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Keywords: Groundwater, flow, measurement, bedrock, borehole, electric conductivity, single point resistance, Posiva Flow Log.

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. This report presents the principles of the method as well as the results of the measurements carried out in borehole KOV01 at Oskarshamn in February and March 2001.

The aim of the measurements presented in this report was to determine the depth and flow rate of flowing fractures in borehole KOV01 prior to groundwater sampling.

The measurements in borehole KOV01 were carried out between 100–1000 m depth using the so called detailed flow logging mode; the flow rate into a 5 m long test section was measured. Detailed flow logging was repeated at the location of the detected flow anomalies using 0.5 m section length and 0.1 m point intervals. The borehole was pumped during these measurements.

The occurrence of saline water in the borehole was studied by electric conductivity measurements. The flow guide encloses also an electrode for measuring of single point resistance of the bedrock. It was measured with 0.01 m point intervals during the detailed flow logging.

Depth calibration was made on the basis of the known depth marks in the borehole. The depth marks were detected by caliper measurements and by single point resistance measurements.

Contents

1 Introduction

The measurements were carried out in borehole KOV01 at Oskarshamn in February and March 2001. Borehole KOV01 is about 1000 m deep and its inclination is about 80 degrees. The diameter below 100 m depth is about 76 mm and greater above 100 m. The flow measurements were done between 100 m and 1000 m depth.

The aim of the measurements was to determine the depth and flow rate of flowing fractures prior to groundwater sampling. It is important that the natural groundwater conditions are kept as undisturbed as far as possible. The occurrence of saline water in the borehole because of pumping was studied by electric conductivity (EC) measurements.

The field work was conducted by PRG-Tec Oy. 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. Borehole KLX02 in Laxemar has also been measured using the Posiva Flow Log /Rouhiainen, 2000/.

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 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 and detailed flow logging modes. The normal mode is used for determination of hydraulic conductivity and head /Öhberg and Rouhiainen, 2000/. The detailed mode is mostly used to determine the exact location of hydraulically conductive fractures and to classify them by flow rates.

In the normal mode, the flow rate is measured by thermal pulse and thermal dilution method. In the detailed mode, only thermal dilution method is used. The thermal pulse and thermal dilution methods have to be calibrated to known flow rates. The flow rates for calibration are measured by a weighing machine. The points obtained by calibration are plotted on the scale where y-axis is flow rate and x-axis is transfer time (thermal pulse) or increase of temperature (thermal dilution). A calibration function is fitted to these points. In both cases these functions are the form of:

$$Y = a\times\exp(-b\times X)+c\times\exp(-d\times X)+e\times\exp(-f\times X)+... ,$$

where a, b, c … are chosen for the best fit to the calibration points.

The flow sensor was originally calibrated on November 10, 2000. The calibration was checked on January 26, 2001. The calibration functions were not changed on the basis of this checking.

The EC electrode was calibrated on November 10, 2000 to known concentrations of NaCl.

The detailed flow logging was used in this study. It was used while the borehole was pumped. The length of the test section was 5 m in this study and the spacing between two sequential test sections was 0.5 m. The observed flow anomalies were double-checked using a 0.5 m long test section and a spacing of 0.1 m.

Electric conductivity (EC) of borehole water was measured before and after detailed flow logging while the borehole was at rest (no pumping). The occurrence of saline water in the borehole was monitored using the EC measurements.

For the measurement of EC from fracture-specific water, the borehole is pumped so that the flow direction is always from the fractures into the borehole. Both electric conductivity and temperature of flowing water from the fractures are measured /Rouhiainen, 1999/. In this study fracture specific water was measured at some depths.

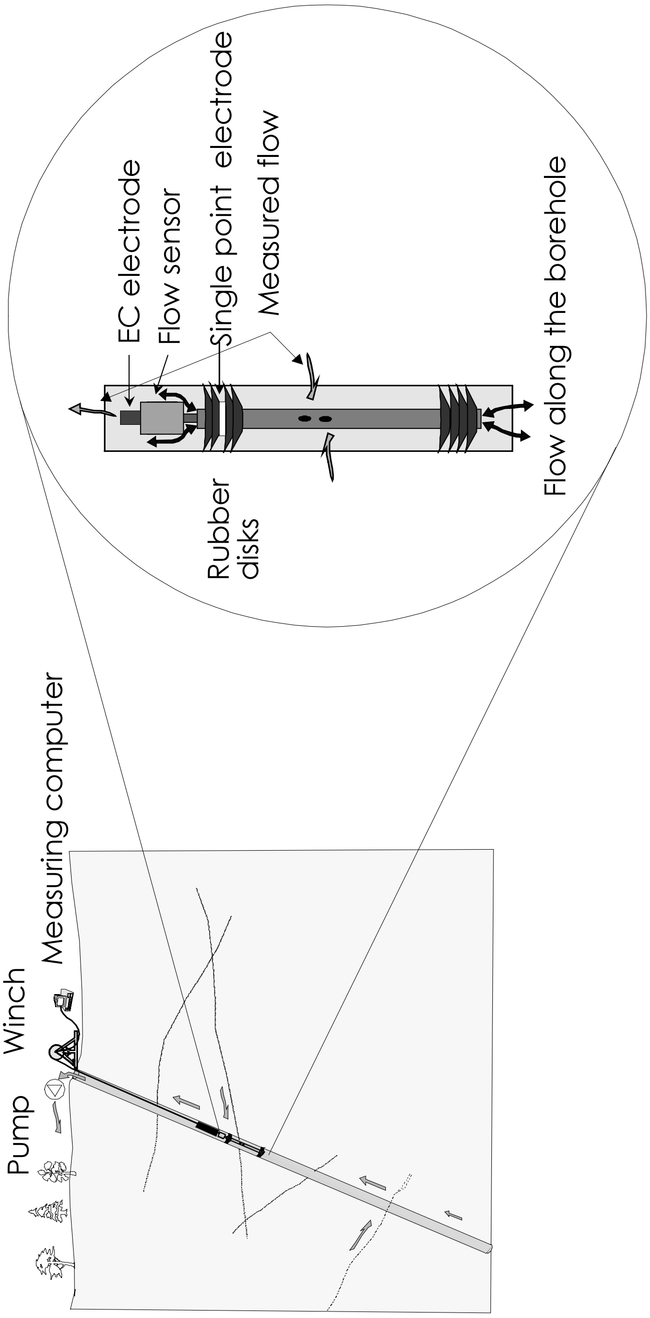

Figure 2-1. *Schematic of the downhole equipment used in the Difference flowmeter.*

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 sensitive method is used for high resolution depth determination of fractures and geological structures. In this study it was also used for detection of the depth marks drilled on the wall of the borehole.

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 and Pöllänen, 1998/.

Type of instrument:	Posiva Flow Log/Difference Flowmeter
Borehole diameters:	56 mm, 66 mm and 76 mm.
Length of test section:	A variable length flow guide is used.
Method of flow measurement:	Thermal pulse and/or thermal dilution.
Range 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
Software	Based on MS Visual Basic
Total power consumption:	1.5–2.5 kW depending on the pumps
Calibrated	January 2001
Method of calibration	Field calibration unit
Calibration of cable	Using depth marks in the borehole

4 Results

4.1 Field work

The field work was done in the borehole KOV01 in February and March 2001. The activity schedule is presented in Table 4-1. Electric conductivity of borehole water was first measured while the borehole was at rest (no pumping). Pumping was then started again and the detailed flow logging was carried out (section length 5 m, step 0.5 m) between 100–1000 m depth.

Depth marks had been previously drilled on the borehole wall. They were measured using a caliper tool connected to the cable of the flowmeter.

The detailed flow logging was then continued, i.e. the previously measured flow anomalies were double checked with 0.5 m section length and 0.1 m step. The tool got stuck during this measurement. Pumping was stopped for three days. During this time groundwater recovery was measured.

After the tool was unfastened a second set of borehole EC was measured during lifting. Pumping was then started again and the detailed flow logging with the shorter section length was finished.

Table 4-1. Detailed flow logging and testing in KOV01. Activity schedule.

Started		Finished		Activity
27.2.2001	*7:30*	27.2.2001	*16:00*	Borehole EC without pumping.
28.2.2001	*10:40*	1.3.2001	*19:00*	Detailed flow logging (section 5 m, step 0.5 m) 100–1000 m.
2.3.2001	*13:00*	2.3.2001	*15:00*	Depth calibration of the logging cable.
3.3.2001	*12:30*	4.3.2001	*8:30*	Detailed flow logging (section 0.5 m, step 0.1 m) 650–680 m and 750–931 m. The tool got stuck during lifting at the depth of 916.4 m.
4.3.2001	*13:10*	6.3.2001	*11:40*	Groundwater recovery measurements.
5.3.2001	*7:00*	7.3.2001	*9:30*	Rescue operation.
7.3.2001	*9:30*	7.3.2001	*15:30*	Borehole EC without pumping during lifting.
7.3.2001	*17:40*	8.3.2001	*14:00*	Detailed flow logging (section 0.5 m, step 0.1 m) 102–227 m and 387–470 m.

4.2 Electric conductivity

4.2.1 Borehole EC

Borehole EC was first measured before pumping the borehole both downwards and upwards, see Appendix 2.1. After the rescue operation borehole EC was measured a second time, see Appendix 2.1. These two measurements were carried out while the borehole was at rest (no pumping), although the borehole had been pumped several days prior to the second measurement, see Table 4-1.

Another difference between the two measurements was that the first set of measurements was carried out without the lower rubber disks while the second measurement was done with the lower rubber disks in place. The measuring geometry in the first measurement is much more representative to borehole water since the flow guide in its normal configuration (with both upper and lower rubber disks) may carry water with it making the results less representative, especially if the section length is long.

Temperature of borehole water was measured during the EC measurements. The EC values are temperature corrected to 25 °C to make them more comparable with other EC measurements.

Borehole EC (Appendix 2.1 triangles) is between 0.5–0.6 S/m above 140 m where there is a transition zone to about 2 S/m. There is a large fresh water anomaly between about 800 and 900 m. It is unlikely that this represent water condition in the bedrock at this depth. The borehole was flushed with fresh water during the drilling and these EC measurements were carried out as a first measurement after drilling. There were no clear flowing fractures below the depth of 660 m, see Appendix 1. Flushing water can stay a long time at the bottom of an impermeable borehole.

Borehole EC measurements were repeated after pumping period (four days) and non pumping period (three days), see Appendix 2.1 crosses. As mentioned earlier, this measurement is not as reliable as the previously done because both upper and lower rubber disks were used. However some changes compared with the earlier EC results can be seen. The bottom of the borehole (below 450 m) is more saline although the fresh water anomaly is still visible. There is a large fresh water anomaly between 100 m and 170 m. Fresh water had probably entered into the borehole from the fractures at the depth of 137.9 m, 146.0 m and 151.6 m, see Appendices 1.2 and 1.3.

4.2.2 Fracture specific EC

EC was measured also during the detailed flow logging. The results of these measurements are presented in Appendix 2.2. “Noise” in the results is caused by the flow guide carrying water with it along the borehole since both upper and lower rubber disks were used. This geometry is not good for measurement of borehole water but it is well adapted to measurement of fracture specific water.

For measurement of fracture specific EC, the flow guide is stopped on a flowing fracture. The target fracture can be found on the basis of the measured flow rate. Flow rate determines also measuring time on a given fracture. EC measuring time is usually chosen so that the water volume within the section was flushed at least three times. The minimum measuring time, 700 seconds, was in this case enough to fulfil this criteria.

Electric conductivity of fracture-specific water was measured from selected fractures at the depths of 658.07 m, 445.93 m, 145.97 m, 145.57 m and 137.47 m. The last point in these measurements is the most representative result of fracture specific water, black crosses in Appendix 2.2. EC from the deepest fracture (658.07 m) is slightly more saline than the borehole water at the same depth while the rest fracture specific waters are less saline than borehole water at the same depth.

EC transients as a function of time at these depths are presented in Appendices 3.1–3.2. The result at the depth of 146.97 m is more noisy than results at the other depths. Gas bubbles in measured water is a probable reason of noise.

4.3 Temperature of borehole water

Temperature of borehole water was measured simultaneously with the EC measurements. The temperature results in Appendix 4 correspond to the EC results in Appendix 2.1. The three temperature results are similar except some dependence on the direction of measurement, especially above 50 m. The tool contains steel parts that can carry heat when moving along the borehole.

4.4 Detailed flow logging

The detailed flow logging was performed with a 5 m section length and with 0.5 m depth increments, see Appendices 1.1–1.45. The method gives the depth and the thickness of the conductive zones with a depth resolution of 0.5 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 detailed flow logging was repeated in the vicinity of identified flow anomalies using a 0.5 m long test section and a spacing of 0.1 m.

The depths of flowing fractures are marked with lines in the appendices of the detailed flow logs. Long line represents the depth of a leaky fracture, short line denotes that the existence of a leaky fracture is uncertain.

There was an increased noise level during detailed flow logging in some part of borehole. Some small flows may be missing because of the increased noise level. One possible reason for the increased noise level is gas. The noise level may also increase if the water contains small solid particles like drilling cuttings.

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.

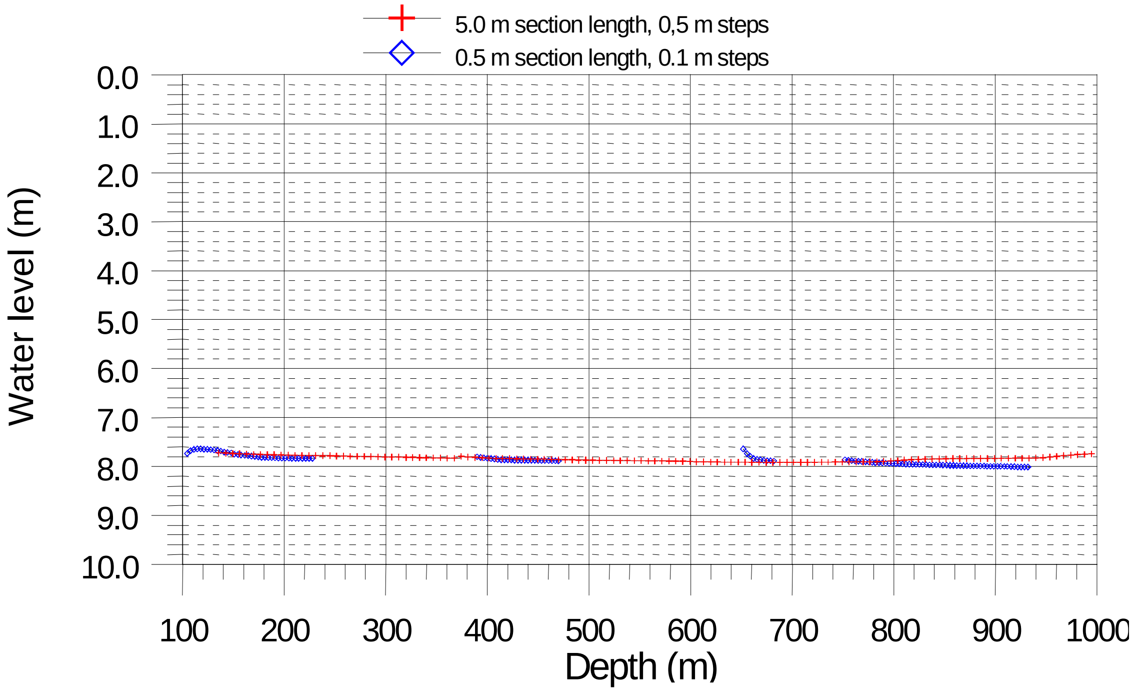

Figure 4-1. *Water level in the borehole during the detailed flow logging (vertical depth below zero depth).*

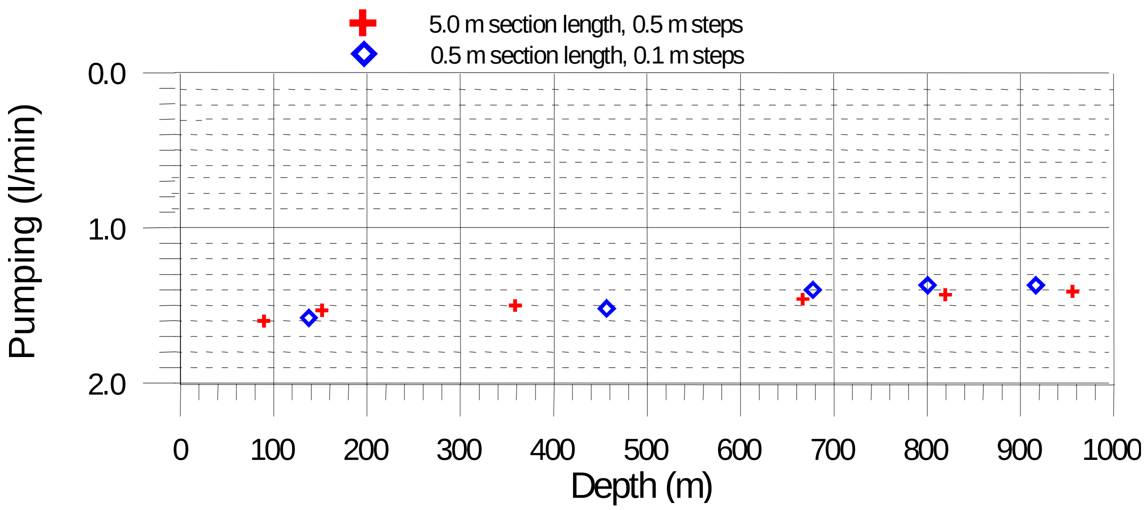

Figure 4-2. *Pumping rates during the detailed flow logging.*

There is a level difference between the two detailed flow loggings. At some depths resistance of 5 m measurement is larger than resistance of 0.5 m measurement. Level of single point resistance depends among others on EC of borehole water. This seems to explain the difference, see Appendix 2.2.

Water level in the borehole during the detailed flow logging (during pumping) is presented in Figure 4-1. Zero depth is the same reference level as in all other depth scales. The undisturbed water level is a little higher than zero depth, see the recovery curve, Appendix 5. The aim was to keep drawdown constant during the flow measurements.

Pumping rate was measured, see Figure 4-2. It showed a decreasing trend from the beginning of each pumping period, changing from about 1.6 l/min to 1.4 l/min. This can be compared with the summed up flow result from of detailed flow measurements from the entire borehole. The sum is about 1.3 l/min.

4.5 Groundwater recovery

Groundwater recovery was measured during the rescue operation. Results of these measurements are presented in Appendix 5-1.

4.6 Depth calibration

Depth marks were drilled in the borehole for depth calibration of various logging tools. The depth marks in the borehole make it possible very accurate correction because the cable can be calibrated in the borehole to be measured.

Each mark includes two 20 mm wide tracks on the borehole wall. Distance between the tracks is 100 mm. The upper track of these two represents the reference level.

Depth marks were logged using a caliper probe provided by SKB. The caliper tool was attached to the flowmeter cable. The depth marks were clearly visible in the caliper results, see Appendices 6.1–6.12. Only the results near the borehole depth marks are presented.

During the caliper logging, water leaked between the cable head and the cable connector of the caliper probe. Because of that signal level decreased below 238 m during the caliper measurements, see Appendix 6.

Depth marks can also be seen in single point resistance results of the flowmeter. Results of these measurements are presented in Appendices 6.1–6.12. These results were chosen for the basis of flowmeter depth calibration because they were made during the flow measurement. Cable tension is therefore more correct than during the caliper measurement that was a separate measurement without the flowmeter tool.

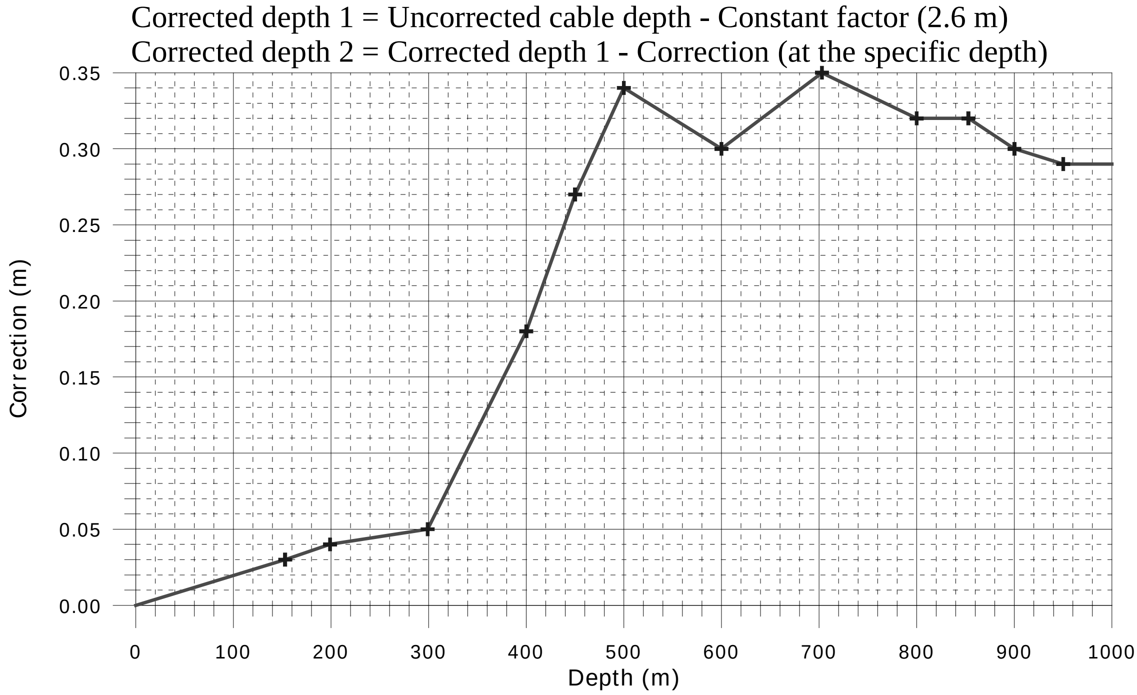

Figure 4-3. *Depth correction using depth marks in the borehole.*

Single point resistance tool sees a low resistance when one of the upper rubber disks hits a depth mark track. There are four rubber disks at the upper end of the section. The single point electrode is between the two middle rubber disks.

The depth reference is the upper end of the section that is the same as the lowest one of the four upper rubber disks. The point where the lowest rubber disks hits the upper one of the two tracks is presented as a line in Appendices 6.1–6.12.

The first borehole depth mark is at the depth of 153 m. The flowmeter sees it at the depth of 153.03 m, see Appendix 6.1. The error or correction at this depth is then 0.03 m, see Figure 4-3. The correction in Figure 4-3 shows the error that is left after normal depth correction ("Corrected depth 1"). All other points in Figure 4-3 are obtained in the same way.

Cable depth of the flowmeter is based on depth marks attached on the cable. An optical sensor at the winch can detect these cable marks. A cable counter is used for depth measurement between the cable marks.

"Corrected depth 1" is the normal correction that takes into account the distance from the winch to the depth reference and a constant factor (2.6 m) that is the distance from the cable zero reference to the upper end to the test section.

"Corrected depth 2" can be calculated by subtracting the correction from "Corrected depth 1". "Corrected depth 2" is then the final, borehole depth mark corrected depth.

Corrections between the borehole depth marks were obtained for each depth by linear interpolation.

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 for groundwater sampling. Measurements were done during pumping using 5 m section length with 0.5 m depth increments. Measurements were also carried out using 0.5 m section length with 0.1 m depth increments over flow anomalies. The movement of saline water in the borehole was followed by electric conductivity measurements.

The measurements were performed right after drilling. The detailed flow logging was used because it is fast way to find out base information of flowing fractures. On the basis of these measurements there are only a few flowing fractures in the borehole KOV01. The movement of saline water was small.

Depth calibration was made using depth marks in the borehole. Depth marks can be seen from single point resistance results of flowmeter. Depth correction can be done very exactly because single point resistance was measured at the same time as the flow measurements.

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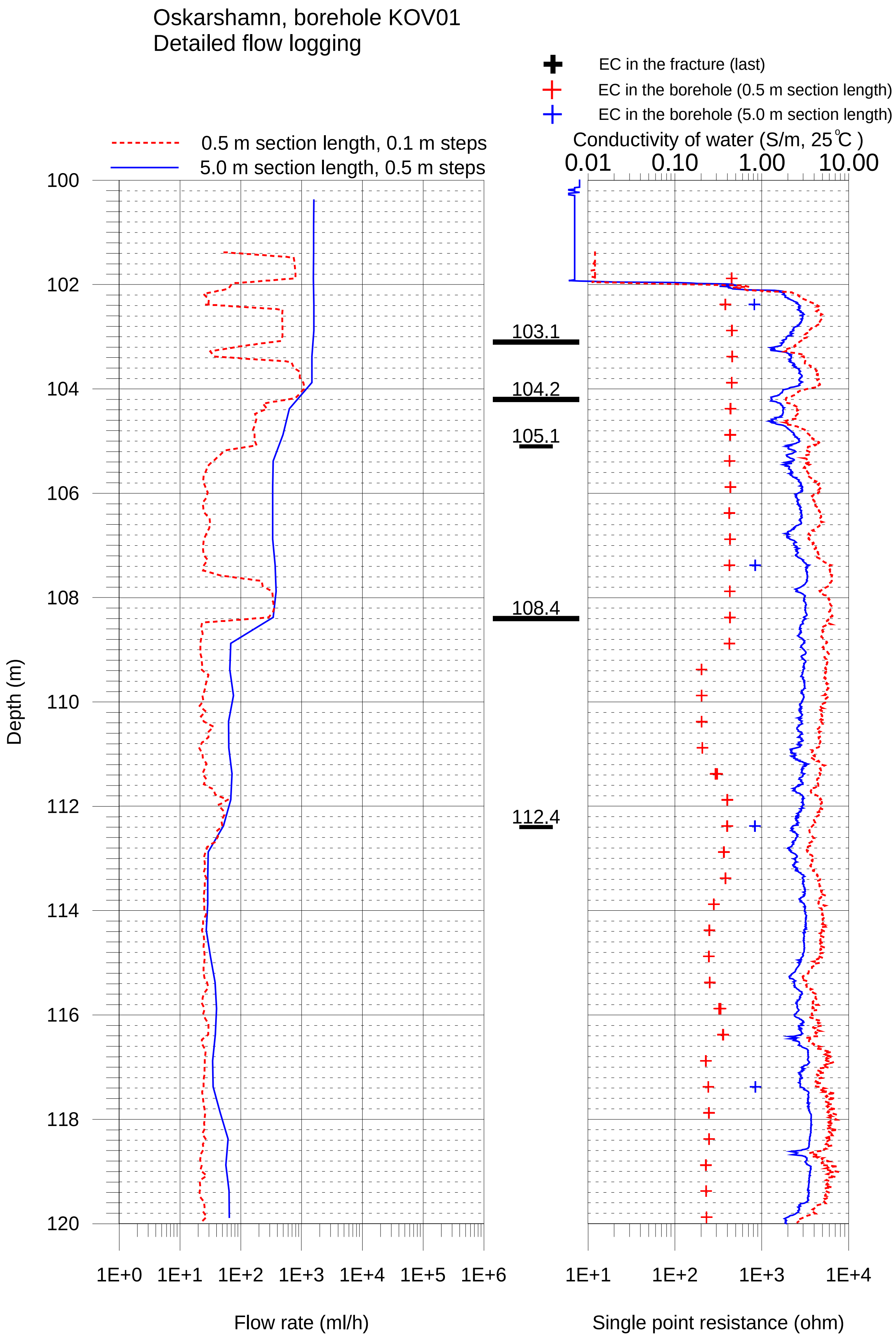
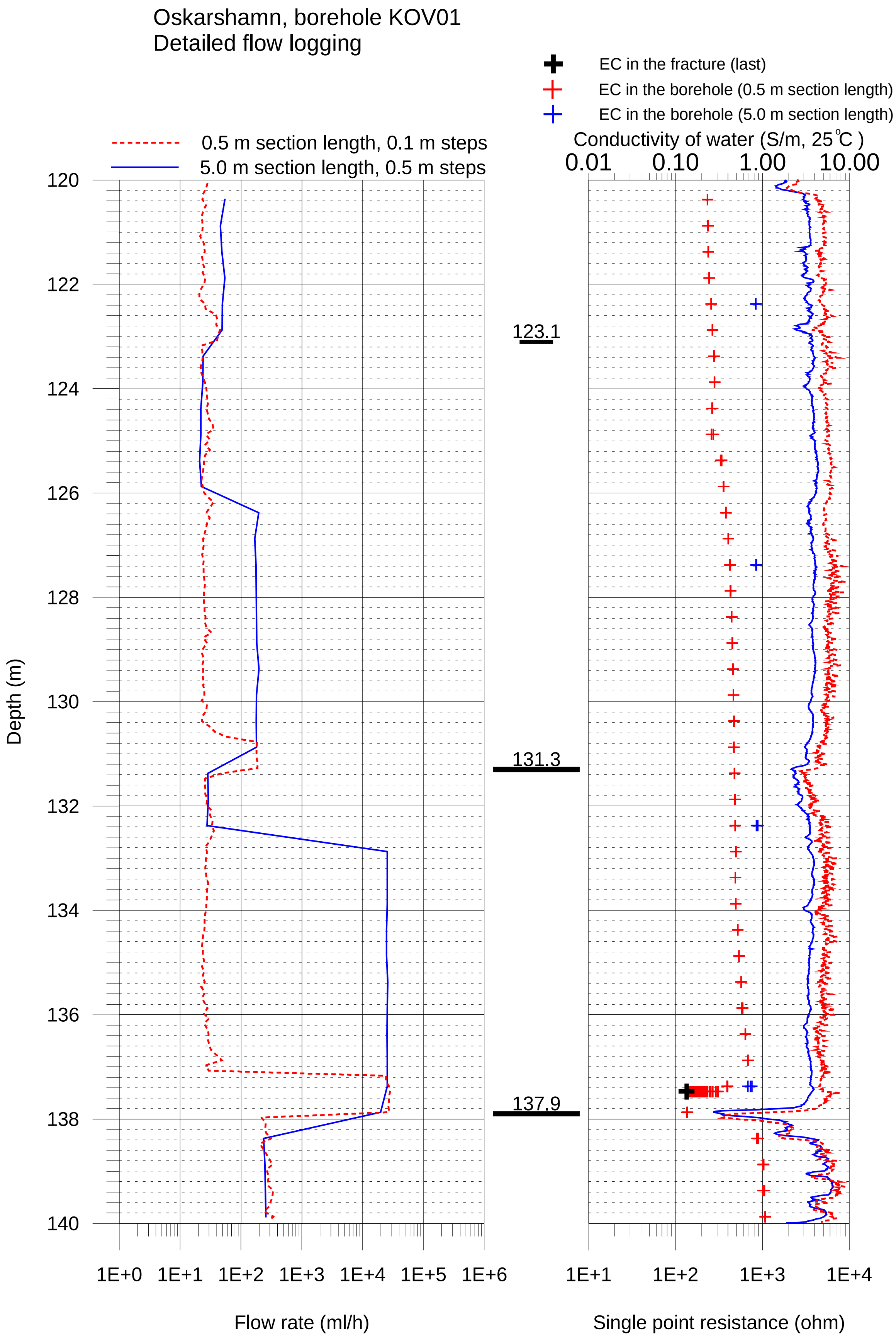
Appendices


Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01 0.10 1.00 10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Depth (m)
100
102
104
106
108
110
112
114
116
118
120
103.1
104.2
105.1
108.4
112.4
1E+0 1E+1 1E+2 1E+3 1E+4 1E+5 1E+6
Flow rate (ml/h)
1E+1 1E+2 1E+3 1E+4
Single point resistance (ohm)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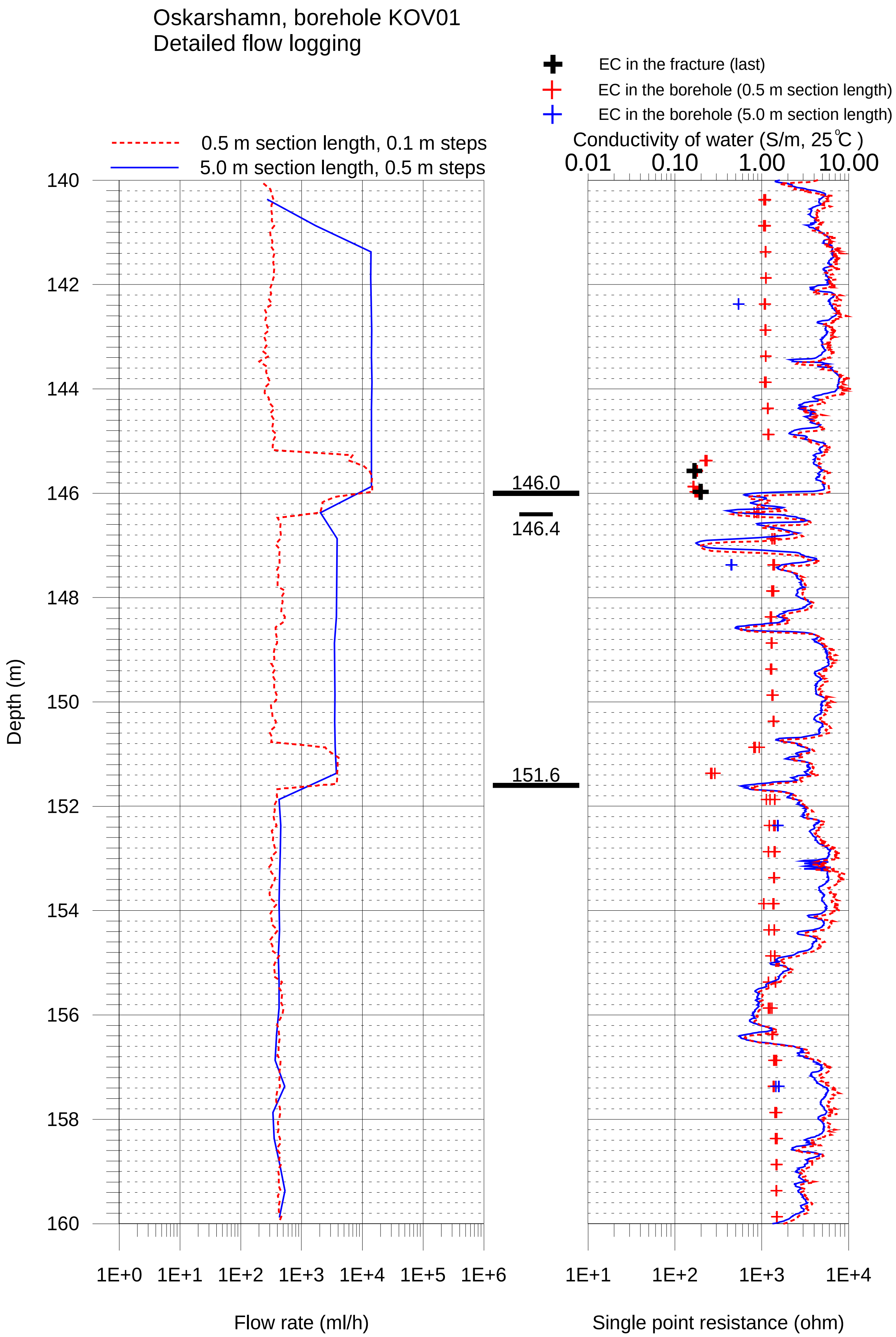
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Conductivity of water (S/m, 25°C)
0.01
0.10
1.00
10.00
120
122
124
126
128
130
132
134
136
138
140
Depth (m)
123.1
131.3
137.9
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)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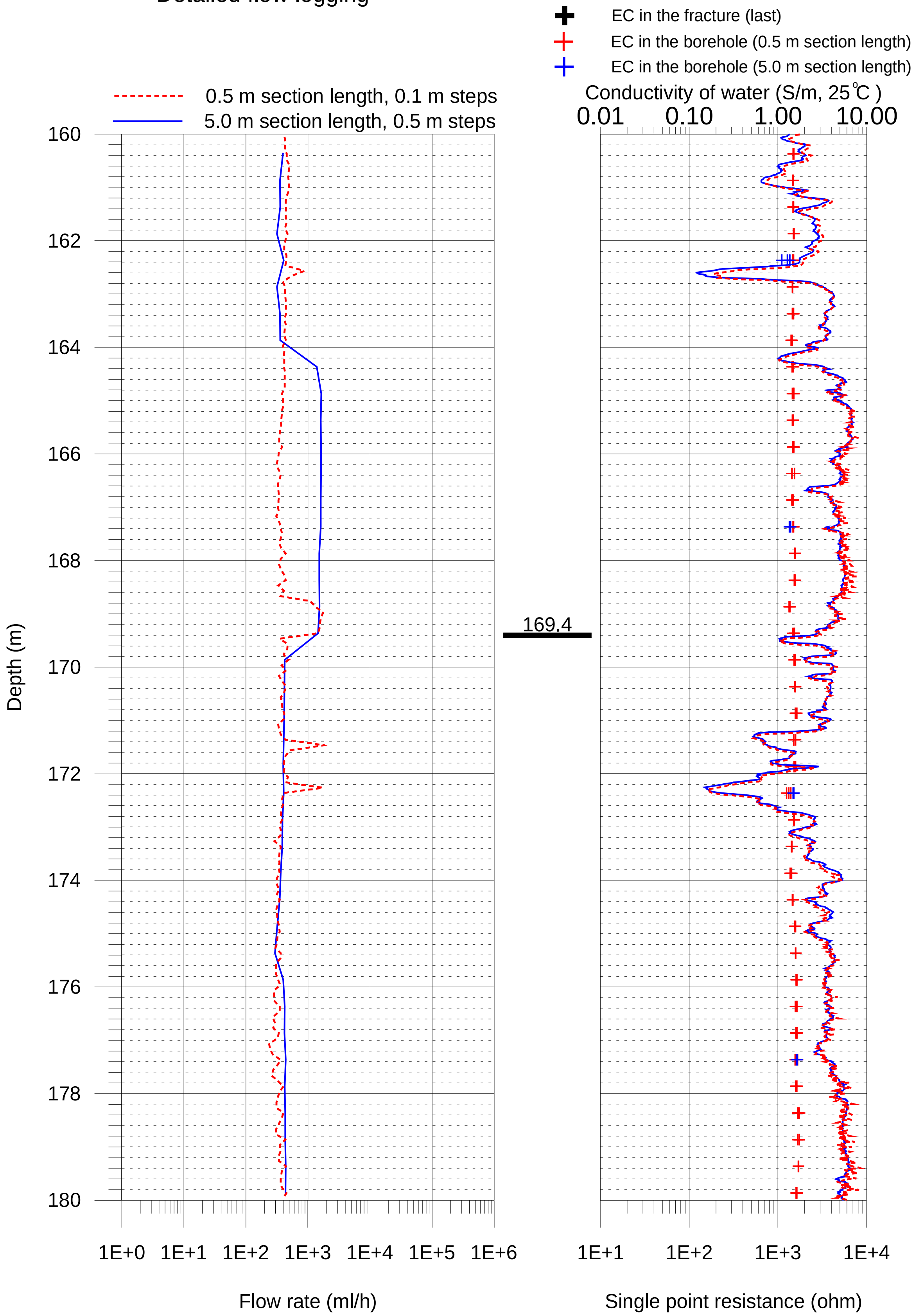
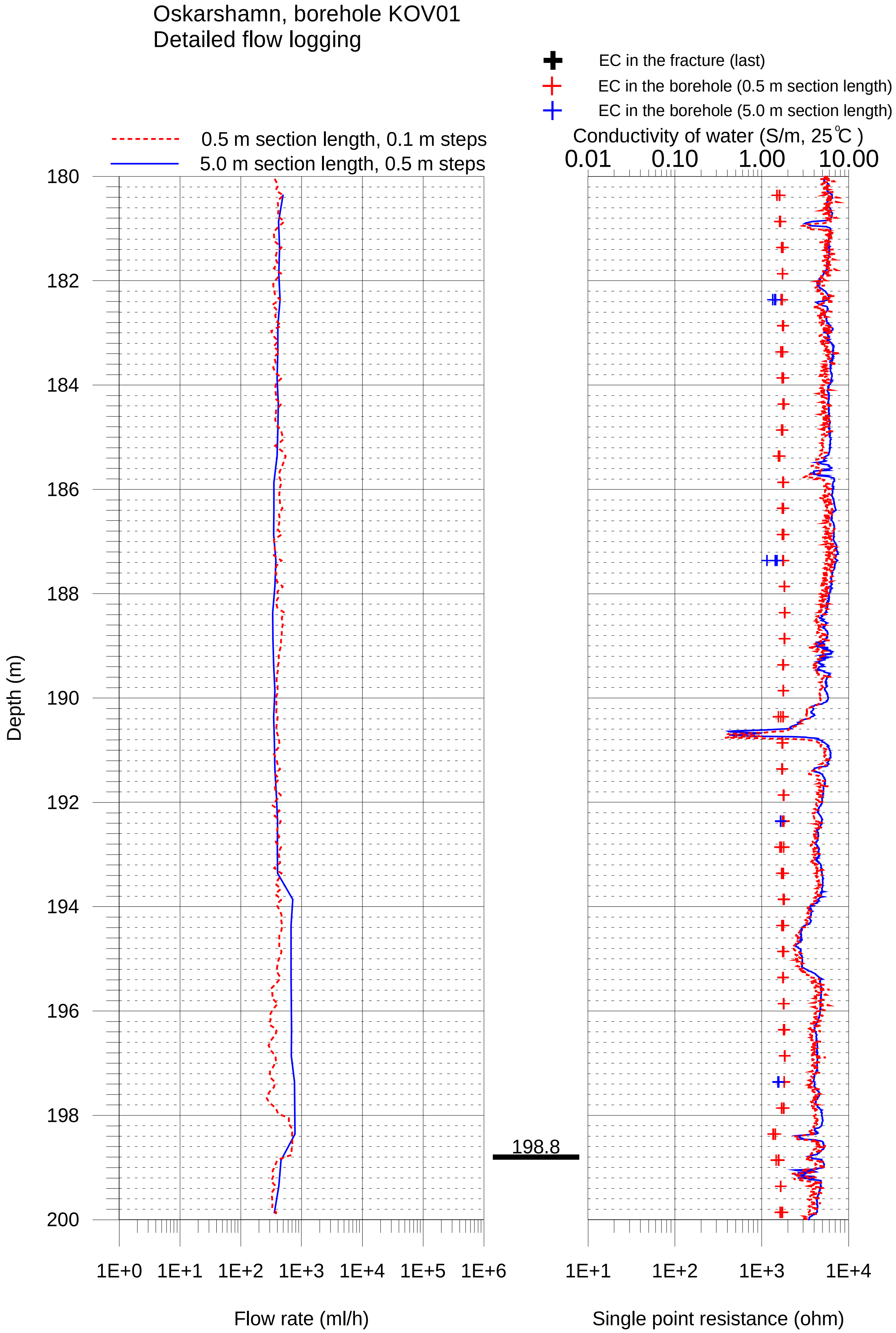
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
140
142
144
146
148
150
152
154
156
158
160
146.0
146.4
151.6
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

Oskarshamn, borehole KOV01
Detailed flow logging

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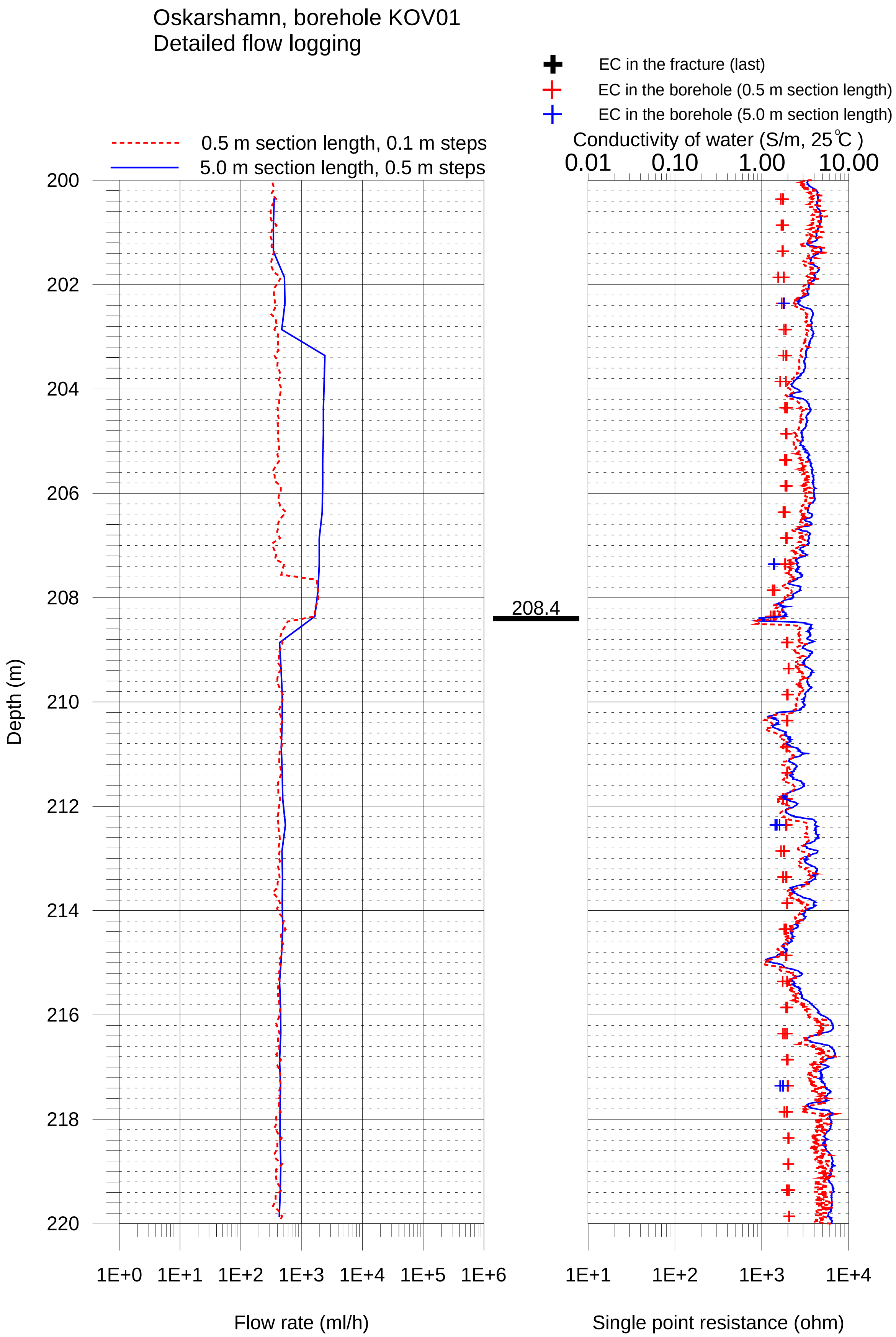
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
180
182
184
186
188
190
192
194
196
198
200
198.8
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)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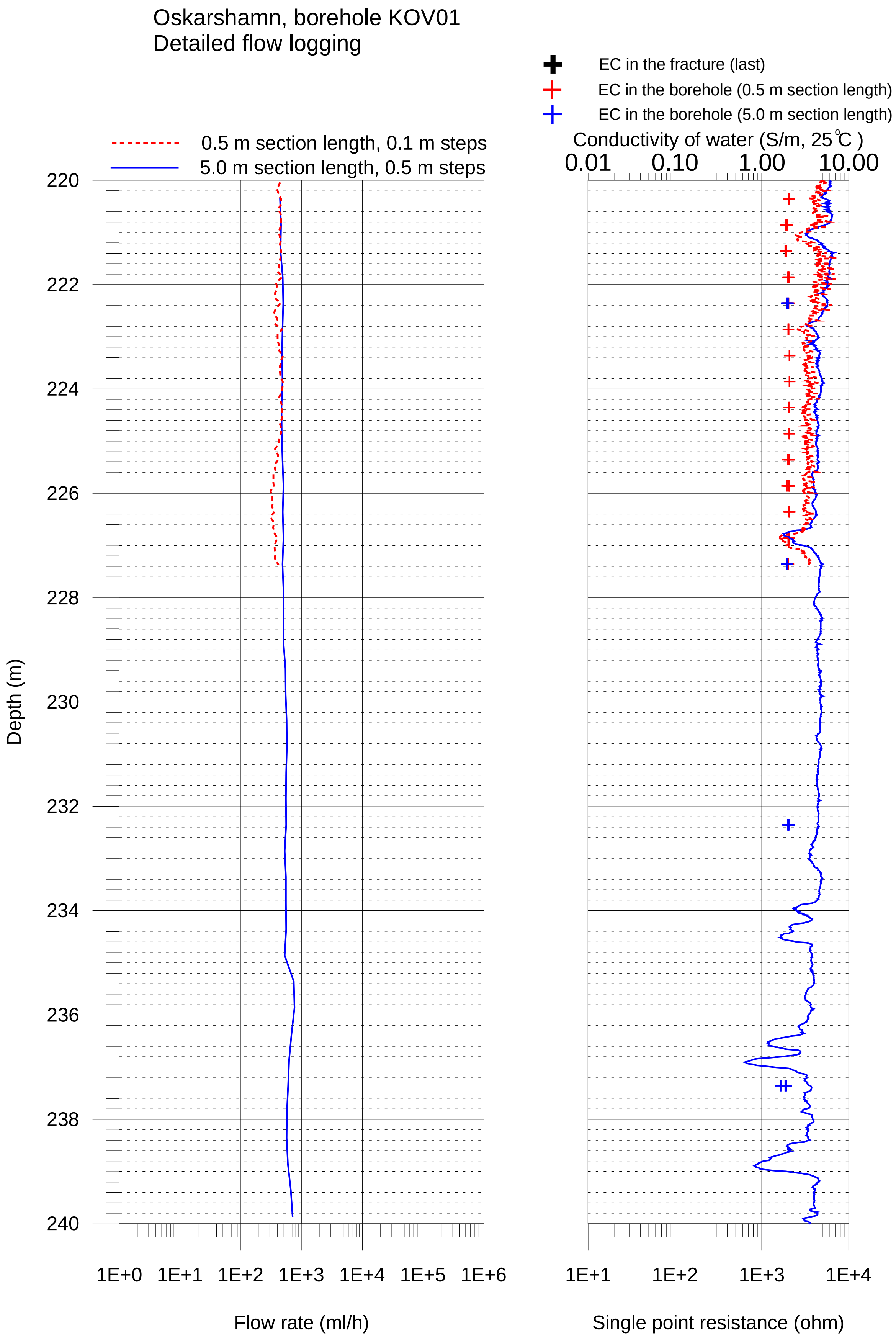
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
200
202
204
206
208
210
212
214
216
218
220
Depth (m)
208.4
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)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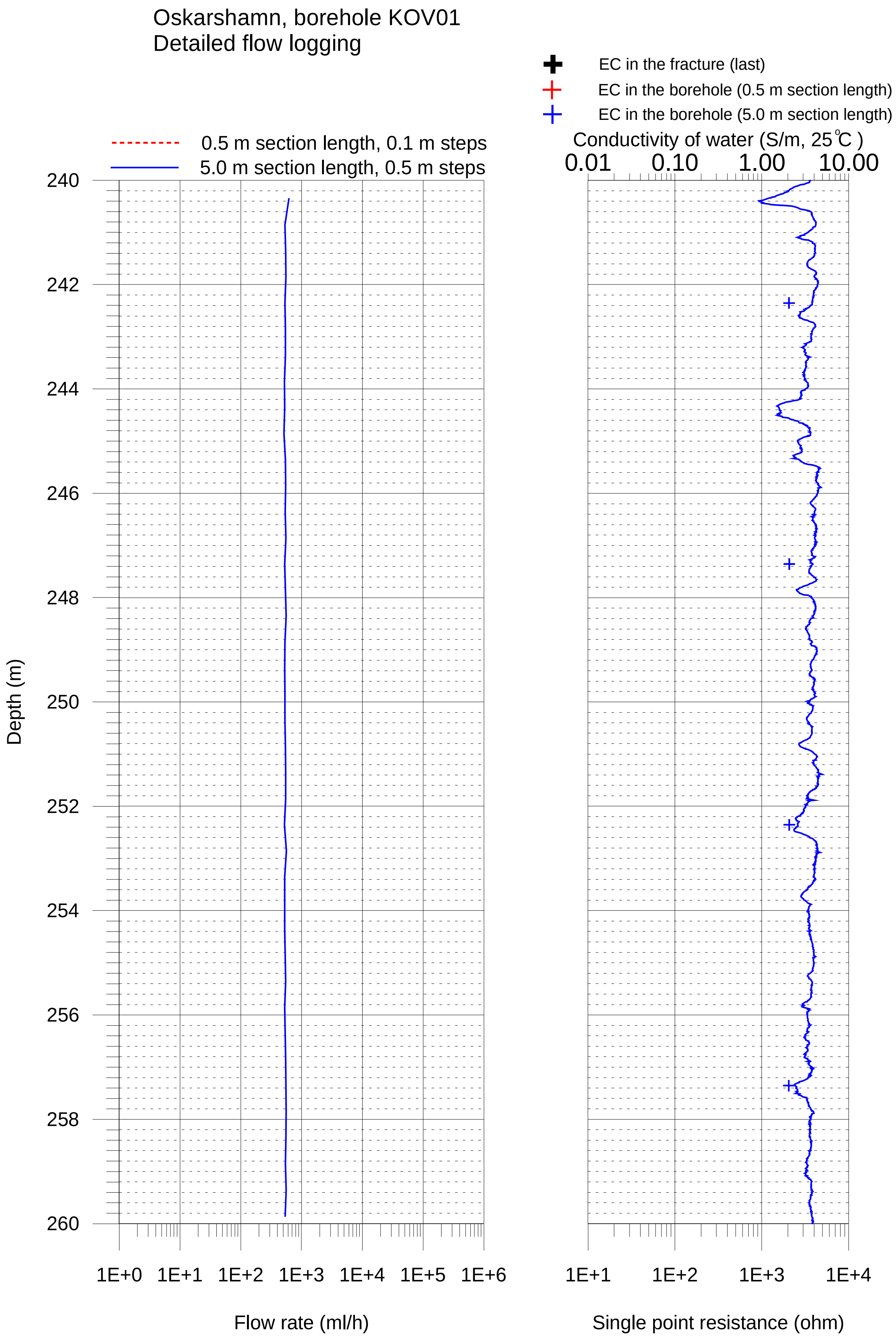
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
220
222
224
226
228
230
232
234
236
238
240
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)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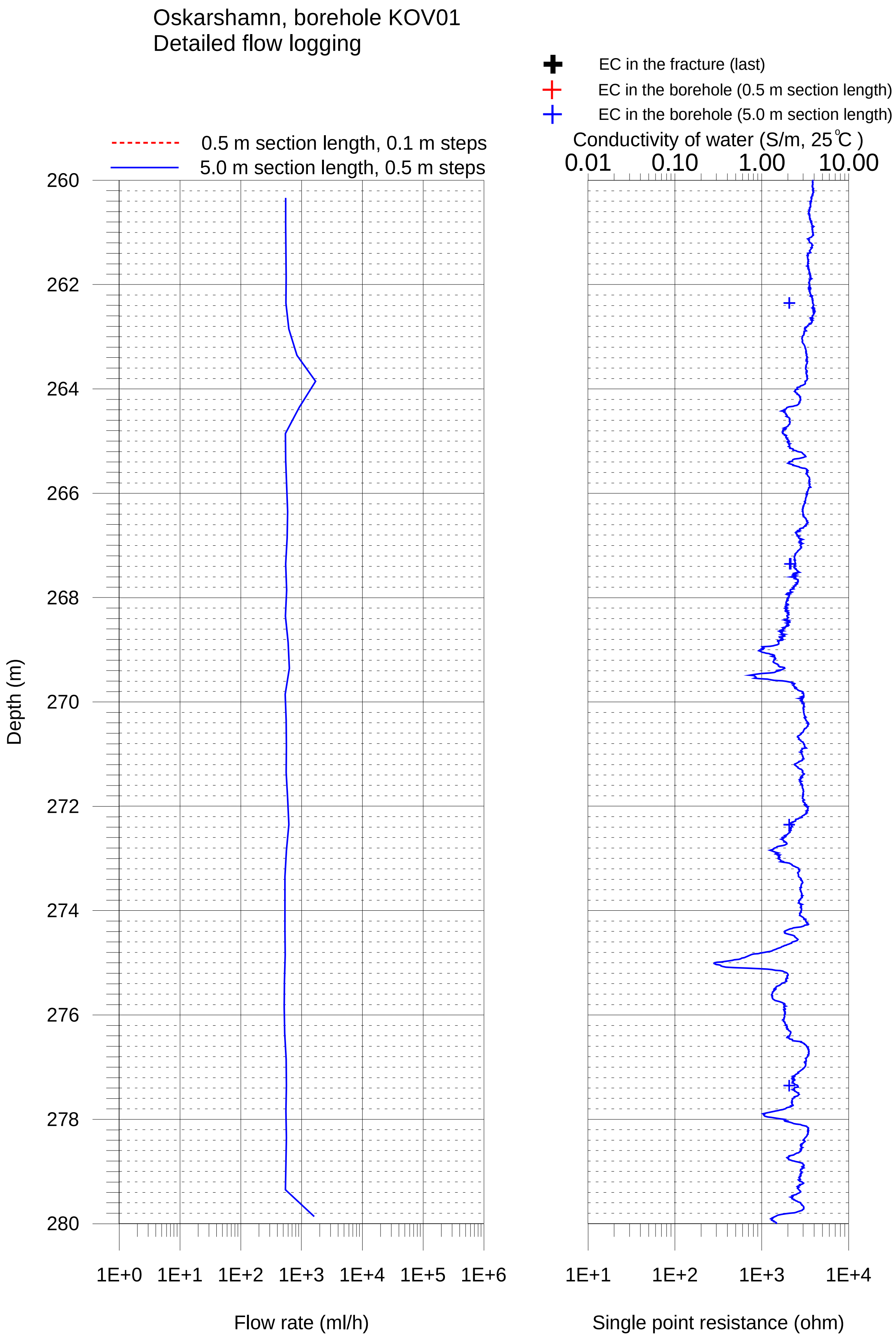
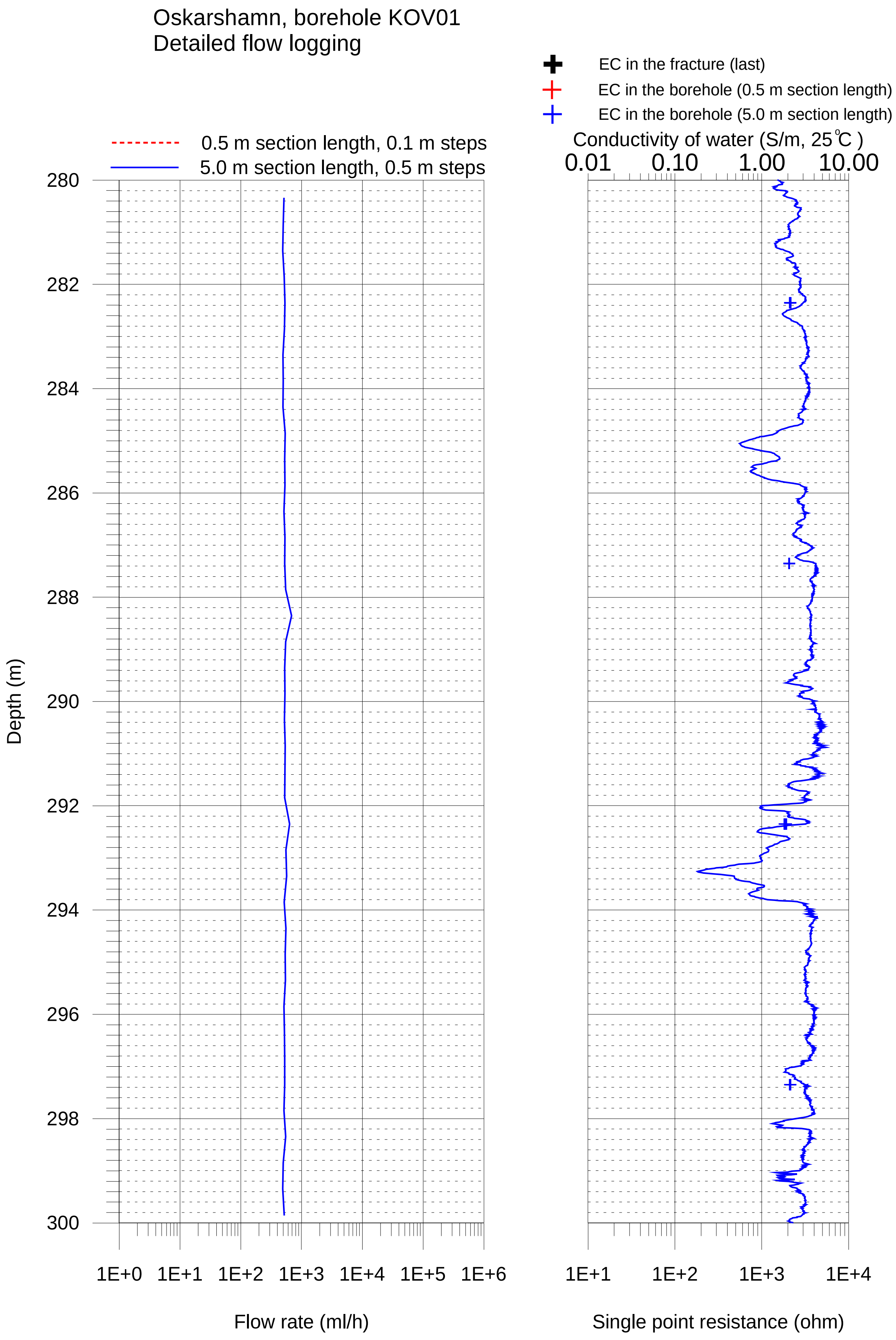
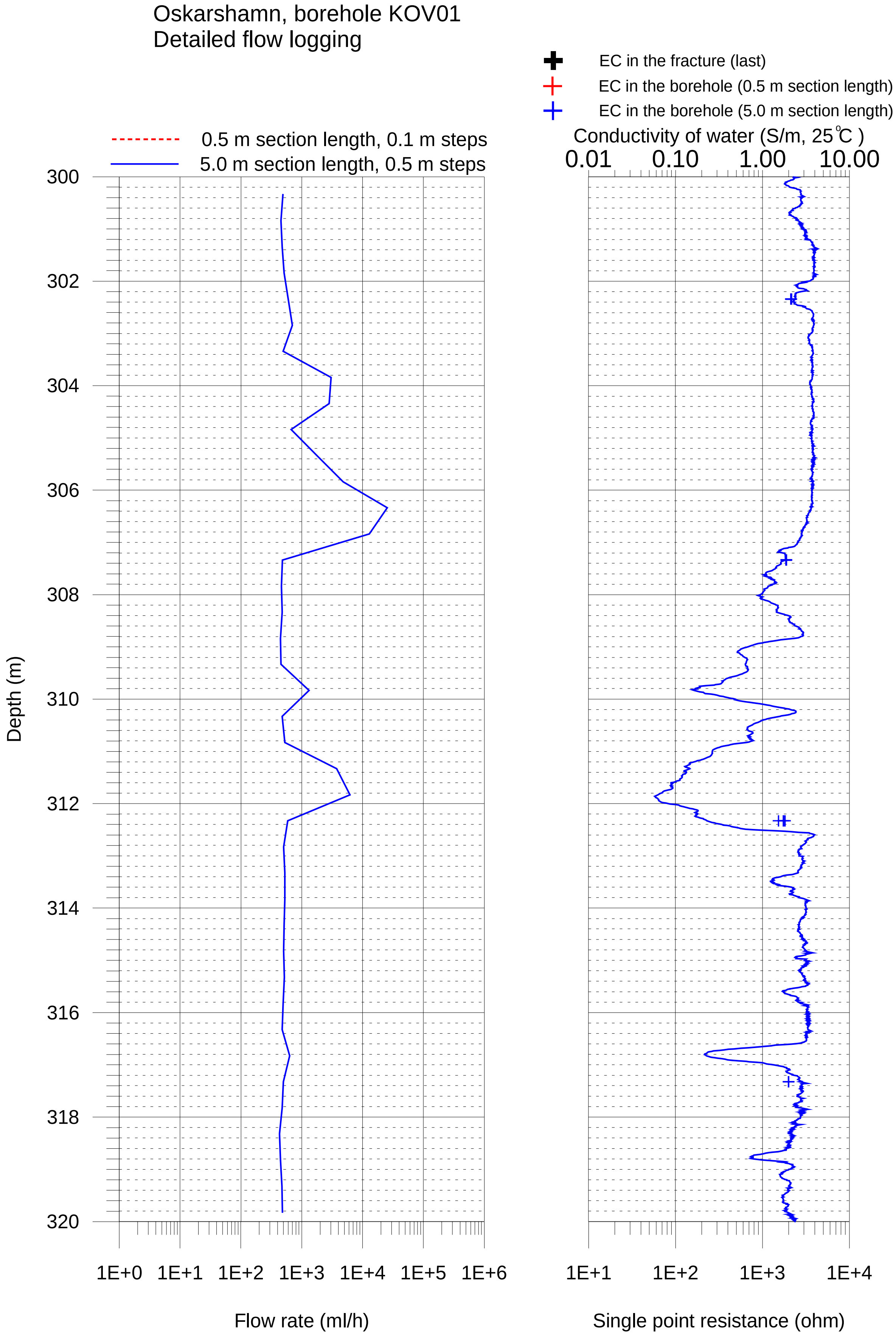
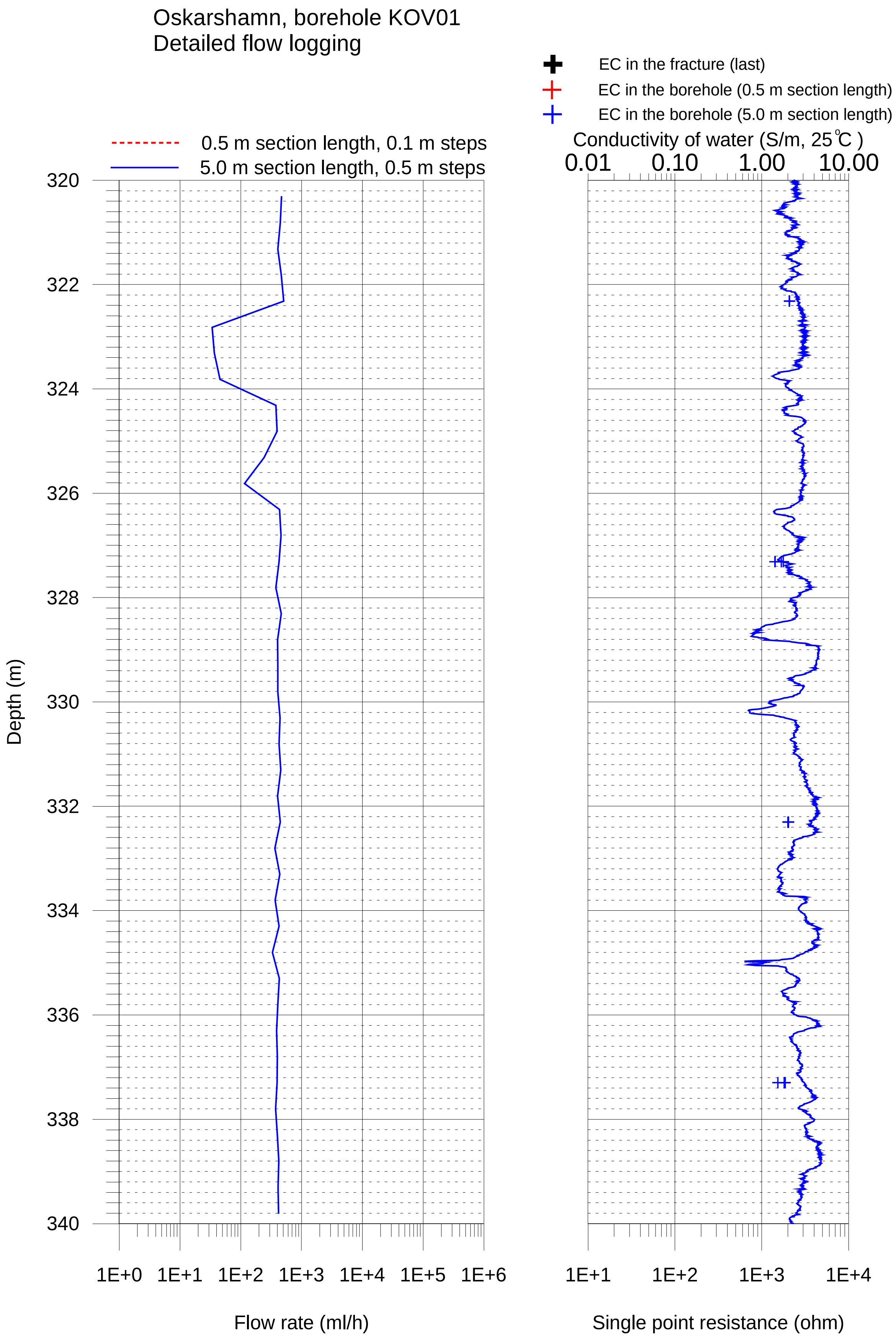
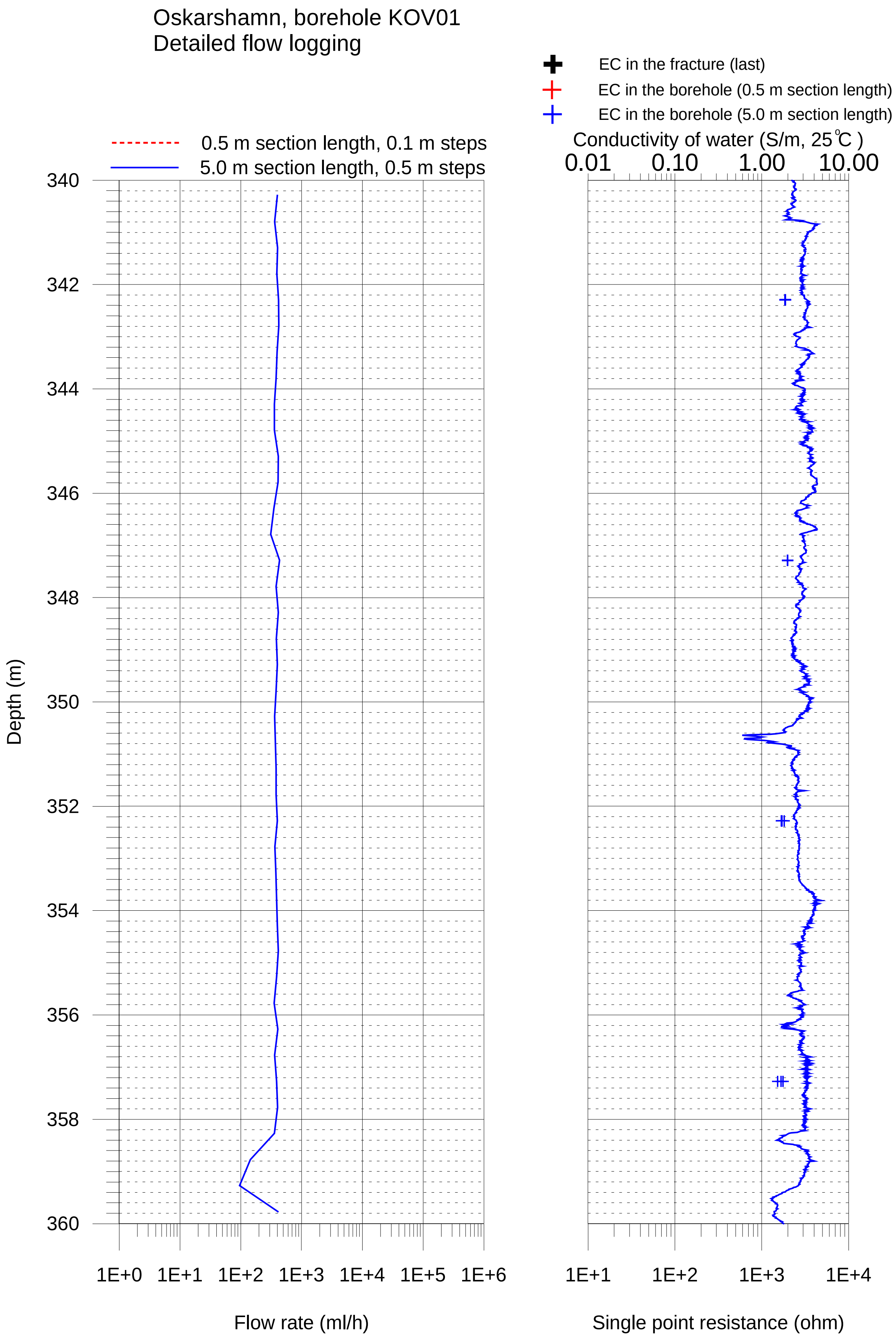
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
240
242
244
246
248
250
252
254
256
258
260
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

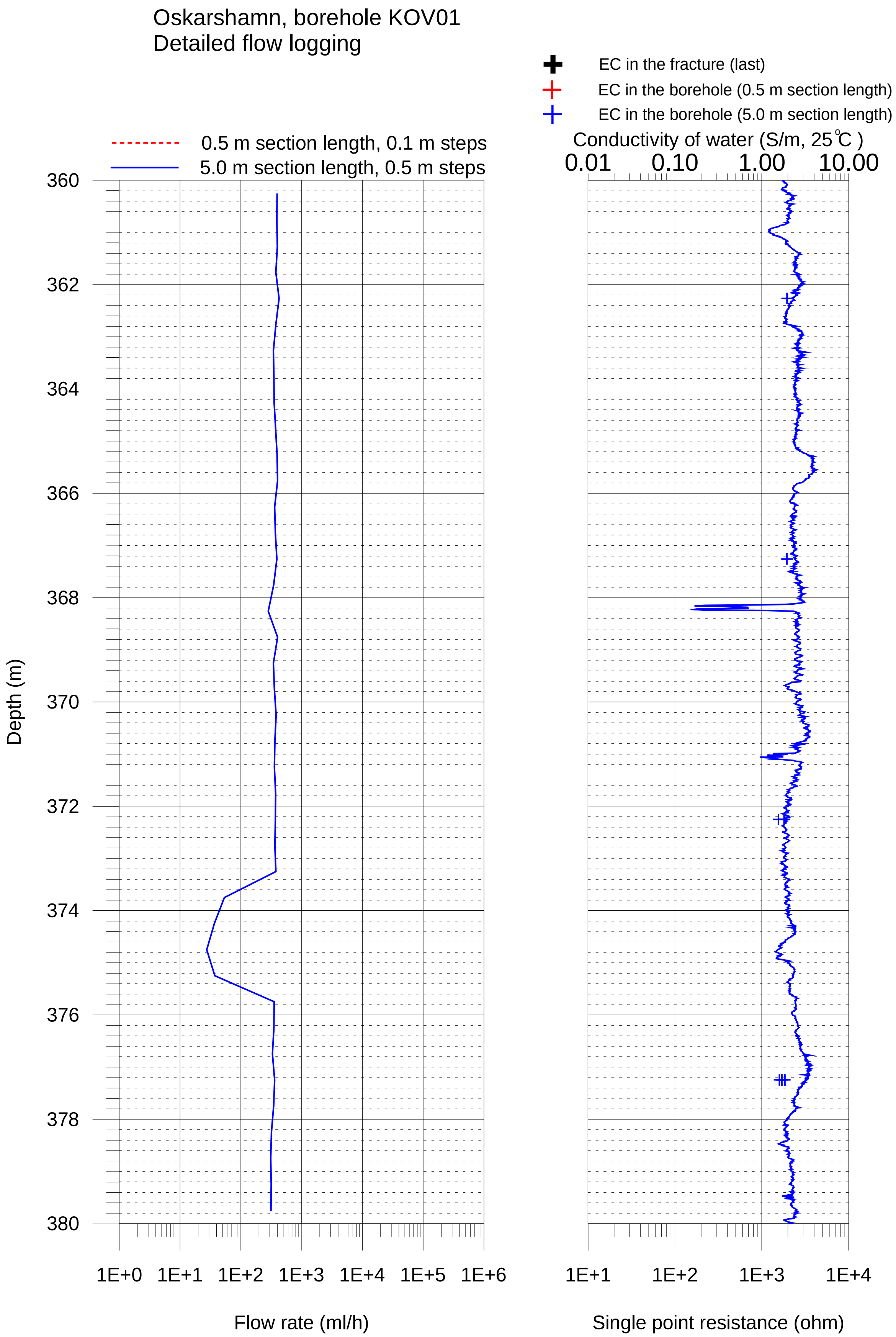

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
260
262
264
266
268
270
272
274
276
278
280
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

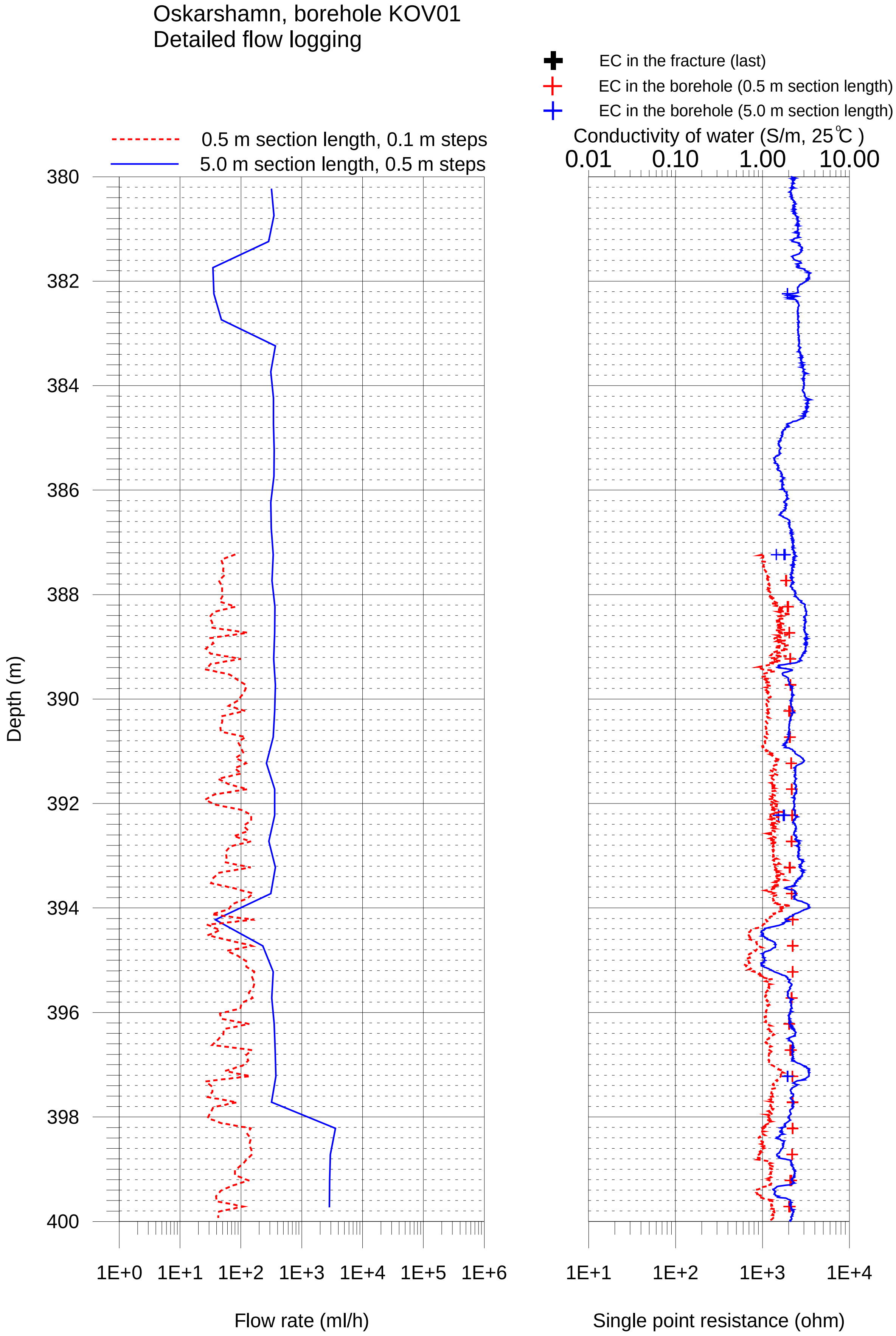

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
280
282
284
286
288
290
292
294
296
298
300
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)


Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Depth (m)
300
302
304
306
308
310
312
314
316
318
320
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

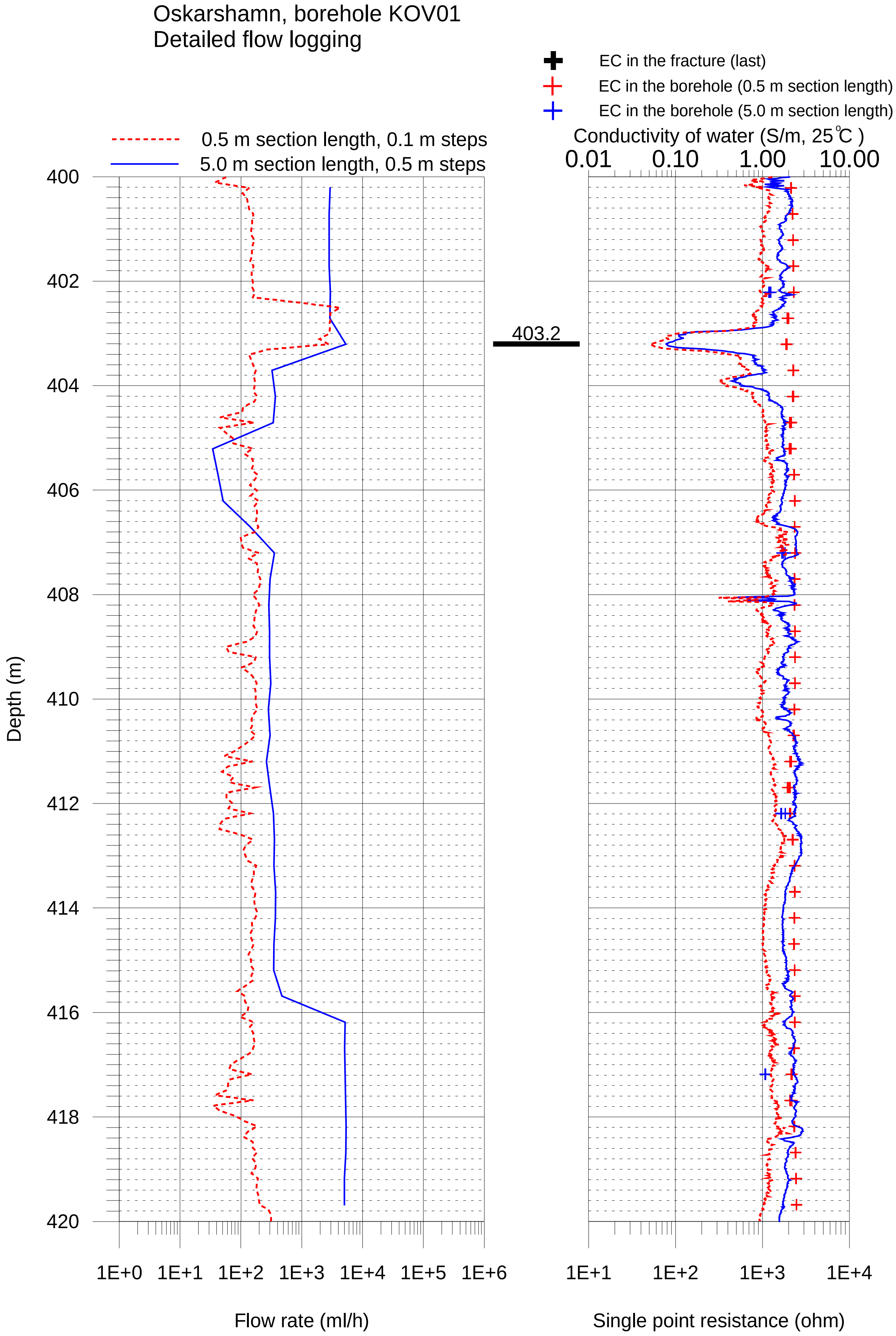

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
320
322
324
326
328
330
332
334
336
338
340
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

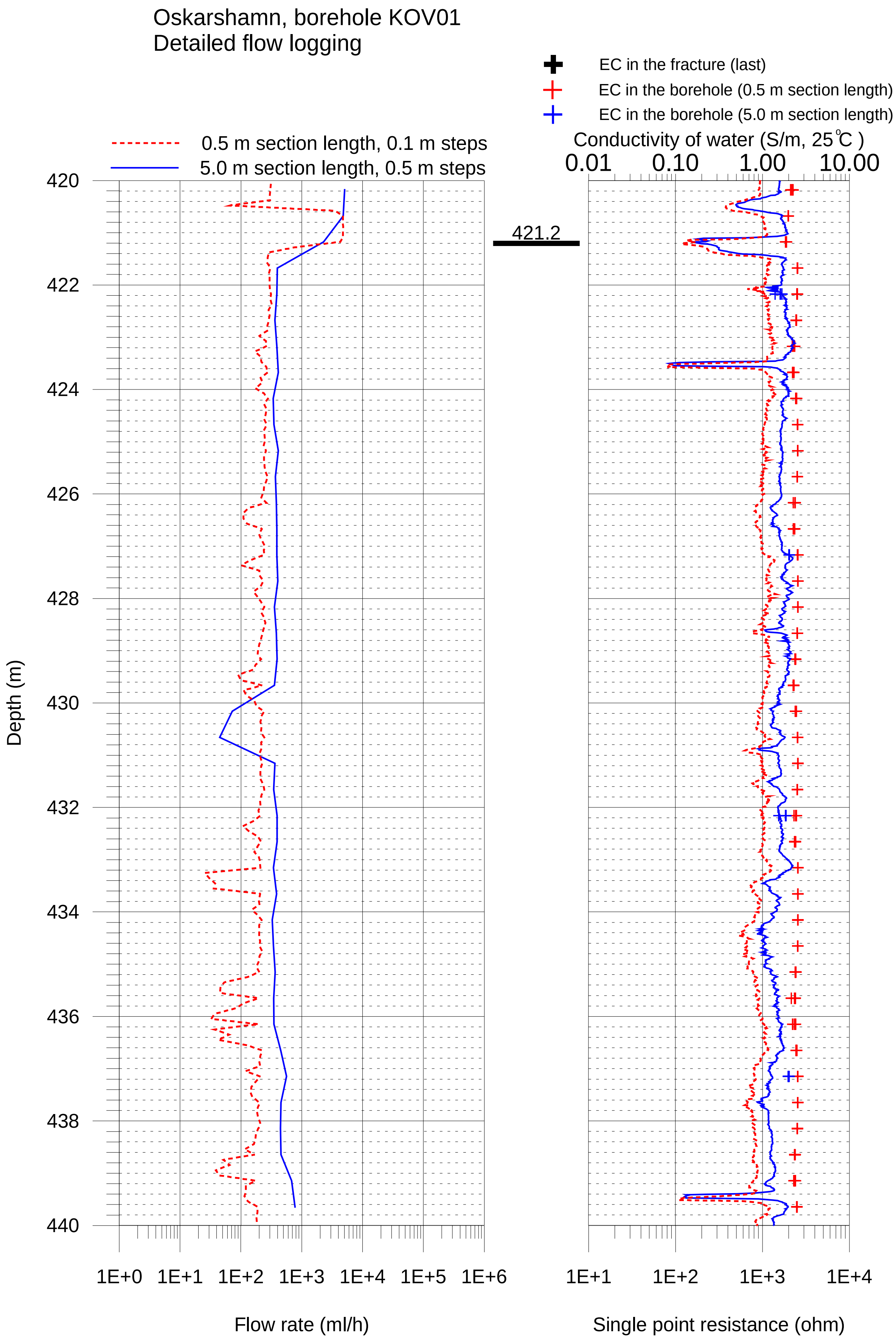

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
340
342
344
346
348
350
352
354
356
358
360
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

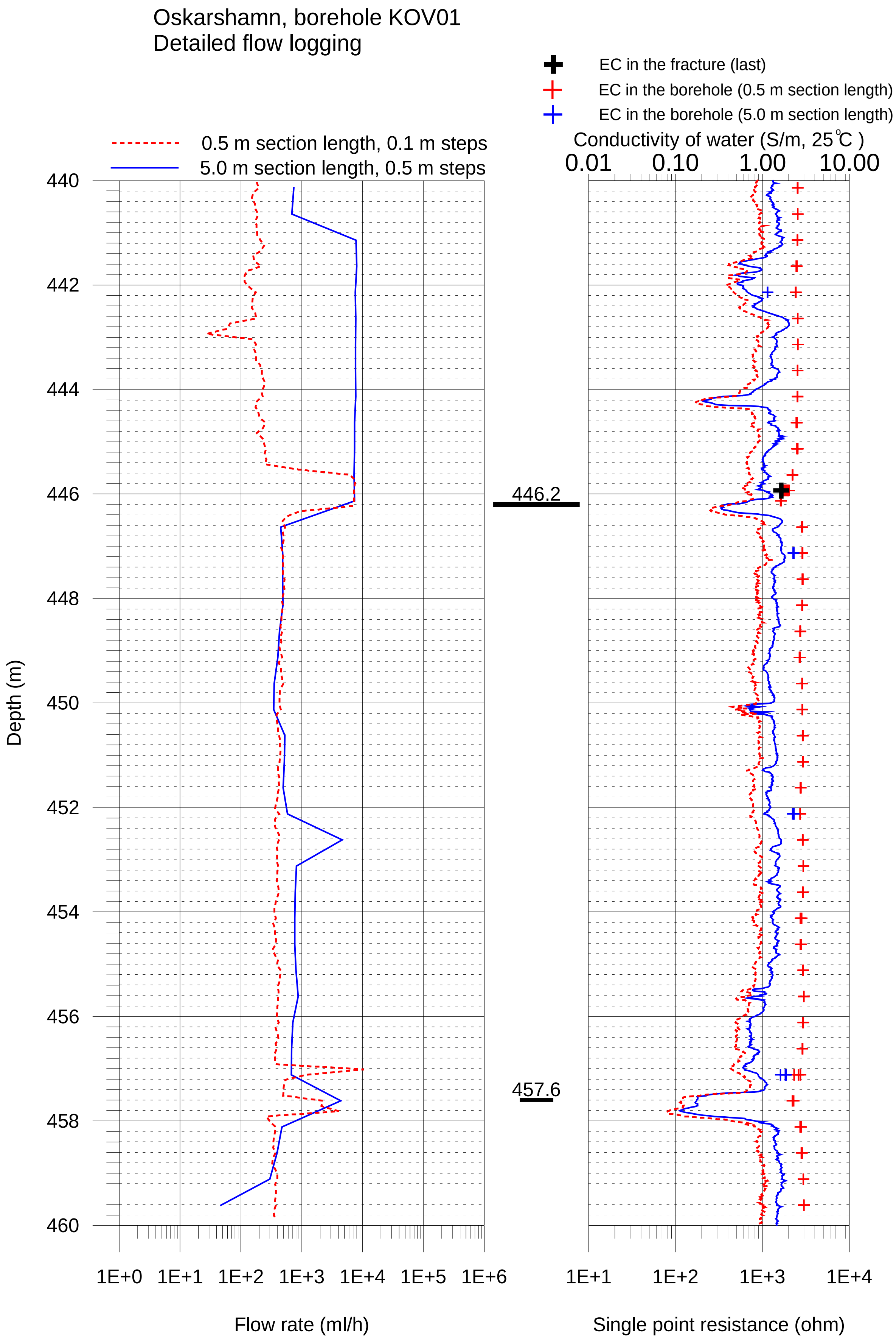

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
360
362
364
366
368
370
372
374
376
378
380
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

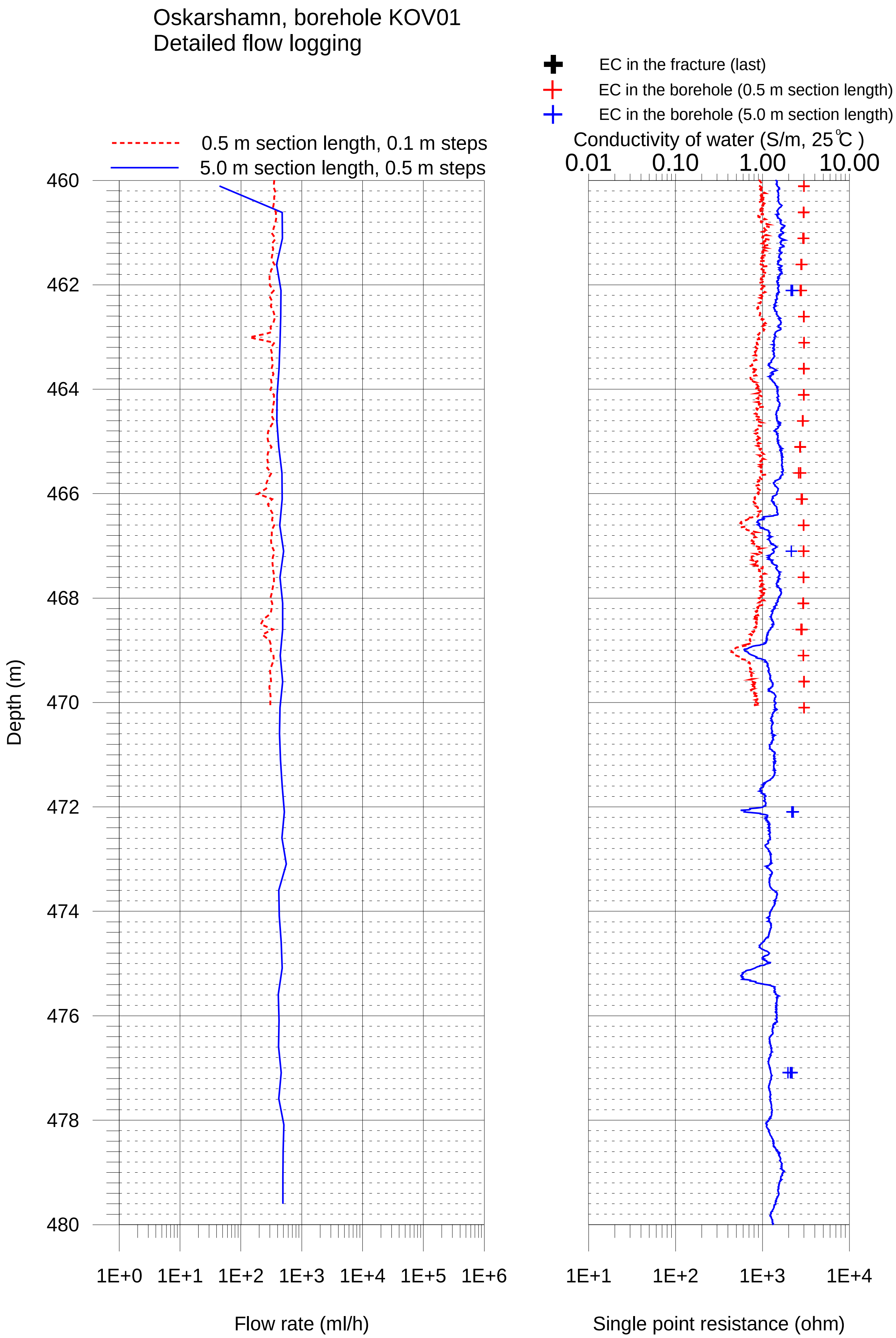


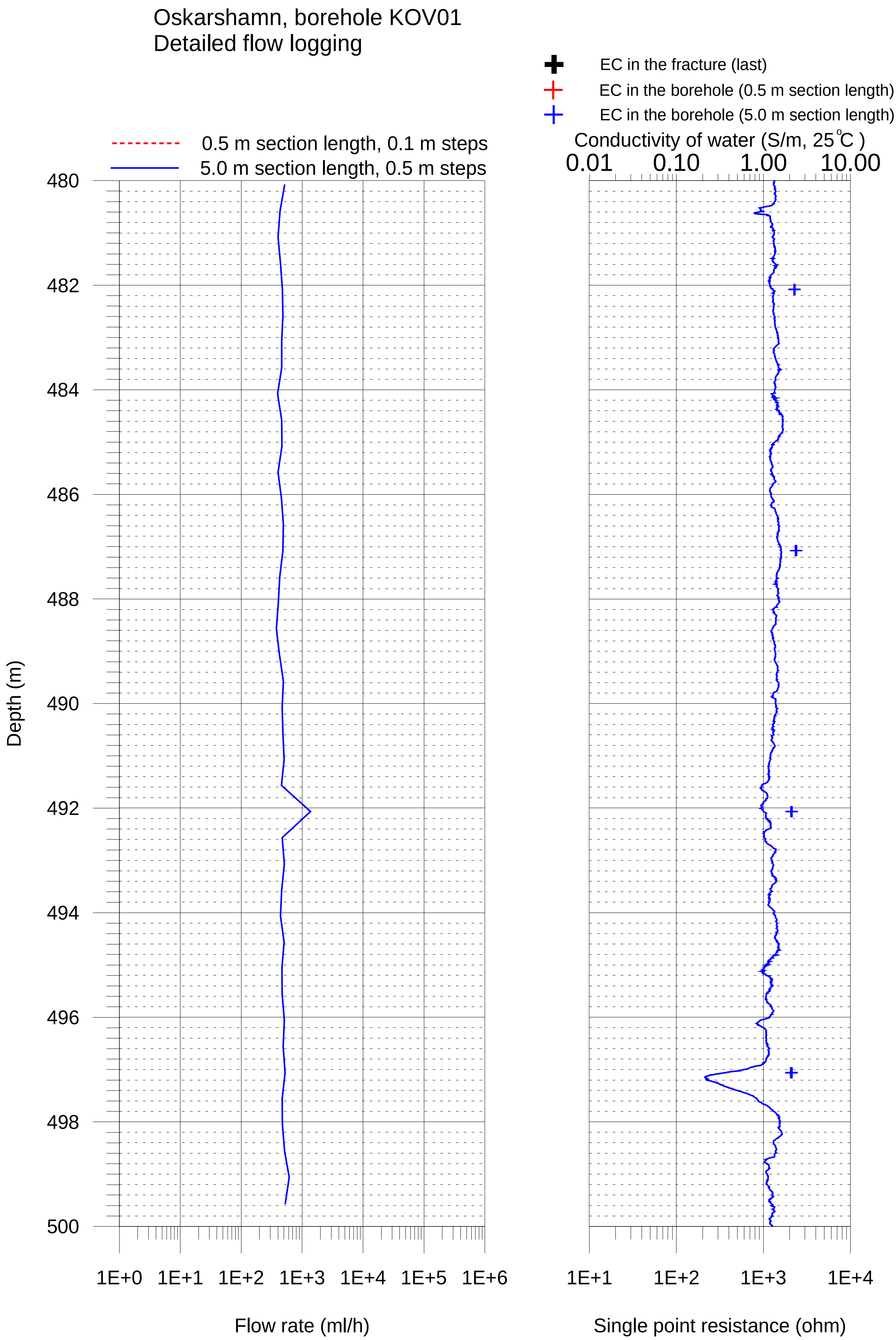
Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
380
382
384
386
388
390
392
394
396
398
400
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

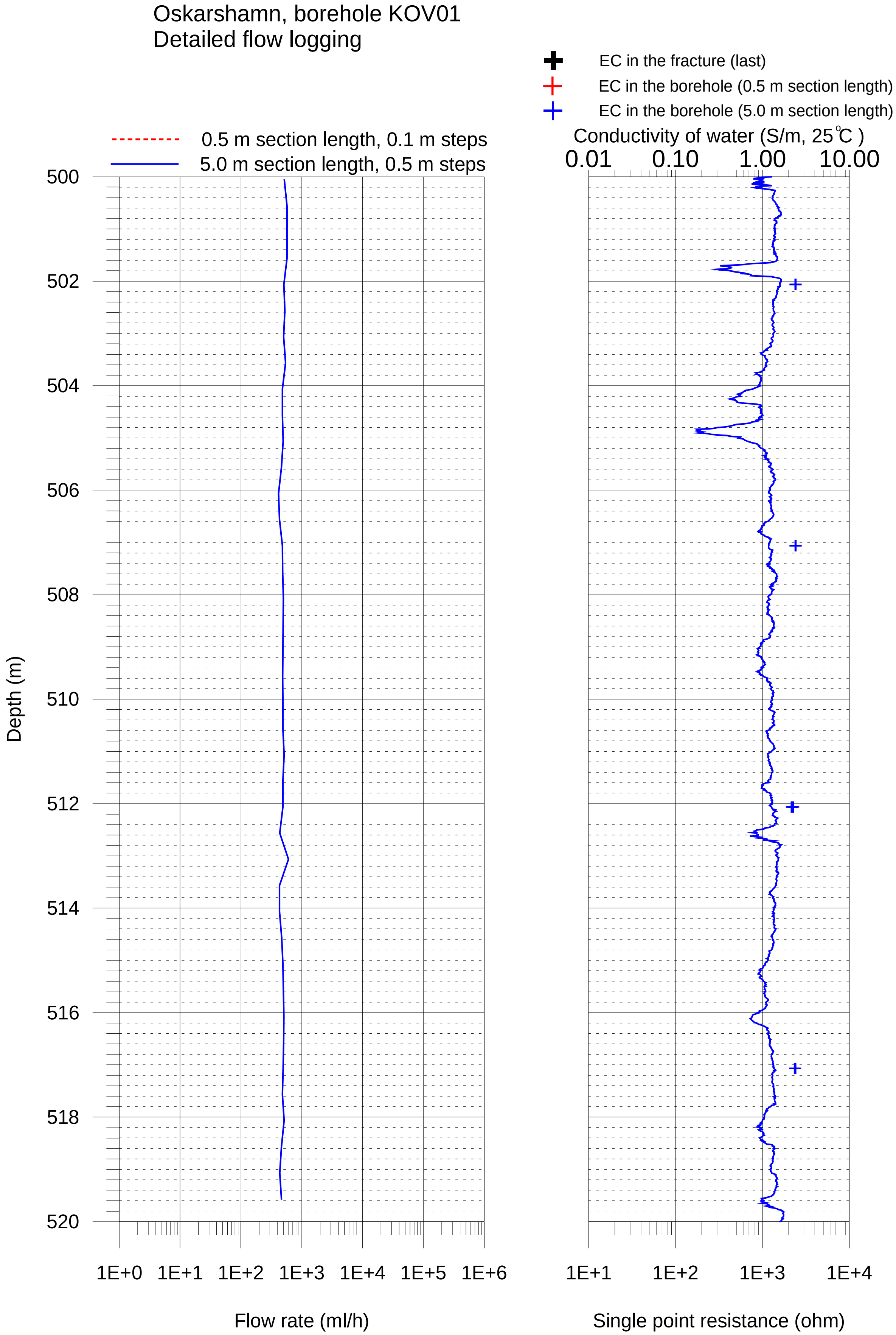

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
400
402
404
406
408
410
412
414
416
418
420
Depth (m)
403.2
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

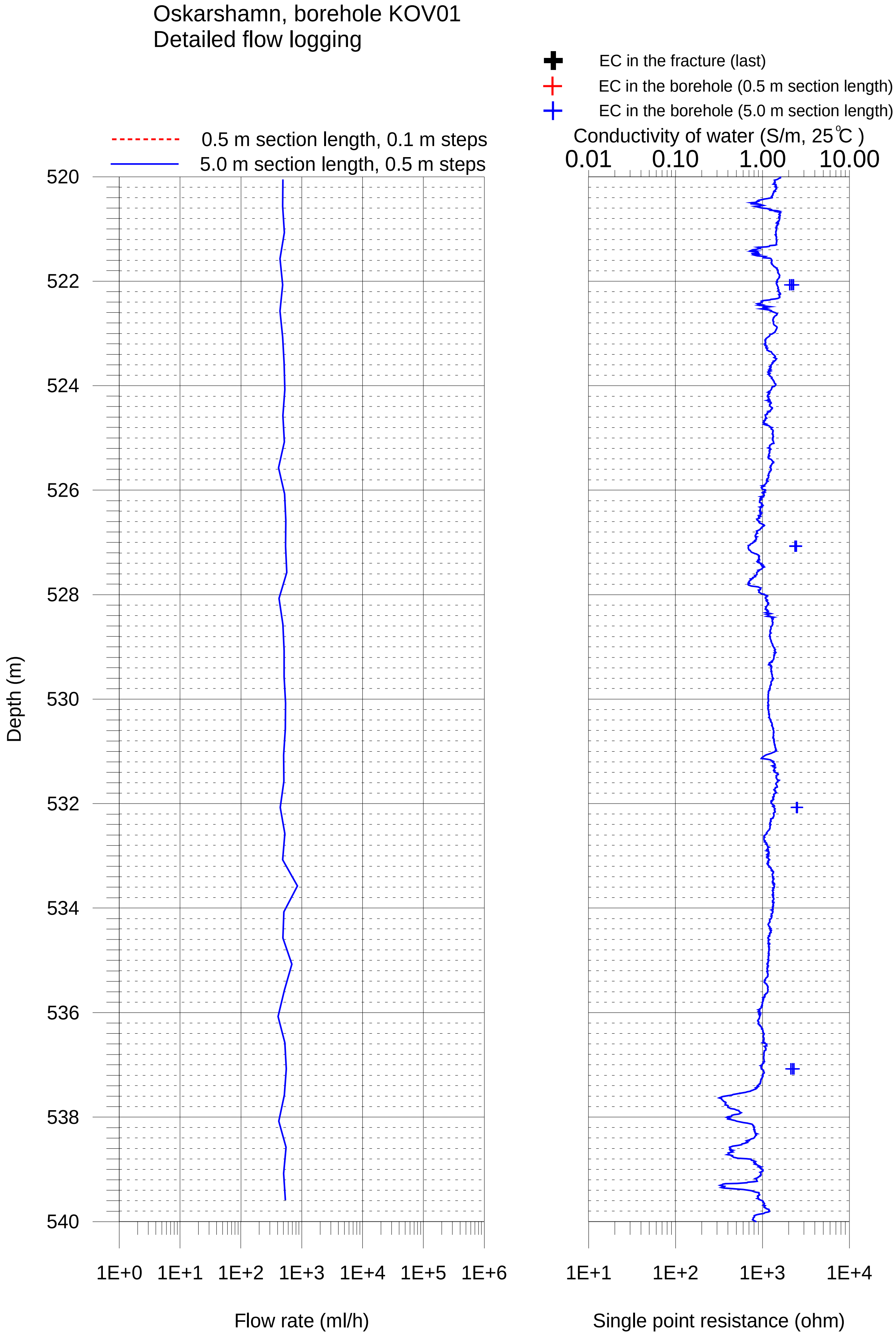

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
421.2
Depth (m)
420
422
424
426
428
430
432
434
436
438
440
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
1E+1
1E+2
1E+3
1E+4
Flow rate (ml/h)
Single point resistance (ohm)

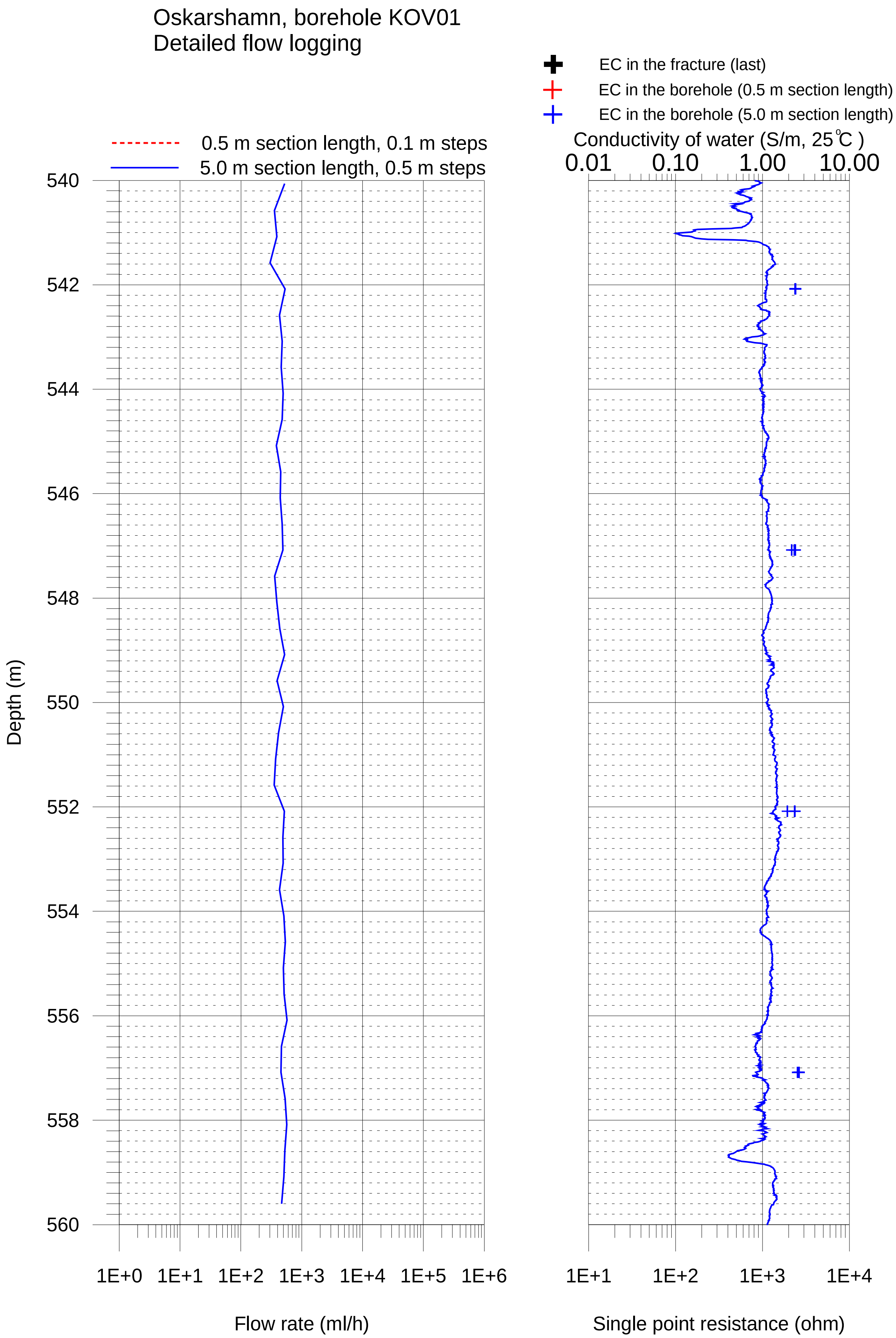

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
440
442
444
446
448
450
452
454
456
458
460
Depth (m)
446.2
457.6
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

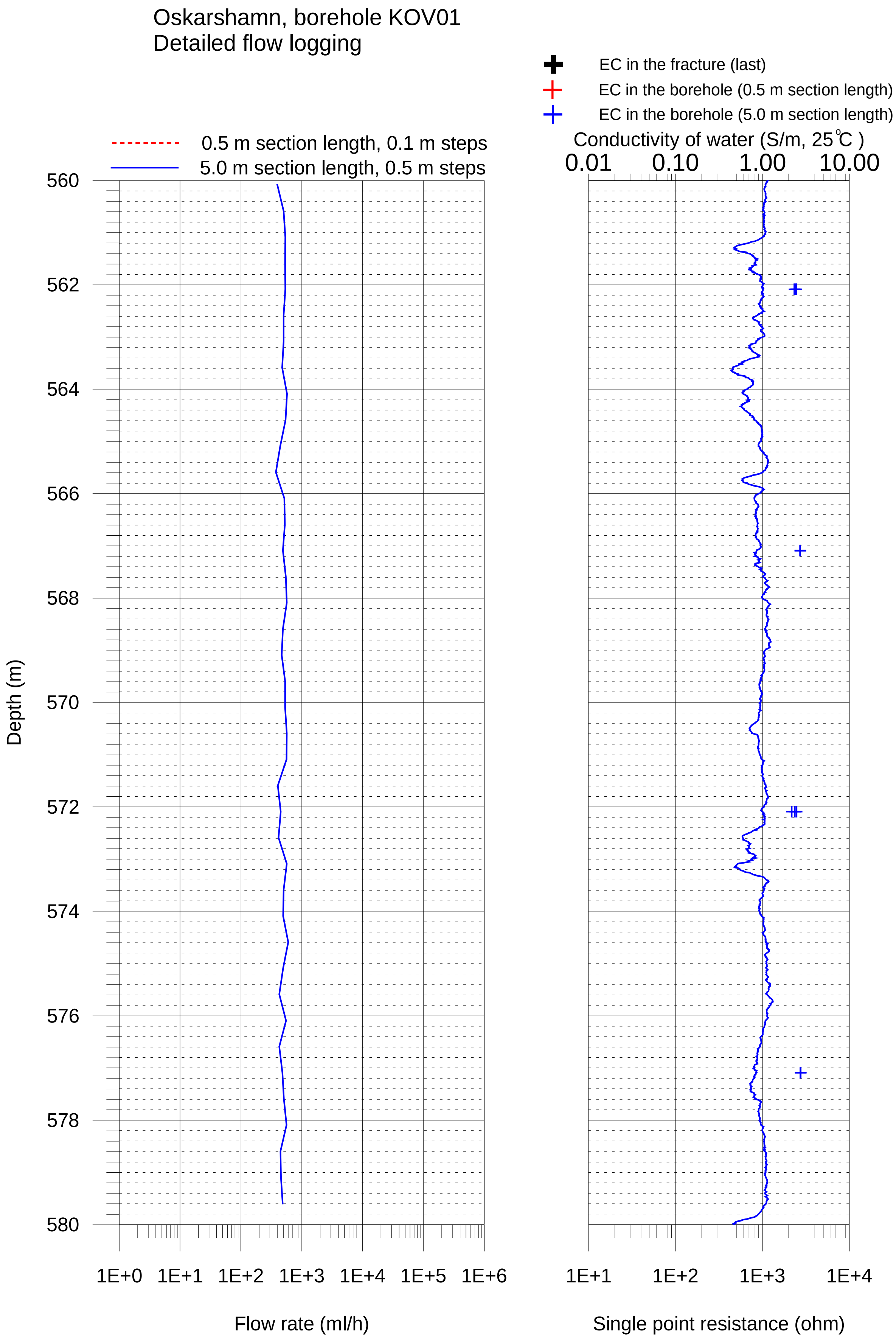

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Conductivity of water (S/m, 25°C)
0.01
0.10
1.00
10.00
Depth (m)
460
462
464
466
468
470
472
474
476
478
480
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

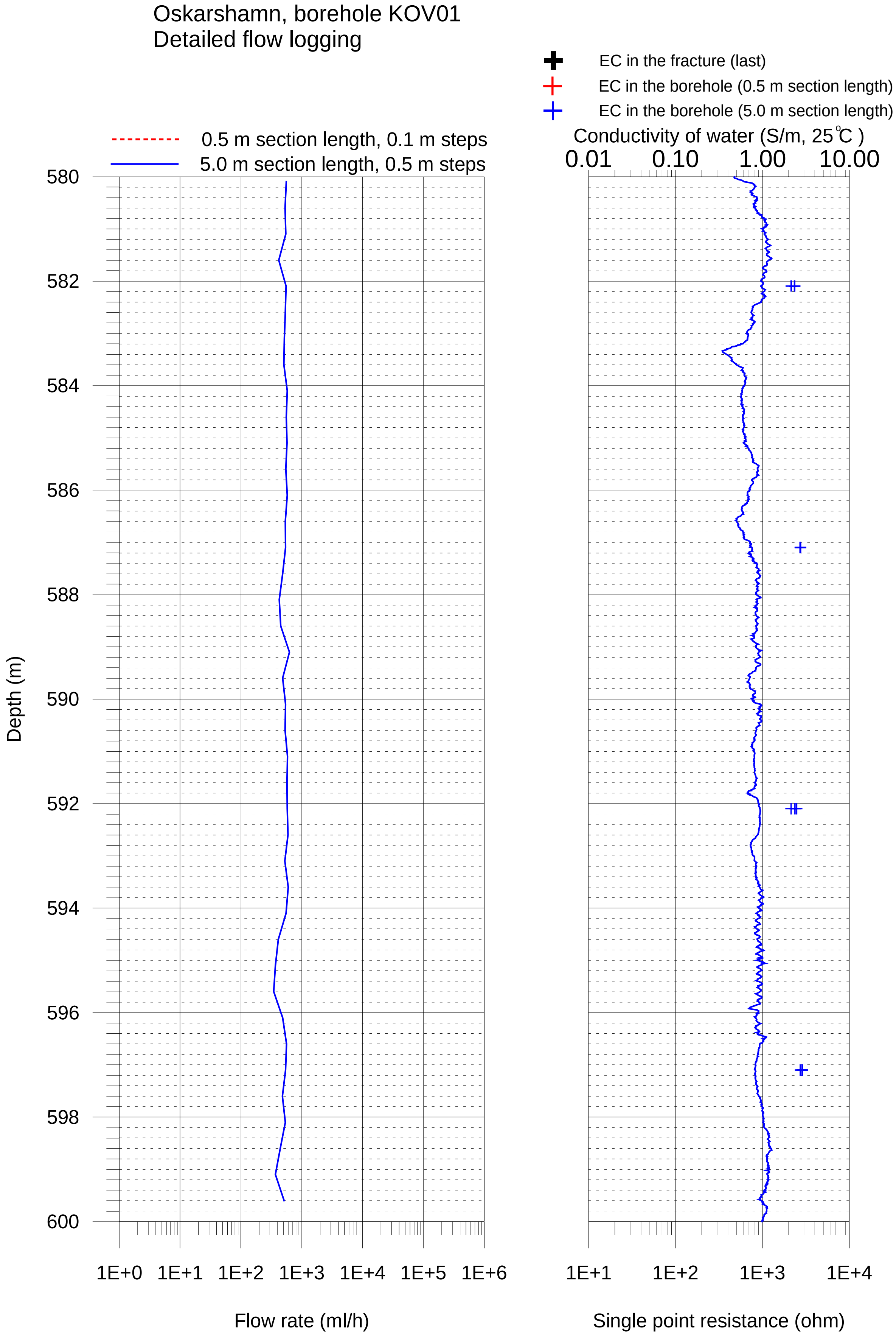

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25°C)
0.01
0.10
1.00
10.00
Depth (m)
480
482
484
486
488
490
492
494
496
498
500
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

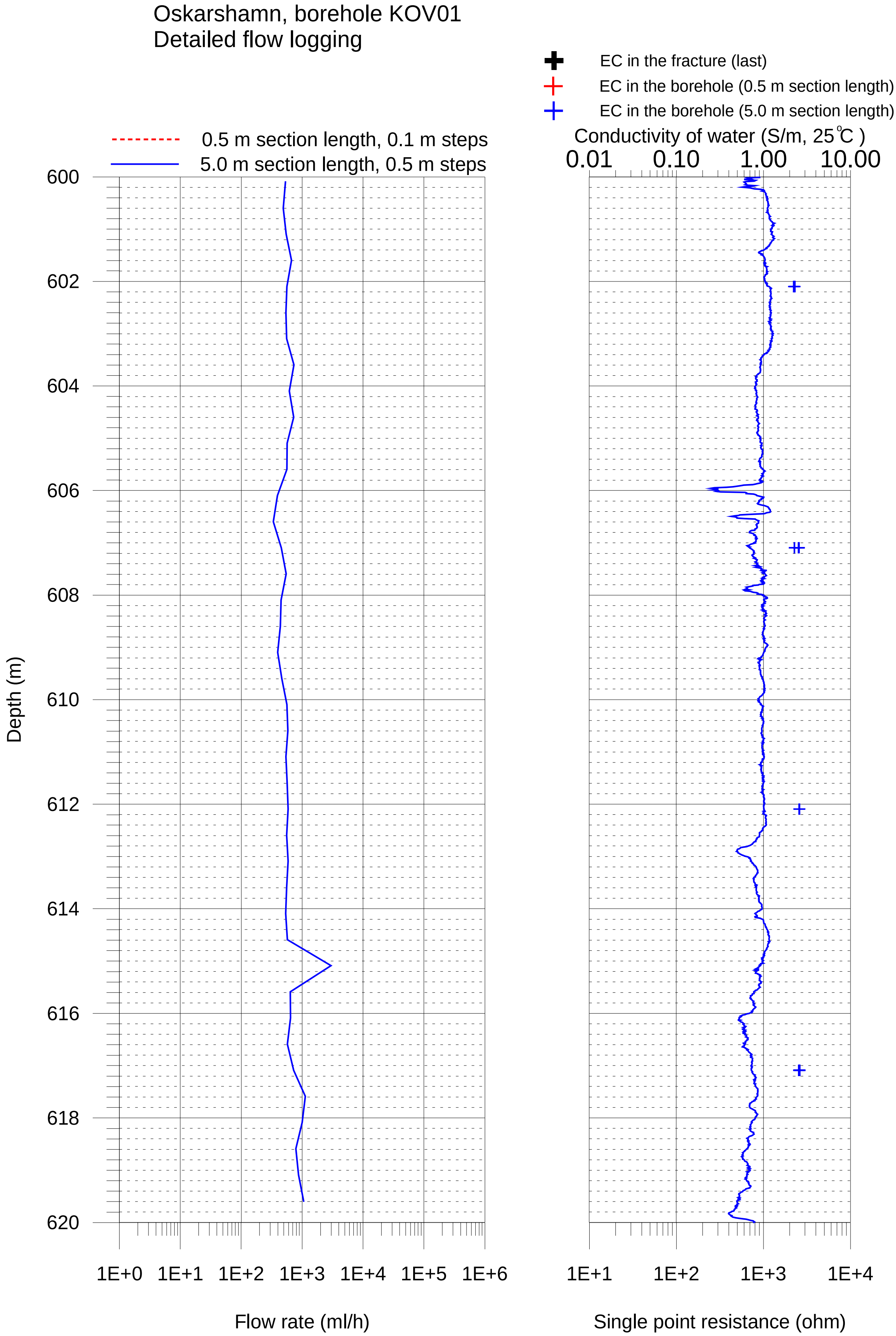

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25°C)
0.01
0.10
1.00
10.00
Depth (m)
500
502
504
506
508
510
512
514
516
518
520
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

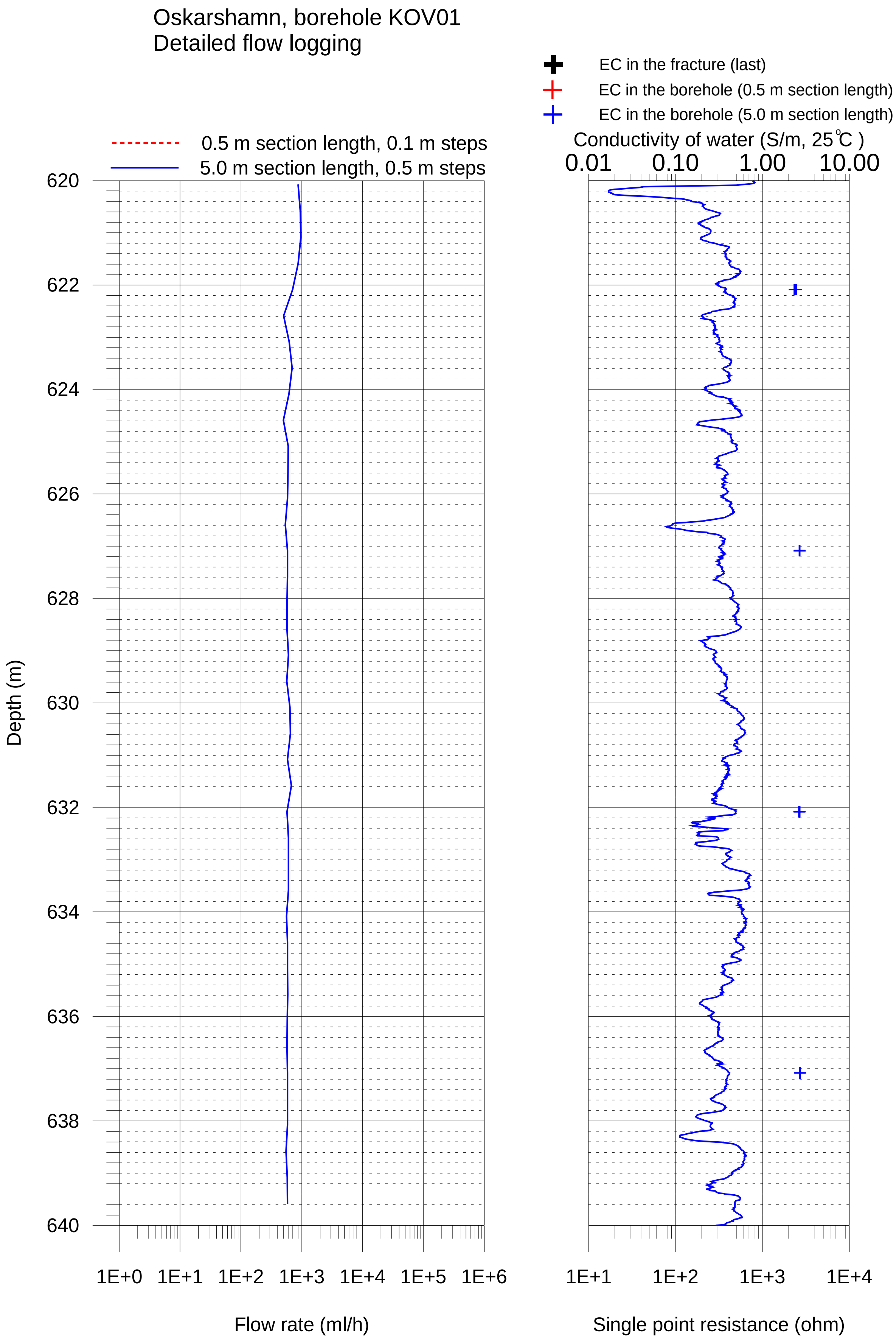

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
520
522
524
526
528
530
532
534
536
538
540
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

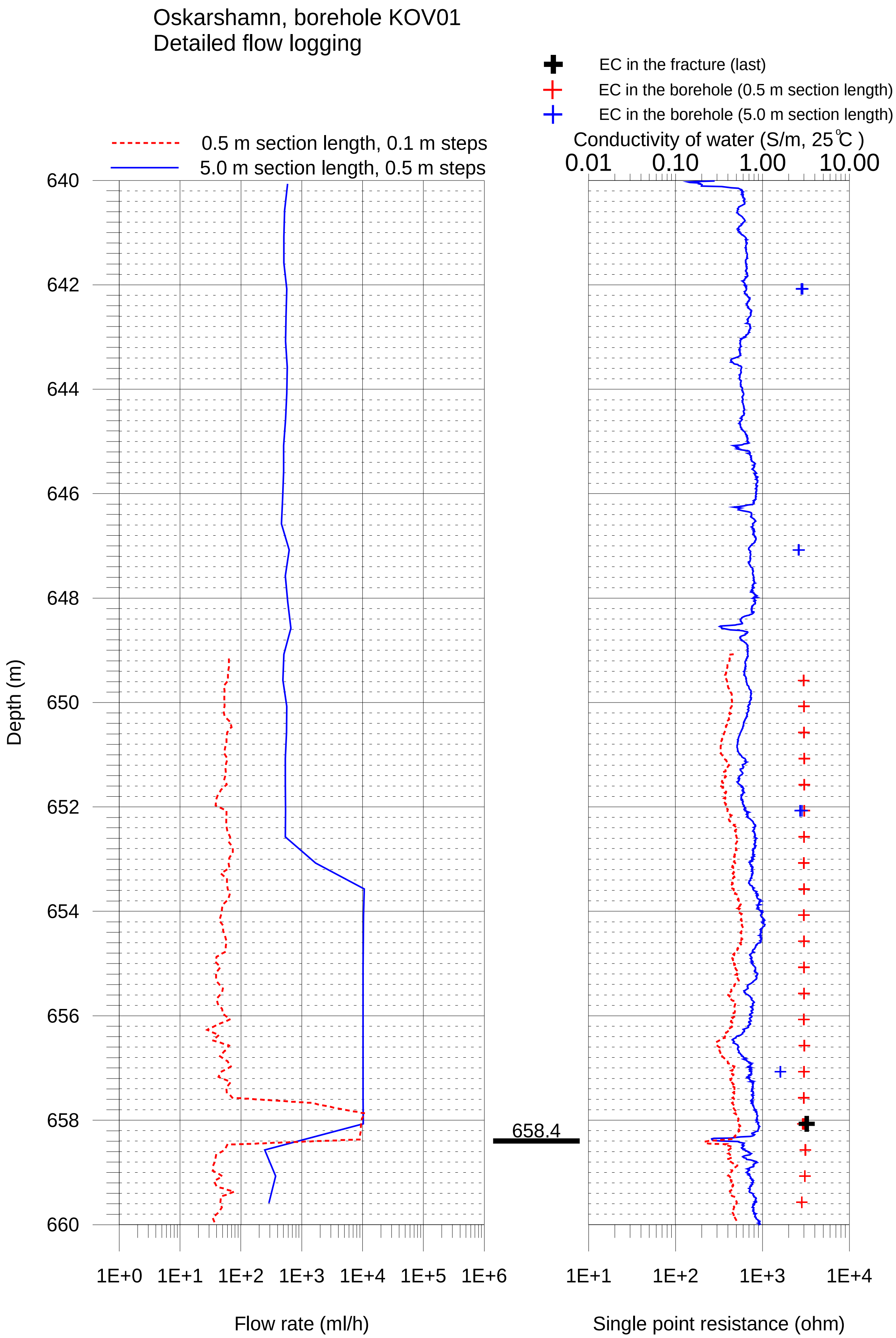

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
540
542
544
546
548
550
552
554
556
558
560
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)


Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
560
562
564
566
568
570
572
574
576
578
580
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

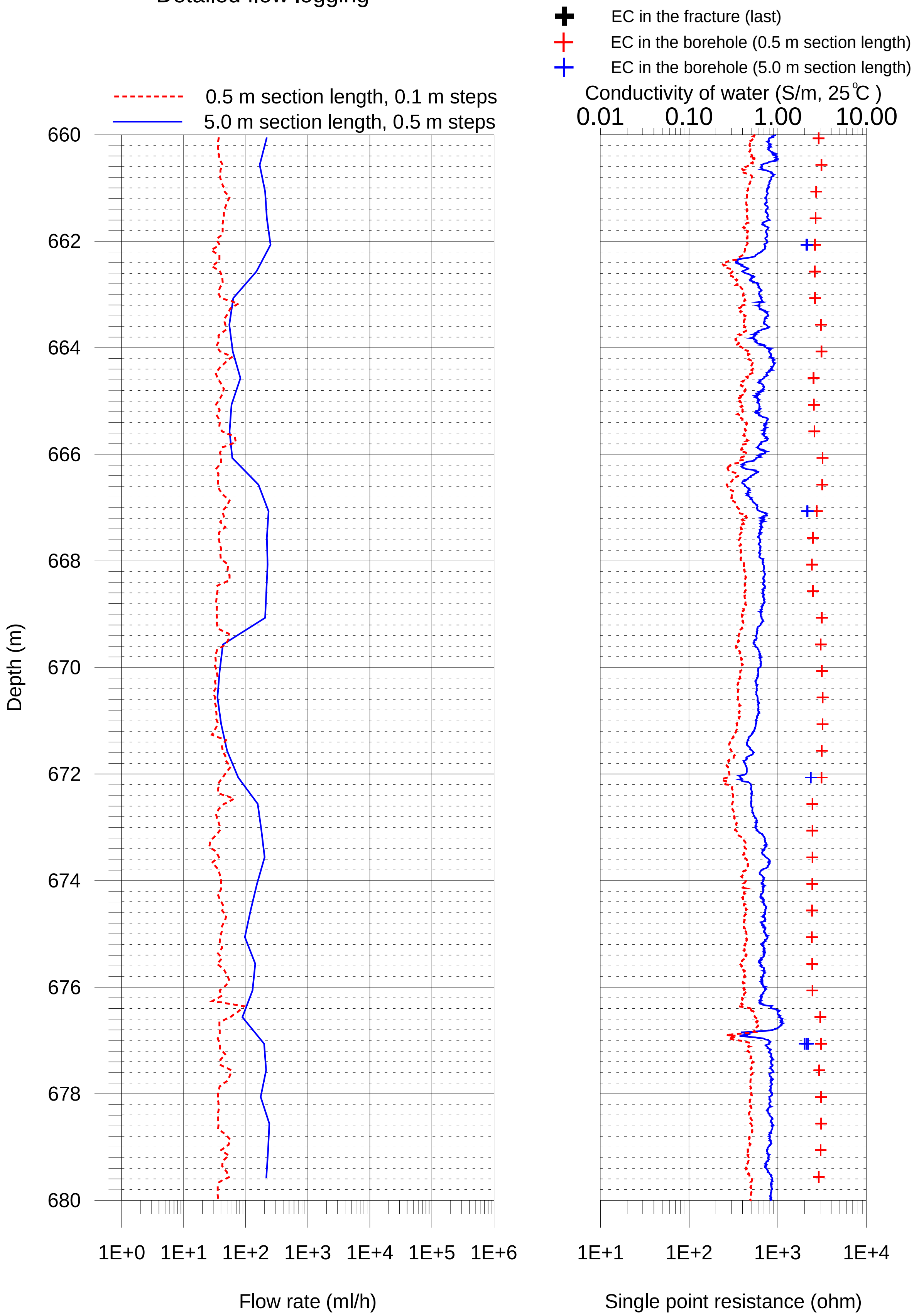

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01 0.10 1.00 10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
580
582
584
586
588
590
592
594
596
598
600
Depth (m)
1E+0 1E+1 1E+2 1E+3 1E+4 1E+5 1E+6
Flow rate (ml/h)
1E+1 1E+2 1E+3 1E+4
Single point resistance (ohm)

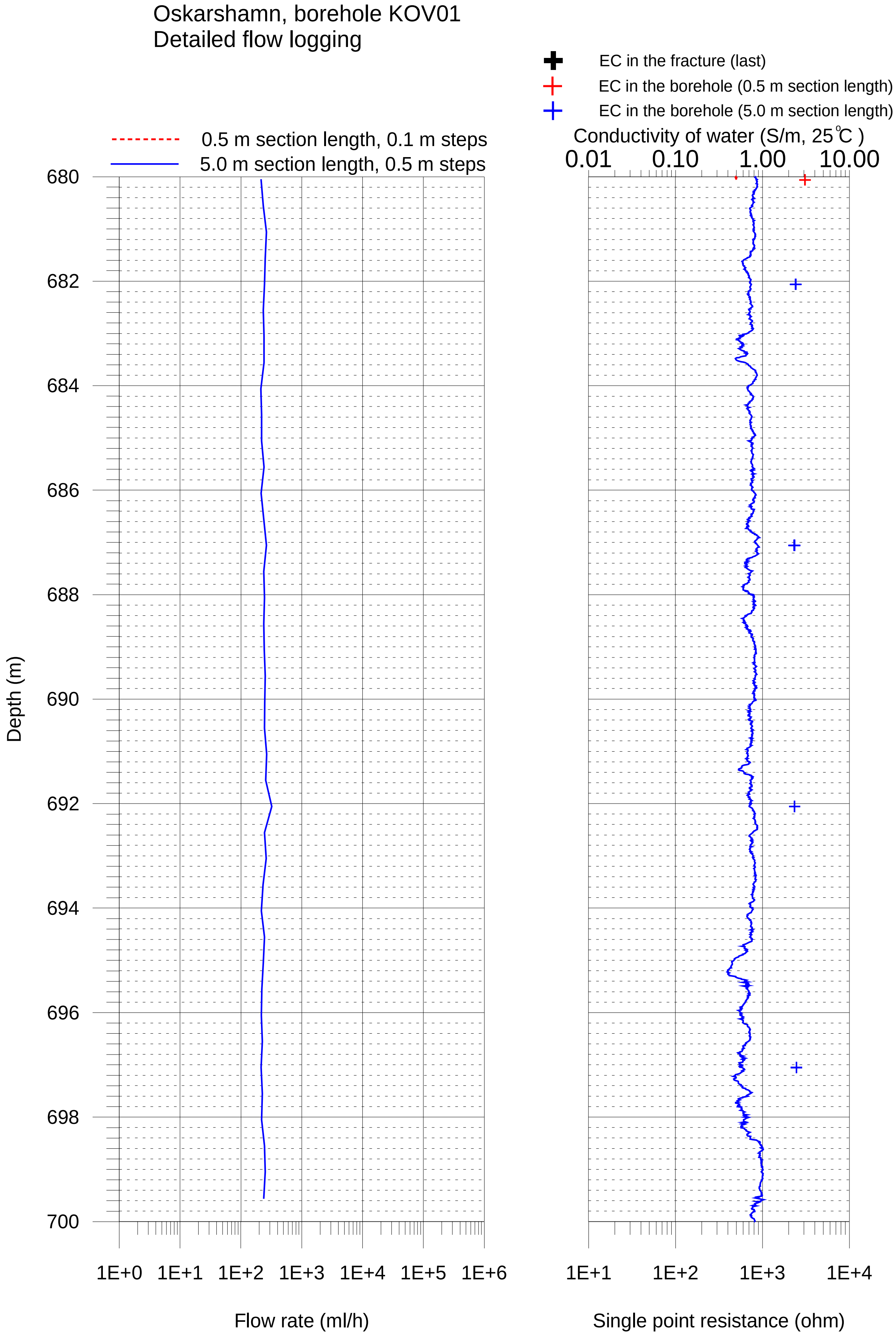

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
600
602
604
606
608
610
612
614
616
618
620
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

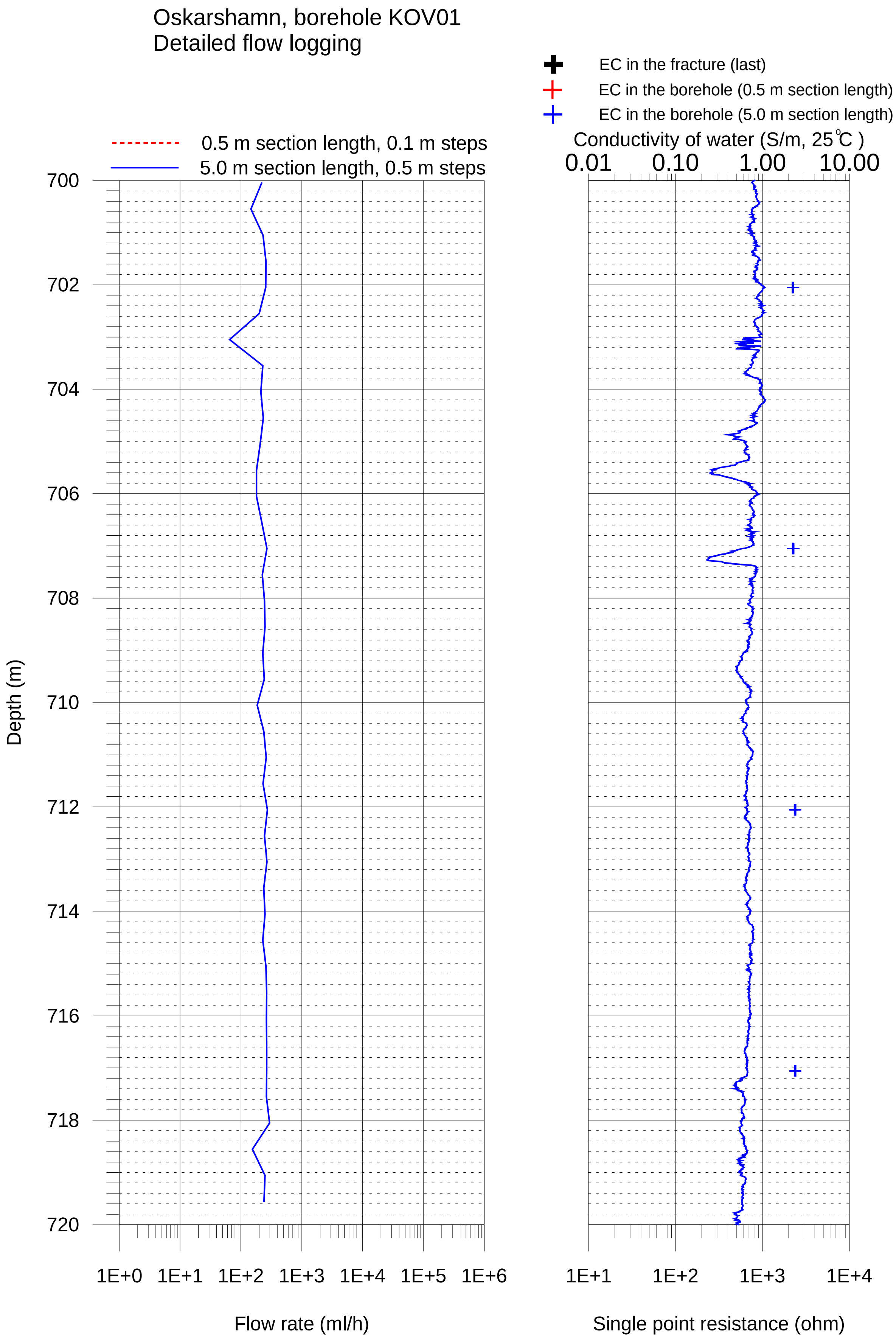

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Depth (m)
620
622
624
626
628
630
632
634
636
638
640
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

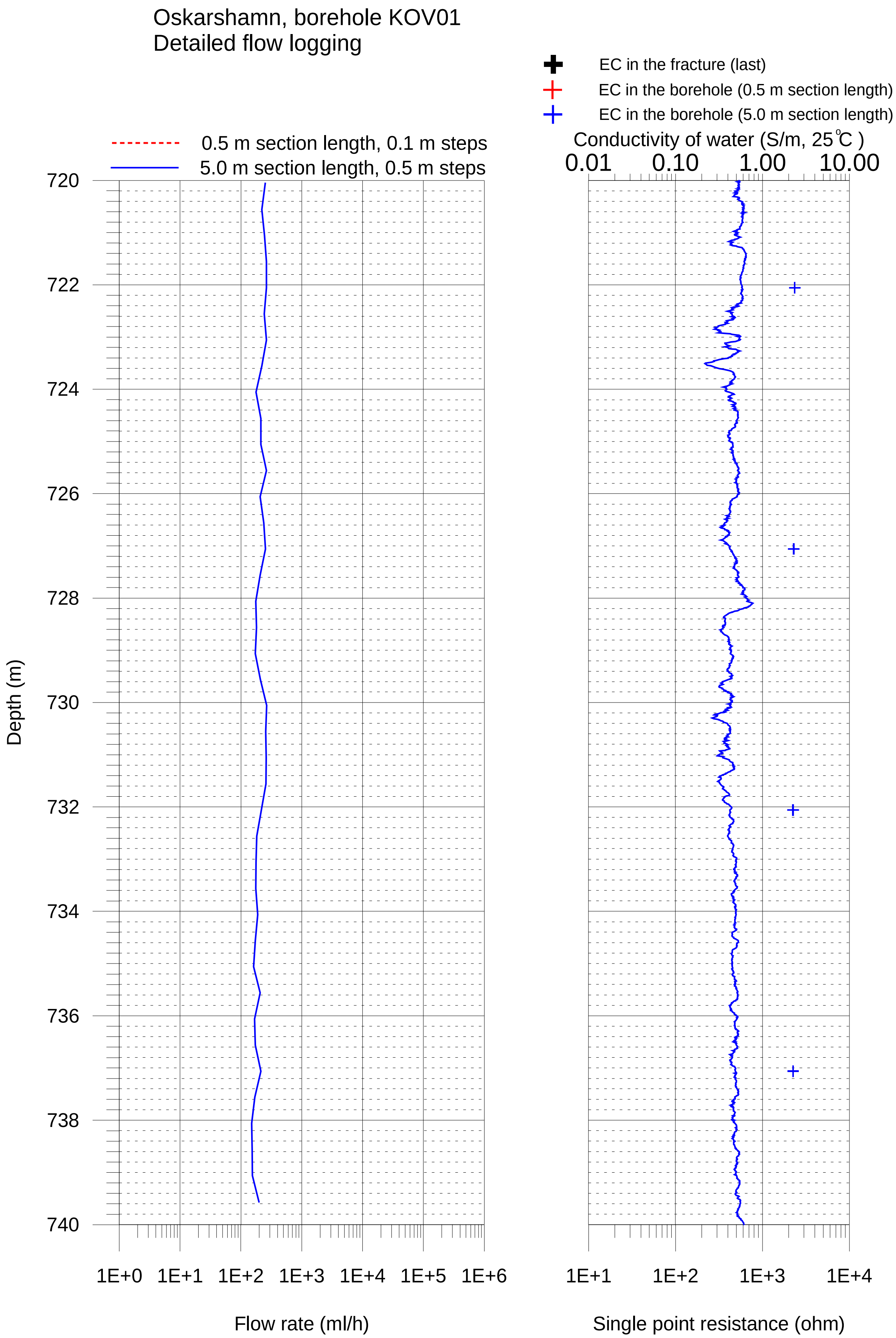

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
640
642
644
646
648
650
652
654
656
658
660
658.4
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

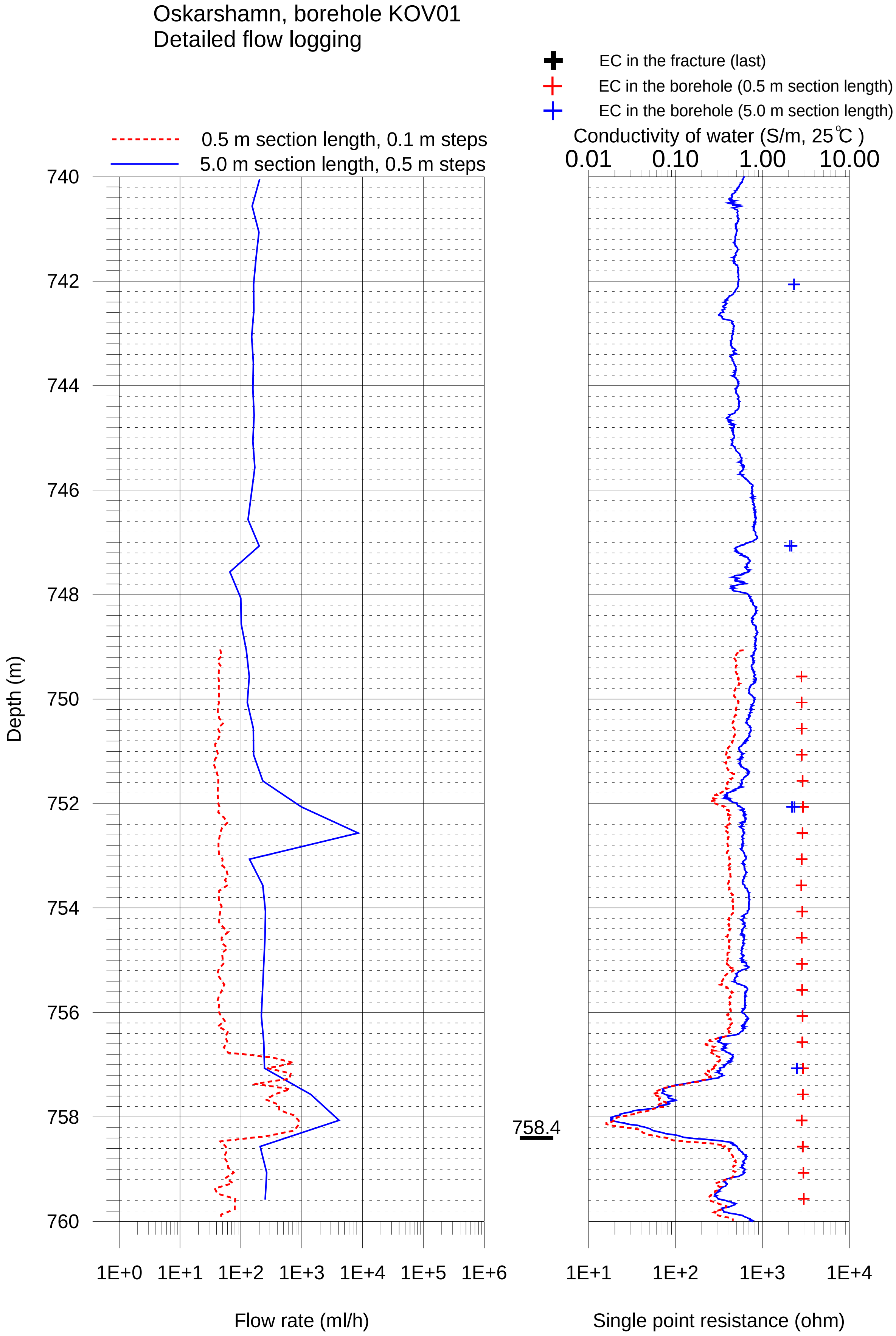
Oskarshamn, borehole KOV01
Detailed flow logging

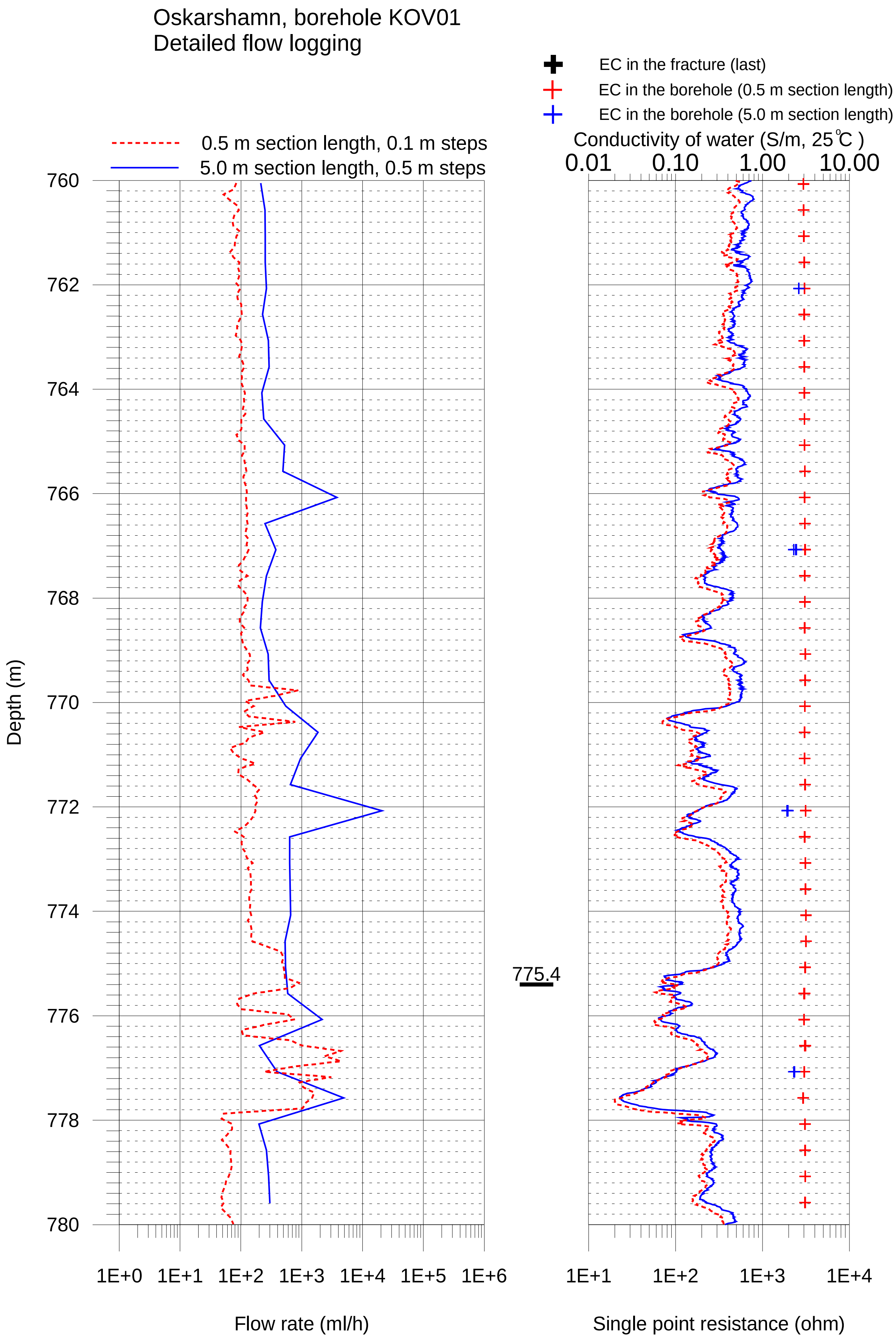


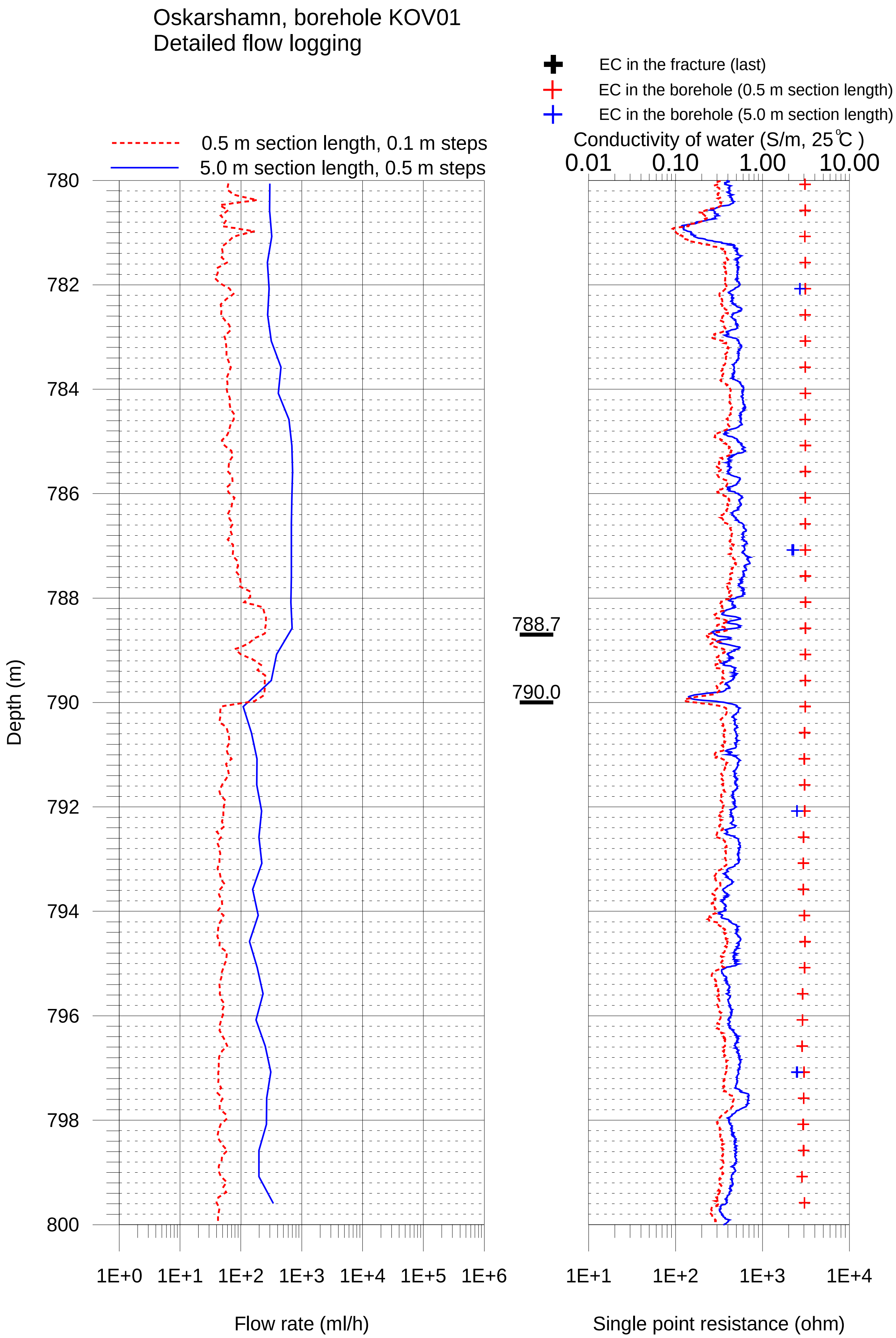

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25°C)
0.01
0.10
1.00
10.00
680
682
684
686
688
690
692
694
696
698
700
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)


Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
700
702
704
706
708
710
712
714
716
718
720
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)


Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
720
722
724
726
728
730
732
734
736
738
740
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

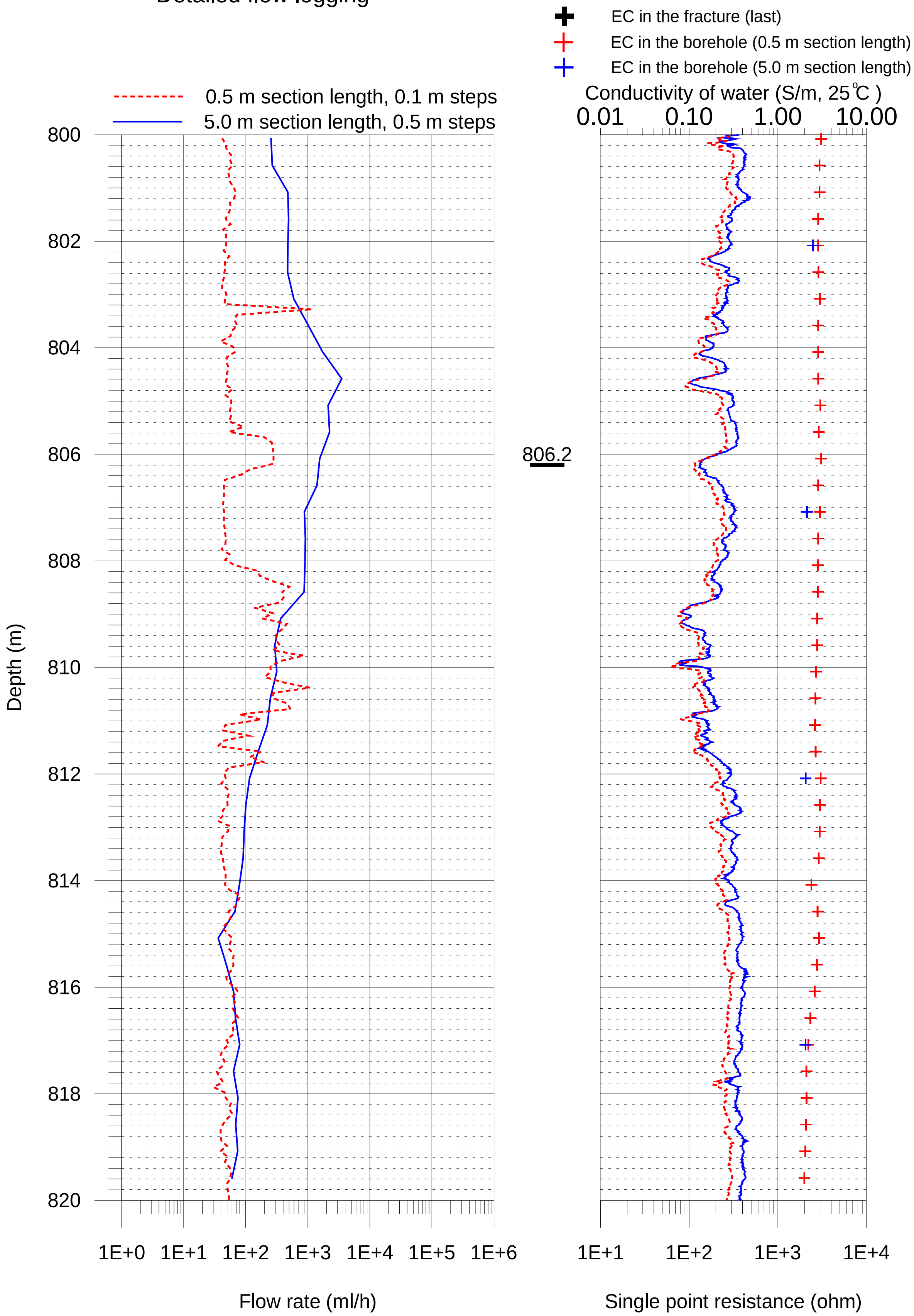

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
740
742
744
746
748
750
752
754
756
758
760
Depth (m)
758.4
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

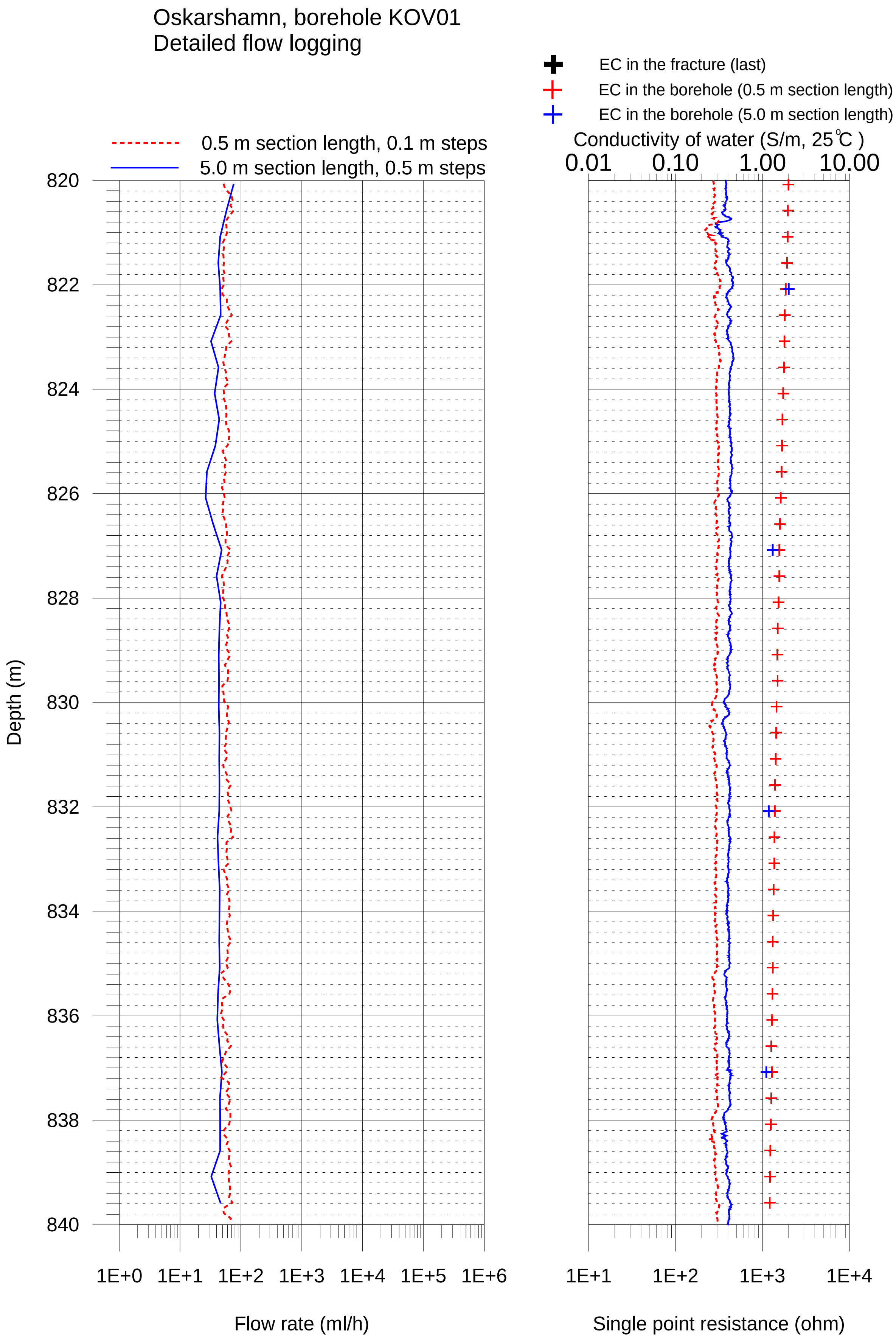

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
760
762
764
766
768
770
772
774
776
778
780
775.4
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)



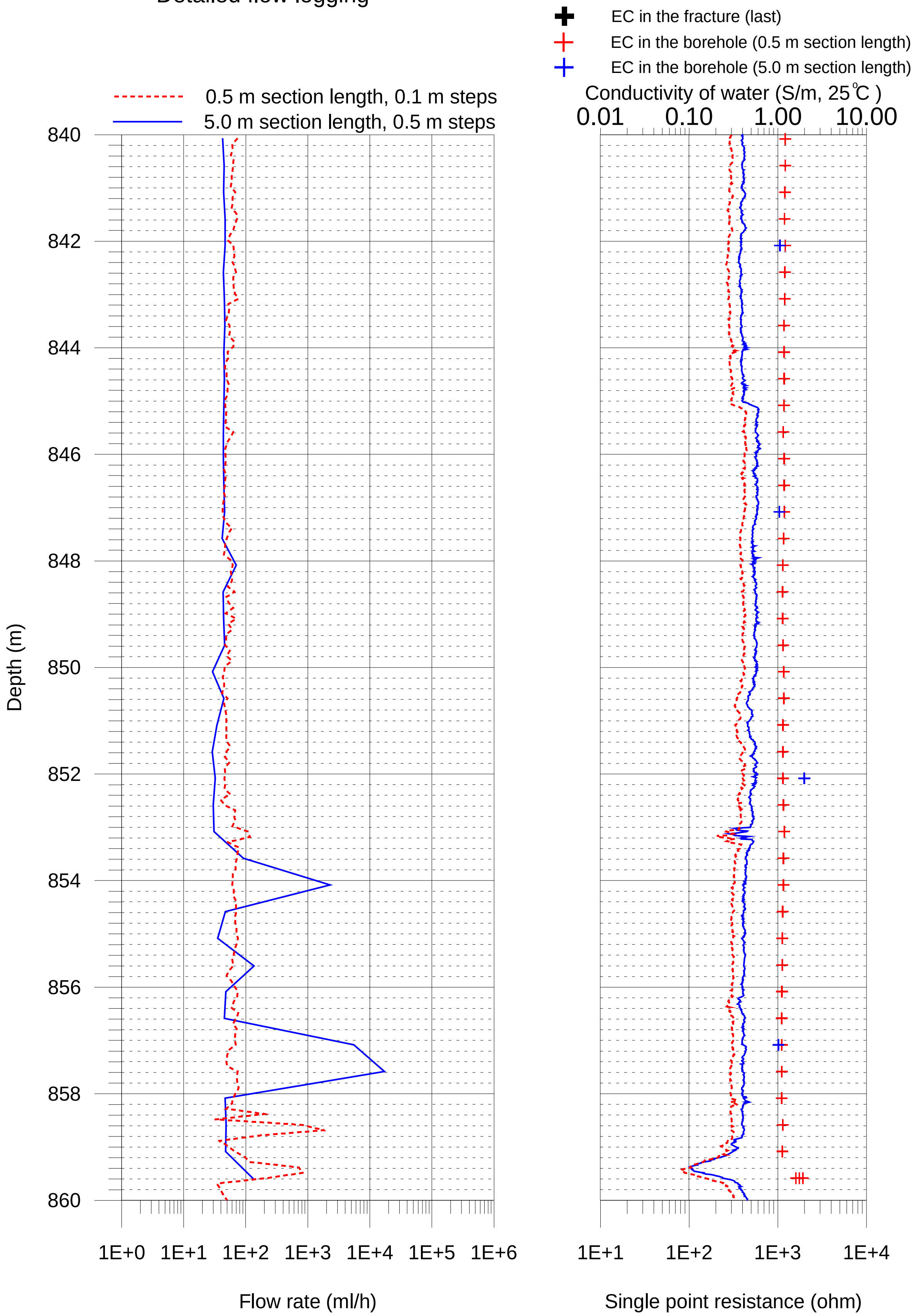
Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
780
782
784
786
788
790
792
794
796
798
800
Depth (m)
788.7
790.0
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

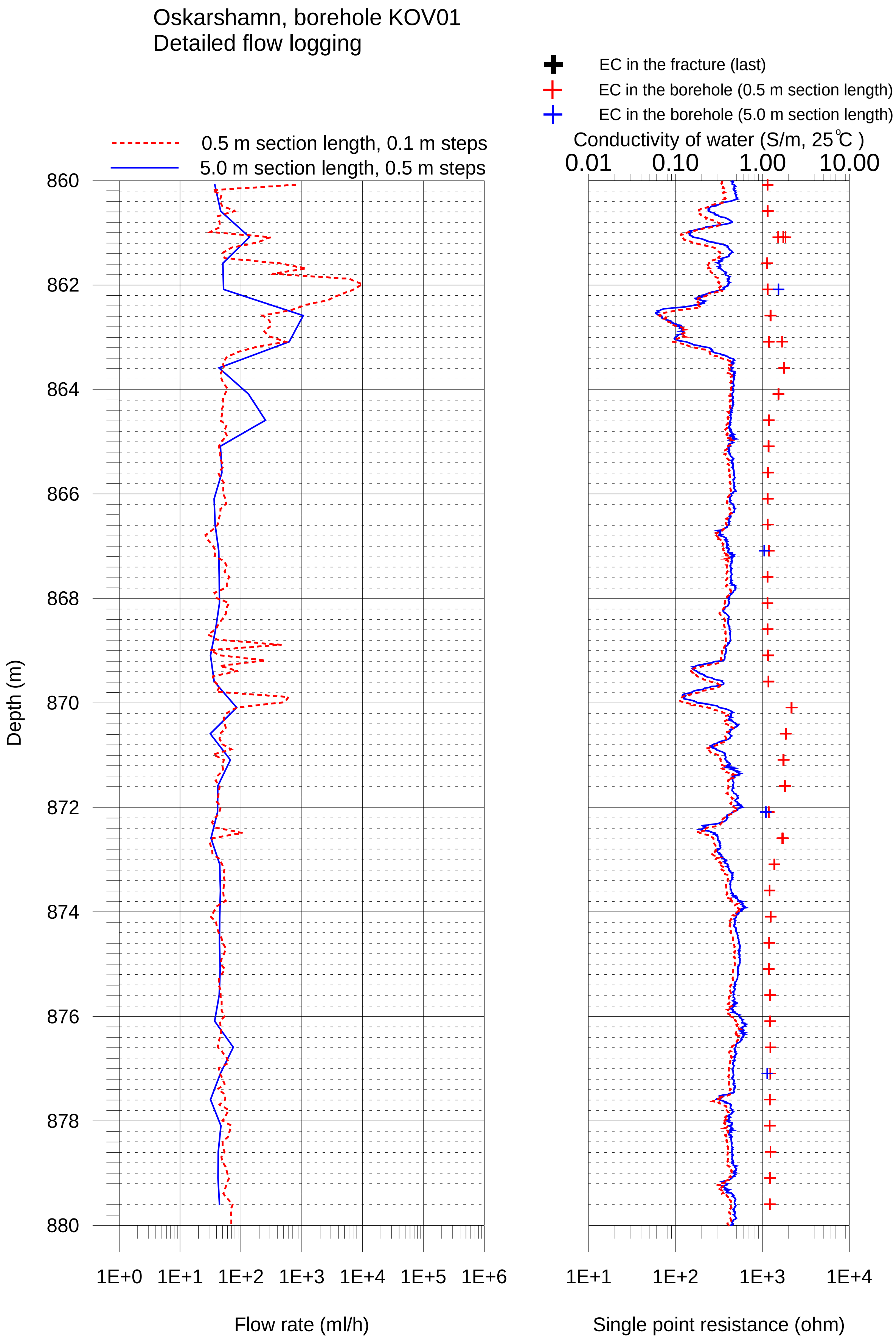
Oskarshamn, borehole KOV01
Detailed flow logging



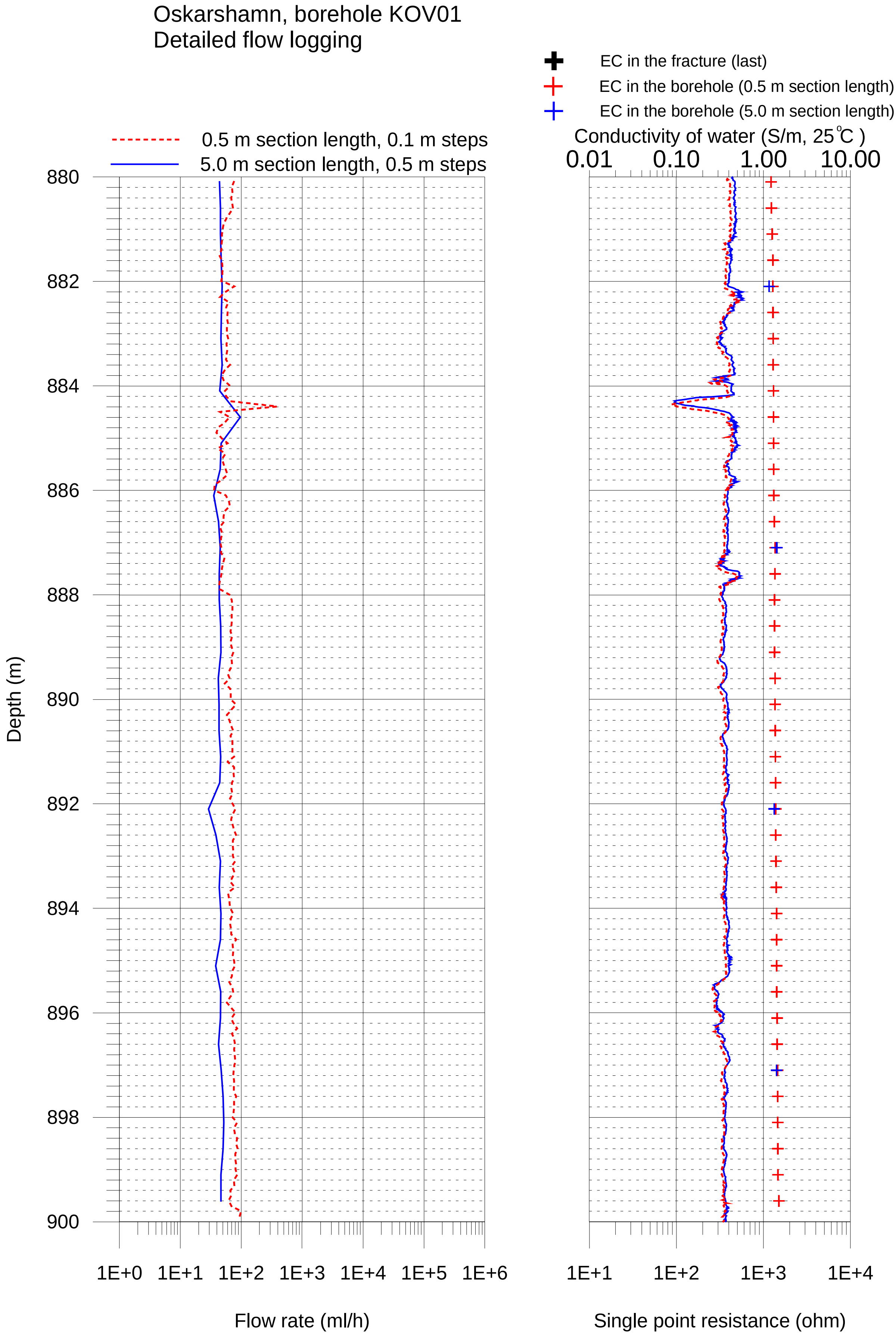

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
820
822
824
826
828
830
832
834
836
838
840
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

Oskarshamn, borehole KOV01
Detailed flow logging

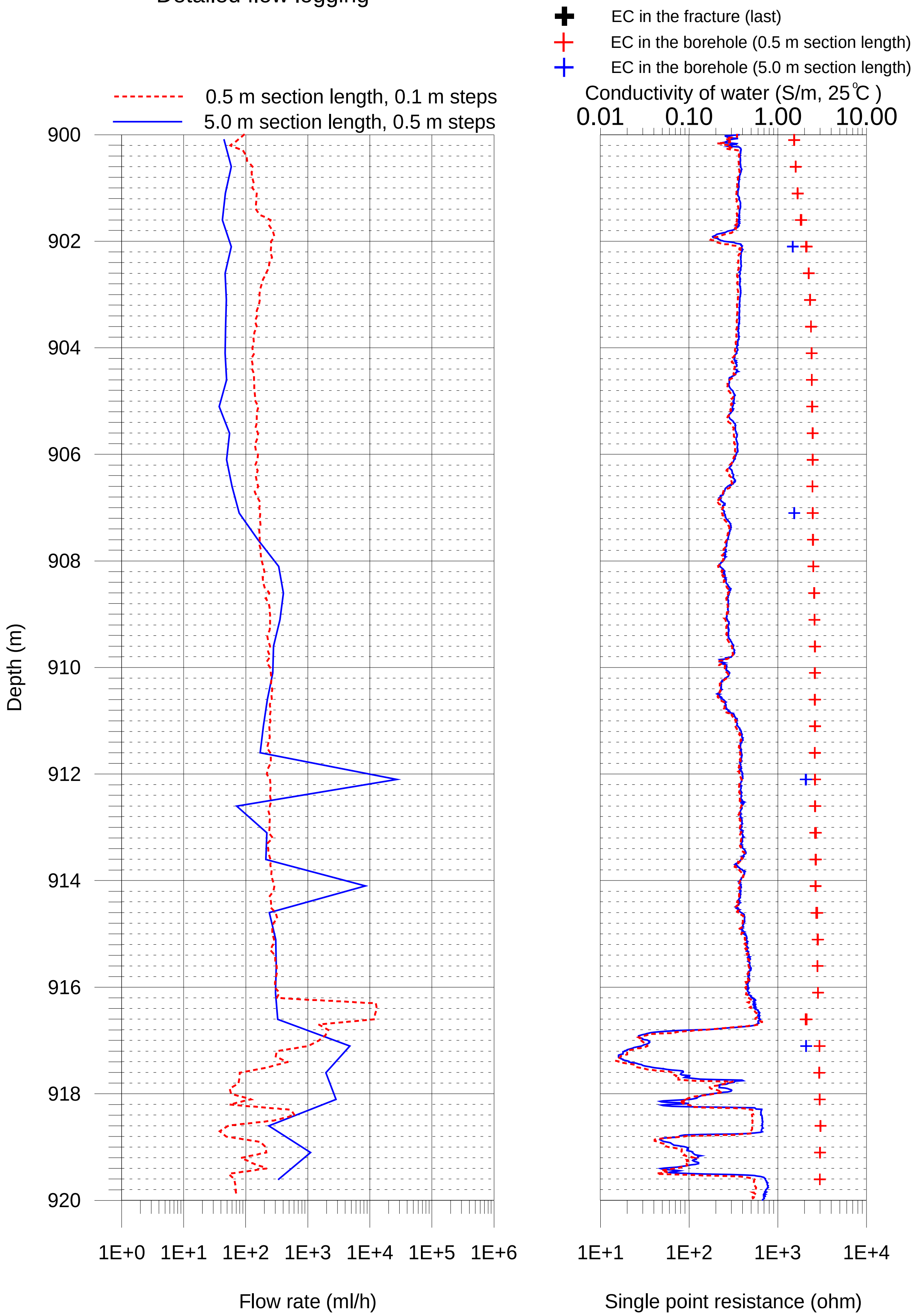


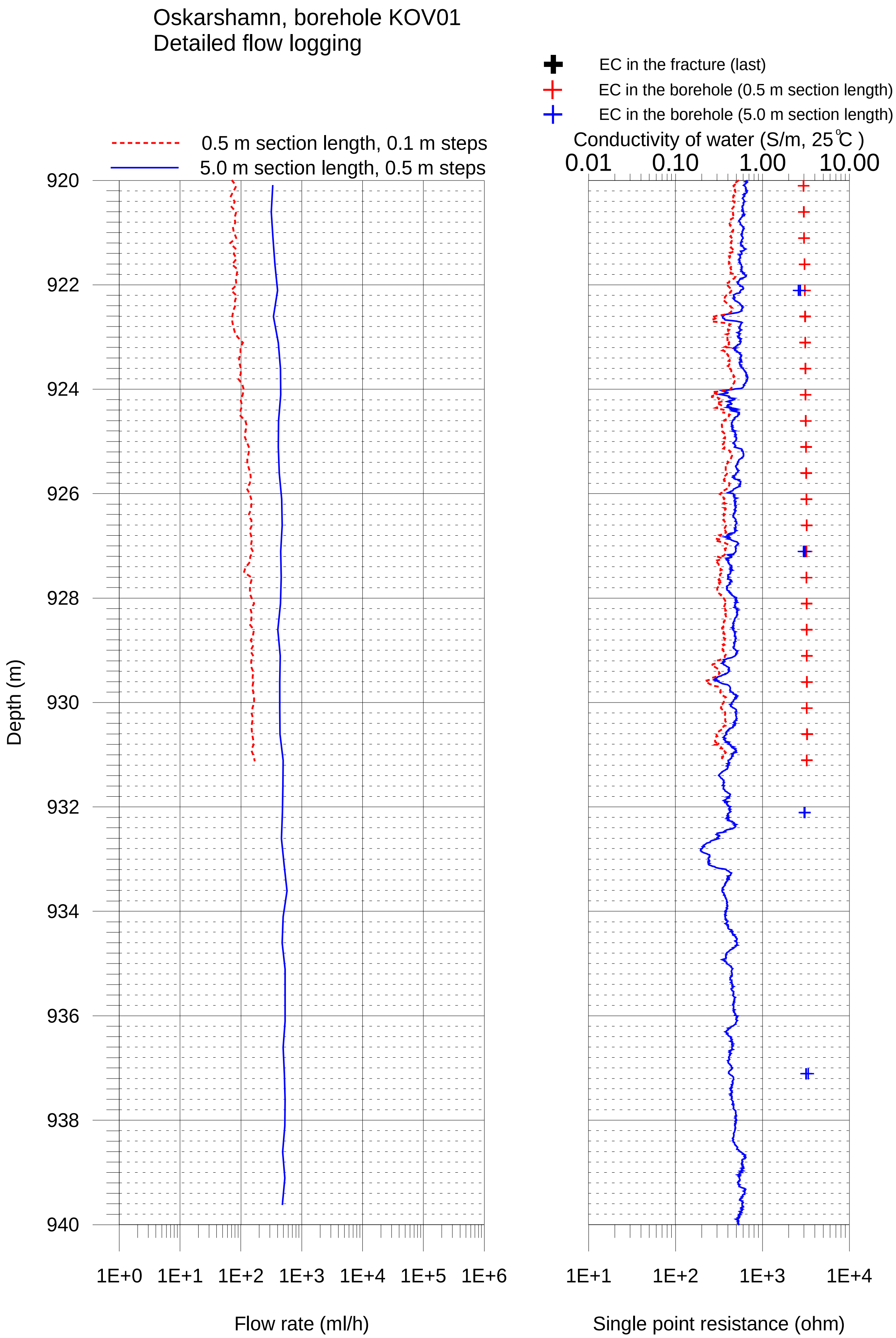


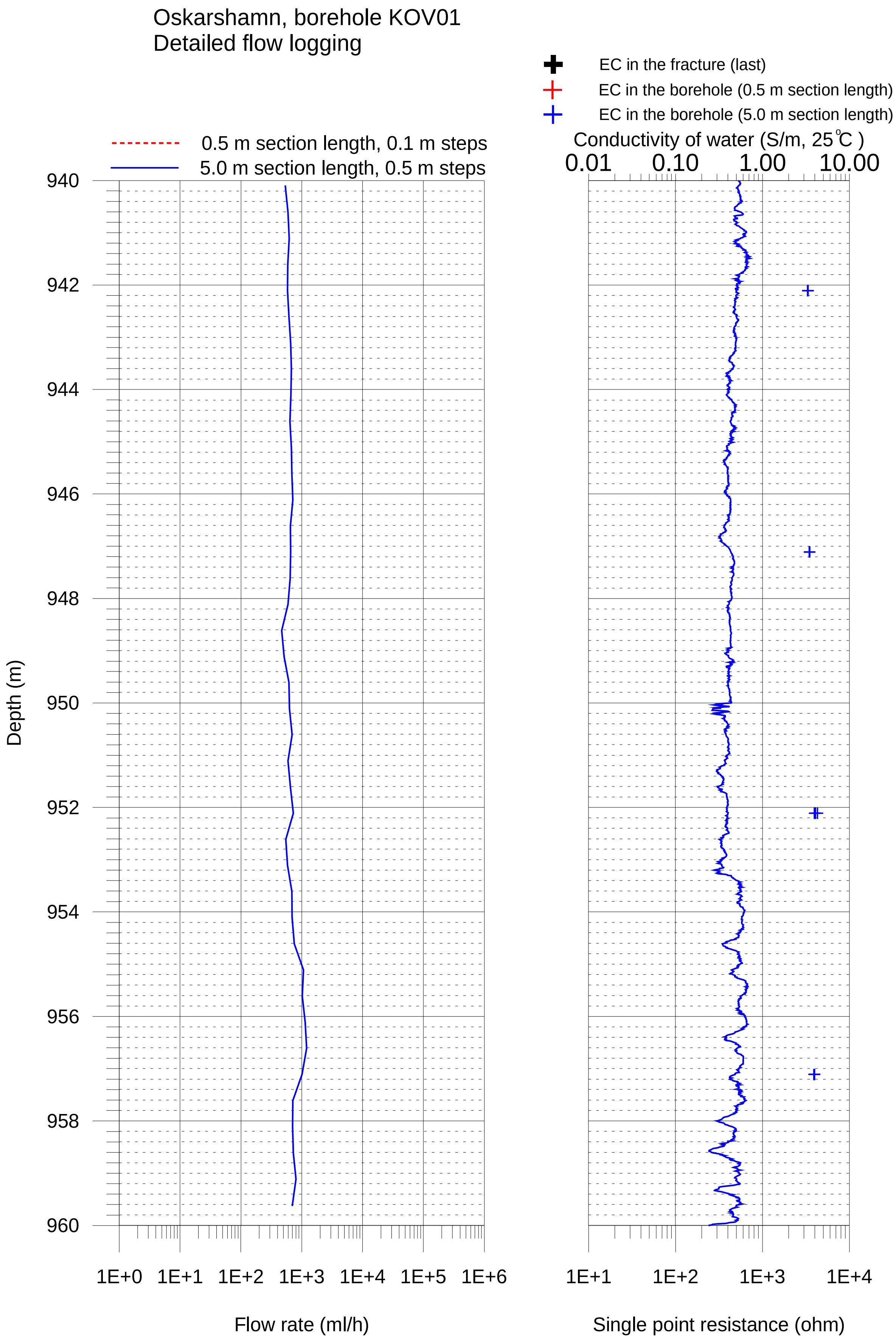
Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
860
862
864
866
868
870
872
874
876
878
880
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

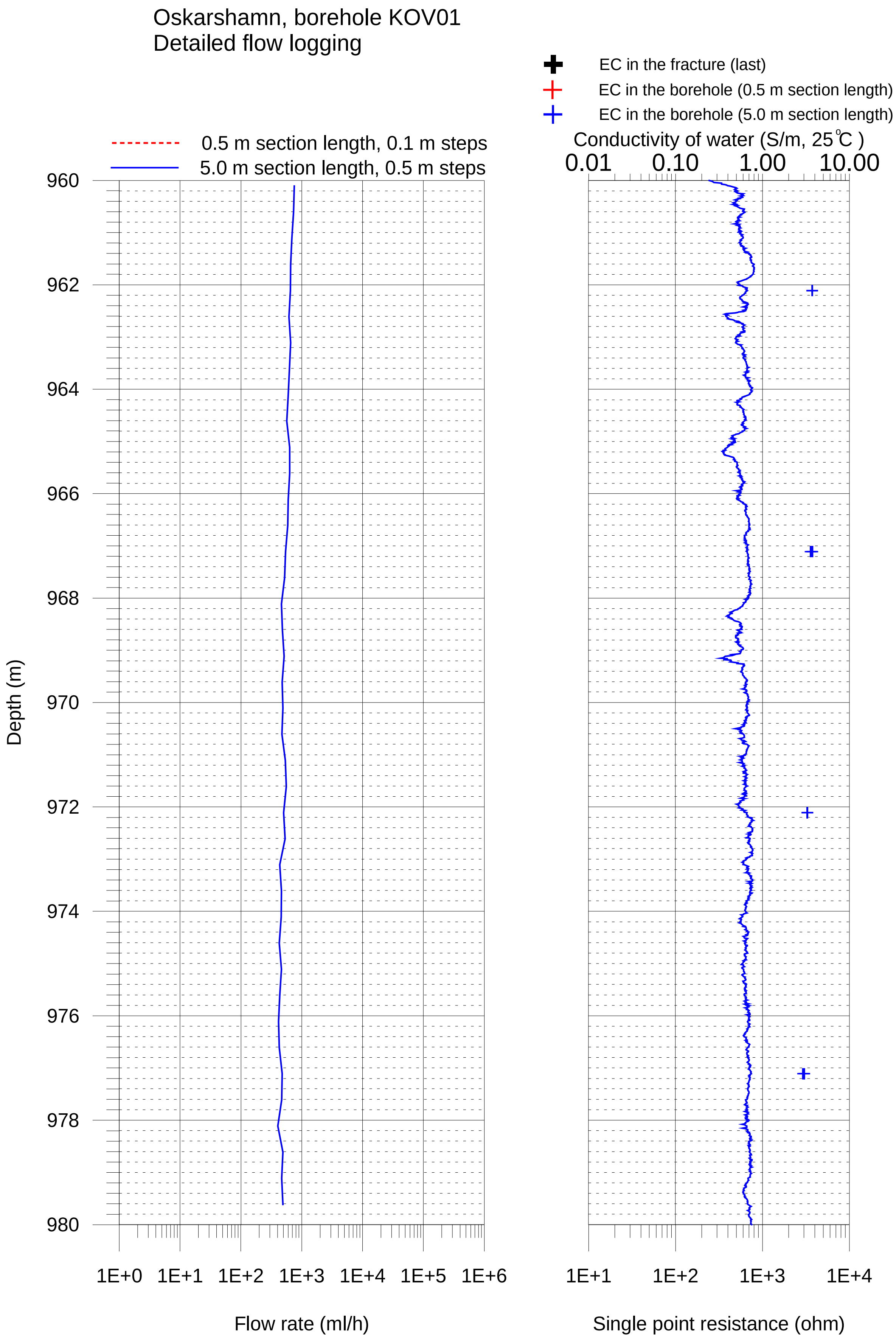

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
880
882
884
886
888
890
892
894
896
898
900
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

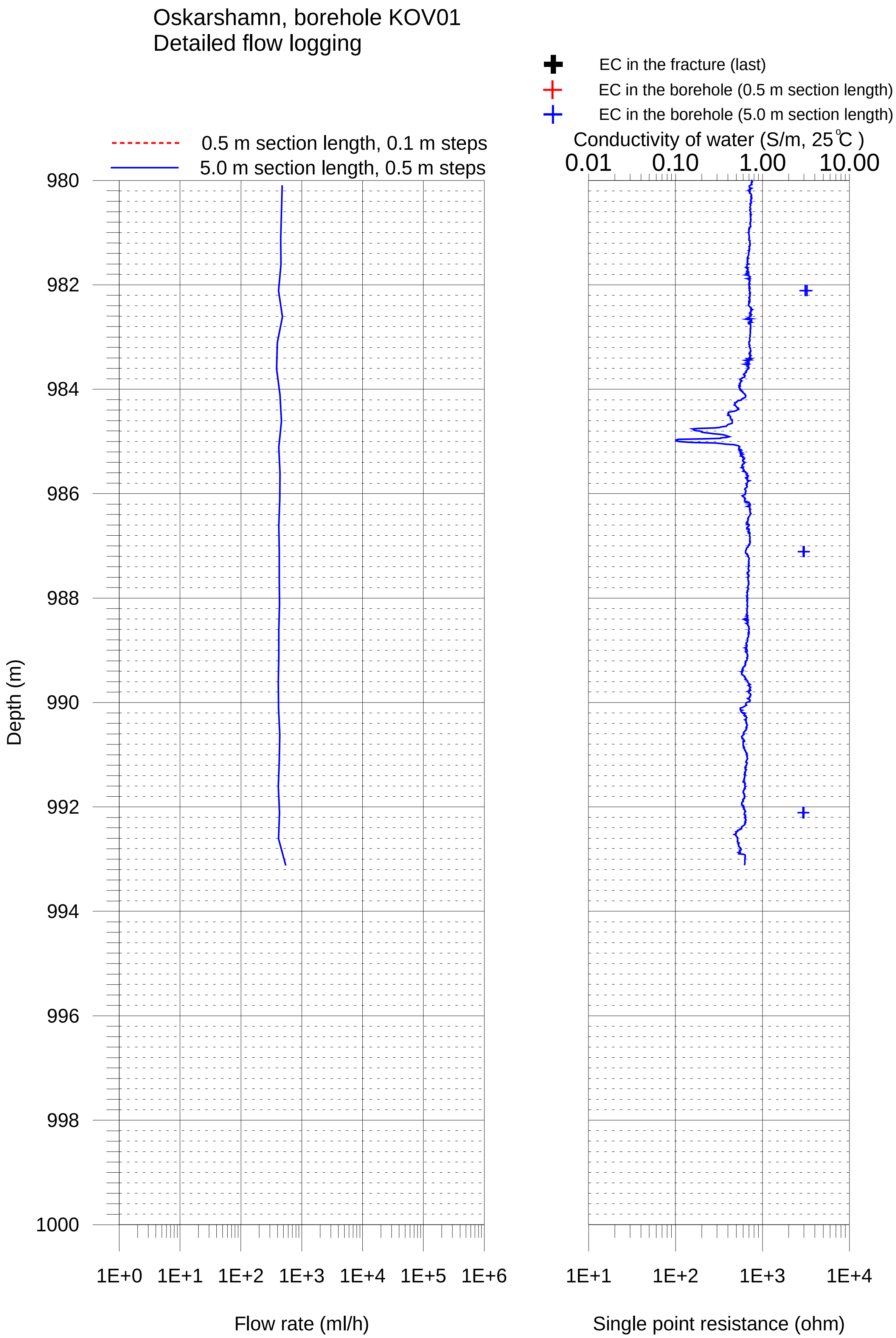
Oskarshamn, borehole KOV01
Detailed flow logging



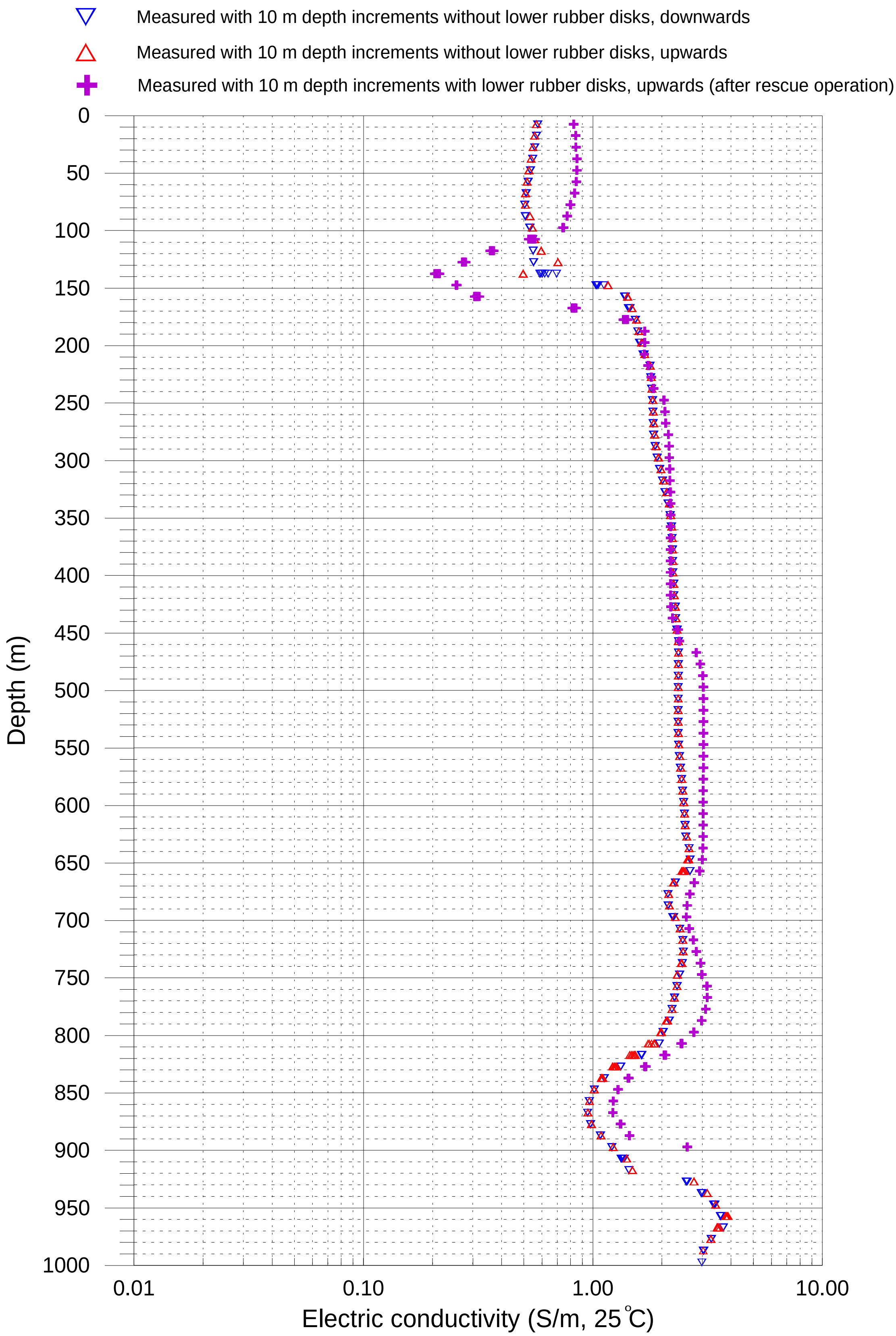

Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
920
922
924
926
928
930
932
934
936
938
940
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)


Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Depth (m)
940
942
944
946
948
950
952
954
956
958
960
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

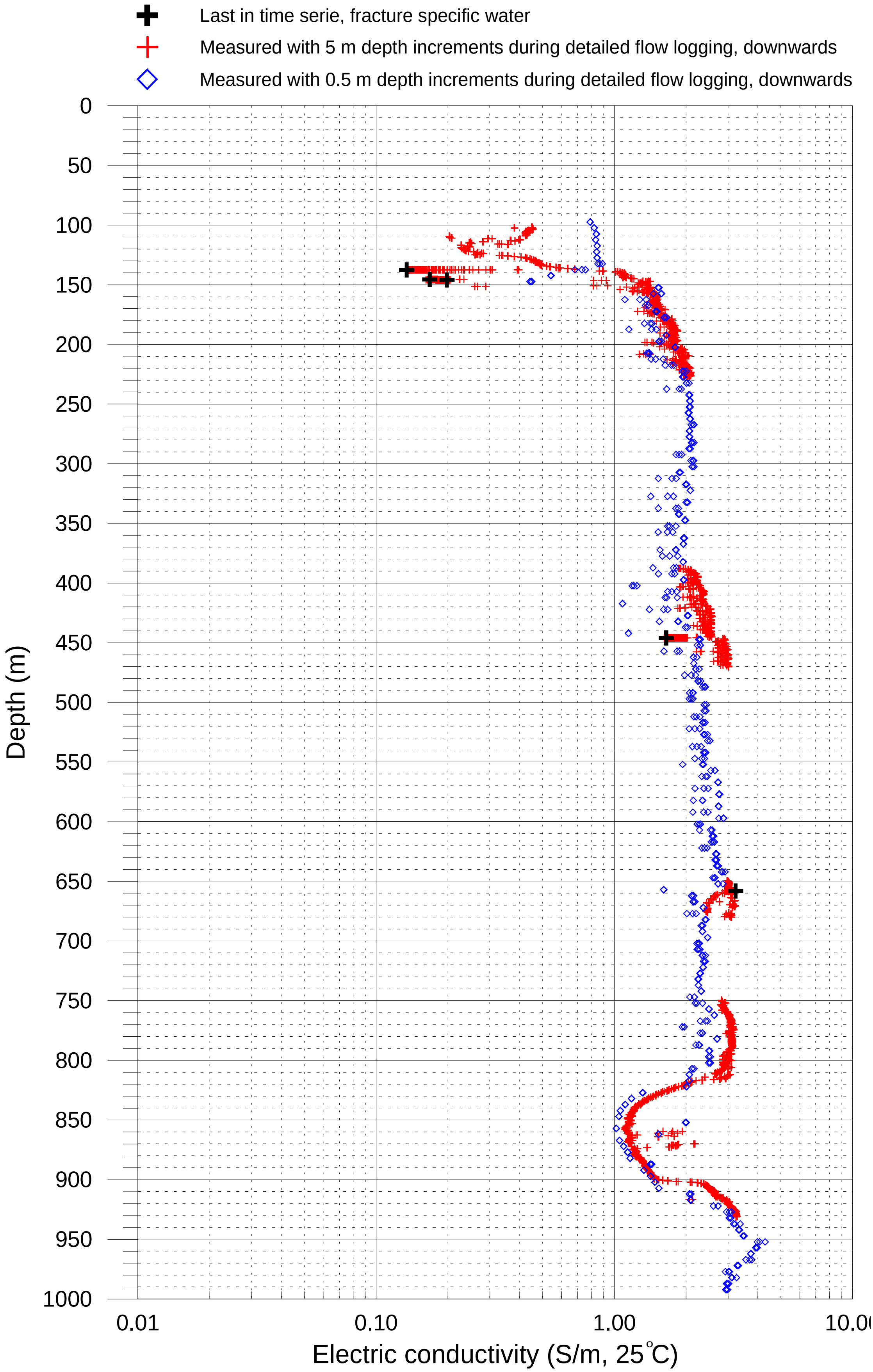

Oskarshamn, borehole KOV01
Detailed flow logging
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
Depth (m)
960
962
964
966
968
970
972
974
976
978
980
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)


Oskarshamn, borehole KOV01
Detailed flow logging
EC in the fracture (last)
EC in the borehole (0.5 m section length)
EC in the borehole (5.0 m section length)
0.5 m section length, 0.1 m steps
5.0 m section length, 0.5 m steps
Conductivity of water (S/m, 25℃)
0.01
0.10
1.00
10.00
980
982
984
986
988
990
992
994
996
998
1000
Depth (m)
1E+0
1E+1
1E+2
1E+3
1E+4
1E+5
1E+6
Flow rate (ml/h)
1E+1
1E+2
1E+3
1E+4
Single point resistance (ohm)

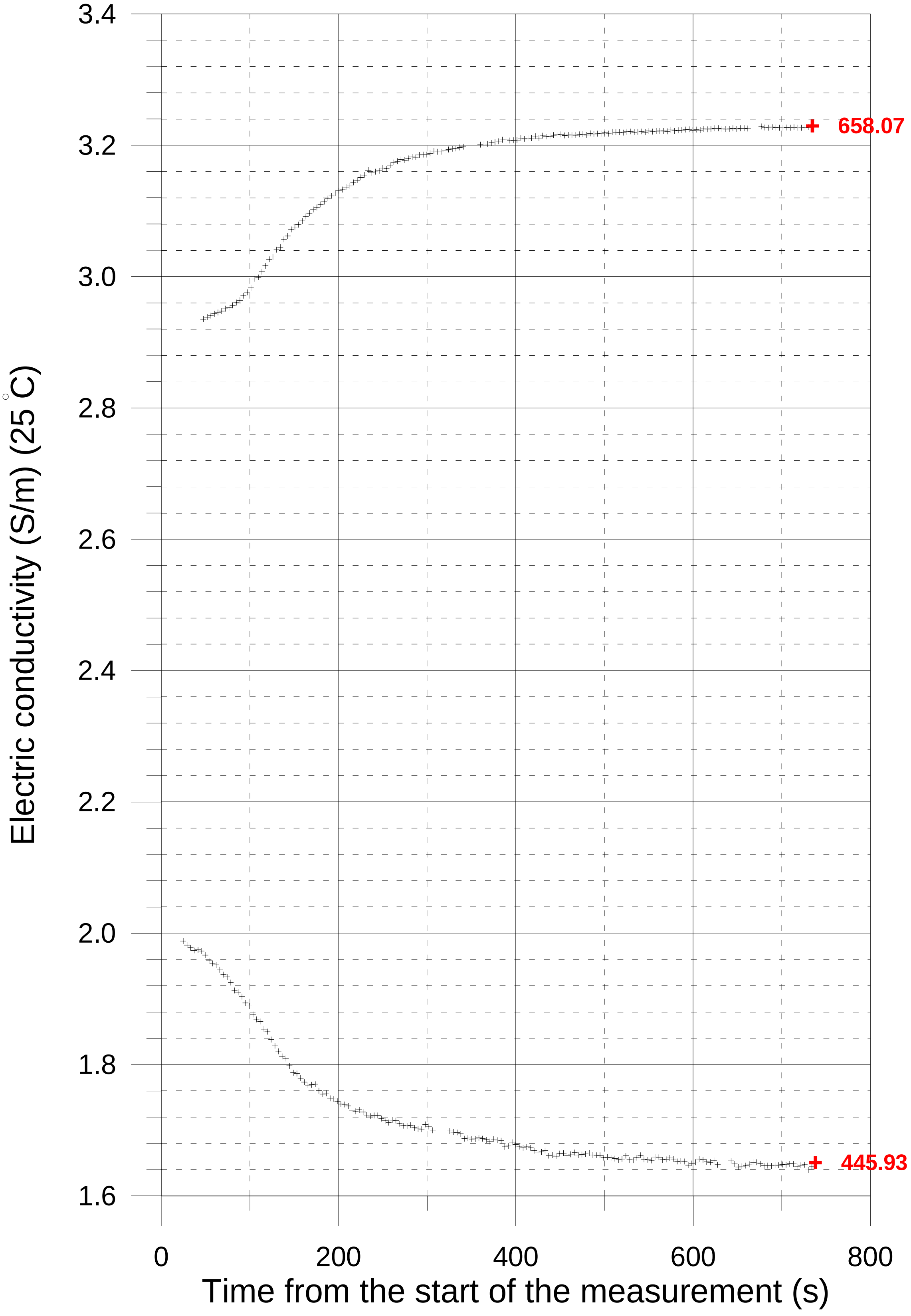
Electric conductivity of borehole water
Oskarshamn, borehole KOV01



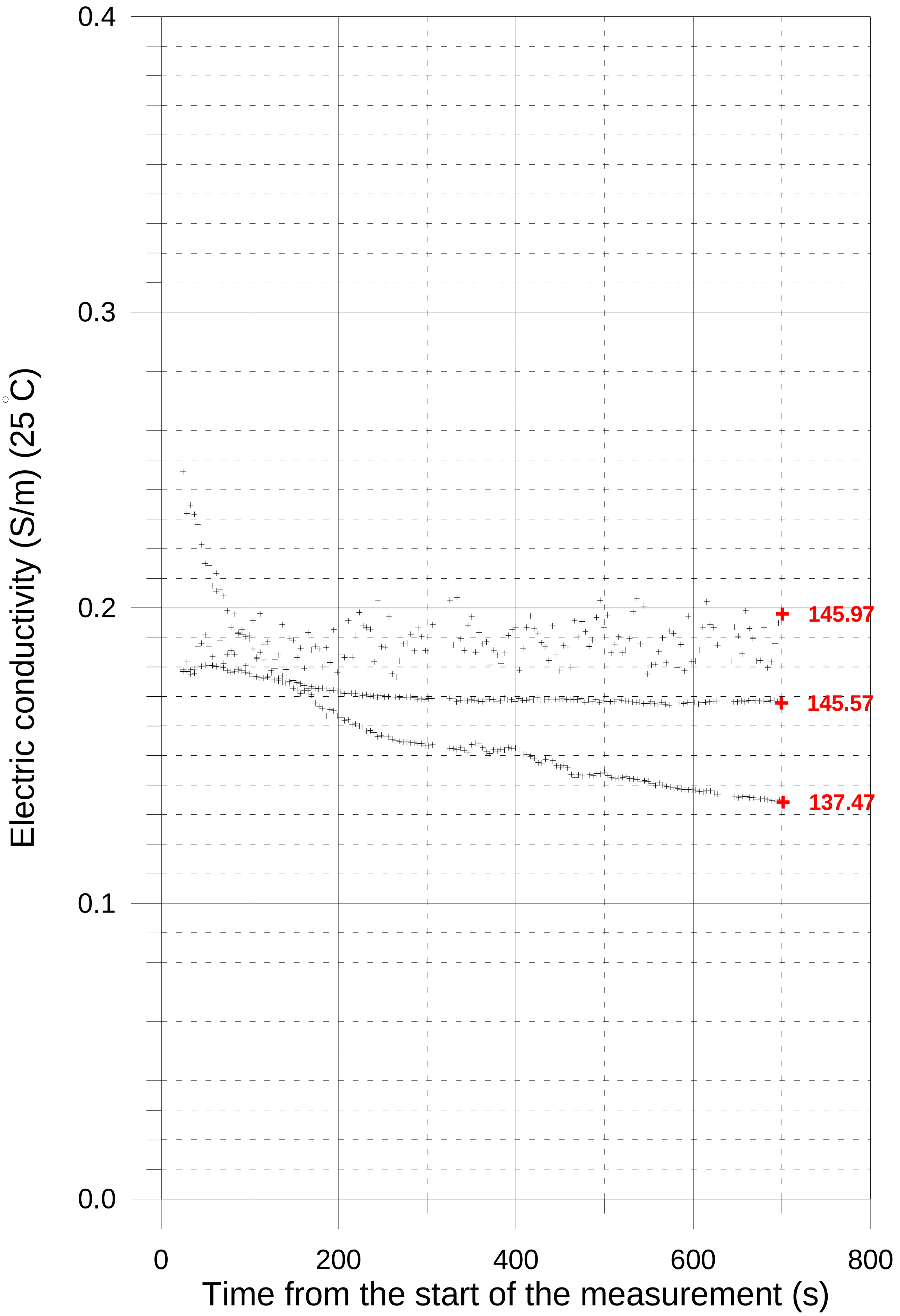
Electric conductivity of borehole water
Oskarshamn, borehole KOV01



TIME SERIES OF ELECTRIC CONDUCTIVITY
Oskarshamn, KOV01

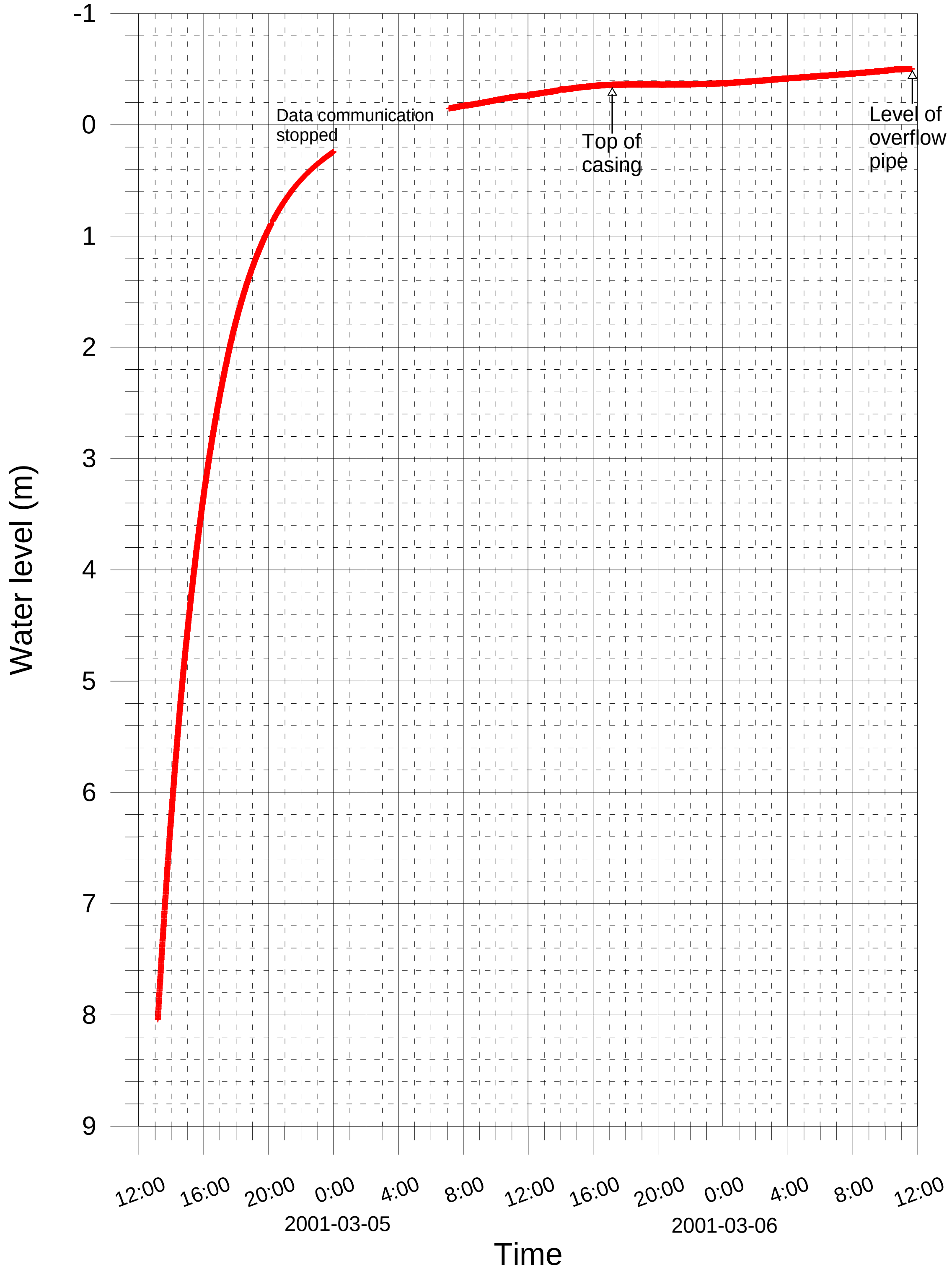


TIME SERIES OF ELECTRIC CONDUCTIVITY
Oskarshamn, KOV01



Temperature of borehole water
Oskarshamn, borehole KOV01

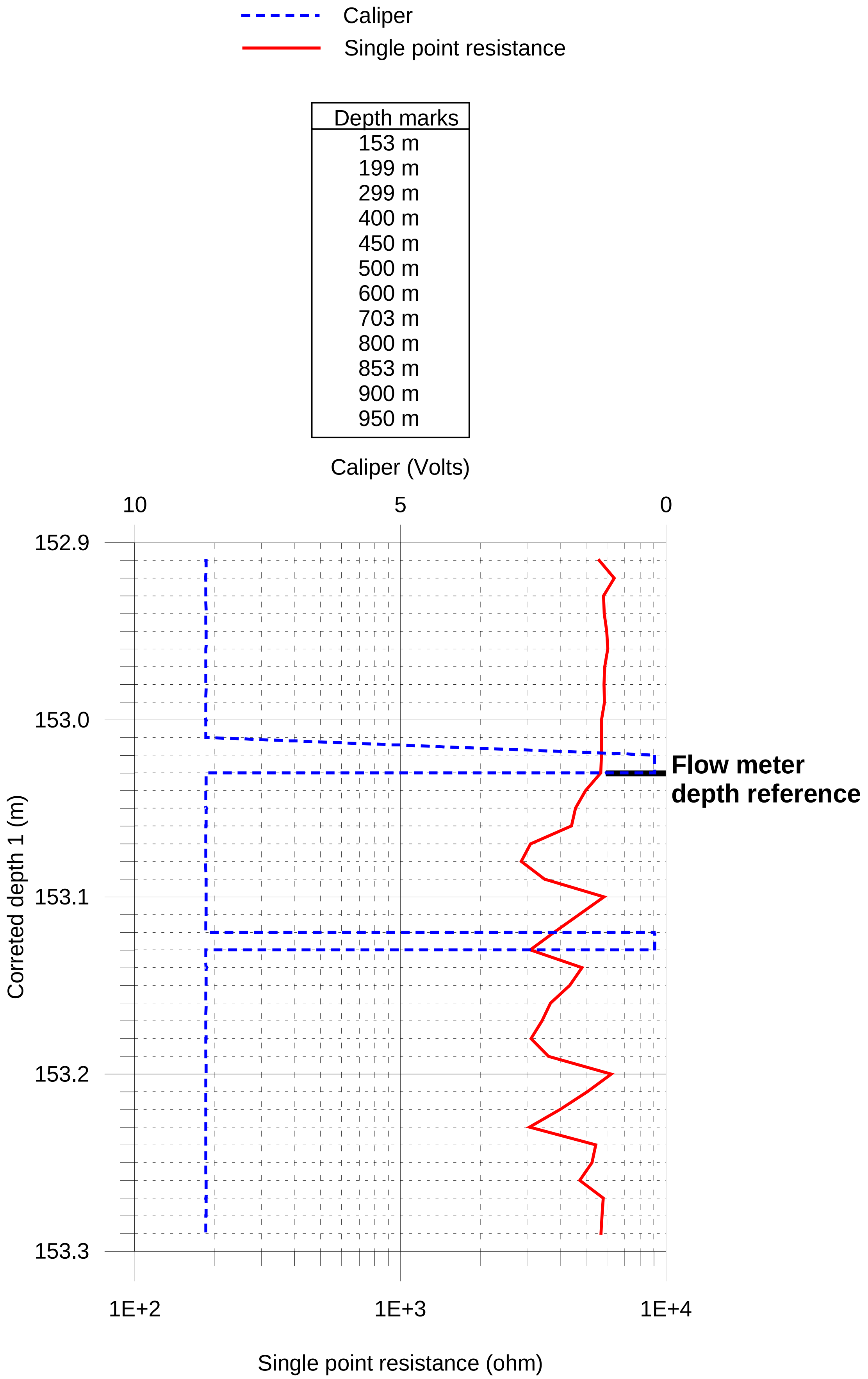
Oskarshamn, borehole KOV01
Measurement of groundwater recovery
Vertical water level below zero level



Oskarshamn, borehole KOV01, depth calibrations in the borehole

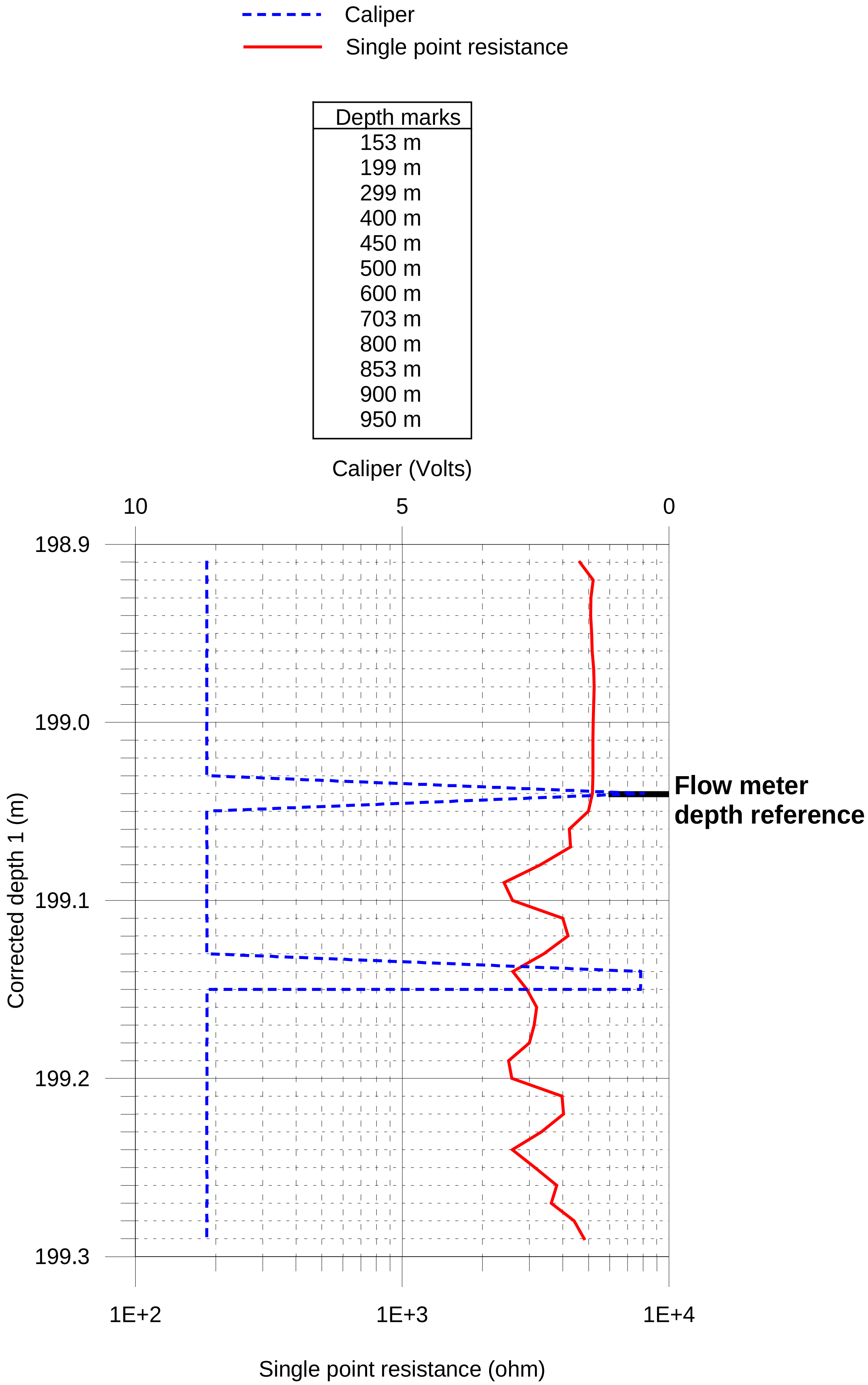
Correted depth 1 = Uncorrected cable depth - 2.6 m

Depth marks
153 m
199 m
299 m
400 m
450 m
500 m
600 m
703 m
800 m
853 m
900 m
950 m



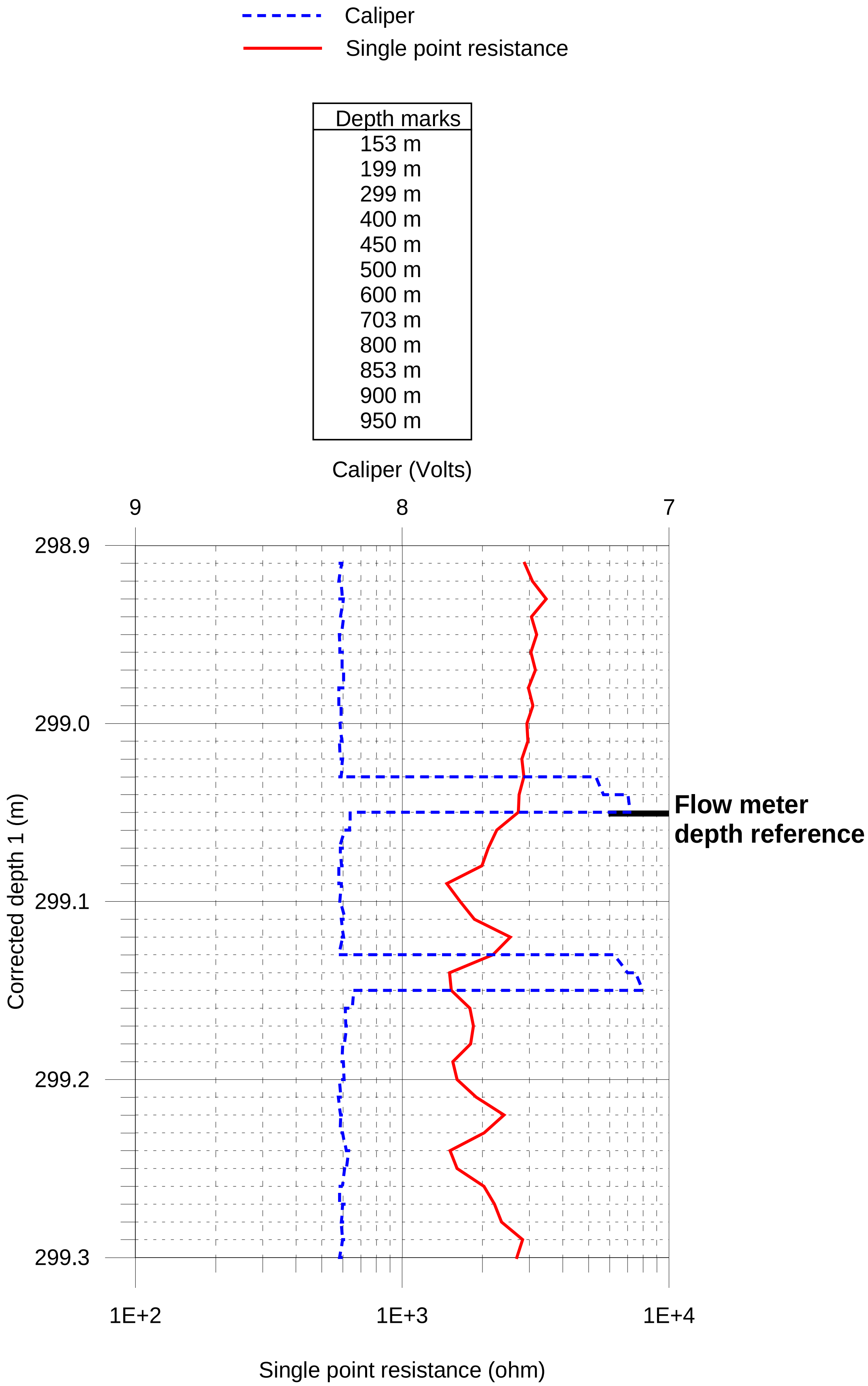
Oskarshamn, borehole KOV01, depth calibrations in the borehole

Correted depth 1 = Uncorrected cable depth - 2.6 m



Oskarshamn, borehole KOV01, depth calibrations in the borehole

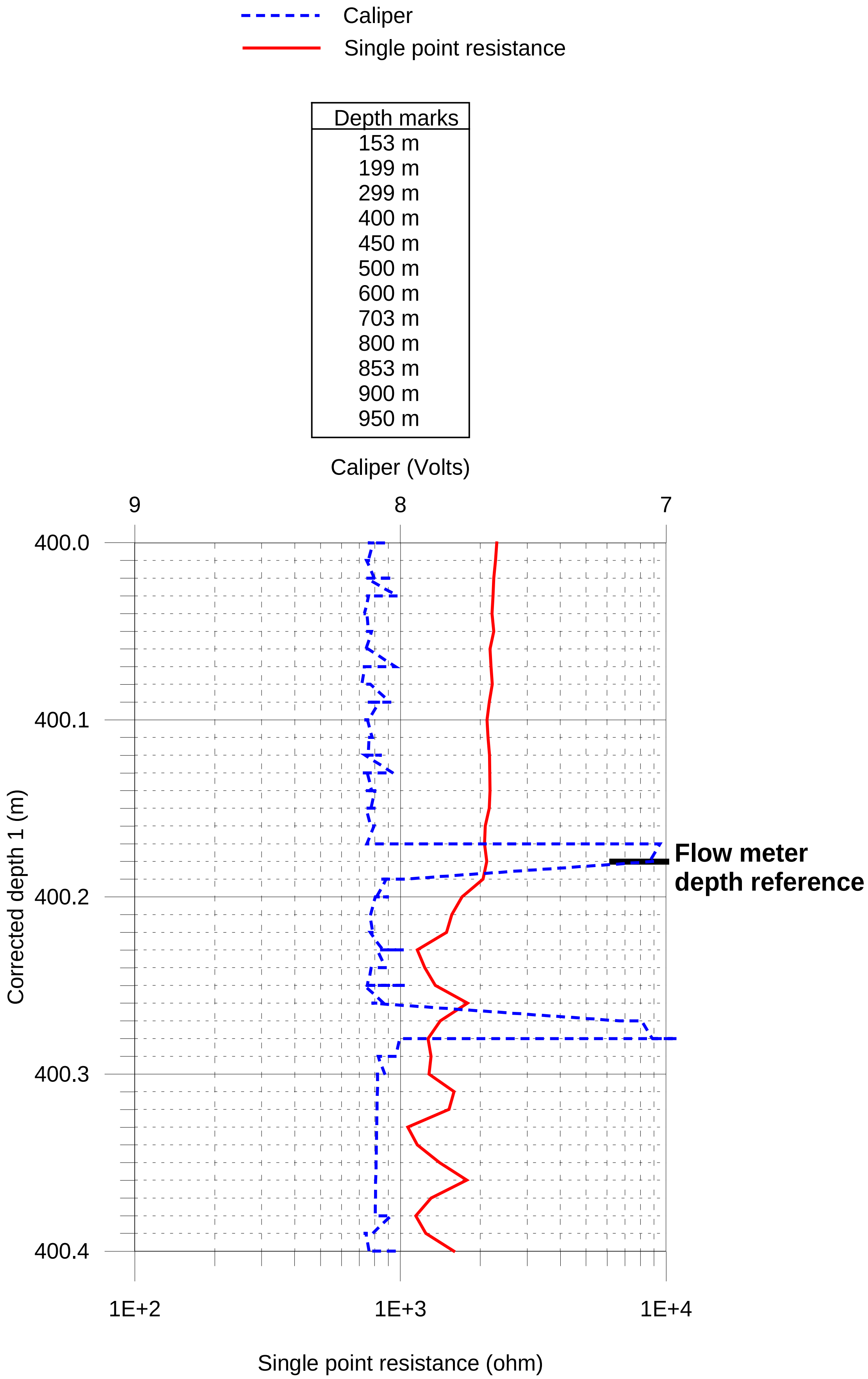
Correted depth 1 = Uncorrected cable depth - 2.6 m



Oskarshamn, borehole KOV01, depth calibrations in the borehole

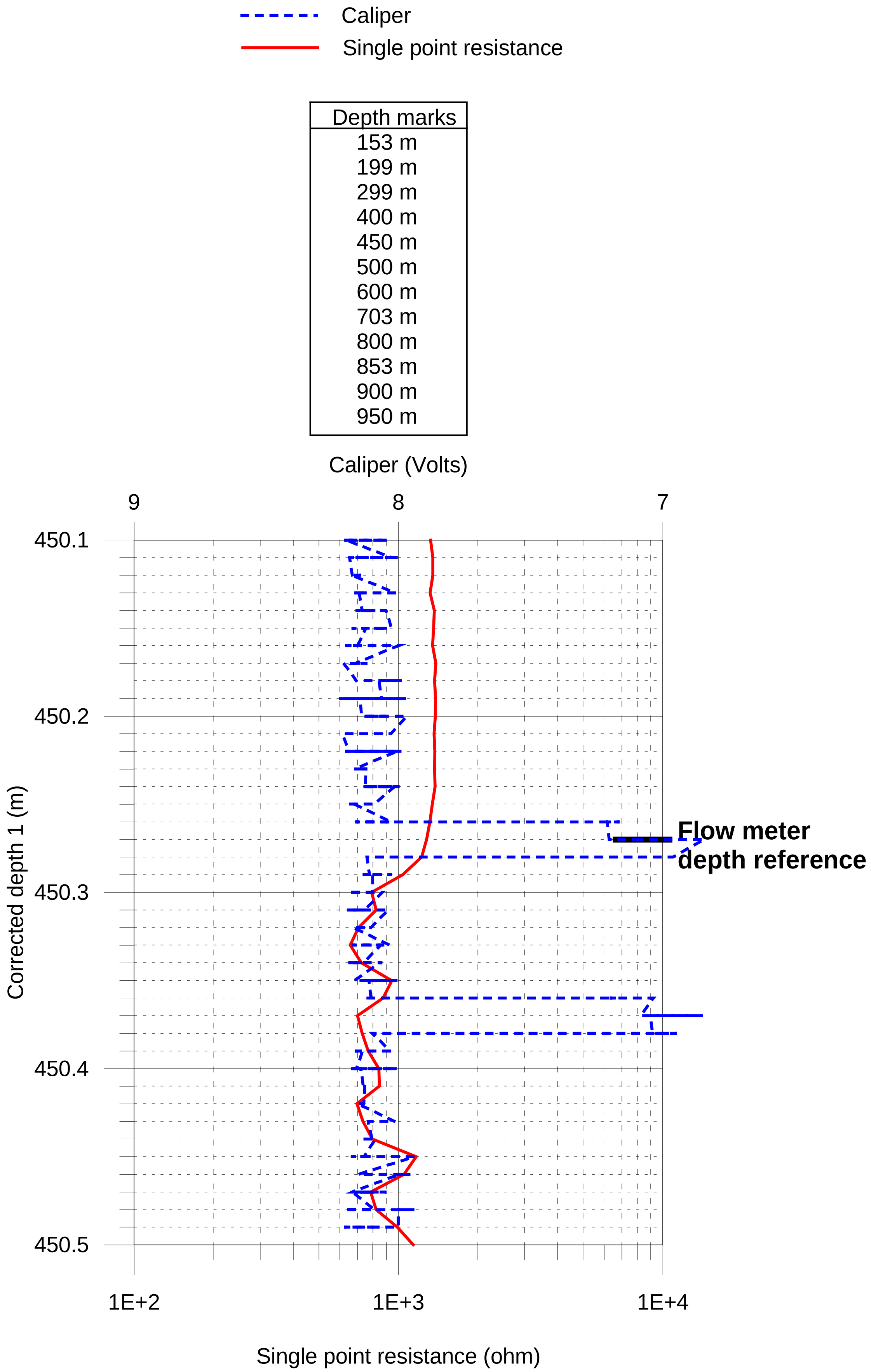
Correted depth 1 = Uncorrected cable depth - 2.6 m

Depth marks
153 m
199 m
299 m
400 m
450 m
500 m
600 m
703 m
800 m
853 m
900 m
950 m



Oskarshamn, borehole KOV01, depth calibrations in the borehole

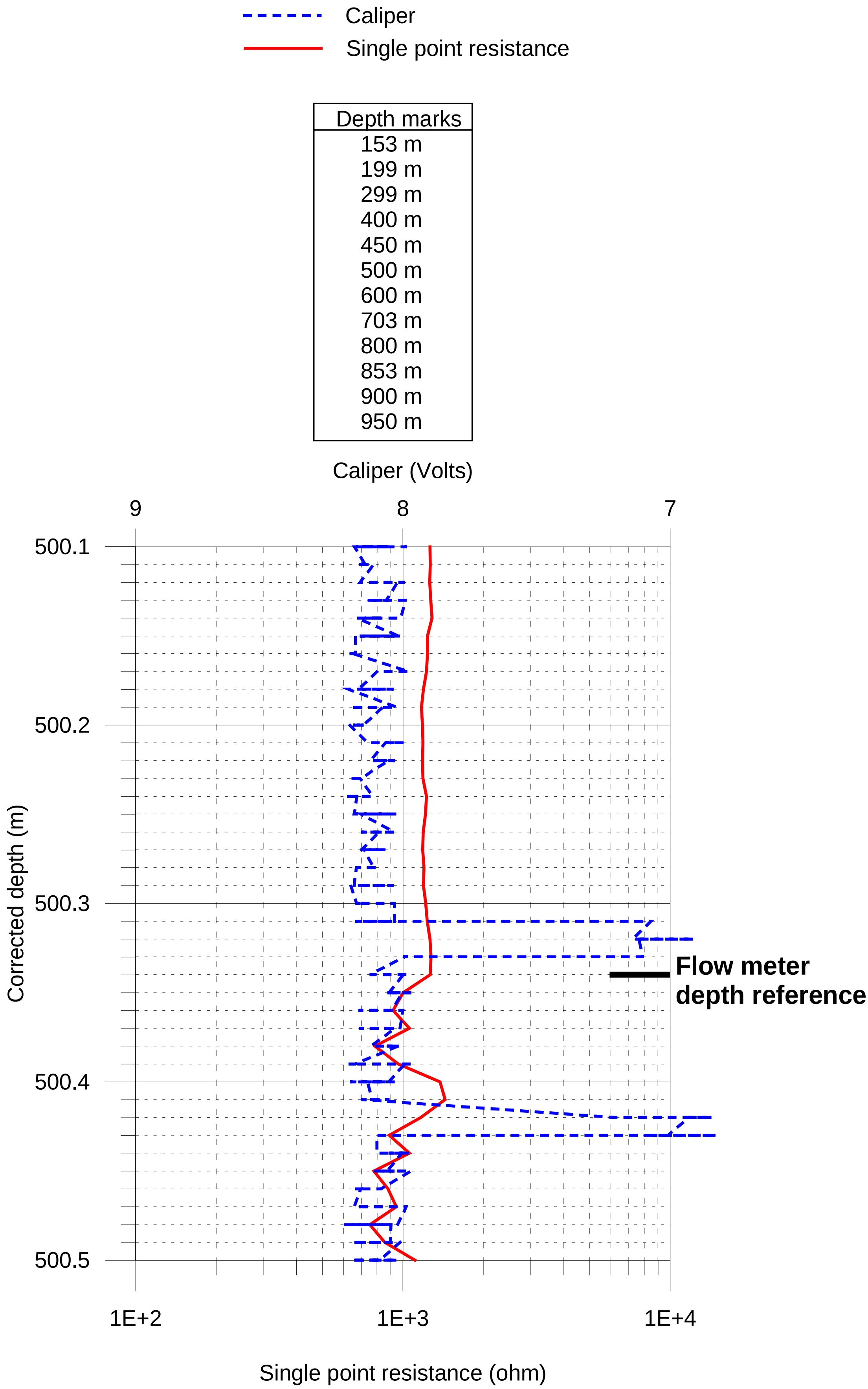
Correted depth 1 = Uncorrected cable depth - 2.6 m



Oskarshamn, borehole KOV01, depth calibrations in the borehole

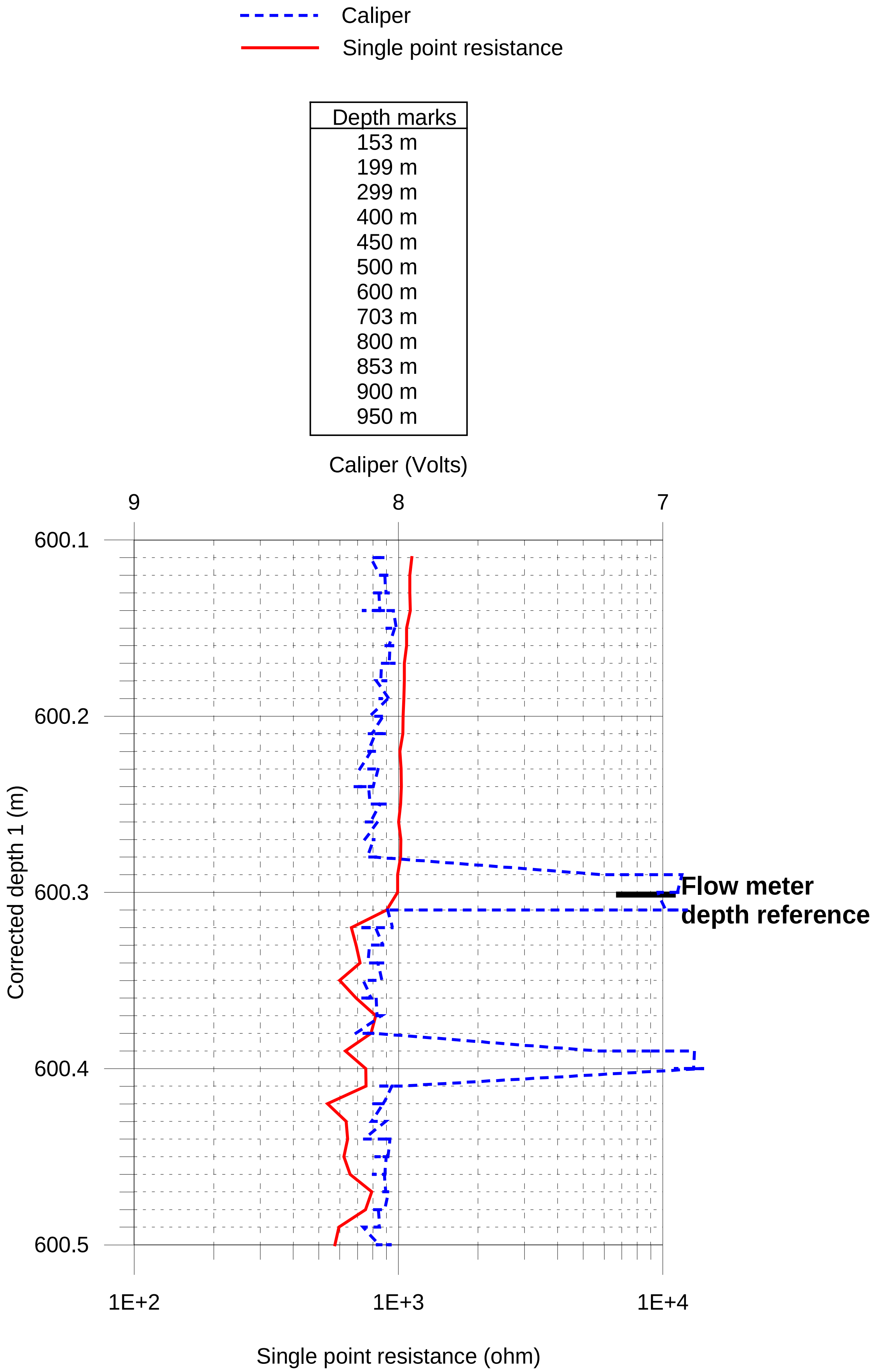
Correted depth 1 = Uncorrected cable depth - 2.6 m

Depth marks
153 m
199 m
299 m
400 m
450 m
500 m
600 m
703 m
800 m
853 m
900 m
950 m



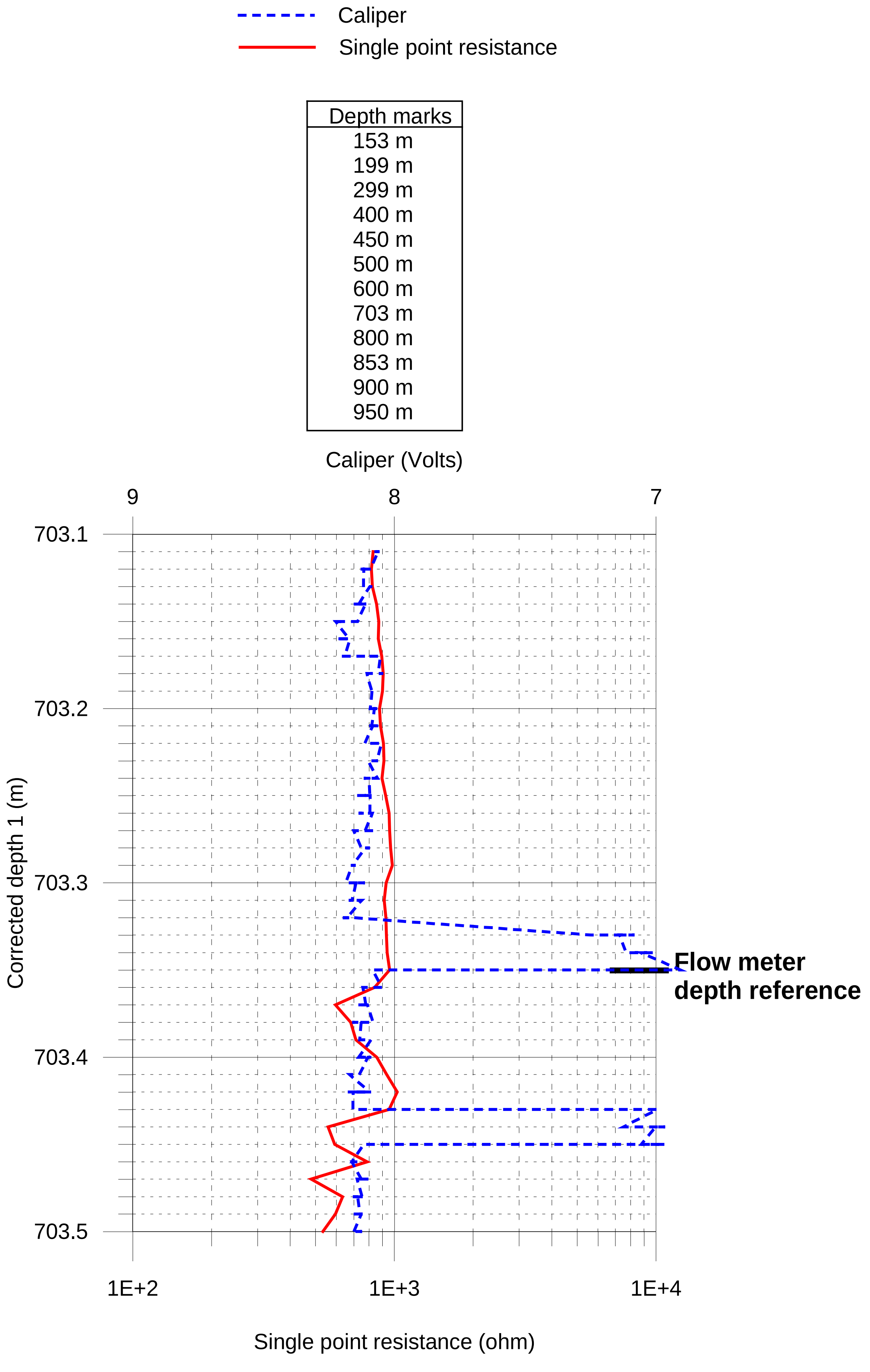
Oskarshamn, borehole KOV01, depth calibrations in the borehole

Correted depth 1 = Uncorrected cable depth - 2.6 m



Oskarshamn, borehole KOV01, depth calibrations in the borehole

Correted depth 1 = Uncorrected cable depth - 2.6 m

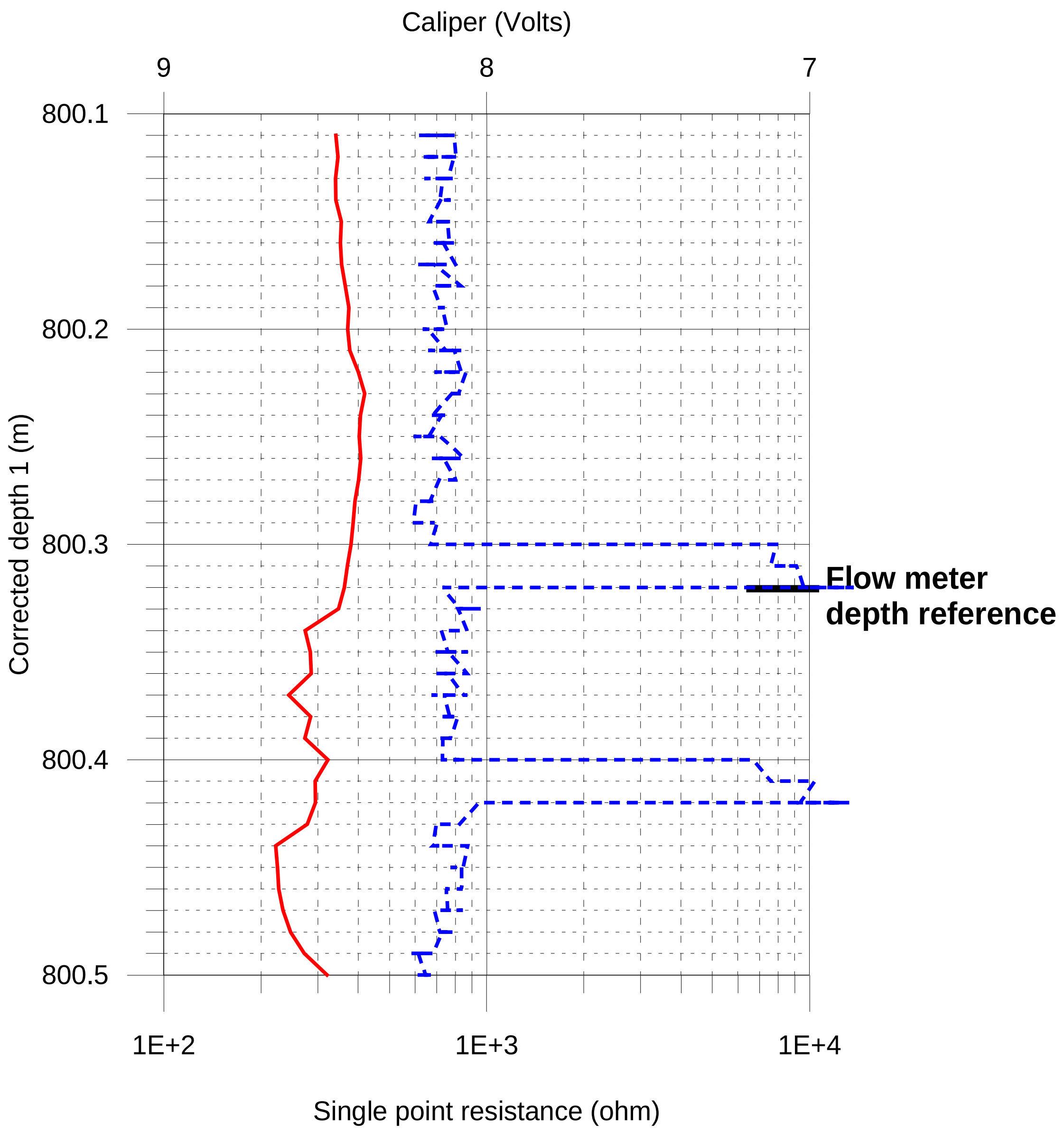


Depth marks
153 m
199 m
299 m
400 m
450 m
500 m
600 m
703 m
800 m
853 m
900 m
950 m

Oskarshamn, borehole KOV01, depth calibrations in the borehole

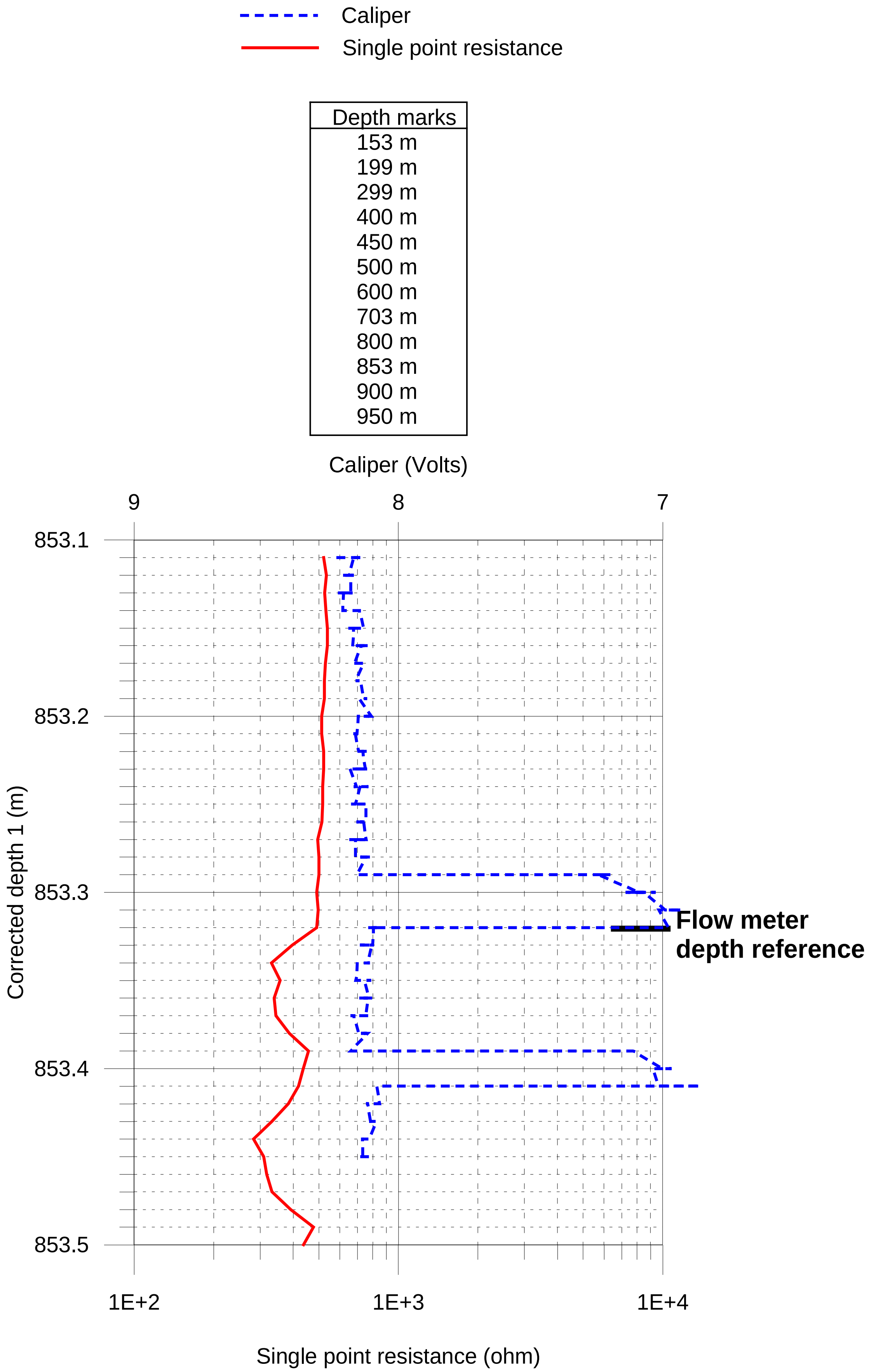
Correted depth 1 = Uncorrected cable depth - 2.6 m

Depth marks
153 m
199 m
299 m
400 m
450 m
500 m
600 m
703 m
800 m
853 m
900 m
950 m



Oskarshamn, borehole KOV01, depth calibrations in the borehole

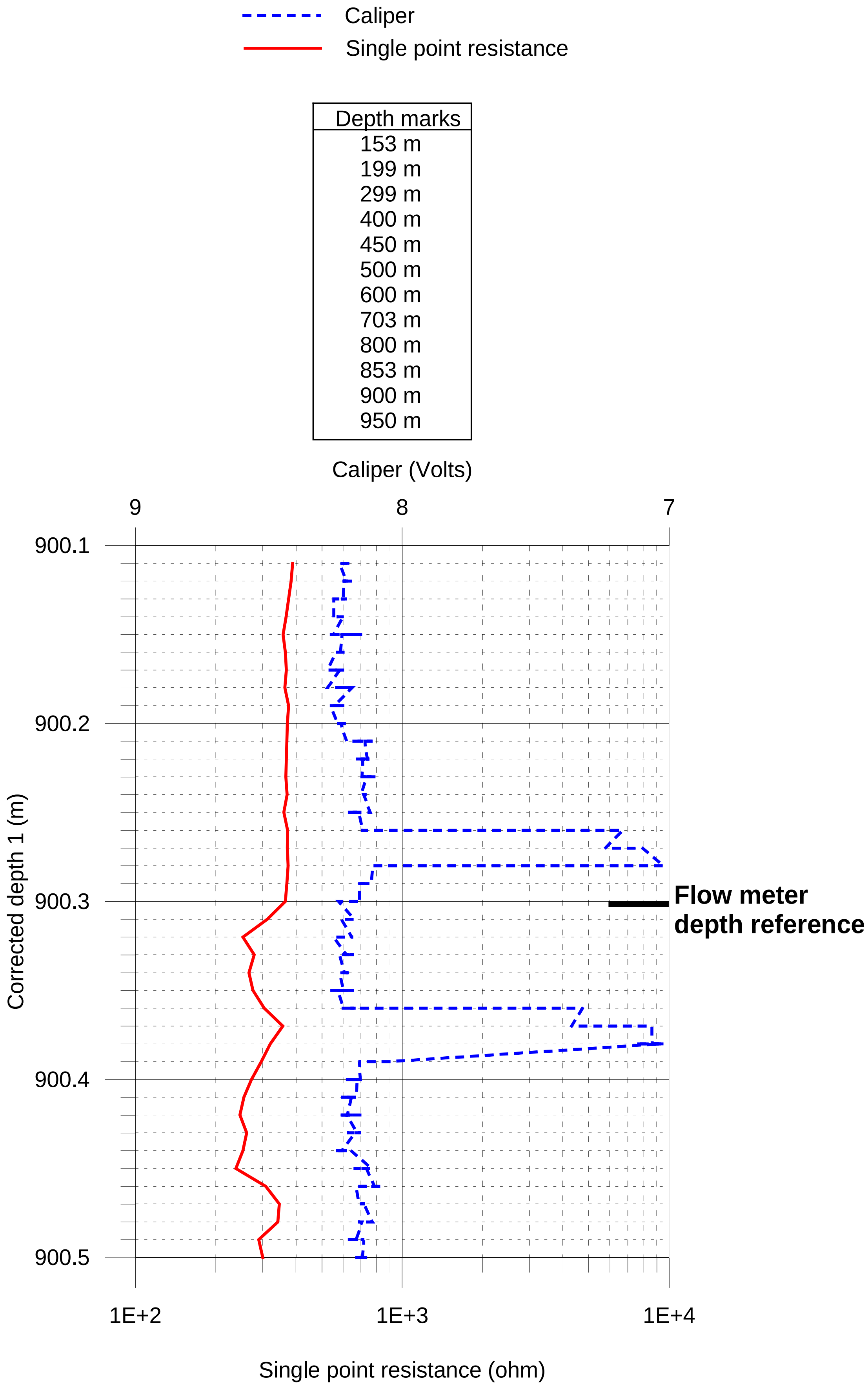
Correted depth 1 = Uncorrected cable depth - 2.6 m



Oskarshamn, borehole KOV01, depth calibrations in the borehole

Correted depth 1 = Uncorrected cable depth - 2.6 m

Depth marks
153 m
199 m
299 m
400 m
450 m
500 m
600 m
703 m
800 m
853 m
900 m
950 m



Oskarshamn, borehole KOV01, depth calibrations in the borehole

Correted depth 1 = Uncorrected cable depth - 2.6 m

Depth marks
153 m
199 m
299 m
400 m
450 m
500 m
600 m
703 m
800 m
853 m
900 m
950 m