Difference flow and electric conductivity measurements at the Olkiluoto site in Eurajoki, boreholes KR13 and KR14

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DIFFERENCE FLOW AND ELECTRIC CONDUCTIVITY MEASUREMENTS AT THE OLKILUOTO SITE IN EURAJOKI, BOREHOLES KR13 AND KR14

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. The flow sensor for flow along a borehole and special flow guide are used for this measurement. This report presents the principles of the method as well as the results of the measurements carried out in boreholes KR13 and KR14 at Olkiluoto between June and September 2001.

The boreholes were measured with 2 m section length. Flow into or out from the borehole was monitored in these test sections. The flow was measured first with pumping water from the borehole. Depth intervals were measured also without pumping if flow was detected with pumping. In addition to this, a detailed flow log was performed with 0.1 m point intervals using 0.5 m section length. The flow guide encloses an electrode for single point resistance measurement, which was also carried out with 0.01 m point intervals during the flow measurements.

Electric conductivity (EC) of fracture specific water was measured at chosen fractures. These fractures were chosen on the basis of the measured flow rate from the fractures into the borehole.

Keywords: Groundwater, flow, measurement, bedrock, borehole, electric conductivity, Posiva Flow Log.
VIRTAUSERO- JA SÄHKÖNJOHTAVUUSMITTAUKSET EURAJOEN OLKILUODOSSA, KAIRANREIÄT KR13 JA KR14

TIIVISTELMÄ


Eromittausmenetelmällä voidaan suhteellisen nopeasti mitata reiässä vyöhykkeiden vedenjohtavuus ja painekorkeus. Menetelmässä käytetään virtausmittarin pystyvirtausanturia ja uudentyyppistä virtausohjainta.

Mittaukset tehtiin kahden metrin mittausvälillä. Mittausväliltä mitattiin veden virtaus reikään tai reiästä kellion. Tämä tehtiin sekä pumppauksen aikana että ilman pumppausta. Lisäksi tehtiin yksityiskohtainen virtausmittaus 0,1 m pistevälein käyttäen 0,5 m mittausväliä. Virtausohjaimessa on myös elektrodi yksipistemäaidusvastusmittaukseen. Tämä mitattiin virtausmittausten yhteydessä 0,01 m pistevälein.

Veden sähkönjohtavuutta (EC) mitattiin valittujen rakojen kohdalla. Raot valittiin raosta reikään mitatun virtauksen perusteella.

Avainsanat: Pohjavesi, virtaus, mittaus, peruskallio, kairanreikä, sähkönjohtavuus, Posiva Flow Log.
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INTRODUCTION

Posiva Oy started operating on January 1st, 1996 and it is a company founded jointly by Teollisuuden Voima Oy (TVO) and Fortum Oy (previously Imatran Voima Oy). Posiva Oy is responsible for the final disposal of spent fuel from the Olkiluoto and Loviisa nuclear power plants. The research and development work related to the final disposal of spent fuel has been transferred to Posiva.

The preliminary bedrock investigations related to the final disposal of spent nuclear fuel have been carried out in five areas during the years 1987-1992. The site investigation programme continued with detailed investigations in three areas during 1993-2000: Romuvaara in Kuhmo, Kivetty in Äänekoski and Olkiluoto in Eurajoki. Posiva decided to begin investigations also at Hästholmen in Loviisa during 1997. In 1999 Posiva submitted an application to the government for the decision in principle. Posiva proposed the Olkiluoto site as the final disposal site for the deep repository. The Council of State issued a positive policy decision in December 2000. The Parliament ratified the decision in May 2001. Thus the investigations will be concentrated on Olkiluoto.

One of the objectives of the site investigations is the determination of groundwater conditions in the bedrock. Using a special flow guide, flow into the borehole or out from the hole at a chosen depth interval can be measured directly, instead of measuring flow along the borehole. This method is called difference flow logging because differences of flow along the borehole are measured. Flows from fractures into (the borehole) or from the borehole (into the fractures) are all changes of flow along the borehole. The method makes it possible to obtain the hydraulic conductivity of the bedrock and the hydraulic head in fractures. One of the advantages of the method is that it is faster than the conventional double packer injection test.

The equipment can be used in boreholes with a diameter of 56 mm or larger and with a depth less than 1500 m. The equipment consists of a trailer-mounted winch and a cable, a downhole probe and a PC computer.

Difference flow tests were performed in boreholes KR13 and KR14 at the Olkiluoto investigation site. The locations of the boreholes are shown in Figure 1-1.
Figure 1-1. Locations of boreholes at the Olkiluoto site.
2 PRINCIPLES OF OPERATION

The ordinary borehole flowmeters measure flow along a borehole. However, the changes of flow with depth are generally useful, not the flow along the borehole itself. The changes of flow are leaks from the bedrock into the borehole or flows from the borehole into the bedrock. High flow rate along the borehole may conceal small changes of the flow when ordinary flowmeters are used. This problem can be avoided if flow into or out from the borehole is measured directly (Öhberg and Rouhiainen 2000).

With the flow guide, 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. Instead of inflatable packers, rubber disks are used at both ends of the test section. These disks guide the flow to be measured, see Figure 2-1.

The difference flow meter can be used in normal or detailed flow logging modes. In the normal mode both thermal pulse and thermal dilution flow measurement techniques are used. The normal mode is used for determination of hydraulic conductivity and head (Öhberg and Rouhiainen 2000). In the detailed flow logging mode only thermal dilution method is used to make the measurement faster and the depth increment between measurements is small.

Groundwater level in the borehole is kept constant by using a pump in the upper part of the borehole. The hydraulic head in the borehole is then constant, since the hydraulic conductivity of the borehole is very high compared with the conductivity of bedrock. The difference in head over the rubber disks used in the flow guide is small since the tube connecting the section through the flow sensor to the rest of the borehole is open. The rubber disks are designed in such a way that they are always pressed against the borehole wall. Difference flow measurements differ from the conventional double packer tests in that there is no extra hydraulic pressure in the borehole section being measured.

Constant hydraulic head in the borehole implies that the water density in the hole is constant and that there are no losses due to friction. If this is not the case, the hydraulic head at the measuring depth needs to be ascertained.

A single difference flow measurement in normal mode at one depth interval normally takes 12 minutes. This time includes waiting time for temperature stabilisation, a flow measurement by the thermal pulse method, a flow measurement by the thermal dilution method and lifting of the cable to the next depth interval. The thermal dilution method is used to expand the range of measurement to include higher flow rates.
The detailed flow logging mode was also used in this study. It is normally used only with the borehole being pumped. The borehole section to be measured is separated by the flow guide. The length of the section is usually small, 0.5 m in this study. The flow rate is measured in small depth increments, typically 0.1 m. Only the thermal dilution method is used for flow measurement. This is done to speed up the measurement. The measuring range for flow rate is normally 2 – 5000 ml/min. The results are used to determine the exact location of hydraulically conductive fractures and to classify them by flow rates.

The single point resistance measurement (grounding resistance) is another option in Posiva Flow Log. 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 exact depth determination of fractures and geological structures.

For the measurement of electric conductivity (EC) of groundwater, the borehole is pumped so that the flow direction is always from the fractures into the borehole. This enables the determination of electric conductivity from fracture specific water. Both electric conductivity and temperature of flowing water from the fractures are measured (Rouhiainen 1999).

The water flowing from the fractures is guided through the flow sensor and through the EC electrode attached above it, see Figure 2.1. The flow measurement makes it possible to find the fractures suitable for the EC measurement. The tool is moved so that the fracture to be tested will be located at the lower end of the test section. The EC measurement begins if the flow rate is higher than a predetermined limit (Rouhiainen 1999).

The tool was kept on the selected fracture. The measurement was continued at the given depth allowing the fracture-specific water to enter the section. The waiting time for the EC measurement was automatically calculated from the measured flow rate. The aim was to flush the water volume within the test section well enough. The measuring computer was programmed to change the water volume (0.3 l) three times within the 0.5 m long test section. All these phases of the measurement can be carried out automatically controlled by the logging computer.
Figure 2-1. Schematic description of the downhole equipment used in difference flowmeter in normal mode.
3 INTERPRETATION

If measurements are carried out using two levels of potential in the borehole, then the hydraulic head in each of the sections and their conductivity can be calculated. It is assumed that a static flow condition exists (Rouhiainen 1996).

\[ Q_{n1} = K_n \cdot a \cdot (h_0 - h_1) \]
\[ Q_{n2} = K_n \cdot a \cdot (h_0 - h_2) \]

where \( Q_{n1} \) and \( Q_{n2} \) are the measured flows in a section, \( K_n \) is hydraulic conductivity, \( a \) is a constant depending on the flow geometry, \( h_1 \) and \( h_2 \) are the hydraulic heads in the hole, \( h_0 \) is the head of the measured zone far from the hole.

Since, in general, very little is known of the flow geometry, cylindrical flow without skin zones is assumed. Cylindrical flow geometry is also justified because the borehole is at a constant head and there are no strong pressure gradients along the borehole, except at the ends of the borehole. For cylindrical flow, constant \( a \) is:

\[ a = 2 \cdot \pi \cdot L / \ln(R/r_0) \]

where \( L \) is the length of the measured section, \( R \) is the distance to constant potential \( h_0 \) and \( r_0 \) is the radius of the hole.

The distance to constant potential \( h_0 \) is not known and it must be chosen. Here \( R/r_0 \) is chosen to be 500.

Hydraulic head and conductivity can be deduced from the two measurements:

\[ h_0 = (h_1 - b \cdot h_2) / (1 - b) \]
\[ K_n = \frac{(1/a) \cdot (Q_{n1} - Q_{n2})}{(h_2 - h_1)} \]

where \( b = Q_{n1} / Q_{n2} \)

Since the actual flow geometry is not known, calculated conductivity values should be taken as indicating orders of magnitude. As the calculated hydraulic heads do not depend on geometrical properties but only on the ratio of the flows measured at different heads in the borehole they should be less sensitive to unknown fracture geometry (Rouhiainen 1996).
4 EQUIPMENT SPECIFICATIONS

Type of instrument: Difference flowmeter
Winch: Mount Sopris Wna 10, 0.55 kW, 220 V/50 Hz.
Borehole diameters: 56 mm, 66 mm and 76 mm
Geometry of measurement: A variable length of test section can be used
Method of flow measurement: Thermal pulse and thermal dilution methods
Speed of measurement: Depends on the rate of flows to be measured
Range of flow rate: 0.1 - 5000 ml/min, both directions when both thermal pulse and thermal dilution methods are used
2 - 5000 ml/min when only thermal dilution method is used
Accuracy of flow rate: +/- 10 % of the current result.
Temperature: 0 – 40 °C, accuracy +/- 0.1 °C
Single point resistance: 1 – 100000 Ohm
Electric conductivity of water: Four point graphite electrode, 0.02 – 10 S/m, accuracy +/- 5 % of the current result
5 RESULTS

5.1 Difference flow logging in normal mode

The activity schedules of the measurements are presented in Table 5-1 and Table 5-2. Before the actual measurements the uppermost part of borehole KR13 was first studied because a highly conductive zone had been observed in the upper part of the borehole during drilling.

A casing tube was installed into borehole KR13 down to 4.2 m below ground surface on 4th of April 2001. Detailed flow logging measurements and flow measurements along the borehole were carried out in the upper part of the borehole, see Figure 5-1. There was fractured zone right below the casing tube. During pumping main part of flowing water came from that zone, see Figure 5-1. Pumping rate during the measurement of Figure 5-1 was 5 l/min and drawdown only 0.14 m.

Because of the high flow rate a longer casing tube was installed into borehole KR13 down to 10.28 m below ground surface.

![Figure 5-1. Flow measurements before reinstallation of casing tube in the borehole KR13](image)

Flow measurements were carried out in boreholes KR13 and KR14 using two meters section length. Normal mode (section 2 m, step 2 m) and detailed mode (section 2 m, step 0.5 m) measurements were carried out during the same run. The results of these measurements are presented in Appendices 4 and 11 (flow rates), 5 and 12 (fresh water heads and hydraulic conductivities), 7.1 and 14.1 (temperature of water in the borehole) for boreholes KR13 and KR14.

There was a strongly fractured zone in the borehole KR13 at depth between 451.04 – 459.23 m. The tool got stuck there after the normal mode measurements with pumping when the tool was lifted up. Risk that the tool would get stuck again was remarkable and measurements below 450 m were left out from the program. Because
of that only detailed mode (section 2 m, step 0.5 m) and normal mode (section 2 m, step 2 m) with pumping were measured below 450 m (see Appendices 1.23 – 1.25).

The depths of the plotted results represent the distance from the ground surface to the middle point of the test section. Flow values in the flow rate plots are shown using a logarithmic scale, see Appendices 4 and 11. The flows are shown in both directions, the left hand side of each diagram represents flow out from the borehole within a test section and the right hand side represents flow into the borehole within a test section. If the measured flow was zero it is not visible in the logarithmic scale of the appendices though all sections were measured.

Table 5-1. Measurements in borehole KR13, Activity schedule.

<table>
<thead>
<tr>
<th>Started</th>
<th>Finished</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.6.2001 9:00</td>
<td>20.7.2001 10:13</td>
<td>Pumping water from the borehole (see Figure 5-1.)</td>
</tr>
<tr>
<td>9.7.2001 11:00</td>
<td>9.7.2001 19:00</td>
<td>Pressure profile measurement using a plastic tube and borehole EC with pumping (without lower rubber disks).</td>
</tr>
<tr>
<td>10.7.2001 14:50</td>
<td>16.7.2001 14:10</td>
<td>Difference flow measurements, detailed flow logging (2 m section, 0.5 m step), single point resistance and borehole EC with pumping.</td>
</tr>
<tr>
<td>18.7.2001 9:45</td>
<td>20.7.2001 3:10</td>
<td>Detailed flow logging with pumping, single point resistance, borehole EC and EC of fracture specific water (0.5 m section, 0.1 m step).</td>
</tr>
<tr>
<td>1.8.2001 12:30</td>
<td>1.8.2001 15:00</td>
<td>Pressure profile measurement using a plastic tube and borehole EC without pumping (without lower rubber disks).</td>
</tr>
<tr>
<td>1.8.2001 16:20</td>
<td>2.8.2001 14:00</td>
<td>Difference flow measurements, detailed flow logging (2 m section, 0.5 m step), single point resistance and borehole EC without pumping.</td>
</tr>
</tbody>
</table>

Saline groundwater is typical in the bedrock at the Olkiluoto site. Variations of salinity cause variation in the density of the borehole water. Because of this hydraulic head is not constant with depth in the boreholes. Instead of hydraulic head, fresh water heads are used because hydraulic head is defined only for constant density groundwater conditions. Fresh water heads had to be measured separately.

Fresh water heads of borehole water were measured in the immediate vicinity of the test section in the boreholes with a plastic tube lowered from the ground surface. The plastic tube was filled with fresh water. The water level in the plastic tube determines the fresh water heads in the borehole at the test section. The sea level is the reference level. The ground surface is the reference level of the depth scale.

<table>
<thead>
<tr>
<th>Started</th>
<th>Finished</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.8.2001 17:47</td>
<td>20.8.2001 15:30</td>
<td>Pumping water from the borehole (see Figure 5-2.)</td>
</tr>
<tr>
<td>6.8.2001 13:00</td>
<td>6.8.2001 17:40</td>
<td>Pressure profile measurement using a plastic tube and borehole EC with pumping (without lower rubber disks).</td>
</tr>
<tr>
<td>6.8.2001 18:30</td>
<td>9.8.2001 5:30</td>
<td>Difference flow measurements, detailed flow logging (2 m section, 0.5 m step), single point resistance and borehole EC with pumping.</td>
</tr>
<tr>
<td>9.8.2001 9:40</td>
<td>20.8.2001 12:00</td>
<td>Detailed flow logging with pumping, single point resistance, borehole EC and EC of fracture specific water. (0.5 m section, 0.1 m step).</td>
</tr>
<tr>
<td>29.8.2001 11:20</td>
<td>29.8.2001 16:00</td>
<td>Pressure profile measurement using a plastic tube and borehole EC without pumping (without lower rubber disks).</td>
</tr>
<tr>
<td>3.9.2001 8:30</td>
<td>4.9.2001 14:30</td>
<td>Difference flow measurements, detailed flow logging (2 m section, 0.5 m step), single point resistance and borehole EC without pumping.</td>
</tr>
</tbody>
</table>

Technical information on the boreholes is presented in Table 5-3.

Table 5-3. Technical information on the boreholes.

<table>
<thead>
<tr>
<th>Borehole</th>
<th>Z-ground-level (m)</th>
<th>Z-top of casing (m)</th>
<th>Inclination (degrees)</th>
<th>Diameter (mm)</th>
<th>Depth (m)</th>
<th>Casing (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KR13</td>
<td>5.80</td>
<td>6.22</td>
<td>55.0</td>
<td>76</td>
<td>500.21</td>
<td>0 – 10.28</td>
</tr>
<tr>
<td>KR14</td>
<td>8.27</td>
<td>8.77</td>
<td>69.9</td>
<td>76</td>
<td>514.10</td>
<td>0 – 9.52</td>
</tr>
</tbody>
</table>

Flows were measured using two different pressure profiles in the borehole. Measurements were done first with pumping (Pressure profile 2). Depth intervals were measured also without pumping (Pressure profile 1) if there was any flow measured with pumping. The pumping rates are presented in Figures 5-2 and 5-3.

Very high flow rate was measured at the depth of 50.24 m in borehole KR13. During measurements at the depth of 50.24 m in borehole KR13 pumping rate decreased from about 20 l/min to 10 l/min, apparently because of friction of flow in the flow sensor. Therefore the actually measured flow (183 l/h with the pumping rate of 10 l/min) was changed to 783 l/h, which is 10 l/min higher than measured flow. The assumption is that the flow rate of 783 l/h corresponds the unrestrained flow from the depth of 50.24 m with pumping rate of 20 l/min.
Fresh water head of fractures and hydraulic conductivities can be calculated from the flows using the method described in Chapter 3. Fresh water heads in the borehole (pressure profiles) were used instead of hydraulic heads. Fresh water head of fractures is presented in the plots if both of the flows at the same depth are not equal to zero. Hydraulic conductivity is presented if both or either of the flows are not equal to zero.

Figure 5-2. Pumping rate during the difference flow measurements in borehole KR13.

Figure 5-3. Pumping rate during the difference flow measurements in the borehole KR14.
5.2 Detailed flow and single point resistance logs

A detailed flow logging was performed in the boreholes with 0.1 m point intervals (steps). Depth intervals were measured if there was any flow detected in normal mode. This method provides the depth and thickness of the conductive zones with a depth resolution of 0.1 m. To make measurements more quickly, only the thermal dilution method was used for flow determination. The single point resistance logging was done simultaneously with the flow measurements. Detailed flow logging was also performed during normal mode with and without pumping with 0.5 m point intervals using 2 m section length. When comparing results from normal mode with detailed flow logging, erroneous flow values (leaks of rubber disks) can be detected. However, in boreholes KR13 and KR14 no such erroneous flow values were found on the basis of detailed flow loggings.

The width of a flow anomaly of a single fracture is equal to the section length. If the distance between leaky fractures is less than section length the anomalies will be overlapped. The depths of the plotted flow results are measured from the ground surface to the upper end of the test section.

The electrode of the resistance tool is located within the upper rubber disks. The rubber disks obstruct both water and electric charge flow along a borehole. The results of the detailed flow and single point resistance logs are presented in Appendices 1.1 - 1.30 and 8.1 - 8.31. There was an increased noise level during detailed flow logging especially in lower part of boreholes. 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 be increased if the water contains small solid particles like drilling cuttings.

The depths of leaky 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 or flow was under lower limit of measurable flow rate (120 ml/h). Smaller flow anomalies can be seen but flow rate of those is qualitative. Depths of fractures and flow values were presented in table in Appendix 15.

5.3 EC results

Electric conductivity of groundwater in each borehole was measured with 0.5 m depth increments. In addition to this, electric conductivity of fracture specific water was measured from certain selected fractures. The waiting time at these fractures was long enough to flush the water volume within the test section. No extra waiting time
was spent in the measurements with 0.5 m depth increments. Electric conductivity in borehole water was also measured during the normal mode measurements.

Electric conductivity in borehole water was measured without lower rubber disks. The measuring geometry is then 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.

A general view of electric conductivity of groundwater in both boreholes is presented in Appendices 6.1 – 6.2 and 13.1 – 13.2 which show both EC of borehole water and fracture specific EC.

The conductivity values are temperature corrected to 25 °C using a new mathematical model (Heikkonen et al. 2001). Mathematical modeling of temperature adjustment for groundwater electric conductivity was made on basis of synthetic water sample analysis (Mäntynen 2001). Results were also corrected using SFS standard (SFS-EN27888, 1994), but these results are not presented in this report.

The combined plots of flow rate, single point resistance and electric conductivity are presented in more detailed scale in Appendices 1.1 – 1.30 and 8.1 – 8.31. The EC results are also presented as time series in Appendices 2.1 – 2.3 and 9.1 – 9.3. Calendarial time series are presented in Appendices 3.1 – 3.2 and 10.1 – 10.2.

The simultaneous measurement of flow rate and single point resistance makes it possible to evaluate the representativeness of the measured electric conductivity. Note that the reference depth point is the upper end of the 0.5 m test section. If the tool is correctly positioned the cross representing fluid conductivity is on the corresponding flow anomaly, at the upper end of it. Then the fracture to be tested is at the lower end of the test section.

Fracture 448.0 m in borehole KR14 was measured twice. Duration of the first measuring period was six days at depth of 447.74 m. In the beginning of the period EC increased strongly. After that the increase was linear. Unfortunately measurements stopped once because of power failure. The tool was lifted up about 10 m and lowered back to depth 447.64 m. Duration of the second period was four days. Measurements stopped also this time because of power failure. Nevertheless the increase of EC was still linear. It is obvious that water volume within the test section was flushed many times during measurements. Therefore it is clear that salinity of inflowing water from fracture increased when the borehole was pumped.
5.4 Temperature of borehole water

Temperature of borehole water was measured simultaneously with the EC and normal mode measurements, see Appendices 7.1 – 7.2 and 14.1 – 14.2. The temperature results in correspond to the EC results in Appendix 7.2 and 14.2.
Flow measurements in bedrock are an important part of the investigation program for final disposal of spent nuclear fuel. The difference flow method is used to determine hydraulic conductivity and hydraulic head in fractures or fracture zones.

In this study groundwater flows were measured using the difference flow method in normal mode and in detailed mode. Single point resistance was also measured during the flow measurements.

Detailed flow logging with 2 m section length and by 0.5 m steps was performed in conjunction with normal mode measurement with and without pumping. This improved reliability of the results.

Saline groundwater is typical at the Olkiluoto site. The fresh water head measurements were carried out using a long plastic tube filled with fresh water. The measured fresh water head values in the borehole were used in the interpretation of hydraulic conductivity and relative pressure of bedrock.

Electric conductivity measurements were carried out during the detailed mode measurements with 0.5 m section length. EC was measured from borehole water and fracture specific water. EC results have been temperature corrected to 25 °C using a new mathematical model. Temperature was measured at the same time with EC.

This was the first time, when measurements with pumping were made before than measurements without pumping. After pumping period waiting time was about one week. The combined normal mode and detailed mode with pumping (normal mode with 2 m section and 2 m step, detailed mode with 2 m section and 0.5 m step) were the only measurements that were carried out entirely in both boreholes. Chosen depth intervals were then measured without pumping if there was any flow detected with pumping. The same combined procedure was used with and without pumping. The working time in this method was a little shorter than in the usual method when the borehole is measured entirely without and with pumping. Waiting time after pumping period means that total time of measurements was about the same as before.
REFERENCES


**Eurajoki, Olkiluoto, KR13**

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping

---

Flow directions:

- ✦ out from the borehole
- △ into the borehole

---

Conductivity of water (S/m, 25 °C):

- **0.01**
- **0.1**
- **1**
- **10**

---

Flow rate (ml/h):

- **13.4**
- **14.9**
- **15.9**
- **16.3**
- **17.4**
- **18.0**
- **19.3**
- **19.8**

---

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
• out from the borehole
• into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping + EC in the fracture (last)

Flow directions:
v out from the borehole
▲ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:

- ▽ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

- 60.5
- 61.0
- 63.4
- 64.0
- 65.7
- 66.2
- 67.2

Flow rates (ml/h)

- Single point resistance (ohm)

- SPR during normal mode with pumping
- + EC in the borehole
- + EC in the fracture (last)
Eurajoki, Olkiluoto, KR13

Flow directions:
- Out from the borehole
- Into the borehole

Flow rate (ml/h)

Conductivity of water (S/m, 25 °C)

Single point resistance (ohm)

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping + EC in the fracture (last)

Appendix 1.5
-- SPR during normal mode with pumping
+ EC in the borehole
+ EC in the fracture (last)
Eurajoki, Olkiluoto, KR13

**Flow directions:**
- Out from the borehole
- Into the borehole

**Conductivity of water (S/m, 25 °C):**
- 100.1
- 105.3
- 110.8
- 113.8
- 114.4
- 114.7
- 120.0

**Flow rate (mllh):**
- 100
- 101
- 102
- 103
- 104
- 105
- 106
- 107
- 108
- 109
- 110
- 111
- 112
- 113
- 114
- 115
- 116
- 117
- 118
- 119
- 120

**Single point resistance (ohm):**
- 0.01
- 0.1
- 1
- 10
- 100
- 1000
- 10000

**Legend:**
- Normal mode (section 2 m, step 2 m), With pumping
- Normal mode (section 2 m, step 2 m), Without pumping
- Detailed mode (section 2 m, step 0.5 m), With pumping
- Detailed mode (section 2 m, step 0.5 m), Without pumping
- Detailed mode (section 0.5 m, step 0.1 m), With pumping and EC in the fracture (last)
- SPR during normal mode with pumping
- EC in the borehole
- EC in the fracture (last)
Eurajoki, Olkiluoto, KR13

Flow directions:
- ▲: out from the borehole
- △: into the borehole

Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping
Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
SPR during normal mode with pumping
EC in the borehole
EC in the fracture (last)

Conductivity of water (S/m, 25 °C)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
- out from the borehole
- into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)

SPR during normal mode with pumping
+ EC in the borehole
+ EC in the fracture (last)
Eurajoki, Olkiluoto, KR13

Flow directions:

- out from the borehole
- into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping

Flow directions:
△ out from the borehole
▽ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping

SPR during normal mode with pumping
+ EC in the borehole
+ EC in the fracture (last)

Flow directions:
▼ out from the borehole
▲ into the borehole

Conductivity of water (S/m, 25 °C )

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping

SPR during normal mode with pumping
EC in the borehole
EC in the fracture (last)

Flow rate (ml/h)

Conductivity of water (S/m, 25 °C)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
- △ into the borehole
- ▼ out from the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)

Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
SPR during normal mode with pumping
EC in the borehole
EC in the fracture (last)
Eurajoki, Olkiluoto, KR13

Flow directions:
v out from the borehole
△ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Flow directions:
△ out from the borehole
▽ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
- ♦ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

- Red line: SPR during normal mode
  - with pumping
- Blue line: Normal mode (section 2 m, step 2 m), With pumping
- Light blue line: Normal mode (section 2 m, step 2 m), Without pumping
- Dash line: Detailed mode (section 2 m, step 0.5 m), With pumping
- Dark blue line: Detailed mode (section 2 m, step 0.5 m), Without pumping
- Green line: Detailed mode (section 0.5 m, step 0.1 m), With pumping
- Yellow line: EC in the borehole
- Pink line: EC in the fracture (last)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping

Flow directions:
- out from the borehole
- into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)

SPR during normal mode with pumping
EC in the borehole
EC in the fracture (last)
**Eurajoki, Olkiluoto, KR13**

**Flow directions:**
- ▼ out from the borehole
- △ into the borehole

**Conductivity of water (S/m, 25 °C)**

**Flow rate (ml/h)**

**Single point resistance (ohm)**
Eurajoki, Olkiluoto, KR13

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
- △ into the borehole
- ▽ out from the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping
SPR during normal mode with pumping
EC in the borehole
EC in the fracture (last)
### Eurajoki, Olkiluoto, KR13

**Flow directions:**
- **out from the borehole**
- **into the borehole**

**Conductivity of water (S/m, 25 °C)**

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<th>Conductivity (S/m)</th>
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**Flow rate (ml/h)**

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**Single point resistance (ohm)**

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**Legend:**
- Normal mode (section 2 m, step 2 m), With pumping
- Normal mode (section 2 m, step 2 m), Without pumping
- Detailed mode (section 2 m, step 0.5 m), With pumping
- Detailed mode (section 2 m, step 0.5 m), Without pumping
- SPR during normal mode with pumping
- EC in the borehole
- EC in the fracture (last)

**Appendix 1.23**

-- SPR during normal mode with pumping
+ EC in the borehole
+ EC in the fracture (last)
Eurajoki, Olkiluoto, KR13

Flow directions:
- out from the borehole
- into the borehole

Flow rate (ml/h)

Conductivity of water (S/m, 25 °C)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR13

Flow directions:
- out from the borehole
- into the borehole

Conductivity of water (S/m, 25 °C)

Single point resistance (ohm)

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping
Detailed mode (section 0.5 m, step 0.1 m), Without pumping

SPR during normal mode with pumping
+ EC in the borehole
+ EC in the fracture (last)
Time series of electric conductivity
Eurajoki, Olkiluoto, borehole KR13

Appendix 2.1
Time series of electric conductivity
Eurajoki, Olkiluoto, borehole KR13

Electric conductivity (S/m) (25°C)

Time from the start of the measurement (s)
Time series of electric conductivity
Eurajoki, Olkiluoto, borehole KR13
Calendarial time series of EC results
Eurajoki, Olkiluoto, borehole KR13
Appendix 3.2

Calendarial time series of EC results
Eurajoki, Olkiluoto, borehole KR13
Difference flow measurement in normal mode, length of section 2 m
Eurajoki, Olkiluoto, borehole KR13
Flow rates

- Without pumping
- With pumping

Flow rate (ml/h)

Depth (m)

OUT FROM HOLE  ◀  ▶ INTO HOLE
Difference flow measurement in normal mode, length of section 2 m
Eurajoki, Olkiluoto, borehole KR13

Fracture head
Pressure profile in the borehole without pumping
Pressure profile in the borehole with pumping

Hydraulic conductivity (K)
Lower limit of K

Fresh water head (m above sea level)
Hydraulic conductivity (m/s)
Electric conductivity of borehole water
Eurajoki, Olkiluoto, borehole KR13

- Measured with 0.5 m depth increments in the borehole during detailed flow logging
- Last in time series, fracture specific water
- Measured with 2 m depth increments in the borehole during normal mode without pumping
- Measured with 2 m depth increments in the borehole during normal mode with pumping
Electric conductivity of borehole water
Eurajoki, Olkiluoto, borehole KR13
Without lower rubber disks

- Measured before pumping (downwards)
- Measured with pumping during fresh water head measurements before normal mode (upwards)
- Measured with pumping after detailed mode (downwards)
- Measured with pumping after detailed mode (upwards)
- Measured after pumping during fresh water head measurements (downwards)
- Measured after pumping during fresh water head measurements (upwards)
Temperature of borehole water
Eurajoki, Olkiluoto, borehole KR13

- Measured with 2 m depth increments in the borehole during normal mode without pumping
- Measured with 2 m depth increments in the borehole during normal mode with pumping
Temperature of borehole water
Eurajoki, Olkiluoto, borehole KR13
Without lower rubber disks

- Measured before pumping (downwards)
- Measured with pumping during fresh water head measurements before normal mode (upwards)
- Measured with pumping after detailed mode (downwards)
- Measured with pumping after detailed mode (upwards)
- Measured after pumping during fresh water head measurements (downwards)
- Measured after pumping during fresh water head measurements (upwards)
Eurajoki, Olkiluoto, KR14

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:
△ out from the borehole
▽ into the borehole
Eurajoki, Olkiluoto, KR14

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)  Single point resistance (ohm)

Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping
SPR during normal mode
+ EC in the borehole
+ EC in the fracture (last)

Normal mode (section 2 m, step 2 m), Without pumping
Normal mode (section 2 m, step 2 m), With pumping

Appendix 8.3
Eurajoki, Olkiluoto, KR14

Flow directions:
- out from the borehole
- into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping

SPR during normal mode with pumping
EC in the borehole
EC in the fracture (last)
Eurajoki, Olkiluoto, KR14

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping
+ EC in the borehole
+ EC in the fracture (last)

Flow directions:
▽ out from the borehole
△ into the borehole

Conductivity of water (S/m, 25 °C )

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:

- Out of the borehole
- Into the borehole

Conductivity of water (S/m, 25 °C)

- SPR during normal mode with pumping
- EC in the borehole
- EC in the fracture (last)

Flow rate (ml/h)

Single point resistance (ohm)

Depth (m)

Appendix 8.6
Eurajoki, Olkiluoto, KR14

- Normal mode (section 2 m, step 2 m), With pumping
- Normal mode (section 2 m, step 2 m), Without pumping
- Detailed mode (section 2 m, step 0.5 m), With pumping
- Detailed mode (section 0.5 m, step 0.1 m), With pumping

Flow directions:
- △ out from the borehole
- ▲ into the borehole

Conductivity of water (S/m, 25°C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:
- Out from the borehole
- Into the borehole

Conductivity of water (S/m, 25°C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:
△ out from the borehole
▽ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

- Normal mode (section 2 m, step 2 m), With pumping
- Normal mode (section 2 m, step 2 m), Without pumping
- Detailed mode (section 2 m, step 0.5 m), With pumping
- Detailed mode (section 2 m, step 0.5 m), Without pumping
- Detailed mode (section 0.5 m, step 0.1 m), With pumping

Flow directions:
- △ out from the borehole
- ▼ into the borehole

Conductivity of water (S/m, 25 °C)

- SPR during normal mode with pumping
- + EC in the borehole
- + EC in the fracture (last)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:

- ▽ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)

Detailed mode (section 2 m, step 0.5 m), With pumping
- Normal mode (section 2 m, step 2 m), Without pumping
- Detailed mode (section 2 m, step 0.5 m), Without pumping
- Detailed mode (section 0.5 m, step 0.1 m), With pumping

SPR during normal mode
with pumping

+ EC in the borehole
+ EC in the fracture (last)
Eurajoki, Olkiluoto, KR14

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping
+ EC in the borehole
+ EC in the fracture (last)

Flow directions:
- out from the borehole
- into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping + EC in the fracture (last)

Flow directions:
- out from the bore hole
- into the bore hole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

**Flow directions:**
- ▽: out from the borehole
- △: into the borehole

**Conductivity of water (S/m, 25 °C):**

- **SPR during normal mode**
  - With pumping
- **EC in the borehole**
- **EC in the fracture (last)**

**Flow rate (ml/h):**

- **Depth (m):**
  - 340
  - 341
  - 342
  - 343
  - 344
  - 345
  - 346
  - 347
  - 348
  - 349
  - 350
  - 351
  - 352
  - 353
  - 354
  - 355
  - 356
  - 357
  - 358
  - 359
  - 360

**Single point resistance (ohm):**

- **Flow rate (ml/h):**
  - 1
  - 10
  - 100
  - 1000
  - 10000
  - 100000

- **Conductivity of water (S/m, 25 °C):**
  - 0.01
  - 0.1
  - 1
  - 10
Eurajoki, Olkiluoto, KR14

Flow directions:
△ into the borehole
▽ out from the borehole

- Normal mode (section 2 m, step 2 m), With pumping
- Normal mode (section 2 m, step 2 m), Without pumping
- Detailed mode (section 2 m, step 0.5 m), With pumping
- Detailed mode (section 2 m, step 0.5 m), Without pumping
- Detailed mode (section 0.5 m, step 0.1 m), With pumping

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping

Flow directions:
- out from the borehole
- into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:

- ▼ out from the borehole
- △ into the borehole

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping + EC in the borehole
Detailed mode (section 0.5 m, step 0.1 m), With pumping + EC in the fracture (last)

Flow rate (ml/h)

Conductivity of water (S/m, 25 °C)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow directions:

\[\text{\n}\begin{array}{c}
\rightarrow \text{out from the borehole} \\
\triangle \text{into the borehole}
\end{array}\]

Conductivity of water (S/m, 25°C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Normal mode (section 2 m, step 2 m), With pumping
Normal mode (section 2 m, step 2 m), Without pumping
Detailed mode (section 2 m, step 0.5 m), With pumping
Detailed mode (section 2 m, step 0.5 m), Without pumping
Detailed mode (section 0.5 m, step 0.1 m), With pumping

SPR during normal mode with pumping
EC in the borehole
EC in the fracture (last)

Flow directions:
▽ out from the borehole
△ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h)

Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

- Normal mode (section 2 m, step 2 m), With pumping
- Normal mode (section 2 m, step 2 m), Without pumping
- Detailed mode (section 2 m, step 0.5 m), With pumping
- Detailed mode (section 2 m, step 0.5 m), Without pumping
- Detailed mode (section 0.5 m, step 0.1 m), With pumping + EC in the fracture (last)

Flow directions:
\[\text{out from the borehole}\]
\[\text{into the borehole}\]

Conductivity of water \((S/m, 25\degree C)\)

Flow rate (ml/h) vs. Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

- Normal mode (section 2 m, step 2 m), With pumping
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- Detailed mode (section 2 m, step 0.5 m), With pumping
- Detailed mode (section 2 m, step 0.5 m), Without pumping
- Detailed mode (section 0.5 m, step 0.1 m), With pumping + EC in the fracture (last)

Flow directions:
- ▼ out from the borehole
- △ into the borehole

Conductivity of water (S/m, 25 °C)

Flow rate (ml/h) Single point resistance (ohm)
Eurajoki, Olkiluoto, KR14

Flow rates (ml/h)

Conductivity of water (S/m, 25 °C)

Flow directions:

- ▲ out from the borehole
- △ into the borehole

Spr during normal mode with pumping

EC in the borehole

EC in the fracture (last)
Time series of electric conductivity
Eurajoki, Olkiluoto, borehole KR14
Time series of electric conductivity
Eurajoki, Olkiluoto, borehole KR14
Time series of electric conductivity
Eurajoki, Olkiluoto, borehole KR14

Electric conductivity (S/m) (25°C)

Time from the start of the measurement (s)
Calendarial time series of EC results
Eurajoki, Olkiluoto, borehole KR14
Fracture specific EC results
Eurajoki, Olkiluoto, borehole KR14
Difference flow measurement in normal mode, length of section 2 m
Eurajoki, Olkiluoto, borehole KR14

Flow rates

- Pressure profile 1
- Pressure profile 2

Flow rate (ml/h)

OUT FROM HOLE  <  ➤ INTO HOLE
Appendix 12

Difference flow measurement in normal mode, length of section 2 m
Eurajoki, Olkiluoto, borehole KR14

Fracture head
Pressure profile in the borehole without pumping
Pressure profile in the borehole with pumping

Hydraulic conductivity (K)
Lower limit of K

Fresh water head (m above sea level)
Hydraulic conductivity (m/s)
Electric conductivity of borehole water
Eurajoki, Olkiluoto, borehole KR14

- Measured with 0.5 m depth increments in the borehole during detailed flow logging
- Last in time series, fracture specific water
- Measured with 2 m depth increments in the borehole during normal mode without pumping
- Measured with 2 m depth increments in the borehole during normal mode with pumping

Electric conductivity (S/m, 25 °C)
Electric conductivity of borehole water
Eurajoki, Olkiluoto, borehole KR14
Without lower rubber disks

- Measured before pumping (downwards)
- Measured with pumping during fresh water head measurements before normal mode (upwards)
- Measured with pumping after detailed mode (downwards)
- Measured with pumping after detailed mode (upwards)
- Measured after pumping during fresh water head measurements (downwards)
- Measured after pumping during fresh water head measurements (upwards)
- Measured after normal mode without pumping (downwards)
- Measured after normal mode without pumping (upwards)
Temperature of borehole water
Eurajoki, Olkiluoto, borehole KR14

- Measured with 2 m depth increments in the borehole during normal mode without pumping
- Measured with 2 m depth increments in the borehole during normal mode with pumping
Temperature of borehole water
Eurajoki, Olkiluoto, borehole KR14
Without lower rubber disks

- Measured before pumping (downwards)
- Measured with pumping during fresh water head measurements before normal mode (upwards)
- Measured with pumping after detailed mode (downwards)
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- Measured after pumping during fresh water head measurements (downwards)
- Measured after pumping during fresh water head measurements (upwards)
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