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Oskarshamn site investigation

Pumping tests and flow logging in boreholes KSH03A and HSH02

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September 2004

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Abstract

Pumping test and flow logging has been conducted in the percussion drilled part of the core bored hole KFM03A and in HSH02, percussion drilled bore hole situated in the vicinity of core bore hole number two, KSH02. Both bore holes are drilled within the frame of the site investigation at Simpevarp peninsula, Oscarshamn. Tests in KSH03A was conducted after finished percussion drilling down to 100.6 m with a diameter of 160 mm. KSH03A is in its final form a telescopic bore hole witch means that the interval 0–101.4 m is percussion drilled and sealed by a casing of larger dimension (200 mm inner diameter) than the core drilled interval (101.4–1000.7 m) of 76 mm diameter.

Main objective with the measuring campaign was to perform hydrological characterization of bore holes, identify position and size of inflow and to estimate transmissivity for single flow anomalies (i.e. fractures/fracture zones). Water samples were taken at three occasions during pumping of the whole bore holes to make a geochemical characterization by chemical analyses of the bore hole fluid possible.

Open hole pumping tests with a withdrawal and recovery phase or c 10 and 12 hours respectively were conducted in both KSH03A and HSH02. In conjunction with these tests flow logging was performed. To complete and ensure quality of flow logging data shorter complementary pumping tests was conducted above a single packer in the bore hole interval that was not flow logged due to practical reasons (position of the bore hole pump is the upper limit for flow logging)

Low transmissivity close to measurement limit of the system, limited by the need of cooling of the bore hole pump, was indicated in both boreholes. To enable complementary tests above flow logged interval part of the pumped volume was shunted back into the bore hole. This made it possible to verify and ensure flow logging data quality even though pumped flow was below specified measuring limit of the system. A comparison of transmissivity of flow logged bore hole interval with and without data from complementary test showed a high degree of agreement.

Sammanfattning

Provpumpning och flödesloggning har genomförts i den hammarborrade delen av kärnborrhålet KSH03A samt i HSH02, hammarborrhål beläget i närheten av kärnborrhål nummer två. Båda hålen borrade inom ramen för platsundersökningarna i Oskarshamn på Simpevarpshalvön. Tester genomfördes i KSH03A efter hammarborrning av de första 100,6 metrarna då borrhålets diameter var 160 mm. KSH03A är i sin slutliga utformning ett s k teleskopborrhål, vilket innebär att avsnittet 0–101,4 m är hammarborrat och avtätat med foderrör av grövre dimension (200 mm innerdiameter) än det kärnborrade avsnittet (101,4–1000,7 m) som håller en diameter av 76 mm.

Huvudskaliga syftet med mätkampanjen var att hydrauliskt karaktärisera borrhålen, bestämma position och storlek för inflöden i borrhålen samt att uppskatta transmissivitet för enskilda flödesanomalier (dvs sprickor/sprickzoner). Vattenprover togs vid tre tillfällen under pumpning av hela hålen för att möjliggöra geokemisk karakterisering av borrhålen genom kemisk analys av borrhålsvattnet.

Pumptester i öppet hål med störningsfas och återhämtningsfas på ca 10 respektive 12 timmar utfördes i både KSH03A och HSH02. I samband med dessa tester utfördes flödesloggning. För att komplettera och säkra kvalitén på flödesloggningsdata utfördes i båda hålen kortare kompletterande pumptester ovan manschett för det borrhålsintervall som ej flödesloggats på grund av praktiska skäl (borrhålspump utgör övre begränsning för flödesloggning).

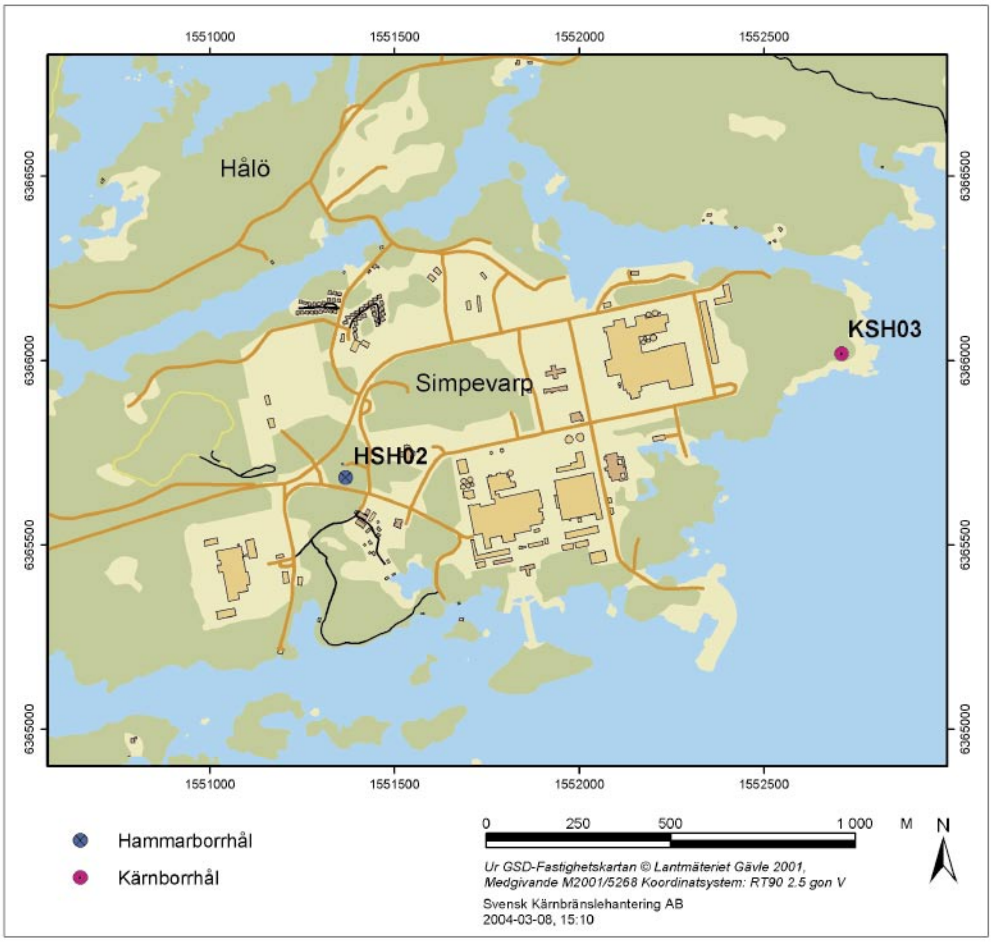
Låg transmissivitet nära systemets mätgräns, vilken begränsas av borrhålspumpens behov av kylning, konstaterades i båda hålen. För att möjliggöra kompletterande tester ovan flödesloggat borrhålsintervall shuntades en del av flödet tillbaks ned i pumpat borrhål. På detta sätt kunde en verifikation och kvalitetssäkring av data från flödesloggning genomföras trots att flödet var mindre än den specificerade mätgränsen för systemet. Vid en jämförelse av transmissivitet för flödesloggat borrhålsintervall beräknat med och utan data från kompletterande test konstaterades en mycket god överensstämmelse.

Contents

1 Introduction

A general program for site investigations presenting survey methods has been prepared /1/, as well as a site-specific program for the investigations in the Simpevarp area /2/. The hydraulic pumping tests form part of the site characterization program in the work breakdown structure of the execution programme /3/ with WBS # 1.1.5.5.

Measurements were carried out in borehole KSH03A and HSH02 during 21st–29th August, 2003 following the methodology described in SKB MD 323.003 and 322.009 and the activity plan AP PF 400-03-46 (SKB internal controlling document). Data and results were delivered to the SKB site characterization database SICADA with field note no Simpevarp 134.



Figur 1-1. *Transportbehållare för bränsleelement på transportfordon.*

2 Objectives

Pumping tests, flow logging and water sampling was performed in HSH02 and percussion drilled part of KSH03A. Objectives of the tests were to determine the hydraulic properties of the rock formation penetrated by the boreholes and to identify position and transmissivity of individual flow anomalies (e.g. fractures/fracture zones).

In addition, water samples were taken during pumping of the entire bore holes for later analysis of the borehole fluid to enable a general hydrogeochemical characterization of the boreholes.

3 Scope

3.1 Boreholes tested

Technical data of the boreholes tested are shown in Table 3-1. The reference point in the boreholes is top of casing (ToC). The Swedish National coordinate system (RT90) is used in the x-y-direction together with RHB70 in the z-direction. The reported borehole diameter for KSH03A in Table 3-1 refers to the percussion-drilled interval at the time of test with temporary casing installed. The borehole diameters reported in Table 3-1 are nominal values. Actual values (measured as the diameter of the drill bit) are reported in section 6.

Table 3-1. Technical data of the tested boreholes.

Borehole data Bh 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) (°)	Dip-direction-top of borehole (from local N) (°)	Remarks	Drilling finished Date (YYYY-MM-DD)
[1)]KSH03A	4.267	0.00–11.80	[2)]0.165	–59.254	125.088		2003-09-03
		11.80–100.60	[3)]0.160				
HSH02	6.649	0.000–12.000	[2)]0.160	–80.088	186.103		2002-07-08
		12.000–12.030	[2)]0.148				
		12.030–200.000	[3)]0.140				

[1]) Data valid for percussion-drilled interval at the time of the test.
[2]) Casing.
[3]) Bore hole.

Table 3-2. Coordinates of the tested boreholes. (From SICADA).

Borehole data Bh ID	Northing (m)	Easting (m)
KSH03A	6366018.632	1552711.204
HSH02	6365682.896	1551368.337

3.2 Tests performed

The tests performed in the boreholes are listed in Table 3-3 according to Activity Plan AP PF 400-03-046 (SKB internal controlling document). Pumping tests and impeller flow meter logging were carried out with the HTHB (HydroTestutrustning i Hammar-Borrhål) unit. Both types of tests are described in the corresponding methodology descriptions for single-hole pumping tests (SKB MD 321.003: Metodbeskrivning för hydrauliska enhålspumptester) and flow logging (SKB MD 322.009: Metodbeskrivning för flödesloggning). In conjunction with the flow logging, temperature- and electric conductivity logging of the borehole water was also performed.

Table 3-3. Borehole tests performed.

Borehole tests Bh ID	Test section (m)	Test type[1]	Test start date and time (YYYY-MM-DD tt:mm)	Test stop date and time (YYYY-MM-DD tt:mm)
KSH03A	11.80–100.60	1B	2003-08-21 08:43	2003-08-22 06:58
”	28.0–97.0	6, L-Te, L-EC	2003-08-21 14:56	2003-08-21 19:10
”	11.80–28.0	1B	2003-08-26 06:46	2003-08-26 12:34
HSH02	12.03–200.00	1B	2003-08-27 08:25	2003-08-28 11:01
”	33.0–195.0	6, L-Te, L-EC	2003-08-27 13:30	2003-08-27 19:48
”	12.03–33.0	1B	2003-08-28 15:55	2003-08-29 08:20

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

During the pumping tests, water samples were taken and analysed. Manual observations of the groundwater level in the pumped boreholes were also made during the tests.

4 Description of equipment

4.1 Overview

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

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 down-hole flow rate are also used. At the top of the bore hole 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.

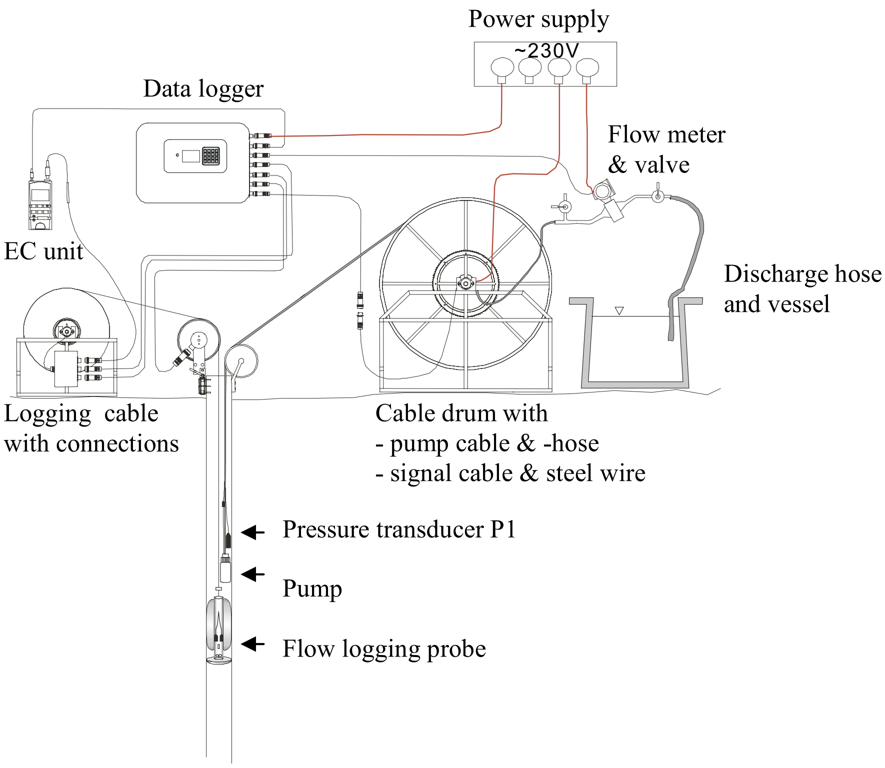


Figure 4-1. *Schematic test set-up for a pumping test in an open borehole inbination with flow logging with HTHB.*

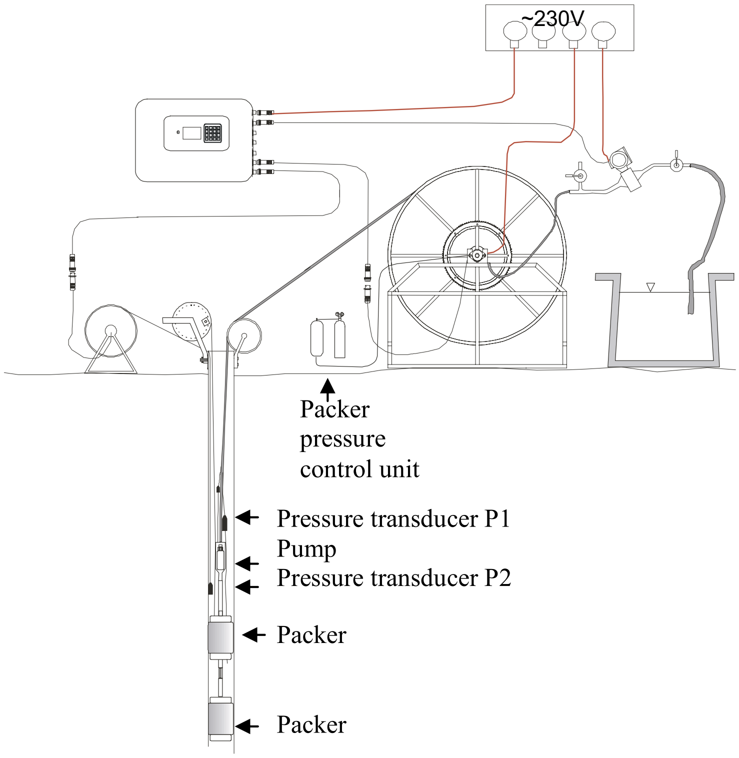


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB.*

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.

4.2 Measurement sensors

Technical data of the sensors used 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 measurement sensors used together with estimated data specifications of the HTHB test system for pumping tests and flow logging (based on current laboratory and field experiences).

Technical specification Parameter		Unit	Sensor	HTHB system	Comments
Absolute pressure	Output signal	mA	4–20		
	Meas. range	kPa	0–1,500	0–1,500	
	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	0–50,000	0–50,000	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 and 100 s sampling time
	Accuracy***	% o.r.**		± 20	
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 repeatability
** 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 data. For example, the flow logging probe is very sensitive to variations in the borehole diameter, cf Figure 4-3. Borehole deviation and uncertainties in the borehole inclination may also affect the accuracy of measured data.

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 recorded flow at each position during flow logging was found to be rather insensitive to the measurement time (50, 100 or 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.

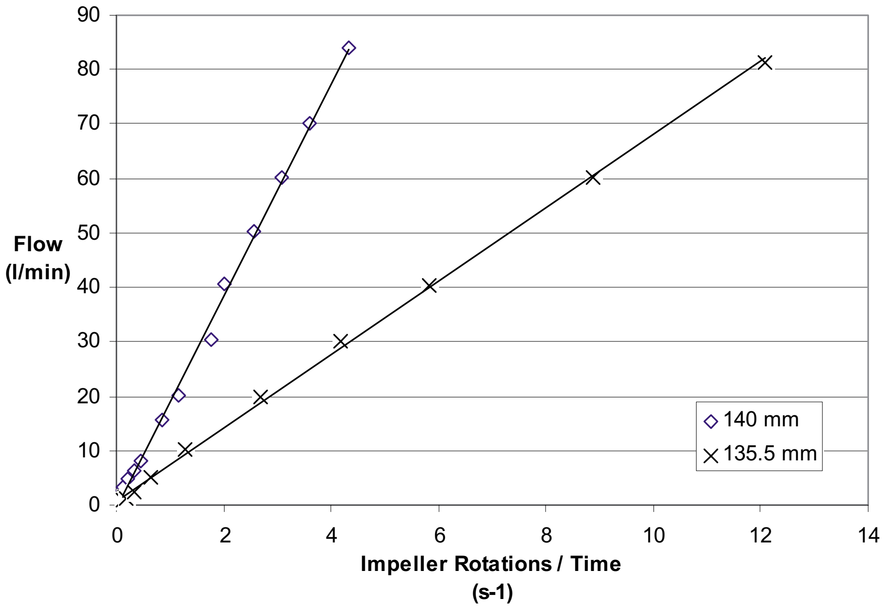


Figure 4-3. *Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).*

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.

In addition the theoretical well-bore storage coefficient C for the actual test configurations and the geometrical data of the boreholes has been calculated, see Table 4-2. These values on C may be compared with the estimated ones from the test interpretations described in Chapter 6.

Table 4-2. Position of sensors (from ToC) and of equipment that may affect well bore storage for the different hydraulic tests performed.

Borehole information				Sensors		Equipment affecting wellbore storage (WBS)			
ID	Test interval (m)	Test config	Test type[1]	Type	Position (m b ToC)	Function	Position[2] relative test section	Outer diameter (mm)	C (m^3/Pa) for actual test[3)]
KSH03A	11.8–100.6	Open hole	1B	Pump-intake	29.5	Pump	In section		$2.05 \cdot 10^{-6}$
						Pump hose	In section	33.5	
						Pump cable	In section	14.5	(based on a casing diameter of 165 mm)
						Tecalan hose	In section	6	
						Steel wire	In section	6	
			1B	P (P1)	26.72	Signal cable	In section	8	
			6	EC, Te, Q	28–99.6	Signal cable	In section	13.5	
KSH03A	11.8–28.0	Open hole above single packer	1B	Pump-intake	24.5	Pump	In section		$2.06 \cdot 10^{-6}$
						Pump hose	In section	33.5	
						Pump cable	In section	14.5	(based on a casing diameter of 165 mm)
						Tecalan hose	In section	6	
						Steel wire	In section	6	
			1B	P (P1)	21.72	Signal cable	In section	8	
HSH02	12.0–200.0	Open hole	1B	Pump-intake		Pump	In section		$1.92 \cdot 10^{-6}$
					29.5	Pump hose	In section	33.5	
						Pump cable	In section	14.5	(based on a casing diameter of 160 mm)
						Tecalan hose	In section	6	
						Steel wire	In section	6	
			1B	P (P1)	26.72	Signal cable	In section	8	
			6	EC, Te, Q	33–195	Signal cable	In section	13.5	
HSH02	12.0–33	Open hole above single packer	1B	Pump-intake		Pump	In section		$1.93 \cdot 10^{-6}$
					29.5	Pump hose	In section	33.5	
						Pump cable	In section	14.5	(based on a casing diameter of 160 mm)
						Tecalan hose	In section	6	
						Steel wire	In section	6	
			1B	P (P1)	26.72	Signal cable	In section	8	

1) 1B: Pumping test-submersible pump, 6: Flow logging–Impeller incl. EC-logging (EC-sec) and temperature logging (Te-sec)

2) Position of equipment that can affect well bore storage. Position given as "In Section" or "Above Section"

3) Based on the casing diameter and the actual borehole diameter for open-hole tests together with the compressibility of water for tests in isolated sections, respectively (net values)

5 Test performance

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 frequent if needed. Date of last sensor calibrations of HTHB2, prior to tests considered in this report, are presented in Table 5-1. Calibration protocols were submitted in the delivery of raw data after the test campaign.

An equipment check was performed at the site prior to the tests to establish the operating status of sensors and other equipment. In addition, calibration constants were implemented and checked and logger time was synchronised.

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 while lowering, P1 coincided well to the total head of water ($p/\rho g$). The temperature sensor showed expected values in both air and water.

The sensor for electric conductivity was checked against calibration fluids ranging from 10 to 1000 mS/m with satisfying result. As indicated by registered rotations while lowering the flow logging probe the impeller indicating flow through the probe was in working order. The measuring wheel (used to check the position of the flow logging probe) and the pulse transducer attached to it indicated a length that corresponded well to the pre-measured cable length.

Table 5-1. Date of latest sensor calibration prior to tests.

Sensor	Symbol	SKB ID	Calibration date
Flow meter	Q_{surf}	2788	2003-03-03
Pressure transducer	P1	2766	2003-03-07
Pressure transducer	P2	2535	2003-03-07
Temperature transducer	T	2784	2003-03-07
Flow impeller	Spinner	2785	2003-03-05
EC sensor	Cond	2783	2003-05-15
Measuring wheel	Pos	2787	2003-06-04

5.2 Procedure

5.2.1 Overview

The pumping tests were carried out as single-hole, constant head tests followed by a pressure recovery period.

The flow logging was performed while pumping. Discrete flow measurements were made, starting from the bottom and upward along the borehole, at fixed step lengths of 5 m until the first detectable flow was found. After the first detectable flow, the fixed step length was shortened to 2 m. To verify the position and extension of each anomaly found, with a precision of 0.5 m, flow measurements were undertaken with a step length of 0.5 m above and under indicated anomaly. The flow logging survey was terminated at 3 m below the submersible pump in the borehole. A pumping test was carried out in the remaining part above a single packer positioned at highest position of the flow logging probe to verify the discrepancy between actual flow at surface and flow indicated by flow logging probe at highest position.

5.2.2 Details

Single-hole pumping tests

Before the tests, functioning checks and cleaning of equipment together with time synchronisation of clocks and data loggers were performed according to the Activity Plan (AP PF 400-03-46, SKB internal controlling document). Short flow capacity tests were carried out to choose an appropriate flow rate for the tests. The pumped water from KSH03A was discharged into a container and taken care of. The pumped water from HSH02 was discharged on the ground, sloping downhill from the pumping borehole towards a ditch.

The main test in each borehole was a c 10 h long pumping test in the open hole in combination with flow logging, followed by a recovery period of approximately the same length. The sampling frequency of pressure during the pumping tests was according to Table 5-1 or higher. The hydraulic tests in the boreholes were performed in the following order of time: KSH03A (11.80–100.6 m), KSH03A (11.80–28.0 m), HSH02 (12.03–200.0 m) and HSH02 (12.03–33.0 m).

The test program performed in the boreholes was mainly according to the Activity Plan. Compared to the Methodology Description for single-hole pumping tests, some deviations were made regarding the recommended test times:

- The recommended test time (24h+24h for drawdown/recovery) for the longer tests during flow logging was decreased to c10 h +12 h 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 general is sufficient to estimate the hydraulic properties of the borehole, e.g. wellbore storage effects and other disturbing factors have expired.

Table 5-1. Sampling frequency used for pressure registration during the pumping tests.

Time interval (s) from start/stop of pumping	Sampling frequency (s)
1–300	1
301–600	10
601–3,600	60
>3,600	600

Flow logging

Before start of the flow logging, the probe was lowered to the bottom of the borehole. While lowering along the borehole at a maximal speed of 0.5 m/s (limited by swivel connection to signal- and supporting cable), temperature- and electric conductivity data were sampled. The flow logging probe was halted for c 10 seconds every fifth meter allowing sensors to adapt to changing conditions.

Flow logging was performed during withdrawal phase of the open hole pumping test (c 10 h pumping), starting from the bottom of the hole going upward. Flow logging started when pressure in the borehole was approximately stable. The time needed to complete the flow logging survey depends on the length and character of the borehole. In general, between 3–7 hours is normal for a percussion borehole of 100–200 m length.

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 files 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.

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. Diagrams listed in the Instruction for analysis of injection- and single-hole pumping tests (SKB MD 320.004) were produced using the code SKB-plot.

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 Single-hole pumping tests

As discussed in Section 5.2.1 the pumping tests were performed as constant head tests followed by a pressure recovery period. Firstly, a qualitative evaluation of actual flow regimes (wellbore storage, pseudo-linear, pseudo-radial and pseudo-spherical flow respectively) and possible outer boundary conditions during the tests was performed. The qualitative evaluation was made from analyses of log-log diagrams of draw down and/or recovery data together with the corresponding pressure derivatives versus time. In particular, pseudo-radial flow is reflected by a constant (horizontal) derivative in the diagrams whereas no-flow- and constant head boundaries are reflected by an increase and decrease of the derivative, respectively.

From the results of the qualitative evaluation, appropriate interpretation models for the tests were selected. For tests where a certain period with pseudo-radial flow could be identified methods for single-hole, constant-head tests in an equivalent porous medium were used for the evaluation.

For tests indicating a fractured- or borehole storage dominated response, corresponding type curves were used in the analyses.

If possible, transient analysis was made both on the draw down- and recovery phase of the tests. The recovery data were plotted versus equivalent time. The analysis of the draw down- and recovery data was generally made both in log-log and lin-log diagrams according to standard methods described in the above instruction. In addition, a steady-state analysis (e.g. Moye's formula) was made for all tests for comparison.

The transient analysis of tests dominated by wellbore storage was made according to the single-hole methods described in /1/. Estimation of the borehole storage coefficient C in appropriate pumping tests was based on the early borehole response with 1:1 slope in a log-log diagram. These values on C may be compared with the well-bore storage coefficient calculated above, based on borehole geometrical data, bore hole equipement and assumed fluid properties (net values). The estimated values on C from the test data may differ from the net values due to deviations of the actual geometrical borehole properties from the anticipated, e.g. borehole diameter. Furthermore, the effective compressibility is usually higher than the water compressibility in an isolated section due to e.g. packer compliance resulting in a higher C-value.

For pumping tests in an open borehole (and in the interval above a single packer), the wellbore storage coefficient may be calculated as:

$$C=\pi\, r_{we}^2/\rho g \qquad (5\text{-}1)$$

For an isolated pumped section (and the section below a single packer) the corresponding well-bore storage coefficient may be calculated as:

$$C= \pi\, r_w^2 \cdot L_w \cdot c_w \qquad (5\text{-}2)$$

r_{we} = borehole radius where the changes of the groundwater level occur (either r_w or r_c)

r_w = nominal borehole radius (m)

r_c = inner radius of the borehole casing (m)

ρ = density of water (kg/m^3)

g = acceleration of gravity (m/s^2)

L_w = section length (m)

c_w = compressibility of water (Pa^{-1})

7.4.2 Flow logging

The measured parameters during the flow logging (flow, temperature and electric conductivity of the borehole fluid) are plotted versus borehole length. From these plots, flow anomalies were identified along the borehole, i.e. borehole intervals over which changes of flow larger than c 1 L/min occur. The magnitude of the inflow at the flow anomaly is determined by the actual change in flow rate or registered rounds of impeller on the interval. In many cases, interpretation of flow anomalies indicated by flow data are supported by corresponding changes in temperature and/or electric conductivity of the fluid.

Flow logging can only be carried out up to a certain distance below the borehole pump (when logging from the bottom of the hole upward). The remaining part of the borehole (i.e. 4 m below pump position up to the casing) can not be flow-logged, although high inflow zones may sometimes be located in this part. Such superficial inflows can, in cases were actual bore hole diameter accord with nominal, be identified by comparing the cumulative flow at the top of the flow-logged interval (Q_T) 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. This method of proceeding requires that registered flow of flow logging probe is accurate. In cases were there are suspicions of inaccurate registered value of flow by flow logging probe (due to divergence of bore hole diameter from nominal, fracture zone at highest position etc) complementary pump or injection test(s) are carried out to verify and/or quantify the size of inflow above highest possible position of flow logging probe.

Depending on if additional complementary test(s) is carried out two different methods are employed for estimating transmissivity for the flow logged interval of the borehole (T_{FT}). In both cases, the transmissivity of the entire borehole (T) is estimated from the analysis of the pumping test performed in conjunction with flow logging.

Method 1

If no additional tests are performed in the interval above the flow-logged interval, the total transmissivity of these anomalies may be estimated from Equation (5-3). The accuracy of calculated cumulative transmissivity depends on the uncertainty in the value of registered flow by the flow-logging probe at highest position, Q_T.

The cumulative transmissivity at the top of the flow-logged interval ($T_{FT}=\Sigma T_i$) is calculated according to the Methodology description for Impeller flow logging (assuming zero natural flow in the borehole):

$$T_{FT} = \Sigma T_i = T \cdot Q_T / Q_p \qquad (5\text{-}3)$$

The transmissivity of an individual flow anomaly (T_i) is calculated from the measured inflow (ΔQ_i) at the anomaly and the calculated transmissivity of the entire borehole (T) according to:

$$T_i = T \cdot \Delta Q_i / Q_p \qquad (5\text{-}4)$$

The cumulative transmissivity $T_F(L)$ along the borehole length (L) as determined from the flow logging may be calculated as:

$$T_F(L) = T \cdot Q(L) / Q_p \qquad (5\text{-}5)$$

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

Method 2

If additional tests are carried out, borehole parameters in the non flow-logged interval are given values from evaluation of these tests. Calculation of cumulative transmissivity of anomalies indicated by flow logging (T_{FT}) is based on estimated transmissivity from pumping test of the whole borehole and estimated transmissivity from tests of non logged interval:

$$T_{FT} = \Sigma T_i = (T - T_A) \qquad (5\text{-}6)$$

where T_A is the transmissivity of the non flow-logged interval.

The transmissivity of an individual flow anomaly (T_i) is calculated from the relative contribute to total flow registered by the flow logging probe at the highest position($\Delta Q_i/Q_T$) and the calculated transmissivity of the flow-logged interval of the borehole (T_{FT}) :

$$T_i = T_{FT} \cdot \Delta Q_i / Q_T \qquad (5\text{-}7)$$

The cumulative transmissivity $T_F(L)$ along the borehole length (L) as determined from the flow logging may be calculated as:

$$T_F(L) = T_{FT} \cdot Q(L) / Q_T \qquad (5\text{-}8)$$

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

The specified lower limit of transmissivity (T_{min}) in flow logging may be estimated by:

$$T_{min} = T \cdot Q_{min} / Q_p \qquad (5\text{-}9)$$

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

For comparison, estimations of the transmissivities of the identified flow anomalies were also made from the specific flows, simply by dividing the measured inflow (ΔQ_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.

6 Results

6.1 Nomenclature and symbols

The nomenclature and symbols used for the results of the pumping tests and flow logging are according to the Instruction for analysis of single-hole injection- and pumping tests (SKB MD 320.004) and Methodology description for flow logging (SKB MD 322.009), respectively. Additional symbols used are explained in the text.

6.2 Water sampling

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

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

Bh ID	Date and time of sample	Pumped section (m)	Pumped volume (m^3)	Sample type	Sample ID no	Remarks
KSH03A	2003-08-21 10:15	11.8–100.6	1.0	WC080	5799	Open-hole test
	2003-08-21 14:10	11.8–100.6	2.8	WC080	5800	Open-hole test
	2003-08-21 19:15	11.8–100.6	5.4	WC080	5801	Open-hole test
HSH02	2003-08-27 10:30	12.0–200.0	0.5	WC080	5802	Open-hole test
	2003-08-27 15:20	12.0–200.0	1.5	WC080	5803	Open-hole test
	2003-08-27 19:30	12.0–200.0	2.6	WC080	5804	Open-hole test

6.3 Single-hole pumping 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. In single-hole tests such corrections are generally not needed unless test time is long (changes on a synoptic scale can influence barometric pressure) and/or very small drawdowns are applied in the boreholes (i.e. relative changes large). Furthermore, no subtractions of the barometric pressure from the measured absolute pressure were made since the pressure differences, e.g. drawdown, are used for the evaluation of the tests.

The lower measurement limit for the HTHB system, presented in the tables below, is expressed in terms of specific flow (Q/s). The 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. These values correspond to a lower measurement limit of $Q/s\text{–}L=2\cdot10^{-6}\ m^2/s$.

To be able to perform pumping tests in sections with low transmissivity using moderate drawdown (e.g. complementary pumping test in non-flow logged interval) part of the pumped flow was shunted back into the borehole. This technique enables the system to lower the minimal flow rate from 5 L/min to 0.5 L/min. Relative errors in flow measurements are increased by this procedure but accuracy is still good enough to evaluate parameters with satisfying result. Also, manual measurements were made to verify flow indicated by flow meter.

6.3.1 Borehole KSH03A 11.80–100.60 m

General test data for the open-hole pumping test in the upper, percussion-drilled interval of borehole KSH03A are presented in Table 6-2. Flow logging was performed during this test.

Table 6-2. General test data for the open-hole pumping test in the upper, percussion-drilled interval of borehole KSH03A in conjunction with flow logging.

General test data			
Borehole	KSH03A		
Test type[1]	Constant Head withdrawal and recovery		
Test section (open borehole/packed-off section):	open borehole		
Test No	2		
Field crew	T. Svensson, J. Jönsson (GEOSIGMA AB)		
Test equipment system	HTHB2		
General comment	Single hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	100.60
Casing length	L_c	m	11.80
Test section – secup	Secup	m	11.80
Test section – seclow	Seclow	m	100.60
Test section length	L_w	m	88.8
Test section diameter	$2 \cdot r_w$	mm	top 159.5
			bottom 159.2
Test start (start of pressure registration)		yymmdd hh:mm	20030821 08:43
Packer expanded		yymmdd hh:mm:ss	–
Start of flow period		yymmdd hh:mm:ss	20030821 09:02:03
Stop of flow period		yymmdd hh:mm:ss	20030821 19:21:29
Test stop (stop of pressure registration)		yymmdd hh:mm	2003-08-22 06:58
Total flow time	t_p	min	619.4
Total recovery time	t_F	min	696.5

[1]) Constant Head injection and recovery, Constant Head withdrawal and recovery or Constant Rate withdrawal and recovery.

Pressure and groundwater 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	284.3	0.26
Absolute pressure in test section before stop of flow period	p_p	kPa	156.3	–12.80
Absolute pressure in test section at stop of recovery period	p_F	kPa	285.0	0.33
Maximal pressure change during flow period	dp_p	kPa	128.0	13.05

Manual groundwater level measurements in KSH03A (11.80–100.6 m)			GW level	
Date YYYY-MM-DD	Time tt:mm	[1)]Time (min)	(m b. ToC)	(m a s l)
2003-08-20	12:35	–	4.63	0.29
2003-08-20	14:15	–	4.63	0.29
2003-08-20	18:21	–	4.35	0.53
2003-08-20	18:57	–	4.17	0.68
2003-08-21	08:53	–9	4.66	0.26
2003-08-25	17:00	–	4.36	0.52
2003-08-25	18:46	–	4.20	0.66
2003-08-25	19:02	–	3.95	0.87

[1]) Time=0 for start of flow period

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.21 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q^m	m^3/s	$1.35 \cdot 10^{-4}$
Total volume discharged during flow period	V^p	m^3	5.0

Comments on the test

The test was carried out as a c 10 hour pumping test with constant head followed by a recovery phase of c 12 hours. Flow logging is conducted during the latter part of the disturbance phase of the test and the intention is to achieve approximate steady-state conditions prior to the flow logging.

Position of first flow detected by the flow logging probe coincided with highest possible position of flow logging probe. Highest possible position of flow logging probe was limited by the borehole pump positioned at 30 m. To verify and possibly determine the extent of anomaly indicated at highest measuring position the borehole pump was repositioned, without interrupting the pumping, 5 m higher up in the borehole. This made it possible to prolong the flow logging interval, now reaching up to 28 m below reference point.

Repositioning the borehole pump inevitably means repositioning the pressure sensor, P1, attached to the pump hose with the corresponding length, see Figure 4-1. The repositioning of P1 gave rise to a drop in pressure registration of c 42 kPa, see Appendix 2 Figure A2-1.

For steady-state evaluation and presented final pressure, p_p, compensation for pressure drop due to repositioning of pressure sensor is made by adding the reduction in pressure caused by repositioning to final data. Theoretical calculations and pressure observations are considered in deciding size of added pressure.

Transient evaluation is not affected by repositioning since test is performed as constant head test i.e. flow data is used for transient evaluation. Flow is continuous during repositioning of pump and pressure sensor and repositioning had no injurious effects on flow data.

During the withdrawal phase a malfunction of the borehole pump occurred. This resulted in two shorter interruptions of the pumping between 15:36 and 15:39. The interruptions had no significant effect to data evaluation.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-1–5 in Appendix 2.

A qualitative analysis of the flow period identifying distinct flow regimes in the derivative plot is not possible due to the noisy derivative. However one might suggest that the noise are distributed around a constant value from c 50 minutes and forward indicating pseudo radial flow regime during this period. This is not sufficient to support a unique interpretation.

The recovery derivative plot clearly shows well bore storage dominating up to c 12 minutes. After c 12 minutes to the end of recovery a transition phase takes place. The abrupt change in slope associated with the transition is due to a change in borehole diameter as the water table rises up into the casing at 11.80 m below reference point (top of casing). Pseudo radial flow regime is never reached during the recovery period.

Interpreted parameters

Transient quantitative interpretation of the flow- or recovery period of the test was not possible to carry out due to noisy derivative during flow period and the fact that pseudo radial flow regime was not achieved during recovery, i.e. the pumping- and recovery period was not long enough to support a transient analysis based on the assumption of pseudo radial flow. Steady-state evaluation is considered most representative value of transmissivity.

The results are shown in Tables 6-10, 6-11, 6-12 and Test Summary Sheet in Section 6.5.

6.3.2 Borehole KSH03A 11.80–28.0 m

General test data for the open-hole pumping test above a single packer in borehole KSH03A are presented in Table 6-3.

Table 6-3. General test data for the open-hole pumping test above a single packer in KSH03A.

General test data			
Borehole	KSH03A		
Test type[1]	Constant Head withdrawal and recovery		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	T. Svensson, J. Jönsson (GEOSIGMA AB)		
Test equipment system	HTHB2		
General comment	Single hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	100.60
Casing length	L_c	m	11.80
Test section – secup	Secup	m	11.80
Test section – seclow	Seclow	m	28.0
Test section length	L_w	m	16.2
Test section diameter	$2 \cdot r_w$	mm	top 159.5 bottom 159.2
Test start (start of pressure registration)		yymmdd hh:mm	20030825 20:04
Packer expanded		yymmdd hh:mm:ss	20030825 20:06
Start of flow period		yymmdd hh:mm:ss	20030826 07:10:08
Stop of flow period		yymmdd hh:mm:ss	20030826 09:58:33
Test stop (stop of pressure registration)		yymmdd hh:mm	20030826 12:34
Total flow time	t_p	min	168.0
Total recovery time	t_F	min	155.5

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

Pressure and groundwater 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	244.5	0.53
Absolute pressure in test section before stop of flow period	p_p	kPa	114.6	–12.71
Absolute pressure in test section at stop of recovery period	p_F	kPa	197.0	–4.31
Maximal pressure change during flow period	dp_p	kPa	129.9	13.24

Manual groundwater level measurements in KSH03A 11.80–28.0 m. Date YYYY-MM-DD	 Time tt:mm.ss	 [1])Time (min)	GW level (m b. ToC)	 (m a s l)
2003-08-26	06:37	–33	4.35	0.53
2003-08-26	12:43	333	9.73	–4.10
2003-08-26	13:22	372	7.78	–2.42

[1]) Time=0 for start of flow period

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$3.17 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q^m	m^3/s	$8.12 \cdot 10^{-5}$
Total volume discharged during flow period	V^p	m^3	0.8

Comments on the test

The test was carried out to verify flow logging data. The ambition was to get an estimate of transmissivity and the extent of the test was limited by practical considerations.

The test was performed as a constant head pumping test above a single packer positioned at 28.0–29.0 m below reference point. The reason to perform the test was to verify and ensure quality of flow logging data hence packer position was chosen based on the highest position of the flow logging probe.

Predicted, and actual, flow rates in this section was below the lower limit of the borehole pump. To avoid damage on the borehole pump due to overheating and extend the working range of the system part of the pumped flow was shunted back into the borehole. This procedure had not been tested prior to this test but did not introduce noise to pressure registration and worked well during pumping.

In connection to stop of pumping a rapid rise of registered pressure are observed (c 4 kPa in 10 seconds). This is probably an combined effect of leakage from the shunt hose into the borehole due to existing water in the shunt hose; contraction of pump hose as pressure falls after stopping the bore hole pump (elasticity effects) and the fact that the bore hole pump does not stop momentarily due to moment of inertia..

Interpreted flow regimes

Relevant diagrams are presented in Figures A2-6–12 in Appendix 2.

No distinct period of pseudo radial flow regime during the flow period could be identified. During the latter part of the flow period, the noisy derivative seems to vary around an approximately constant value and this can, not unambiguously, be interpreted as a period of pseudo radial flow.

Well bore storage effects are dominating throughout the recovery period. Notable are the local maximum at 0.1 minutes (dte) in the derivative plot (Figure A2-11) due to the previous discussed in leakage from the shunt hose and the abrupt change in slope after 40 minutes due to a change in bore hole diameter as the water table rises into the casing.

Interpreted parameters

Due to the fact that no distinct period of pseudo-radial flow can be identified during flow period, the most representative parameter value is based on a steady-state analysis (e.g. Moye’s formula).

No quantitative transient analysis was made from the recovery period since no well-defined pseudo-radial flow period was developed during this period. The steady-state analysis of the recovery period is not representative since recovery was interrupted.

The results are shown in Tables 6-10–12 and Test Summary Sheet in Section 6.5.

6.3.3 Borehole HSH02 12.03–200.0 m

General test data for the open-hole pumping test in the interval 12.03–200.0 m in borehole HSH02 are presented in Table 6-4.

Table 6-4. General test data for pumping test in conjunction with flow logging in borehole HSH02.

General test data			
Bore hole	HSH02		
Test type[1]	Constant Head withdrawal and recovery test		
Test section (open borehole/packed-off section):	open borehole		
Test No	2		
Field crew	T. Svensson, J. Jönsson (GEOSIGMA AB)		
Test equipment system	HTHB2		
General comment	Single-hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	200.0
Casing length	L_c	m	12.03
Test section – secup	Secup	m	12.03
Test section – seclow	Seclow	m	200.0
Test section length	L_w	m	188.0
Test section diameter	$2 \cdot r_w$	mm	top 139.9 bottom 139.6
Test start (start of pressure registration)		yymmdd hh:mm	030827 08:25
Packer expanded		yymmdd hh:mm:ss	–
Start of flow period		yymmdd hh:mm:ss	030827 09:03:14
Stop of flow period		yymmdd hh:mm:ss	030827 20:01:03
Test stop (stop of pressure registration)		yymmdd hh:mm	030828 11:01
Total flow time	t_p	min	657.8
Total recovery time	t_F	min	904.6

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

Pressure and groundwater 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	289.0	–0.06
Absolute pressure in test section before stop of flow period	p_p	kPa	105.3	–18.79
Pressure in test section at stop of recovery period	p^F	kPa	279.2	–1.06
Maximal pressure change during flow period	dp^p	kPa	183.7	18.73

Manual groundwater level measurements in HSH02 0–200 m Date YYYY-MM-DD	Time tt:mm.ss	Time[1)] (min)	GW level (m b. ToC)	(m a s l)
2003-08-26	15:43		7.21	–0.45
	16:32		5.59	1.14
	20:15		8.06	–1.29
	20:26		7.23	–0.47
2003-08-27	07:59	–64	7.30	–0.54
	08:33	–30	6.76	–0.01
	08:45	–18	6.81	–0.06
	09:48	45	25.46	–18.43
	15:28	385	25.55	–18.52
	16:00	417	25.92	–18.88
	19:58	655	26.0	–18.96
2003-08-28	10:56	1553	8.01	–1.24

1) Time=0 at start of flow period

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$7.58\cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q^m	m^3/s	$8.75\cdot 10^{-5}$
Total volume discharged during flow period	V^p	m^3	3.4

Comments on the test

The test was carried out as a c 11 hour pumping test with constant head followed by a c 15 hour recovery phase. Differences in length of disturbance and recovery phases are due to practical reasons (i.e. overnight recovery). Flow logging is conducted during the latter part of the disturbance phase of the test and the intention is to achieve approximate steady-state conditions prior to the flow logging.

Derivative of inverse flow data during drawdown is noisy due to imperfect flow regulation. Noisy derivative during flow period is a reoccurring problem for test performed as constant head tests. This complicates unique interpretation of flow regimes.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-12–14 in Appendix 2.

Unambiguous identification of pseudo radial flow regime during disturbance phase is not possible.

First part of the recovery period, up to c 5 minutes, is dominated by wellbore storage effects. This period is followed by a transition phase and a distinct pseudo-radial flow regime starting at approximately 200 minutes.

Interpreted parameters

Unique transient quantitative evaluation of the flow period is not possible. Most representative parameter value is based on a steady-state analysis (e.g. Moye's formula).

An estimation of the wellbore storage coefficient was made from recovery data. The results are shown in the Test Summary Sheet and in Table 6-10–12.

6.3.4 Borehole HSH02 12.03–33.0 m

General test data for the open-hole pumping test in the interval 12.03–33.0 m in borehole HSH02 are presented in Table 6-5.

Table 6-5. General test data for pumping test above a single packer in borehole HSH02.

General test data			
Bore hole	HSH02		
Test type[1]	Constant Head withdrawal and recovery test		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	T. Svensson, J. Jönsson (GEOSIGMA AB)		
Test equipment system	HTHB2		
General comment	Single-hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	200.0
Casing length	L_c	m	12.03
Test section – secup	Secup	m	12.03
Test section – seclow	Seclow	m	33.0
Test section length	L_w	m	21.0
Test section diameter	$2 \cdot r_w$	mm	139.9
Test start (start of pressure registration)		yymmdd hh:mm	20030828 15:55
Packer expanded		yymmdd hh:mm:ss	20030828 16:15
Start of flow period		yymmdd hh:mm:ss	20030828 16:32:02
Stop of flow period		yymmdd hh:mm:ss	20030828 19:32:07
Test stop (stop of pressure registration)		yymmdd hh:mm	20030829 08:29
Total flow time	t_p	min	180.0
Total recovery time	t_F	min	776.5

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

Pressure and groundwater 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	290.8	0.22
Absolute pressure in test section before stop of flow period	p_p	kPa	194.5	–9.60
Pressure in test section at stop of recovery period	p_F	kPa	292.2	0.36
Maximal pressure change during flow period	dp_p	kPa	96.3	9.82

Manual groundwater level measurements			GW level	
Date YYYY-MM-DD	Time tt:mm.ss	Time (min)	(m b. ToC)	(m a s l)
2003-08-28	15:50	–42	6.53	0.22
2003-08-28	19:29	177	16.68	–9.78
2003-08-28	19:32	180	16.38	–9.49
2003-08-28	19:41	189	15.90	–9.01
2003-08-29	08:15	1003	6.01	0.73

1) Time=0 for start of flow period

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.42 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q^m	m^3/s	$2.87 \cdot 10^{-5}$
Total volume discharged during flow period	V^p	m^3	0.30

Comments on the test

The test was performed as a constant head pumping test, followed by a recovery period, above a single packer positioned at 33.0–34.0 m below reference point. The reason to perform the test was to verify and ensure quality of flow logging data. Hence, the choice of packer position was based on the highest position of the flow logging probe during flow logging.

Predicted, and actual, flow rates in this section was below the lower limit of the borehole pump, therefore part of pumped flow was shunted back into the borehole to avoid damage on the borehole pump due to overheating. This procedure did not introduce noise to pressure registration above packer.

In connection with stop of pumping, a rapid rise of registered pressure is observed (c 2 kPa in 10 seconds). This is probably an combined effect of leakage from the shunt hose into the borehole due to existing water in the shunt hose; contraction of pump hose as pressure falls after stopping the bore hole pump (elasticity effects) and the fact that the bore hole pump does not stop momentarily due to moment of inertia. This unwanted effect was also observed in KSH03A (Section 11.80–28.0 m) when applying the same pumping technique (shunting part of flow back into the bore hole).

Interpreted flow regimes

Teat diagrams are presented in Figures A2-16–18 in Appendix 2. As in previous tests difficulties in accomplishing a smooth flow regulation lead to irregular behaviour of flow derivative during disturbance phase. No distinct identification of pseudo-radial flow is possible. Though noisy, there is a change of the derivative trend towards a constant value, indicating possible pseudo-radial flow regime, c 40 minutes into the disturbance phase.

During the first 10 seconds of the recovery period the effects of in leakage from shunt hose can be observed, cf Figure A2-16 and A2-18 in Appendix 2. In leakage initially overshadows well bore storage witch is dominating throughout the rest of the recovery period.

Interpreted parameters

No distinct period of pseudo-radial flow can be identified during flow- or recovery period. Hence, the most representative parameter value is based on steady-state analysis (e.g. Moye's formula). The results are shown in the Test Summary Sheets and Tables 6-10–12.

6.4 Flow logging

6.4.1 Borehole KSH03A

General test data for the flow logging in borehole KSH03A are presented in Table 6-6.

Table 6-6. General test data for the flow logging in borehole KSH03A.

General test data			
Borehole	KSH03A		
Test type[1]	6, L-EC, L-Te		
Test section	Open borehole		
Test No	1		
Field crew	T. Svensson, J. Jönsson (GEOSIGMA AB)		
Test equipment system	HTHB2		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	100.60
Pump position (lower level)		m	25
Flow logged section – Secup	Secup	m	28.0
Flow logged section – Seclow	Seclow	m	97.0
Test section diameter	2·rw	mm	top 159.5
			bottom 159.2
Start of flow period		yymmdd hh:mm	20030821 09:02
Start of flow logging		yymmdd hh:mm	20030821 14:55
Stop of flow logging		yymmdd hh:mm	20030821 19:10
Stop of flow period		yymmdd hh:mm	20030821 19:21

[1)] 6: Flow logging-Impeller, L-EC: EC-logging, L-TE: temperature logging

Groundwater level and flow data

Groundwater level	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	4.66	0.26
Level (steady state) in borehole, at pumping rate Q^p	h^p	m	–	–
Final drawdown during flow logging	s^{FL}	m	13.04*	

Flow data	Nomen-clature	Unit	Flow rate
Pumping rate from borehole at surface	Q_p	m^3/s	$1.21 \cdot 10^{-4}$
Cumulative flow rate at Secup at pumping rate Q_p	Q_T	m^3/s	$1.03 \cdot 10^{-4}$
Measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$6.67 \cdot 10^{-5}$
Minimal change of borehole flow rate to detect flow anomaly	ΔQ_{Anom}	m^3/s	$1.7 \cdot 10^{-5}$

*Calculated from pressure registration

Comments on the test

Flow logging was carried out from 97.0 m upward. The step length between flow measurements was maximally 5 m in the borehole interval 97.0–75.0 m and maximally 2 m in the interval 75.0–34.5 m. From 34.5 m to highest position of flow probe, 28.0 m below reference point, flow measurement was made every 0.5 m. The first detectable flow was found at 34.0 m.

Position of first flow detected by the flow logging probe coincided with highest possible position of flow logging probe. Highest possible position of flow logging probe was under current configuration of borehole equipment limited by the borehole pump positioned at 30 m. To verify and possibly determine the extent of anomaly indicated at highest measuring position the borehole pump was repositioned, without interrupting the pumping, to a position 5 m higher up in the borehole. This made it possible to prolong the flow logging interval, now reaching up to 28.0 m below reference point. Repositioning of the borehole pump also had consequences to pressure registration, see Section 6.3.1

The nomenclature used for the flow logging is according to the method description for flow logging, SKB MD 322.009.

For manual measurements of ground water level, see Section 6.3.1

Logging results

The results of the flow logging in borehole KSH03A are presented in Table 6-7 below. The cumulative transmissivity (T_{FT}) at the top of the flow-logged borehole interval and the transmissivity of anomalies were calculated according to Method 1 and Method 2 respectively i.e. calculated value of T_{FT} is solely based on flow logging data and evaluation of pumping test conducted during flow logging whereas T_i also consider the complementary pumping test performed in the non-flow logged interval 28.0–11.80 m. for a complete description of calculations see Section 5.4.2. An estimation of the transmissivity of the interpreted flow anomaly was also made by calculation of specific flow ($\Delta Q_i/s_{FL}$). The transmissivity of the entire borehole was assigned value from evaluation of pumping test during flow logging.

Approximately 85% of the total flow at the surface was registered by flow-logging probe at highest position. The discrepancy between registered and total flow was verified to be an actual inflow above highest position of flow-logging probe by an additional pumping test above a single packer. For a complete description of the additional test, see Section 6.3.2.

The Q_T/ Q_P - ratio of c 85% is to be compared with the $(T–T_A)/T$–ratio of c 81%, the results show a very high degree of agreement. The discrepancy is due to deviation from nominal borehole diameter; the actual diameter is slightly smaller than the 160 mm that the equipment is calibrated for. The consequence of this deviation is an overestimation of flow through the flow logging probe, i.e. less of pumped water volume is passing on the outside of the flow logging probe due to the smaller gap between bore hole wall and the disc at the bottom of the probe.

The measured flow distribution along the hole during the flow logging together with electric conductivity (EC) and temperature (Te) of the borehole fluid is presented in Figure 6-1.

Figure 6-2 shows the calculated, cumulative transmissivity $T_F(L)$ along the borehole length (L). Since the position of the flow anomaly verified by a pump test above the highest position of flow-logging probe (28 m below reference point) is not known in detail, the change in transmissivity for the anomaly is represented by a sloping line from 28 m up to the casing. The estimated lower limit of T and the total T of the borehole are also shown in the figure.

Table 6-7. Results of flow logging in borehole KSH03A. Q_T=cumulative flow registered at the top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}= drawdown during flow logging, T_A=estimated transmissivity above 28.0 m from complementary pumping test (11.80–28.0m).

KSH03A Flow anom.		$Q_T=1.03 \cdot 10^{-4}$ (m^3/s)	$Q_p=1.21 \cdot 10^{-4}$ (m^3/s)	$T=1.08 \cdot 10^{-5}$ (m^2/s)	$s_{FL}=13.04$ (m)	$T_A=2.08 \cdot 10^{-6}$ (m^2/s)
Interval (m) (from ToC)	**B.h. length (m)**	**ΔQ_i (m^3/s)**	**T_{FT} (m^3/s)**	**T_i (m^2/s)**	**$\Delta Q_i/s_{FL}$ (m^2/s)**	**Supporting information**
32.0–34.5	2.5	$1.03 \cdot 10^{-4}$	$9.19 \cdot 10^{-6}$	$8.72. \cdot 10^{-6}$	$7.90 \cdot 10^{-6}$	Te, EC
Difference		$Q_p–Q_T=0.18 \cdot 10^{-4}$				

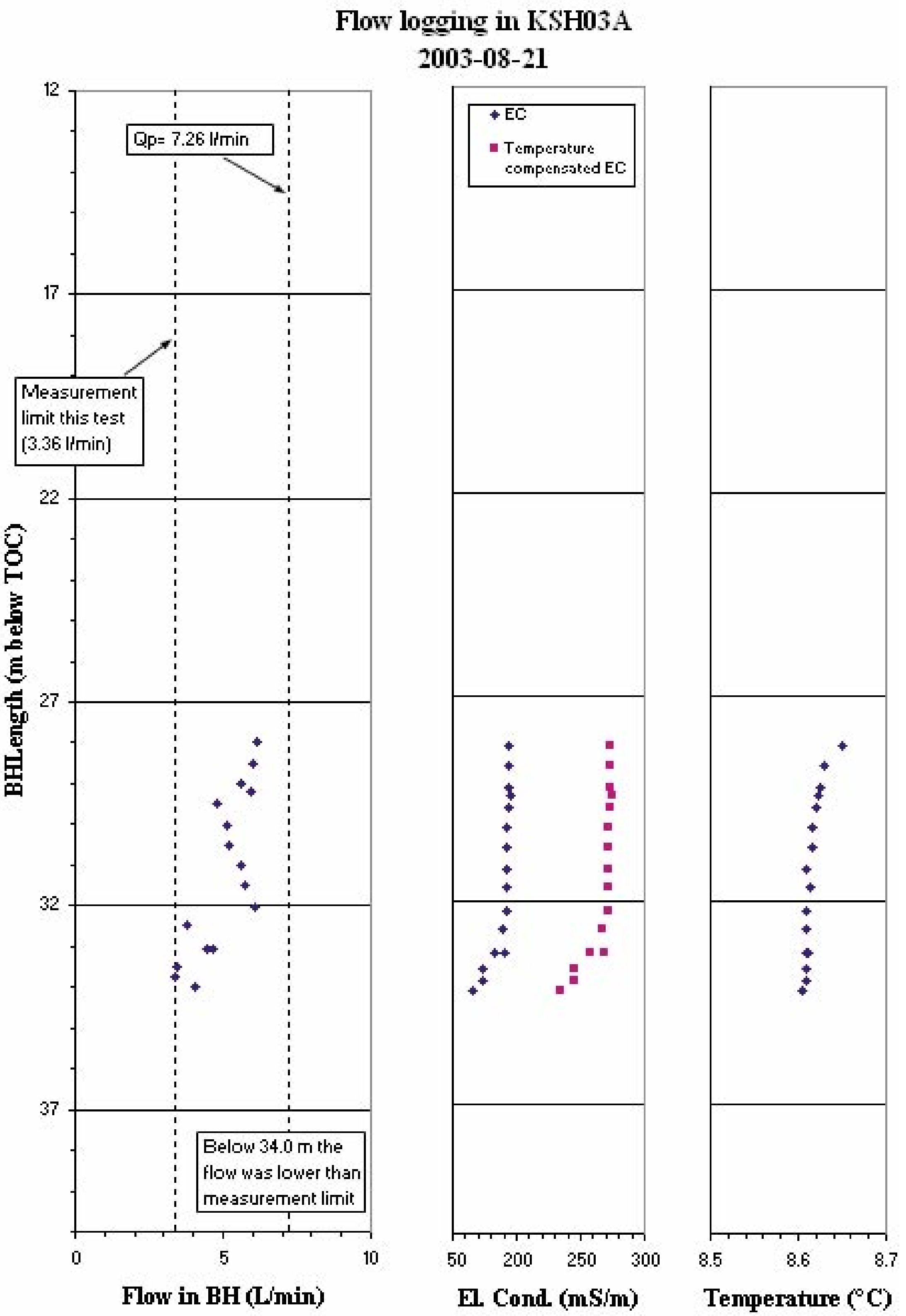


Figure 6-1. Measured flow distribution along borehole KSH03A during the flow logging together with the electric conductivity (EC) and temperature (Te) of the borehole fluid.

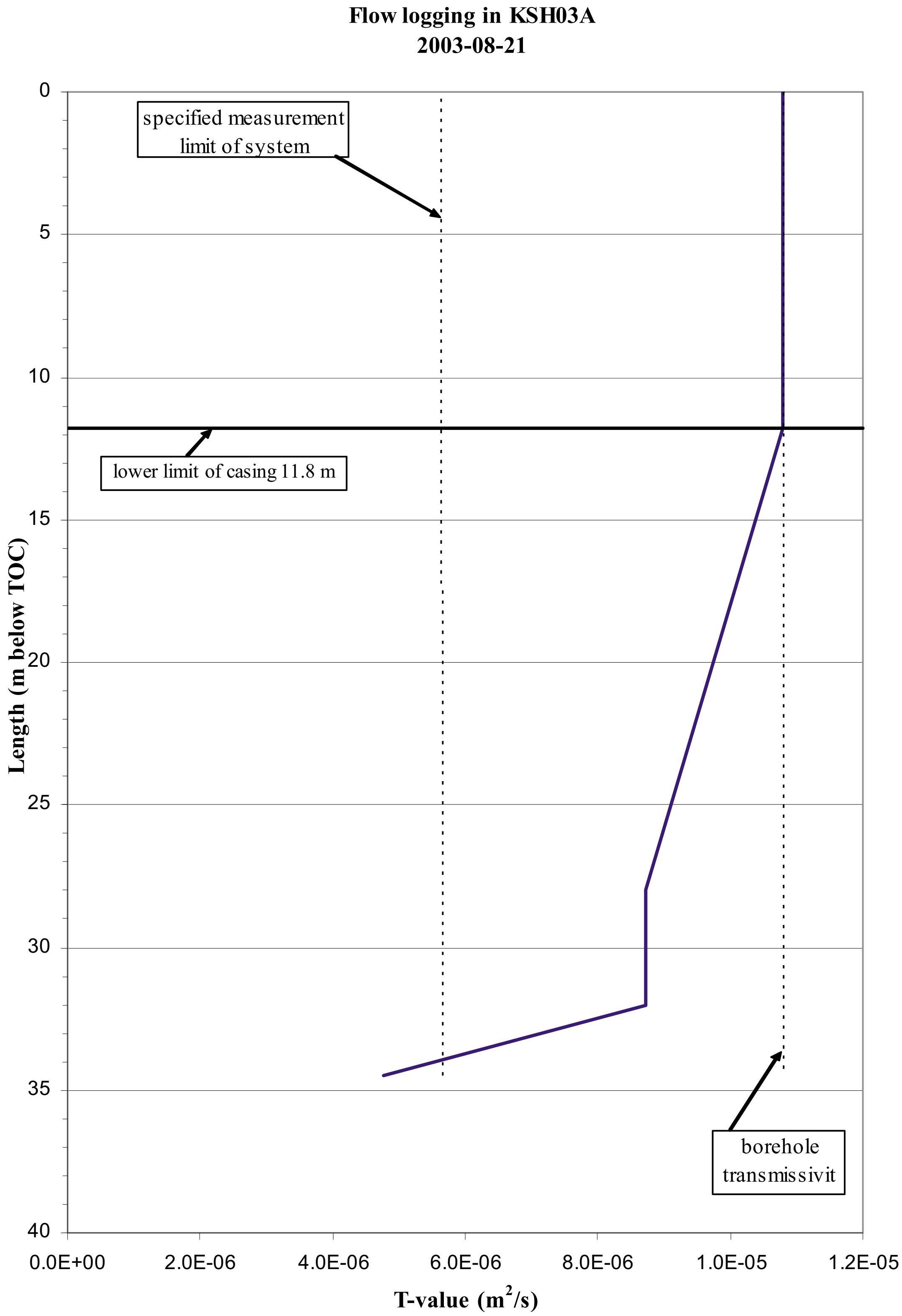


Figure 6-2. *Calculated, cumulative transmissivity of borehole KSH03A. Below 34.0 m, the borehole transmissivity was below the measurement limit. Total borehole transmissivity was calculated from pumping test during flow logging.*

6.4.2 Borehole HSH02

General test data for the flow logging in borehole HSH02 are presented in Table 6-8.

Table 6-8. General test data for the flow logging in borehole HSH02.

General test data			
Borehole	HSH02		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	T. Svensson, J. Jönsson (GEOSIGMA AB)		
Test equipment system	HTHB 2		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	200
Pump position (lower level)		m	30
Flow logged section – Secup	Secup	m	33
Flow logged section – Seclow	Seclow	m	195
Test section diameter	2·rw	mm	top 139.9 bottom 139.2
Start of flow period		yymmdd hh:mm	030827 09:03
Start of flow logging		yymmdd hh:mm	030827 13:20
Stop of flow logging		yymmdd hh:mm	030827 19:49
Stop of flow period		yymmdd hh:mm	030827 20:01

[1)] 6: Flow logging-Impeller, L-EC: EC-logging, L-TE: temperature logging

Groundwater level and flow data

Groundwater level	**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	6.81	–0.06
Level (steady state) in borehole, at pumping rate Q_p	h_p	m	26.0	–18.96
Drawdown during flow logging	s_{FL}	m	18.72*	

Flow data	**Nomen-clature**	**Unit**	**Flow rate**
Pumping rate from borehole at surface	Q_p	m^3/s	$7.58 \cdot 10^{-5}$
Cumulative flow rate at Secup at pumping rate Q_p	Q_T	m^3/s	$4.67 \cdot 10^{-5}$
Measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$8.33 \cdot 10^{-6}$
Minimal change of borehole flow rate to detect flow anomaly	ΔQ_{Anom}	m^3/s	$1.67 \cdot 10^{-5}$

*Calculated from pressure registration

Comments on the test

The flow logging was made from the bottom of the hole upward with a step length of 2 m. To position flow anomalies with a theoretical accuracy (not considering the uncertainty of length measurement) of ±0.25 m the flow-logging probe is lowered and elevated in steps of 0.5 m below and above registered flow anomaly.

Total registered inflow was below the specified measurement limit of the system, this is possible under favourable circumstances. The consistency of data ensures and verifies the size and position of anomalies even though flow is below specified measurement limit.

When elevating the flow-logging probe the first detectable inflow was registered at 75 m depth. When lowering the probe to establish the position of the inflow it was possible to detect flow all the way down to 79 m even though attempts at 77 and 79 m had proceeded during elevation. This inconsistency is due to the fact that very small changes in external circumstances can overcome the moment of inertia of the impeller when pushing the measurement limit of the system.

Logging results

First detectable inflow located at 79.0 m below reference point. Measured flow on the interval 79.0–75.0 m showed very small variations with a variation in registered flow of ± 4%. Between 75.0 and 73.5 there was a linear increase in flow indicating a fracture zone. The absolute values of the increase are not large enough to alone support an unambiguous interpretation of a flow anomaly on the interval 75.0–73.5 m. However, temperature and electric conductivity data support the suggested anomaly. All data considered the interpretation is that there is a small inflow on the interval 75.0–73.5 m.

Above 73.5 m there is no additional inflow. The variations of registered flow are due to the sensitivity of the flow logging probe to small changes in physical parameters in the borehole. In addition, the time to reach a stable flow through the flow-logging probe is significantly prolonged when measuring below the specified measurement limit. For practical reasons (i.e. limited time) there might be points that would show a slightly higher flow above 72.0 m. This uncertainties are not of significance for the over all interpretation and result of the flow-logging.

Table 6-9. Results of the flow logging in borehole HSH02. Q_T=cumulative flow at the top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}= drawdown during flow logging, T_A=estimated transmissivity above 33.0 m from complementary pumping test (12.03–33.0m).

HSH02 Flow anom.		**Q_T=4.67·10^{-5} (m³/s)**	**Q_p=7.58·10^{-5} (m³/s)**	**T=2.94·10^{-6} (m²/s)**	**s_{FL}=18.7 m**	**T_A =1.45·10^{-6} (m²/s)**
Interval (m bToC)	**B.h. length (m)**	**ΔQ_i (m³/s)**	**T_{FT} (m³/s)**	**T_i (m²/s)**	**$\Delta Q_i/s_{FL}$ (m²/s)**	**Supporting information**
79.0–79.5	0.5	$4.27 \cdot 10^{-5}$	$1.66 \cdot 10^{-6}$	$1.36 \cdot 10^{-6}$	$2.28 \cdot 10^{-6}$	
75.0–73.5	2.5	$4.0 \cdot 10^{-6}$	$1.55 \cdot 10^{-7}$	$1.28 \cdot 10^{-7}$	$2.13 \cdot 10^{-6}$	Te, EC
Total		**Σ= 4.67·10^{-5}**	**Σ=1.82·10^{-6}**	**ΣT_i= 1.49·10^{-6}**	**Σ=4.41·10^{-6}**	
Difference		$Q_P–Q_T$= $2.91 \cdot 10^{-5}$				

Approximately 62% of the total flow at the surface was registered by flow-logging probe at highest position. The discrepancy between registered and total flow was verified to be an actual inflow at a position above highest position of flow logging probe by an additional pumping test above a single packer. For a complete description of the additional test, see Section 6.3.4.

The $Q_{T/}$ Q_P - ratio of c 62% is to be compared with the $(T–T_A)/T$–ratio of c 51%. The main reason for this discrepancy is the deviation from nominal borehole diameter; the actual diameter is slightly smaller than the 140 mm that the equipment is calibrated for. The consequence of this deviation is an overestimation of flow through the flow logging probe, i.e. less of pumped water volume is passing on the outside of the flow logging probe due to the smaller gap between bore hole wall and the disc at the bottom of the probe. Considering the technique of measurement used the deviation is relatively small. Nevertheless the result stresses the value and importance of conducting a complementary test if there is a suspicion of flow anomalies above the flow logged interval.

The measured flow distribution along the hole during the flow logging together with the electric conductivity (EC) and temperature (Te) of the borehole fluid is presented in Figure 6-3.

Figure 6-4 shows the calculated, cumulative transmissivity $T_F(L)$ along the borehole length (L). Since the position of the flow anomaly verified by a pump test above the highest position of flow-logging probe (33.0 m below reference point) is not known in detail, the change in transmissivity for the anomaly is represented by a sloping line from 33.0 m up to the casing. The estimated lower limit of T and the total T of the borehole are also shown in the figure.

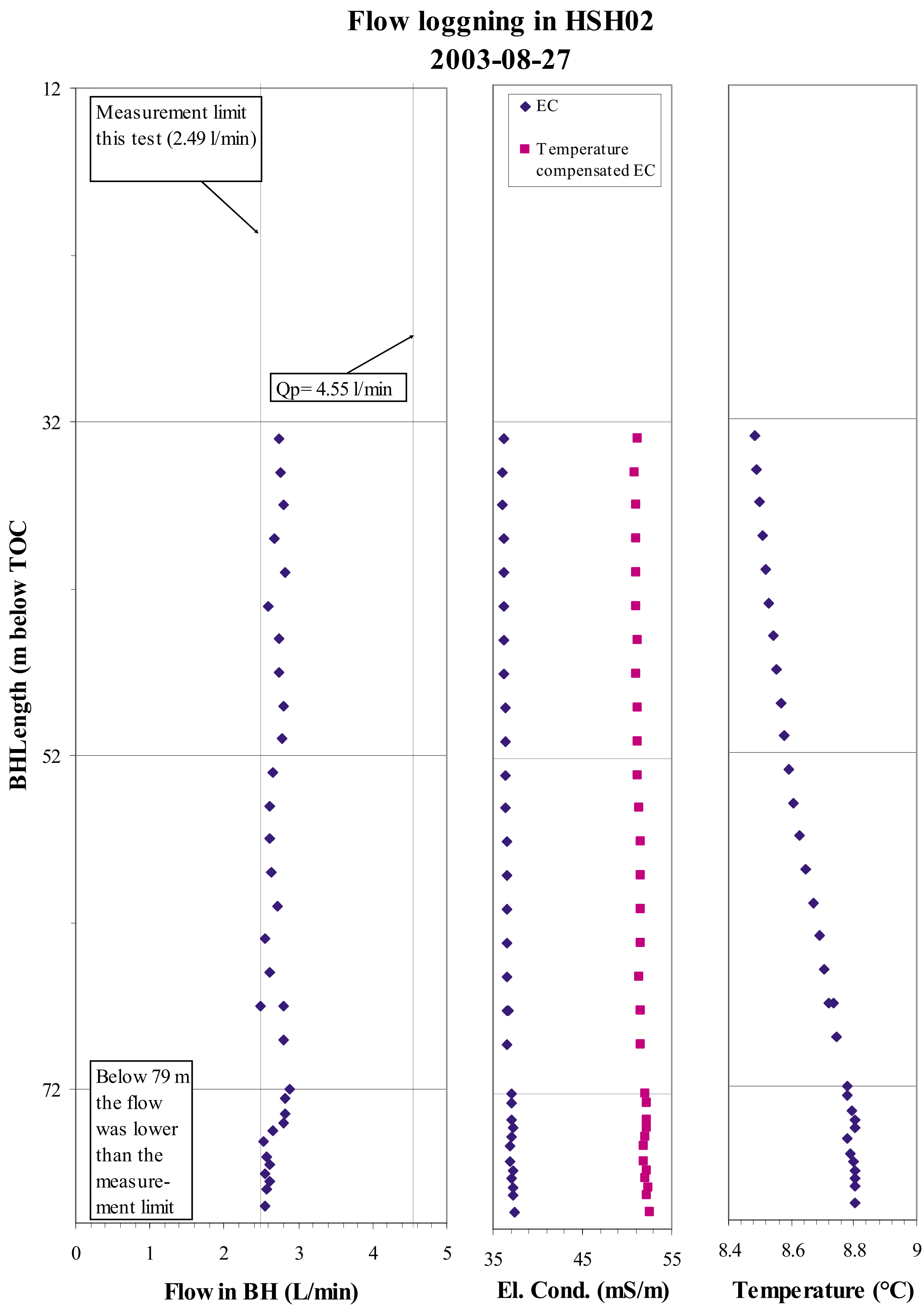


Figure 6-3. *Measured flow distribution along borehole HSH02 during the flow logging together with the electric conductivity (EC) and temperature (Te) of the borehole fluid.*

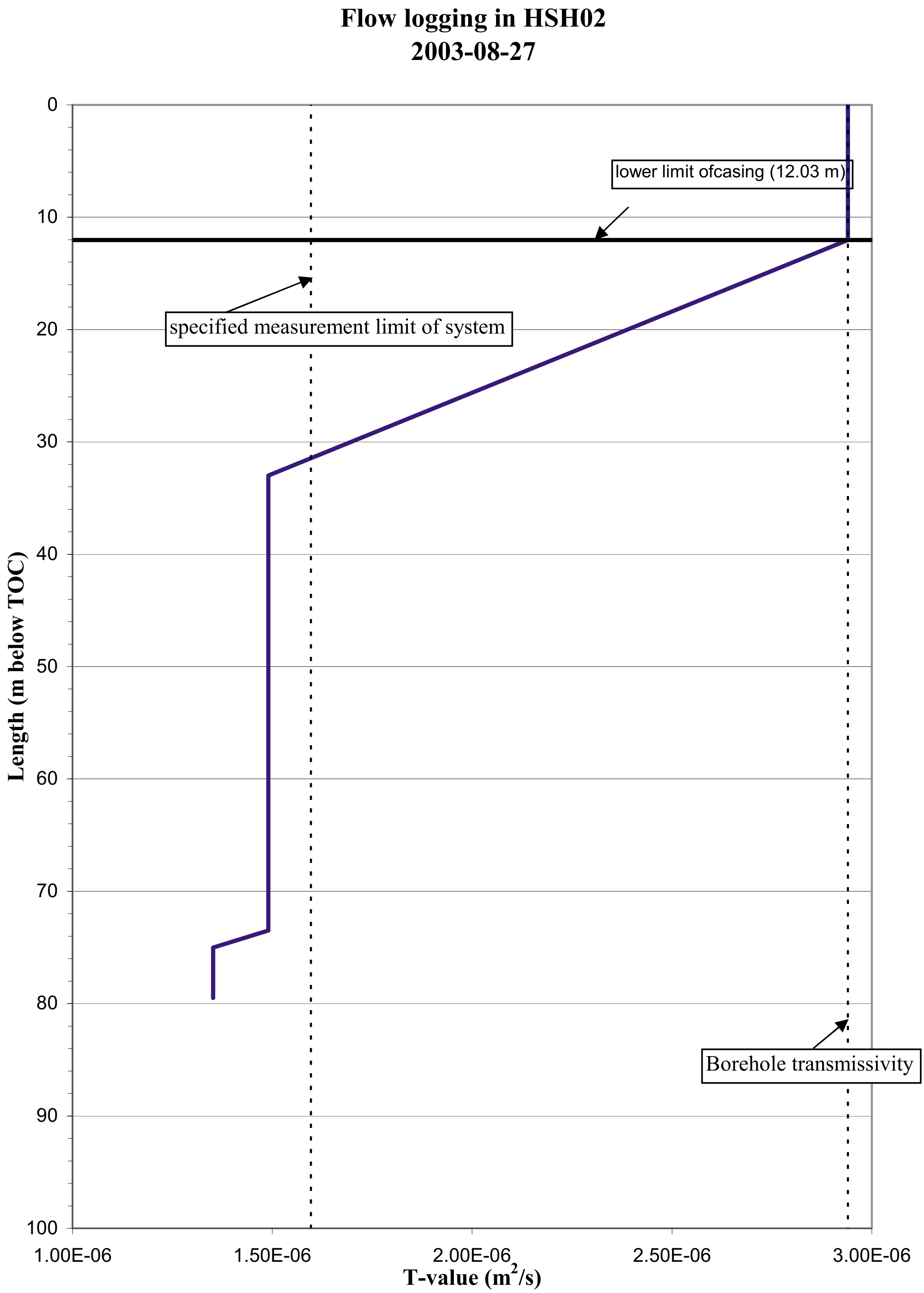


Figure 6-4. *Calculated cumulative transmissivity along the flow-logged interval of borehole HSH02. Below 79.0 m the borehole transmissivity was below the measurement limit. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.5 Summary of hydraulic tests

A compilation of measured test data from the hydraulic tests carried out in the test campaign is shown in Table 6-10. In Table 6-11 and 6-12 calculated hydraulic parameters of the formation and borehole from the tests, respectively, are shown. 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. These values correspond to a practical lower measurement limit of Q/s–L=$2\cdot10^{-6}$ m^2/s of the pumping 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 6-10. Summary of test data for the hydraulic tests performed in borehole HSH02 and the percussion drilled part of KSH03.

Borehole ID	Section (m)	Test type[1)]	p_i (kPa)	p_p (kPa)	p_F (kPa)	Q_p (m^3/s)	Q_m (m^3/s)	V_p (m^3)
KSH03	11.8–100.6	1B	284.3	113.3	243.0	$1.21\cdot10^{-4}$	$1.35\cdot10^{-4}$	5.0
KSH03	11.8–28.0	1B	244.5	114.6	197.0	$3.17\cdot10^{-5}$	$8.12\cdot10^{-4}$	0.8
KSH03	28.0–99.6	6, L-EC, L-Te	*					
HSH02	12.0–200.0	1B	289.0	105.3	279.2	$7.58\cdot10^{-5}$	$8.75\cdot10^{-5}$	3.4
HSH02	12.0–33.0	1B	290.8	194.5	292.2	$1.42\cdot10^{-5}$	$2.87\cdot10^{-5}$	0.3
HSH02	33.0–195.0	6, L-EC, L-Te	*					

1) 1B: Pumping test-submersible pump, 6: Flow logging–Impeller. L-EC: EC-logging, L-Te: temperature logging.
* Flow logging conducted in conjunction with pump test in section 11.80–100.6 and 12.03–200.0 respectively.

Table 6-11. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed in borehole HSH02 and the percussion drilled part of KSH03.

Borehole ID	Section (m)	Flow Anomaly interval (m)	Test type[1)]	Q/s (m^2/s)	T_{Moye} (m^2/s)	T_1 (m^2/s)	T_i (m^2/s)	S* (–)
KSH03A	11.8–100.6		1B	$9.27\cdot10^{-6}$	$1.08\cdot10^{-5}$	–		–
KSH03A	11.8–28.0		1B	$2.39\cdot10^{-6}$	$2.08\cdot10^{-6}$	–		
KSH03A	28.0–99.6	32.0–34.5	6, L-EC, L-Te				$8.72\cdot10^{-6}$	
HSH02	12.0–200.0		1B	$4.05\cdot10^{-6}$	$5.28\cdot10^{-6}$	$2.94\cdot10^{-6}$		$1\cdot10^{-5}$
HSH02	12.0–33.0		1B	$1.38\cdot10^{-6}$	$1.45\cdot10^{-6}$	–		
HSH02	33.0–195.0	75.0–73.5	6, L-EC, L-Te				$1.28\cdot10^{-7}$	
		79.0–79.5					$1.36\cdot10^{-6}$	

1) 1B: Pumping test-submersible pump, 6: Flow logging–Impeller. L-EC: EC-logging, L-Te: temperature logging

In Table 6-10 and 6-11, the parameter explanations are according to the Instruction for analysis of injection tests and single-hole pumping tests. The parameters are also explained in the text above, except the following parameters:

T_M = steady-state transmissivity calculated from Moye's formula

T_1 = transient transmissivity from the first pseudo-radial flow regime

T_i = estimated transmissivity of flow anomaly

S* = assumed value on storativity used in single-hole tests for calculation of the skin factor.

Table 6-12. Summary of calculated hydraulic parameters of the borehole from hydraulic test performed in borehole HSH02 and the percussion drilled part of KSH03A.

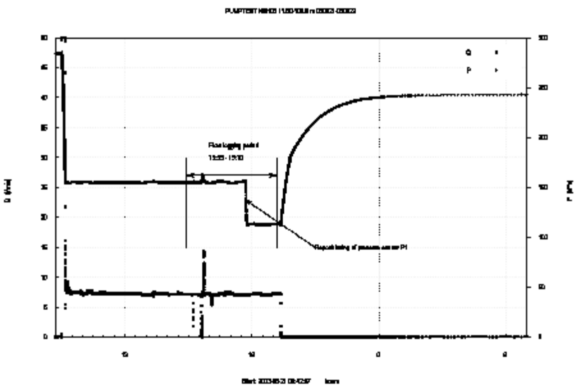
Borehole ID	Section (m)	Test type	S* (–)	C (m^3/Pa)	ζ (–)
KSH03A	11.8–100.6	1B	–	$2.34 \cdot 10^{-6}$	–
KSH03A	11.8–28.0	1B	–	–	–
HSH02	12.0–200.0	1B	$1 \cdot 10^{-5}$	$1.69 \cdot 10^{-6}$	–3.13
HSH02	12.0–33.0	1B	–	–	–

C = wellbore storage coefficient
ζ = skin factor

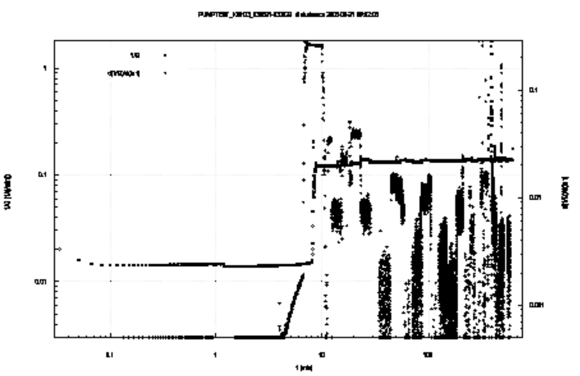
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Osskarshamn	Test no:	2
Borehole ID:	KSH03A(0-100.6 m)	Test start:	2003-08-21 08:43
Test section (m):	11.80-100.6	Responsible for test performance:	GEOSIGMA AB T. Svensson
Section diameter, $2 \cdot r_w$ (m):	top 0.1595 bottom 0.1592	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

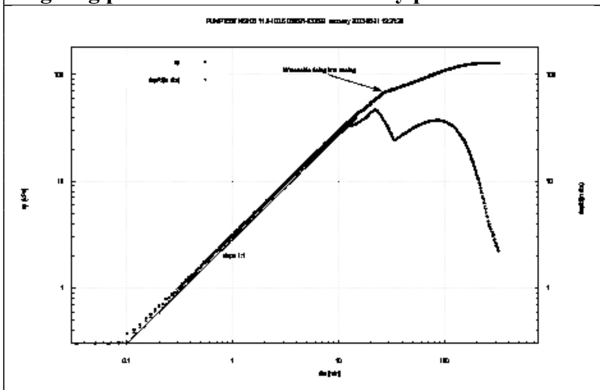
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	284.3		
p_p(kPa)	156.3	p_F (kPa)	285.0
Q_p (m^3/s)	$1.21 \cdot 10^{-4}$		
tp (min)	619.4	t_F (min)	696.5
S*	$1 \cdot 10^{-5}$	S*	$1 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m^2/s)	$9.27 \cdot 10^{-6}$		
T_{Moye}(m^2/s)	$1.08 \cdot 10^{-5}$	T_{Moye}(m^2/s)	$1.09 \cdot 10^{-5}$
Flow regime:		Flow regime:	WBS
t_1 (min)	-	dt_{e1} (min)	0.1
t_2 (min)	-	dt_{e2} (min)	10
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)	$2.34 \cdot 10^{-6}$
C_D (-)	-	C_D (-)	-
ξ (-)	-	ξ (-)	-
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Interpreted formation and well parameters.

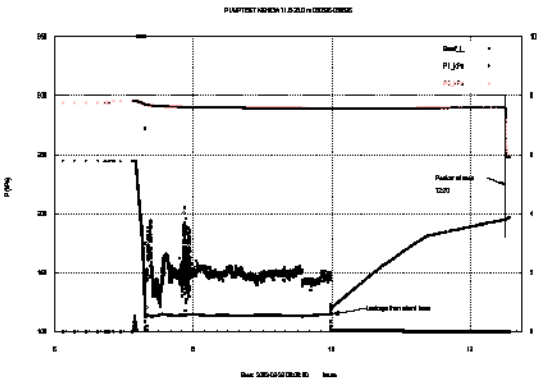
Flow regime:		C (m^3/Pa)	$2.34 \cdot 10^{-6}$
t_1 (min)	-	C_D (-)	-
t_2 (min)	-	ξ (-)	-
T_T (m^2/s)	$1.08 \cdot 10^{-5}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Abrupt drop in pressure during flow period due to repositioning of bore hole pump.
Noisy derivative during flow period, due to difficulties in achieving smooth flow regulation, makes unique transient qualitative and quantitative evaluation difficult.
WBS dominating recovery period, PRF never reached.

Test Summary Sheet

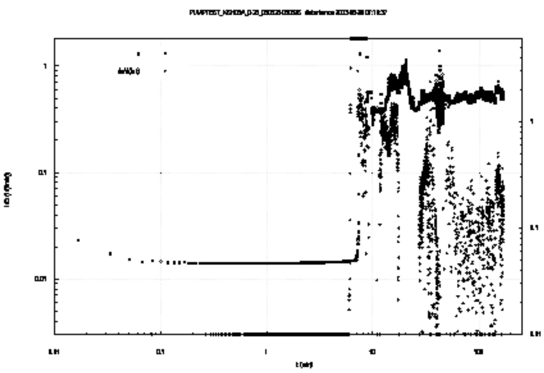
Project:	PLU	Test type:	1B
Area:	Oskarshamn	Test no:	1
Borehole ID:	KSH03A	Test start:	2003-08-25 20:04
Test section (m):	11.80-28.0	Responsible for test performance:	GEOSIGMA AB T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.1595	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

Linear plot Q and p

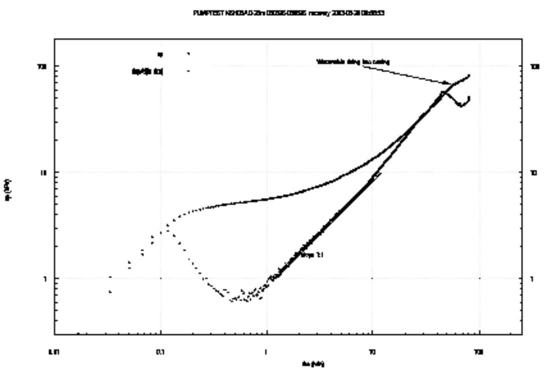


Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	245.0		
p_i (kPa)	244.5		
p_p(kPa)	114.6	p_F (kPa)	197.0
Q_p (m^3/s)	$3.17 \cdot 10^{-5}$		
tp (min)	168.4	t_F (s)	155.5
S*	-	S*	-
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m^2/s)	$2.39 \cdot 10^{-6}$		
T_{Moye}(m^2/s)	$2.08 \cdot 10^{-6}$		
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. derivate- flow period



Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.

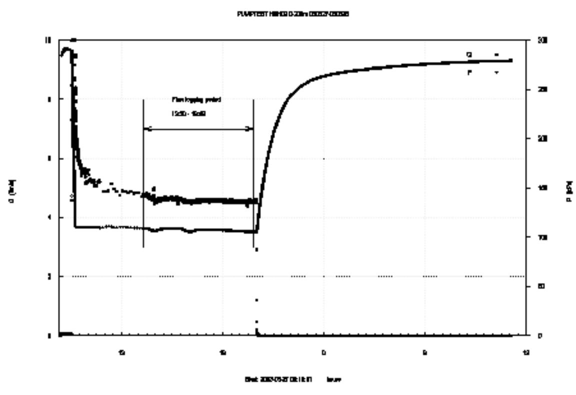
Flow regime:	-	C (m^3/Pa)	-
t_1 (min)	-	C_D (-)	-
t_2 (min)	-	ξ (-)	-
T_T (m^2/s)	$2.08 \cdot 10^{-6}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Test was performed to support and verify flow logging data Part of the pumped flow was shunted back into the borehole. No distinct period PRF during the flow period could be identified due to noisy derivative. A local maximum of derivative and rapid rise of c. 4 kPa during recovery is due to in leakage from shunt hose at pump stop. Recovery was interrupted due to limited time.

Test Summary Sheet

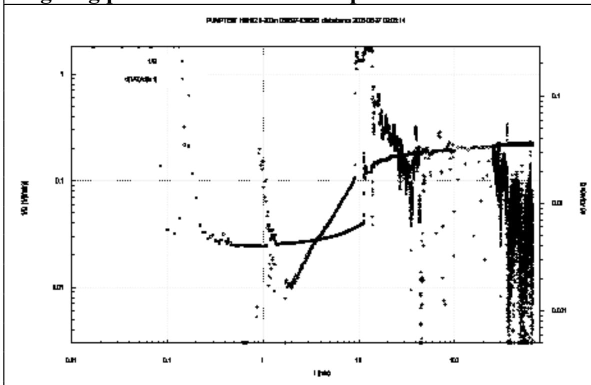
Project:	PLU	Test type:	1B
Area:	Osakrshamn	Test no:	2
Borehole ID:	HSH02	Test start:	2003-08-25 20:04
Test section (m):	12.03-200.0	Responsible for test performance:	GEOSIGMA AB T. Svensson
Section diameter, $2 \cdot r_w$ (m):	top 0.1399 bottom 0.1396	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

Linear plot Q and p

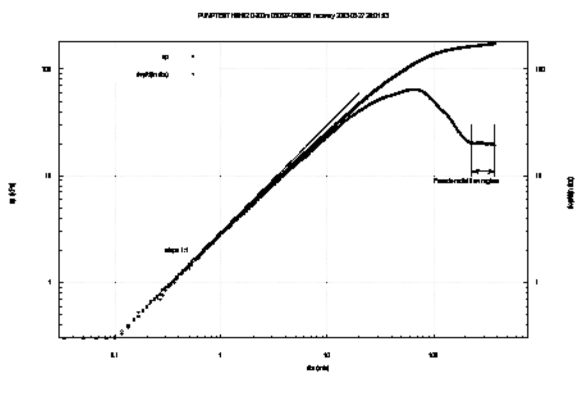


Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	289.0		
p_p(kPa)	105.3	p_F (kPa)	279.2
Q_p (m^3/s)	$7.58 \cdot 10^{-5}$		
tp (min)	657.8	t_F (min)	904.6
S*		S*	$1 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m^2/s)	$4.05 \cdot 10^{-6}$		
T_{Moye}(m^2/s)	$5.28 \cdot 10^{-6}$	T_{Moye}(m^2/s)	$5.59 \cdot 10^{-6}$
Flow regime:	-	Flow regime:	PRF
t_1 (min)	-	dt_{e1} (min)	230
t_2 (min)	-	dt_{e2} (min)	400
T_w (m^2/s)	-	T_w (m^2/s)	$2.94 \cdot 10^{-6}$
S_w (-)	-	S_w (-)	-
K_{sw} (m/s)	-	K_{sw} (m/s)	$1.56 \cdot 10^{-8}$
S_{sw} (1/m)	-	S_{sw} (1/m)	-
C (m^3/Pa)	-	C (m^3/Pa)	$1.69 \cdot 10^{-6}$
C_D (-)	-	C_D (-)	-
ξ (-)	-	ξ (-)	-3.13
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



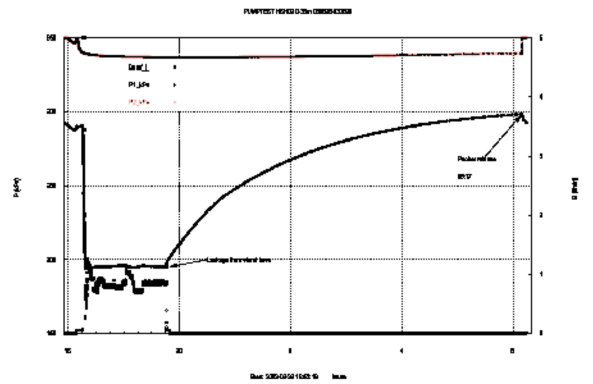
Interpreted formation and well parameters.			
Flow regime:	PRF	C (m^3/Pa)	$1.69 \cdot 10^{-6}$
t_1 (min)	230	C_D (-)	-
t_2 (min)	400	ξ (-)	-3.13
T_T (m^2/s)	$2.94 \cdot 10^{-6}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Derivative of inverse flow data during drawdown is noisy due to imperfect flow regulation. First part of the recovery period, up to c. 5 minutes, is dominated by wellbore storage effects. This period is followed by a transition phase and a distinct pseudo-radial flow regime after 200 minutes.

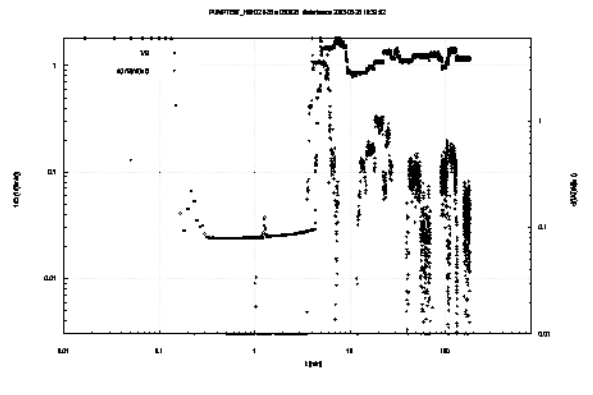
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Oskarshamn	Test no:	1
Borehole ID:	HSH02	Test start:	2003-08-28 15:52
Test section (m):	12.03-33.0	Responsible for test performance:	GEOSIGMA AB T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.1399	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

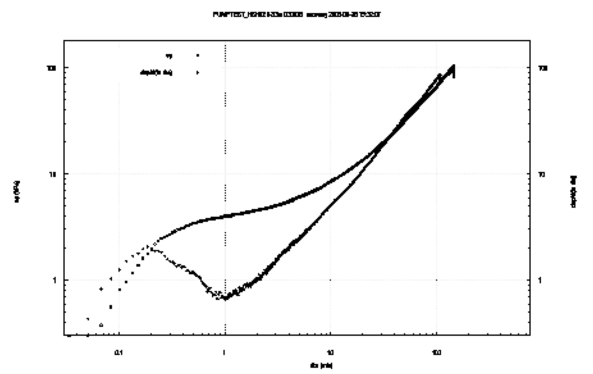
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	290.8		
p_p(kPa)	194.5	p_F (kPa)	292.2
Q_p (m^3/s)	$1.42 \cdot 10^{-5}$		
tp (min)	180.1	t_F (min)	776.5
S*		S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m^2/s)	$1.38 \cdot 10^{-6}$		
T_{Moye}(m^2/s)	$1.45 \cdot 10^{-6}$		
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} (-)	

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)	$1.45 \cdot 10^{-6}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: The test was conducted to support and verify flow logging data. To extend the working range of the system part of the pumped flow was shunted back into the borehole. No period of PRF during the flow period could be identified due to noisy derivative. A rapid recovery of c. 2 kPa is due to in leakage from shunt hose at stop of pumping

7 References

1 **SKB 2001a.** Site investigations: Investigation methods and general execution programme. R-01-29 Svensk Kärnbränslehantering AB.

2 **SKB 2001b.** Geoveteskapligt program för platsundersökning vid Simpevarp. R-01-44 Svensk Kärnbränslehantering AB.

3 **SKB 2002.** Execution programme for the initial site investigations at Simpevarp. P-02-06 Svensk Kärnbränslehantering AB.

4 **Almén K-E et al. 1986.** Hydraulic testing in crystalline rock. A comparative study of single-hole test methods. Technical Report 86-27, Svensk Kärnbränslehantering AB.

Appendix 1

List of test data files

Files are named ”bhnamn_secup_yymmdd_XX”, where yymmdd is the date of 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 flow logging. Spinne contains data from spinner measurements, Inject contains data from injection test and Pumpin from pumping tests (no combined flow logging).

Bh ID	Test section (m)	Test type[1]	Test no	Test start Date, time YYYY-MM-DD tt:mm:ss	Test stop Date, time YYY-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	Content (parameters)2	Comments
KSH03A	0–100.6	1B	1	030820 17:11:37	20030821 07:31:16	030820 17:11:37	20030821 07:31:16	KSH03_000_030821_FlowLo00.dat	P, Q, T, EC	Capacity test preceding 10 h pumping test
						020905 09:22:04	03-08-21 07:31:19	KSH03_000_030821_Ref_Da00.DAT	R, C	
KSH03A	0–100.6	1B	2	03-08-21 08:43:06	03-08-22 06:57:57	030821 08:42:57	03-08-22 06:57:57	KSH03_000a_030821_FlowLo00.DAT	P, Q, T, EC	For overnight pressure registration preceding this test see KSH03_000_030821_ FlowLo00.dat
						030820 10:21:54	03-08-22 08:06:43	KSH03_000a_030821_Ref_Da00.DAT	R, C	
KSH03A	28–97	6:L-EC, L-T	1	030821 14:56	030821 19:10:18	030821 16:11:54	030821 19:10:18	KSH03_028_030821_Spinne00.DAT	P, Q, T, EC, SP	For temperature and electric conductivity at positions with no registered flow by flow logging probe see KSH03_000a_030821_ FlowLo00.DAT
						03-08-20 10:21:54	03-08-21 19:23:50	KSH03_028_030821_Ref_Da00.DAT	R, C	
KSH03A	0 –28	1B	1	03-08-26 06:46:06	03-08-26 12:34:03	03-08-25 20:04:26	03-08-26 12:34:03	KSH03_000_030825_Pumpin00.DAT	P, Q	Test conducted to support and verify flow logging data
						03-08-20 10:21:54	03-08-26 12:34:12	KSH03_000_030825_Ref_Da00.DAT	R, C	

Bh ID	Test section (m)	Test type[1]	Test no	Test start Date, time YYYY-MM-DD tt:mm:ss	Test stop Date, time YYY-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	Content (para-meters)2	Comments
HSH02	0–200	1B	1	03-08-26 16:42:33	03-08-26 17:58:04	03-08-25 20:04:26	03-08-26 17:58:04	HSH02_000_030826_Pumpin00.DAT	P, Q	Capacity test and overnight pressure registration preceding 10 h pumping test
HSH02	0–200					03-08-20 10:21:54	03-08-27 07:49:45	HSH02_000_030826_Ref_Da00.DAT	R, C	
HSH02	0–200	1B	2	03-08-27 08:25:30	03-08-28 11:05:39	03-08-27 08:18:01	03-08-28 11:05:39	HSH02_000_030827_FlowLo00.DAT	P, Q, T, EC	
HSH02	0–200					02-09-05 09:22:04	03-08-28 11:05:43	HSH02_000_030827_Ref_Da00.DAT	R, C	
HSH02	195–33	6: L-EC, L-T	1	03-08-27 13:30:00	03-08-27 19:48:51	03-08-27 16:12:27	03-08-27 19:48:51	HSH02_33_030827_Spinne00.DAT	P, Q, T, EC, Sp	For temperature and electric conductivity at positions with no registered flow by flow logging probe see HSH02_000_030827_ FlowLO00.DAT
HSH02	195–33					03-08-26 06:42:51	03-08-27 19:58:39	HSH02_33_030827_Ref_Da00.DAT	R, C	
HSH02	0–33	1B	1	03-08-28 15:55	03-08-29 08:20	03-08-28 15:52:16	03-08-29 08:28:36	HSH02_000_030828_Pumpin00.DAT	P, Q	Test conducted to support and verify flow logging data
HSH02	0–33	1B				03-08-27 07:49:42	03-08-29 08:42:58	HSH02_000_030828_Ref_Da00.DAT	R, C	

1: 1A: Pumping test-wire-line equipment, 1B: Pumping test-submersible pump, 1C: Pumping test-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging-PFL-DIFF_sequential, 5B: Difference flow logging-PFL-DIFF_overlapping, 6: Flow logging-Impeller, Logging-EC: L-EC, Logging temperature: L-T, Logging single point resistance: L-SPR

2: P =Pressure, Q =Flow, Te =Temperature, EC =El. conductivity. SPR =Single Point Resistance, C =Calibration file, R =Reference file, Sp= Spinner rotations

Diagram of test responses

Diagrams are presented for the following tests:

1. Pumping test in KSH03A: 11.80–100.6 m
2. Pumping test in KSH03A: 11.80–28.0 m
3. Pumping test in HSH02: 12.03–200.0 m
4. Pumping test in HSH02: 12.03–33.0 m

Pumping test in KSH03A: 11.80–100.6 m

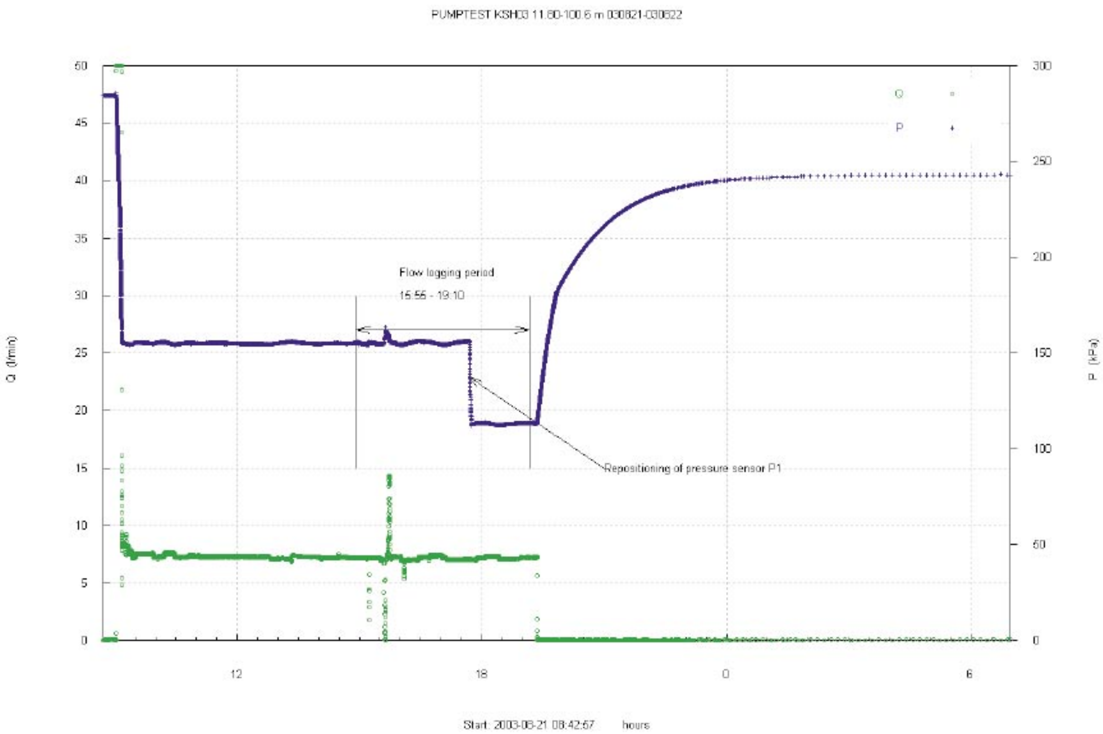


***Figure A2-1.** Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in KSH03A (11.80–100.6 m) in conjunction with flow logging.*

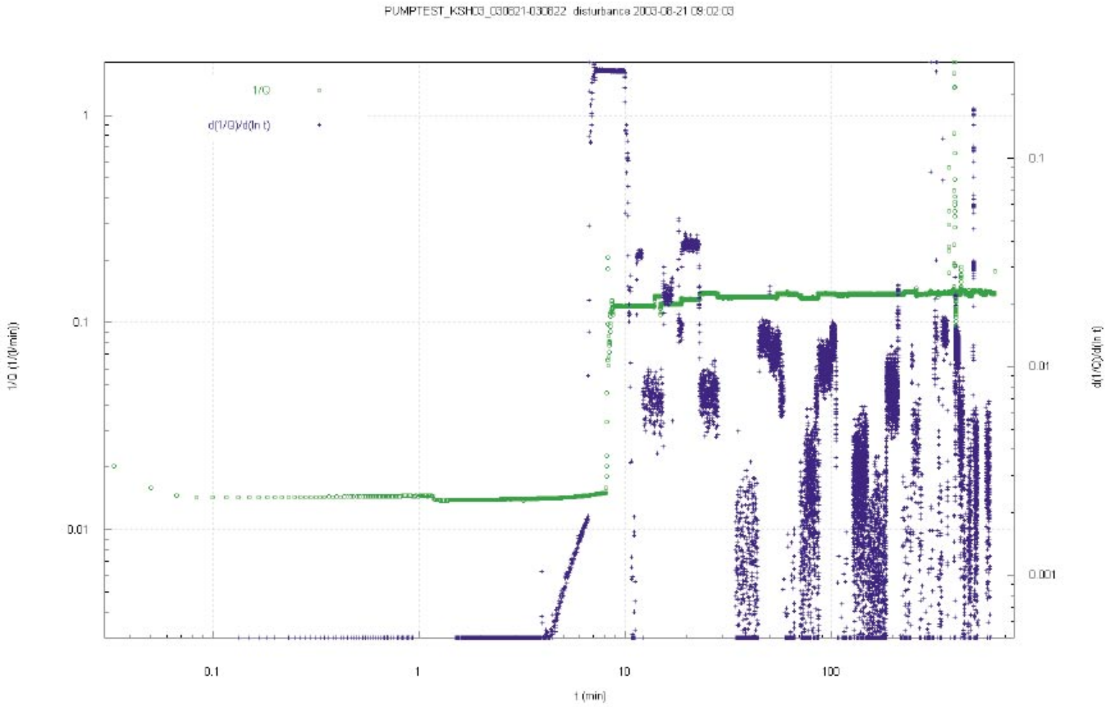


Figure A2-2. *Log-log plot of inverse flow (1/Q) and inverse flow derivative, d(1/Q)/d(ln t), versus time (t) during the open-hole pumping test in KSH03A (11.80–100.6 m).*

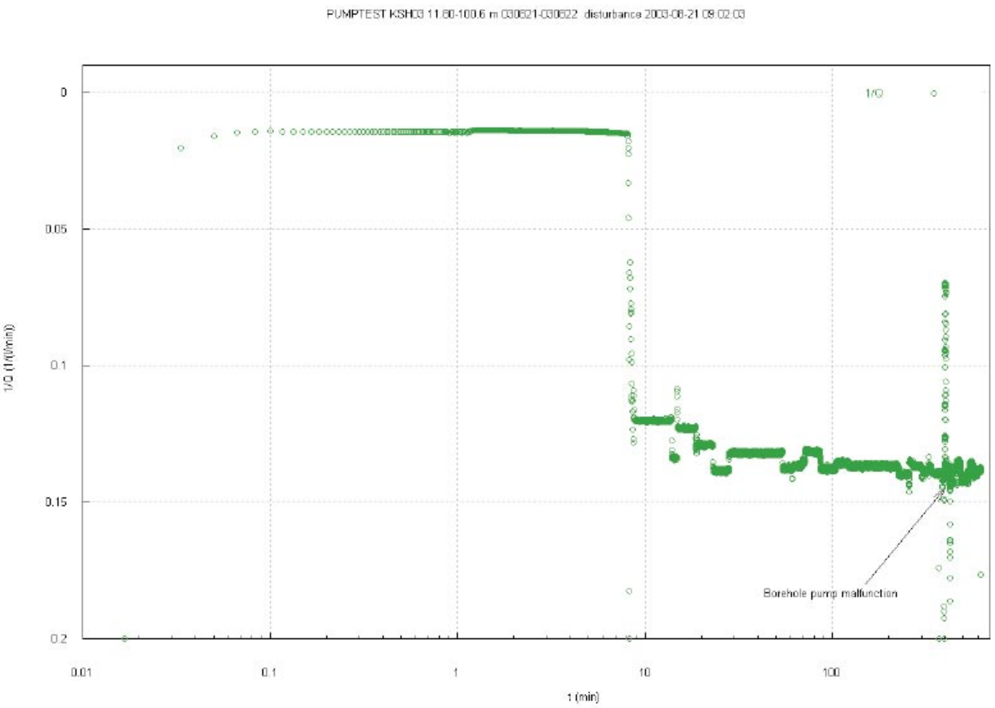


Figure A2-3. *Lin-log plot of inverse flow (1/Q) versus time (t) during the open-hole pumping test in KSH03A (11.80–100.6 m).*

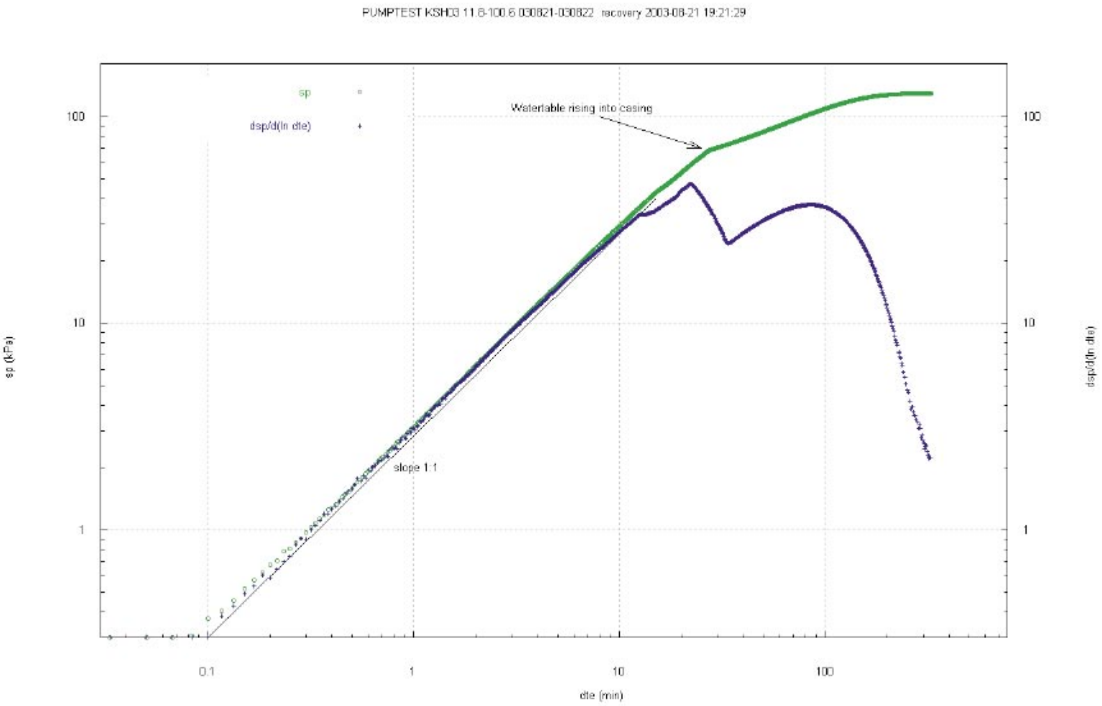


Figure A2-4. *Log-log plot of pressure recovery (sp) and – derivative, dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in KSH03A (11.80–100.6 m).*

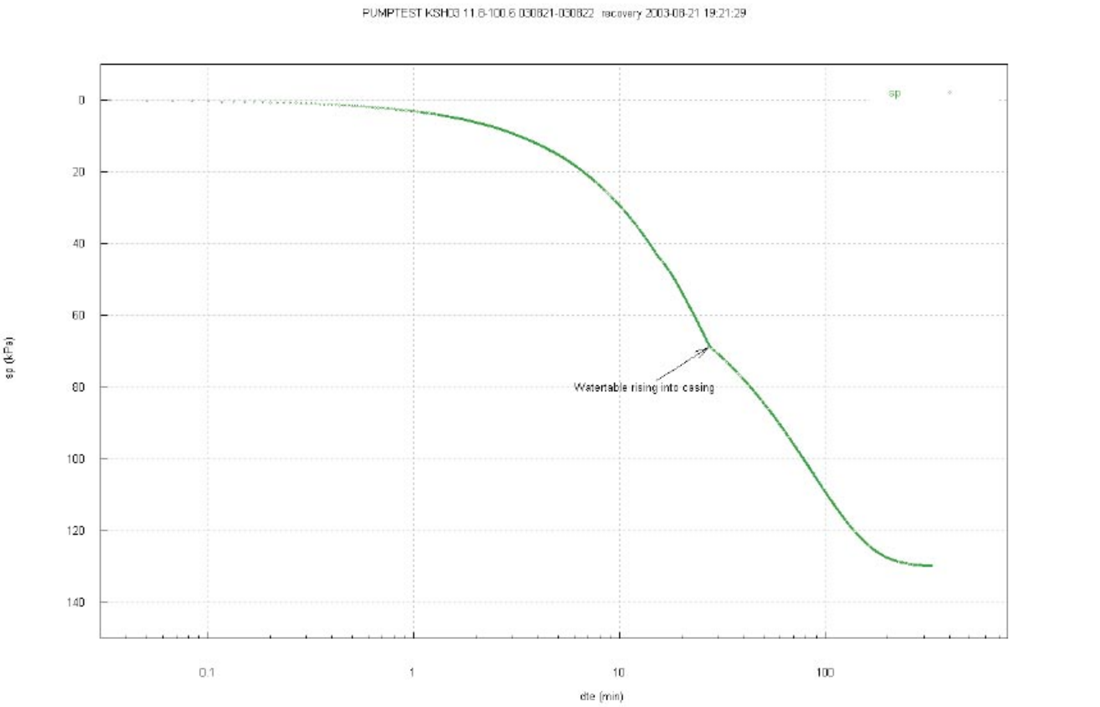


Figure A2-5. *Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the open-hole pumping test in KSH03A (11.80–100.6 m).*

Pumping test in KSH03A: 11.80–28.0 m

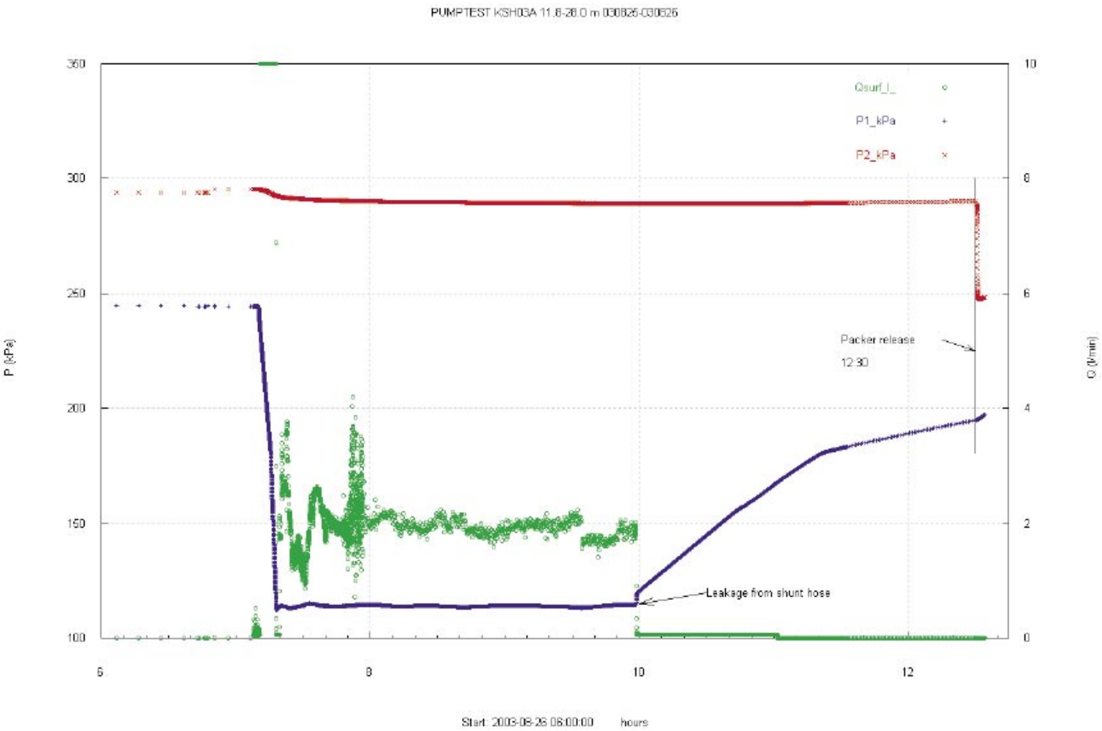


Figure A2-6. *Linear plot of flow rate (Q), pressure in section (P1) and pressure below section (P2) versus time during the open-hole pumping test in KSH03A, section 11.80–28.0 m.*

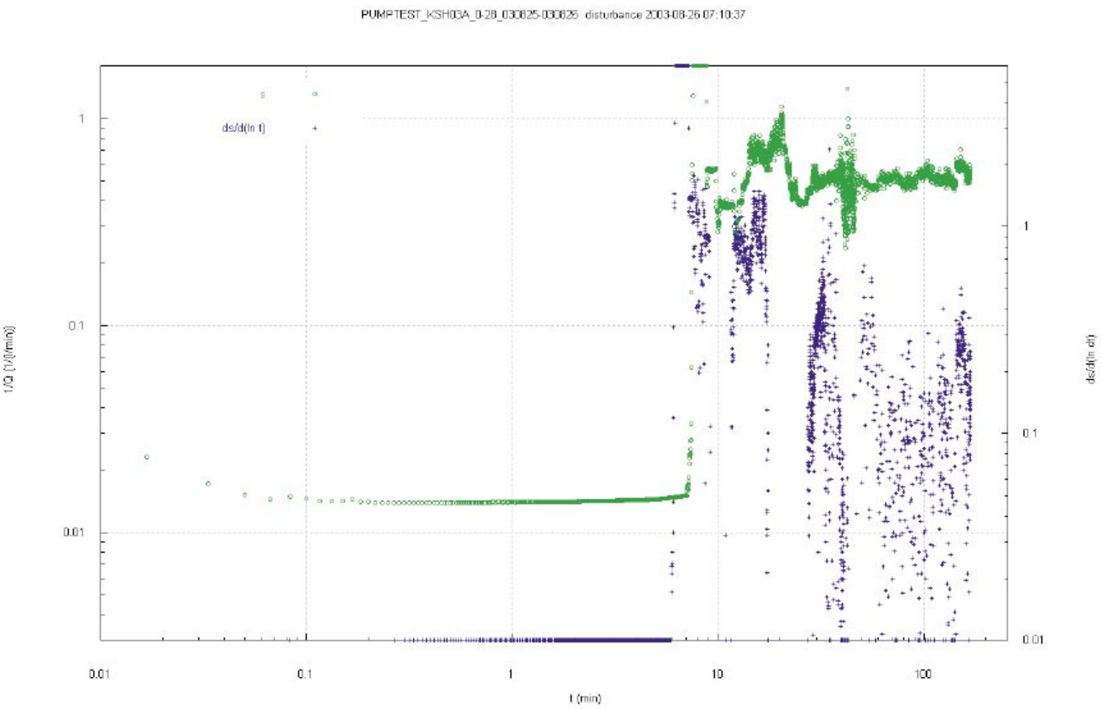


Figure A2-7. *Log-log plot of inverse flow (1/Q) and inverse flow derivative, d(1/Q)/d(ln t), versus time (t) during the open-hole pumping test above a single packer in KSH03A, section 11.80–28.0 m.*

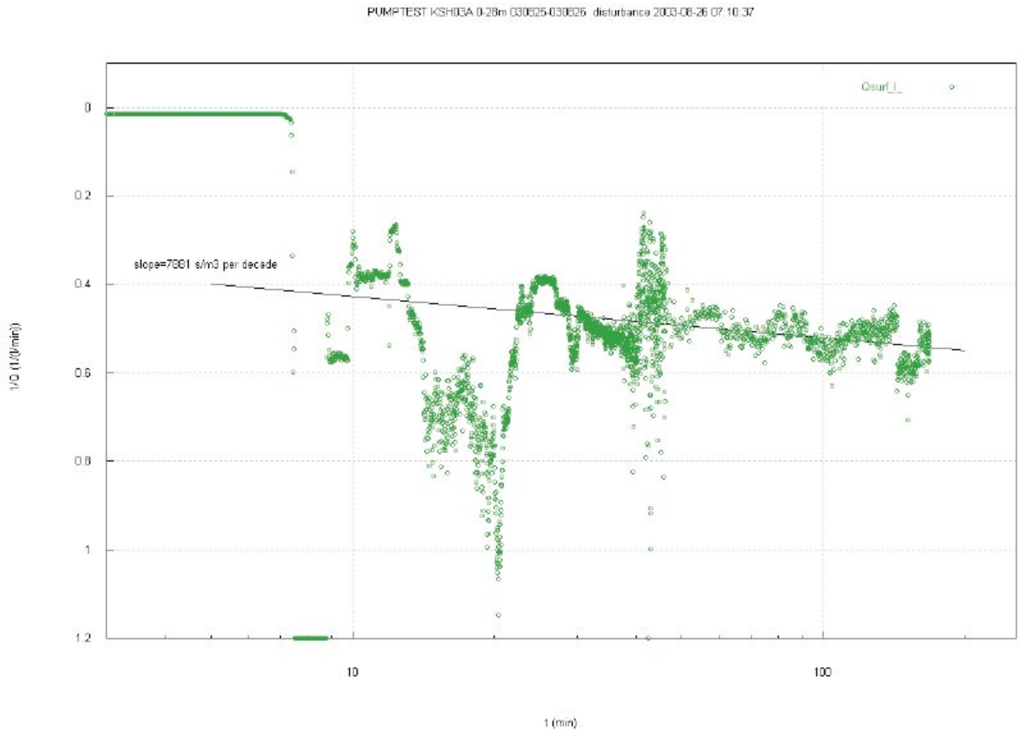


Figure A2-8. Lin-log plot of inverse flow (1/Q) versus time (t) during the open-hole pumping test above a single packer in KSH03A, section 11.80–28.0 m.

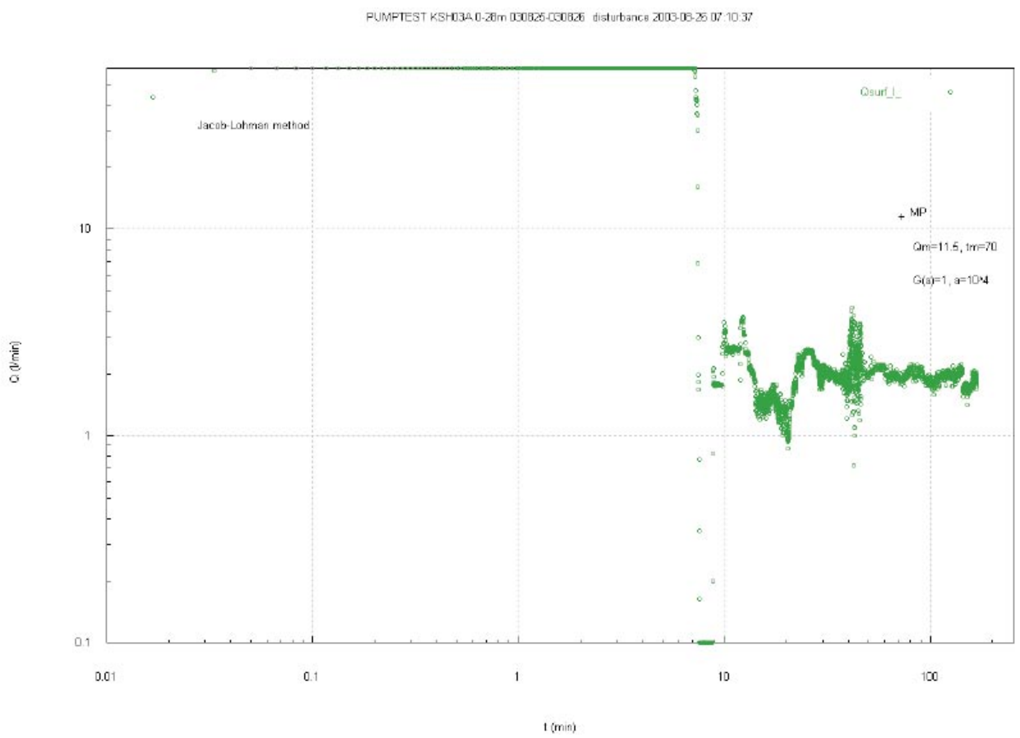


Figure A2-9. Log-log plot of flow (Q) versus time (t) during the open-hole pumping test above a single packer in KSH03A, section 11.80–28.0 m.

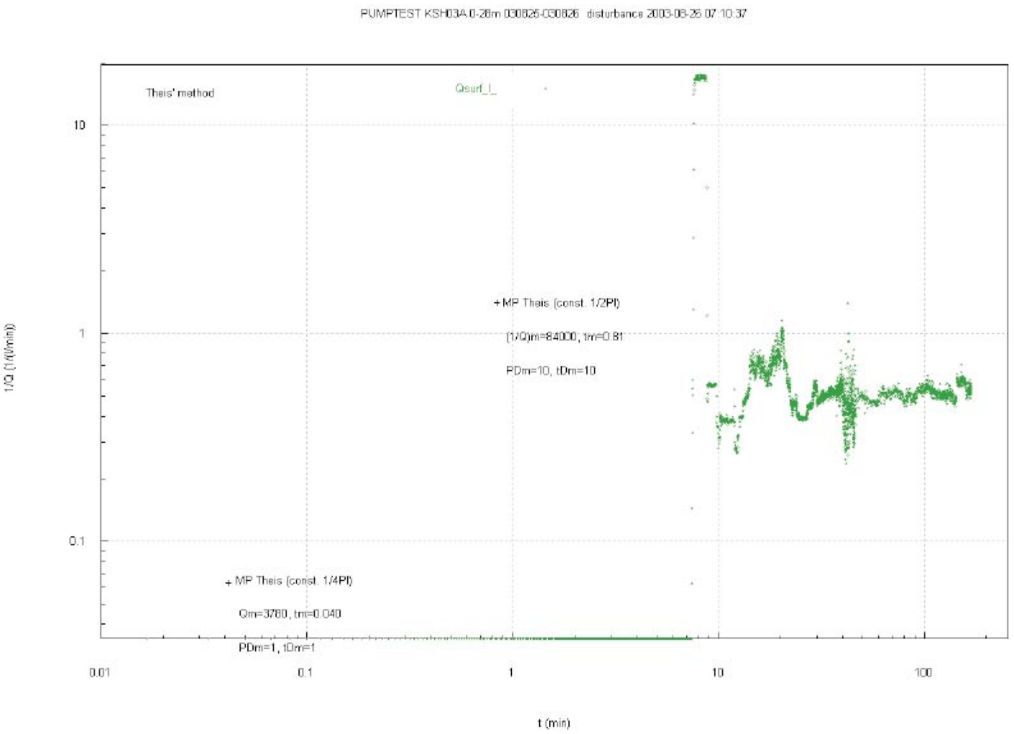


Figure A2-10. *Log-log plot of inverse flow (1/Q) versus time (t) during the open-hole pumping test above a single packer in KSH03A, section 11.80–28.0 m.*

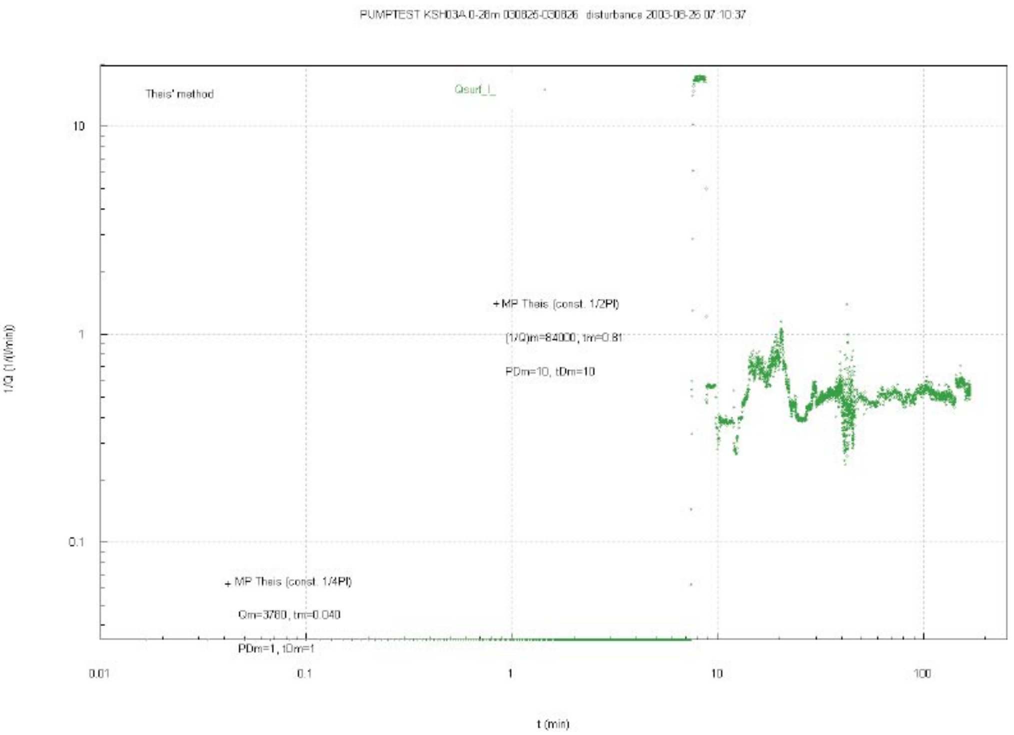


Figure A2-11. *Detailed examination of rapid rise in pressure at pump stop during open-hole test in KSH03A, section 11.80–28.0 m.*

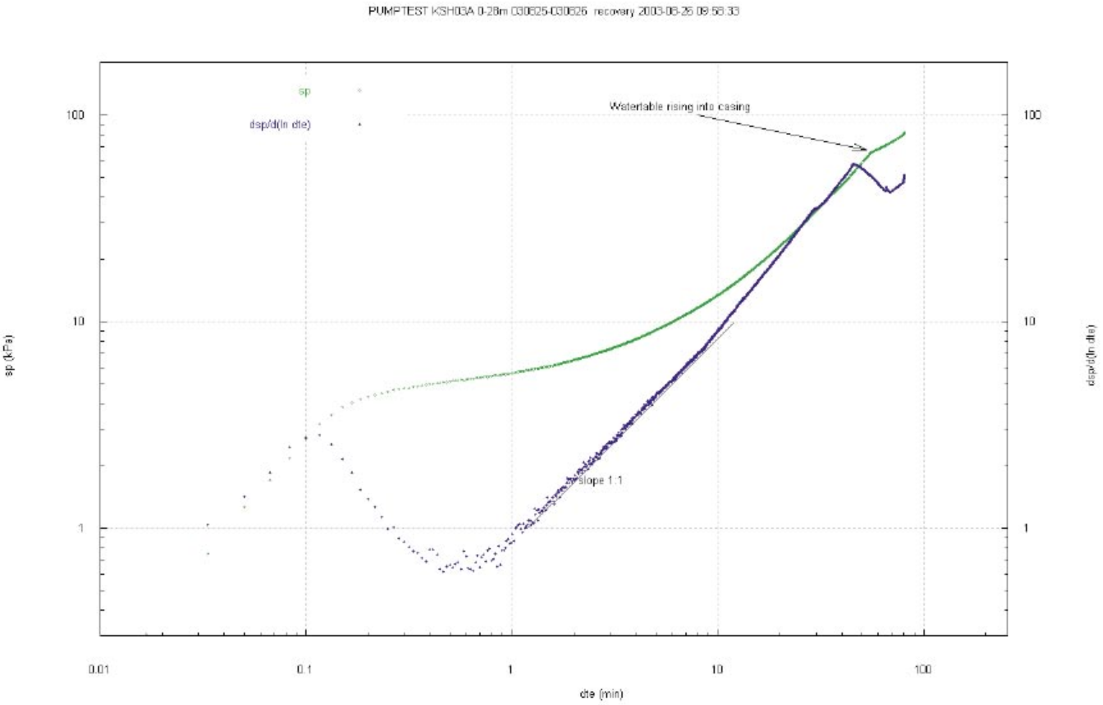


Figure A2-12. *Log-log plot of pressure recovery (sp) and pressure derivative, dsp/d(ln t), versus time (t) during the open-hole pumping test in KSH03A, section 11.80–28.0 m*

Pumping test in HSH02: 12.03–200.0 m

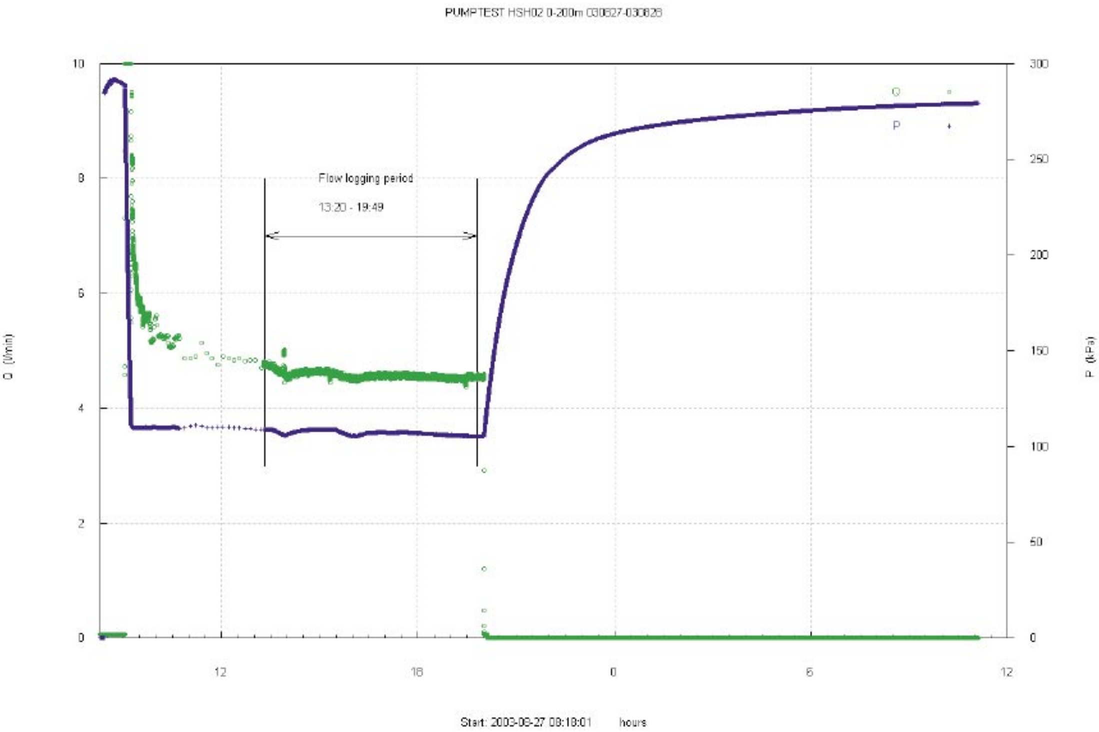


Figure A2-13. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HSH02 (12.03–200.0 m).*

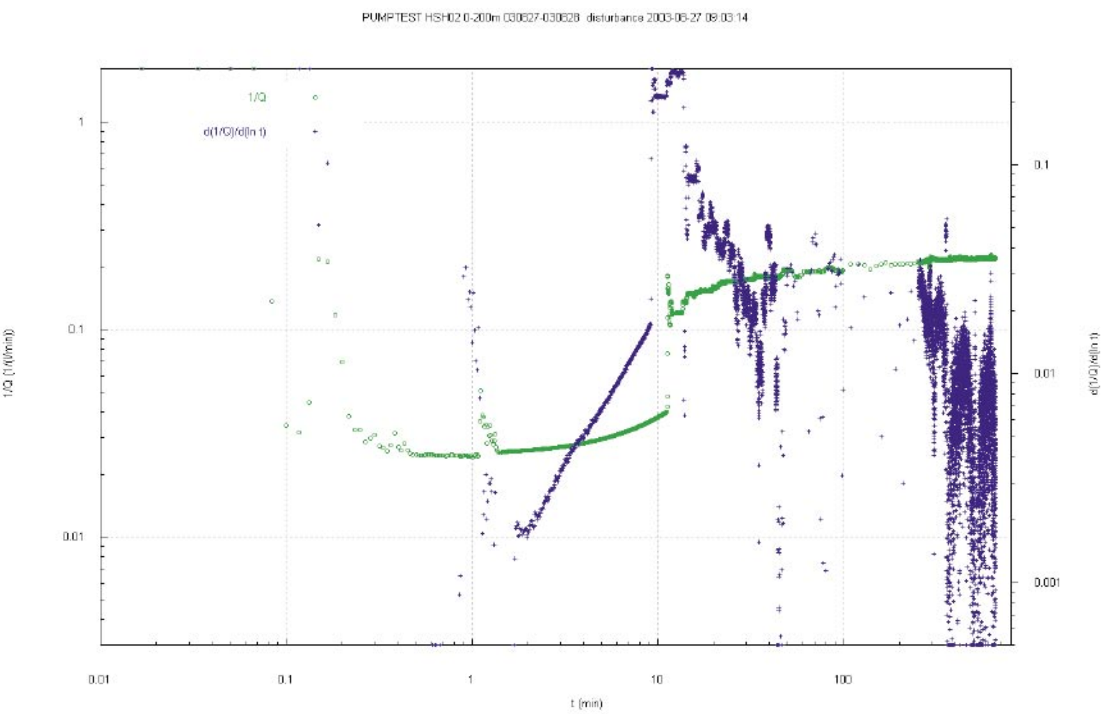


Figure A2-14. *Log-log plot of inverse flow (1/Q) and inverse flow derivative d(1/Q)/d(lnt) versus time (t) during the open-hole pumping test in HSH02 (12.03–200.0 m).*

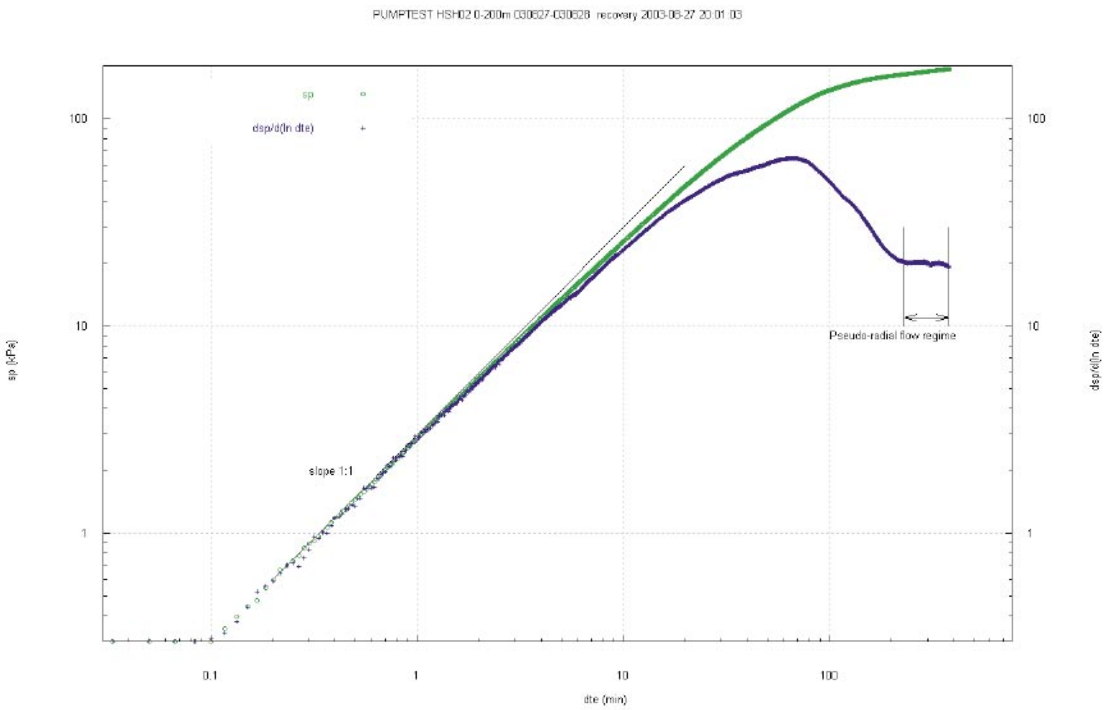


Figure A2-15. *Log-log plot of pressure recovery (sp) and pressure recovery derivative, dsp/d(ln dte) versus equivalent time (dte) the open-hole pumping test in HSH02 (12.03–200.0 m).*

Pumping test in HSH02: 12.03–33.0 m

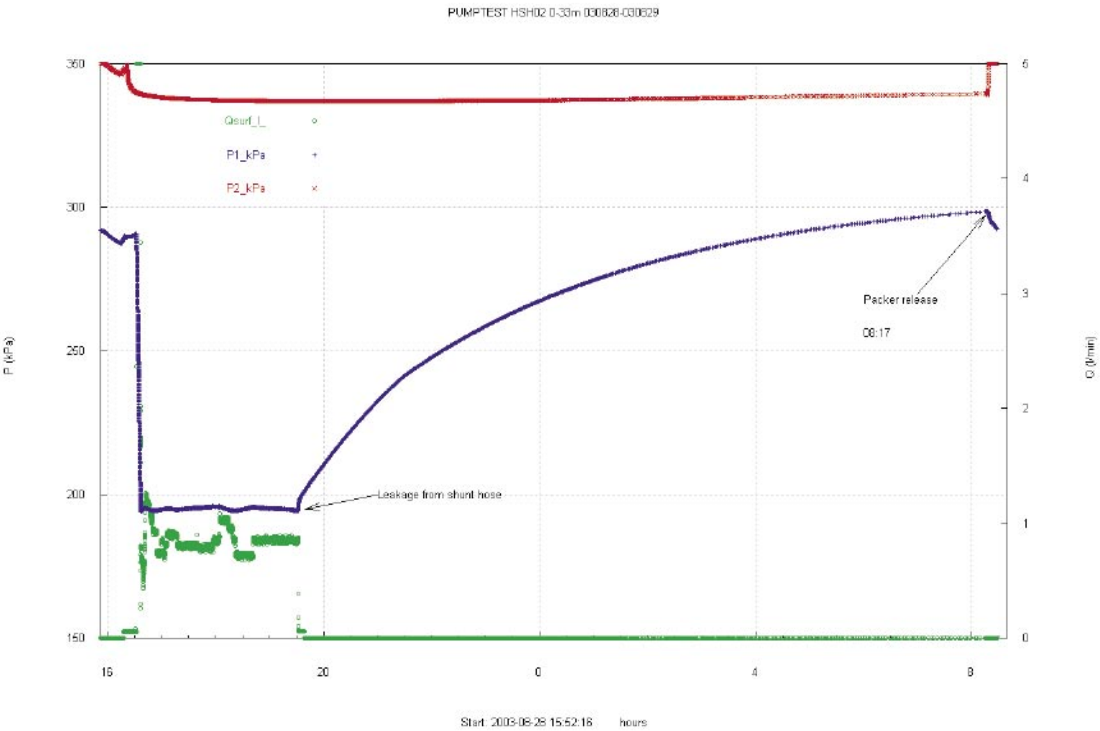


Figure A2-16. *Linear plot of flow rate (Q), pressure in section (P1) and pressure below section (P2) versus time during the open-hole pumping test above a single packer in HSH02 (12.03–33.0 m).*

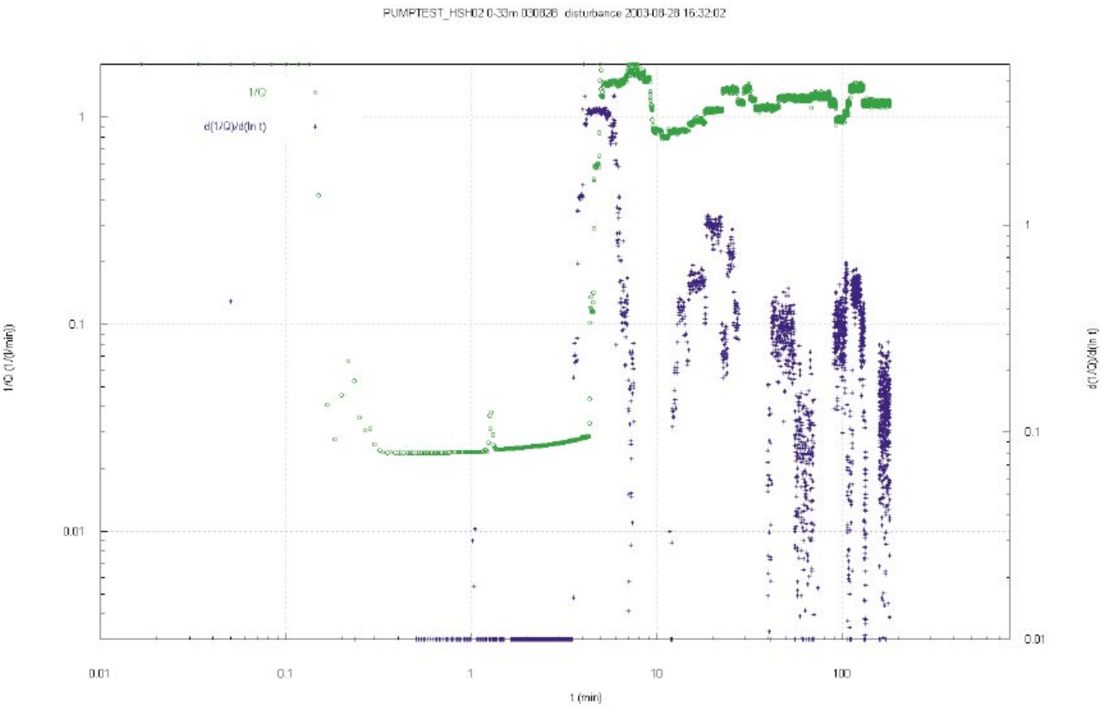


Figure A2-17. *Log-log plot of inverse flow (1/Q) and inverse flow derivative d(1/Q)/d(lnt) versus time (t) during the open-hole pumping test above a single packer in HSH02 (12.03–33.0 m).*

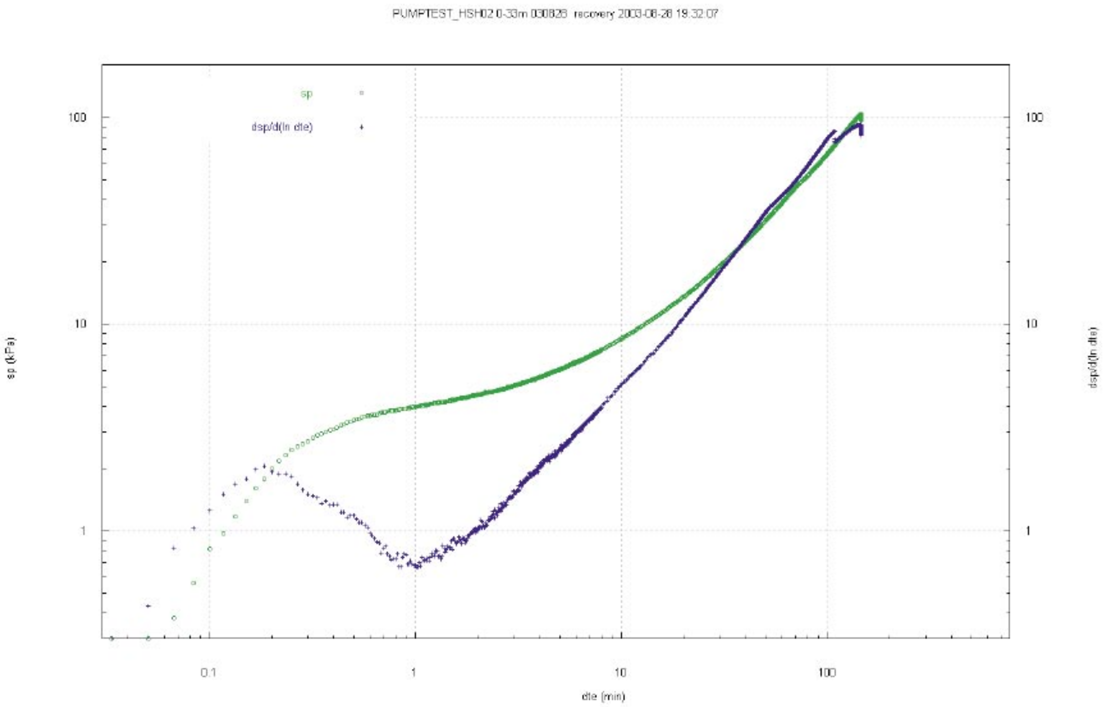


Figure A2-18. *Log-log plot of pressure recovery (sp) and pressure recovery derivative, dsp/d(ln dte) versus equivalent time (dte) the open-hole pumping test in HSH02, 12.03–33.0 m.*

Appendix 3

Result Tables to Sicada

The following Result Tables are presented:

1. Result Tables for Single-hole pumping and injection tests
2. Result Tables for flow meter logging

Result Table for Single hole tests in bore hole HSH02 and percussion drilled part of KSH03A at Simpevarp peninsula, Oskarshamn, for submission to Sicada.

Singlehole tests, Pumping and injection, s_hole_test_d; General information.

Borehole idcode	Borehole secup (m)	Borehole seclow (m)	Test type (1–6)	Formation type (–)	Date and time for test, start YYYYMMDD hh:mm	Date and time for test, stop YYYYMMDD hh:mm	Date and time for flow period, start YYYYMMDD hh:mm:ss	Date and time for flow period, stop YYYYMMDD hh:mm:ss	Qp (m**3/s)	Value type (–1, 0 or 1)	Q-measl-L (m**3)/s	Q-measl-U (m**3)/s
KSH03A	11.80	100.60	1B	1	20030821 08:43	20030822 06:58	20030821 09:02:03	20030821 19:21:29	$1.21 \cdot 10^{-4}$	0	$8.3 \cdot 10^{-5}$	$1.3 \cdot 10^{-3}$
KSH03A	11.80	28.00	1B	1	20030825 20:04	20030826 12:34	20030826 07:10:08	20030826 09:58:33	$3.17 \cdot 10^{-5}$	–1	$8.3 \cdot 10^{-5}$	$1.3 \cdot 10^{-3}$
HSH02	12.00	200.00	1B	1	20030827 08:25	20030828 11:01	20030827 09:03:14	20030827 20:01:03	$7.58 \cdot 10^{-5}$	–1	$8.3 \cdot 10^{-5}$	$1.3 \cdot 10^{-3}$
HSH03	12.00	33.00	1B	1	20030828 15:52	20030829 08:20	20030828 16:32:02	20030828 19:32:07	$1.42 \cdot 10^{-5}$	–1	$8.3 \cdot 10^{-5}$	$1.3 \cdot 10^{-3}$

Cont.

V_p (m**3)	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 (°C)	EC_w (mS/m)	TDS_{wm} (mg/ L)	Reference	Comments (–)
39.4	1.09E–03	37,166	41,788	0.26			284.3	156.3	285.3					
14.6	4.03E–04	10,105	9,330	0.53			244.5	114.6	197.0					
39.0	1.08E–03	39,469	54,276	–0.06	–18.96		289.0	105.3	279.2					
		10,804	46,589	0.22	–9.78	0.73	290.8	194.5	292.2					

Singlehole tests, Pumping and injection, s_hole_test_ed1; Basic evaluation.

Borehole	Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YYYYMMDD hh:mm	Q/s (m2/s)	Value type (–1, 0 or 1)	T_Q (m2/ s)	T_M (m^2/ s)	b (m)	B (m)	TB (1D) (m3/ s)	TB-measl-L (1D) (m3/ s)	TB-measl-U (1D) (m3/ s)	SB (1D) (m)	SB* (1D) (m)	L_f (1D) (m)	TT (2D) (m^2/ s)
KSH03A	11.80	100.60	20030821 08:43	$9.27 \cdot 10^{-6}$	0		$1.08 \cdot 10^{-5}$	88.80								
KSH03A	11.80	28.0	20030825 20:04	$2.39 \cdot 10^{-6}$	0		$2.08 \cdot 10^{-6}$	16.2								
HSH02	12.00	200.00	20030827 08:25	$4.05 \cdot 10^{-6}$	0		$5.28 \cdot 10^{-6}$	188.00								$2.94 \cdot 10^{-6}$
HSH02	12.00	33.0	20030828 15:52	$1.38 \cdot 10–^{6}$	–1		$1.45 \cdot 10^{-6}$	21.0								

Cont.

Value type (–1, 0 or 1)	Q/s-measl-L (m2/ s)	Q/s-measl-U (m^2/ s)	S (2D) (–)	S* (2D) (–)	K´/b´ (2D) (1/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 (–)	t_1 (s)	t_2 (s)	Comments (–)
	$2.0 \cdot 10^{-6}$	$2.0 \cdot 10^{-3}$									$2.34 \cdot 10^{-6}$							
	$2.0 \cdot 10^{-6}$	$2.0 \cdot 10^{-3}$									$1.73 \cdot 10^{-6}$							
	$2.0 \cdot 10^{-6}$	$2.0 \cdot 10^{-3}$		$1 \cdot 10^{-5}$							$1.69 \cdot 10^{-6}$		–3.13			13,800	24,000	
	$2.0 \cdot 10^{-6}$	$2.0 \cdot 10^{-3}$																

Header	Unit	Explanatio
Borehole		ID for borehole
Borehole secup	m	Length coordinate along the borehole for the upper limit of the test section
Borehole seclow	m	Length coordinate along the borehole for the lower limit of the test section
Test type (1– 7)	(–)	1A: Pumping test – wireline eq, 1B:Pumping test-submersible pump, 1C: Pumpingtest-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging-PFL-DIFF-sequential, 5B: Difference flow logging-PFL-DIFF-overlapping, 6:Flow logging_Impeller,7:Grain size analysis
Date for test start		Date for the start of the pumping or injection test (YYYYMMDD hh:mm)
Start flow / injection		Date and time for the start of the pumping or injection period (YYMMDD hh:mm:ss)
Start flow / injection		Date and time for the end of the pumping or injection period (YYMMDD hh:mm:ss)
Q_m	m^3/s	Arithmetic mean flow rate of the pumping/injection period.
Q_p	m^3/s	Flow rate at the end of the pumping/injection period.
Value type	–	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	m^3/s	Estimated lower measurement limit for flow rate
Q-measl_U	m^3/s	Estimated upper measurement limit for flow rate
V_p	m^3	Total volume pumped (positive) or injected (negative) water during the flow period.
t_p	s	Time for the flowing phase of the test
t_F	s	Time for the recovery phase of the test
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.
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.
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.
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_w	gr C	Fluid temperature in the test section representative for the evaluated parameters
EC_w	mS/m	Electrical conductivity of the fluid in the test section representative for the evaluated parameters
TDS_w	mg/L	Total salinity of the fluid in formation at test section based on EC.
TDS_{wn}	mg/L	Total salinity of the fluid in formation at test section based on water sampling and chemical analysis.

Sec.type,	(–)	Test section (pumping or injection) is labeled 1 and all observation sections are labeled 2
Q/s	m^2/s	Specific capacity, based on Qp and s=abs(pi-pp). Only given for test section (label 1) in interference test.
T_Q	m^2/s	Transmissivity based on specific capacity and a a function for T=f(Q/s). The function used should be refered in ”Comments”
T_M	m^2/s	Transmissivity based on Moye (1967)
b	m	Interpreted formation thickness representative for evaluated T ot TB.
B	m	Interpreted witdth of a formation with evaluated TB
TB	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-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 greater than TB-measlim
SB	m	1D model for evaluation of formation properties. S= Storativity, B=width of formation
SB*	m	1D model for evaluation of formation properties. Assumed SB. S= Storativity, B=width of formation
L_f	m	1D model for evaluation of Leakage factor
T_T	m^2/s	2D model for evaluation of formation properties. T=transmissivity
T-measl-L	m^2/s	Estimated measurement limit for evaluated T (TT, TQ, TM). 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 (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or grater than T-measlim
S	(–)	2D model for evaluation of formation properties. S= Storativity
S*	(–)	2D model for evaluation of formation properties. Assumed S. 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_S	m/s	3D model for evaluation of formation properties. K=Hydraulic conductivity
K_S-measl-L	m/s	Estimated measurement limit for evaluated KS. If estimated KS equals KS-measlim in the table actual KS is considered to be equal or less than KS-measlim
K_S-measl-U	m/s	Estimated measurement limit for evaluated KS. If estimated KS equals KS-measlim in the table actual KS is considered to be equal or greater than KS-measlim
S_S	1/m	3D model for evaluation of formation properties. Ss=Specific Storage
S_S*	1/m	3D model for evaluation of formation properties. Assumed Ss. Ss=Specific Storage

L_p	m	Hydraulic point of appication, based on hydraulic conductivity distribution (if available) or the midpoint of the borehole test section
C		(m^3/Pa)Wellbore storage coefficient
C_D	(–)	Dimensionless wellbore storage coefficient
ξ	(–)	Skin factor
ω	(–)	Storativity ratio
λ	(–)	Interporosity flow coefficient
dt_1	s	Estimated start time after pump/injection start OR recovery start, for the period used for the evaluated parameter
dt_2	s	Estimated stop time after pump/injection start OR recovery start, for the period used for the evaluated parameter
	m	Length coordinate along the borehole for the upper limit of the observation section
	m	Length coordinate along the borehole for the lower limit of the observation section
p_{ai}	kPa	Initial formation pressure of the observation section, which is located above the test section in the borehole
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
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
p_{bi}	kPa	Initial formation pressure of the observation section, which is located below the test section in the borehole
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
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
References		SKB report No for reports describing data and evaluation
Index w		Active borehole or borehole section

Result Table for Flow logging in HSH02 and percussion drilled interval of KSH03A at Simpevarp peninsula, Oskarshamn, for submission to Sicada.

Flowlogg-impeller tests-plu_impeller_basic

Borehole	Borehole secup (m)	Borehole seclow (m)	Test type (1–7)	Formation type (–)	Date and time of test, start YYYYMMDD hh:mm	Date and time of stop of flow period YYYYMMDD hh:mm	Date and time of flowl., start YYYYMMDD hh:mm:ss	Date and time of flowl., stop YYYYMMDD hh:mm:ss	Q-measl-L (m^3/s)	Q-measl-U (m^3/s)
KSH03A	28.00	97.00	6	1	20030821 09:02	20030821 19:21	20030821 14:55	20030821 19:10	6.7E–05	1.7E–03
HSH02	33.00	195.00	6	1	20030827 09:03	20030827 20:01	20030827 13:20	20030827 19:49	5.0E–05	1.7E–03

Cont.

Q_p (m^3/s)	t_p (s)	t_{FL} (s)	h_0 (m a s l)	h_p (m a s l)	s_{FL} (m)	Reference (–)	Comments (–)
1.21E–04	37.166	15,300	0.257	–12.78	13.04		hp based on pressure registration
7.58E–05	39.469	23,340	–0.22	–18.96	18.72		

Flowlogg-impeller tests plu_impell-main_res

Borehole ID	Borehole secup (m)	Borehole seclow (m)	L Corrected (m)	Te_{w0} (°C)	EC_{w0} (mS/m)	TDS_{w0} (mg/ L)	Q_0 (m**3/s)	Te_w (°C)	EC_w (mS/m)	TDS_w (mg/ L)	Q_{1T} (m**3/s)	Q_T (m**3/s)	Q_{Tcorr}	T Entire hole (m²/ s)
KSH03A	28.00	97.00									$1.03 \cdot 10^{-4}$	$1.03 \cdot 10^{-4}$		$1.08 \cdot 10^{-5}$
HSH02	33.00	195.00									$4.67 \cdot 10^{-5}$	$4.67 \cdot 10^{-5}$		$2.94 \cdot 10^{-6}$

Cont.

T_{FT} (m²/ s)	T_F-measl-L (m²/ s)	T_F-measl-U (m²/ s)	Reference (–)	Comments (–)
$9.19 \cdot 10^{-6}$	2.0E–06	2.0E–03		
$1.81 \cdot 10^{-6}$	2.0E–06	2.0E–03		

Header	Unit	Description
Date/time test start	date	Date for the stop of the test (YYYY-MM-DD hh:mm)
Date/time test stop	date	Date for the stop of the test (YYYY-MM-DD hh:mm)
Borehole	idcode	Object or borehole identification code
Borehole secup	m	Lengt coordinate along the borehole for the upper limit of the logged section (Based on corrected length L)
Borehole seclow	m	Lengt coordinate along the borehole for the lower limit of the logged section. (Based on corrected length L)
date and time, start	date_s	Date and time of flowlogging start (YYYY-MM-DD hh:mm:ss)
date and time, stop	date_s	Date and time of flowlogging stop (YYYY-MM-DD hh:mm:ss)
Test type (1–7)		1A: Pumping test – wireline eq, 1B:Pumping test-submersible pump, 1C: Pumpingtest-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging-PFL-DIFF-comb.Sequentia, 5B: Difference flow logging-PFL-DIFF-Overlapping, 6: Flow logging-Impeller 7: Grain size analysis
Formation type		1: Rock, 2: Soil (supeficial deposits)
Q-measl-L	m^3/s	Estimated lower measurement limit for borehole flow rate in flowlogging probe
Q-measl-U	m^3/s	Estimated upper measurement limit for borehole flow rate in flowlogging probe
Q_p	m^3/s	Flow rate at surface during flowlogging
tp	s	Time for the flowing phase of the test
t_{FL}	s	Duration of the flowlogging survey
s_{FL}	m	Average drawdown of the water level in open borehole during flowlogging
h_0	masl	Initial hydraulic head. Measured as water level in open borehole with reference level in the local coordinates system with z=0 m.
h_p	masl	Stabilised hydraulic head during first pumping 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 to point considered representative for measured value
Q	m**3/s	Cumulative flow rate:Q1-Qo. Position for measurement is related to L (corrected length)
Q_0	m^3/s	Natural (undisturbed) measured cummulative flow rate. Position for measurement is related to L (corrected lenght)
Q_1	m^3/s	Cumulative flow rate during pumping. Position for measurement is related to L (corrected length)
Q_{1T}	m^3/s	Cummulative flow rate:Q_1 at the top of measured interval
Q_T	m^3/s	Cummulative flow rate:Q at the top of measured interval
$Q_T$corr	m^3/s	Cummulative flow rate:QTat the top of measured interval, based on corrected borehole diameter
T(Entire hole)	m**2/s	Evaluated transmissivity for the entire hole section that is considered representative for the flowlogging (also reported in data file for single-hole interpretation)

T_F	m**2	Cumulative transmissivity based on impeller measurement. 2D model for evaluation of formation properties of the test section. T_F = Óti = T*(Q_T/Q_p)
T_{FT}	m**2	Cumulative transmissivity of the entire measured interval, based on impeller measurement
T_F-measl-L	m**2/s	Estimated lower measurement limit for evaluated T_F. If estimated T_F equals T-measlim in the table, the actual T_F is considered to be equal or less than T_F - measlim
T_F-measl-U	m**2/s	Estimated upper measurement limit for evaluated T_F. If estimated T_F equals T-measlim in the table, the actual T_F is considered to be equal or greater than T_F - measlim
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 length)
TDS_{w0}	mg/L	Natural (undisturbed) total salinity of the fluid in the test section representative for the evaluated parameters based on EC. Position for measurement is related to L (corrected length)
Upper limit	m	Corrected length coordinate along the borehole for the upper limit of the flow anomaly
Lower limit	m	Corrected length coordinate along the borehole for the lower limit of the flow anomaly
Te_w	centigrade	Natural (undisturbed) fluid temperature in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected lenght)
EC_w	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_w	mg/L	Natural (undisturbed) total salinity of the fluid in the test section representative for the evaluated parameters based on EC. Position for measurement is related to L (corrected lenght)
deltaQ$_i$	m**3/s	deltaQi : Flow rate of interpreted flow anomaly i
deltaQ$_{icorr}$	m**3/s	deltaQicorr : Flow rate of interpreted flow anomaly calculated with corrected borehole diameter.
deltaQ$_i$/S_{FL}	m**2/s	deltaQi/s_{FL}: Specific capacity of interpreted flow anomaly
b_i	m	Interpreted formation thickness representative for evaluated Ti of anomaly i.
T_i	m**2/s	Evaluated transmissivity of flow anomaly i considered representative for the flow logging
T_i-measlim-L	m**2/s	Estimated lower measurement limit for evaluated $T_{i.}$ If estimated T_i equals T-measlim in the table actual T_i is considered to be equal or less thanT_i-measlim
T_i-measlim-L	m**2/s	Estimated upper measurement limit for evaluated $T_{i.}$ If estimated T_i equals T_i-measlim in the table actual T_i is considered to be equal or greater thanT_i-measlim
Reference		SKB number for reports describing data and results
Comments		Short comment on evaluated parameters