Working Report 2006-39

Monitoring Measurements by Difference Flow Method During the Year 2005, Boreholes KR2, KR4, KR7, KR8, KR10, KR14, KR22, KR22B, KR27 and KR28

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July 2006

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ABSTRACT

The Posiva Flow Log/Difference flow method can be used for the relatively fast determination of water conductivity and hydraulic head in fractures/fractured zones in cored boreholes. In this method, a flow meter and a connected flow guide are used. This report presents the principles and results of the measurements carried out in boreholes KR2, KR4, KR7, KR8, KR10, KR14, KR22, KR22B, KR27 and KR28 at the Olkiluoto investigation site during the year 2005. These measurements were part of the monitoring program.

The section length of the flow guide was 2 m and 0.5 m. The flow into the borehole or from the borehole to the bedrock was measured within the section lengths. This was carried out both with pumping and in natural (unpumped) conditions. Transmissivity (T) and hydraulic head of zones are calculated for the results, if a measurement in natural conditions was performed.

The device also includes a sensor for single point resistance (SPR). SPR was always measured in connection with flow measurements, and it was registered when the tool was moving.

The electric conductivity of fracture-specific water (EC) was measured in chosen fractures in some of the boreholes. The fractures were chosen on the basis of the measured flow from the fracture to the borehole. Fracture-specific EC was meauserd if flow rate was over 10 000 mL/h and measurement depth was less than 150 m. Respectively if flow rate was over 1000 mL/h and measurement depth was over 150 m fracture-specific EC was measured. In addition to this some previously selected fractures was measured. The EC of the borehole water was measured separately.

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

SEURANTAMITTAUKSET VIRTAUSEROMITTAUSMENETELMÄLLÄ VUODEN 2005 AIKANA, KAIRANREIÄT KR2, KR4, KR7, KR8, KR10, KR14, KR22, KR22B, KR27 JA KR28

TIIVISTELMÄ

Posiva Flow Log/Virtauseromittausmenetelmää voidaan käyttää suhteellisen nopeasti vedenjohtavuuksien ja virtauspaineiden määrittämiseen raoista tai rakovyöhykkeistä kairanrei'issä. Menetelmässä käytetään virtausmittarin pystyvirtausanturia ja virtausohjainta. Tässä raportissa esitetään mittauksen periaatteet ja tulokset mittauksista, jotka tehtiin kairanrei'issä KR2, KR4, KR7, KR8, KR10, KR14, KR22, KR22B, KR27 ja KR28. Olkiluodon tutkimusalueella vuoden 2005 aikana. Mittaukset olivat osa seurantamittausohjelmaa.

Mittausvälin pituus virtausohjaimessa oli 2 m ja 0.5 m. Mittausväleiltä mitattiin veden virtaus reikään tai reiästä kallioon. Tämä tehtiin sekä pumppauksen aikana että luonnontilassa (pumppaamatta). Tuloksista on laskettu Transmissiviteetit (T) ja lisäksi vyöhykkeiden paineet (Head), jos luonnontilamittaus oli tehty.

Laite sisältää myös maadoitusvastusanturin (single point resistance, SPR). SPR:ää mitattiin aina virtausmittauksen yhteydessä siirtojen aikana.

Rakoveden sähkönjohtavuutta (EC) mitattiin valittujen rakojen kohdalla joissakin rei'issä. Raot valittiin raosta reikään mitatun virtauksen perusteella siten. Yli 150 m syvyydessä rakoveden EC mitattiin mikäli virtaus ylitti 1000 mL/h ja alle 150 m syvyydessä virtaukseltaan 10 000 mL/h ylittävät raot mitattiin. Näiden lisäksi mitattiin muutama ennalta valittu rako joka tapauksessa. Reikäveden EC mitattiin erillisenä mittauksena.

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

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1 INTRODUCTION

In July 2004 Posiva began to construct an underground rock characterization facility called ONKALO, which is planned to be in use by 2010. The construction of ONKALO and subsequently the construction of the repository, will affect the surrounding rock mass and the groundwater flow system as well as the environment. In December 2003 a programme for monitoring at Olkiluoto during construction and operation of ONKALO was presented (Posiva 2003-05) in which the monitoring programmes of different disciplines are presented. The difference flow logging is part of the hydrogeological monitoring programme.

The flow loggings for the monitoring programme are carried out yearly. The programme is presented in Chapter 5. It contains repeated measurements of flow rate (both when the borehole is at rest and when it is pumped), EC and temperature of borehole water and EC of fracture-specific water from selected fractures. The first year of the monitoring measurements was 2005. The earlier results can be used as reference.

In 2005 the monitoring measurements by difference flow meter were performed in boreholes KR2, KR4, KR7, KR8, KR10, KR14, KR22, KR22B, KR27 and KR28. The locations of the boreholes at the Olkiluoto site are shown in Figure 1-1. The results obtained from these boreholes are presented in this Report. Earlier results are presented together with the new ones.

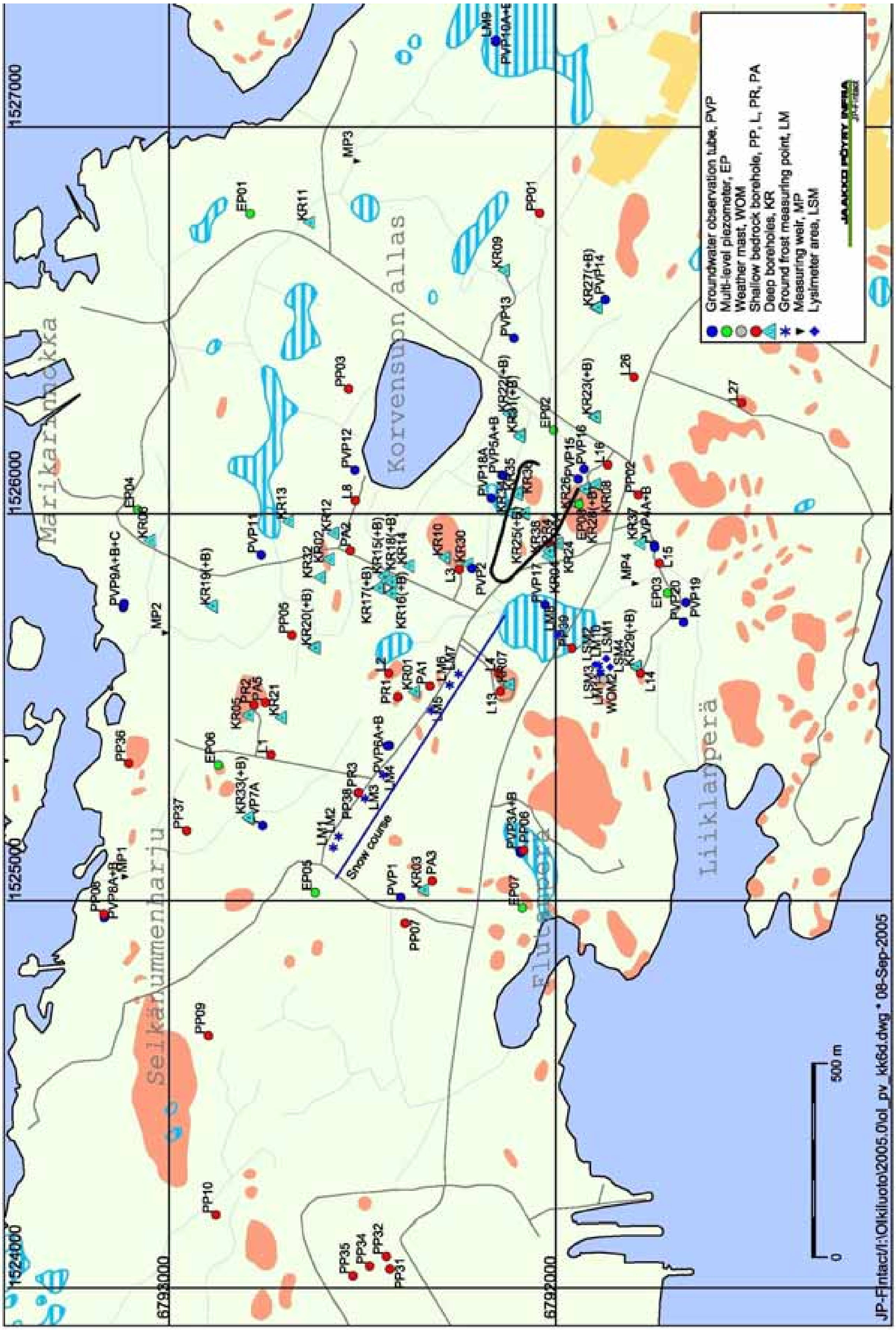

Figure 1-1. *Locations of boreholes at the Olkiluoto site.*

2 PRINCIPLES OF OPERATION

Unlike traditional types of borehole flowmeters, the Difference flowmeter method measures the flow rate into or out of limited sections of the borehole instead of measuring the total cumulative flow rate along the borehole. The advantage of measuring the flow rate in isolated sections is a better detection of the incremental changes of flow along the borehole, which are generally very small and can easily be missed using traditional types of flowmeters.

Rubber disks at both ends of the downhole tool are used to isolate the flow rate in the test section from the flow rate in the remaining part of the borehole, see Figure 2-1. The flow rate along the borehole outside the isolated test section passes through the test section by means of a bypass pipe and is discharged at the upper end of the downhole tool.

The Difference flowmeter measures the flow rate into or out of the test section by means of thermistors, which track both the dilution (cooling) of a thermal pulse and the transfer of a thermal pulse with moving water. In the sequential mode, both methods are used, whereas in the overlapping mode, only the thermal dilution method is used, because it is faster than the thermal pulse method (Öhberg, Rouhiainen 2002).

Besides incremental changes of flow, the downhole tool of the Difference flowmeter can also be used to measure:

- The electric conductivity (EC) of the borehole water and fracture-specific water. The electrode for the EC measurements is placed on top of the flow sensor, Figure 2-1.
- The single point resistance (SPR) of the borehole wall (grounding resistance). The electrode of the Single point resistance tool is located in between the uppermost rubber disks, see Figure 2-1. This method is used for high-resolution depth/length determination of fractures and geological structures.
- The prevailing water pressure profile in the borehole. The pressure sensor is located inside the electronics tube and connected through a tube to the borehole water, Figure 2-2.
- Temperature of the borehole water. The temperature sensor is placed in the flow sensor, Figure 2-1.

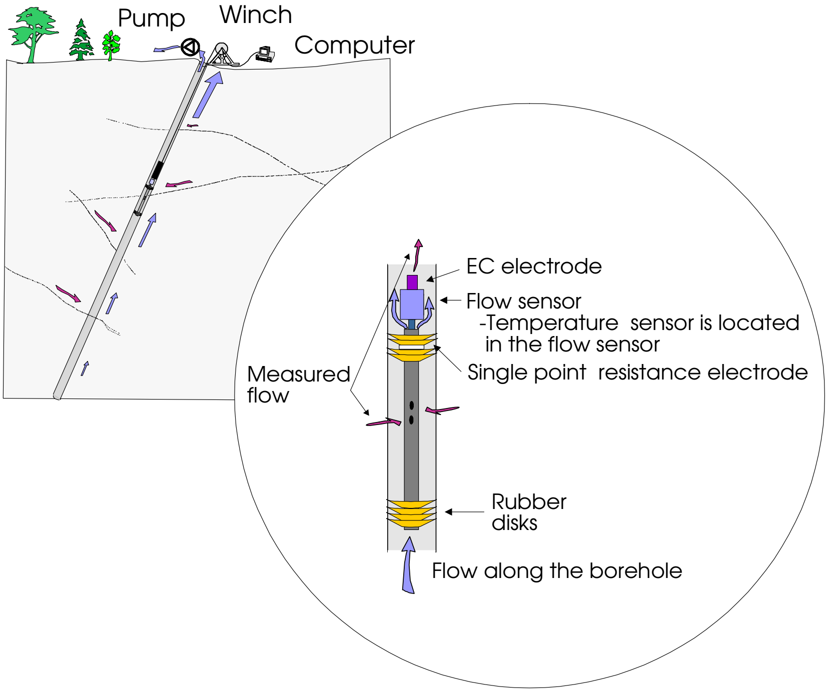

Figure 2-1. *Schematic of the downhole equipment used in the Difference flowmeter.*

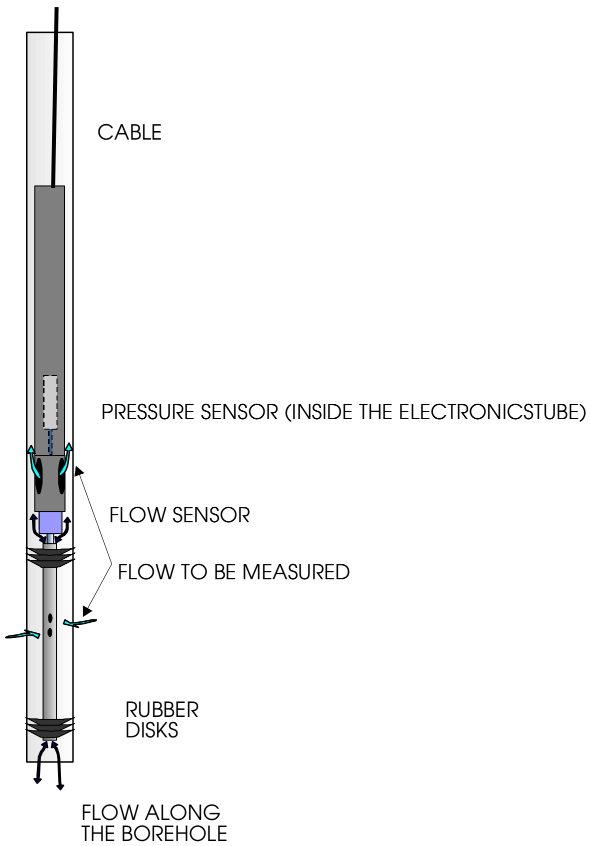

Figure 2-2. *The absolute pressure sensor is located inside the electronics tube and connected through a tube to the borehole water.*

The principles of difference flow measurements are described in Figures 2-3 and 2-4. The flow sensor consists of three thermistors, see Figure 2-3 a. The central thermistor, A, is used as a heating element and for the thermal pulse method and for the registration of temperature changes in the thermal dilution method, Figures 2-3 b and c. The side thermistors, B1 and B2, serve to detect the moving thermal pulse, Figure 2-3 d, caused by the constant power heating in A, Figure 2-3 b.

Flow rate is measured during constant power heating (Figure 2-3 b). If the flow rate exceeds 600 mL/h, the constant power heating is increased, Figure 2-4 a, and the thermal dilution method is applied.

If the flow rate during constant power heating (Figure 2-3 b) falls below 600 mL/h, the measurement continues with the monitoring of thermal dilution transient and thermal pulse response (Figure 2-3 d). When applying the thermal pulse method, thermal dilution is also always measured. The same heat pulse is used for both methods.

Flow is measured when the tool is at rest. After transfer to a new position, there is a waiting time (the duration can be adjusted according to the prevailing circumstances) before the heat pulse (Figure 2-3 b) is launched. The waiting time after the constant power thermal pulse can also be adjusted, but is normally 10 s long for thermal dilution and 100 s long for thermal pulse. The measuring range for each method is given in Table 2-1.

The lower end limits of the thermal dilution and the thermal pulse methods in Table 2-1 are theoretical lowest measurable values. Nowadays the pulse method is used only without pumping. Due to that, the lower limit of the flow rate is 30 mL/h Depending on the borehole conditions, these limits may not always prevail. Examples of disturbing conditions are floating drilling debris in the borehole water, gas bubbles in the water and high flow rates (above about 30 L/min i.e. 1800000 mL/h) along the borehole. If the disturbing conditions are significant, a practical measurement limit is calculated for each set of data.

Table 2-1. *Ranges of flow measurement.*

Method	Range of measurement (mL/h)
Thermal dilution P1	30 – 6 000
Thermal dilution P2	600 – 300 000
Thermal pulse	6 – 600

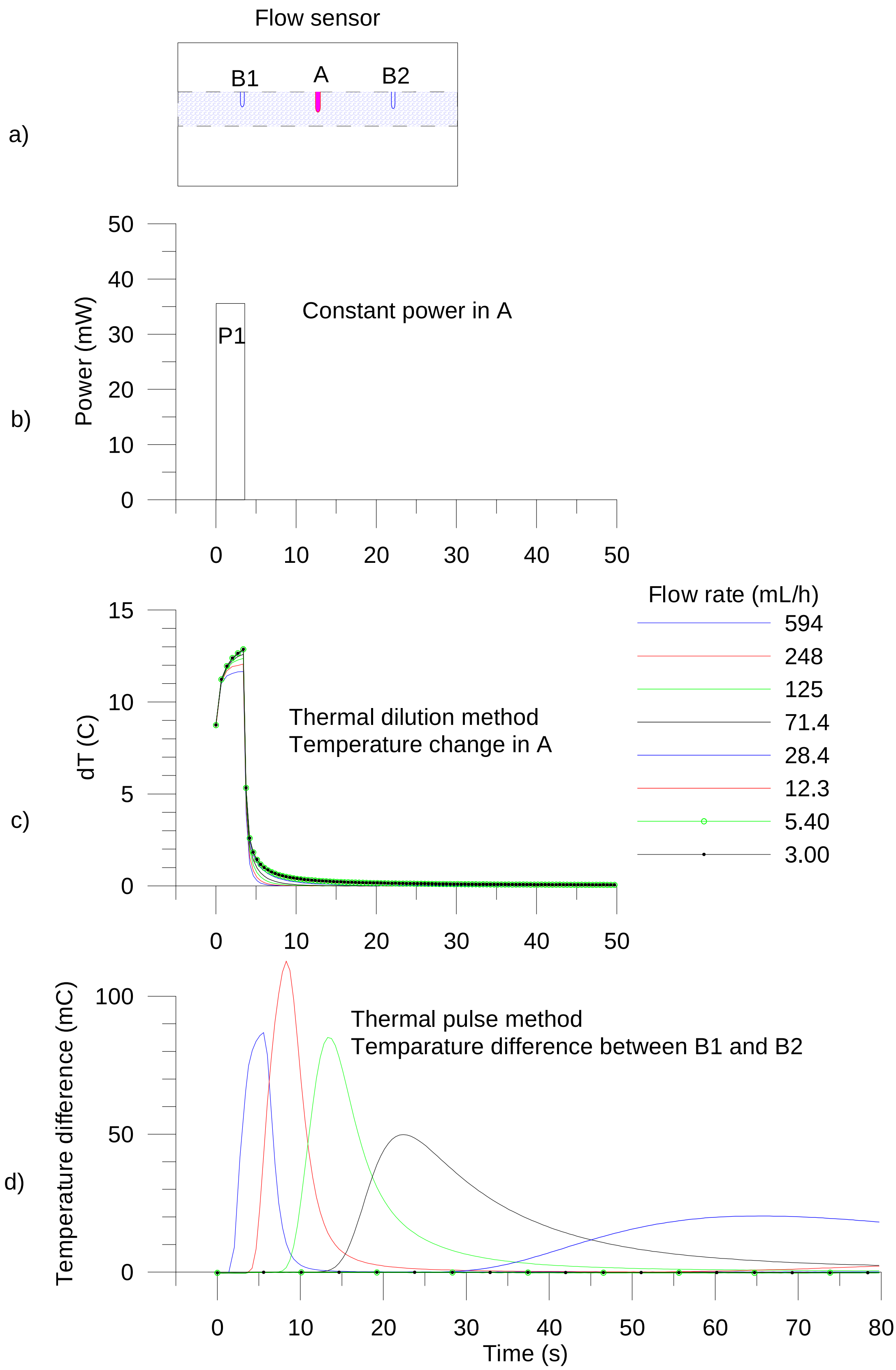

Figure 2-3. *Flow measurement, flow rate <600 mL/h.*

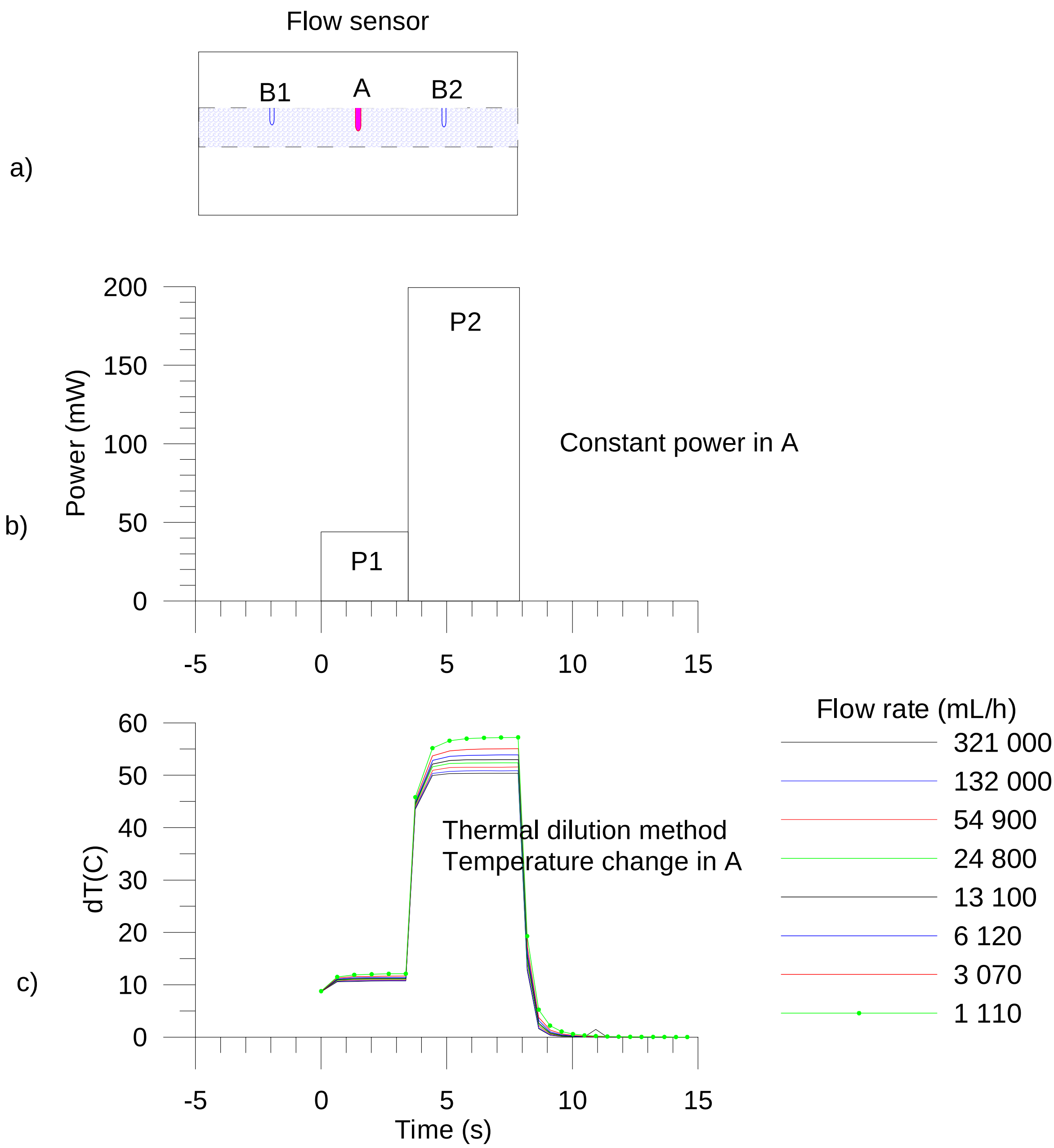

Figure 2-4. *Flow measurement, flow rate >600 mL/h.*

3 INTERPRETATION

3.1 Hydraulic head

The pressure sensor measures the sum of hydrostatic pressure in the borehole and air pressure. Air pressure was also registered. Hydraulic head along the borehole at natural and pumped conditions respectively is determined in the following way: the monitored air pressure at the site is subtracted from the absolute pressure measured by the pressure sensor.

Fresh water head, which was decided to be used at Olkiluoto, signifies the pressure measured with a fresh water-filled tube open at both ends at measured depths. It is important to note that the density of the water in the tube is not exactly 1000 kg/m^3, but that it also depends on temperature and compressibility. Compressibility increases, and thermal expansion decreases the pressure measured with the absolute pressure sensor (Pöllänen 2002). A density correction was applied to the results obtained with the absolute pressure sensor to render them comparable with the measurements made with the fresh water-filled tube, and the effect of the factors mentioned was eliminated with calculation. In the forthcoming study, fresh water head is referred to by hydraulic head.

The hydraulic head (h) at a certain elevation z is then calculated according to the following expression:

$$h = (p_{abs} - p_b)/\rho_{fw}\, g + z + Corr_{Temp} - Corr_{Compr} \qquad (3\text{-}1)$$

where

h is the hydraulic head (masl)

p_{abs} is absolute pressure (Pa)

p_b is barometric (air) pressure (Pa)

ρ_{fw} is unit density 1000 kg/m^3

g is standard gravity 9.80665 m/s^2 and

z is the elevation of measurement (masl)

$Corr_{Temp}$ = Corrections for thermal expansion

$Corr_{Compr}$ = Corrections for compressibility

An offset is subtracted from all absolute pressure results.

Exact z-coordinates are important in head calculation, 10 cm error in z-coordinate means 10 cm error in head.

3.2 Transmissivity and head of section and fracture

The interpretation is based on Thiems or Dupuits formula, which describes a steady state and two-dimensional radial flow into the borehole (Marsily 1986):

$$h_s - h = Q/(T \cdot a) \qquad 3\text{-}2$$

where h is hydraulic head (fresh water head) in the vicinity of the borehole and h_s is hydraulic head at the radius of influence (R),

Q is the flow rate into the borehole,

T is the transmissivity of the test section,

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

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

where

r_0 is the radius of the well and

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

If flow rate measurements are carried out using two levels of hydraulic heads in the borehole, i.e. natural or pump-induced hydraulic heads, then the undisturbed (natural) hydraulic head and transmissivity of the tested borehole sections can be calculated. Two equations can be written directly from equation 3-2:

$$Q_{s0} = T_s \cdot a \cdot (h_s - h_0) \qquad 3\text{-}4$$

$$Q_{s1} = T_s \cdot a \cdot (h_s - h_1) \qquad 3\text{-}5$$

where

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

Q_{s0} and Q_{s1} are the measured flow rates in the test section,

T_s is the transmissivity of the test section and

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

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 its ends.

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

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

$h_s = (h_0 - b \cdot h_1)/(1-b)$ 3-6

$T_s = (1/a)\ (Q_{s0} - Q_{s1})/(h_1 - h_0)$ 3-7

Where

$b = Q_{s0}/Q_{s1}$

Transmissivity (T_f) and hydraulic head (h_f) of individual fractures can be calculated provided that the flow rates of individual fractures are known. Similar assumptions as above must be used (a steady state cylindrical flow regime without skin zones).

$h_f = (h_0 - b \cdot h_1)/(1-b)$ 3-8

$T_f = (1/a)\ (Q_{f0} - Q_{f1})/(h_1 - h_0)$ 3-9

Where

Q_{f0} and Q_{f1} are the flow rates at a fracture and

h_f and T_f are the hydraulic head (far away from borehole) and the transmissivity of a fracture, respectively.

Since the actual flow geometry and the skin effects are unknown, transmissivity 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. A discussion of potential uncertainties in the calculation of transmissivity and hydraulic head is provided in Ludvigson et al. (2002).

4 EQUIPMENT SPECIFICATIONS

The Posiva Flow Log/Difference flowmeter monitors the flow of groundwater into or out of a borehole by means of a flow guide. The flow guide thereby defines the test section to be measured without altering the hydraulic head. Groundwater flowing into or out of the test section is guided to the flow sensor. The flow is measured using the thermal pulse and/or thermal dilution methods. Measured values are transferred into digital form to the PC computer.

Type of instrument:	Posiva Flow Log/Difference Flowmeter
Borehole diameters:	56 mm, 66 mm and 76 mm (or larger)
Length of test section:	A variable length flow guide is used.
Method of flow measurement:	Thermal pulse and/or thermal dilution.
Range and accuracy of measurement:	Table 4-1.
Additional measurements:	Temperature, Single point resistance, Electric conductivity of water, Water pressure
Winch:	Mount Sopris Wna 10, 0.55 kW, conductors, Gerhard -Owen cable head.
Depth determination	Based on the digital length counter.
Logging computer:	PC, Windows XP
Software	Based on MS Visual Basic
Total power consumption:	1.5 - 2.5 kW depending on the pumps

Range and accuracy of sensors is presented in Table 4-1.

Table 4-1. *Range and accuracy of sensors.*

Sensor	Range	Accuracy
Flow	6 – 300 000 mL/h	+/- 10% curr.value
Temperature (middle thermistor)	0 – 50 °C	0.1 °C
Temperature difference (between outer thermistors)	-2 - + 2 °C	0.0001 °C
Electric conductivity of water (EC)	0.02 – 11 S/m	+/- 5% curr.value
Single point resistance	5 – 500 000 Ω	+/- 10% curr.value
Groundwater level sensor	0 – 0.1 MPa	+/- 1 % fullscale
Absolute pressure sensor	0 - 20 MPa	+/- 0.01 % fullscale

5 PERFORMANCE

Flow loggings and additional measurements were performed according to the monitoring programme:

1. EC and temperature of borehole water without pumping.
2. Flow logging without pumping in selected depth intervals, see Table 5-1 (Length of section = 2 m, step = 0.25 m).
3. Flow logging with pumping in selected depth intervals, see Table 5-1 (Length of section = 0.5 m, step = 0.1 m).
4. EC of fracture-specific water. Flow limits for fracture-specific EC: 10 000 mL/h at depths 0 m - 150 m and 1000 mL/h at depths larger than 150 m). In addition to that, some pre-selected fractures will be measured, see Table 5-1.
5. EC and temperature of borehole water with pumping.

Table 5-1. *Depth intervals of flow logging and additional depths of fracture-specific EC.*

Borehole	**Depth interval or fracture (m)**	**Additional Fracture-Specific EC**
KR2	40-340, 540-545, 590-635	108, 600.5, 602.5
KR4	40-145, 300-315, 365-375, 505-525, 560-570,	510.5, 564
KR7	40-125, 170-310, 405-420	410, 415
KR8	20-155, 245-350, 410-455, 540-565	-
KR10	40-265, 320-500, 560-565	417, 500, 565
KR14	10-185, 330, 445-455, 477	448, 454
KR22	40-180, 391, 420-440	-
KR22B	21-45	-
KR27	40-135, 190-300, 325-340, 365-475, 500-515,	371, 399, 545
KR27B	10-42	-
KR28	40-410, 440-450, 520-570, 599	569

The measurements are listed chronologically in Table 5-2. The results are discussed in more detail in Chapter 6.

Table 5-2. *Activity schedule.*

Started	Finished	Borehole	Activity
26.1.2005 *16:58*	27.1.2005 *18:22*	KR14	Flow logging without pumping, section 2 m.
31.1.2005 *14:23*	31.1.2005 *18:16*	KR14	Borehole EC without pumping.
1.2.2005 *10:22*	2.2.2005 *15:32*	KR14	Flow logging and fracture EC with pumping, section 0.5 m.
3.2.2005 *11:17*	3.2.2005 *13:41*	KR14	Borehole EC with pumping.
3.2.2005 *15:50*	4.2.2005 *7:38*	KR22	Borehole EC without pumping.
6.2.2005 *20:35*	8.2.2005 *12:03*	KR22	Flow logging without pumping, section 2 m.
8.2.2005 *20:49*	9.2.2005 *21:56*	KR22	Flow logging and fracture EC with pumping, section 0.5 m.
7.3.2005 *15:31*	9.3.2005 *11:57*	KR22	Flow logging without pumping, section 2 m.
9.3.2005 *17:00*	15.3.2005 *8:30*	KR22	Flow along the borehole without pumping.
15.3.2005 *12:19*	21.3.2005 *11:46*	KR22	Time series of flow at some depth interval, section 2 m.
21.3.2005 *14:58*	22.3.2005 *10:03*	KR22	Borehole EC without pumping.
22.3.2005 *18:19*	31.3.2005 *9:29*	KR22	Flow logging and fracture EC with pumping, section 0.5 m.
4.4.2005 *15:52*	4.4.2005 *18:17*	KR22	Borehole EC with pumping.
5.4.2005 *11:00*	5.4.2005 *12:30*	KR22B *	Borehole EC without pumping.
5.4.2005 *15:55*	6.4.2005 *7:10*	KR22B *	Flow logging without pumping, section 2 m.
6.4.2005 *11:57*	6.4.2005 *16:40*	KR22B *	Flow along the borehole without pumping.
7.4.2005 *10:05*	8.4.2005 *8:38*	KR22B *	Flow logging with pumping, section 0.5 m.
8.4.2005 *9:04*	8.4.2005 *9:23*	KR22B *	Borehole EC with pumping.
27.4.2005 *20:30*	28.4.2005 *7:50*	KR22B	Flow logging without pumping, section 2 m.
3.5.2005 *16:43*	4.5.2005 *8:10*	KR22B	Borehole EC without pumping.
4.5.2005 *15:28*	4.5.2005 *17:36*	KR22B	Flow logging with pumping, section 0.5 m.
5.5.2005 *8:18*	5.5.2005 *8:42*	KR22B	Borehole EC with pumping.
16.5.2005 *13:56*	17.5.2005 *12:51*	KR27	Borehole EC without pumping.
17.5.2005 *15:15*	19.5.2005 *10:45*	KR27	Flow logging without pumping, section 2 m.
23.5.2005 *17:53*	25.5.2005 *11:52*	KR27	Flow logging and fracture EC with pumping, section 0.5 m.
25.5.2005 *15:21*	25.5.2005 *18:43*	KR27	Borehole EC with pumping.
14.6.2005 *8:45*	14.6.2005 *14:44*	KR4	Borehole EC without pumping.
14.6.2005 *17:20*	15.6.2005 *18:31*	KR4	Flow logging without pumping, section 2 m.
20.6.2005 *21:00*	23.6.2005 *3:41*	KR4	Flow logging and fracture EC with pumping, section 0.5 m.
22.6.2005 *10:13*	22.6.2005 *12:49*	KR4	Borehole EC with pumping.
28.6.2005 *10:46*	28.6.2005 *17:32*	KR7	Borehole EC without pumping.
29.6.2005 *11:42*	4.7.2005 *15:48*	KR7	Flow logging without pumping, section 2 m.
5.7.2005 *21:00*	13.7.2005 *17:24*	KR7	Flow logging and fracture EC with pumping, section 0.5 m.
14.7.2005 *12:29*	15.7.2005 *7:25*	KR7	Borehole EC with pumping.
18.7.2005 *13:31*	19.7.2005 *17:01*	KR2	Borehole EC without pumping.
20.7.2005 *9:30*	25.7.2005 *20:50*	KR2	Flow logging without pumping, section 2 m.
4.8.2005 *8:58*	4.8.2005 *16:02*	KR2	Borehole EC with pumping.
28.7.2005 *18:00*	8.8.2005 *23:01*	KR2	Flow logging and fracture EC with pumping, section 0.5 m.
12.9.2005 *10:17*	27.9.2005 *13:31*	KR10	Borehole EC without pumping.
13.9.2005 *10:08*	4.10.2005 *22:19*	KR10	Flow logging without pumping, section 2 m.
11.10.2005 *13:31*	13.10.2005 *10:01*	KR10	Flow logging and fracture EC with pumping, section 0.5 m.
13.10.2005 *14:36*	13.10.2005 *16:19*	KR10	Borehole EC with pumping.
16.11.2005 *14:27*	16.11.2005 *17:30*	KR7	Borehole EC without pumping.
17.11.2005 *12:15*	24.11.2005 *13:25*	KR7	Flow logging without pumping, section 2 m.
25.11.2005 *7:21*	29.11.2005 *5:09*	KR7	Flow logging and fracture EC with pumping, section 0.5 m.
29.11.2005 *12:27*	29.11.2005 *20:21*	KR7	Borehole EC with pumping.
1.12.2005 *14:12*	2.12.2005 *7:34*	KR8	Borehole EC without pumping.
2.12.2005 *10:02*	8.12.2005 *6:30*	KR8	Flow logging without pumping, section 2 m.
9.12.2005 *0:00*	14.12.2005 *16:32*	KR8	Flow logging and fracture EC with pumping, section 0.5 m.

15.12.2005 *15:07*	16.12.2005 *13:05*	KR8	Flow logging with pumping, section 2 m.
19.12.2005 *10:20*	19.12.2005 *17:21*	KR8	Borehole EC with pumping.
21.12.2005 *8:36*	21.12.2005 *15:35*	KR28	Borehole EC without pumping.
22.12.2005 *9:16*	28.12.2005 *10:57*	KR28	Flow logging without pumping, section 2 m.
29.12.2005 *8:49*	3.1.2006 *15:56*	KR28	Flow logging and fracture EC with pumping, section 0.5 m.
24.1.2006 *11:31*	24.1.2006 *15:37*	KR28	Borehole EC with pumping.

* Flow sensor was broken. Results were not reported.

6 RESULTS

The results are presented in Appendices. The list of Appendices can be found after the table of contents. The names of Appendices are referred to in general comments, Chapters 6.1 – 6.7. Borehole-specific results are discussed in Chapters 6.8 – 6.17. Some earlier results are presented together with new ones.

6.1 Flow logging and single point resistance

The measuring program contains several flow logging sequences. They were gathered on the same diagram with single point resistance (right hand side), see Appendix "Flow rate and single point resistance". Single point resistance usually shows a low resistance value on a fracture where flow is detected. There are also many other resistance anomalies from other fractures and geological features. The electrode of the Single point resistance tool is located within the upper rubber disks. Thus, the locations of the resistance anomalies of the leaky fractures fit with the lower end of the flow anomalies.

Detected fractures are shown on the depth scale with their positions. They are interpreted on the basis of the flow curves and therefore represent flowing fractures. A long line represents the location of a leaky fracture; a short line denotes that the existence of a leaky fracture is uncertain. A short line is used if the flow rate is less than 30 mL/h or if the flow anomalies are overlapping or they are unclear because of noise. Coloured triangles show magnitude and direction of flows. Triangles have same colour than corresponding curves.

6.2 Flow rate, transmissivity and hydraulic head of fractures

An attempt was made to evaluate the magnitude of fracture-specific flow rates. The results for a 0.5 m section length and for 0.1 m length increments were used for this purpose. In cases where the fracture distance is less than half a meter, it may be difficult to evaluate the flow rate. The increase or decrease of a flow anomaly at the fracture location is used for the determination of flow rate.

Hydraulic head and transmissivity of fractures can be calculated from flow data using the method described in Chapter 3. Hydraulic head of fractures is presented in the plots if none of the two flow values at the same length is equal to zero. Transmissivity is presented if none or just one of the flows is equal to zero.

Since sections with a 0.5 m length were not used in un-pumped conditions, the results for the 2 m section length were used instead for evaluating fracture flow. The fracture locations are important when evaluating flow rate in un-pumped conditions. The fracture locations are known on the basis of the measurements for a 0.5 m section length. It is not a problem to evaluate the flow rate in un-pumped conditions when the distance between flowing fractures is larger than 2 m. The evaluation may be problematic when the distance between fractures is less than 2 m. In this case, the increase or decrease of a flow anomaly at the fracture location determines the flow rate. However, this evaluation is used conservatively, it is only used in the clearest cases and no flow value is usually evaluated in un-pumped conditions in densely fractured parts of the bedrock. If the flow for a specific fracture cannot be determined conclusively, the flow rate is marked with “-“ and value 0 is used in transmissivity calculation. The flow direction is evaluated as well.

Some fracture-specific results were rated to be “uncertain”. The criterion of “uncertain” was in most cases the minor flow rate (< 30 mL/h). In some cases, fracture anomalies were unclear, since the distance between fractures was less than one meter or since the form of the anomaly was unclear because of noise.

6.4 Theoretical and practical measurements limits of flow and transmissivity

The theoretical minimum of measurable flow rate in the overlapping measurements (thermal dilution method only) is about 30 mL/h. The thermal pulse method can also be used when the borehole is not pumped. Its theoretical lower limit is about 6 mL/h. In this borehole the thermal pulse method was only used for flow direction, not for flow rate. The upper limit of flow measurement is 300 000 mL/h. These limits are determined on the basis of flow calibration. It is assumed that flow can be reliably detected between the upper and lower theoretical limits during favorable borehole conditions.

The minimum measurable flow rate may however be much higher in practice. Borehole conditions may have an influence on the base level of flow (noise level). The noise level can be evaluated for intervals of the borehole without flowing fractures or other structures. The noise level may vary along the borehole.

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

1) Rough borehole wall
2) Solid particles in the water such as clay or drilling debris
3) Gas bubbles in the water
4) High flow rate along the borehole

A rough borehole wall always causes a high noise, not only in the flow, but also in single point resistance results. The flow curve and SPR curves are typically spiky when the borehole wall is rough.

Drilling debris usually increases the noise level. This kind of noise is typically seen both without pumping and with pumping.

Pumping causes a pressure drop in the borehole water and in the fracture water near the borehole. This may lead to the release of gas from dissolved form to gas bubbles. Some fractures may produce more gas than others. Sometimes an increased noise level is obtained just above certain fractures (when the borehole is measured upwards). The reason is assumed to be gas bubbles. Bubbles may cause a decrease of the average density of the water and therefore also a decrease of measured head in the borehole.

The effect of a high flow rate along the borehole can often be seen above high flowing fractures. Any minor leak at the lower rubber disks is directly measured as increased noise in the flow.

A high noise level in the flow masks a “real” flow that is smaller than the noise. Real flows are totally invisible if they are about ten times smaller than the noise. Real flows are registered correctly if they are approximately ten times larger than the noise. By experience, real flows between 1/10 times noise and 10 times noise are summed up with the noise. Therefore, noise level could be subtracted from the measured flow to obtain the real flow. This correction has not been done so far because it is not clear whether it is applicable in each case.

The upper measurement limit of transmissivity can be evaluated using the maximum flow rate (300 000 mL/h) at the actual head difference as above.

6.5 Fresh water head, water level, air pressure and pumping rate

Head in the borehole during measurements, as described in Chapter 3.1, is presented in Appendices “Fresh water head in the borehole”. Air pressure, water level in the borehole and pumping rate are shown together in the other plot.

6.6 Electric conductivity and temperature of borehole water

Appendix ”Electric conductivity of borehole water” presents the EC profile of the borehole water, and appendix “Temperature of borehole water” the temperature measured simultaneously with EC. The results marked with “Without lower rubber disks” are most suitable to represent the borehole water. The problem with the measurements with lower rubber disks is that the flow guide carries water with it and the results may not be representative.

The temperature of the borehole water was measured simultaneously with the EC-measurements. The EC-values are temperature corrected to 25 °C to make them more comparable with other EC measurements (Heikkonen et. al, 2002). The temperature results in Appendix “Temperature of borehole water” correspond to the EC results in Appendix “Electric conductivity of borehole water”.

6.7 EC of fracture-specific water

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

The flow measurement makes it possible to find the fractures for the EC measurement. The tool is moved so that the fracture to be tested is located within the test section. The EC measurements begin if the flow rate is larger than the predetermined limit described in Chapter 5. The tool is kept on the selected fracture. The measurement is continued at the given length allowing the fracture-specific water to enter the section. The waiting time for the EC measurement can be automatically calculated from the measured flow rate. The aim is to flush the water volume within the test section well enough. The measuring computer is programmed to change the water volume within the test section about three times.

The electric conductivity of fracture-specific water is presented on a time scale. The blue symbol represents the value when the tool was moved (one meter point interval) and the red symbol signifies that the tool was stopped on a fracture for a fracture-specific EC measurement.

Borehole depths, the upper and lower ends of the section, fracture locations and the final EC values are listed in tables.

6.8 Borehole KR2

Borehole KR2 was measured earlier in 1996 (Pöllänen & Rouhiainen 1996a), (Rouhiainen 1999), 2001 (Pöllänen & Rouhiainen 2002) and 2003 (Pöllänen & Rouhiainen 2005). This measurement campaign was carried out in June – August 2005. Selected parts of borehole were measured with a natural water level using 2 m section length and with the drawdown 10 m using 0.5 m section length (Appendices 1.1.1 – 1.1.20). Flow anomalies at depth interval 600 – 603 m were unclear. Due to that depth interval 540 – 635 m was measured also with the drawdown of 4 m. Calculated transmissivity of fracture 600.4 m with 4 m drawdown was only half of the transmissivity calculated on the basis of 10 m drawdown. It is not known which one is right.

The level of noise was quite high in some depth intervals especially in the measurements without pumping. Due to this, not all of the small flows were found.

Fracture-specific (Appendices 1.2 – 1.3.3) transmissivity and head values were calculated for the results. For comparison, the earlier results (2003) were plotted together with the new ones.

Fresh water head in the borehole was measured during flow logging, see Appendix 1.4. The water level in the borehole, air pressure and pumping rate were monitored during measurements (Appendices 1.5.1 – 1.5.2). The sum of the measured flow rates (4.0 L/min) corresponds well to the pumping rate, which was between 3.3 – 4.5 L/min.

Borehole EC and temperature were measured without lower rubber disks, see Appendices 1.9 and 1.10. These were measured with and without pumping. Fracture-specific EC was measured using a 0.5 m section length, see Appendices 1.8.1 – 1.8.4 and Table 6-1.

Table 6-1. Fracture-specific EC in borehole KR2.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	EC of fracture specific water (S/m, at 25 °C), last point in time series	EC of fracture specific water (S/m, at 25 °C), average of 10 last points in time series
49.26	49.76	49.6	0.206	0.206
86.34	86.84	86.7	0.088	0.088
107.33	107.83	107.8	0.430	0.433
217.27	217.77	217.6	1.212	1.212
236.36	236.86	236.7	0.922	0.923
600.28	600.78	600.4	4.338	4.338
602.28	602.78	602.5	4.349	4.349

6.9 Borehole KR4

Borehole KR4 was measured earlier in 1996 (Pöllänen & Rouhiainen 1996a), 1999 (Rouhiainen 1999), 2001 (Pöllänen & Rouhiainen 2002) and 2003 (Pöllänen & Rouhiainen 2005). These results are presented similarly for comparison as those for KR2.

This measurement campaign was conducted in June 2005. The measurements were carried out with a natural water level and with the drawdown of 5 m using 2 m and 0.5 m section lengths (Appendices 2.1.1 – 2.1.13). Measured flow rates at depths of 116.8 m and 313.5 m were over upper limit of the flow rate (300 000 mL/h). Therefore depth intervals 110 – 120 m and 300 – 317 m were repeated also with 2 m drawdown. The level of noise during measurements was relatively good. At depth interval 60.33 – 62.33 flow was measured over the weekend (i.e. three days), see Appendix 2.9. This measurement was not included in monitoring programme but was an additional test. Flow rate varies between 500 – 1100 mL/h. Water level in the borehole was not stable at the same time and it is probable reason reason for unstable flow. Fresh water head was measured during flow measurements (Appendix 2.4). Air pressure, water level in the borehole and pumping rate were also monitored (Appendices 2.5.1 – 2.5.2). Sum of measured flows was about 22 L/min. Pumping rate was about 80 L/min. At the depths of 116.8 m and 313.5 m measured flows were over upper limit of the measurable flow rate as mentioned above. It is possible that true values of flow at these depths are higher than measured value. It is also possible that casing tube is leaking causing higher pumping rate.

The borehole EC and the temperature profiles were measured without lower rubber disks (Appendices 2.8 and 2.7). Fracture-specific EC results are plotted (Appendices 2.8.1 – 2.8.4) and the last values of these are listed in Table 6-2.

Table 6-2. Fracture-specific EC in borehole KR4.

Upper end of section (m)	Lower end of section (m)	Measured fractures (m)	EC of fracture specific water (S/m, at 25 °C), last point in time series	EC of fracture specific water (S/m, at 25 °C), average of 10 last points in time series
82.03	82.53	82.3	0.130	0.130
115.83	116.33	116.0	0.153	0.152
116.63	117.13	116.8, 117.1	0.144	0.144
300.73	301.23	301.0	0.192	0.191
306.83	307.33	307.3	0.262	0.262
307.23	307.73	307.3	0.256	0.256
307.63	308.13	307.8	0.225	0.225
313.23	313.73	313.5	0.306	0.306
313.63	314.13	313.9	0.300	0.300
314.83	315.33	315.2	0.776	0.774
365.85	366.35	366.3	1.714	1.715

6.10 Borehole KR7

Borehole KR7 was measured in 1996, (Pöllänen & Rouhiainen 1996a), 1999 (Rouhiainen 1999), 2000 (Pöllänen & Rouhiainen 2001b) and (Pöllänen & Rouhiainen 2005).

Borehole KR7 was measured twice during the year 2005 using 2 m and 0.5 m section lengths. First campaign was performed in June – July with a natural water level and with the drawdown of 10 m. At the depth of 239.8 m measured flow was over upper limit of the flow rate. Due to that depth interval 232 – 243 m were measured also with 3.5 m drawdown. Second campaign was performed in November a natural water level and with the drawdown of 8.5 m (Appendices 3.1.1 – 3.1.14).

The level of noise during measurements was good. Fracture-specific (Appendices 3.2 – 3.4.3) results were calculated on the basis of the flow measurements. Fresh water head was measured in connection with the flow measurements (Appendix 3.5). Air pressure and water level in the borehole were registered during flow logging (Appendix 3.6). The sum of measured flow rates was in July about 20 L/min and in November about 15 L/min. These correspond well to the pumping rates.

The EC and the temperature profile of the borehole were measured without lower rubber disks (Appendices 3.7 and 3.8). Fracture-specific EC results are plotted (Appendices 3.10.1 – 3.10.5) and the last values of these are listed in Tables 6-3 and 6-4.

Table 6-3. *Fracture-specific EC in borehole KR7 (measured July 2005).*

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	EC of fracture specific water (S/m, at 25 ℃), last point in time series	EC of fracture specific water (S/m, at 25 ℃), average of 10 last points in time series	Measured
211.84	212.34	212.1	0.389	0.389	July 2005
215.64	216.14	215.8	0.431	0.431	July 2005
218.94	219.44	219.2	0.429	0.429	July 2005
223.14	223.64	223.4	0.405	0.405	July 2005
225.24	225.74	225.5	0.430	0.430	July 2005
227.14	227.64	227.5	0.436	0.436	July 2005
227.54	228.04	227.9	0.436	0.436	July 2005
227.94	228.44	228.4	0.443	0.443	July 2005
228.34	228.84	228.4	0.443	0.443	July 2005
239.34	239.84	239.8	0.406	0.406	July 2005
239.74	240.24	239.8	0.406	0.406	July 2005
241.24	241.74	241.6	0.394	0.394	July 2005
248.84	249.34	249.1	0.458	0.458	July 2005
253.94	254.44	254.2	0.686	0.686	July 2005
261.94	262.44	262.2	0.510	0.510	July 2005
272.54	273.04	272.8	0.456	0.456	July 2005
278.84	279.34	279.1	0.552	0.552	July 2005
280.54	281.04	280.8	0.470	0.470	July 2005
284.84	285.34	285.1	0.517	0.517	July 2005
285.84	286.34	286.3	0.687	0.687	July 2005
286.24	286.74	286.3	0.665	0.666	July 2005
287.44	287.94	287.8	0.745	0.745	July 2005

Table 6-4. *Fracture-specific EC in borehole KR7 (measured November 2005).*

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	EC of fracture specific water (S/m, at 25 ℃), last point in time series	EC of fracture specific water (S/m, at 25 ℃), average of 10 last points in time series	Measured
211.81	212.31	212.1	0.425	0.425	November 2005
215.51	216.01	215.8	0.451	0.450	November 2005
218.91	219.41	219.2	0.432	0.433	November 2005
223.11	223.61	223.4	0.406	0.406	November 2005
225.21	225.71	225.5	0.419	0.419	November 2005
227.11	227.61	227.5	0.432	0.432	November 2005
227.51	228.01	227.9	0.429	0.428	November 2005
227.91	228.41	228.4	0.437	0.437	November 2005
228.31	228.81	228.4	0.438	0.437	November 2005
239.31	239.81	239.8	0.394	0.394	November 2005
239.71	240.21	239.8	0.394	0.394	November 2005
241.21	241.71	241.6	0.408	0.412	November 2005
248.71	249.21	249.1	0.437	0.437	November 2005
254.01	254.51	254.2	0.584	0.584	November 2005
261.91	262.41	262.2	0.484	0.483	November 2005
272.51	273.01	272.8	0.447	0.447	November 2005
278.81	279.31	279.1	0.534	0.534	November 2005
280.51	281.01	280.8	0.455	0.455	November 2005
284.81	285.31	285.1	0.513	0.513	November 2005
285.81	286.31	286.3	0.642	0.642	November 2005
286.21	286.71	286.3	0.631	0.630	November 2005
287.41	287.91	287.8	0.735	0.735	November 2005

6.11 Borehole KR8

Borehole KR8 was previously measured in 1996 (Pöllänen & Rouhiainen 1996a), 1999 (Rouhiainen 1999) and 2002 & 2004 (Pöllänen & Rouhiainen 2005).

This measurement campaign was carried out in December 2005. Selected parts of borehole were measured with a natural water level using 2 m section length and with the drawdown 5 m using 0.5 m section length (Appendices 4.1.1 – 4.1.17). Depth interval 71 – 85 m was also measured with the drawdowns 5 m using 2 m length of section, because 0.5 m section was too short at the depth of 82 m. Measured flow rate with 2 m length of section and 5 m drawdown was over upper limit of the flow rate. Due to that depth interval was re-measured with 2 m drawdown, see Appendices 4.1.1 – 4.1.17. The level of noise was quite high in some depth intervals especially in the measurements without pumping. Due to this, not all of the small flows were found.

Fracture-specific transmissivity and head values were calculated for the results (Appendices 4.2 – 4.3.5) Fresh water head in the borehole was measured during flow logging (Appendix 4.4). Water level in the borehole, air pressure and pumping rate were registered during flow logging (Appendices 4.5.1 – 4.5.2). The sum of the measured flow rates was about 12 L/min, which was 40 % less than pumping rate. The difference between the pumping rate and the measured flow rates is relatively large. The reason for this remains unknown.

Temperature and EC profiles in the borehole were measured without lower rubber disks (Appendices 4.6 and 4.7). Fracture-specific EC was measured using a 0.5 m section length (Appendices 4.8.1 – 4.8.8 and Table 6-5).

Table 6-5. *Fracture-specific EC in borehole KR8.*

Upper end of section (m)	Lower end of section (m)	Measured fractures (m)	EC of fracture specific water (S/m, at 25 ℃), last point in time series	EC of fracture specific water (S/m, at 25 ℃), average of 10 last points in time series
21.98	22.48	22.0	0.057	0.056
77.50	78.00	77.7	0.076	0.073
81.40	81.90	81.5, 81.8	0.082	0.082
81.80	82.30	82.3	0.078	0.078
82.20	82.70	82.3	0.084	0.086
106.61	107.11	106.8	0.371	0.371
107.01	107.51	107.4	0.401	0.400
109.62	110.12	109.8	0.327	0.327
113.52	114.02	113.8	0.355	0.357
122.22	122.72	122.4	0.648	0.652
126.22	126.72	126.3	0.831	0.834
249.97	250.47	250.1	1.707	1.715
254.69	255.19	255.0	1.476	1.476
255.50	256.00	255.6	2.035	2.035
256.50	257.00	256.8	3.400	3.400
272.24	272.74	272.3	3.368	3.368
348.54	349.04	348.7	3.085	3.063
548.42	548.92	548.5	3.651	3.650
554.82	555.32	555.2	3.907	3.907
559.82	560.32	560.0	3.974	3.974

6.12 Borehole KR10

Borehole KR10 was previously measured in 1996 (Pöllänen & Rouhiainen 1996b) and 1999 (Rouhiainen 1999).

Diameter of the borehole is not constant. Diameter as function of depth is presented in table 6-6. Due to un-constant diameter, the borehole had to be measured using three different sets of rubber disks.

Table 6-6. *Diameters of borehole KR10*

Depth interval (m)	Diameter (mm)
0 – 40.46	130 (Casing tube)
40.46 – 100	115 mm
100 – 177.63	86
177.63 – 614.40	76

This measurement campaign was carried out in October 2005. Selected parts of borehole were measured with a natural water level using 2 m section length and with the drawdown 10 m using 0.5 m section length (Appendices 5.1.1 – 5.1.28). The level of noise was higher (over 100 mL/h) at depth interval below 470 m.

Fracture-specific transmissivity and head values were calculated for the results (Appendices 5.2 – 5.3.2). Fresh water head in the borehole was measured during flow logging (Appendix 5.4). Water level in the borehole, air pressure and pumping rate were registered during flow logging (Appendix 5.5). The pumping rate corresponds well to the sum of the measured flow rates (~1.3 L/min).

Temperature and EC profiles in the borehole were measured without lower rubber disks (Appendices 5.6 – 5.7). Fracture-specific EC was measured using a 0.5 m section length (Appendices 5.8.1 – 5.8.2 and Table 6-7).

Table 6-7. *Fracture-specific EC in borehole KR10.*

Upper end of section (m)	Lower end of section (m)	Measured fractures (m)	EC of fracture specific water (S/m, at 25 ℃), last point in time series	EC of fracture specific water (S/m, at 25 ℃), average of 10 last points in time series
260.19	260.69	260.6	0.497	0.498
260.59	261.09	260.6	0.490	0.490
326.29	326.79	326.5	1.273	1.272
327.19	327.69	327.5	1.381	1.381
499.69	500.19	499.8	3.377	3.377

6.13 Borehole KR14

Borehole KR14 was measured for the first time in August – October 2001 (Pöllänen & Rouhiainen 2001a). It was also measured 2003 (Pöllänen & Rouhiainen 2005).
This measurement campaign was carried out in January - February 2005. Selected parts of borehole were measured with a natural water level using 2 m section length and with the drawdown 2.5 m using 0.5 m section length (Appendices 6.1.1 – 6.1.15). The level of noise was relatively good all the time. Lower part of borehole KR14 was not measured, because hole was not entirely open.

Fracture-specific transmissivity and head values were calculated for the results (Appendices 6.2 – 6.4.4) Fresh water head in the borehole was measured during flow logging (Appendix 6.5). Water level in the borehole, air pressure and pumping rate were registered during flow logging (Appendix 6.6). The sum of the measured flow rates was about three times higher than pumping rate. Fracture-specific flow at the depth of 50.5 m was 1430 000 mL/h (23.8 L/min), which is almost five times higher than upper limit of the measurable flow rate. Thus, it seems that this flow is reason for big difference between measured flow rate and pumping rate.

Temperature and EC profiles in the borehole were measured without lower rubber disks (Appendices 6.7 and 6.8). Fracture-specific EC was measured using a 0.5 m section length (Appendices 6.9.1 – 6.10 and Table 6-8).

Table 6-8. Fracture-specific EC in borehole KR14.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	EC of fracture specific water (S/m, at 25 ℃), last point in time series	EC of fracture specific water (S/m, at 25 ℃), average of 10 last points in time series
13.19	13.69	13.4	0.103	0.103
27.89	28.39	28, 28.2	0.087	0.087
30.09	30.59	30.3	0.071	0.072
34.29	34.79	34.5	0.076	0.076
41.59	42.09	41.8	0.103	0.103
50.19	50.69	50.5	0.097	0.097
79.89	80.39	80.1	0.111	0.111
183.19	183.69	183.2	0.125	0.125
13.29	13.79	13.4	0.101	0.101
34.29	34.79	34.5	0.079	0.079
50.29	50.79	50.5	0.110	0.110

6.14 Borehole KR22

Borehole KR22 was previously measured with pumping in October and November in 2002. Measurements in natural conditions were carried out in March 2004 (Pöllänen et. al 2005).

During February - March 2005 borehole KR22 was measured twice. The borehole was firstly measured without pumping using 2 m length of section and with drawdown 1 m using 0.5 m length of section. The same program was then repeated (Appendices 7.1.1 – 7.1.10) because there were some problems with sensor during the first measurement.

Fracture-specific transmissivity and head values were calculated for the results (Appendices 7.2 – 7.3.5). Transmissivities and heads were calculated using several flow couples. Fresh water head in the borehole was measured during flow logging (Appendix 7.4). Water level in the borehole, air pressure and pumping rate were registered during flow logging (Appendices 7.5.1 – 7.5.3). The sum of measured flow rates (about 20 L/min) corresponds well to the pumping rates.

Temperature and EC profiles in the borehole were measured without lower rubber disks (Appendices 7.6 and 7.7). Fracture-specific EC was measured using a 0.5 m section length (Appendices 7.8.1 – 7.8.8 and Table 6-9). There were some problems with calibration during measurements. Measured temperature of water seems to be about 0.7 ^{o}C lower than during the previous measurements.

Flow along the borehole was measured at the depth of 386.71 m during the weekend, see Appendix 7.9. Time series of flow were measured at depth interval 110.71 – 112.71 m, 146.71 – 148.71 m and 390.71 – 392.71 m, see Appendix 7.10. These measurements were not in the original monitoring programme. Aim of the measurements was find out influence of the ONKALO construction work for groundwater flow in short time period.

Table 6-9. Fracture-specific EC in borehole KR22.

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	EC of fracture specific water (S/m, at 25 ℃), last point in time series	EC of fracture specific water (S/m, at 25 ℃), average of 10 last points in time series	Measured
46.01	46.51	46.3	0.104	0.103	February 2005
101.61	102.11	101.7	0.161	0.162	February 2005
109.11	109.61	109.3	0.145	0.143	February 2005
111.91	112.41	112.1	0.112	0.112	February 2005
147.81	148.31	147.9	0.298	0.295	February 2005
151.41	151.91	151.7	0.429	0.429	February 2005
391.11	391.61	391.4	0.267	0.266	February 2005
46.01	46.51	46.3	0.101	0.101	March 2005
101.61	102.11	101.7	0.160	0.160	March 2005
111.91	112.41	112.1	0.107	0.108	March 2005
147.81	148.31	147.9	0.293	0.292	March 2005
151.51	152.01	151.7	0.493	0.493	March 2005
391.01	391.51	391.4	0.537	0.537	March 2005

6.15 Borehole KR22B

Borehole KR22B was previously measured in May 2003 (Pöllänen et. al 2005). This measurement campaign was carried out in May 2005. The borehole was measured with a natural water level using 2 m section length and with the drawdown 5 m using 0.5 m section length (Appendices 8.1.1 – 8.1.2).

Fracture-specific transmissivity and head values were calculated for the results (Appendices 8.2 – 8.3.2) Fresh water head in the borehole was measured during flow logging (Appendix 8.4). Water level in the borehole, air pressure and pumping rate were registered during flow logging (Appendices 8.5.1 – 8.5.2). The sum of measured flow rates (about 1.8 L/min) correspond well to the pumping rates.

Temperature and EC profiles in the borehole were measured without lower rubber disks (Appendices 8.6 and 8.7).

6.16 Borehole KR27

Borehole KR27 was previously measured in 2003 and 2004 (Pöllänen et. al 2005).

This measurement campaign was carried out in May 2005. Selected parts of borehole were measured with a natural water level using 2 m section length and with the drawdown 10 m using 0.5 m section length (Appendices 9.1.16 – 9.1.16).

Fracture-specific transmissivity and head values were calculated for the results (Appendices 9.2 – 9.3.4) Fresh water head in the borehole was measured during flow logging (Appendix 9.4). Water level in the borehole, air pressure and pumping rate were registered during flow logging (Appendices 9.5.1 – 9.5.2). The sum of measured flow rates (about 11.5 L/min) correspond well to the pumping rates.

Temperature and EC profiles in the borehole were measured without lower rubber disks (Appendices 9.6 and 9.7). Fracture-specific EC was measured using a 0.5 m section length (Appendices 9.8.1 – 9.8.7 and Table 6-10).

Table 6-10. *Fracture-specific EC in borehole KR22.*

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	EC of fracture specific water (S/m, at 25 ℃), last point in time series	EC of fracture specific water (S/m, at 25 ℃), average of 10 last points in time series
44.10	44.60	44.2	0.091	0.091
48.20	48.70	48.6	0.095	0.095
56.00	56.50	56.3	0.086	0.086
60.70	61.20	60.8	0.089	0.089
62.10	62.60	62.3	0.089	0.089
64.00	64.50	64.2	0.084	0.084
64.40	64.90	64.8	0.084	0.084
65.40	65.90	65.6	0.081	0.081
69.80	70.30	69.8	0.082	0.082
86.40	86.90	86.6	0.080	0.080
92.70	93.20	92.8	0.181	0.181
130.90	131.40	131.0	0.337	0.337
206.70	207.20	207.1	0.565	0.563
208.00	208.50	208.4	0.723	0.723
257.50	258.00	257.8	0.343	0.343
261.50	262.00	261.8	0.404	0.404
284.80	285.30	285.0	0.490	0.490
370.90	371.40	371.1	1.099	1.100
398.60	399.10	398.9	0.976	0.981
423.90	424.40	424.2	0.709	0.712
426.30	426.80	426.8	1.434	1.434
451.00	451.50	451.2	1.553	1.553
504.90	505.40	505.2	1.656	1.656

6.17 Borehole KR28

Borehole KR28 was previously measured in 2003 and 2004 (Pöllänen et. al 2005).

This measurement campaign was carried out in December 2005 – January 2006. Selected parts of borehole were measured with a natural water level using 2 m section length and with the drawdown 1.5 m using 0.5 m section length (Appendices 10.1.16 – 10.1.25).

Fracture-specific transmissivity and head values were calculated for the results (Appendices 10.2 – 10.3.2) Fresh water head in the borehole was measured during flow logging (Appendix 10.4). Water level in the borehole, air pressure and pumping rate were registered during flow logging (Appendix 10.5.1 – 10.5.2). The sum of the measured flow rates was about 8.3 L/min, which was only half of the pumping rate. The difference between the pumping rate and the measured flow rates is relatively large. The reason for this remains unknown.

Temperature and EC profiles in the borehole were measured without lower rubber disks (Appendices 10.6 and 10.7). Fracture-specific EC was measured using a 0.5 m section length (Appendices 10.8.1 – 10.8.3 and Table 6-11).

Table 6-11. *Fracture-specific EC in borehole KR28.*

Upper end of section (m)	Lower end of section (m)	Measured fracture (m)	EC of fracture specific water (S/m, at 25 °C), last point in time series	EC of fracture specific water (S/m, at 25 °C), average of 10 last points in time series
155.25	155.75	155.4	0.334	0.334
158.65	159.15	158.8	0.389	0.389
173.05	173.55	173.2	0.746	0.745
389.76	390.26	390.0	0.402	0.402
443.73	444.23	444.1	1.560	1.560
521.23	521.73	521.6	1.592	1.591

7 SUMMARY

Difference flow measurements were performed in boreholes KR2, KR4, KR7, KR8, KR10, KR14, KR22, KR22B, KR27 and KR28 between January 2005 and January 2006. These measurements are part of the monitoring program.

The measurement results are presented graphically and in tables. The most important results are the locations of the water-conductive fractures and the transmissivity of these fractures. The transmissivity of borehole sections was calculated, as well as hydraulic head. Calculated transmissivities and heads are presented together with previous results.

The results gained with the absolute pressure sensor are converted to correspond to the fresh water tube measurements used earlier. Fresh water tube measurements are still used in multipacker pressure monitoring systems. The result of these measurements is fresh water head. However, the conversion from absolute pressure to fresh water head entails some uncertainties. An error in the Z coordinate is probably the most significant error source in fresh water head.

The EC and temperature of the borehole water were measured both separately and in connection with flow measurements. The results measured separately and without the lower rubber disks are of better quality, as the flushing of the water in the EC electrode is then better. If separate EC measurements without the lower rubber disks were not performed, the EC result gained during flow measurement is presented. The EC of fracture-specific water was also measured in several boreholes.

Long term changes caused by tunnel construction were not yet evident in flow nor EC. Short term changes (within a day) could often been seen in flow rates and ground water level. A part of these could be connected to working phases in the tunnel.

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