Working Report 2010-19

Slug-Tests in PP- and PVP-Holes at Olkiluoto in 2009

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November 2010

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ABSTRACT

As part of the program for the final disposal of the nuclear fuel waste, Posiva Oy investigates the hydrological conditions at the Olkiluoto Island. The hydraulic conductivity in the shallow holes OL-PP36, OL-PP39, OL-PVP4A, OL-PVP4B, OL-PVP6A, OL-PVP6B, OL-PVP14, OL-PVP30, OL-PVP31A, OL-PVP31B, OL-PVP32, OL-PVP33, OL-PVP34A, OL-PVP34B, OL-HP1, OL-HP2, OL-HP3 and OL-HP4 was measured in summer 2009. The length of PP-holes was between 12 and 14 m, and the test sections (1 m) are located in the bedrock. PVP-tubes have an average length between 3 – 11 m, and the test sections (mostly 2 m) are located in the overburden.

The measurements were done using the slug-test technique. In the slug-test, the hydraulic head in the borehole is abruptly changed either by pouring water into the borehole or by lowering the pressure sensor. The hydraulic conductivity is interpreted from the recovery of the water level. This report presents the field measurements and their interpretation. The interpretation has been done using the Hvorslev's method, and for reference, conductivity has also been calculated according to Thiem's equation.

According to the results, hydraulic conductivity in PP-holes ranges from 10^{-10} m/s to 10^{-6} m/s and in PVP-tubes from 10^{-8} m/s to 10^{-5} m/s. The observed range is quite similar as in the previous measurements in 2002 and 2004 – 2008. In general, the results are consistent with the results obtained in earlier measurements. In OL-PVP14, there seems to be a lowering trend of the conductivity. Also, the results agree relatively well with hydraulic conductivity interpreted from the pre-pumping done in connection with the groundwater sampling.

Keywords: Hydraulic conductivity, slug-test, disposal of spent nuclear fuel, hydrology

Vedenjohtavuusmittaukset PP- ja PVP -rei'issä Olkiluodossa 2009

TIIVISTELMÄ

Osana ydinjätteen loppusijoitustutkimusta Posiva Oy selvittää Olkiluodon saaren hydrologisia olosuhteita. Matalien reikien vedenjohtavuuksia mitattiin rei'istä OL-PP36, OL-PP39, OL-PVP4A, OL-PVP4B, OL-PVP6A, OL-PVP6B, OL-PVP14, OL-PVP30, OL-PVP31A, OL-PVP31B, OL-PVP32, OL-PVP33, OL-PVP34A, OL-PVP34B, OL-HP1, OL-HP2, OL-HP3 ja OL-HP4 kesällä 2009. PP-reikien syvyys oli 12 – 14 m maanpinnasta, ja mittausjaksot (1 m) sijaitsevat kallion yläosassa. PVP-reiät ovat keskimäärin 3 – 11 m syviä. Mittausvälit (useimmiten 2 m) ovat maapeiteosuudella.

Mittaukset suoritettiin käyttäen slug-tekniikkaa. Mittauksessa kairanreikään saadaan ylipaine joko kaatamalla sinne vettä tai laskemalla paineanturia. Vedenjohtavuus lasketaan vedenpinnan palautumisajan perusteella. Tässä raportissa kuvataan kenttämittaukset ja niiden tulkinta. Mittaukset on tulkittu käyttäen Hvorslevin menetelmää ja tarkistusta varten vedenjohtavuus on laskettu myös Thiemin kaavalla.

Tulosten mukaan vedenjohtavuus PP-rei'issä vaihtelee välillä 10^{-10} m/s - 10^{-6} m/s ja PVP-rei'issä välillä 10^{-8} m/s - 10^{-5} m/s. Vaihteluväli on lähes sama kuin vuosien 2002 ja 2004 – 2008 mittauksissa. Pääosin tulkitut vedenjohtavuudet sopivat hyvin yhteen aiempien tulosten kanssa. Reiän OL-PVP14 tuloksissa näyttäisi olevan laskeva suuntaus. Vedenjohtavuustulokset sopivat kohtuullisen hyvin myös pohjavesinäytteenoton yhteydessä saatuihin esipumppauksista tulkittuihin vedenjohtavuuksiin.

Avainsanat: Vedenjohtavuus, slug-testi, käytetyn ydinpolttoaineen loppusijoitus, hydrologia

PREFACE

This report is part of the program for the final disposal of the nuclear fuel waste at the Olkiluoto Island. The main aim of the study is to investigate the hydraulic conductivity close ground surface.

The field measurements were done by Ossi Isola and Maarit Yli-Kaila Posiva Oy, using the technique and equipment developed by PRG-Tec Oy (Hellä & Heikkinen 2004). The interpretation of the results has been done at Posiva Oy by Ossi Isola. The report has been compiled at Posiva Oy by Ossi Isola.

Katriina Keskitalo (Pöyry Environment Oy), Pirjo Hellä (Pöyry Environment Oy), and Susanna Lindgren (Posiva Oy) are thanked for the valuable comments and guidance of the interpretation work and reporting. Maarit Yli-Kaila (Posiva Oy) is thanked for guidance and help in the field measurements.

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1 INTRODUCTION

As part of the program for the final disposal of the nuclear fuel waste, Posiva Oy investigates the prevailing hydrological conditions at the Olkiluoto Island. Since 2002, hydraulic testing has been carried out in the upper parts of the bedrock and in the overburden. The measurement technique applied has been the slug-test technique using the equipment developed by PRG-Tec Oy (Hellä & Heikkinen 2004). The slug-tests are done in all new shallow holes. In addition, the slug-tests are repeated yearly in the holes and tubes, which belong to the monitoring program.

The results of previous measurement campaigns in 2002, 2004–2008 are reported by Hellä & Heikkinen (2004), Tammisto et al. (2005), Tammisto & Lehtinen (2006), Keskitalo & Lindgren (2007) and Keskitalo (2008−2009). The latest slug-test measurements were done in 2009, when PP-holes were measured in July 2009 and PVP-tubes in June and July 2009. The measurements were done in PP-holes, which represent the upper part of the bedrock, and in PVP- and HP-tubes which are located in the overburden.

This report describes these measurements, the method of interpretation, results and detection limits. The results of the measurements from different years are also compared. The descriptions of interpretation, data processing and detection limits are based on the first slug-test report (Hellä & Heikkinen 2004).

2 FIELD MEASUREMENTS

The field measurements were done in June and July 2009. The measured shallow boreholes and groundwater tubes are presented in Figure 2-1 and listed in Table 2-1 and Table 2-2. Drilling of the holes and the installation of the casings are reported by Suomen Malmi Oy 1989; Lehto 2001; Niemi & Roos 2004; Niinimäki & Rautio 2004; Rautio 2004; Toropainen 2009. Details of the studied holes and tubes are presented in Appendices 2 to 21.

From the holes and tubes measured in 2009 OL-PP39 has also been measured in 2004, 2005, 2006, 2007 and 2008, OL-PP36 in 2006, 2007 and 2008. PVP-tubes OL-PVP4A and OL-PVP4B have been measured in 2002, 2004, 2005, 2006, 2007 and 2008, OL-PVP14 in 2004, 2005, 2006, 2007 and 2008, OL-PVP6A and OL-PVP6B in 2002, 2006, 2007 and 2008. PVP-tubes OL-PVP30 – OL-PVP34B were installed in January and February 2009 and measured for the first time. Also observation tubes OL-HP1, OL-HP2 and OL-HP4 near the Korvensuo basin have been measured in 2008.

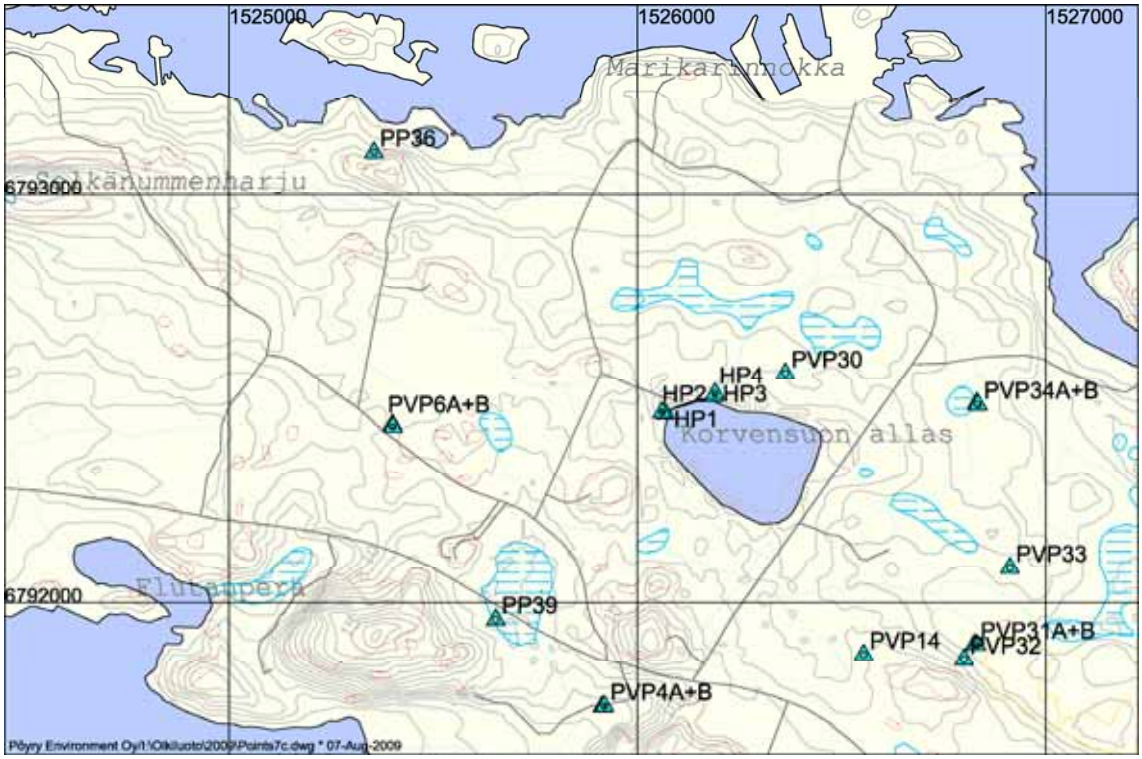


Figure 2-1. *Locations of the shallow holes where slug-tests have been done in summer 2009.*

Table 2-1. *Measured PP-holes, measurement times and operators*

Area	Hole	Diam. (mm)	Length (m)	Date start	Time start	Date stop	Time stop	Operator
Olkiluoto	OL-PP36	56	12.05	2.7.2009	9:30	2.7.2009	12:55	Maarit Yli-Kaila, Ossi Isola Posiva Oy
Olkiluoto	OL-PP39	56	13.71	1.7.2009	10:00	1.7.2009	14:30	Maarit Yli-Kaila, Ossi Isola Posiva Oy

Table 2-2. *Measured PVP- and HP-tubes, measurement times and main information of the measurements.*

Hole	Diam. (mm)	Length (m)/ perforated section (m)	Date	Time	Operator	Pressure sensor movement (m)
OL-PVP4A	56	9.55/2	8.6.2009	12:30	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
OL-PVP4B	56	8.00/2	8.6.2009	12:55	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
OL-PVP6A	56	7.83/2	8.6.2009	13:35	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
OL-PVP6B	56	3.83/2	8.6.2009	13:55	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
OL-PVP14	56	10.40/2	8.6.2009	14:30	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
OL-PVP30	52	3.80/1	25.6.2009	14:25	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
OL-PVP31A	52	6.50/2	27.7.2009	10:15	Ossi Isola/Posiva Oy	1.5
OL-PVP31B	52	7.00/2	27.7.2009	9:40	Ossi Isola/Posiva Oy	1.5
OL-PVP32	52	4.60/2	27.7.2009	11:00	Ossi Isola/Posiva Oy	1.5
OL-PVP33	52	3.90/1	22.6.2009	14:25	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
OL-PVP34A	52	7.40/2	26.6.2009	9:02	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
OL-PVP34B	52	7.60/2	26.6.2009	8:44	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
HP1	50	5.00/1	22.6.2009	9:40	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1
HP2	50	3.00/1	22.6.2008	10:30	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5
HP3	50	5.00/1	26.6.2009	12:20	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1
HP4	50	3.00/1	22.6.2009	13:20	Maarit Yli-Kaila, Ossi Isola/Posiva Oy	1.5

2.1 Measurements in PP-holes

The PP-holes have been measured using one-meter test section.

The measurement is divided into three stages:

1. **Stabilization:** the water level is stabilized in the hole after moving the equipment.

2. **Inflation:** the pressure level is stabilized in the hole and in the test section after inflating the packers.

3. **Measurement:** the piston is either pushed or pulled in the test section or water is poured into it. In the measurement, the stabilation of the pressure transient is followed up.

Each of the three stages has a specific duration, see Table 2-3. An example of the water levels at different measurement stages is shown in Figure 2–2.

Table 2-3. *Duration of the measurement stages.*

Stage	Time minimum/min	Time maximum/min
1	1	2
2	2	5
3	5	15

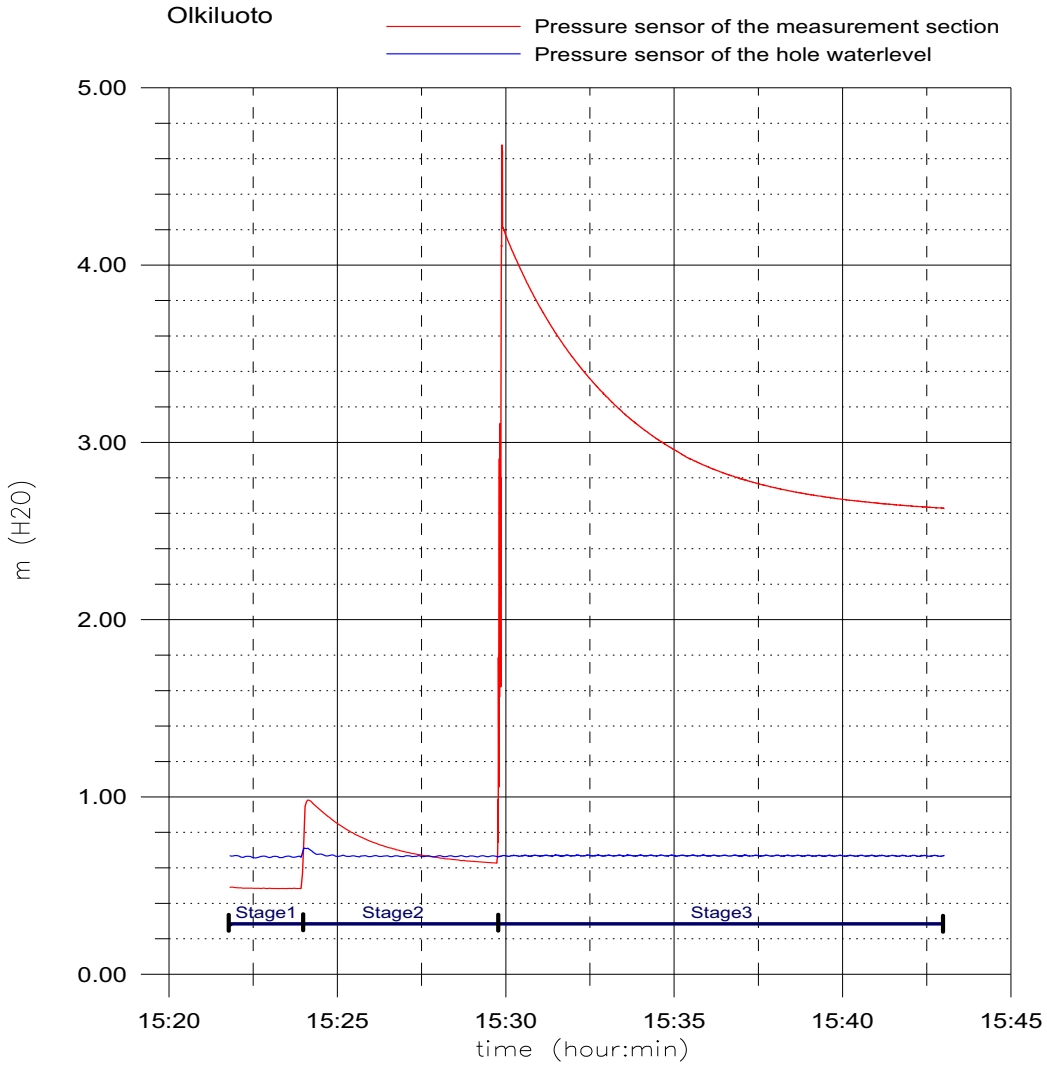


Figure 2-2. *An example of measurement results in a PP-hole.*

2.2 Measurements in PVP- and HP-tubes

The groundwater observation tubes are measured without packers, using only the piston (pressure sensor). A PVC-tube is installed around the pressure sensor in order to increase the diameter of the piston and to generate an adequate pressure change after moving the piston. Only one measurement per each hole is made with this method as each hole consists of a plastic tube with a one to four meters perforated section installed in the overburden.

The measurement is divided into two stages, corresponding Stage 1 and Stage 3 of the PP measurements, see Table 2-3. An example of the measurement is presented in Figure 2-3.

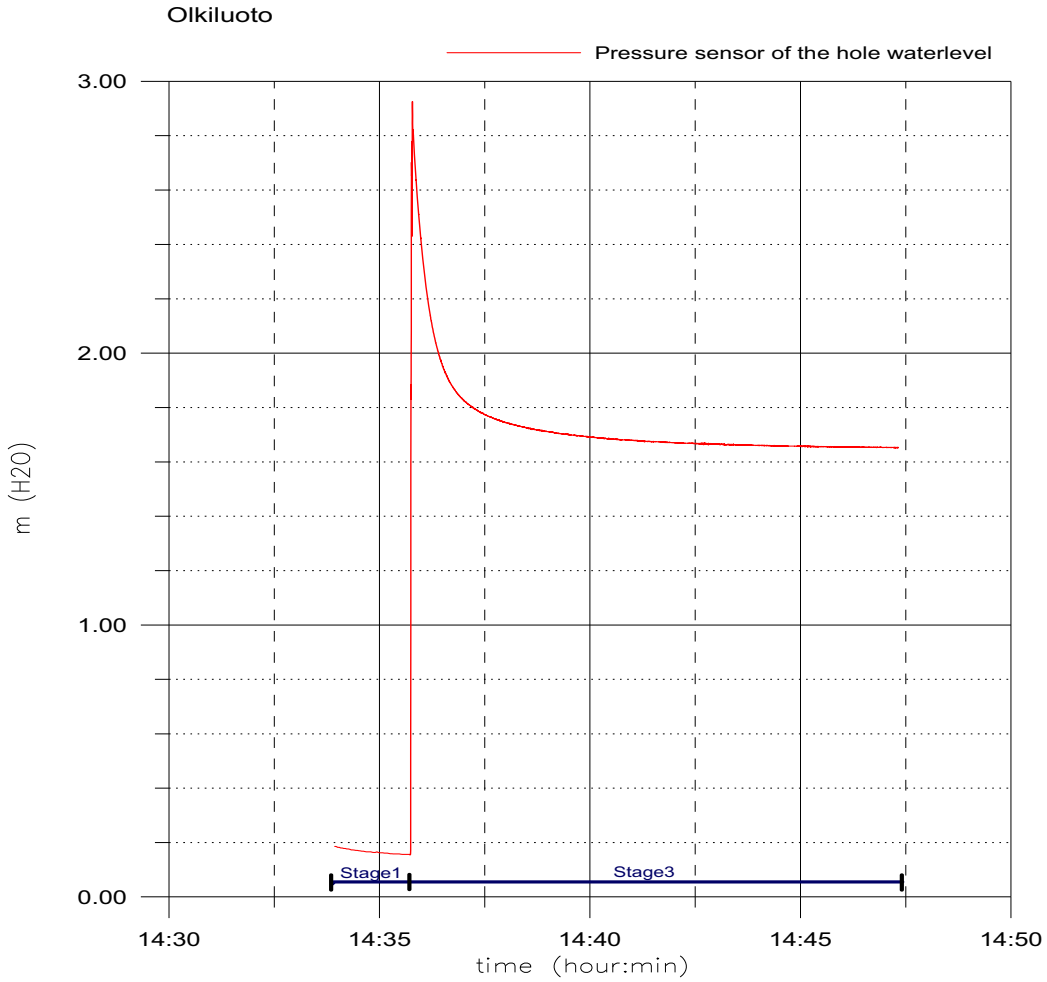


***Figure 2-3**. An example of measurement results in a PVP- or HP-tube.*

3 METHOD OF INTERPRETATION

3.1 Hvorslev's method

The slug-test results were interpreted using Hvorslev's method (Freeze & Cherry 1979). A homogeneous, isotropic, infinite medium in which both soil and water are incompressible is assumed. This assumption is valid, when a fracture or the network of fractures is homogenous and planar (can be seen in the analysis as a linear behaviour). According to Hvorslev, the flow rate q at time t is related to the hydraulic conductivity K and to the unrecovered head difference H-h (H reference water level, h head at time t) according to following equation:

$$q(t) = \pi r^2 \, dh / dt = FK(H-h), \qquad \textit{(Equation 3-1.)}$$

where r is the radius of the hole and F depends on the shape and dimensions of the piezometer. The flow rate will decrease asymptotically to zero with increasing time. Solution of the differential equation 3-1 is

$$H-h = (H-H_0) \, e^{-t/T_0} \qquad \textit{(Equation 3-2.)}$$

with initial condition $h = H_0$ at $t = 0$ and the basic time lag T_0 defined as

$$T_0 = \pi r^2 / FK \, . \qquad \textit{(Equation 3-3.)}$$

Plotting the normalized head recovery $(H-h) / (H-H_0)$ on a logarithmic scale against time results in a straight line, if a fracture or aquifer under measurement is ideal i.e. homogeneous, planar and cylinder-symmetric. The basic time lag T_0 can be defined from the plot being the time t, when $\ln (H-h)/(H-H_0) = -1$. The shape factor suggested by Hvorslev can be applied if $L/R > 8$ (L length and R radius of the piezometer intake). The resulting equation for the hydraulic conductivity K is

$$K = r^2 \ln(L/R) / 2LT_0 \, . \qquad \textit{(Equation 3-4.)}$$

Figure 3-1 clarifies the notation used in the equations above.

3.2 Thiem's formula

For reference, the hydraulic conductivity K was also calculated based on Thiem's formula:

$$K = Q \ln(r_0/r_w) / (2 \pi \, L \, \Delta h). \qquad \textit{(Equation 3-5.)}$$

In Equation 3-5, Q is the flow rate (= Adh/dt, A is the void area between connection rods and the pressure cable, see Figure 3-1, dh change in head during the time interval dt), r_0 is the radius of influence assumed to be 14 m, r_w is radius of the borehole, L is the length of the test section and Δh is the overpressure i.e. the head difference to the reference water level in the test section.

In interpretation different time interval dt was used for tight intervals with hardly any observed recovery and intervals with clear recovery i.e. in the case of clear observed flow, hydraulic conductivity is interpreted based on head change on a short interval dt in the middle of the recovery period. As the recovery is not linear, the result is sensitive to the selection of the time interval used in interpretation (see Figure 3-2 a). If there is hardly any flow, a longer time interval equal to one third of the recovery period is used (see Figure 3-2 b). Slow recovery is approximately linear and the Thiem's formula gives a reliable estimation of the hydraulic conductivity.

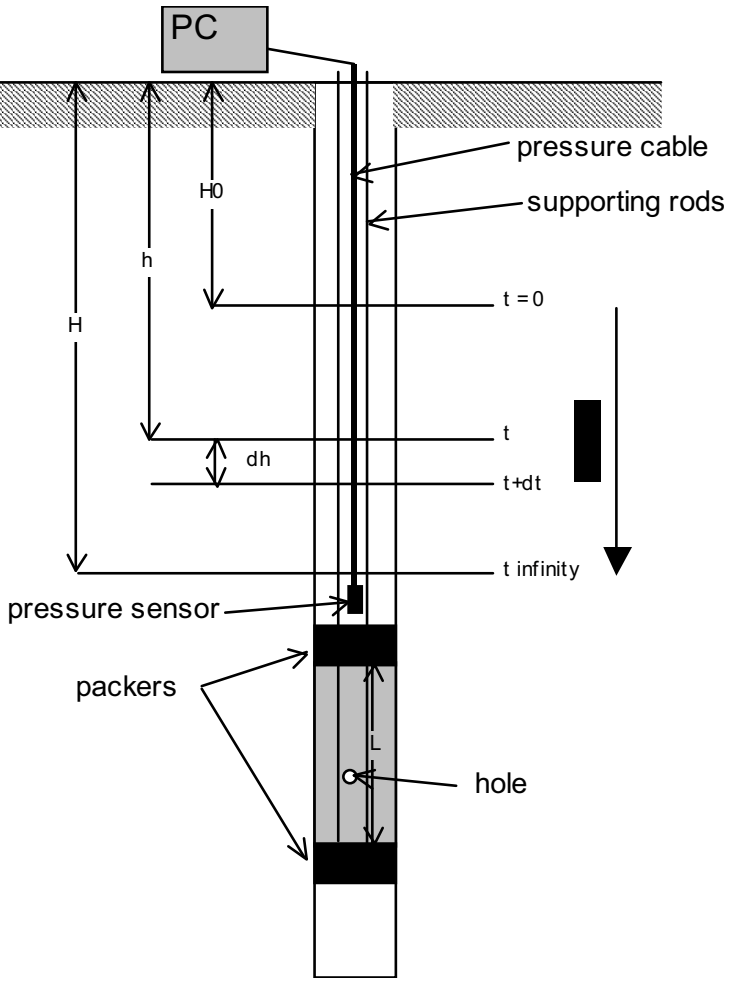
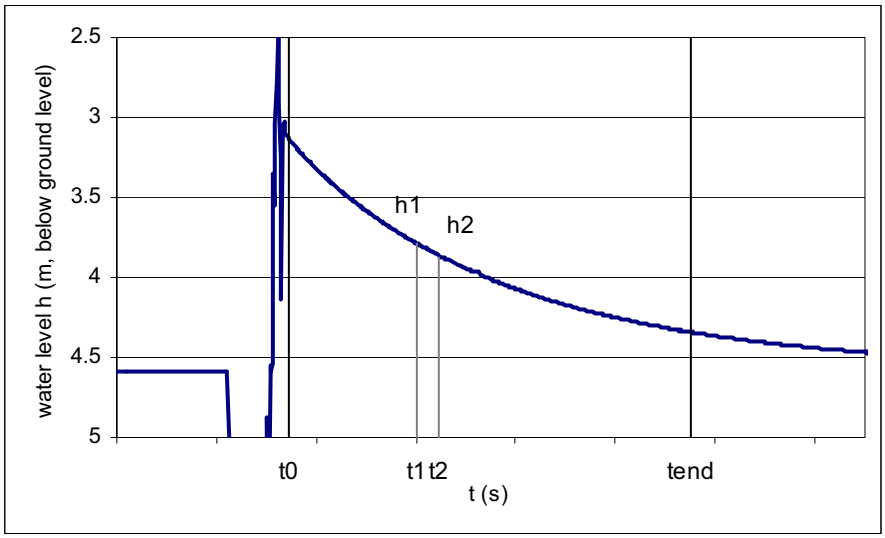


Figure 3-1. *Principle of the slug-test and interpretation according to Hvorslev's method (modified after Freeze and Cherry 1979).*

a)



b)

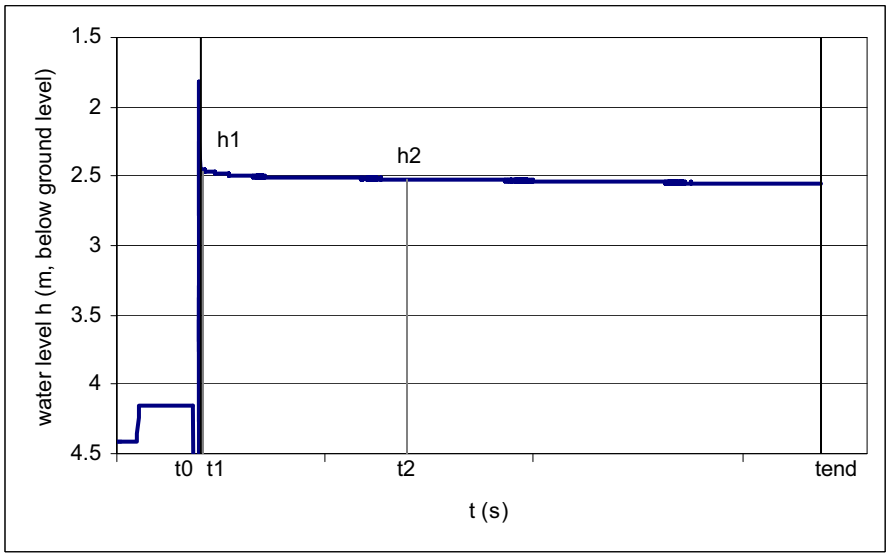


Figure 3-2. *Calculation of the hydraulic conductivity according to Thiem's formula: in case of a) a clear recovery and b) a tight interval with very slow recovery.*

4 DATA PROCESSING

For the interpretation of the first measurements in 2002, a set of MSExcel-macros was developed (see Appendix 1 for the details) (Hellä & Heikkinen 2004). The same macro has been used in the interpretation of the former measurements in 2004, 2005, 2006, 2007 and 2008. The actual analysis of the results uses a template file (xls), which contains the necessary formulas and graph templates (see Appendices 2 to 26). The figures on the template include a graph of the measured water level both in the borehole and in the test section. Another figure depicts the interpretation i.e. (H-h)/(H-H0) is plotted in logarithmic scales versus time. In the latter figure also the fitted line through the measured points is plotted. The macro copies the data from the measurement file to the analysis template file. The functions and images in the template file are modified automatically. Further on, the results, the K-values by Hvorslev's method and the two K-values obtained by Thiem's formula, together with some comments are copied to a separate result file.

The reference for all depth values in the results is the ground level whereas in the data files the reference is the top of the casing (TOC). The subtraction of the TOC is done automatically by the macros. The reference water level H is determined to be the average water level during phase one,

Figure 2-2 and Figure 3-1 are referred for the notation. Phase one is used as the water level during it is more stable than during phase two. H_0, the water level at the test section after the disturbance, either adding water or lowering the pressure sensor in the borehole, is defined to be h at 10 (PP-holes) or 20 (PVP- and HP-tubes) time steps after the minimum observed h. The minimum is not used as the data is very noisy soon after lowering the sensor. A disadvantage is that potentially part of the recovery period on highly conductive intervals is lost. An example is given in Figure 4-1. There is a possibility to adjust the time period used for line fitting manually, if necessary. The time range used is shown in the interpretation plot.

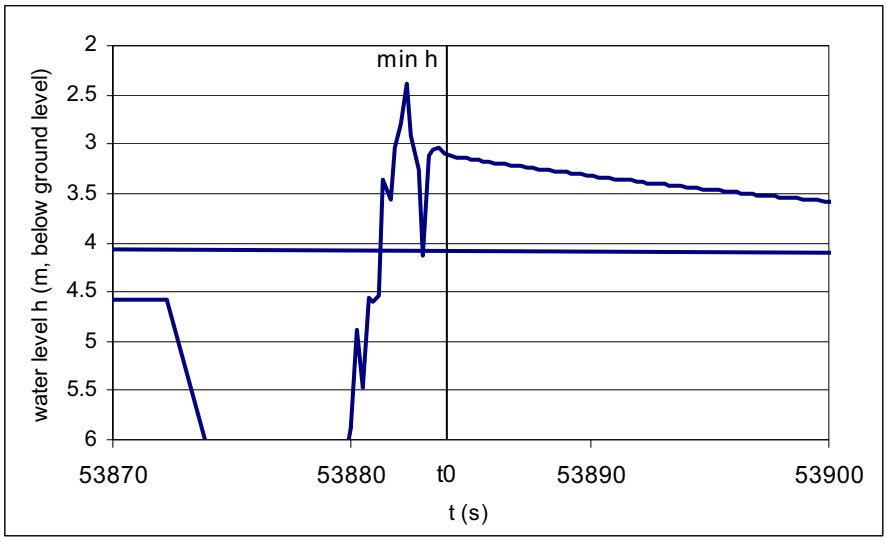


Figure 4-1. *An example of the water level changes in the test section at the time of lowering the pressure sensor.*

A straight line is fitted through $\ln(H-h)/(H-H_0)$ as function of time. The time interval used for the fitting is from t_0, the time corresponding H_0, to t_{end} corresponding either the end time of the test period or the time when $(H-h)/(H-H_0)$ reaches 0.1 or the time when $(H-h)/(H-H_0)$ gets negative. This might happen if the data is noisy at the end of the measurement. The basic time lag T_0 needed for the Hvorslev analysis is then calculated from the resulting line equation. Thereafter the hydraulic conductivity K can be derived from equation 3-4.

The time instants used in the Thiem's formula are determined as described in chapter 3.2 and in Figure 3-2. The water levels h_1 and h_2 corresponding the times t_1 and t_2 are calculated as an average of eleven observed h values around time t. Average is used to compensate the possibly noisy data. Once the corresponding h and t values are defined, an average head difference to borehole can be calculated together with the outflow Q. These are then further used to calculate the hydraulic conductivity K according to equation 3-5.

To check the correctness of the interpretation the quotient of the hydraulic conductivities $K_{Hvorslev}$ / K_{Thiem} is calculated. If the ratio is between 1/3 and three, these two results are considered to be in accordance.

On most of the tight intervals, T_0 is not reached meaning that the value of T_0 has to be extrapolated outside the observed time range and the result is thus more uncertain than in cases when T_0 is reached during the observation period.

5 RESULTS

K-values (m/s) in slug-measurements give information about water conductivity in the soil where test sections are located. K-value tells how thick (m) soil layer water will penetrate in one second. Porosity of the sediment/rock, structure of sediment/rock, fractures in rock, grain size in sediment, grain shape, grain sorting and the way K-values are counted, will affect in K-values. There are K-value estimates for different kind of sediment layers and bedrock types. These estimates (see Figure 3-3) have been discovered in numerous field studies and laboratory studies worldwide over the years.

Sediment type/rock type	K-Values (m/s)
Coarse Gravel	> 10E-01
Medium Gravel	10E-01 - 10E-02
Fine Gravel	10E-02 - 10E-03
Sandy Gravel	10E-02 - 10E-06
Sand	10E-02 - 10E-06
Coarse Sand	10E-01 - 10E-04
Medium Sand	10E-02 - 10E-05
Fine Sand	10E-03 - 10E-06
Silt	10E-05 - 10E-09
Coarse Silt	10E-04 - 10E-06
Fine Silt	10E-05 - 10E-08
Clay	< 10E-08
Gravelly Till	10E-04 - 10E-07
Sandy Till	10E-06 - 10E-08
Silty Till	10E-07 - 10E-09
Fractured igneus rock and Metamorphic rock	10E-04 - 10E-06
Igneus rock and Metamorphic rock with very little fractures	< 10E-09
Schist	< 10E-08
Sandstone	10E-07 - 10E-010

Figure 3-3. *Known estimates for different kind of soil/rock type. (Niemi et al. 1994, Mälkki 1999)*

The interpretation of the hydraulic conductivities in each of the measured holes and sections are presented in Appendices 2 to 19. Three typical recovery curves were observed: a tight section with hardly any recovery, a section with clear recovery resulting in a linear trend on the semi-log plot and a section with rapid recovery, which is not linear on the semi-log plot. An example of each type is given in Figure 5-1.

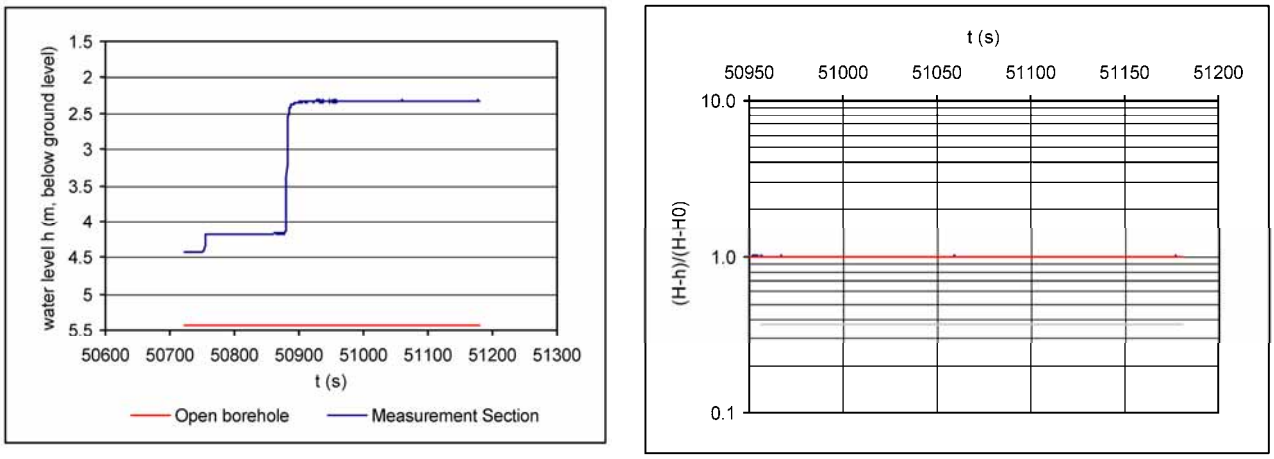
In Figure 5-2, the summary of the results in PP-holes is presented and Figure 5-3 contains the summary of the results in PVP- and HP-tubes. In PP-holes, the test section is one meter along the hole. In PVP- and HP-tubes, the entire hole is measured without packers. The results represent the perforated section, which in tubes measured at 2009 was typically two meters, except tubes OL-PVP30 (1 m), OL-PVP33 (1 m), OL-HP1 (1 m), OL-HP2 (1 m), OL-HP3 (1m) and OL-HP4 (1 m).

The cumulative distributions of the measured hydraulic conductivities are presented in Figures 5-4 and 5-5 including also results from 2002, 2004, 2005, 2006, 2007 and 2008. In PP-holes, the cumulative distribution of the latest measurements agrees well with the results from 2004, 2007 and 2008. The conductivities higher than 10^{-7} agree also relatively well with the results from 2002, 2005 and 2006 (Figure 5-4). Also, the results from PVP- and HP-tubes mostly agree well, although the measurements of 2002, 2004, 2005, 2006, 2007, 2008 and 2009 included partly different tubes (Figure 5-5). In fact there have been only few tubes that have been measured every year and in 2009 there were 8 tubes that have not been measured before (Table 5-1). That explains why results divide quite loosely around average cumulative distribution line. The diagram shows that in 2009 the results agree relatively well with the average cumulative distribution though there is little difference in low conducting values (1.0E-06 - 1.0E-07). In 2004 the conductivities in the overburden were notably higher and in 2002, 2005 and 2006 lower than the average cumulative distribution. The results from 2007 and 2008 seem to follow the average behaviour.

All the PP-holes and PVP- and HP-tubes measured in Olkiluoto Island are presented in Table 5-1. Altogether 12 PP-holes, 42 PVP-tubes and 4 HP-tubes have been measured. In 2002, nine PP-holes and fifteen PVP-tubes were measured. In 2004, the slug-tests included three PP-holes and seven PVP-tubes, in 2005 three PP-holes and nine PVP-tubes, in 2006 included four PP-holes and five PVP-tubes, in 2007 included three PP-holes and 22 PVP-tubes and in 2008 two PP-holes, 14 PVP-tubes and three HP-tubes. The latest measurements in 2009 included two PP-holes, 12 PVP-tubes and 4 HP-tubes. As the number of measured holes is rather small, the results of a single hole do affect considerably to the distributions for a single year shown in Figures 5-4 and 5-5.

Any earlier measurements available from the holes measured in 2009 are given in table 5-1. The results from 2009 are compared with the earlier results in Figures 5-6, 5-7 and in Appendix 20.

a)



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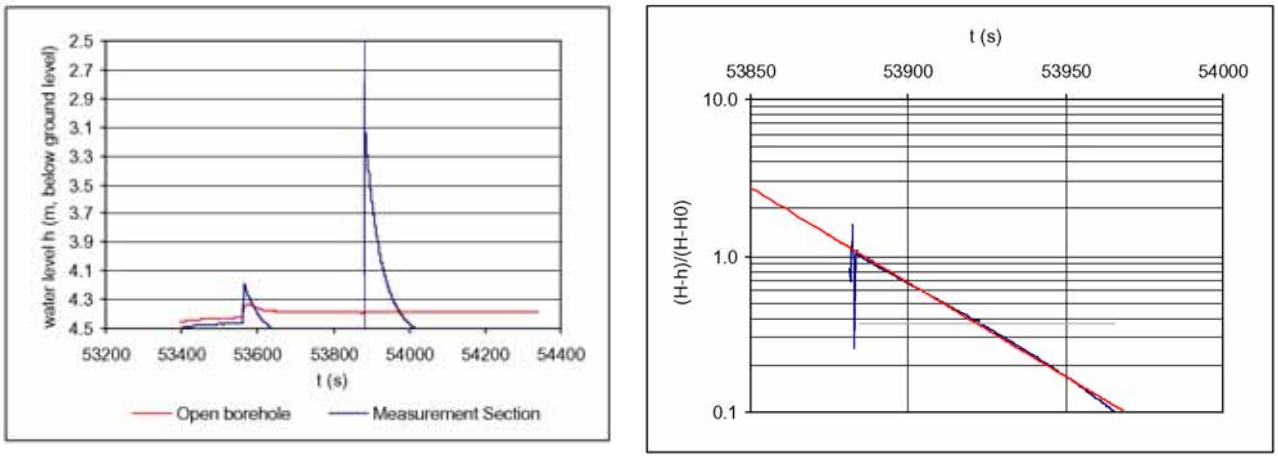

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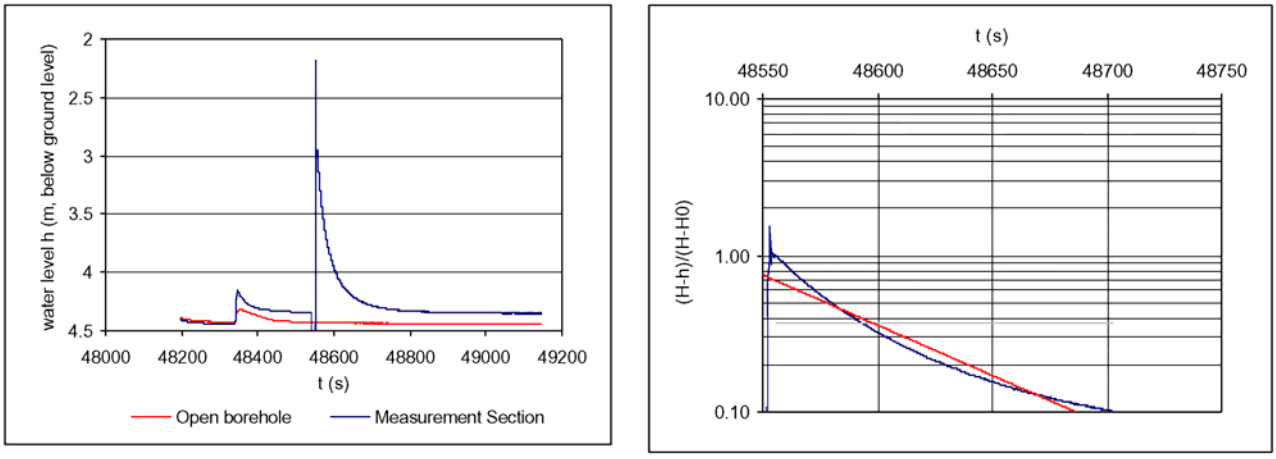


Figure 5-1. *Type of the observed recovery curves, a) a tight section with hardly any recovery, b) a section with clear recovery resulting in a linear trend on the semi-log plot and c) a section with rapid recovery, which is not linear on the semi-log plot.*

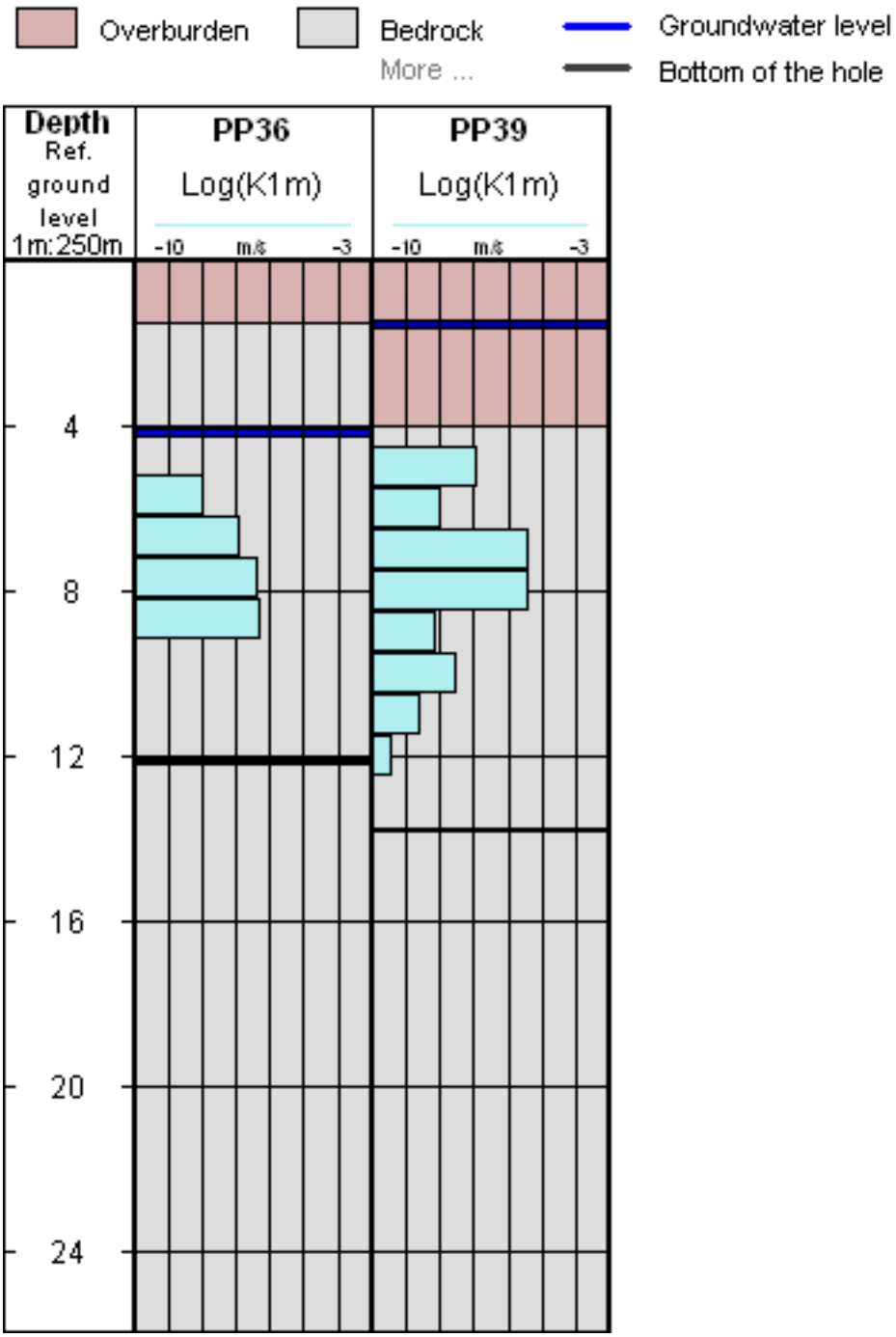


Figure 5-2. *Hydraulic conductivity ($K_{Hvorslev}$ m/s) in PP-holes.*

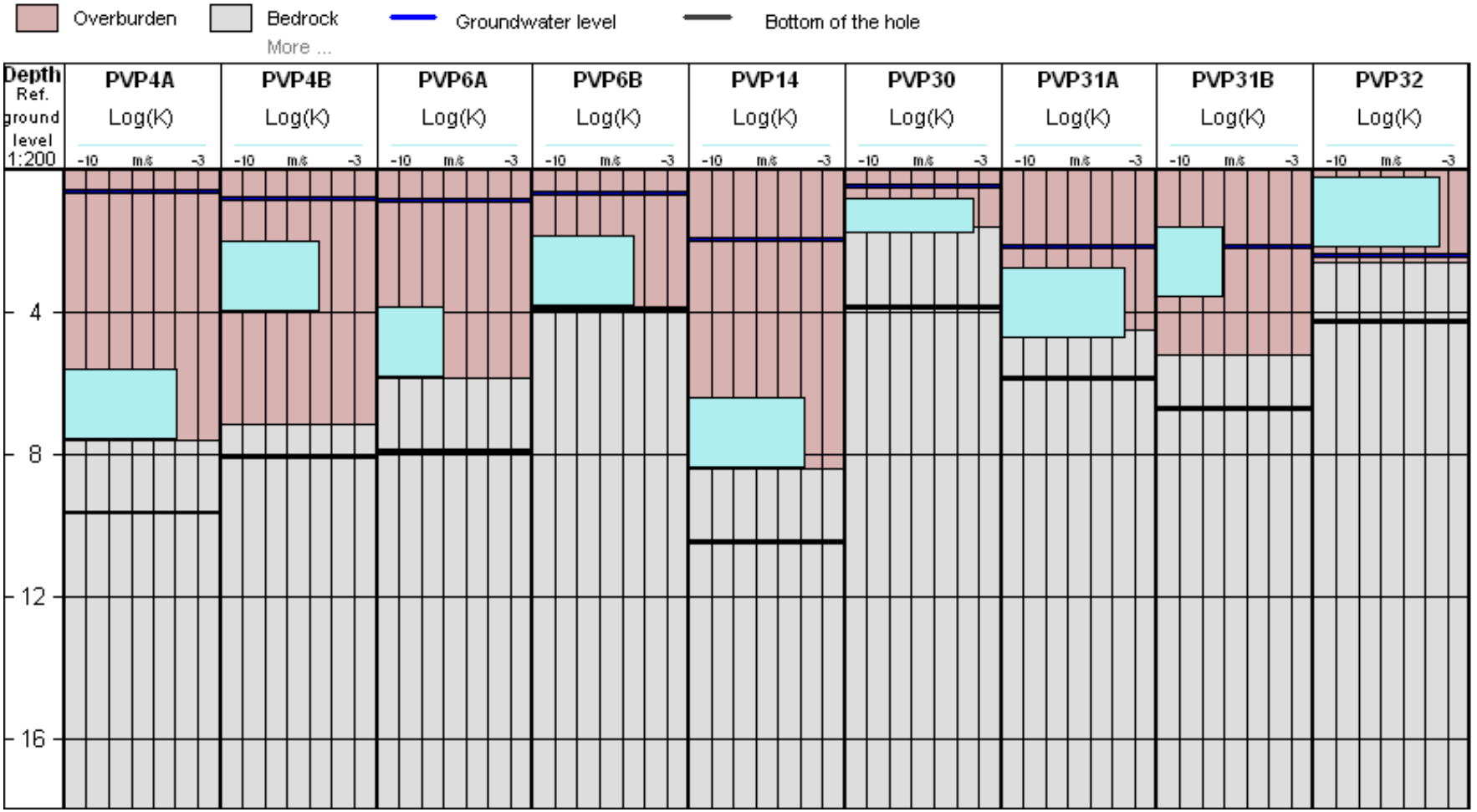


Figure 5-3a. *Hydraulic conductivity (m/s) in PVP-tubes. The perforated section is two meters in PVP-tube except in PVP-30 the perforated section is one meter.*

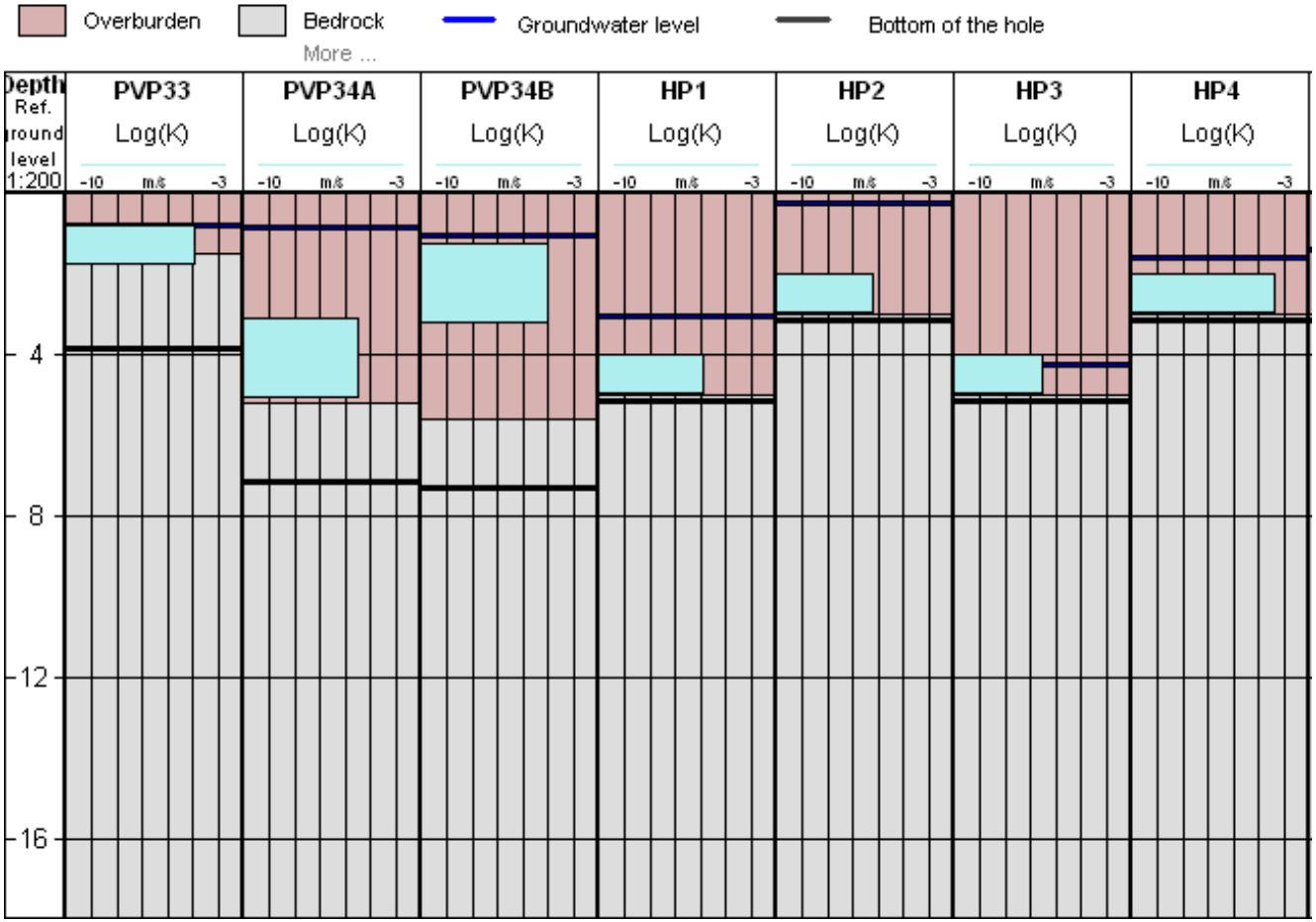


Figure 5-3b. *Hydraulic conductivity (m/s) in PVP- and HP-tubes. The perforated section is two meters in PVP-tubes OL-PVP34A and OL-PVP34B. In OL-PVP33, OL-HP1, OL-HP2, OL-HP3 and OL-HP4 perforated section is 1 m.*

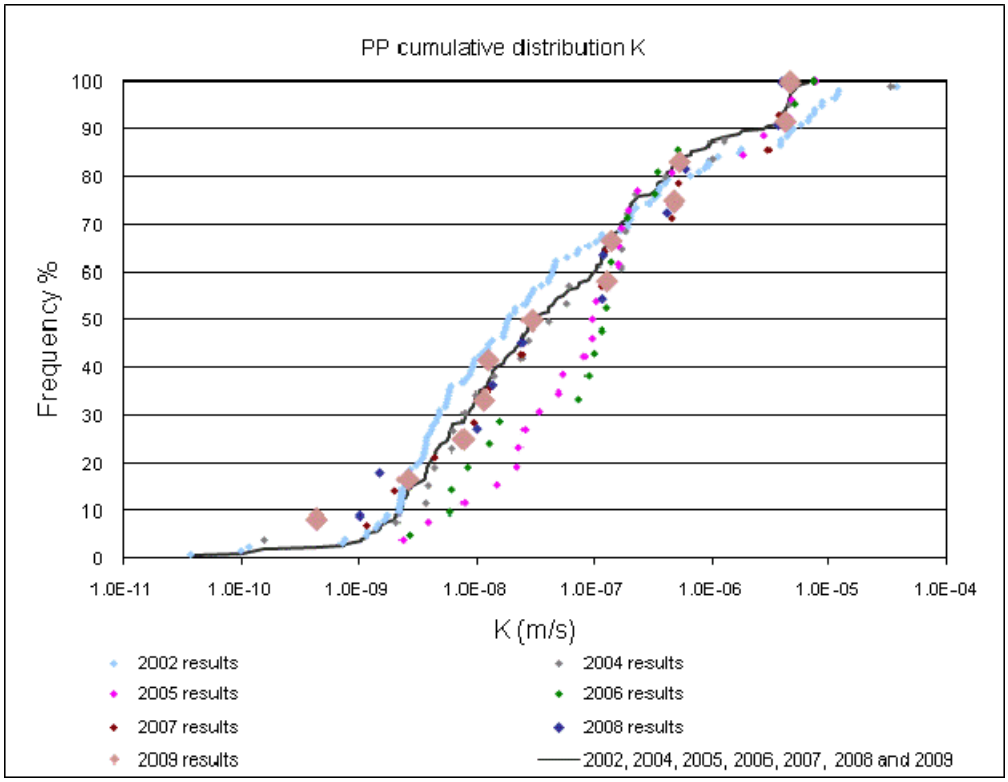


Figure 5-4. *Cumulative distribution of the hydraulic conductivities (Hvorslev) in PP-holes.*

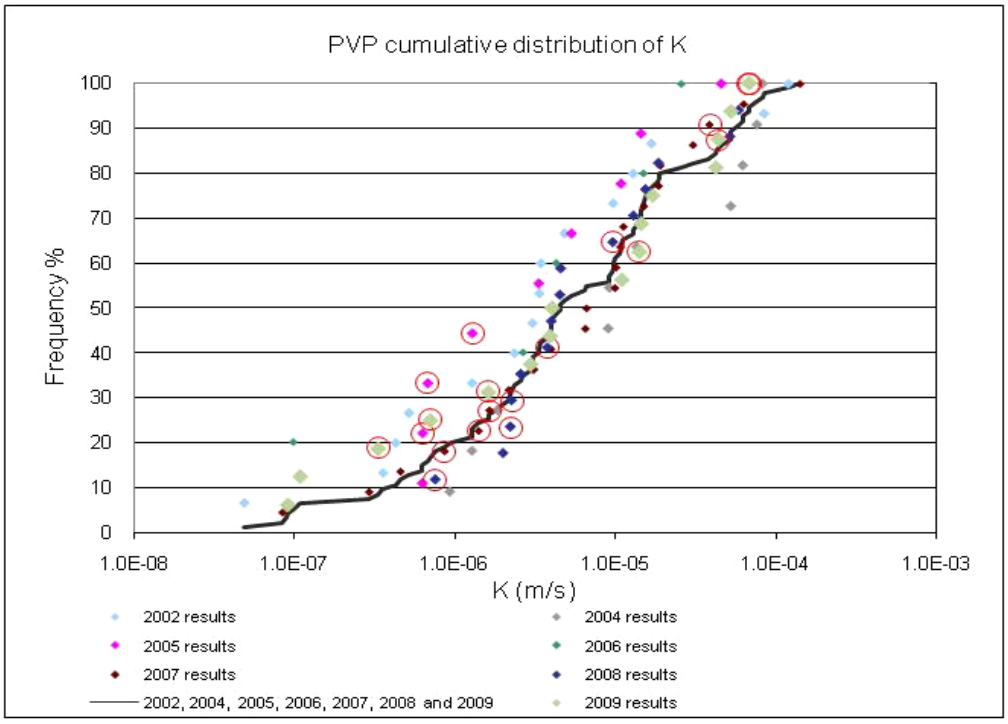


Figure 5-5. *Cumulative distribution of the hydraulic conductivities (Hvorslev) in PVP- and HP-tubes. The tubes, where perforated section is not two meters, are marked with red circles.*

Table 5-1. *The slug-tests done at the Olkiluoto Island at different times. The holes which are included in monitoring program are in bold.*

Hole/Tube	Measured	Note
OL-PP2	2002, 2004	
OL-PP3	2002	collapsed
OL-PP5	2002, 2005, 2006	
OL-PP7	2002	
OL-PP9	2002, 2005, 2006, 2007	
OL-PP10	2002	
OL-PP31	2002	
OL-PP32	2002	
OL-PP35	2002	
OL-PP36	2006, 2007, 2008, 2009	
OL-PP38	2004	destroyed
OL-PP39	2004, 2005, 2006, 2007, 2008, 2009	
OL-PVP2	2004	drilled bedrock hole
OL-PVP3A	2002, 2007	
OL-PVP3B	2002, 2007	
OL-PVP4A	2002, 2004, 2005, 2006, 2007, 2008, 2009	
OL-PVP4B	2002, 2004, 2005, 2006, 2007, 2008, 2009	
OL-PVP5A	2002	destroyed
OL-PVP5B	2002	
OL-PVP6A	2002, 2006, 2007, 2008, 2009	
OL-PVP6B	2002, 2006, 2007, 2008, 2009	
OL-PVP7A	2002, 2007	
OL-PVP8A	2002, 2007	
OL-PVP8B	2002, 2007	
OL-PVP9A	2002, 2007	
OL-PVP9B	2002, 2007	
OL-PVP9C	2002	
OL-PVP10A	2002, 2007	
OL-PVP10B	2002, 2007	
OL-PVP11	2004, 2007	
OL-PVP12	2004, 2007	
OL-PVP13	2004, 2007	
OL-PVP14	2004, 2005, 2006, 2007, 2008, 2009	
OL-PVP17	2005, 2007	
OL-PVP18A	2005, 2007	
OL-PVP18B	2005, 2007	
OL-PVP19	2005, 2007	
OL-PVP20	2005, 2007	
OL-PVP21	2008	
OL-PVP22	2008	
OL-PVP23	2008	

OL-PVP24	2008	
OL-PVP25	2008	
OL-PVP26	2008	
OL-PVP27	2008	
OL-PVP28	2008	
OL-PVP29	2008	
OL-PVP30	2009	
OL-PVP31A	2009	
OL-PVP31B	2009	
OL-PVP32	2009	
OL-PVP33	2009	
OL-PVP34A	2009	
OL-PVP34B	2009	
HP1	2008, 2009	
HP2	2008, 2009	
HP3	2009	
HP4	2008, 2009	

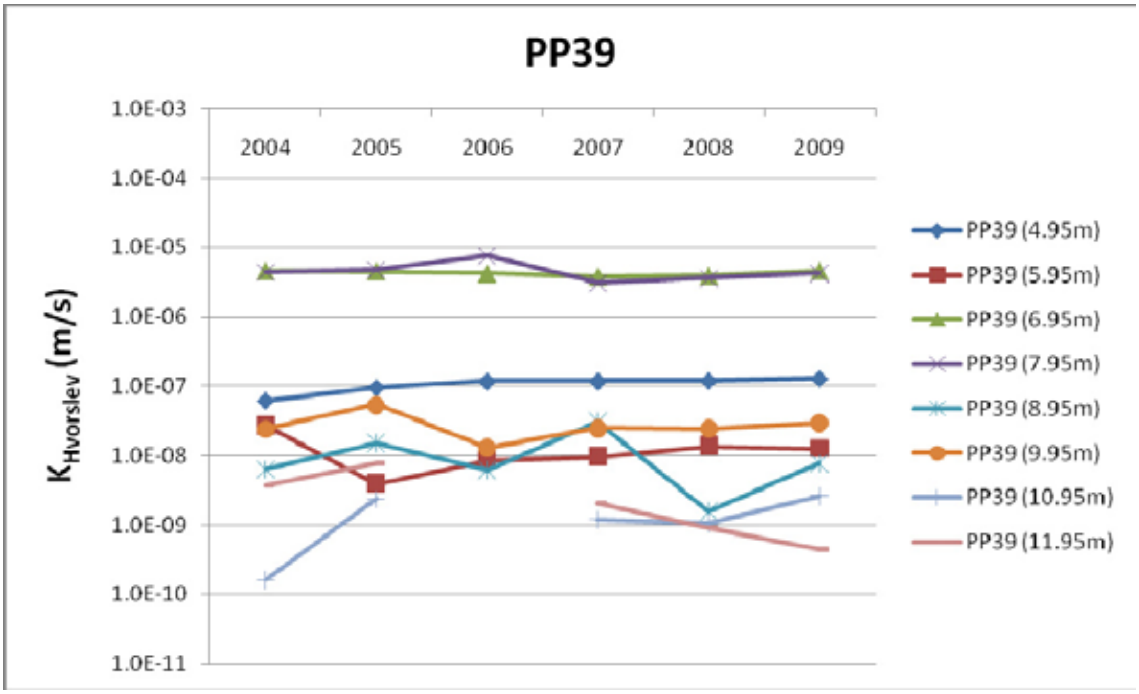


Figure 5-6. *Results from PP39-hole measured 2009 versus results from earlier measurements of this hole. Disturbance factors in measurements are relatively larger in very low K-values, than higher ones, which is one reason why there is bigger variation in sections of low conductivity.*

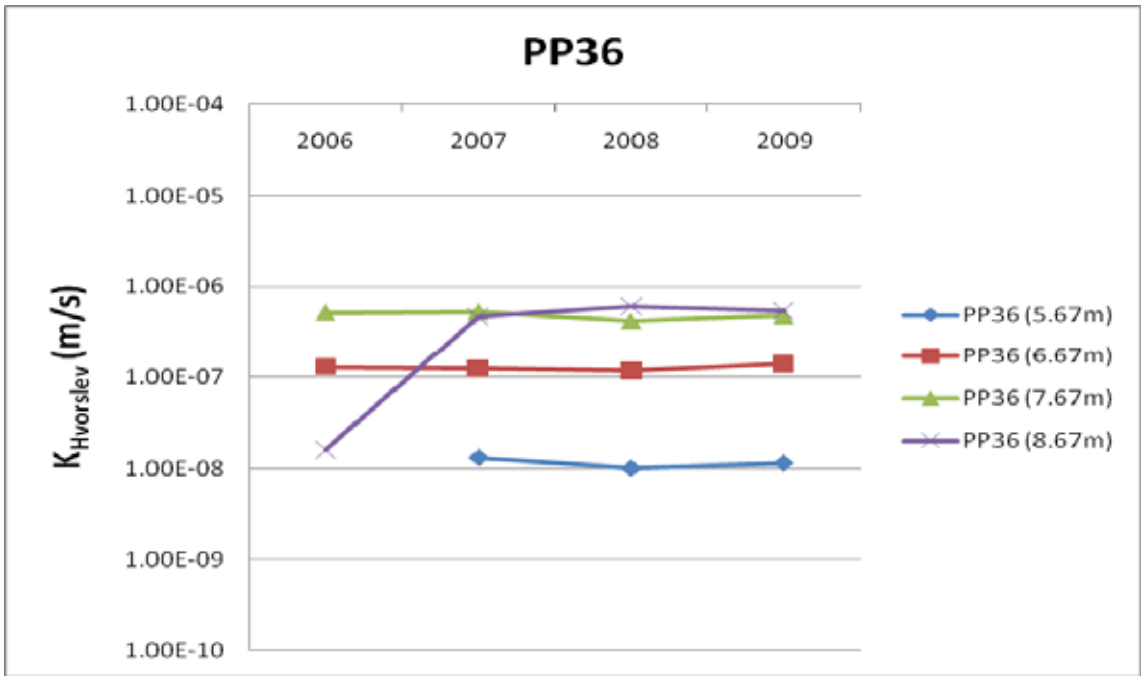


Figure 5-7*. Results from PP36-hole measured 2009 versus results from earlier measurements of this hole. Diverging result 2006 (8.67m) could be measurement error or caused by disturbance factors in measurement. Also changing circumstances of test section after installation of the PP-tube could cause the diverging result to following year(s). Also macro-related "disturbance" could cause the diverging result.*

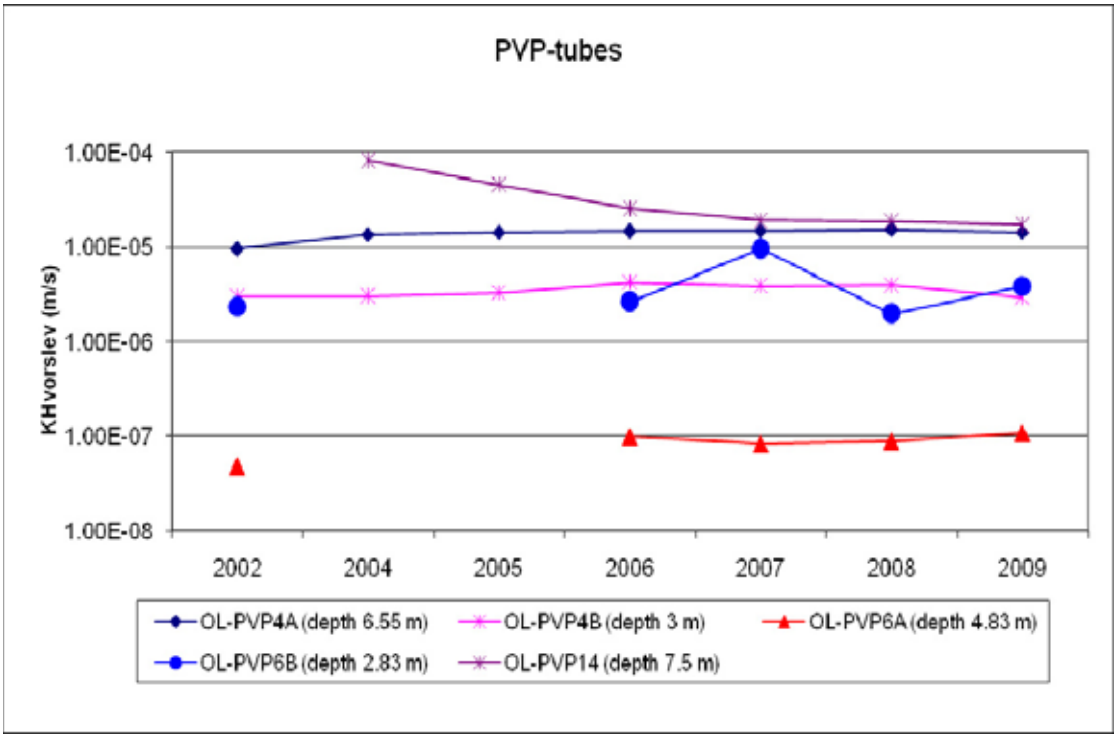


Figure 5-8. *Results from part of PVP-tubes measured 2009 and at least once in the earlier measurements in 2002, 2004, 2005, 2006, 2007 and 2008. OL-PVP14 lowering trend in K-values seems to relent. Changing circumstances (ground frost, tube movement, porosity of sediment next to test section tube-holes) after installation of the PVP-tube could cause the diverging result to following years before K-value "settles down". Diverging result OL-PVP6B 2007 is caused by macro that calculates K-values. For unknown reason 2007 (OL-PVP6B) macro used only 80 seconds of measurement time though the curve was identical with 2002, 2006, 2008 and 2009 curves. Other years macro used +350 seconds measurement time for calculating K-values. Because the curve (OL-PVP6B) that is used for calculating the K-value is exponentially decaying (see figure 6-3), used time-length affects dramatically in K-value.*

Generally the results of 2009 are quite close to the results of the earlier measurements. In OL-PP36, the results from 2009 agree very well with the results from 2008, 2007 and 2006 (Figure 5-7). Only exception was section 8.67m in 2006. The section 5.17 – 6.17 m was not measured in 2006. (Figure 5-6).

In OL-PP39, all the results from 2004, 2005, 2006, 2007, 2008 and 2009 are quite close to each other (Figure 5-6). There is more difference in low K-values than in higher ones. There are two main reasons to this: 1. the accuracy of slug-measurement equipment is not accurate enough for very small values and measurement method errors get bigger in very small conductivities. 2. The macro that calculates k-values could give relatively different values depending on variation of measurement time and error factors on the curve. Slightest difference in the water-level-curve could give very different K-value. Because the water level lowers so slowly in poorly conducting soil, 15 minutes

measurement time is not enough to give reliable result. Also the calculating time should be same every year. Sections 10.45 – 11.45 m and 11.45 – 12.45 m were not measured in 2006. To interpret section 6.45 – 7.45 m shorter time was used in 2007 and 2008 and in section 7.45 – 8.45 m shorter time was used in 2007, 2008 and 2009 because the sections have high conductivity and the recovery is not linear. The time range used is shown in the interpretation plot (Appendix 3).

In PVP-tubes the variations are small (Figure 5-8). In OL-PVP14, there seems to be a lowering trend of conductivity though the trend seems to settle. Same lowering trend can be seen in pre-pumping results from 2004, 2005, 2006 and 2007. The pre-pumping result from 2008 was slightly higher than the results from 2006 and 2007. (Hirvonen 2005; Lehtinen et al. 2006; Partamies et al. 2007; Partamies et al. 2008). In OL-PVP6B, the results from 2002, 2006, 2008 and 2009 agree well but the result from 2007 is somewhat higher (Figure 5-8) that is caused by macro. OL-PVP6A and OL-PVP6B were not measured in 2004-2005.

Results in HP-tubes 2008 are close to results from 2009. K-values are surprisingly high in OL-HP1 (Appendix 16) and in OL-HP4 (Appendix 19) considering that HP-tubes are located in the inhibitory bank of the Korvensuo basin.

6 ON THE ACCURACY OF THE RESULTS

6.1 Detection limits

In measurements of 2009, the interpreted hydraulic conductivities range from 10^{-10} m/s to 10^{-6} m/s in PP-holes and from 10^{-8} m/s to 10^{-5} m/s in PVP-tubes. In the following, the detection limits are discussed.

The accuracy of the water level obtained by the pressure sensor is ±1-2 mm. By analysing the recovery in some of the tight intervals it was noticed that the change in water level has to be at least 5 mm, so that it can be distinguished from the noise. In the lowest measured K-values (10^{-9} - 10^{-10}) the water level change was barely 5 mm in 15 minutes, so longer time would be needed to have more reliability in the results. The recovery period varies from 200 s to 1000 s. Taking the geometry of the tool and the hole into account this leads to minimum observable flow of $2 \cdot 10^{-9}$ - $8 \cdot 10^{-9}$ m^3/s (30 ml/h) in PP-holes. The overpressure is typically 1.5 m and test section 1.0 m leading to hydraulic conductivity $1 \cdot 10^{-9}$ - $5 \cdot 10^{-9}$ m/s according to Thiem's formula. Consequently, the lower detection limit in PP-holes is about $5 \cdot 10^{-9}$ m/s, which corresponds the transmissivity of $5 \cdot 10^{-9}$ m^2/s. The diameter of the PVP-tubes and the instrument used are different and the minimum observable flow is $2.5 \cdot 10^{-8}$ m^3/s. A typical overpressure is 1.5 m leading to the transmissivity of $2 \cdot 10^{-8}$ m^2/s. The minimum detection limit is thus $1 \cdot 10^{-8}$ m/s in tubes with 2 m long perforated section.

The upper limit of the measurement range is not as clear as the lower limit. In PP-holes, the maximum observable transmissivity is estimated to be in the order of $5 \cdot 10^{-5}$ m^2/s, which leads to hydraulic conductivity of $5 \cdot 10^{-5}$ m/s in 1 m test section. This value is deduced assuming a steel rod with a diameter of 2.5 cm, including the pressure sensor hose inside the rod with a diameter of about half of the steel rod, and further more overpressure of 2 m and a 2 m decrease in water level within 10 seconds. The observed conductivity can be higher as the flow is not necessarily steady-state as assumed in the estimation of the detection limit. In PVP-tubes, the geometry is different and the typical overpressure 1.5 m, resulting in the transmissivity of $1.6 \cdot 10^{-4}$ m^2/s. In PVP-tubes with 2 m long perforated section, the upper limit of hydraulic conductivity is thus $8.0 \cdot 10^{-5}$ m/s. The diameter of PP-holes is 46 mm or 56 mm. The detection limits are calculated to 46 mm holes but are practically the same for 56 mm holes.

In 2009 results the highest observed conductivity in the PP-holes is $4.6 \cdot 10^{-6}$ m/s in hole OL-PP39 at the depth 6.95 m (Appendix 3), where the water level in the test section decreased 1.5 m during 730 seconds. The difference between the water level in the test section and in the open hole was about 15 cm at the most.

When the sensor is lowered, there is a period of about 2-3 seconds, when the water level is unstable. The interpretation can be started first after more stabile conditions are reached so the recovery period should last at least 5 seconds. During the first seconds the water table already decreases considerably on sections with high conductivity. The overpressure H_0, used in the interpretation, is therefore considerably less than the theoretical value of 2 m, as the example shows.

In 2009 results the highest observed conductivity in PVP- and HP-tubes is $6.7 \cdot 10^{-5}$ m/s (OL-PVP30, see Appendix 9).

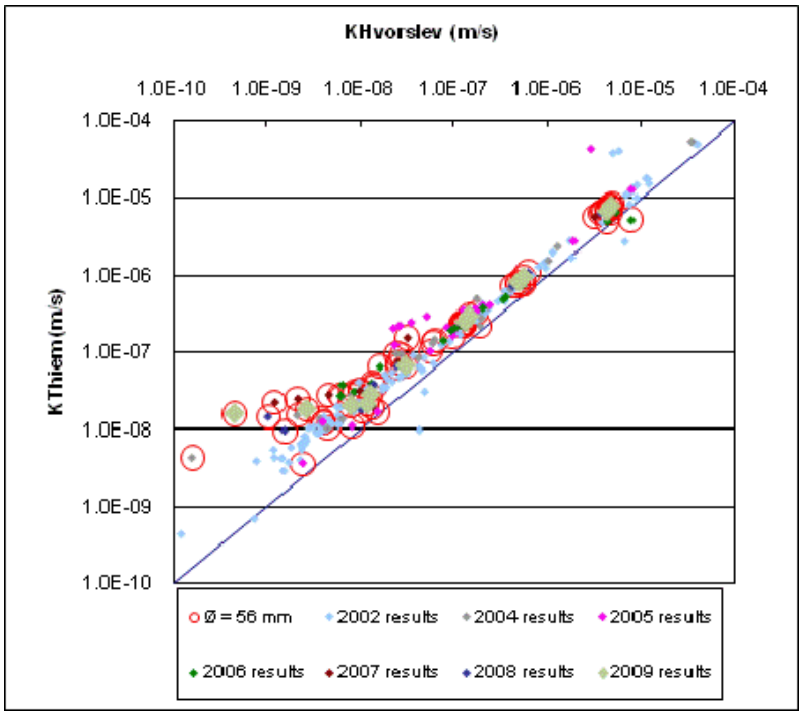
About the same limits are obtained by comparing the hydraulic conductivities resulting from the interpretations using the two methods, Hvorslev and Thiem. In general, the hydraulic conductivities calculated according to Thiem's equation and according to Hvorslev's method seem to be well in accordance, see Figure 6-1. The results from PP-holes agree extremely well, when the conductivity is higher than about $5 \cdot 10^{-8}$ m/s. In these cases T_0 is reached during the observation period. When the hydraulic conductivity is small, i.e. hardly no recovery is observed, the results obtained by the two methods give slightly different results, K_{Thiem} being approximately two to three times higher than $K_{Hvorslev}$. Exception is in OL-PP39, where K_{Thiem} is 36 times higher than $K_{Hvorslev}$ in section 11.45 – 12.45 m and 7 times higher in section 10.45 – 11.45. Both sections had very little water level change (very low K-value) which may be the reason for the large difference between $K_{Hvorslev}$ and K_{Thiem}. Same difference was seen in 2007 and 2008 results.

In the PVP- and HP-tubes, higher conductivities are observed, and the interpreted hydraulic conductivities according to two methods match relatively well. Also in PVP- and HP-tubes higher conductivities correlate better than the lower. An exception is the PVP-tube OL-PVP31B where the K_{Thiem} is more than 9 times higher than $K_{Hvorslev}$. This may be because of the recovery curve has first a small part where recovery is very fast but then recovery allmost stops completely and $K_{Hvorslev}$ does not take account the fast recovery part in calculating the K-value.

The coefficient of correlation (R^2), which measures the linear relationship between $\ln(H-h) / (H-H_0)$ and time t, decreases clearly when the hydraulic conductivity in PP-holes is less than $1 \cdot 10^{-8}$ m/s. In earlier years the correlation decreases little in PVP-tubes when the hydraulic conductivity less than $1 \cdot 10^{-6}$ m/s. In 2009 results, the correlation is poor also for many test sections with higher hydraulic conductivity. This is because in many PVP- and HP-tubes the recovery is not linear, see Figure 6-2. Again OL-PVP31B was exception with lowest R^2 -value (0.33). It is probably caused by the strange recovery curve with two completely different parts (Appendix 11).

Two sections of OL-PP39, 10.45 – 11.45 m and 11.45 – 12.45 m, give low R^2 values. That is because the conductivities in those sections are so low that macro can not recognize lowering linear trend on the semi-log plot (Figure 5-1 a). This was also seen in 2006, 2007 and 2008 results.

a)



b)

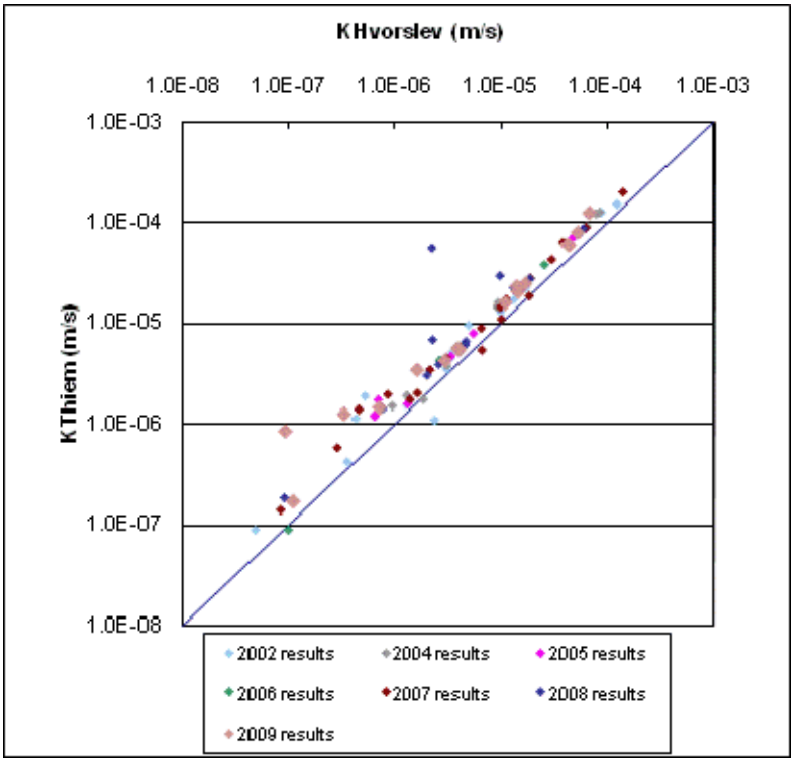
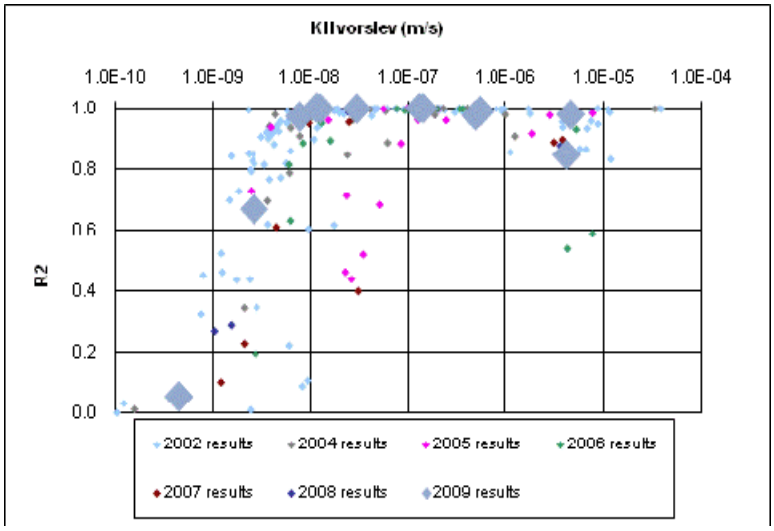


Figure 6-1. *Comparison of the hydraulic conductivities calculated either by the Hvorslev's method or using Thiem's formula a) in PP-holes, the holes with diameter 56 mm are marked with red circles, and b) in PVP- and HP-tubes.*

a)



b)

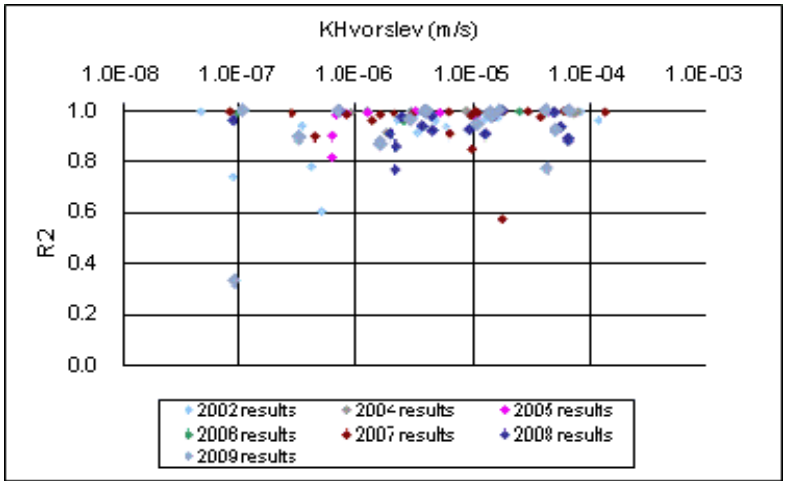


Figure 6-2. *R^2 as a function of hydraulic conductivity K in a) PP-holes and b) PVP- and HP-tubes.*

6.2 Effect of the time used in interpretation

As Figure 6-1 shows, the hydraulic conductivity by Hvorslev's method is normally less than the one obtained by Thiem's formula in PP-holes. This is mainly due to the selection of the time range used in the interpretation. Also the time interval chosen for the interpretation can be a significant source of error in cases of rapid recovery. This has proven to be the biggest source of influence that causes variation when comparing earlier year results. If used time inter interval is different to earlier year, then the K-value is also different even when the observed lowering water level curve would be exacly the same. Selection of the starting time affects also the H_0, the reference water level. Figure 6-3 gives an example of the effect of the selected time range. In the result figures (Appendices 2 to 19), the time range used in the interpretation according to Thiem's formula and in the Hvorslev's method is therefore shown.

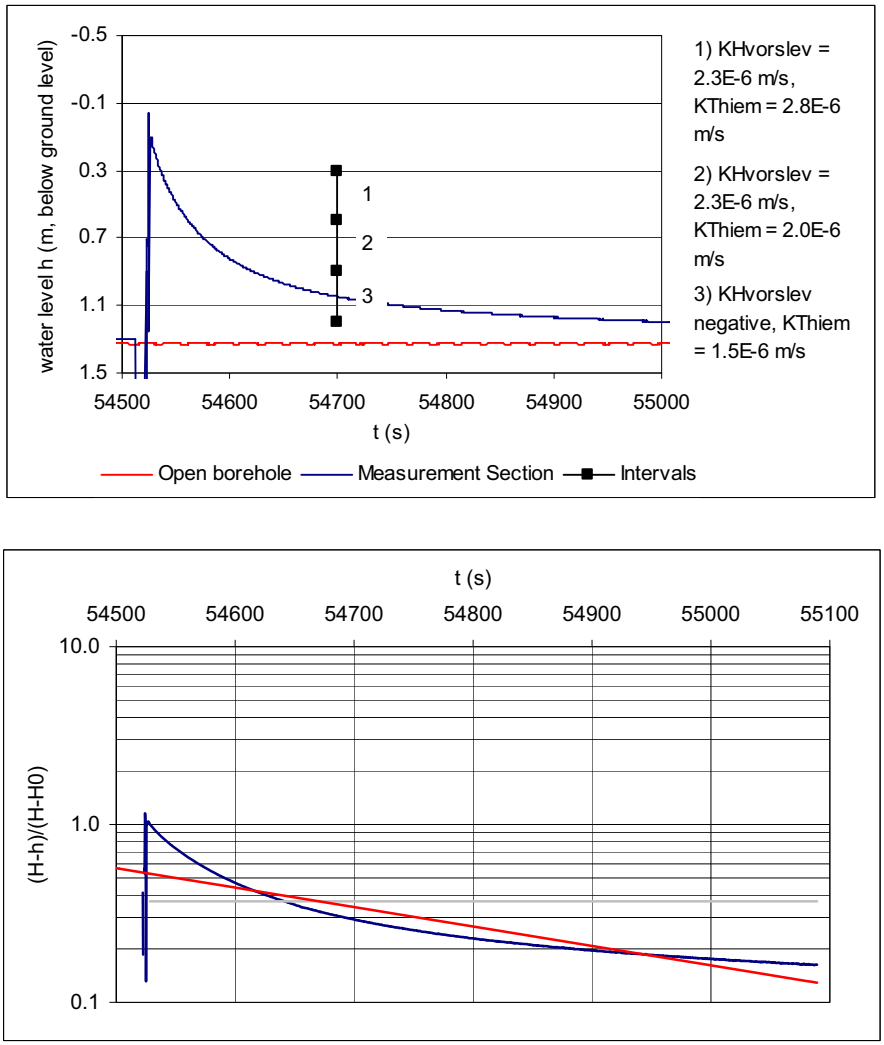


Figure 6-3. *An example how the time selected for the interpretation affects the resulting hydraulic conductivity. Three time intervals were used each corresponding to approximately one third of the recovery. The example is from OL-PP2 at depth of 19.42 m (Hellä & Heikkinen 2004). The interpreted values for this section were* $K_{Hvorslev}$ $1.1 \cdot 10^{-6}$ *m/s and* K_{Thiem} $8.1 \cdot 10^{-7}$ *m/s. For the interval 3 the interpretation according to Hvorslev's method failed as the* T_0 *gets negative.*

6.3 Comparison with the pre-pumping results

Groundwater sampling has been done partly in the same holes as the slug-tests during the spring 2009. Water samples were taken from OL-PP39, OL-PVP30, OL-PVP31A, OL-PVP31B, OL-PVP32, OL-PVP33, OL-PVP34A and OL-PVP34B. Before taking the samples, the hole is pre-pumped for a certain period of time, typically for few hours. The yield (l/min) and the change in the water table (m) are measured.

Using the pumping information and the length of the test section (either part of the hole below the water table or the perforated section in the groundwater observation tubes),

hydraulic conductivity can be estimated according to the Thiem's formula (Equation 3-5). These values were compared to the conductivities interpreted from the slug-tests. In case of the PP-holes, where the slug-tests were performed on 1 m test sections, an average conductivity of the entire hole was used in the comparison. The results are shown in Figure 6-4 and listed in Appendix 21.

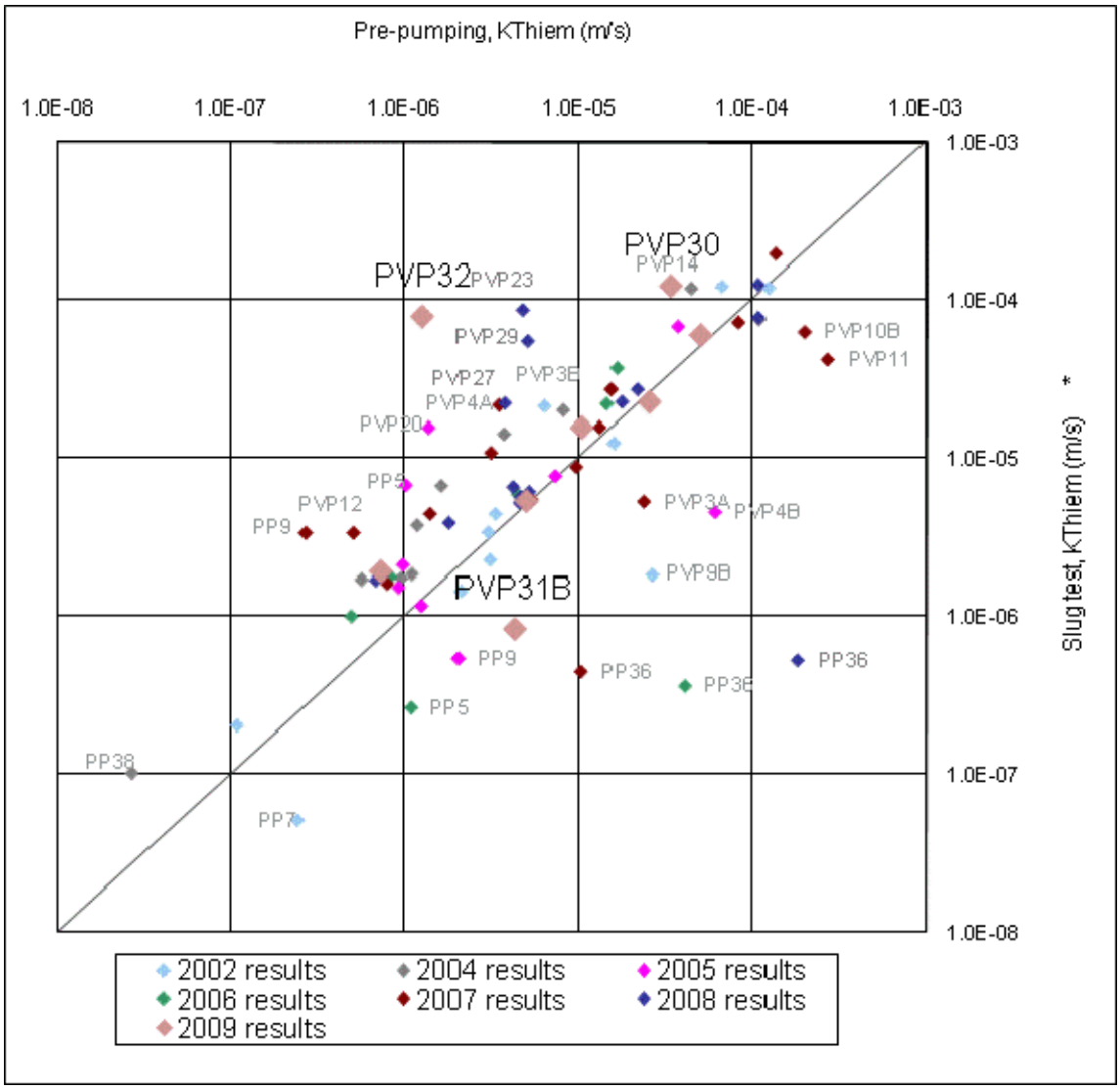


Figure 6-4. *Comparison of the hydraulic conductivities (m/s) obtained by the interpretation of the slug-tests and the pre-pumping in connection with groundwater sampling.*

The results from the pre-pumping spring 2009 are the only results where new PVP-tubes (OL-PVP30-34B) can be compared to since we do not have earlier year results. The results from the pre-pumping match quite well with those from the slug-tests, though there are exceptions (Figure 6-4) (Tuominen 1998; Hatanpää 2002; Kröger 2004; Hellä & Heikkinen 2004; Hirvonen 2005; Tammisto et al. 2005; Tammisto & Lehtinen 2006; Lehtinen et al. 2006; Partamies et al. 2007; Keskitalo & Lindgren 2007; Paratmies et al. 2008; Keskitalo 2008, 2009). In general, pre-pumping values are slightly lower. This is natural, because pre-pumping lasts longer than the slug-test and as a result of natural overtime, decrease of flow lower the hydraulic conductivity based on the pre-pumping results. If the pre-pumping values are higher, it is possible that there is a conductive fracture outside the range measured in slug-tests that affects the pre-pumping that measures the whole open borehole. Another reason could be dirty/clayish water that blocks the small holes in measurement section during slug-test. Longer lasting pre-pumping could clear the holes better.

The results from OL-PVP32 and OL-PVP31B differs the most from the pre-pumping results. In OL-PVP31B, the pre-pumping result is higher. The person who performed the pre-pumping noted that the water was so clayish that no water sample could be taken. And OL-PVP31B was the only tube to have clayish water in spring 2009. The clay must have been blocking the measurement sections holes and there by affecting in water conductivity during the slug-test. Pre-pumping probably cleared the holes little bit so that the conductivity where higher than during the slug-measurement.

The pre-pumping result in OL-PVP32 was significantly lower than in the slug-test. There is a clear explanation for this. In spring 2009 when the pre-pumping was performed, the water level was quite normal and natural conditions surrounding OL-PVP32 were normal. In early summer 2009 a long and deep trench was excavated next to OL-PVP32. This caused dramatic water lever drop in OL-PVP32 and even when the trench was filled up, the water level remained low. During slug-test water level was very low and it was in the limit that slug-test was even possible to perform. Dry soil absorbed water in the PVP-tube effectively during the slug-test and so the K-value in slug-test was much higher than in the pre-pumping. It is likely that in the next year if OL-PVP32 is tested again and water level is higher, the K-value should be significantly lower.

7 CONCLUSIONS

Slug-tests were performed in several shallow PP-holes and PVP/HP-tubes at the Olkiluoto island during the summer 2009. The measurements were done using the same technique and equipment developed by PRG-Tec Oy as in the measurements in 2002, 2004, 2005, 2006 and 2007 (Hellä & Heikkinen 2004; Tammisto et al. 2005; Tammisto & Lehtinen 2006; Keskitalo & Lindgren 2007; Keskitalo 2008, 2009).

The measurement results were interpreted by using Hvorslev's method. For comparison, the conductivity was also calculated using Thiem's formula. The interpretation was done by using MSExcel-macros written for the purpose. The analysis method is easy to use and quick as manual work is hardly needed for the file operations.

In measurements of year 2009, hydraulic conductivities in PP-holes range from 10^{-10} m/s to 10^{-6} m/s and in PVP- and HP-tubes from 10^{-8} m/s to 10^{-5} m/s. The range is quite similar to one in measurements of years 2002 and 2004 – 2008. With the applied technique in PP-holes hydraulic conductivities in the range $4 \cdot 10^{-10}$ – $5 \cdot 10^{-5}$ m/s and $1\ 10^{-5}$ – $7 \cdot 10^{-5}$ m/s in PVP/HP-tubes can be detected. The detection limits of hydraulic conductivity depend on the length of the test sections and the overpressure used.

The results from holes and tubes measured in 2009 and results from earlier measurements were compared. In general, the results are quite close to each other. In OL-PVP14, there seems to be a lowering trend of the conductivity, though lowering trend seems to relent. Overall minor difference to earlier years' results can be explained by disturbance factors in measurement, accuracy limit in Slug-testing method and the slightly different way macro analyzes water-level-drop-curves because of the variation of measuring time used.

The interpreted hydraulic conductivities from the slug-tests were also compared to those obtained by the pumping during the water sampling. The comparison showed that results without disturbance factor are in accordance with each other. Only two or three exceptions were noticed in OL-PVP30, OL-PVP31B and OL-PVP32.

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APPENDIX 1 DESCRIPTION OF THE DATA PROCESSING MACROS

In the interpretation of the measurement data the same macros developed for interpretation of the slug-tests in 2002 (Hellä & Heikkinen 2004) were used. Some modifications were done, when slug-tests of 2004 were interpreted (Tammisto et al. 2005):

- The separate macros for interpreting the results from PP-holes and PVP-tubes were combined.
- An input box was added in the start of program which enables the user to select whether he is processing data from PP-holes or PVP-tubes.
- In the input box it is also possible to select if the time range used in the interpretation is automatically selected or if the user wants to define the time range manually.
- The borehole diameter and section length information can now be given in the makefile, the values replace the erroneous or missing values in the data files.
- The time instants used in Thiem's equation were adjusted. They are now based on the change in head not on the length of the recovery period.
- Handling of errors was enhanced and the user is given information of the reason why the processing stops.

For the interpretation a MSExcel-file containing the necessary functions and graphs was used as a template. The macro copies the necessary data from the measurement file to the analysis template. The functions and graphs in the template file are modified automatically. Further on the results, K-values by Hvorslev's method and the two K-values obtained by Thiem's equation, together with some comments are copied to a separate result file. Also, the sheet with the interpretations is printed both as a paper copy and to a pdf-file.

Input Data

Data from the header of the measurement files used for interpretation:

- Top of the casing (m), reference level of all the depth values in the measurement file
- Depth of the pressure sensor, borehole (m)
- Initial depth of the pressure sensor of the test section (m)
- Depth of the pressure sensor of the test section after movement (m)
- Length of the test section (m)
- Hole diameter (mm)

And from the data columns:

Cable Depth (column A)	depth of the top of the test section (ref TOC), only first value used
Date (column B)	date, only first value used
Time (s) (column C)	Time
Phase (columnD)	1 = open borehole equipment installed 2 = inflation of packers + stabilization of pressure 3 = pressure increase + recovery phase
WaterLevelBorehole(m) (column G)	water column above pressure sensor of borehole water
WaterLevelMeasurementSection(m) (column K)	water column above pressure sensor of test section

The template workbook

The template workbook analysis_template.xls contains three sheets

parameters for input parameters, results and figure of the water level at the borehole and in the test section during the measurement and a figure with the measurement results and the fitted line. The data copied from the input file is marked with italic. The contents with some comments is described below:

- input file, name of the input file containing the hole id and the file number
- date, date of the measurement
- TOC (m), length of the casing above ground level
- depth of pressure sensor open hole (m), measured from the top of the casing
- depth of pressure sensor meas. section (m), measured from the top of the casing
- depth of meas. section (m), top of the section measured from the top of the casing
- depth of meas. section (m), midpoint of the section measured from ground level
- tube diameter (mm), diameter of the tube having an equal area to a double tube with given inner and outer diameter (16.6/24.9 mm in PP-holes and 40/56 mm in PVP-tubes)
- r (mm), radius of the tube with the above diameter
- H, initial water level (m, below ground level) average of the observed values during phase 1
- H_0, water level (m, below ground level) after the disturbance, H_0* = min(water level in test section), H_0 = water level in test section 10 observations after H_0*, the shift is done because the water level changes rapidly just after the moving of the pressure sensor.
- t_0, time corresponding H_0, start time of the line fitting or the time instant given by the user
- t_{end} (s), end time of the line fitting, is either the end time of the measuring period, or the time when $(H-h)/(H-H_0)$ reaches 0.1 or the time when $(H-h)/(H-H_0)$ gets negative, this might happen if the data is noisy at the end of the measurement, the user can also define the t_{end}
- T_0, time when $(H-h)/(H-H_0) = 0.37$, calculated from the estimated line equation
- L (m), length of the test section
- screen diam. (mm), hole diameter

- screen radius R (mm), hole radius
- L/R
- K (m/s), hydraulic conductivity calculated according to equation 4-4.
- logK

For the calculation of hydraulic conductivity according to Thiem's equation following data is used:

Two time instants are used in calculating the flow for the Thiem analysis and two cases are considered:

- flow
    - t_1 (s) corresponds to the time when h is equal to (H + H0) / 2, if such h is not reached t1 is defined to be the time corresponding to one third of the recovery period.
    - t_2 (s) is 20 observations later
- no flow
    - t_1 (s) is 20 observations later than t_0
    - t_2 (s) is determined to be $t_0 + (t_{end} - t_0)/3$, but if the recovery period is short, less than 40 time steps, then the whole recovery is used i.e. t_2 equal to t_{end}
- h_1 (m) is the average of 11 observed h values at time t_1, average is used to compensate the possibly noisy data, otherwise erroneous results are obtained especially in case of no flow
- h_2 (m) is the average of 11 observed h values at time t_2
- dh (m) is the average change in water level, Δh in equation 4-5, $dh = (h_1+h_2)/2 - H_0$
- Q (m^3/s) observed flow in time $t_1 - t_2$
- K_{Thiem} (m/s) hydraulic conductivity assuming $r_0 = 14$ m
- logK
- $K_{Hvorslev}$ / K_{Thiem} quotient of the hydraulic conductivities according to the two methods

The sheet contains also two figures, the first one presents the measured water levels in the open borehole and in the test section. The measured values are corrected so that the reference is always ground level. The other figure shows the results of the Hvorslev's method, the measured $(H-h)/(H-H_0)$ values are plotted on a logarithmic scale as a function of time, also the fitted line is shown as well as the line $(H-h)/(H-H_0) = 0.37$.

data initial measurement data together with the processed one. The columns are the following:

- Time(s), copy of the time column of the input file
- Phase, copy of the phase column of the input file
- WaterLevelBorehole(m), copy of the water level/borehole column of the input file
- WaterLevelMeasurementSection(m), copy of the water level/measurement section column of the input file
- Open borehole, corrected water level in the open borehole below ground level (m) taking into account the depth of the pressure sensor and the casing (=ps_depth – toc - wl)

- Measurement Section, h, corrected water level in the test section below ground level (m) taking into account the depth of the pressure sensor and the casing (=ps_depth – toc - wl). Here, the possible change in the pressure sensor depth is taken into account.
- t, time from t_0 i.e. start of the line fitting
- H-h, change in the water level at the test section
- $H-H_0$, the total over pressure (m)
- $(H-h)/(H-H_0)$
- $\ln((H-h)/(H-H_0))$
- fitted, the fitted values at the given time
- $(H-h)/(H-H_0)<0.1$, used to define the end of the time interval used in the line fitting

support data needed to draw a line $(H-h)/(H-H_0) = 0.37$ in the lower figure on sheet parameters.

Subprograms

The interpretation macro consists of following subprograms:

prepare_file_for_analysis
opens a file containing measurement data and copies the necessary data to the analysis template deleting the header rows of the input data file

preliminary_analysis
modifies the functions and images in the analysis template workbook to correspond the current data file.

Write_results
writes the results of the analysis to the results workbook (filename, depth of test section, hydraulic conductivity K according to Hvorslev's method and the two Thiem approximations, R^2-value of the line fitting and comments:

T0 not reached means that during the recovery period $(H-h)/(H-H_0)$ does not reach value 0.37 corresponding the time needed for the recovery assuming steady state flow. This means that the value of T_0 has to be extrapolated outside the observed time range and the result is thus more uncertain than in the case when T_0 is reached during the observation period.

Thiem different means that the hydraulic conductivity by Hvorslev's method is at least three times greater or smaller than the one obtained by Thiem's method.

q increasing with time means that the fitted line has a positive slope and thus no recovery is observed, indicates an error.

Negative K means hydraulic conductivity obtained by Hvorslev's method is negative indicating an error.

Print_results
prints the paper copy and a pdf-file from the parameters-sheet.

APPENDIX 2 MEASUREMENTS AND RESULTS IN OL-PP36

Area:	Hole:	Measurer:
Olkiluoto	PP36	Maarit Yli-Kaila, Ossi Isola

Water level before starting 4.02 m
The reference level to depth is top of the casing, the length of the casing is 0.78 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
387	2.7.2009	10:05	5.95	4.12	4.12	1.50	460ml water into the tube
389	2.7.2009	12:05	6.95	4.12	4.12	1.50	
390	2.7.2009	12:30	7.95	4.12	4.12	1.50	
391	2.7.2009	12:55	8.95	4.12	4.12	1.50	

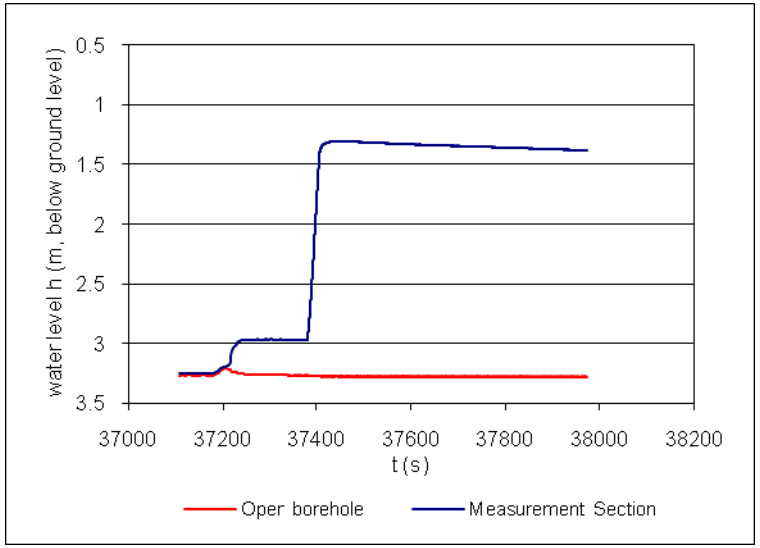
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLPP36000387.DAT	5.67	1.16E-08	0.997	5.41E-09	2.12E-08	T0 not reached
OLPP36000389.DAT	6.67	1.41E-07	0.996	2.25E-07	2.99E-07	T0 not reached
OLPP36000390.DAT	7.67	4.81E-07	0.973	8.25E-07	8.30E-07	
OLPP36000391.DAT	8.67	5.36E-07	0.986	9.58E-07	8.98E-07	

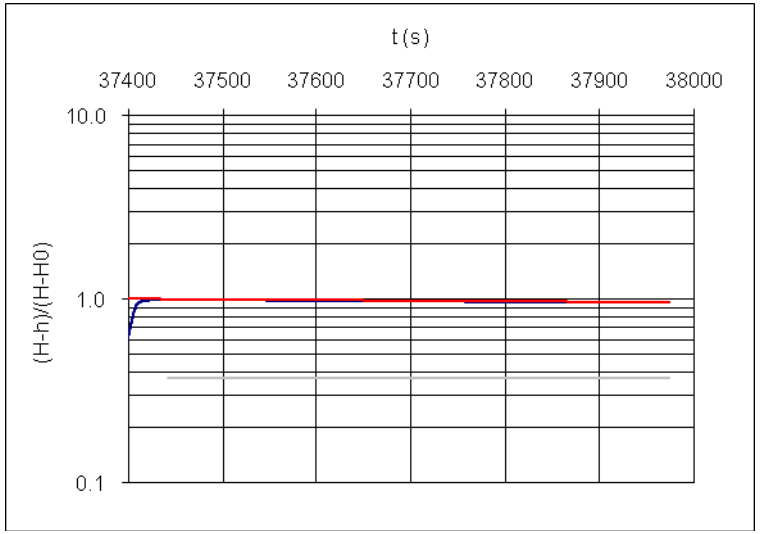
input file	**OLPP36000387.DAT**	date	*2.7.2009*		
TOC (m)	*0.78*				
depth of pressure sensor open hole (m)	*4.12*	ref toc	min open bore-hole pressure (m)	3.28	ref ground level
depth of pressure sensor meas. section (m)	*4.12*	initial, ref toc			
depth of pressure sensor meas. section (m)	*4.12*	final, ref toc			
depth of meas. section (m)	*5.95*	ref TOC, top			
depth of meas. section (m)	5.67	ref ground level, midpoint of the section			
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm			
r (mm)	9.28				
H	3.25	reference water level at the measurement section based on phase 1, ref ground level			
H_0	1.31	water level at the measurement section after disturbance, ref ground level			
t_0	37441.7	time of disturbance			
t_{end} (s)	37973.8	end of time range used to line fitting			
Time range (s)	532.1	Time range used for interpretation			
T_0	13280.0	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1			
L (m)	*1*	length of measurement section			
screen diam. (mm)	*56*	equal to borehole diameter			
screen radius R (mm)	28	equal to borehole radius			
L/R	35.71				
K (m/s)	**1.16E-08**	**T0 not reached**			
logK	-7.94				

ln((H-h)/(H-H0)) = a*t + b	
a	b
-7.53393E-05	0.000508667
8.47593E-08	2.60425E-05
0.9971	0.000620206
790074.9456	2265
0.303907048	0.000871246

Stat tests	
test stat, a <> 0	888.86
test stat, b <> 0	19.53
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	37616.6	h1	1.33
t2	37621.3	h2	1.33
Q (m^3/s)	-1.05E-08	dh (m)	1.92
K_{Thiem} (m/s)	**-5.41E-09**	logK	#LUKU!
$K_{Hvorslev}$ / K_{Thiem}	-2.14		
tight			
t1	37446.4	h1	1.31
t2	37619.0	h2	1.33
Q (m^3/s)	4.15E-08	dh (m)	1.93
K_{Thiem} (m/s)	**2.12E-08**	logK	-7.67
$K_{Hvorslev}$ / K_{Thiem}	0.55		



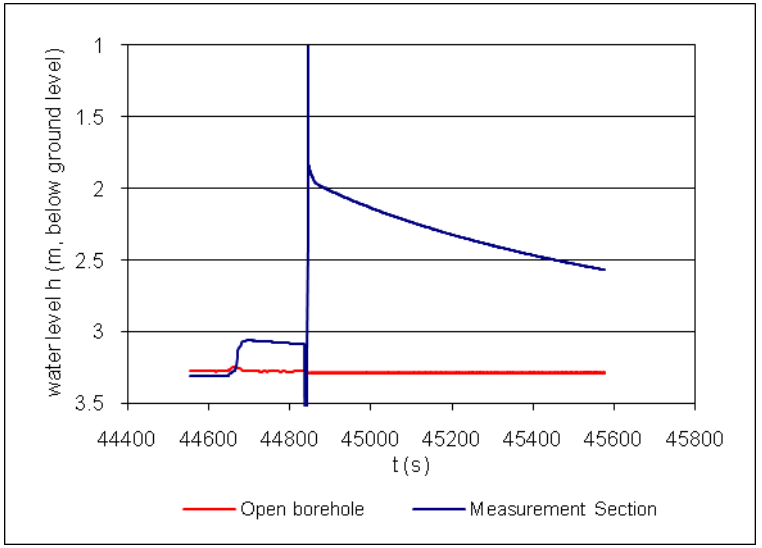


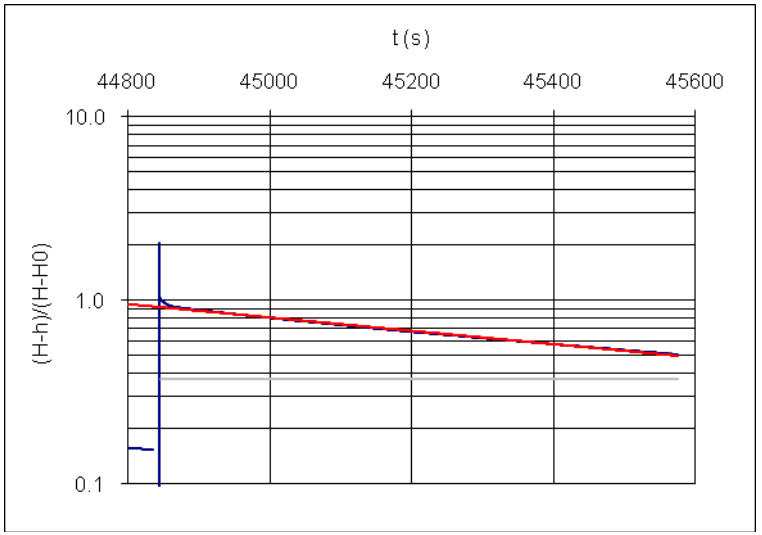
input file	**OLPP36000389.DAT**	date	*2.7.2009*		
TOC (m)	*0.78*				
depth of pressure sensor open hole (m)	*4.12*	ref toc	min open bore-hole pressure (m)	3.29	ref ground level
depth of pressure sensor meas. section (m)	*4.12*	initial, ref toc			
depth of pressure sensor meas. section (m)	*5.62*	final, ref toc			
depth of meas. section (m)	*6.95*	ref TOC, top			
depth of meas. section (m)	6.67	ref ground level, midpoint of the section			
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm			
r (mm)	9.28				
H	3.30	reference water level at the measurement section based on phase 1, ref ground level			
H_0	1.84	water level at the measurement section after disturbance, ref ground level			
t_0	44846.2	time of disturbance			
t_{end} (s)	45575.8	end of time range used to line fitting			
Time range (s)	729.6	Time range used for interpretation			
T_0	1094.1	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1			
L (m)	*1*	length of measurement section			
screen diam. (mm)	*56*	equal to borehole diameter			
screen radius R (mm)	28	equal to borehole radius			
L/R	35.71				
K (m/s)	**1.41E-07**	**T0 not reached**			
logK	-6.85				

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.000833874	-0.0876621
9.77171E-07	0.00041164
0.9958	0.011478549
728215.9117	3107
95.94760438	0.409369257

Stat tests	
test stat, a <> 0	853.36
test stat, b <> 0	212.96
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	45087.1	h1	2.22
t2	45091.8	h2	2.22
Q (m^3/s)	2.46E-07	dh (m)	1.08
K_{Thiem} (m/s)	**2.25E-07**	logK	-6.65
$K_{Hvorslev}$ / K_{Thiem}	0.63		
tight			
t1	44850.9	h1	1.89
t2	45089.4	h2	2.22
Q (m^3/s)	3.78E-07	dh (m)	1.25
K_{Thiem} (m/s)	**2.99E-07**	logK	-6.52
$K_{Hvorslev}$ / K_{Thiem}	0.47		



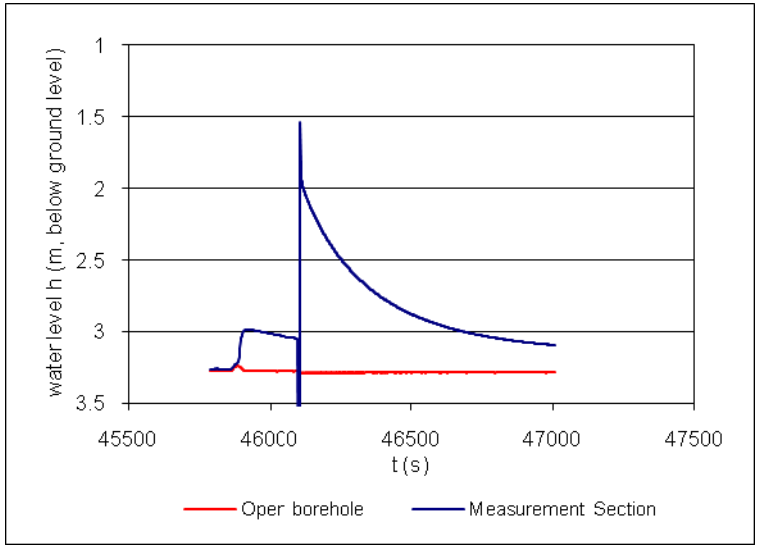


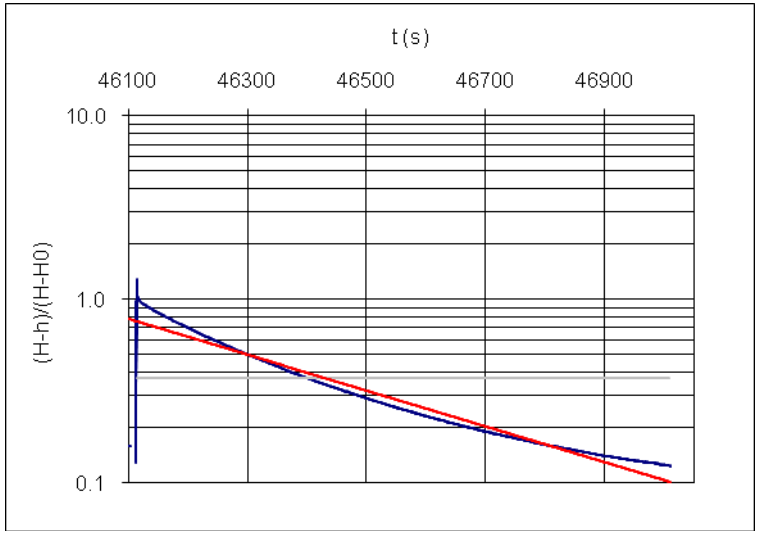
input file	**OLPP36000390.DAT**	date	*2.7.2009*			
TOC (m)	*0.78*					
depth of pressure sensor open hole (m)	*4.12*	ref toc	min open bore-hole pressure (m)	3.29	ref ground level	
depth of pressure sensor meas. section (m)	*4.12*	initial, ref toc				
depth of pressure sensor meas. section (m)	*5.62*	final, ref toc				
depth of meas. section (m)	*7.95*	ref TOC, top				
depth of meas. section (m)	7.67	ref ground level, midpoint of the section				
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm				
r (mm)	9.28					
H	3.26	reference water level at the measurement section based on phase 1, ref ground level				
H_0	1.92	water level at the measurement section after disturbance, ref ground level				
t_0	46114.7	time of disturbance				
t_{end} (s)	47009.0	end of time range used to line fitting				
Time range (s)	894.3	Time range used for interpretation				
T_0	319.8	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1				
L (m)	*1*	length of measurement section				
screen diam. (mm)	*56*	equal to borehole diameter				
screen radius R (mm)	28	equal to borehole radius				
L/R	35.71					
K (m/s)	**4.81E-07**					
logK	-6.32					

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.002244013	-0.282361943
6.03598E-06	0.003116885
0.9732	0.09621035
138214.9798	3808
1279.377484	35.24849091

Stat tests	
test stat, a <> 0	371.77
test stat, b <> 0	90.59
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	46294.1	h1	2.59
t2	46298.8	h2	2.60
Q (m^3/s)	5.61E-07	dh (m)	0.67
K_{Thiem} (m/s)	**8.25E-07**	logK	-6.08
$K_{Hvorslev}$ / K_{Thiem}	0.58		
tight			
t1	46119.4	h1	1.98
t2	46412.7	h2	2.78
Q (m^3/s)	7.40E-07	dh (m)	0.88
K_{Thiem} (m/s)	**8.30E-07**	logK	-6.08
$K_{Hvorslev}$ / K_{Thiem}	0.58		



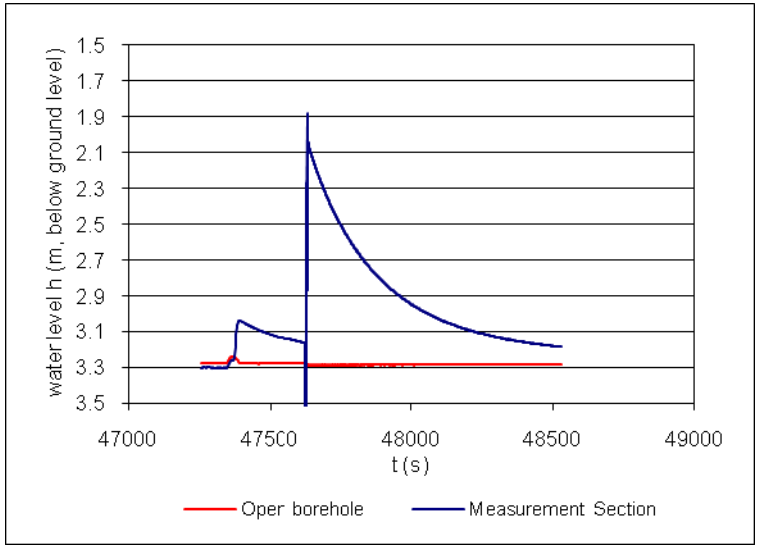


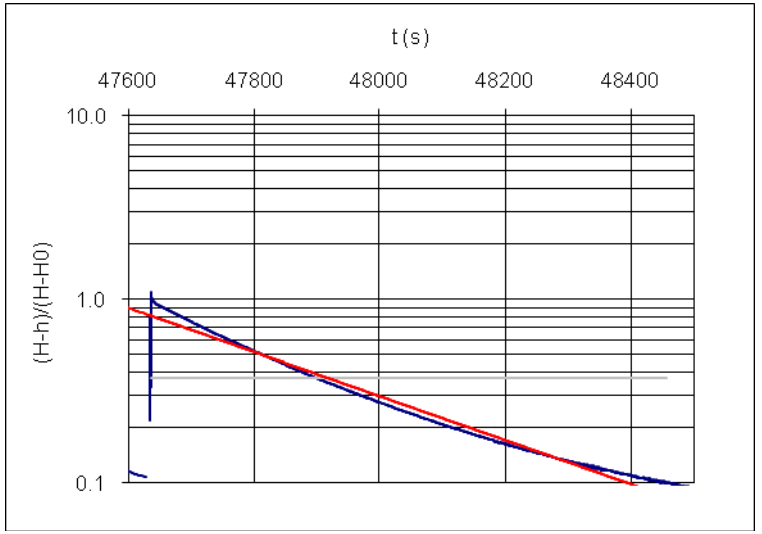
input file	**OLPP36000391.DAT**	date	*2.7.2009*		
TOC (m)	*0.78*				
depth of pressure sensor open hole (m)	*4.12*	ref toc	min open bore-hole pressure (m)	3.29	ref ground level
depth of pressure sensor meas. section (m)	*4.12*	initial, ref toc			
depth of pressure sensor meas. section (m)	*5.62*	final, ref toc			
depth of meas. section (m)	*8.95*	ref TOC, top			
depth of meas. section (m)	8.67	ref ground level, midpoint of the section			
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm			
r (mm)	9.28				
H	3.30	reference water level at the measurement section based on phase 1, ref ground level			
H_0	2.01	water level at the measurement section after disturbance, ref ground level			
t_0	47636.3	time of disturbance			
t_{end} (s)	48456.9	end of time range used to line fitting			
Time range (s)	820.6	Time range used for interpretation			
T_0	287.1	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1			
L (m)	*1*	length of measurement section			
screen diam. (mm)	*56*	equal to borehole diameter			
screen radius R (mm)	28	equal to borehole radius			
L/R	35.71				
K (m/s)	**5.36E-07**				
logK	-6.27				

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.00275672	-0.20859082
5.47787E-06	0.0025957
0.9864	0.076747634
253257.5391	3494
1491.737405	20.58035671

Stat tests	
test stat, a <> 0	503.25
test stat, b <> 0	80.36
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	47808.9	h1	2.65
t2	47813.6	h2	2.66
Q (m^3/s)	6.28E-07	dh (m)	0.65
K_{Thiem} (m/s)	**9.58E-07**	logK	-6.02
$K_{Hvorslev}$ / K_{Thiem}	0.56		
tight			
t1	47641.0	h1	2.06
t2	47909.9	h2	2.83
Q (m^3/s)	7.74E-07	dh (m)	0.85
K_{Thiem} (m/s)	**8.98E-07**	logK	-6.05
$K_{Hvorslev}$ / K_{Thiem}	0.60		





APPENDIX 3 MEASUREMENTS AND RESULTS IN OL-PP39

Area: Olkiluoto **Hole:** PP39 **Measurer:** Maarit Yli-Kaila, Ossi Isola

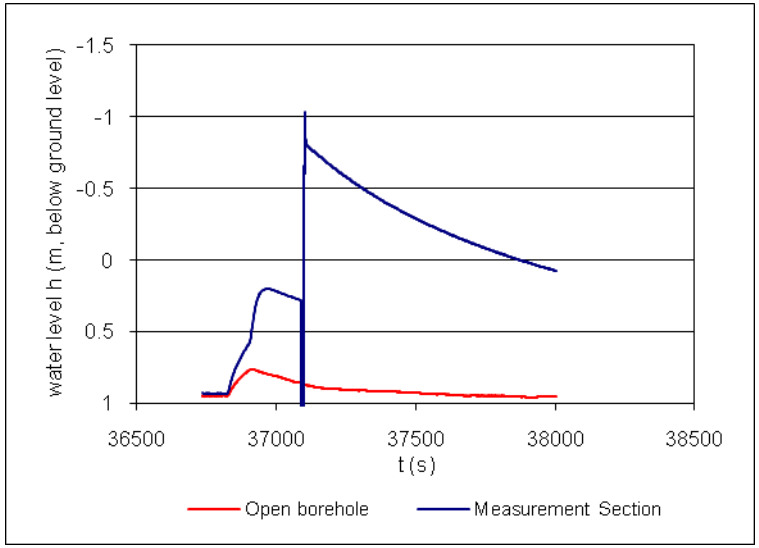
Water level before starting 1.42 m
The reference level to depth is top of the casing, the length of the casing is 0.50 m

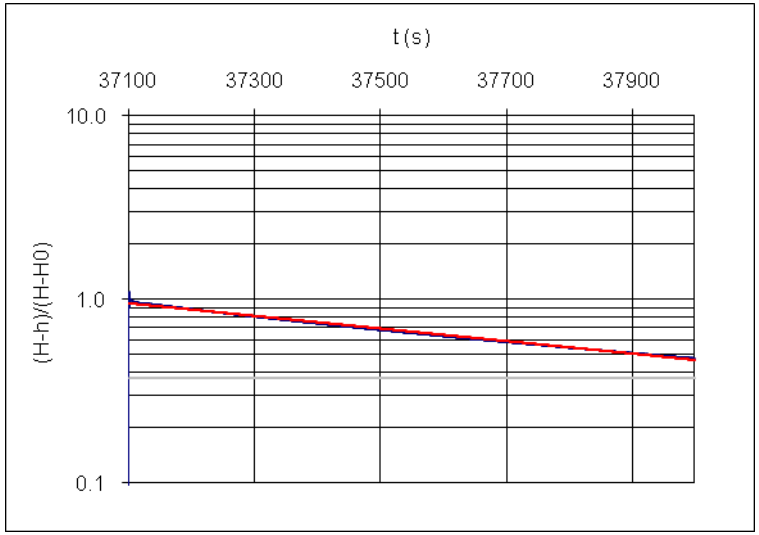
File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
378	1.7.2009	10:00	4.95	1.52	1.52	1.50	
379	1.7.2009	10:35	5.95	1.52	1.52	1.50	
380	1.7.2009	12:10	6.95	1.52	1.52	1.50	
381	1.7.2009	12:30	7.95	1.52	1.52	1.50	
382	1.7.2009	12:55	8.95	1.52	1.52	1.50	
383	1.7.2009	13:15	9.95	1.52	1.52	1.50	
384	1.7.2009	13:40	10.95	1.52	1.52	1.50	
385	1.7.2009	14:30	11.95	1.52	1.52	1.50	

measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLPP39000378.DAT	4.95	1.29E-07	0.996	1.45E-07	2.51E-07	T0 not reached
OLPP39000379.DAT	5.95	1.27E-08	0.994	1.36E-08	2.85E-08	T0 not reached
OLPP39000380.DAT	6.95	4.64E-06	0.975	8.05E-06	7.54E-06	
OLPP39000381.DAT	7.95	4.21E-06	0.843	6.81E-06	5.29E-06	Shorter time used in interpretation
OLPP39000382.DAT	8.95	7.80E-09	0.969	2.23E-08	2.04E-08	T0 not reached
OLPP39000383.DAT	9.95	2.98E-08	0.994	4.82E-08	6.76E-08	T0 not reached
OLPP39000384.DAT	10.95	2.62E-09	0.665	6.57E-09	1.82E-08	T0 not reached Thiem different
OLPP39000385.DAT	11.95	4.43E-10	0.053	6.71E-09	1.60E-08	T0 not reached Thiem different

input file	**OLPP39000378.DAT**	date	*1.7.2009*		
TOC (m)	*0.5*				
depth of pressure sensor open hole (m)	*1.52*	ref toc	min open bore-hole pressure (m)	0.96	ref ground level
depth of pressure sensor meas. section (m)	*1.52*	initial, ref toc			
depth of pressure sensor meas. section (m)	*3.02*	final, ref toc			
depth of meas. section (m)	*4.95*	ref TOC, top			
depth of meas. section (m)	4.95	ref ground level, midpoint of the section			
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm			
r (mm)	9.28				
H	0.92	reference water level at the measurement section based on phase 1, ref ground level			
H_0	-0.86	water level at the measurement section after disturbance, ref ground level			
t_0	37101.6	time of disturbance			
t_{end} (s)	37999.9	end of time range used to line fitting			
Time range (s)	898.4	Time range used for interpretation			
T_0	1196.3	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1			
L (m)	*1*	length of measurement section			
screen diam. (mm)	*56*	equal to borehole diameter			
screen radius R (mm)	28	equal to borehole radius			
L/R	35.71				
K (m/s)	**1.29E-07**	**T0 not reached**			
logK	-6.89				

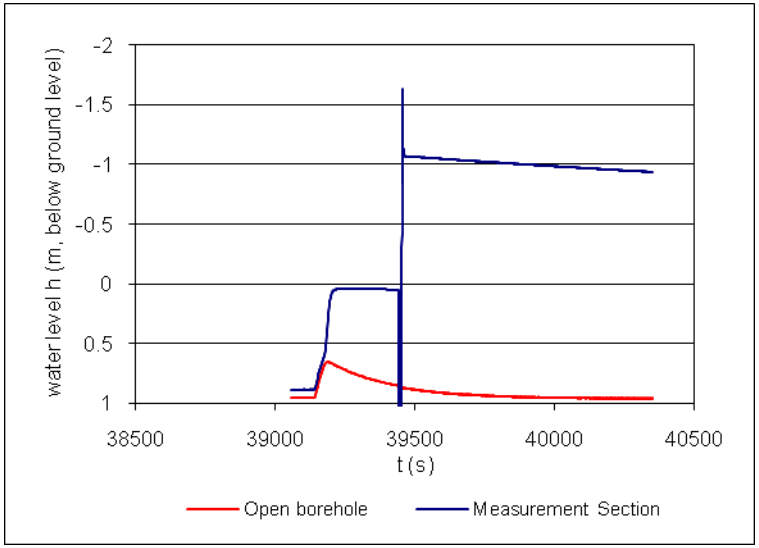
ln((H-h)/(H-H0)) = a*t + b		Thiem analysis for control			
a	b	**flow**			
-0.000785798	-0.059966421	t1	37923.3	h1	0.03
7.97928E-07	0.000413849	t2	37928.0	h2	0.03
0.9961	0.012804793	Q (m^3/s)	1.31E-07	dh (m)	0.89
969826.7868	3826	K_{Thiem} (m/s)	**1.45E-07**	logK	-6.84
159.0154492	0.627321411	$K_{Hvorslev}$ / K_{Thiem}	0.89		
Stat tests		**tight**			
test stat, a <> 0	984.80	t1	37106.3	h1	-0.81
test stat, b <> 0	144.90	t2	37400.8	h2	-0.39
t-critical, 90%	1.96	Q (m^3/s)	3.88E-07	dh (m)	1.53
		K_{Thiem} (m/s)	**2.51E-07**	logK	-6.60
		$K_{Hvorslev}$ / K_{Thiem}	0.51		

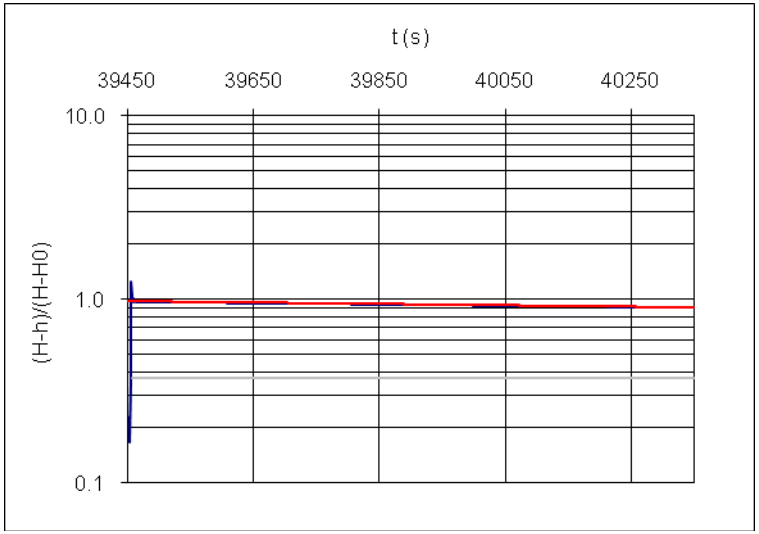




input file	**OLPP39000379.DAT**	date	*1.7.2009*			
TOC (m)	*0.5*					
depth of pressure sensor open hole (m)	*1.52*	ref toc	min open bore-hole pressure (m)	0.97	ref ground level	
depth of pressure sensor meas. section (m)	*1.52*	initial, ref toc				
depth of pressure sensor meas. section (m)	*3.02*	final, ref toc				
depth of meas. section (m)	*5.95*	ref TOC, top				
depth of meas. section (m)	5.95	ref ground level, midpoint of the section				
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm				
r (mm)	9.28					
H	0.89	reference water level at the measurement section based on phase 1, ref ground level				
H_0	-1.12	water level at the measurement section after disturbance, ref ground level				
t_0	39457.9	time of disturbance				
t_{end} (s)	40349.1	end of time range used to line fitting				
Time range (s)	891.2	Time range used for interpretation				
T_0	12169.0	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1				
L (m)	*1*	length of measurement section				
screen diam. (mm)	*56*	equal to borehole diameter				
screen radius R (mm)	28	equal to borehole radius				
L/R	35.71					
K (m/s)	**1.27E-08**	**T0 not reached**				
logK	-7.90					

ln((H-h)/(H-H0)) = a*t + b		Thiem analysis for control			
a	b	**flow**			
-7.98582E-05	-0.028202653	t1	39752.6	h1	-1.02
9.9674E-08	5.12814E-05	t2	39757.3	h2	-1.02
0.9941	0.001580085	Q (m^3/s)	2.62E-08	dh (m)	1.90
641911.6305	3794	K_{Thiem} (m/s)	**1.36E-08**	logK	-7.87
1.602640298	0.009472359	$K_{Hvorslev}$ / K_{Thiem}	0.93		
Stat tests		**tight**			
test stat, a <> 0	801.19	t1	39462.6	h1	-1.08
test stat, b <> 0	549.96	t2	39755.0	h2	-1.02
t-critical, 90%	1.96	Q (m^3/s)	5.58E-08	dh (m)	1.93
		K_{Thiem} (m/s)	**2.85E-08**	logK	-7.54
		$K_{Hvorslev}$ / K_{Thiem}	0.44		



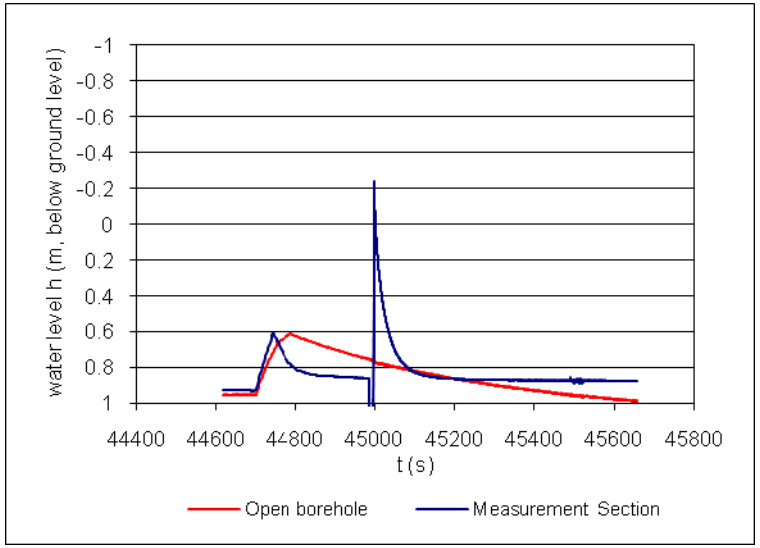


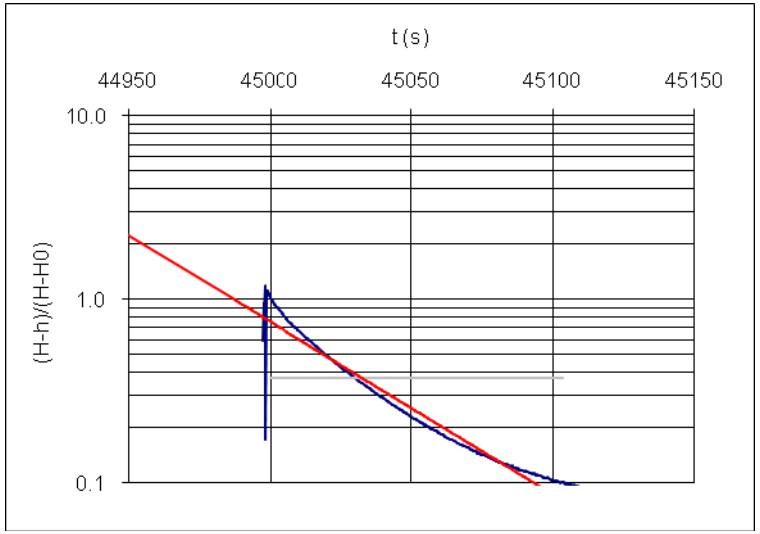
input file	**OLPP39000380.DAT**	date	*1.7.2009*			
TOC (m)	*0.5*					
depth of pressure sensor open hole (m)	*1.52*	ref toc	min open bore-hole pressure (m)	0.99	ref ground level	
depth of pressure sensor meas. section (m)	*1.52*	initial, ref toc				
depth of pressure sensor meas. section (m)	*3.02*	final, ref toc				
depth of meas. section (m)	*6.95*	ref TOC, top				
depth of meas. section (m)	6.95	ref ground level, midpoint of the section				
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm				
r (mm)	9.28					
H	0.93	reference water level at the measurement section based on phase 1, ref ground level				
H_0	-0.06	water level at the measurement section after disturbance, ref ground level				
t_0	45000.0	time of disturbance				
t_{end} (s)	45103.6	end of time range used to line fitting				
Time range (s)	103.6	Time range used for interpretation				
T_0	33.2	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1				
L (m)	*1*	length of measurement section				
screen diam. (mm)	*56*	equal to borehole diameter				
screen radius R (mm)	28	equal to borehole radius				
L/R	35.71					
K (m/s)	**4.64E-06**					
logK	-5.33					

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.021661858	-0.28053519
0.000165549	0.009905665
0.9749	0.104291433
17121.29553	440
186.2232463	4.785749316

Stat tests	
test stat, a <> 0	130.85
test stat, b <> 0	28.32
t-critical, 90%	1.97

Thiem analysis for control			
flow			
t1	45017.1	h1	0.40
t2	45021.8	h2	0.47
Q (m^3/s)	4.03E-06	dh (m)	0.50
K_{Thiem} (m/s)	**8.05E-06**	logK	-5.09
$K_{Hvorslev}$ / K_{Thiem}	0.58		
tight			
t1	45004.7	h1	0.13
t2	45034.5	h2	0.60
Q (m^3/s)	4.29E-06	dh (m)	0.56
K_{Thiem} (m/s)	**7.54E-06**	logK	-5.12
$K_{Hvorslev}$ / K_{Thiem}	0.62		



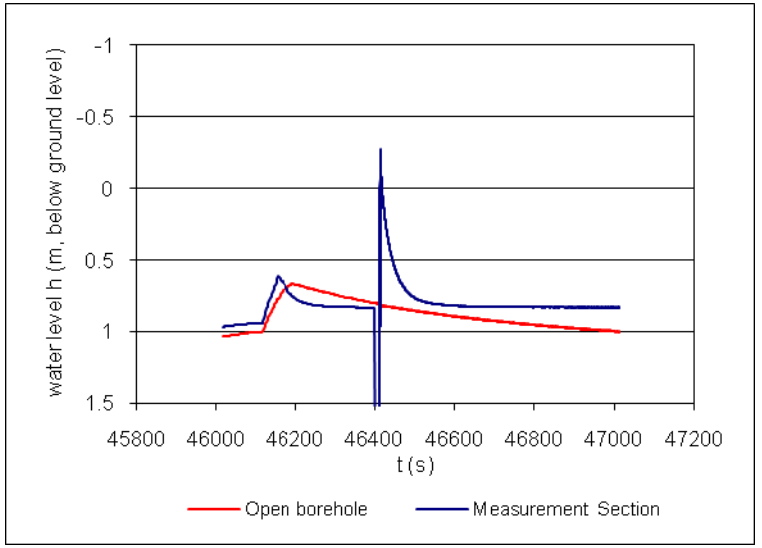


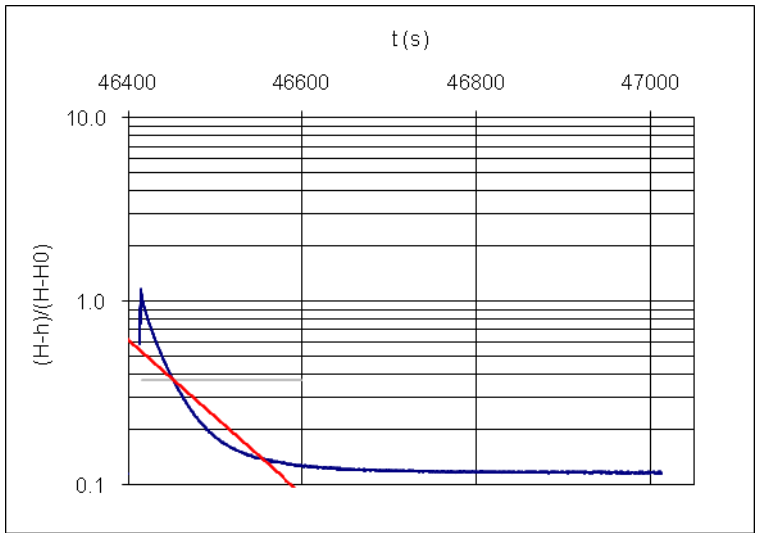
input file	**OLPP39000381.DAT**	date	*1.7.2009*			
TOC (m)	*0.5*					
depth of pressure sensor open hole (m)	*1.52*	ref toc	min open bore-hole pressure (m)	1.03	ref ground level	
depth of pressure sensor meas. section (m)	*1.52*	initial, ref toc				
depth of pressure sensor meas. section (m)	*3.02*	final, ref toc				
depth of meas. section (m)	*7.95*	ref TOC, top				
depth of meas. section (m)	7.95	ref ground level, midpoint of the section				
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm				
r (mm)	9.28					
H	0.95	reference water level at the measurement section based on phase 1, ref ground level				
H_0	-0.10	water level at the measurement section after disturbance, ref ground level				
t_0	46416.0	time of disturbance				
t_{end} (s)	46599.9	end of time range used to line fitting				
Time range (s)	183.9	Time range used for interpretation				
T_0	36.6	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1				
L (m)	*1*	length of measurement section				
screen diam. (mm)	*56*	equal to borehole diameter				
screen radius R (mm)	28	equal to borehole radius				
L/R	35.71					
K (m/s)	**4.21E-06**					
logK	-5.38					

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.009675477	-0.646285694
0.000149111	0.015836186
0.8434	0.221895047
4210.413023	782
207.3098403	38.50365612

Stat tests	
test stat, a <> 0	64.89
test stat, b <> 0	40.81
t-critical, 90%	1.96

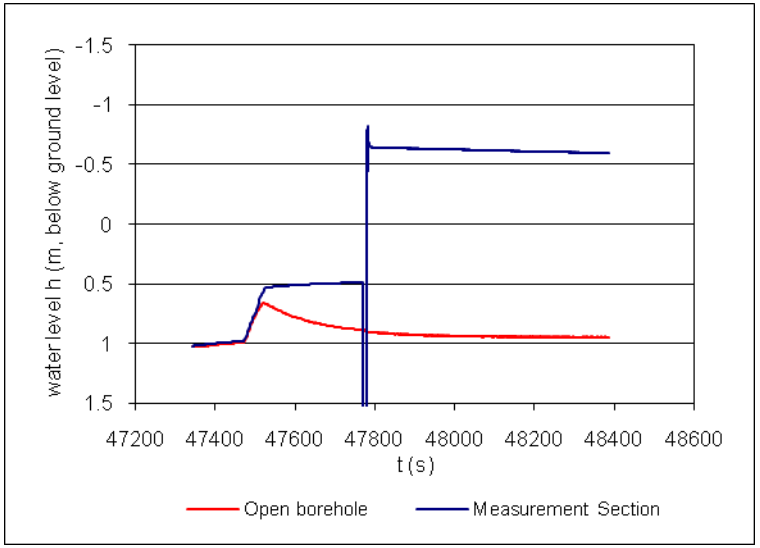
Thiem analysis for control			
flow			
t1	46435.8	h1	0.39
t2	46440.5	h2	0.46
Q (m^3/s)	3.63E-06	dh (m)	0.53
K_{Thiem} (m/s)	**6.81E-06**	logK	-5.17
$K_{Hvorslev}$ / K_{Thiem}	0.62		
tight			
t1	46420.7	h1	0.09
t2	46477.3	h2	0.71
Q (m^3/s)	2.98E-06	dh (m)	0.56
K_{Thiem} (m/s)	**5.29E-06**	logK	-5.28
$K_{Hvorslev}$ / K_{Thiem}	0.80		

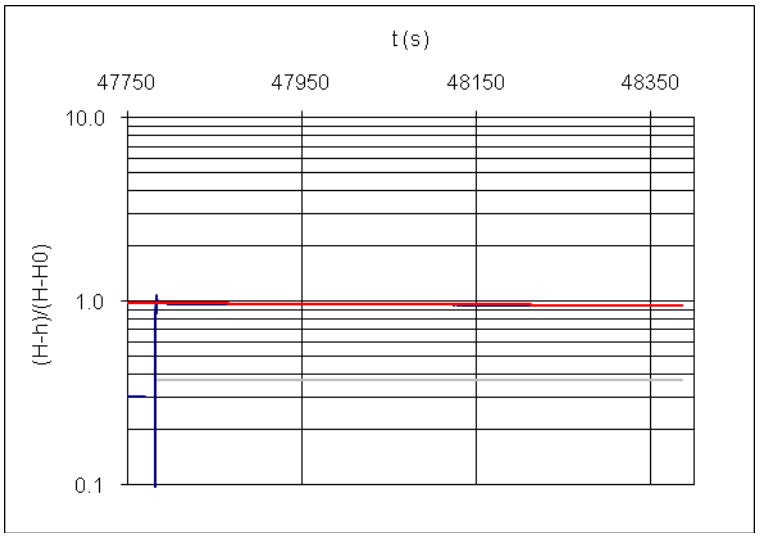




input file	**OLPP39000382.DAT**	date	*1.7.2009*			
TOC (m)	*0.5*					
depth of pressure sensor open hole (m)	*1.52*	ref toc	min open bore-hole pressure (m)	1.03	ref ground level	
depth of pressure sensor meas. section (m)	*1.52*	initial, ref toc				
depth of pressure sensor meas. section (m)	*3.02*	final, ref toc				
depth of meas. section (m)	*8.95*	ref TOC, top				
depth of meas. section (m)	8.95	ref ground level, midpoint of the section				
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm				
r (mm)	9.28					
H	0.99	reference water level at the measurement section based on phase 1, ref ground level				
H_0	-0.69	water level at the measurement section after disturbance, ref ground level				
t_0	47784.2	time of disturbance				
t_{end} (s)	48385.9	end of time range used to line fitting				
Time range (s)	601.7	Time range used for interpretation				
T_0	19747.8	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1				
L (m)	*1*	length of measurement section				
screen diam. (mm)	*56*	equal to borehole diameter				
screen radius R (mm)	28	equal to borehole radius				
L/R	35.71					
K (m/s)	**7.80E-09**	**T0 not reached**				
logK	-8.11					

ln((H-h)/(H-H0)) = a*t + b		Thiem analysis for control			
a	b	**flow**			
-4.92777E-05	-0.026873284	t1	47982.4	h1	-0.63
1.7396E-07	6.04338E-05	t2	47987.1	h2	-0.63
0.9691	0.001530268	Q (m^3/s)	3.66E-08	dh (m)	1.62
80242.14728	2561	K_{Thiem} (m/s)	**2.23E-08**	logK	-7.65
0.187904613	0.005997144	$K_{Hvorslev}$ / K_{Thiem}	0.35		
Stat tests		**tight**			
test stat, a <> 0	283.27	t1	47788.9	h1	-0.65
test stat, b <> 0	444.67	t2	47984.8	h2	-0.63
t-critical, 90%	1.96	Q (m^3/s)	3.38E-08	dh (m)	1.63
		K_{Thiem} (m/s)	**2.04E-08**	logK	-7.69
		$K_{Hvorslev}$ / K_{Thiem}	0.38		



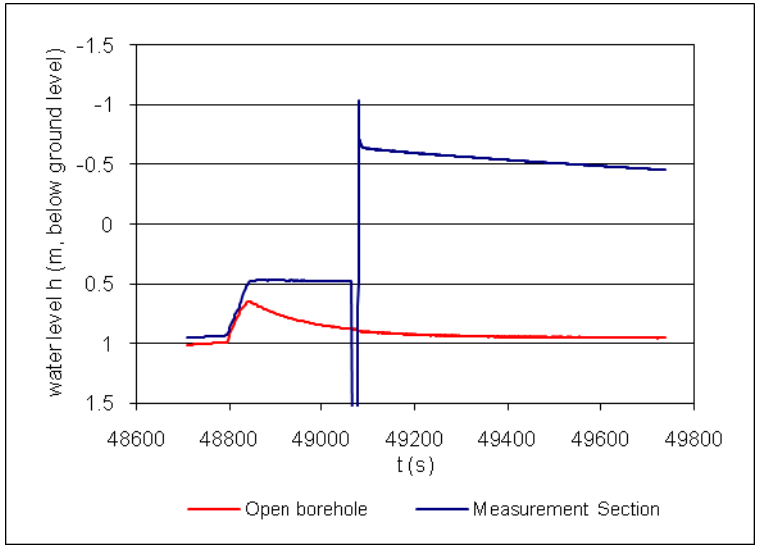


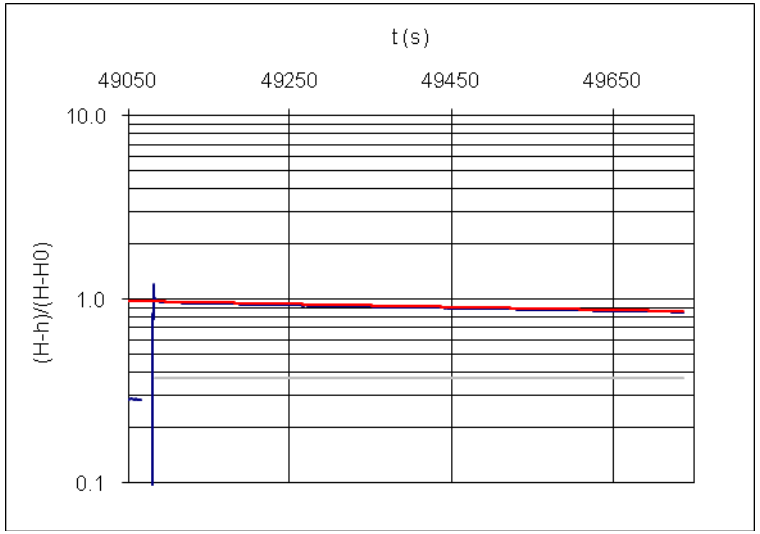
input file	**OLPP39000383.DAT**	date	*1.7.2009*			
TOC (m)	*0.5*					
depth of pressure sensor open hole (m)	*1.52*	ref toc	min open bore-hole pressure (m)	1.01	ref ground level	
depth of pressure sensor meas. section (m)	*1.52*	initial, ref toc				
depth of pressure sensor meas. section (m)	*3.02*	final, ref toc				
depth of meas. section (m)	*9.95*	ref TOC, top				
depth of meas. section (m)	9.95	ref ground level, midpoint of the section				
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm				
r (mm)	9.28					
H	0.94	reference water level at the measurement section based on phase 1, ref ground level				
H_0	-0.69	water level at the measurement section after disturbance, ref ground level				
t_0	49082.7	time of disturbance				
t_{end} (s)	49736.8	end of time range used to line fitting				
Time range (s)	654.1	Time range used for interpretation				
T_0	5166.2	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1				
L (m)	*1*	length of measurement section				
screen diam. (mm)	*56*	equal to borehole diameter				
screen radius R (mm)	28	equal to borehole radius				
L/R	35.71					
K (m/s)	**2.98E-08**	**T0 not reached**				
logK	-7.53					

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.000187205	-0.032853805
2.65905E-07	0.000100417
0.9944	0.002650741
495658.0997	2784
3.482706804	0.01956158

Stat tests	
test stat, a <> 0	704.03
test stat, b <> 0	327.17
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	49298.3	h1	-0.57
t2	49303.0	h2	-0.57
Q (m^3/s)	7.34E-08	dh (m)	1.51
K_{Thiem} (m/s)	**4.82E-08**	logK	-7.32
$K_{Hvorslev}$ / K_{Thiem}	0.62		
tight			
t1	49087.4	h1	-0.65
t2	49300.7	h2	-0.57
Q (m^3/s)	1.06E-07	dh (m)	1.55
K_{Thiem} (m/s)	**6.76E-08**	logK	-7.17
$K_{Hvorslev}$ / K_{Thiem}	0.44		



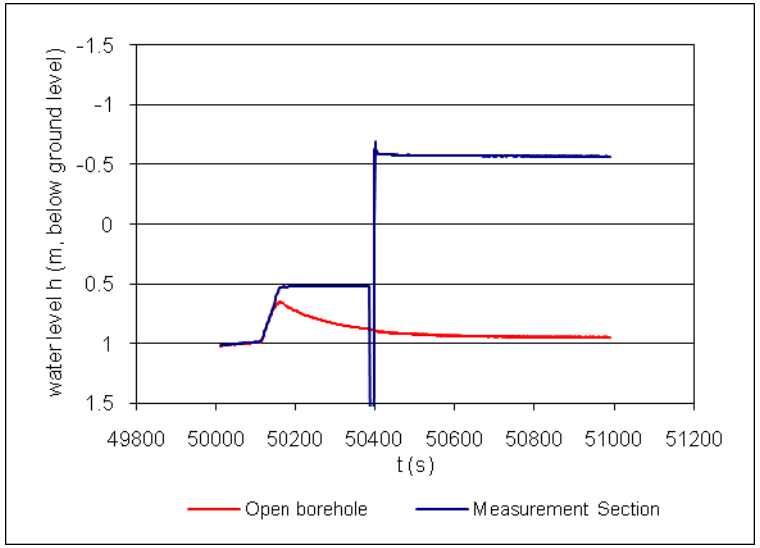


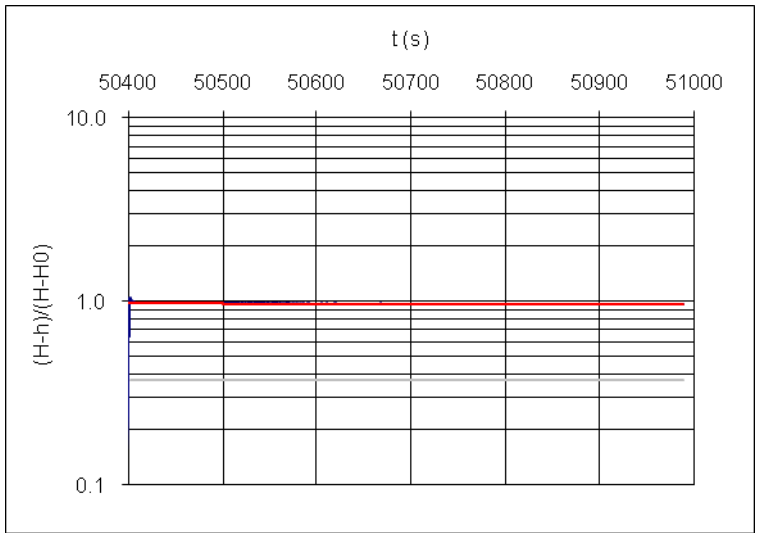
input file	**OLPP39000384.DAT**	date	*1.7.2009*			
TOC (m)	*0.5*					
depth of pressure sensor open hole (m)	*1.52*	ref toc	min open bore-hole pressure (m)	1.02	ref ground level	
depth of pressure sensor meas. section (m)	*1.52*	initial, ref toc				
depth of pressure sensor meas. section (m)	*3.02*	final, ref toc				
depth of meas. section (m)	*10.95*	ref TOC, top				
depth of meas. section (m)	10.95	ref ground level, midpoint of the section				
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm				
r (mm)	9.28					
H	1.00	reference water level at the measurement section based on phase 1, ref ground level				
H_0	-0.63	water level at the measurement section after disturbance, ref ground level				
t_0	50402.6	time of disturbance				
t_{end} (s)	50987.8	end of time range used to line fitting				
Time range (s)	585.3	Time range used for interpretation				
T_0	58744.6	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1				
L (m)	*1*	length of measurement section				
screen diam. (mm)	*56*	equal to borehole diameter				
screen radius R (mm)	28	equal to borehole radius				
L/R	35.71					
K (m/s)	**2.62E-09**	**T0 not reached**				
logK	-8.58					

ln((H-h)/(H-H0)) = a*t + b	
a	b
-1.65629E-05	-0.027017254
2.35417E-07	7.95534E-05
0.6652	0.00198666
4949.931156	2491
0.019536471	0.00983152

Stat tests	
test stat, a <> 0	70.36
test stat, b <> 0	339.61
t-critical, 90%	1.96

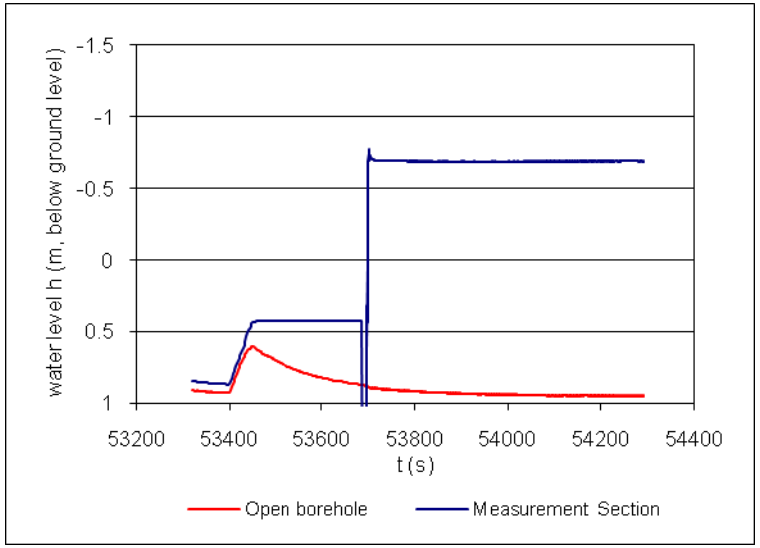
Thiem analysis for control			
flow			
t1	50595.1	h1	-0.58
t2	50599.8	h2	-0.58
Q (m^3/s)	1.05E-08	dh (m)	1.57
K_{Thiem} (m/s)	**6.57E-09**	logK	-8.18
$K_{Hvorslev}$ / K_{Thiem}	0.40		
tight			
t1	50407.3	h1	-0.60
t2	50597.5	h2	-0.58
Q (m^3/s)	2.92E-08	dh (m)	1.58
K_{Thiem} (m/s)	**1.82E-08**	logK	-7.74
$K_{Hvorslev}$ / K_{Thiem}	0.14		

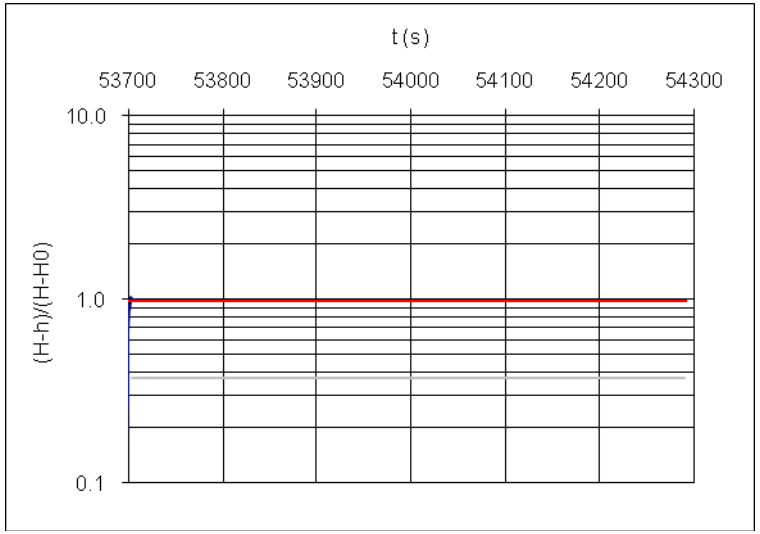




input file	**OLPP39000385.DAT**	date	*1.7.2009*			
TOC (m)	*0.5*					
depth of pressure sensor open hole (m)	*1.52*	ref toc	min open bore-hole pressure (m)	0.95	ref ground level	
depth of pressure sensor meas. section (m)	*1.52*	initial, ref toc				
depth of pressure sensor meas. section (m)	*3.02*	final, ref toc				
depth of meas. section (m)	*11.95*	ref TOC, top				
depth of meas. section (m)	11.95	ref ground level, midpoint of the section				
tube diameter (mm)	18.56	equivalent area to a double tube with outer diam 24.9 mm and inner diam 16.6 mm				
r (mm)	9.28					
H	0.86	reference water level at the measurement section based on phase 1, ref ground level				
H_0	-0.73	water level at the measurement section after disturbance, ref ground level				
t_0	53703.6	time of disturbance				
t_{end} (s)	54290.2	end of time range used to line fitting				
Time range (s)	586.6	Time range used for interpretation				
T_0	347667.8	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1				
L (m)	*1*	length of measurement section				
screen diam. (mm)	*56*	equal to borehole diameter				
screen radius R (mm)	28	equal to borehole radius				
L/R	35.71					
K (m/s)	**4.43E-10**	**T0 not reached**				
logK	-9.35					

ln((H-h)/(H-H0)) = a*t + b		Thiem analysis for control			
a	b	**flow**			
-2.81071E-06	-0.02280606	t1	53896.6	h1	-0.69
2.3742E-07	8.04229E-05	t2	53901.3	h2	-0.69
0.0531	0.002010786	Q (m^3/s)	1.05E-08	dh (m)	1.54
140.1519745	2497	K_{Thiem} (m/s)	**6.71E-09**	logK	-8.17
0.000566671	0.010096017	$K_{Hvorslev}$ / K_{Thiem}	0.07		
Stat tests		**tight**			
test stat, a <> 0	11.84	t1	53708.3	h1	-0.70
test stat, b <> 0	283.58	t2	53898.9	h2	-0.69
t-critical, 90%	1.96	Q (m^3/s)	2.51E-08	dh (m)	1.55
		K_{Thiem} (m/s)	**1.60E-08**	logK	-7.80
		$K_{Hvorslev}$ / K_{Thiem}	0.03		





APPENDIX 4 MEASUREMENTS AND RESULTS IN OL-PVP4A

Area:	Hole:	Measurer:
Olkiluoto	PVP4A	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.24 m
The reference level to depth is top of the casing, the length of the casing is 0.70 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
362	8.6.2009	12:30	1.34	not in use	1.34	1.50	0.5 l water out of tube

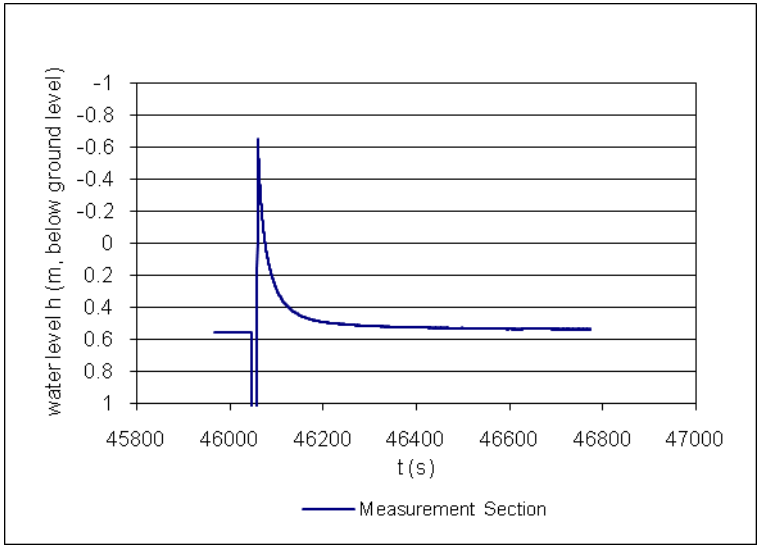
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPV4A000362.DAT	6.55	1.44E-05	9.74E-01	2.01E-05	1.97E-05	

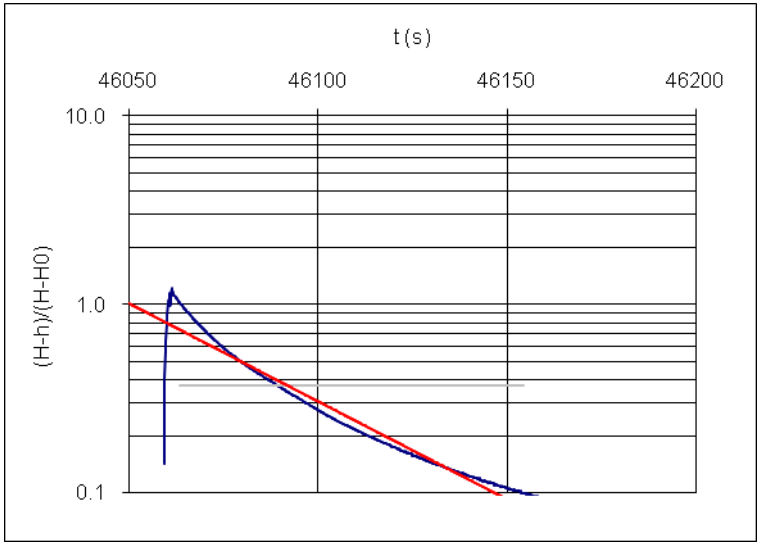
input file	**OLPV4A000362.DAT**	date	*8.6.2009*
TOC (m)	*0.7* *0*		
depth of pressure sensor meas. section (m)	*1.34*	initial, ref toc	
depth of pressure sensor meas. section (m)	*2.84*	final, ref toc	
depth of meas. section (m)	*5.55*	ref ground level, top	
depth of meas. section (m)	6.55	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.55	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-0.4290	water level at the measurement section after disturbance, ref ground level	
t_0	46063.52	time of disturbance	
t_{end} (s)	46154.46	end of time range used to line fitting	
Time range (s)	90.94	Time range used for interpretation	
T_0	28.51	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*56*	equal to borehole diameter	
screen radius R (mm)	28	equal to borehole radius	
L/R	71.43		
K (m/s)	**1.43747E-05**		
logK	-4.84		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.02393223	-0.317740508
0.000142777	0.007500512
0.973865103	0.103195487
28096.3141	754
299.2063149	8.029578564

Stat tests	
test stat, a <> 0	167.62
test stat, b <> 0	42.36
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	46077.98	h1	0.041
t2	46080.4	h2	0.081
Q (m^3/s)	2.00E-05	dh (m)	0.49
K_{Thiem} (m/s)	**2.01E-05**	logK	-4.70
$K_{Hvorslev}$ / K_{Thiem}	0.72		
tight			
t1	46065.94	h1	-0.307
t2	46093.77	h2	0.234
Q (m^3/s)	2.35E-05	dh (m)	0.59
K_{Thiem} (m/s)	**1.97E-05**	logK	-4.71
$K_{Hvorslev}$ / K_{Thiem}	0.73		





APPENDIX 5 MEASUREMENTS AND RESULTS IN OL-PVP4B

Area:	Hole:	Measurer:
Olkiluoto	PVP4B	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.57 m
The reference level to depth is top of the casing, the length of the casing is 0.86 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
363	8.6.2009	12:55	1.67	not in use	1.67	1.50	

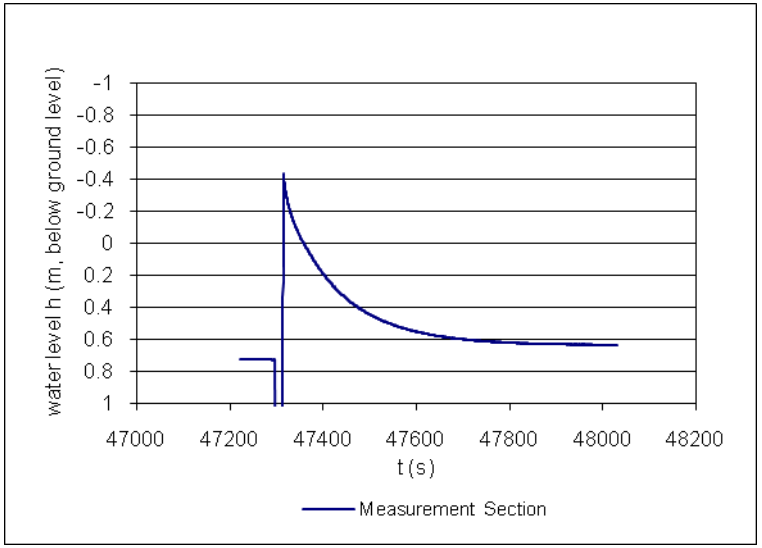
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPV4B000363.DAT	3	2.95E-06	9.62E-01	4.16E-06	4.00E-06	

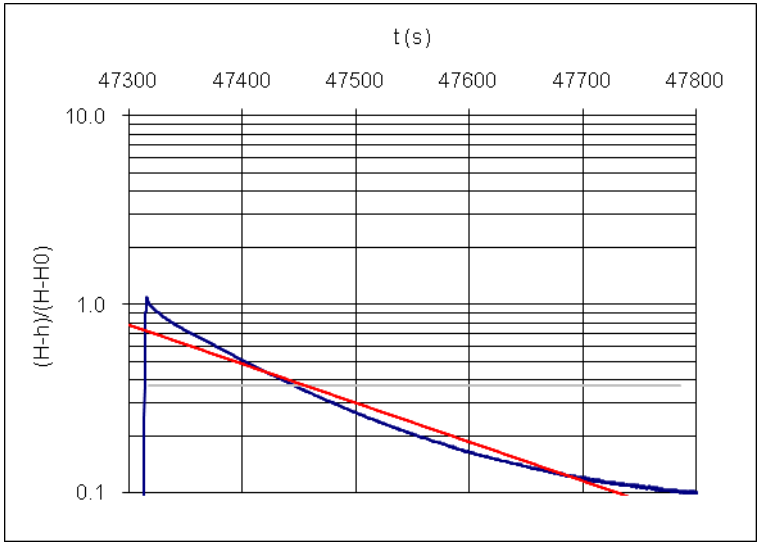
input file	**OLPV4B000363.DAT**	date	*8.6.2009*
TOC (m)	*0.86*		
	0		
depth of pressure sensor meas. section (m)	*1.67*	initial, ref toc	
depth of pressure sensor meas. section (m)	*3.17*	final, ref toc	
depth of meas. section (m)	*2*	ref ground level, top	
depth of meas. section (m)	3	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.73	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-0.3420	water level at the measurement section after disturbance, ref ground level	
t_0	47318.25	time of disturbance	
t_{end} (s)	47785.97	end of time range used to line fitting	
Time range (s)	467.72	Time range used for interpretation	
T_0	139.10	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*56*	equal to borehole diameter	
screen radius R (mm)	28	equal to borehole radius	
L/R	71.43		
K (m/s)	**2.94602E-06**		
logK	-5.53		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.00477175	-0.33624274
1.52954E-05	0.004130546
0.961653092	0.128723947
97326.63953	3881
1612.68827	64.30760589

Stat tests	
test stat, a <> 0	311.97
test stat, b <> 0	81.40
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	47399.93	h1	0.187
t2	47402.35	h2	0.196
Q (m^3/s)	4.49E-06	dh (m)	0.53
K_{Thiem} (m/s)	**4.16E-06**	logK	-5.38
$K_{Hvorslev}$ / K_{Thiem}	0.71		
tight			
t1	47320.65	h1	-0.304
t2	47474.14	h2	0.395
Q (m^3/s)	5.50E-06	dh (m)	0.68
K_{Thiem} (m/s)	**4.00E-06**	logK	-5.40
$K_{Hvorslev}$ / K_{Thiem}	0.74		





APPENDIX 6 MEASUREMENTS AND RESULTS IN OL-PVP6A

Area:	Hole:	Measurer:
Olkiluoto	PVP6A	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.49 m
The reference level to depth is top of the casing, the length of the casing is 0.70 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
364	8.6.2009	13:35	1.59	not in use	1.59	1.50	0.2 l water out of tube

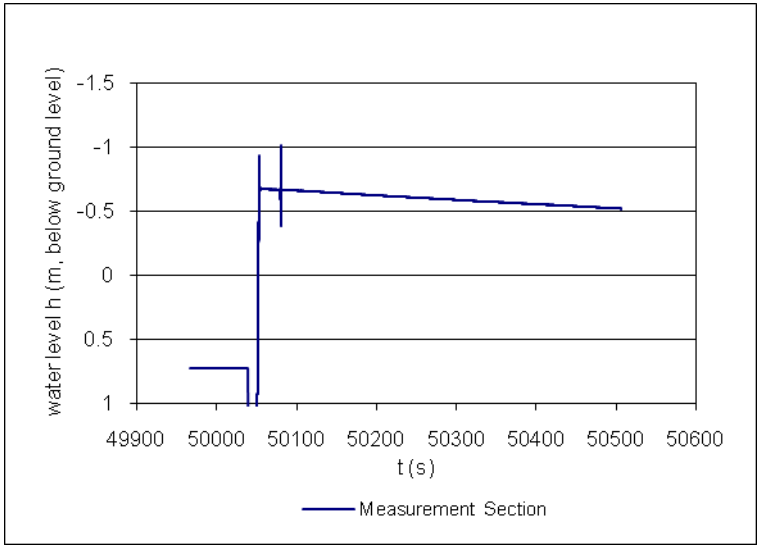
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPV6A000364.DAT	4.83	1.08E-07	9.99E-01	1.50E-07	1.64E-07	T0 not reached

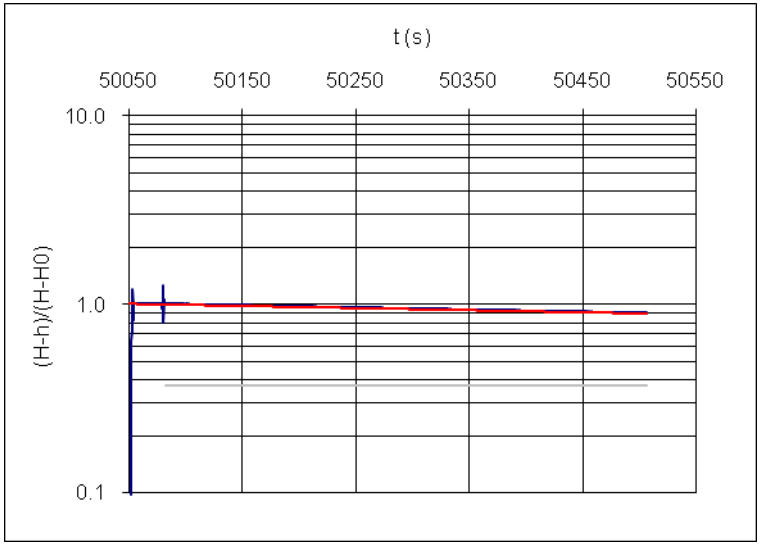
input file	**OLPV6A000364.DAT**	date	*8.6.2009*
TOC (m)	*0.7* *0*		
depth of pressure sensor meas. section (m)	*1.59*	initial, ref toc	
depth of pressure sensor meas. section (m)	*3.09*	final, ref toc	
depth of meas. section (m)	*3.83*	ref ground level, top	
depth of meas. section (m)	4.83	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.72	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-0.6690	water level at the measurement section after disturbance, ref ground level	
t_0	50082.87	time of disturbance	
t_{end} (s)	50506.38	end of time range used to line fitting	
Time range (s)	423.51	Time range used for interpretation	
T_0	3794.61	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*56*	equal to borehole diameter	
screen radius R (mm)	28	equal to borehole radius	
L/R	71.43		
K (m/s)	**1.07994E-07**	**T0 not reached**	
logK	-6.97		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.000263409	-0.000464534
1.1314E-07	2.76656E-05
0.999352125	0.000820413
5420373.81	3514
3.648328028	0.002365192

Stat tests	
test stat, a <> 0	2328.17
test stat, b <> 0	16.79
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	50222.73	h1	-0.617
t2	50225.16	h2	-0.617
Q (m^3/s)	4.06E-07	dh (m)	1.34
K_{Thiem} (m/s)	**1.50E-07**	logK	-6.82
$K_{Hvorslev}$ / K_{Thiem}	0.72		
tight			
t1	50085.27	h1	-0.669
t2	50223.93	h2	-0.617
Q (m^3/s)	4.53E-07	dh (m)	1.36
K_{Thiem} (m/s)	**1.64E-07**	logK	-6.78
$K_{Hvorslev}$ / K_{Thiem}	0.66		





APPENDIX 7 MEASUREMENTS AND RESULTS IN OL-PVP6B

Area:	Hole:	Measurer:
Olkiluoto	PVP6B	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.50 m
The reference level to depth is top of the casing, the length of the casing is 0.90 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
365	8.6.2009	13:55	1.60	not in use	1.60	1.50	

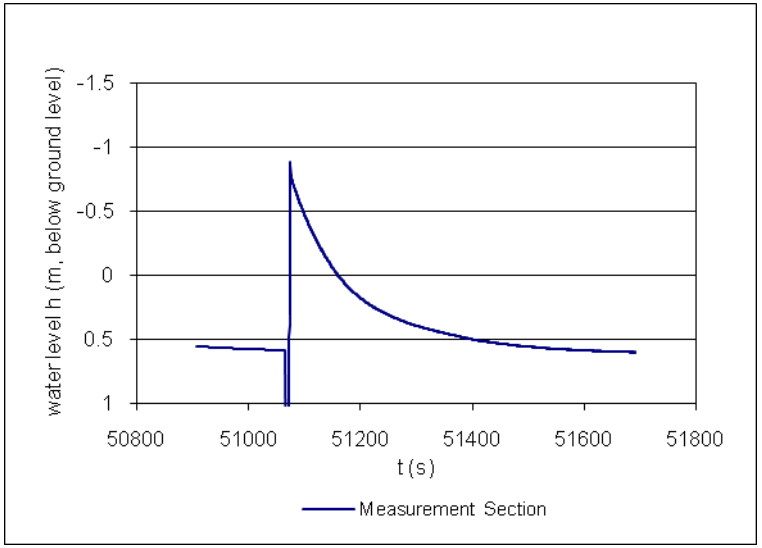
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPV6B000365.DAT	2.83	3.89E-06	9.96E-01	5.53E-06	5.67E-06	

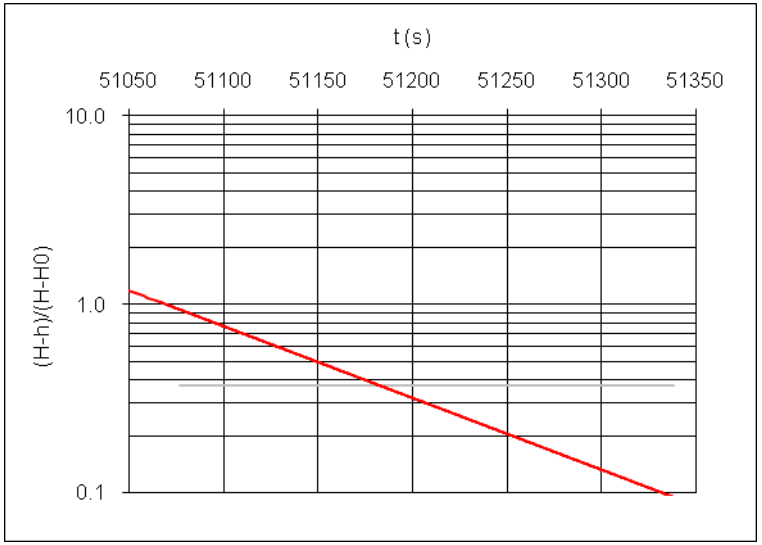
input file	**OLPV6B000365.DAT**	date	*8.6.2009*
TOC (m)	*0.9* *0*		
depth of pressure sensor meas. section (m)	*1.6*	initial, ref toc	
depth of pressure sensor meas. section (m)	*3.1*	final, ref toc	
depth of meas. section (m)	*1.83*	ref ground level, top	
depth of meas. section (m)	2.83	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.57	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-0.7400	water level at the measurement section after disturbance, ref ground level	
t_0	51077.25	time of disturbance	
t_{end} (s)	51338	end of time range used to line fitting	
Time range (s)	260.75	Time range used for interpretation	
T_0	105.39	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*56*	equal to borehole diameter	
screen radius R (mm)	28	equal to borehole radius	
L/R	71.43		
K (m/s)	**3.88838E-06**		
logK	-5.41		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.008750708	-0.077765302
1.13598E-05	0.001711839
0.996401571	0.039633636
593394.615	2143
932.1191551	3.366278188

Stat tests	
test stat, a <> 0	770.32
test stat, b <> 0	45.43
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	51175.19	h1	0.079
t2	51177.61	h2	0.090
Q (m^3/s)	5.44E-06	dh (m)	0.49
K_{Thiem} (m/s)	**5.53E-06**	logK	-5.26
$K_{Hvorslev}$ / K_{Thiem}	0.70		
tight			
t1	51079.65	h1	-0.709
t2	51164.29	h2	0.025
Q (m^3/s)	1.05E-05	dh (m)	0.91
K_{Thiem} (m/s)	**5.67E-06**	logK	-5.25
$K_{Hvorslev}$ / K_{Thiem}	0.69		





APPENDIX 8 MEASUREMENTS AND RESULTS IN OL-PVP14

Area:	Hole:	Measurer:
Olkiluoto	PVP14	Ossi Isola, Maarit Yli-Kaila

Water level before starting 2.57 m
The reference level to depth is top of the casing, the length of the casing is 0.70 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
366	8.6.2009	14:30	2.67	not in use	2.67	1.50	

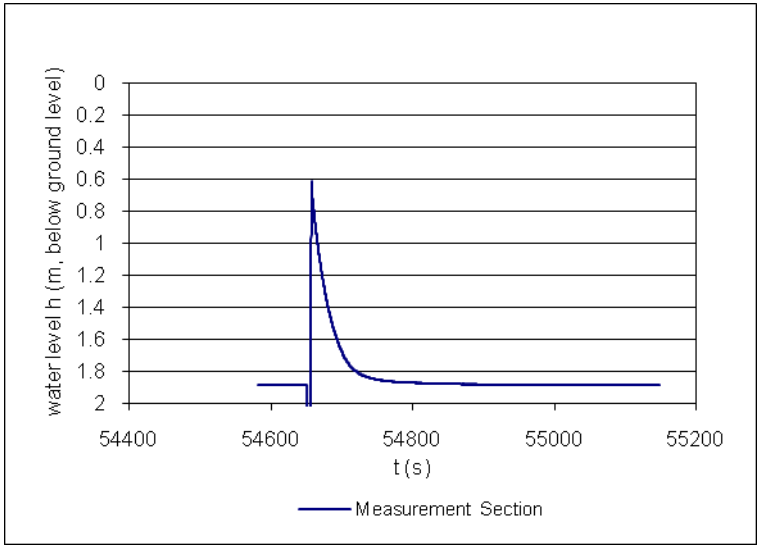
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPV14000366.DAT	7.4	1.69E-05	9.99E-01	2.41E-05	2.31E-05	

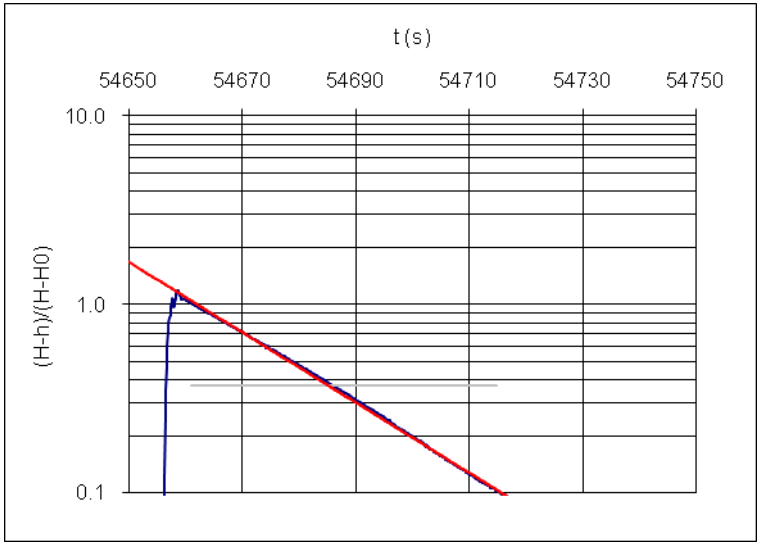
input file	**OLPV14000366.DAT**	date	*8.6.2009*
TOC (m)	*0.7* *0*		
depth of pressure sensor meas. section (m)	*2.67*	initial, ref toc	
depth of pressure sensor meas. section (m)	*4.17*	final, ref toc	
depth of meas. section (m)	*6.4*	ref ground level, top	
depth of meas. section (m)	7.4	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	1.89	reference water level at the measurement section based on phase 1, ref ground level	
H_0	0.8020	water level at the measurement section after disturbance, ref ground level	
t_0	54660.99	time of disturbance	
t_{end} (s)	54714.85	end of time range used to line fitting	
Time range (s)	53.86	Time range used for interpretation	
T_0	24.25	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*56*	equal to borehole diameter	
screen radius R (mm)	28	equal to borehole radius	
L/R	71.43		
K (m/s)	**1.68997E-05**		
logK	-4.77		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.042885229	0.039907205
6.16587E-05	0.001918656
0.999078897	0.0203352
483756.2074	446
200.0430411	0.184430081

Stat tests	
test stat, a <> 0	695.53
test stat, b <> 0	20.80
t-critical, 90%	1.97

Thiem analysis for control			
flow			
t1	54677.14	h1	1.315
t2	54679.55	h2	1.368
Q (m^3/s)	2.65E-05	dh (m)	0.54
K_{Thiem} (m/s)	**2.41E-05**	logK	-4.62
$K_{Hvorslev}$ / K_{Thiem}	0.70		
tight			
t1	54663.41	h1	0.901
t2	54678.95	h2	1.356
Q (m^3/s)	3.53E-05	dh (m)	0.76
K_{Thiem} (m/s)	**2.31E-05**	logK	-4.64
$K_{Hvorslev}$ / K_{Thiem}	0.73		





APPENDIX 9 MEASUREMENTS AND RESULTS IN OL-PVP30

Area:	Hole:	Measurer:
Olkiluoto	PVP30	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.61 m
The reference level to depth is top of the casing, the length of the casing is 1.24 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
372	22.6.2009	14:25	1.71	not in use	1.71	1.50	0.2 l water out of tube

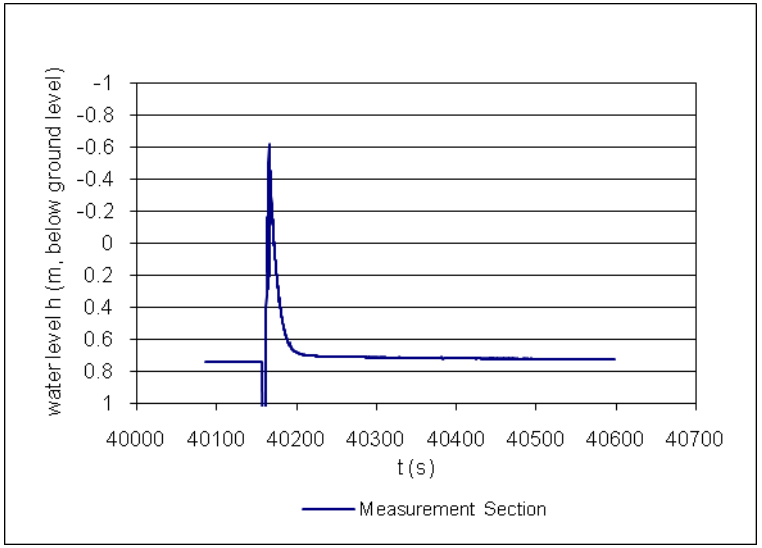
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLPV30000372.DAT	1.3	6.74E-05	9.98E-01	1.23E-04	1.17E-04	

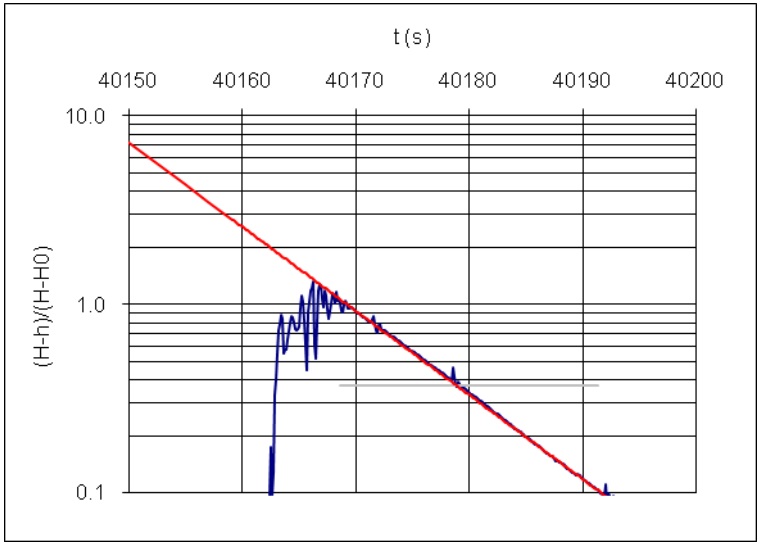
input file	**OLPV30000373.DAT**	date	*25.6.2009*
TOC (m)	*1.2*		
	0		
depth of pressure sensor meas. section (m)	*2.04*	initial, ref toc	
depth of pressure sensor meas. section (m)	*3.54*	final, ref toc	
depth of meas. section (m)	*0.8*	ref ground level, top	
depth of meas. section (m)	1.3	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.74	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-0.2960	water level at the measurement section after disturbance, ref ground level	
t_0	40168.59	time of disturbance	
t_{end} (s)	40191.37	end of time range used to line fitting	
Time range (s)	22.78	Time range used for interpretation	
T_0	10.39	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*1*	length of measurement section	
screen diam. (mm)	*52*	equal to borehole diameter	
screen radius R (mm)	26	equal to borehole radius	
L/R	38.46		
K (m/s)	**6.74178E-05**		
logK	-4.17		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.102727986	0.06774589
0.000299423	0.003944297
0.998405378	0.027285439
117708.3124	188
87.6332699	0.139965092

Stat tests	
test stat, a <> 0	343.09
test stat, b <> 0	17.18
t-critical, 90%	1.97

Thiem analysis for control			
flow			
t1	40174.86	h1	0.149
t2	40177.27	h2	0.279
Q (m^3/s)	6.47E-05	dh (m)	0.52
K_{Thiem} (m/s)	**1.23E-04**	logK	-3.91
$K_{Hvorslev}$ / K_{Thiem}	0.55		
tight			
t1	40171	h1	-0.121
t2	40176.19	h2	0.225
Q (m^3/s)	8.03E-05	dh (m)	0.69
K_{Thiem} (m/s)	**1.17E-04**	logK	-3.93
$K_{Hvorslev}$ / K_{Thiem}	0.58		





APPENDIX 10 MEASUREMENTS AND RESULTS IN OL-PVP31A

Area:	Hole:	Measurer:
Olkiluoto	PVP31A	Ossi Isola

Water level before starting 3.24 m
The reference level to depth is top of the casing, the length of the casing is 1.17 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
393	27.7.2009	10:15	3.34	not in use	3.34	1.50	

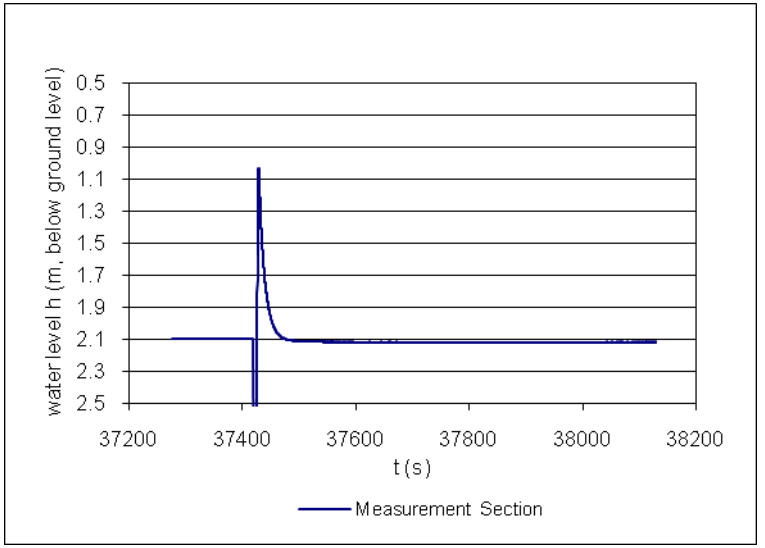
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLPV31A000393.DAT	3.72	4.19E-05	1.00E+00	6.01E-05	5.94E-05	

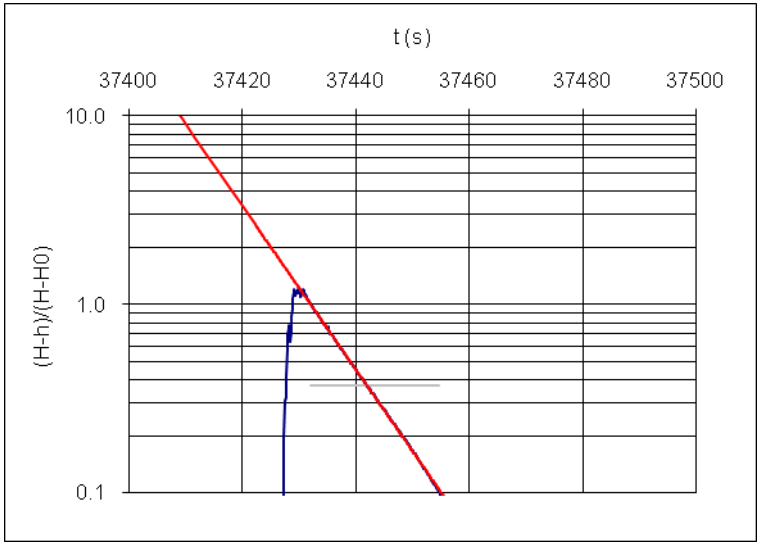
input file	**OLPV31A000393.DAT**	date	*27.7.2009*
TOC (m)	*1.17*		
	0		
depth of pressure sensor meas. section (m)	*3.34*	initial, ref toc	
depth of pressure sensor meas. section (m)	*4.84*	final, ref toc	
depth of meas. section (m)	*2.72*	ref ground level, top	
depth of meas. section (m)	3.72	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	2.09	reference water level at the measurement section based on phase 1, ref ground level	
H_0	1.2040	water level at the measurement section after disturbance, ref ground level	
t_0	37432.12	time of disturbance	
t_{end} (s)	37454.65	end of time range used to line fitting	
Time range (s)	22.53	Time range used for interpretation	
T_0	9.94	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*52*	equal to borehole diameter	
screen radius R (mm)	26	equal to borehole radius	
L/R	76.92		
K (m/s)	**4.19367E-05**		
logK	-4.38		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.099744447	-0.008400125
0.000115409	0.001504298
0.999752393	0.01029891
746965.6279	185
79.22881474	0.019622497

Stat tests	
test stat, a <> 0	864.27
test stat, b <> 0	5.58
t-critical, 90%	1.97

Thiem analysis for control			
flow			
t1	37437.75	h1	1.591
t2	37440.16	h2	1.698
Q (m^3/s)	5.36E-05	dh (m)	0.45
K_{Thiem} (m/s)	**6.01E-05**	logK	-4.22
$K_{Hvorslev}$ / K_{Thiem}	0.70		
tight			
t1	37434.57	h1	1.403
t2	37439.68	h2	1.679
Q (m^3/s)	6.52E-05	dh (m)	0.55
K_{Thiem} (m/s)	**5.94E-05**	logK	-4.23
$K_{Hvorslev}$ / K_{Thiem}	0.71		





APPENDIX 11 MEASUREMENTS AND RESULTS IN OL-PVP31B

Area:	Hole:	Measurer:
Olkiluoto	PVP31B	Ossi Isola

Water level before starting 3.08 m
The reference level to depth is top of the casing, the length of the casing is 0.98 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
392	27.7.2009	9:40	3.18	not in use	3.18	1.50	

measurement/hole&run	measurement depth (m) below ground level midpoint of the section	KHvorslev (m/s)	R2	KThiem (m/s) flow	KThiem (m/s)tight	comments
OLPV31B000392.DAT	2.59	9.05E-08	3.30E-01	5.31E-08	8.31E-07	T0 not reached Thiem different

input file	**OLPV31B000392.DAT**	date	*27.7.2009*
TOC (m)	*0.98*		
	0		
depth of pressure sensor meas. section (m)	*3.18*	initial, ref toc	
depth of pressure sensor meas. section (m)	*4.68*	final, ref toc	
depth of meas. section (m)	*1.59*	ref ground level, top	
depth of meas. section (m)	2.59	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	2.08	reference water level at the measurement section based on phase 1, ref ground level	
H_0	1.2650	water level at the measurement section after disturbance, ref ground level	
t_0	35282.16	time of disturbance	
t_{end} (s)	36204.22	end of time range used to line fitting	
Time range (s)	922.06	Time range used for interpretation	
T_0	4604.28	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*52*	equal to borehole diameter	
screen radius R (mm)	26	equal to borehole radius	
L/R	76.92		
K (m/s)	**9.05482E-08**	**T0 not reached**	
logK	-7.04		

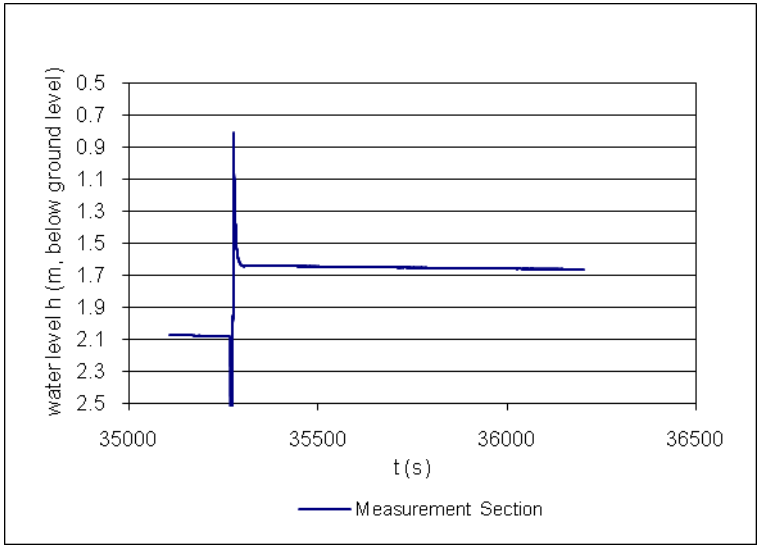
ln((H-h)/(H-H0)) = a*t + b	
a	b
-8.5249E-05	-0.607490002
1.38869E-06	0.000739189
0.330382513	0.032313316
3768.512142	7638
3.93489351	7.975220856

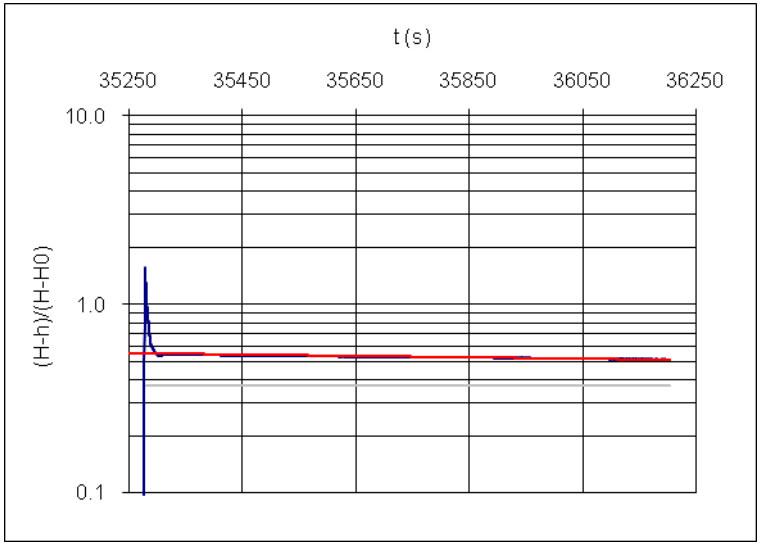
Stat tests	
test stat, a <> 0	61.39
test stat, b <> 0	821.83
t-critical, 90%	1.96

Thiem analysis for control

flow			
t1	35588.13	h1	1.649
t2	35590.55	h2	1.649
Q (m^3/s)	4.53E-08	dh (m)	0.43
K_{Thiem} (m/s)	**5.31E-08**	logK	-7.28
$K_{Hvorslev}$ / K_{Thiem}	1.71		

tight			
t1	35284.57	h1	1.422
t2	35589.34	h2	1.649
Q (m^3/s)	8.97E-07	dh (m)	0.54
K_{Thiem} (m/s)	**8.31E-07**	logK	-6.08
$K_{Hvorslev}$ / K_{Thiem}	0.11		





APPENDIX 12 MEASUREMENTS AND RESULTS IN OL-PVP32

Area:	Hole:	Measurer:
Olkiluoto	PVP32	Ossi Isola

Water level before starting 3.39 m
The reference level to depth is top of the casing, the length of the casing is 1.08 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
394	27.7.2009	11:00	3.49	not in use	3.49	1.50	Water level very low

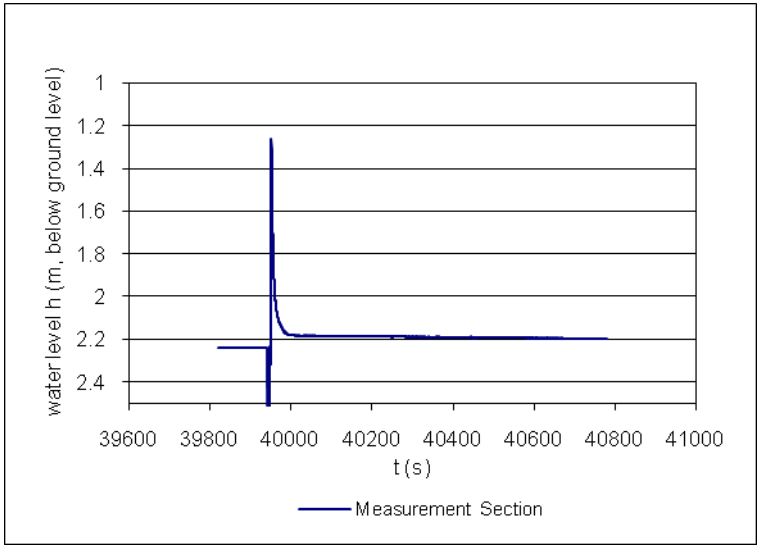
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLPV32000394.DAT	1.2	5.21E-05	9.19E-01	7.90E-05	5.68E-05	

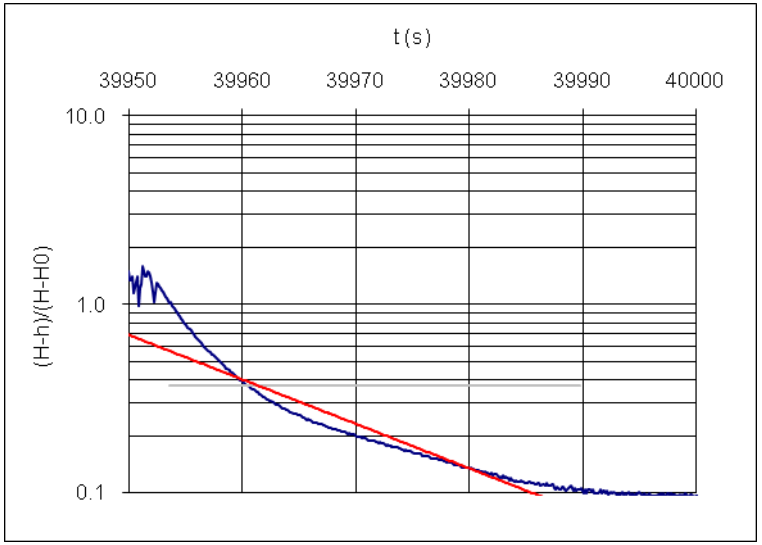
input file	**OLPV32000394.DAT**	date	*27.7.2009*
TOC (m)	*1.08*		
	0		
depth of pressure sensor meas. section (m)	*3.49*	initial, ref toc	
depth of pressure sensor meas. section (m)	*4.99*	final, ref toc	
depth of meas. section (m)	*0.2*	ref ground level, top	
depth of meas. section (m)	1.2	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	2.24	reference water level at the measurement section based on phase 1, ref ground level	
H_0	1.6220	water level at the measurement section after disturbance, ref ground level	
t_0	39953.57	time of disturbance	
t_{end} (s)	39989.82	end of time range used to line fitting	
Time range (s)	36.25	Time range used for interpretation	
T_0	8.01	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*52*	equal to borehole diameter	
screen radius R (mm)	26	equal to borehole radius	
L/R	76.92		
K (m/s)	**5.2069E-05**		
logK	-4.28		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.054265311	-0.565504707
0.000930899	0.019488193
0.919126425	0.1693179
3398.12852	299
97.41942192	8.571896849

Stat tests	
test stat, a <> 0	58.29
test stat, b <> 0	29.02
t-critical, 90%	1.97

Thiem analysis for control			
flow			
t1	39956.61	h1	1.873
t2	39959.02	h2	1.973
Q (m^3/s)	4.98E-05	dh (m)	0.32
K_{Thiem} (m/s)	**7.90E-05**	logK	-4.10
$K_{Hvorslev}$ / K_{Thiem}	0.66		
tight			
t1	39956.01	h1	1.837
t2	39965.65	h2	2.088
Q (m^3/s)	3.13E-05	dh (m)	0.28
K_{Thiem} (m/s)	**5.68E-05**	logK	-4.25
$K_{Hvorslev}$ / K_{Thiem}	0.92		





APPENDIX 13 MEASUREMENTS AND RESULTS IN OL-PVP33

Area:	Hole:	Measurer:
Olkiluoto	PVP33	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.94 m
The reference level to depth is top of the casing, the length of the casing is 1.20 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
373	25.6.2009	10:25	2.04	not in use	2.04	1.50	

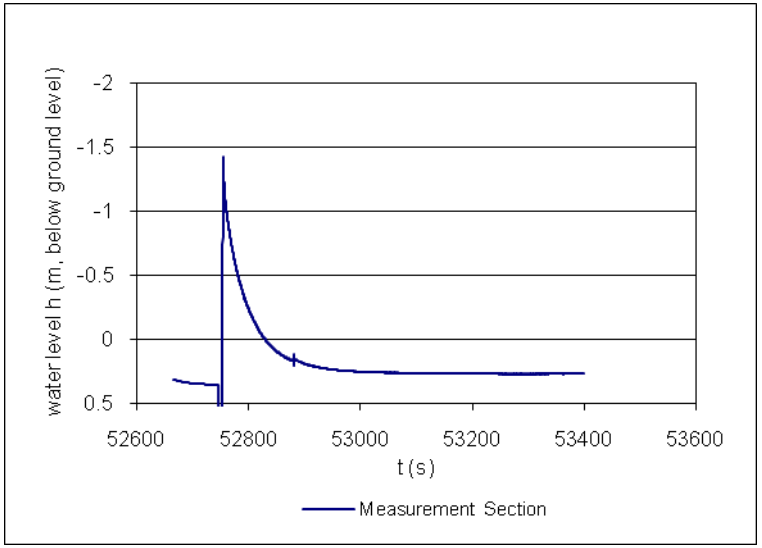
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLPV33000373.DAT	1.26	1.40E-05	9.91E-01	2.26E-05	2.45E-05	

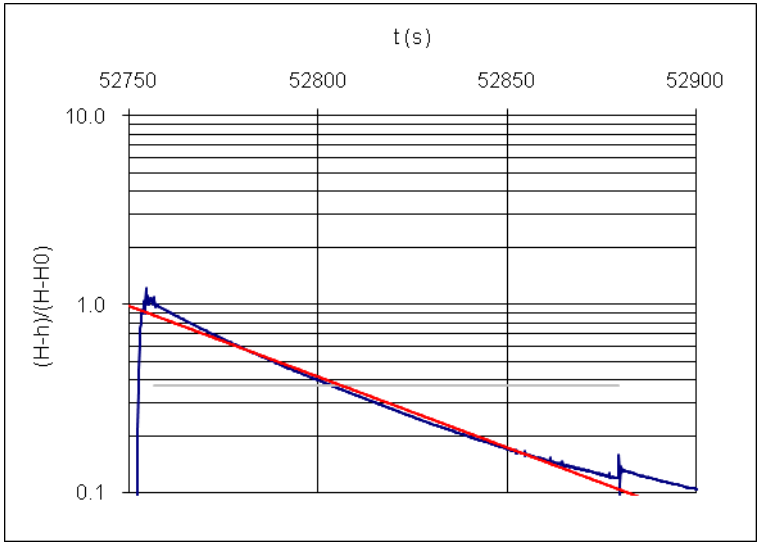
input file	**OLPV33000372.DAT**	date	*22.6.2009*
TOC (m)	*1.24*		
	0		
depth of pressure sensor meas. section (m)	*1.71*	initial, ref toc	
depth of pressure sensor meas. section (m)	*3.21*	final, ref toc	
depth of meas. section (m)	*0.76*	ref ground level, top	
depth of meas. section (m)	1.26	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.34	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-1.0990	water level at the measurement section after disturbance, ref ground level	
t_0	52756.86	time of disturbance	
t_{end} (s)	52879.57	end of time range used to line fitting	
Time range (s)	122.71	Time range used for interpretation	
T_0	50.04	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*1*	length of measurement section	
screen diam. (mm)	*52*	equal to borehole diameter	
screen radius R (mm)	26	equal to borehole radius	
L/R	38.46		
K (m/s)	**1.40045E-05**		
logK	-4.85		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.017287599	-0.134988666
5.16219E-05	0.003658052
0.991022094	0.058382046
112150.6961	1016
382.2615263	3.462998664

Stat tests	
test stat, a <> 0	334.89
test stat, b <> 0	36.90
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	52796.6	h1	-0.269
t2	52799.01	h2	-0.242
Q (m^3/s)	1.34E-05	dh (m)	0.59
K_{Thiem} (m/s)	**2.26E-05**	logK	-4.65
$K_{Hvorslev}$ / K_{Thiem}	0.62		
tight			
t1	52759.3	h1	-1.018
t2	52797.8	h2	-0.255
Q (m^3/s)	2.39E-05	dh (m)	0.98
K_{Thiem} (m/s)	**2.45E-05**	logK	-4.61
$K_{Hvorslev}$ / K_{Thiem}	0.57		





APPENDIX 14 MEASUREMENTS AND RESULTS IN OL-PVP34A

Area:	Hole:	Measurer:
Olkiluoto	PVP34A	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.70 m
The reference level to depth is top of the casing, the length of the casing is 0.92 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
375	26.6.2009	9:02	1.80	not in use	1.80	1.50	

measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLPV34A000375.DAT	4.08	3.99E-06	9.96E-01	5.36E-06	5.69E-06	

input file	**OLPV34A000375.DAT**	date	*26.6.2009*
TOC (m)	*0.92* *0*		
depth of pressure sensor meas. section (m)	*1.8*	initial, ref toc	
depth of pressure sensor meas. section (m)	*3.3*	final, ref toc	
depth of meas. section (m)	*3.08*	ref ground level, top	
depth of meas. section (m)	4.08	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.76	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-0.5320	water level at the measurement section after disturbance, ref ground level	
t_0	33577.37	time of disturbance	
t_{end} (s)	33852.78	end of time range used to line fitting	
Time range (s)	275.41	Time range used for interpretation	
T_0	104.40	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*52*	equal to borehole diameter	
screen radius R (mm)	26	equal to borehole radius	
L/R	76.92		
K (m/s)	**3.99356E-06**		
logK	-5.40		

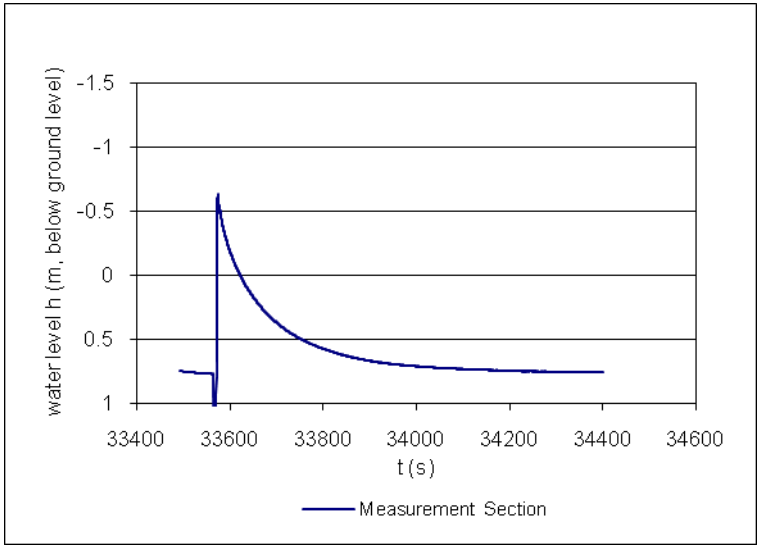
ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.007989602	-0.165923204
1.1037E-05	0.001753853
0.995681105	0.041884273
524018.978	2273
919.2824686	3.987506443

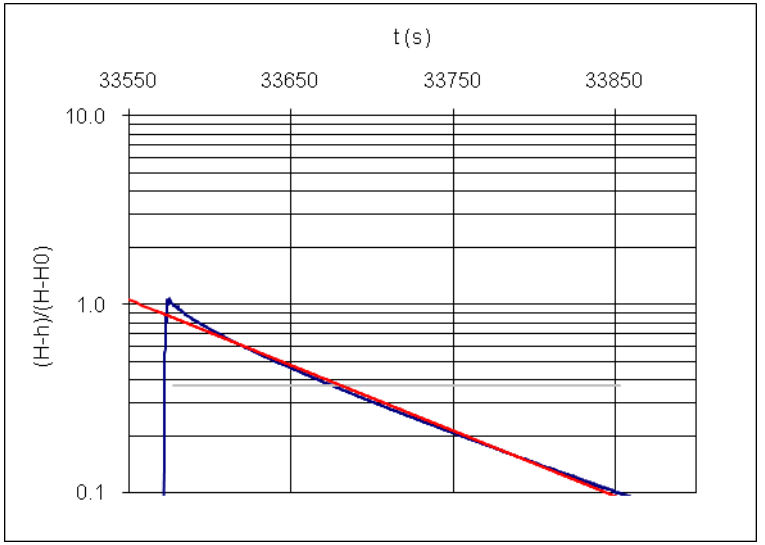
Stat tests	
test stat, a <> 0	723.89
test stat, b <> 0	94.60
t-critical, 90%	1.96

Thiem analysis for control

flow			
t1	33639.04	h1	0.107
t2	33641.45	h2	0.120
Q (m^3/s)	6.92E-06	dh (m)	0.65
K_{Thiem} (m/s)	**5.36E-06**	logK	-5.27
$K_{Hvorslev}$ / K_{Thiem}	0.74		

tight			
t1	33579.78	h1	-0.482
t2	33668.93	h2	0.253
Q (m^3/s)	9.94E-06	dh (m)	0.87
K_{Thiem} (m/s)	**5.69E-06**	logK	-5.24
$K_{Hvorslev}$ / K_{Thiem}	0.70		





APPENDIX 15 MEASUREMENTS AND RESULTS IN OL-PVP34B

Area:	Hole:	Measurer:
Olkiluoto	PVP34B	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.77 m
The reference level to depth is top of the casing, the length of the casing is 0.79 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
374	26.6.2009	8:44	1.87	not in use	1.87	1.50	

measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLPV34B000374.DAT	2.21	1.09E-05	9.44E-01	1.56E-05	7.00E-06	

input file	**OLPV34B000374.DAT**	date	*26.6.2009*
TOC (m)	*0.79* *0*		
depth of pressure sensor meas. section (m)	*1.87*	initial, ref toc	
depth of pressure sensor meas. section (m)	*3.37*	final, ref toc	
depth of meas. section (m)	*1.21*	ref ground level, top	
depth of meas. section (m)	2.21	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.97	reference water level at the measurement section based on phase 1, ref ground level	
H_0	0.5190	water level at the measurement section after disturbance, ref ground level	
t_0	32482.19	time of disturbance	
t_{end} (s)	32766.74	end of time range used to line fitting	
Time range (s)	284.55	Time range used for interpretation	
T_0	38.26	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*2*	length of measurement section	
screen diam. (mm)	*52*	equal to borehole diameter	
screen radius R (mm)	26	equal to borehole radius	
L/R	76.92		
K (m/s)	**1.08981E-05**		
logK	-4.96		

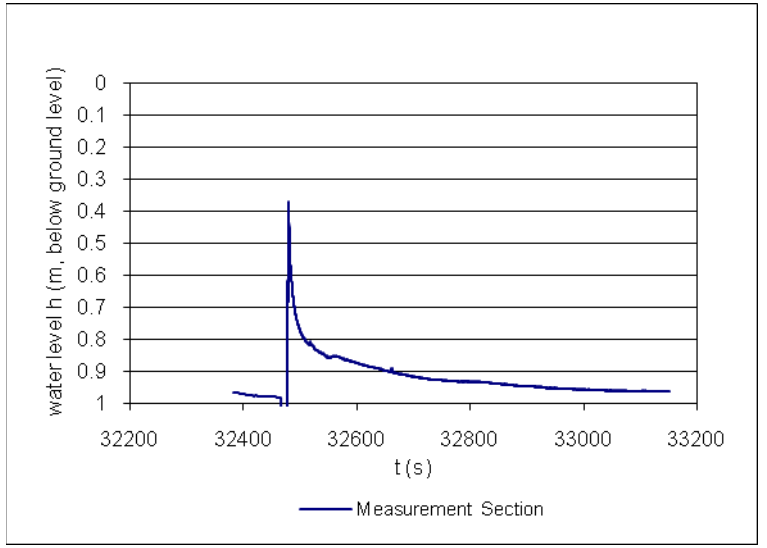
ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.005776117	-0.779033044
2.90375E-05	0.004770336
0.943804311	0.115870418
39568.92409	2356
531.2505452	31.63154706

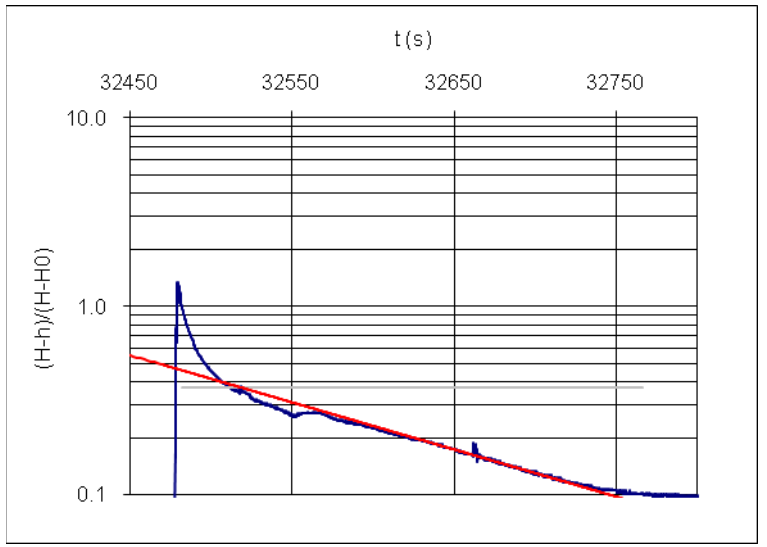
Stat tests	
test stat, a <> 0	198.92
test stat, b <> 0	163.31
t-critical, 90%	1.96

Thiem analysis for control

flow			
t1	32494.63	h1	0.738
t2	32497.03	h2	0.752
Q (m^3/s)	7.13E-06	dh (m)	0.23
K_{Thiem} (m/s)	**1.56E-05**	logK	-4.81
$K_{Hvorslev}$ / K_{Thiem}	0.70		

tight			
t1	32484.61	h1	0.598
t2	32576.94	h2	0.860
Q (m^3/s)	3.42E-06	dh (m)	0.24
K_{Thiem} (m/s)	**7.00E-06**	logK	-5.16
$K_{Hvorslev}$ / K_{Thiem}	1.56		





APPENDIX 16 MEASUREMENTS AND RESULTS IN OL-HP1

Area:	Hole:	Measurer:
Olkiluoto	HP1 Korvensuo	Ossi Isola, Maarit Yli-Kaila

Water level before starting 4.02 m
The reference level to depth is top of the casing, the length of the casing is 1.03 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
368	22.6.2009	9:40	4.12	not in use	4.12	1.50	

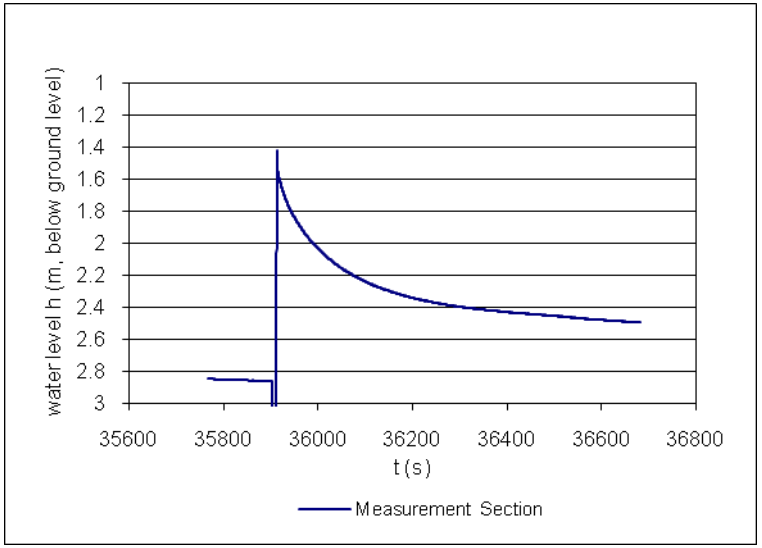
measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPP1000368.DAT	4.5	1.60E-06	8.69E-01	3.35E-06	3.86E-06	

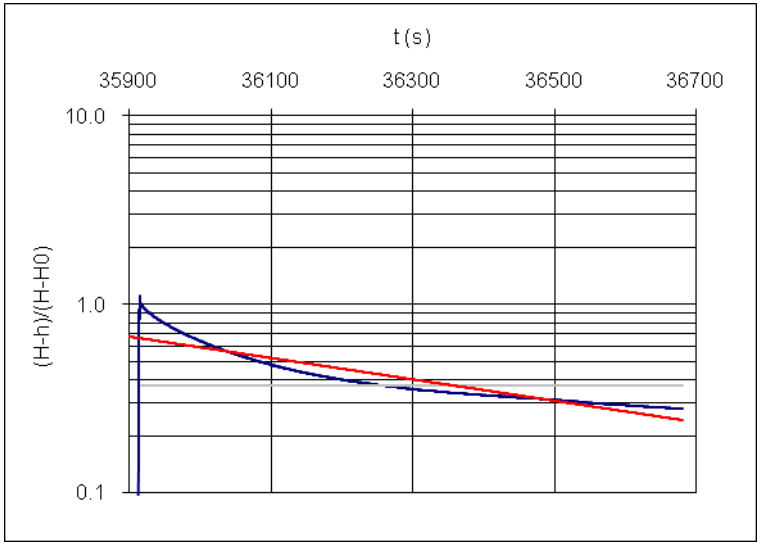
input file	**OLHPP1000368.DAT**	date	*22.6.2009*
TOC (m)	*1.03*		
	0		
depth of pressure sensor meas. section (m)	*4.12*	initial, ref toc	
depth of pressure sensor meas. section (m)	*5.12*	final, ref toc	
depth of meas. section (m)	*4*	ref ground level, top	
depth of meas. section (m)	4.5	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	2.85	reference water level at the measurement section based on phase 1, ref ground level	
H_0	1.5700	water level at the measurement section after disturbance, ref ground level	
t_0	35917.86	time of disturbance	
t_{end} (s)	36681.29	end of time range used to line fitting	
Time range (s)	763.43	Time range used for interpretation	
T_0	441.29	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*1*	length of measurement section	
screen diam. (mm)	*50*	equal to borehole diameter	
screen radius R (mm)	25	equal to borehole radius	
L/R	40.00		
K (m/s)	**1.60497E-06**		
logK	-5.79		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.001315106	-0.419651801
6.42189E-06	0.002830686
0.868980191	0.112571669
41936.87784	6323
531.4400779	80.12746264

Stat tests	
test stat, a <> 0	204.78
test stat, b <> 0	148.25
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	36082.75	h1	2.209
t2	36085.17	h2	2.214
Q (m^3/s)	2.13E-06	dh (m)	0.64
K_{Thiem} (m/s)	**3.35E-06**	logK	-5.48
$K_{Hvorslev}$ / K_{Thiem}	0.48		
tight			
t1	35920.27	h1	1.600
t2	36172.38	h2	2.316
Q (m^3/s)	3.43E-06	dh (m)	0.89
K_{Thiem} (m/s)	**3.86E-06**	logK	-5.41
$K_{Hvorslev}$ / K_{Thiem}	0.42		





APPENDIX 17 MEASUREMENTS AND RESULTS IN OL-HP2

Area: Olkiluoto **Hole:** HP2 Korvensuo **Measurer:** Ossi Isola, Maarit Yli-Kaila

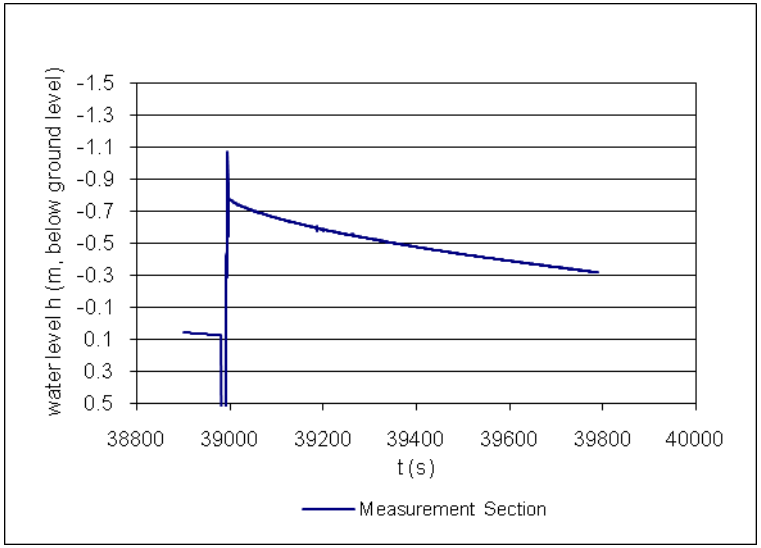
Water level before starting 0.97 m
The reference level to depth is top of the casing, the length of the casing is 0.80 m

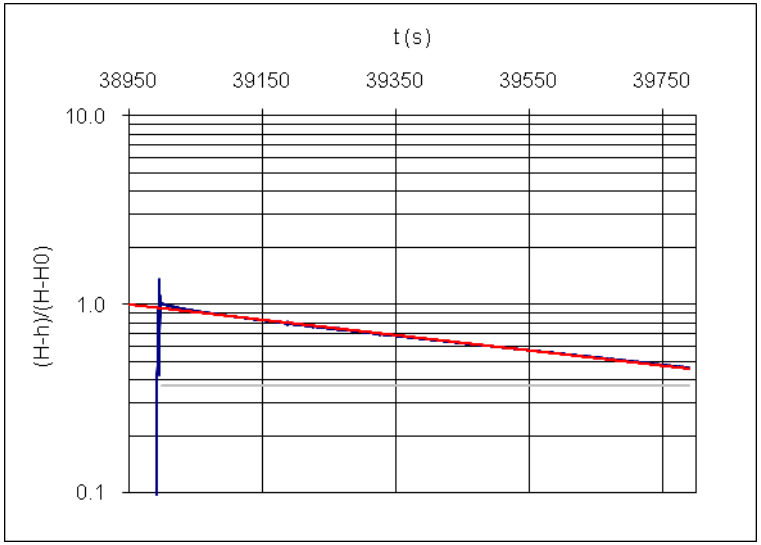
File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
369	22.6.2009	10:30	1.07	not in use	1.07	1.50	1 l water out of tube

measurement/hole&run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPP2000369.DAT	2.5	6.99E-07	9.97E-01	8.07E-07	1.42E-06	T0 not reached

input file	**OLHPP2000369.DAT**	date	*22.6.2009*
TOC (m)	*0.8* *0*		
depth of pressure sensor meas. section (m)	*1.07*	initial, ref toc	
depth of pressure sensor meas. section (m)	*2.57*	final, ref toc	
depth of meas. section (m)	*2*	ref ground level, top	
depth of meas. section (m)	2.5	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	0.07	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-0.7720	water level at the measurement section after disturbance, ref ground level	
t_0	38999.25	time of disturbance	
t_{end} (s)	39790.56	end of time range used to line fitting	
Time range (s)	791.31	Time range used for interpretation	
T_0	1013.64	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*1*	length of measurement section	
screen diam. (mm)	*50*	equal to borehole diameter	
screen radius R (mm)	25	equal to borehole radius	
L/R	40.00		
K (m/s)	**6.98732E-07**	**T0 not reached**	
logK	-6.16		

ln((H-h)/(H-H0)) = a*t + b		Thiem analysis for control			
a	b	**flow**			
-0.000932383	-0.054896943	t1	39261.69	h1	-0.548
6.15137E-07	0.00028103	t2	39264.14	h2	-0.547
0.997154951	0.011380551	Q (m^3/s)	4.92E-07	dh (m)	0.61
2297447.84	6555	K_{Thiem} (m/s)	**8.07E-07**	logK	-6.09
297.558422	0.848983565	$K_{Hvorslev}$ / K_{Thiem}	0.87		
Stat tests		**tight**			
test stat, a <> 0	1515.73	t1	39001.66	h1	-0.768
test stat, b <> 0	195.34	t2	39262.89	h2	-0.547
t-critical, 90%	1.96	Q (m^3/s)	1.02E-06	dh (m)	0.73
		K_{Thiem} (m/s)	**1.42E-06**	logK	-5.85
		$K_{Hvorslev}$ / K_{Thiem}	0.49		





APPENDIX 18 MEASUREMENTS AND RESULTS IN OL-HP3

Area:	Hole:	Measurer:
Olkiluoto	HP3 Korvensuo	Ossi Isola, Maarit Yli-Kaila

Water level before starting 5.28 m
The reference level to depth is top of the casing, the length of the casing is 1.12 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
376	26.6.2009	12:20	5.38	not in use	5.38	1.00	

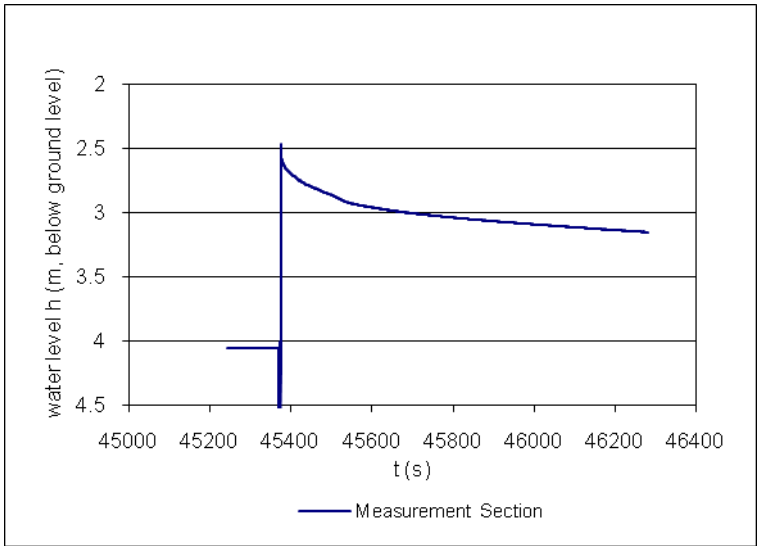
measurement/hole &run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPP3000376.DAT	4.5	3.30E-07	8.91E-01	3.48E-07	1.22E-06	T0 not reached Thiem different

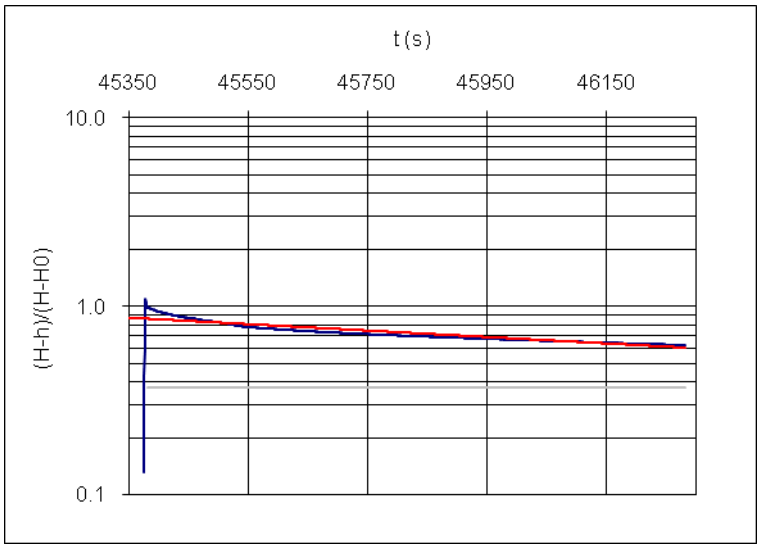
input file	**OLHPP3000377.DAT**	date	*26.6.2009*
TOC (m)	*1.12*		
	0		
depth of pressure sensor meas. section (m)	*5.38*	initial, ref toc	
depth of pressure sensor meas. section (m)	*6.38*	final, ref toc	
depth of meas. section (m)	*4*	ref ground level, top	
depth of meas. section (m)	4.5	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	4.06	reference water level at the measurement section based on phase 1, ref ground level	
H_0	2.6120	water level at the measurement section after disturbance, ref ground level	
t_0	45381.45	time of disturbance	
t_{end} (s)	46281.86	end of time range used to line fitting	
Time range (s)	900.41	Time range used for interpretation	
T_0	2145.00	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*1*	length of measurement section	
screen diam. (mm)	*50*	equal to borehole diameter	
screen radius R (mm)	25	equal to borehole radius	
L/R	40.00		
K (m/s)	**3.30194E-07**	**T0 not reached**	
logK	-6.48		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.000392867	-0.157302131
1.58835E-06	0.000825811
0.891340244	0.035664202
61178.26664	7458
77.81479688	9.486093461

Stat tests	
test stat, a <> 0	247.34
test stat, b <> 0	190.48
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	45680.44	h1	2.999
t2	45682.84	h2	3.000
Q (m^3/s)	3.66E-07	dh (m)	1.06
K_{Thiem} (m/s)	**3.48E-07**	logK	-6.46
$K_{Hvorslev}$ / K_{Thiem}	0.95		
tight			
t1	45383.86	h1	2.627
t2	45681.64	h2	3.000
Q (m^3/s)	1.51E-06	dh (m)	1.24
K_{Thiem} (m/s)	**1.22E-06**	logK	-5.91
$K_{Hvorslev}$ / K_{Thiem}	0.27		





APPENDIX 19 MEASUREMENTS AND RESULTS IN OL-HP4

Area:	Hole:	Measurer:
Olkiluoto	HP4 Korvensuo	Ossi Isola, Maarit Yli-Kaila

Water level before starting 1.98 m
The reference level to depth is top of the casing, the length of the casing is 0.44 m

File	Date	Time	Depth	Depth of pressure sensor open borehole (m)	Depth of pressure sensor meas. section (m)	Moving piston (m)	NOTE!
371	22.6.2009	13:20	2.08	not in use	2.08	1.50	

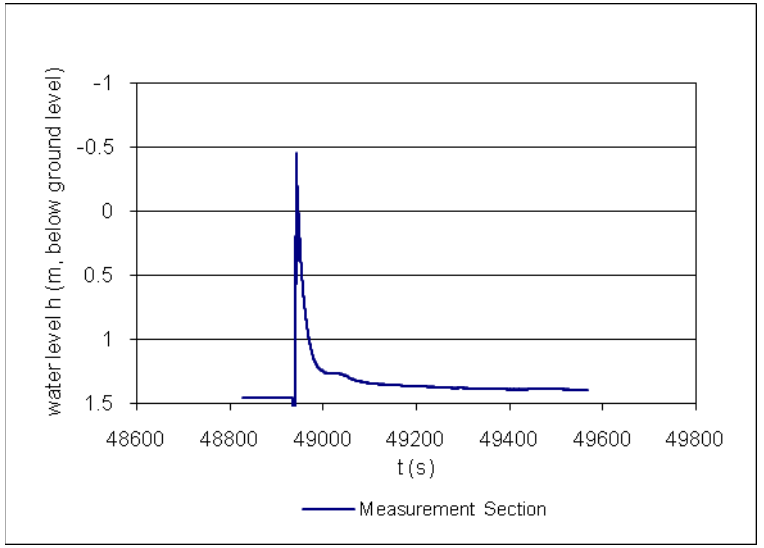
measurement/hole &run	measurement depth (m) below ground level midpoint of the section	$K_{Hvorslev}$ (m/s)	R2	K_{Thiem} (m/s) flow	K_{Thiem} (m/s)tight	comments
OLHPP4000371.DAT	2.5	4.33E-05	7.71E-01	5.85E-05	4.54E-05	

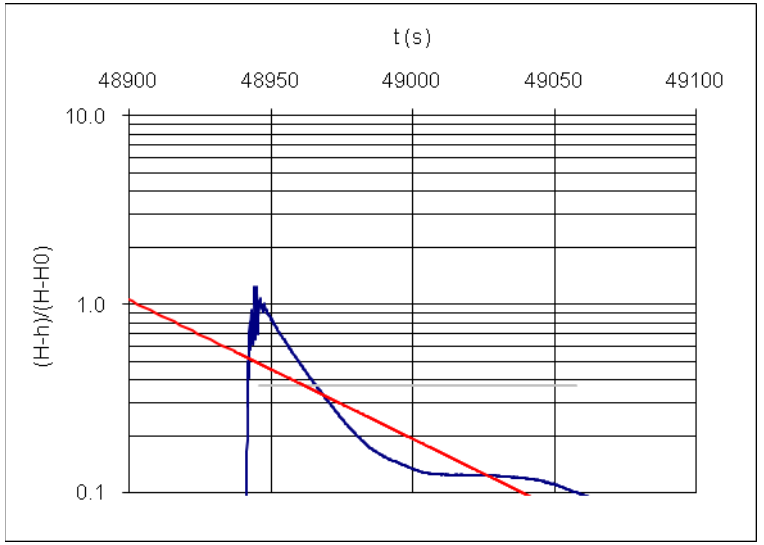
input file	**OLHPP4000371.DAT**	date	*22.6.2009*
TOC (m)	*0.44*		
	0		
depth of pressure sensor meas. section (m)	*2.08*	initial, ref toc	
depth of pressure sensor meas. section (m)	*3.58*	final, ref toc	
depth of meas. section (m)	*2*	ref ground level, top	
depth of meas. section (m)	2.5	ref ground level, midpoint of the section	
tube diameter (mm)	39.19	equivalent area to a double tube with outer diam 56 mm and inner diam 40 mm	
r (mm)	19.60		
H	1.46	reference water level at the measurement section based on phase 1, ref ground level	
H_0	-0.0740	water level at the measurement section after disturbance, ref ground level	
t_0	48946.15	time of disturbance	
t_{end} (s)	49057.67	end of time range used to line fitting	
Time range (s)	111.52	Time range used for interpretation	
T_0	15.62	basic time lag, t corresponding the time when ln((H-h)/(H-H0)) = -1	
L (m)	*1*	length of measurement section	
screen diam. (mm)	*59*	equal to borehole diameter	
screen radius R (mm)	29.5	equal to borehole radius	
L/R	33.90		
K (m/s)	**4.33144E-05**		
logK	-4.36		

ln((H-h)/(H-H0)) = a*t + b	
a	b
-0.016983133	-0.734756952
0.000304684	0.019617917
0.770965828	0.298690419
3106.96633	923
277.1910032	82.34633683

Stat tests	
test stat, a <> 0	55.74
test stat, b <> 0	37.45
t-critical, 90%	1.96

Thiem analysis for control			
flow			
t1	48958.21	h1	0.645
t2	48960.61	h2	0.736
Q (m^3/s)	4.57E-05	dh (m)	0.77
K_{Thiem} (m/s)	**5.85E-05**	logK	-4.23
$K_{Hvorslev}$ / K_{Thiem}	0.74		
tight			
t1	48948.55	h1	0.075
t2	48983.3	h2	1.179
Q (m^3/s)	3.83E-05	dh (m)	0.83
K_{Thiem} (m/s)	**4.54E-05**	logK	-4.34
$K_{Hvorslev}$ / K_{Thiem}	0.96		





APPENDIX 20 SUMMARY OF THE RESULTS

	2009			2008			2007			2006			2005			2004			
Hole	Test section, ref ground level, midpoint of the section (m)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	Test section, ref ground level, midpoint of the section (m)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	Test section, ref ground level, midpoint of the section (m)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	Test section, ref ground level, midpoint of the section (m)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	Test section, ref ground level, midpoint of the section (m)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	Test section, ref ground level, midpoint of the section (m)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	Comments
OL-PP5													2.69	2.8E-06	4.5E-05				depths of test sections in 2002 and 2005 differ 19 cm
OL-PP5													2.69	1.6E-05	3.8E-05				the measurement has not succeeded
OL-PP5													3.69	4.6E-07	7.3E-07				depths of test sections in 2002 and 2005 differ 46 cm
OL-PP5													4.69	7.7E-06	1.3E-05				depths of test sections in 2002 and 2005 differ 46 cm
OL-PP5										5.7	2.0E-07	3.9E-07	5.69	2.4E-07	4.1E-07				depths of test sections in 2002 and 2005 differ 46 cm
OL-PP5										6.7	1.0E-07	2.1E-07	6.69	2.0E-07	4.1E-07				depths of test sections in 2002 and 2005 differ 46 cm
OL-PP5										7.7	7.6E-08	1.5E-07	7.69	9.6E-08	1.9E-07				depths of test sections in 2002 and 2005 differ 46 cm
OL-PP5										8.7	9.1E-08	2.0E-07	8.69	1.0E-07	2.1E-07				depths of test sections in 2002 and 2005 differ 46 cm
OL-PP5										9.7	1.5E-07	3.2E-07	9.69	1.6E-07	3.3E-07				depths of test sections in 2002 and 2005 differ 46 cm
OL-PP5										10.7	1.4E-07	3.3E-07	10.69	1.6E-07	3.6E-07				depths of test sections in 2002 and 2005 differ 46 cm
OL-PP5																			
OL-PP9																			
OL-PP9																			
OL-PP9													3.8	8.3E-08	2.1E-07				
OL-PP9							4.83	4.7E-06	6.7E-06	4.83	5.2E-06	6.7E-06	4.8	1.9E-06	2.8E-06				
OL-PP9							5.83	4.5E-09	1.3E-08	5.83	-9.6E-10	2.1E-09	5.8	2.3E-08	1.3E-07				
OL-PP9													6.8	5.3E-06	1.0E-05				K-value differs radically from two other measurements from the same section in 2002 and 2005
OL-PP9										6.83	6.3E-09	3.9E-08	6.8	2.2E-08	2.1E-07				
OL-PP9										7.83	1.3E-07	2.2E-07	7.8	1.2E-07	3.5E-07				
OL-PP9										8.83	3.5E-07	5.4E-07	8.8	5.0E-08	3.0E-07				
OL-PP9										9.83	3.3E-07	4.9E-07	9.8	1.7E-07	3.6E-07				
OL-PP9										10.83	-6.0E-10	1.4E-08	10.8	3.4E-08	2.5E-07				
OL-PP9										11.83	2.7E-09	2.1E-08	11.8	2.6E-08	2.3E-07				
OL-PP9																			
OL-PP9																			
OL-PP36	5.67	1.2E-08	2.1E-08	5.67	1.0E-08	1.8E-08	5.67	1.3E-08	2.3E-08										T0 not reached
OL-PP36	6.67	1.4E-07	3.0E-07	6.67	1.2E-07	2.4E-07	6.67	1.3E-07	2.2E-07	6.67	1.3E-07	2.4E-07							T0 not reached
OL-PP36				7.67	6.8E-07	1.4E-06													
OL-PP36	7.67	4.8E-07	8.3E-07	7.67	4.2E-07	7.3E-07	7.67	5.3E-07	7.8E-07	7.67	5.2E-07	7.7E-07							
OL-PP36	8.67	5.4E-07	9.6E-07	8.67	6.0E-07	1.1E-06	8.67	4.7E-07	7.5E-07	8.67	1.6E-08	5.2E-08							
OL-PP39	4.95	1.3E-07	2.5E-07	4.95	1.2E-07	2.4E-07	4.95	1.2E-07	1.8E-07	4.95	1.2E-07	2.3E-07	4.94	9.6E-08	1.7E-07	4.92	6.2E-08	1.5E-07	T0 not reached
OL-PP39	5.95	1.3E-08	2.9E-08	5.95	1.4E-08	3.9E-08	5.95	9.7E-09	6.0E-09	5.95	8.5E-09	3.2E-08	5.94	3.9E-09	1.3E-08	5.92	2.7E-08	9.5E-08	T0 not reached
OL-PP39	6.95	4.6E-06	8.0E-06	6.95	3.9E-06	6.6E-06	6.95	3.8E-06	6.7E-06	6.95	4.2E-06	5.1E-06	6.94	4.5E-06	8.1E-06	6.94	4.6E-06	7.6E-06	
OL-PP39	7.95	4.2E-06	6.8E-06	7.95	3.6E-06	6.4E-06	7.95	3.1E-06	5.9E-06	7.95	7.5E-06	5.3E-06	7.94	4.8E-06	8.4E-06	7.94	4.3E-06	7.2E-06	shorter time used in interpretation
OL-PP39	8.95	7.8E-09	2.0E-08	8.95	1.5E-09	9.7E-09	8.95	3.1E-08	4.4E-08	8.95	6.1E-09	2.8E-08	8.94	1.5E-08	1.7E-08	8.94	6.2E-09	2.7E-08	T0 not reached
OL-PP39	9.95	3.0E-08	6.8E-08	9.95	2.5E-08	6.6E-08	9.95	2.5E-08	4.8E-08	9.95	1.3E-08	4.1E-08	9.94	5.5E-08	1.0E-07	9.94	2.4E-08	9.7E-08	T0 not reached
OL-PP39	10.95	2.6E-09	1.8E-08	10.95	1.0E-09	1.5E-08	10.95	1.2E-09	-3.5E-09	10.95	-1.5E-09	-2.0E-21	10.94	2.4E-09	3.6E-09	10.94	1.6E-10	4.3E-09	T0 not reached Thiem different
OL-PP39	11.95	4.4E-10	1.6E-08	11.95	-9.1E-10	1.7E-08	11.95	2.1E-09	6.6E-09				11.94	7.9E-09	1.1E-08	11.94	3.7E-09	1.4E-08	T0 not reached Thiem different

		2009		2008		2007		2006		2005		2004		2002		
Tube	Perforated section from ground surface (m-m)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	$K_{Hvorslev}$ (m/s)	K_{Thiem} (m/s)	Comments
OL-PVP3A	3.80-5.80					6.51995E-06	5.3E-06							1.3E-05	1.6E-05	
OL-PVP3B	1.80-3.80					1.1E-05	1.7E-05							1.7E-05	2.1E-05	
OL-PVP4A	5.55-7.55	1.4E-05	2.0E-05	1.5E-05	2.2E-05	1.5E-05	2.2E-05	1.5E-05	2.2E-05	1.4E-05	2.1E-05	1.4E-05	2.0E-05	9.7E-06	1.3E-05	
OL-PVP4B	2.00-4.00	2.9E-06	4.2E-06	4.0E-06	5.2E-06	3.9E-06	5.5E-06	4.2E-06	6.0E-06	3.3E-06	4.6E-06	3.1E-06	3.7E-06	3.0E-06	3.4E-06	
OL-PVP5A														3.3E-06	4.4E-06	
OL-PVP5B														1.3E-06	1.5E-06	
OL-PVP6A	3.83-5.83	1.1E-07	1.6E-07	8.8E-08	1.8E-07	8.3E-08	1.4E-07	9.8E-08	8.9E-08					4.8E-08	8.6E-08	T0 not reached
OL-PVP6B	1.83-3.83	3.9E-06	5.5E-06	2.0E-06	3.0E-06	9.8E-06	1.4E-05	2.6E-06	4.3E-06					2.3E-06	1.1E-06	
OL-PVP7A	1.75-3.75					2.9E-07	4.1E-07							3.5E-07	4.1E-07	
OL-PVP8A	4.45-6.45					1.1E-05	1.6E-05							3.4E-06	5.0E-06	
OL-PVP8B	2.45-4.45					4.5E-07	6.3E-07							4.2E-07	1.1E-06	
OL-PVP9A	5.00-7.00					6.2E-05	8.9E-05							8.5E-05	1.2E-04	
OL-PVP9B	3.00-5.00					1.8E-05	7.3E-05							5.1E-07	6.0E-06	
OL-PVP10A	1.00-3.00					1.4E-04	2.0E-04							1.2E-04	1.5E-04	
OL-PVP10B	0.30-0.50					3.8E-05	6.3E-05							4.8E-06	9.3E-06	
OL-PVP11	1.20-3.20					3.0E-05	4.2E-05					5.2E-05	7.5E-05			
OL-PVP12	2.30-4.30					2.1E-06	3.4E-06					1.8E-06	1.7E-06			
OL-PVP13	3.10-5.10					6.4E-06	8.8E-06			5.3E-06	7.7E-06	9.2E-06	1.6E-05			
OL-PVP14	6.40-8.40	1.7E-05	2.4E-05	1.9E-05	2.7E-05	1.9E-05	2.7E-05	2.6E-05	3.7E-05	4.5E-05	6.9E-05	8.2E-05	1.2E-04			
OL-PVP17	2.30-4.30					3.1E-06	4.5E-06			6.2E-07	1.2E-06					
OL-PVP18A	3.00-6.00					1.6E-06	2.0E-06			1.3E-06	1.5E-06					
OL-PVP18B	2.00-3.00					8.5E-07	1.2E-06			8.4E-07	2.0E-06					
OL-PVP18B	2.00-3.00									6.7E-07	1.7E-06					
OL-PVP19	9.15-11.15 13.15-15.15					1.4E-06	1.7E-06			6.2E-07	1.3E-06					two separate perforated sections
OL-PVP20	8.60-10.60					1.0E-05	1.1E-05			1.1E-05	1.6E-05					
OL-PVP21	6.75-8.75			4.5E-06	6.1E-06											
OL-PVP22	5.22-7.22			2.5E-06	3.9E-06											
OL-PVP23	2.43-4.43			5.9E-05	8.6E-05											
OL-PVP24	1.91-3.91			4.5E-06	6.5E-06											
OL-PVP25	1.91-2.91			6.8E-05	1.2E-04											
OL-PVP26	0.81-2.81			5.2E-05	7.7E-05											
OL-PVP27	0.59-2.59			1.3E-05	2.2E-05											
OL-PVP28	1.32-2.82			3.7E-06	5.6E-06											
OL-PVP29	1.59-3.09			2.2E-06	5.5E-05											
OL-PVP30	0.80-1.80	6.7E-05	1.2E-04													
OL-PVP31A	1.59-3.59	4.2E-05	6.0E-05													
OL-PVP31B	2.72-4.72	9.1E-08	8.3E-07													T0 not reached Thiem different
OL-PVP32	0.20-2.20	5.2E-05	7.9E-05													
OL-PVP33	0.76-1.76	1.4E-05	2.3E-05													
OL-PVP34A	3.08-5.08	4.0E-06	5.4E-06													
OL-PVP34B	1.21-3.21	1.1E-05	1.6E-05													
OL-HP1	4.00-5.00	1.6E-06	3.3E-06	2.2E-06	6.8E-06											
OL-HP2	2.00-3.00	7.0E-07	1.4E-06	7.4E-07	1.4E-06											T0 not reached
OL-HP3	4.00-5.00	3.3E-07	1.2E-06													Thiem different, T0 not reached
OL-HP4	2.00-3.00	4.3E-05	5.9E-05	9.6E-06	2.9E-05											

APPENDIX 21 COMPARISON OF THE K-VALUES WITH THE PRE-PUMPING RESULTS

Yield l/min	Yield m3/s	water table at start (m)	water table at the end (m)	dh m	length outside casing m	L m	KThiem m/s	T m2/s	**Slug test** Kthiem	L m	**Comparison** Kpump/Kslug
1.3	2.17E-05	1.73	2.38	0.65		1	3.4E-05	3.3E-05	1.2E-04	1	0.28
0.45	7.50E-06	1.7	2.47	0.77		2	5.0E-06	9.7E-06	5.4E-06	2	0.927
0.80	1.33E-05	1.72	2.37	0.65		2	1.0E-05	2.1E-05	1.6E-05	2	0.670
0.06	1.00E-06	2.78	2.82	0.04		1	2.6E-05	2.5E-05	2.3E-05	1	1.130
1.10	1.83E-05	1.21	3.3	2.09	12.5		7.2E-07	8.8E-06	1.9E-06	8	0.375
4.00	6.67E-05	1.92	2.59	0.67		2	5.1E-05	1.0E-04	6.0E-05	2	0.844
0.38	6.25E-06	1.52	2.27	0.75		2	4.3E-06	8.3E-06	8.3E-07	2	5.119
0.06	1.00E-06	2.6	3.01	0.41		2	1.2E-06	2.4E-06	7.9E-05	2	0.016