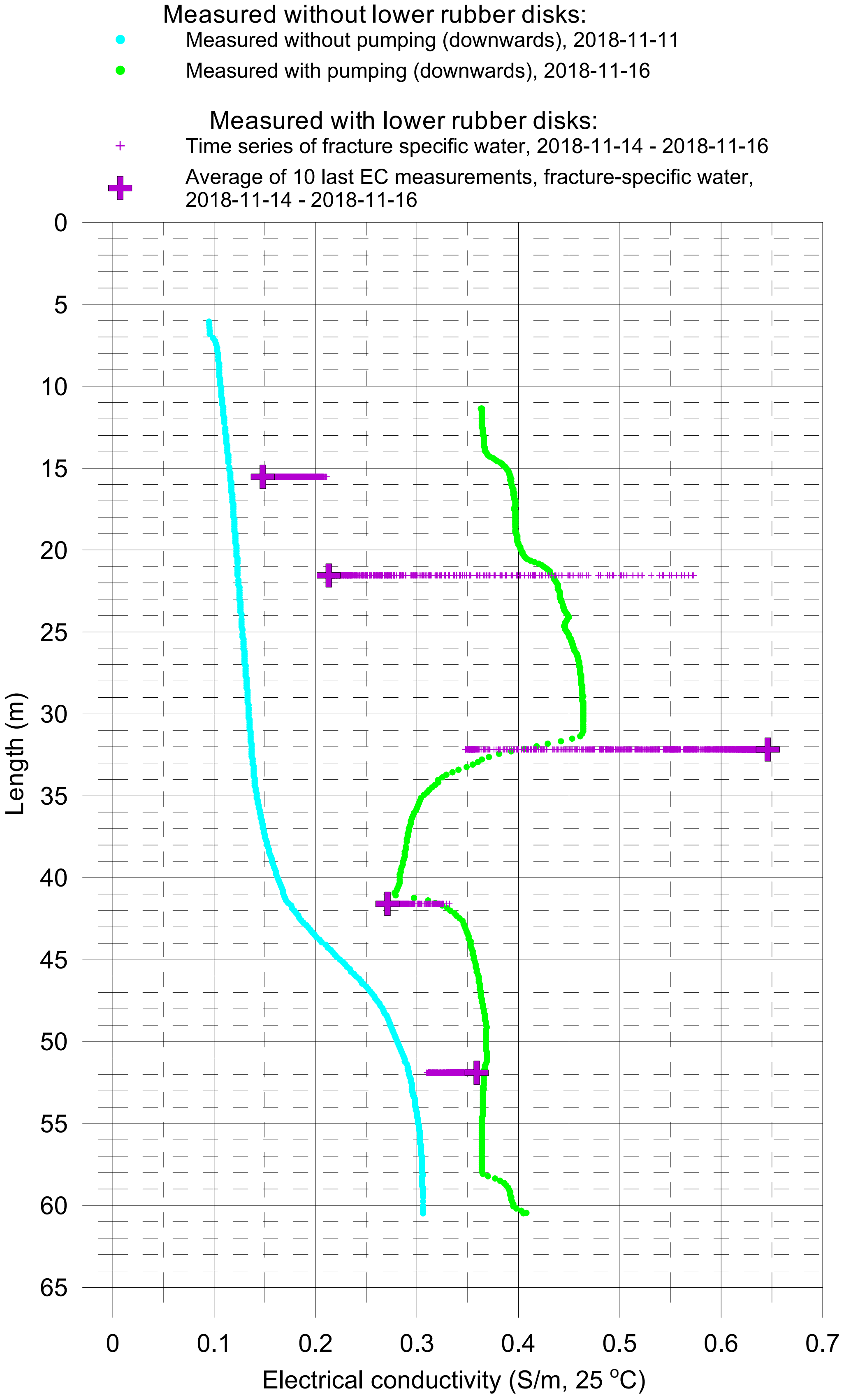


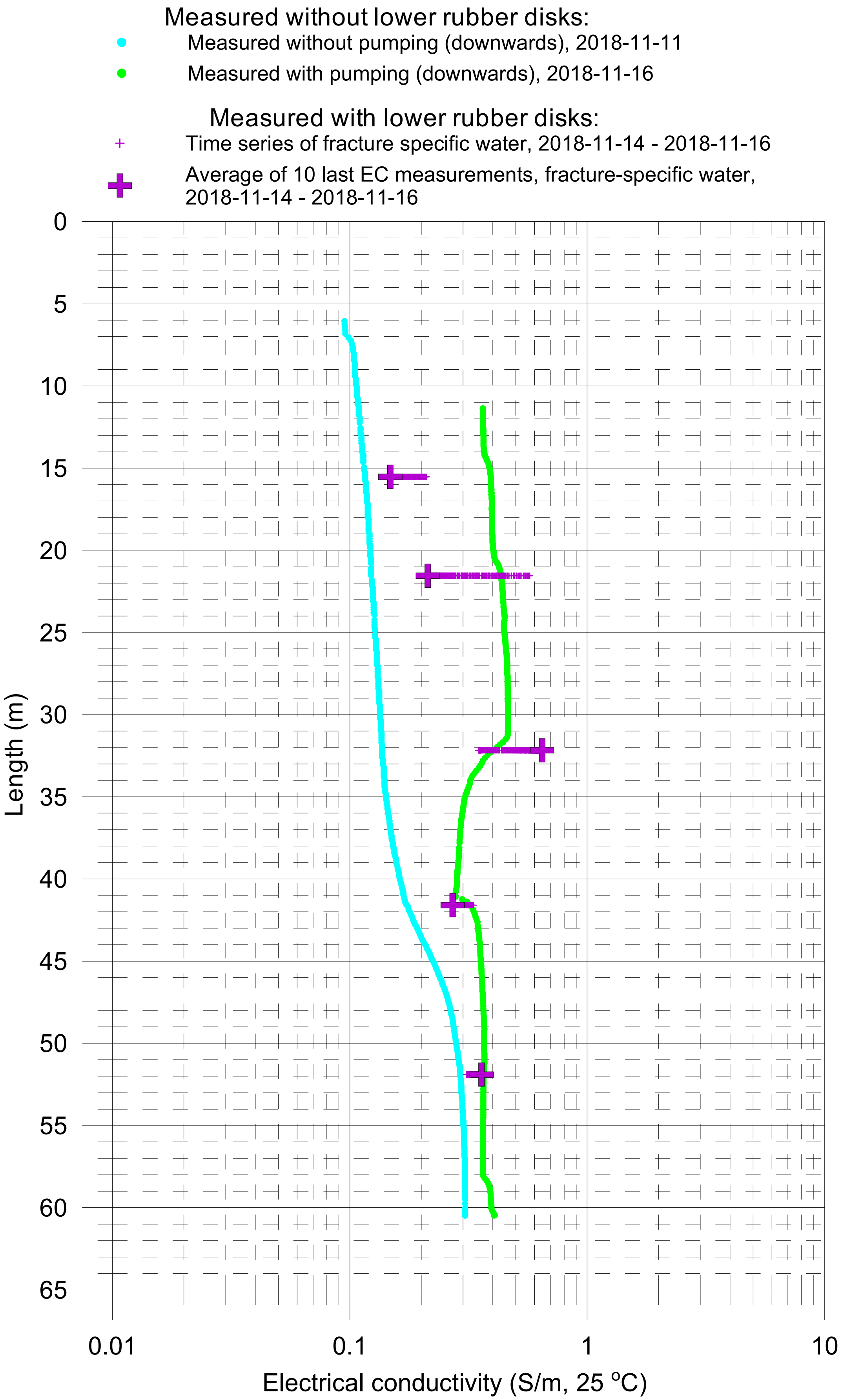


Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-24
Extra 1 measurement without pumping (L = 1 m, dL = 0.1 m), 2018-11-25
Flow 2 with pumping (Drawdown 3 m, L = 5 m, dL = 0.5 m), 2018-11-26
Flow 3 with pumping (Drawdown 3 m, L = 1 m, dL = 0.1 m), 2018-11-27 - 2018-11-28
Extra 2 measurement with pumping (Drawdown 1 m, L = 1 m, dL = 0.1 m), 2018-11-28
Pumping rate during Extra 2 measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, Flow into the hole)
Flow 1 (L = 5 m, Flow into the bedrock)
Flow 2 (L = 5 m, Flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Values used in interpretation:
Fresh water head (Flow 2)
Head with pumping (Flow 2)
Fresh water head (Flow 3)
Head with pumping (Flow 3)
Head with pumping (Extra 2)
Water level during Extra 2 measurement
Length (m)
47
48
49
50
51
52
53
54
55
56
57
48.4
53.3
54.6
Interpreted fracture-specific flows under natural conditions for fractures at 53.3 m and 54.6 m are from Extra 1 measurement.
Interpreted fracture-specific flow under pumped conditions for fracture at 53.3 m is from Extra 2 measurement.
See Section 6.4.3 for details.
Interpreted section flow under natural conditions for section 54.31 m (SecUp) is from Extra 1 measurement. Corresponding section flow under pumped conditions is from Flow 3 measurement. See Section 6.4.2 for details.
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^1 10^2 10^3 10^4 10^5
Single point resistance (ohm)
-4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0 -0.5
Head (masl) / Water level (masl)

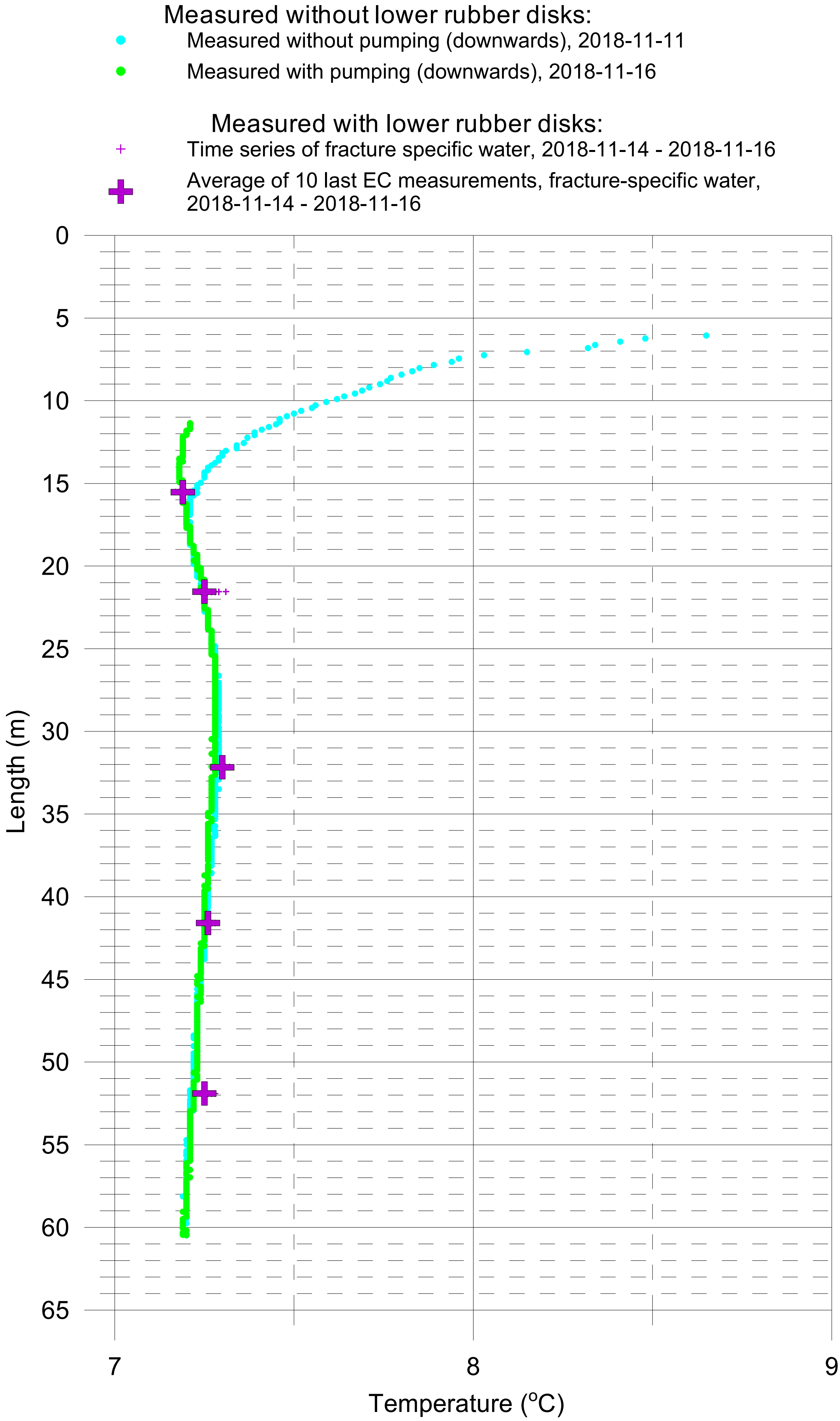
Appendix B

KFM15.1.1–KFM15.1.2 Electrical conductivity of borehole water

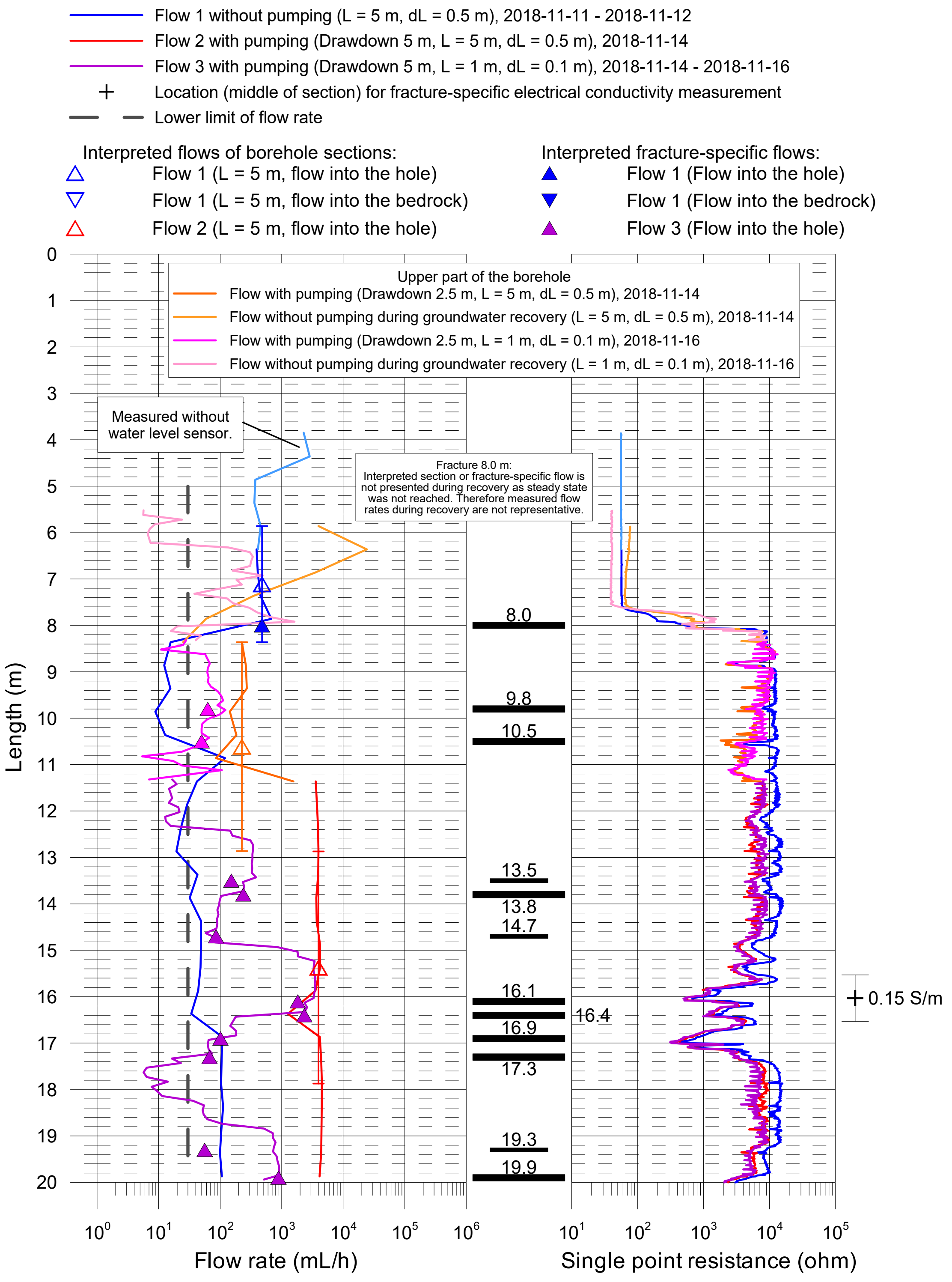


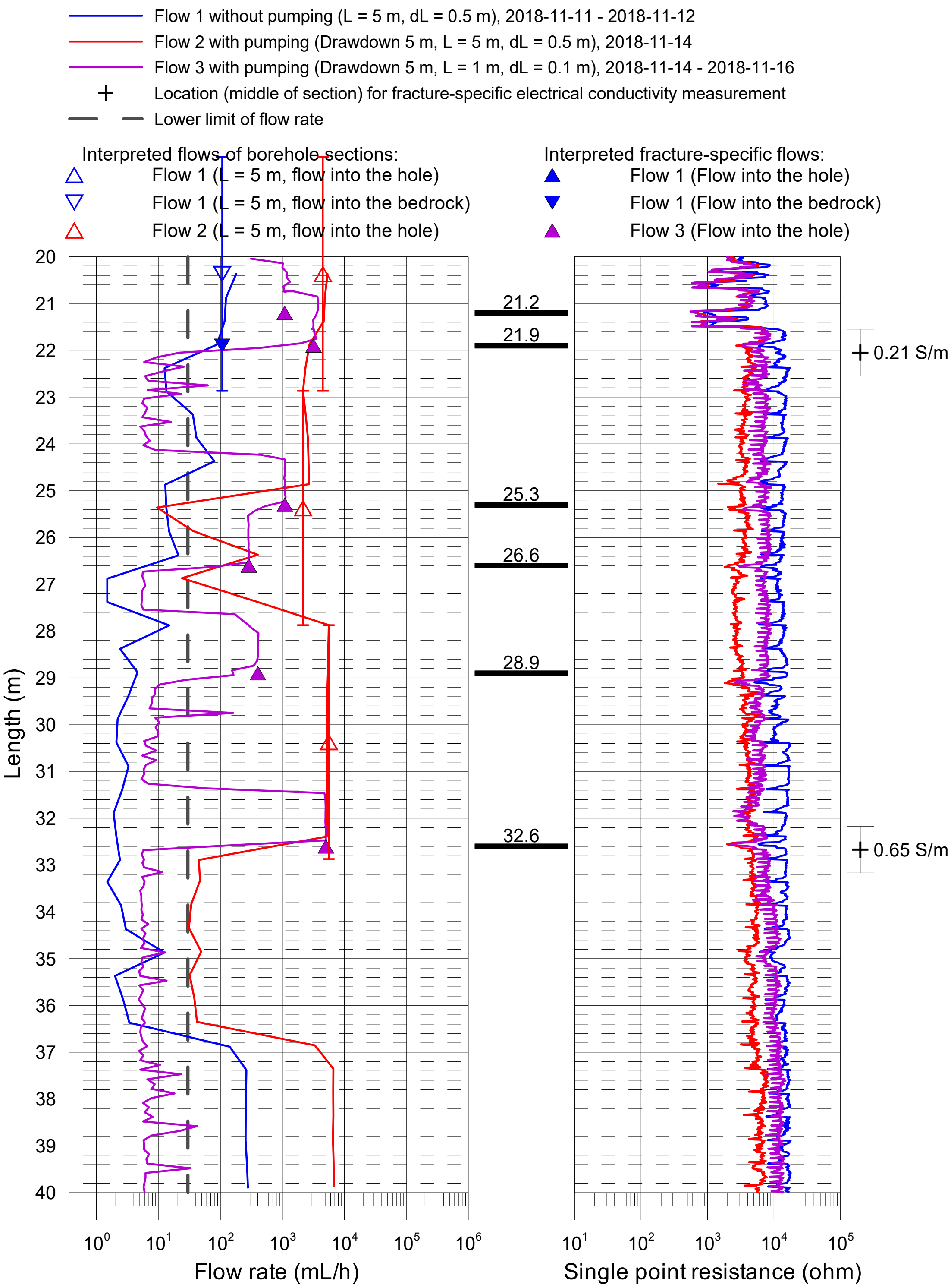

Measured without lower rubber disks:
Measured without pumping (downwards), 2018-11-11
Measured with pumping (downwards), 2018-11-16
Measured with lower rubber disks:
Time series of fracture specific water, 2018-11-14 - 2018-11-16
Average of 10 last EC measurements, fracture-specific water, 2018-11-14 - 2018-11-16
Length (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
0.01
0.1
1
10
Electrical conductivity (S/m, 25 °C)

KFM15.1.3 Temperature of borehole water

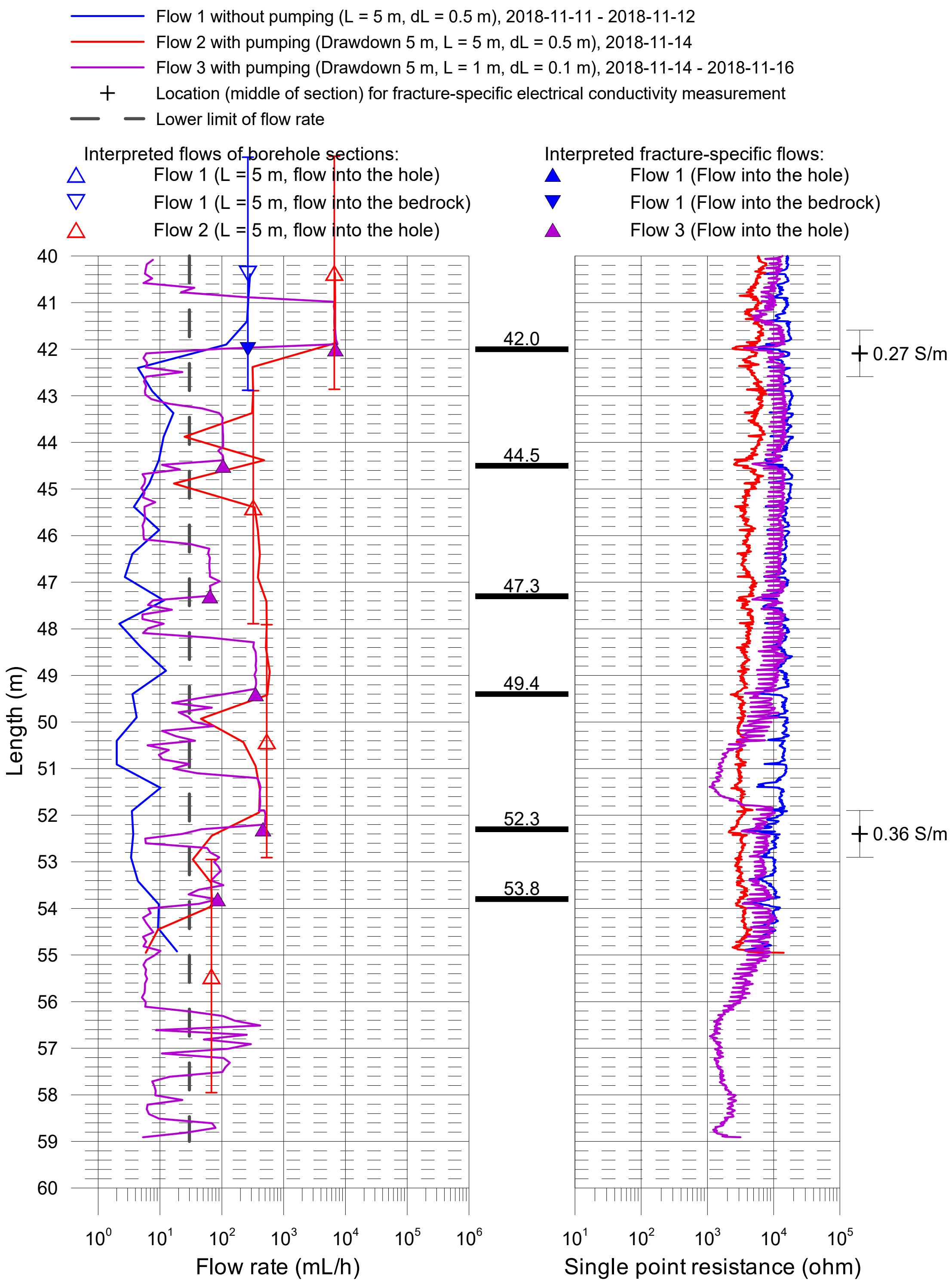


KFM15.2.1–KFM15.2.3 Flow rate and single point resistance



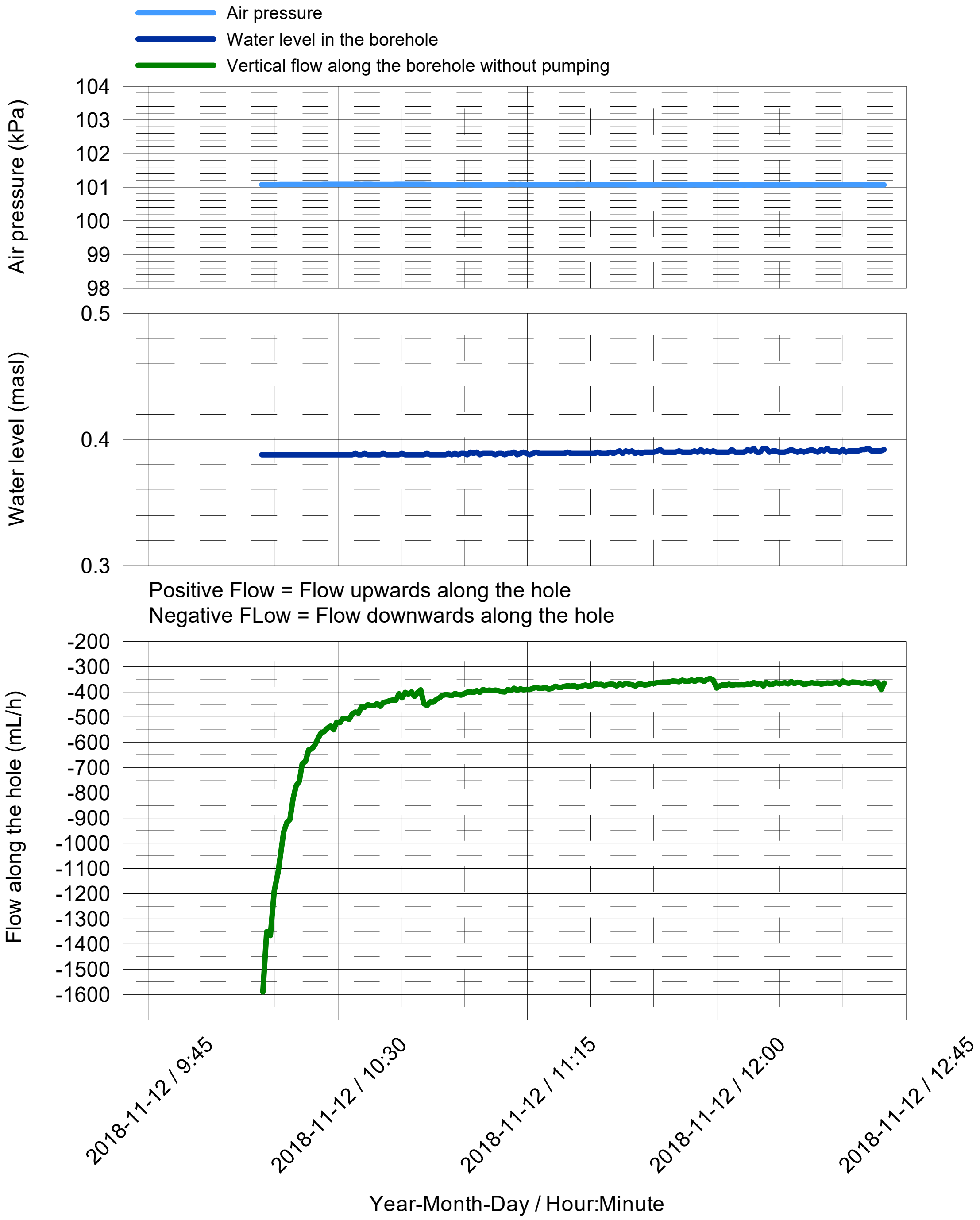


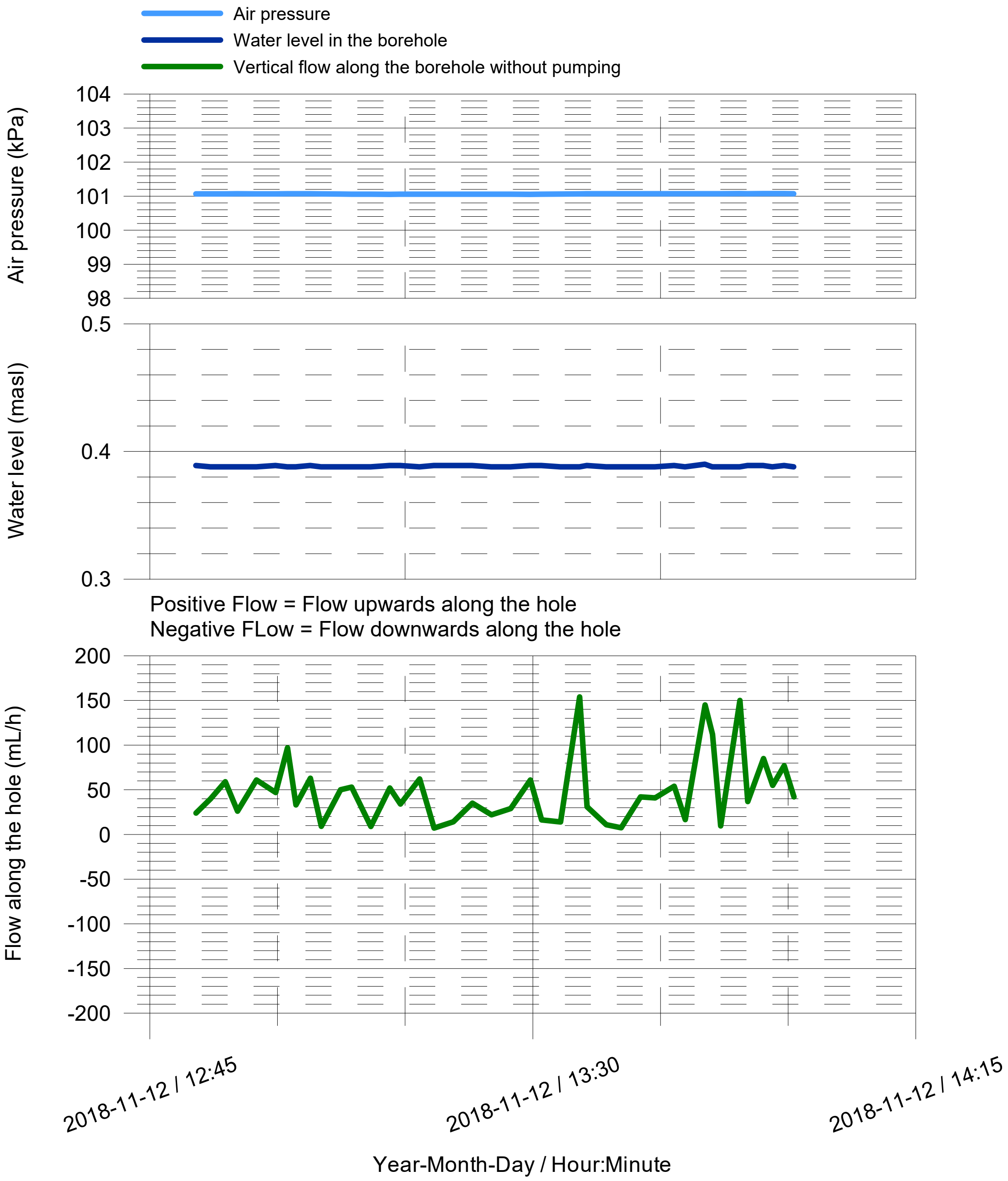
Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-11 - 2018-11-12
Flow 2 with pumping (Drawdown 5 m, L = 5 m, dL = 0.5 m), 2018-11-14
Flow 3 with pumping (Drawdown 5 m, L = 1 m, dL = 0.1 m), 2018-11-14 - 2018-11-16
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)
21.2
21.9
25.3
26.6
28.9
32.6
0.21 S/m
0.65 S/m



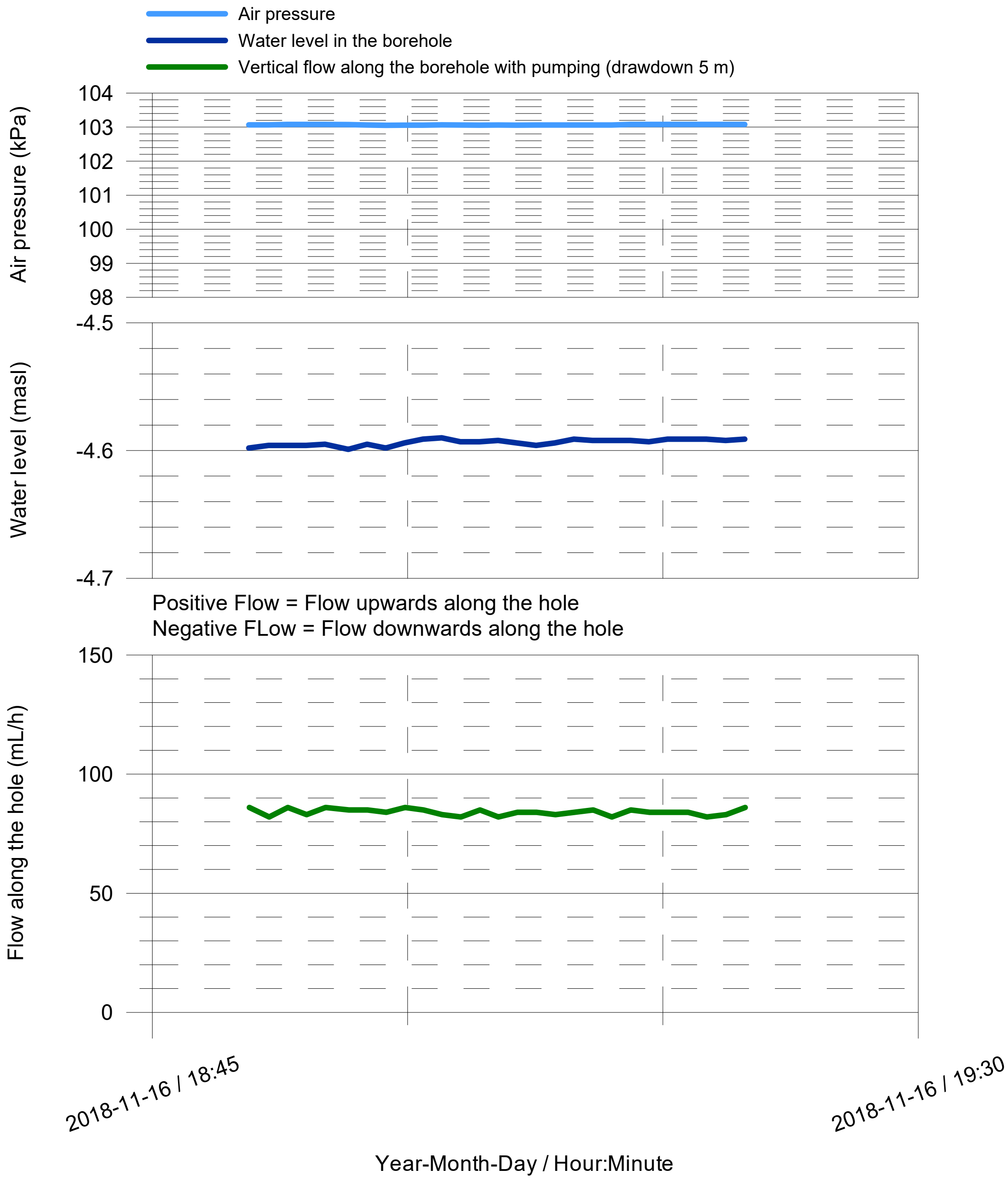
Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-11 - 2018-11-12
Flow 2 with pumping (Drawdown 5 m, L = 5 m, dL = 0.5 m), 2018-11-14
Flow 3 with pumping (Drawdown 5 m, L = 1 m, dL = 0.1 m), 2018-11-14 - 2018-11-16
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
42.0
44.5
47.3
49.4
52.3
53.8
0.27 S/m
0.36 S/m
Flow rate (mL/h)
Single point resistance (ohm)

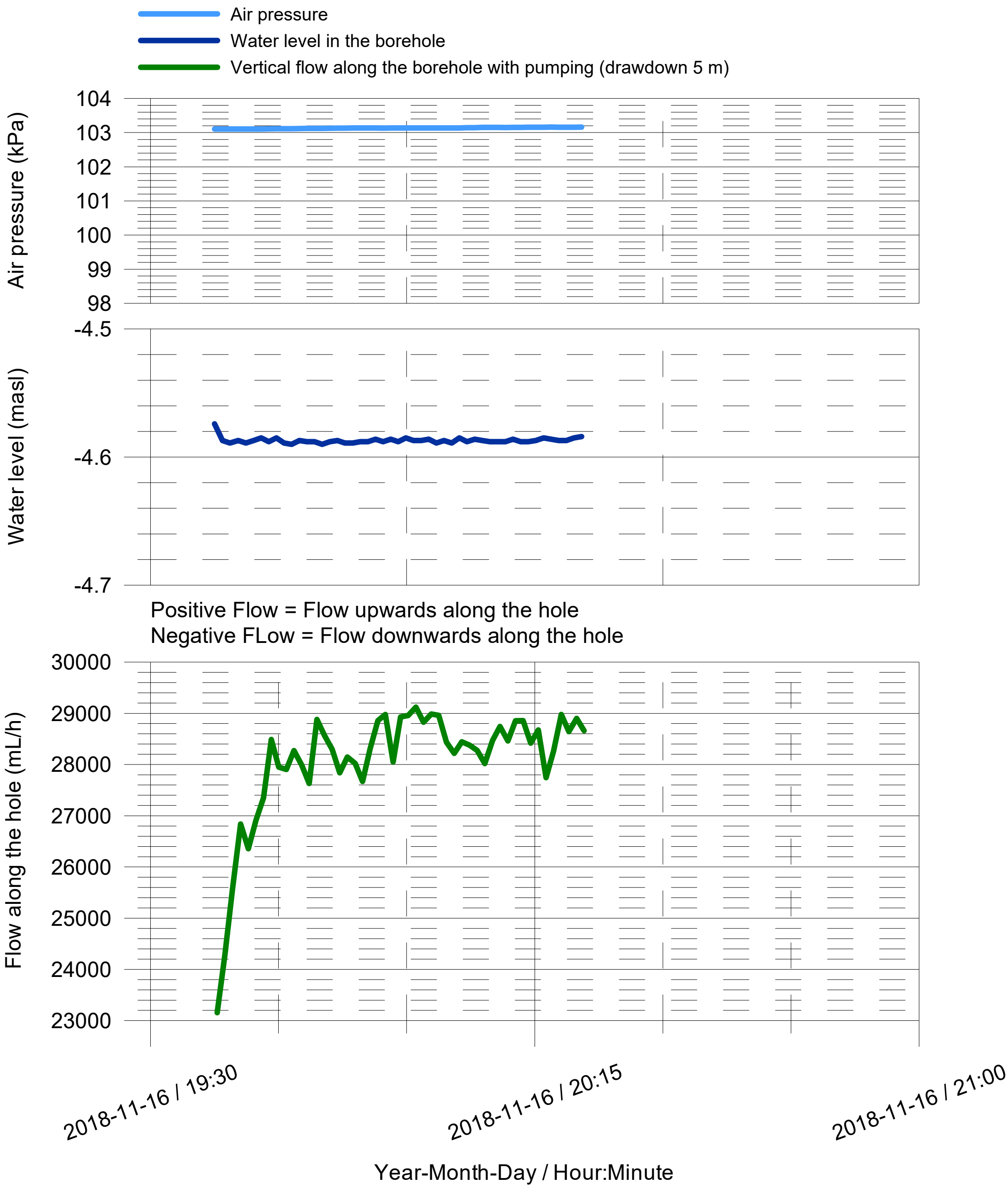
KFM15.2.4–KFM15.2.7 Vertical flow along the borehole at 6.0 m, 9.0 m, 11.2 m and 55.1 m





Air pressure
Water level in the borehole
Vertical flow along the borehole without pumping
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
0.5
0.4
0.3
Positive Flow = Flow upwards along the hole
Negative FLow = Flow downwards along the hole
Flow along the hole (mL/h)
200
150
100
50
0
-50
-100
-150
-200
2018-11-12 / 12:45
2018-11-12 / 13:30
2018-11-12 / 14:15
Year-Month-Day / Hour:Minute


Air pressure
Water level in the borehole
Vertical flow along the borehole with pumping (drawdown 5 m)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-4.5
-4.6
-4.7
Positive Flow = Flow upwards along the hole
Negative FLow = Flow downwards along the hole
Flow along the hole (mL/h)
150
100
50
0
2018-11-16 / 18:45
2018-11-16 / 19:30
Year-Month-Day / Hour:Minute



Air pressure
Water level in the borehole
Vertical flow along the borehole with pumping (drawdown 5 m)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-4.5
-4.6
-4.7
Positive Flow = Flow upwards along the hole
Negative FLow = Flow downwards along the hole
Flow along the hole (mL/h)
30000
29000
28000
27000
26000
25000
24000
23000
2018-11-16 / 19:30
2018-11-16 / 20:15
2018-11-16 / 21:00
Year-Month-Day / Hour:Minute

KFM15.3 Explanations for the tables in Appendices

Header	Unit	Explanations
Borehole ID		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)
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with h=h0 in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first 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
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.
Q-lower limit P	mL/h	Practical lower measurement limit for flow rate.
T-$measl_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-$measl_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-$meas_{lU}$	m^2/s	Estimated upper measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

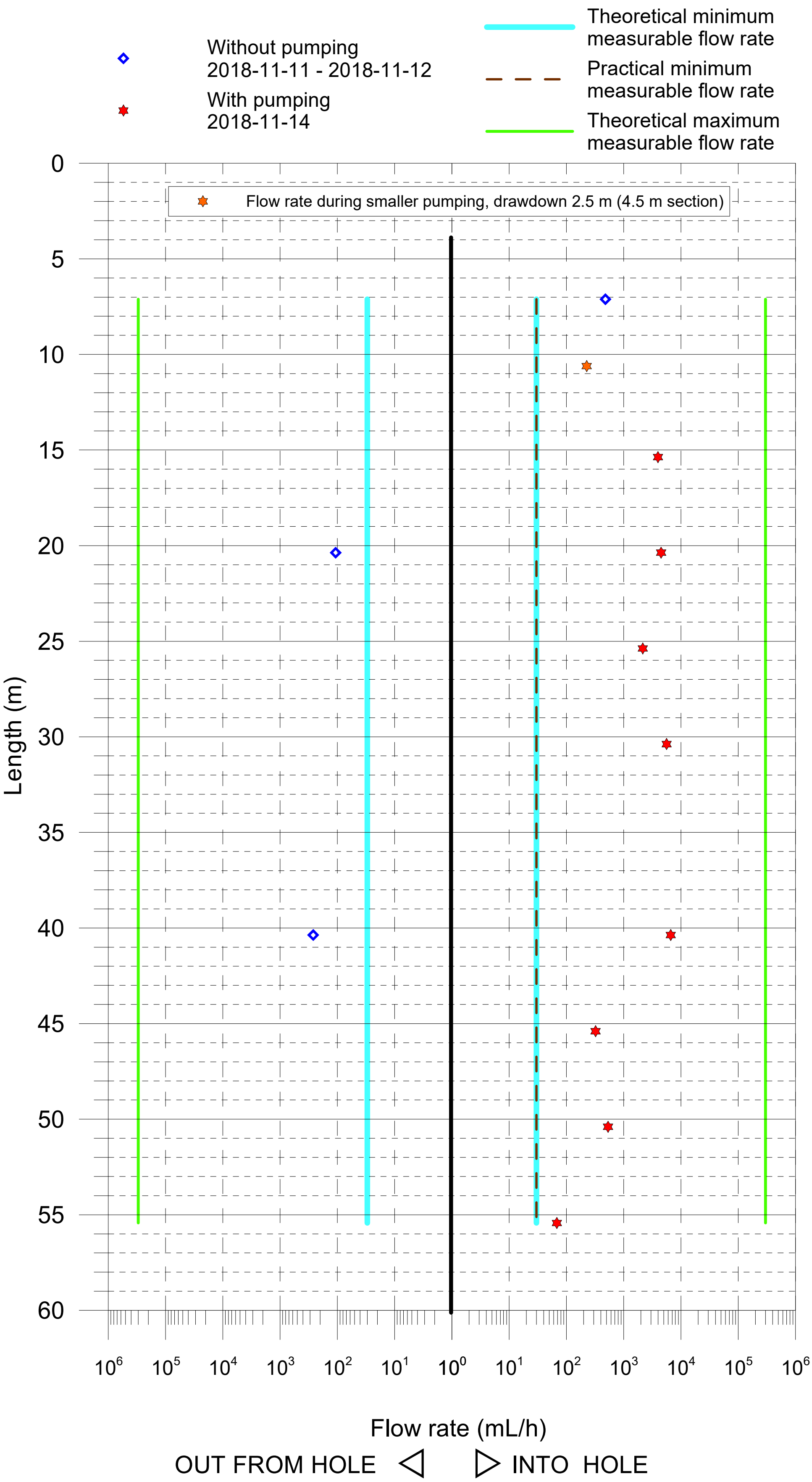
KFM15.4 Results of section flows

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)	T_D-$measl_{LT}$ (m^2/s)	T_D - $measl_{LP}$ (m^2/s)	T_D - $measl_U$ (m^2/s)	Comments
KFM15	5.86	8.36	2.5	1.33E-07	0.67	–	−1.59	–	–	30	3.6E-09	3.6E-09	3.6E-05	*
KFM15	8.36	12.86	4.5	–	0.69	6.28E-08	−2.04	2.3E-08	–	30	3.0E-09	3.0E-09	3.0E-05	**
KFM15	12.87	17.87	5	–	0.61	1.10E-06	−4.38	2.2E-07	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM15	17.87	22.87	5	−2.97E-08	0.60	1.25E-06	−4.40	2.5E-07	0.5	30	1.6E-09	1.6E-09	1.7E-05	
KFM15	22.88	27.88	5	–	0.58	5.98E-07	−4.40	1.2E-07	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM15	27.88	32.88	5	–	0.54	1.56E-06	−4.37	3.1E-07	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM15	32.89	37.89	5	–	0.53	–	−4.42	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM15	37.87	42.87	5	−7.33E-08	0.54	1.84E-06	−4.38	3.8E-07	0.4	30	1.7E-09	1.7E-09	1.7E-05	
KFM15	42.90	47.90	5	–	0.52	8.97E-08	−4.34	1.8E-08	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM15	47.90	52.90	5	–	0.48	1.48E-07	−4.42	3.0E-08	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM15	52.93	57.93	5	–	0.23	1.89E-08	−4.58	3.9E-09	–	30	1.7E-09	1.7E-09	1.7E-05	

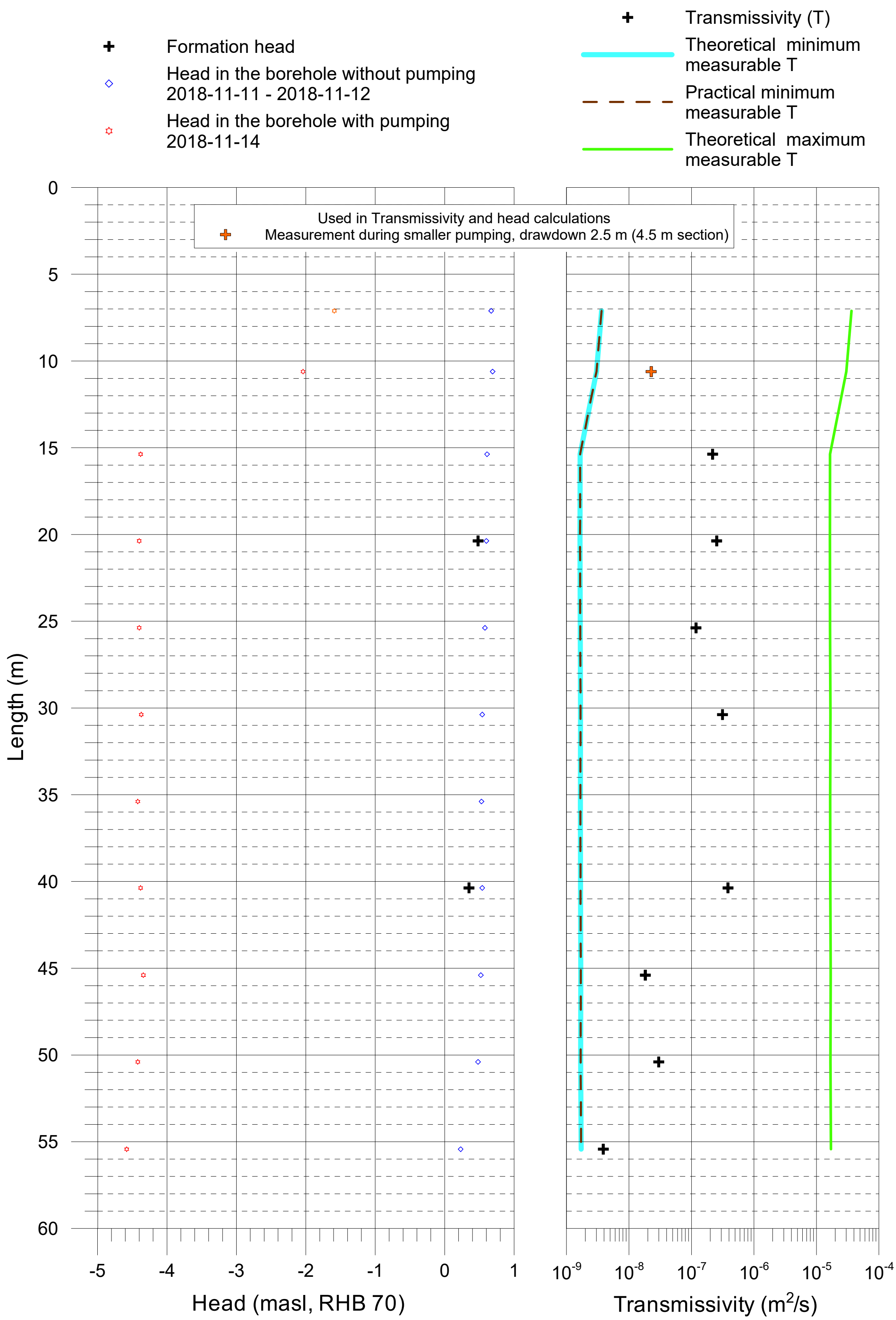
* Measurement without pumping, during recovery (Q_1) was unreliable; a steady state was not reached and therefore measured flow rate is not presented. The upper part of the borehole could not be measured while pumping (while the pump remained in the borehole). Flow (Q_0) possibly from the joint of casing tube and borehole.

** Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made with smaller pumping (drawdown 2.5 m). The upper part of the borehole could not be conducted during larger drawdown.

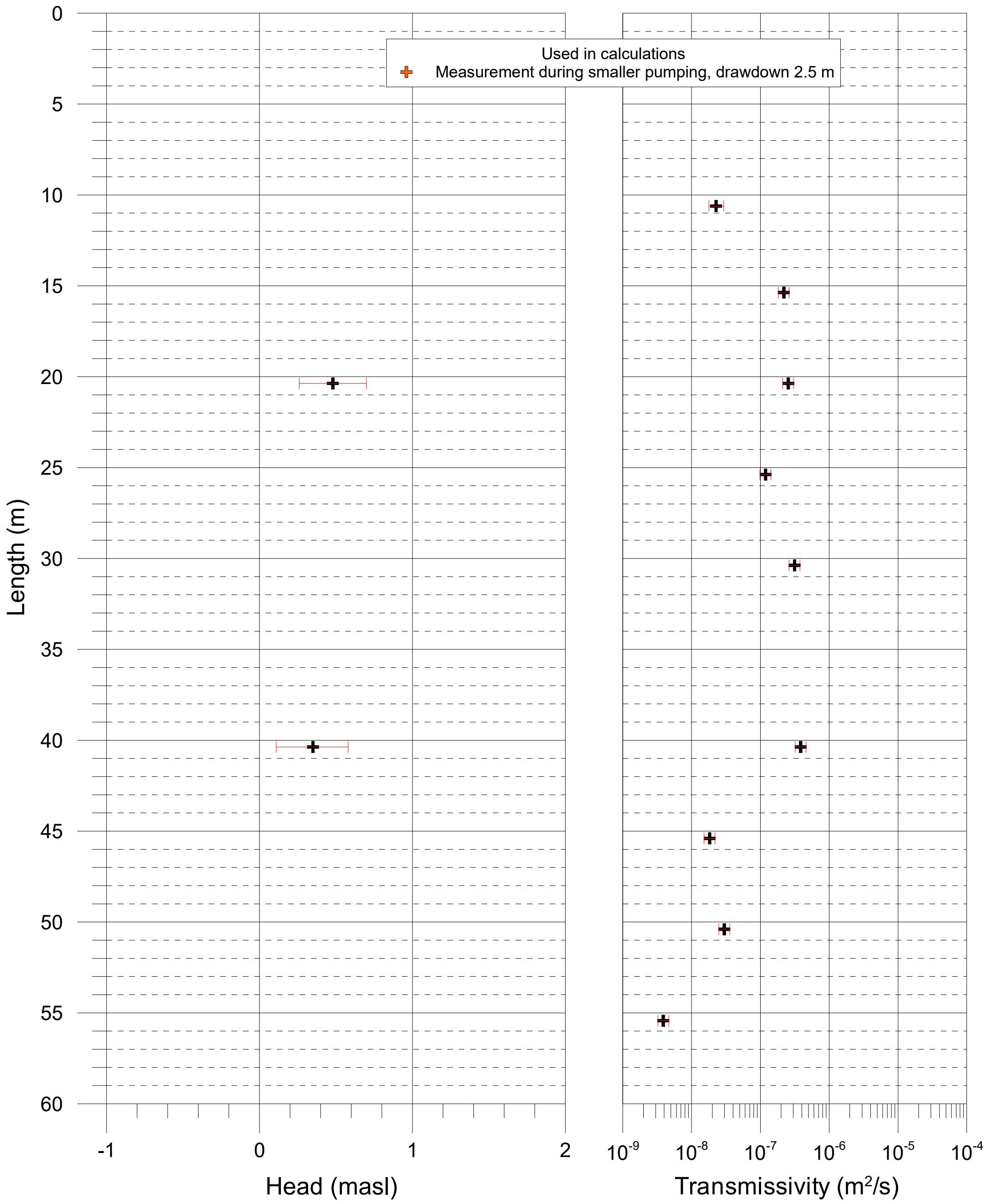
KFM15.5.1 Plotted flow rates of 5 m sections



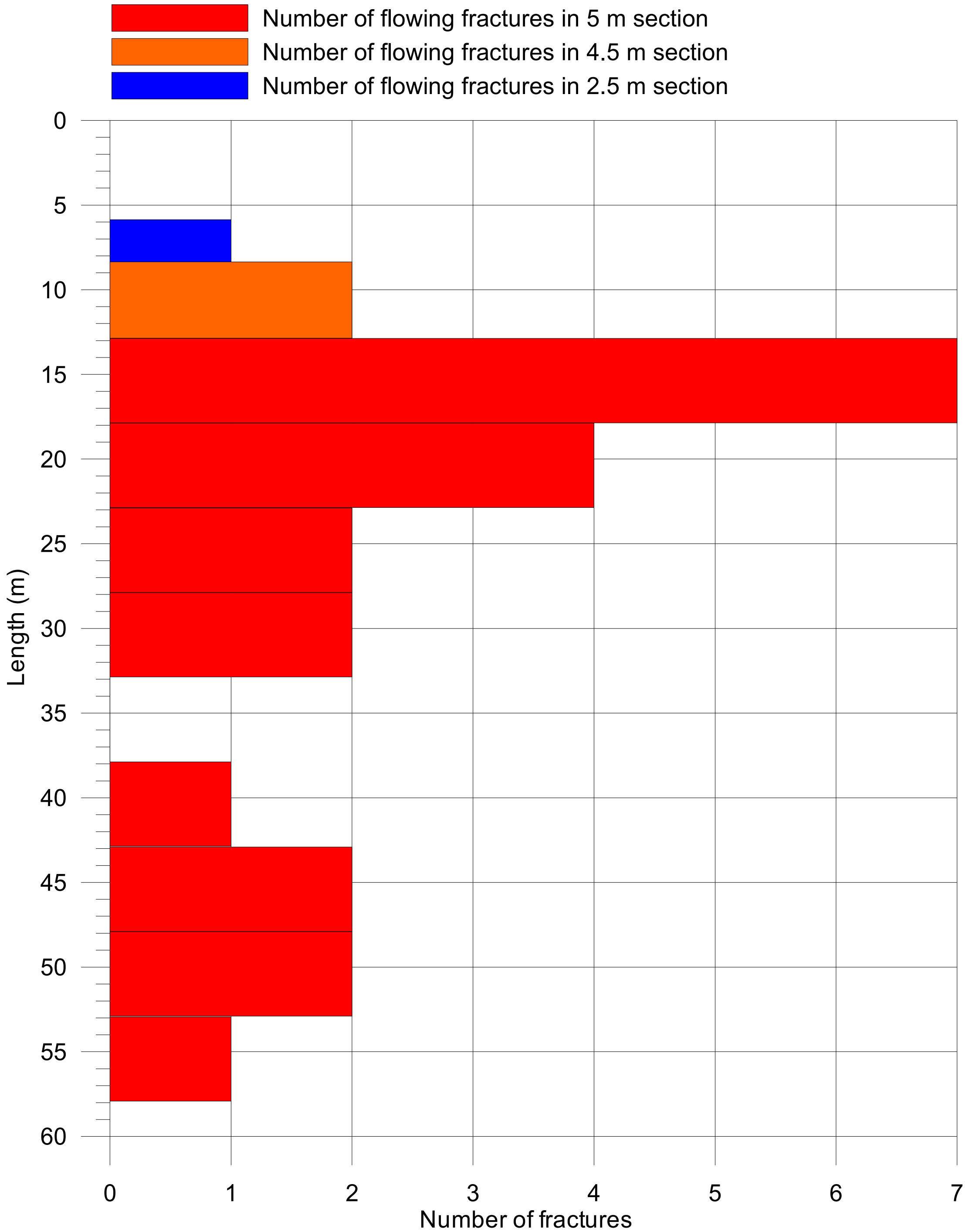
KFM15.5.2 Plotted transmissivity and head of 5 m sections



KFM15.5.3 Transmissivity and head of 5 m sections with calculated error limits



KFM15.5.4 Conductive fracture frequency



KFM15.6 Inferred fracture flow anomalies from 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
KFM15	8.0	1	0.1	1.33E-07	0.63	–	−1.54	–	–	**, ****
KFM15	9.8	1	0.1	–	0.70	1.75E-08	−1.90	6.7E-09	–	***
KFM15	10.5	1	0.1	–	0.65	1.39E-08	−1.91	5.4E-09	–	***
KFM15	13.5	1	0.1	–	0.62	4.22E-08	−4.33	8.4E-09	–	*
KFM15	13.8	1	0.1	–	0.64	6.61E-08	−4.34	1.3E-08	–	
KFM15	14.7	1	0.1	–	0.62	2.39E-08	−4.34	4.8E-09	–	*
KFM15	16.1	1	0.1	–	0.61	5.08E-07	−4.36	1.0E-07	–	
KFM15	16.4	1	0.1	–	0.61	6.47E-07	−4.37	1.3E-07	–	
KFM15	16.9	1	0.1	–	0.61	2.81E-08	−4.34	5.6E-09	–	
KFM15	17.3	1	0.1	–	0.62	1.86E-08	−4.35	3.7E-09	–	
KFM15	19.3	1	0.1	–	0.6	1.56E-08	−4.36	3.1E-09	–	
KFM15	19.9	1	0.1	–	0.61	2.46E-07	−4.37	4.9E-08	–	
KFM15	21.2	1	0.1	–	0.62	3.03E-07	−4.38	6.0E-08	–	
KFM15	21.9	1	0.1	−2.97E-08	0.62	8.83E-07	−4.40	1.8E-07	0.5	
KFM15	25.3	1	0.1	–	0.58	3.06E-07	−4.39	6.1E-08	–	*
KFM15	26.6	1	0.1	–	0.61	7.97E-08	−4.36	1.6E-08	–	
KFM15	28.9	1	0.1	–	0.57	1.12E-07	−4.36	2.2E-08	–	
KFM15	32.6	1	0.1	–	0.54	1.39E-06	−4.39	2.8E-07	–	
KFM15	42.0	1	0.1	−7.33E-08	0.53	1.91E-06	−4.41	4.0E-07	0.4	
KFM15	44.5	1	0.1	–	0.52	2.92E-08	−4.42	5.8E-09	–	
KFM15	47.3	1	0.1	–	0.53	1.78E-08	−4.42	3.6E-09	–	
KFM15	49.4	1	0.1	–	0.49	9.81E-08	−4.43	2.0E-08	–	
KFM15	52.3	1	0.1	–	0.46	1.29E-07	−4.44	2.6E-08	–	
KFM15	53.8	1	0.1	–	0.39	2.39E-08	−4.45	4.9E-09	–	

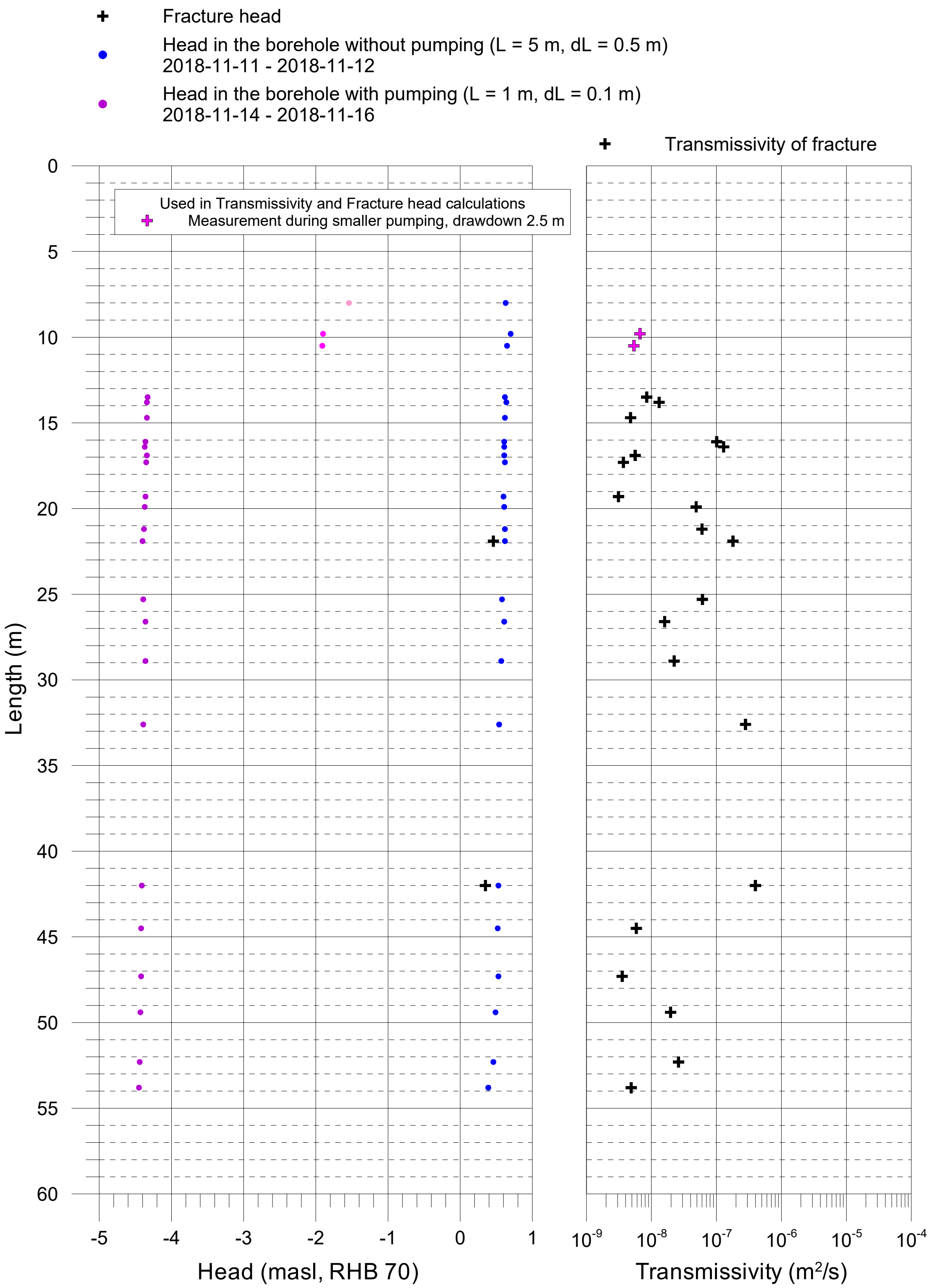
* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

** Value for Head (h_{1FW}) is from the measurement made without pumping, during recovery. Value for Flow (Q_1) during recovery was unreliable; a steady state was not reached and therefore is not presented. The upper part of the borehole could not be measured while pumping (while the pump remained in the borehole).

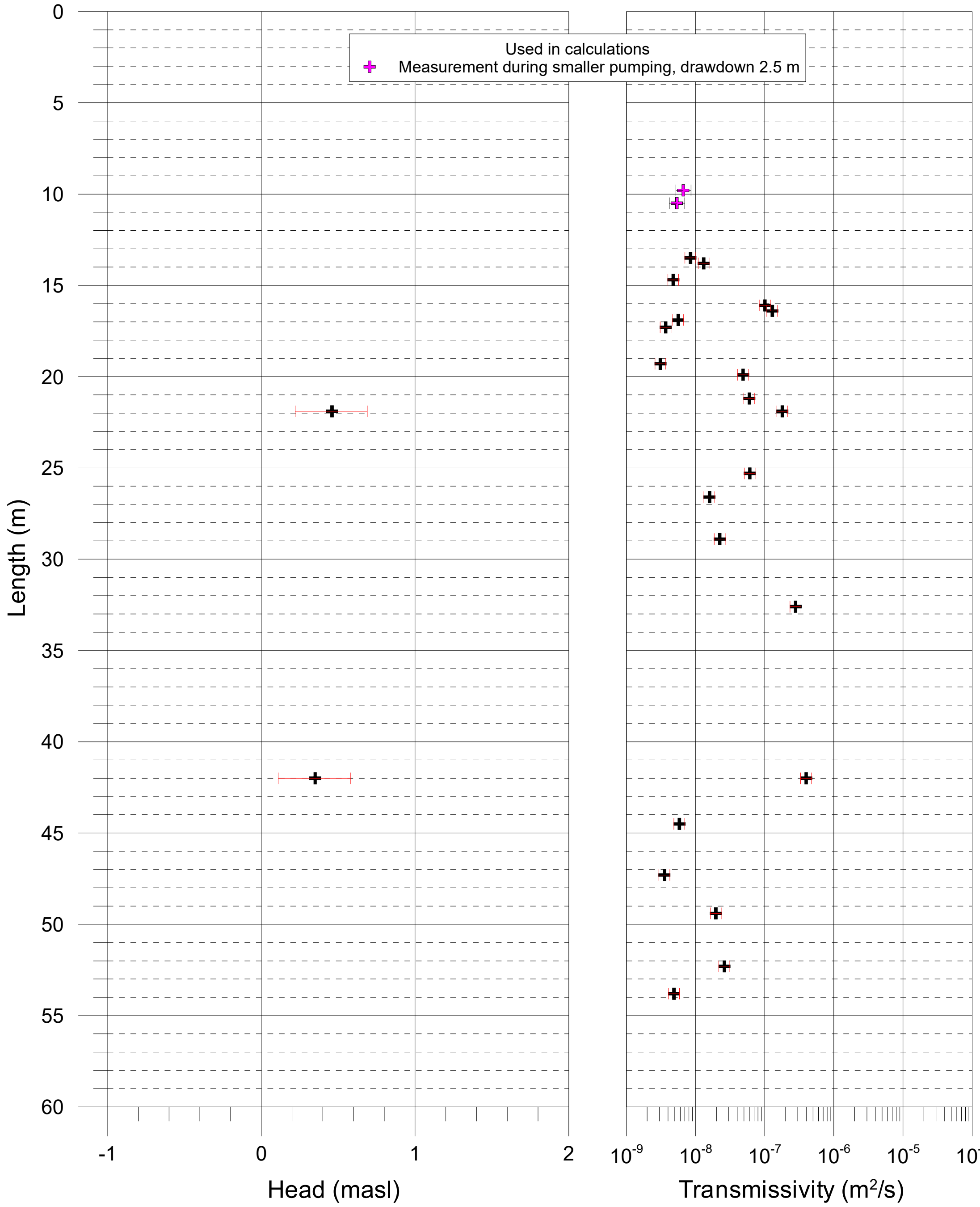
*** Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made with smaller pumping (drawdown 2.5 m). The upper part of the borehole could not be measuredduring larger drawdown.

**** Flow possibly from the joint of casing tube and borehole.

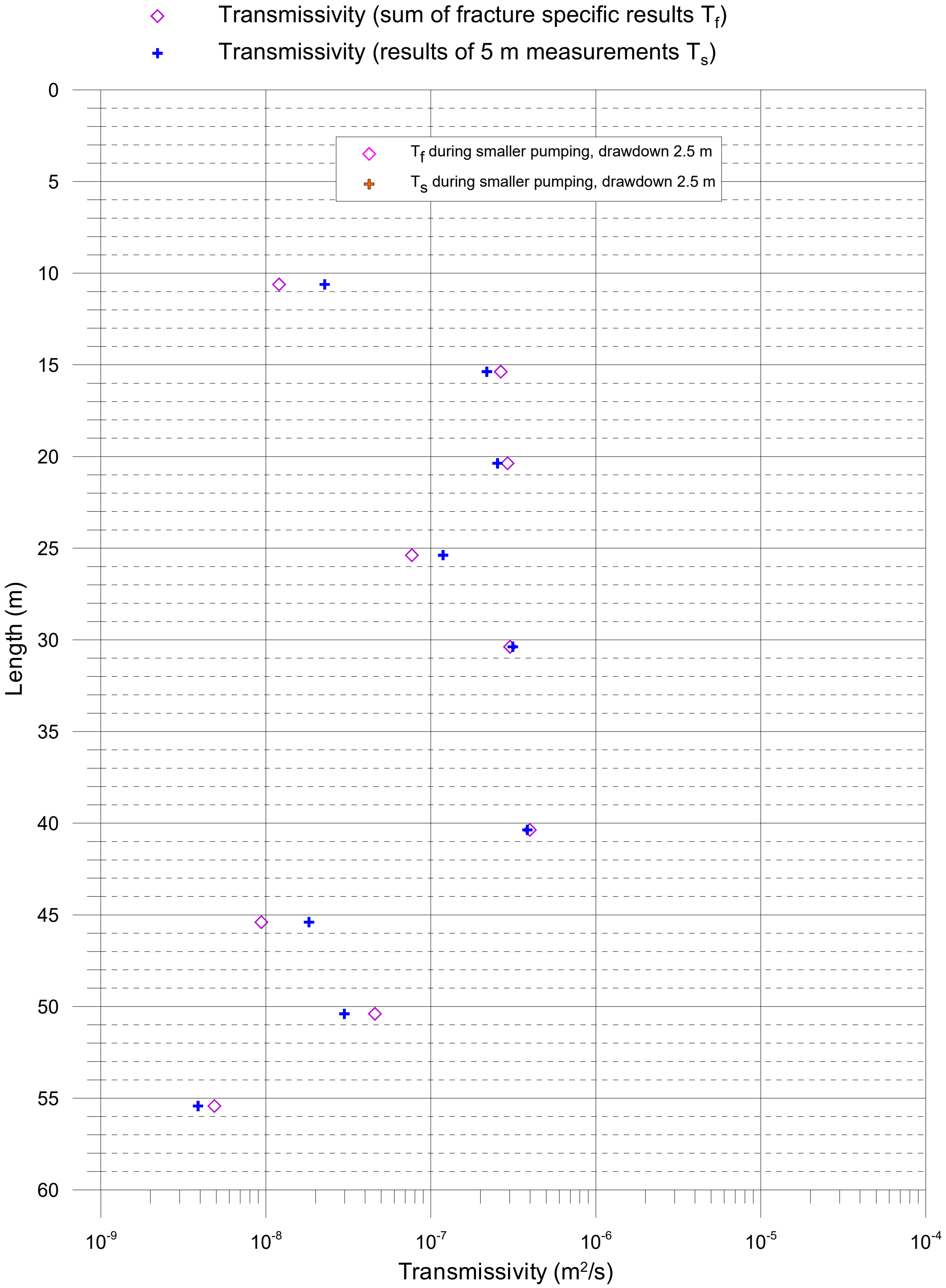
KFM15.7.1 Plotted transmissivity and head of detected fractures



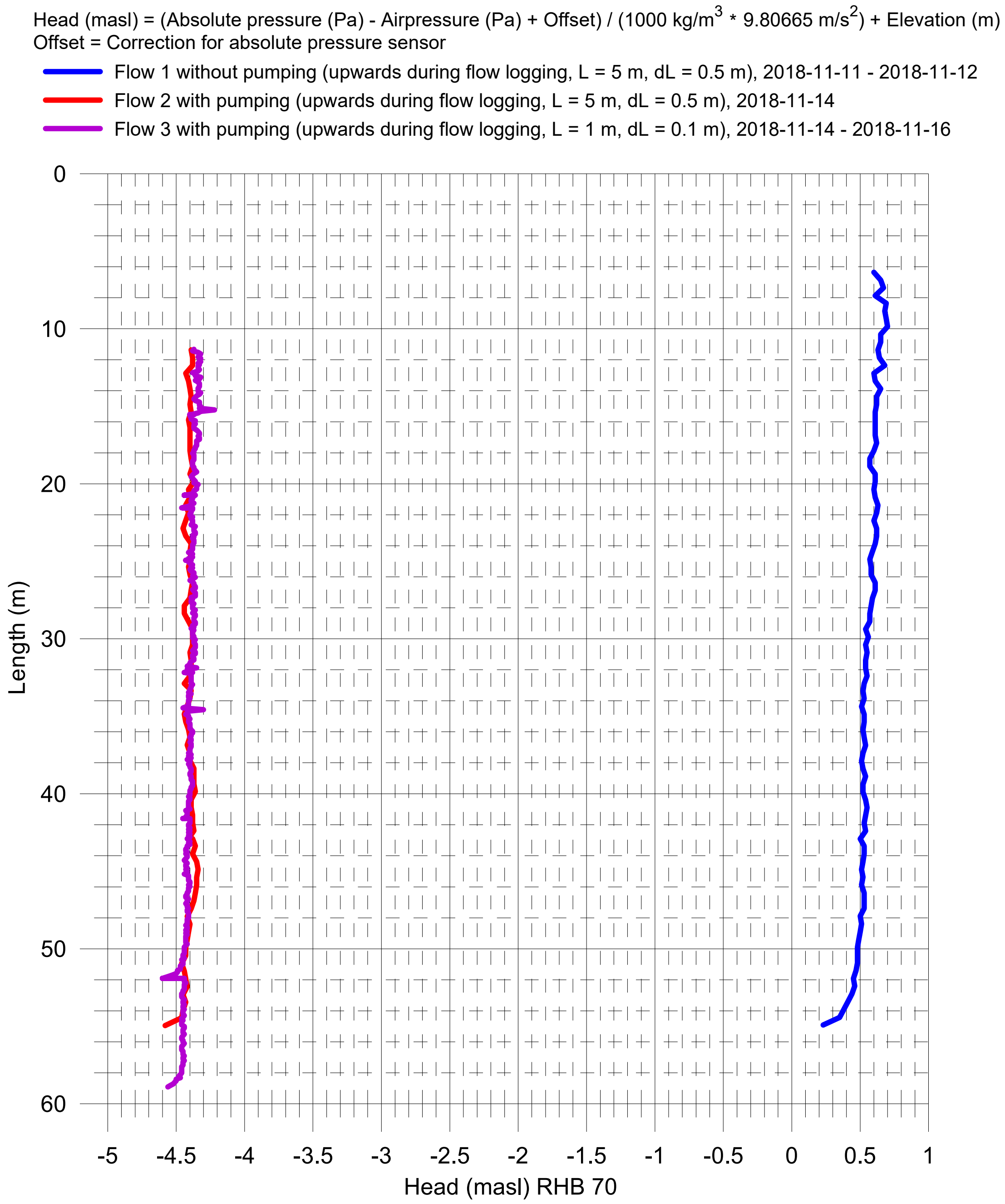
KFM15.7.2 Transmissivity and head of detected fractures with calculated error limits.



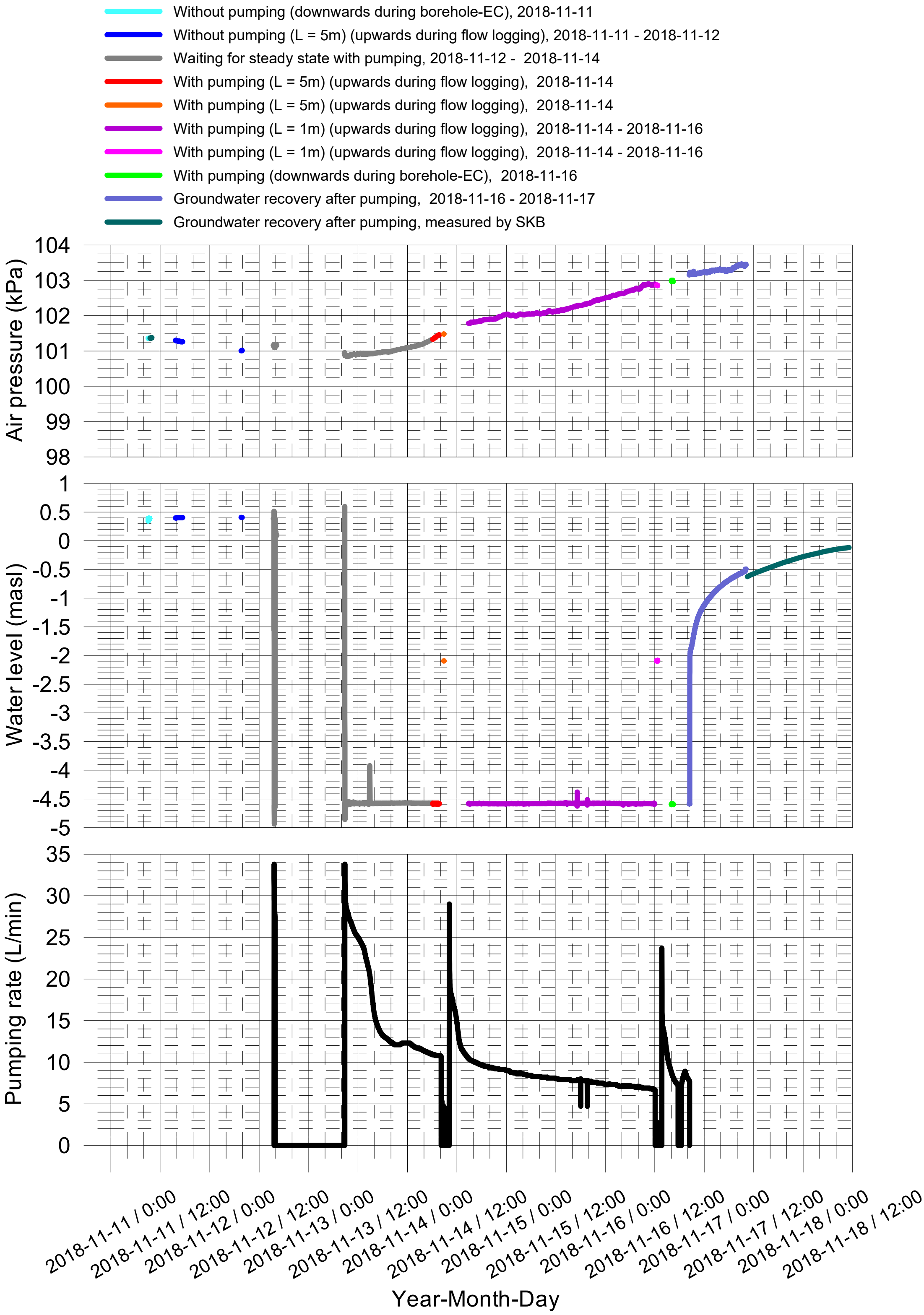
KFM15.8 Comparison between section transmissivity and fracture transmissivity



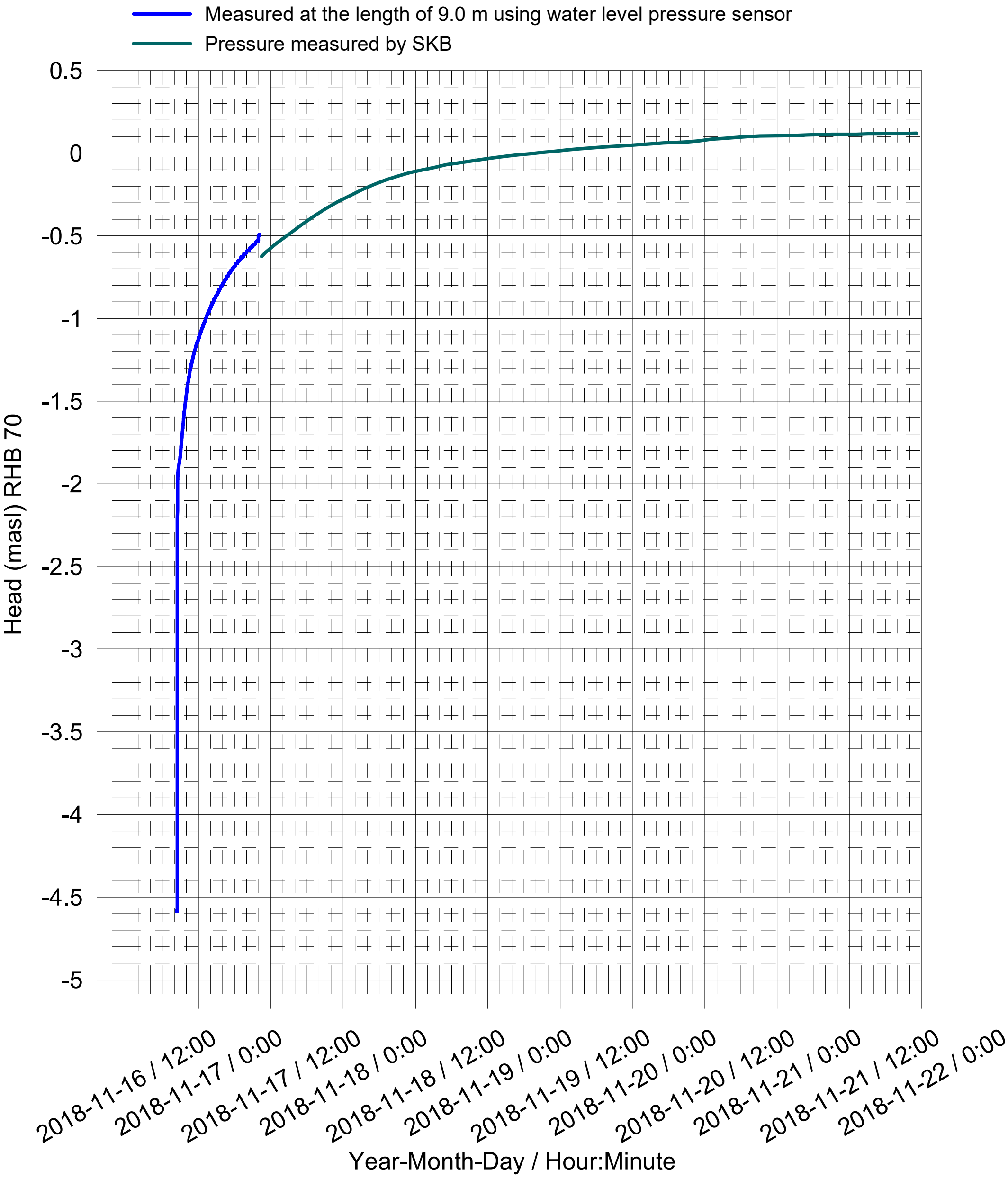
KFM15.9.1 Head in the borehole during flow logging



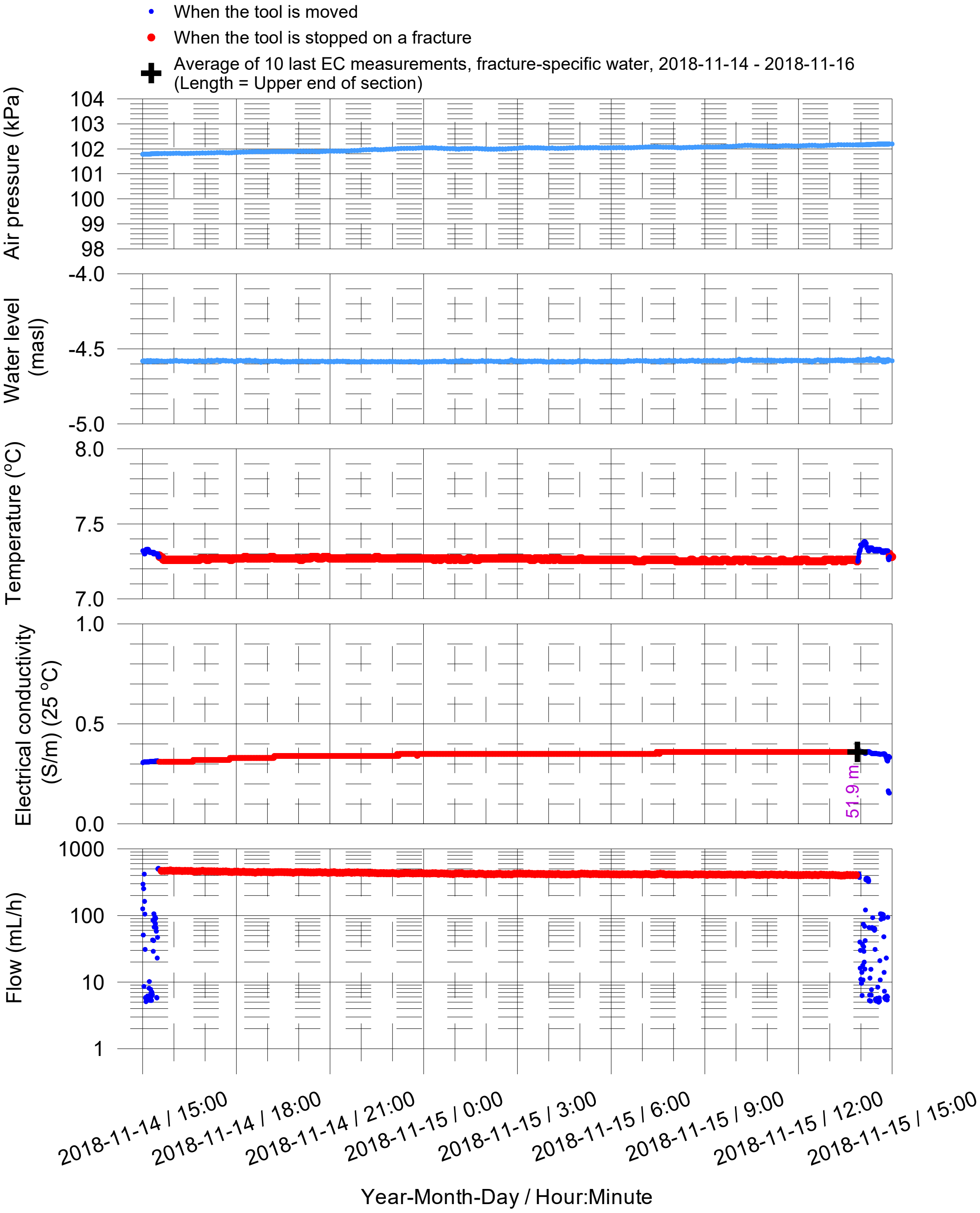
KFM15.9.2 Air pressure, water level in the borehole and pumping rate during flow logging

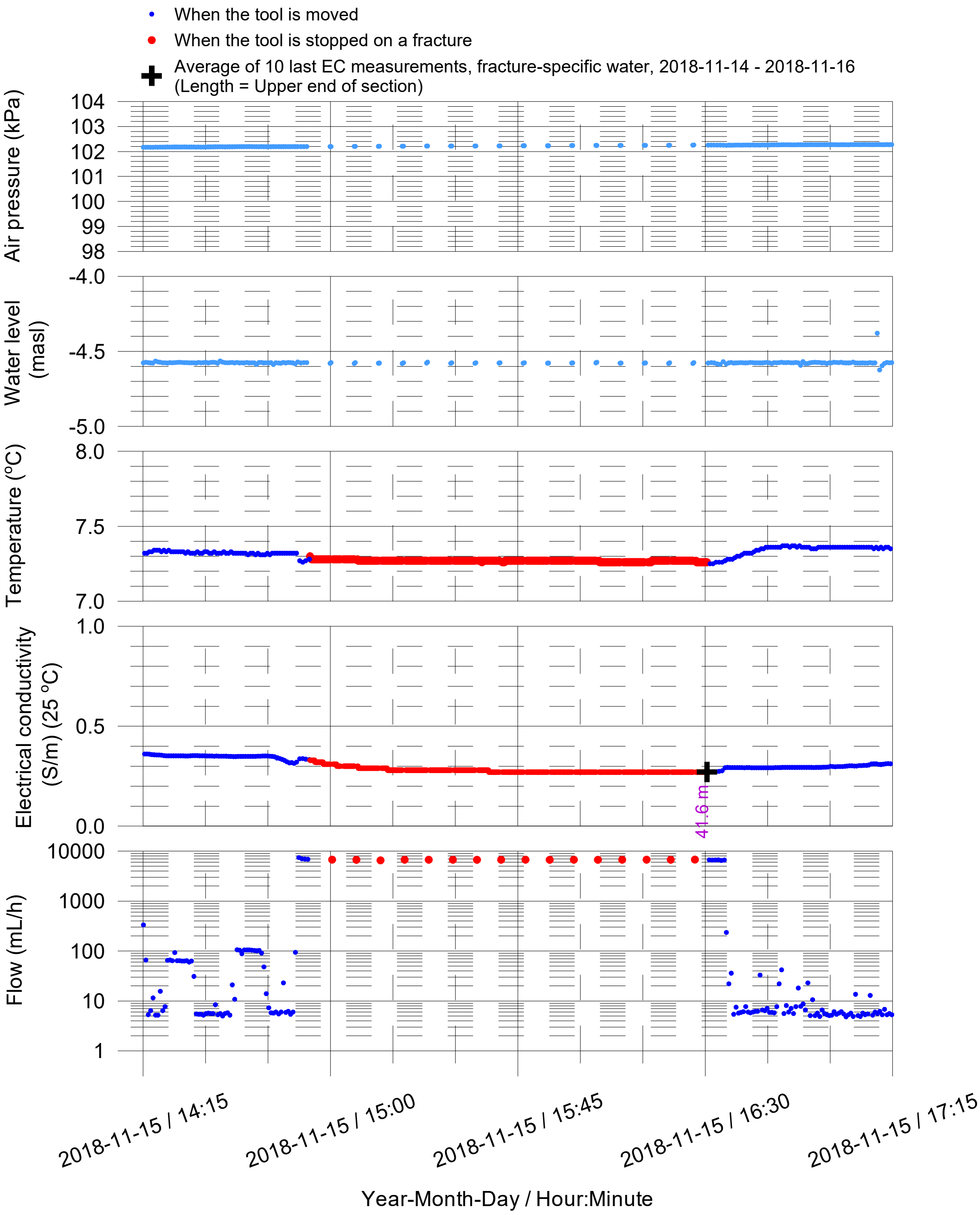


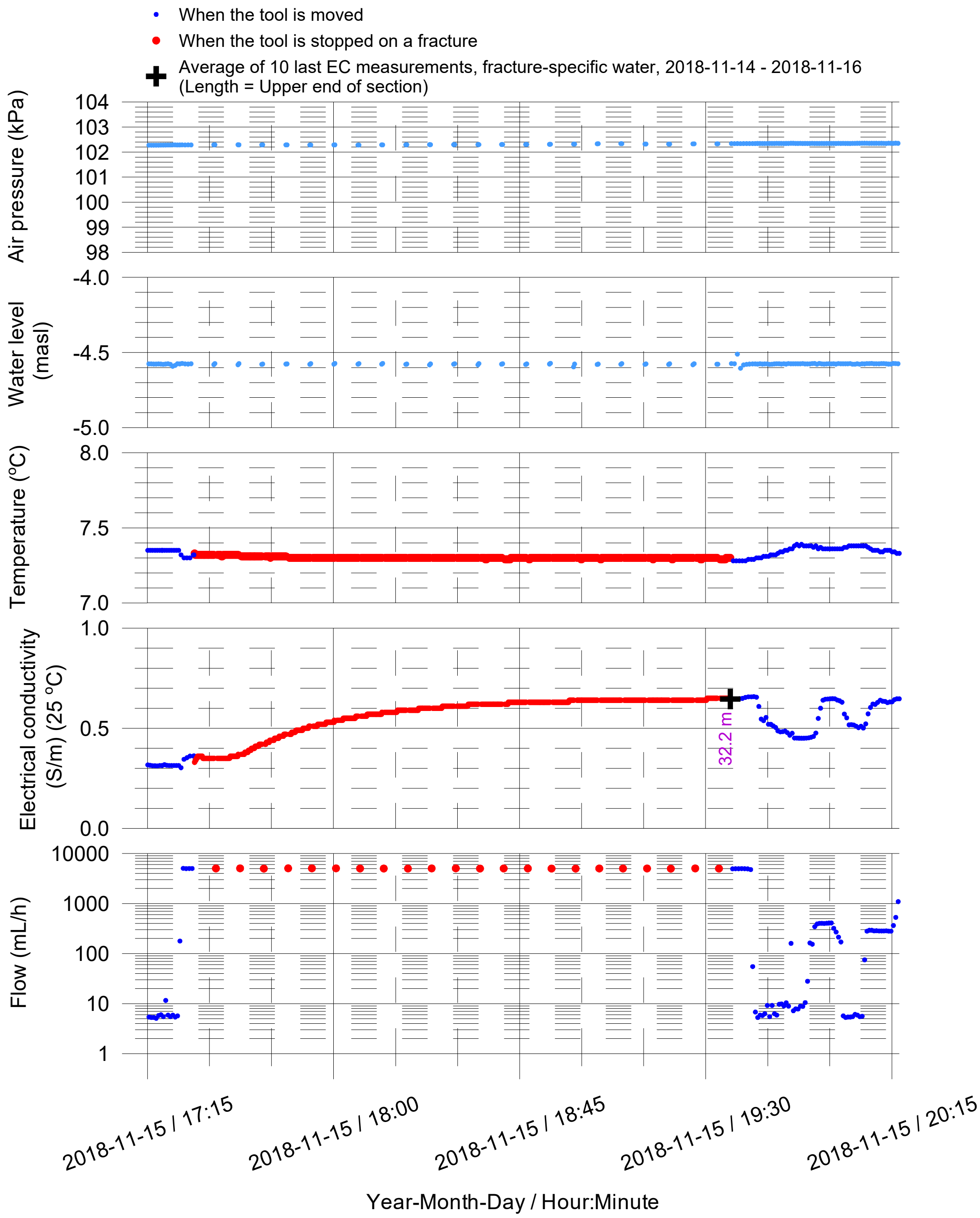
KFM15.9.3 Groundwater recovery after pumping

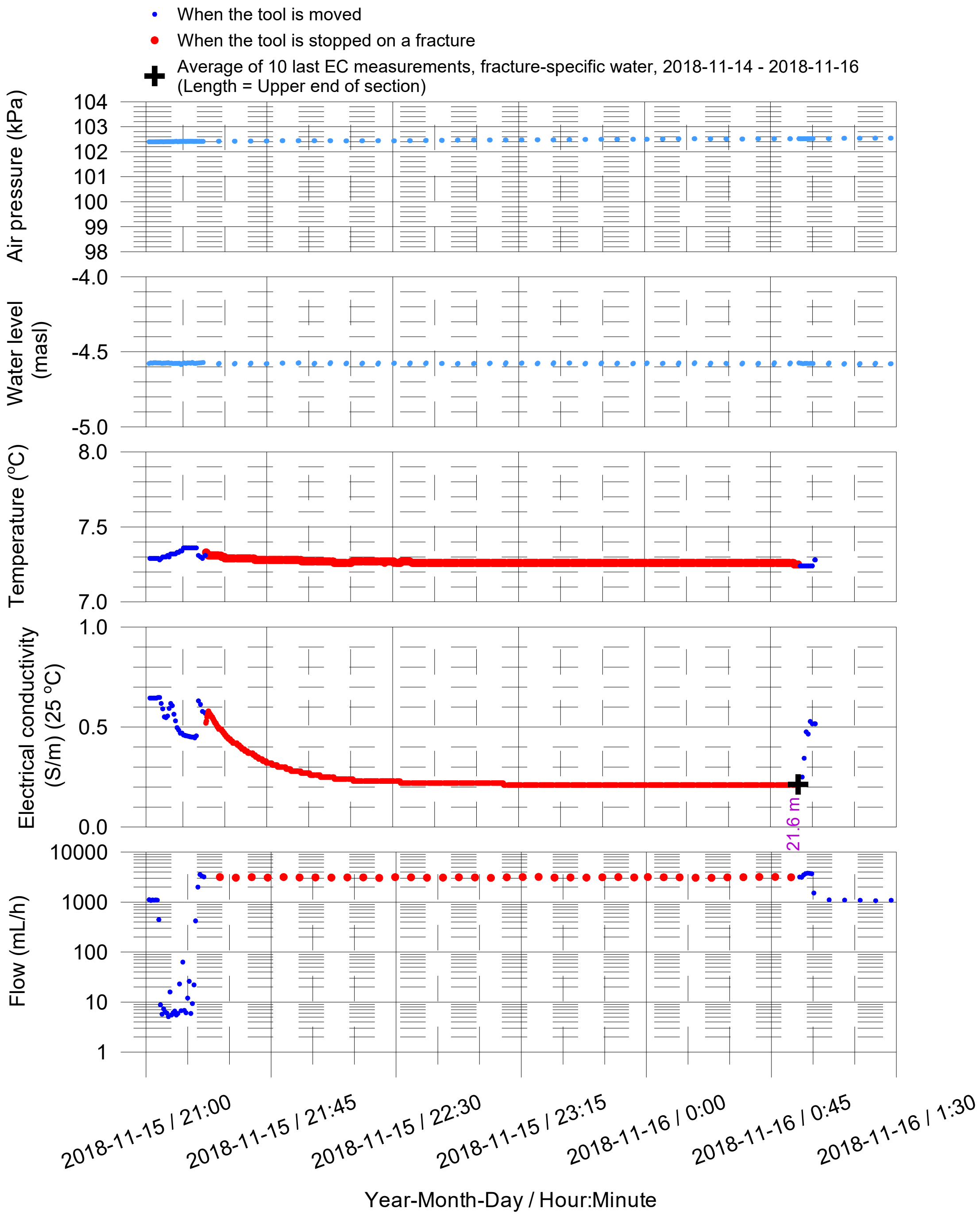


KFM15.10.1–KFM15.10.5 Fracture-specific EC results by date

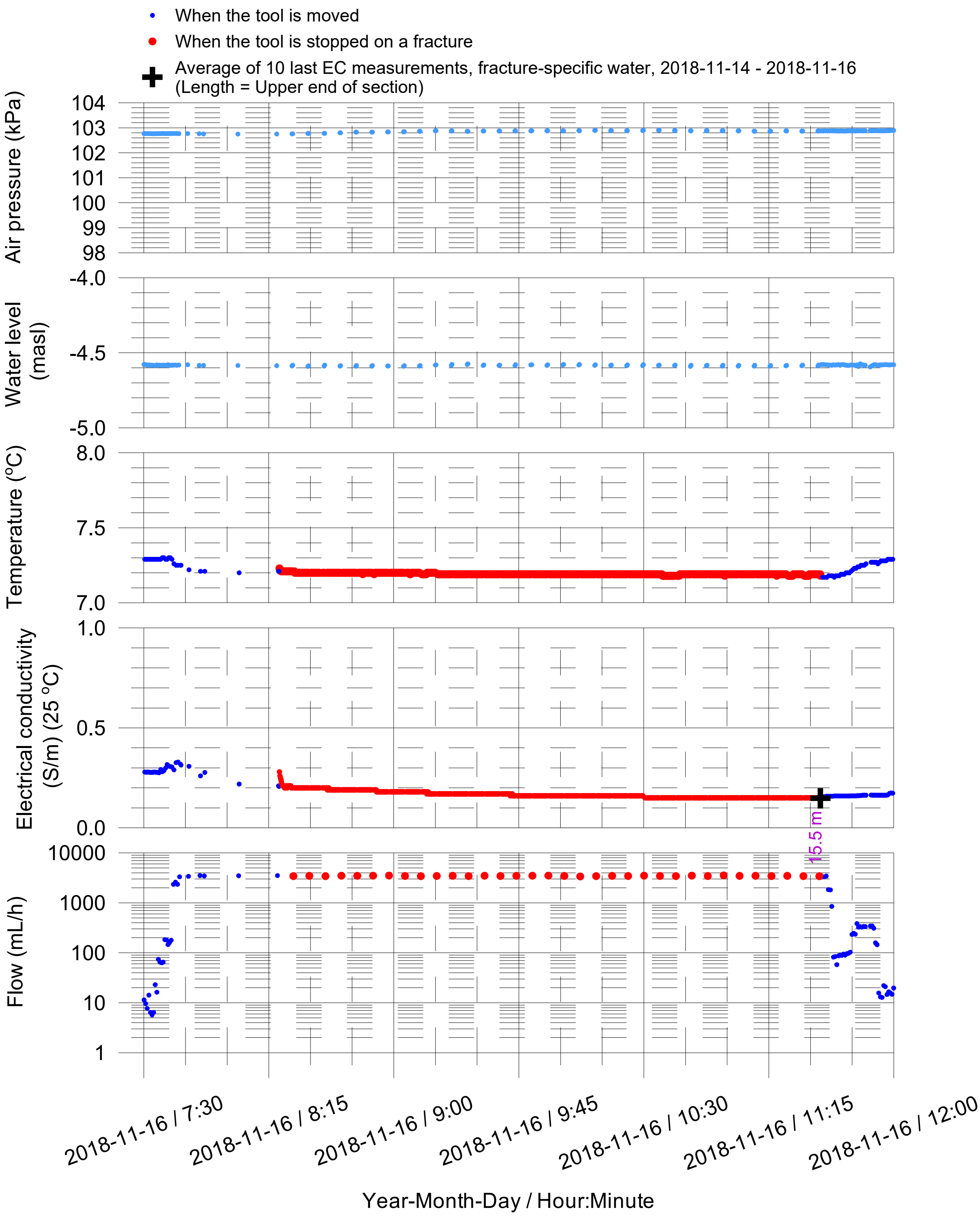



When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-14 - 2018-11-16 (Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-4.0
-4.5
-5.0
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
41.6 m
Flow (mL/h)
10000
1000
100
10
1
2018-11-15 / 14:15
2018-11-15 / 15:00
2018-11-15 / 15:45
2018-11-15 / 16:30
2018-11-15 / 17:15
Year-Month-Day / Hour:Minute

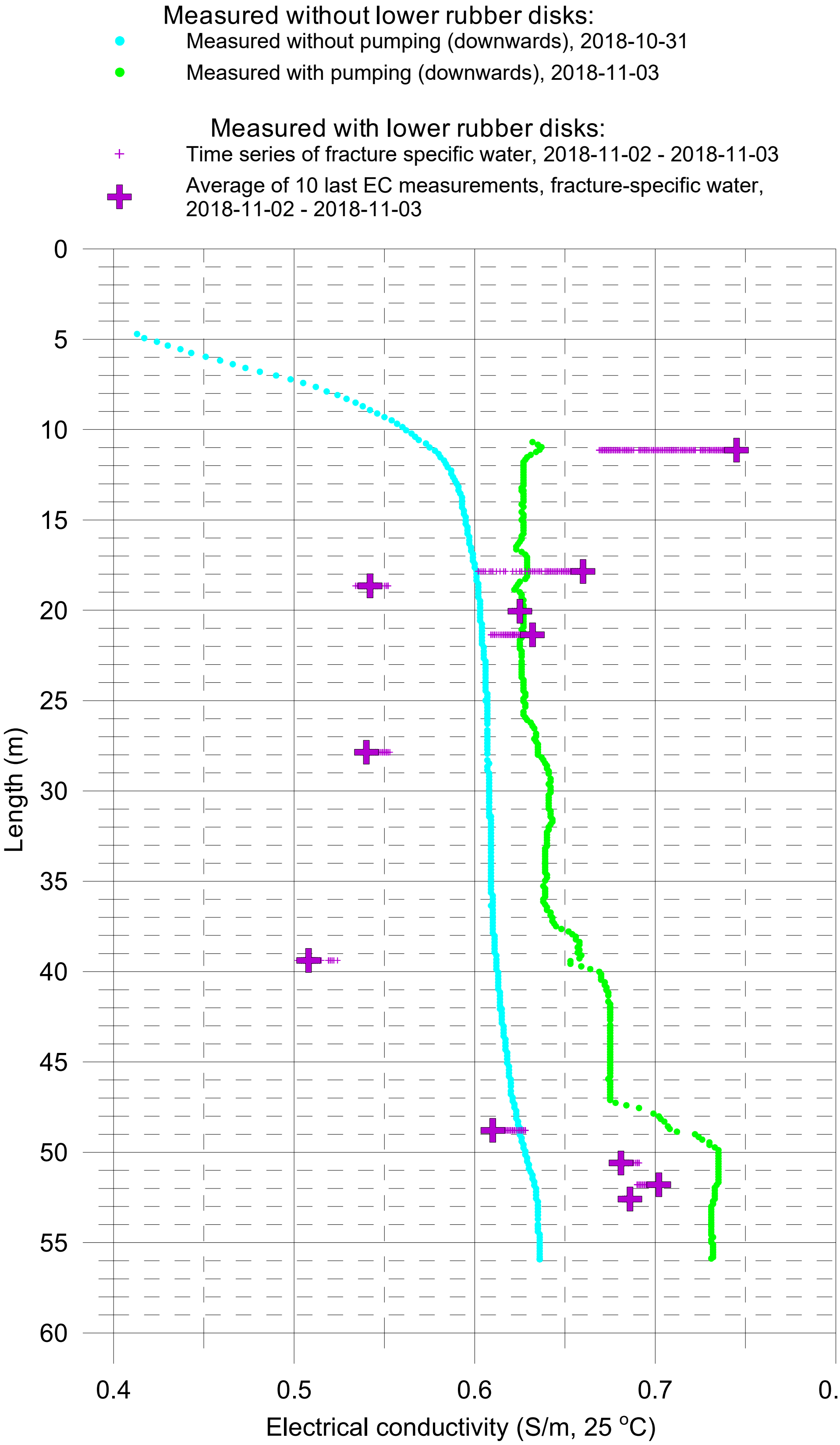

When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-14 - 2018-11-16
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level
(masl)
-4.0
-4.5
-5.0
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity
(S/m) (25 °C)
1.0
0.5
0.0
32.2 m
Flow (mL/h)
10000
1000
100
10
1
2018-11-15 / 17:15
2018-11-15 / 18:00
2018-11-15 / 18:45
2018-11-15 / 19:30
2018-11-15 / 20:15
Year-Month-Day / Hour:Minute

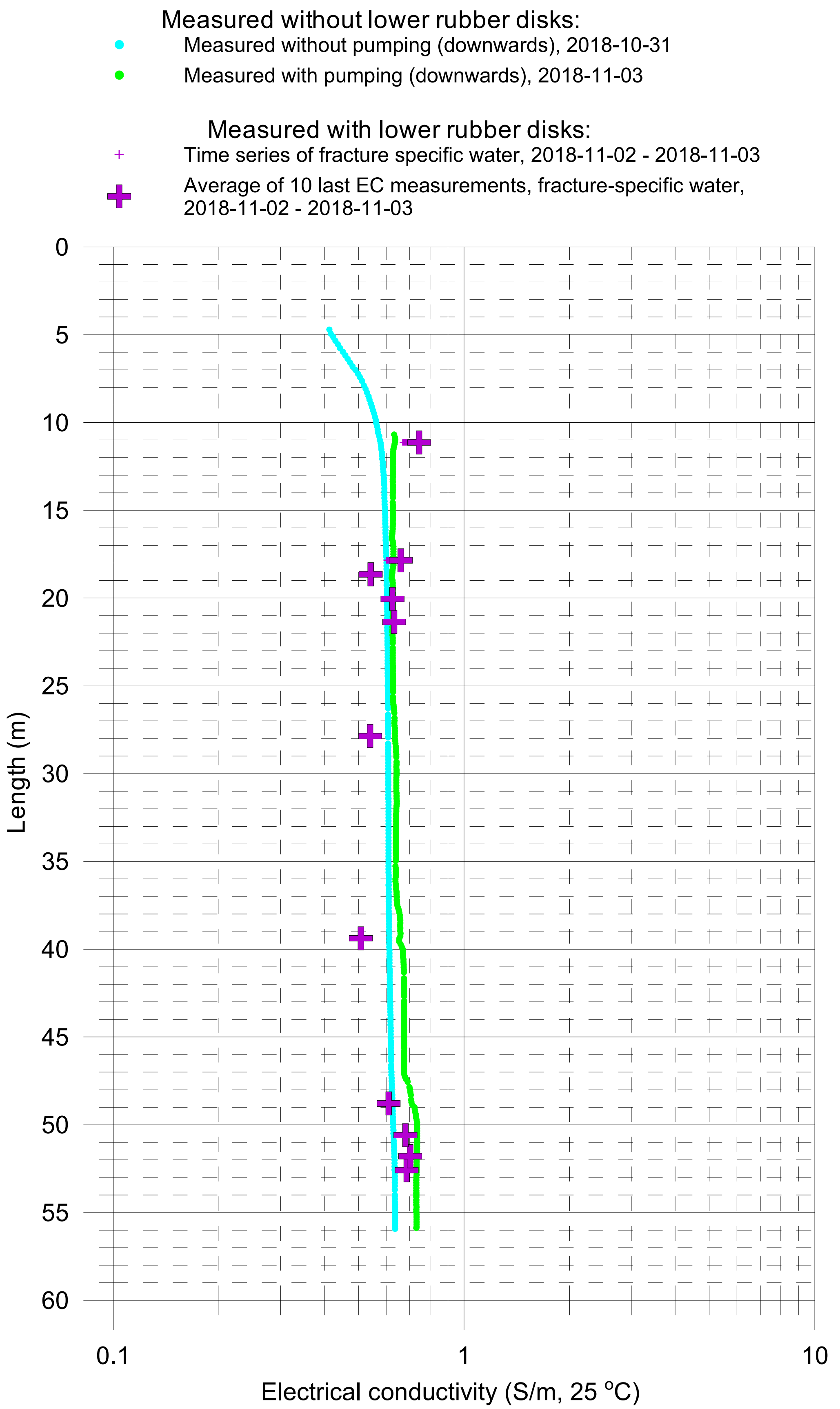


When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-14 - 2018-11-16 (Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-4.0
-4.5
-5.0
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
21.6 m
Flow (mL/h)
10000
1000
100
10
1
2018-11-15 / 21:00
2018-11-15 / 21:45
2018-11-15 / 22:30
2018-11-15 / 23:15
2018-11-16 / 0:00
2018-11-16 / 0:45
2018-11-16 / 1:30
Year-Month-Day / Hour:Minute


When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-14 - 2018-11-16 (Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-4.0
-4.5
-5.0
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
15.5 m
Flow (mL/h)
10000
1000
100
10
1
2018-11-16 / 7:30
2018-11-16 / 8:15
2018-11-16 / 9:00
2018-11-16 / 9:45
2018-11-16 / 10:30
2018-11-16 / 11:15
2018-11-16 / 12:00
Year-Month-Day / Hour:Minute

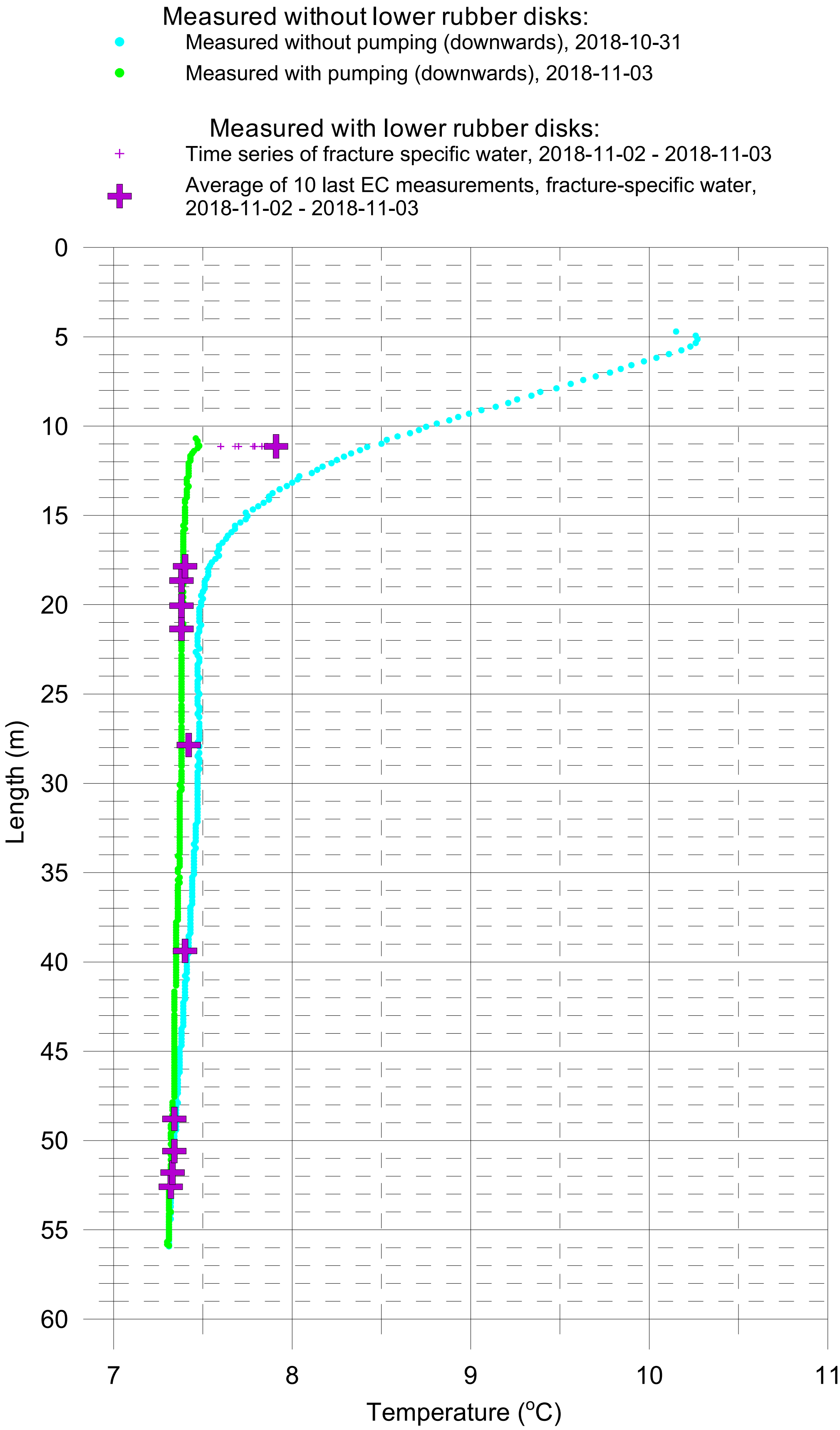
KFM16.1.1–KFM16.1.2 Electrical conductivity of borehole water



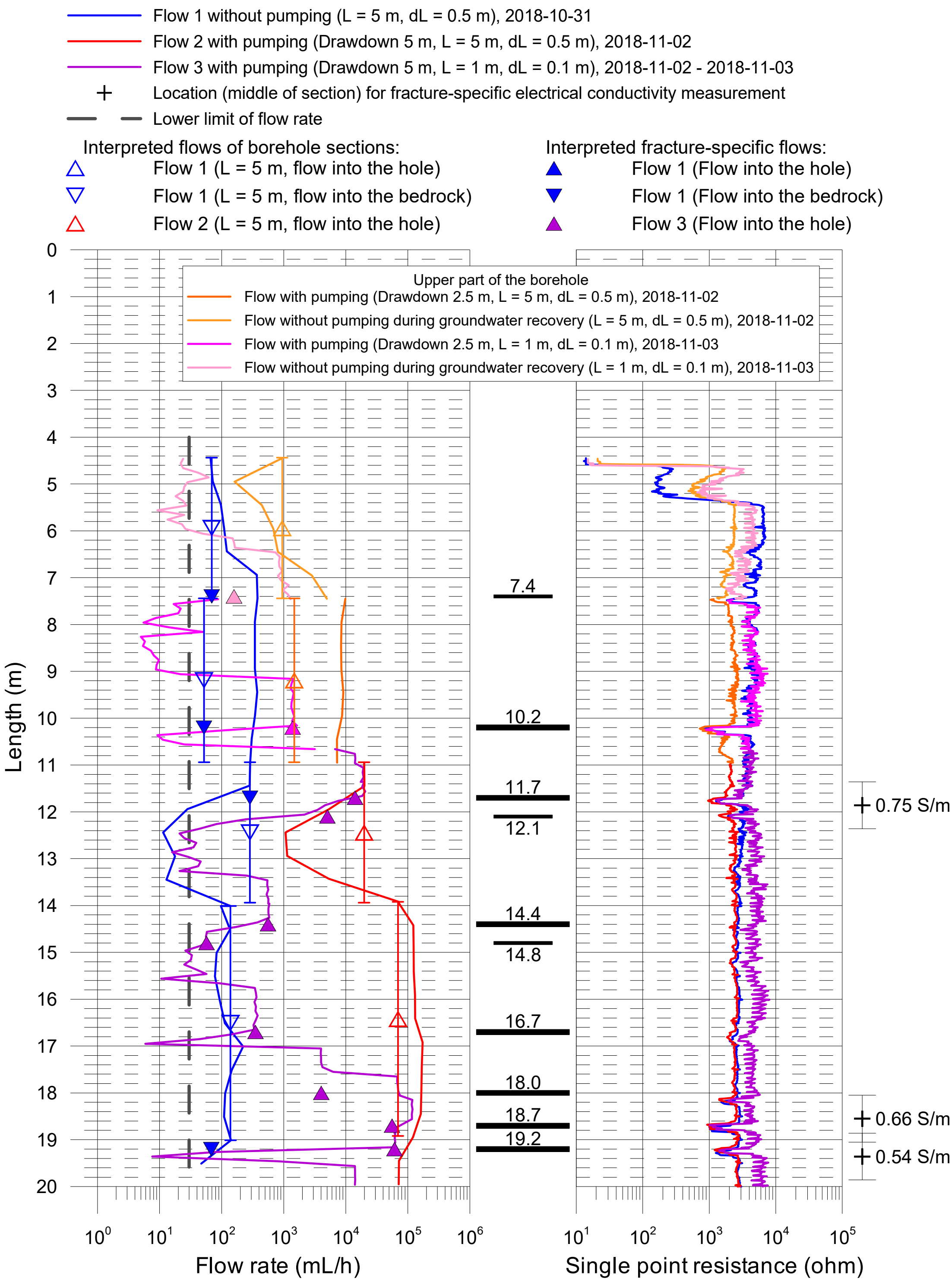


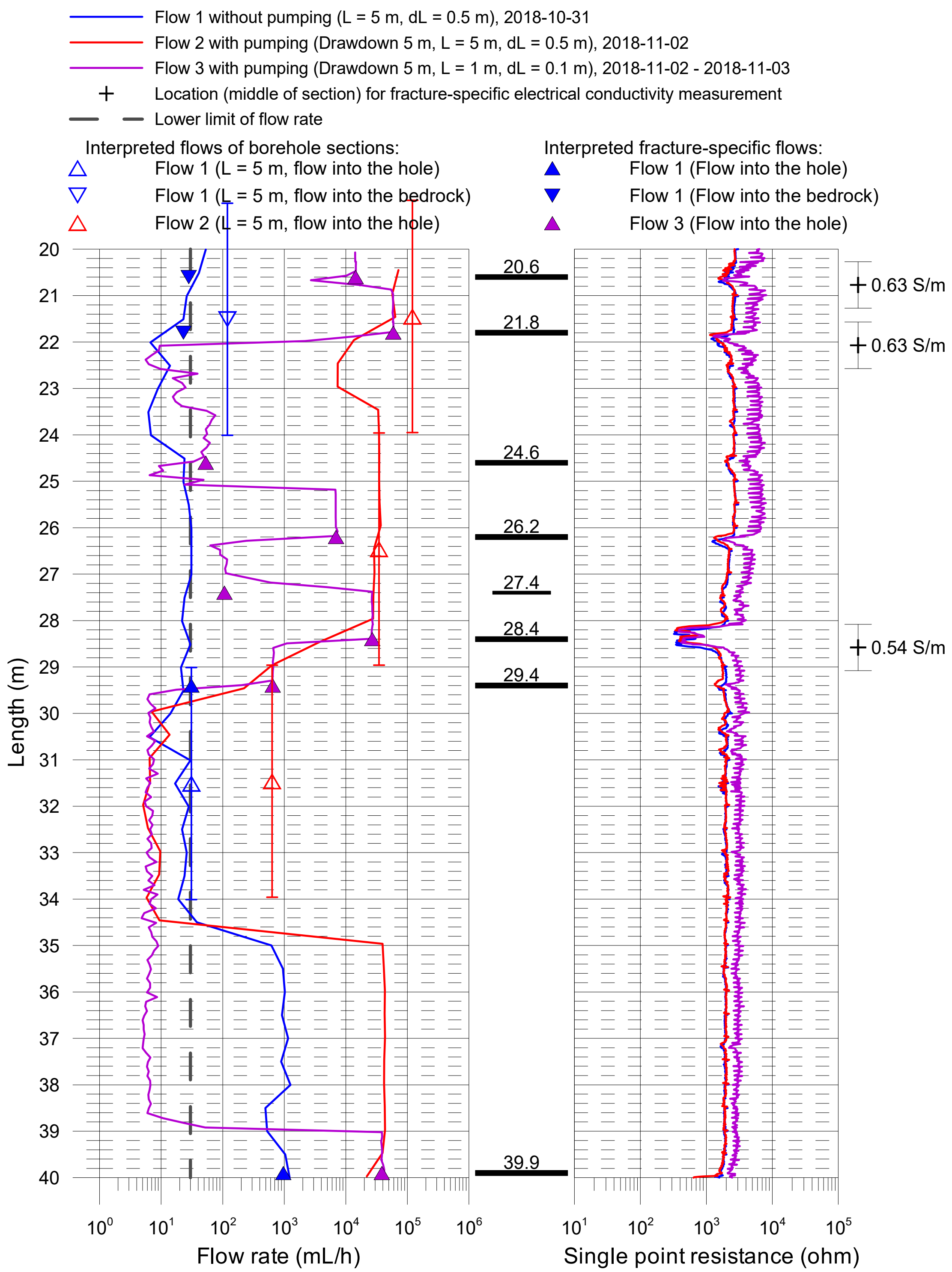
Measured without lower rubber disks:
Measured without pumping (downwards), 2018-10-31
Measured with pumping (downwards), 2018-11-03
Measured with lower rubber disks:
Time series of fracture specific water, 2018-11-02 - 2018-11-03
Average of 10 last EC measurements, fracture-specific water, 2018-11-02 - 2018-11-03
Length (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
0.1
1
10
Electrical conductivity (S/m, 25 °C)

KFM16.1.3 Temperature of borehole water

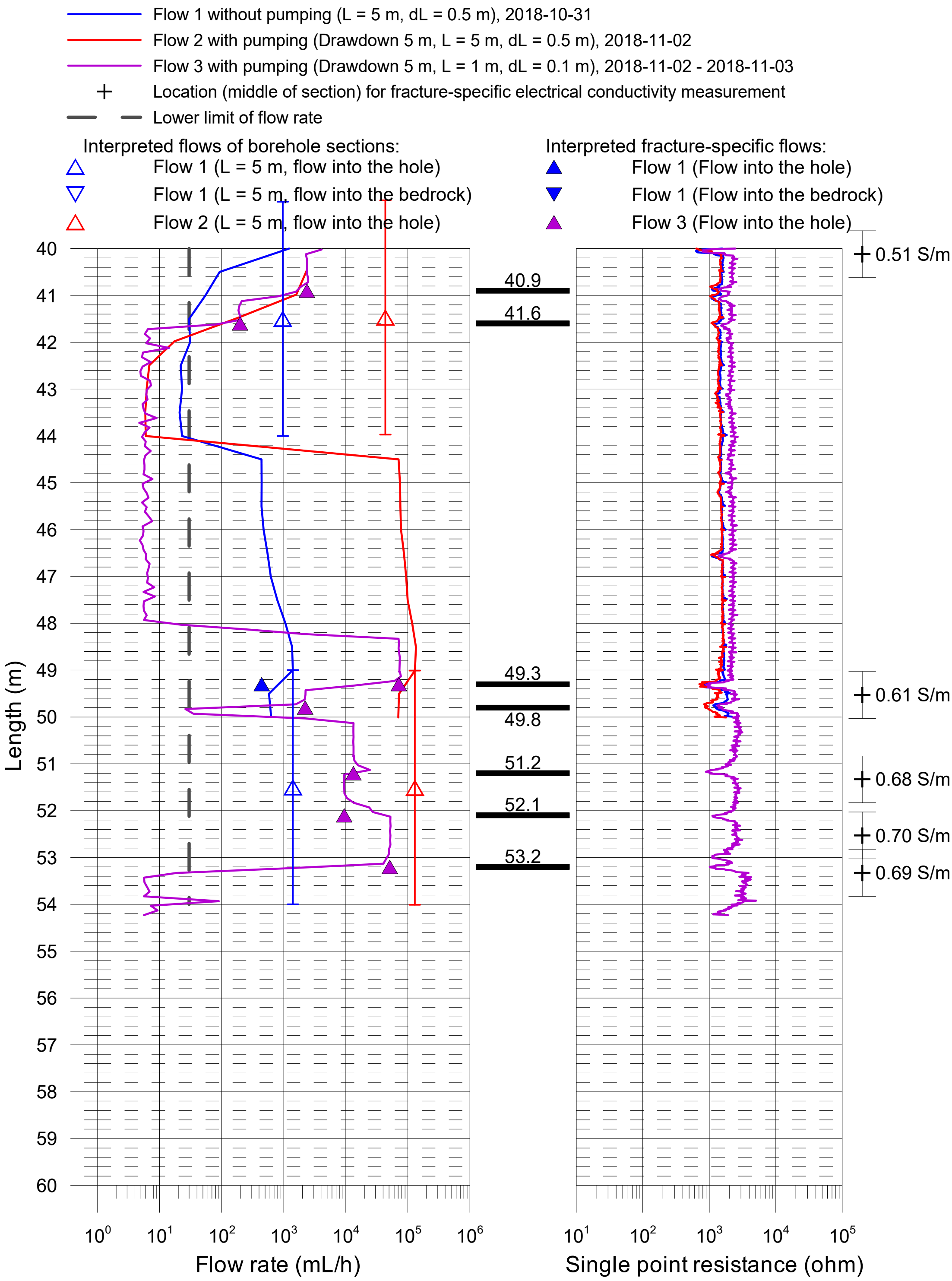


KFM16.2.1–KFM16.2.3 Flow rate and single point resistance



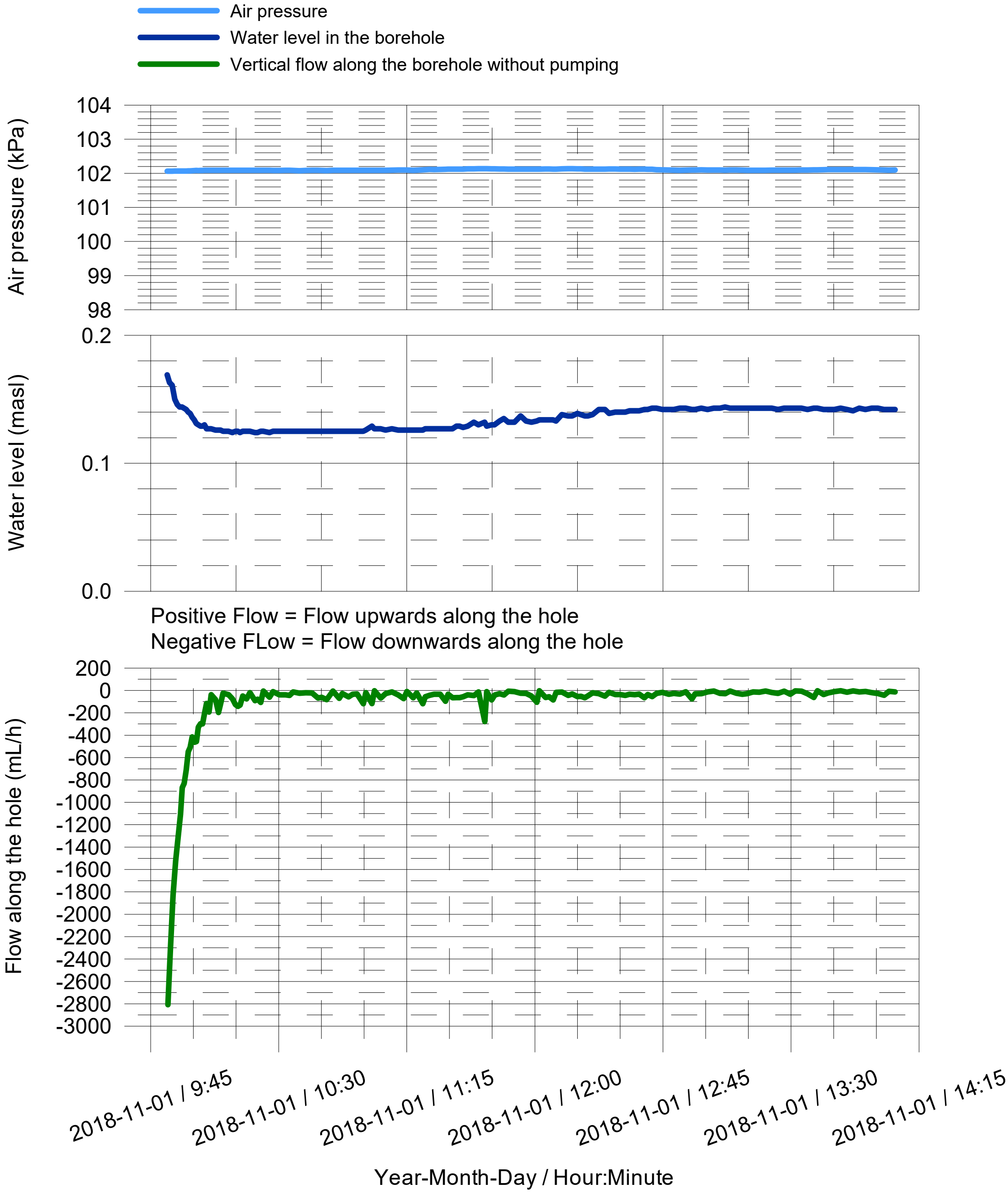


Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-10-31
Flow 2 with pumping (Drawdown 5 m, L = 5 m, dL = 0.5 m), 2018-11-02
Flow 3 with pumping (Drawdown 5 m, L = 1 m, dL = 0.1 m), 2018-11-02 - 2018-11-03
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
20.6
21.8
24.6
26.2
27.4
28.4
29.4
39.9
0.63 S/m
0.63 S/m
0.54 S/m
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)



Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-10-31
Flow 2 with pumping (Drawdown 5 m, L = 5 m, dL = 0.5 m), 2018-11-02
Flow 3 with pumping (Drawdown 5 m, L = 1 m, dL = 0.1 m), 2018-11-02 - 2018-11-03
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
40.9
41.6
49.3
49.8
51.2
52.1
53.2
0.51 S/m
0.61 S/m
0.68 S/m
0.70 S/m
0.69 S/m
Flow rate (mL/h)
Single point resistance (ohm)

KFM16.2.4 Vertical flow along the borehole at 6.2 m



KFM16.3 Explanations for the tables in Appendices

Header	Unit	Explanations
Borehole ID		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)
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with h = h0 in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid before pumping
h_{1FW}	m.a.s.l.	Corrected hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period
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.
Q-lower limit P	mL/h	Practical lower measurement limit for flow rate.
T-measl$_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-measl$_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-meas$_{lU}$	m^2/s	Estimated upper measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

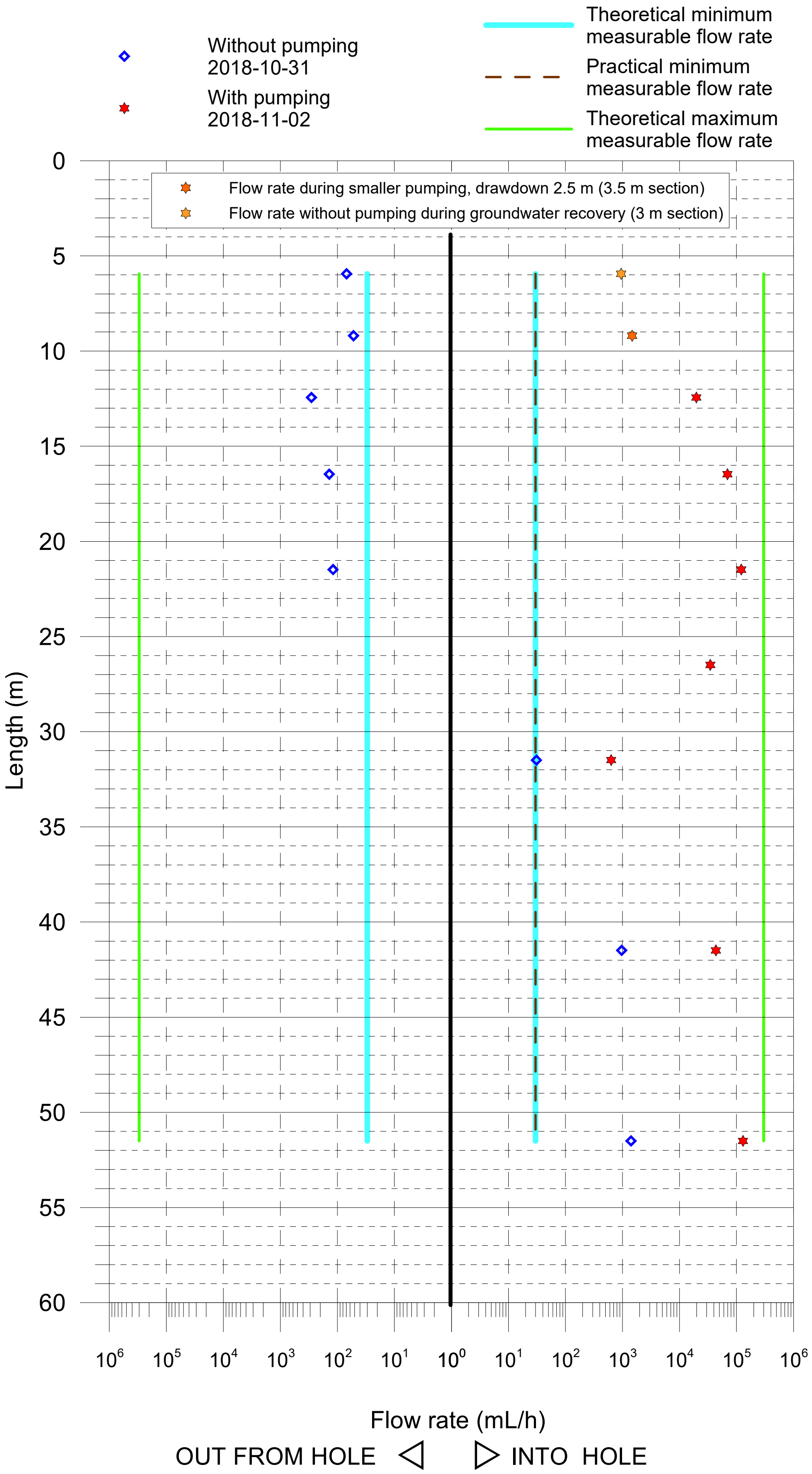
KFM16.4 Results of section flows

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)	T_D-measl$_{LT}$ (m^2/s)	T_D-measl$_{LP}$ (m^2/s)	T_D-measl$_U$ (m^2/s)	Comments
KFM16	4.44	7.44	3	−1.92E-08	0.11	2.63E-07	−1.50	1.7E-07	0.0	30	5.1E-09	5.1E-09	5.1E-05	*
KFM16	7.44	10.94	3.5	−1.44E-08	0.07	4.10E-07	−2.14	1.9E-07	0.0	30	3.7E-09	3.7E-09	3.7E-05	**
KFM16	10.94	13.94	3	−7.94E-08	0.12	5.47E-06	−4.64	1.2E-06	0.1	30	1.7E-09	1.7E-09	1.7E-05	
KFM16	13.97	18.97	5	−3.86E-08	0.11	1.93E-05	−4.26	4.4E-06	0.1	30	1.9E-09	1.9E-09	1.9E-05	
KFM16	18.98	23.98	5	−3.31E-08	0.14	3.35E-05	−4.49	7.2E-06	0.1	30	1.8E-09	1.8E-09	1.8E-05	
KFM16	23.99	28.99	5	–	0.18	9.63E-06	−4.57	2.0E-06	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM16	28.99	33.99	5	8.61E-09	0.18	1.76E-07	−4.60	3.5E-08	0.4	30	1.7E-09	1.7E-09	1.7E-05	
KFM16	33.99	38.99	5	–	0.18	–	−4.63	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM16	38.99	43.99	5	2.68E-07	0.20	1.21E-05	−4.57	2.5E-06	0.3	30	1.7E-09	1.7E-09	1.7E-05	
KFM16	44.00	49.00	5	–	0.19	–	−4.60	–	–	30	1.7E-09	1.7E-09	1.7E-05	
KFM16	49.00	54.00	5	3.91E-07	0.04	3.61E-05	−4.40	8.0E-06	0.1	30	1.9E-09	1.9E-09	1.9E-05	

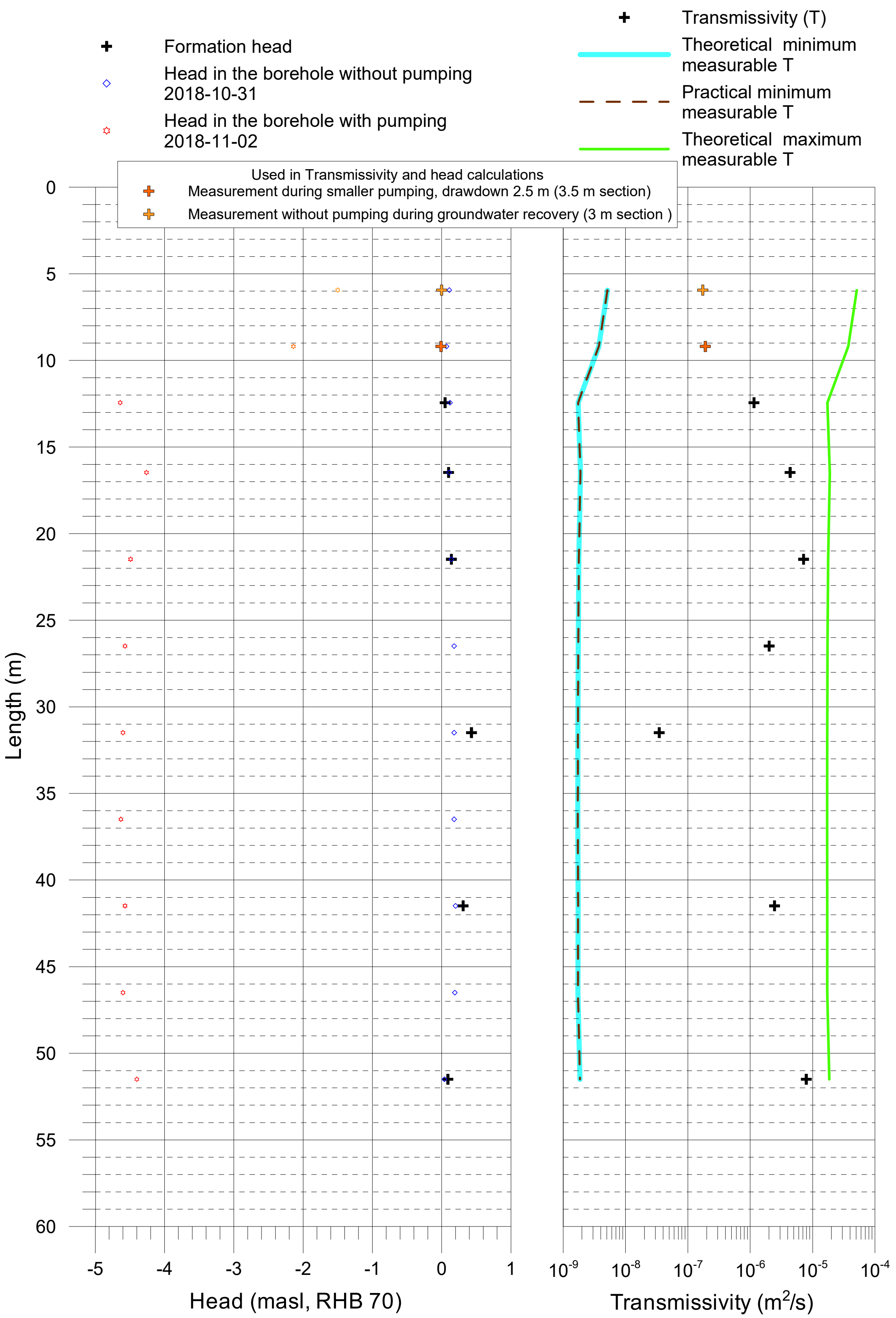
* Values for Flow (Q1) and Head (h1FW) are from the measurement made without pumping, during recovery. The upper part of the borehole could not be measured while pumping the borehole (while the pump remained in the borehole).

** Values for Flow (Q1) and Head (h1FW) are from the measurement made with smaller pumping (drawdown 2.5 m). The upper part of the borehole could not be measured during larger drawdown.

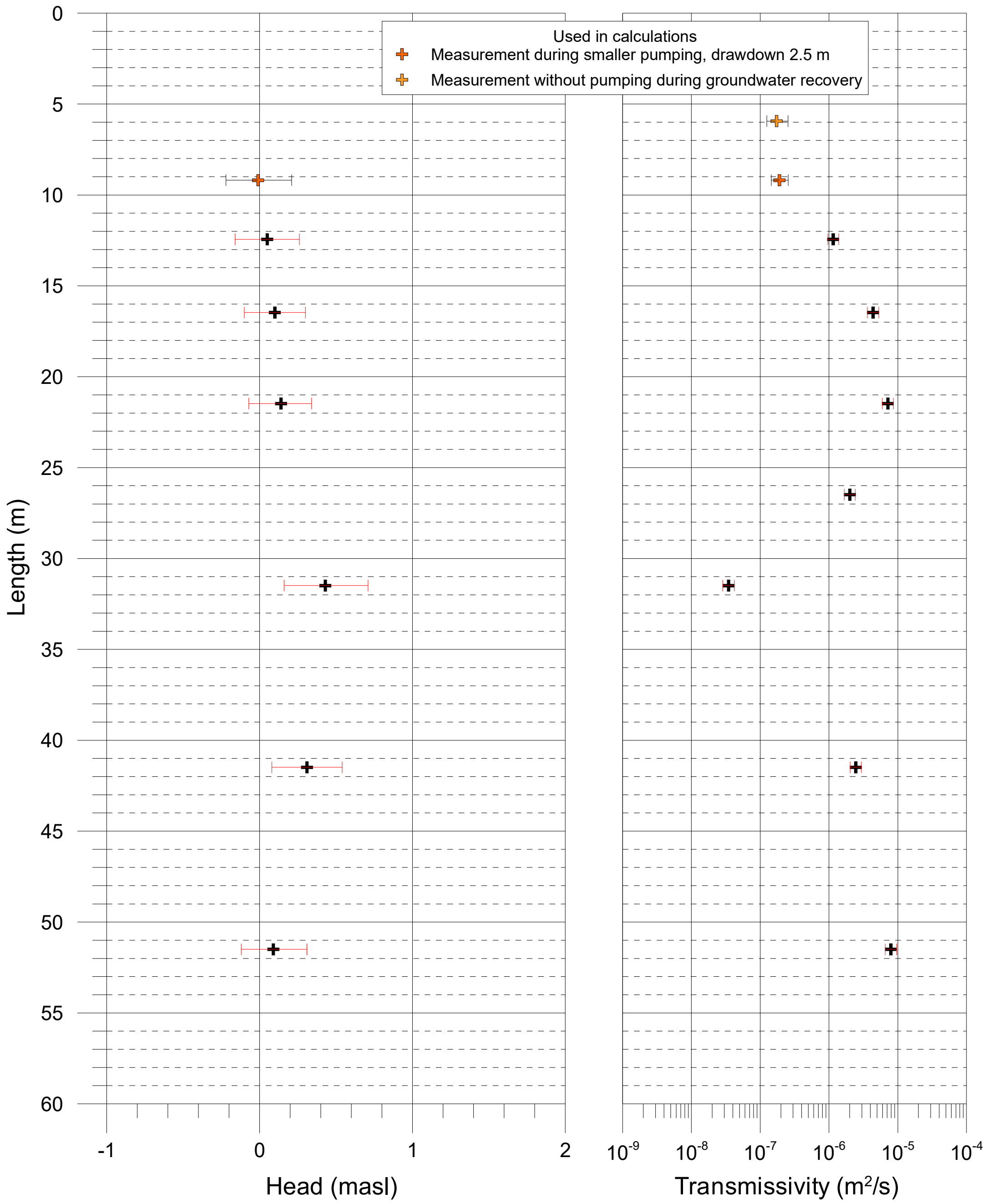
KFM16.5.1 Plotted flow rates of 5 m sections



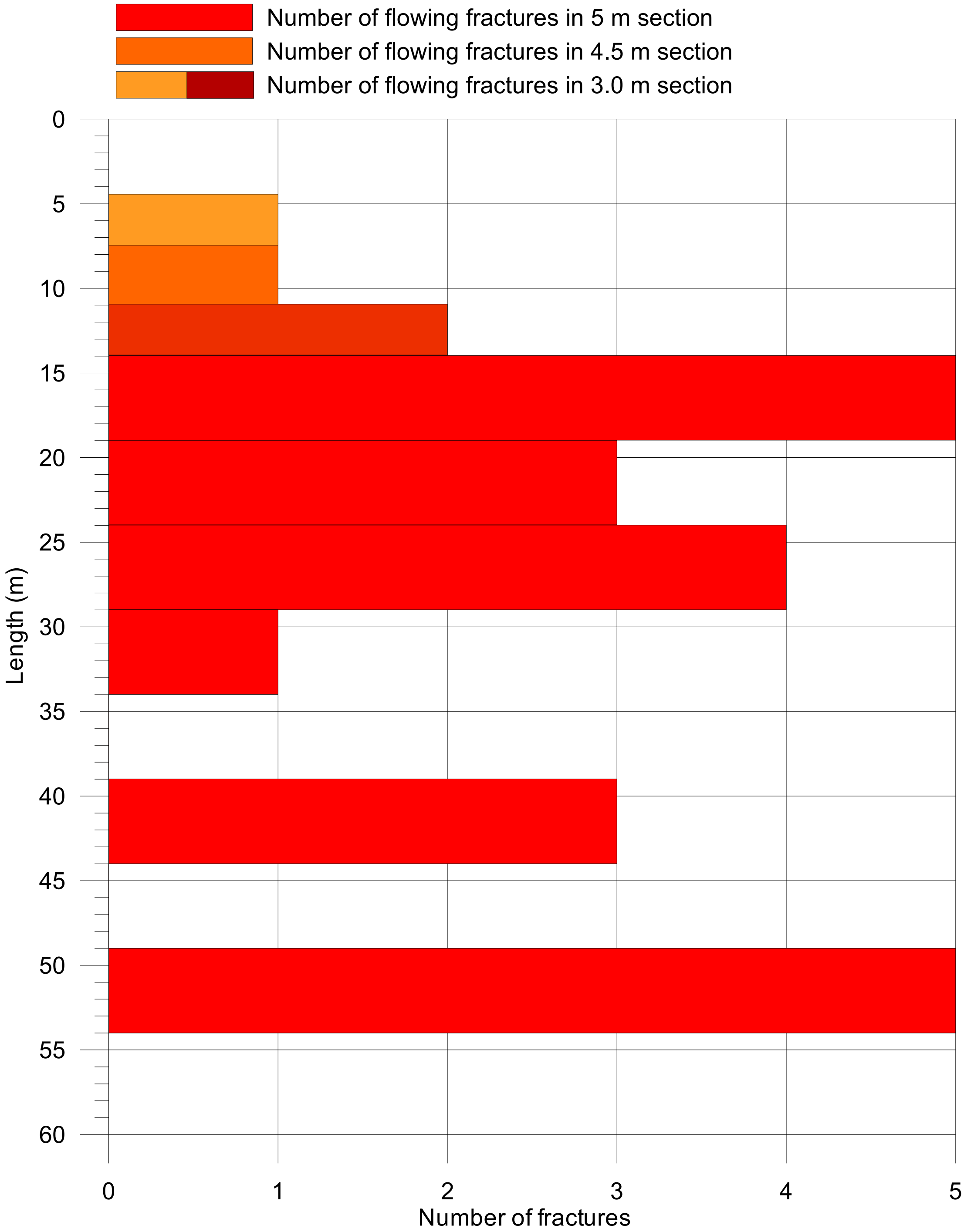
KFM16.5.2 Plotted transmissivity and head of 5 m sections



KFM16.5.3 Transmissivity and head of 5 m sections with calculated error limits



KFM16.5.4 Conductive fracture frequency



KFM16.6 Inferred fracture flow anomalies from flow logging

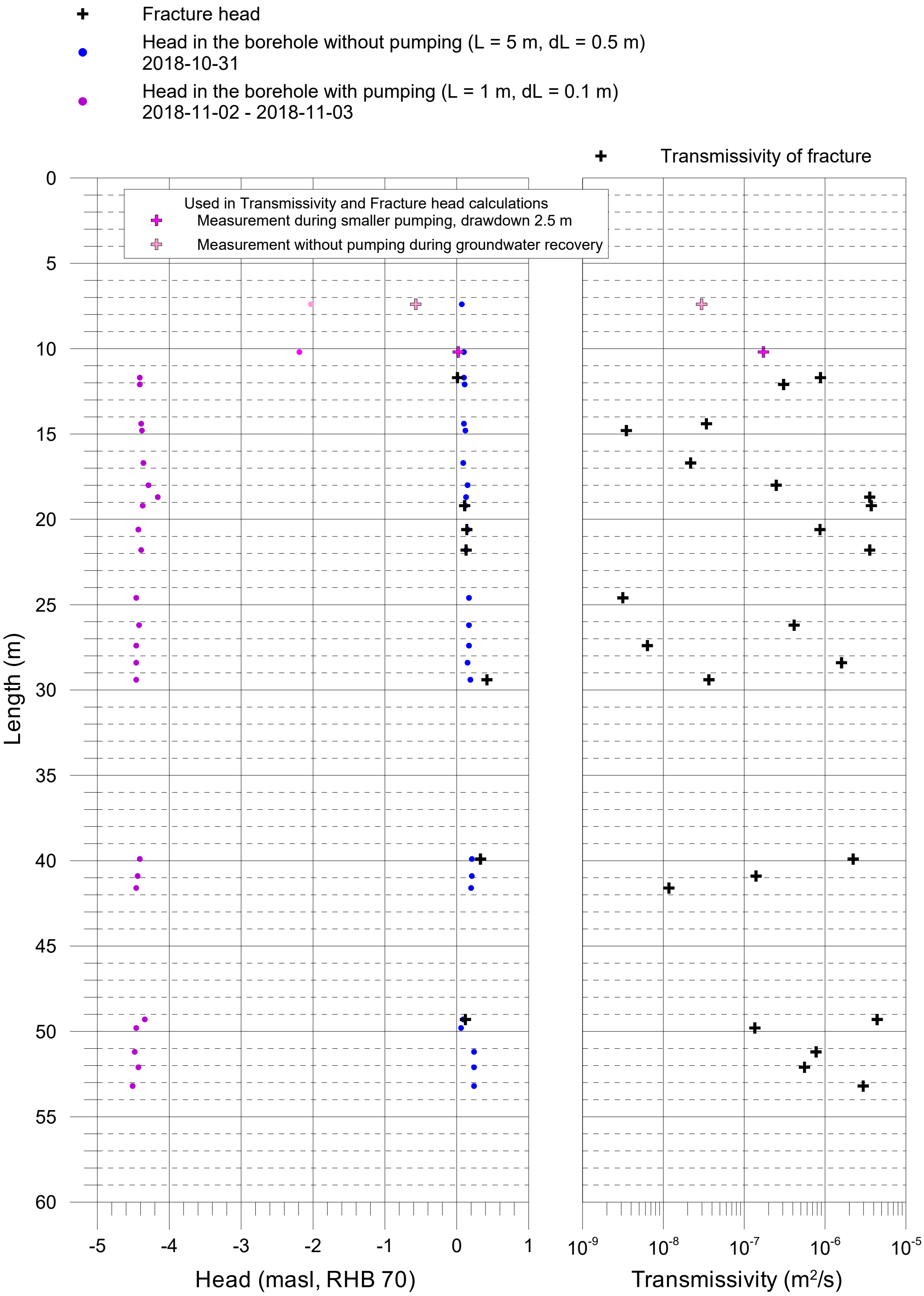
Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KFM16	7.4	1	0.1	−1.92E-08	0.07	4.39E-08	−2.03	3.0E-08	−0.6	*, **
KFM16	10.2	1	0.1	−1.44E-08	0.10	3.86E-07	−2.19	1.7E-07	0.0	***
KFM16	11.7	1	0.1	−7.94E-08	0.10	3.92E-06	−4.41	8.8E-07	0.0	
KFM16	12.1	1	0.1	–	0.11	1.40E-06	−4.41	3.1E-07	–	*
KFM16	14.4	1	0.1	–	0.10	1.55E-07	−4.39	3.4E-08	–	
KFM16	14.8	1	0.1	–	0.12	1.58E-08	−4.38	3.5E-09	–	*
KFM16	16.7	1	0.1	–	0.09	9.75E-08	−4.36	2.2E-08	–	
KFM16	18.0	1	0.1	–	0.15	1.12E-06	−4.29	2.5E-07	–	
KFM16	18.7	1	0.1	–	0.13	1.55E-05	−4.16	3.6E-06	–	
KFM16	19.2	1	0.1	−1.89E-08	0.12	1.69E-05	−4.37	3.7E-06	0.1	
KFM16	20.6	1	0.1	−7.78E-09	0.15	4.00E-06	−4.43	8.7E-07	0.1	
KFM16	21.8	1	0.1	−6.39E-09	0.13	1.63E-05	−4.39	3.6E-06	0.1	
KFM16	24.6	1	0.1	–	0.17	1.47E-08	−4.46	3.2E-09	–	
KFM16	26.2	1	0.1	–	0.17	1.92E-06	−4.42	4.1E-07	–	
KFM16	27.4	1	0.1	–	0.17	2.97E-08	−4.46	6.4E-09	–	*
KFM16	28.4	1	0.1	–	0.15	7.47E-06	−4.46	1.6E-06	–	
KFM16	29.4	1	0.1	8.61E-09	0.19	1.81E-07	−4.46	3.7E-08	0.4	
KFM16	39.9	1	0.1	2.68E-07	0.21	1.07E-05	−4.41	2.2E-06	0.3	
KFM16	40.9	1	0.1	–	0.21	6.58E-07	−4.44	1.4E-07	–	
KFM16	41.6	1	0.1	–	0.20	5.50E-08	−4.46	1.2E-08	–	
KFM16	49.3	1	0.1	1.23E-07	0.09	1.99E-05	−4.34	4.4E-06	0.1	
KFM16	49.8	1	0.1	–	0.06	6.17E-07	−4.46	1.4E-07	–	
KFM16	51.2	1	0.1	–	0.24	3.69E-06	−4.48	7.7E-07	–	
KFM16	52.1	1	0.1	–	0.24	2.63E-06	−4.43	5.6E-07	–	
KFM16	53.2	1	0.1	–	0.24	1.43E-05	−4.51	3.0E-06	–	

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

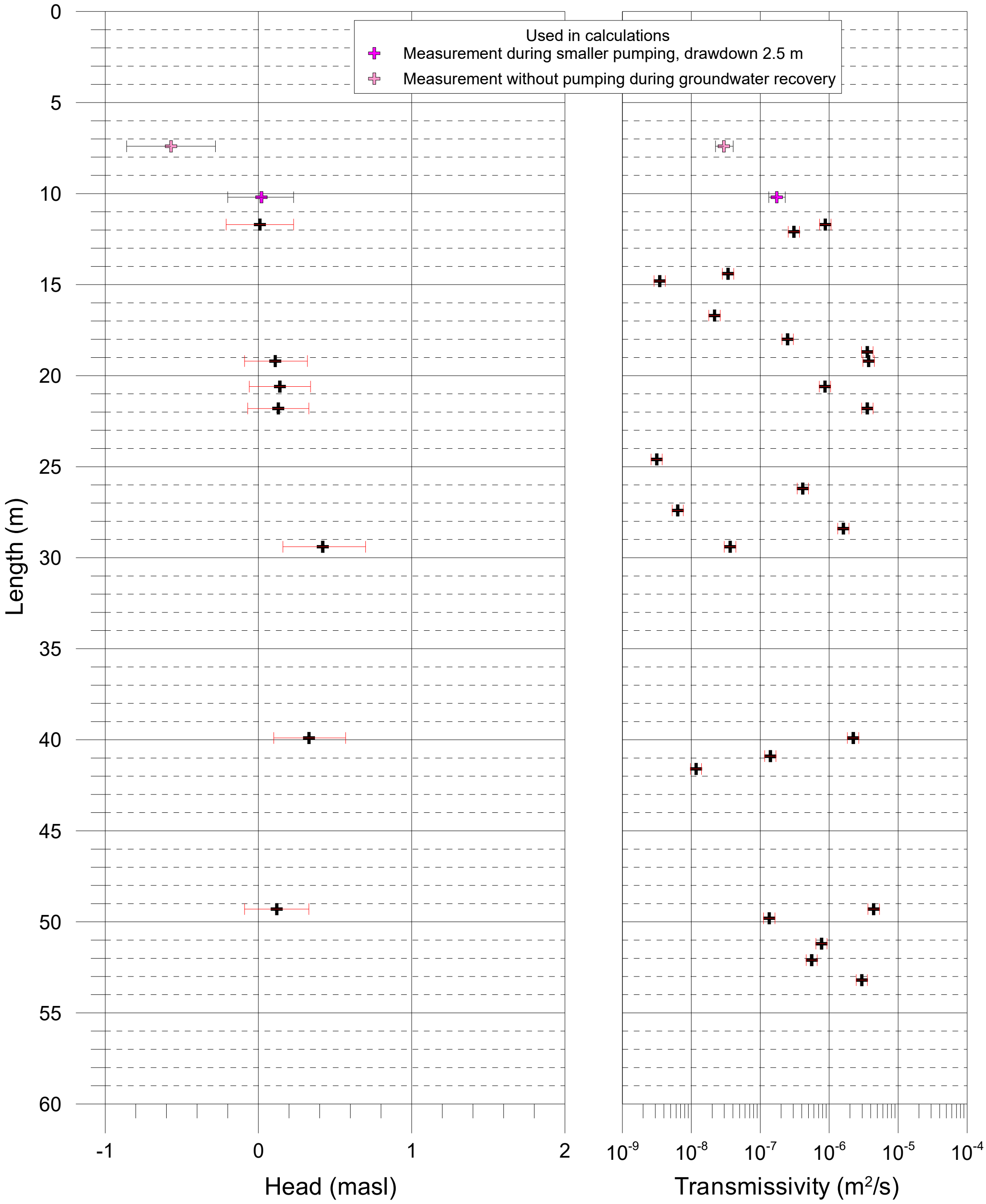
** Values for Flow (Q1) and Head (h1FW) are from the measurement made without pumping, during recovery. The upper part of the borehole could not be measured while pumping (while the pump remained in the borehole).

*** Values for Flow (Q1) and Head (h1FW) are from the measurement made with smaller pumping (drawdown 2.5 m). The upper part of the borehole could not be measured during larger drawdown.

KFM16.7.1 Plotted transmissivity and head of detected fractures



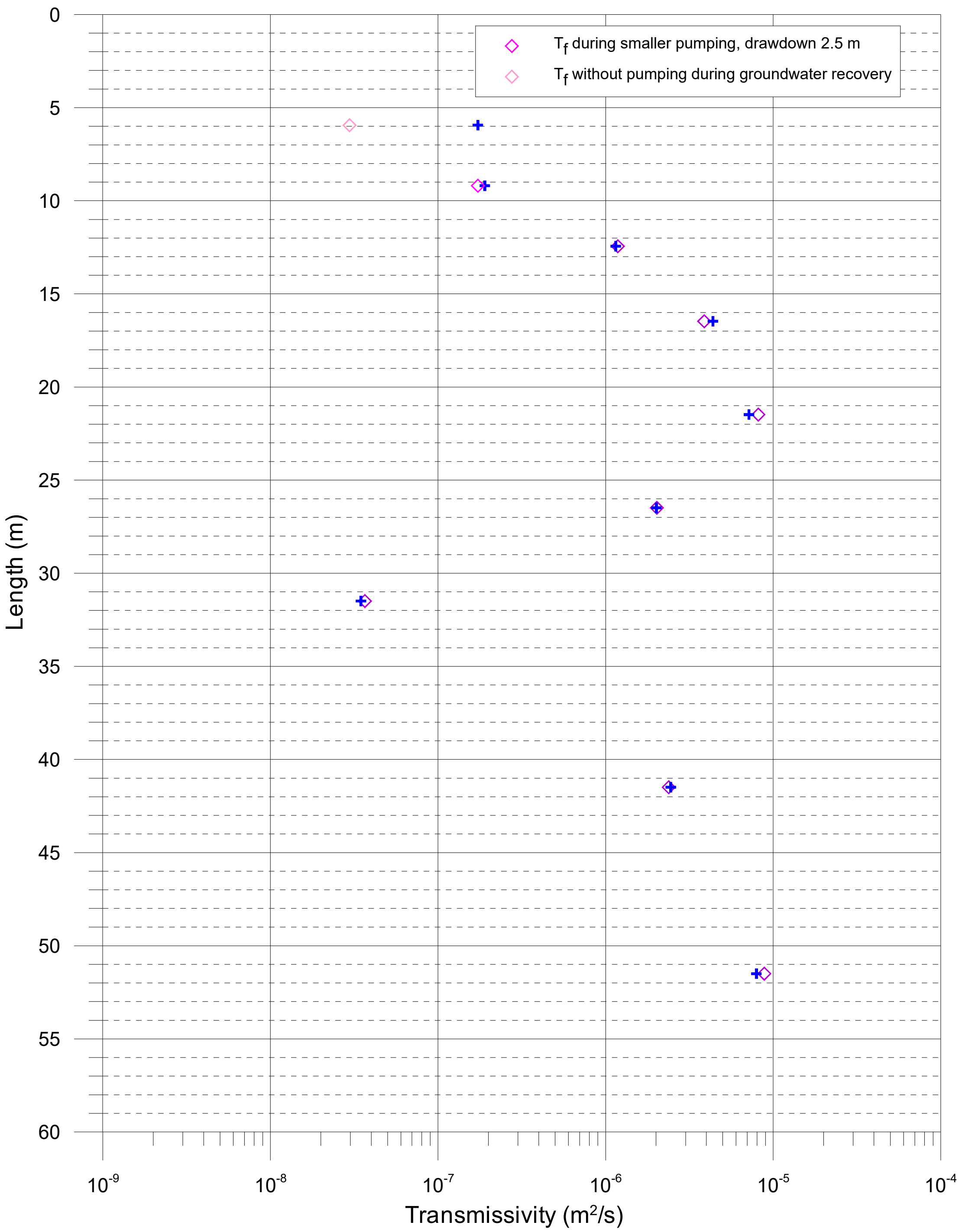
KFM16.7.2 Transmissivity and head of detected fractures with calculated error limits.



KFM16.8 Comparison between section transmissivity and fracture transmissivity

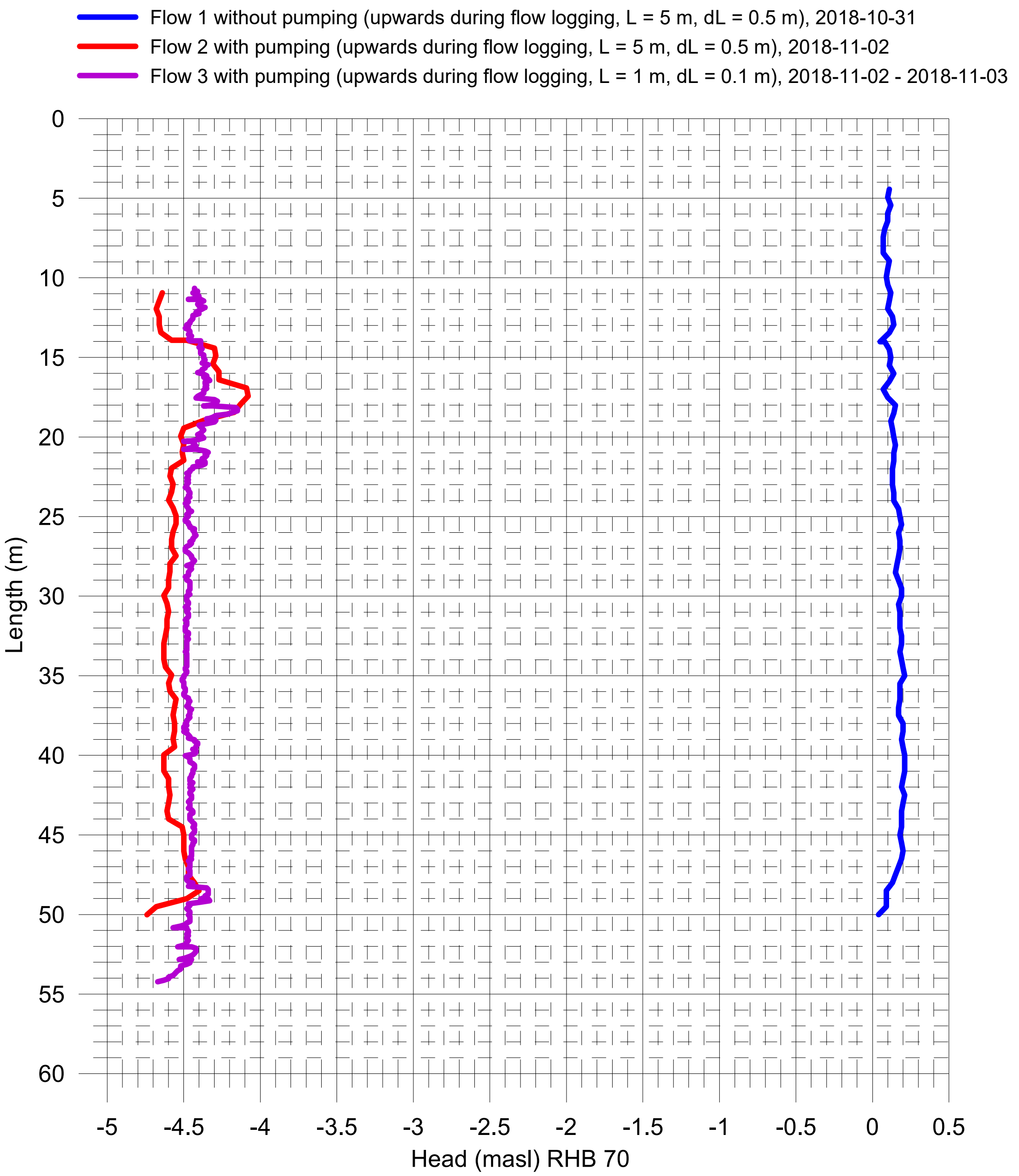
◇ Transmissivity (sum of fracture specific results T_f)

\+ Transmissivity (results of 5 m measurements T_s)

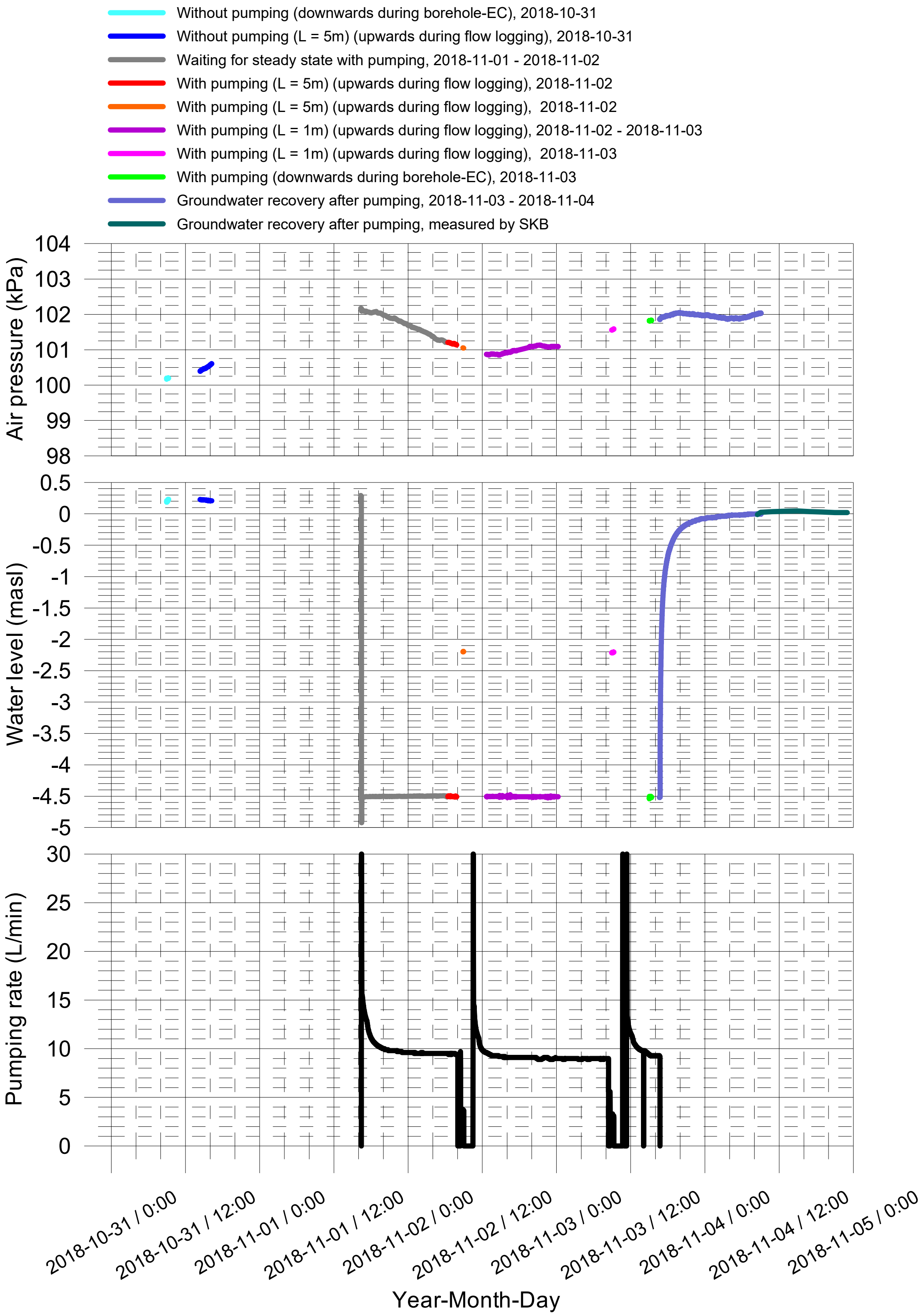


KFM16.9.1 Head in the borehole during flow logging

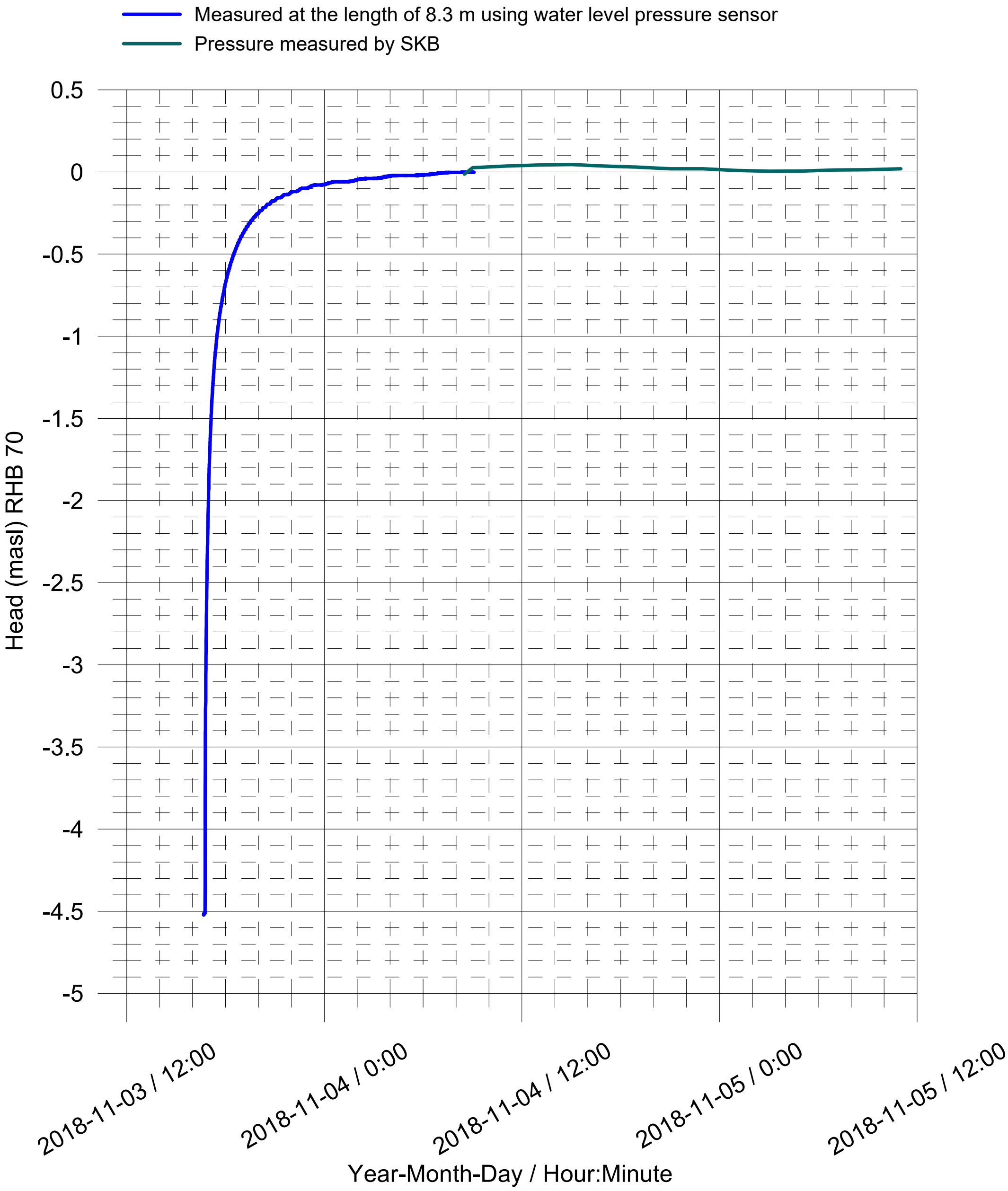
Head (masl) = (Absolute pressure (Pa) - Airpressure (Pa) + Offset) / (1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = Correction for absolute pressure sensor



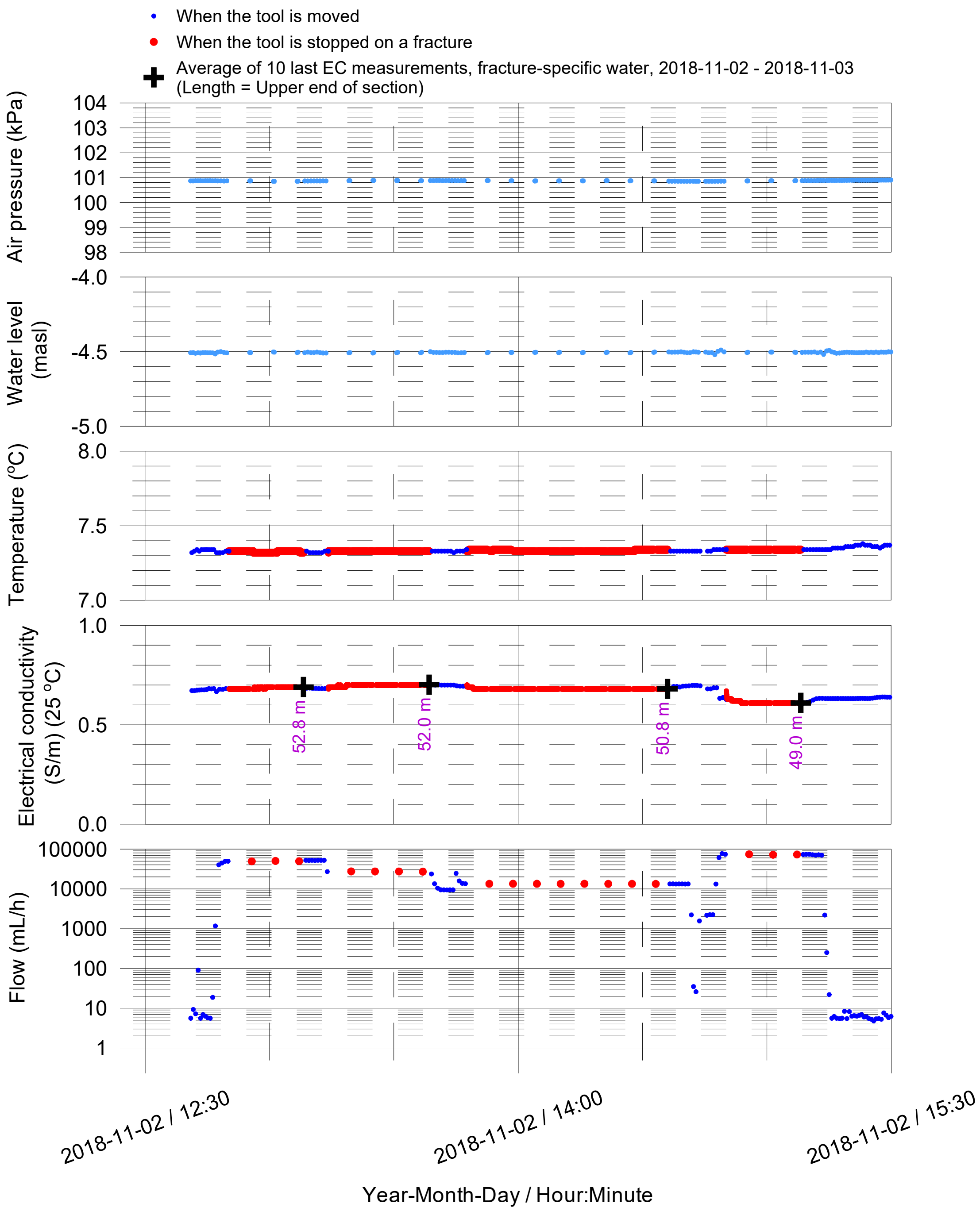
KFM16.9.2 Air pressure, water level in the borehole and pumping rate during flow logging

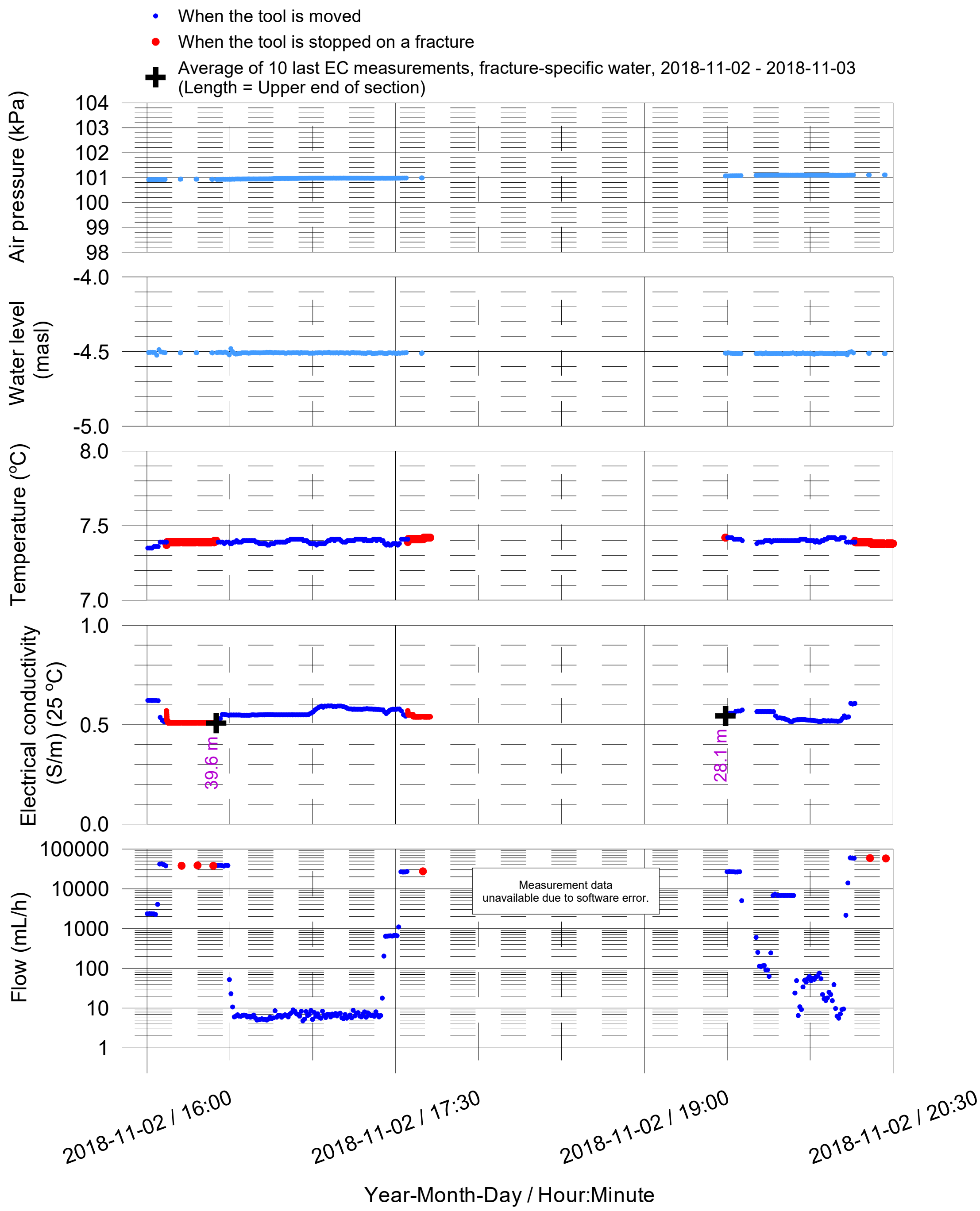


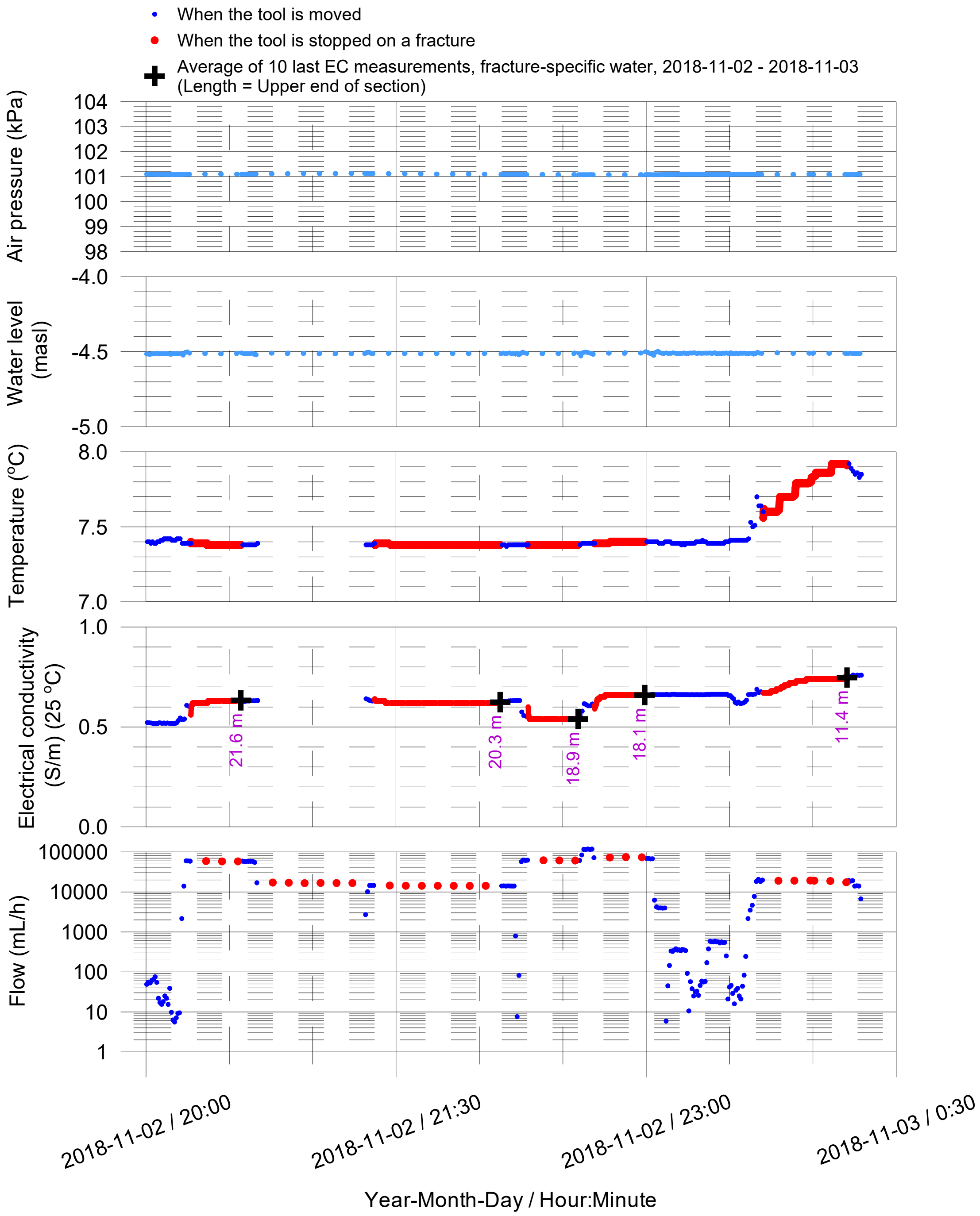
KFM16.9.3 Groundwater recovery after pumping



KFM16.10.1–KFM16.10.3 Fracture-specific EC results by date

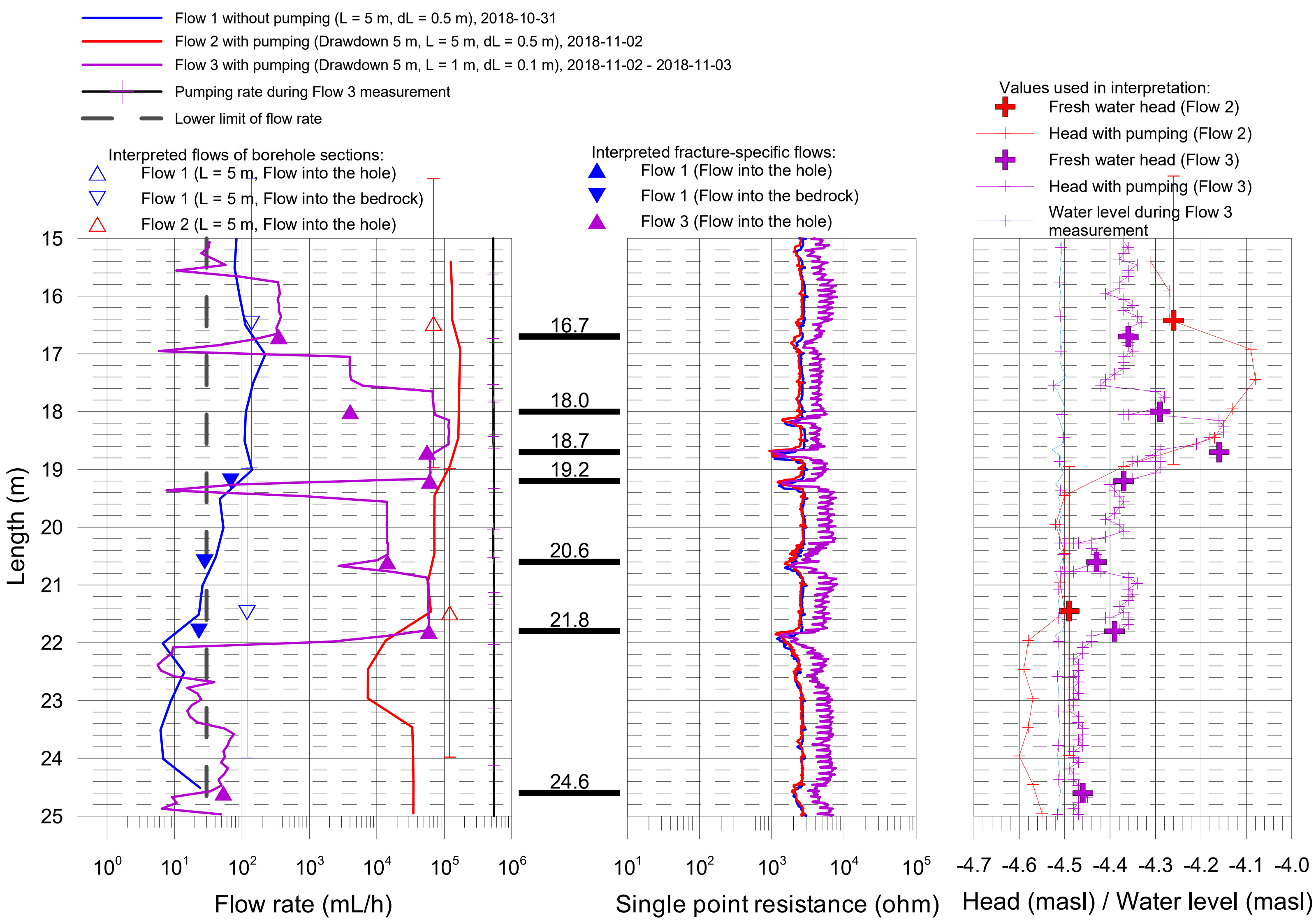


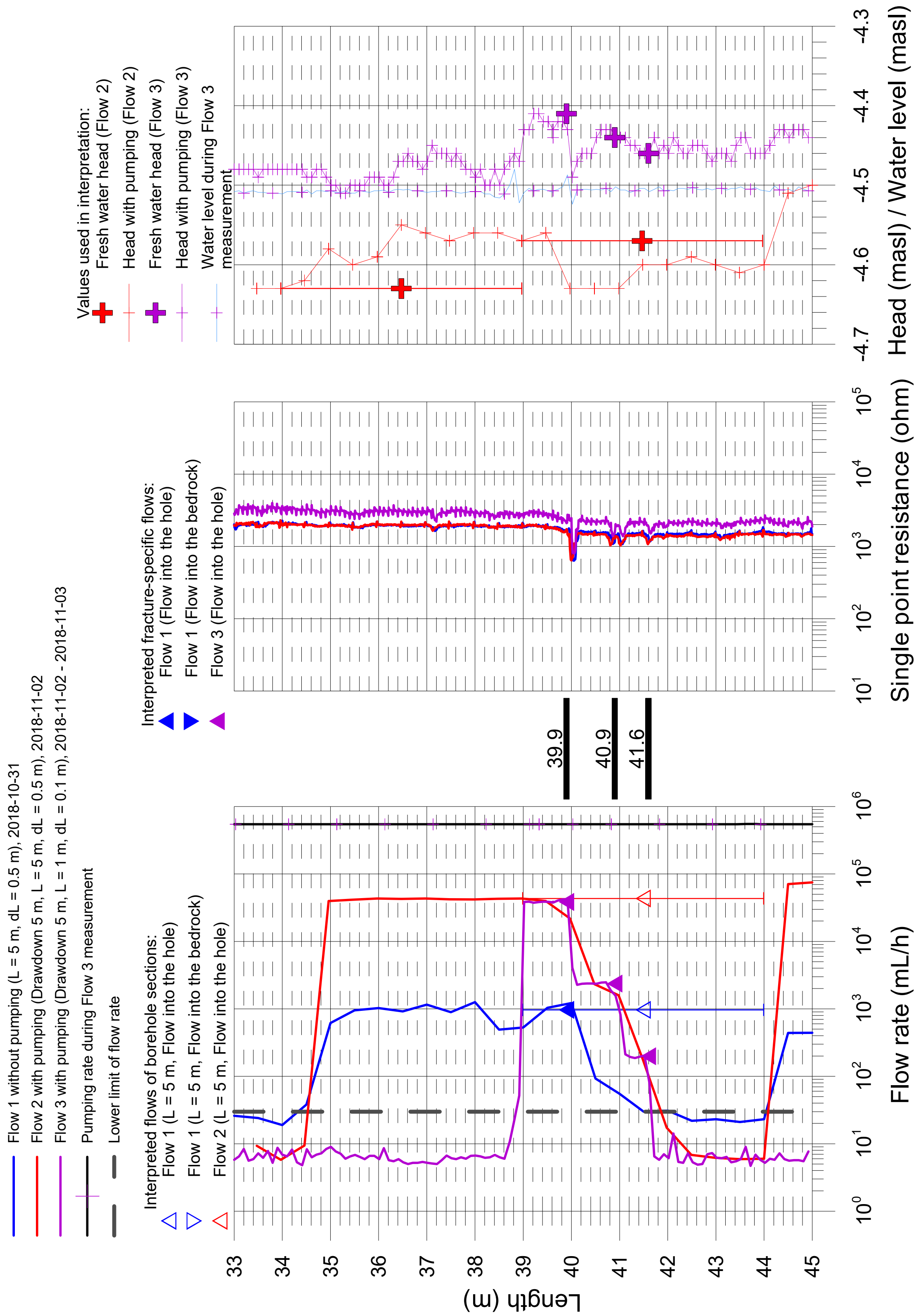

When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-02 - 2018-11-03 (Length = Upper end of section)
Air pressure (kPa)
Water level (masl)
Temperature (ºC)
Electrical conductivity (S/m) (25 ºC)
Flow (mL/h)
39.6 m
28.1 m
Measurement data unavailable due to software error.
2018-11-02 / 16:00
2018-11-02 / 17:30
2018-11-02 / 19:00
2018-11-02 / 20:30
Year-Month-Day / Hour:Minute



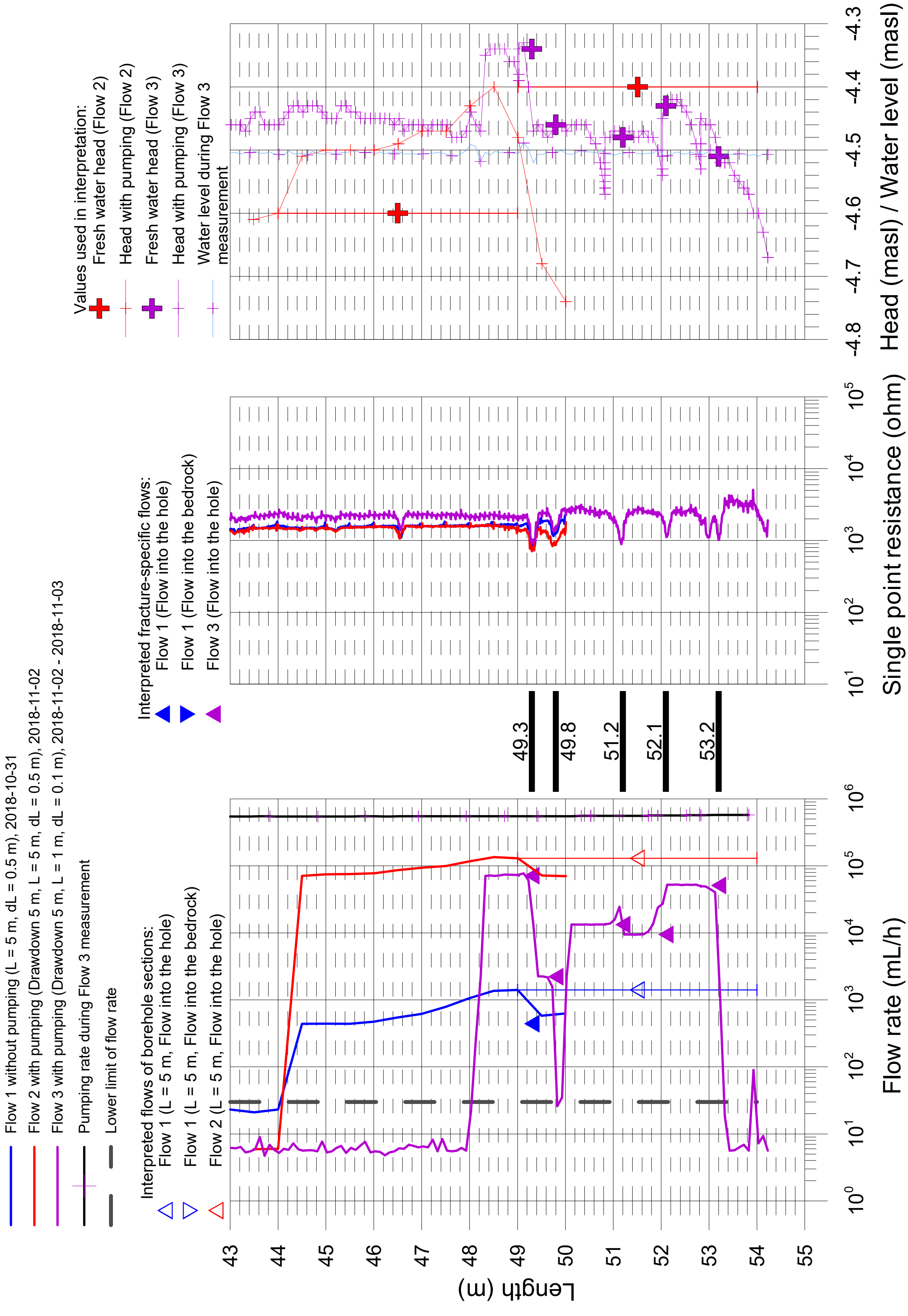
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-02 - 2018-11-03
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-4.0
-4.5
-5.0
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
21.6 m
20.3 m
18.9 m
18.1 m
11.4 m
Flow (mL/h)
100000
10000
1000
100
10
1
2018-11-02 / 20:00
2018-11-02 / 21:30
2018-11-02 / 23:00
2018-11-03 / 0:30
Year-Month-Day / Hour:Minute

KFM16.11.1–KFM16.11.3 Flow rate, single point resistance and head in the borehole during flow logging



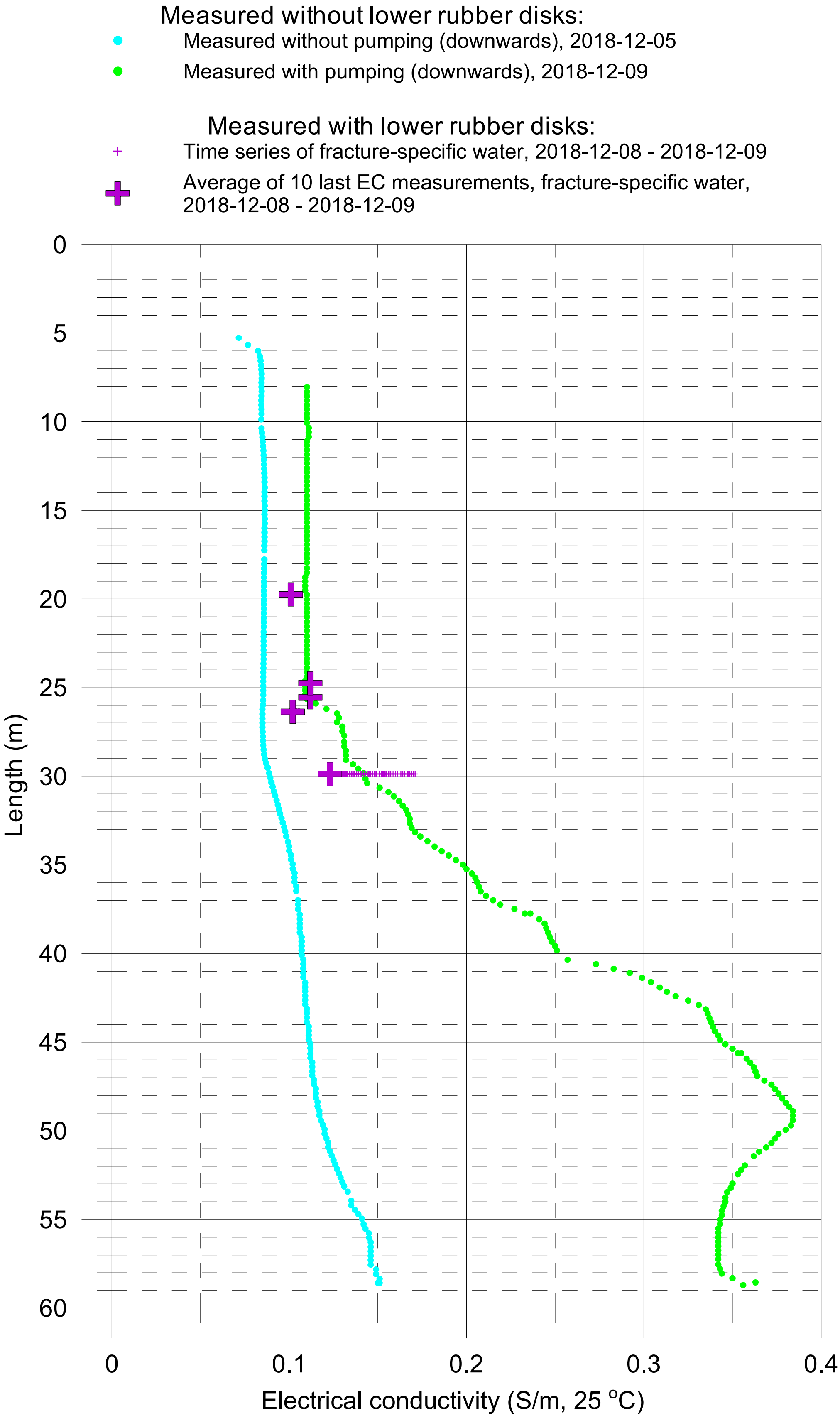


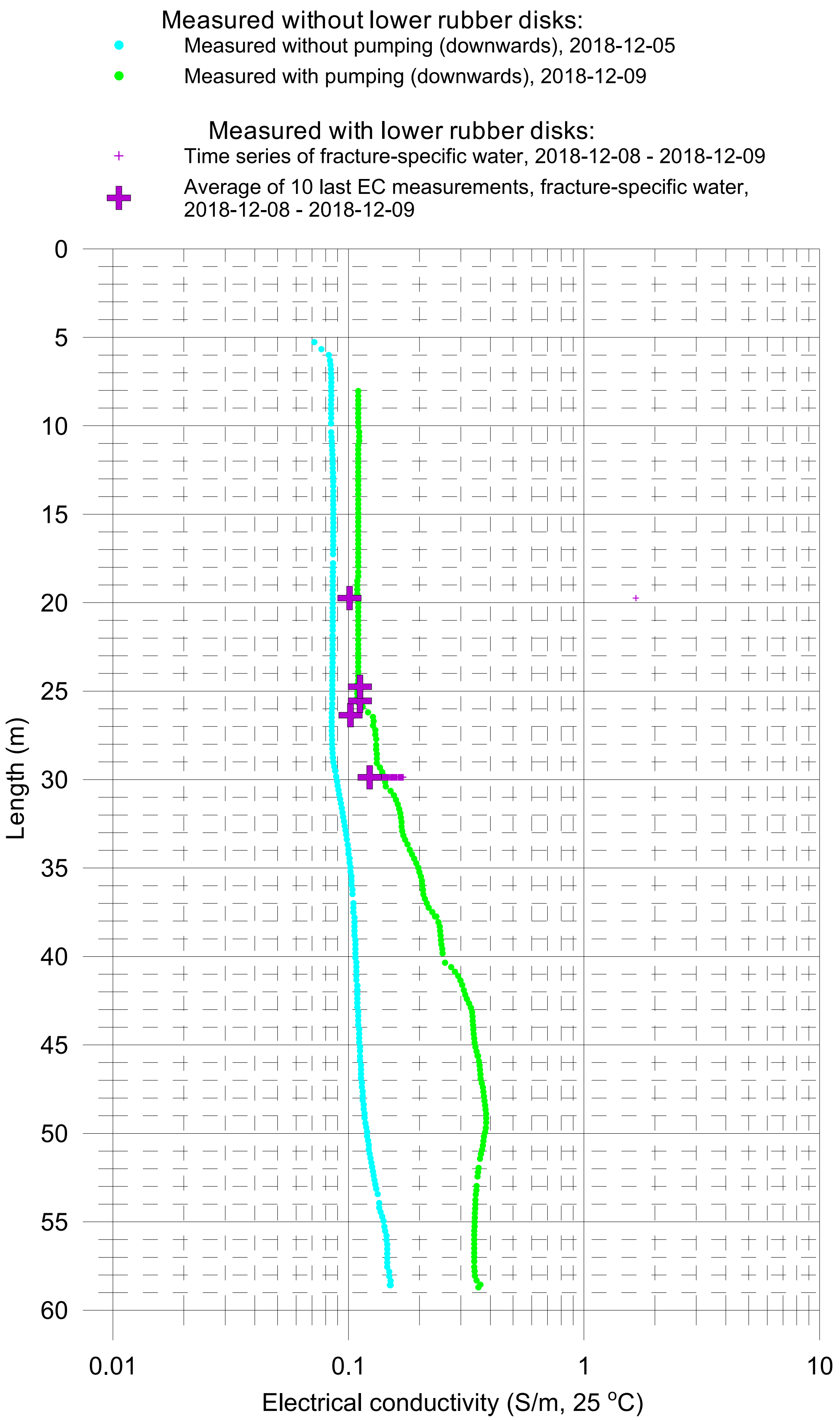
Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-10-31
Flow 2 with pumping (Drawdown 5 m, L = 5 m, dL = 0.5 m), 2018-11-02
Flow 3 with pumping (Drawdown 5 m, L = 1 m, dL = 0.1 m), 2018-11-02 - 2018-11-03
Pumping rate during Flow 3 measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, Flow into the hole)
Flow 1 (L = 5 m, Flow into the bedrock)
Flow 2 (L = 5 m, Flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Values used in interpretation:
Fresh water head (Flow 2)
Head with pumping (Flow 2)
Fresh water head (Flow 3)
Head with pumping (Flow 3)
Water level during Flow 3 measurement
Length (m)
33
34
35
36
37
38
39
40
41
42
43
44
45
39.9
40.9
41.6
Flow rate (mL/h)
10^0
10^1
10^2
10^3
10^4
10^5
10^6
Single point resistance (ohm)
10^1
10^2
10^3
10^4
10^5
Head (masl) / Water level (masl)
-4.7
-4.6
-4.5
-4.4
-4.3



Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-10-31
Flow 2 with pumping (Drawdown 5 m, L = 5 m, dL = 0.5 m), 2018-11-02
Flow 3 with pumping (Drawdown 5 m, L = 1 m, dL = 0.1 m), 2018-11-02 - 2018-11-03
Pumping rate during Flow 3 measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, Flow into the hole)
Flow 1 (L = 5 m, Flow into the bedrock)
Flow 2 (L = 5 m, Flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Values used in interpretation:
Fresh water head (Flow 2)
Head with pumping (Flow 2)
Fresh water head (Flow 3)
Head with pumping (Flow 3)
Water level during Flow 3 measurement
Length (m)
49.3
49.8
51.2
52.1
53.2
Flow rate (mL/h)
Single point resistance (ohm)
Head (masl) / Water level (masl)

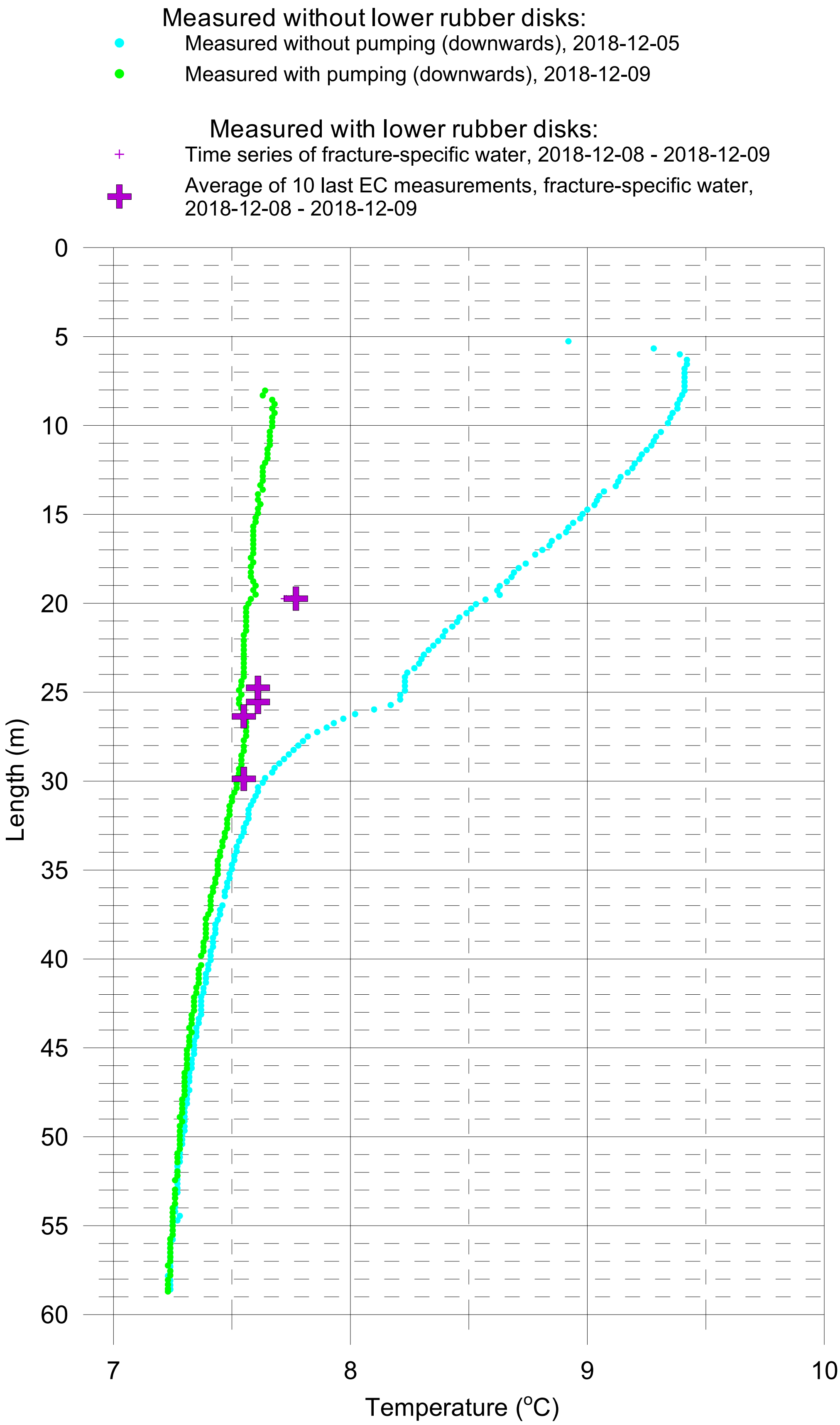
KFM20.1.1–KFM20.1.2 Electrical conductivity of borehole water



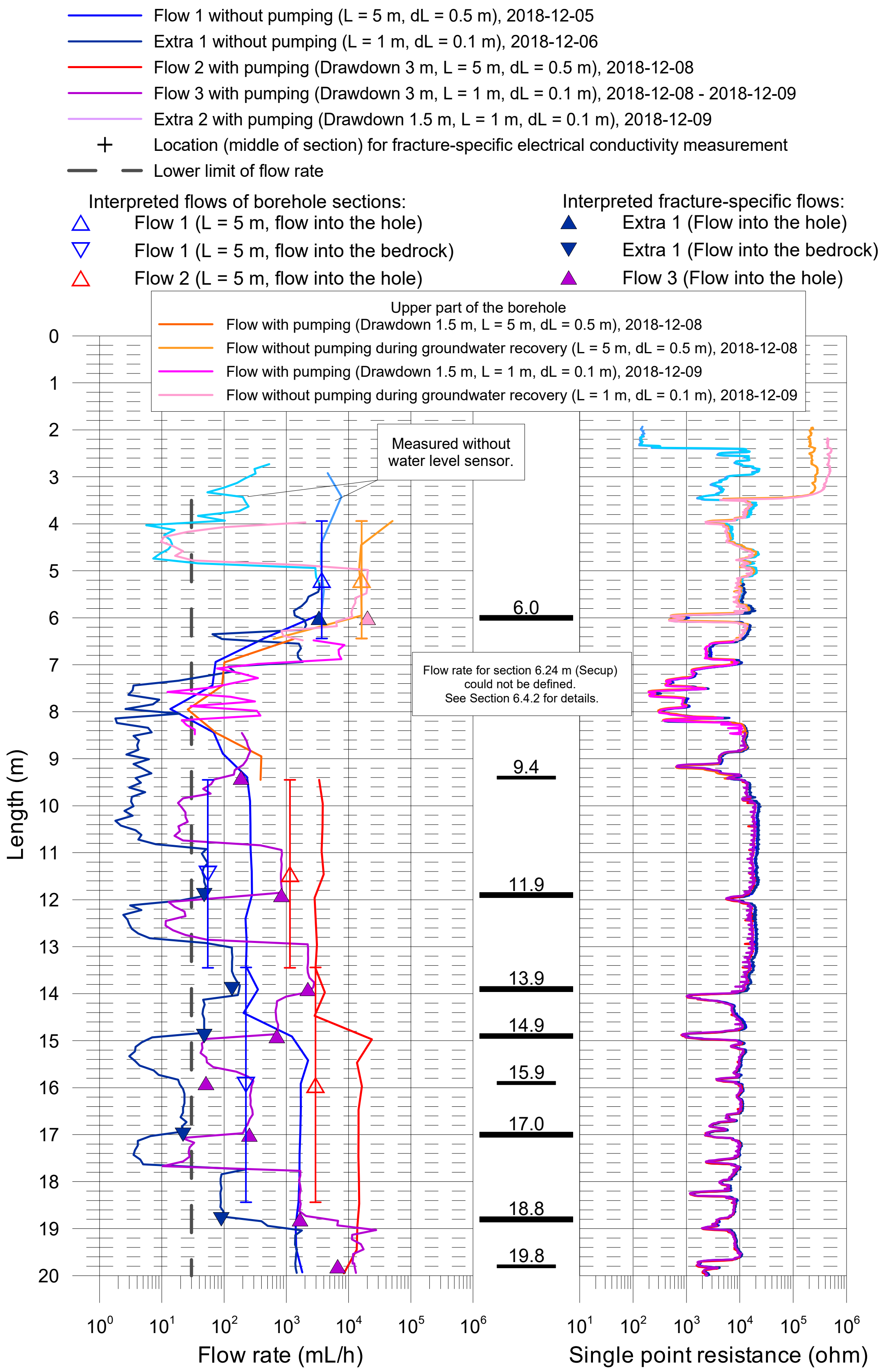


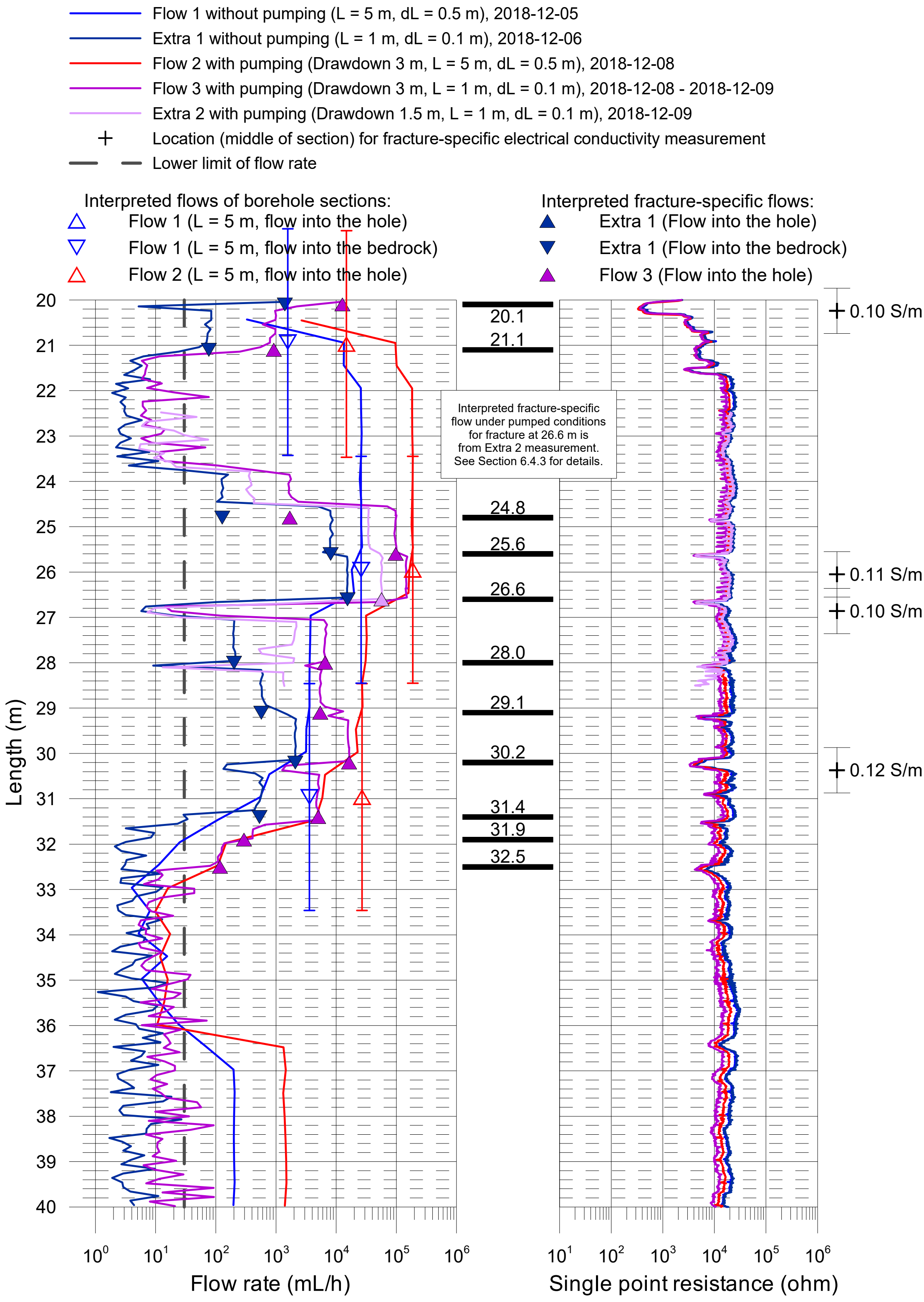
Measured without lower rubber disks:
Measured without pumping (downwards), 2018-12-05
Measured with pumping (downwards), 2018-12-09
Measured with lower rubber disks:
Time series of fracture-specific water, 2018-12-08 - 2018-12-09
Average of 10 last EC measurements, fracture-specific water, 2018-12-08 - 2018-12-09
Length (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
0.01
0.1
1
10
Electrical conductivity (S/m, 25 °C)

KFM20.1.3 Temperature of borehole water

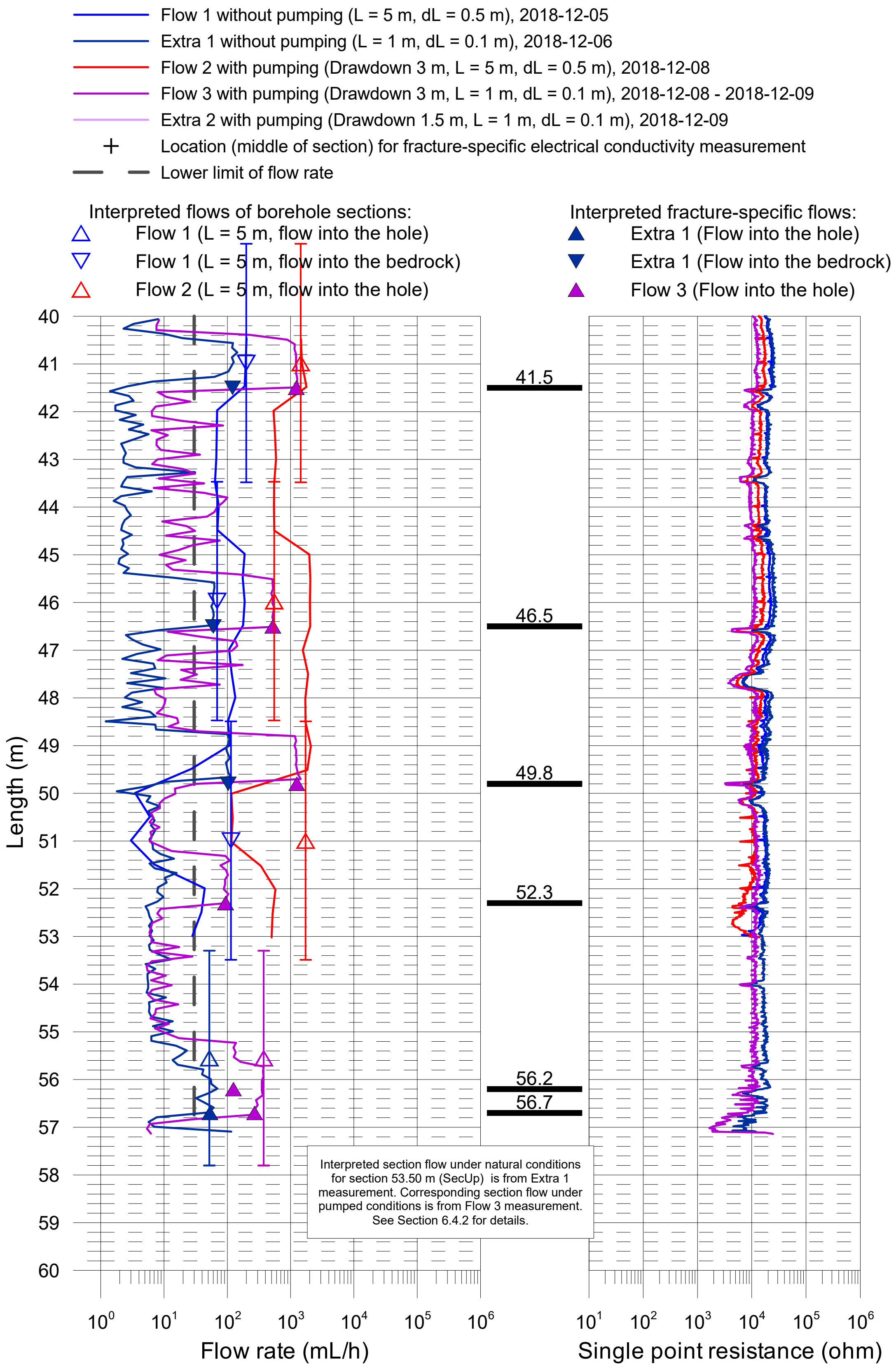


KFM20.2.1–KFM20.2.3 Flow rate and single point resistance



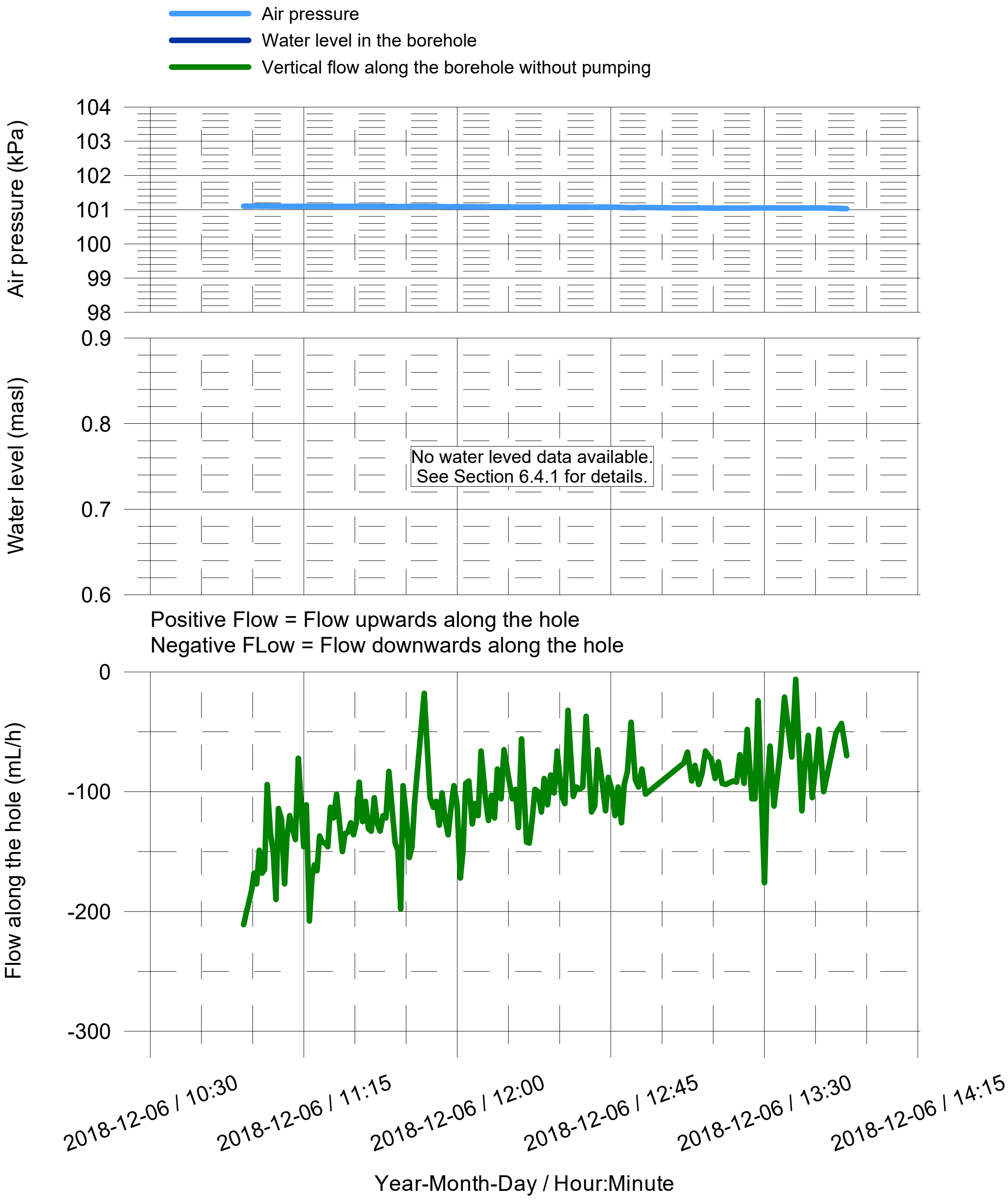


Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-12-05
Extra 1 without pumping (L = 1 m, dL = 0.1 m), 2018-12-06
Flow 2 with pumping (Drawdown 3 m, L = 5 m, dL = 0.5 m), 2018-12-08
Flow 3 with pumping (Drawdown 3 m, L = 1 m, dL = 0.1 m), 2018-12-08 - 2018-12-09
Extra 2 with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-12-09
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Extra 1 (Flow into the hole)
Extra 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Interpreted fracture-specific flow under pumped conditions for fracture at 26.6 m is from Extra 2 measurement. See Section 6.4.3 for details.
20.1
21.1
24.8
25.6
26.6
28.0
29.1
30.2
31.4
31.9
32.5
0.10 S/m
0.11 S/m
0.10 S/m
0.12 S/m
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)



Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-12-05
Extra 1 without pumping (L = 1 m, dL = 0.1 m), 2018-12-06
Flow 2 with pumping (Drawdown 3 m, L = 5 m, dL = 0.5 m), 2018-12-08
Flow 3 with pumping (Drawdown 3 m, L = 1 m, dL = 0.1 m), 2018-12-08 - 2018-12-09
Extra 2 with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-12-09
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Extra 1 (Flow into the hole)
Extra 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
41.5
46.5
49.8
52.3
56.2
56.7
Interpreted section flow under natural conditions for section 53.50 m (SecUp) is from Extra 1 measurement. Corresponding section flow under pumped conditions is from Flow 3 measurement. See Section 6.4.2 for details.
Flow rate (mL/h)
Single point resistance (ohm)

KFM20.2.4 Vertical flow along the borehole at 2.8 m



KFM20.3 Explanations for the tables in Appendices

Header	Unit	Explanations
Borehole ID		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)
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with h=h0 in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid before pumping
h_{1FW}	m.a.s.l.	Corrected hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period
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.
Q-lower limit P	mL/h	Practical lower measurement limit for flow rate.
T-$measl_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-$measl_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-$meas_{lU}$	m^2/s	Estimated upper measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

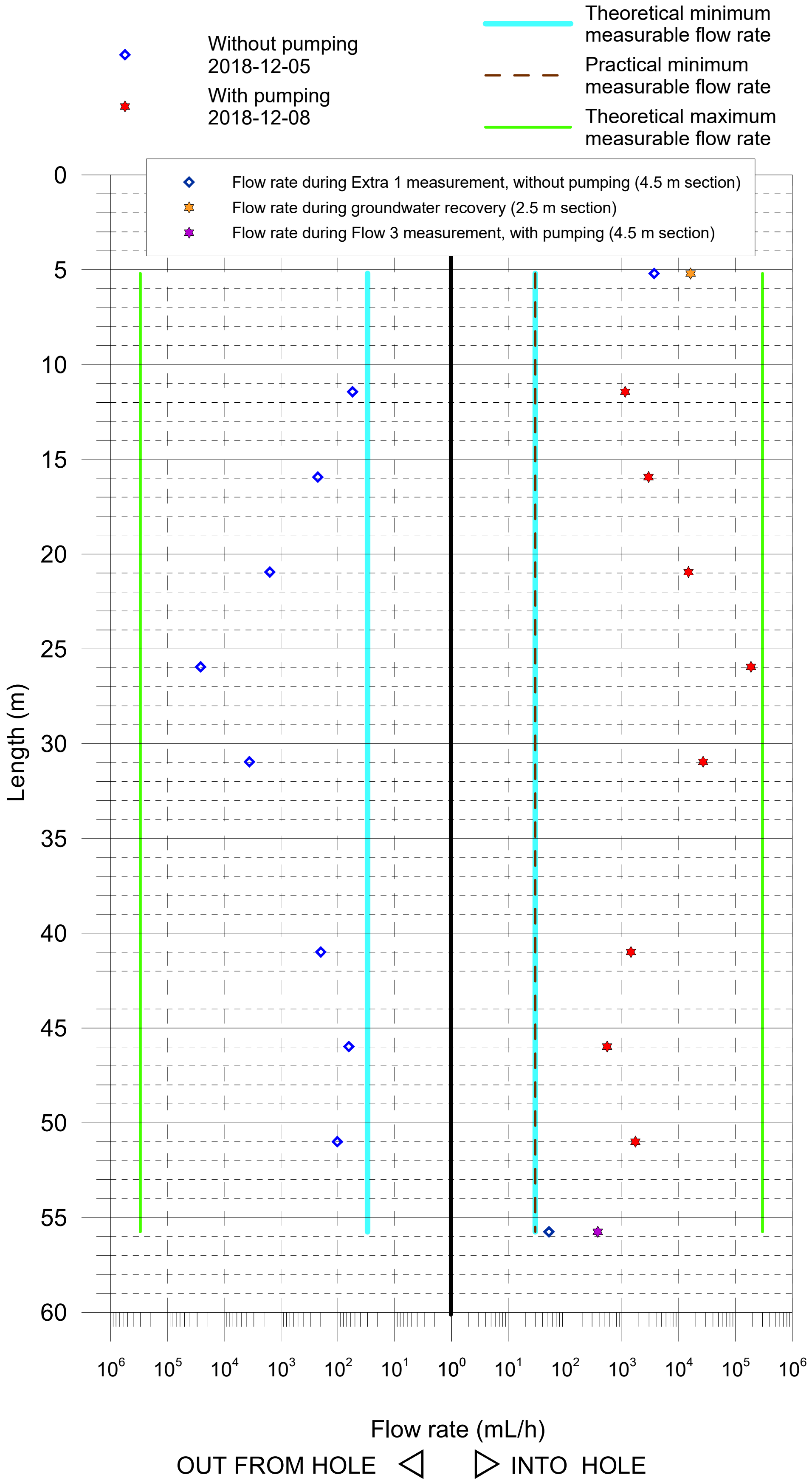
KFM20.4 Results of section flows

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)	T_D-$measl_{LT}$ (m^2/s)	T_D-$measl_{LP}$ (m^2/s)	T_D-$measl_U$ (m^2/s)	Comments
KFM20	3.94	6.44	2.5	1.03E-06	0.73	4.51E-06	−0.55	2.7E-06	1.1	30	6.4E-09	6.4E-09	6.4E-05	*
KFM20	6.45	9.45	3	–	0.70	–	−0.76	–	–	30	5.6E-09	5.6E-09	5.6E-05	
KFM20	9.45	13.45	4	−1.53E-08	0.67	3.17E-07	−2.31	1.1E-07	0.5	30	2.8E-09	2.8E-09	2.8E-05	
KFM20	13.44	18.44	5	−6.25E-08	0.67	8.19E-07	−2.31	2.9E-07	0.5	30	2.8E-09	2.8E-09	2.8E-05	
KFM20	18.45	23.45	5	−4.37E-07	0.63	4.13E-06	−2.30	1.5E-06	0.4	30	2.8E-09	2.8E-09	2.8E-05	
KFM20	23.45	28.45	5	−7.23E-06	0.61	5.21E-05	−1.45	2.9E-05	0.4	30	4.0E-09	4.0E-09	4.3E-05	
KFM20	28.46	33.46	5	−1.00E-06	0.61	7.48E-06	−2.30	2.9E-06	0.3	30	2.8E-09	2.8E-09	2.9E-05	
KFM20	33.47	38.47	5	–	0.62		−2.29	–	–	30	2.8E-09	2.8E-09	2.8E-05	
KFM20	38.49	43.49	5	−5.53E-08	0.60	4.02E-07	−2.29	1.6E-07	0.3	30	2.9E-09	2.9E-09	2.9E-05	
KFM20	43.48	48.48	5	−1.78E-08	0.60	1.53E-07	−2.32	5.8E-08	0.3	30	2.8E-09	2.8E-09	2.8E-05	
KFM20	48.50	53.50	5	−2.83E-08	0.58	4.81E-07	−2.36	1.7E-07	0.4	30	2.8E-09	2.8E-09	2.8E-05	
KFM20	53.50	58.00	4.5	1.44E-08	0.56	1.04E-07	−2.34	3.1E-08	1.0	30	2.8E-09	2.8E-09	2.8E-05	**

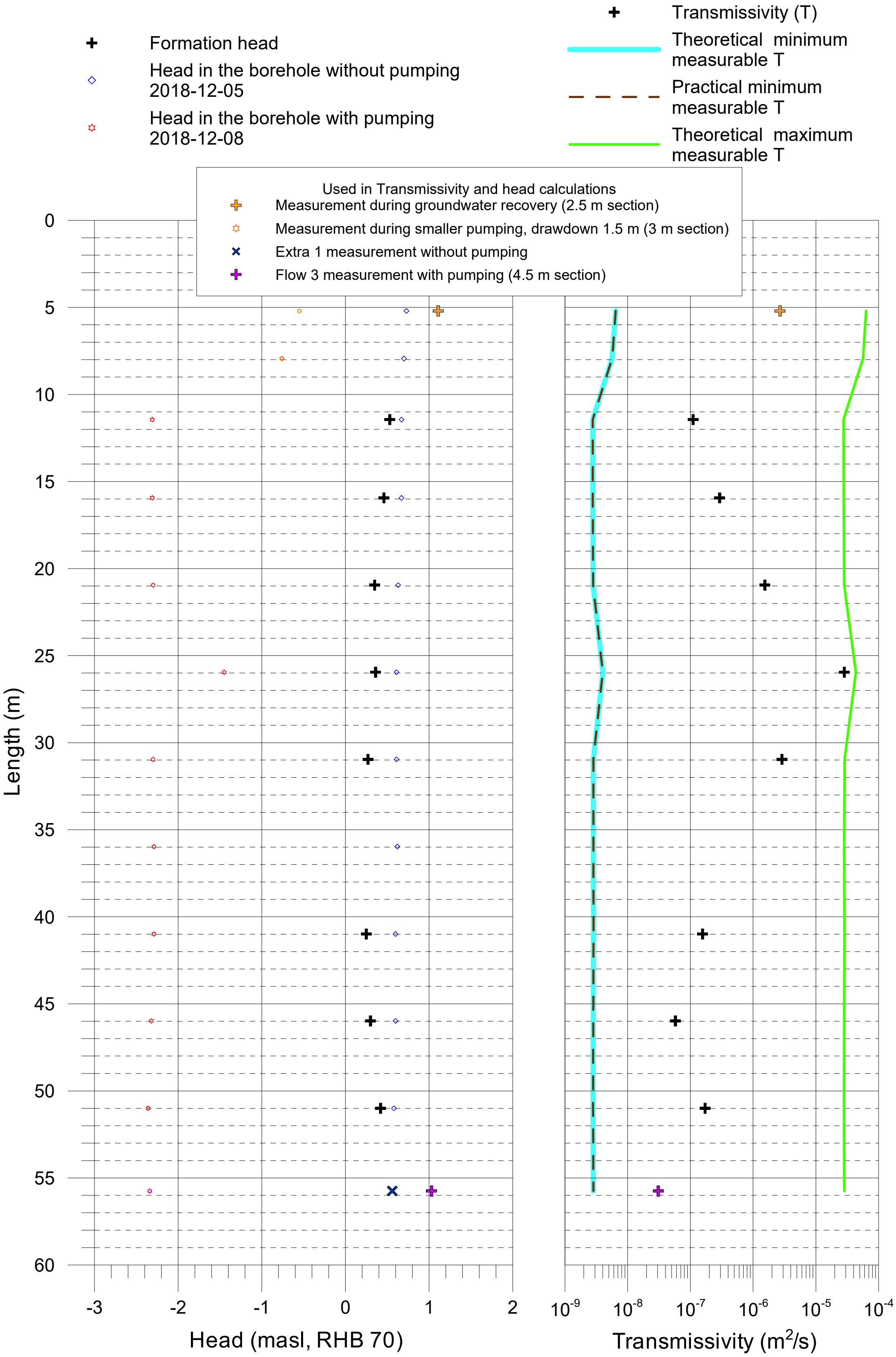
* Values for Flow (Q1) and Head (h1FW) are from the measurement made without pumping, during recovery. The upper part of the borehole could not be measured while pumping the borehole (while the pump remained in the borehole).

** Values for Flow (Q0) and Head (h0FW) are from Extra 1 measurement. Values for Flow (Q1) and Head (h1FW) are from the Flow 3 measurement.

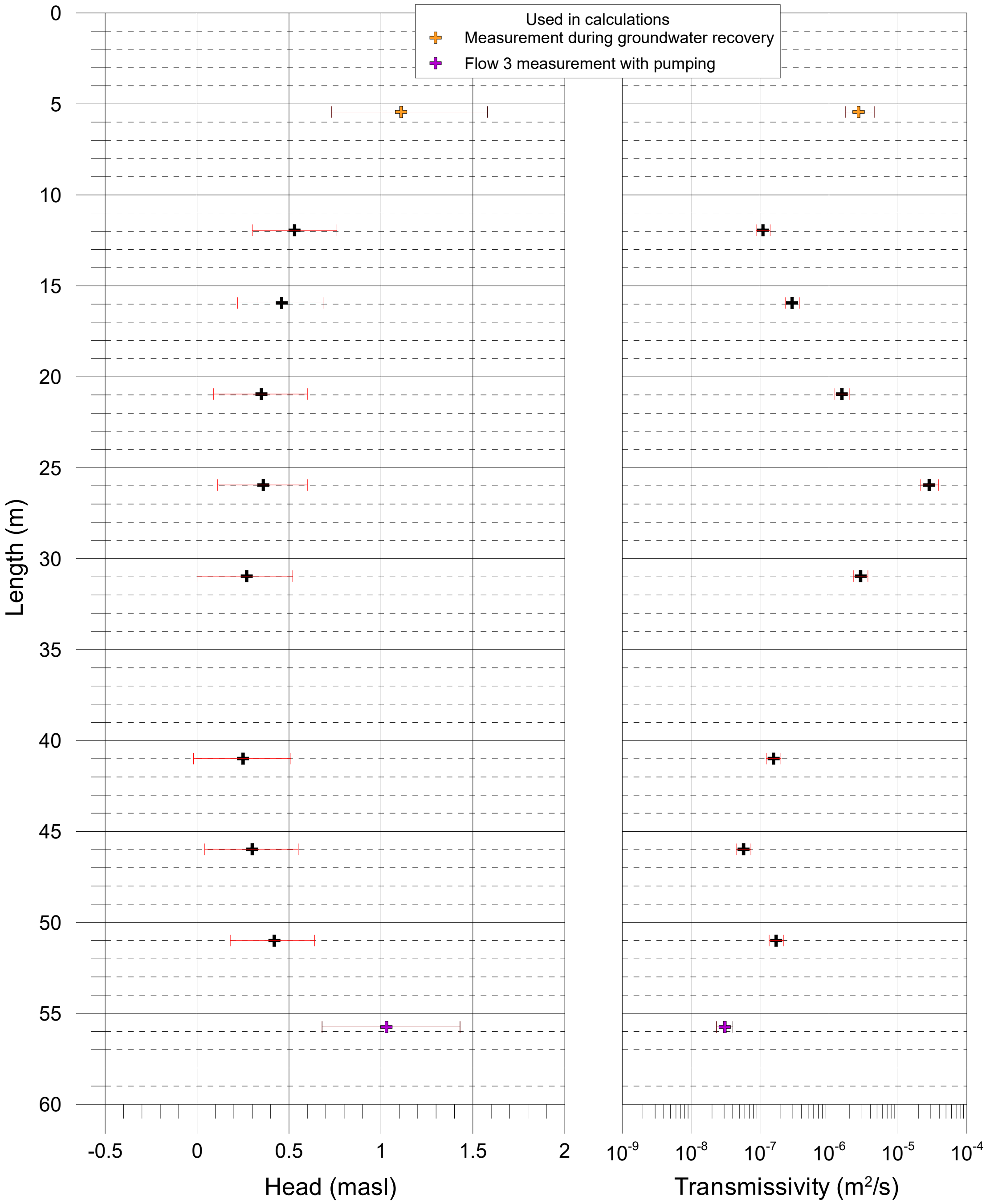
KFM20.5.1 Plotted flow rates of 5 m sections



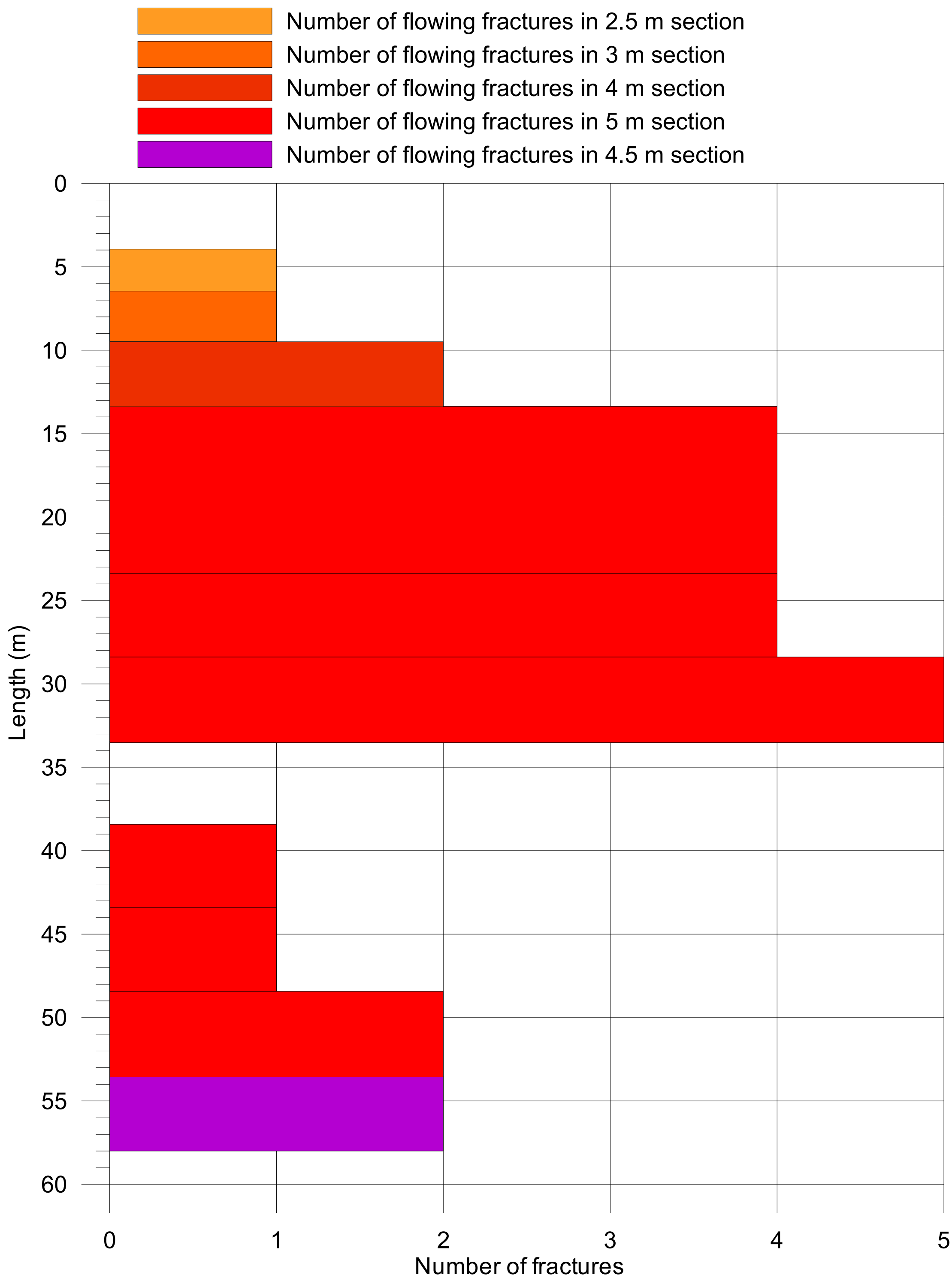
KFM20.5.2 Plotted transmissivity and head of 5 m sections



KFM20.5.3 Transmissivity and head of 5 m sections with calculated error limits



KFM20.5.4 Conductive fracture frequency



KFM20.6 Inferred fracture flow anomalies from 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
KFM20	6.0	1	0.1	9.31E−07	0.65	5.58E-06	−0.63	3.6E-06	0.9	**
KFM20	9.4	1	0.1	–	0.66	5.19E-08	−2.27	1.8E-08	–	*
KFM20	11.9	1	0.1	−1.33E−08	0.66	2.32E-07	−2.27	8.3E-08	0.5	
KFM20	13.9	1	0.1	−3.72E−08	0.66	6.17E-07	−2.28	2.2E-07	0.5	
KFM20	14.9	1	0.1	−1.33E−08	0.65	1.96E-07	−2.29	7.0E-08	0.5	
KFM20	15.9	1	0.1	–	0.65	1.42E-08	−2.29	4.8E-09	–	*
KFM20	17.0	1	0.1	−6.11E−09	0.64	7.06E-08	−2.29	2.6E-08	0.4	
KFM20	18.8	1	0.1	−2.50E−08	0.63	4.61E-07	−2.26	1.7E-07	0.5	
KFM20	19.8	1	0.1	–	0.63	1.86E-06	−2.32	6.2E-07	–	*
KFM20	20.1	1	0.1	−3.92E−07	0.64	3.53E-06	−2.34	1.3E-06	0.3	
KFM20	21.1	1	0.1	−2.14E−08	0.61	2.55E-07	−2.30	9.4E-08	0.4	
KFM20	24.8	1	0.1	−3.56E−08	0.61	4.69E-07	−2.34	1.7E-07	0.4	
KFM20	25.6	1	0.1	−2.25E−06	0.62	2.71E-05	−2.09	1.1E-05	0.4	
KFM20	26.6	1	0.1	−4.28E−06	0.62	1.58E-05	−0.78	1.4E-05	0.3	***
KFM20	28.0	1	0.1	−5.58E−08	0.63	1.82E-06	−2.35	6.2E-07	0.5	
KFM20	29.1	1	0.1	−1.58E−07	0.62	1.51E-06	−2.34	5.6E-07	0.3	
KFM20	30.2	1	0.1	−5.81E−07	0.60	4.56E-06	−2.35	1.7E-06	0.3	
KFM20	31.4	1	0.1	−1.48E−07	0.61	1.40E-06	−2.34	5.2E-07	0.3	
KFM20	31.9	1	0.1	–	0.61	8.17E-08	−2.36	2.7E-08	–	
KFM20	32.5	1	0.1	–	0.61	3.25E-08	−2.35	1.1E-08	–	
KFM20	41.5	1	0.1	−3.36E−08	0.57	3.42E-07	−2.34	1.3E-07	0.3	
KFM20	46.5	1	0.1	−1.67E−08	0.58	1.46E-07	−2.35	5.5E-08	0.3	
KFM20	49.8	1	0.1	−2.86E−08	0.57	3.47E-07	−2.35	1.3E-07	0.4	
KFM20	52.3	1	0.1	–	0.56	2.61E-08	−2.34	8.9E-09	–	
KFM20	56.2	1	0.1	–	0.54	3.47E-08	−2.41	1.2E-08	–	
KFM20	56.7	1	0.1	1.47E−08	0.54	7.50E-08	−2.39	2.0E-08	1.3	

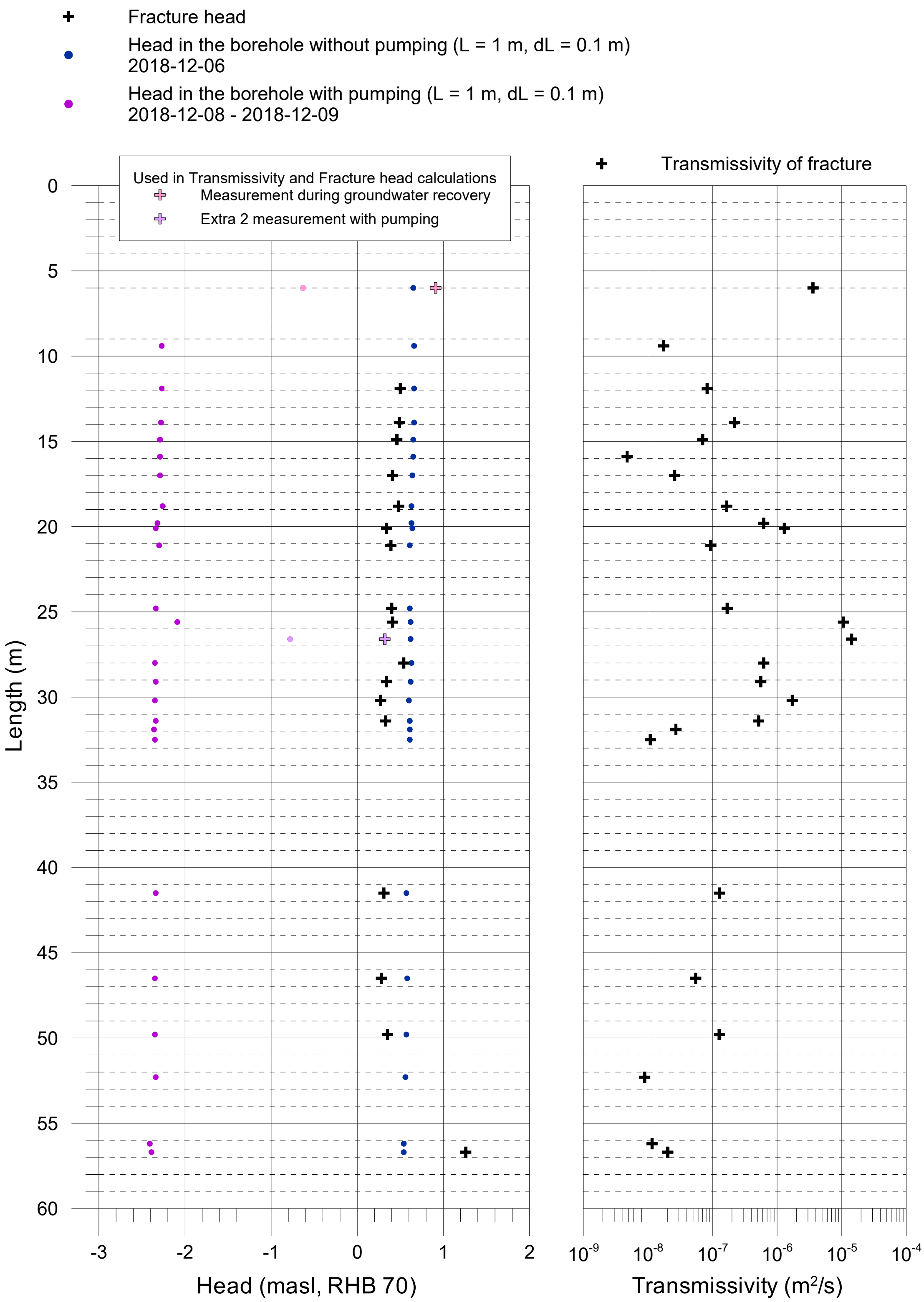
* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

** Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made without pumping, during recovery. The upper part of the borehole could not be measured while pumping (while the pump remained in the borehole).

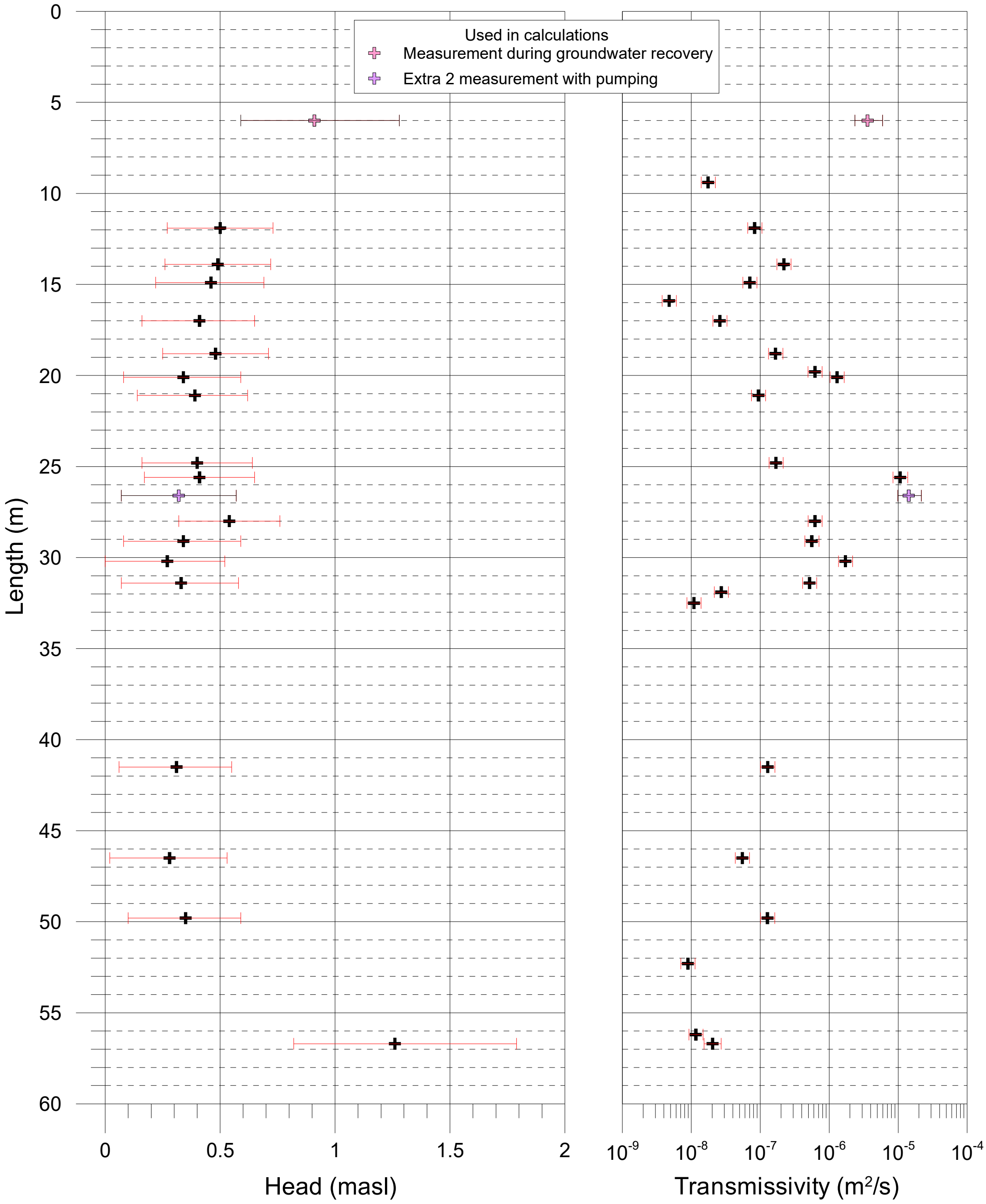
*** Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made with smaller pumping (drawdown 1.5 m) because flow rate was near the upper measurement limit during 3 m drawdown in Flow3 measurement.

**** All Values for Flow (Q_0) and Head (h_{0FW}) are from Extra 1 measurement.

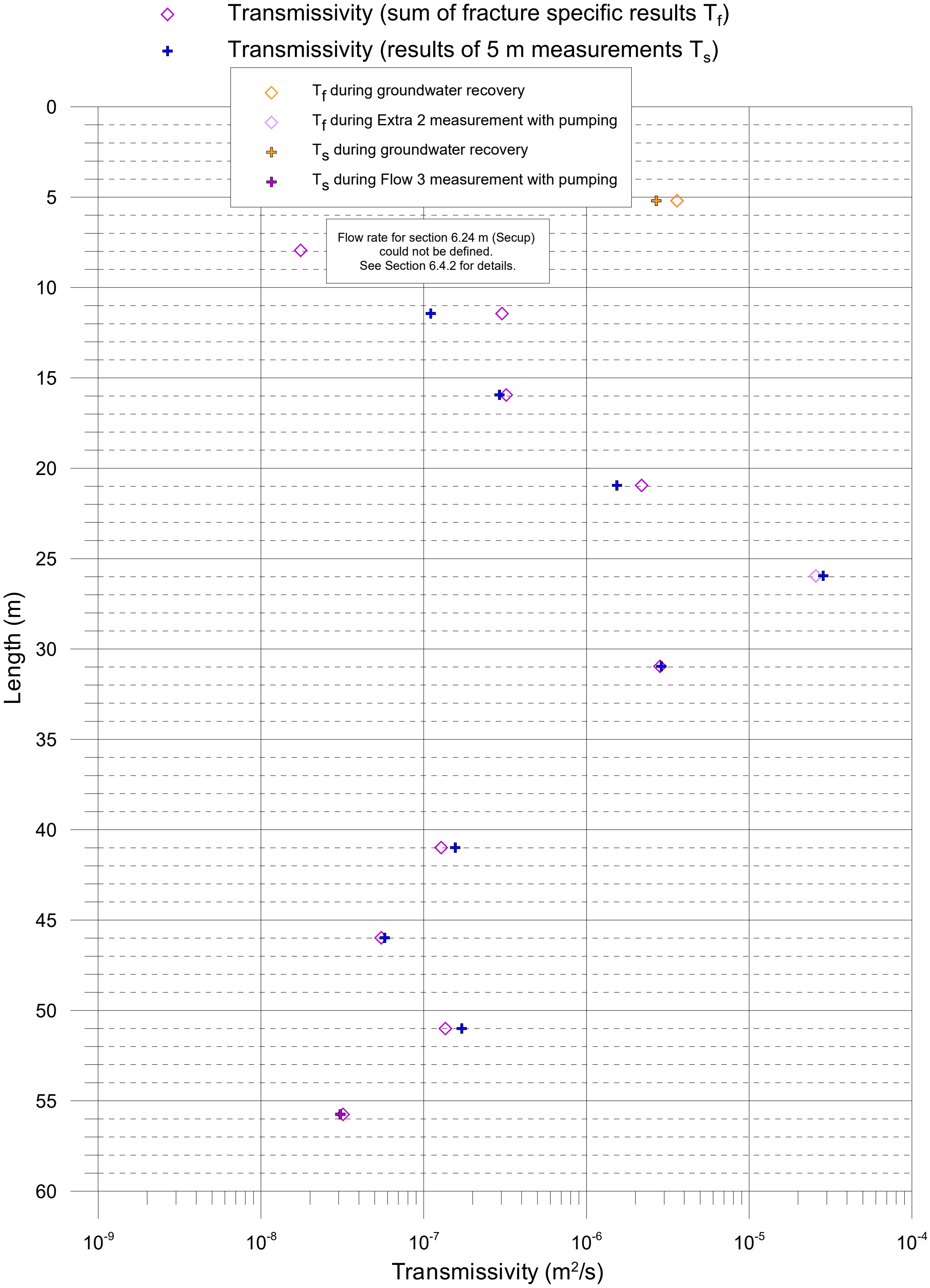
KFM20.7.1 Plotted transmissivity and head of detected fractures



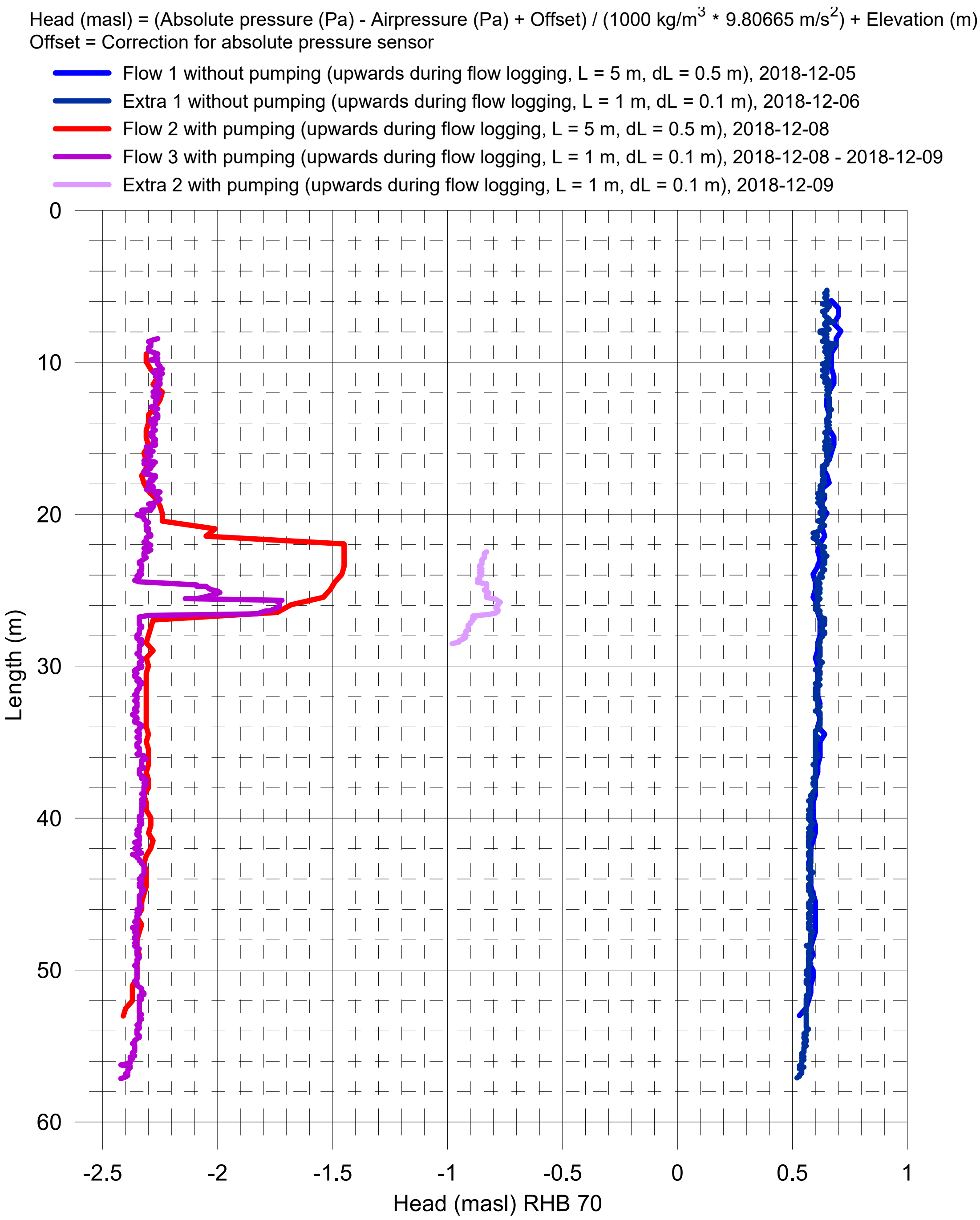
KFM20.7.2 Transmissivity and head of detected fractures with calculated error limits.



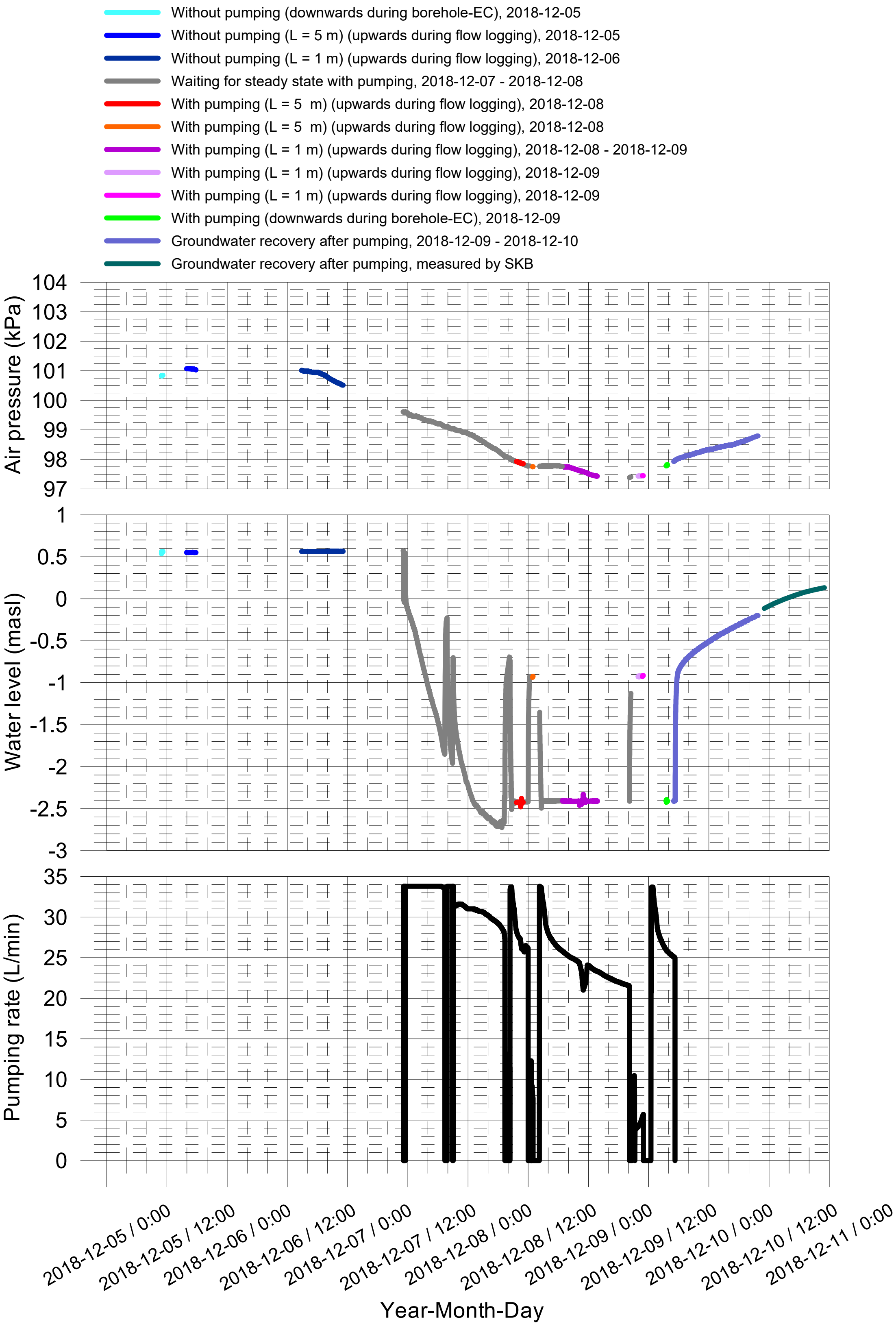
KFM20.8 Comparison between section transmissivity and fracture transmissivity



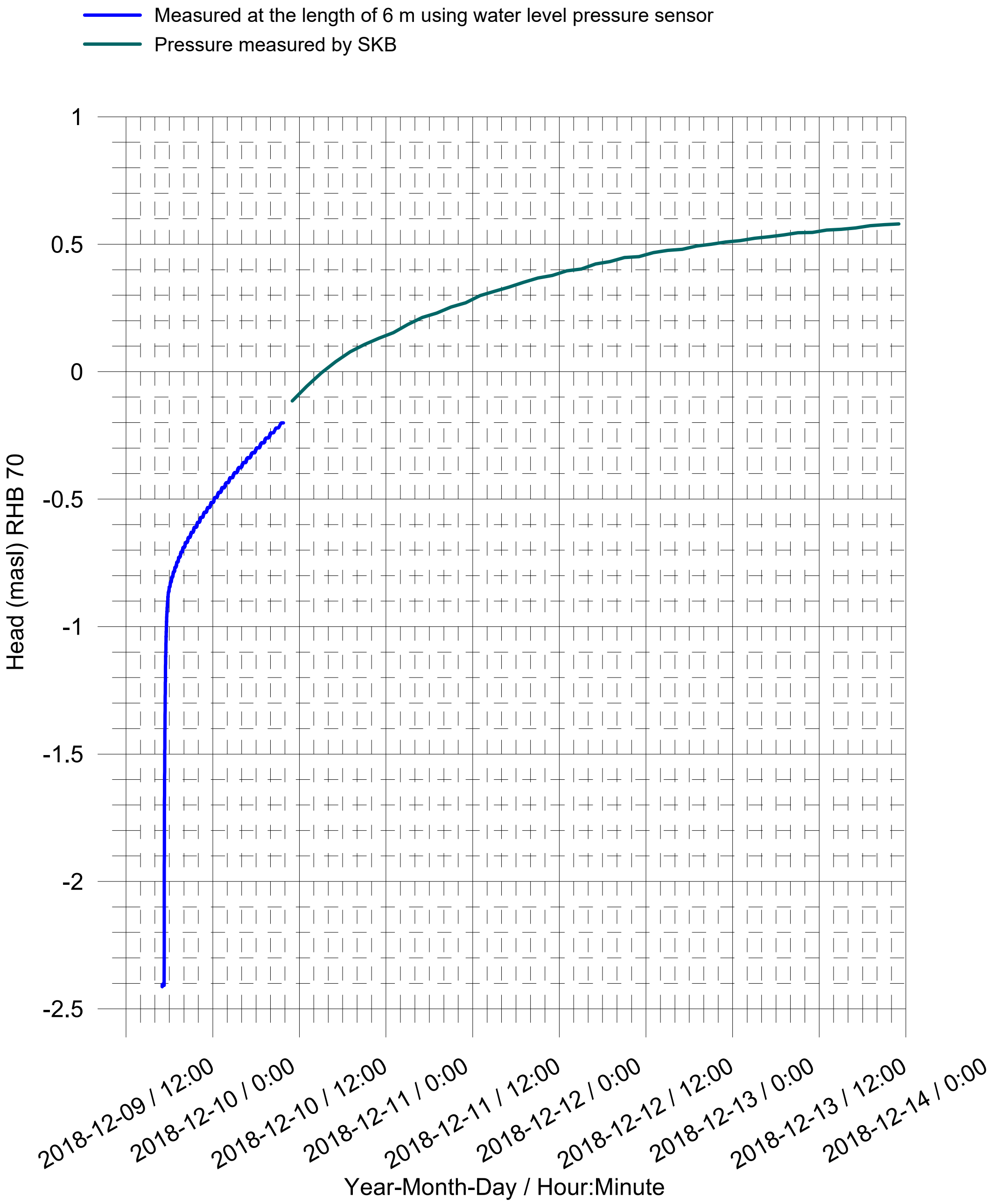
KFM20.9.1 Head in the borehole during flow logging



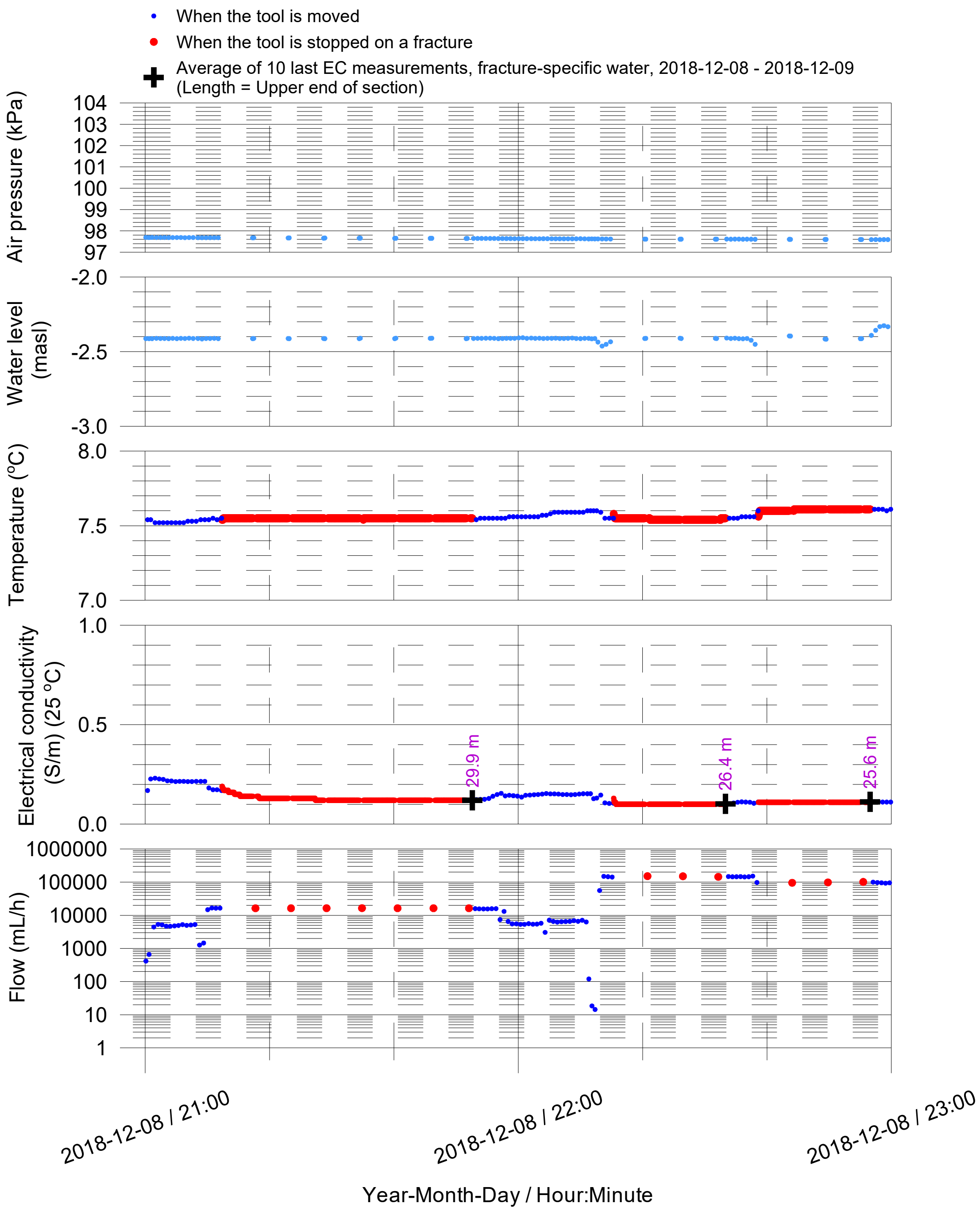
KFM20.9.2 Air pressure, water level in the borehole and pumping rate during flow logging

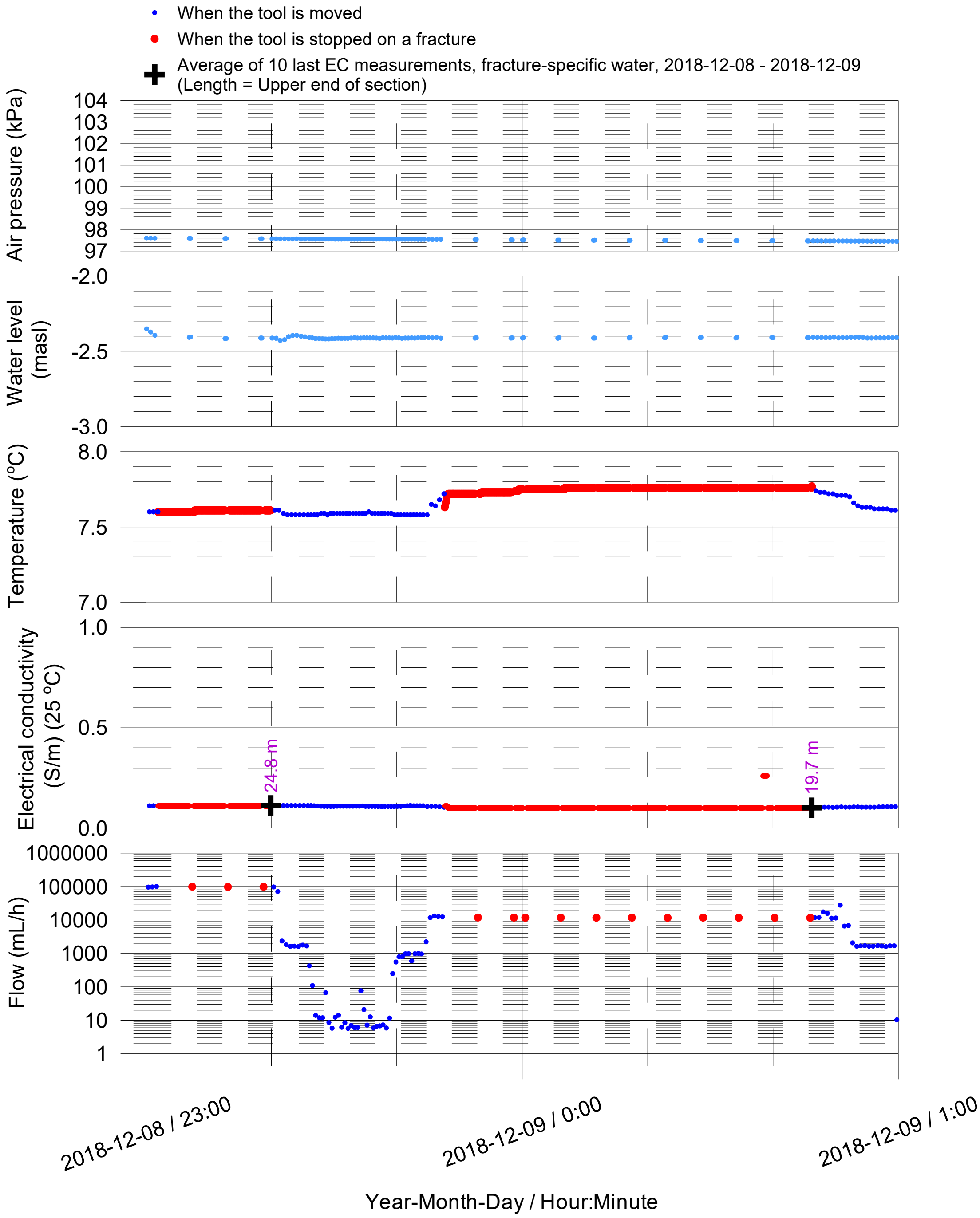


KFM20.9.3 Groundwater recovery after pumping



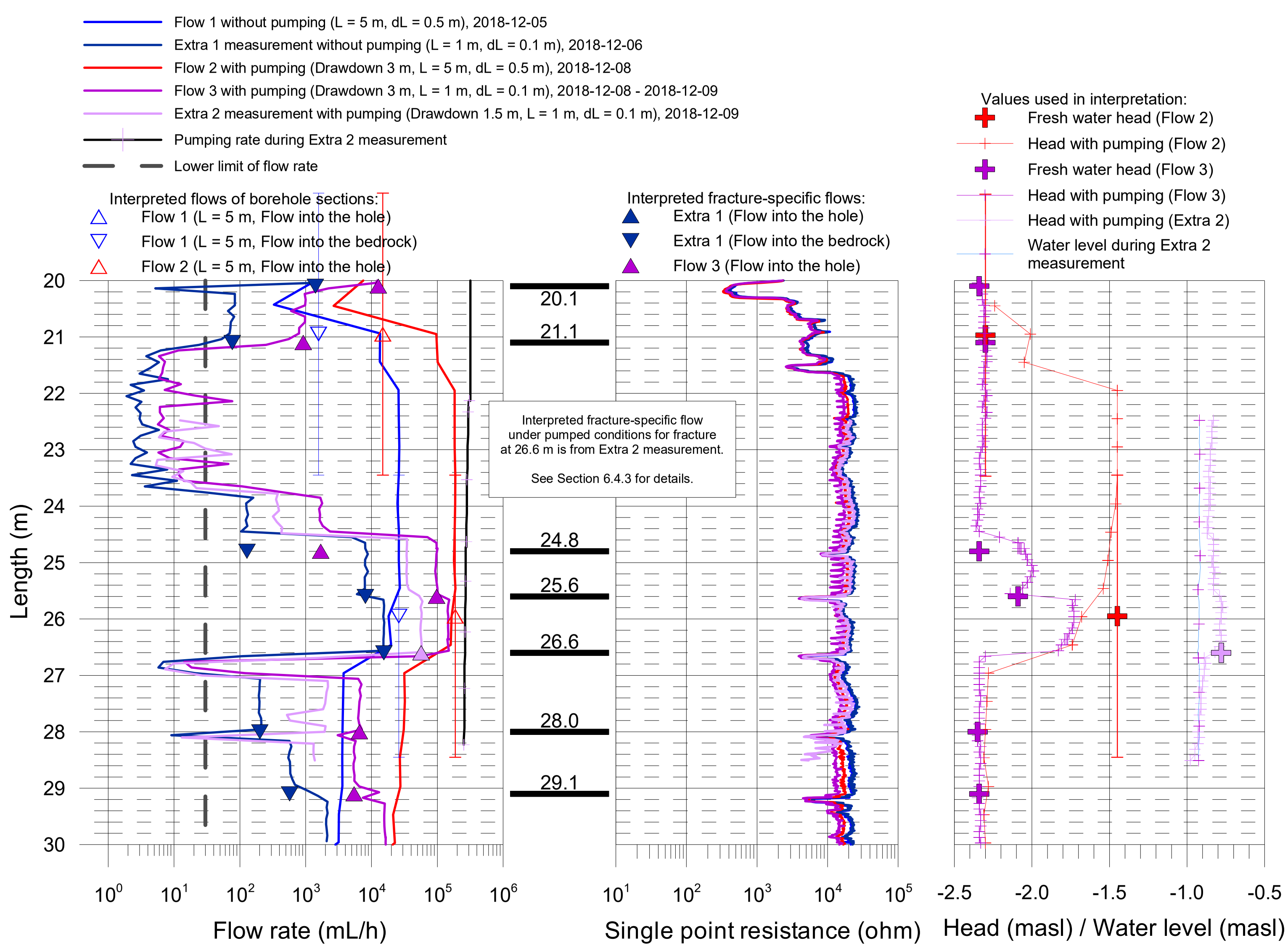
KFM20.10.1–KFM20.10.2 Fracture-specific EC results by date



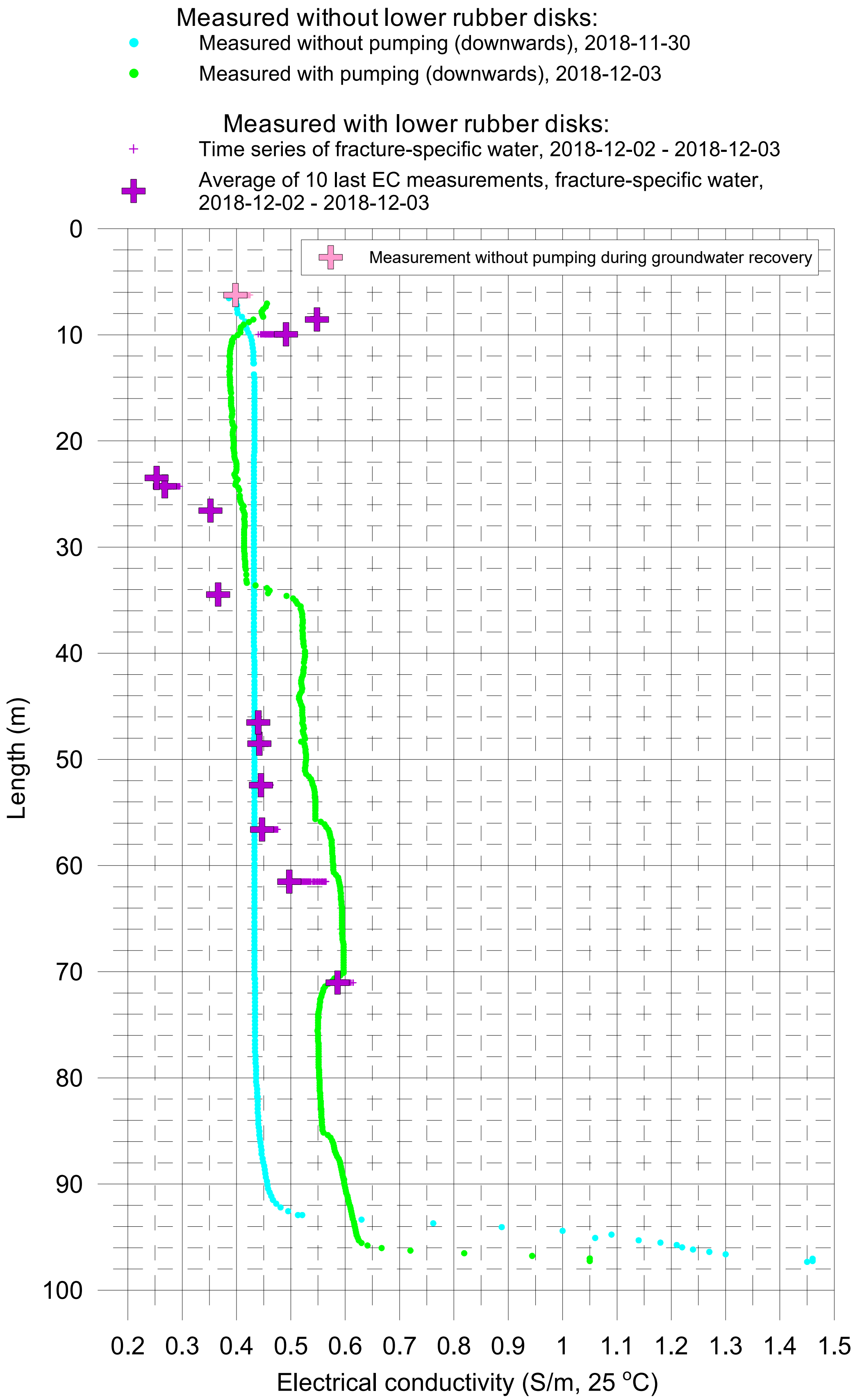


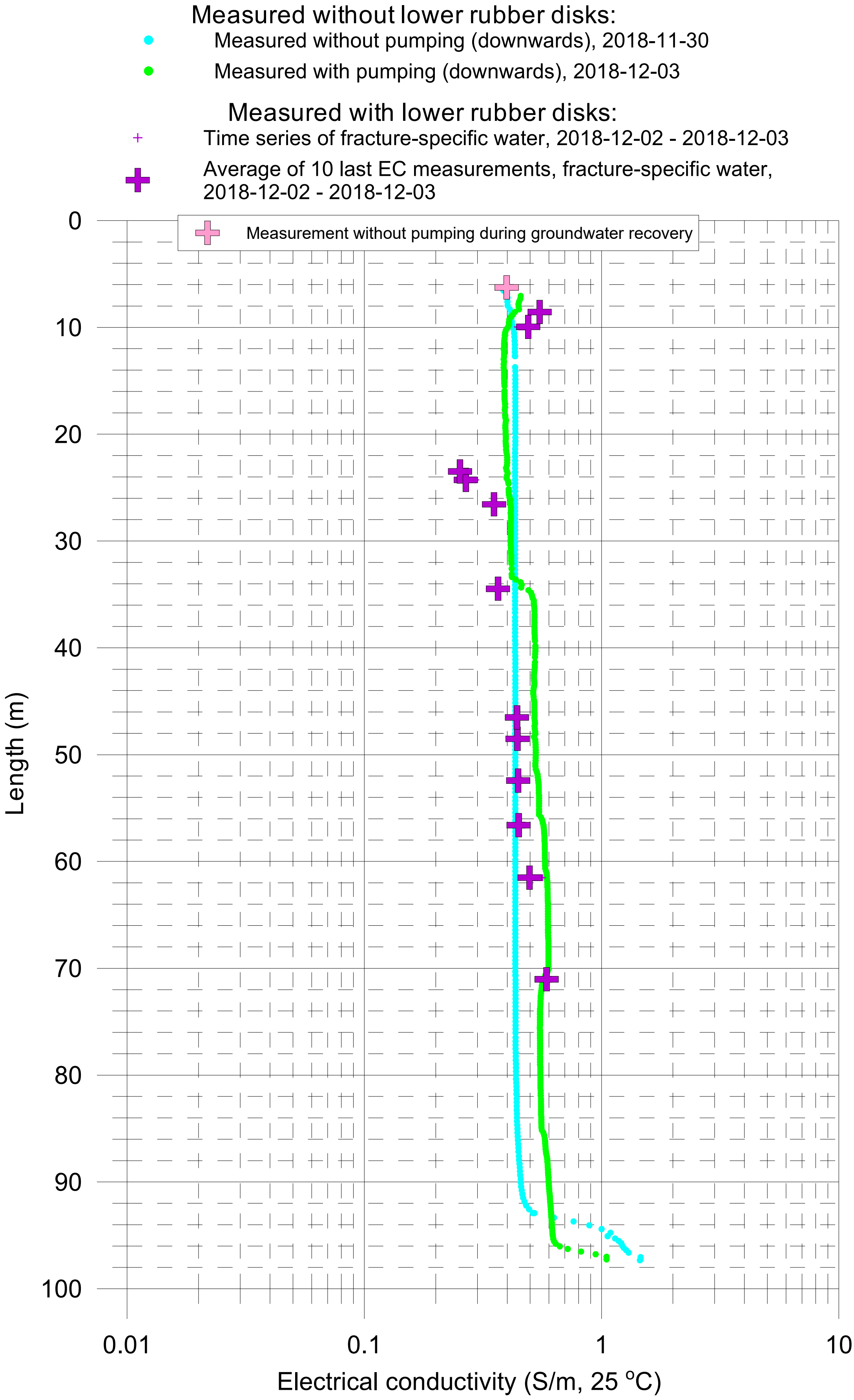
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-12-08 - 2018-12-09 (Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
97
Water level (masl)
-2.0
-2.5
-3.0
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
24.8 m
19.7 m
Flow (mL/h)
1000000
100000
10000
1000
100
10
1
2018-12-08 / 23:00
2018-12-09 / 0:00
2018-12-09 / 1:00
Year-Month-Day / Hour:Minute

KFM20.11 Flow rate, single point resistance and head in the borehole during flow logging



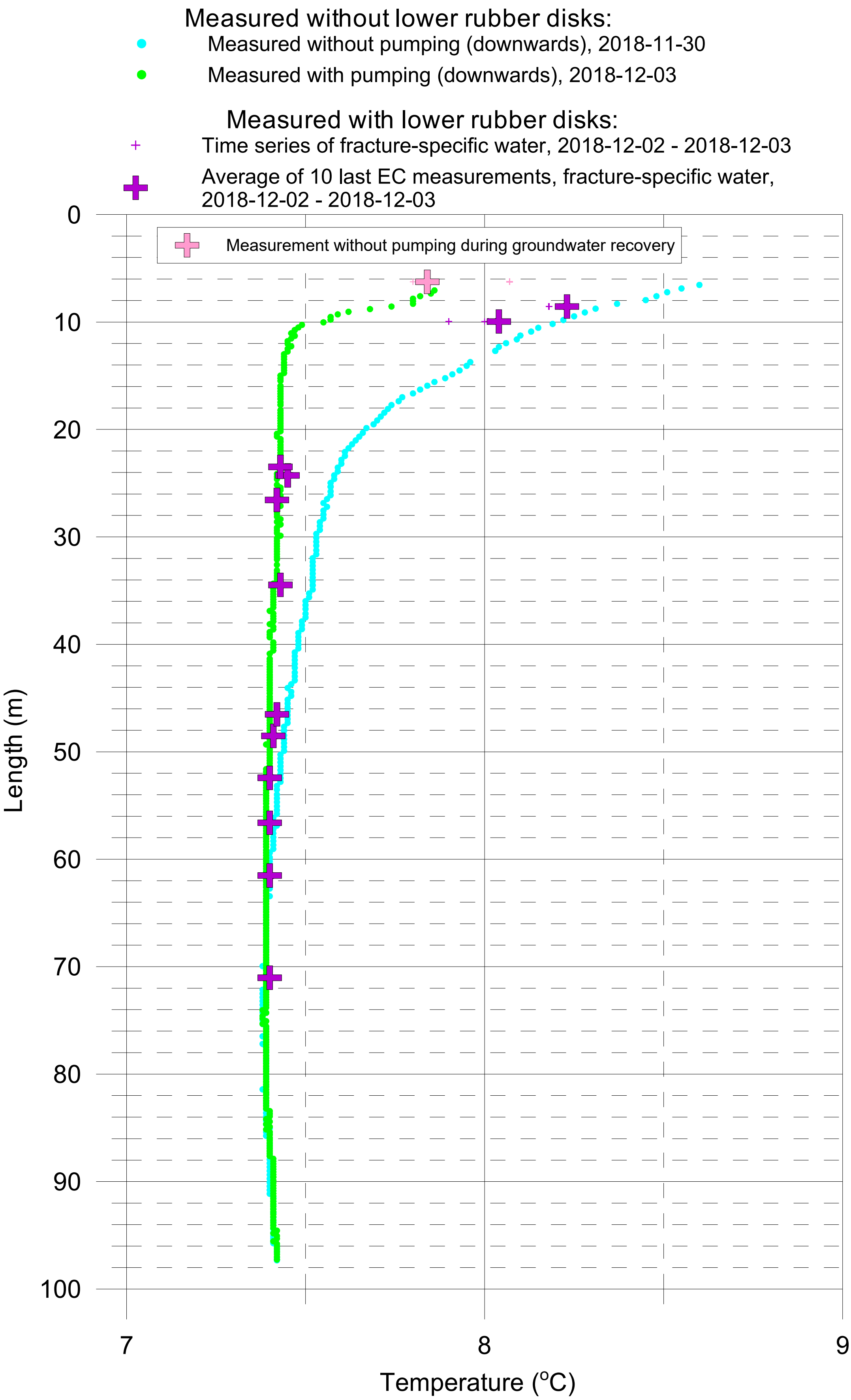
KFM21.1.1–KFM21.1.2 Electrical conductivity of borehole water



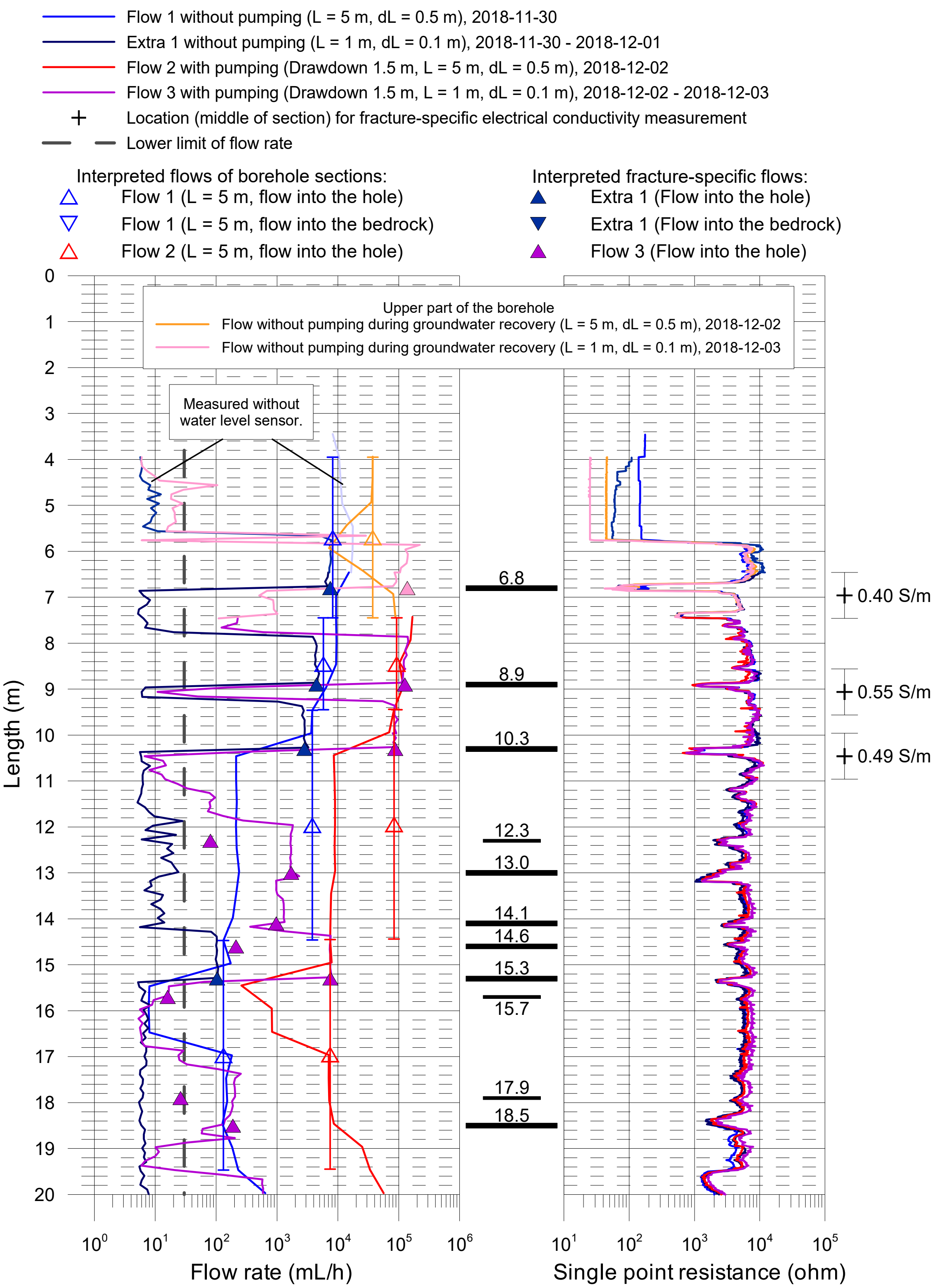


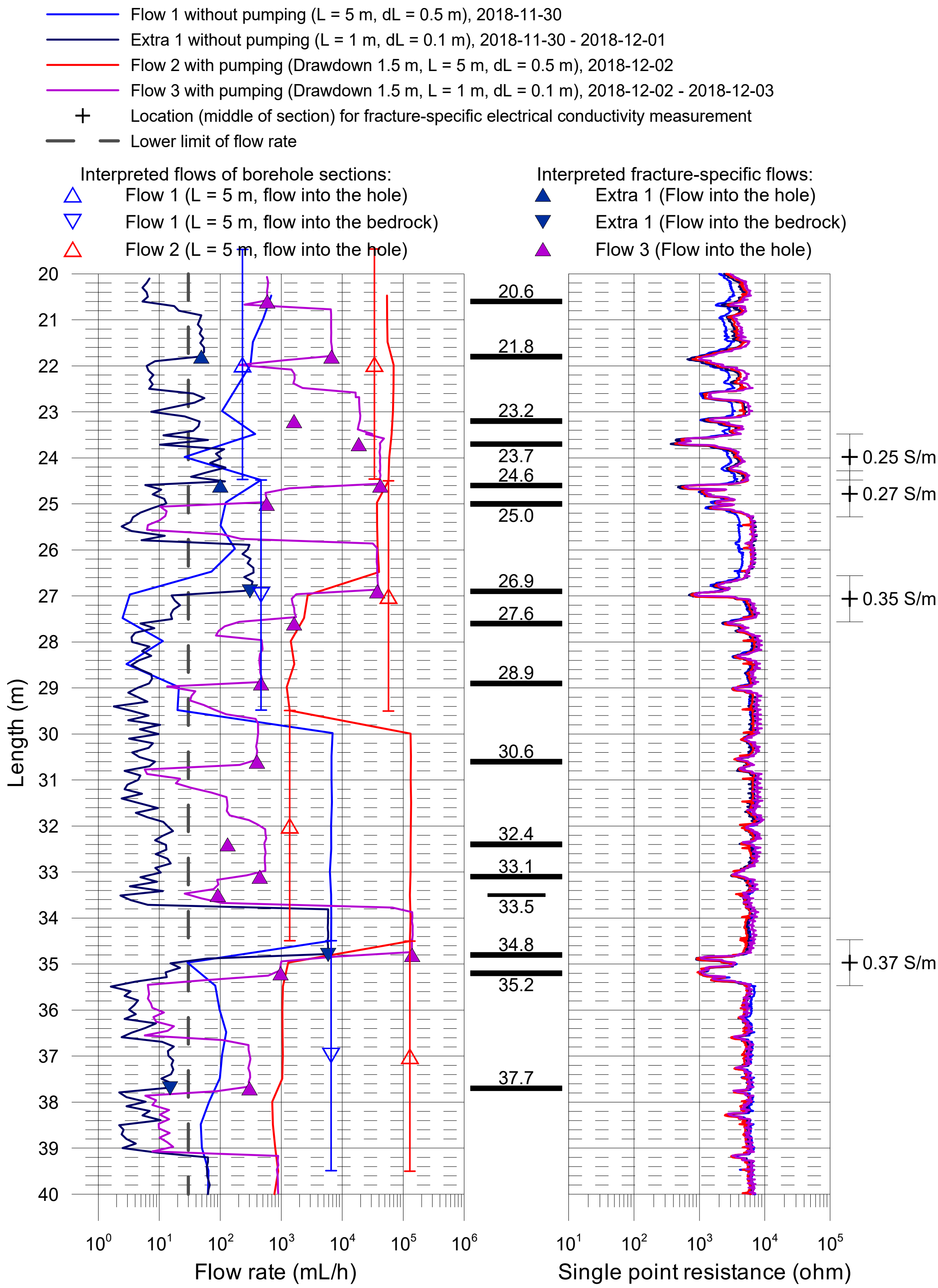
Measured without lower rubber disks:
Measured without pumping (downwards), 2018-11-30
Measured with pumping (downwards), 2018-12-03
Measured with lower rubber disks:
Time series of fracture-specific water, 2018-12-02 - 2018-12-03
Average of 10 last EC measurements, fracture-specific water, 2018-12-02 - 2018-12-03
Measurement without pumping during groundwater recovery
Length (m)
0
10
20
30
40
50
60
70
80
90
100
0.01
0.1
1
10
Electrical conductivity (S/m, 25 °C)

KFM21.1.3 Temperature of borehole water

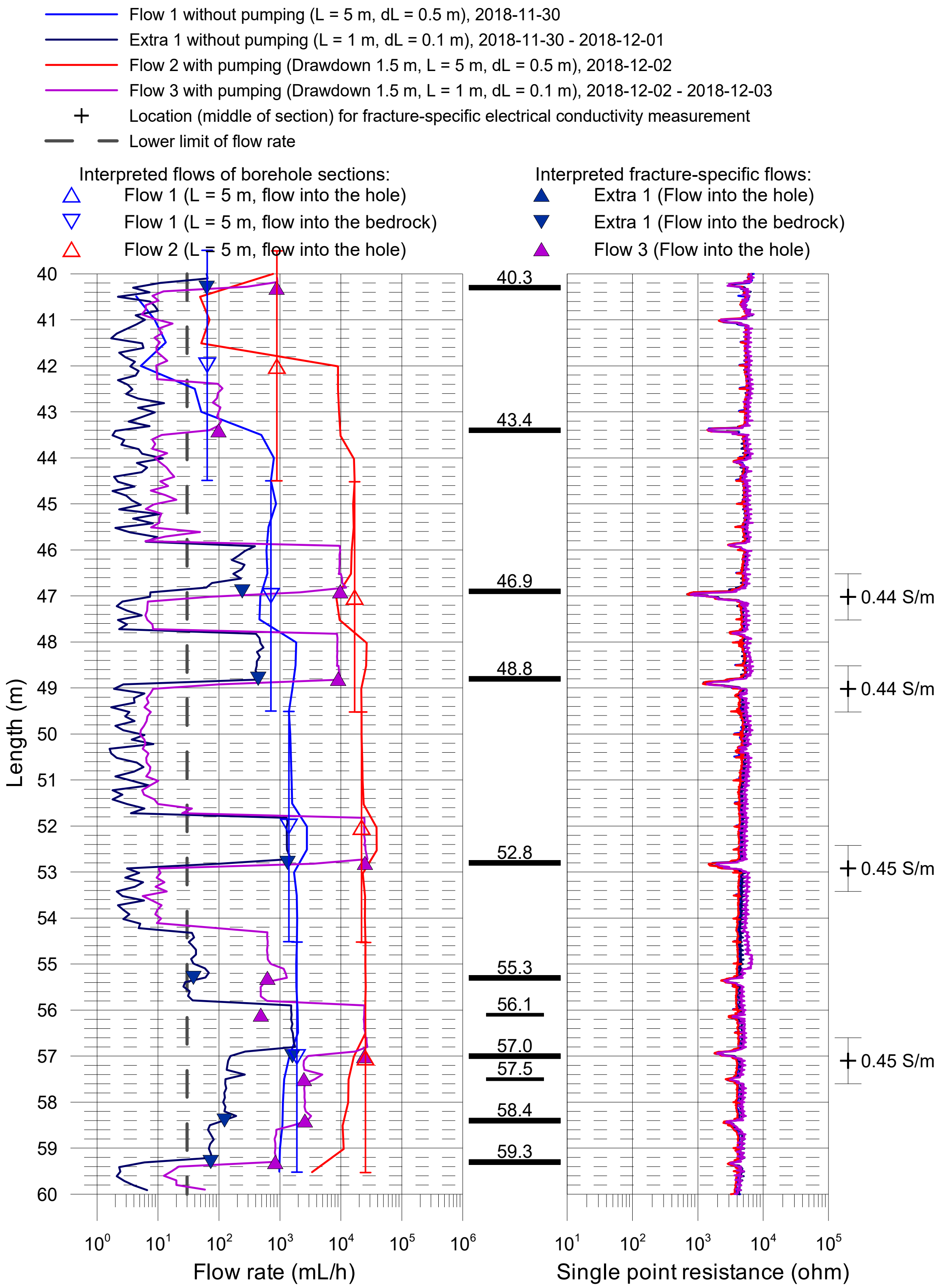


KFM21.2.1–KFM21.2.5 Flow rate and single point resistance

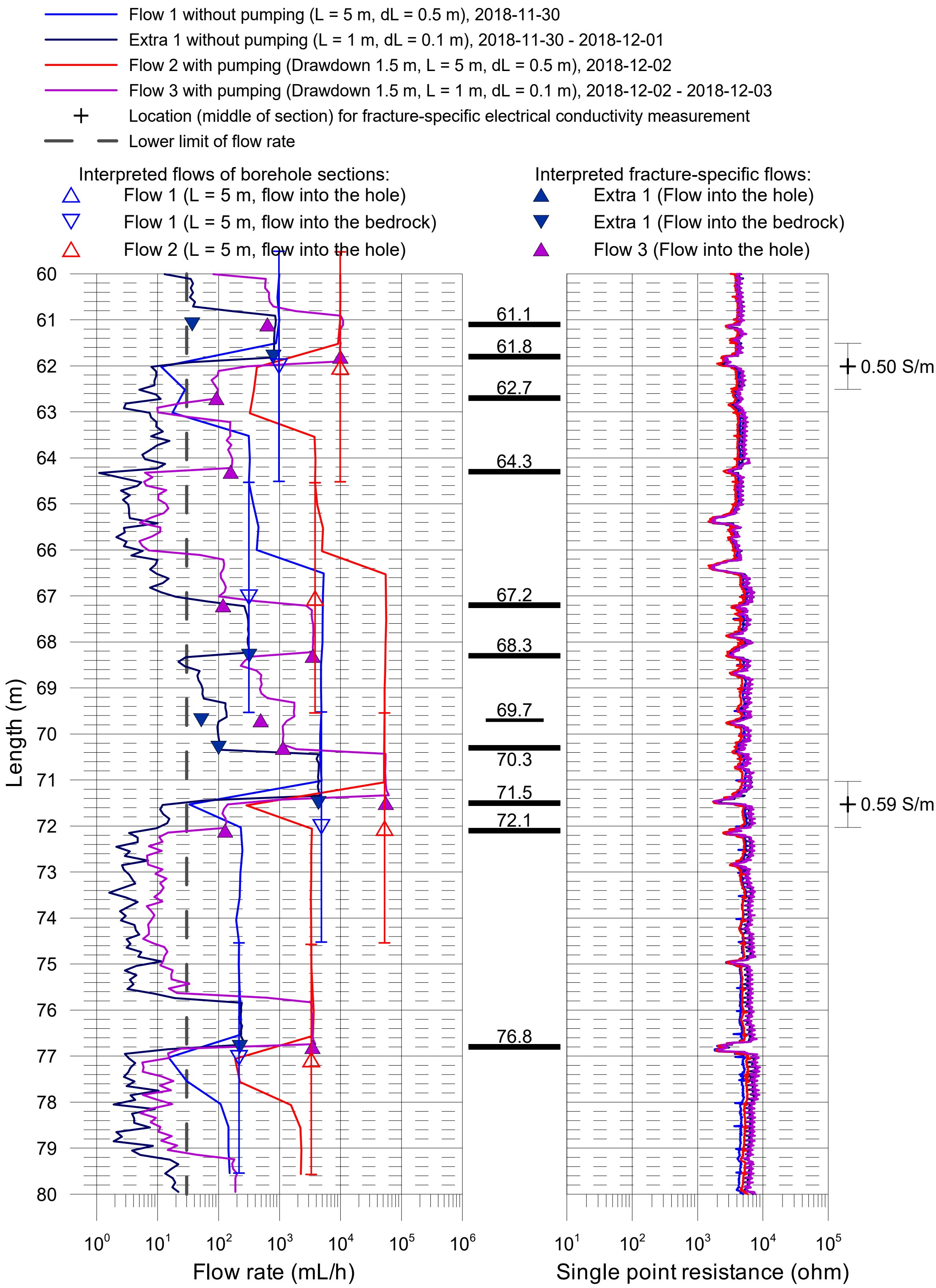




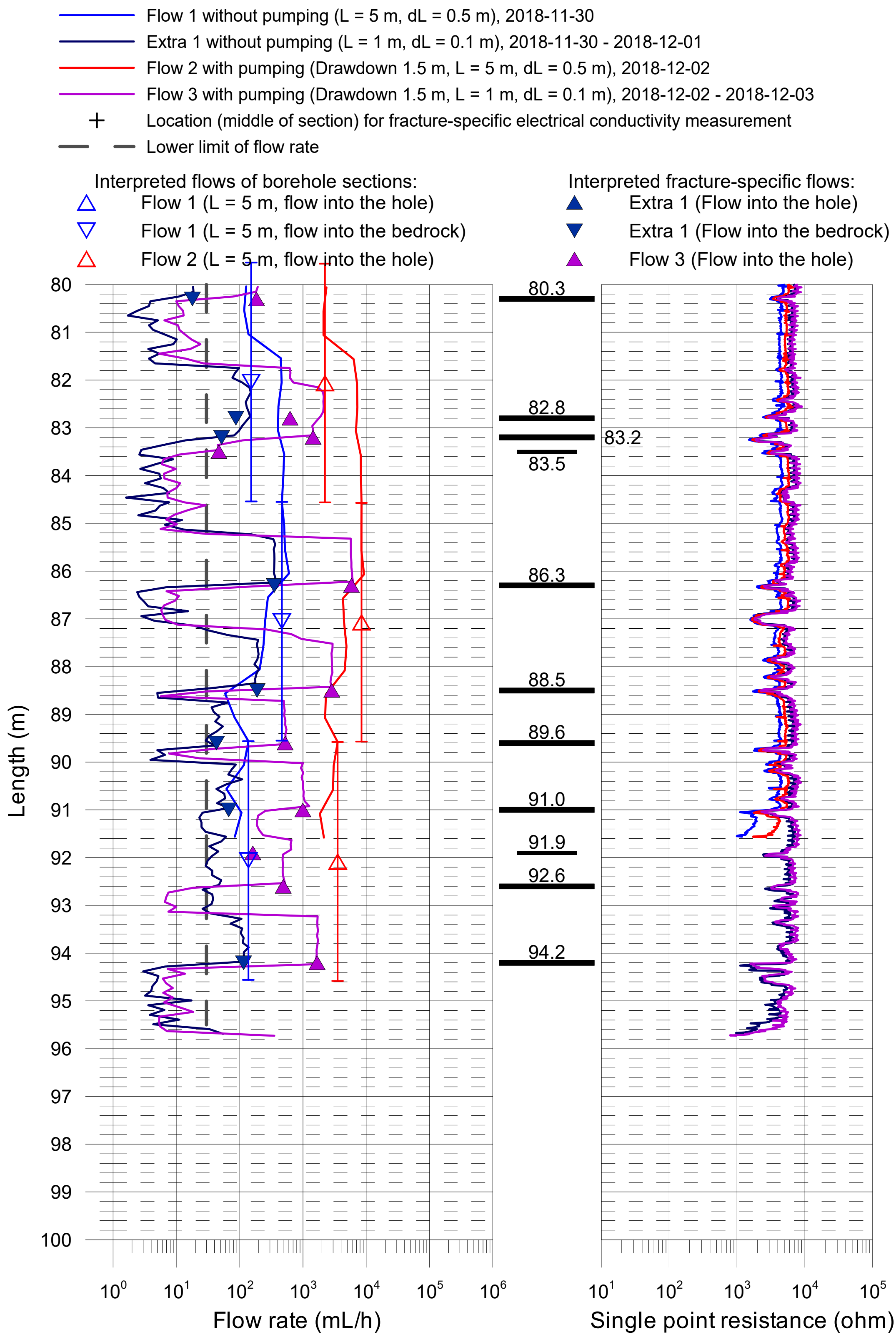
Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-30
Extra 1 without pumping (L = 1 m, dL = 0.1 m), 2018-11-30 - 2018-12-01
Flow 2 with pumping (Drawdown 1.5 m, L = 5 m, dL = 0.5 m), 2018-12-02
Flow 3 with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-12-02 - 2018-12-03
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Extra 1 (Flow into the hole)
Extra 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
20.6
21.8
23.2
23.7
24.6
25.0
26.9
27.6
28.9
30.6
32.4
33.1
33.5
34.8
35.2
37.7
0.25 S/m
0.27 S/m
0.35 S/m
0.37 S/m
Flow rate (mL/h)
Single point resistance (ohm)



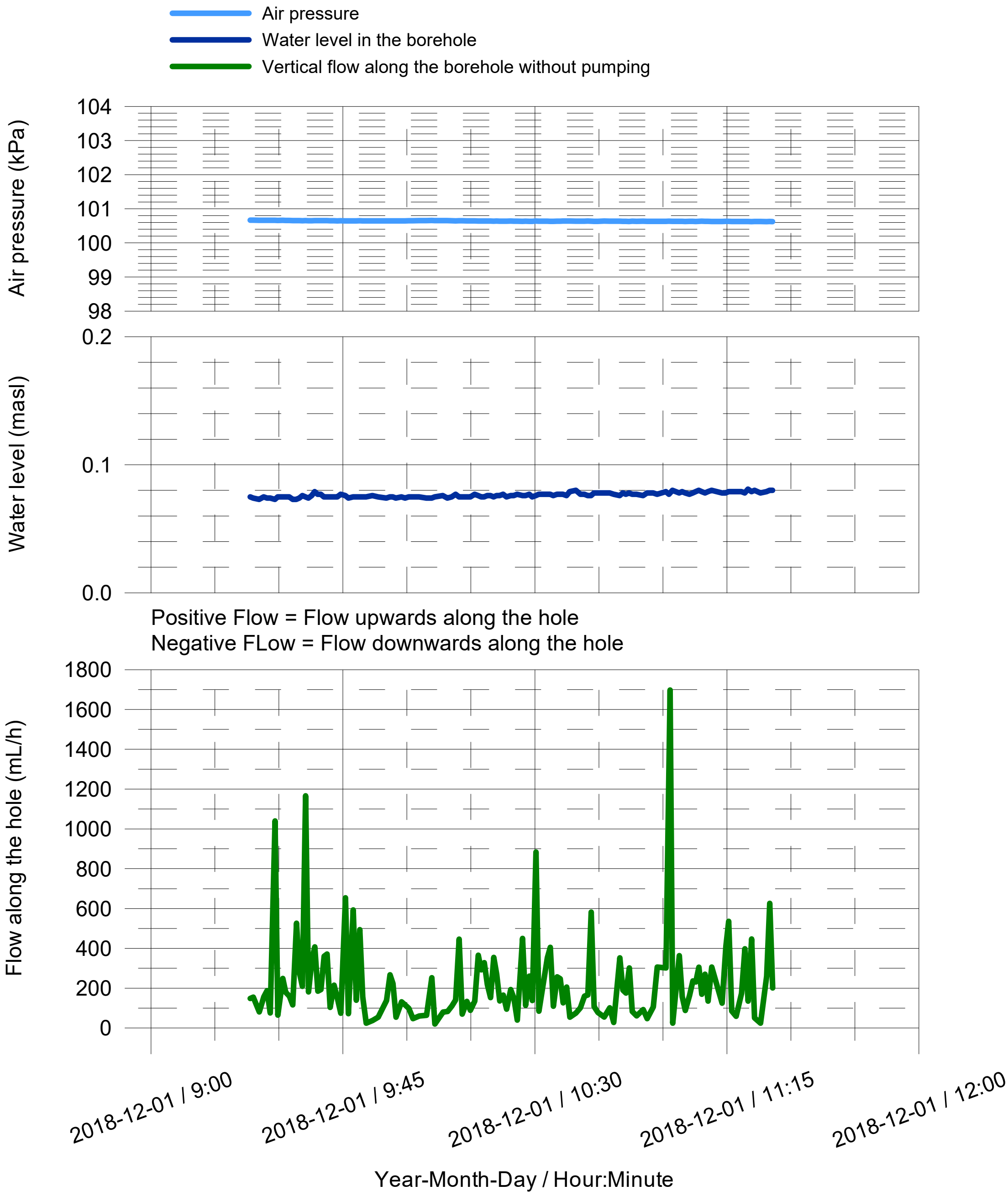
Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-30
Extra 1 without pumping (L = 1 m, dL = 0.1 m), 2018-11-30 - 2018-12-01
Flow 2 with pumping (Drawdown 1.5 m, L = 5 m, dL = 0.5 m), 2018-12-02
Flow 3 with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-12-02 - 2018-12-03
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Extra 1 (Flow into the hole)
Extra 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
40.3
43.4
46.9
48.8
52.8
55.3
56.1
57.0
57.5
58.4
59.3
0.44 S/m
0.44 S/m
0.45 S/m
0.45 S/m
Flow rate (mL/h)
Single point resistance (ohm)



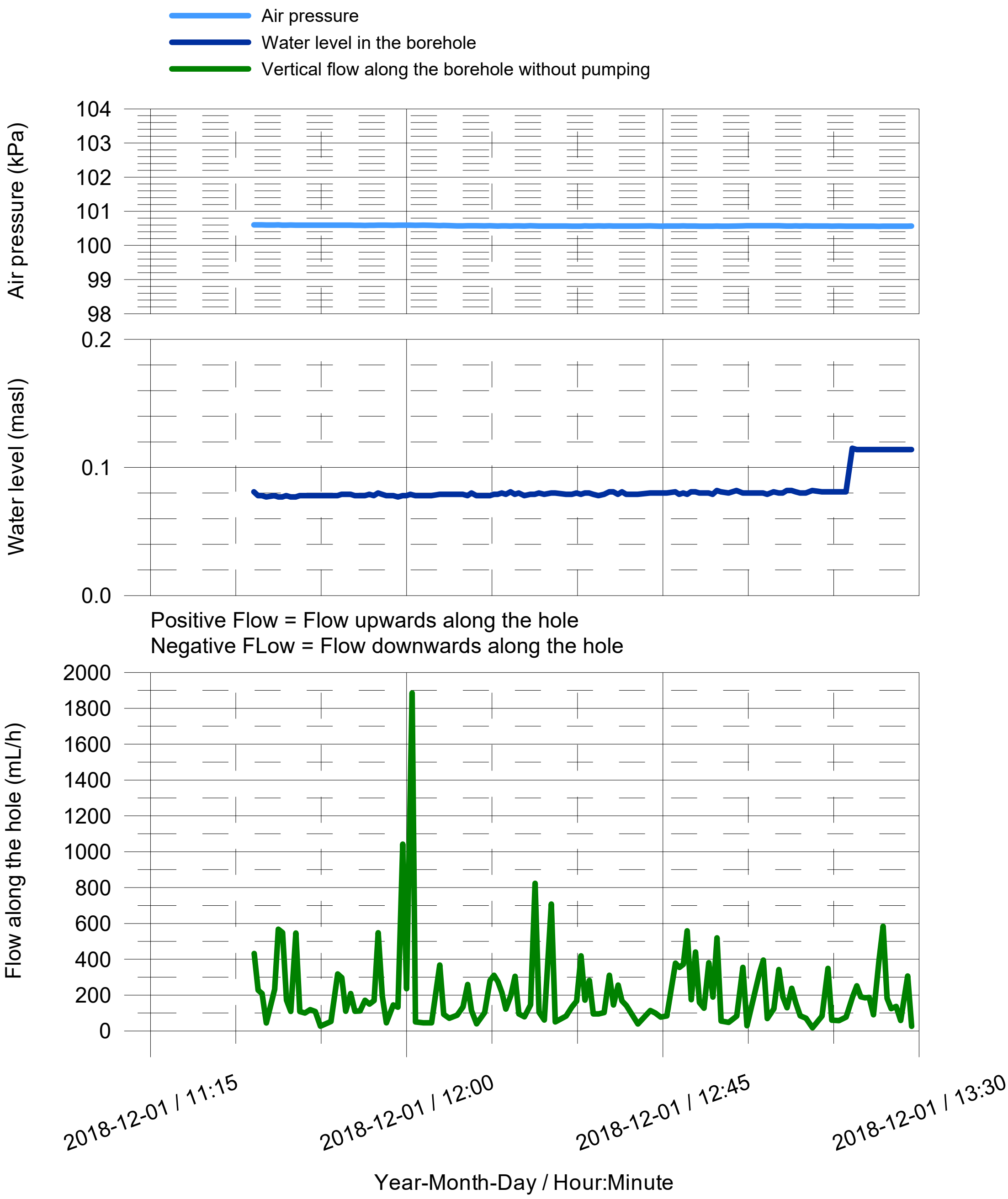
Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-30
Extra 1 without pumping (L = 1 m, dL = 0.1 m), 2018-11-30 - 2018-12-01
Flow 2 with pumping (Drawdown 1.5 m, L = 5 m, dL = 0.5 m), 2018-12-02
Flow 3 with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-12-02 - 2018-12-03
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Extra 1 (Flow into the hole)
Extra 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
61.1
61.8
62.7
64.3
67.2
68.3
69.7
70.3
71.5
72.1
76.8
0.50 S/m
0.59 S/m
Flow rate (mL/h)
Single point resistance (ohm)


Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-30
Extra 1 without pumping (L = 1 m, dL = 0.1 m), 2018-11-30 - 2018-12-01
Flow 2 with pumping (Drawdown 1.5 m, L = 5 m, dL = 0.5 m), 2018-12-02
Flow 3 with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-12-02 - 2018-12-03
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Extra 1 (Flow into the hole)
Extra 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)
80.3
82.8
83.2
83.5
86.3
88.5
89.6
91.0
91.9
92.6
94.2

KFM21.2.6 Vertical flow along the borehole at 6.2 m



KFM21.2.7 Vertical flow along the borehole at 5.4 m



KFM21.3 Explanations for the tables in Appendices

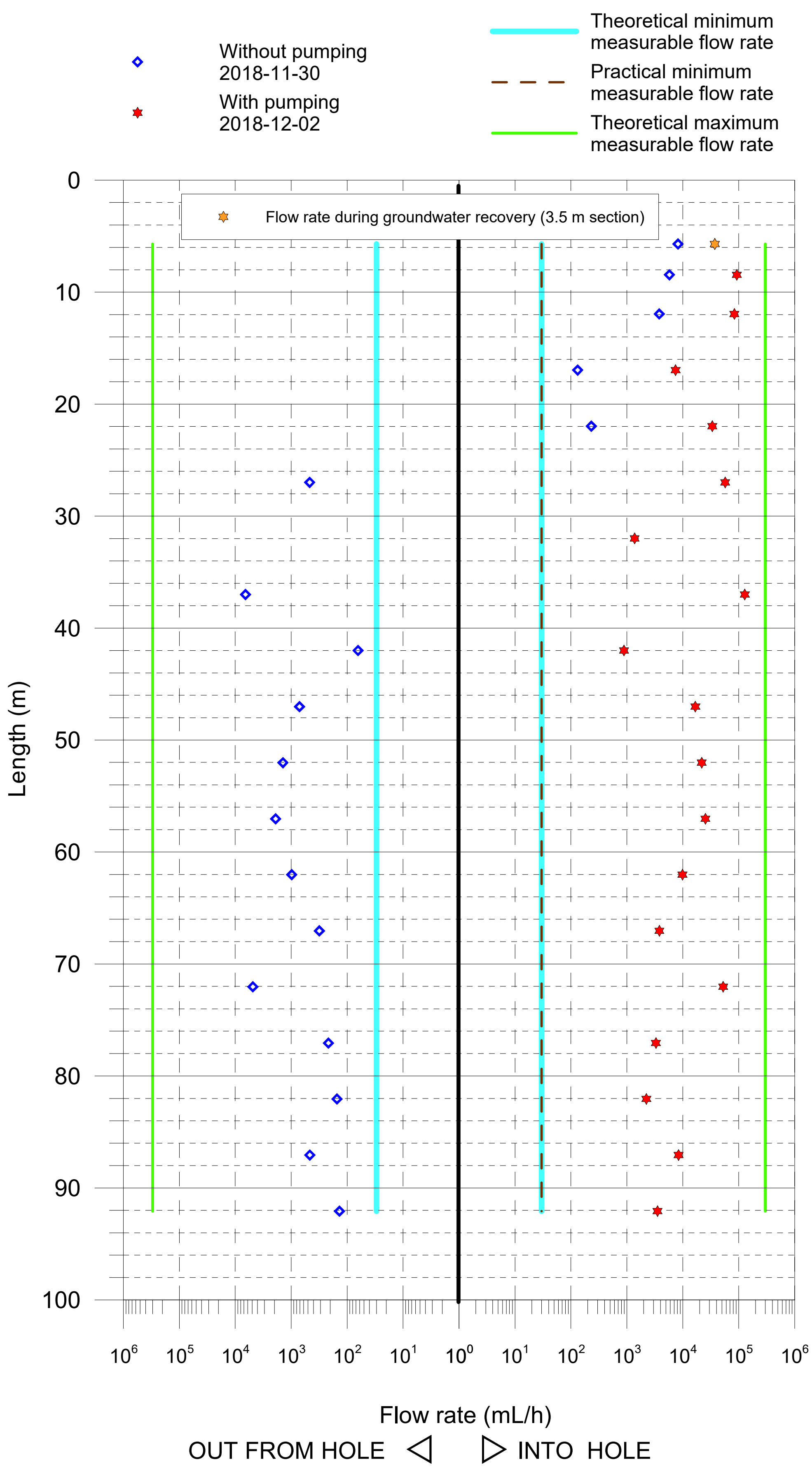
Header	Unit	Explanations
Borehole ID		ID for borehole
Secup	m	Length along the borehole for the upper limit of the test section (based on corrected length L)
Seclow	m	Length along the borehole for the lower limit of the test section (based on corrected length L)
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with h=h0 in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid before pumping
h_{1FW}	m.a.s.l.	Corrected hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period
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.
Q-lower limit P	mL/h	Practical lower measurement limit for flow rate.
T-$measl_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-$measl_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-$meas_{lU}$	m^2/s	Estimated upper measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

KFM21.4 Results of section flows

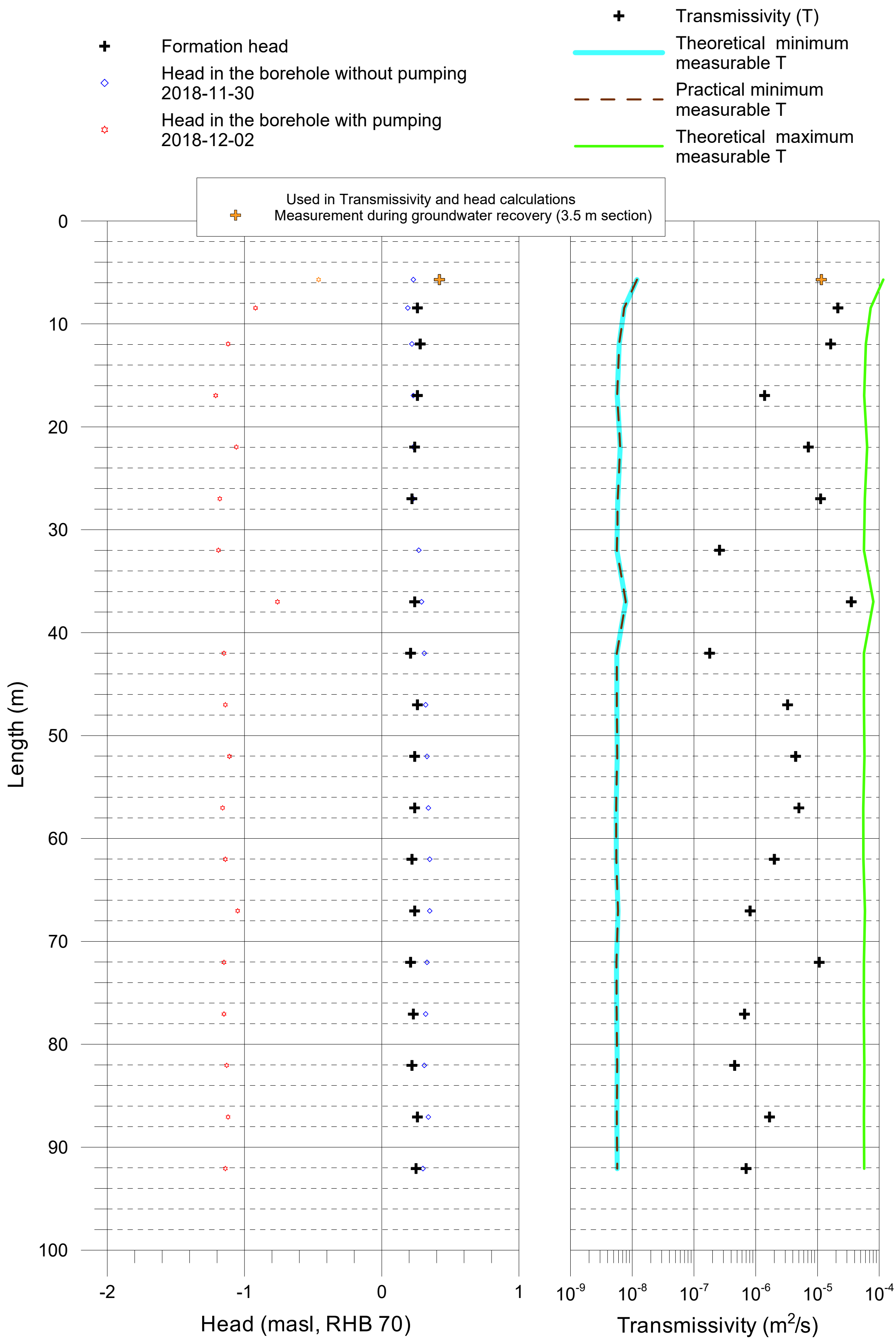
Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D-measl$_{LP}$ (m^2/s)	T_D-measl$_U$ (m^2/s)	Comments
KFM21	3.95	7.45	3.5	2.28E-06	0.23	1.04E-05	−0.46	1.2E-05	0.4	30	1.2E-08	1.2E-08	1.2E-04	*
KFM21	7.45	9.45	2	1.60E-06	0.19	2.57E-05	−0.92	2.1E-05	0.3	30	7.4E-09	7.4E-09	7.3E-05	
KFM21	9.45	14.45	5	1.06E-06	0.22	2.32E-05	−1.12	1.6E-05	0.3	30	6.2E-09	6.2E-09	6.1E-05	
KFM21	14.46	19.46	5	3.67E-08	0.23	2.07E-06	−1.21	1.4E-06	0.3	30	5.7E-09	5.7E-09	5.7E-05	
KFM21	19.47	24.47	5	6.44E-08	0.23	9.37E-06	−1.06	7.1E-06	0.2	30	6.4E-09	6.4E-09	6.4E-05	
KFM21	24.49	29.49	5	−1.30E-07	0.23	1.59E-05	−1.18	1.1E-05	0.2	30	5.8E-09	5.8E-09	5.9E-05	
KFM21	29.49	34.49	5	–	0.27	3.83E-07	−1.19	2.6E-07	–	30	5.6E-09	5.6E-09	5.6E-05	
KFM21	34.50	39.50	5	−1.82E-06	0.29	3.57E-05	−0.76	3.5E-05	0.2	30	7.9E-09	7.9E-09	8.0E-05	
KFM21	39.50	44.50	5	−1.78E-08	0.31	2.47E-07	−1.15	1.8E-07	0.2	30	5.6E-09	5.6E-09	5.6E-05	
KFM21	44.51	49.51	5	−1.97E-07	0.32	4.66E-06	−1.14	3.3E-06	0.3	30	5.6E-09	5.6E-09	5.7E-05	
KFM21	49.52	54.52	5	−3.91E-07	0.33	6.06E-06	−1.11	4.4E-06	0.2	30	5.7E-09	5.7E-09	5.8E-05	
KFM21	54.53	59.53	5	−5.28E-07	0.34	7.06E-06	−1.16	5.0E-06	0.2	30	5.5E-09	5.5E-09	5.5E-05	
KFM21	59.52	64.52	5	−2.72E-07	0.35	2.75E-06	−1.14	2.0E-06	0.2	30	5.5E-09	5.5E-09	5.6E-05	
KFM21	64.54	69.54	5	−8.72E-08	0.35	1.06E-06	−1.05	8.1E-07	0.2	30	5.9E-09	5.9E-09	5.9E-05	
KFM21	69.53	74.53	5	−1.35E-06	0.33	1.47E-05	−1.15	1.1E-05	0.2	30	5.6E-09	5.6E-09	5.7E-05	
KFM21	74.56	79.56	5	−6.00E-08	0.32	9.19E-07	−1.15	6.6E-07	0.2	30	5.6E-09	5.6E-09	5.6E-05	
KFM21	79.55	84.55	5	−4.22E-08	0.31	6.21E-07	−1.13	4.6E-07	0.2	30	5.7E-09	5.7E-09	5.7E-05	
KFM21	84.56	89.56	5	−1.29E-07	0.34	2.34E-06	−1.12	1.7E-06	0.3	30	5.6E-09	5.6E-09	5.7E-05	
KFM21	89.57	94.57	5	−3.81E-08	0.30	9.81E-07	−1.14	7.0E-07	0.3	30	5.7E-09	5.7E-09	5.7E-05	

* Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made without pumping, during recovery. The upper part of the borehole could not be measured while pumping the borehole (while the pump remained in the borehole).

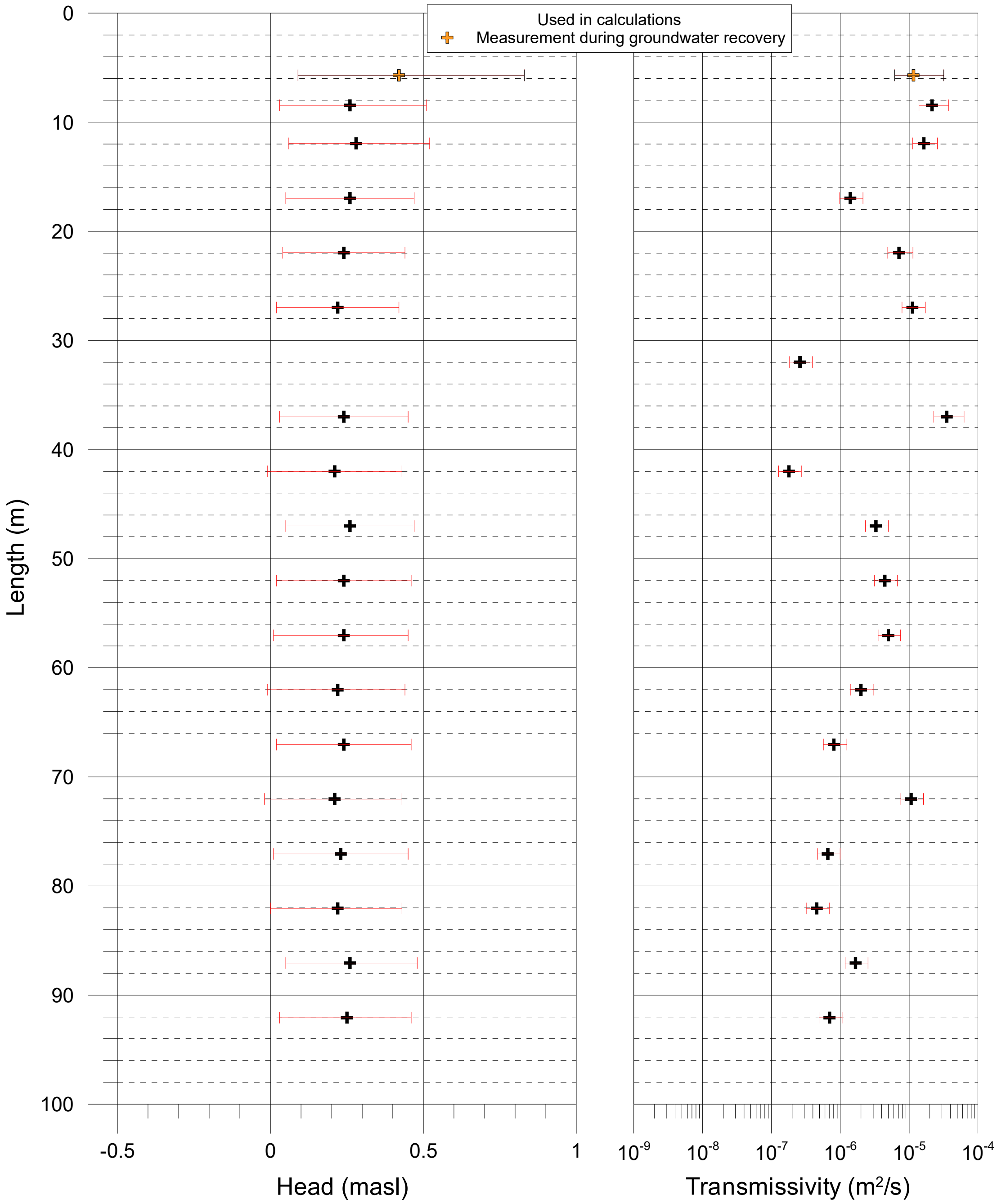
KFM21.5.1 Plotted flow rates of 5 m sections



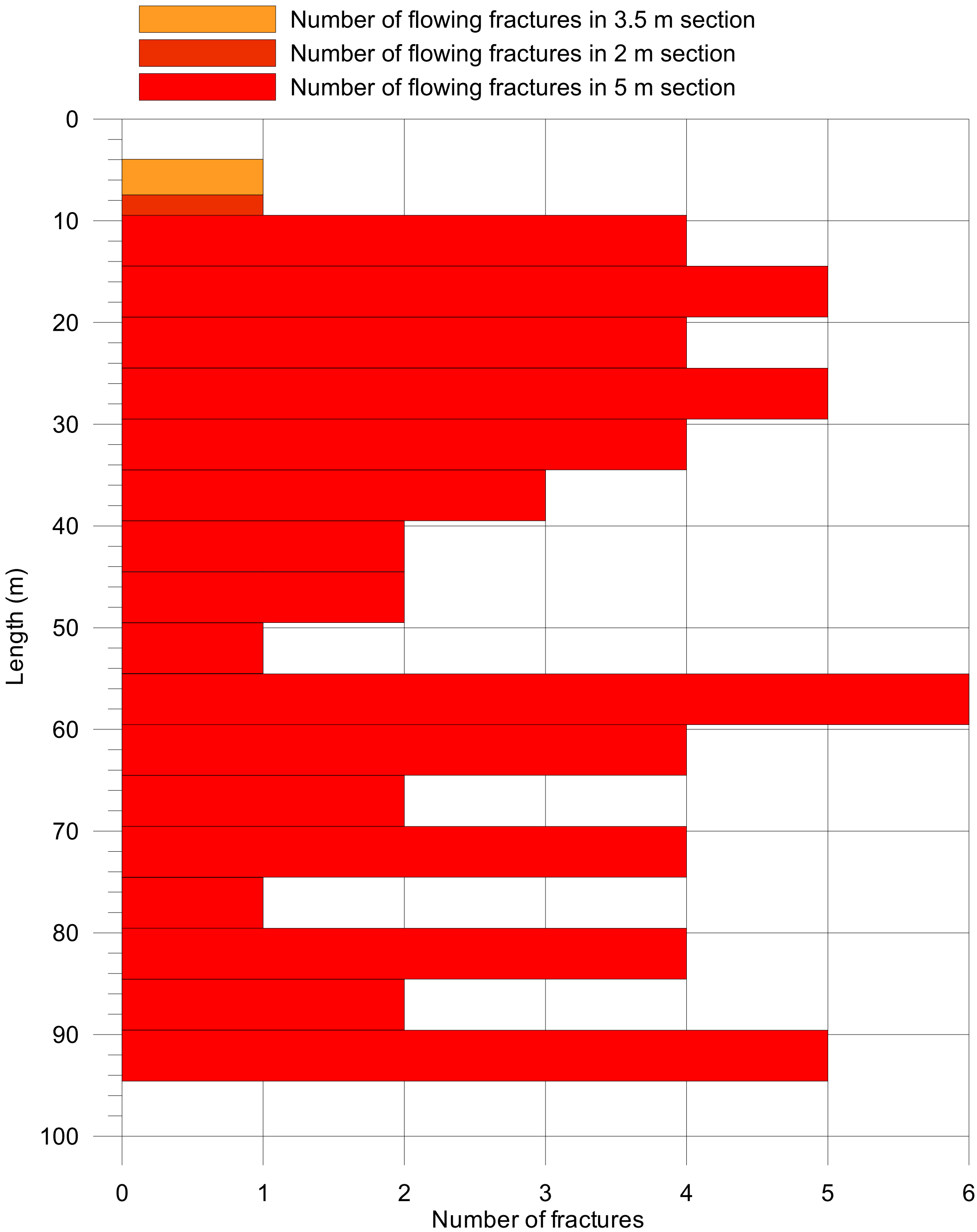
KFM21.5.2 Plotted transmissivity and head of 5 m sections



KFM21.5.3 Transmissivity and head of 5 m sections with calculated error limits



KFM21.5.4 Conductive fracture frequency



KFM21.6.1–KFM21.6.2 Inferred fracture flow anomalies from 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
KFM21	6.8	1	0.1	2.09E-06	0.22	3.83E-05	−0.66	4.1E-05	0.3	**
KFM21	8.9	1	0.1	1.24E-06	0.25	3.50E-05	−0.92	2.9E-05	0.3	
KFM21	10.3	1	0.1	7.83E-07	0.23	2.43E-05	−1.11	1.7E-05	0.3	
KFM21	12.3	1	0.1	–	0.22	2.25E-08	−1.28	1.5E-08	–	*
KFM21	13.0	1	0.1	–	0.18	4.75E-07	−1.28	3.2E-07	–	
KFM21	14.1	1	0.1	–	0.21	2.69E-07	−1.29	1.8E-07	–	
KFM21	14.6	1	0.1	–	0.19	5.92E-08	−1.29	4.0E-08	–	
KFM21	15.3	1	0.1	2.89E-08	0.20	2.10E-06	−1.28	1.4E-06	0.2	
KFM21	15.7	1	0.1	–	0.22	4.44E-09	−1.29	2.9E-09	–	*
KFM21	17.9	1	0.1	–	0.23	7.22E-09	−1.27	4.8E-09	–	*
KFM21	18.5	1	0.1	–	0.23	5.22E-08	−1.29	3.4E-08	–	
KFM21	20.6	1	0.1	–	0.25	1.64E-07	−1.28	1.1E-07	–	
KFM21	21.8	1	0.1	1.36E-08	0.27	1.86E-06	−1.27	1.2E-06	0.3	
KFM21	23.2	1	0.1	–	0.26	4.50E-07	−1.23	3.0E-07	–	
KFM21	23.7	1	0.1	–	0.27	5.19E-06	−1.21	3.5E-06	–	
KFM21	24.6	1	0.1	2.78E-08	0.29	1.18E-05	−1.21	7.7E-06	0.3	
KFM21	25.0	1	0.1	–	0.28	1.60E-07	−1.25	1.0E-07	–	
KFM21	26.9	1	0.1	−8.50E-08	0.29	1.04E-05	−1.20	7.0E-06	0.3	
KFM21	27.6	1	0.1	–	0.28	4.53E-07	−1.23	3.0E-07	–	
KFM21	28.9	1	0.1	–	0.29	1.29E-07	−1.21	8.5E-08	–	
KFM21	30.6	1	0.1	–	0.29	1.11E-07	−1.23	7.2E-08	–	
KFM21	32.4	1	0.1	–	0.28	3.67E-08	−1.20	2.5E-08	–	
KFM21	33.1	1	0.1	–	0.27	1.24E-07	−1.18	8.4E-08	–	
KFM21	33.5	1	0.1	–	0.27	2.53E-08	−1.17	1.7E-08	–	*
KFM21	34.8	1	0.1	−1.63E-06	0.26	3.89E-05	−0.73	4.1E-05	0.2	
KFM21	35.2	1	0.1	–	0.27	2.71E-07	−1.17	1.9E-07	–	
KFM21	37.7	1	0.1	−4.17E-09	0.27	8.36E-08	−1.18	6.0E-08	0.2	
KFM21	40.3	1	0.1	−1.75E-08	0.27	2.46E-07	−1.18	1.8E-07	0.2	
KFM21	43.4	1	0.1	–	0.28	2.72E-08	−1.21	1.8E-08	–	
KFM21	46.9	1	0.1	−6.69E-08	0.30	2.71E-06	−1.20	1.8E-06	0.3	
KFM21	48.8	1	0.1	−1.23E-07	0.30	2.51E-06	−1.17	1.8E-06	0.2	
KFM21	52.8	1	0.1	−3.72E-07	0.31	6.92E-06	−1.16	4.9E-06	0.2	
KFM21	55.3	1	0.1	−1.06E-08	0.31	1.73E-07	−1.15	1.3E-07	0.2	
KFM21	56.1	1	0.1	–	0.32	1.35E-07	−1.14	9.1E-08	–	*
KFM21	57.0	1	0.1	−4.44E-07	0.32	6.72E-06	−1.15	4.8E-06	0.2	
KFM21	57.5	1	0.1	–	0.33	6.89E-07	−1.14	4.6E-07	–	*
KFM21	58.4	1	0.1	−3.44E-08	0.32	7.14E-07	−1.15	5.0E-07	0.3	
KFM21	59.3	1	0.1	−2.03E-08	0.32	2.33E-07	−1.13	1.7E-07	0.2	
KFM21	61.1	1	0.1	−1.03E-08	0.32	1.76E-07	−1.12	1.3E-07	0.2	
KFM21	61.8	1	0.1	−2.21E-07	0.34	2.76E-06	−1.12	2.0E-06	0.2	
KFM21	62.7	1	0.1	–	0.33	2.56E-08	−1.12	1.7E-08	–	
KFM21	64.3	1	0.1	–	0.34	4.39E-08	−1.12	3.0E-08	–	
KFM21	67.2	1	0.1	–	0.33	3.28E-08	−1.12	2.2E-08	–	
KFM21	68.3	1	0.1	−8.81E-08	0.33	9.72E-07	−1.14	7.10E-07	0.2	

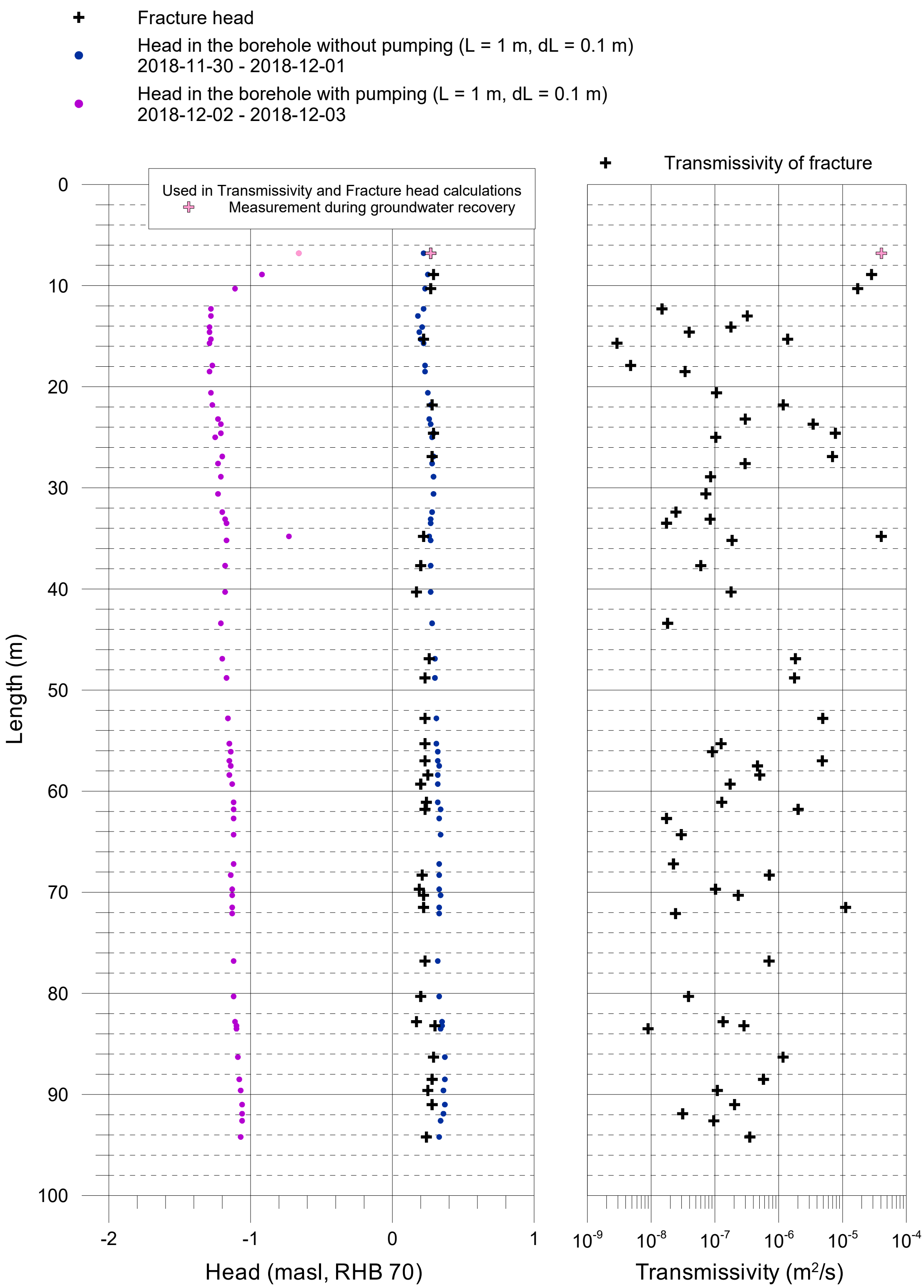
Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0*** (m^3/s)	h_{0FW}*** (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KFM21	69.7	1	0.1	−1.44E-08	0.33	1.36E-07	−1.13	1.0E-07	0.2	*
KFM21	70.3	1	0.1	−2.78E-08	0.34	3.17E-07	−1.13	2.3E-07	0.2	
KFM21	71.5	1	0.1	−1.21E-06	0.33	1.54E-05	−1.13	1.1E-05	0.2	
KFM21	72.1	1	0.1	–	0.33	3.56E-08	−1.13	2.4E-08	–	
KFM21	76.8	1	0.1	−6.22E-08	0.32	9.64E-07	−1.12	7.1E-07	0.2	
KFM21	80.3	1	0.1	−5.00E-09	0.33	5.14E-08	−1.12	3.9E-08	0.2	
KFM21	82.8	1	0.1	−2.42E-08	0.35	1.73E-07	−1.11	1.3E-07	0.2	
KFM21	83.2	1	0.1	−1.44E-08	0.35	4.03E-07	−1.10	2.9E-07	0.3	
KFM21	83.5	1	0.1	–	0.34	1.31E-08	−1.10	9.0E-09	–	*
KFM21	86.3	1	0.1	−9.81E-08	0.37	1.62E-06	−1.09	1.2E-06	0.3	
KFM21	88.5	1	0.1	−5.25E-08	0.37	7.92E-07	−1.08	5.8E-07	0.3	
KFM21	89.6	1	0.1	−1.19E-08	0.36	1.46E-07	−1.07	1.1E-07	0.3	
KFM21	91.0	1	0.1	−1.86E-08	0.37	2.76E-07	−1.06	2.0E-07	0.3	
KFM21	91.9	1	0.1	–	0.36	4.47E-08	−1.06	3.1E-08	–	*
KFM21	92.6	1	0.1	–	0.34	1.36E-07	−1.06	9.6E-08	–	
KFM21	94.2	1	0.1	−3.19E-08	0.33	4.67E-07	−1.07	3.5E-07	0.2	

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

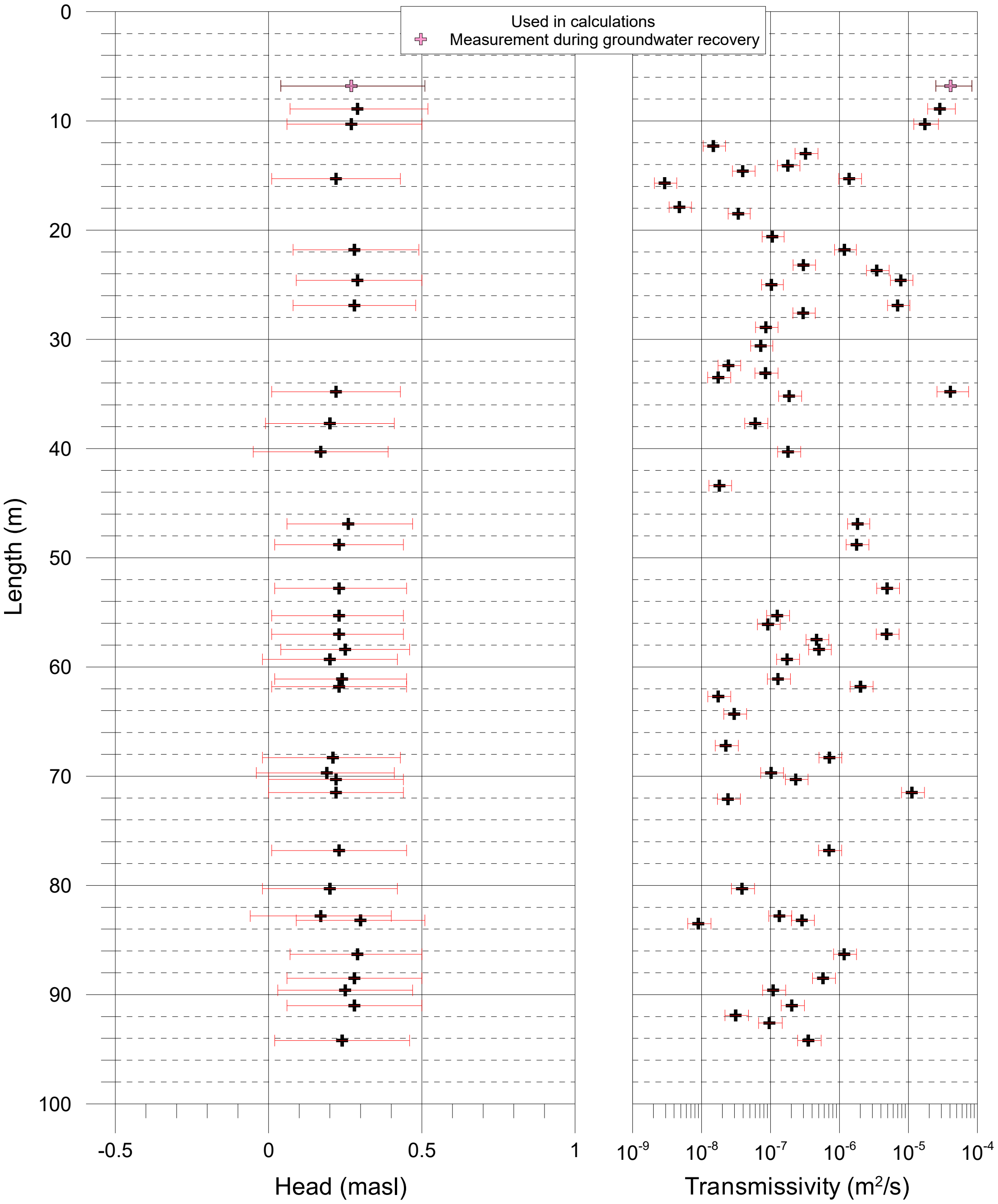
** Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made without pumping, during recovery. The upper part of the borehole could not be measured while pumping (while the pump remained in the borehole).

*** All Values for Flow (Q_0) and Head (h_{0FW}) are from Extra 1 measurement.

KFM21.7.1 Plotted transmissivity and head of detected fractures



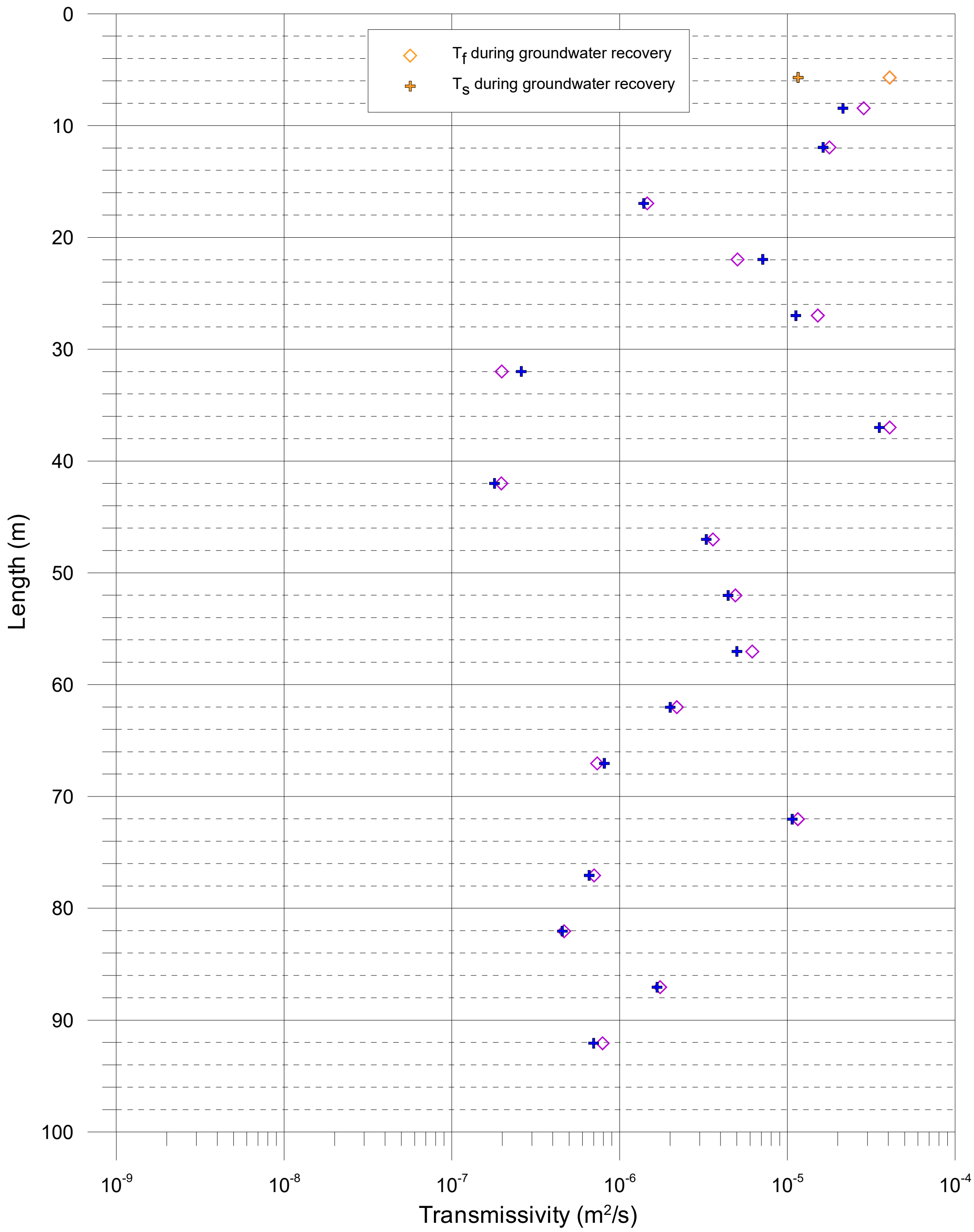
KFM21.7.2 Transmissivity and head of detected fractures with calculated error limits.



KFM21.8 Comparison between section transmissivity and fracture transmissivity

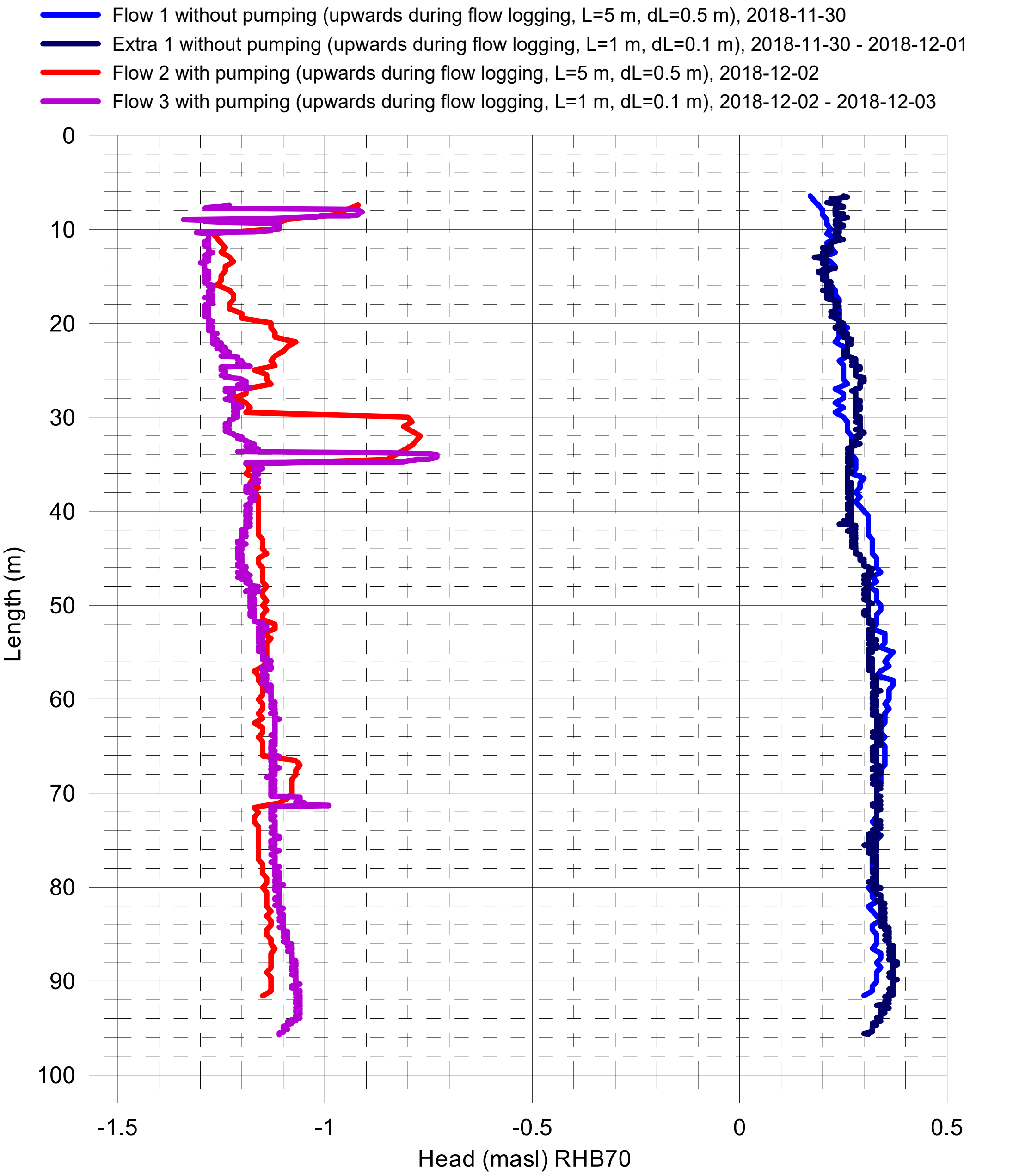
◇ Transmissivity (sum of fracture specific results T_f)

+ Transmissivity (results of 5 m measurements T_s)

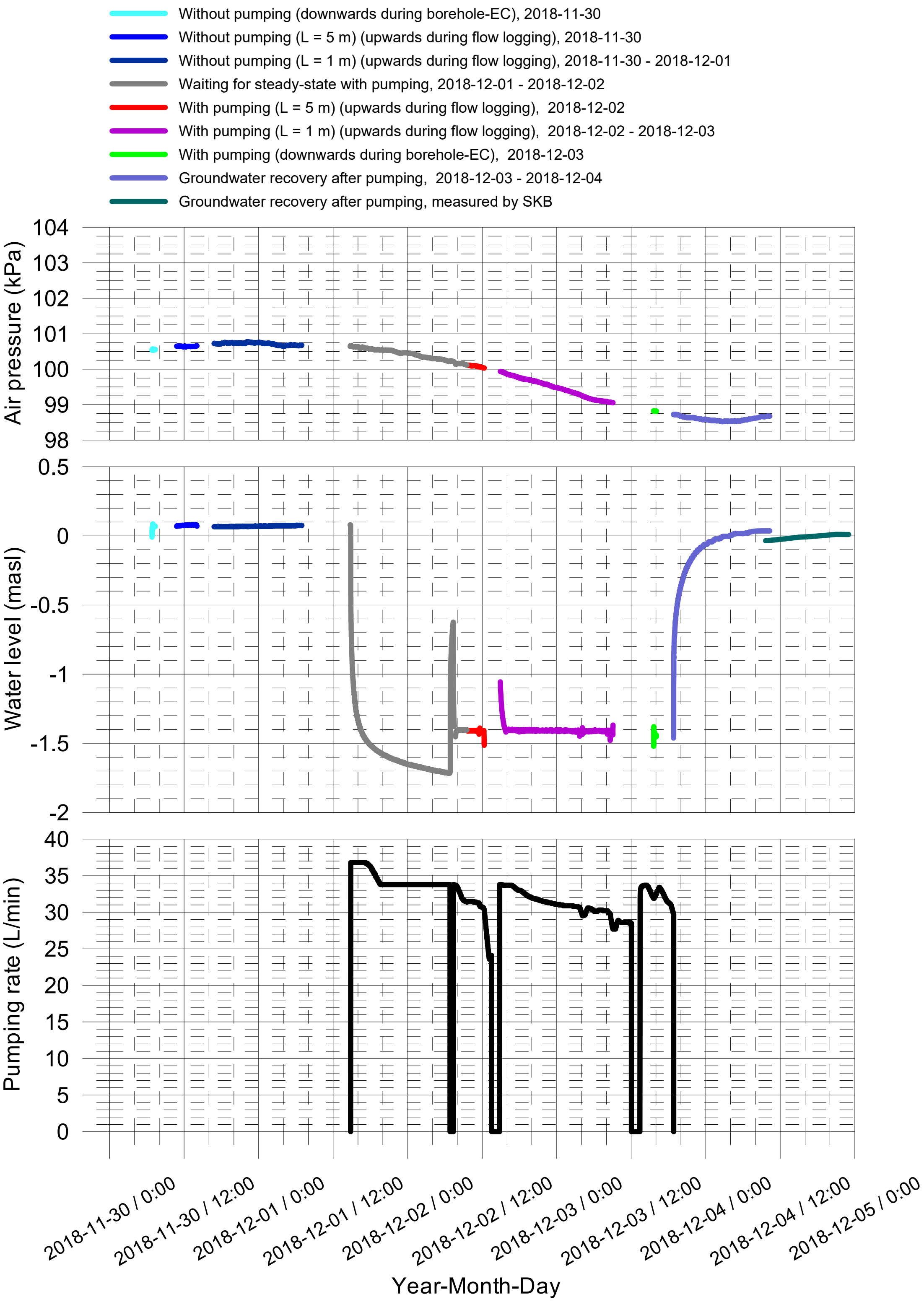


KFM21.9.1 Head in the borehole during flow logging

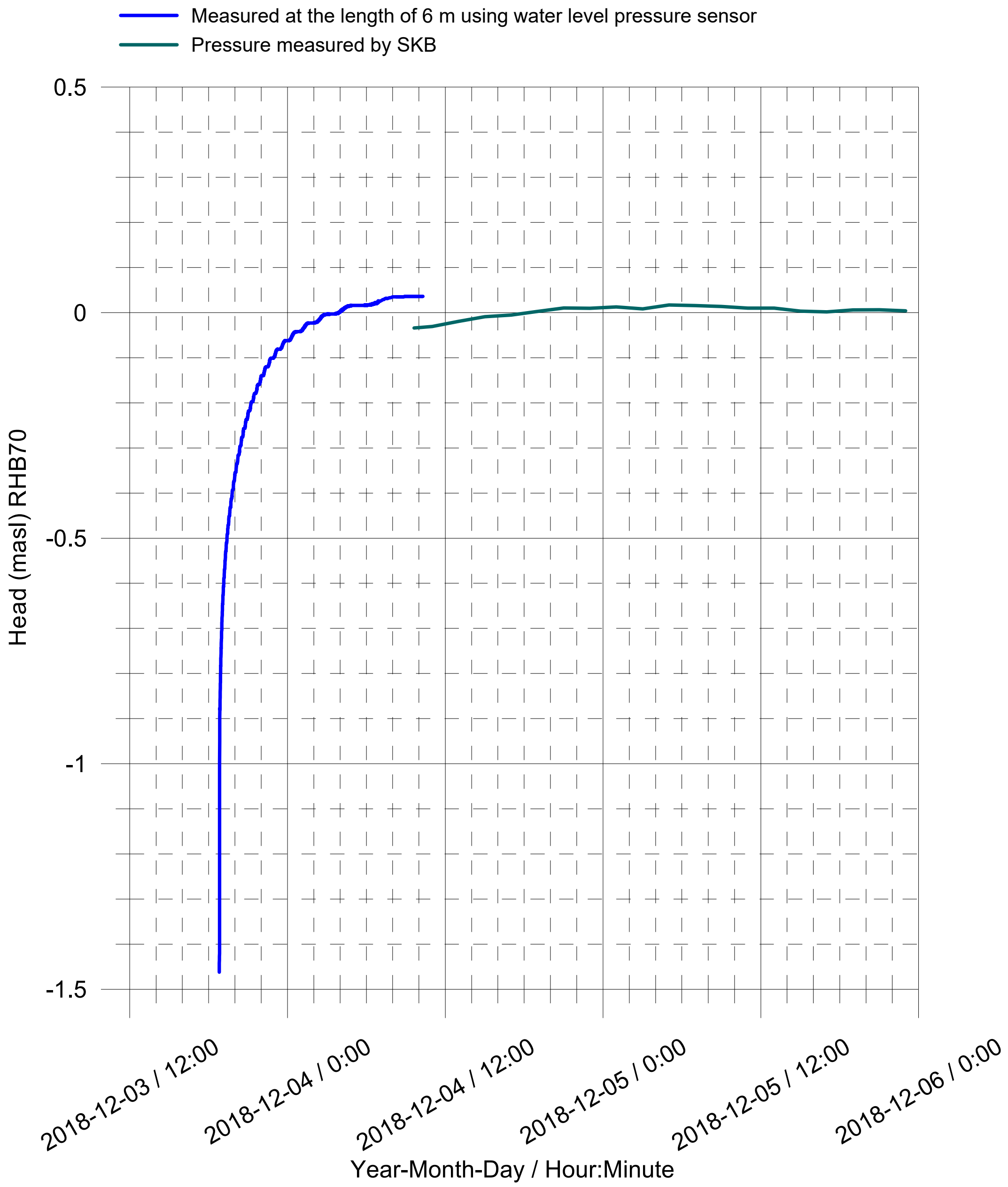
Head(masl) = (Absolute pressure (Pa) - Airpressure (Pa) + Offset) / (1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = Correction for absolute pressure sensor



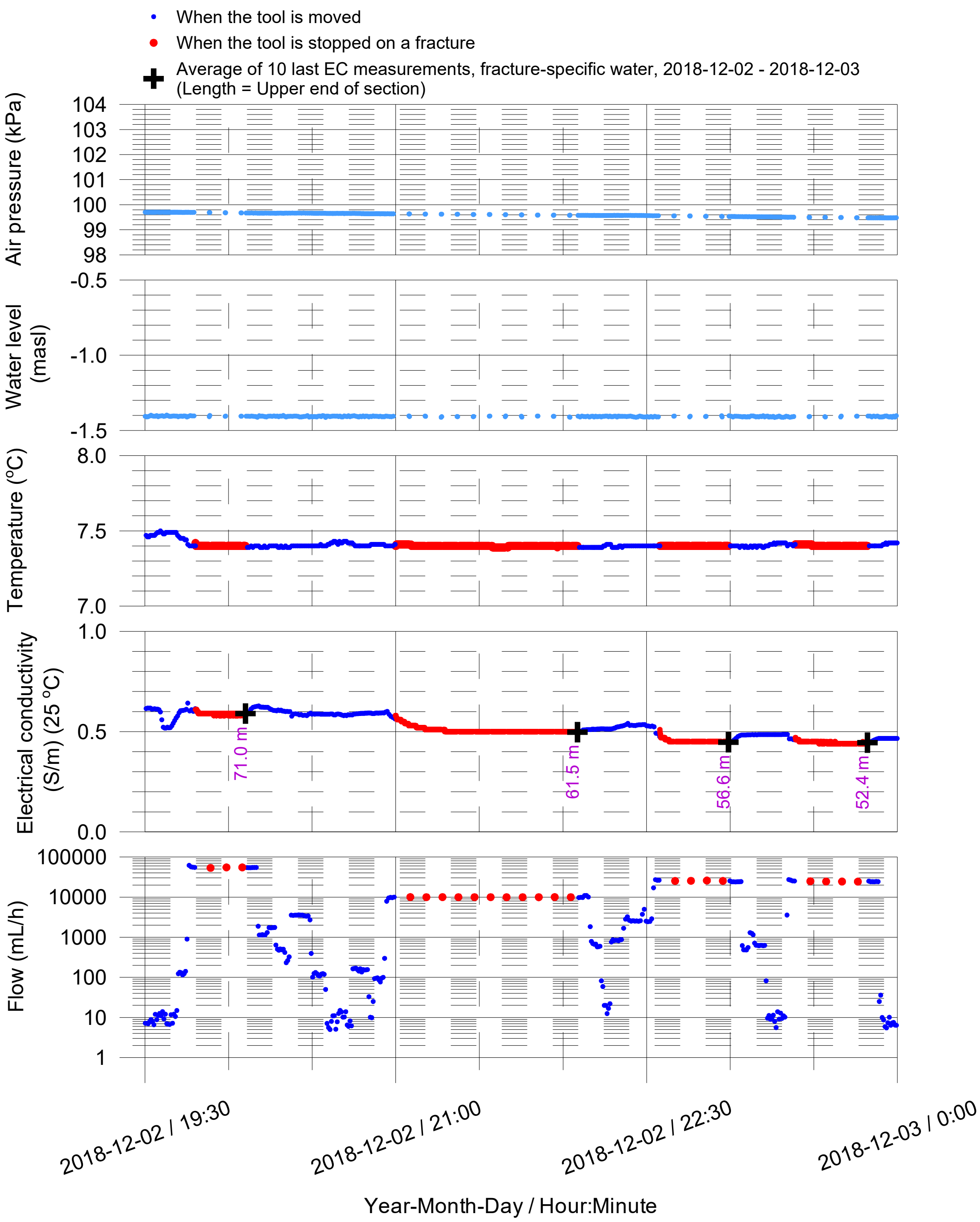
KFM21.9.2 Air pressure, water level in the borehole and pumping rate during flow logging

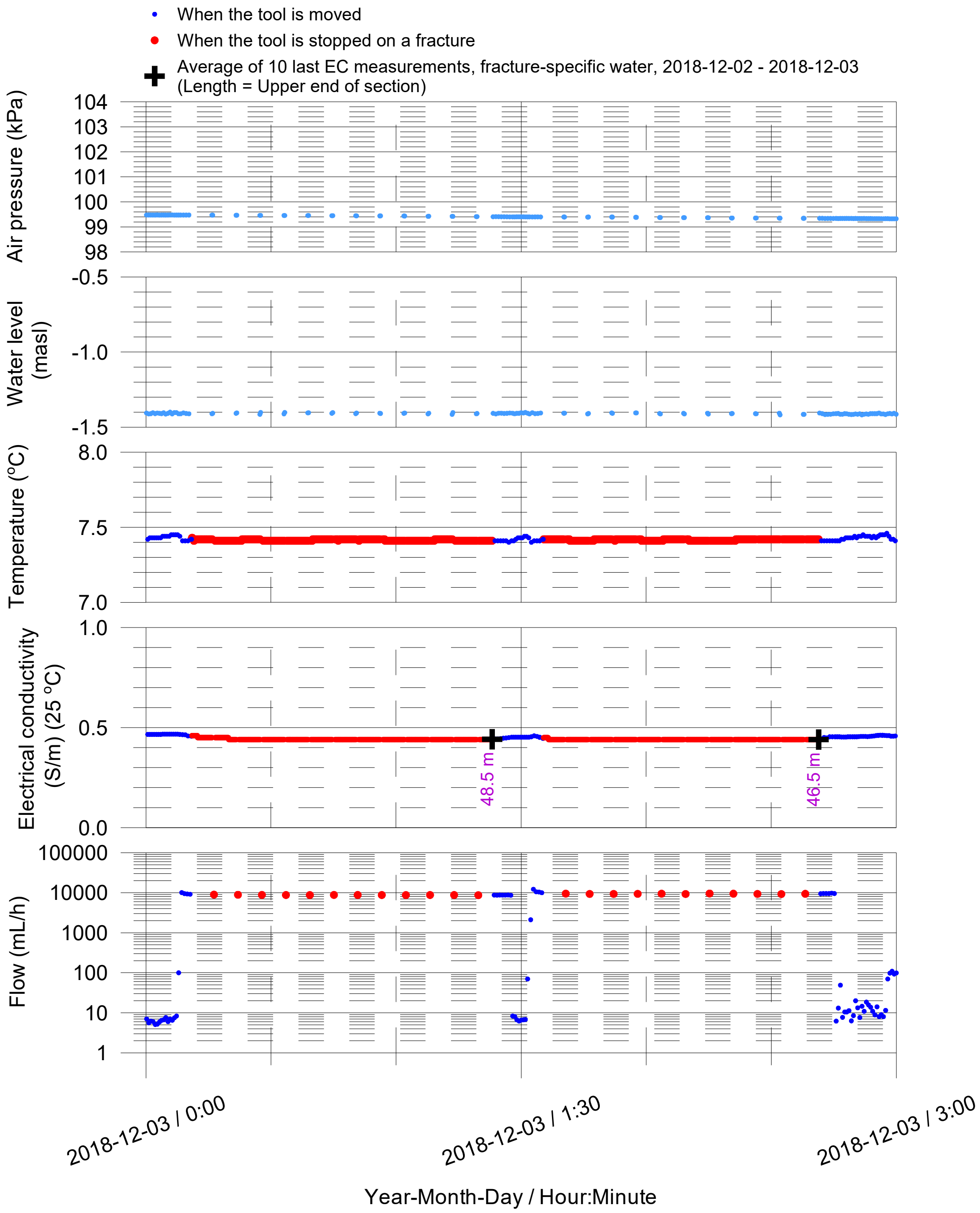


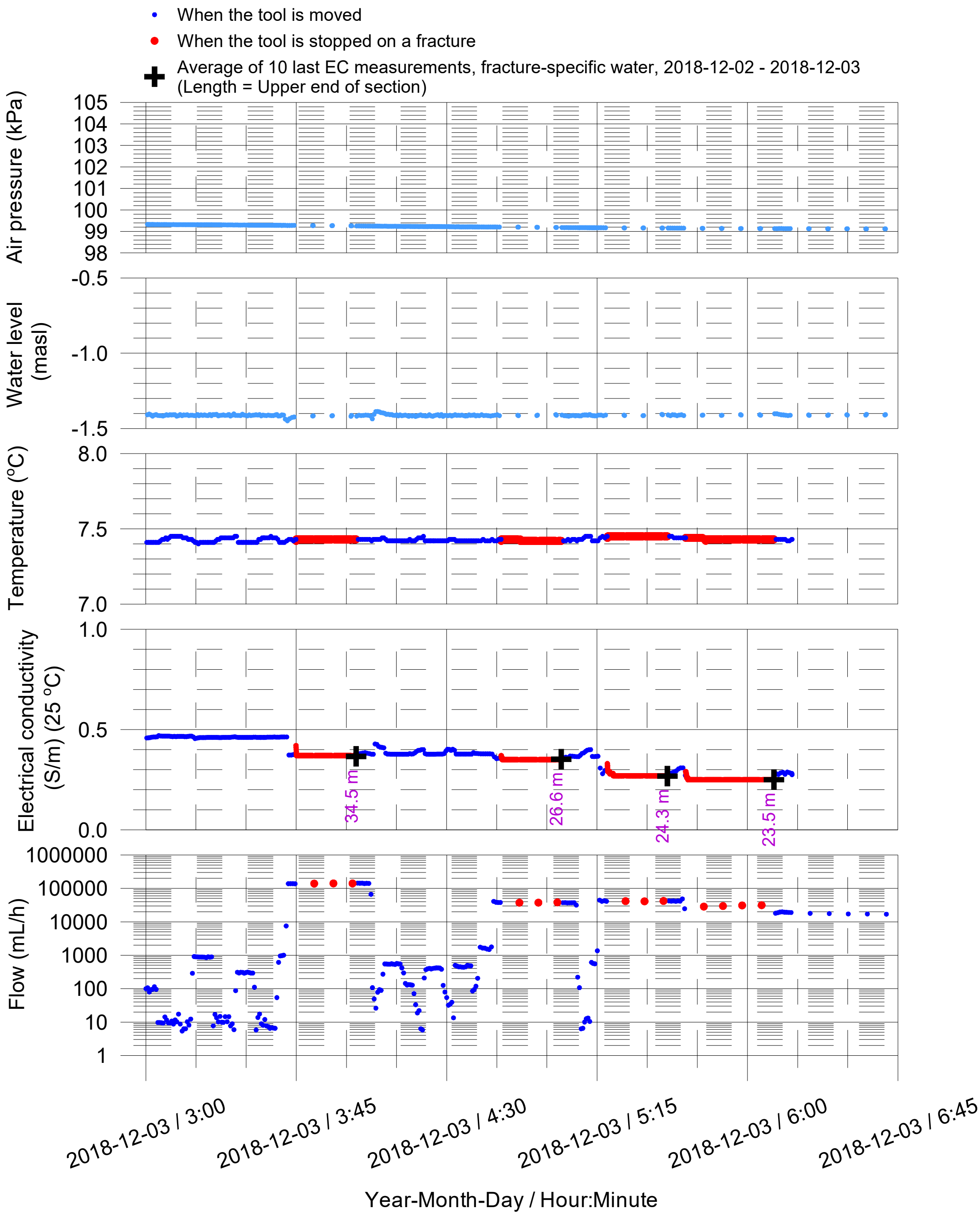
KFM21.9.3 Groundwater recovery after pumping



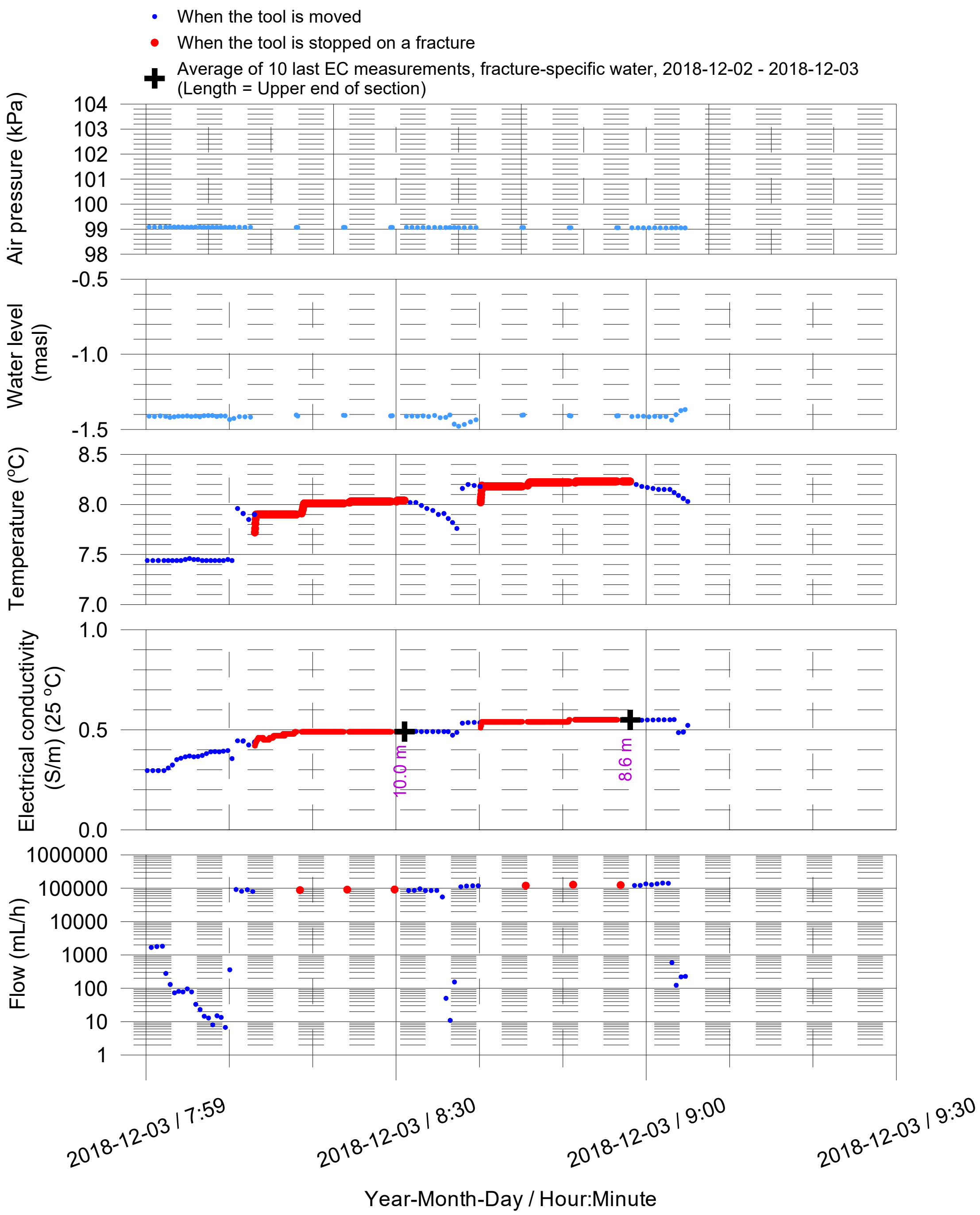
KFM21.10.1–KFM21.10.5 Fracture-specific EC results by date



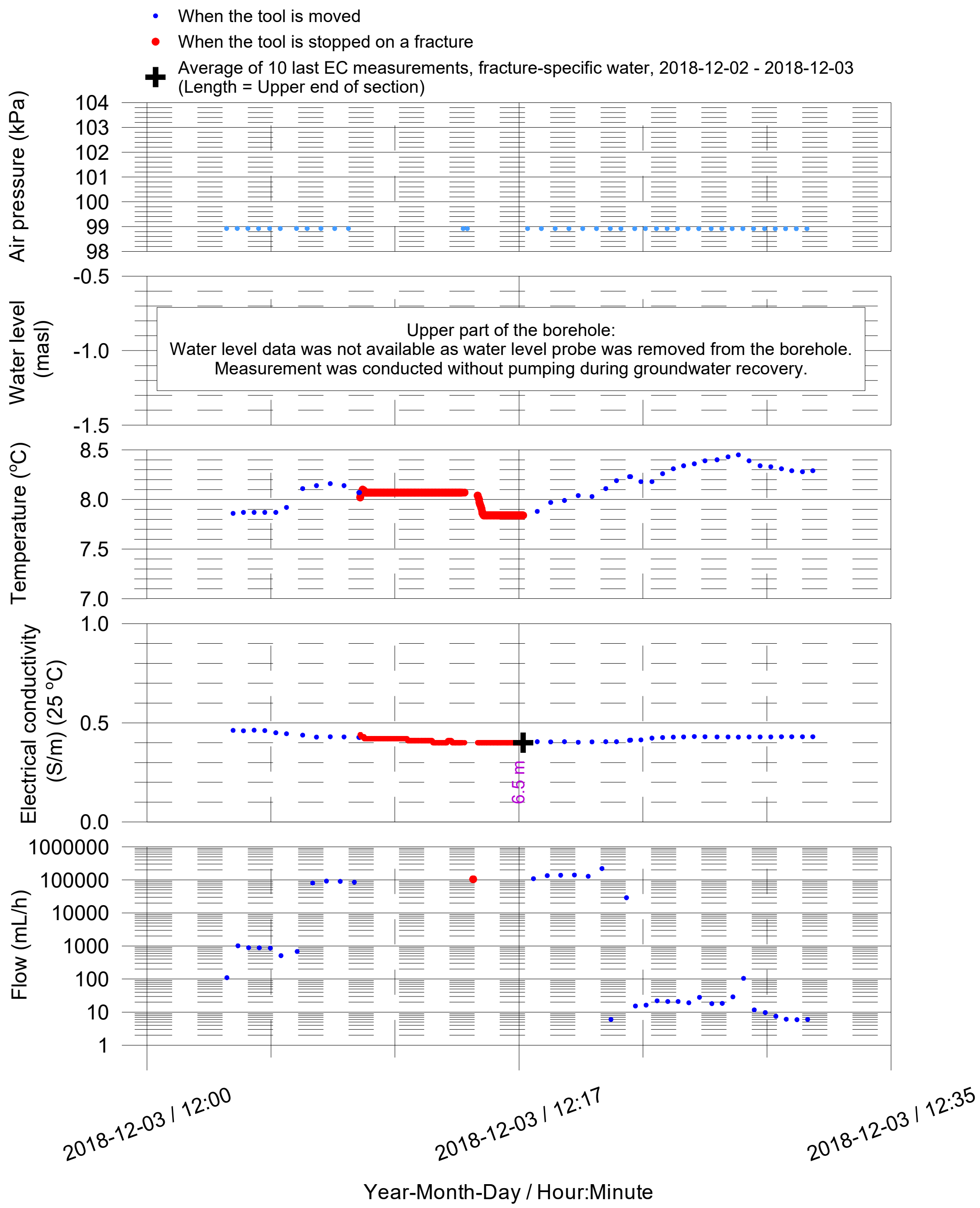

When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-12-02 - 2018-12-03
(Length = Upper end of section)
Air pressure (kPa)
Water level (masl)
Temperature (°C)
Electrical conductivity (S/m) (25 °C)
Flow (mL/h)
48.5 m
46.5 m
2018-12-03 / 0:00
2018-12-03 / 1:30
2018-12-03 / 3:00
Year-Month-Day / Hour:Minute



When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-12-02 - 2018-12-03
(Length = Upper end of section)
Air pressure (kPa)
105
104
103
102
101
100
99
98
Water level (masl)
-0.5
-1.0
-1.5
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
34.5 m
26.6 m
24.3 m
23.5 m
Flow (mL/h)
1000000
100000
10000
1000
100
10
1
2018-12-03 / 3:00
2018-12-03 / 3:45
2018-12-03 / 4:30
2018-12-03 / 5:15
2018-12-03 / 6:00
2018-12-03 / 6:45
Year-Month-Day / Hour:Minute

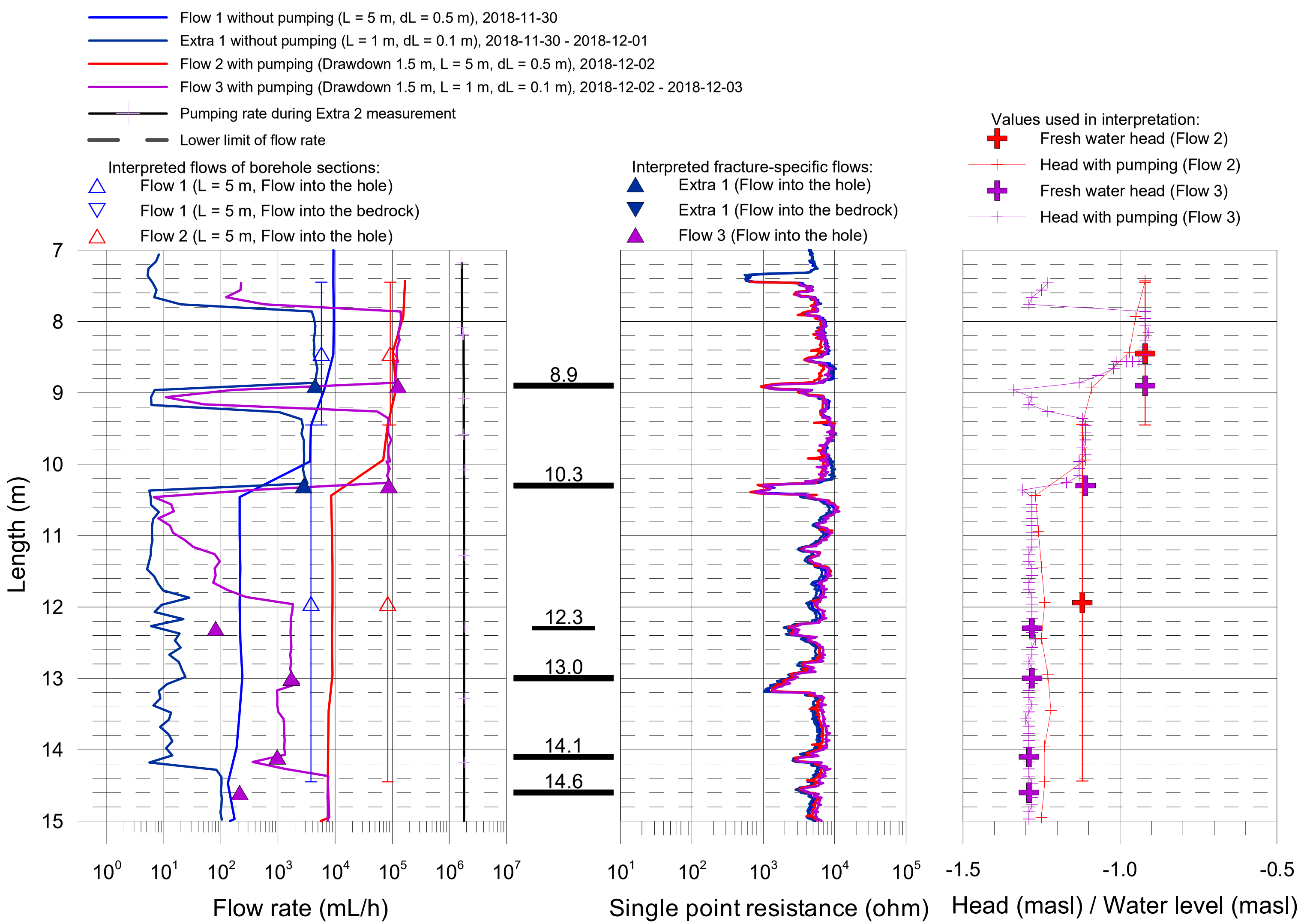


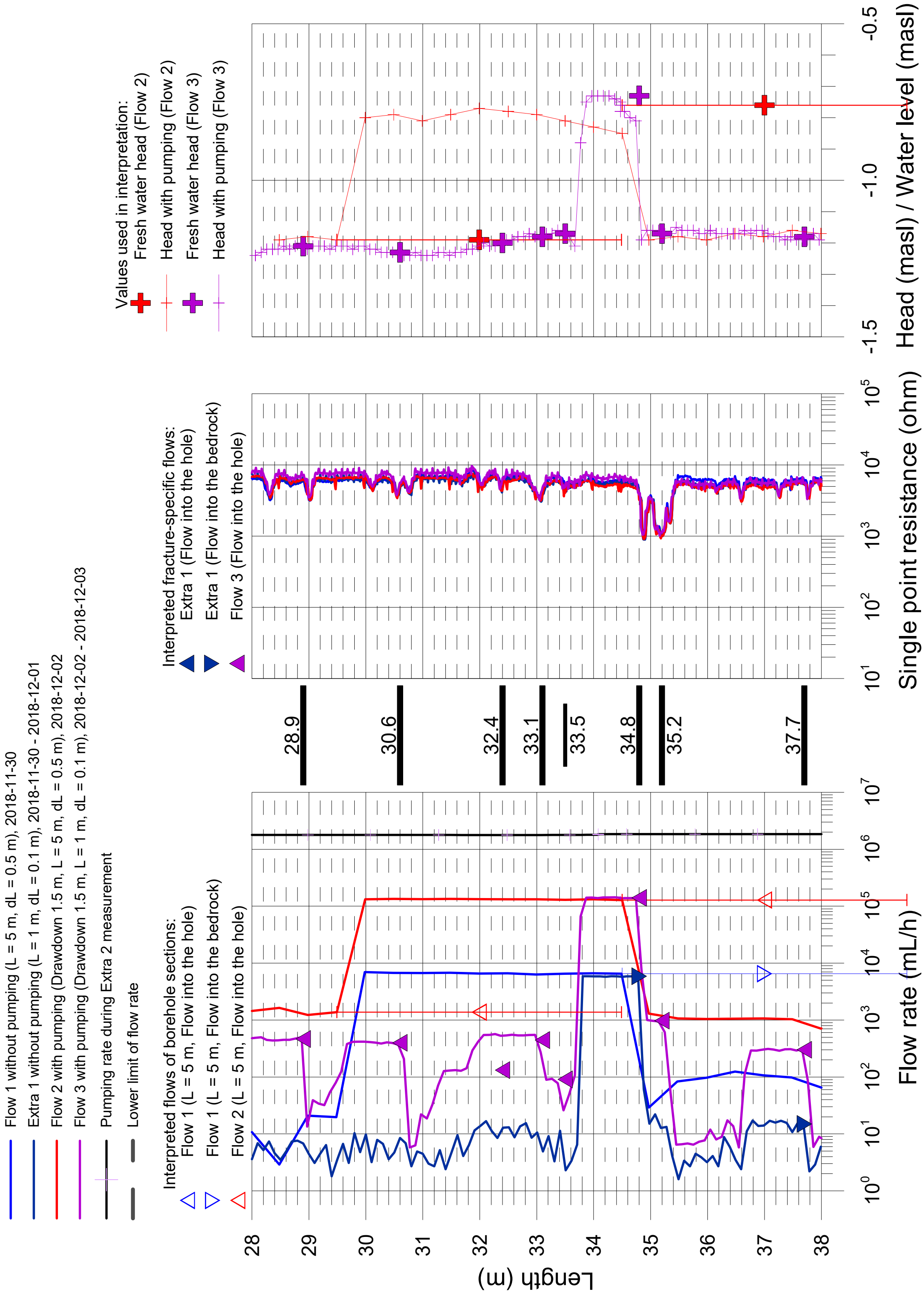
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-12-02 - 2018-12-03 (Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-0.5
-1.0
-1.5
Temperature (°C)
8.5
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
10.0 m
8.6 m
Flow (mL/h)
1000000
100000
10000
1000
100
10
1
2018-12-03 / 7:59
2018-12-03 / 8:30
2018-12-03 / 9:00
2018-12-03 / 9:30
Year-Month-Day / Hour:Minute



When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-12-02 - 2018-12-03 (Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-0.5
-1.0
-1.5
Upper part of the borehole:
Water level data was not available as water level probe was removed from the borehole.
Measurement was conducted without pumping during groundwater recovery.
Temperature (°C)
8.5
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
6.5 m
Flow (mL/h)
1000000
100000
10000
1000
100
10
1
2018-12-03 / 12:00
2018-12-03 / 12:17
2018-12-03 / 12:35
Year-Month-Day / Hour:Minute

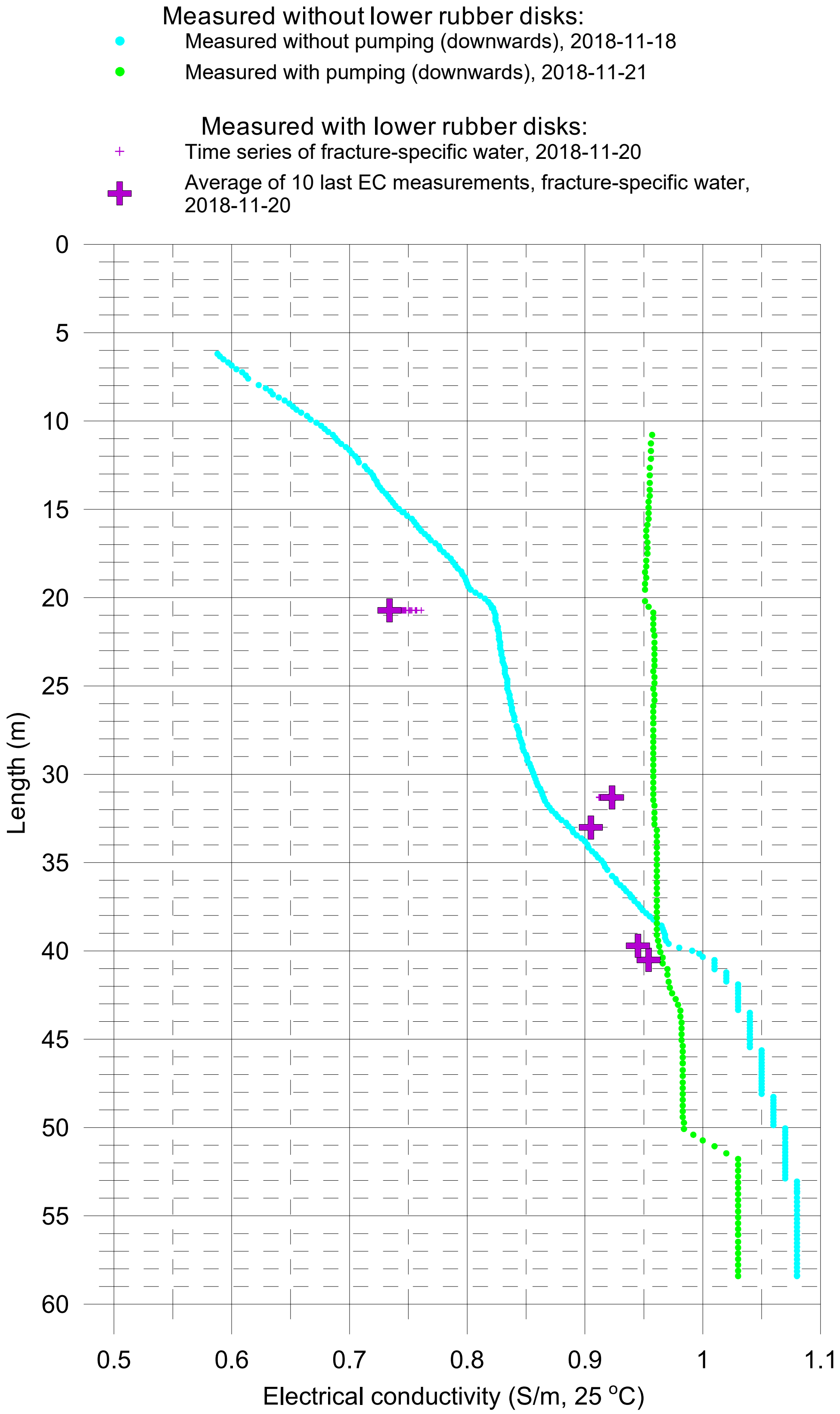
KFM21.11.1–KFM21.11.2 Flow rate, single point resistance and head in the borehole during flow logging

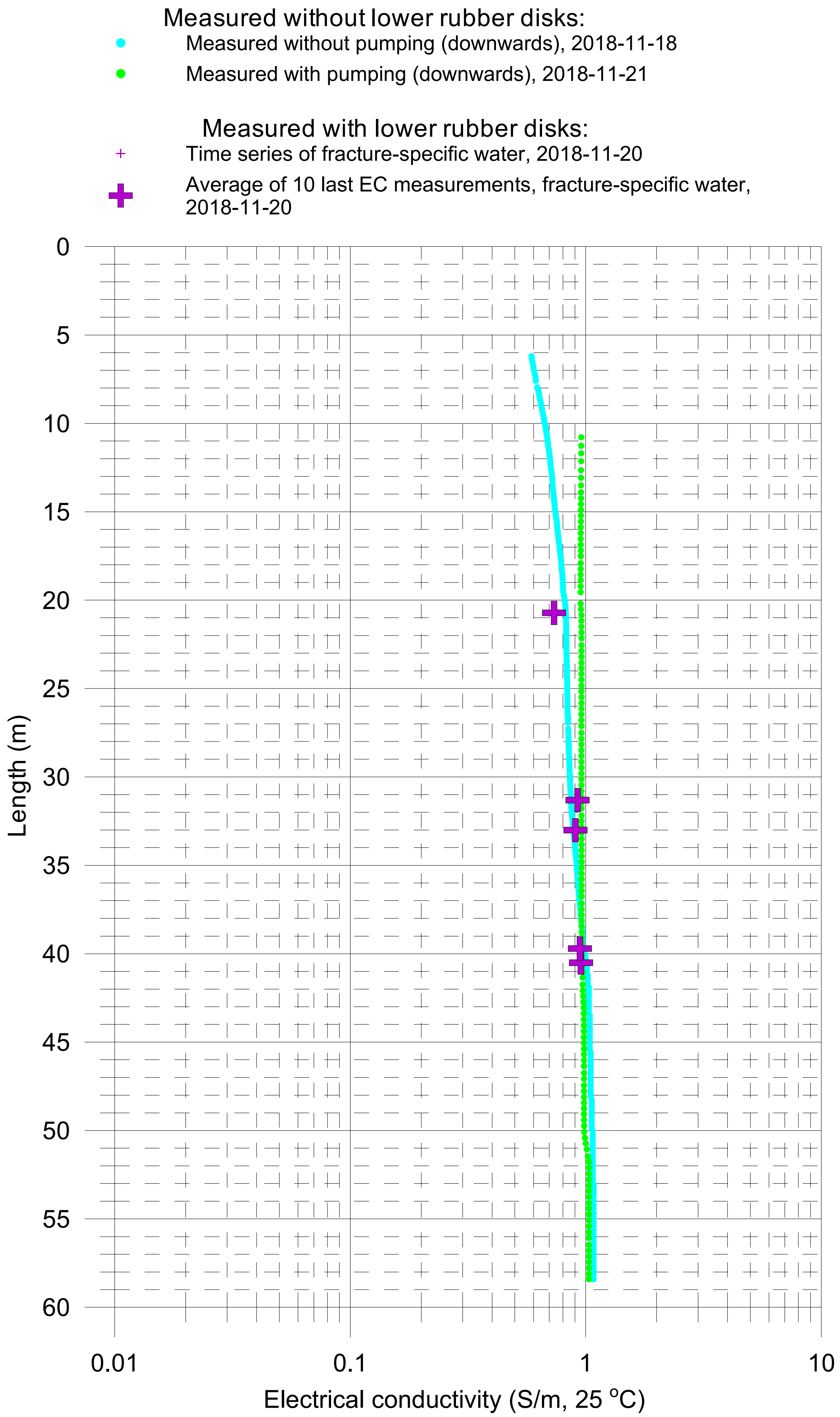




Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-30
Extra 1 without pumping (L = 1 m, dL = 0.1 m), 2018-11-30 - 2018-12-01
Flow 2 with pumping (Drawdown 1.5 m, L = 5 m, dL = 0.5 m), 2018-12-02
Flow 3 with pumping (Drawdown 1.5 m, L = 1 m, dL = 0.1 m), 2018-12-02 - 2018-12-03
Pumping rate during Extra 2 measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, Flow into the hole)
Flow 1 (L = 5 m, Flow into the bedrock)
Flow 2 (L = 5 m, Flow into the hole)
Interpreted fracture-specific flows:
Extra 1 (Flow into the hole)
Extra 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Values used in interpretation:
Fresh water head (Flow 2)
Head with pumping (Flow 2)
Fresh water head (Flow 3)
Head with pumping (Flow 3)
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)
Head (masl) / Water level (masl)
28.9
30.6
32.4
33.1
33.5
34.8
35.2
37.7

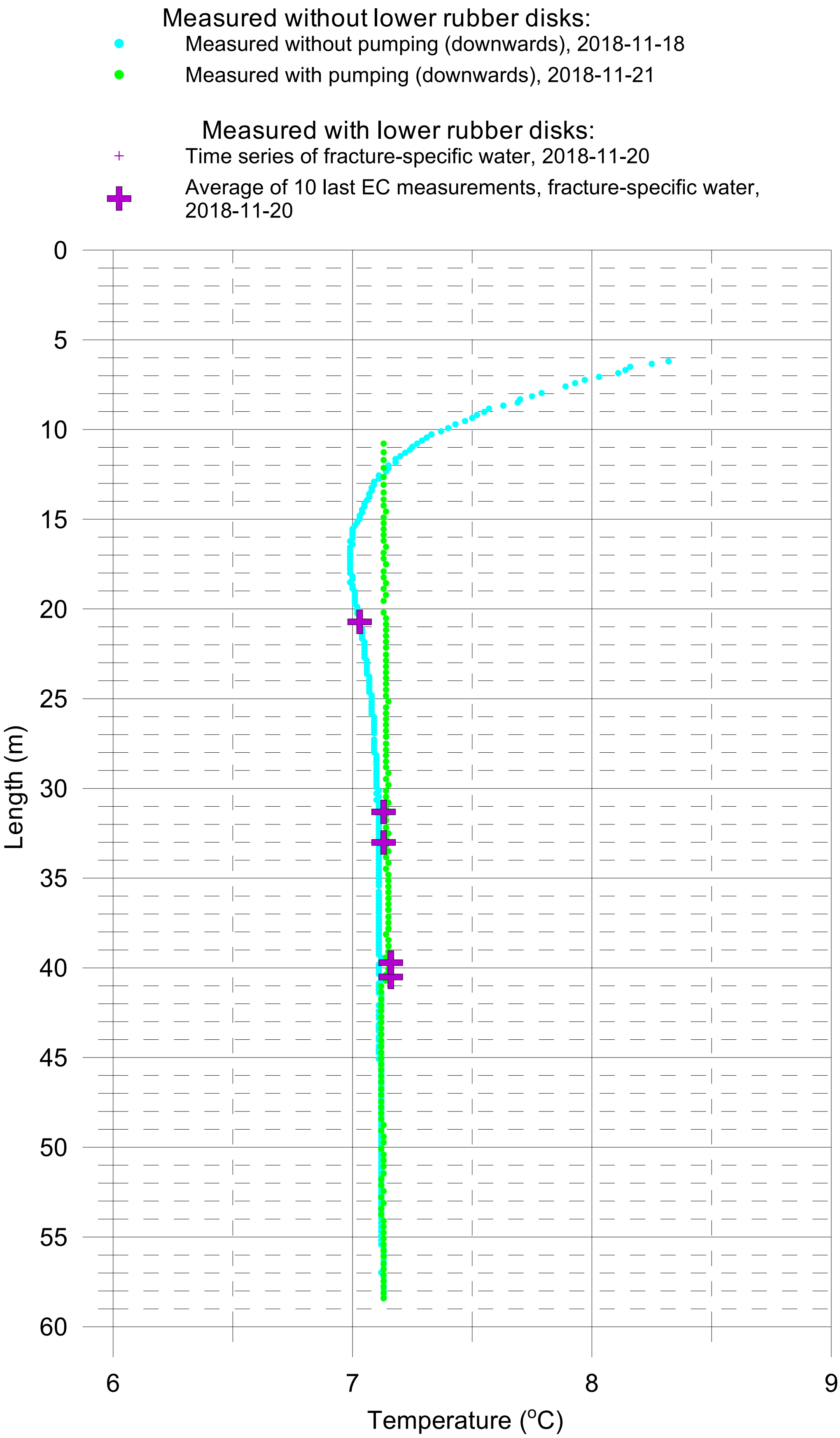
KFM22.1.1–KFM22.1.2 Electrical conductivity of borehole water



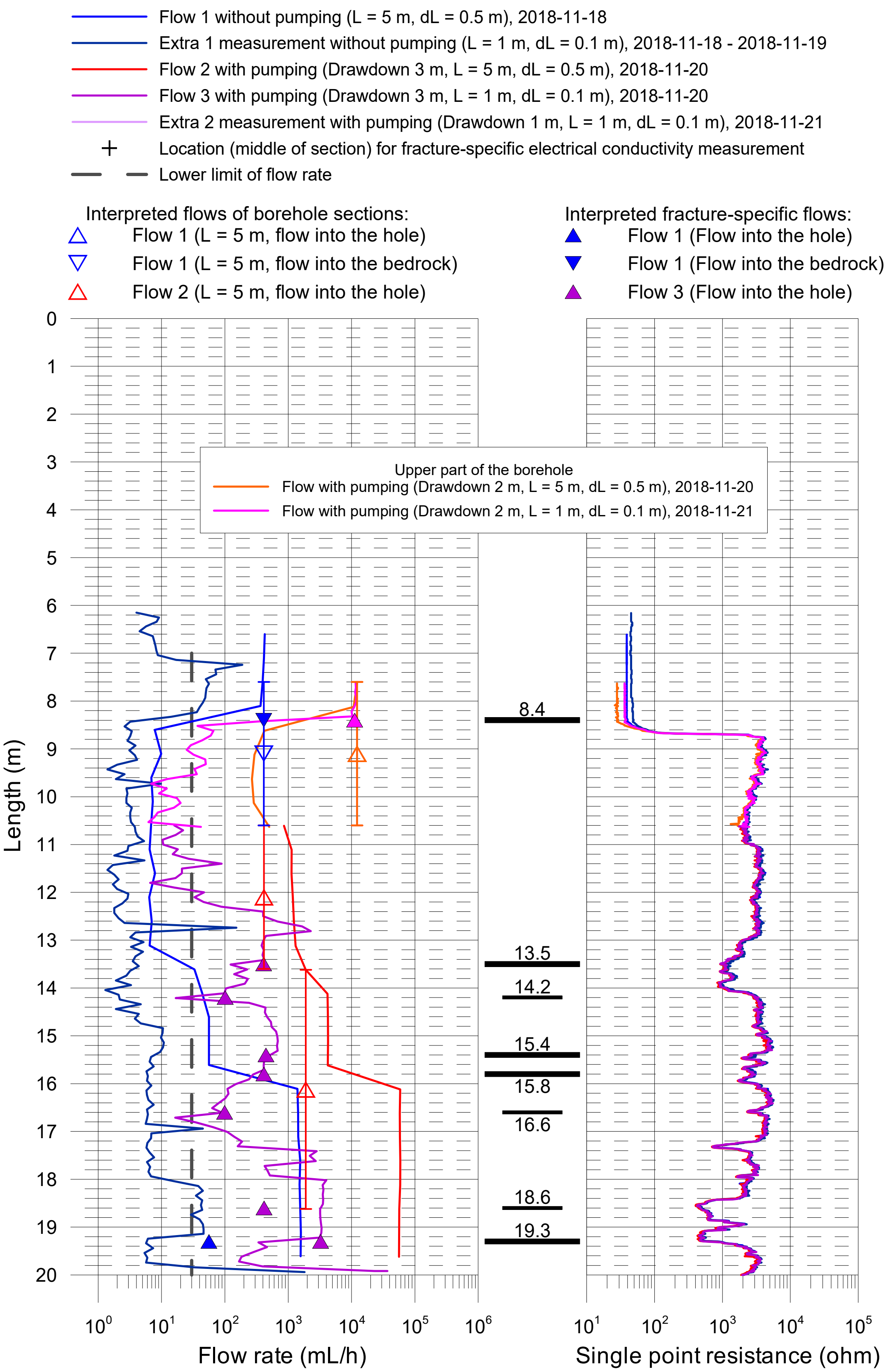


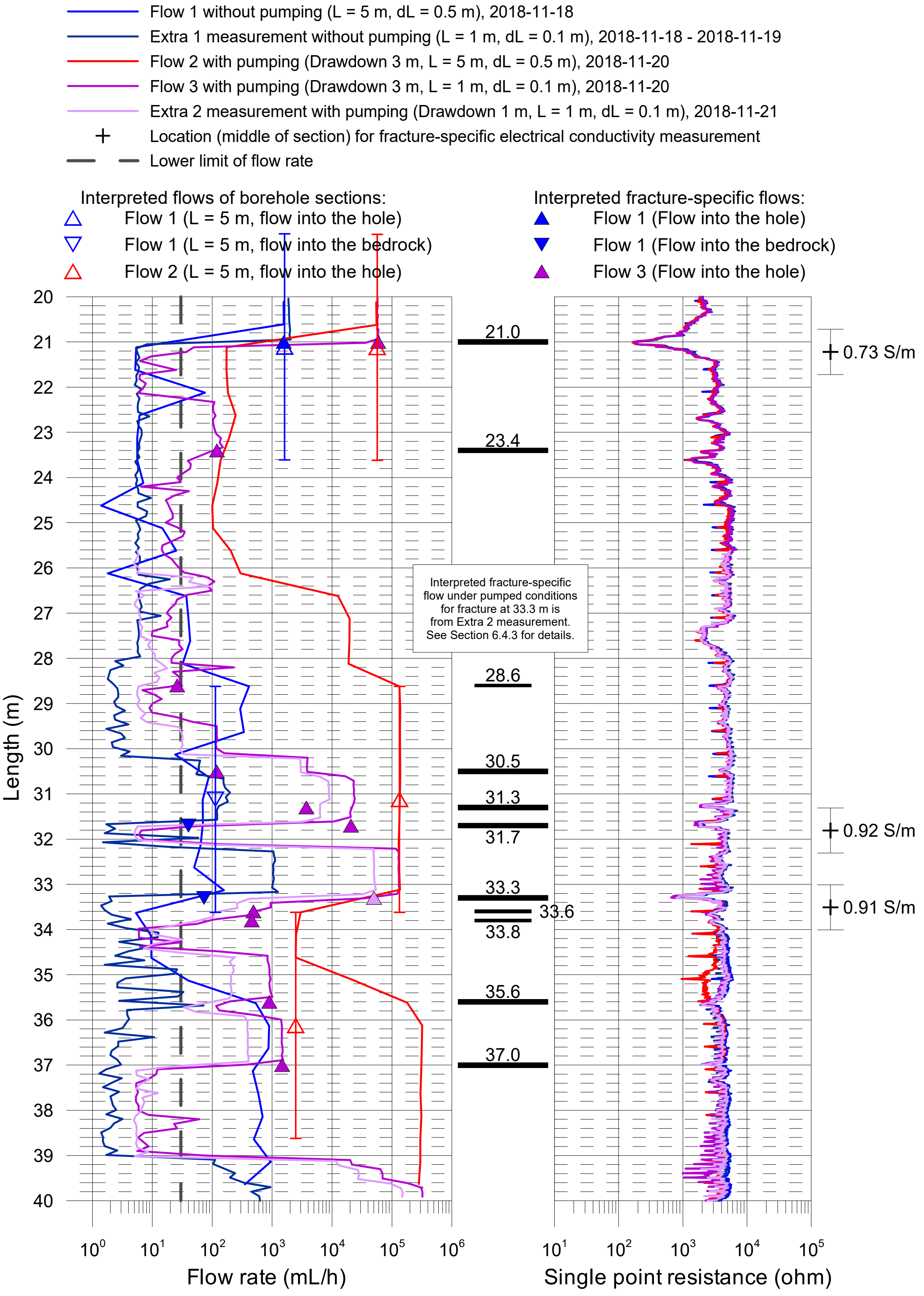
Measured without lower rubber disks:
Measured without pumping (downwards), 2018-11-18
Measured with pumping (downwards), 2018-11-21
Measured with lower rubber disks:
Time series of fracture-specific water, 2018-11-20
Average of 10 last EC measurements, fracture-specific water, 2018-11-20
Length (m)
0
5
10
15
20
25
30
35
40
45
50
55
60
0.01
0.1
1
10
Electrical conductivity (S/m, 25 °C)

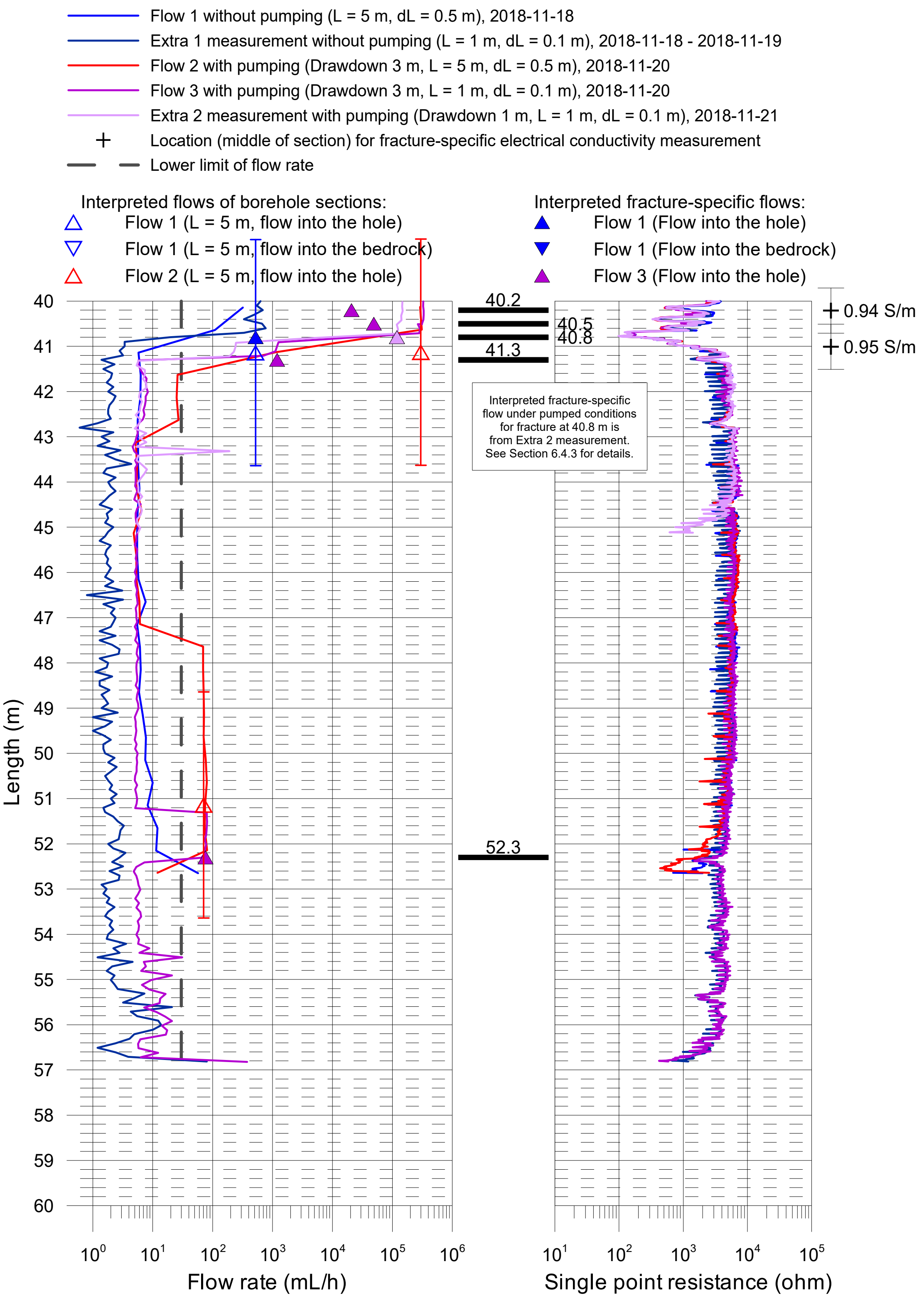
KFM22.1.3 Temperature of borehole water



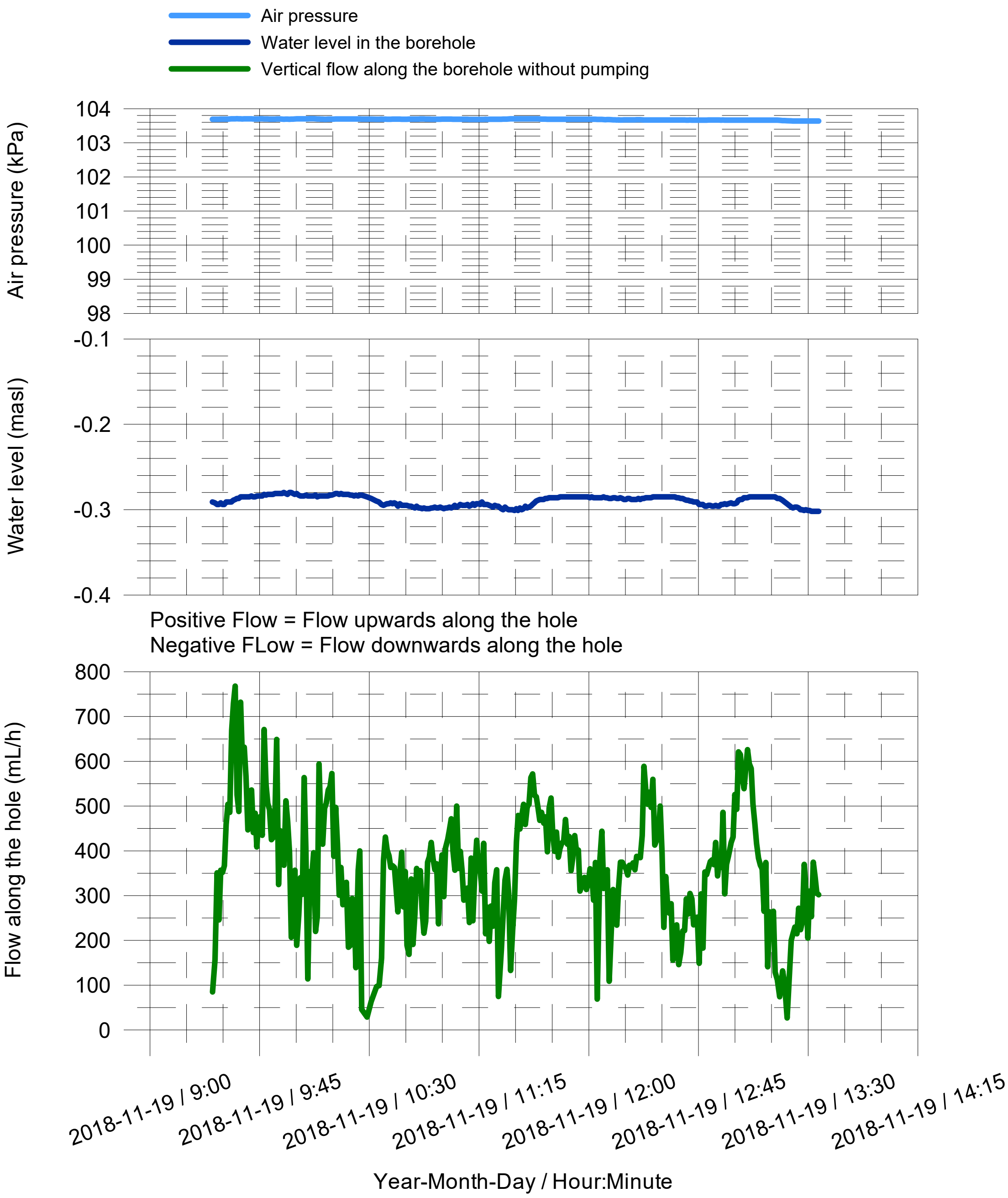
KFM22.2.1–KFM22.2.3 Flow rate and single point resistance




Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-18
Extra 1 measurement without pumping (L = 1 m, dL = 0.1 m), 2018-11-18 - 2018-11-19
Flow 2 with pumping (Drawdown 3 m, L = 5 m, dL = 0.5 m), 2018-11-20
Flow 3 with pumping (Drawdown 3 m, L = 1 m, dL = 0.1 m), 2018-11-20
Extra 2 measurement with pumping (Drawdown 1 m, L = 1 m, dL = 0.1 m), 2018-11-21
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Interpreted fracture-specific flow under pumped conditions for fracture at 33.3 m is from Extra 2 measurement. See Section 6.4.3 for details.
21.0
23.4
28.6
30.5
31.3
31.7
33.3
33.6
33.8
35.6
37.0
0.73 S/m
0.92 S/m
0.91 S/m
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)


Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-18
Extra 1 measurement without pumping (L = 1 m, dL = 0.1 m), 2018-11-18 - 2018-11-19
Flow 2 with pumping (Drawdown 3 m, L = 5 m, dL = 0.5 m), 2018-11-20
Flow 3 with pumping (Drawdown 3 m, L = 1 m, dL = 0.1 m), 2018-11-20
Extra 2 measurement with pumping (Drawdown 1 m, L = 1 m, dL = 0.1 m), 2018-11-21
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
40.2
40.5
40.8
41.3
52.3
0.94 S/m
0.95 S/m
Interpreted fracture-specific flow under pumped conditions for fracture at 40.8 m is from Extra 2 measurement. See Section 6.4.3 for details.
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)

KFM22.2.4 Vertical flow along the borehole at 9.0 m



KFM22.3 Explanations for the tables in Appendices

Header	Unit	Explanations
Borehole ID		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)
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with h=h0 in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first pumping period
h_{0FW}	m.a.s.l.	Corrected initial hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid before pumping
h_{1FW}	m.a.s.l.	Corrected hydraulic head along the borehole due to e.g. varying salinity conditions of the borehole fluid during the first pumping period
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.
Q-lower limit P	mL/h	Practical lower measurement limit for flow rate.
T-measl$_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-measl$_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-meas$_{lU}$	m^2/s	Estimated upper measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

KFM22.4 Results of section flows

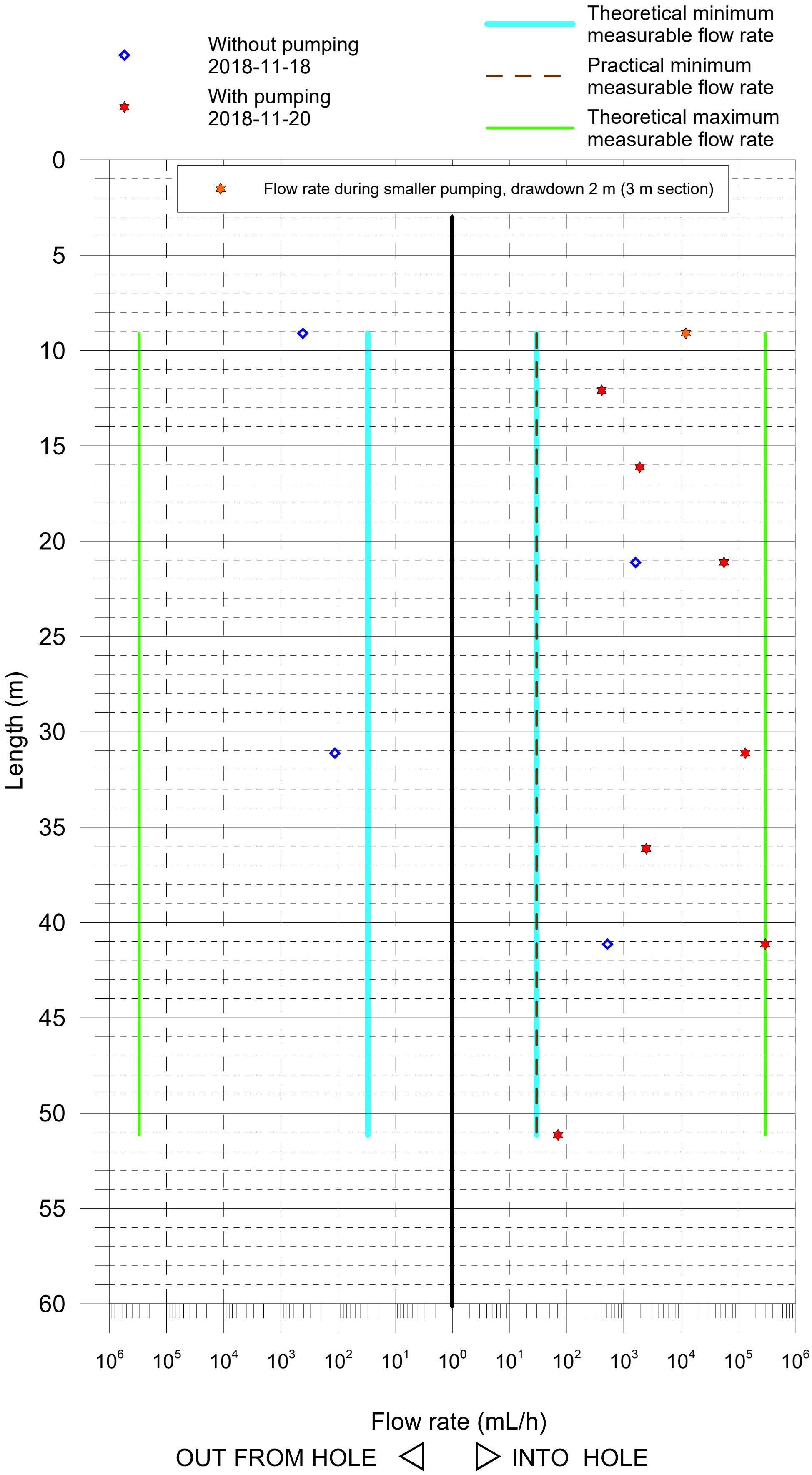
Borehole ID	Secup L(m)	Seclow L(m)	L_w (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Q-lower limit P (mL/h)	T_D-measl$_{LT}$ (m^2/s)	T_D-measl$_{LP}$ (m^2/s)	T_D - measl$_U$ (m^2/s)	Comments
KFM22	7.60	10.60	3	−1.14E-07	0.06	3.40E-06	−2.01	1.7E-06	0	30	4.0E-09	4.0E-09	4.0E-05	*, ***
KFM22	10.60	13.60	3	–	0.06	1.15E-07	−3.08	3.6E-08	–	30	2.6E-09	2.6E-09	2.6E-05	
KFM22	13.62	18.62	5	–	0.09	5.28E-07	−2.98	1.7E-07	–	30	2.7E-09	2.7E-09	2.7E-05	
KFM22	18.62	23.62	5	4.49E-07	0.13	1.58E-05	−3.04	4.8E-06	0.2	30	2.6E-09	2.6E-09	2.6E-05	
KFM22	23.62	28.62	5	–	0.12	–	−2.99	–	–	30	2.7E-09	2.7E-09	2.7E-05	
KFM22	28.62	33.62	5	−3.14E-08	0.13	3.72E-05	−2.60	1.4E-05	0.1	30	3.0E-09	3.0E-09	3.0E-05	**
KFM22	33.63	38.63	5	–	0.13	6.86E-07	−2.93	2.2E-07	–	30	2.7E-09	2.7E-09	2.7E-05	
KFM22	38.64	43.64	5	1.45E-07	0.14	8.31E-05	−1.16	6.3E-05	0.1	30	6.3E-09	6.3E-09	6.3E-05	**
KFM22	43.64	48.64	5	–	0.13	–	−2.88	–	–	30	2.7E-09	2.7E-09	2.7E-05	
KFM22	48.65	53.65	5	–	0.11	1.97E-08	−2.96	6.4E-09	–	30	2.7E-09	2.7E-09	2.7E-05	

* Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made with smaller pumping (drawdown 2 m). The upper part of the borehole could not be measured during larger drawdown.

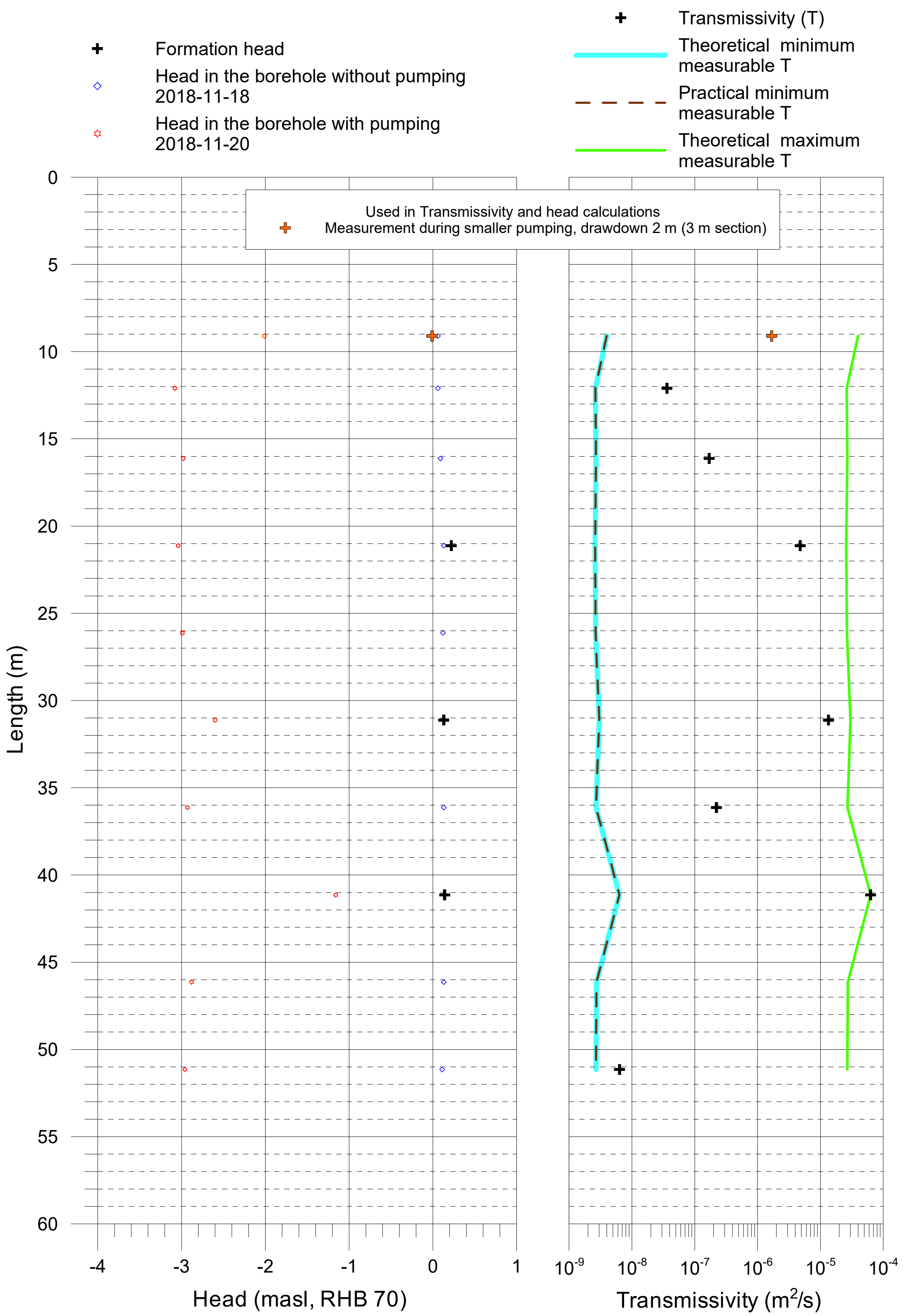
** Measured flow rate is near or exceeds the upper measurement limit. Due to friction loss in the PFL DIFF probe's flow guide, the actual flow rate would probably be higher than the measured flow rate.

*** Flow possibly from the joint of casing tube and borehole.

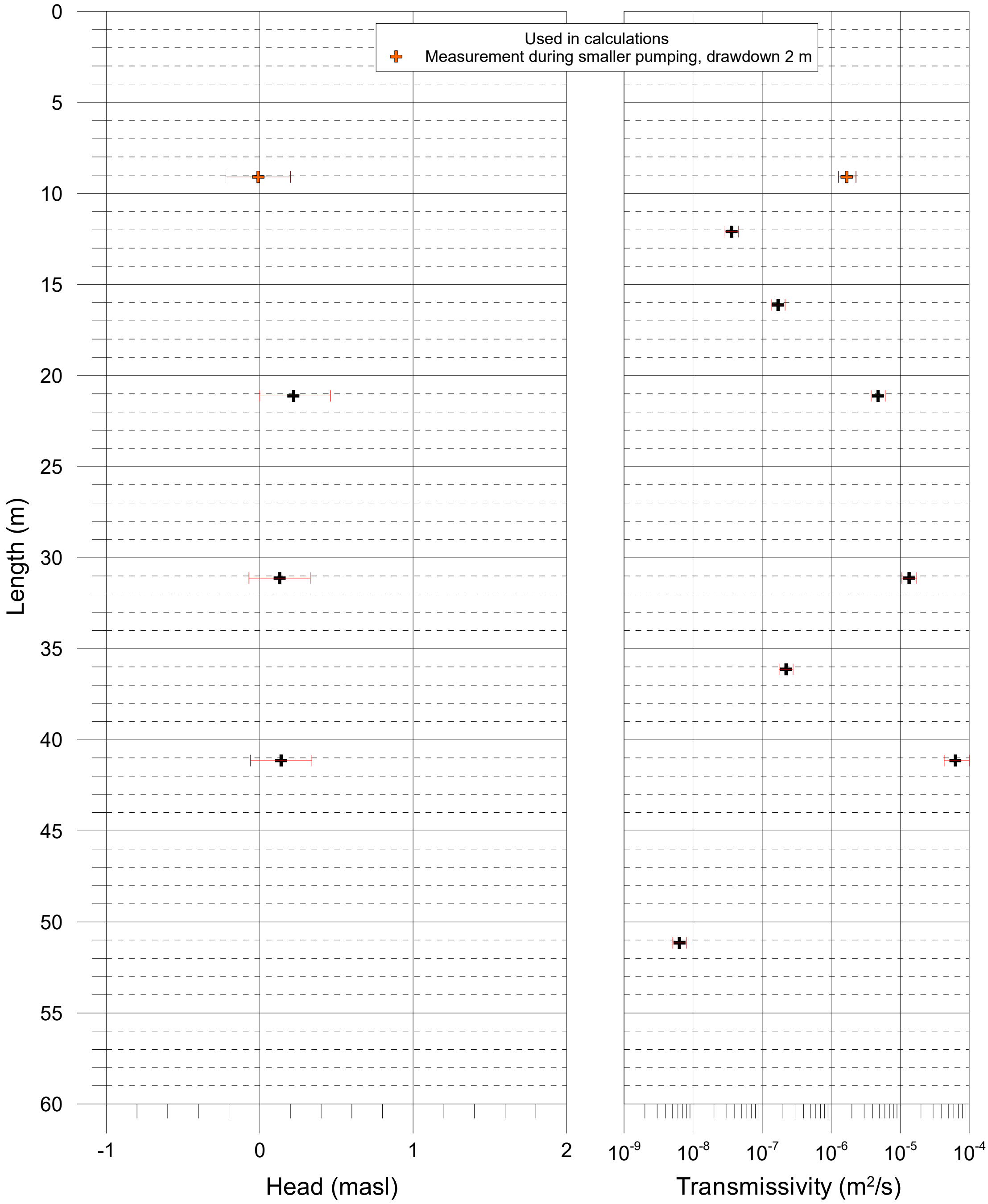
KFM22.5.1 Plotted flow rates of 5 m sections



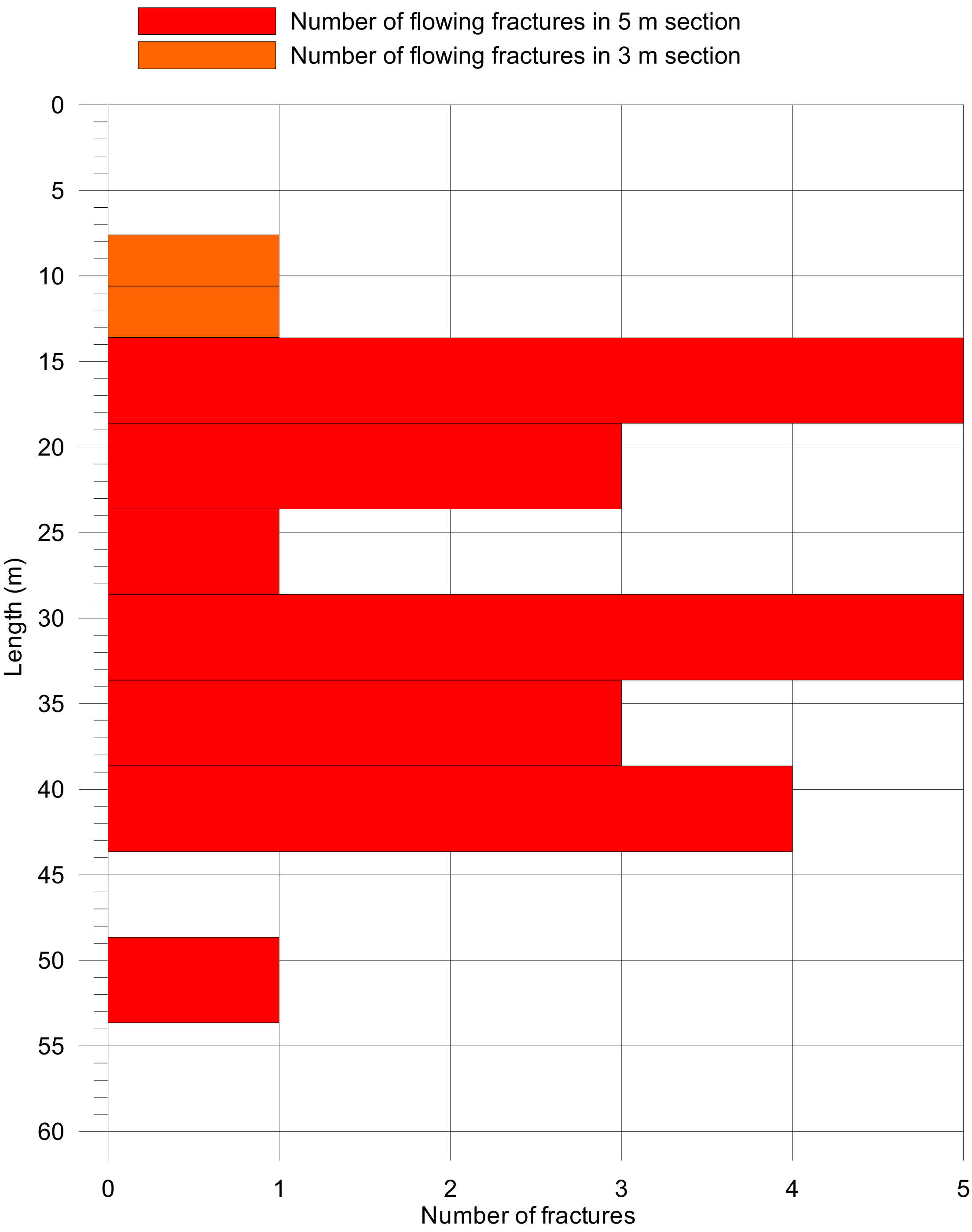
KFM22.5.2 Plotted transmissivity and head of 5 m sections



KFM22.5.3 Transmissivity and head of 5 m sections with calculated error limits



KFM22.5.4 Conductive fracture frequency



KFM22.6 Inferred fracture flow anomalies from 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
KFM22	8.4	1	0.1	−1.14E-07	0.06	3.11E-06	−2.00	1.6E-06	0.0	*,**,****
KFM22	13.5	1	0.1	–	0.06	1.14E-07	−3.03	3.7E-08	–	
KFM22	14.2	1	0.1	–	0.09	2.81E-08	−3.05	8.8E-09	–	*
KFM22	15.4	1	0.1	–	0.07	1.24E-07	−3.05	3.9E-08	–	
KFM22	15.8	1	0.1	–	0.07	1.15E-07	−3.03	3.7E-08	–	
KFM22	16.6	1	0.1	–	0.10	2.75E-08	−3.01	8.8E-09	–	*
KFM22	18.6	1	0.1	–	0.12	1.15E-07	−3.02	3.6E-08	–	*
KFM22	19.3	1	0.1	1.56E-08	0.15	9.00E-07	−3.01	2.8E-07	0.2	
KFM22	21.0	1	0.1	4.33E-07	0.13	1.63E-05	−2.98	5.1E-06	0.2	
KFM22	23.4	1	0.1	–	0.10	3.33E-08	−3.01	1.1E-08	–	
KFM22	28.6	1	0.1	–	0.12	7.22E-09	−2.96	2.3E-09	–	*
KFM22	30.5	1	0.1	–	0.14	3.31E-08	−2.97	1.1E-08	–	
KFM22	31.3	1	0.1	–	0.13	1.04E-06	−2.97	3.3E-07	–	
KFM22	31.7	1	0.1	−1.11E-08	0.12	5.75E-06	−2.98	1.8E-06	0.1	
KFM22	33.3	1	0.1	−2.03E-08	0.12	1.39E-05	−0.92	1.3E-05	0.1	***
KFM22	33.6	1	0.1	–	0.12	1.36E-07	−2.98	4.3E-08	–	*
KFM22	33.8	1	0.1	–	0.12	1.27E-07	−2.96	4.1E-08	–	*
KFM22	35.6	1	0.1	–	0.13	2.49E-07	−2.99	7.9E-08	–	
KFM22	37.0	1	0.1	–	0.13	4.08E-07	−2.95	1.3E-07	–	
KFM22	40.2	1	0.1	–	0.12	5.78E-06	−2.96	1.9E-06	–	
KFM22	40.5	1	0.1	–	0.14	1.36E-05	−2.86	4.5E-06	–	
KFM22	40.8	1	0.1	1.45E-07	0.15	3.31E-05	−0.72	3.7E-05	0.2	***
KFM22	41.3	1	0.1	–	0.14	3.31E-07	−2.91	1.1E-07	–	
KFM22	52.3	1	0.1	–	0.08	2.11E-08	−2.89	7.0E-09	–	

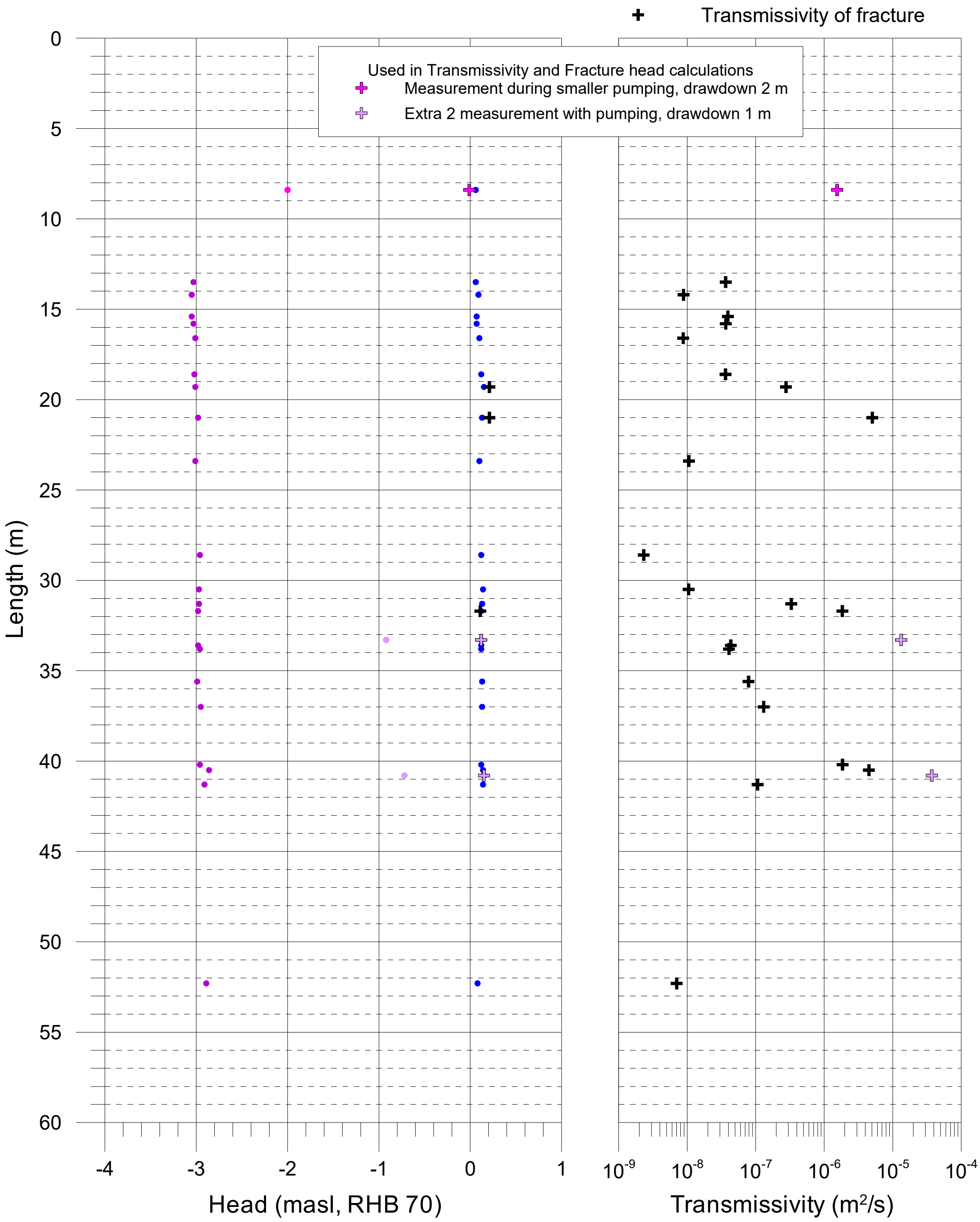
* Uncertain = The flow rate is less than 30 mL/h or the flow anomalies are overlapping or they are unclear because of noise.

** Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made with smaller pumping (drawdown 2 m). The upper part of the borehole could not be measured during larger drawdown.

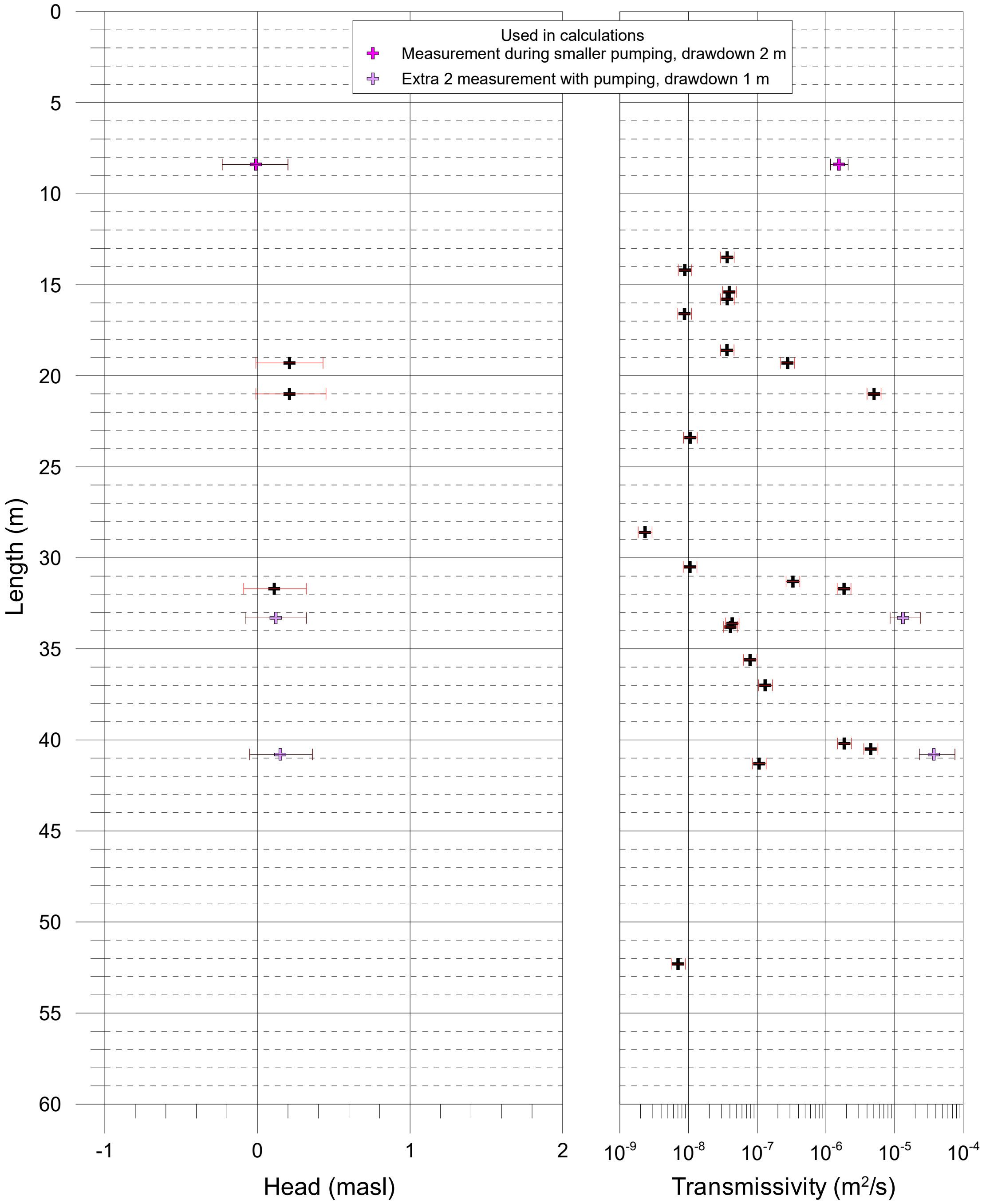
*** Values for Flow (Q_1) and Head (h_{1FW}) are from the measurement made with smaller pumping (drawdown 1 m) due to exceeding of the upper measurement limit during 3 m drawdown in Flow3 measurement.

KFM22.7.1 Plotted transmissivity and head of detected fractures

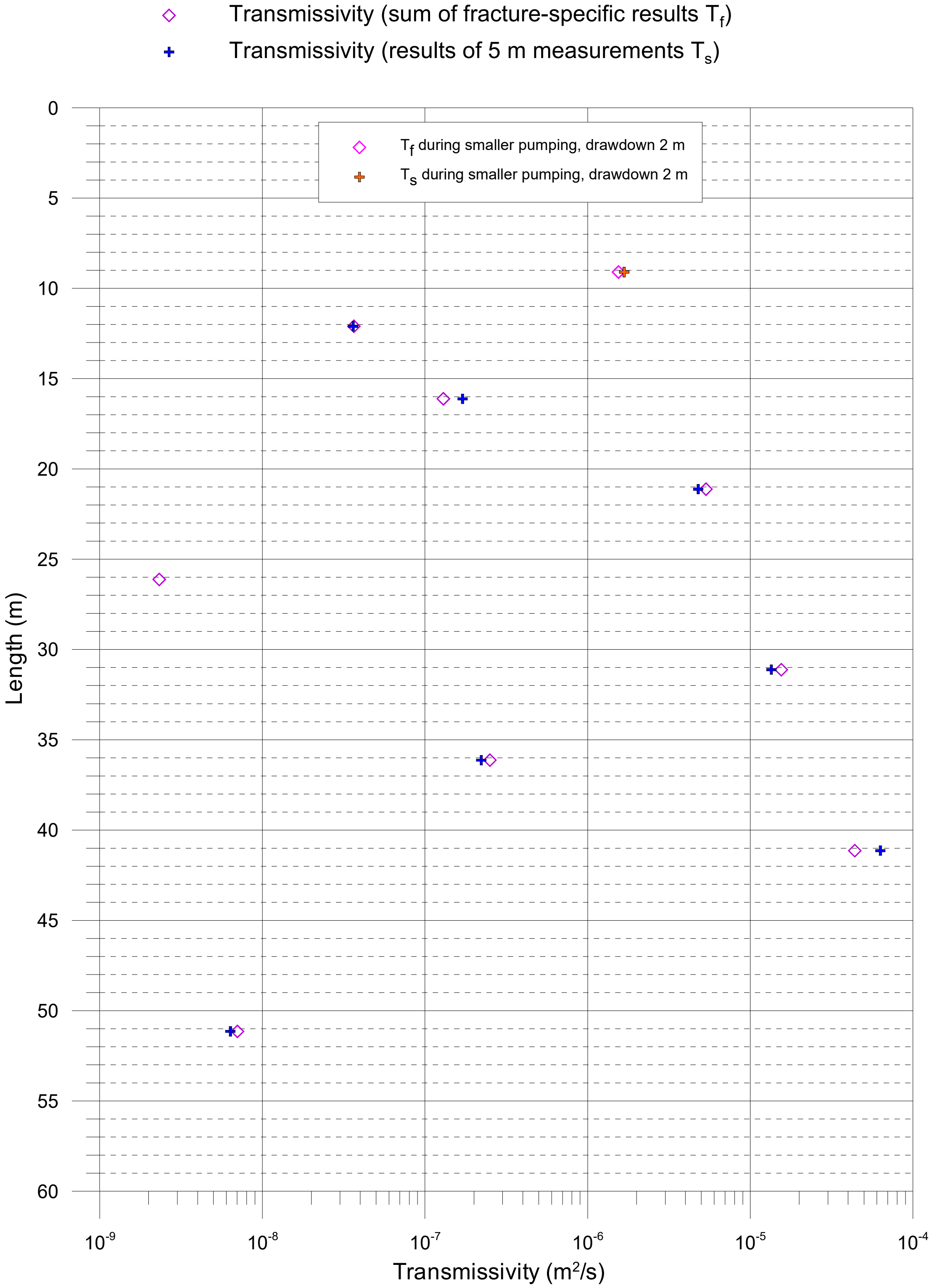
+ Fracture head
● Head in the borehole without pumping (L = 5 m, dL = 0.5 m) 2018-11-18
● Head in the borehole with pumping (L = 1 m, dL = 0.1 m) 2018-11-20



KFM22.7.2 Transmissivity and head of detected fractures with calculated error limits.

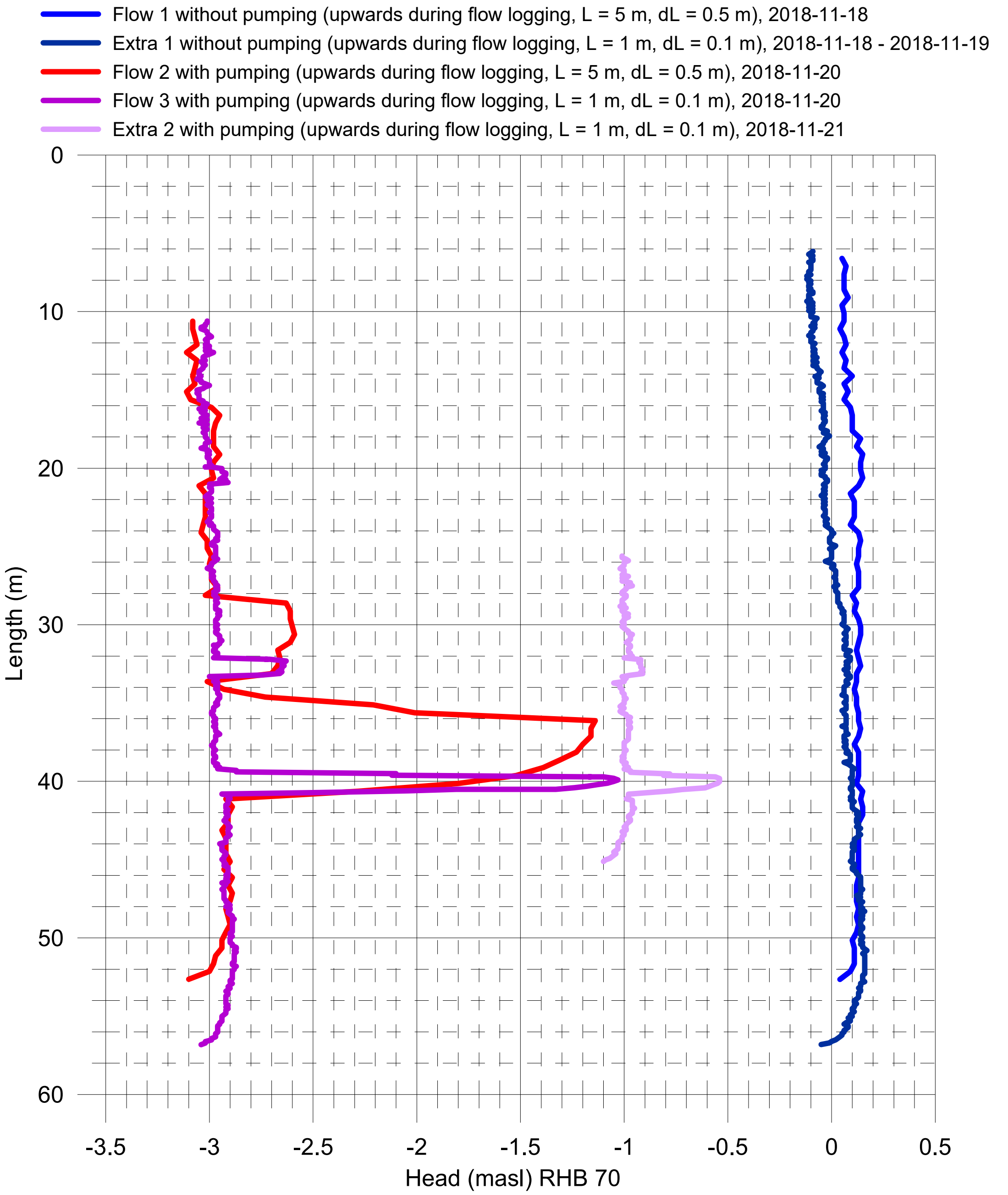


KFM22.8 Comparison between section transmissivity and fracture transmissivity

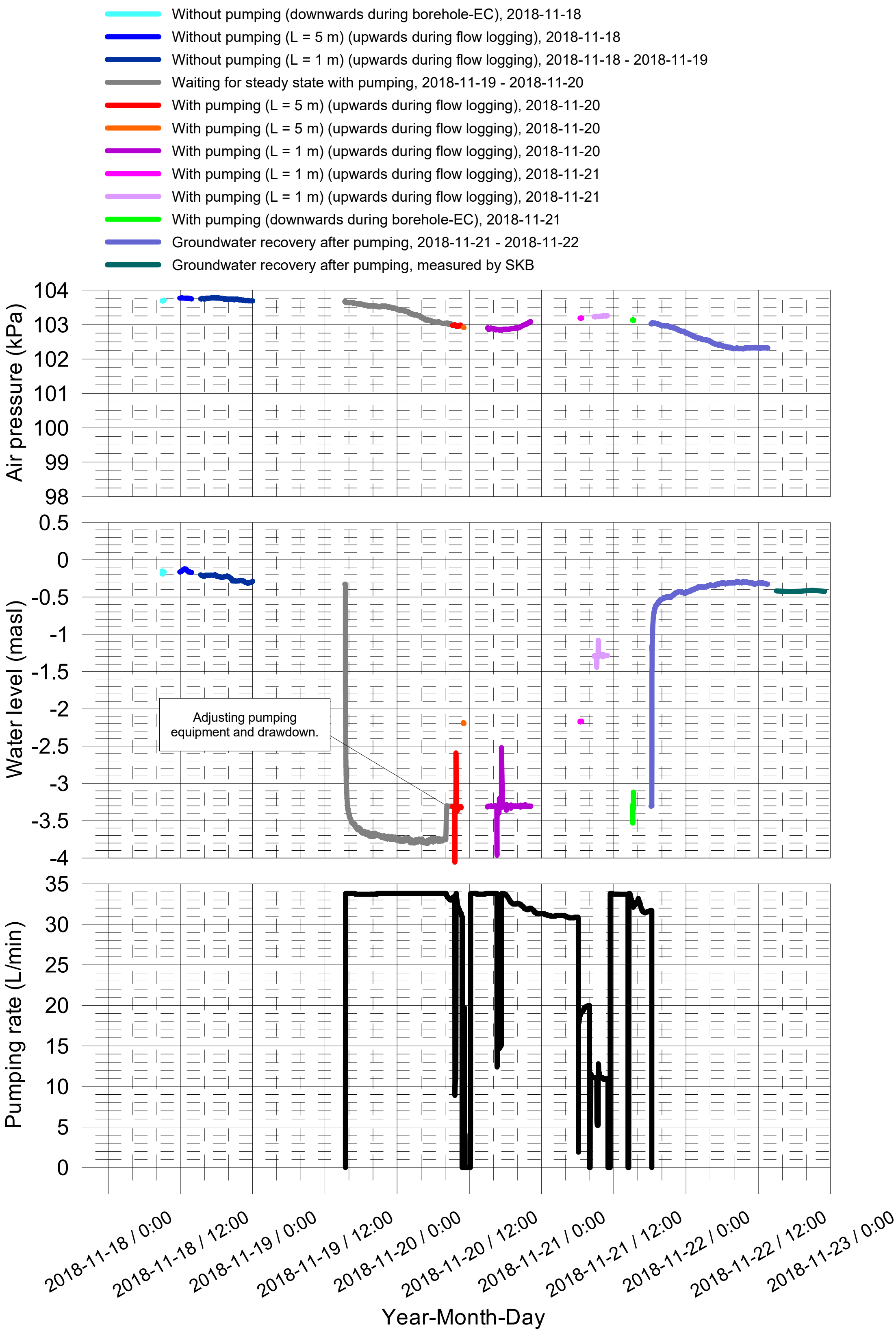


KFM22.9.1 Head in the borehole during flow logging

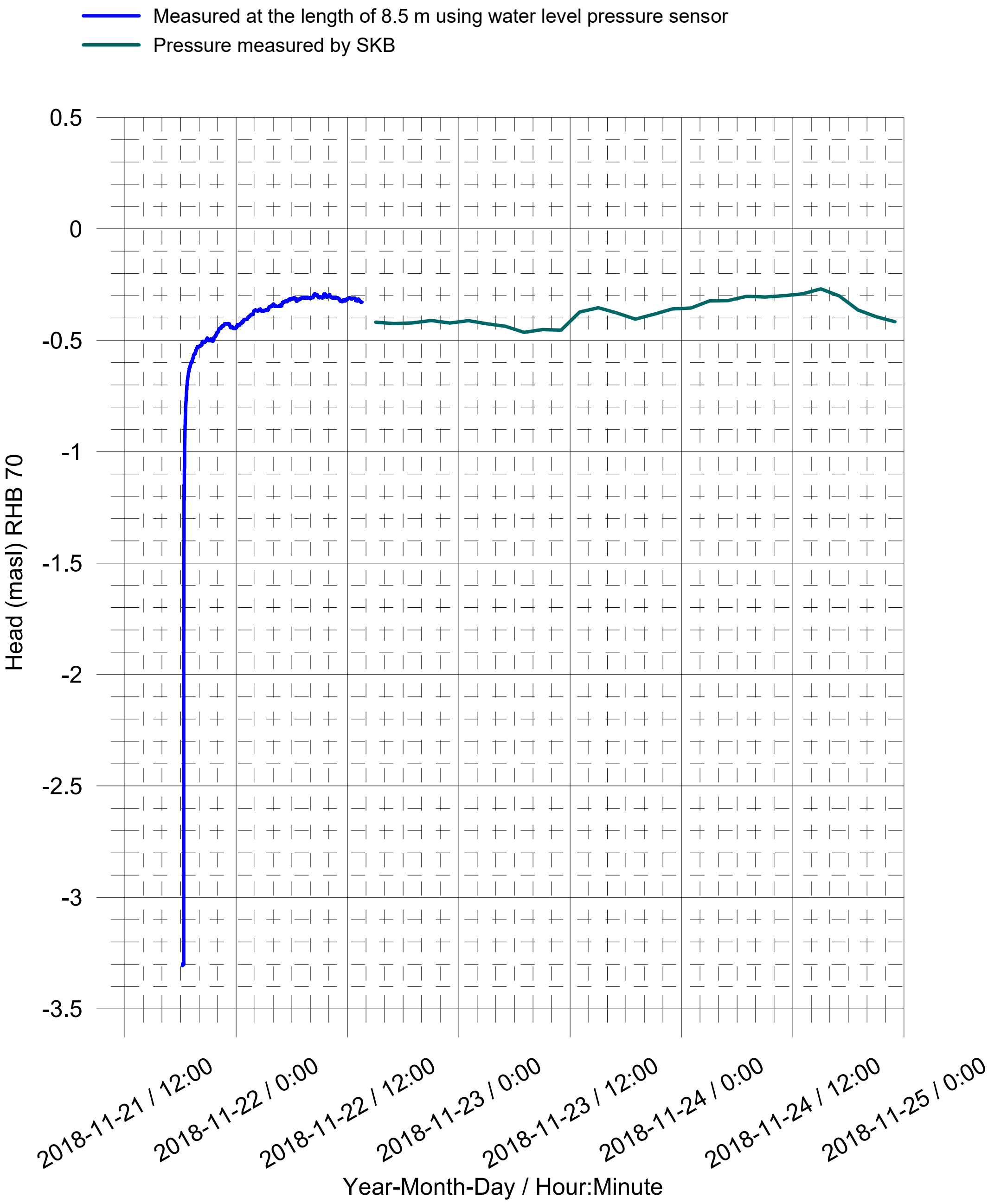
Head (masl) = (Absolute pressure (Pa) - Airpressure (Pa) + Offset) / (1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = Correction for absolute pressure sensor



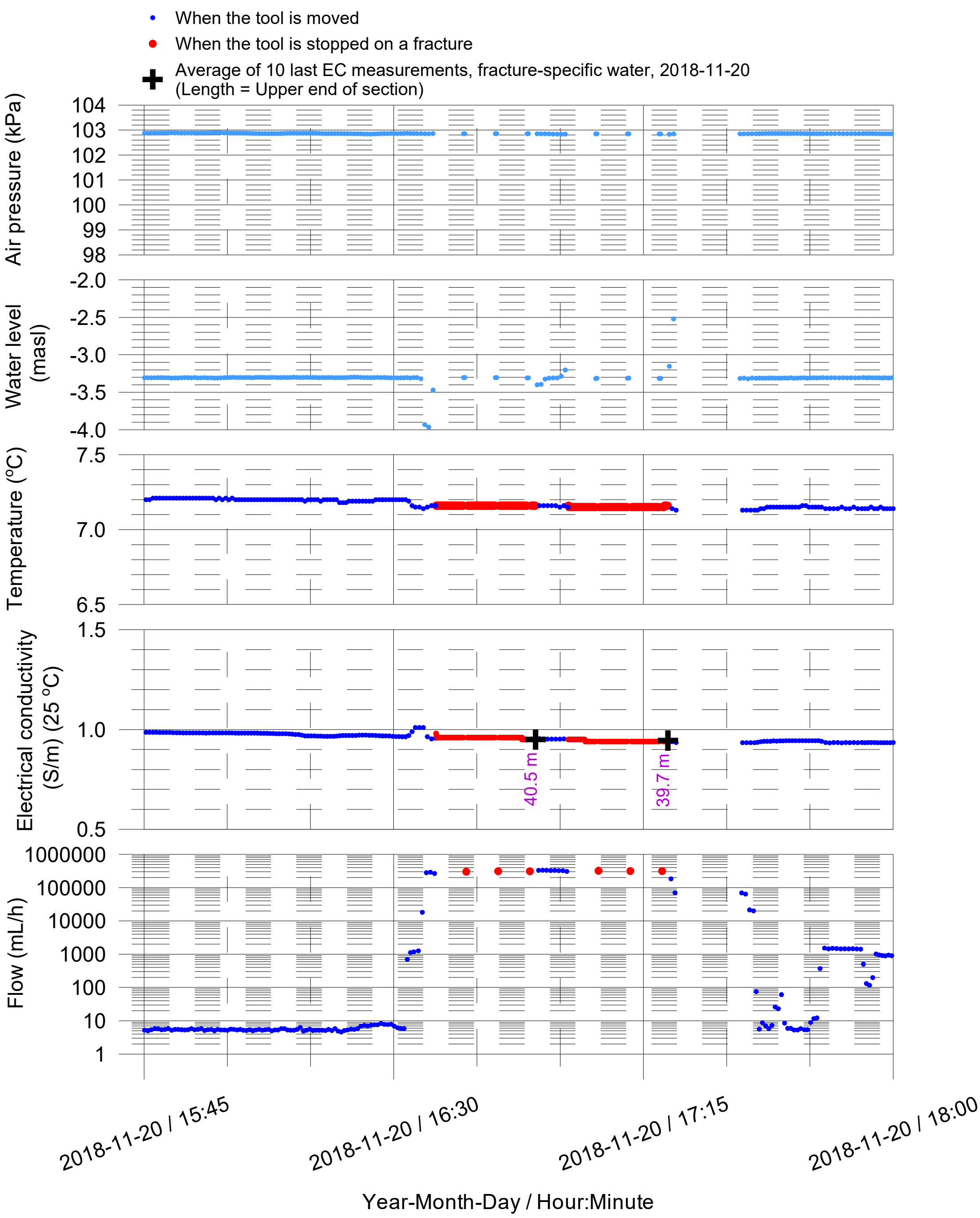
KFM22.9.2 Air pressure, water level in the borehole and pumping rate during flow logging

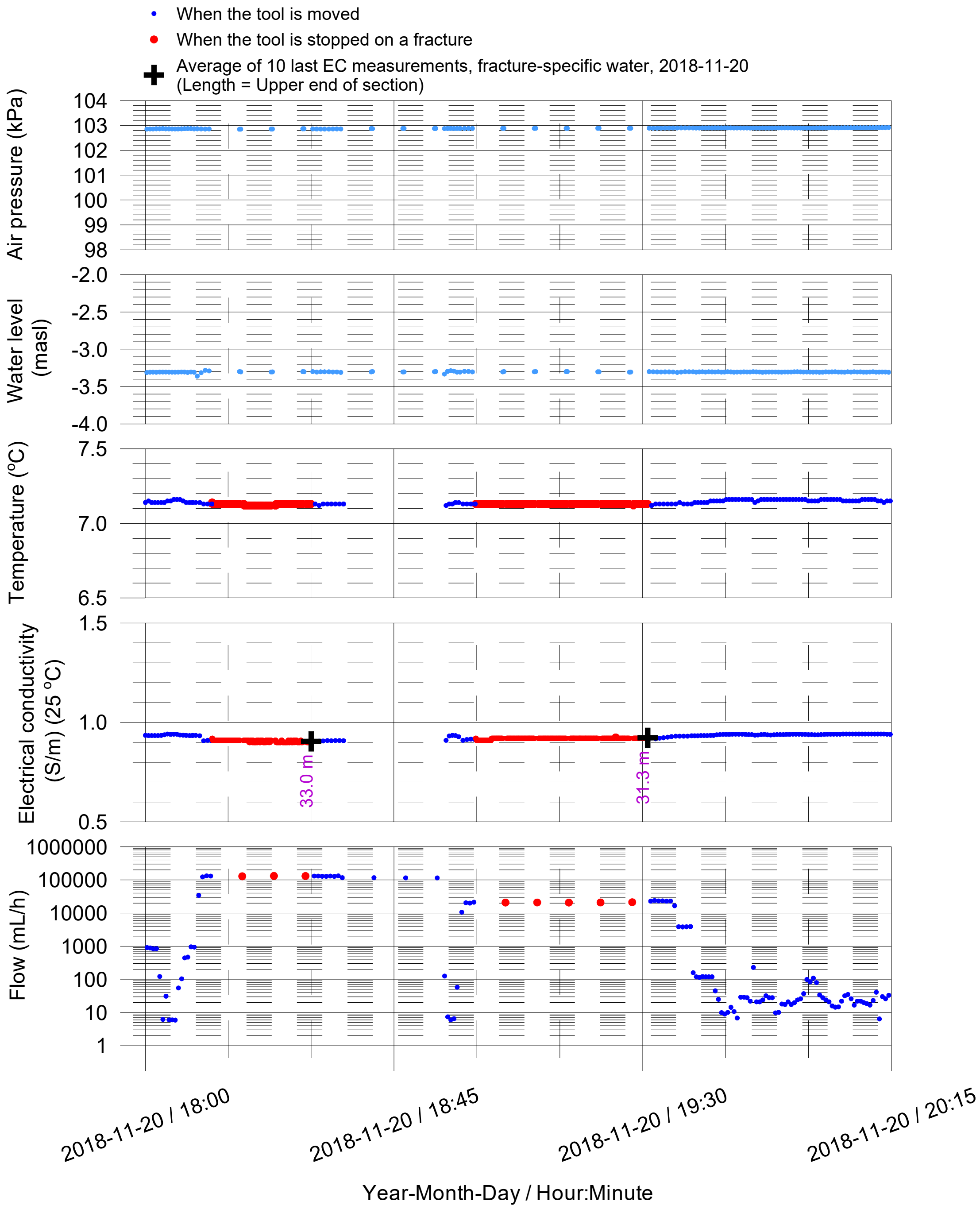


KFM22.9.3 Groundwater recovery after pumping

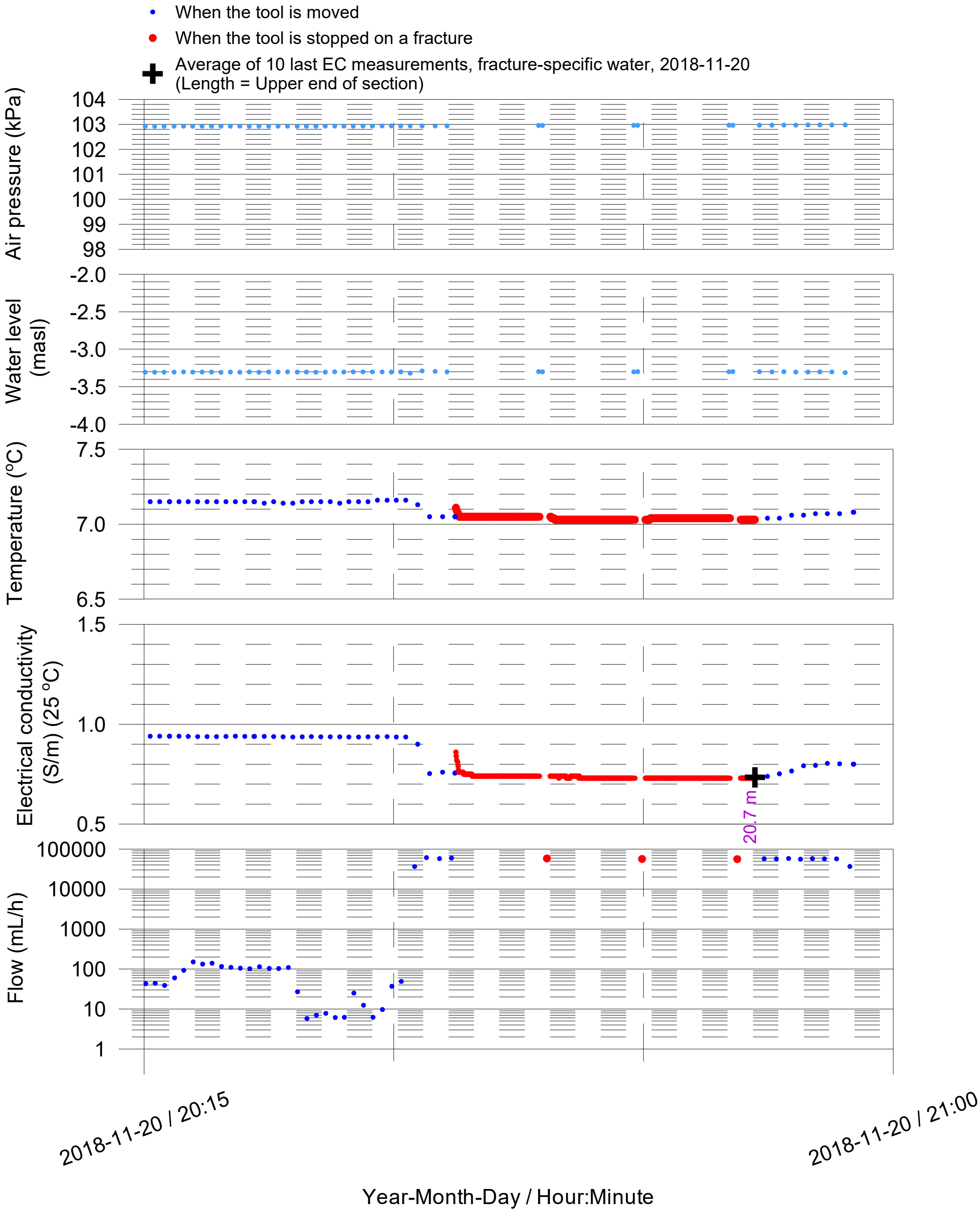


KFM22.10.1–KFM22.10.3 Fracture-specific EC results by date



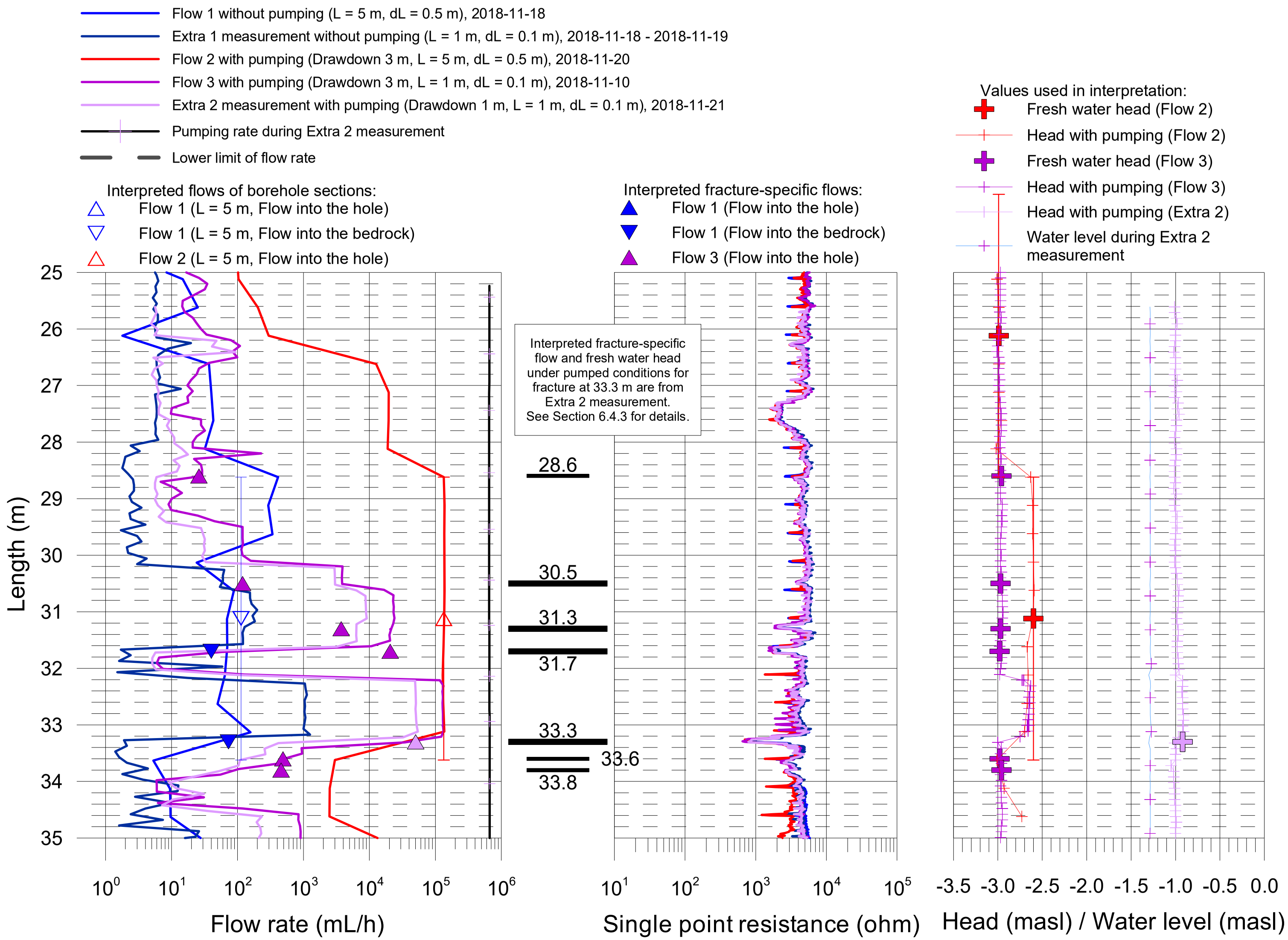


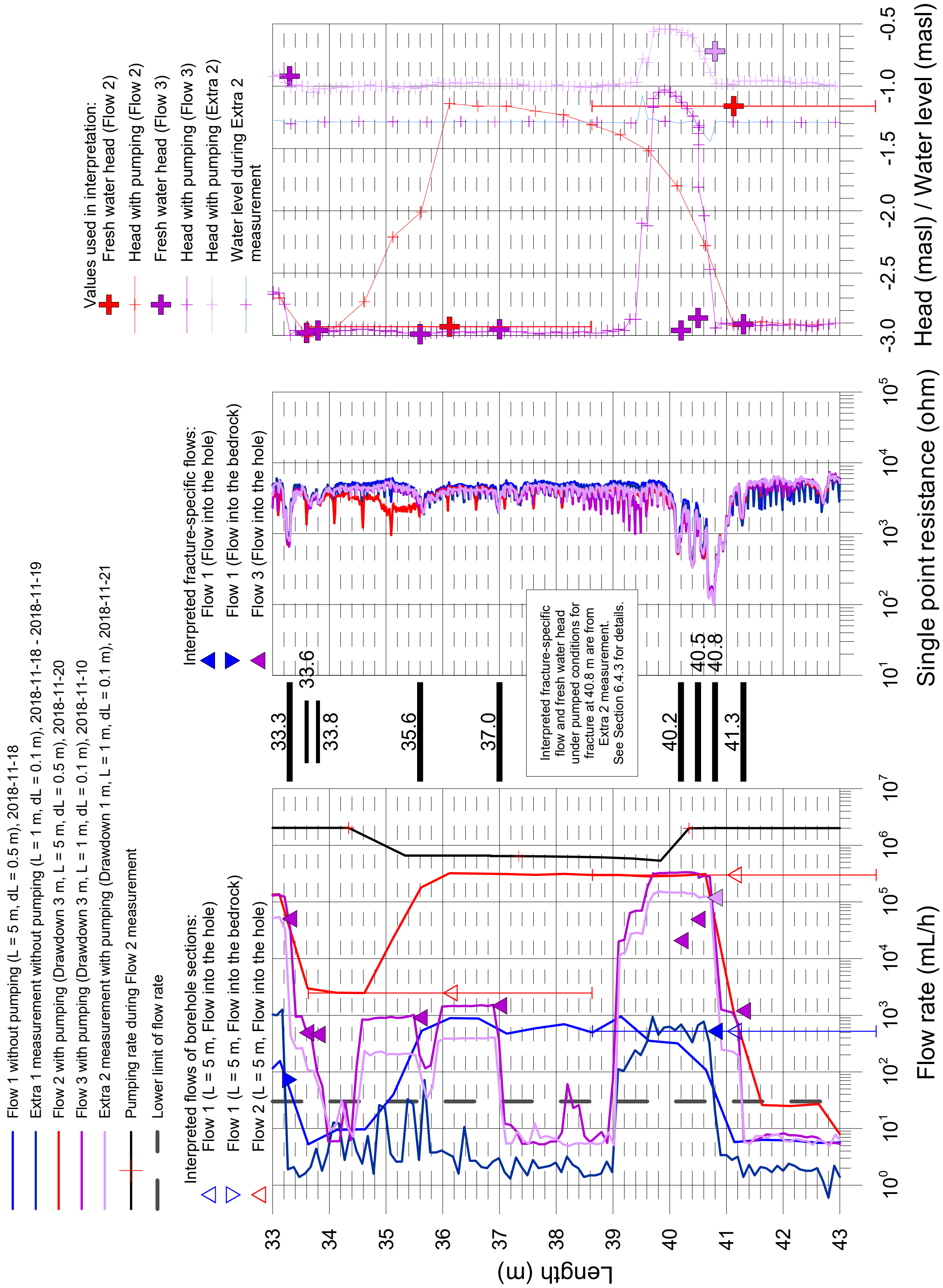
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-20
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-2.0
-2.5
-3.0
-3.5
-4.0
Temperature (°C)
7.5
7.0
6.5
Electrical conductivity (S/m) (25 °C)
1.5
1.0
0.5
33.0 m
31.3 m
Flow (mL/h)
1000000
100000
10000
1000
100
10
1
2018-11-20 / 18:00
2018-11-20 / 18:45
2018-11-20 / 19:30
2018-11-20 / 20:15
Year-Month-Day / Hour:Minute



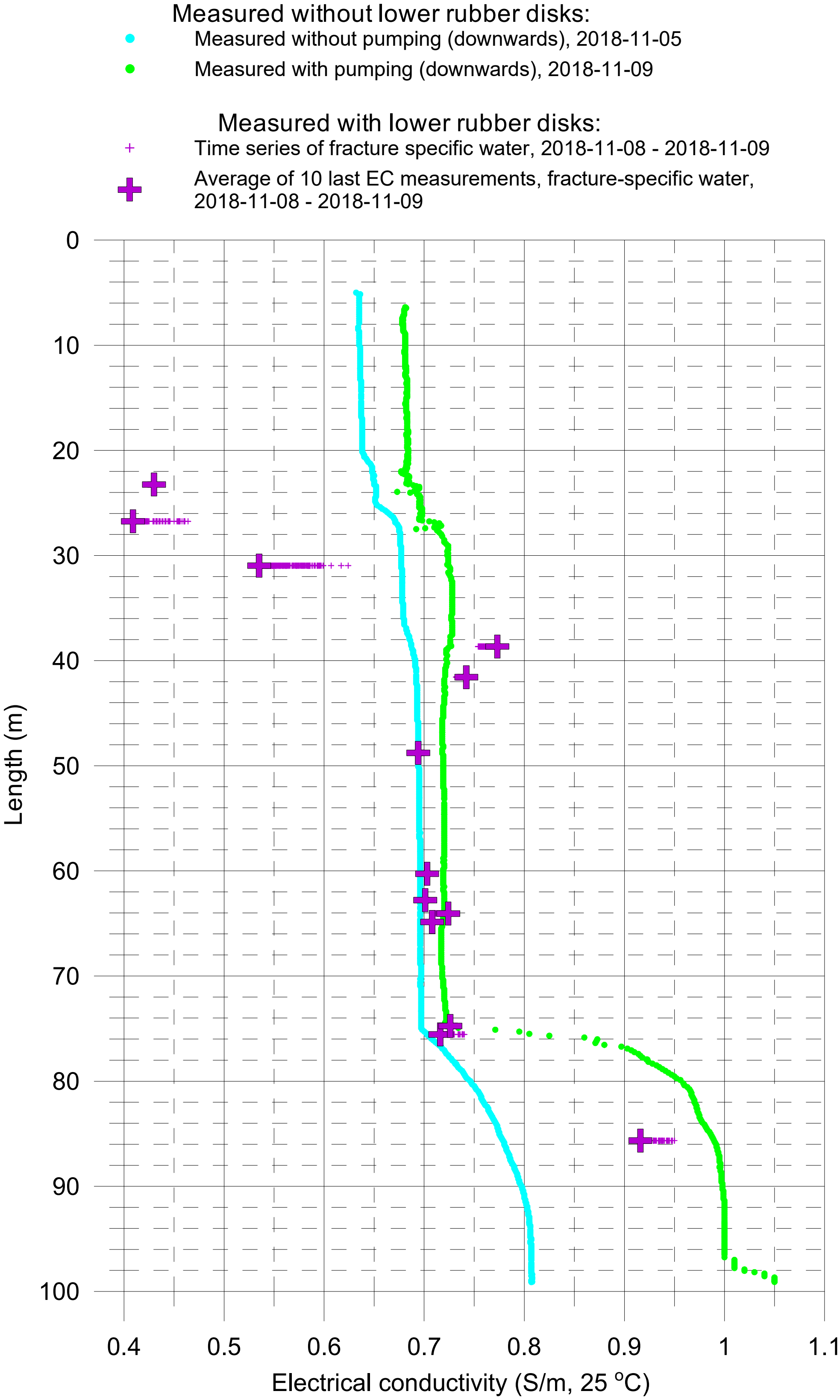
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-20
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-2.0
-2.5
-3.0
-3.5
-4.0
Temperature (°C)
7.5
7.0
6.5
Electrical conductivity (S/m) (25 °C)
1.5
1.0
0.5
20.7 m
Flow (mL/h)
100000
10000
1000
100
10
1
2018-11-20 / 20:15
2018-11-20 / 21:00
Year-Month-Day / Hour:Minute

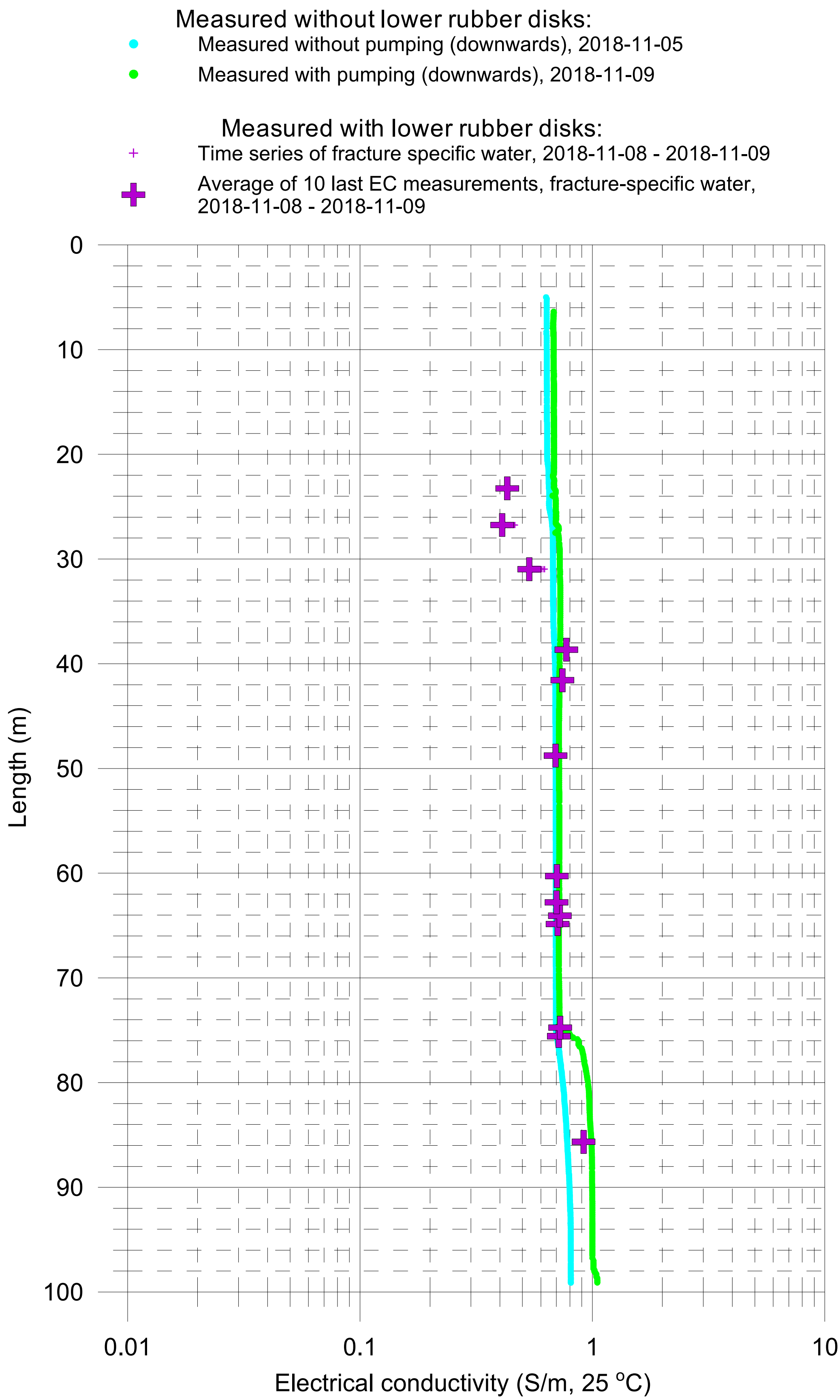
KFM22.11.1–KFM22.11.2 Flow rate, single point resistance and head in the borehole during flow logging




Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-18
Extra 1 measurement without pumping (L = 1 m, dL = 0.1 m), 2018-11-18 - 2018-11-19
Flow 2 with pumping (Drawdown 3 m, L = 5 m, dL = 0.5 m), 2018-11-20
Flow 3 with pumping (Drawdown 3 m, L = 1 m, dL = 0.1 m), 2018-11-10
Extra 2 measurement with pumping (Drawdown 1 m, L = 1 m, dL = 0.1 m), 2018-11-21
Pumping rate during Flow 2 measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, Flow into the hole)
Flow 1 (L = 5 m, Flow into the bedrock)
Flow 2 (L = 5 m, Flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Values used in interpretation:
Fresh water head (Flow 2)
Head with pumping (Flow 2)
Fresh water head (Flow 3)
Head with pumping (Flow 3)
Head with pumping (Extra 2)
Water level during Extra 2 measurement
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)
Head (masl) / Water level (masl)
33.3
33.6
33.8
35.6
37.0
40.2
40.5
40.8
41.3
Interpreted fracture-specific flow and fresh water head under pumped conditions for fracture at 40.8 m are from Extra 2 measurement. See Section 6.4.3 for details.

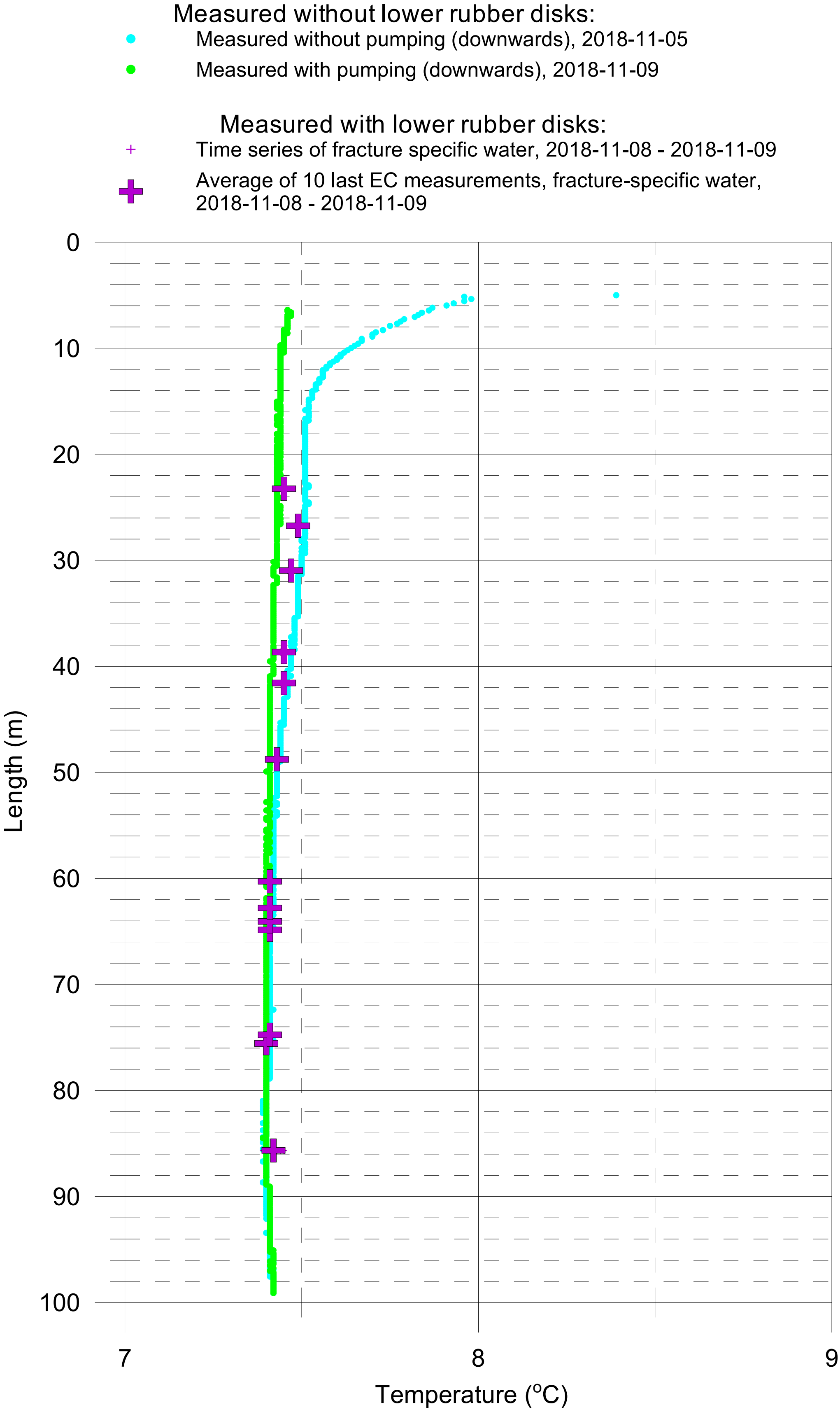
KFM23.1.1–KFM23.1.2 Electrical conductivity of borehole water



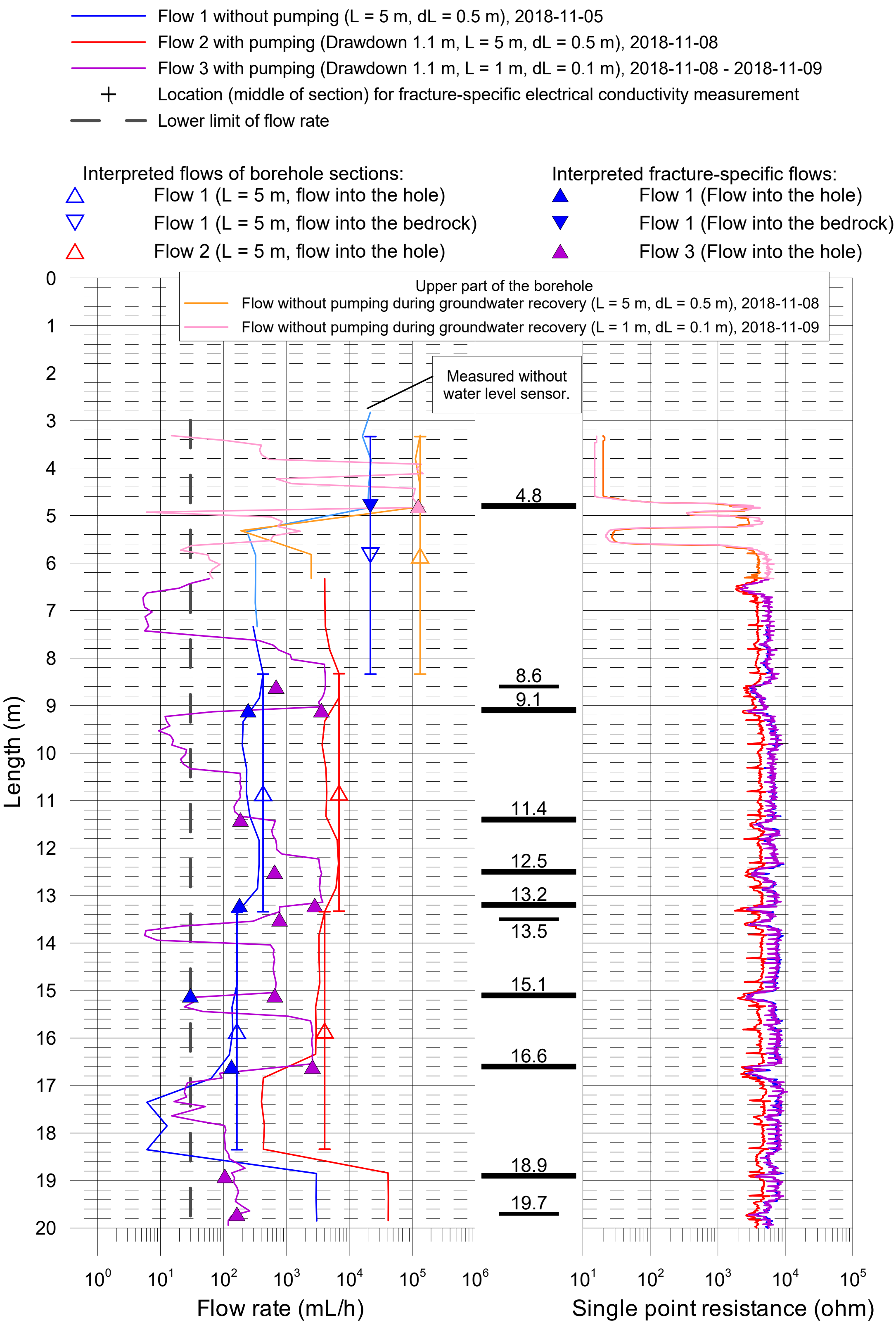


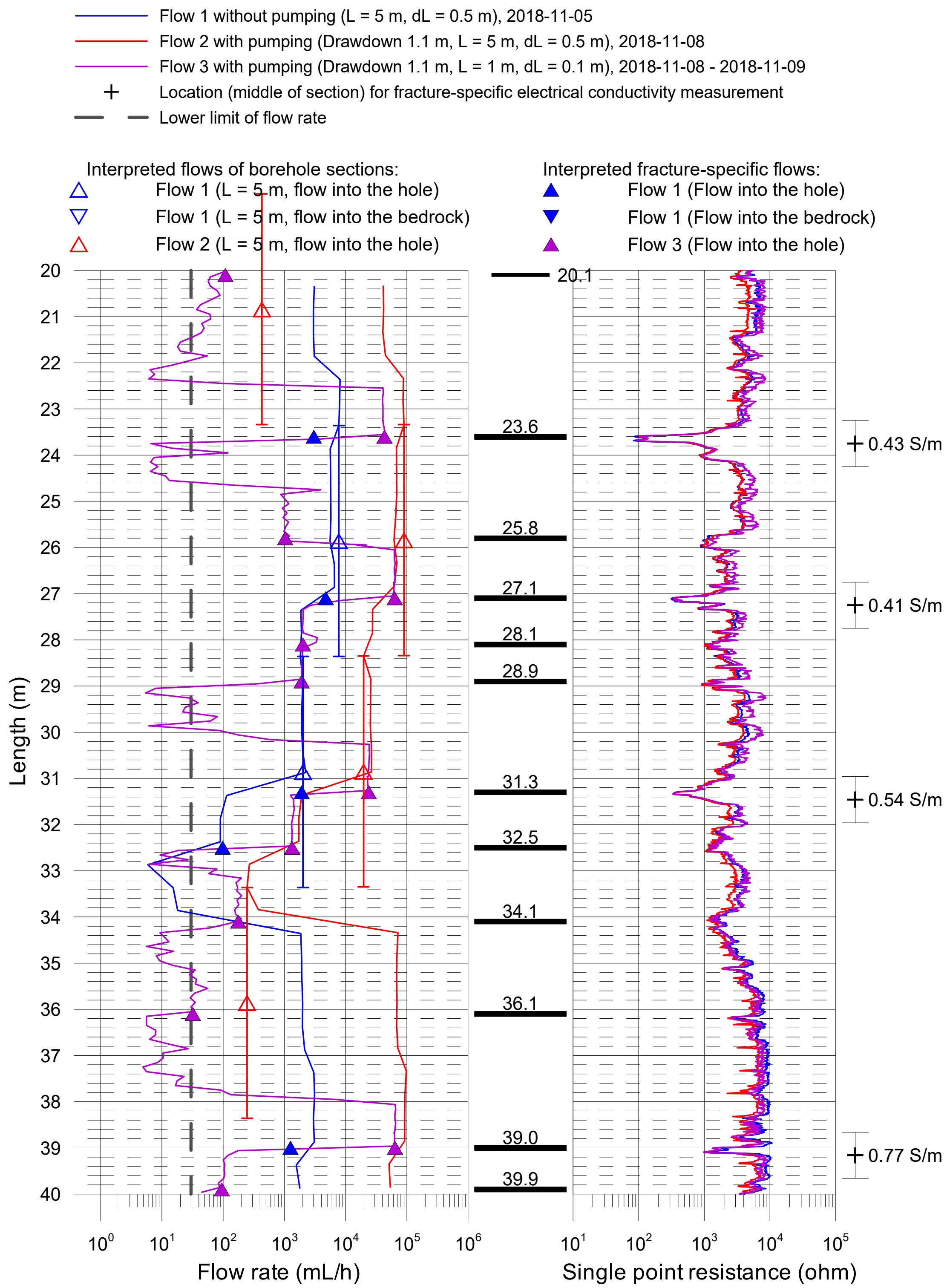
Measured without lower rubber disks:
Measured without pumping (downwards), 2018-11-05
Measured with pumping (downwards), 2018-11-09
Measured with lower rubber disks:
Time series of fracture specific water, 2018-11-08 - 2018-11-09
Average of 10 last EC measurements, fracture-specific water, 2018-11-08 - 2018-11-09
Length (m)
Electrical conductivity (S/m, 25 °C)
0
10
20
30
40
50
60
70
80
90
100
0.01
0.1
1
10

KFM23.1.3 Temperature of borehole water

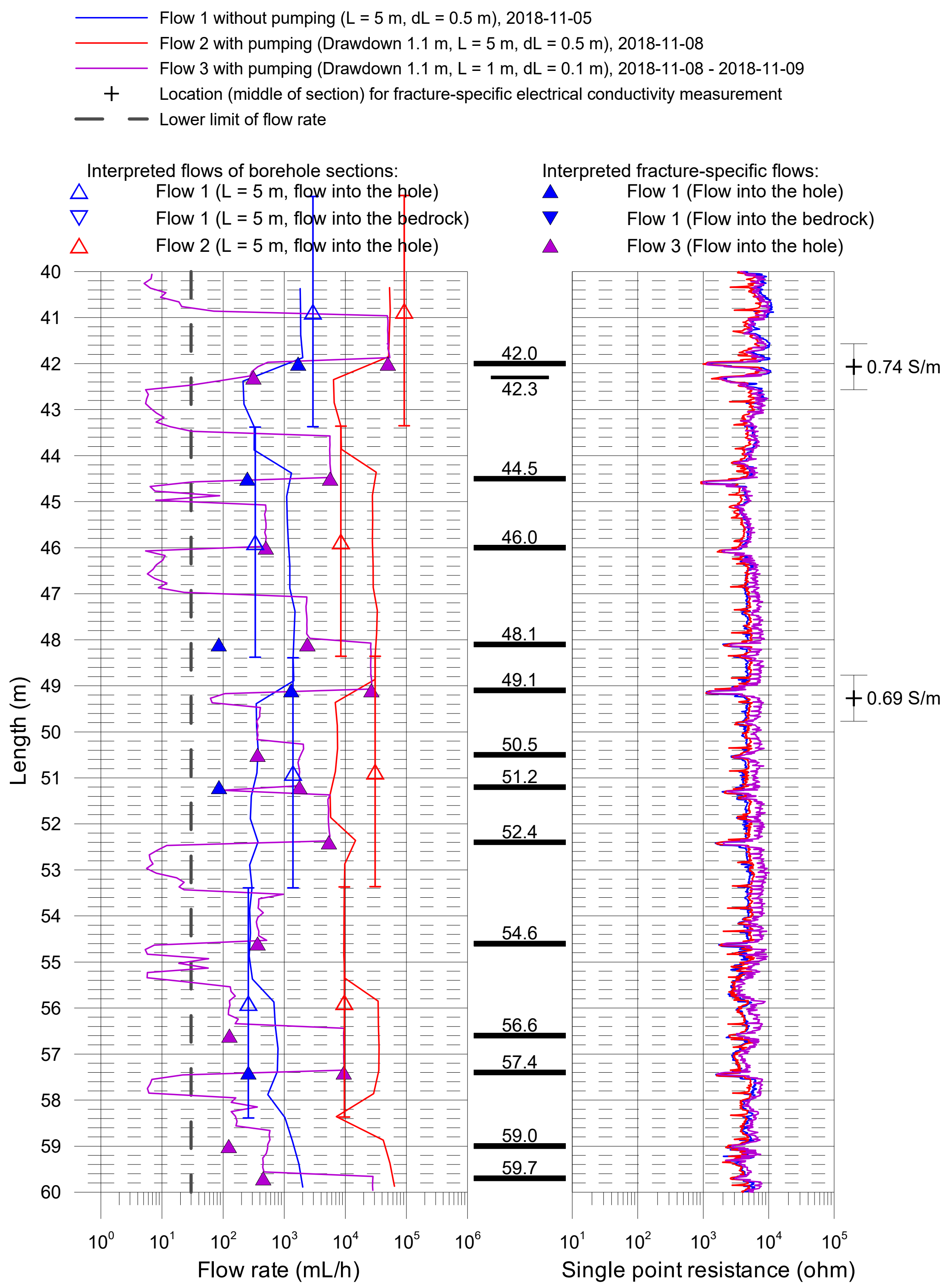


KFM23.2.1–KFM23.2.5 Flow rate and single point resistance

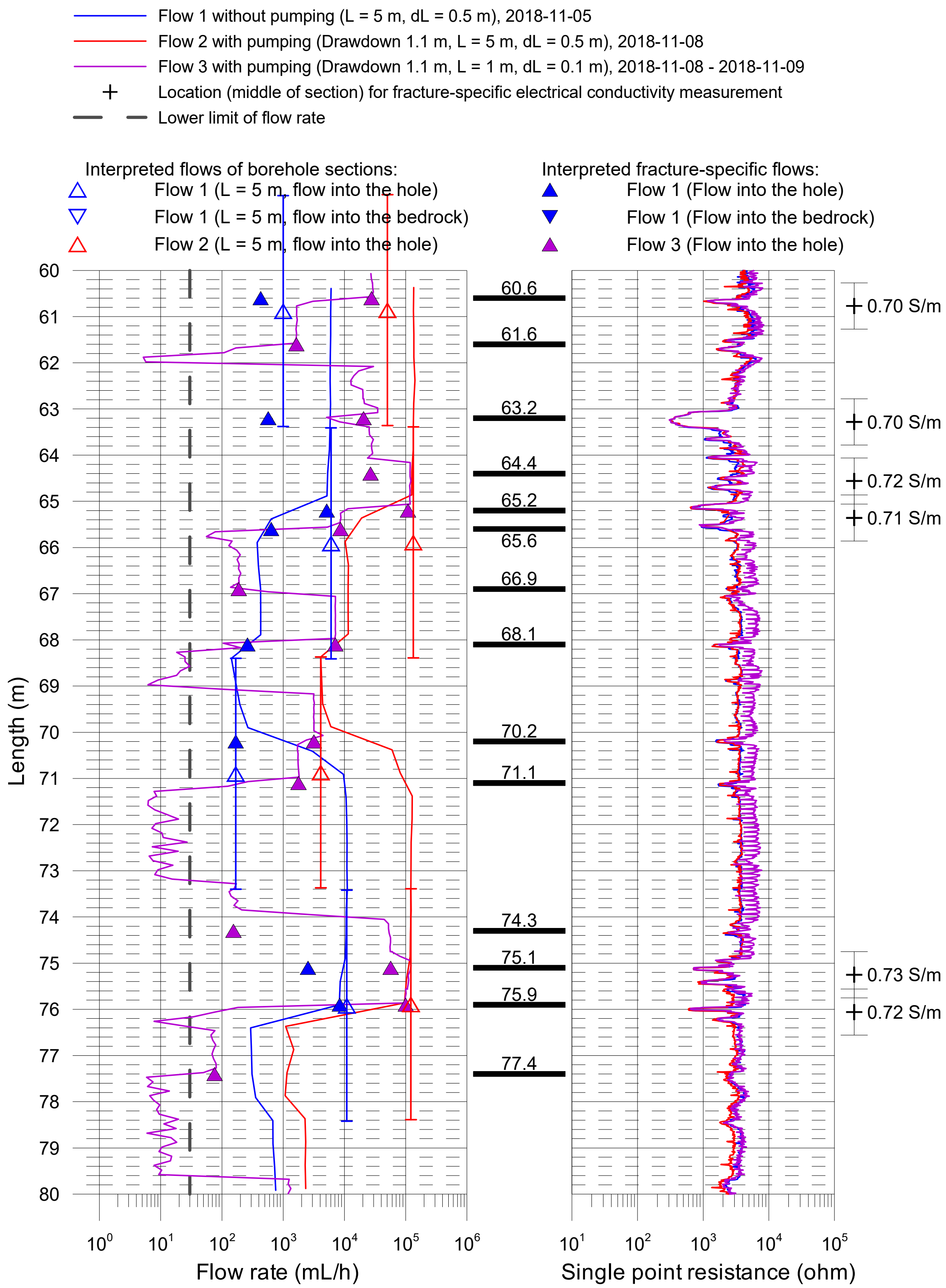




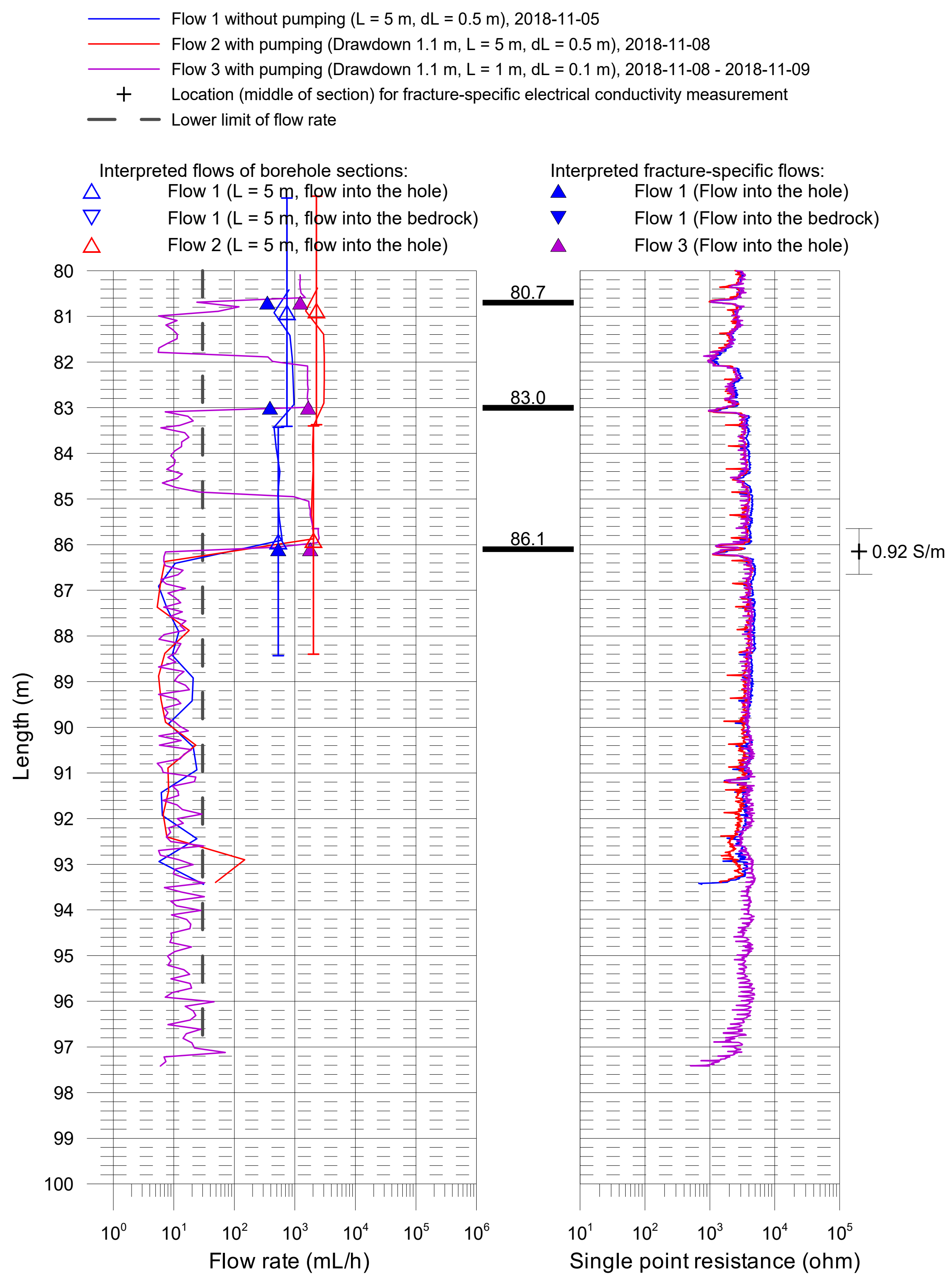
Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-05
Flow 2 with pumping (Drawdown 1.1 m, L = 5 m, dL = 0.5 m), 2018-11-08
Flow 3 with pumping (Drawdown 1.1 m, L = 1 m, dL = 0.1 m), 2018-11-08 - 2018-11-09
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
20.1
23.6
25.8
27.1
28.1
28.9
31.3
32.5
34.1
36.1
39.0
39.9
0.43 S/m
0.41 S/m
0.54 S/m
0.77 S/m
Flow rate (mL/h)
Single point resistance (ohm)



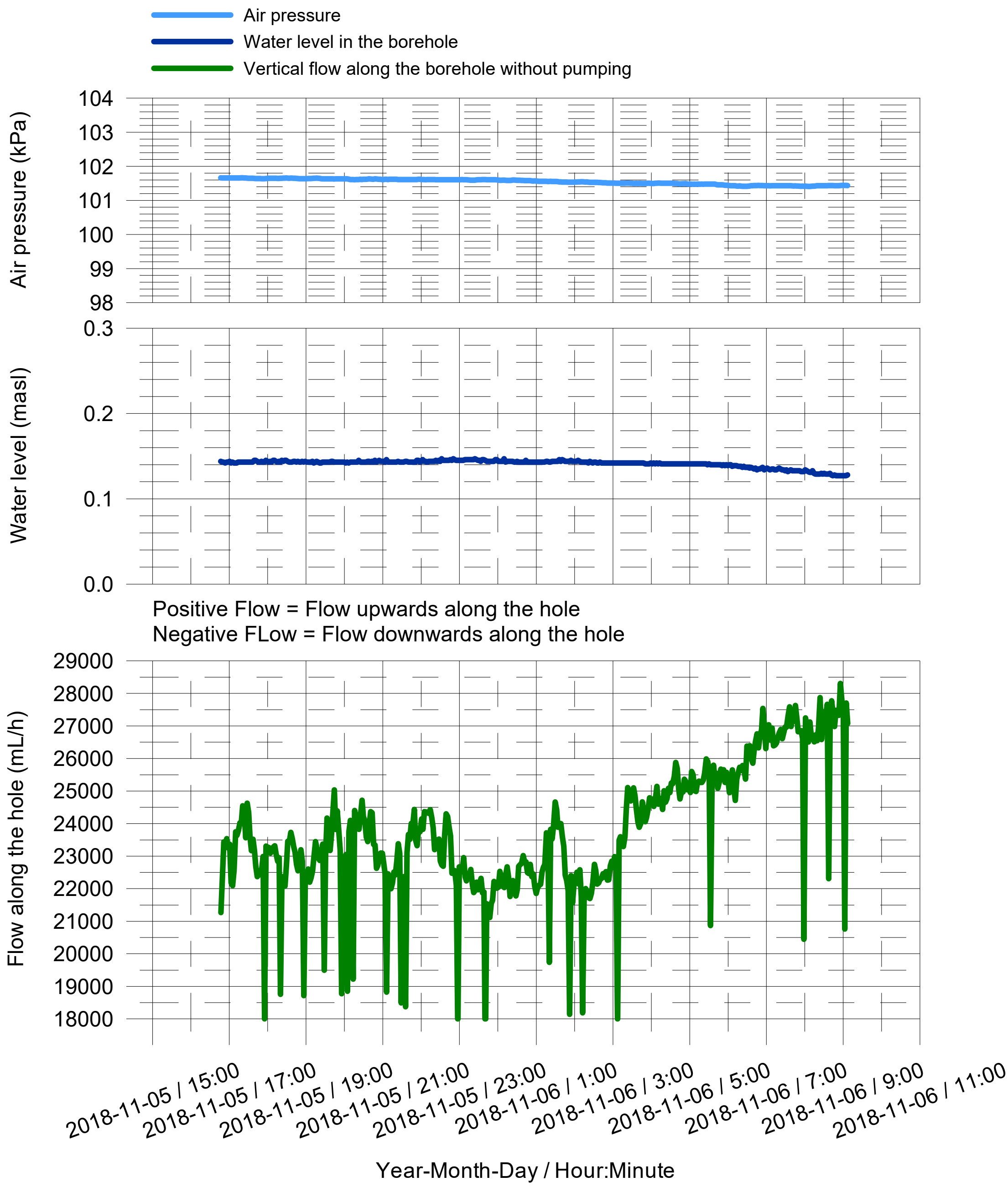
Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-05
Flow 2 with pumping (Drawdown 1.1 m, L = 5 m, dL = 0.5 m), 2018-11-08
Flow 3 with pumping (Drawdown 1.1 m, L = 1 m, dL = 0.1 m), 2018-11-08 - 2018-11-09
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
42.0
42.3
44.5
46.0
48.1
49.1
50.5
51.2
52.4
54.6
56.6
57.4
59.0
59.7
0.74 S/m
0.69 S/m
10^0 10^1 10^2 10^3 10^4 10^5 10^6
Flow rate (mL/h)
10^1 10^2 10^3 10^4 10^5
Single point resistance (ohm)



Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-05
Flow 2 with pumping (Drawdown 1.1 m, L = 5 m, dL = 0.5 m), 2018-11-08
Flow 3 with pumping (Drawdown 1.1 m, L = 1 m, dL = 0.1 m), 2018-11-08 - 2018-11-09
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Length (m)
60.6
61.6
63.2
64.4
65.2
65.6
66.9
68.1
70.2
71.1
74.3
75.1
75.9
77.4
0.70 S/m
0.70 S/m
0.72 S/m
0.71 S/m
0.73 S/m
0.72 S/m
Flow rate (mL/h)
Single point resistance (ohm)


Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-05
Flow 2 with pumping (Drawdown 1.1 m, L = 5 m, dL = 0.5 m), 2018-11-08
Flow 3 with pumping (Drawdown 1.1 m, L = 1 m, dL = 0.1 m), 2018-11-08 - 2018-11-09
Location (middle of section) for fracture-specific electrical conductivity measurement
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, flow into the hole)
Flow 1 (L = 5 m, flow into the bedrock)
Flow 2 (L = 5 m, flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
80.7
83.0
86.1
0.92 S/m
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)

KFM23.2.6 Vertical flow along the borehole at 7.3 m



KFM23.3 Explanations for the tables in Appendices

Header	Unit	Explanations
Borehole ID		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)
Length to flow anom.	m	Length along the borehole to inferred flow anomaly during overlapping flow logging
L_w	m	Section length used in the difference flow logging
dL	m	Step length (increment) used in the difference flow logging
Q_0	m^3/s	Measured flow rate through the test section or flow anomaly under natural conditions (no pumping) with h=h0 in the open borehole
Q_1	m^3/s	Measured flow rate through the test section or flow anomaly during the first 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
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.
Q-lower limit P	mL/h	Practical lower measurement limit for flow rate.
T-measl$_{LT}$	m^2/s	Estimated theoretical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-measl$_{LP}$	m^2/s	Estimated practical lower measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
T-meas$_{lU}$	m^2/s	Estimated upper measurement limit for evaluated TD. If the estimated TD equals TD-measlim, the actual TD is considered to be equal or less than TD-measlim.
h_i	m.a.s.l.	Calculated relative, natural freshwater head for test section or flow anomaly (undisturbed conditions)

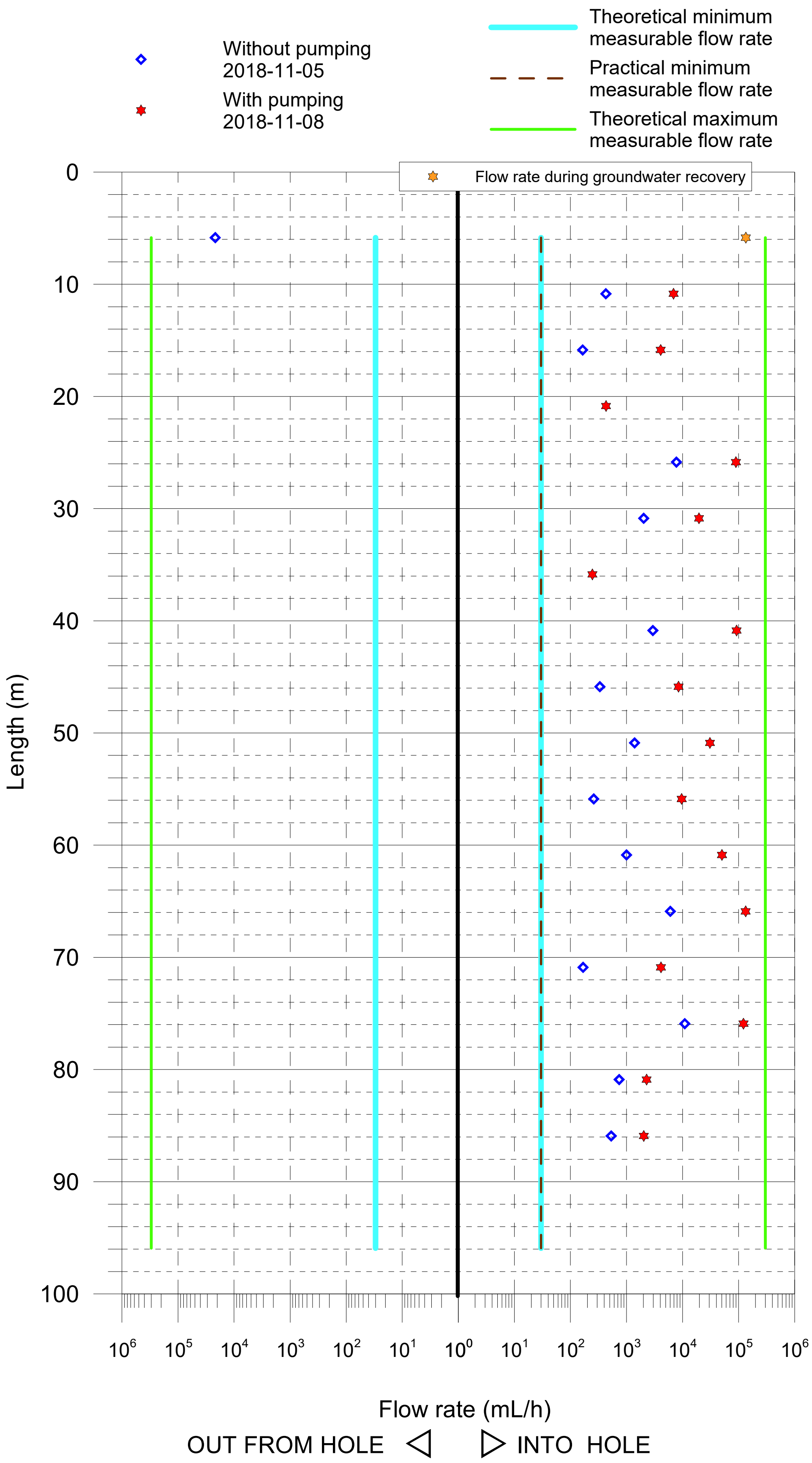
KFM23.4 Results of section flows

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)	T_D-measl$_{LT}$ (m^2/s)	T_D - measl$_{LP}$ (m^2/s)	T_D - measl$_U$ (m^2/s)	Comments
KFM23	3.33	8.34	5	−6.04E-06	0.35	3.73E-05	−0.42	5.6E-05	0.2	30	1.1E-08	1.1E-08	1.1E-04	*,**
KFM23	8.34	13.34	5	1.19E-07	0.35	1.92E-06	−0.85	1.5E-06	0.4	30	6.9E-09	6.9E-09	6.9E-05	
KFM23	13.35	18.35	5	4.58E-08	0.34	1.13E-06	−0.79	9.5E-07	0.4	30	7.3E-09	7.3E-09	7.3E-05	
KFM23	18.35	23.35	5	–	0.30	1.20E-07	−0.76	1.1E-07	–	30	7.8E-09	7.8E-09	7.8E-05	
KFM23	23.35	28.35	5	2.15E-06	0.36	2.49E-05	−0.82	1.9E-05	0.5	30	7.0E-09	7.0E-09	6.8E-05	
KFM23	28.36	33.36	5	5.61E-07	0.38	5.45E-06	−0.83	4.0E-06	0.5	30	6.8E-09	6.8E-09	6.8E-05	
KFM23	33.36	38.36	5	–	0.37	6.83E-08	−0.73	6.1E-08	–	30	7.5E-09	7.5E-09	7.5E-05	
KFM23	38.36	43.36	5	8.19E-07	0.32	2.55E-05	−0.73	2.3E-05	0.4	30	7.9E-09	7.9E-09	7.8E-05	
KFM23	43.37	48.37	5	9.31E-08	0.34	2.36E-06	−0.78	2.0E-06	0.4	30	7.4E-09	7.4E-09	7.4E-05	
KFM23	48.38	53.38	5	3.87E-07	0.37	8.56E-06	−0.78	7.0E-06	0.4	30	7.2E-09	7.2E-09	7.1E-05	
KFM23	53.38	58.38	5	7.22E-08	0.35	2.68E-06	−0.74	2.4E-06	0.4	30	7.6E-09	7.6E-09	7.6E-05	
KFM23	58.37	63.37	5	2.78E-07	0.40	1.40E-05	−0.76	1.2E-05	0.4	30	7.1E-09	7.1E-09	7.1E-05	
KFM23	63.40	68.40	5	1.68E-06	0.38	3.70E-05	−0.49	4.0E-05	0.4	30	9.5E-09	9.5E-09	9.3E-05	
KFM23	68.39	73.39	5	4.67E-08	0.34	1.14E-06	−0.79	9.6E-07	0.4	30	7.3E-09	7.3E-09	7.3E-05	
KFM23	73.41	78.41	5	3.04E-06	0.34	3.38E-05	−0.49	3.7E-05	0.4	30	9.9E-09	9.9E-09	9.6E-05	
KFM23	78.39	83.39	5	2.05E-07	0.33	6.34E-07	−0.72	4.0E-07	0.8	30	7.9E-09	7.9E-09	7.8E-05	
KFM23	83.42	88.42	5	1.48E-07	0.29	5.64E-07	−0.72	4.1E-07	0.7	30	8.2E-09	8.2E-09	8.1E-05	
KFM23	88.40	93.40	5	–	0.23	–	−0.84	–	–	30	7.7E-09	7.7E-09	7.7E-05	
KFM23	93.42	98.42	5	–	0.08	–	−0.98	–	–	30	7.8E-09	7.8E-09	7.8E-05	

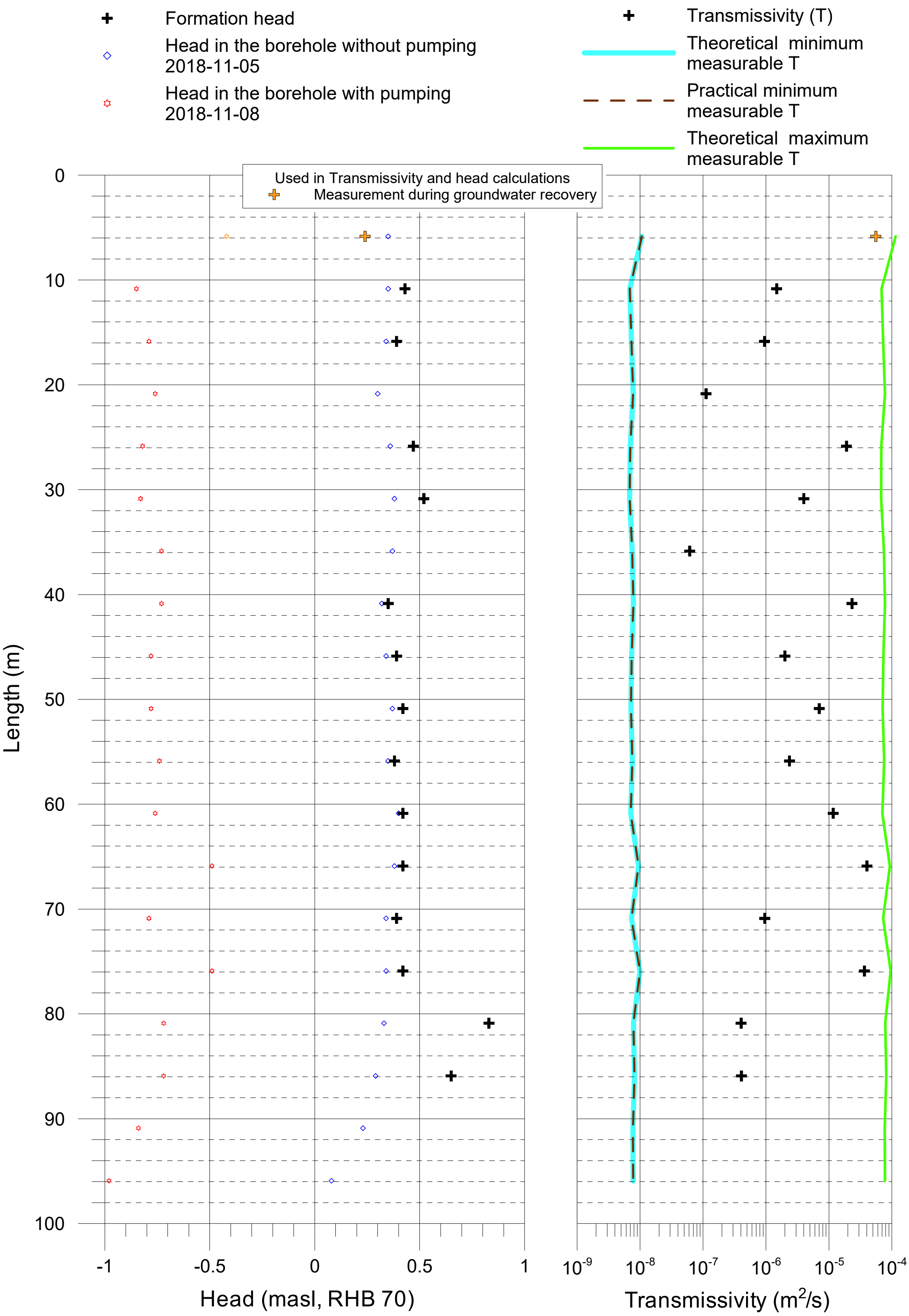
* Values for Flow (Q1) and Head (h1FW) are from the measurement made without pumping, during recovery. The upper part of the borehole could not be measured while pumping the borehole (while the pump remained in the borehole).

** Flow (Q0 and Q1) possibly from the joint of casing tube and borehole.

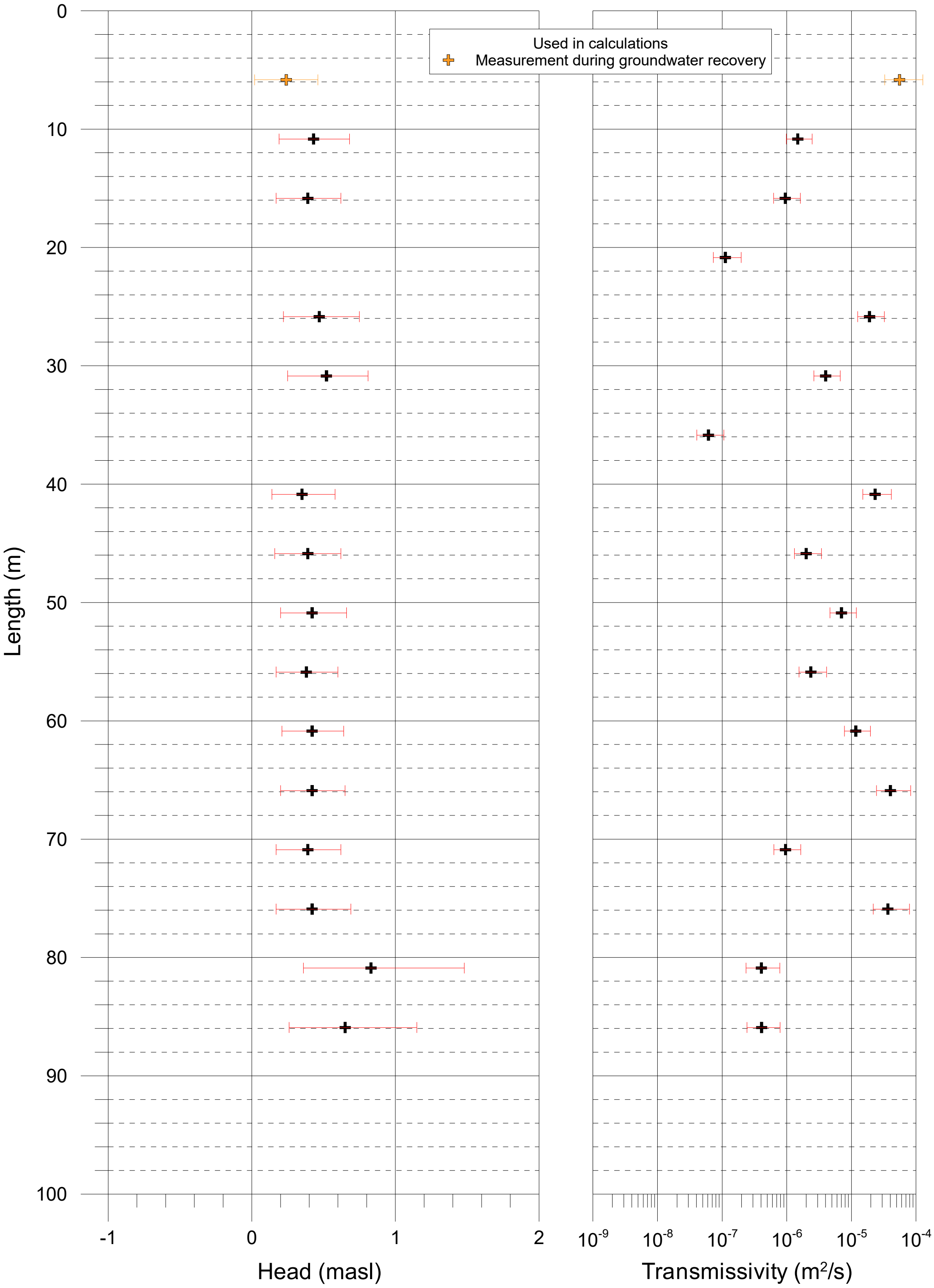
KFM23.5.1 Plotted flow rates of 5 m sections



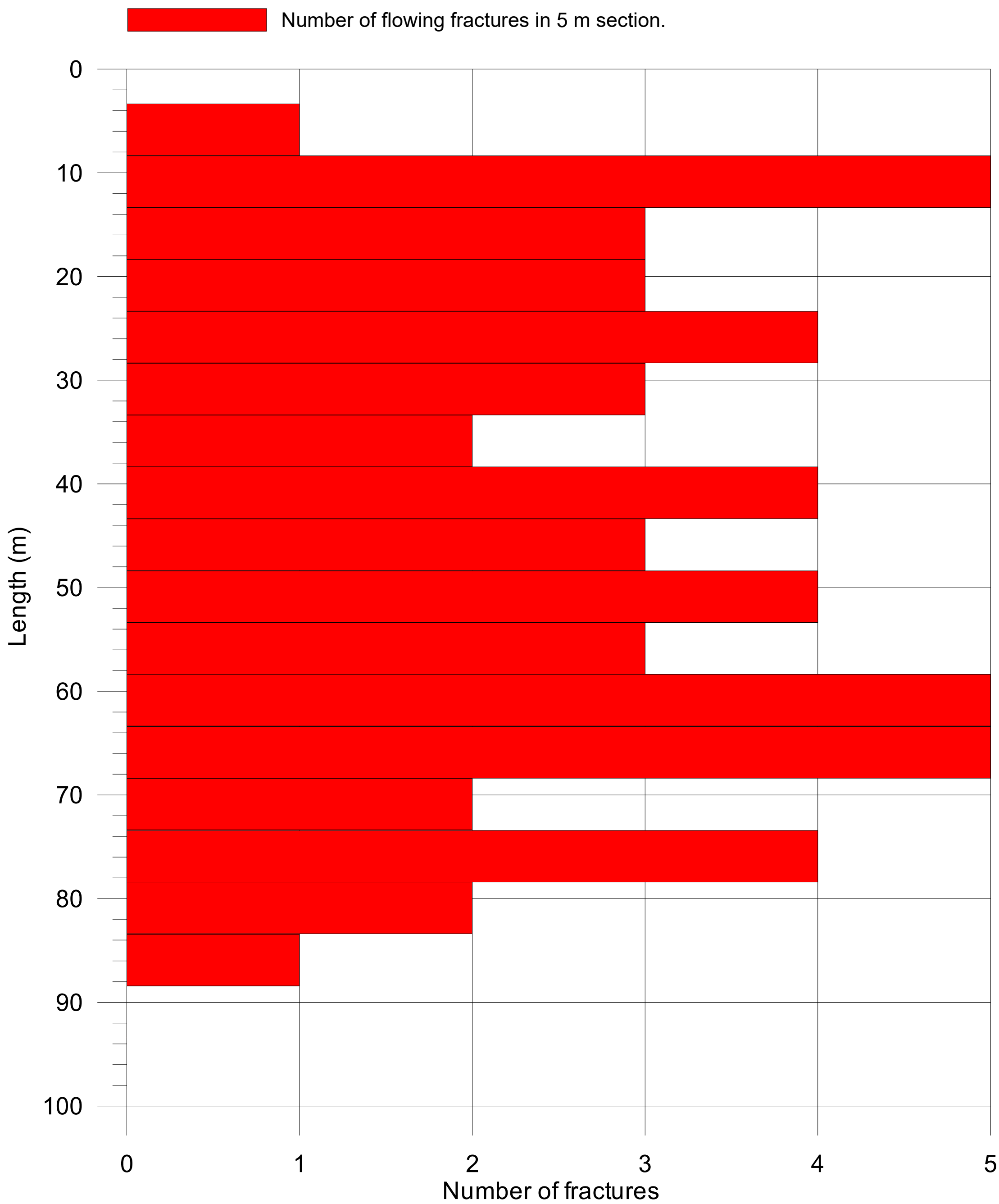
KFM23.5.2 Plotted transmissivity and head of 5 m sections



KFM23.5.3 Transmissivity and head of 5 m sections with calculated error limits



KFM23.5.4 Conductive fracture frequency



KFM23.6.1–KFM23.6.2 Inferred fracture flow anomalies from flow logging

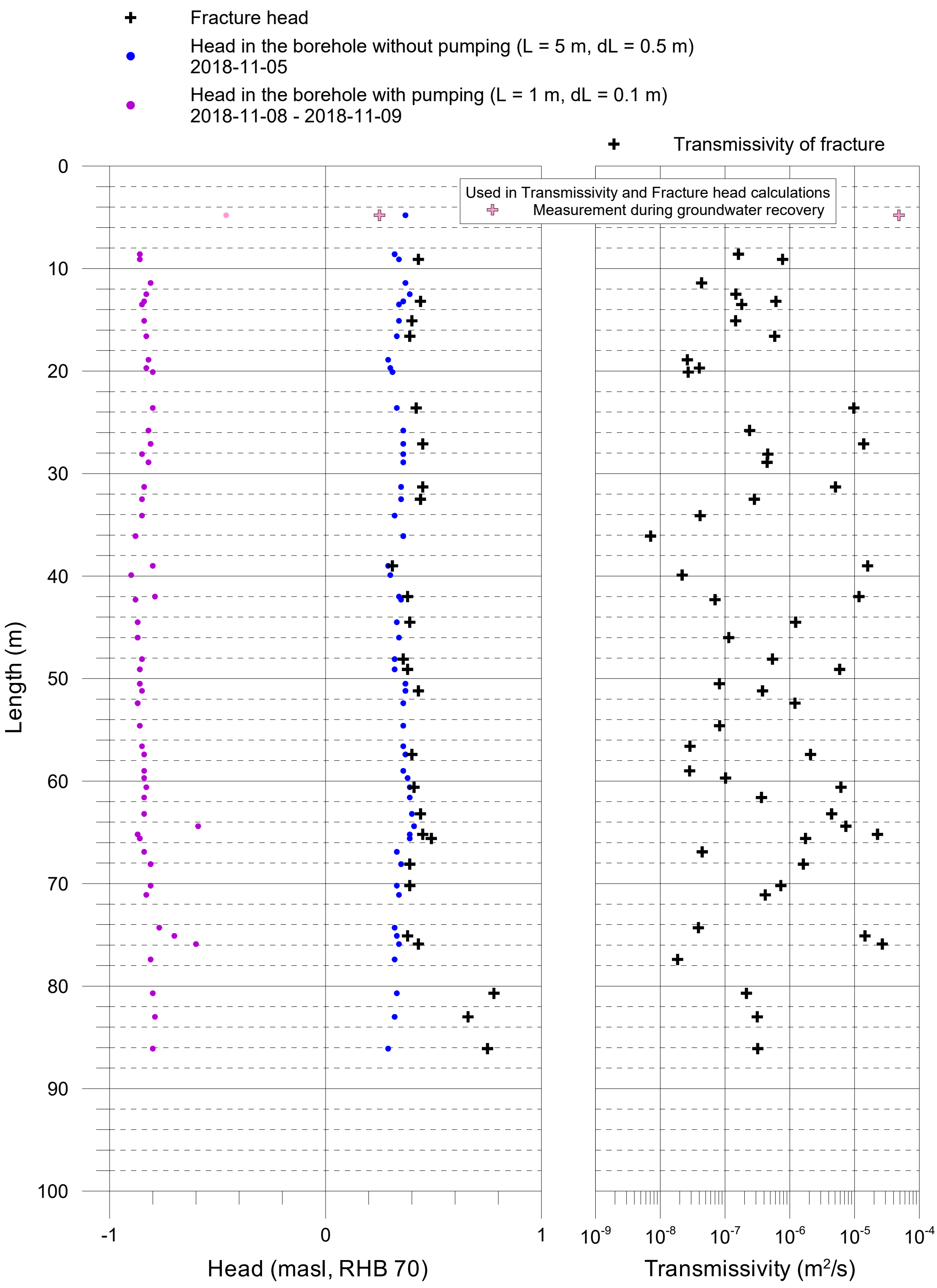
Borehole ID	Length to flow anom. L (m)	L_w (m)	dL (m)	Q_0 (m^3/s)	h_{0FW} (m.a.s.l.)	Q_1 (m^3/s)	h_{1FW} (m.a.s.l.)	T_D (m^2/s)	h_i (m.a.s.l.)	Comments
KFM23	4.8	1	0.1	−6.04E-06	0.37	3.47E-05	−0.46	4.9E-05	0.3	**,***
KFM23	8.6	1	0.1	–	0.32	1.92E-07	−0.86	1.6E-07	–	*
KFM23	9.1	1	0.1	6.89E-08	0.34	1.01E-06	−0.86	7.7E-07	0.4	
KFM23	11.4	1	0.1	–	0.37	5.19E-08	−0.81	4.4E-08	–	
KFM23	12.5	1	0.1	–	0.39	1.81E-07	−0.83	1.5E-07	–	
KFM23	13.2	1	0.1	5.03E-08	0.36	7.89E-07	−0.84	6.1E-07	0.4	
KFM23	13.5	1	0.1	–	0.34	2.18E-07	−0.85	1.8E-07	–	*
KFM23	15.1	1	0.1	8.33E-09	0.34	1.82E-07	−0.84	1.5E-07	0.4	
KFM23	16.6	1	0.1	3.75E-08	0.33	7.22E-07	−0.83	5.8E-07	0.4	
KFM23	18.9	1	0.1	–	0.29	2.94E-08	−0.82	2.6E-08	–	
KFM23	19.7	1	0.1	–	0.30	4.58E-08	−0.83	4.0E-08	–	*
KFM23	20.1	1	0.1	–	0.31	3.03E-08	−0.80	2.7E-08	–	*
KFM23	23.6	1	0.1	8.42E-07	0.33	1.20E-05	−0.80	9.7E-06	0.4	
KFM23	25.8	1	0.1	–	0.36	2.86E-07	−0.82	2.4E-07	–	
KFM23	27.1	1	0.1	1.31E-06	0.36	1.76E-05	−0.81	1.4E-05	0.5	
KFM23	28.1	1	0.1	–	0.36	5.58E-07	−0.85	4.6E-07	–	
KFM23	28.9	1	0.1	–	0.36	5.33E-07	−0.82	4.5E-07	–	
KFM23	31.3	1	0.1	5.33E-07	0.35	6.64E-06	−0.84	5.1E-06	0.5	
KFM23	32.5	1	0.1	2.72E-08	0.35	3.72E-07	−0.85	2.8E-07	0.4	
KFM23	34.1	1	0.1	–	0.32	4.89E-08	−0.85	4.1E-08	–	
KFM23	36.1	1	0.1	–	0.36	8.89E-09	−0.88	7.1E-09	–	
KFM23	39.0	1	0.1	3.50E-07	0.29	1.79E-05	−0.80	1.6E-05	0.3	
KFM23	39.9	1	0.1	–	0.30	2.64E-08	−0.90	2.2E-08	–	
KFM23	42.0	1	0.1	4.69E-07	0.34	1.38E-05	−0.79	1.2E-05	0.4	
KFM23	42.3	1	0.1	–	0.35	8.72E-08	−0.88	7.0E-08	–	*
KFM23	44.5	1	0.1	6.94E-08	0.33	1.57E-06	−0.87	1.2E-06	0.4	
KFM23	46.0	1	0.1	–	0.34	1.39E-07	−0.87	1.1E-07	–	
KFM23	48.1	1	0.1	2.36E-08	0.32	6.64E-07	−0.85	5.4E-07	0.4	
KFM23	49.1	1	0.1	3.63E-07	0.32	7.39E-06	−0.86	5.9E-06	0.4	
KFM23	50.5	1	0.1	–	0.37	1.02E-07	−0.86	8.2E-08	–	
KFM23	51.2	1	0.1	2.39E-08	0.37	4.92E-07	−0.85	3.8E-07	0.4	
KFM23	52.4	1	0.1	–	0.36	1.49E-06	−0.87	1.2E-06	–	
KFM23	54.6	1	0.1	–	0.36	1.02E-07	−0.86	8.3E-08	–	
KFM23	56.6	1	0.1	–	0.36	3.53E-08	−0.85	2.9E-08	–	
KFM23	57.4	1	0.1	7.22E-08	0.37	2.63E-06	−0.84	2.1E-06	0.4	
KFM23	59.0	1	0.1	–	0.36	3.44E-08	−0.84	2.8E-08	–	
KFM23	59.7	1	0.1	–	0.38	1.26E-07	−0.84	1.0E-07	–	
KFM23	60.6	1	0.1	1.19E-07	0.39	7.72E-06	−0.83	6.2E-06	0.4	
KFM23	61.6	1	0.1	–	0.39	4.56E-07	−0.84	3.7E-07	–	
KFM23	63.2	1	0.1	1.59E-07	0.40	5.69E-06	−0.84	4.4E-06	0.4	
KFM23	64.4	1	0.1	–	0.41	7.42E-06	−0.59	7.3E-06	–	
KFM23	65.2	1	0.1	1.43E-06	0.39	3.03E-05	−0.87	2.3E-05	0.5	
KFM23	65.6	1	0.1	1.77E-07	0.39	2.39E-06	−0.86	1.8E-06	0.5	
KFM23	66.9	1	0.1	–	0.33	5.25E-08	−0.84	4.4E-08	–	
KFM23	68.1	1	0.1	7.25E-08	0.35	1.97E-06	−0.81	1.6E-06	0.4	
KFM23	70.2	1	0.1	4.67E-08	0.33	8.83E-07	−0.81	7.3E-07	0.4	
KFM23	71.1	1	0.1	–	0.34	4.94E-07	−0.83	4.2E-07	–	
KFM23	74.3	1	0.1	–	0.32	4.28E-08	−0.77	3.9E-08	–	
KFM23	75.1	1	0.1	7.06E-07	0.33	1.58E-05	−0.70	1.5E-05	0.4	
KFM23	75.9	1	0.1	2.33E-06	0.34	2.78E-05	−0.60	2.7E-05	0.4	
KFM23	77.4	1	0.1	–	0.32	2.11E-08	−0.81	1.9E-08	–	
KFM23	80.7	1	0.1	9.75E-08	0.33	3.42E-07	−0.80	2.1E-07	0.8	
KFM23	83.0	1	0.1	1.08E-07	0.32	4.61E-07	−0.79	3.2E-07	0.7	
KFM23	86.1	1	0.1	1.48E-07	0.29	5.00E-07	−0.80	3.2E-07	0.8	

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

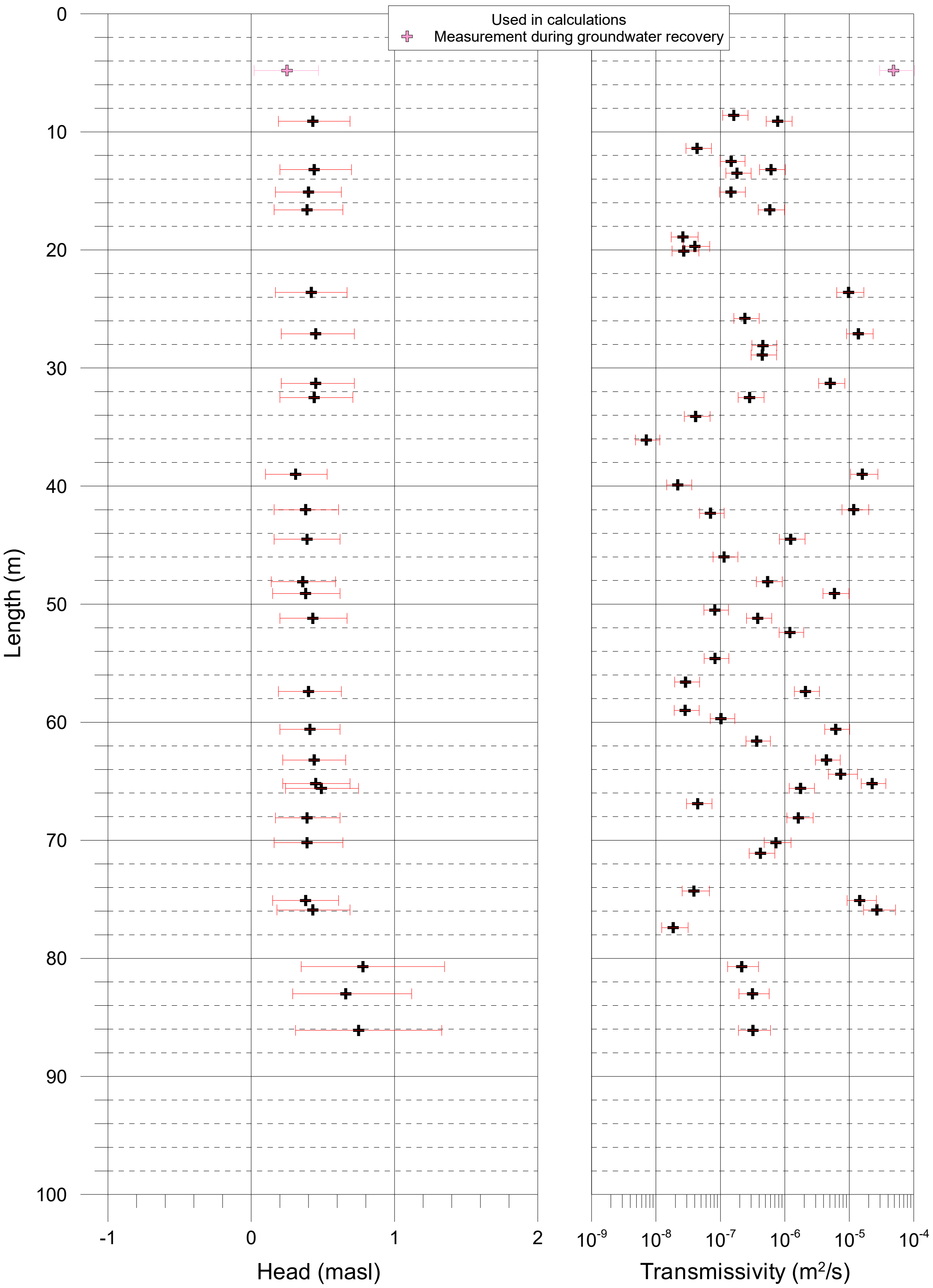
** Values for Flow (Q1) and Head (h1FW) are from the measurement made without pumping, during recovery. The upper part of the borehole could not be measured while pumping (while the pump remained in the borehole).

*** Flow (Q0 and Q1) possibly from the joint of casing tube and borehole.

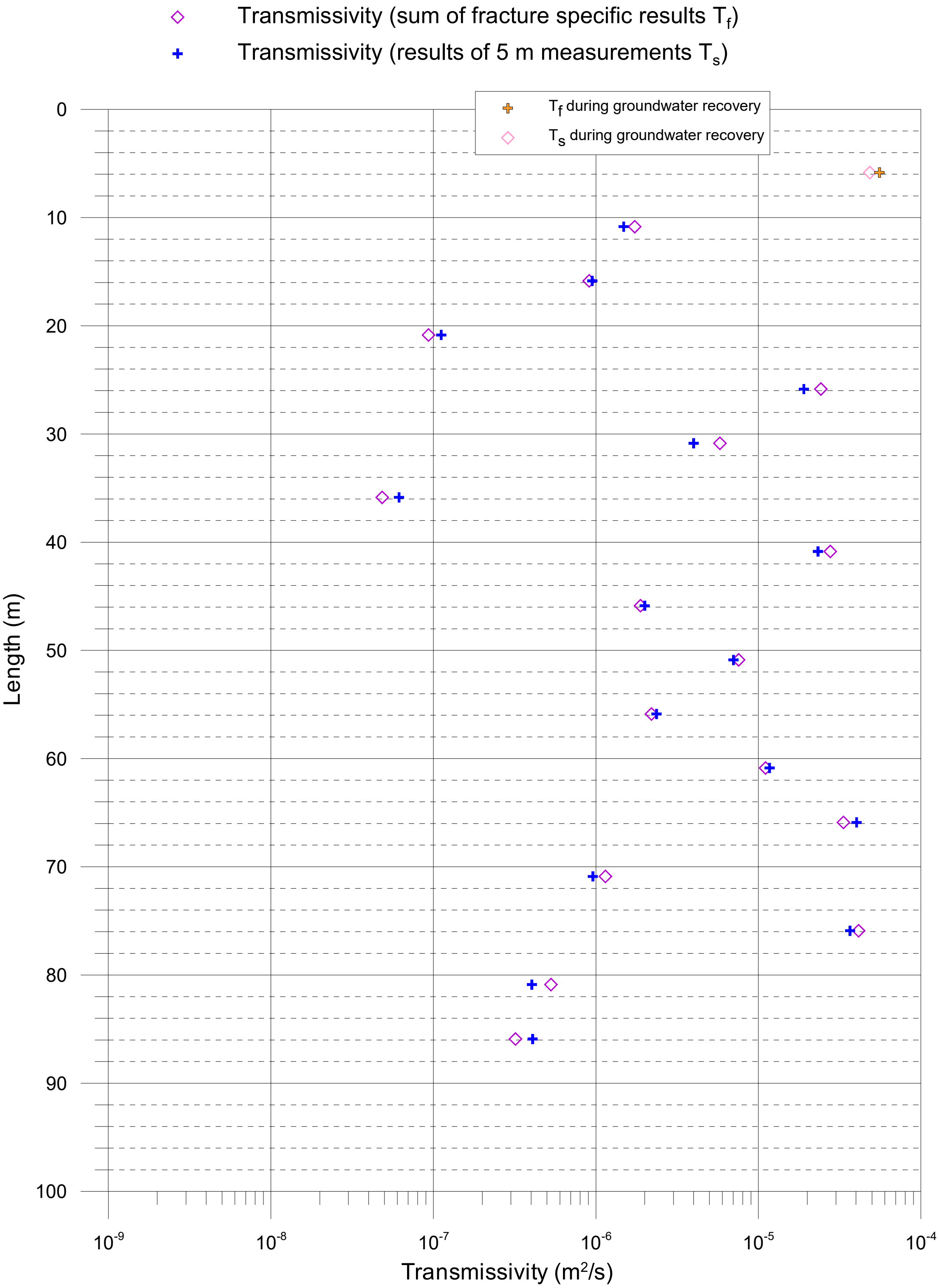
KFM23.7.1 Plotted transmissivity and head of detected fractures



KFM23.7.2 Transmissivity and head of detected fractures with calculated error limits.

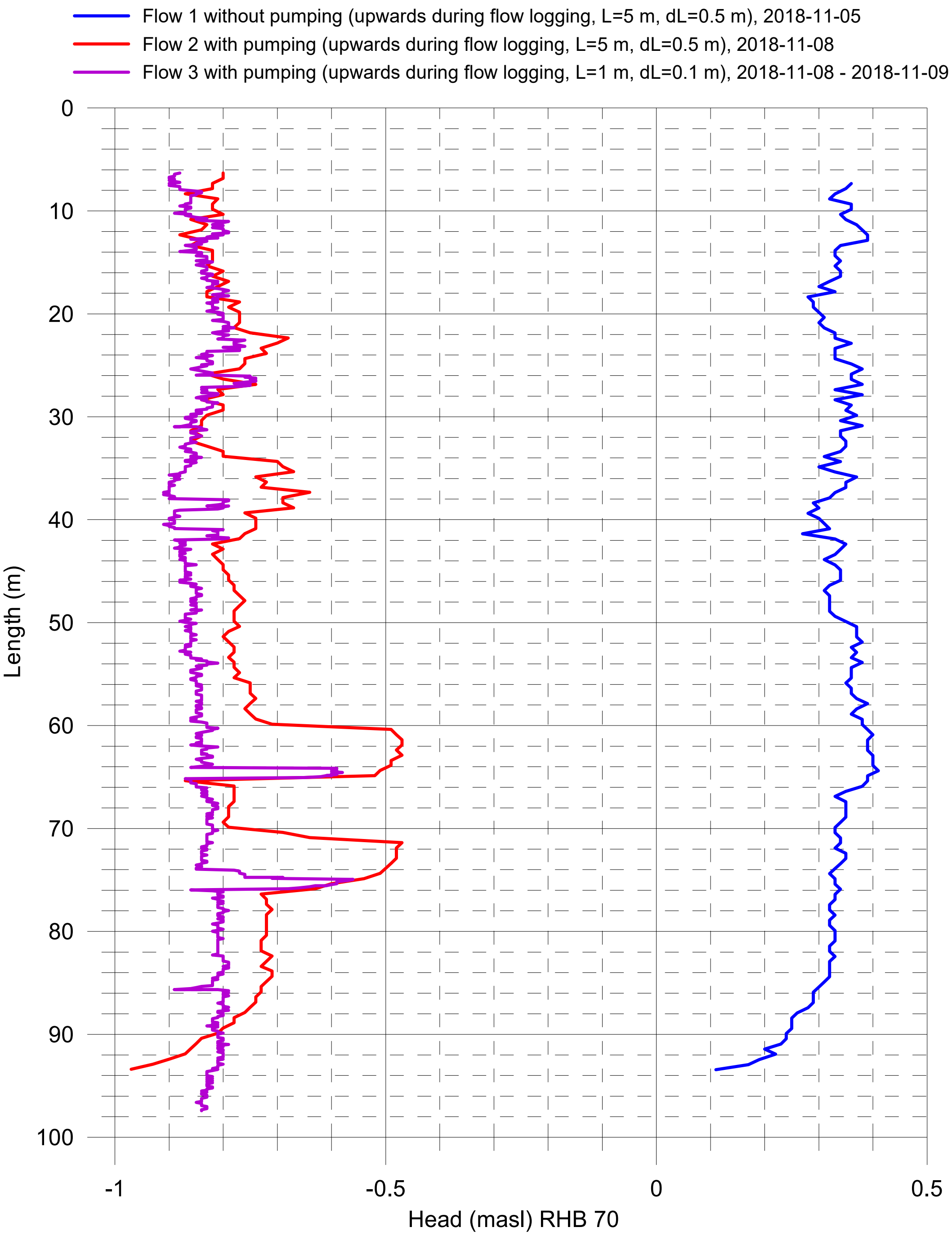


KFM23.8 Comparison between section transmissivity and fracture transmissivity

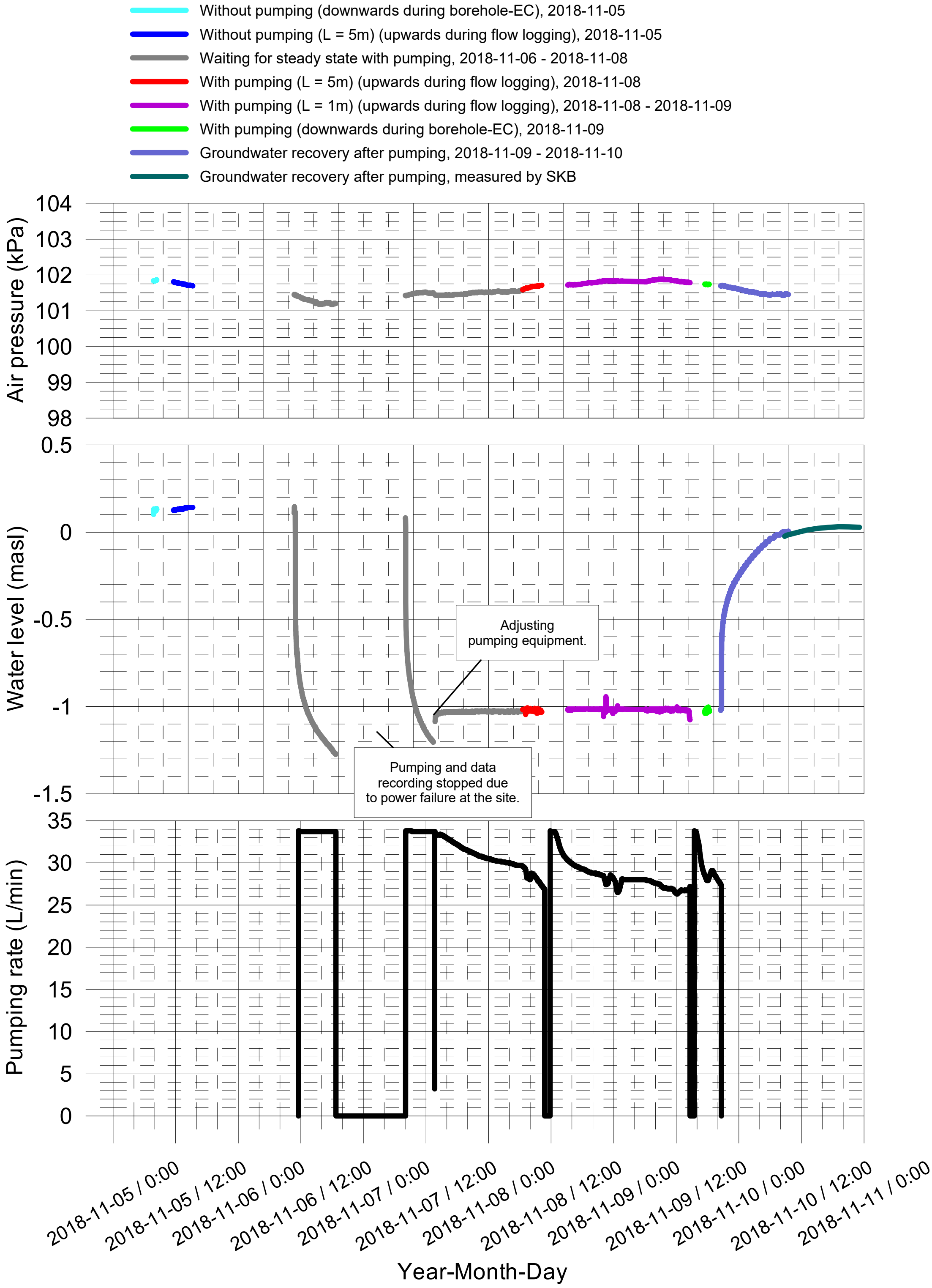


KFM23.9.1 Head in the borehole during flow logging

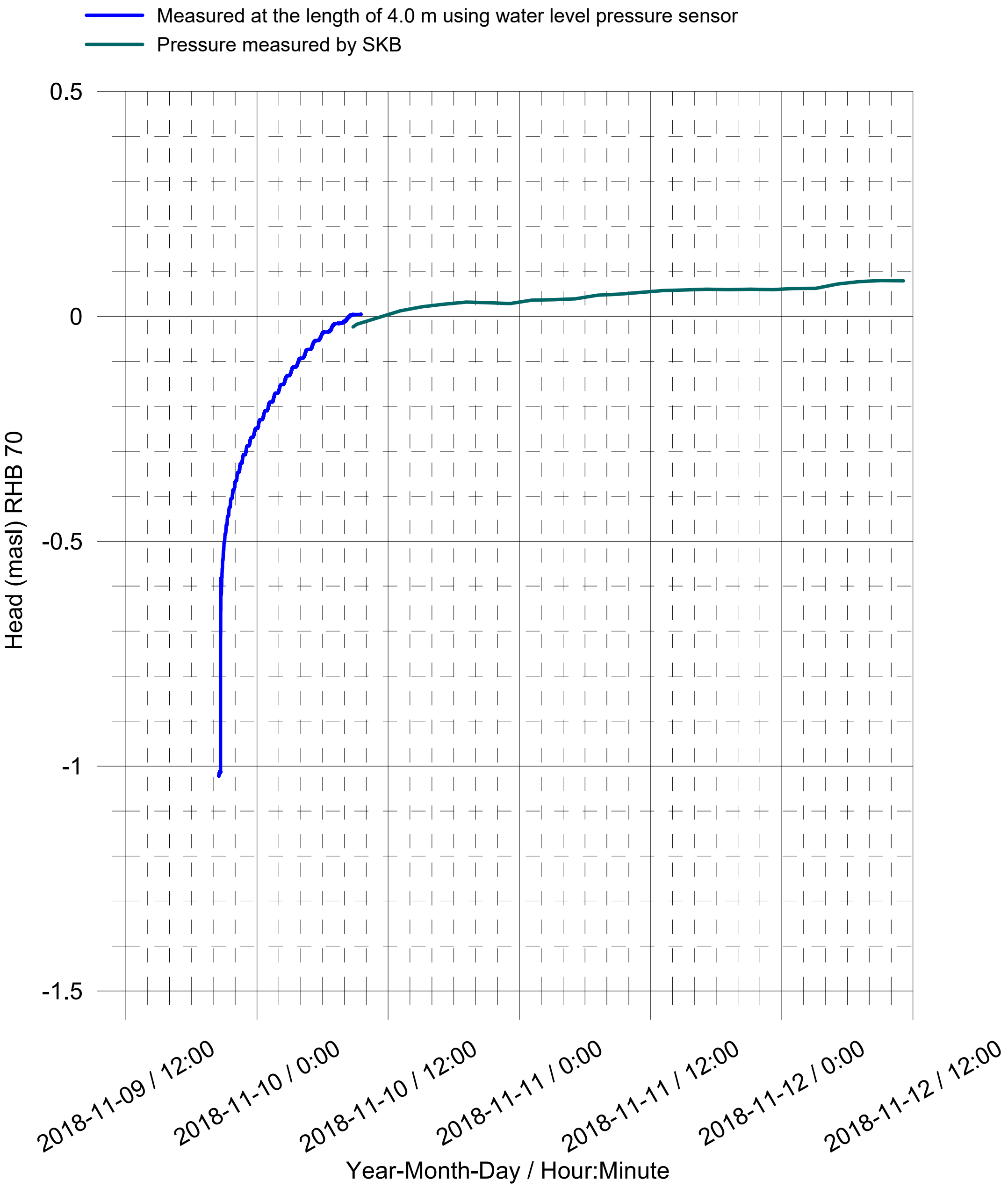
Head (masl) = (Absolute pressure (Pa) - Airpressure (Pa) + Offset) / (1000 kg/m^3 * 9.80665 m/s^2) + Elevation (m)
Offset = Correction for absolute pressure sensor



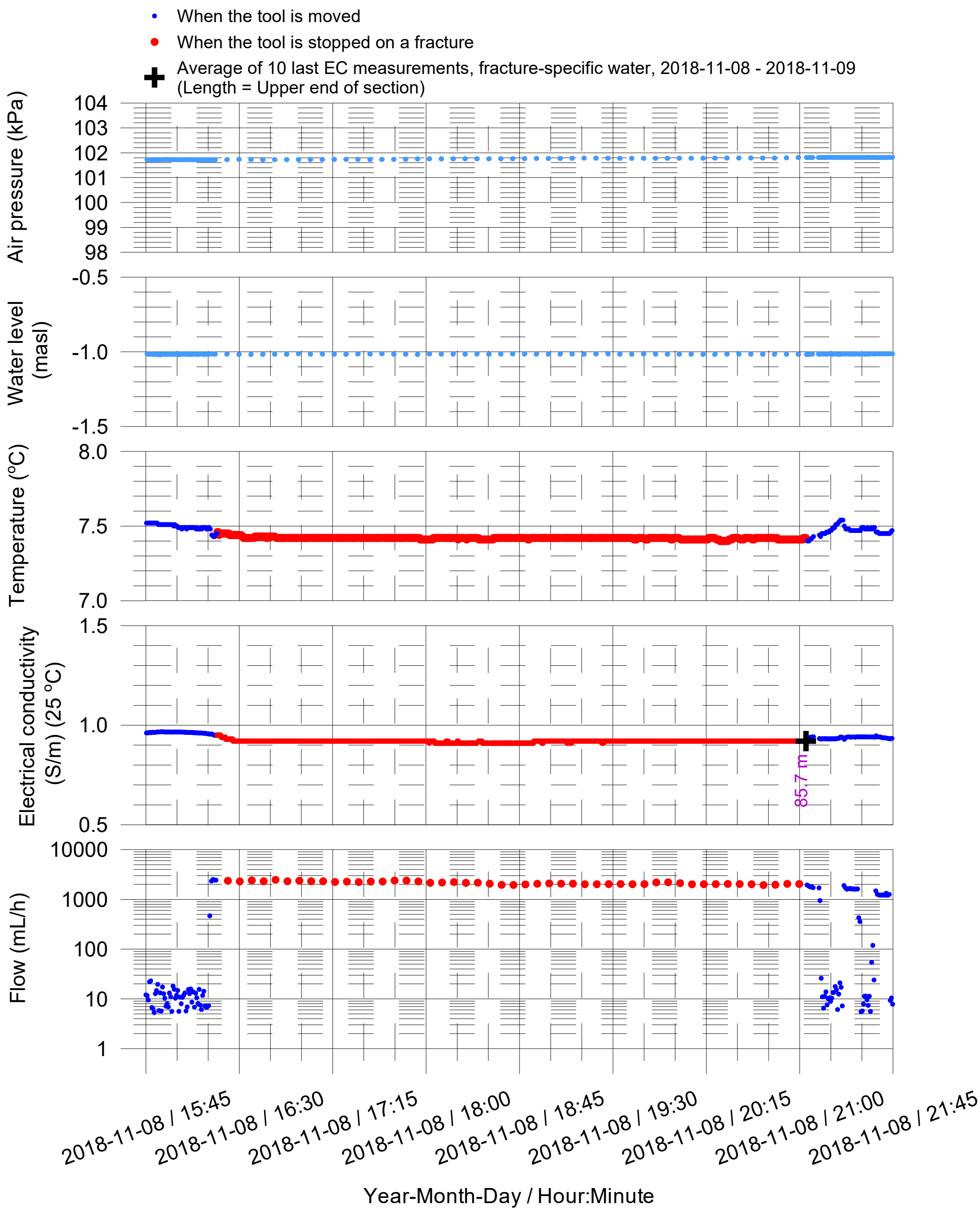
KFM23.9.2 Air pressure, water level in the borehole and pumping rate during flow logging

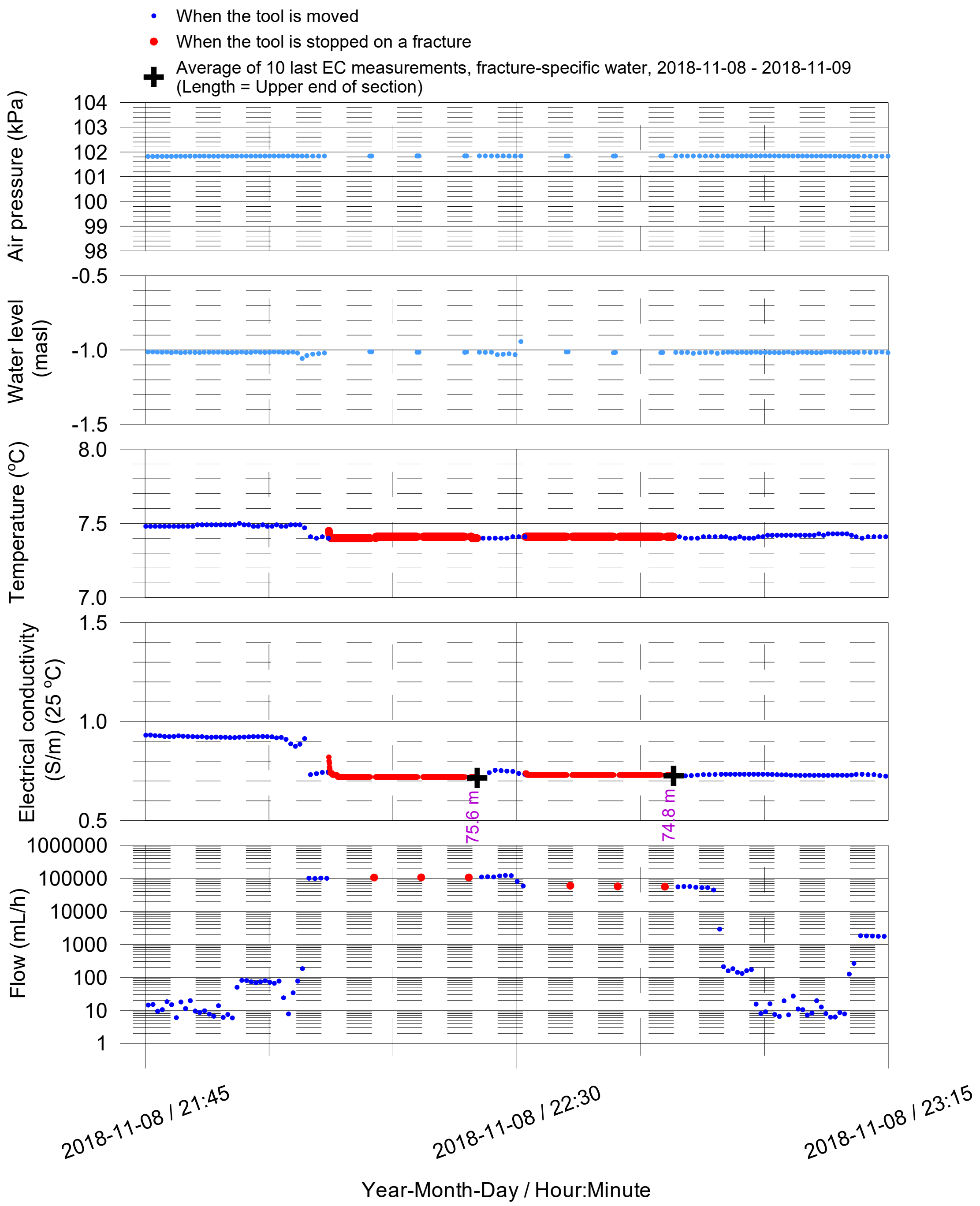


KFM23.9.3 Groundwater recovery after pumping

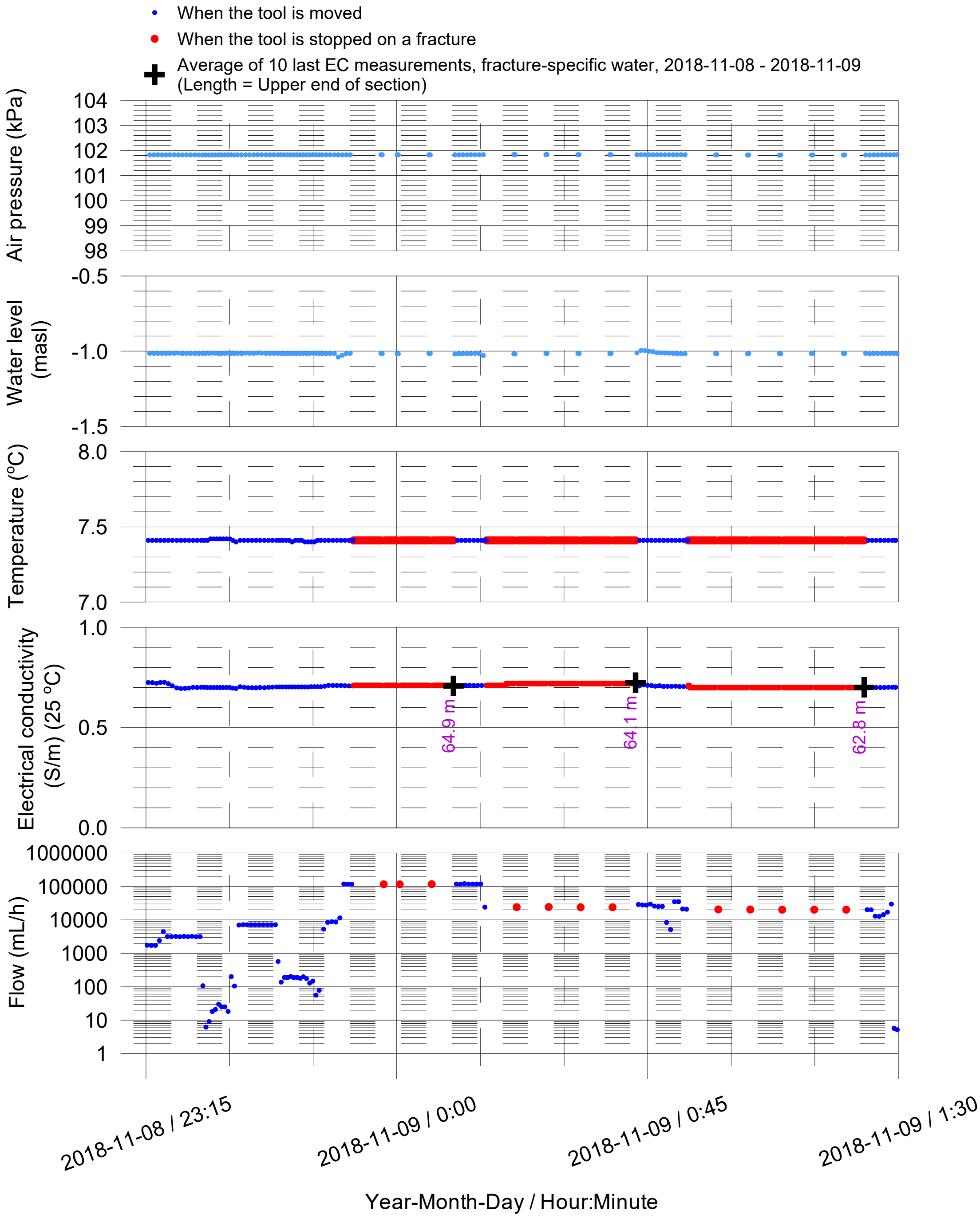


KFM23.10.1–KFM23.10.6 Fracture-specific EC results by date

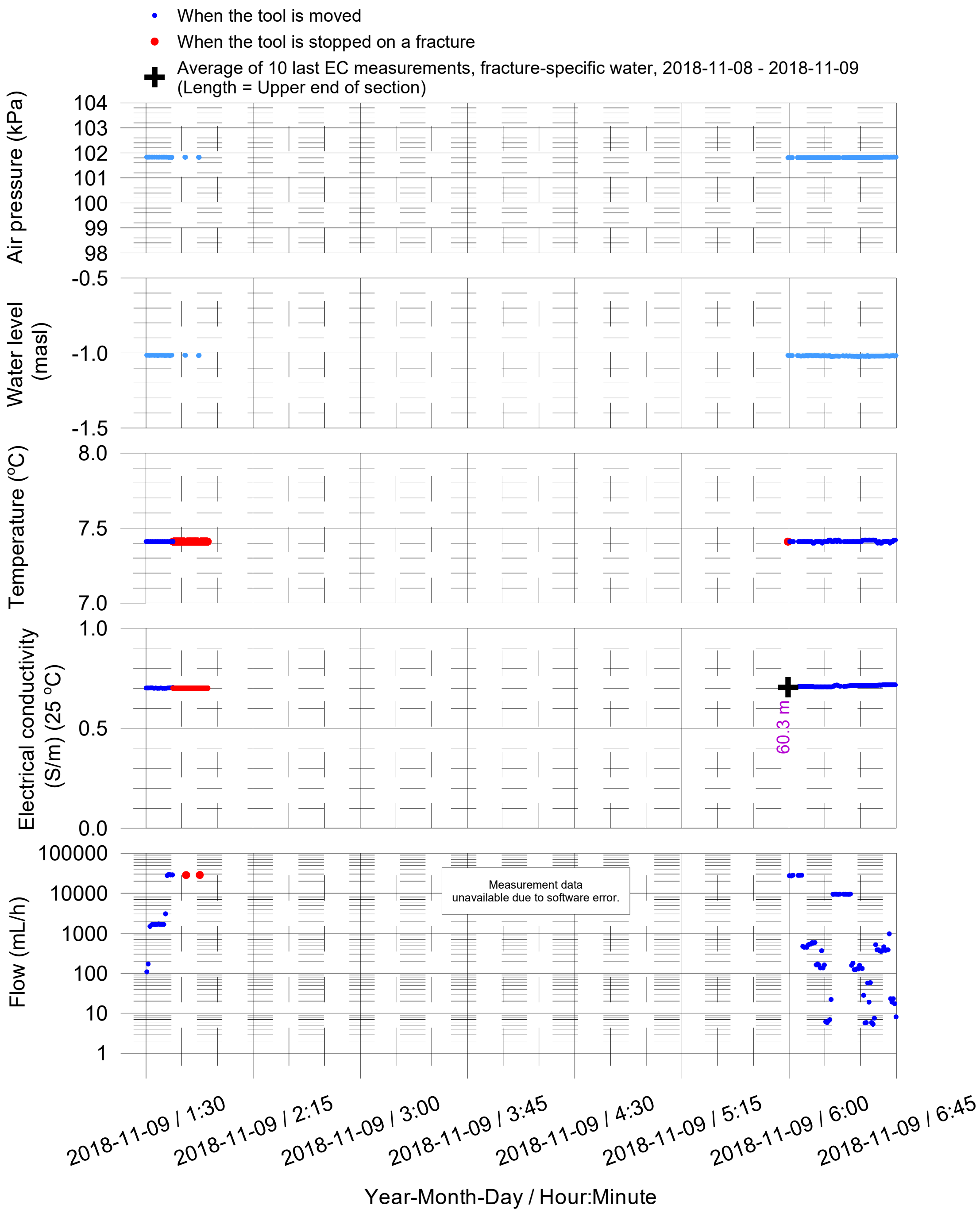




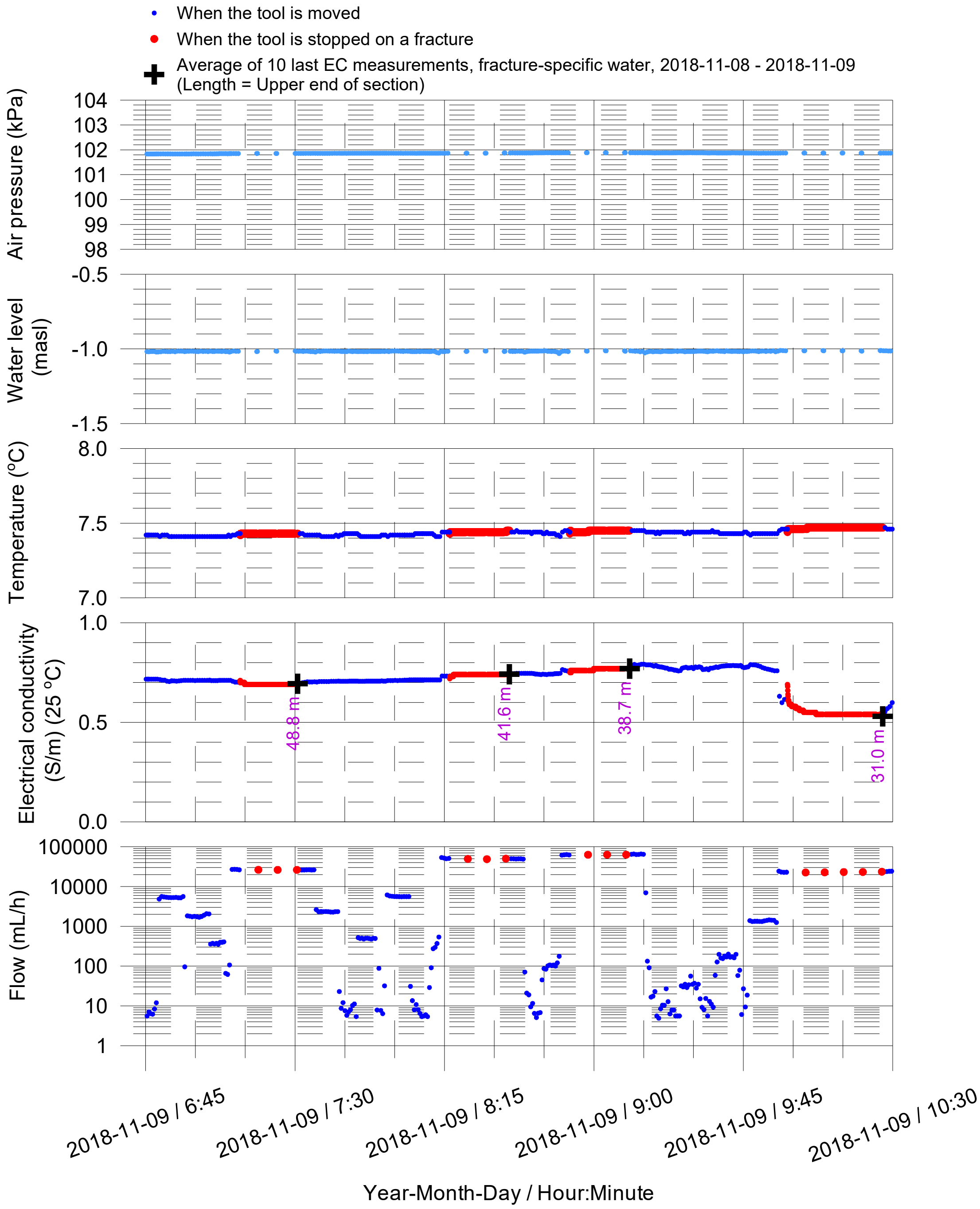
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-08 - 2018-11-09
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-0.5
-1.0
-1.5
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.5
1.0
0.5
75.6 m
74.8 m
Flow (mL/h)
1000000
100000
10000
1000
100
10
1
2018-11-08 / 21:45
2018-11-08 / 22:30
2018-11-08 / 23:15
Year-Month-Day / Hour:Minute



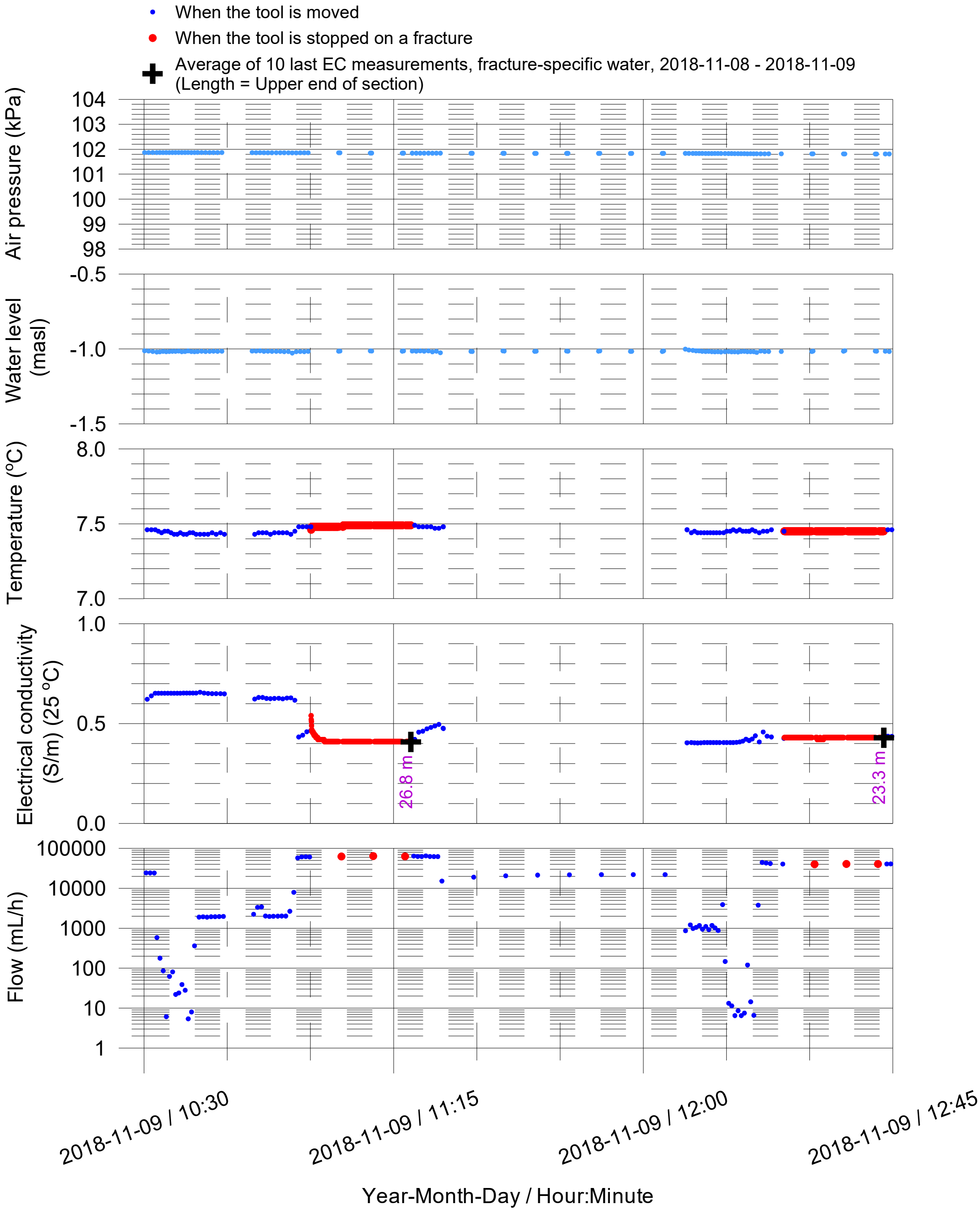
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-08 - 2018-11-09
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-0.5
-1.0
-1.5
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
64.9 m
64.1 m
62.8 m
Flow (mL/h)
1000000
100000
10000
1000
100
10
1
2018-11-08 / 23:15
2018-11-09 / 0:00
2018-11-09 / 0:45
2018-11-09 / 1:30
Year-Month-Day / Hour:Minute



When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-08 - 2018-11-09
(Length = Upper end of section)
Air pressure (kPa)
Water level (masl)
Temperature (°C)
Electrical conductivity (S/m) (25 °C)
Flow (mL/h)
60.3 m
Measurement data unavailable due to software error.
2018-11-09 / 1:30
2018-11-09 / 2:15
2018-11-09 / 3:00
2018-11-09 / 3:45
2018-11-09 / 4:30
2018-11-09 / 5:15
2018-11-09 / 6:00
2018-11-09 / 6:45
Year-Month-Day / Hour:Minute

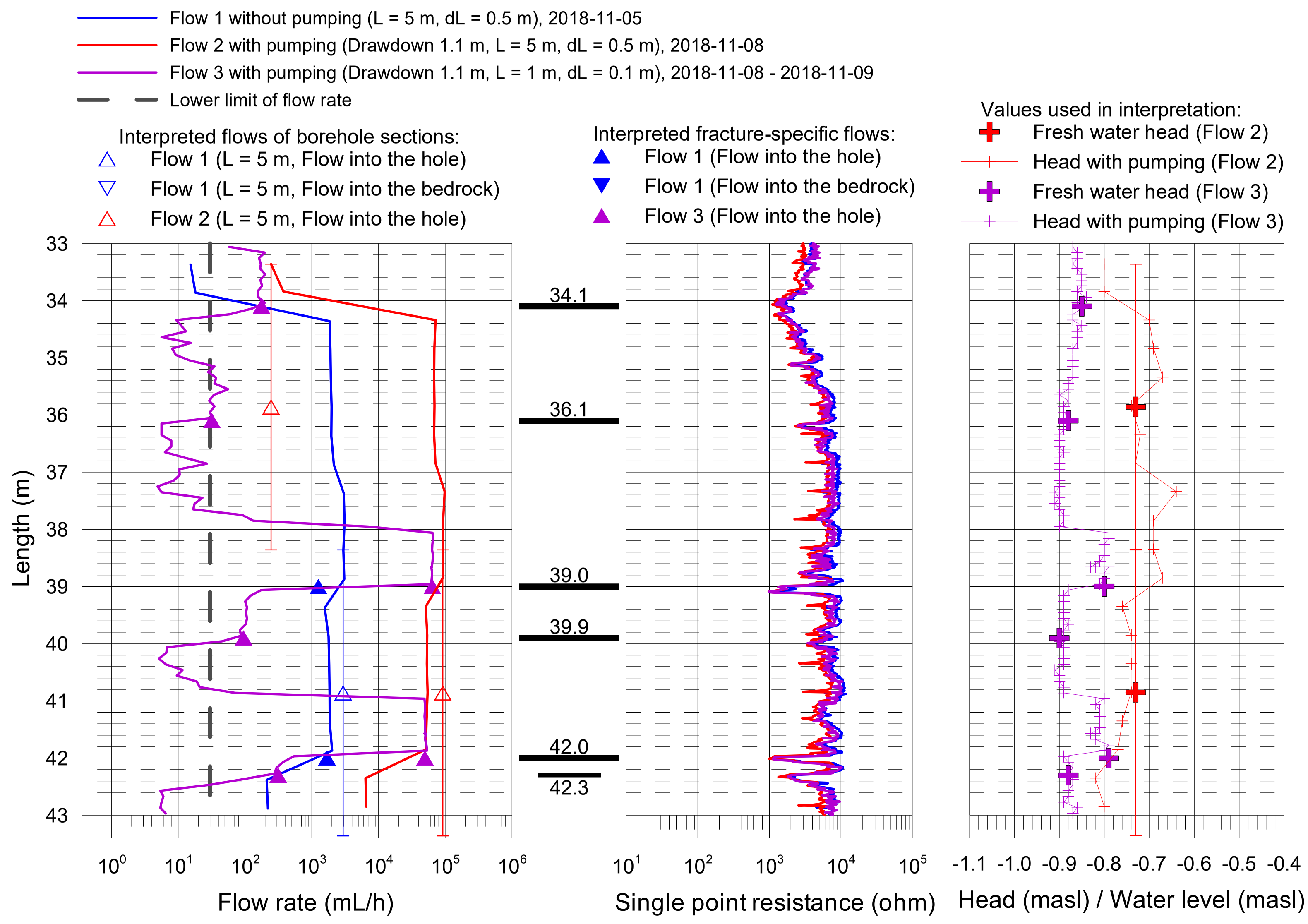


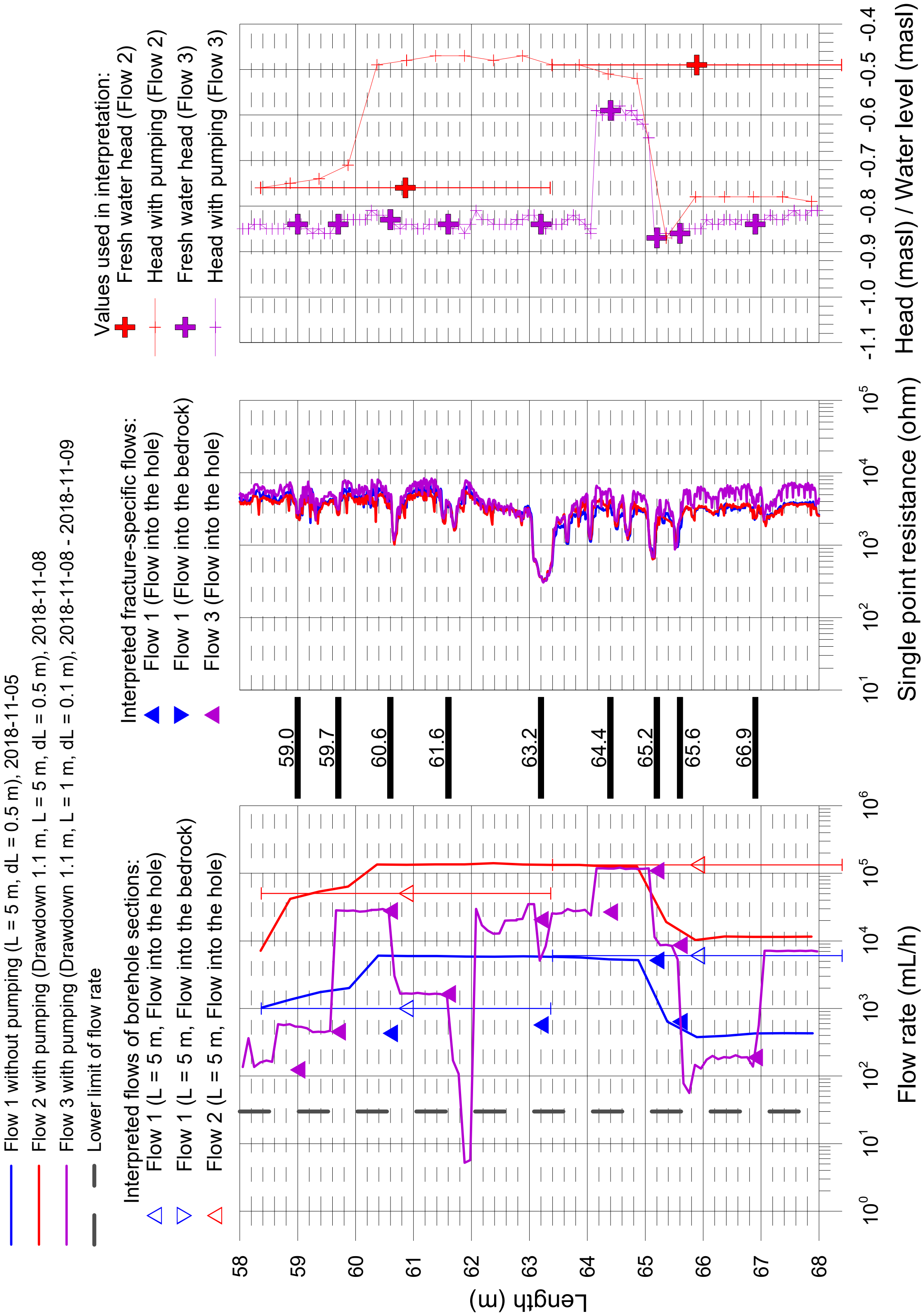
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-08 - 2018-11-09
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-0.5
-1.0
-1.5
Temperature (ºC)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 ºC)
1.0
0.5
0.0
48.8 m
41.6 m
38.7 m
31.0 m
Flow (mL/h)
100000
10000
1000
100
10
1
2018-11-09 / 6:45
2018-11-09 / 7:30
2018-11-09 / 8:15
2018-11-09 / 9:00
2018-11-09 / 9:45
2018-11-09 / 10:30
Year-Month-Day / Hour:Minute



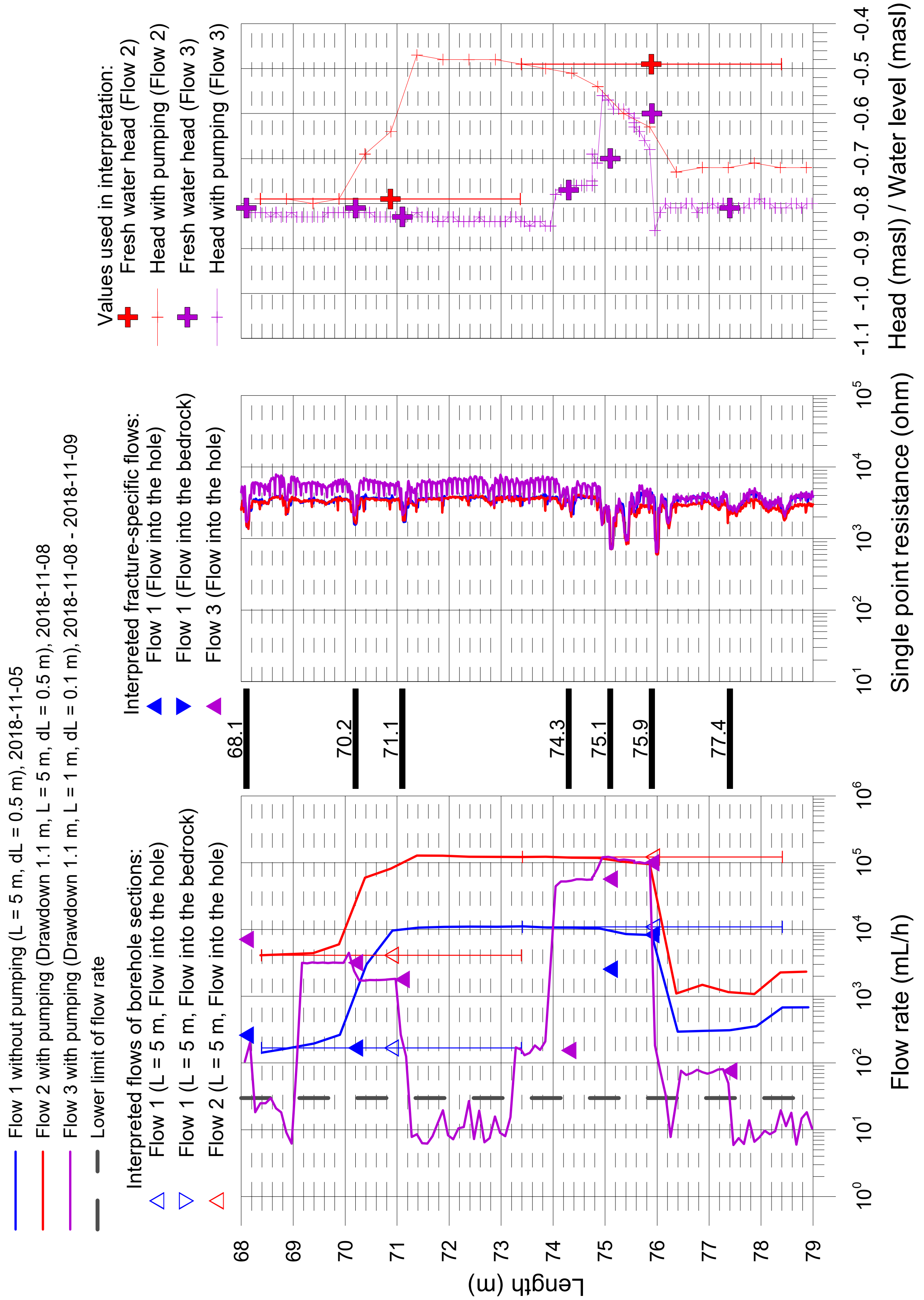
When the tool is moved
When the tool is stopped on a fracture
Average of 10 last EC measurements, fracture-specific water, 2018-11-08 - 2018-11-09
(Length = Upper end of section)
Air pressure (kPa)
104
103
102
101
100
99
98
Water level (masl)
-0.5
-1.0
-1.5
Temperature (°C)
8.0
7.5
7.0
Electrical conductivity (S/m) (25 °C)
1.0
0.5
0.0
26.8 m
23.3 m
Flow (mL/h)
100000
10000
1000
100
10
1
2018-11-09 / 10:30
2018-11-09 / 11:15
2018-11-09 / 12:00
2018-11-09 / 12:45
Year-Month-Day / Hour:Minute

KFM23.11.1–KFM23.11.3 Flow rate, single point resistance and head





Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-05
Flow 2 with pumping (Drawdown 1.1 m, L = 5 m, dL = 0.5 m), 2018-11-08
Flow 3 with pumping (Drawdown 1.1 m, L = 1 m, dL = 0.1 m), 2018-11-08 - 2018-11-09
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, Flow into the hole)
Flow 1 (L = 5 m, Flow into the bedrock)
Flow 2 (L = 5 m, Flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Values used in interpretation:
Fresh water head (Flow 2)
Head with pumping (Flow 2)
Fresh water head (Flow 3)
Head with pumping (Flow 3)
Length (m)
58
59
60
61
62
63
64
65
66
67
68
59.0
59.7
60.6
61.6
63.2
64.4
65.2
65.6
66.9
Flow rate (mL/h)
Single point resistance (ohm)
Head (masl) / Water level (masl)
-1.1 -1.0 -0.9 -0.8 -0.7 -0.6 -0.5 -0.4



Flow 1 without pumping (L = 5 m, dL = 0.5 m), 2018-11-05
Flow 2 with pumping (Drawdown 1.1 m, L = 5 m, dL = 0.5 m), 2018-11-08
Flow 3 with pumping (Drawdown 1.1 m, L = 1 m, dL = 0.1 m), 2018-11-08 - 2018-11-09
Lower limit of flow rate
Interpreted flows of borehole sections:
Flow 1 (L = 5 m, Flow into the hole)
Flow 1 (L = 5 m, Flow into the bedrock)
Flow 2 (L = 5 m, Flow into the hole)
Interpreted fracture-specific flows:
Flow 1 (Flow into the hole)
Flow 1 (Flow into the bedrock)
Flow 3 (Flow into the hole)
Values used in interpretation:
Fresh water head (Flow 2)
Head with pumping (Flow 2)
Fresh water head (Flow 3)
Head with pumping (Flow 3)
68.1
70.2
71.1
74.3
75.1
75.9
77.4
Length (m)
Flow rate (mL/h)
Single point resistance (ohm)
Head (masl) / Water level (masl)

Arkitektkopia AB, Bromma, 2019

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