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Oskarshamn site investigation

Hydraulic tests and flow logging in borehole HSH03

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Keywords: Simpevarp, hydrogeology, hydraulic tests, pumping tests, injection tests, interference tests, storage coefficient, flow logging, water sampling, hydraulic parameters, transmissivity, flow anomaly.

Abstract

Hydraulic tests together with flow logging and water sampling were performed in percussion borehole HSH03. The main purpose of the percussion boreholes is to serve as supply wells for flushing water of sufficient amount (c 60 L/min) and water quality by the drilling of the cored boreholes in the investigation area.

The main purpose of the hydraulic testing, water sampling and flow logging in borehole HSH03 was to make a hydraulic characterisation of the hole and investigate the water quality of the borehole.

Three pumping tests (one of them as a step drawdown test) and one short injection test were carried out. Flow logging was performed during the open-hole pumping test.

The flow logging showed that the main inflow of water (c 75%) to the borehole is located to the intervals 53–56 m and 58.5–59.5 m. The remaining 25% of the flow is assumed to be located in the interval 12–29 m which was not covered by the flow logging.

The total transmissivity of the borehole was calculated to c $1.5 \cdot 10^{-5}$ m^2/s. Below c 59 m, the borehole transmissivity was below the measurement limit. Hydraulic fracturing did not significantly improve the specific capacity of the borehole. The step drawdown test indicated a high well loss coefficient which may correspond to high head losses in inflowing fractures to the borehole.

Sammanfattning

Hydrauliska tester tillsammans med flödesloggning och vattenprovtagning utfördes i hammarborrhål HSH03. Det huvudsakliga syftet med hammarborrhålen är att tjäna som spolvattenbrunnar med tillräcklig mängd (ca 60 L/min) och vattenkvalitet vid borrningen av kärnborrhålen i undersökningsområdet.

Huvudsyftet med den hydrauliska testningen, vattenprovtagningen och flödesloggningen i borrhål HSH03 var att göra en hydraulisk karaktärisering av hålet och undersöka vattenkvaliteten från borrhålet.

Tre pumptester (en av dom utfördes som en stegprovpumpning) och en kort injektionstest utfördes. Flödesloggningen utfördes under testen i öppet hål.

Flödesloggningen visade att det huvudsakliga vatteninflödet (ca 75%) till borrhålet är lokaliserat till intervallen 53–56 m och 58.5–59.5 m. De återstående ca 25% av flödet antas vara beläget i intervallet 12–29 m som inte täcktes av flödesloggningen.

Den totala transmissiviteten för borrhålet beräknades till ca $1.5 \cdot 10^{-5}$ m^2/s. Under ca 59 m var borrhålets transmissivitet under mätgränsen. Hydraulisk spräckning förbättrade inte nämnvärt borrhålets specifika kapacitet. Stegprovpumpningen indikerade en hög brunnsförlust-koefficient som kan motsvara höga tryckförluster i inflödande sprickor till borrhålet.

Contents

1 Introduction

Hydraulic tests together with flow meter logging and water sampling were performed in borehole HSH03. Three pumping tests (one of them as a step drawdown test) and one injection test were carried out. Flow meter logging was performed during the open-hole pumping test. The location of borehole HSH03 is shown in Figure 1-1.

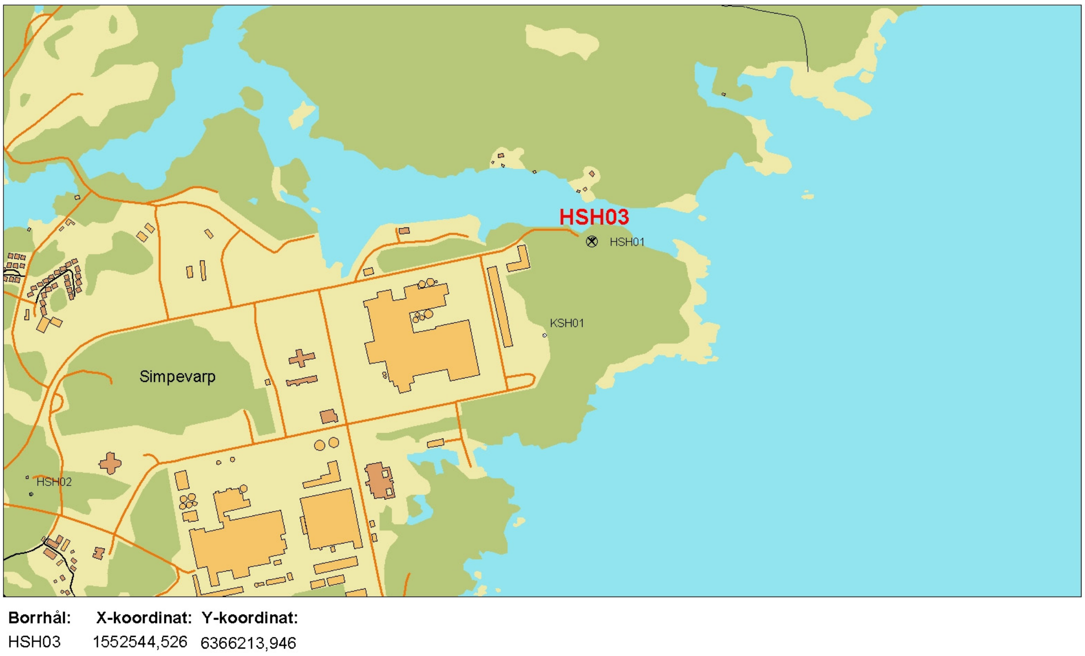


***Figure 1-1.** Map showing the location of borehole HSH03.*

2 Objectives

The main purpose of the percussion boreholes is to serve as supply wells for flushing water of sufficient amount (c 60 L/min) and water quality by the drilling of the cored boreholes in the investigation area.

The main purpose of the hydraulic testing, water sampling and flow logging in borehole HSH03 was to make a hydraulic characterisation of the hole including the water quality in the borehole.

3 Scope

3.1 Boreholes

Technical data of the tested borehole HSH03 are shown in Table 3-1. The reference point in the boreholes is always top of casing (ToC). Borehole HSH01 was used as an observation borehole. Technical data of borehole HSH03 are shown in Table 3-2. The borehole data are according to RT90-RHB70 except the bearing, which is according to local north.

Table 3-1. Technical data of tested borehole HSH03 (from SICADA).

Borehole HSH03							
ID	Elevation of top of casing (ToC) (m a s l)	Borehole interval from ToC (m)	Casing/ Bh-diam. (m)	Inclination-top of bh (from horizontal plane) (º)	Dip-direction-top of borehole (from local N) (º)	Remarks	Drilling finished Date (YYYY-MM-DD)
HSH03	2.52	0.0–12.00	0.160	–79.49	218.94	Casing ID	
”		12.00–12.03	0.148			Casing ID	
”		12.03–201.00	0.139			Open hole	2002-07-09

Table 3-2. Technical data of observation borehole HSH01 (from SICADA).

Borehole HSH01							
ID	Elevation of top of casing (ToC) (m a s l)	Borehole interval from ToC (m)	Casing/ Bh-diam. (m)	Inclination-top of bh (from horizontal plane) (º)	Dip-direction-top of borehole (from local N) (º)	Remarks	Drilling finished Date (YYYY-MM-DD)
HSH01	2.86	0.0–12.00	0.160	–69.994	4.994	Casing ID	
”		12.00–12.03	0.148			Casing ID	
”		12.03–200.00	0.140			Open hole	2002-07-02

3.2 Hydraulic tests

The hydraulic tests performed in the borehole are listed in Table 3-3 according to activity plan AP PS 400-02-008 (SKB internal controlling document). Pumping tests, injection tests and flow meter logging with the HTHB (HydroTestutrustning i Hammar-Borrhål) system were carried out. A step-drawdown test was carried out in the open borehole as the final step of the hydraulic testing campaign in HSH03. The different test types are described in the corresponding methodology descriptions for single-hole pumps tests (SKB MD 321.003, Metodbeskrivning för hydrauliska enhålspumptester), hydraulic injection tests (SKB MD 323.001, Metodbeskrivning för hydrauliska injektionstester) and impeller flow meter logging (SKB MD 322.009,

Table 3-3. Borehole tests performed in HSH03.

Bh ID	Test section (m)	Test type[1]	Test no	Test start date and time (YYYY-MM-DD tt:mm)	Test stop date and time (YYYY-MM-DD tt:mm)
HSH03	12.03–201	1B	1	2002-08-20 18:00	2002-08-22 08:15
”	29–198.7	6, L-Te, L-EC	1	2002-08-21 09:22	2002-08-21 15:02
”	12.03–103	1B	1	2002-08-22 15:00	2002-08-23 06:05
”	80.5–201	3	1	2002-08-23 12:42	2002-08-23 14:41
”	12.03–201	1B	2	2002-09-05 09:24	2002-09-06 06:30

[1] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller. L-EC: EC-logging, L-Te: temperature logging

Metodbeskrivning för flödesloggning). In conjunction with the flow logging, temperature- and electric conductivity logging of the borehole water was performed.

During the pumping tests, water samples were taken and submitted for analysis, see Section 6.2. Of primary interest was to decide if the borehole water was of sufficient quality to be used as flushing water for drilling of the cored borehole KSH01A.

In addition, groundwater level measurements were made in borehole HSH01. The responses in HSH01 were measured during the pumping tests in the intervals 12.03–201 m and 12.03–103 m, respectively, cf Section 6.3.2.

3.3 Equipment check

An equipment check was performed at the site as a simple and fast test to establish the operating status of sensors and other equipment. In addition, calibration constants were implemented and checked.

To check the function of the pressure sensors P1 and P2 (cf Figures 4-1 and 4-2), the pressure in air was recorded and found to be as expected. Submerged in water, P1 coincided well, while lowering, to the total head of water. The temperature sensor showed expected values in both air and water.

The sensor for electric conductivity showed zero in air. The impeller used in the flow logging equipment worked well as indicated by the rotation on the logger while lowering. The measuring wheel (used to check the position of the flow logging probe) and the sensor attached to it indicated a length that corresponded well to the pre-measured cable length.

4 Equipment

4.1 Description of equipment

The equipment used in these tests is referred to as HTHB (Swedish shortening for Hydraulic Test System for Percussion Boreholes). The HTHB is used in percussion boreholes and designed to perform pumping- and injection tests in open boreholes or in defined sections of the boreholes. It is also possible to combine a pumping test with a flow logging survey along the borehole, see Figure 4-1. The tests can be performed with either constant hydraulic head or alternatively, with constant flow rate. Hydraulic tests can also be performed in isolated borehole sections down to a total depth of 200 m, see Figure 4-2. For injection tests, however, the upper packer can not be located deeper than c 80 m due to limitations in the number of pipes available.

All equipment that belongs to the HTHB is, when not used, stored on a trailer and can be easily transported with a standard car. The equipment used in borehole includes submersible borehole pump with housing, expandable packers, pressure sensors and a pipe string and/or hose. During flow logging, sensors measuring temperature and electric conductivity as well as downhole flow rate are also used. At the top of the borehole the total flow/injection rate is manually adjusted by a control valve and monitored by an electromagnetic flow meter. A data logger samples data at a frequency determined by the operator.

The packers are normally expanded by water (nitrogen gas is used to pressurize the water) unless the depth to the groundwater level is large. In such cases, the packers are expanded by nitrogen gas. A folding pool is used to collect and store the discharged water from the borehole for subsequent use in injection tests.

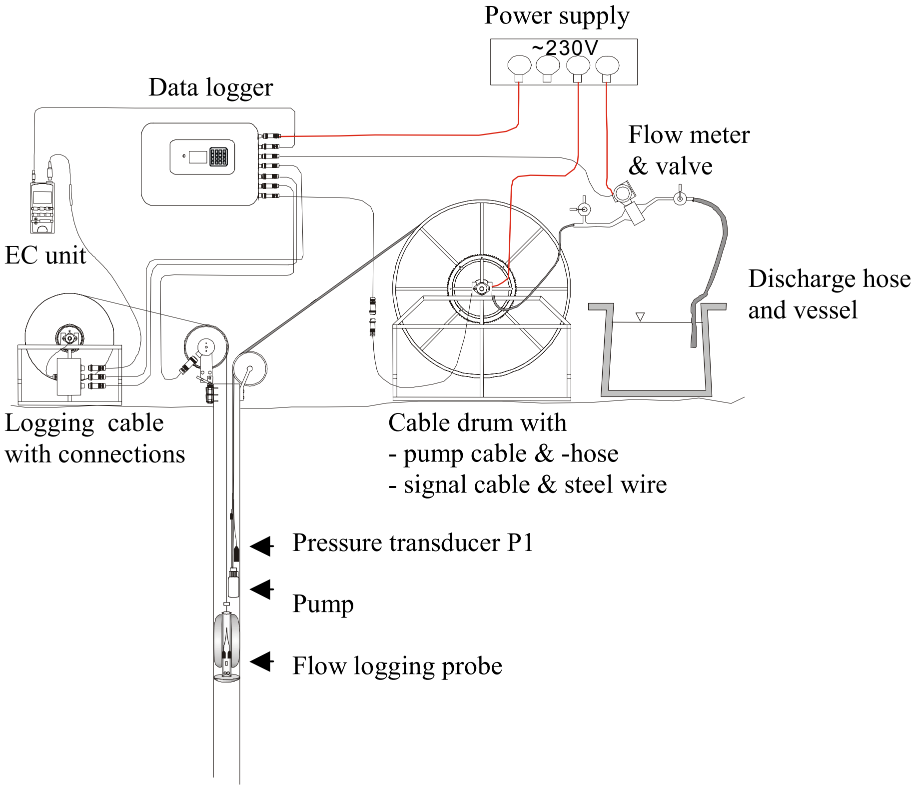


Figure 4-1. *Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB.*

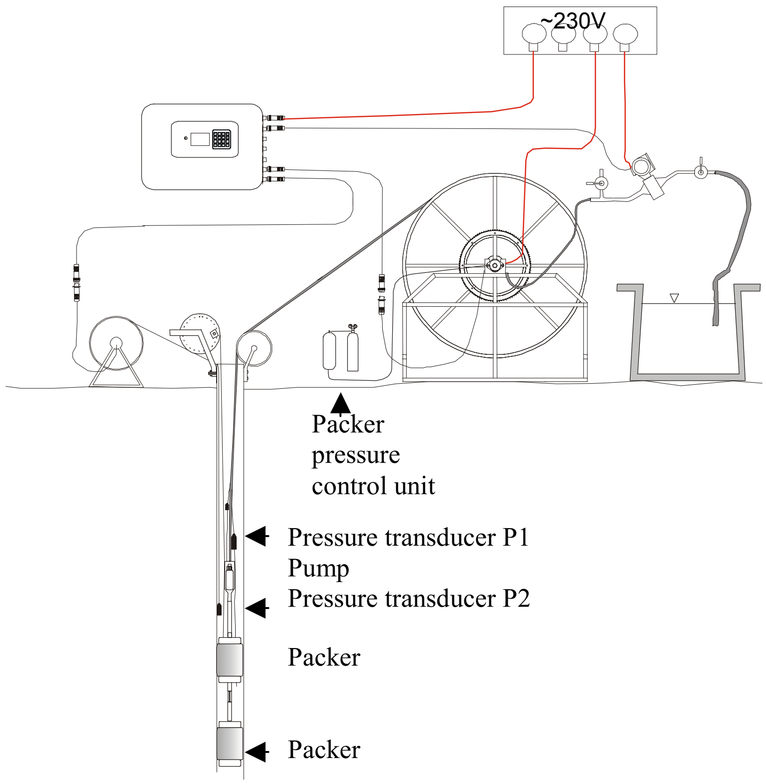


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB.*

4.2 Sensors

Technical data of sensors together with estimated data specifications of the HTHB test system for pumping tests and flow logging are given in Table 4-1.

Table 4-1. Technical data of sensors together with estimated data specifications of the HTHB test system for pumping tests and flow logging (based on current laboratory experiences).

Technical specification Parameter		Unit	Sensor	HTHB system	Comments
Absolute pressure	Output signal	mA	4 – 20		
	Meas. range	kPa	0 – 1500	0 – 1500	
	Resolution	kPa	0.05		
	Accuracy	kPa	±1.5 *	±10	Depending on uncertainties of the sensor position
Temperature	Output signal	mA	4 – 20		
	Meas. range	°C	0 – 50	0 – 50	
	Resolution	°C	0.1		
	Accuracy	°C	± 0.6	±0.6	
Electric Conductivity	Output signal	V	0 – 2		
	Meas. range	mS/m	0 – 50000	0 – 50000	With conductivity meter
	Resolution	% o.r.**		1	
	Accuracy	% o.r.**		± 10	
Flow (Spinner)	Output signal	Pulses/s	c 0.1 – c 15		
	Meas. range	L/min		2 – 100	115 mm borehole diameter
				3 – 100	140 mm borehole diameter
				4 – 100	165 mm borehole diameter
	Resolution***	L/min		0.2	140 mm borehole diameter
	Accuracy***	% o.r.**		± 20	and 100 s sampling time
Flow (surface)	Output signal	mA	4 – 20		Passive
	Meas. range	L/min	1 – 150	5 – c 80****	Pumping tests
	Resolution	L/min	0.1	0.1	
	Accuracy	% o.r.**	± 0.5	± 0.5	

* Includes hysteresis, linearity and repeatibility
** Maximum error in % of actual reading (% o.r.).
*** Applicable to boreholes with a borehole diameter of 140 mm and 100 s sampling time
**** For injection tests the minimal flow rate is 1 L/min

Errors in reported borehole data (diameter etc) may significantly increase the error in measured and calculated data. For example, the probe for flow logging is very sensitive to variations in the borehole diameter, cf Figure 4-3. Borehole deviation and uncertainties in inclination may also affect the accuracy of data.

In general the flow-logging probe is calibrated for different borehole diameters (e.g. different pipe diameters), i.e. 111.3, 135.5, 140 and 160 mm. During calibration the probe is installed in a vertically orientated pipe and a water flow is pumped through. Spinner rotations and the total discharge are measured. Calibration gives excellent correlation ($R^2 > 0.99$) between total discharge and the number of spinner rotations. The calibration also clearly shows how sensible the probe is to deviations in the borehole diameter, cf Figure 4-3).

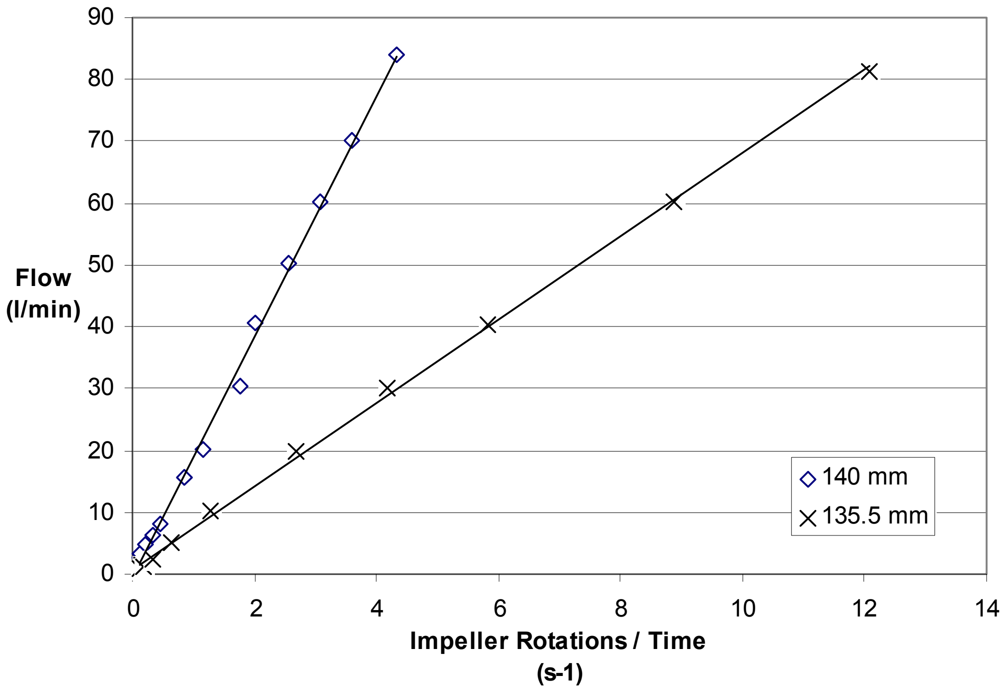


Figure 4-3. *Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).*

Tests prior to those in HSH03 showed that the recorded flow at each position during flow logging was found to be rather insensitive to the measurement time (50, 100, 200 s), provided that sufficient stabilisation time is allowed to a change in flow. The stabilisation time may be up to 30 s at flows close to the lower measurement limit whereas this time is almost instantaneous at high flows.

Table 4-2 shows the position of sensors for each test. The following type of sensors is used: pressure (p), temperature (Te), electric conductivity (EC) together with the (lower) level of the submersible pump (Pump). Positions are given in meter from the reference point, i.e. top of casing (ToC), lower part. The sensors measuring temperature and electric conductivity are placed in the impeller flow-logging probe and the position is thus varying (top-bottom-top of section) during a test. For specific information about the position at a certain time, the actual data files have to be consulted.

Equipment affecting the wellbore storage coefficient is given in terms of diameter of the submerged item. Position is given as "in section" or "above section". The volume of the submerged pump (~4 dm^3) is in most cases of minor importance.

Table 4-2. Position(from ToC) of sensors and equipment affecting wellbore storage for the different hydraulic tests performed in HSH03.

Borehole information			Sensors		Equipment affecting wellbore storage (WBS)		
ID	**Test section (m)**	**Test no**	**Type**	**Position (m from ToC)**	**Position ***	**Function**	**Outer diameter (mm)**
HSH03	12.03–201	1	Pump (lower) P (P1) Flow logging Equipment	25 21.72 variable (29–198.7)	In Section	Pump string (hose) Signal cable Signal cable	37 8 13.5
HSH03	12.03–103	1	Pump (lower) P (P1) P (P2)	50 46.72 97.5	In Section	Pump string (hose) Signal cable Signal cable	37 8 8
HSH03	80.5–201	1	Pump P (P2)	0 (surface) 74	In Test section	–	–
HSH03	12.03–201	2	Pump (lower) P (P1)	80 76.72	In Section	Pump string (hose) Signal cable	37 8

* Position of equipment that can affect wellbore storage. Position given as “In Section” or “Above Test section”.

5 Execution

5.1 Preparations

All sensors included in the HTHB system are calibrated at GEOSIGMAs engineering workshop in Librobäck, Uppsala. Calibration is performed on a yearly basis, or more often if needed. The last calibration before the tests in HSH03 was done in June, 2002. Calibration protocol was submitted in the delivery of raw data after the test campaign. Calibration of the flow logging probe was done according to 4.2.

Function checks of the equipment were performed before each hydraulic test (cf Section 3.3). No errors were detected during these checks.

5.2 Execution of tests/measurements

5.2.1 Test principle

Pumping tests

The pumping test in conjunction with the flow logging was carried out as single-hole, constant flow rate tests followed by a pressure recovery period. The intention was to obtain approximately steady-state conditions during the flow logging. The pumping test in the interval 12.03–103 m, above a single packer, was also carried out as a constant flow rate test.

Injection test

The injection test was performed as a constant-head injection test with stepwise increased injection pressure in the interval 80.5–201 m, below a single packer.

Step drawdown test

Finally, a step drawdown test was carried out in the open borehole (12.03–201 m) with four steps. This test was carried out after hydraulic fracturing of the borehole.

Flow logging

The flow logging was performed during pumping with flow measurements at fixed length intervals, starting from the bottom and upward along the borehole. The duration to complete the flow logging survey depends on the length and character of the borehole. In general, the duration is between 3–7 hours in a percussion borehole.

5.2.2 Test procedure

The timetable of the hydraulic tests in borehole HSH03 is shown in Table 3-3. Before the tests, function checks and cleaning of equipment together with time synchronisation of clocks and data loggers were performed according to the Activity Plan. All hydraulic tests including the flow logging were carried out after drilling to full depth of the boreholes using the HTHB-system.

Pumping tests

A short flow capacity test was carried out to choose an appropriate flow rate for the test. The extracted water was discharged on the ground (hard rock), sloping downhill to the sea from the pumping borehole.

The main hydraulic test in HSH03 was the c 10-h pumping test in the open borehole (12.03–201 m) in combination with flow logging. The flow rate was slightly adjusted after c 6 h to maintain a constant flow rate. The flow period was followed by a recovery period of c 15-h. The duration of the flow period during the pumping test in the interval 12.03–103 m, above a single-packer, was c 4 h and that of the recovery period c 11 h, cf Table 3-3. In general, the sampling frequency of pressure during the pumping tests was according to Table 5-1.

Table 5-1. General sampling frequency for pressure registration during the pumping tests.

Time interval (s) from start/stop of pumping	Sampling frequency (s)
1–300	1
301–600	10
601–3600	60
>3600	600

Injection test

The pumping test below the packer was substituted by an injection test in the interval 80.5–201 m due to the assumed low conductivity of this interval, as indicated from the flow logging. The latter test constitutes an option in the Activity Plan in low-conductive borehole intervals.

Step drawdown test

The step drawdown test was carried out with four steps with constant flow rate (except the last one) and duration, ranging from c 30–195 min. The duration of the first step was increased due to wellbore storage effects in the borehole. During the last step, the flow rate decreased due to the increased drawdown and the flow rate approached the flow rate of the previous step by the end of the step.

The test program was mainly according to the Activity Plan with a few exceptions (decided by the activity leader):

– the flow period of the pumping test in the interval 12.03–103 m was prolonged to c 4 h (instead of 2 h),
– the recommended test time (1h+1h for drawdown/recovery) for the injection test in borehole section 80.5–201 m was shortened to c 20 min+80 min due to practical reasons since the section was low-conductive. The main purpose of this test was to obtain a rough estimation of the hydraulic properties of the section and furthermore, to confirm the results of the flow logging,
– the duration and flow rate during the different steps of the step drawdown test were slightly modified.

Compared to the Methodology description for single-hole pumping tests (SKB MD 321.003, Metodbeskrivning för hydrauliska enhålspumptester), some deviations were made regarding the recommended test times:

– the recommended test time (24h+24h for drawdown/recovery) for the pumping test during flow logging was shortened to c 10h+15h due to practical reasons (mainly to avoid uncontrolled pumping over-night and to eliminate the risk of freezing, theft/sabotage etc). Experience from similar tests also indicates that c 10 h of pumping and 12 h of recovery in most cases is sufficient to estimate the hydraulic properties of the borehole regarding, e.g. wellbore storage effects and other disturbing factors.

Flow logging

Before start of the flow logging, the probe was lowered to the bottom of the borehole. While lowering (max 0.5 m/s), data of temperature and electric conductivity are sampled along the borehole. The probe was halted (15 s) at every two meters to sample data with a sampling interval of 5 s.

The flow logging in HSH03 was performed during the longer pumping test (10 h flow period) and started c 3 h after start of pumping when the drawdown was relatively constant. Starting from the bottom of the hole, the probe was lifted in steps of 10 m and halted for measurements until the first flow anomaly was detected. After that, the probe was lifted in 2 m intervals for measurements at a time period of 100 s. When a flow anomaly was found, the probe was then lowered in 0.5 m steps until the previous flow was retrieved for detailed identification of the anomaly. The flow logging then continued in 2 m intervals along the hole. The duration of the flow logging in borehole HSH03 was c 6 h. The detailed performance of the flow logging is described in Section 6-4. After the flow logging was finished the logger scan time was altered to 60 s.

5.3 Data handling

Data are downloaded from the logger (Campell CR 5000) to a laptop with the program PC9000 and are, already in the logger, transformed to engineering units. All files are comma-separated (*.DAT) when copied to a computer. Data used for transient evaluation are further converted to *.mio-files by the code Camp2mio. The operator can choose the parameters to be included in the conversion (normally pressure and discharge). Data from the flow logging are evaluated in Excel and therefore not necessarily transformed to *.mio-files. A list of the data files from the data logger is shown in Appendix 1. The data files were submitted in the delivery of raw data.

Processed data files (*.mio-files) from the hydraulic tests with pressure versus time data were converted to drawdown- and recovery files by the code PUMPKONV and plotted in different diagrams listed in the Instruction for injection- and single-hole pumping tests /64 by the code SKB-plot. The diagrams are presented in Appendix 2.

By the conversion to drawdown- and recovery files, different values were applied on the filter coefficient (step length) by the calculation of the pressure derivative to investigate the effect of this coefficient on the derivative. It is desired to achieve maximal smoothing of the derivative without altering the original shape of the data.

5.4 Analyses and interpretation

5.4.1 Hydraulic tests

As discussed in Section 5.2.1 the pumping tests were performed as constant flow rate tests although some minor adjustments of the flow rate were made. Towards the end of the pumping tests, pseudo-radial flow occurred. Consequently, methods for single-hole, constant-flow rate tests in an equivalent fractured, porous medium were used by the analyses and interpretation of the tests. The injection test was performed as a constant head test.

Firstly, a qualitative evaluation of the actual flow regimes (pseudo-linear, pseudo-radial and pseudo-spherical flow) and eventual outer boundary conditions during the tests was performed. The qualitative analyses were made from log-log diagrams of drawdown and/or recovery data together with its corresponding derivatives versus time. In particular, pseudo-radial flow is reflected by a constant (horizontal) derivative in the diagrams.

From the results of the qualitative analyses, appropriate interpretation models for the tests were selected. The quantitative, transient interpretation of the hydraulic parameters (e.g. transmissivity and skin factor) was primarily based on the identified pseudo-radial flow regime during the tests in logarithmic and semi-logarithmic data diagrams. For tests indicating a fractured- or borehole storage dominated response, respectively corresponding type curves were used by the analyses.

If possible, transient analysis was made both on the drawdown- and recovery phase of the tests. The recovery data were plotted versus equivalent time. The analysis of the drawdown- and recovery data was generally made both according to Theis-Walton's and Cooper-Jacob's methods, cf standard textbooks. In addition, a preliminary steady-state analysis (e.g. Moye's formula) was made for all tests for comparison. The step drawdown test was analysed according to Jacob´s method, discussed in /3/.

The transient analysis of tests dominated by wellbore storage was made according to the single-hole methods described in /2/. The estimation of the borehole storage coefficient, in appropriate pumping tests, was based on the early borehole response with 1:1 slope.

5.4.2 Flow logging

The measured parameters during the flow logging (flow, temperature and electric conductivity of the borehole fluid) are firstly plotted versus borehole length. From these plots, flow anomalies are identified along the borehole, i.e. borehole intervals over which the flow changes more than c 1 L/min (in this case) occur. The magnitude of the inflow at the flow anomaly is determined by the actual change in flow rate over the interval. In some cases, the flow changes are accompanied by corresponding changes in temperature and/or electric conductivity.

Flow logging can only be carried out in the borehole interval from the bottom of the hole to just below the submersible pump. The remaining part of the borehole (i.e. from the pump to the groundwater level) can not be flow-logged although high inflow zones may sometimes be located in this part. Such superficial inflows may be identified by comparing the cumulative flow at the top of the flow-logged interval (ΣQ_i) with the discharged flow rate (Q_p) from the hole at the surface during the flow logging. If the latter flow rate is significantly higher than the cumulative flow rate, one or several inflow zones are likely to exist above the flow-logged interval.

The transmissivity (T) of the entire borehole was calculated from the analysis of the pumping test during the flow logging. The cumulative transmissivity at the top of the flow-logged interval (ΣT_i) was then calculated according to the Methodology description for Impeller flow logging (SKB MD 322.009, Metodbeskrivning för flödesloggning) (assuming zero natural flow in the borehole):

$$\Sigma T_i = T \cdot \Sigma Q_i / Q_p \qquad (5\text{-}1)$$

If $\Sigma Q_i < Q_p$, one or several flow anomalies may be located above the flow-logged interval. In such cases, the (order of magnitude) of the transmissivity of these anomalies may be estimated from Equation (5-1).

The transmissivity of an individual flow anomaly (T_i) was calculated from the measured inflow (Q_i) at the anomaly and the calculated transmissivity of the entire borehole (T) according to (SKB MD 322.009, Metodbeskrivning för flödesloggning):

$$T_i = T \cdot Q_i / Q_p \qquad (5\text{-}2)$$

For comparison, estimations of the transmissivities of the identified flow anomalies were also made from the specific flows, simply by dividing the measured inflow (Q_i) at the anomaly by the drawdown (s_{FL}) in the hole during the flow logging (assuming negligible head losses). The sum of the specific flows may then be compared with the total transmissivity (and specific flow) of the borehole.

The cumulative transmissivity $\Sigma T_i(L)$ along the borehole length (L) as determined from the flow logging may be calculated according to (SKB MD 322.009, Metodbeskrivning för flödesloggning):

$$\Sigma T_i (L) = T \cdot \Sigma Q_i (L) \qquad (5\text{-}3)$$

where ΣQ_i (L) =cumulative flow at borehole length L

The lower limit of transmissivity ($T_{l\text{–}measl}$) in flow logging may be estimated similar to Equation (5-1):

$$T_{Fmeasl\text{-}L} = T \cdot Q_{Fmeasl\text{-}L} / Q_p \qquad (5\text{-}4)$$

In a 140 mm borehole, $Q_{Fmeasl\text{-}L}$=3 L/min, see Table 4-1, whereas Q_p is the actual flow rate during flow logging.

The measured EC of the borehole fluid was temperature-compensated by multiplication of a correction factor, k, according to data presented in /1/:

$$EC_{corr} = k \cdot EC_{meas}$$

$$k=0.0005 \cdot Te^2 - 0.041 \cdot Te + 1.73 \qquad (5\text{-}5)$$

where Te=temperature (^{o}C)

6 Results

Data has been delivered to the SKB's database SICADA, Field note Simpevarp 18.

6.1 Nomenclature and symbols

The nomenclature and symbols used for the results of the hydraulic tests and flow logging are according to the Instruction for analysis of single-hole injection- and pumping tests (SKB MD 320.004, Instruktion för analys av injektions- och enhålspumptester) and Methodology description for flow logging (SKB MD 322.009, Metodbeskrivning för flödesloggning), respectively. Additional symbols used are explained in the text.

6.2 Water sampling

The water samples taken during the pumping tests in borehole HSH03 and submitted for analysis are listed in Table 6-1.

Table 6-1. Data of water samples taken during the pumping tests in borehole HSH03 and submitted for analysis.

Date of sampling	Time (UTC+1h)	Section (m)	Pumped volume (m^3)	Sample type	Sample ID no	Remarks
20020821	16:30	12.03–201	11,1	WC080	3759	Open-hole test
20020822	18:00	12.03–103	15,4	WC080	3760	Above single packer
20020905	15:55	12.03–201	12	WC080	3761	Step drawdown test

6.3 Hydraulic tests

Below, the results of the pumping tests are presented test by test. No corrections of measured data, e.g. for changes of the barometric pressure or tidal fluctuations, have been made by the analysis of the data. In particular, for single-hole tests, such corrections are generally not needed unless very small drawdowns are applied in the boreholes.

Furthermore, no subtractions of the barometric pressure from the measured absolute pressure were made since the pressure differences, e.g. drawdown, are used by the evaluation of the tests.

The storativity was calculated from the interference of the groundwater level in HSH01 during the open-hole pumping test in HSH03. This storativity value was then used in the calculation of the skin factor from the single-hole tests.

6.3.1 Open-hole pumping test (12.03–201 m)

General test data for the open-hole pumping test in the interval 12.03–201 m of borehole HSH03 in conjunction with the flow logging, are presented in Table 6-2. During this test interferences of the groundwater level in borehole HSH01 were measured and analysed, see Section 6.3.2.

Table 6-2. General test data for the open-hole pumping test in the interval 12.03–201 m of borehole HSH03.

General test data			
Borehole	HSH03 (12.03–201 m)		
Testtype[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	T. Svensson, J. Levén (GEOSIGMA AB)		
Test equipment system	HTHB		
General comment	Interferences measured in borehole HSH01		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	201
Casing length	L_c	m	12.03
Test section – secup	Secup	m	12.03
Test section – seclow	Seclow	m	201
Test section length	L_w	m	188.97
Test section diameter	$2{\cdot}r_w$	mm	139
Test start (start of pressure registration)		yymmdd hh:mm	020820 18:00
Packer expanded		yymmdd hh:mm:ss	–
Start of flow period		yymmdd hh:mm:ss	020821 06:30:00
Stop of flow period		yymmdd hh:mm:ss	020821 16:46:02
Test stop (stop of pressure registration)		yymmdd hh:mm	020822 08:15
Total flow time	t_p	min	616
Total recovery time	t_F	min	929

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and water level data

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in borehole before start of flow period	p_i	kPa	285	0.10
Absolute pressure in test section before stop of flow	p_p	kPa	153.479	–13.29
Absolute pressure in test section at stop of recovery period	p_F	kPa	280.069	–0.40
Maximal pressure change during flow period	dp_p	kPa	131.521	

Manual water level measurements (along borehole)				
Date YYYY-MM-DD	Time tt:mm.ss	Time from start of pumping (min)	GW level (m b ToC)	GW level (m a s l)
2002-08-19	14:47:00		2.36	0.20
2002-08-19	19:36:00		2.36	0.20
2002-08-20	09:09:30		2.355	0.20
2002-08-20	13:30:00		2.765	–0.20
2002-08-20	14:57:30		2.83	–0.26
2002-08-20	16:26:30		2.565	0
2002-08-21	05:45:00	–45	2.46	0.10
2002-08-21	08:43:30	133.5	13.70	–10.95
2002-08-21	16:43:00	613	16.12	–13.33
2002-08-22	08:16:00		2.975	–0.40
2002-08-22	13:05:00		2.82	–0.25
2002-08-22	14:36:30		2.375	0.18

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$2.85 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	–
Total volume discharged during flow period	V_p	m^3	c 10

Manual measurements (M) or readings on display (R)			
Date YYYY-MM-DD	Time tt:mm.ss	Time after start of pumping (min)	Flow rate (L/min)
2002-08-21	06:31:00	1	17.8 R
2002-08-21	06:49:00	19	17.7 R
2002-08-21	06:51:00	21	17.6 R
2002-08-21	06:55:00	25	17.5 R
2002-08-21	09:10:00	160	17.4 R
2002-08-21	09:23:00	173	17.3 R
2002-08-21	09:48:00	198	17.2 R
2002-08-21	10:30:00	240	17.1 R
2002-08-21	12:49:00	379	17.4 R
2002-08-21	12:53:00	383	17.3 R
2002-08-21	13:26:00	416	17.2 R
2002-08-21	15:02:00	512	17.2 R

Comments to the test

During the flow period the flow rate was slightly increased at time c 12.45 from c 17.1 L/min to c 17.3 L/min due to the decreasing flow rate, see Figure A2-1 in Appendix 2. In the same figure the disturbing effects of the flow logging on the pressure registration can also be seen as a faint noise, which is mainly due to the volume change of the cable by the movement of the flow probe along the hole.

Interpreted flow regimes

Selected test diagrams according to (SKB MD 320.004, Instruktion för analys av injektions- och enhålspumptester) are presented in Figures A2-1–5 in Appendix 2. Clear effects of wellbore storage (WBS) dominated the early response during the flow period as well as the recovery period. After c 150 min of pumping, a rather well defined pseudo-radial flow regime occurred, lasting to c 500 min.

The response during the recovery phase confirms the WBS-dominated early flow regime. The recovery response was slightly different from the response during the flow period and showed weak indications of a double porosity or double-permeability system. The first part of the response was masked by wellbore storage effects. An assumed pseudo-radial flow regime occurred between c 200–400 min of equivalent time according to the pressure recovery derivative. This regime is assumed to represent the total system of fractures activated by the test.

The transition of the water level between the uncased borehole and the casing can be seen as a slight disturbance in the pressure derivative plots of the flow- as well as the recovery phase (at c 5 min in the latter phase). The transition corresponds to a change in the diameter of the borehole (139 mm) and the inner diameter of the casing (160 mm), respectively, cf Table 3-1. Thus, the wellbore storage coefficient C changes accordingly when the water level in the borehole passes the lower part of the casing. Only the wellbore storage coefficient that represents the situation when the water level is located below the casing has been calculated.

Calculated parameters

The transient, quantitative interpretation of the flow- and recovery period of the tests (whenever possible) is indicated in appropriate diagrams in Figures A2-2–3 and A2-4–5, respectively in Appendix 2. The results are shown in the Test Summary sheets in Section 6.5.

Quantitative analysis was made for both the flow- and recovery phases in lin-log- and log-log diagrams according to the methods described in Section 5.4.1.

Selected representative parameters

The selected representative parameters from the test in the interval 12.03–201 m in HSH03 are presented in the Test Summary Sheets in Section 6.5. The selected parameters are derived from the flow period since this period showed a more well-defined pseudo-radial flow regime than the recovery period. However, the calculated parameters from the flow- and recovery period were similar.

6.3.2 Open-hole pumping test (12.03–201 m), observation borehole HSH01

Data on the groundwater level in observation borehole HSH01 during the open-hole pumping test in borehole HSH03 are presented in Table 6-3. The groundwater level, expressed in m a s l, was calculated from manual observations of the groundwater level in HSH01 taking the inclination of the borehole into account. Geometrical data of borehole HSH01 are presented in Table 3-2.

The distance between HSH01 and HSH03 was calculated as the distance between the position of the dominating flow anomaly in HSH03 (c 59 m, cf Section 6.4) and the midpoint of the uncased part of borehole HSH01 (94 m). This distance is c 60 m.

Table 6-3. Test data from the observation borehole HSH01 during the open-hole pumping test in the interval 12.03–201 m of borehole HSH03.

Water level data in observation borehole HSH01	Nomen-clature	Unit	Value
Groundwater level in borehole before start of flow period	h_i	m a s l	–0.029
Groundwater level in test section before stop of flow period	h_p	m a s l	–5.292
Groundwater level in test section at stop of recovery period	h_F	m a s l	–4.004
Maximal drawdown during flow period	s_p	m	5.263

Interpreted flow regimes

Selected test diagrams according to (SKB MD 320.004, Instruktion för analys av injektions- och enhålspumptester) are presented in Figures A2-6–10 in Appendix 2. Only the flow period was interpreted in this case since the recovery period was short. During the flow period, a well-defined pseudo-radial flow period developed between c 60 min to c 250 min according to the drawdown derivative in Fig. A2-7. By the end of the flow period a slight leakage flow occurred.

The response during the short recovery period was similar to the early response during the flow period, cf Figures A2-9–10.

Calculated parameters

Quantitative analysis was only made from the flow period in Figures A2-7–8 according to the methods described in section 5.4.1.

Selected representative parameters

The selected representative parameters for the observation borehole HSH01 during the test in the interval 12.03–103 m in HSH03 are presented in the Test Summary Sheets in Section 6.5. The selected parameters are derived from the flow period since this period showed a well-defined pseudo-radial flow regime.

6.3.3 Pumping test in section 12.03 – 103 m

General test data for the short pumping test in the interval 12.03–103 above a single packer in borehole HSH03 are presented in Table 6-4. No manual flow measurements of the flow rate from HSH03 were made. During this test, interferences of the groundwater level in borehole HSH01 were measured and analysed preliminary. The calculated hydraulic parameters were similar to those calculated from the previous test and are not reported here.

Table 6-4. General test data for the short pumping test in the interval 12.03–103 m in borehole HSH03.

General test data			
Borehole	HSH03		
Testtype[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	Section above a single-packer located at 103–104 m		
Test No	1		
Field crew	T. Svensson, J. Levén (GEOSIGMA AB)		
Test equipment system	HTHB		
General comment	Interferences measured in borehole HSH01		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	201.0 (Total length)
Casing length	L_c	m	12.03
Test section – secup	Secup	m	12.03
Test section – seclow	Seclow	m	103
Test section length	L_w	m	90.97
Test section diameter	$2 \cdot r_w$	mm	139
Test start (start of pressure registration)		yymmdd hh:mm	020822 15:00
Packer expanded		yymmdd hh:mm:ss	020822 13:36:00
Start of flow period		yymmdd hh:mm:ss	020822 15:00:00
Stop of flow period		yymmdd hh:mm:ss	020822 18:46:00
Test stop (stop of pressure registration)		yymmdd hh:mm	020823 06:05
Total flow time	t_p	min	226
Total recovery time	t_F	min	679

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and water level data

Pressure data	Nomen-clature	Unit	Value	GW level (m a s l)
Absolute pressure in test section before start of flow period	p_i	kPa	522.07	0.18
Absolute pressure in section below packer before start of flow period	p_{bi}	kPa	1007.78	
Absolute pressure in test section at stop of flow period	p_p	kPa	363.049	–16.01
Absolute pressure in section below the packer at stop of flow period	p_{bp}	kPa	1006.02	
Absolute pressure in test section at stop of recovery	p_F	kPa	518.555	–0.18
Absolute pressure in section below the packer at stop of recovery	p_{bF}	kPa	998.661	
Maximal pressure change in test section during the flow period	dp_p	kPa	159.021	
Maximal pressure change in section below packer during flow period	dp_{bp}	kPa	1.76	

Manual water level measurements (along borehole)				
Date YYYY-MM-DD	**Time tt:mm.ss**	**Time (min) from start of pumping**	**GW level (m b ToC)**	**GW level (m a s l)**
2002-08-22	08:16:00		2.975	–0.40
2002-08-22	13:05:00		2.82	–0.25
2002-08-22	14:36:30	–24	2.375	0.18
2002-08-22	18:44:00	224	19.225	–16.38
2002-08-23	06:15:00		3.145	–0.57

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$3.70 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	–
Total volume discharged during flow period	V_p	m^3	c 5

Comments to the test

The test was carried out as an open hole-pumping test with constant flow rate above a single packer at 103–104 m. The pressure was measured in the test section and below the packer. The pressure below the packer decreased only c 1.8 kPa, which indicates a good sealing of the packer and bad hydraulic connection between the upper and lower section in the borehole during the pumping test.

Interpreted flow regimes

Selected test diagrams according to (SKB MD 320.004, Instruktion för analys av injektions- och enhålspumptester) are presented in Figures A2-11–15 in Appendix 2. The initial flow regime of both the flow-and recovery phase of the test was dominated by wellbore storage, very similar to the previous test when the entire borehole was pumped. During the flow period, a well-defined pseudo-radial flow period developed between c 80 min to the end of this phase (226 min), cf Figure A2-12.

The recovery response was similar to the corresponding recovery response during the previous test. However, no well-defined pseudo-radial flow regime developed during the recovery period, cf Figure A2-14.

Calculated parameters

Quantitative analysis was only made from the flow period in Figures A2-12–13 according to the methods described in section 5.4.1.

Selected representative parameters

The selected representative parameters from the test in the interval 12.03–103 m in HSH03 are presented in the Test Summary Sheets in Section 6.5. The selected parameters are derived from the flow period since this period showed a well-defined pseudo-radial flow regime.

6.3.4 Injection test in section 80.5–201 m

General test data for the short injection test in the interval 80.5–201 m in borehole HSH03 below a single packer are presented in Table 6-5. No registrations of the pressure above the packer were made during the test.

Table 6-5. General test data for the short injection test in section 80.5–201 m in borehole HSH03.

General test data			
Borehole	HSH03		
Testtype[1]	Constant Head injection and recovery test		
Test section (open borehole/packed-off section):	section below a single-packer located at 79.5–80.5 m		
Test No	1		
Field crew	T. Svensson, J. Levén (GEOSIGMA AB)		
Test equipment system	HTHB		
General comment	Single hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	201.0 (Total length)
Casing length	L_c	m	12.03
Test section – secup	Secup	m	80.5
Test section – seclow	Seclow	m	201.0
Test section length	L_w	m	120.5
Test section diameter	$2 \cdot r_w$	mm	139
Test start (start of pressure registration)		yymmdd hh:mm	020823 12:42
Packer expanded		yymmdd hh:mm:ss	020823 10:19:00
Start of flow period		yymmdd hh:mm:ss	020823 12:53:20
Stop of flow period		yymmdd hh:mm:ss	020823 13:14:00
Test stop (stop of pressure registration)		yymmdd hh:mm	020823 14:41
Total flow time	t_p	min	20.7
Total recovery time	t_F	min	84

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and water level data

Pressure data	Nomen-clature	Unit	Value
Absolute pressure in test section before start of flow period	p_i	kPa	785.609
Absolute pressure in test section at stop of flow period	p_p	kPa	1185.64
Absolute pressure in test section at stop of recovery period	p_F	kPa	801.844
Maximal pressure change during the flow period	dp_p	kPa	400.031

Manual water level measurements (along the borehole)				
Date YYYY-MM-DD	**Time tt:mm.ss**	**Time (min) from start of pumping**	**GW level (m b ToC)**	**GW level (m a s l)**
2002-08-23	12:39:00	–14	2.84	–0.27

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate to test section just before stop of flowing	Q_p	m^3/s	$<1.7 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$<1.7 \cdot 10^{-5}$
Total volume injected during flow period	V_p	m^3	<0.01

Comments to the test

The test was carried out as a short injection test with constant head since the section was assumed to be rather low conductive as indicated from the results of the flow logging. No measurable injection flow (less than 1 L/min) was registered, neither at 50 kPa, c 100 kPa nor 400 kPa injection pressure, respectively. The test was therefore stopped. It was concluded that the rock was below the measurement limit of the test system used.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-16–17 in Appendix 2. No transient qualitative or quantitative analysis could be made for this test. Only rough estimations of the lower measurement limit for transmissivity were made by steady-state methods, see Test Summary Sheet in Section 6.5.

6.3.5 Step drawdown test in open hole (12.03–201 m)

General test data for the step drawdown pumping test after hydraulic fracturing of borehole HSH03 are presented in Table 6-6.

Table 6-6. General test data for the step drawdown pumping test in HSH03.

General test data			
Bore hole	HSH03		
Testtype[1]	Step drawdown flow and recovery test		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	T. Svensson, J. Levén (GEOSIGMA AB)		
Test equipment system	HTHB		
General comment	Single hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	201.0 (total length)
Casing length	L_c	m	12.03
Test section – secup	Secup	m	12.03
Test section – seclow	Seclow	m	201.0
Test section length	L_w	m	188.97
Test section diameter	$2 \cdot r_w$	mm	139
Test start (start of pressure registration)		yymmdd hh:mm	020905 09:24
Packer expanded		yymmdd hh:mm:ss	–
Start of flow period		yymmdd hh:mm:ss	020905 09:30:01
Stop of flow period		yymmdd hh:mm:ss	020905 16:00:01
Test stop (stop of pressure registration)		yymmdd hh:mm	020906 06:30
Total flow time	t_p	min	390
Total recovery time	t_F	min	873

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure data

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in borehole before start of flow period	p_i	kPa	804.903	0.03
Absolute pressure in test section at stop of flow period	p_p	kPa	257.411	–55.72
Absolute pressure in test section at stop of recovery period	p_F	kPa	798.158	–0.66
Maximal pressure change during the flow period	dp_p	kPa	547.492	

Manual water level measurements (along borehole)

Date YYYY-MM-DD	**Time tt:mm.ss**	**Time (min)**	**GW level (m b ToC)**	**GW level (m a s l)**
2002-09-05	08:23:00		2.955	–0.39
2002-09-05	09:06:00	–24	2.535	0.03
2002-09-05	09:57:00	27	15.895	–13.11
2002-09-05	12:44:00	194	22.065	–19.17
2002-09-06	06:28:00		3.495	–0.92

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$7.60 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$5.77 \cdot 10^{-4}$
Total volume discharged during flow period	V_p	m^3	13.5

Flow and drawdown data during each step

Step #	Q (L/min)	Duration (min)	dp_p (m)	Q/dp_p (m^2/s)	Q_{30} (L/min)	dp_{30} (m)	dp_{30}/Q_{30} (s/m^2)
1	25	195	c 20	$2.1 \cdot 10^{-5}$	25	c 13.2	31680
2	35	30	c 28	$2.1 \cdot 10^{-5}$	35	c 28	48000
3	45	75	c 46	$1.6 \cdot 10^{-5}$	45	c 40	53333
4	57→45.6 (max)	90	55.75	$1.4 \cdot 10^{-5}$	c 50	c 55	66000

Comments to the test

The intention was to perform the test as a step drawdown test with four steps with constant flow rate. Since the last step was carried out at full capacity of the pump, the flow rate decreased significantly during this step to roughly that of step 3 (c 45 L/min), see table above. The duration of the steps was different in each step.

A submersible pump failure happened by the end of the first step of the test due to a thunderstorm at the site. The pump was restarted after c 3 min. A break in the signal from the pressure transducer caused loss of pressure data during c 20 min during the third step.

Interpreted flow regimes

Linear test diagrams of flow and pressure during the step drawdown test are presented in Figures A2-18–19 in Appendix 2. Log-log and lin-log plots of the first step of the flow period (Figures A2-20–21) and from the recovery period (Figures A2-22–23), respectively are presented.

Analysis of transient flow regimes was done on the first step and on the recovery phase of the step drawdown test. The initial phase of both the first drawdown step and of the recovery phase showed clear effects of wellbore storage. Well-defined pseudo-radial flow regimes developed between c 70–120 min during the first drawdown step and between c 70–300 min of equivalent time during the recovery phase, respectively (the latter time corresponds to the end of recovery).

Calculated parameters

According to the flow and drawdown data in the table above, the hydraulic fracturing of the borehole did not seem to significantly improve the specific capacity. The specific capacity ($Q/dp_p=2.1 \cdot 10^{-5}$ m^2/s) calculated from the first step was similar to the one calculated from the first pumping test in the borehole during flow logging ($Q/s= 2.2 \cdot 10^{-5}$ m^2/s). During the later steps the specific capacity decreased.

Transient, quantitative interpretation of hydraulic parameters was made in the lin-log- and log-log diagrams on the first drawdown step and on the recovery period, respectively in accordance with the flow regimes identified. The interpretation of the hydraulic parameters is shown in Figures A2-20–23 in Appendix 2.

Calculated borehole parameters

A special analysis of borehole parameters was also made from the step drawdown test according to the method described in Chapter 5.4.1. Since the duration of the different steps was different and the flow rate was decreasing during the last step, an approximate analysis was made from the actual flow rates (Q_{30}) and drawdown (dp_{30}), truncated at t=30 min at each step, see Table 6-7. The results are presented in Table 6-8. The calculated well loss coefficient is rather high which may indicate high head losses in inflowing fractures intersecting the borehole.

Table 6-7. Approximate flow and drawdown data during each step, truncated at 30 min.

Step #	Q_{30} (L/min)	dp_{30} (m)	dp_{30}/Q_{30} (s/m^2)
1	25	c 13.2	31680
2	35	c 28	48000
3	45	c 40	53333
4	c 50	c 55	66000

Table 6-8. Results of the analysis of the step drawdown pumping test in HSH03.

Borehole HSH03_12.03–201.0 m **Parameter** **Step drawdown test**	**Symbol**	**Unit**	**Value**	**Comments**
Formation factor	B_w	s/m^2	1390	Jacob's method
Well loss coefficient	C_w	s^2/m^5	$7.49 \cdot 10^7$	Jacob's method

Selected representative parameters

The selected representative parameters from the step drawdown test in HSH03 are presented in the Test Summary Sheet in Section 6.5 and Table 6-12–13. The selected parameters are derived from the recovery period since this period showed a well-defined pseudo-radial flow regime by the end of the period.

The calculated value on the skin factor from the first step of the drawdown test is significantly lower than that from the recovery period. The latter value on the skin factor thus corresponds to the final drawdown conditions in the borehole. This fact may possibly explain the difference between the calculated skin factors, i.e. increased head losses in conductive fractures intersecting the borehole at increased flow rate. This item is discussed in more detail in /3/.

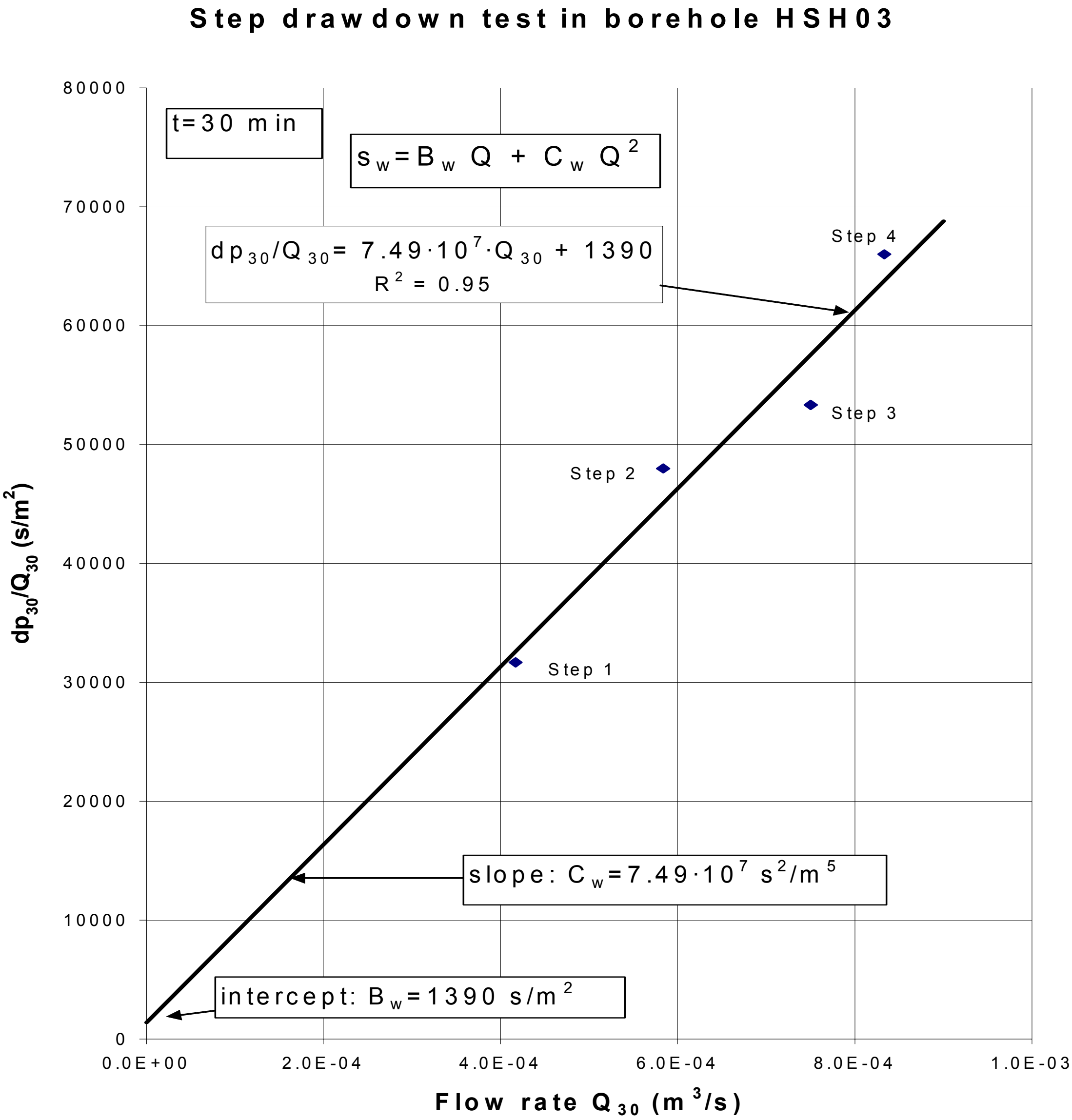


Figure 6-1. *Analysis of the step drawdown test in borehole HSH03.*

6.4 Flow logging

General test data for the flow logging in borehole HSH03 are presented in Table 6-9. The flow logging was performed during the pumping test in the open hole, see Section 6.3.1.

Table 6-9. General test data from the flow logging in borehole HSH03.

General test data			
Borehole	HSH03		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	T. Svensson, J. Levén (GEOSIGMA AB)		
Test equipment system	HTHB		
General comments			
	Nomen-clature	**Unit**	**Value**
Borehole length		m	201.0
Pump position (lower level)		m	25
Flow logged section – Secup		m	29
Flow logged section – Seclow		m	198.7
Test section diameter	2·rw	mm	139
Start of flow period		yymmdd hh:mm	020821 06:30
Start of flow logging		yymmdd hh:mm	020821 09:22
Stop of flow logging		yymmdd hh:mm	020821 15:02
Stop of flow period		yymmdd hh:mm	020821 16:46

[1] 6: Flow logging-Impeller, Logging-EC, L-EC, Logging temperature, L-Te

Groundwater level data

Groundwater level in HSH03	**Nomen-clature**	**Unit**	**G.w-level (m b ToC)**	**G.w-level (m a s l)**
Level in borehole, at undisturbed conditions, open hole	h_i	m	2.46	0.10
Level in borehole, during flow logging	h_p	m	15.13	–12.36
Drawdown during flow logging	s_{FL}	m		12.46

Flow data

Flow data	**Nomen-clature**	**Unit**	**Flow rate**
Pumping rate at surface during flow logging	Q_p	m^3/s	$2.87 \cdot 10^{-4}$
Cumulative flow rate at Secup during pumping	ΣQ_i	m^3/s	$2.15 \cdot 10^{-4}$
Measurement limit for borehole flow rate during flow logging	$Q_{measl-L}$	m^3/s	$5.0 \cdot 10^{-5}$ *
Minimal change in borehole flow rate to detect flow anomaly	$Q_{Fmeasl-L}$	m^3/s	$1.7 \cdot 10^{-5}$

* for 140 mm borehole diameter

Comments to test

The flow logging was made from the bottom of the hole upward. The first detectable flow anomaly was found at 59 m. The step length between flow measurements in the borehole interval 59–198.7 m below this anomaly was maximally 5 m. In the interval 29–59 m, above the anomaly, the step length was 2 m. The flow logging was only performed down to 198.7 m to avoid lowering the probe into possible drilling mud at the bottom of the borehole.

Logging results

The nomenclature used for the flow logging is according to the method description for flow logging (SKB MD 322.009, Metodbeskrivning för flödesloggning). The measured flow distribution along the hole during the flow logging together with the (temperature-compensated) electric conductivity (EC) and temperature (Te) of the borehole fluid is presented in Figure 6-2. According to analysis of the water samples at the Äspö Hard Rock Laboratory, the electric conductivity of the borehole water in HSH03 is in the order of 70–80 mS/m (after circulating about two borehole water volumes). The EC-curve shown in Figure 6-2 is only relative due to potential problems with electronic interference from the flow-logging probe on the EC-sensor.

The measured inflow at the identified flow anomalies (Q_i) together with their percentages of the total flow rate at the surface are shown in Table 6-10. The cumulative transmissivity (ΣT_i) at the top of the flow-logged borehole interval was calculated from Equation (5-1) and the transmissivity of individual flow anomalies (T_i) from Equation (5-2). An estimation of the transmissivity of the interpreted flow anomalies was also made by their specific flow (Q_i/s_{FL}). The results of the flow logging in borehole HSH03 are presented in the table below. The transmissivity of the entire borehole was calculated from the transient interpretation of the pumping test during flow logging to $T=1.46\cdot10^{-5}$ m^2/s.

Table 6-10. Results of the flow logging in borehole HSH03. ΣQ_i=cumulative flow at the top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}=drawdown during flow logging.

HSH03 Flow anom.		$\Sigma Q_i=2.16\cdot10^{-4}$ (m^3/s)	$Q_p=2.87\cdot10^{-4}$ (m^3/s)	$\Sigma T_i=1.10\cdot10^{-5}$ (m^2/s)	s_{FL}=12.46 m	
Interval (m) (from ToC)	**B h length (m)**	**Q_i (m^3/s)**	**Q_i/Q_p (%)**	**T_i (m^2/s)**	**Q_i/s_{FL} (m^2/s)**	**Supporting information**
53–56	3	$3.30\cdot10^{-5}$	11.5	$1.67\cdot10^{-6}$	$2.65\cdot10^{-6}$	–
58.5–59.5	1	$1.83\cdot10^{-4}$	64	$9.33\cdot10^{-6}$	$1.47\cdot10^{-5}$	–
Total		$\mathbf{2.16\cdot10^{-4}}$	**75.5**	$\mathbf{1.10\cdot10^{-5}}$	$\mathbf{1.73\cdot10^{-5}}$	
Difference		$Q_p-\Sigma Q_i=7.1\cdot10^{-5}$	24.5	$T-\Sigma T_i= 3.6\cdot10^{-6}$		Flow anomaly at 12–29 m?

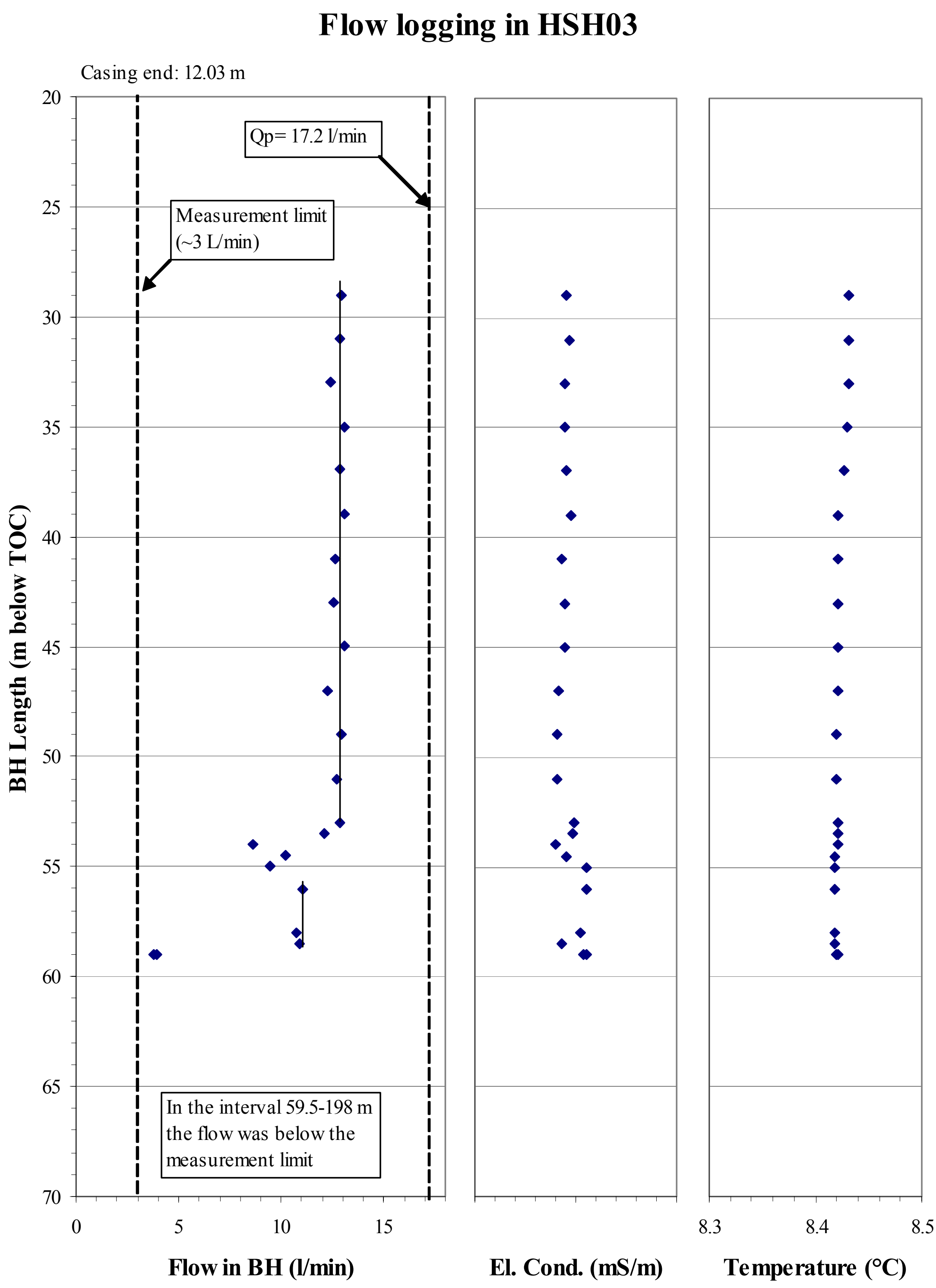


Figure 6-2. *Measured flow distribution along the hole during the flow logging together with the (temperature-compensated) relative electric conductivity (EC) and temperature (Te) of the borehole fluid.*

As can be seen in the table, only c 75% of the total flow at the surface was measured within the flow logged interval 29–198.7 m. Most of the flow is concentrated to the interval 58.5–59.5 m. The difference between the cumulative flow rate at the top of the logged interval (ΣQ_i) and the discharged flow rate from the borehole (Q_p) indicates that there might be one or more, additional flow anomaly(ies) between casing at c 12 m and the level c 29 m (top of logged interval), not covered by the flow logging. The additional inflow can be roughly estimated to c $7.1 \cdot 10^{-5}$ m^3/s (4.3 L/min) from the flow difference corresponding to a transmissivity of c $T = 3.6 \cdot 10^{-6}$ m^2/s. The presence of this flow anomaly can be investigated by e.g. injection tests.

Figure 6-3 shows the calculated, cumulative transmissivity ΣT_i along the borehole length (L) from the flow logging from Equation (5-3). Since the detailed positions of the flow anomalies in the borehole are not known the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated lower limit of transmissivity and the total borehole transmissivity are also shown in the figure, cf Section 5.4.2.

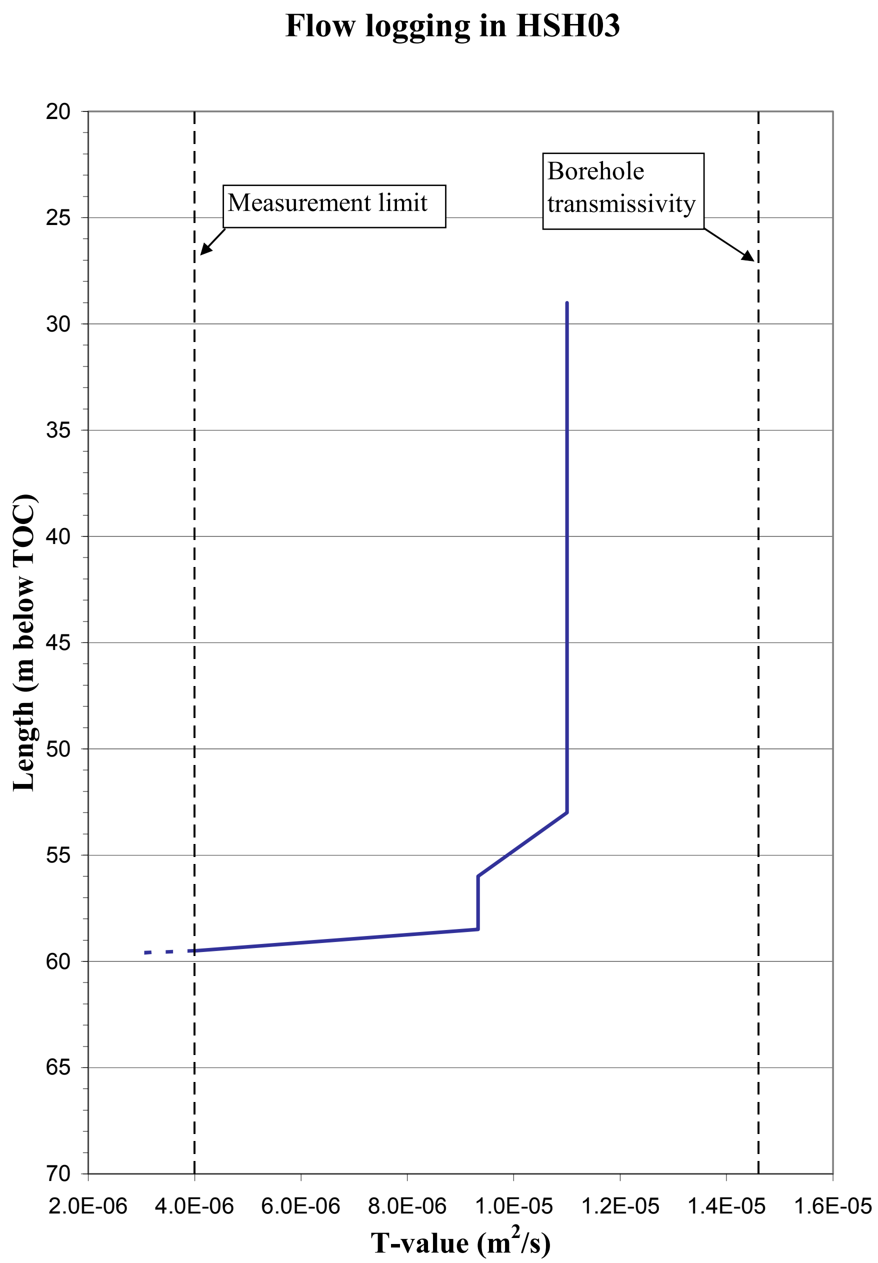


Figure 6-3. *Calculated, cumulative transmissivity along the flow-logged interval of the borehole. Below c 59 m, the borehole transmissivity was below the measurement limit. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.5 Summary of hydraulic tests

A compilation of measured test data from the hydraulic tests carried out in borehole HSH03 are shown in Table 6-11. In Table 6-12 and 6-13 calculated hydraulic parameters of the formation and borehole from the tests, respectively, are shown. Flow regime corresponds to the dominating flow regimes occurring during the test. The results of the flow logging are presented in Section 6.4.

The lower measurement limit for the HTHB system, presented in the tables below, is expressed in terms of specific flow (Q/s). For pumping tests, the practical lower limit is based on the minimal flow rate Q, for which the system is designed (5 L/min) and an estimated maximal allowed drawdown for practical purposes (c 50 m) in a percussion borehole, cf Table 4-1. These values correspond to a practical lower measurement limit of Q/s-L=$2\cdot10^{-6}$ m^2/s of the pumping tests. For injection tests, the minimal flow rate is c 1 L/min, corresponding to a practical lower measurement limit of Q/s-L=$4\cdot10^{-7}$ m^2/s for injection tests.

Similarly, the practical, upper measurement limit of the HTHB-system is estimated from the maximal flow rate (c 80 L/min) and a minimal drawdown of c 0.5 m, which is considered significant in relation to e.g. background fluctuations of the pressure before and during the test. These values correspond to an estimated, practical upper measurement limit of Q/s-U=$2\cdot10^{-3}$ m^2/s for both pumping tests and injection tests.

Table 6-11. Summary of test data for the hydraulic tests performed in borehole HSH03 in the Simpevarp area. Section type: 1=pumping section, 2=adjacent (passive) observation section in the pumping borehole.

Borehole ID	Section (m)	Test type[1)]	Section Type	p_i (kPa)	p_p (kPa)	p_F (kPa)	Q_p (m^3/s)	Q_m (m^3/s)	V_p (m^3)
HSH03	12.03–201	1B+6	1	285	153.479	280.069	$2.85\cdot10^{-4}$	–	c 10
HSH03	12.03–103	1B	1	522.07	363.049	518.555	$3.70\cdot10^{-4}$	–	c 5
HSH03	104–201	1B	2	1007.78	1006.02	998.661	–	–	–
HSH03	80.5–201	3	1	785.609	1185.64	801.844	$<1.7\cdot10^{-5}$	–	0
HSH03	12.03–201	1B	1	804.903	257.411	798.158	$7.60\cdot10^{-4}$	$5.77\cdot10^{-4}$	13.5

[1] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller. L-EC: EC-logging, L-Te: temperature logging

Table 6-12. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed in borehole HSH03. Bh type: 1=pumping borehole, 2=observation borehole.

Borehole ID	Interval/ Section (m)	Bh Type	Q/s (m^2/s)	T_M (m^2/s)	T (m^2/s)	S* (–)	S (–)	K'/b' (s^{-1})	Q/s-L (m^2/s)	Q/s-U (m^2/s)
HSH03	12.03–201	1	$2.17\cdot10^{-5}$	$2.83\cdot10^{-5}$	$1.46\cdot10^{-5}$	$1.11\cdot10^{-5}$	–	–	$2\cdot10^{-6}$	$2\cdot10^{-3}$
HSH01	12.03–200	2	–	–	$1.43\cdot10^{-5}$		$1.11\cdot10^{-5}$	$1.31\cdot10^{-10}$	$2\cdot10^{-6}$	$2\cdot10^{-3}$
HSH03	12.03–103	1	$2.33\cdot10^{-5}$	$2.76\cdot10^{-5}$	$1.21\cdot10^{-5}$	$1.11\cdot10^{-5}$	–	–	$2\cdot10^{-6}$	$2\cdot10^{-3}$
HSH03	80.5–201	1	<m.l.	<m.l.	<m.l.	–	–	–	$4\cdot10^{-7}$	$2\cdot10^{-3}$
HSH03	12.03–201	1	$1.39\cdot10^{-5}$	$1.51\cdot10^{-5}$	$1.55\cdot10^{-5}$	$1.11\cdot10^{-5}$	–	–	$2\cdot10^{-6}$	$2\cdot10^{-3}$

In Table 6-12, the parameter explanations are according to (SKB MD 320.004, Instruktion för analys av injektions- och enhålspumptester). The parameters are also explained in the text above, except the following parameters:

T_M = steady-state transmissivity calculated from Moye's formula
S* = assumed value on storativity used in single-hole tests for calculation of the skin factor
S = calculated storativity from observation borehole during the actual test. If such values are available, they are normally used as S* in other tests
K'/b' = leakage coefficient
Q/s-L = lower measurement limit for specific flow for the test system used
Q/s-U = upper measurement limit for specific flow for the test system used
<m.l. = below measurement limit

Table 6-13. Summary of calculated hydraulic parameters of the borehole from the hydraulic tests performed in borehole HSH03.

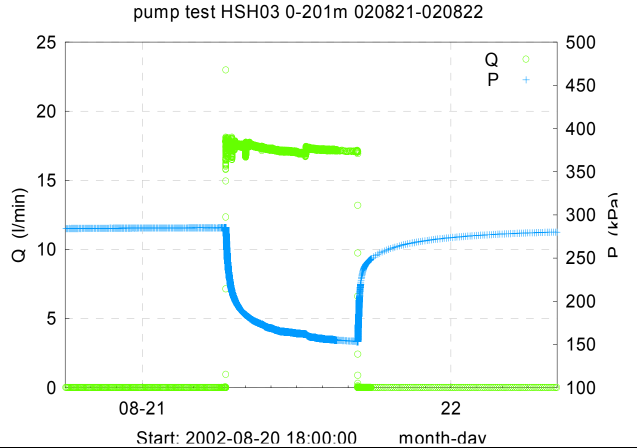
Borehole ID	Section (m)	C (m^3/Pa)	ζ (–)	B_w (s/m^2)	C_w (s^2/m^5)	Remarks
HSH03	12.03–201	$1.71 \cdot 10^{-6}$	–4.17	–	–	
HSH03	12.03–103	$2.22 \cdot 10^{-6}$	–4.53	–	–	
HSH03	80.5–201	–	–	–	–	Below meas.limit
HSH03	12.03–201		–4.33	$1.39 \cdot 10^{3}$	$7.49 \cdot 10^{7}$	Step drawdown test
HSH03	12.03–201	$1.82 \cdot 10^{-6}$	–1.19	–	–	D:o, recovery period

C = wellbore storage coefficient
ζ = skin factor
B_w = formation factor (step drawdown tests)
C_w = well loss coefficient (step drawdown tests)

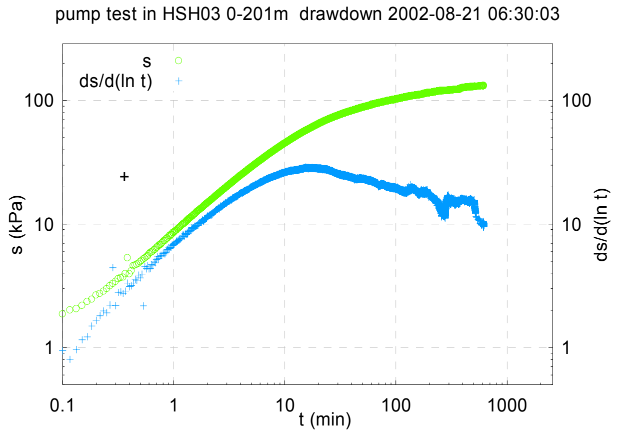
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Simpevarp	Test no:	1
Borehole ID:	HSH03	Test start:	2002-08-20 18:00
Test section (m):	12.03–201.0	Responsible for test performance:	GEOSIGMA AB J. Levén/Thomas Svensson
Section diameter, $2 \cdot r_w$ (m):	0.1396	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

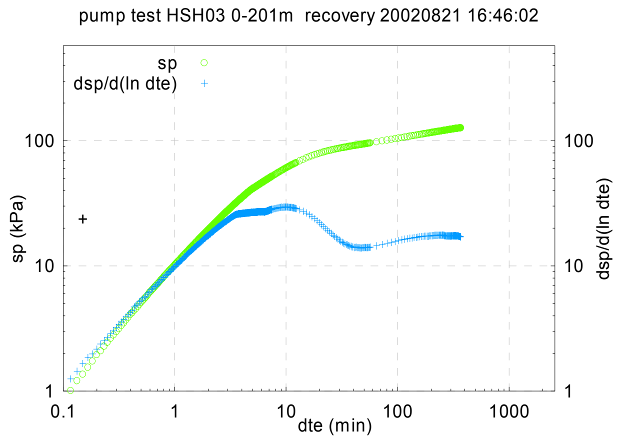
Linear plot Q and p



Log-Log plot incl. derivate – flow period



Log-Log plot incl. derivative – recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	285		
p_i (kPa)	285		
p_p(kPa)	153.479	p_F (kPa)	280.069
Q_p (m^3/s)	$2.85 \cdot 10^{-4}$		
tp (min)	616	t_F (s)	929
S*	$1.11 \cdot 10^{-5}$	S*	$1.11 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$2.17 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$2.83 \cdot 10^{-5}$		
Flow regime:	PRF	Flow regime:	PRF
t_1 (min)	150	dt_{e1} (min)	200
t_2 (min)	500	dt_{e2} (min)	400
T_w (m^2/s)	$1.46 \cdot 10^{-5}$	T_w (m^2/s)	$1.74 \cdot 10^{-5}$
S_w (–)	–	S_w (–)	–
K_{sw} (m/s)	–	K_{sw} (m/s)	–
S_{sw} (1/m)	–	S_{sw} (1/m)	–
C (m^3/Pa)	$1.71 \cdot 10^{-6}$	C (m^3/Pa)	$1.69 \cdot 10^{-6}$
C_D (–)		C_D (–)	
ξ (–)	–4.17	ξ (–)	–3.72
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters.

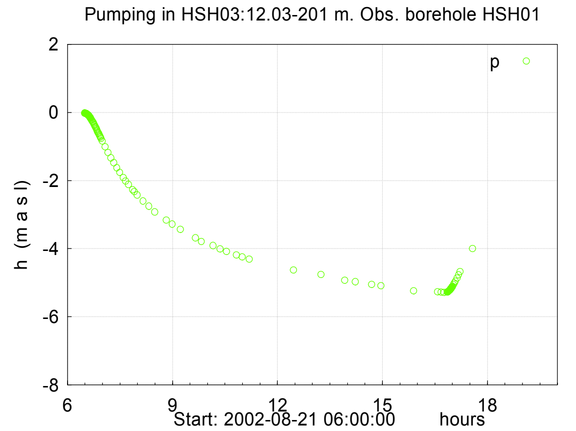
Flow regime:	PRF	C (m^3/Pa)	$1.71 \cdot 10^{-6}$
t_1 (min)	150	C_D (–)	
t_2 (min)	500	ξ (–)	–4.17
T_T (m^2/s)	$1.46 \cdot 10^{-5}$		
S (–)	–		
K_s (m/s)	–		
S_s (1/m)	–		

Comments: Wellbore storage dominated flow transiting to pseudo-radial flow (PRF).

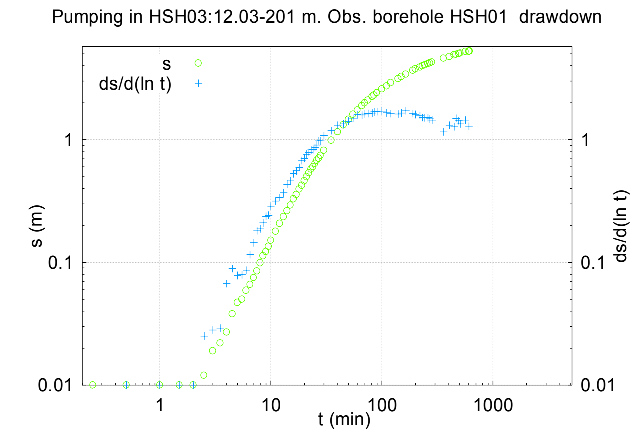
Test Summary Sheet

Project:	PLU	Test type:	2
Area:	Simpevarp	Test no:	1
Borehole ID:	HSH01	Test start:	2002-08-21 06:30
Test section (m):	12.03–200.0	Responsible for test performance:	GEOSIGMA AB J. Levén/Thomas Svensson
Section diameter, $2 \cdot r_w$ (m):	0.140	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

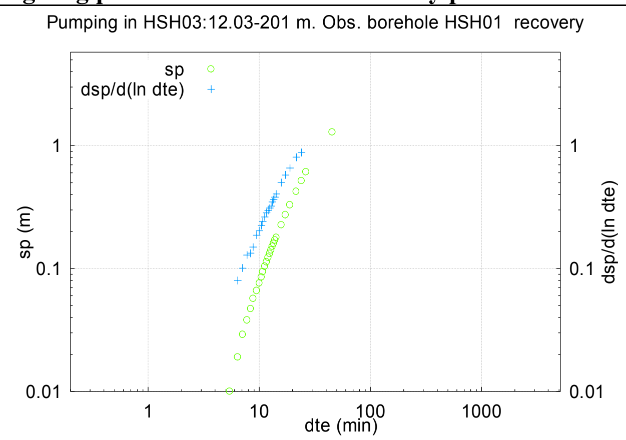
Linear plot Q and p



Log-Log plot incl. derivate – flow period



Log-Log plot incl. derivative – recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
h_0 (masl)	–0.029		
h_i (masl)	–0.029		
h_p(masl)	–5.292	h_F (masl)	–4.004
Q_p (m^3/s)	$2.85 \cdot 10^{-4}$		
tp (min)	616	t_F (s)	49
S*		S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.1	Derivative fact.	0.1
Results		**Results**	
Q/s (m^2/s)	–		
T_{Moye}(m^2/s)	–		
Flow regime:	PRF	Flow regime:	
t_1 (min)	60	dt_{e1} (min)	
t_2 (min)	250	dt_{e2} (min)	
T_w (m^2/s)	$1.43 \cdot 10^{-5}$	T_w (m^2/s)	
S_w (–)	$1.11 \cdot 10^{-5}$	S_w (–)	
K_{sw} (m/s)	–	K_{sw} (m/s)	
S_{sw} (1/m)	–	S_{sw} (1/m)	
K'/b'_o (s^{-1})	$1.31 \cdot 10^{-10}$		
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters.

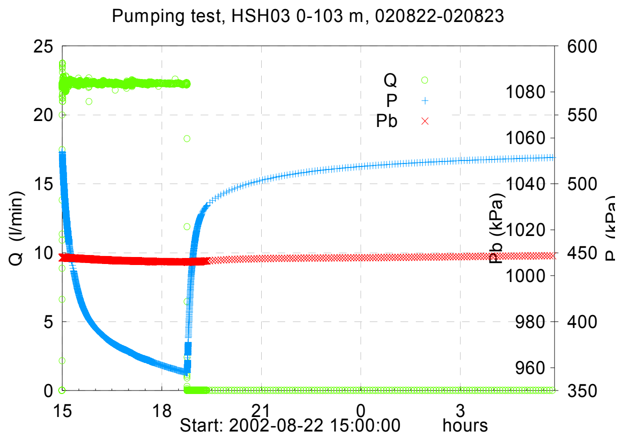
Flow regime:	PRF		–
t_1 (min)	60	K'/b'_o (s^{-1})	$1.31 \cdot 10^{-10}$
t_2 (min)	250		
T_T (m^2/s)	$1.43 \cdot 10^{-5}$		
S (–)	$1.11 \cdot 10^{-5}$		
K_s (m/s)	–		
S_s (1/m)	–		

Comments: Pseudo-radial flow transiting to slightly leakage flow by the end of the flow period.

Test Summary Sheet

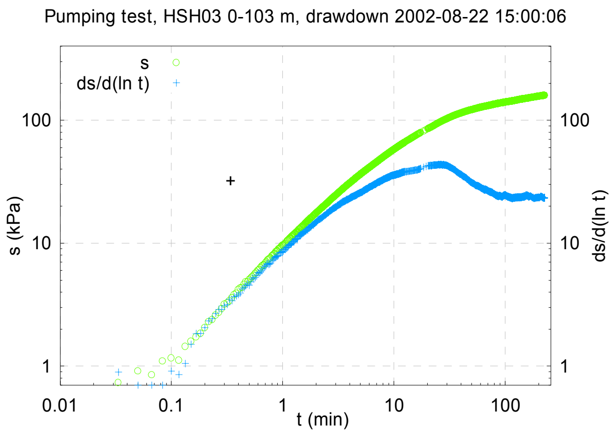
Project:	PLU	Test type:	1B
Area:	Simpevarp	Test no:	1
Borehole ID:	HSH03	Test start:	2002-08-22 15:00
Test section (m):	12.03–103	Responsible for test performance:	GEOSIGMA AB J. Levén/Thomas Svensson
Section diameter, $2 \cdot r_w$ (m):	0.139	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

Linear plot Q and p



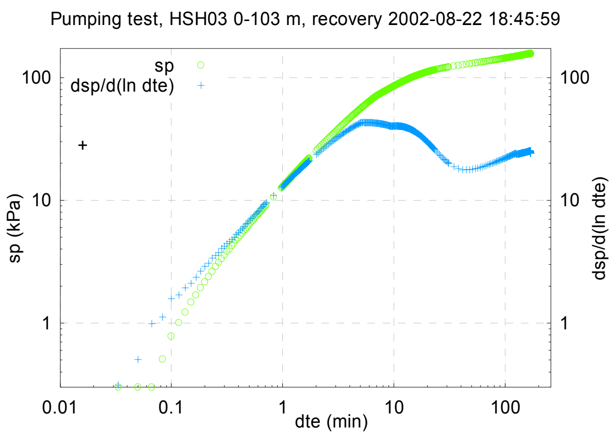
Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	522.07		
p_{bi} (kPa)	1007.78		
p_p (kPa)	363.049	p_F (kPa)	518.555
p_{bp} (kPa)	1006.02	p_{bF} (kPa)	998.661
Q_p (m^3/s)	$3.70 \cdot 10^{-4}$		
tp (min)	226	t_F (min)	679
S*	$1.11 \cdot 10^{-5}$	S*	
EC_w (mS/m)			
Te_w (gr C)			
Derivative fact.	0.3	Derivat. fact.	0.3

Log-Log plot incl. derivate – flow period



Results		Results	
Q/s (m^2/s)	$2.33 \cdot 10^{-5}$		
T_{Moye} (m^2/s)	$2.76 \cdot 10^{-5}$		
Flow regime:	PRF	Flow regime:	
t_1 (min)	80	dt_{e1} (min)	
t_2 (min)	226	dt_{e2} (min)	
T_w (m^2/s)	$1.21 \cdot 10^{-5}$	T_w (m^2/s)	
S_w (–)	–	S_w (–)	
K_{sw} (m/s)	–	K_{sw} (m/s)	
S_{sw} (1/m)	–	S_{sw} (1/m)	
C (m^3/Pa)	$2.22 \cdot 10^{-6}$	C (m^3/Pa)	$1.58 \cdot 10^{-6}$
C_D (–)		C_D (–)	
ξ (–)	–4.53	ξ (–)	
T_{GRF} (m^2/s)		T_{GRF} (m^2/s)	
S_{GRF} (–)		S_{GRF} (–)	

Log-Log plot incl. derivative – recovery period



Interpreted formation and well parameters

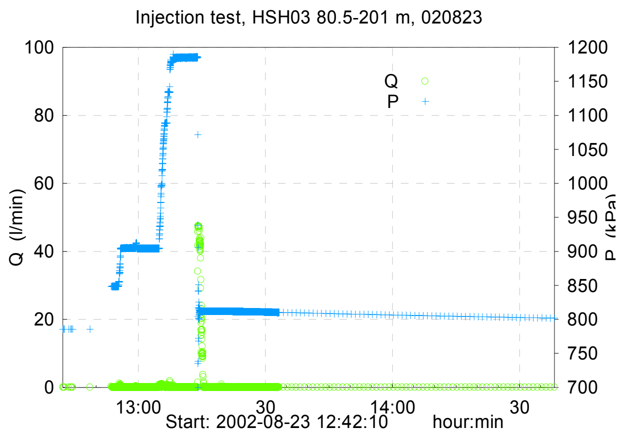
Flow regime:	PRF	C (m^3/Pa)	$2.22 \cdot 10^{-6}$
t_1 (min)	80	C_D (–)	
t_2 (min)	226	ξ (–)	–4.53
T_T (m^2/s)	$1.21 \cdot 10^{-5}$		
S (–)	–		
K_s (m/s)	–		
S_s (1/m)	–		

Comments: Wellbore storage dominated early flow. A well-defined pseudo-radial flow regime developed during the flow period but not during the recovery period.

Test Summary Sheet

Project:	PLU	Test type:	3
Area:	Simpevarp	Test no:	1
Borehole ID:	HSH03	Test start:	2002-08-23 12:42
Test section (m):	80.5–201	Responsible for test performance:	GEOSIGMA AB J. Levén/Thomas Svensson
Section diameter, $2 \cdot r_w$ (m):	0.139	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

Linear plot Q and p



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	785.609		
p_{ai} (kPa)	–		
p_p(kPa)	1185.64	p_F (kPa)	801.844
p_{ap} (kPa)	–	p_{aF} (kPa)	–
Q_p (m^3/s)	$<1.7 \cdot 10^{-5}$		
tp (min)	20.7	t_F (min)	84
S*	–	S*	–
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	–	Derivat. fact.	–

Log-Log plot incl. derivate – flow period

Results		**Results**	
Q/s (m^2/s)	$<3.4 \cdot 10^{-7}$		
T_{Moye}(m^2/s)	$<4.4 \cdot 10^{-7}$		
Flow regime:	–	Flow regime:	–
t_1 (min)		dt_{e1} (min)	–
t_2 (min)		dt_{e2} (min)	–
T_w (m^2/s)	–	T_w (m^2/s)	–
S_w (–)	–	S_w (–)	–
K_{sw} (m/s)	–	K_{sw} (m/s)	–
S_{sw} (1/m)	–	S_{sw} (1/m)	–
C (m^3/Pa)	–	C (m^3/Pa)	–
C_D (–)	–	C_D (–)	–
ξ (–)	–	ξ (–)	–
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Log-Log plot incl. derivative – recovery period

Interpreted formation and well parameters			
Flow regime:	–	C (m^3/Pa)	–
t_1 (min)	–	C_D (–)	–
t_2 (min)	–	ξ (–)	–
T_T (m^2/s)	–		
S (–)	–		
K_s (m/s)	–		
S_s (1/m)	–		

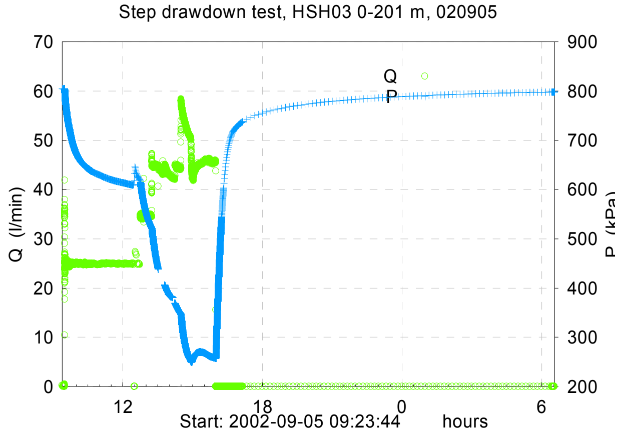
Comments: Injection test, no measurable flow

Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Simpevarp	Test no:	2
Borehole ID:	HSH03	Test start:	2002-09-05 09:23
Test section (m):	12.03–201.0 Step drawdown test	Responsible for test performance:	GEOSIGMA AB J. Levén/Thomas Svensson
Section diameter, $2 \cdot r_w$ (m):	0.139	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

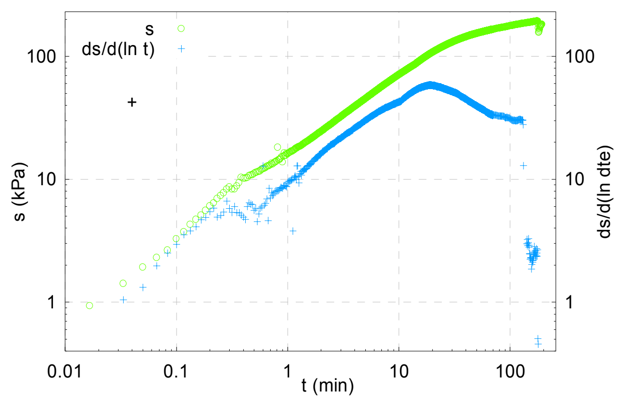
Linear plot Q and p

Step drawdown test, HSH03 0-201 m, 020905



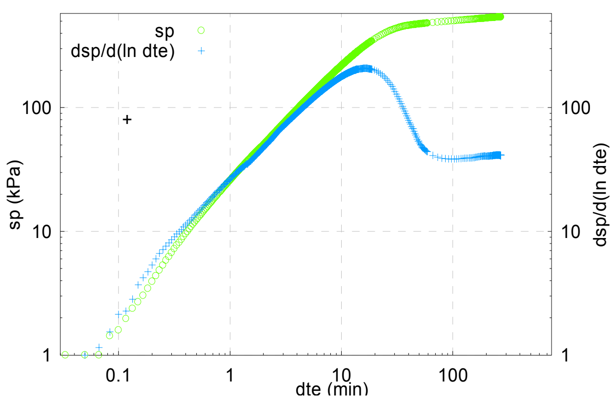
Log-Log plot incl. derivate – flow period

Step drawdown test, step 1, HSH03 0-201 m, drawdown 2002-09-05 09:30:1



Log-Log plot incl. derivative – recovery period

Step Drawdown Test, HSH03 0-201 m, recovery 2002-09-05 16:00:01



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	804.903		
p_i (kPa)	804.903		
p_p(kPa)	257.411	p_F (kPa)	798.158
Q_p (m^3/s)	$7.60 \cdot 10^{-4}$		
tp (min)	390	t_F (s)	873
S*	$1.11 \cdot 10^{-5}$	S*	$1.11 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$1.39 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$1.51 \cdot 10^{-5}$		
Flow regime:	PRF	Flow regime:	PRF
t_1 (min)	70	dt_{e1} (min)	70
t_2 (min)	120	dt_{e2} (min)	300
T_w (m^2/s)	$1.16 \cdot 10^{-5}$	T_w (m^2/s)	$1.55 \cdot 10^{-5}$
S_w (–)	–	S_w (–)	–
K_{sw} (m/s)	–	K_{sw} (m/s)	–
S_{sw} (1/m)	–	S_{sw} (1/m)	–
C (m^3/Pa)	$1.13 \cdot 10^{-6}$	C (m^3/Pa)	$1.82 \cdot 10^{-6}$
C_D (–)		C_D (–)	
ξ (–)	–4.33	ξ (–)	–1.19
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters.

Flow regime:	PRF	C (m^3/Pa)	$1.82 \cdot 10^{-6}$
t_1 (min)	70	C_D (–)	
t_2 (min)	300	ξ (–)	–1.19
T_T (m^2/s)	$1.55 \cdot 10^{-5}$		
S (–)	–		
K_s (m/s)	–		
S_s (1/m)	–		

Comments: Step drawdown test. Wellbore storage dominated flow transiting to pseudo-radial flow (PRF).

7 References

/1/ **Svensk Standard.** SIS 02 81 23 Utgåva 1, 1974-07-01. Sveriges standariseringskommission. Standardkommitten för miljömätteknik.

/2/ **Almén K-E, Andersson J-E, Carlsson L, Hansson K, Larsson N-Å, 1986.** Hydraulic testing in crystalline rock. A comparative study of single-hole test methods. Technical Report 86-27, Svensk Kärnbränslehantering AB.

/3/ **Atkinson L E, Gale J E and Dudgeon C R, 1994.** New insight into the step drawdown test in fractured-rock aquifers. Applied Hydrogeology 1/94.

Appendix 1

Dumped and created data files

Files are named "*bhnamn_secup_yymmdd_XX*", where *yymmdd* is the date for test start, *secup* is top of section and XX is the original file name from the HTHB data logger. If necessary, a letter is added (a, b, c, ..) after "*secup*" to separate identical names. XX can be one of five alternatives; *Ref_Da* containing constants of calibration and background data, *FlowLo* containing data from pumping test in combination with flowlogging. *Spinne* contains data from spinner measurements, *Inject* contains data from injection test and *Pumpin* from pumping tests (no combined flowlogging).

Bh ID	Test section (m)	Test type[1]	Test no	Test start Date, time YYYY-MM-DD tt:mm:ss	Test stop Date, time YYYY-MM-DD tt:mm:ss	Datafile, start Date, time YYYY-MM-DD tt:mm:ss	Datafile, stop Date, time YYYY-MM-DD tt:mm:ss	Data files of raw and primary data	Parameters[2]	Comments
HSH03	0–201	(1B), 6, L-EC, L-Te	1	020821 06:25:00	020822 15:04:00	020617 08:48	020821 15:04	HSH03_000_020821_Spinner.DAT	(P, Q) Te, Sp, EC	P, Q only at Spinner data
HSH03	0–201		1	020821 06:25:00	020822 08:14:50	020614 07:36	020822 08:14:50	HSH03_000a_020821_Ref_Da.DAT	C, R	
HSH03	0–201	1B, 6, L-EC, L-Te	1	020820 18:00:00	020822 08:14:50	020820 16:23	020822 08:14:50	HSH03_000a_020821_FlowLo.DAT	P, Q, Te, EC	
HSH03	0–201		1	020820 18:00:00	020822 08:14:50	020614 07:36	020822 08:14:50	HSH03_000b_020821_Ref_Da.DAT	C, R	
HSH03	0–201	1B, 6, L-EC, L-Te	1	020820 18:00:00	020822 08:14:50	020820 16:23	020822 08:14:50	HSH03_000b_020821_FlowLo.DAT	P, Q, Te, EC	
HSH03	0–103	1B	1	020822 15:00:00	020823 06:05:30	020822 11:13	020823 06:05:30	HSH03_000_020822_Pumpin.DAT	P, Q	
HSH03	0–103		1	020822 15:00:00	020823 06:05:30	020614 07:36	020823 06:05:30	HSH03_000_020822_Ref_Da.DAT	C, R	
HSH03	80.5–201	3	1	020823 12:53:20	020823 14:41:00	020823 10:01	020823 14:41:00	HSH03_080_020823_Inject.DAT	P, Q	
HSH03	80.5–201		1	020823 12:53:20	020823 14:41:00	020614 07:36	020823 12:29	HSH03_080_020823_Ref_Da.DAT	C, R	
HSH03	0–201	1B	2	020905 09:30:00	020906 06:32:17	020905 09:23:44	020906 06:32:59	HSH03_000_020905_Pumpin.DAT	P, Q	
HSH03	0–201		2	020905 09:30:00	020906 06:32:17	020905 09:22:04	020906 06:33:10	HSH03_000_020905_Ref_Da.DAT	C, R	

[1] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging-Impeller, Logging-EC: L-EC, Logging temperature: L-Te

[2] P =Pressure, Q =Flow, Te =Temperature, EC =El. conductivity. C =Calibration file, R =Reference file, Sp= Spinner rotations.

Appendix 2

Diagram

Diagrams are presented for the following tests: Page

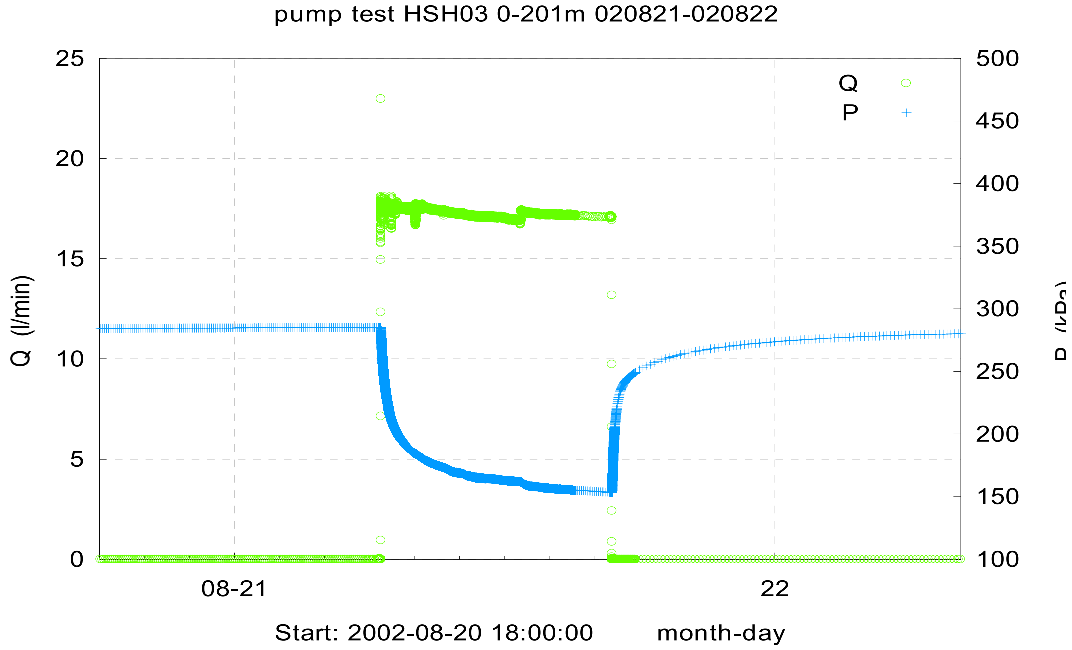


Figure A2-1. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HSH03 in conjunction with flow logging.*

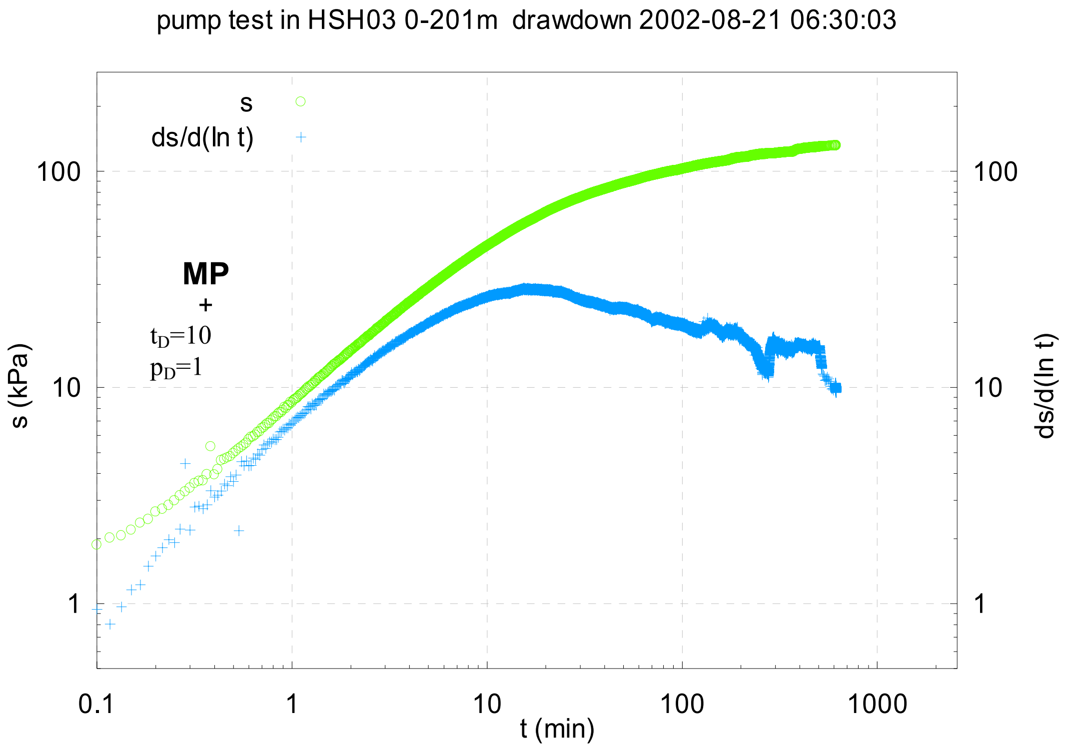


***Figure A2-2.** Logarithmic plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the open-hole pumping test in HSH03.*

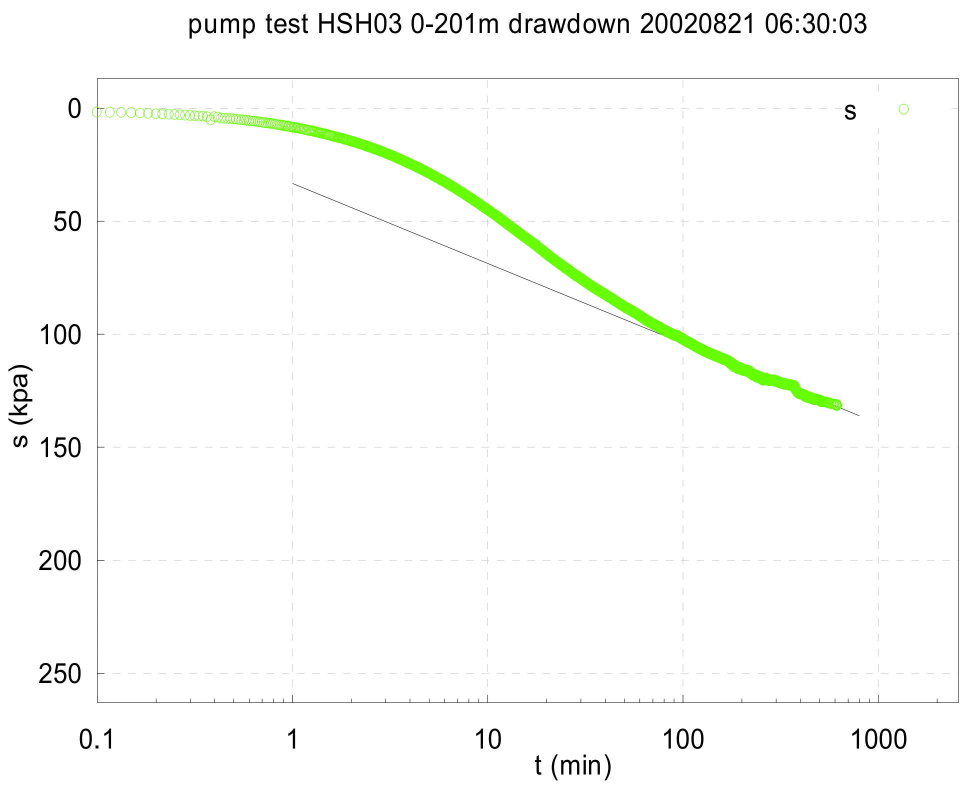


***Figure A2-3.** Semi-logarithmic plot of drawdown (s) versus time (t) during the open-hole pumping test in HSH03.*

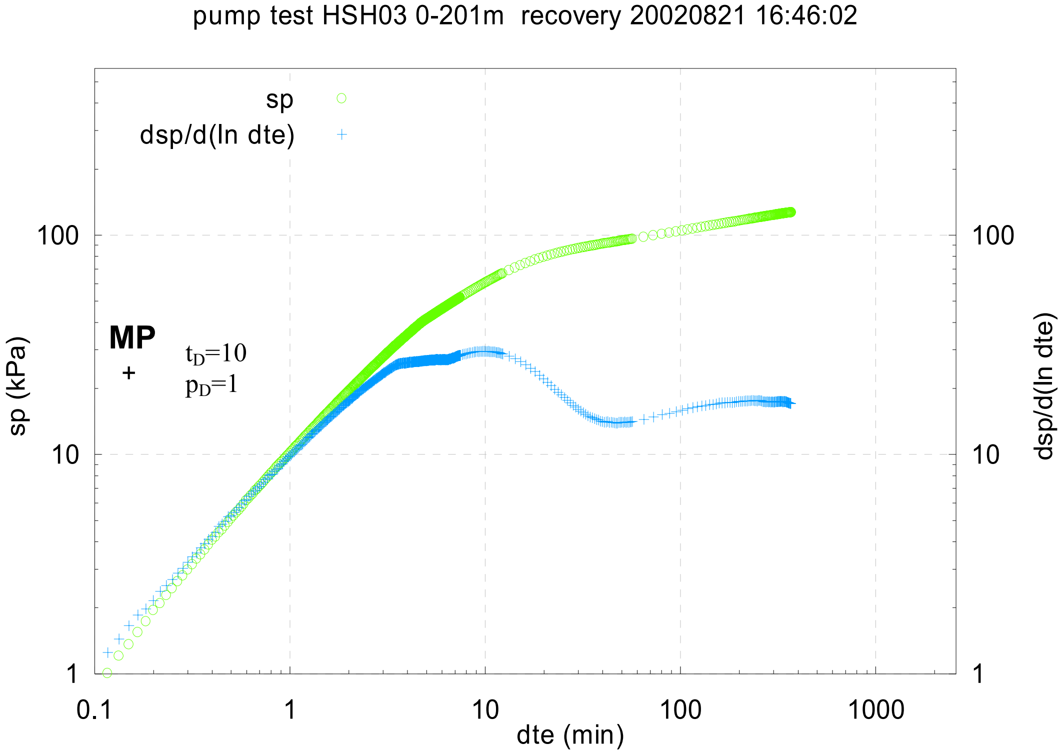


Figure A2-4. *Logarithmic plot of pressure recovery (sp) and – derivative, dsp/d(ln dte), versus equivalent time (dte) from the open-hole pumping test in HSH03.*

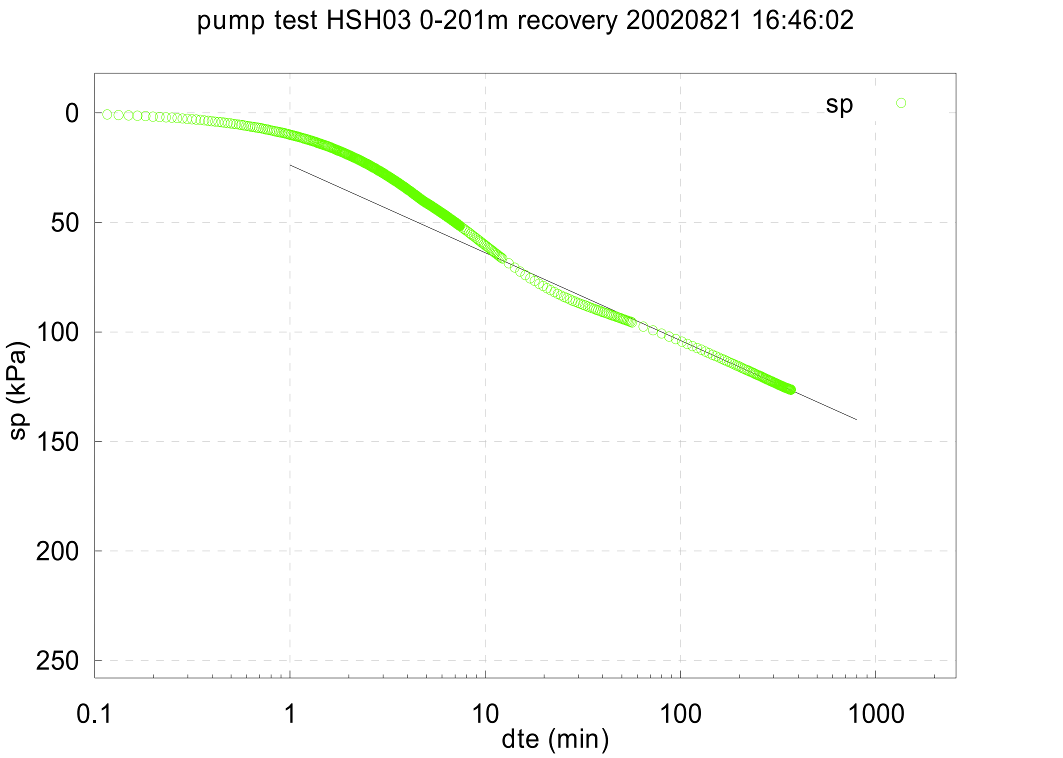


Figure A2-5. *Semi-logarithmic plot of pressure recovery (sp) versus equivalent time (dte) from the open-hole pumping test in HSH03.*

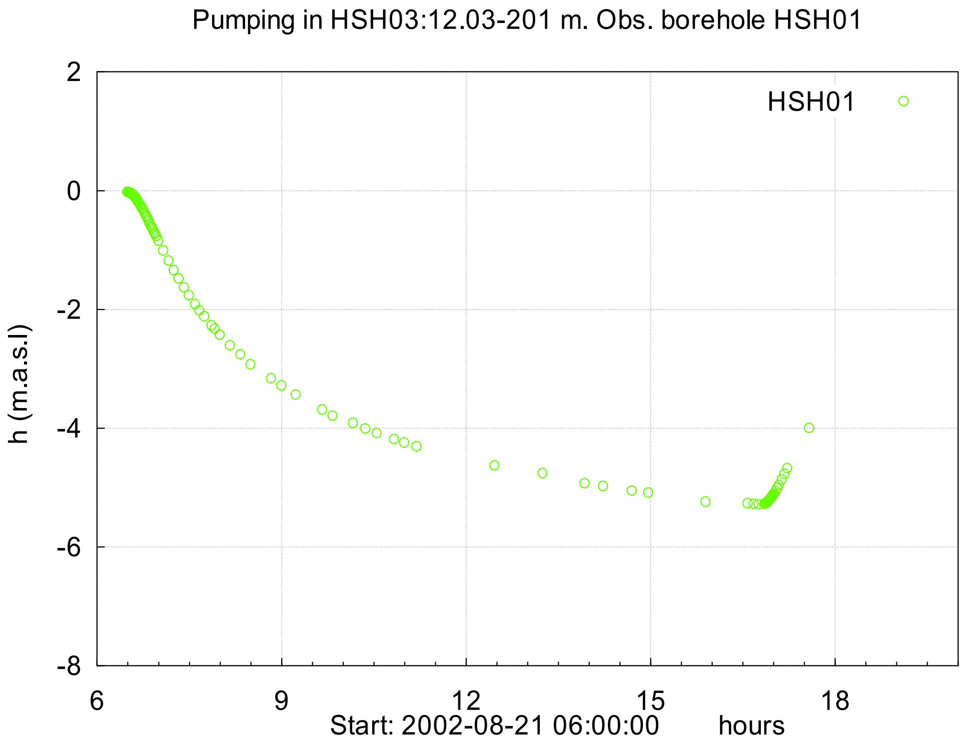


Figure A2-6. *Linear plot of the groundwater level (m a s l) versus time in observation borehole HSH01 during the open-hole pumping test in HSH03 in conjunction with flow logging.*

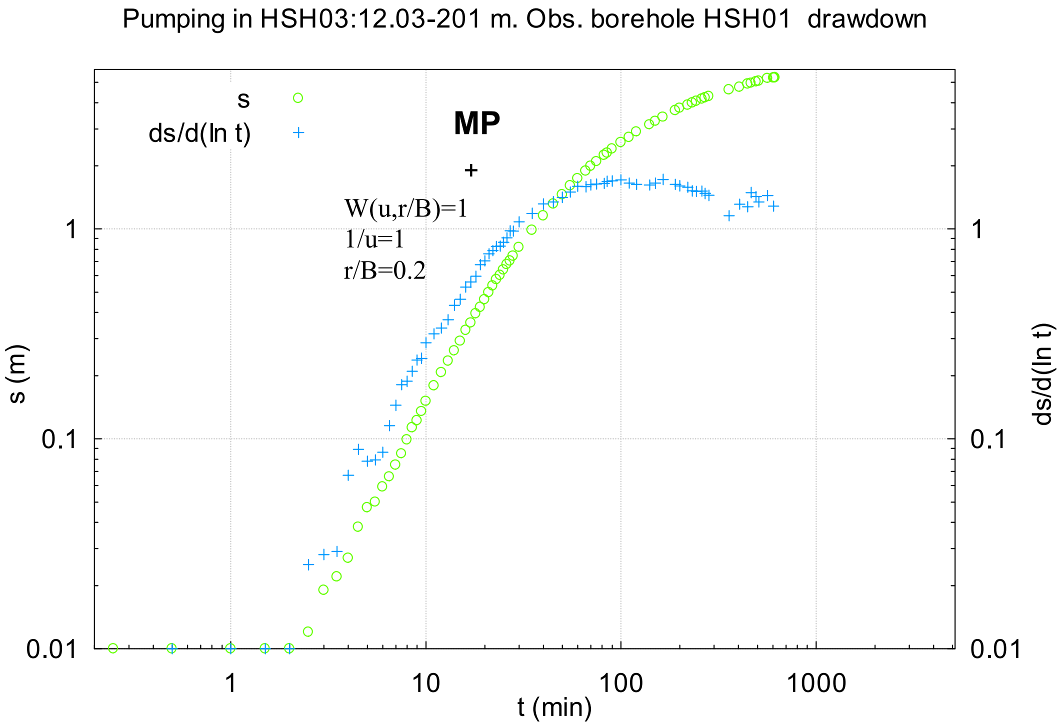


***Figure A2-7**. Logarithmic plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time in observation borehole HSH01during pumping test in HSH03.*

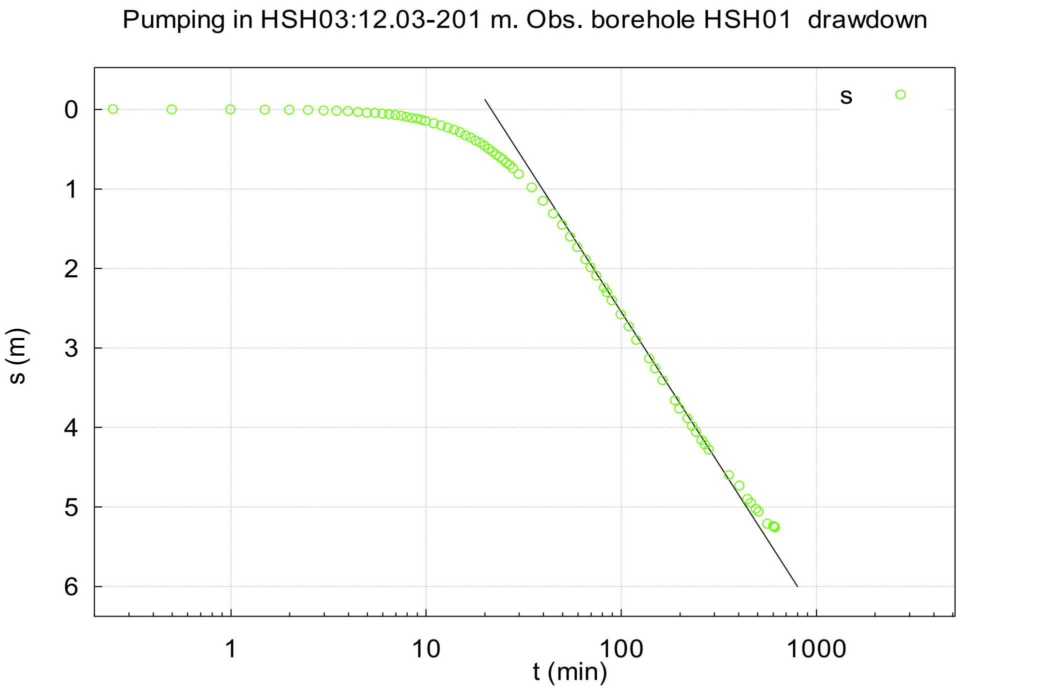


***Figure A2-8.** Semi-logarithmic plot of drawdown (s) versus time (t) in observation borehole HSH01during pumping test in HSH03*

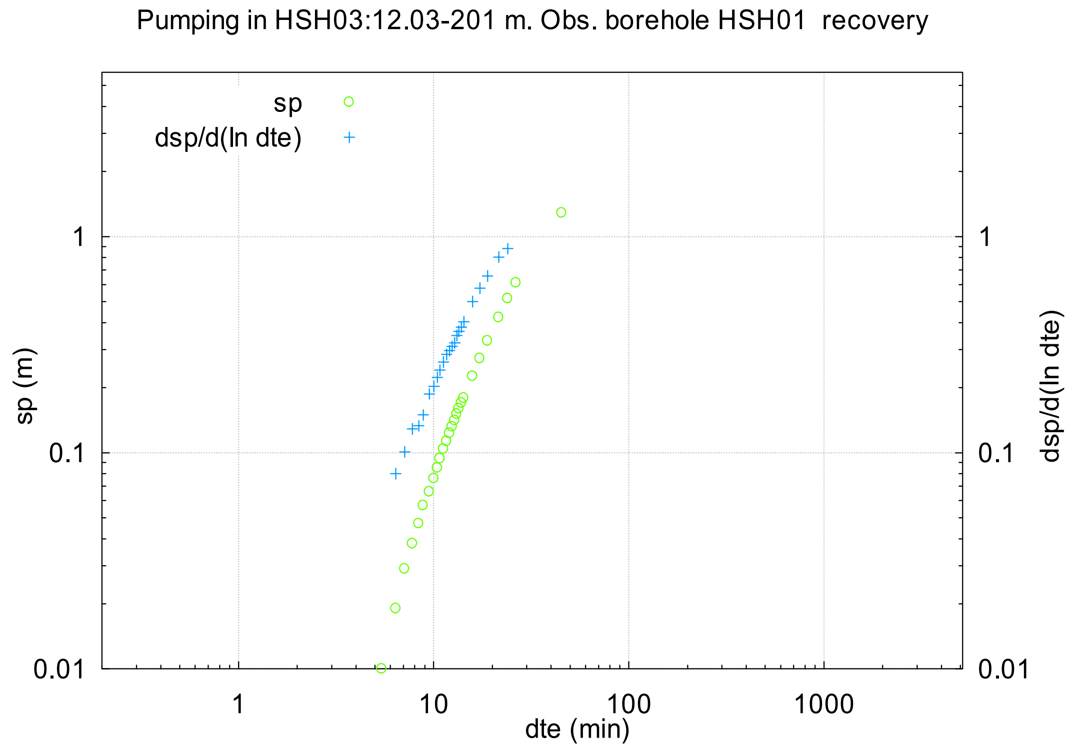


Figure A2-9. *Logarithmic plot of pressure recovery (sp) and – derivative, dsp/d(ln dte), versus equivalent time (dte) in observation borehole HSH01 during pumping test in HSH03.*

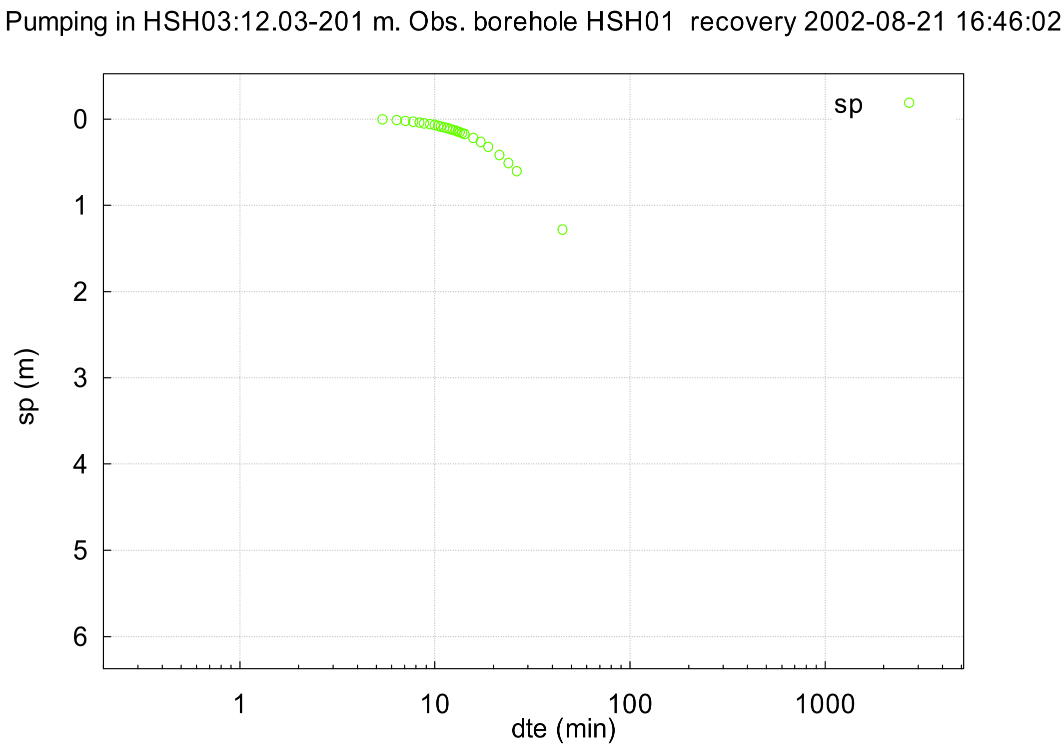


Figure A2-10. *Logarithmic plot of pressure recovery (sp) versus equivalent time (dte) in observation borehole HSH01 during pumping test in HSH03.*

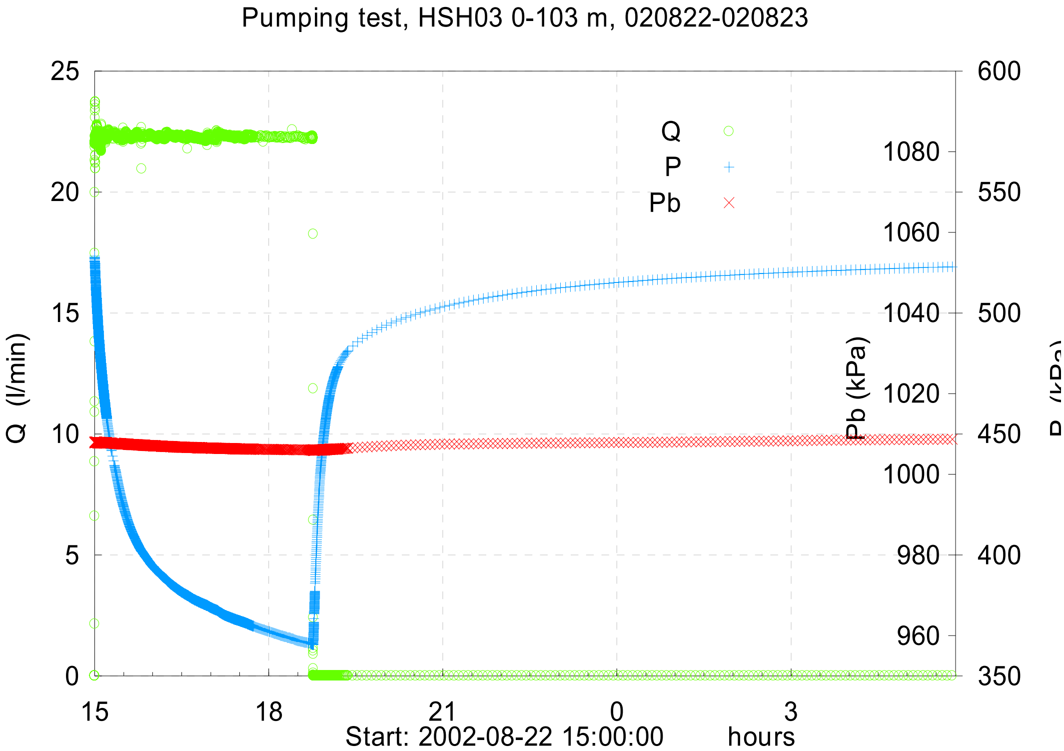


Figure A2-11. *Linear plot of flow rate (Q) and pressure (p) versus time during the pumping test in the interval 12.03–103 m in HSH03.*

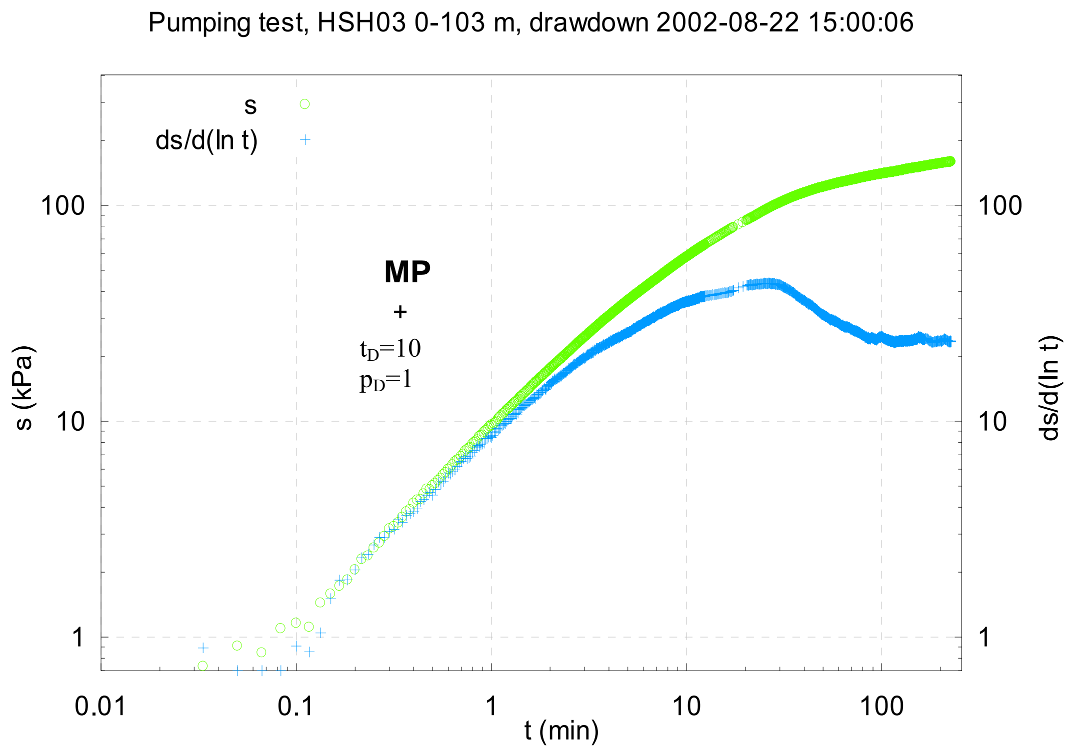


Figure A2-12. *Logarithmic plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the pumping test in the interval 12.03–103 m in HSH03.*

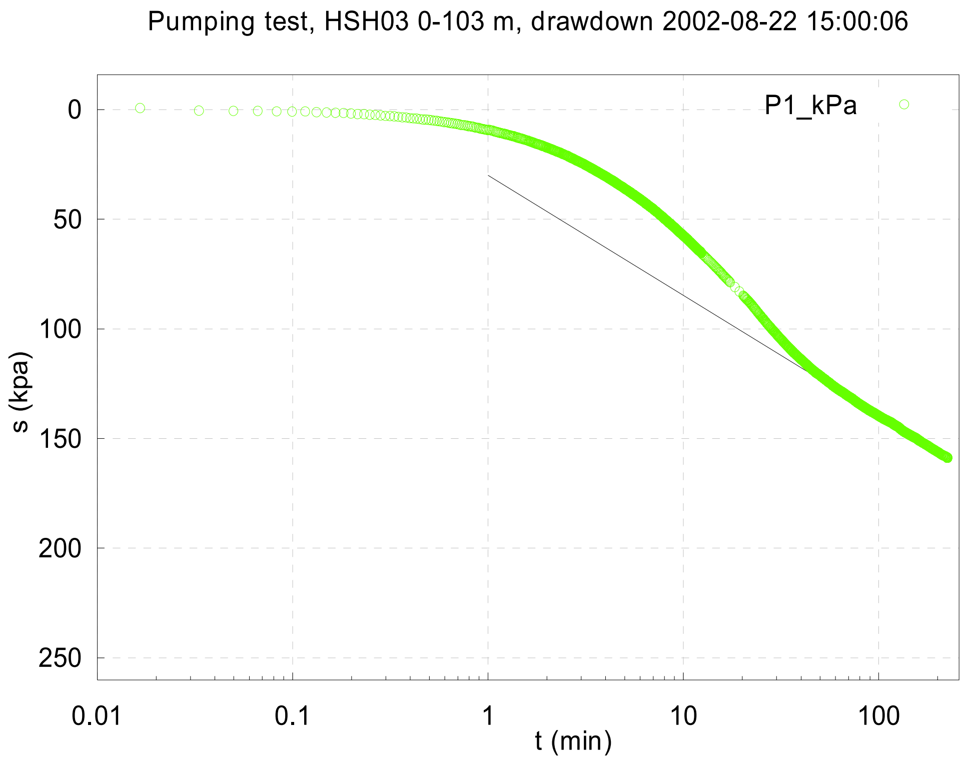


Figure A2-13. *Semi-logarithmic plot of drawdown (s) versus time (t) during the pumping test in the interval 12.03–103 m in HSH03.*

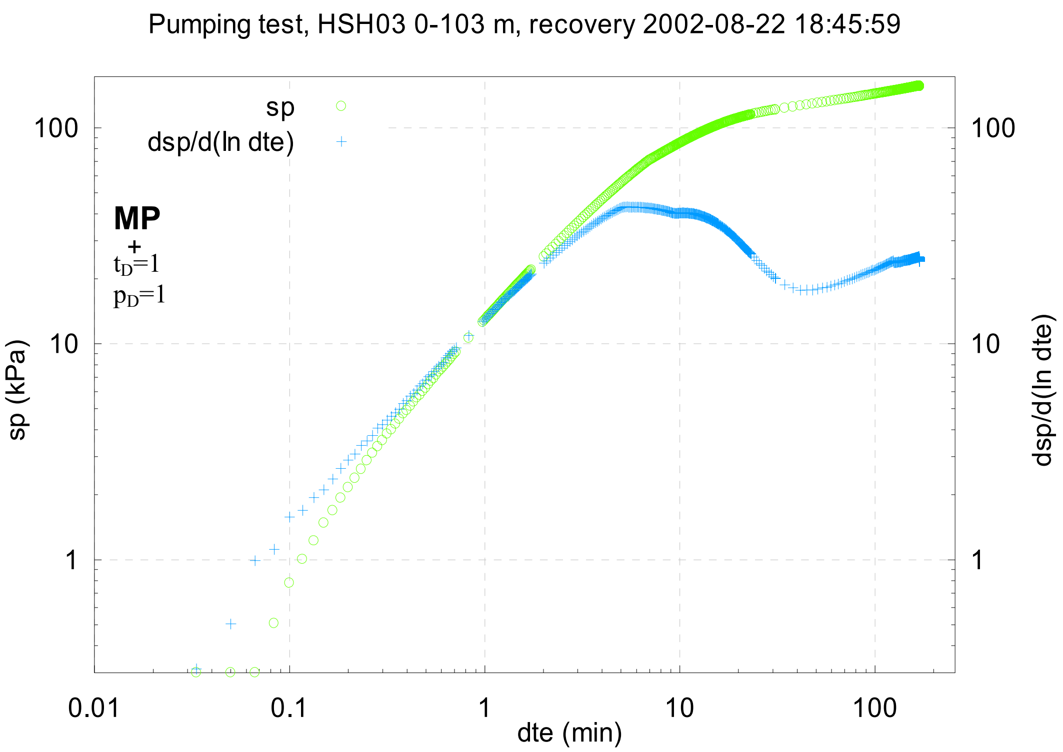


Figure A2-14. *Logarithmic plot of pressure recovery (sp) and – derivative, dsp/d(ln dte), versus equivalent time (dte) from the pumping test in the interval 12.03–103 m in HSH03.*

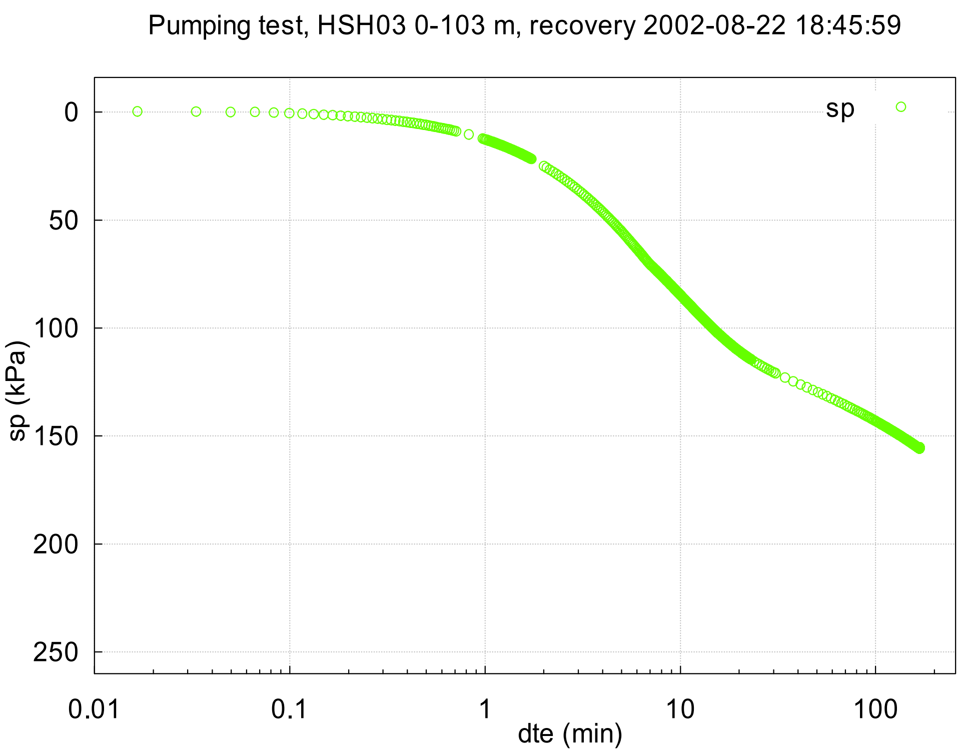


Figure A2-15. *Semi-logarithmic plot of pressure recovery (sp) versus equivalent time (dte) from the pumping test in the interval 12.03–103 m in HSH03.*

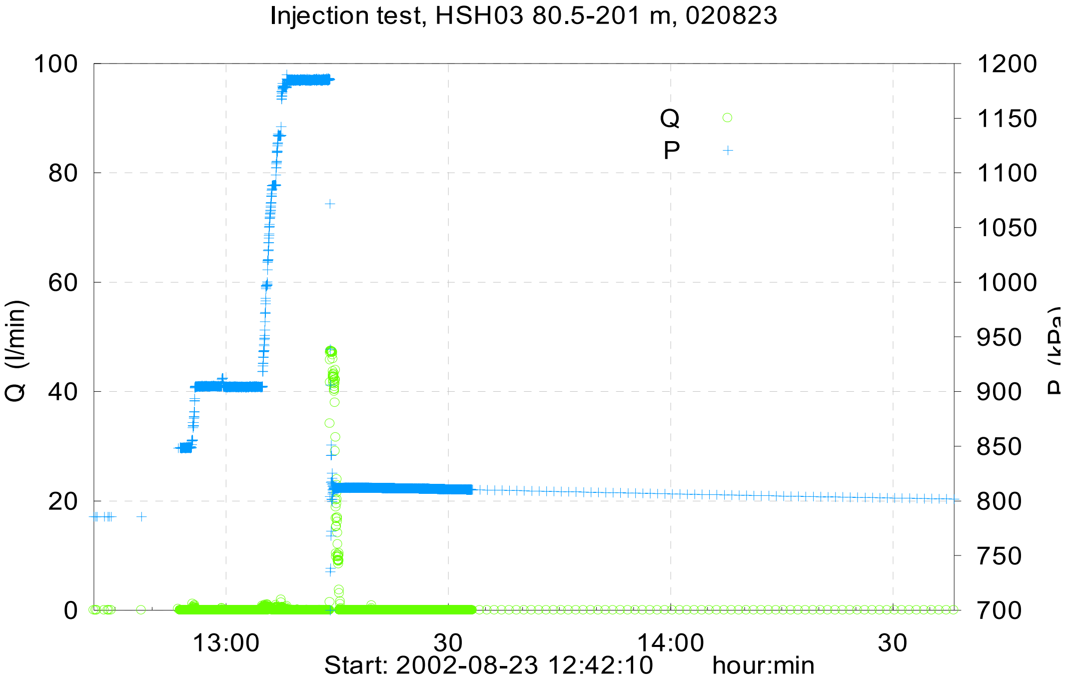


Figure A2-16. *Linear plot of flow rate (Q) and pressure (p) versus time during the injection test in the interval 80.5–201 m in HSH03.*

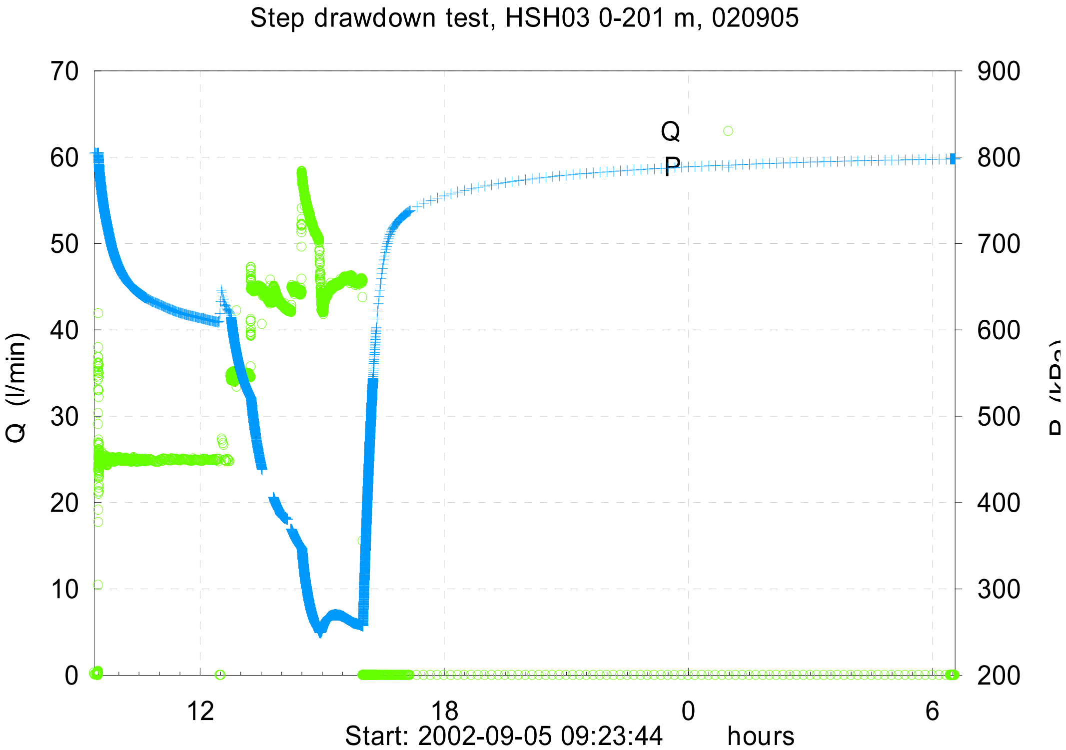


Figure A2-17. *Linear plot of flow rate (Q) and pressure (p) versus time during the step drawdown test in in HSH03.*

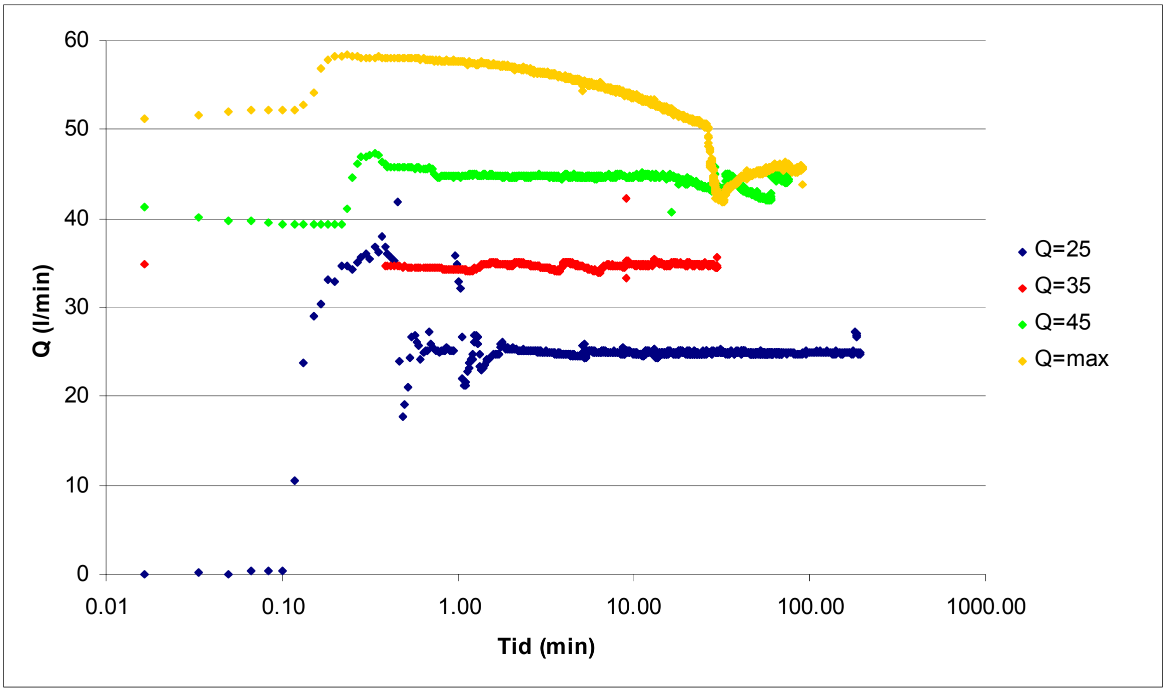


Figure A2-18. *Linear plot of flow rate (Q) versus time during the different steps of the step drawdown test in HSH03.*

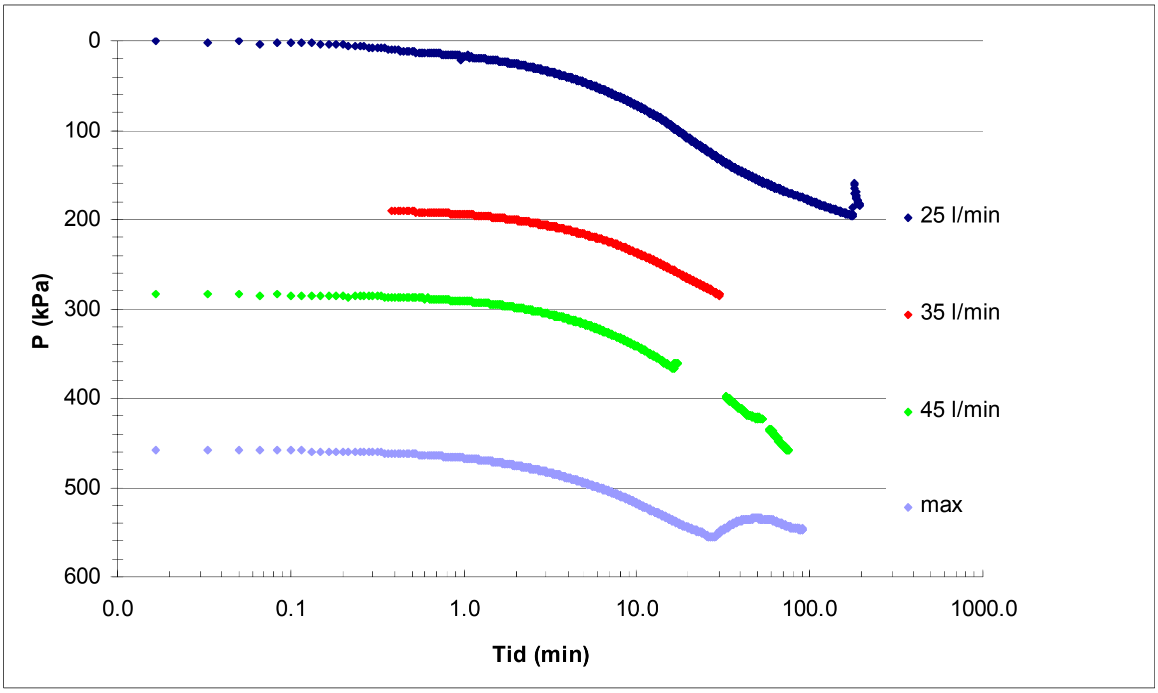


Figure A2-19. *Linear plot of pressure (p) versus time during the different steps of the step drawdown test in HSH03.*

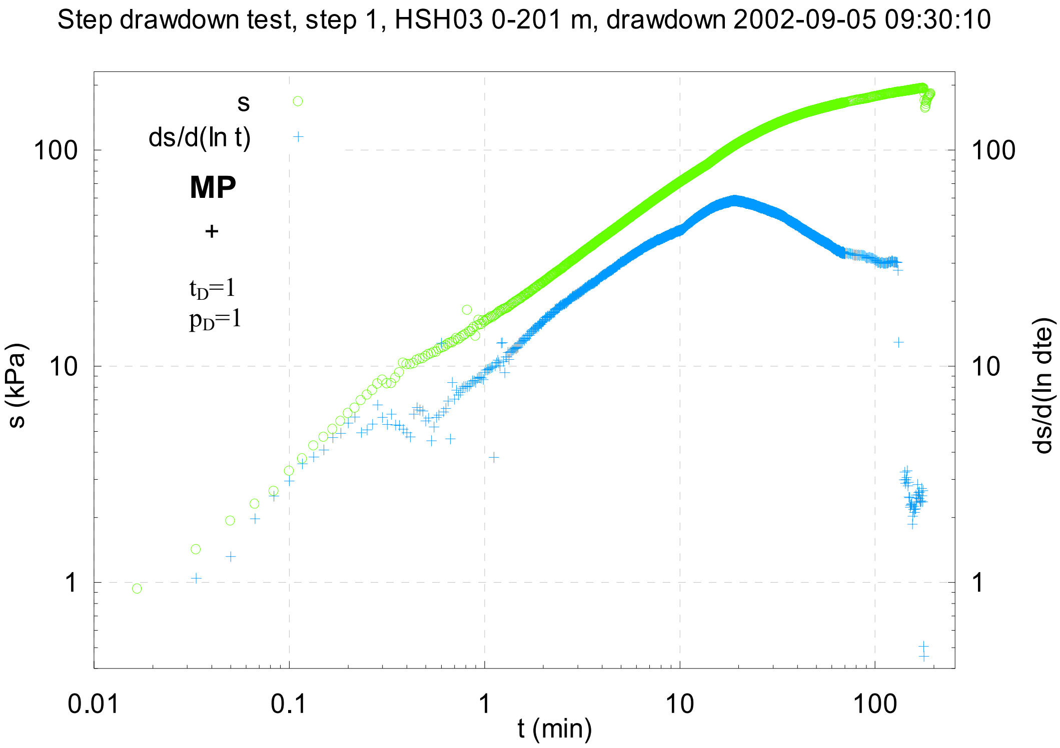


Figure A2-20. *Logarithmic plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the first step of the step drawdown test in HSH03.*

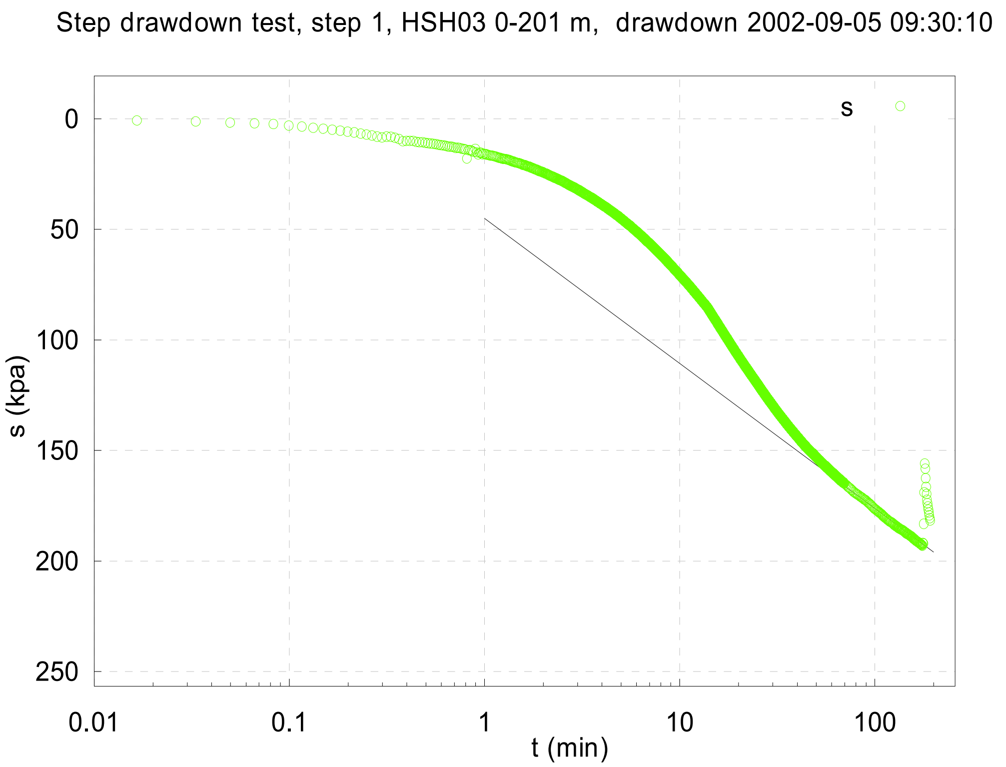


Figure A2-21. *Semi-logarithmic plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the first step of the step drawdown test in HSH03.*

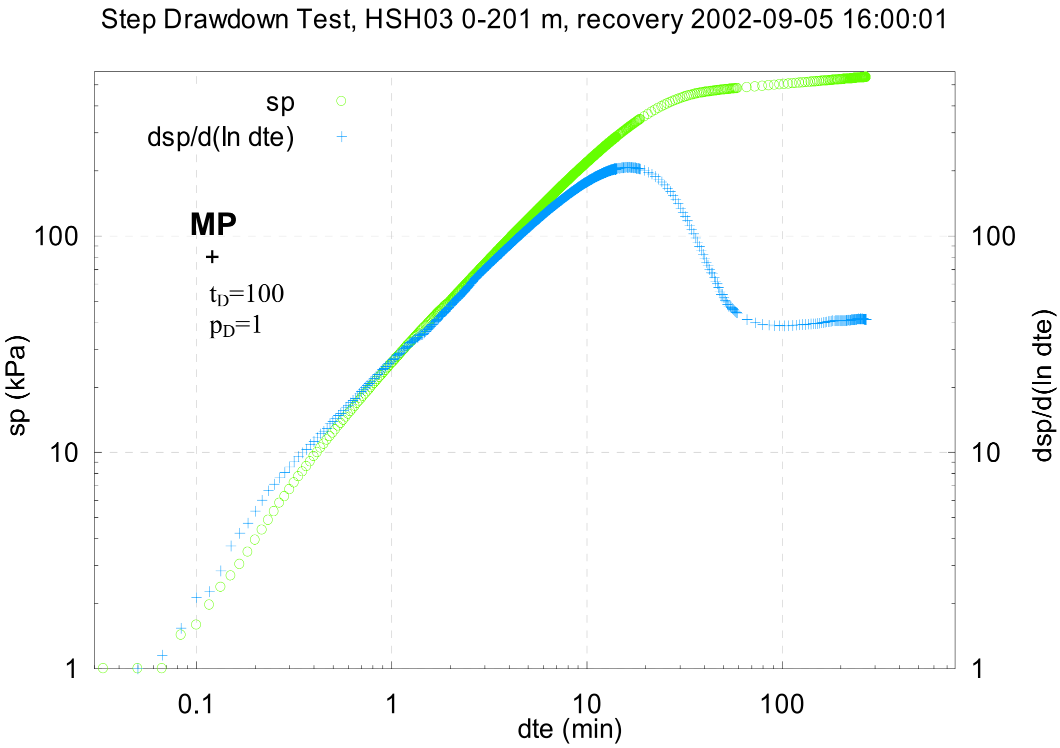


Figure A2-22. *Logarithmic plot of pressure recovery (sp) and – derivative, dsp/d(ln dte), versus equivalent time (dte) from the step drawdown test in HSH03.*

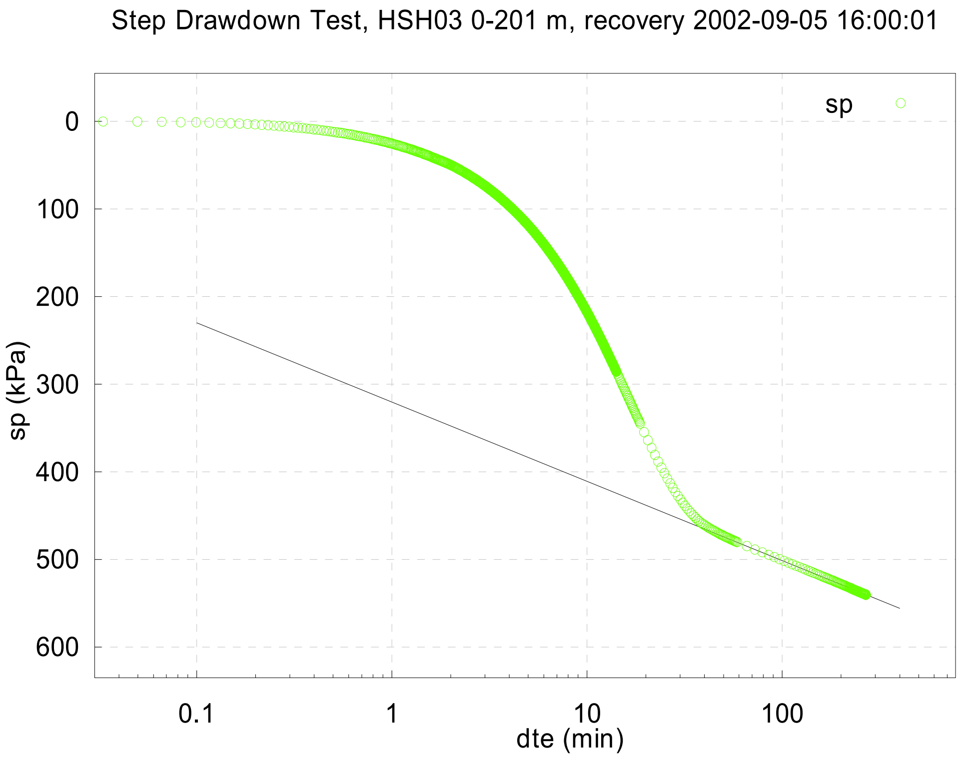


Figure A2-23. *Semi-logarithmic plot of pressure recovery (sp) versus equivalent time (dte) from the step drawdown test in HSH03.*

Parameter files – Single hole tests

Appendix 3

PLU Injection and Pumping tests. General information

SICADA Header	Header	Unit	Explanation
Idcode	Borehole		ID for borehole
Secup	Borehole secup	m	Length coordinate along the borehole for the upper limit of the test section
Seclow	Borehole seclow	(-)	Length coordinate along the borehole for the lower limit of the test section
Test_type	Test type (1- 7)	(-)	1: Pumpingtest-wireline eq., 2: Pumpingtest-submersible pump, 3: Pumpingtest-airlift pumping, 4: Injection test, 5: Slug test, 6: Flowlogging-PFL-DIFF, 7: Flowlogging-Impeller
start_date	Date for test start	Y	Date for the start of the pumping or injection test (YYYYMMDD hh:mm)
start_flow_period	Start flow / injection		Date and time for the start of the pumping or injection period (YYMMDD hh:mm:ss)
stop_flow_period	Start flow / injection		Date and time for the end of the pumping or injection period (YYMMDD hh:mm:ss)
lp	L_p	m	Hydraulic point of appication, based on hydraulic conductivity distribution (if available) or the midpoint of the borehole test section
mean_flow_rate_end_qm	Q_m	m^3/s	Arithmetricmean flow rate of the pumping/injection period.
flow_rate_end_qp	Q_p	m^3/s	Flow rate at the end of the pumping/injection period.
value_type_qp		m^3/s	Code for Q_p-value; -1 means Q_p<lower measurement limit, 0 means measured value, 1 means Q_p> upper measurement value of flowrate
q_measl_l	Q-measl_L	m^3/s	Estimated lower measurement limit for flow rate
q_measl_u	Q-measl_U	m^3/s	Estimated upper measurement limit for flow rate
total_volume_vp	V_p	m^3	Total volume pumped (positive) or injected (negative) water during the flow period.
dur_flow_phase_tp	t_p	s	Time for the flowing phase of the test
dur_rec_phase_tf	t_F	s	Time for the recovery phase of the test
initial_head_hi	h_i	m	Initial formation hydraulic head. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
head_at_flow_end_hp	h_p	m	Final hydraulic head at the end of the pumping/injection period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
final_head_hf	h_F	m	Final hydraulic head at the end of the recovery period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
initial_press_pi	p_i	kPa	Initial formation pressure.
press_at_flow_end_pp	p_p	kPa	Final pressure at the end of the pumping/injection period.
final_press_pf	p_F	kPa	Final pressure at the end of the recovery period.
fluid_temp_tew	Te_w	gr C	Fluid temperature in the test section representative for the evaluated parameters
fluid_elcond_ecw	EC_w	mS/m	Electrical conductivity of the fluid in the test section representative for the evaluated parameters
fluid_salinity_tdsw	TDS_w	mg/L	Total salinity of the fluid in formation at test section based on EC.
fluid_salinity_tdswn	TDS_{wn}	mg/L	Total salinity of the fluid in formation at test section based on water sampling and chemical analysis.
reference	references		SKB report No for reports describing data and evaluation
comments	comments		Short comment to data

Data from observation sections during singel hole pump- or injection tests. As a rule the observation sections are located above or below the tested interval in the same borehole.

SICADA Header	Header	Unit	Explanation
Idcode	Borehole		ID for borehole
Secup	Borehole secup	m	Length coordinate along the borehole for the upper limit of the injected or pumped test section
Seclow	Borehole seclow	m	Length coordinate along the borehole for the lower limit of the injected or pumped test section
start_date	Date for test start		Date for the start of the pumping or injection test (YYYYMMDD hh:mm)
obs_secup		m	Length coordinate along the borehole for the upper limit of the observation section
obs_seclow		m	Length coordinate along the borehole for the lower limit of the observation section
pi_above	p_{ai}	kPa	Initial formation pressure of the observation section, which is located above the test section in the borehole
pp_above	p_{ap}	kPa	Final pressure at the end of the pumping/injection period in the observation section, which is located above the test section in the borehole
pf_above	p_{aF}	kPa	Final pressure at the end of the recovery period in the observation section, which is located above the test section in the borehole
pi_below	p_{bi}	kPa	Initial formation pressure of the observation section, which is located below the test section in the borehole
pp_below	p_{bp}	kPa	Final pressure at the end of the pumping/injection period in the observation section, which is located below the test section in the borehole
pf_below	p_{bF}	kPa	Final pressure at the end of the recovery period in the observation section, which is located below the test section in the borehole

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_d; General information

idcode	secup	seclow	seclen_class	test_type	formation_type	start_date (YYYY-MM-DD hh:mm)	stop_date (YYYY-MM-DD hh:mm)	start_flow_period (YYYY-MM-DD hh:mm:ss)	stop_flow_period (YYYY-MM-DD hh:mm:ss)	flow_rate_end_qp	value_type_qp (-1, 0 or 1)	q_measl_l	q_measl_u	tot_volume_vp
Borehole	Borehole secup (m)	Borehole seclow (m)	(m)	Test type (1-6)	Formation type (-)	Date and time for test, start YYYYMMDD hh:mm		Start flow/ injection hhmmss	Stop flow/ injection hhmmss	Qp (m**3/s)		Q-measl-L (m**3)/s	Q-measl-U (m**3)/s	V_p (m**3)
HSH03	12,03	201,00		1B	1	20020820 18:00	20020822 08:15	20020821 06:30:00	20020821 06:30:00	2,85E-04	0	8,3E-05	1,3E-03	10,0
HSH03	12,03	103,00		1B	1	20020822 15:00	20020823 06:05	20020822 15:00:00	20020822 18:46:00	3,70E-04	0	8,3E-05	1,3E-03	5,0
HSH03	80,50	201,00		3	1	20020823 12:42	20020823 14:41	20020823 12:53:20	20020823 13:14:00		-1	1,7E-05	1,3E-03	0,0
HSH03	12,03	201,00		1B	1	20020905 09:24	20020906 06:30	20020905 09:30:01	20020905 16:00:01	7,60E-04	0	8,3E-05	1,3E-03	13,5

mean_flow_rate_qm	dur_flow_phase_tp	dur_rec_phase_tf	initial_head_hi	head_at_flow_end_hp	final_head_hf	initial_press_pi	press_at_flow_end_pp	final_press_pf	fluid_temp_tew	fluid_elcond_ecw	fluid_salinity_tdsw	fluid_salinity_tdswn	reference	comments
Q_m (m**3/s)	tp (s)	t_F (s)	h_i (m a sl)	h_p (m a sl)	h_F (m a sl)	p_i (kPa)	p_p (kPa)	p_F (kPa)	Te_w (^{o}C)	EC_w (mS/m)	TDS_w (mg/ L)	TDS_{wm} (mg/ L)	Reference	Comments (-)
	36960	55740	0,10	-13,29	-0,40	285,00	153,48	280,07						
	13560	40740	0,18	-16,01	-0,18	522,07	363,05	518,56						
	1242	5040	-0,27			785,61	1185,64	801,84						
5,77E-04	23400	52380	0,03	-55,72	-0,66	804,90	257,41	798,16						

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_obs

idcode	secup	seclow	start_date (YYYY-MM-DD hh:mm)	obs_secup	obs_seclow	pi_above	pp_above	pf_above	pi_below_	pp_below	pf_below
Borehole	Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YYYYMMDD hh:mm	Upper limit of observation section(m)	Lower limit of observation section (m)	p_{ai} (kPa)	p_{ap} (kPa)	p_{aF} (kPa)	p_{bi} (kPa)	p_{bp} (kPa)	p_{bF} (kPa)
HSH03	12,03	103,00	20020822 15:00	104,00	201,00				1007,78	1006,02	1008,68

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_ed1; Basic evaluation

idcode	secup	seclow	start_date (YYYY-MM-DD hh:mm)	seclen_class	spec_capacity_q_s	value_type_q_s (-1, 0 or 1)	transmissivity_tq	transmissivity_moye	formation_width_b	width-of_channel b	tb	l_measl_tb	u_measl_tb	sb	assumed_sb	leakage_factor_lf	transmissivity_tt
Borehole	Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YYYYMMDD hh:mm	(m)	Q/s (m^2/ s)		T_Q (m^2/ s)	T_M (m^2/ s)	b (m)	B (m)	TB (1D) (m^3/ s)	TB-measl-L (1D) (m^3/ s)	TB-measl-U (1D) (m^3/ s)	SB (1D) (m)	SB* (1D) (m)	L_f (1D) (m)	T_T (2D) (m^2/ s)
HSH03	12,03	201,00	20020820 18:00		2,17E-05	0		2,83E-05	188,97								1,46E-05
HSH03	12,03	103,00	20020822 15:00		2,33E-05	0		2,76E-05	90,97								1,21E-05
HSH03	80,50	201,00	20020823 12:42			-1			120,5								
HSH03	12,03	201,00	20020905 09:24		1,39E-05	0		1,51E-05	188,97								1,55E-05

value_type_tt (-1, 0 or 1)	l_measl_q_s	u_measl_q_s	storativity_s	assumed_s	leakage_koeff	hydr_kond_ks	value_type_ks (-1, 0 or 1)	l_meas_limit_ks	u_meas_limit_ks	spec_storage_ss	assumed_ss	lp	c	cd	skin	storativity_ratio	interflow_coeff
	Q/s-measl-L (m^2/ s)	Q/s-measl-U (m^2/ s)	S (2D) (-)	S* (2D) (-)	K´/b´ (2D) (1/s)	K_S (3D) (m/s)		K_S-measl-L (3D) (m/s)	K_S-measl-U (3D) (m/s)	S_S (3D) (1/m)	S_S* (3D) (1/m)	L_p (m)	C (m**3/Pa)	C_D (-)	ξ (2D) (-)	ω (-)	λ (-)
0	2,0E-06	2,0E-03		1,11E-05									1,71E-06		-4,17		
0	2,0E-06	2,0E-03		1,11E-05									2,22E-06		-4,53		
-1	4,0E-07	2,0E-03															
0	2,0E-06	2,0E-03		1,11E-05									1,82E-06		-1,19		

dt1	dt1	comments
t_1 (s)	t_2 (s)	Comments (-)
9000	30000	
4800	13560	
4200	18000	

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_ed2; IRL and GRF evaluation

Borehole	Borehole secup (m)	Borehole seclow (m)	Date for test, start YYYYMMDD	T_{ILR} (m^2/ s)	S_{ILR} (-)	$C_{,ILR}$ (m**3/Pa)	$C_{D,ILR}$ (-)	ξ_{ILR} (-)	ω_{ILR} (-)	λ_{ILR} (-)	T_{GRF} (m^2/ s)	S_{GRF} (-)	D_{GRF} (-)	Comments (-)

Appendix 4

Parameter files – Observation tests

INTERFERENCE TESTS - OBSERVATION SECTIONS: plu_inf_test_obs_d

idcode	**secup**	**seclow**	test_type	formation_type	**test_borehole**	**test_secup**	test_seclow	start_date (YYYY-MM-DD hh:mm)	stop_date (YYYY-MM-DD hh:mm)	start_flow_period (YYYY-MM-DD hh:mm:ss)	stop_flow_period (YYYY-MM-DD hh:mm:ss)	lp	radial_distance_rs	shortest_distance_rt
ID Obs. Borehole	Borehole secup (m)	Borehole seclow (m)	Test type (1-7)	Formation type (-)	ID Pumped Borehole	Test secup	Test seclow	Date for test, start YY-MM-DD	Date for test, stop YY-MM-DD	Start flow hh:mm:ss	Stop flow hh:mm:ss	Lp (m)	r_s (m)	r_t (m)
HSH01	12,03	200,00	2	1	HSH03	12,03	201	20020820 18:00	20020822 08:15	20020821 06:30:00	20020821 16:46:02	94	60,3	

time_lag_press_dtl	initial_head_hi	head_at_flow_end_hp	final_head_hf	initial_press_pi	press_at_flow_end_p	final_press_pf	fluid_temp_teo	fluid_elcond_eco	fluid_salinity_tdso	fluid_salinity_tdsom	reference	comments
dt_L (s)	h_i (m)	h_p (m)	h_F m)	p_i (kPa)	p_p (kPa)	p_F (kPa)	Te_o (^oC)	EC_o (mS/m)	TDS_o (mg/ L)	TDS_{om} (mg/ L)	Reference	Comments (-)
120	-0,03	-5,29	-4,00									

INTERFERENCE TESTS - OBSERVATION SECTIONS: plu_inf_test_obs_ed

idcode	**secup**	**seclow**	start_date (YYYY-MM-DD hh:mm)	stop_date (YYYY-MM-DD hh:mm)	**test_borehole**	**test_secup**	test_seclow	formation_width_b	width_of_channel_b	tbo	l_meas_limit_tb	u_meas_limit_tb	sbo	leakage_factor_lfo	transmissivity_tto	l_meas_limit_t	u_meas_limit_t	storativity_so
ID Obs. Borehole	Borehole secup (m)	Borehole seclow (m)	Date for test, start YY-MM-DD	Date for test, stop YY-MM-DD	ID Pumped Borehole	Test secup	Test seclow	b (m)	B (m)	TB_o (1D) (m^3/ s)	TB-measl-L (1D) (m^3/ s)	TB-measl-U (1D) (m^3/ s)	SB_o (1D) (m)	L_{f0} (1D) (m)	T_o (2D) (m^2/ s)	T-measl-L (2D) (m^2/ s)	T-measl-U (2D) (m^2/ s)	S_o (2D) (-)
HSH01	12,03	200,00	20020820 18:00	20020822 08:15	HSH03	12,03	201	188							1,45E-05	2,00E-06	2,00E-03	1,11E-05

leakage_coeff_o	hydr_kond_kso	l_meas_limit_ks	u_meas_limit_ks	spec_storage_sso	dt1	dt2	
K'/b'_o (2D) (1/s)	K_{so} (3D) (m/s)	$K_{S\text{-measl-L}}$ (3D) (m/s)	$K_{S\text{-measl-U}}$ (3D) (m/s)	S_{so} (3D) (1/m)	t_1 or dt_1 (s)	t_2 or dt_2 (s)	Comments (-)
					3000	18000	

EXPLANATIONS

Header	SICADA Header	Unit	Explanation
ID Obs. Borehole			ID for obsevation borehole
Borehole secup		m	Length coordinate along the borehole for the upper limit of the observation section
Borehole seclow		(-)	Length coordinate along the borehole for the lower limit of the observation section
Test type (1- 7)		(-)	1A: Pumpingtest-wireline eq., 1B: Pumpingtest-submersible pump, 1C: Pumpingtest-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Flowlogging-PFL-DIFF_sequential, 5B: Flowlogging-PFL-DIFF_overlapping, 6: Flowlogging-Impeller, 7: Grain size analysis
Formation type		(-)	Rock: 1, Soil (superficial deposits): 2
ID- Pumped borehole		(-)	ID for pumped/injected borehole
Test secup	test_secup	(m)	Length coordinate along the borehole for the upper limit of pumped or injected section
Test seclow	test_seclow	(m)	Length coordinate along the borehole for the lower limit of pumped or injected section
	Date for test start	YY-MM-DD	Date for the start of the interference test (YYYY-MM-DD hh:mm)
	Date for test stop	YY-MM-DD	Date for the stop of the interference test (YYYY-MM-DD hh:mm)
Start flow	start_ flow_period		Time for the start of the pumping/injection period(YYYY-MM-DD hh:mm:ss)
Stop flow	stop_flow_period		Time for the stop of the pumping/injection period (YYYY-MM-DD hh:mm:ss)
L_p		m	Hydraulic point of application. Based on the hydraulic conductivity distribution (if available) or the midpoint of the borehole section
r_s		m	Radial distance from point of application of T (or K)-distribution (or mid-point) of test section to point of applicationT(or K)-distribution (or mid-point) of observation section
r_t		m	Shortest distance from point of application of T (or K)-distribution (or mid-point) of test section to point of applicationT(or K)-distribution (or mid-point) of observation section via interptered major conductive features. In the "Comments" the Model version X.Y used shall be reported.
dt_L		s	Time lag for pressure response to reach observation well after stop pumping/injecting, based on a reponse of0.01 m in the observation section
h_i		m. a. s. l.	Initial formation hydraulic head. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
h_p		m. a. s. l.	Final hydraulic head at the end of the pumping/injection period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
h_F		m. a. s. l.	Final hydraulic head at the end of the recovery period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
p_i		kPa	Initial formation pressure
p_p		kPa	Final pressure at the end of the pumping/injection period.
p_F		kPa	Final pressure at the end of the recovery period.
Te_o		gr C	Fluid temperature in formation at obsevation section
EC_o		mS/m	Electrical conductivity of the fluid in formation at observation section
TDS_o		mg/L	Total salinity of the fluid in formation at observation section based on EC
TDS_{om}		mg/L	Total salinity of the fluid in formation at observation section based on water sample and chemical analysis
b		m	Interpreted formation thickness or section length representative for evaluated T or TB.
B		m	Interpreted witdth of a formation with evaluated TB
TB_o		m^3/s	1D model for evaluation of formation properties. T=transmissivity, B=width of formation
TB-measl-L		m^2/s	Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or less than TB-measlim
TB-measl-U		m^2/s	Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or greater than TB-measlim
SB_o		m	1D model for evaluation of formation properties. S= Storativity, B=width of formation
L_{fo}		m	1D model for evaluation of Leakage factor
T_o		m^2/s	2D model for evaluation of formation properties. T=transmissivity
T-measl-L		m^2/s	Estimated measurement limit for evaluated T (T_T, T_Q, T_M). If estimated T equals T-measlim in the table actual T is considered to be equal or less than T-measlim
T-measl-U		m^2/s	Estimated measurement limit for evaluated T (T_T, T_Q, T_M). If estimated T equals T-measlim in the table actual T is considered to be equal or greater than T-measlim

S_o		(-)	2D model for evaluation of formation properties. S= Storativity
K´/b´		(1/s)	2D model for evaluation of leakage coefficient. K´= hydraulic conductivity in direction of leaking flow for the aquitard, b´= Saturated thickness of aquitard (leaking formation)
K_{so}		m/s	3D model for evaluation of formation properties. K=Hydraulic conductivity
K_S-measl-L		m/s	Estimated measurement limit for evaluated K_S. If estimated K_S equals K_S-measlim in the table actual K_S is considered to be equal or less than K_S-measlim
K_S-measl-U		m/s	Estimated measurement limit for evaluated K_S. If estimated K_S equals K_S-measlim in the table actual K_S is considered to be equal or greater than K_S-measlim
S_{so}		1/m	3D model for evaluation of formation properties. Ss=Specific Storage
t1 or dt_1		s	Estimated start time after pump/injection start OR recovery start, for the period used for the evaluated paramete
t2 or dt_2		s	Estimated stop time after pump/injection start OR recovery start, for the period used for the evaluated paramete
References			SKB report No for reports describing data and evaluation
Comments			Short comment to the evaluated parameters (Optional)

Parameter files – Flow logging tests

FLOWLOGG-IMPELLER TESTS-plu_impeller_basic

idcode	secup	seclow	test_type	start_date (YYYY-MM-DD hh:mm)	stop_date (YYYY-MM-DD hh:mm)	start_flowlogging (YYYY-MM-DD hh:mm:ss)	stop_flowlogging (YYYY-MM-DD hh:mm:ss)	surface_flow_qp	dur_flow_phase_tp	dur_flowlog_tfl	initial_head_ho	head_first_pump_hp	reference	comments
Borehole	**Borehole secup**	**Borehole seclow**	**Test type**	**Date and time of test, start**	**Date and time of stop of flow period**	**Date and time of flowl., start**	**Date and time of flowl., stop**	**Q_p**	**tp**	**t_{FL}**	**h_0**	**h_p**	**Reference**	**Comments**
	(m)	(m)	(1-7)	YYYYMMDD hh:mm		YYYYMMDD hh:mm	YYYYMMDD hh:mm	(m^3/s)	(s)	(s)	(m a s l)	(m a s l)	(-)	(-)
HSH03	29,00	198,70	6	2002-08-21 06:30	2002-08-21 16:46	2002-08-21 09:22	2002-08-21 15:02	2,87E-04	36960	20400	0,1	-12,36		

plu_impell-main_res

idcode	secup	seclow	l_corr	fluid_temp_tewo	fluid_elcond_ecwo	fluid_salinity_tdswo	cum_flow_qo	fluid_temp_tew	fluid_elcond_ecw	fluid_salinity_tdsw	cum_flow_q1t	cum_flow_qt	transmissivivy_hole_t	cum_transmissivity_tf	l_meas_limit_tf	u_meas_limit_tf	reference	comments
Borehole	**Borehole secup**	**Borehole seclow**	**L Corrected**	**Te_{w0}**	**EC_{w0}**	**TDS_{w0}**	**ΣQ_0**	**Te_w**	**EC_w**	**TDS_w**	**ΣQ_1**	**ΣQ**	**T Entire hole**	**ΣT_i**	**T_F-measl-L**	**T_F-measl-U**	**Reference**	**Comments**
	(m)	(m)	(m)	(^{o} C)	(mS/m)	(mg/ L)	(m**3/s)	(^{o} C)	(mS/m)	(mg/ L)	(m**3/s)	(m**3/s)	(m^2/ s)	(m^2/ s)	(m^2/ s)	(m^2/ s)	(-)	(-)
HSH03	29,00	198,70									2,16E-04	2,16E-04	1,46E-05	1,10E-05	2,0E-06	2,0E-03		

FLOWLOGG-IMPELLER TESTS plu_impeller_anomaly

idcode	secup	seclow	upper_limit	lower_limit	fluid_temp_tew	fluid_elcond_ecw	fluid_salinity_tdsw	deltaqi	spec_cap_deltaqi_sfl	bi	transmissivity_ti	l_meas_limit_ti	u_meas_limit_ti	reference	comments
Borehole	**Borehole secup**	**Borehole seclow**	**Upper limi**	**Lower limi**	**Te_w**	**EC_w**	**TDS_w**	**Q_i**	**Q_i/s_{FL}**	**b_i**	**T_i**	**T_i-measl-L**	**T_i-measl-U**	**Reference**	**Comments**
	(m)	(m)	L (m)	L (m)	(^{o} C)	(mS/m)	(mg/ L)	(m**3/s)	(m**2/s)	(m)	(m^2/ s)	(m^2/ s)	(m^2/ s)	(-)	(-)
HSH03	29,00	198,70	53	56				3,30E-05	2,65E-06	3	1,67E-06				
HSH03	29,00	198,70	58,5	59,5				1,83E-04	1,47E-05	1	9,33E-06				

EXPLANATIONS

Header	Unit	Explanation
Borehole		ID for borehole
Borehole secup	m	Length along the borehole of the upper limit of the logged section (Based on corrected length L)
Borehole seclow	m	Length along the borehole of the lower limit of the logged section (Based on corrected length L)
Test type (1-6)	(-)	1A: Pumpingtest-wireline eq., 1B: Pumpingtest-submersible pump, 1C: Pumpingtest-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Flowlogging-PFL-DIFF_sequential, 5B: Flowlogging-PFL-DIFF_overlapping, 6: Flowlogging-Impeller
Date and time for test start	YY-MM-DD hh:mm	Date and time for start of the flow period
Date and time for test stop	YY-MM-DD hh:mm	Date and time for stop of the flow period
Date and time for start flowl.	YY-MM-DD hh:mm	Date and time for start of the flow logging
Date and time for start flowl.	YY-MM-DD hh:mm	Date and time for stop of the flow logging
Q_p	m^3/s	Flow rate at surface during flow logging
tp	s	Time duration of the flow period
t_{FL}	s	Time duration of the flow logging
h_0	m. a. s. l.	Initial hydraulic head. Measured as water level in open borehole with reference level in the local coordinates system with z=0 m.
h_p	m. a. s. l.	Stabilised hydraulic head during flow period. Measured as water level in open borehole with reference level in the local coordinates system with z=0 m.
L , Corrected	m	Corrected length scale along the borehole
Te_{w0}	gr C	Natural (undisturbed) fluid temperature in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected lenght)
EC_{w0}	mS/m	Natural (undisturbed) electrical conductivity of the fluid in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected lenght)
TDS_{w0}	mg/L	Natural (undisturbed) total salinity of the fluid in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected lenght)
ΣQ_0	m^3/s	Natural (undisturbed) measured cumulative flow rate at the top of the flow logged interval. Position for measurement is related to L (corrected length)
Te_w	gr C	Fluid temperature in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected lenght)
EC_w	mS/m	Electrical conductivity of the fluid in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected lenght)
TDS_w	mg/L	Total salinity of the fluid in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected lenght)
ΣQ_i	m^3/s	Measured cumulative flow rate at the top of the flow logged interval during flow period. Position for measurement is related to L (corrected lenght)
ΣQ	m^3/s	Corrected cumulative flow rate $\Sigma Q= \Sigma Q_i - \Sigma Q_0$ at the top of the flow logged interval during flow period. Position for measurement is related to L (corrected length)
T (Entire hole)	m^2/s	Evaluated transmissivity for the entire borehole section considered representative for the flow logging
ΣT_i	m^2/s	Cumulative transmissivity of flow logged interval. 2D model for evaluation of formation properties of the test section$\Sigma Ti = T^* (\Sigma Qi/Q_p)$
T_F-measl-L	m	Lower measurement limit for borehole transmissivity from flow logging
T_F-measl-U	m	Upper measurement limit for borehole transmissivity from flow logging
Upper limit	m	Corrected length along the borehole for the upper limit of the flow anomaly
Lower limit	m	Corrected length along the borehole for the lower limit of the flow anomaly
Q_i	m^3/s	Flow rate of interpreted flow anomaly i
Q_i/s_{FL}	m^2/s	Specific capacity of interpreted flow anomaly i
b_i	m	Interpreted formation thickness representative for evaluated T_i of anomaly i.
T_i	m^2/s	Evaluated transmissivity of flow anomaly i
Ti-measl-L	m^2/s	Estimated lower measurement limit for evaluated Ti. If estimated Ti equals Ti-measlim-L, the actual Ti is considered to be equal or less thanTi-measlim-L
Ti-measl-U	m^2/s	Estimated upper measurement limit for evaluated Ti. If estimated Ti equals Ti-measlim-U, the actual Ti is considered to be equal or higher thanTi-measlim-U
Comments		Short comment to the evaluated parameters (Optional)

Index w Pumped borehole or -test section (w short for well)