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Äspö Hard Rock Laboratory

Difference flow measurements in boreholes KA3386A01, KF0066A01 and KF0069A01 at the Äspö HRL

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August 2002

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Abstract

Posiva Flow Log/Difference Flow method can be used for relatively fast determination of hydraulic conductivity and hydraulic head in fractures or fractured zones in cored boreholes. These measurements were carried out in boreholes KA3386A01, KF0066A01 and KF0069A01 at Äspö Hard Rock Laboratory in August 2002.

The measurements were carried out using the detailed (overlapping) flow logging mode; the flow rate into 1 m long test section was measured. Point interval was 0.1 m. The boreholes were open during these measurements.

In addition to flow, single point resistance (SPR) of the bedrock was also measured. It was measured with 0.01 m point interval during the detailed flow logging. Electric conductivity (EC) and temperature of borehole water was also measured time with flow measurements.

Inclination of borehole KF0066A01 is 0.5 decrees upwards and the borehole is partially air filled. Therefore some of the results in this borehole are wrong.

Sammanfattning

Posiva:s flödeslog/ differensflödesmetod kan användas för att relativt snabbt kunna bestämma hydraulisk konduktivitet och det absoluta vattentrycket i sprickor och sprickzoner i känrborrade borrhål. Metoden användes i borrhålen KA3386A01, KF0066A01 och KF0069A01 på Äspölaboratoriet i augusti 2002.

Mätningarna genomfördes genom en detaljerad överlappande loggning vilket innebär att 1 m borrhål mäts i taget och att sonden flyttas 0,1 m mellan varje ny mätning. Under mätningen är hela borrhålet öppet.

Förutom flödet mättes ”single point resistace” (SPR) i berget. Resistansen mättes med intervallet 0,01 m under flödesloggningen. Borrhålsvattnets elektriska konduktivitet (EC) och temperatur mättes också under flödesloggningen.

Borrhålet KF0066A01 har en lutning som är cirka 0,5 grader uppåt sett från horisontalplanet. Detta innebär att vissa delar av borrhålet är delvis fyllda med luft. Luft i borrhålet stör mätningarna och vissa data från detta borrhål är därför felaktiga.

Contents

1 Introduction

Posiva Flow Log/ Difference flow meter with the detailed flow logging mode was used in this study. The measurements were carried out in boreholes KA3386A01, KF0066A01 and KF0069A01 at Äspö Hard Rock Laboratory (HRL) in August 2002.

The Posiva Flow Log/Difference Flow method has been used previously in Posiva's site characterisation in Finland as well as at Äspö Hard Rock Laboratory. Boreholes KLX02 in Laxemar (Rouhiainen 2000) and KOV01 in Oskarshamn (Pöllänen & Rouhiainen 2001) have also been measured using the Posiva Flow Log.

The field work was conducted by PRG-Tec Oy.

2 Principles of measurement and operation

The Posiva Flow Log consists of the Transverse flowmeter and the Difference flowmeter. Only the Difference flowmeter is discussed in this report.

Ordinary borehole flowmeters measure the accumulated flow along the borehole. However, the incremental changes of flow along the borehole are generally very small and can easily be missed unless they are measured directly. The name "Difference flowmeter" comes from the fact that this flowmeter directly measures differences of flow along the borehole. These differences of flow are seepage from the bedrock into the borehole or flows from the borehole into the bedrock.

With the flow guide of the Difference flowmeter, the flow into or out from the borehole in the test section is the only flow that passes through the flow sensor. Flow along the borehole outside the test section is directed so that it does not come into contact with the flow sensor. A set of rubber disks is used at both ends of the equipment to isolate the test section from the borehole. These guide the flow to be measured, see Figure 2-1.

The Difference flowmeter can be used in two modes, in normal (sequential) and in detailed (overlapping) flow logging modes. The normal mode is used for the determination of hydraulic conductivity and head (Öhberg, Rouhiainen 2000). Both thermal dilution and thermal pulse flow measuring techniques are used in the normal mode. The thermal pulse method makes it possible to determine flow direction. The detailed mode using only the thermal dilution method is mostly used to determine the exact location of hydraulically conductive fractures and to classify them by flow rates.

The detailed flow logging was used in this study. It was used while boreholes were open. The length of the test section was 1 m and the spacing between two measuring points (depth increment) was 0.1 m.

Electric conductivity (EC) and temperature of borehole water were measured during the detailed flow logging. The occurrence of saline water in the borehole can be monitored using the EC measurements.

The single point resistance measurement (grounding resistance) is another parameter that is possible to measure with the flowmeter tool. The electrode of the single point resistance tool is located within the upper rubber disks, see Figure 2-1. This method is used for depth determination of fractures and geological structures. The point interval is 0.01 m.

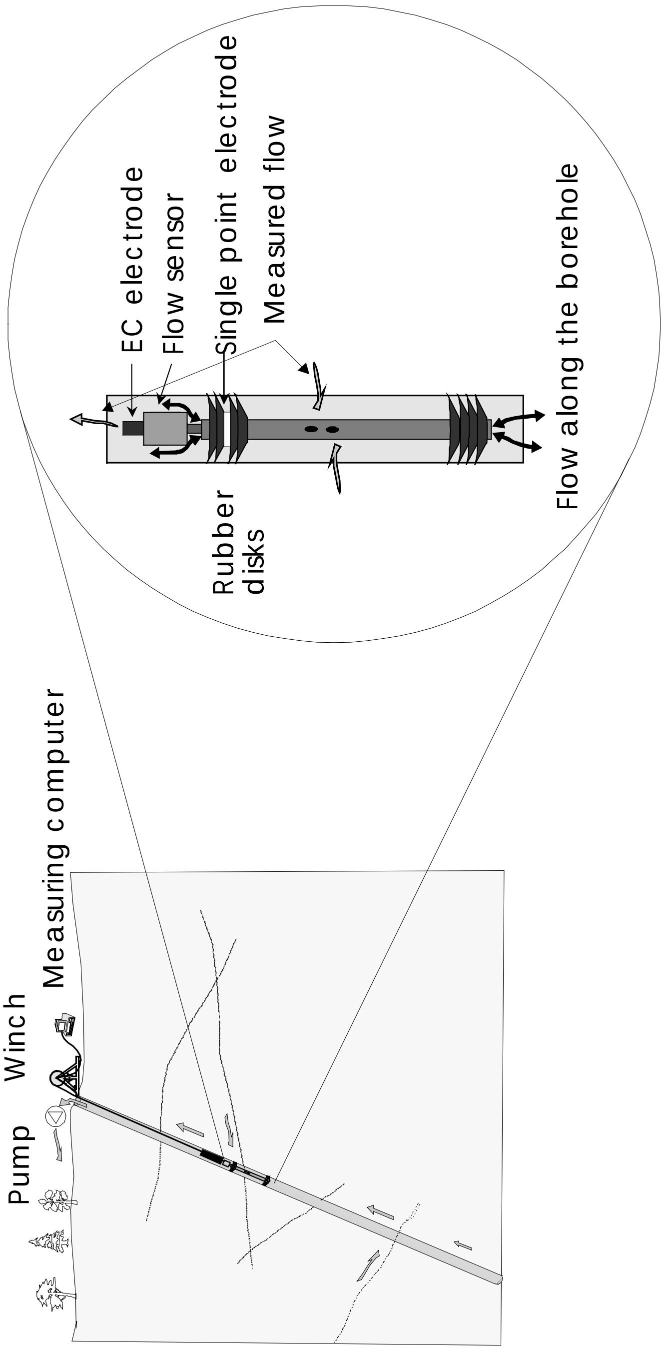

Figure 2-1 *Schematic of the equipment used in the Difference flowmeter.*

3 Equipment specifications

Posiva Flow Log/Difference flow method monitors the flow of groundwater into or out from a borehole by means of a flow guide (discs). That is, the flow guide defines the test section to be measured but does not alter the hydraulic head. Groundwater flowing into or out from the test section is guided to the flow sensor. Flow is measured using the thermal pulse and/or thermal dilution methods. Measured values are sent in digital form to the PC computer (Rouhiainen, Pöllänen 1998).

Type of instrument:	Posiva Flow Log/Difference Flowmeter
Measurable borehole diameters:	56 mm, 66 mm and 76 mm
Length of test section:	A variable length flow guide is used
Method of flow measurement:	Thermal pulse and/or thermal dilution
Range of measurement:	2 - 5000 ml/min with thermal dilution
Additional measurements:	Temperature, Single point resistance, conductivity of water
Winch:	Mount Sopris Wna 10, 0.55 kW, 220V/50Hz. Steel wire cable 1450 m, four conductors, Gerhard -Owen cable head
Depth determination	Based on the marked cable and on the digital depth counter
Logging computer:	PC, Windows 95/98/2000
Software	Based on MS Visual Basic
Total power consumption:	1.5 - 2.5 kW depending on the pumps
Method of calibration	Field calibration unit

4 Results

4.1 Field work

The field work was carried out in the Äspö HRL in August 2002. The activity schedule is presented in Table 4-1.

Table 4-1. Difference flow measurements in the Äspö HRL. Activity schedule.

Started	Finished	Activity
6.8.2002 15:26		Borehole KF0069A01 was opened.
6.8.2002 17:00		Flow rate out from borehole KF0069A01 was 10.7 l/min.
6.8.2002 18:00	7.8.2002 8:45	Detailed flow logging in borehole KF0069A01.
7.8.2002 8:50		Borehole KF0069A01 was closed.
7.8.2002 8:52		Borehole KF0066A01 was opened.
7.8.2002 9:50	7.8.2002 12:53	Detailed flow logging in borehole KF0066A01.
7.8.2002 10:06		Flow rate out from borehole KF0066A01 was 6.04 l/min.
7.8.2002 12:55		Borehole KF0066A01 was closed.
7.8.2002 13:26		Borehole KA3386A01 was opened.
7.8.2002 13:45	7.8.2002 17:55	Detailed flow logging in borehole KA3386A01.
7.8.2002 14:12		Flow rate out from borehole KA3386A01 was 53 l/min.
7.8.2002 17:58		Borehole KA3386A01 was closed.

4.2 Detailed flow logging

The detailed flow logging was performed with 1 m section length and with 0.1 m depth increments, see Appendices 1.1 – 1.4, 2.1 – 2.3 and 3.1 – 3.4. The method gives the depth and the thickness of the conductive zones with a depth resolution of 0.1 m. To make measurements more quickly, only the thermal dilution method is used for flow determination. The test section length determines the width of a flow anomaly of a single fracture. If the distance between flowing fractures is less than the section length, the anomalies will be overlapped resulting in a stepwise flow anomaly.

The depths of flowing fractures are marked with lines in the appendices of the detailed flow logs. A long line represents the depth of a leaky fracture, a short line denotes that the existence of a leaky fracture may be uncertain or the flow rate is uncertain i.e. the flow rate is under or over the range of measurements.

There was an increased noise level in flow in borehole KF0066A01 during the detailed flow logging. Some small flows may be missing because of the increased noise level. An apparent reason for the increased noise level is gas. Borehole KF0066A01 is problematic because its inclination is 0.5 degrees upwards. The borehole is therefore partially air filled. If there are gas bubbles during the flow measurement, the measured flow tends to go to zero and the flow values are not reliable, see Appendices 2.1 - 2.3.

High flow rates were detected at the bottom of borehole KF0069A01. This increased the noise level of flow at smaller depths. The noise level is still satisfactory in this borehole, see Appendices 3.1 - 3.4.

The electrode of the single point resistance tool is located within the upper rubber disks. Thus the depth of the resistance anomalies of the leaky fractures fit with the lower part of the flow anomalies.

4.3 EC and temperature of water

EC of borehole water was measured during detailed flow logging. Measurements were carried out when the flow guide was its normal configuration (with both upper and lower rubber disks). The flow guide may carry water with it making the results less representative at least at tight sections. All boreholes were measured from the bottom upwards.

The EC results of borehole KF0066A01 are not representative at all, because the borehole was partially air filled (see Appendices 2.1 – 2.3). There are only three results, which may be right (fractures 56.1 m, 30.1 m and 8.1 m).

Temperature of borehole water was also measured during the detailed flow logging. The results may be unreliable at some depths for the same reason as the EC measurements, the flow guide carries water with it and there was gas at some depths (see Appendices 4 – 6). The EC values are temperature corrected to 25 °C using a mathematical model to make them more comparable with other EC measurements (Heikkonen et al. 2001).

EC and temperature were measured as supplementary methods because they didn’t increase the duration of the fieldwork. More reliable results of borehole water can be obtained if the tool is used without the lower rubber disks. EC and temperature of fracture-specific water can be measured if the tool using the both sets of rubber disks is stopped on a leaky fracture.

4.4 Transmissivity

Transmissivity of fractures can be calculated on the basis of flow rates if cylindrical flow without skin zones and steady sate flow are assumed (Rouhiainen 1996).

T=1/L*Q/(a*(ho-h1))

where

T is transmissivity,
Q is the measured flow into a section,

a is a constant depending on flow geometry (a=2*π*L/ln(R/r0)

L is the length of test section,

R is radius of influence from the borehole

r is radius of borehole

h1 is hydraulic head in the borehole,

h0 is the head of the measured zone far from the borehole

Some assumptions have to be made for the calculation of transmissivity:

R/r0=500

$h_1 = 0$,

h_0 = is the elevation of fracture in the borehole.

Transmissivity is then

$T = Q /(h_0 \cdot 2 \cdot \pi/\ln(500))$

Hydraulic head of a fracture far from the borehole is chosen to be the same as elevation of fracture in the borehole, because no other information is available. The calculated transmissivities are presented in Appendix 7. They are qualitative because of the assumptions presented above.

5 Discussion and conclusions

In this study Posiva Flow Log/Difference Flow method with the detailed flow logging mode has been used to determine the depth and flow rate of flowing fractures. Measurements were done using 1 m section length with 0.1 m depth increments when the boreholes were open, i.e. water was flowing out of them. Anomalies of open fractures were seen in Single point resistance log with high depth resolution.

Electric conductivity and temperature were also measured during the flow measurement.

The measurements were successful in boreholes KA3386A01 and KF0069A01. High flow rates were detected at the bottom of borehole KF0069A01. This increased the noise level of flow at smaller depths. The noise level was still satisfactory in borehole KF0069A01.

Inclination of borehole KF0066A01 is 0.5 decrees upwards. The borehole is partially air filled. Therefore electric conductivity and temperature results are not correct at most depths. There were also problems with flow measurements. However, the flow rates of the most conductive fractures could be measured. No problems were seen in single point resistance logs.

Transmissivity of fractures was calculated on the basis of measured flow rates. These are qualitative because of the used assumptions.

References

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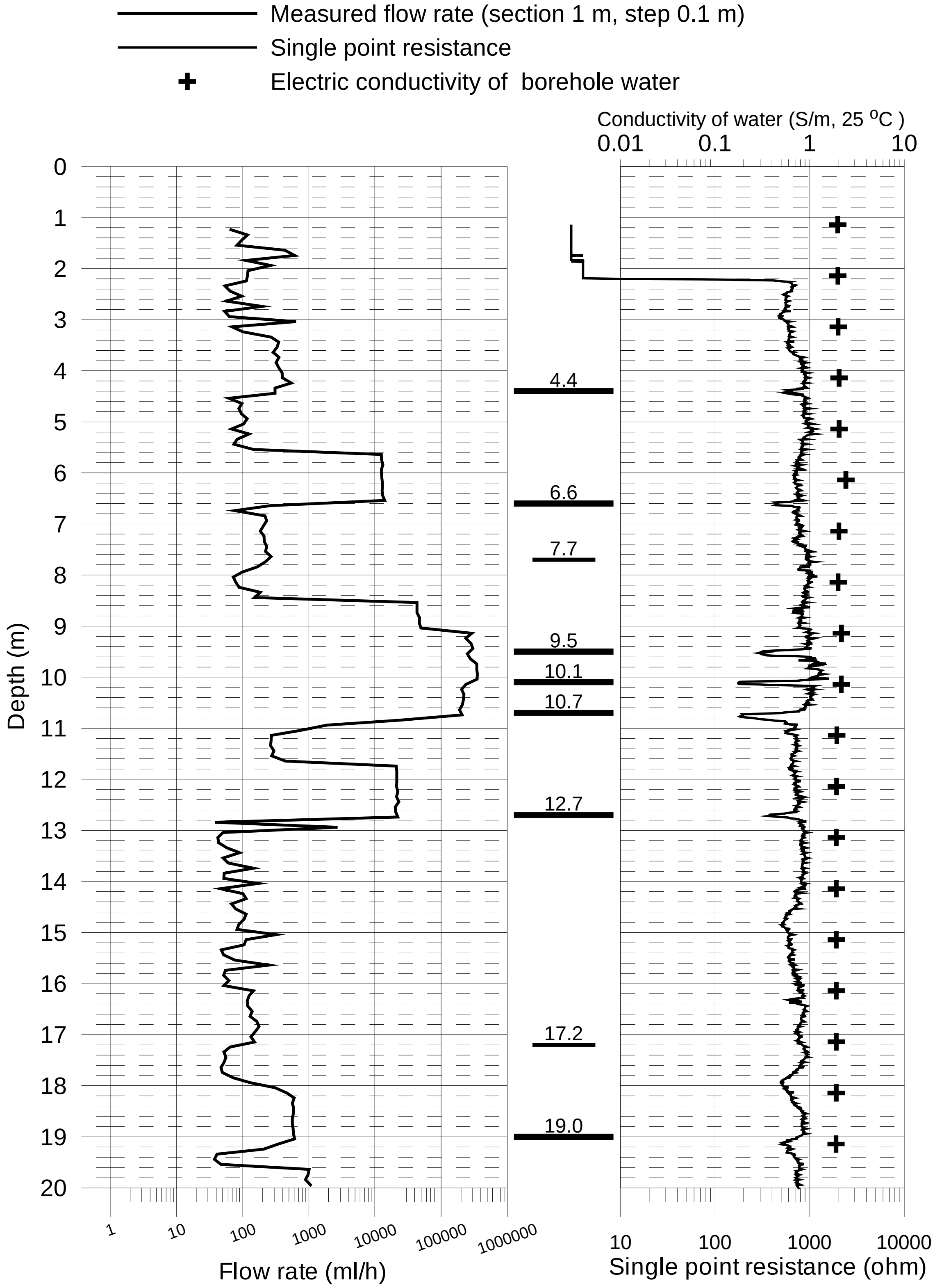
Appendices

ÄSPÖ, Borehole KA3386A01
2002-08-07
(Reference level = rock surface (Top of casing -0.35 m))



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2002-08-07
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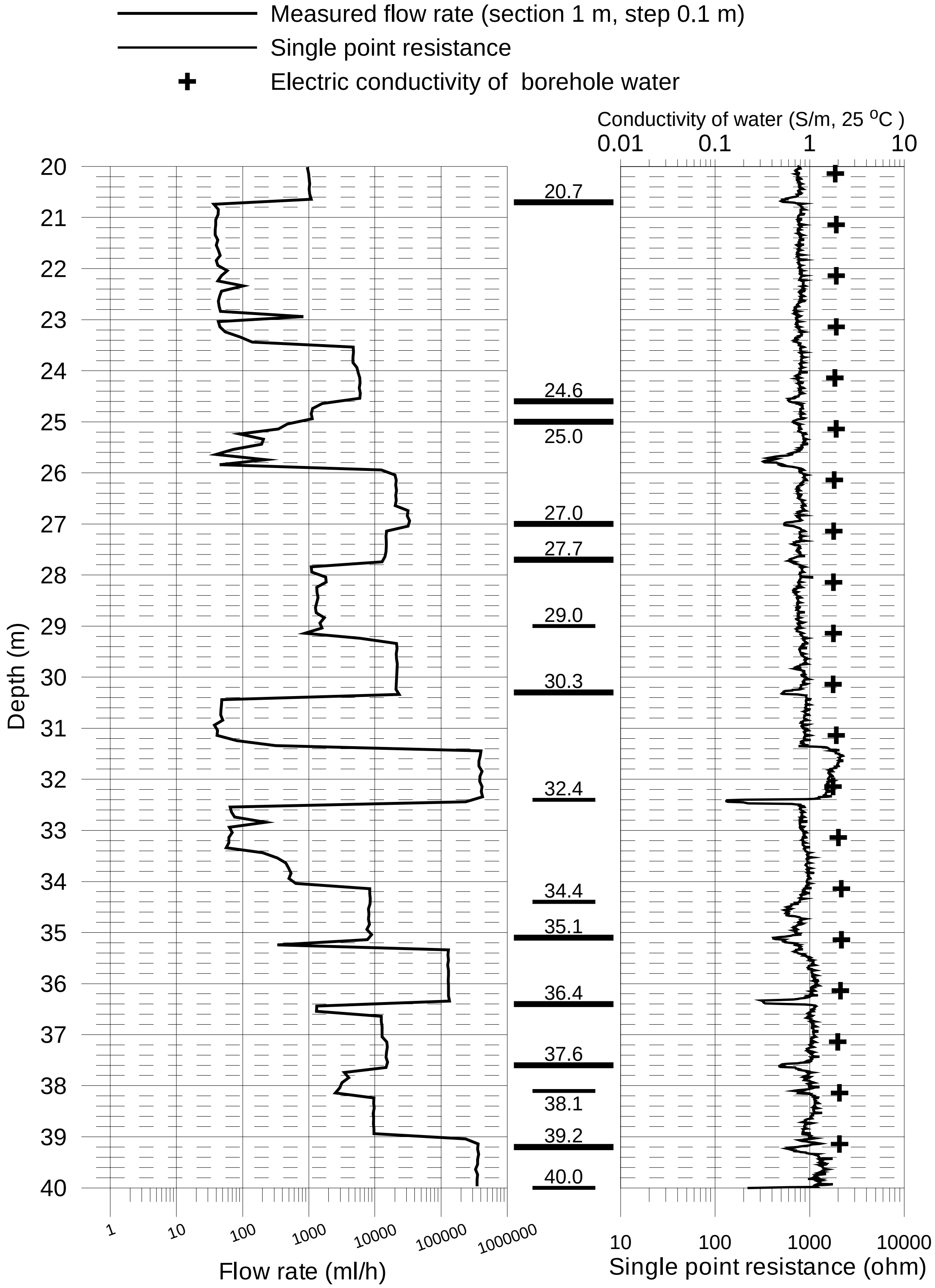

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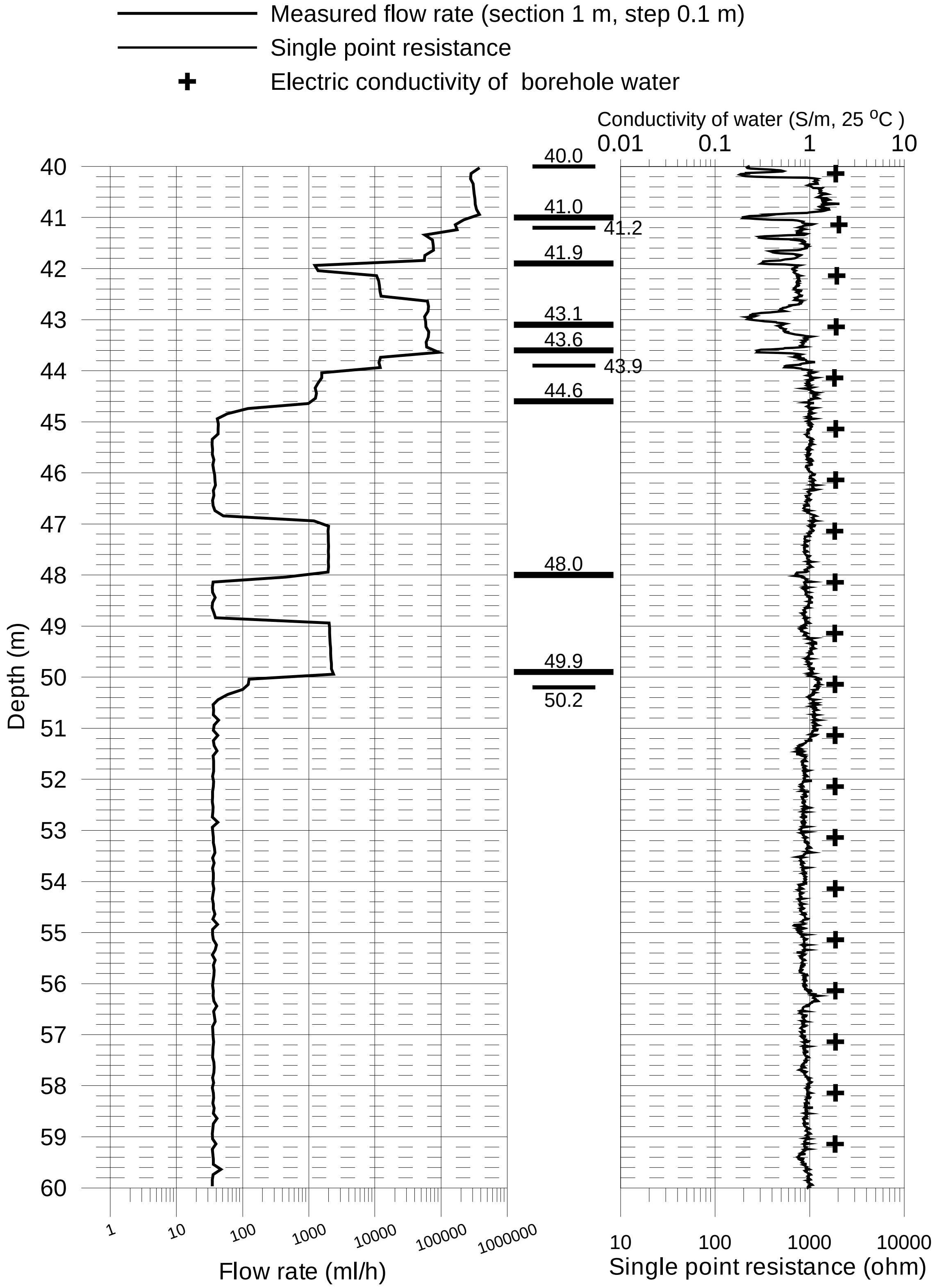

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2002-08-07
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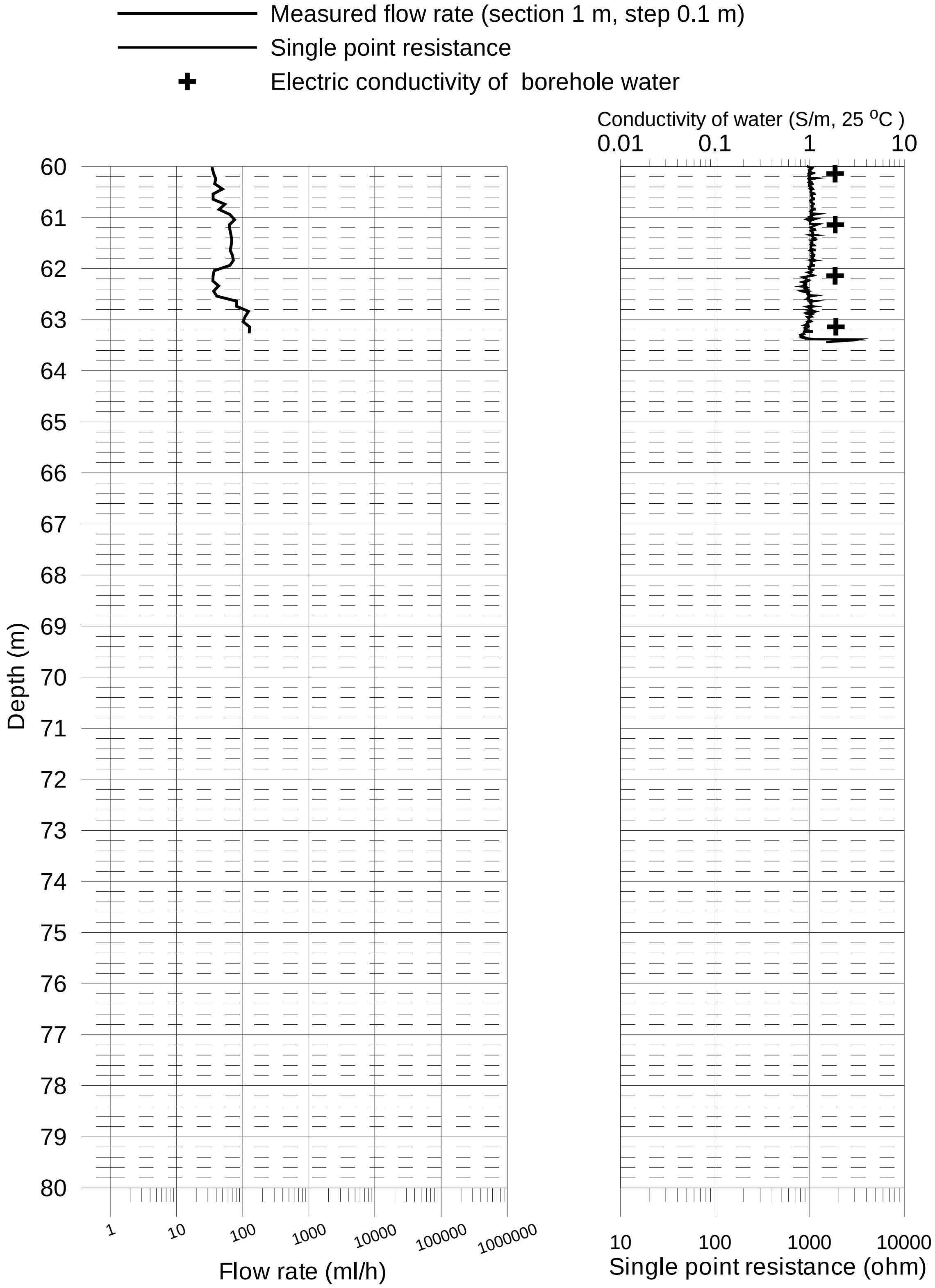
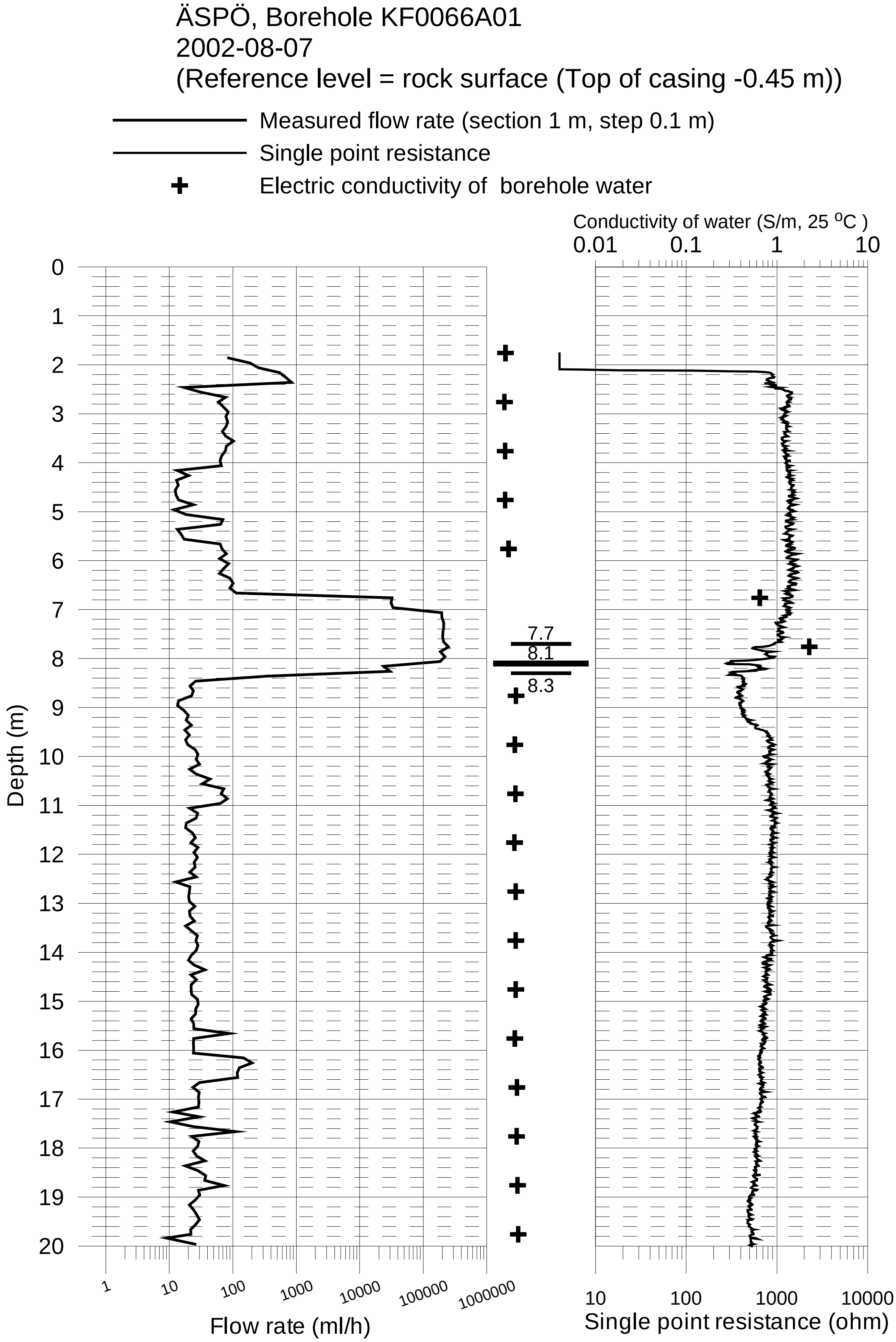
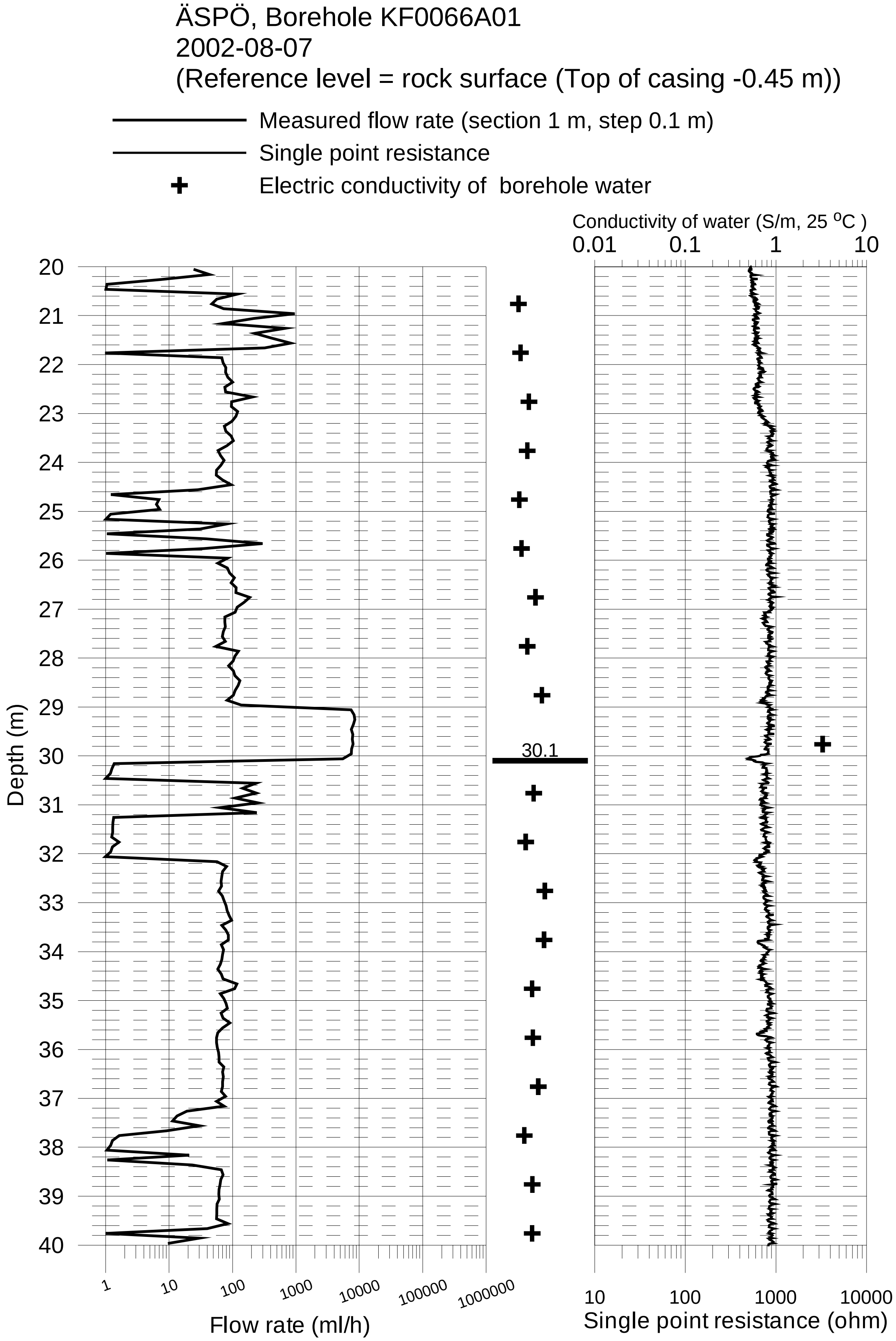
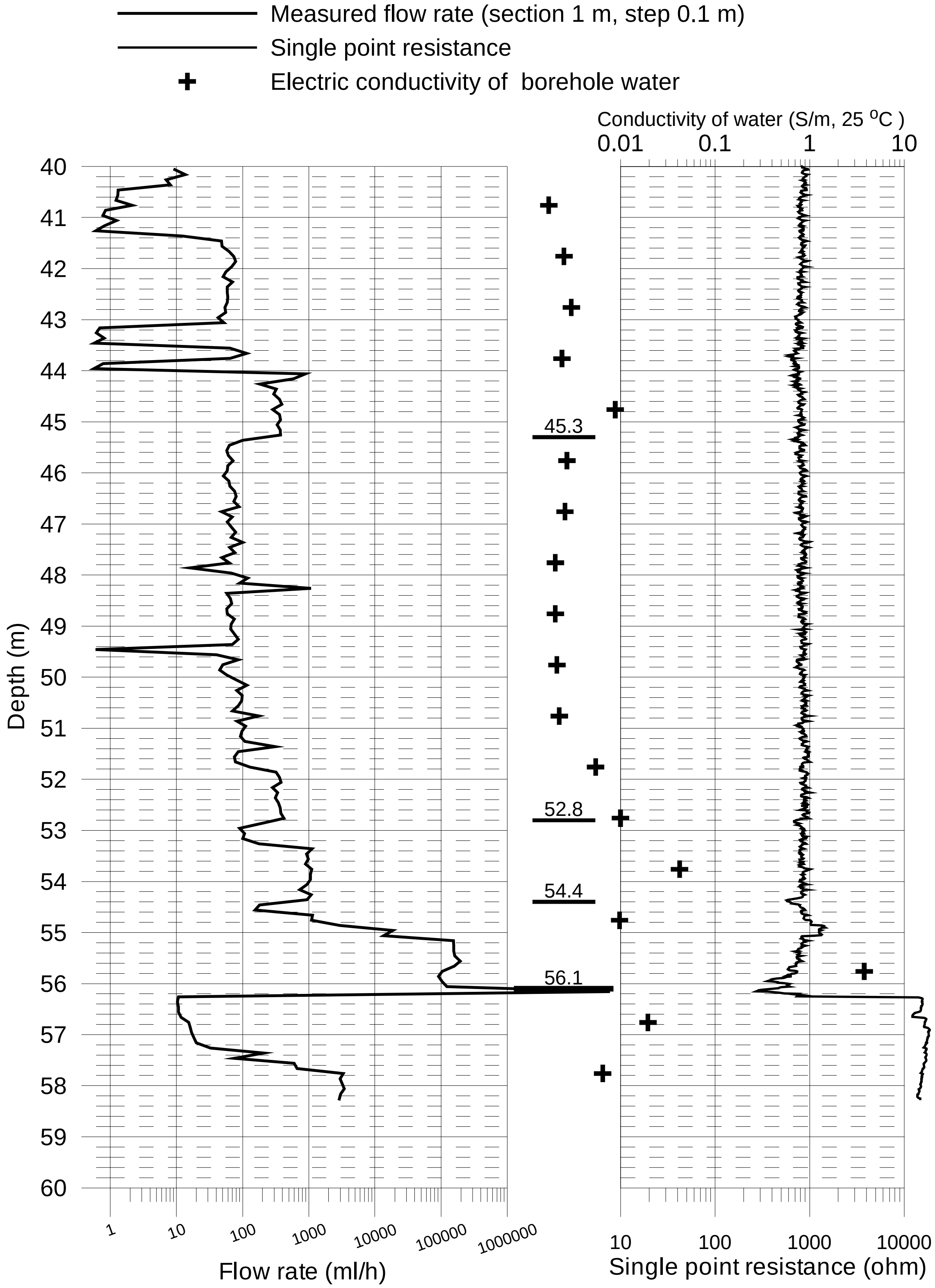


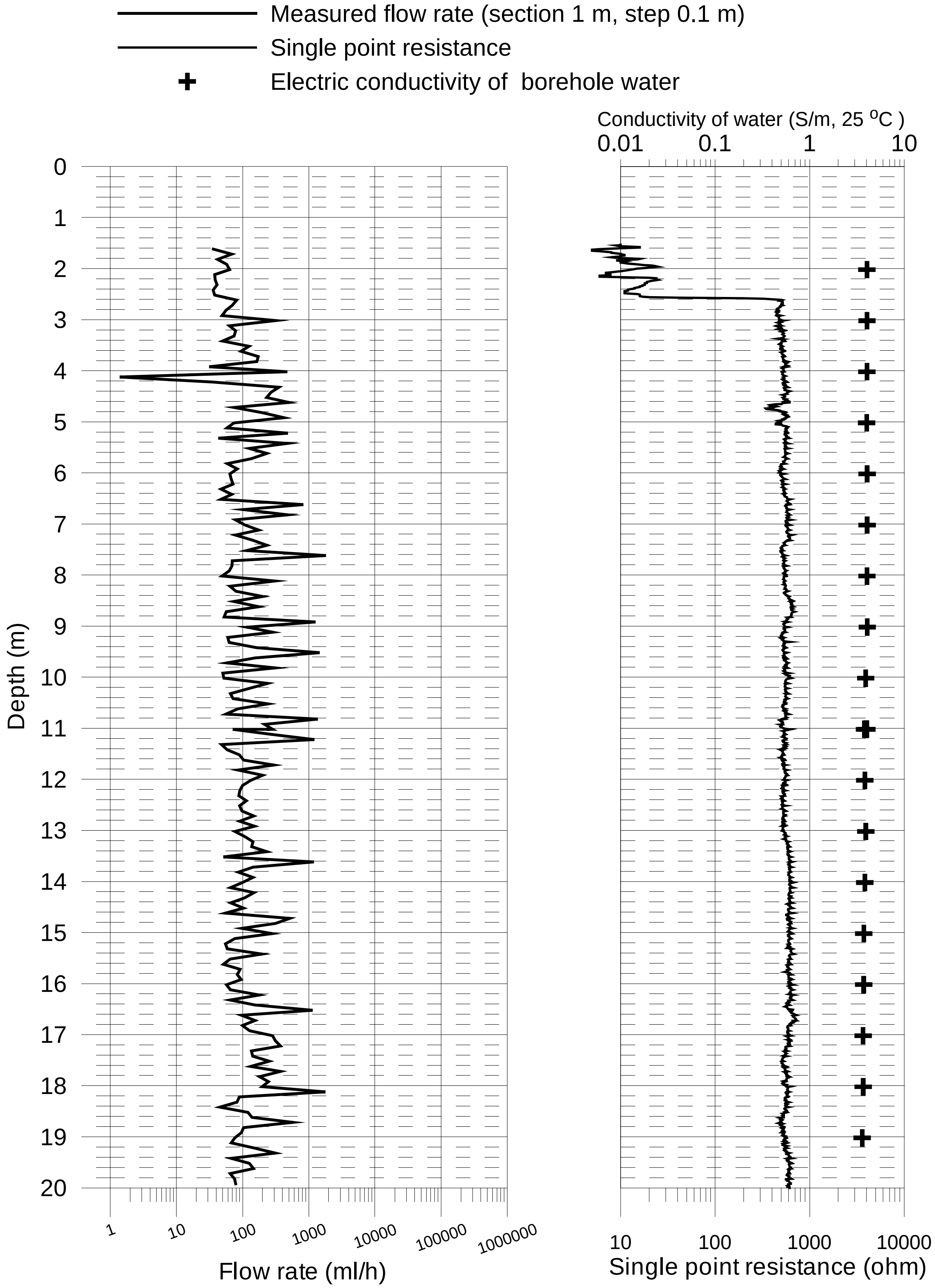

ÄSPÖ, Borehole KF0066A01
2002-08-07
(Reference level = rock surface (Top of casing -0.45 m))
Measured flow rate (section 1 m, step 0.1 m)
Single point resistance
Electric conductivity of borehole water
Conductivity of water (S/m, 25 °C)
0.01
0.1
1
10
Depth (m)
7.7
8.1
8.3
Flow rate (ml/h)
Single point resistance (ohm)


ÄSPÖ, Borehole KF0066A01
2002-08-07
(Reference level = rock surface (Top of casing -0.45 m))
Measured flow rate (section 1 m, step 0.1 m)
Single point resistance
Electric conductivity of borehole water
Conductivity of water (S/m, 25 °C)
0.01
0.1
1
10
Depth (m)
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
30.1
1
10
100
1000
10000
100000
1000000
Flow rate (ml/h)
10
100
1000
10000
Single point resistance (ohm)

ÄSPÖ, Borehole KF0066A01
2002-08-07
(Reference level = rock surface (Top of casing -0.45 m))



ÄSPÖ, Borehole KF0069A01
2002-08-06 - 2002-08-07
(Reference level = rock surface (Top of casing -0.40 m))



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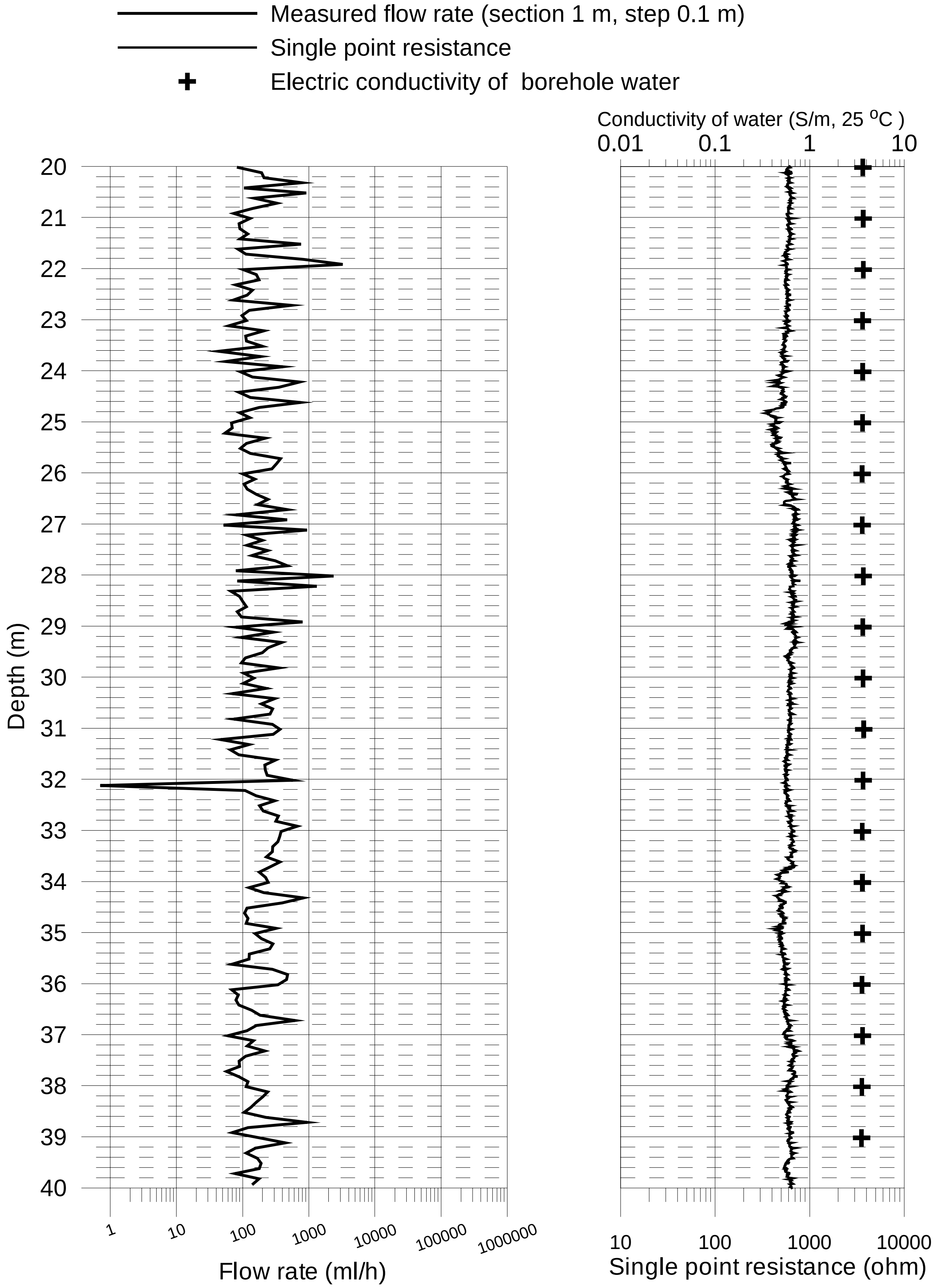
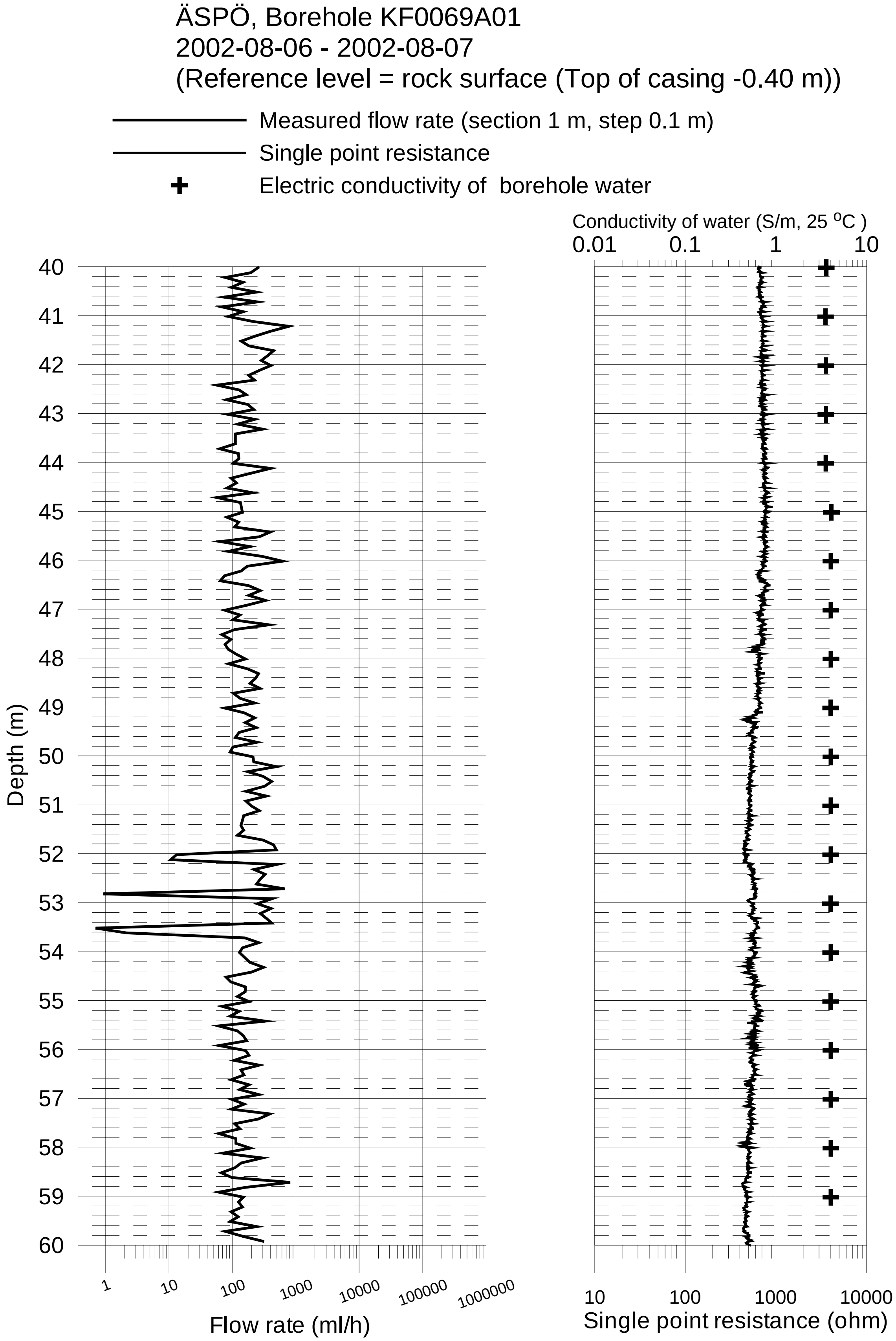
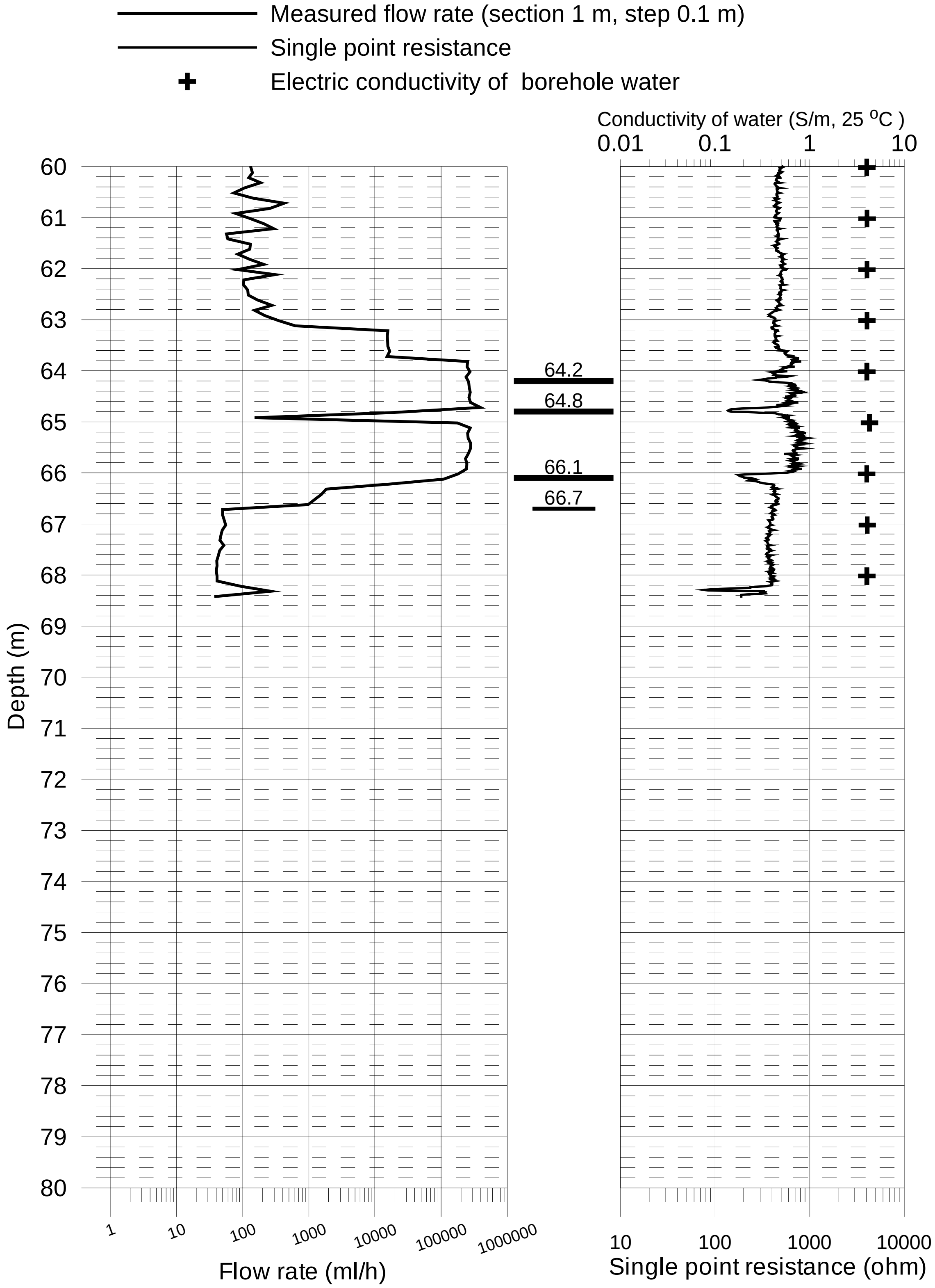
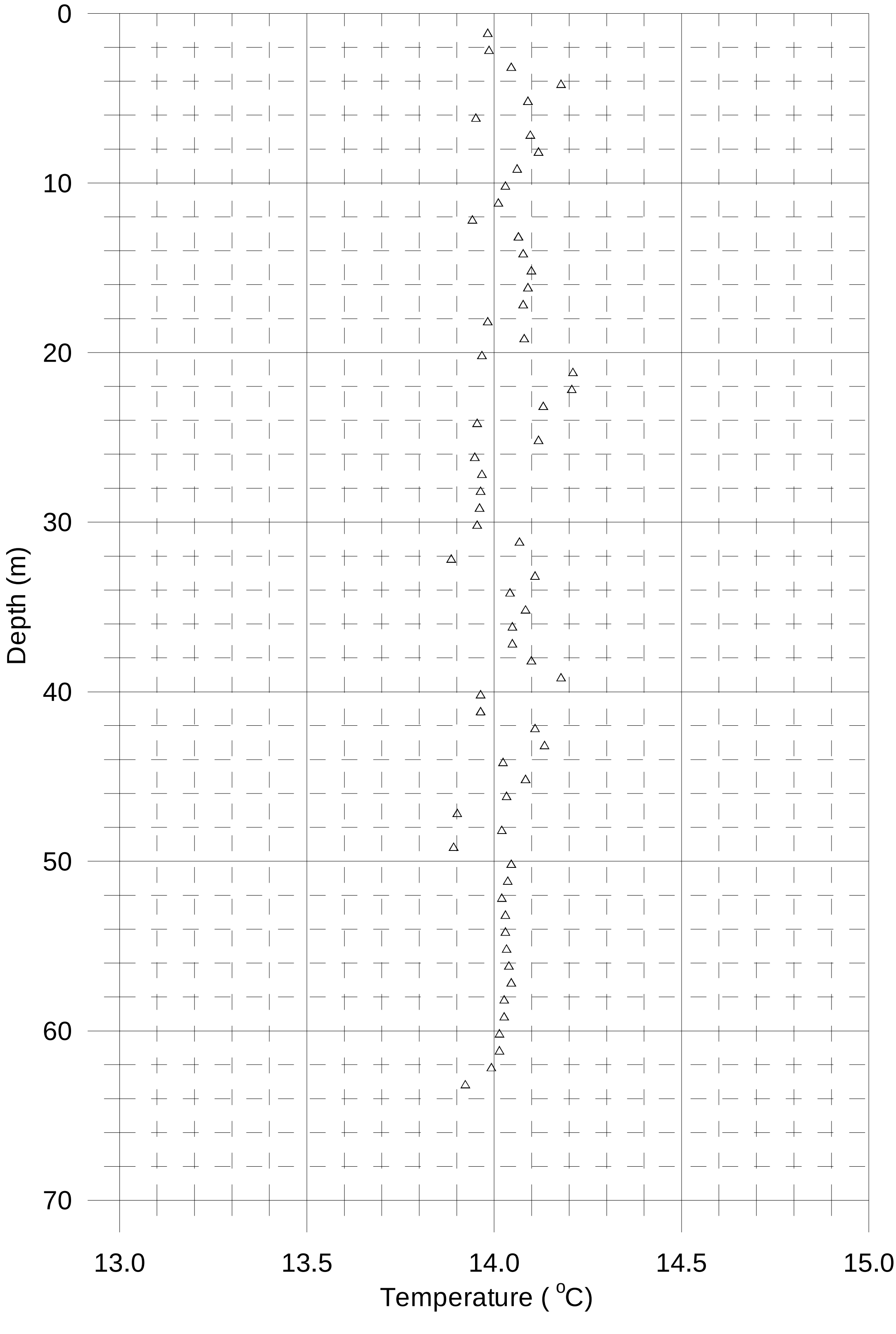



ÄSPÖ, Borehole KF0069A01
2002-08-06 - 2002-08-07
(Reference level = rock surface (Top of casing -0.40 m))
Measured flow rate (section 1 m, step 0.1 m)
Single point resistance
Electric conductivity of borehole water
Conductivity of water (S/m, 25 °C)
0.01
0.1
1
10
Depth (m)
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
1
10
100
1000
10000
100000
1000000
Flow rate (ml/h)
10
100
1000
10000
Single point resistance (ohm)

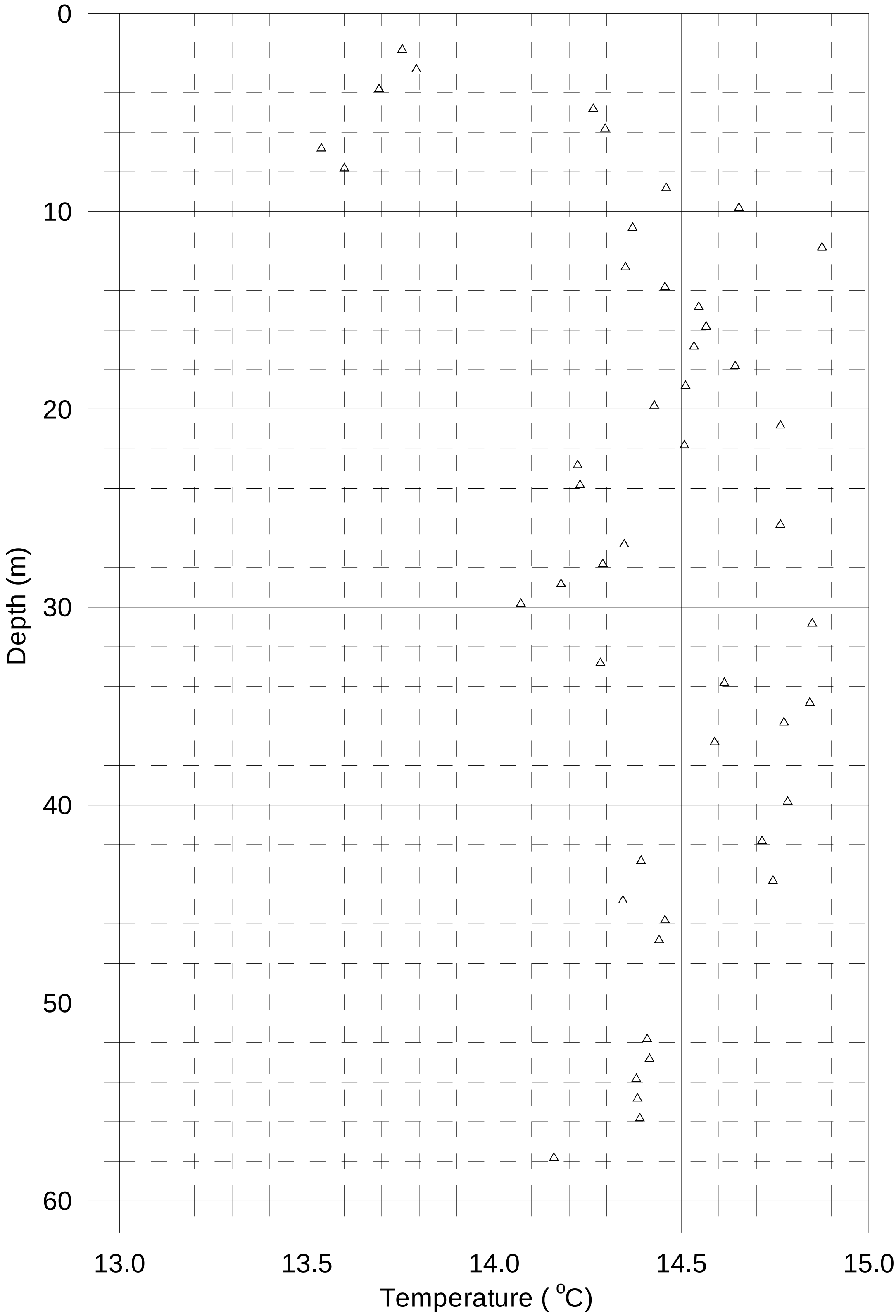
ÄSPÖ, Borehole KF0069A01
2002-08-06 - 2002-08-07
(Reference level = rock surface (Top of casing -0.40 m))



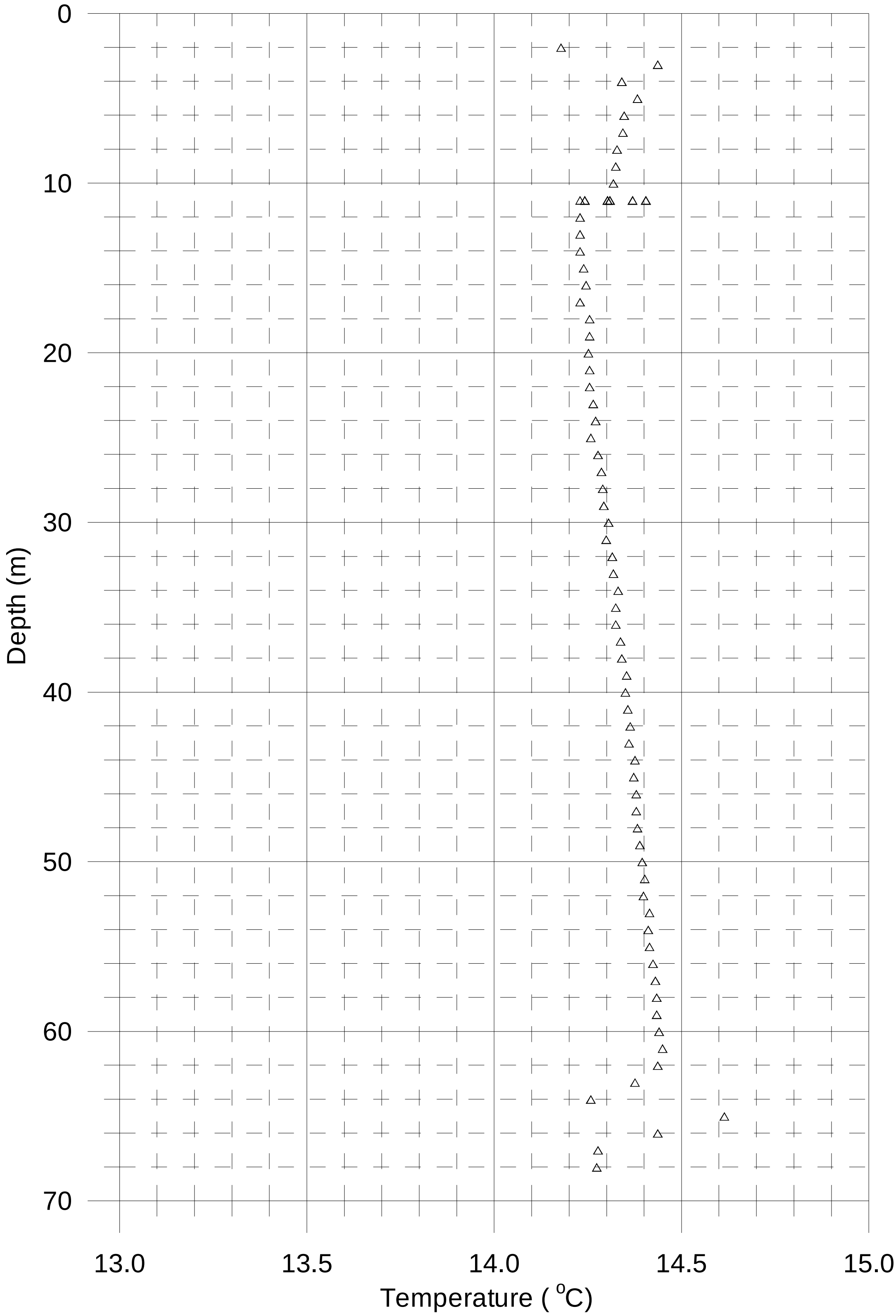
Temperature of borehole water
Äspö HRL, borehole KA3386A01
2002-08-07



Temperature of borehole water
Äspö HRL, borehole KF0066A01
2002-08-07



Temperature of borehole water
Äspö HRL, borehole KF0069A01
2002-08-06 - 2002-08-07



Borehole	Depth (m)	Flow (ml/h)	Elevation (m)	Transmissivity (m2/s)	Flow rate uncertain
KA3386A01	50.2	120	-448	7.36E-11	*
KA3386A01	49.9	2100	-448	1.29E-09	
KA3386A01	48	2000	-448	1.23E-09	
KA3386A01	44.6	1300	-448	7.97E-10	
KA3386A01	43.9	12000	-448	7.36E-09	*
KA3386A01	43.6	60000	-448	3.68E-08	
KA3386A01	43.1	120000	-448	7.36E-08	
KA3386A01	41.9	56000	-448	3.43E-08	
KA3386A01	41.2	170000	-448	1.04E-07	*
KA3386A01	41	280000	-448	1.72E-07	
KA3386A01	40	350000	-448	2.15E-07	*
KA3386A01	39.2	9500	-448	5.83E-09	
KA3386A01	38.1	2500	-448	1.53E-09	*
KA3386A01	37.6	15000	-447	9.22E-09	
KA3386A01	36.4	130000	-447	7.99E-08	
KA3386A01	35.1	8100	-447	4.98E-09	
KA3386A01	34.4	500	-447	3.07E-10	*
KA3386A01	32.4	400000	-447	2.46E-07	*
KA3386A01	30.3	21000	-447	1.29E-08	
KA3386A01	29	1300	-447	7.99E-10	*
KA3386A01	27.7	15000	-447	9.22E-09	
KA3386A01	27	21000	-447	1.29E-08	
KA3386A01	25	1100	-447	6.76E-10	
KA3386A01	24.6	4700	-447	2.89E-09	
KA3386A01	20.7	1000	-447	6.15E-10	
KA3386A01	19	570	-447	3.50E-10	
KA3386A01	17.2	150	-447	9.22E-11	*
KA3386A01	12.7	21000	-446	1.29E-08	
KA3386A01	10.7	200000	-446	1.23E-07	
KA3386A01	10.1	200000	-446	1.23E-07	
KA3386A01	9.5	4500	-446	2.77E-09	
KA3386A01	7.7	210	-446	1.29E-10	*
KA3386A01	6.6	13000	-446	8.01E-09	
KA3386A01	4.4	350	-446	2.16E-10	
KF0066A01	56.1	160000	-454	9.68E-08	
KF0066A01	54.4	900	-454	5.45E-10	*
KF0066A01	52.8	370	-454	2.24E-10	*
KF0066A01	45.3	360	-454	2.18E-10	*
KF0066A01	30.1	7900	-454	4.78E-09	
KF0066A01	8.3	24000	-454	1.45E-08	*
KF0066A01	8.1	210000	-454	1.27E-07	
KF0066A01	7.7	32000	-454	1.94E-08	*
KF0069A01	66.70	1200	-457	7.21E-10	*
KF0069A01	66.10	260000	-457	1.56E-07	
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