P-07-22

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Pumping tests and flow logging

Boreholes HFM36, HFM37 and HFM38

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ISSN 1651-4416
SKB P-07-22

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Keywords: Forsmark, Hydrogeology, Hydraulic tests, Pumping tests, Flow meter logging, Water sampling, Hydraulic parameters, Transmissivity, Flow anomaly, AP PF 400-06-086.

Abstract

The main objectives of the hydraulic tests in the percussion boreholes HFM36, HFM37 and HFM38 were to investigate the hydraulic characteristics (e.g. occurrence and hydraulic transmissivity of different hydraulic conductors) and the water chemistry characteristics of the boreholes. No other hydraulic tests had been carried out in the actual boreholes before this campaign.

HFM36 was drilled to provide flush water to the core drilling at drill site 12. The aim with the borehole HFM37 was to characterize the Forsmark Zone in superficial sections and to achieve an observation borehole during the core drilling of borehole KFM12. HFM38 was drilled close to the cooling water channel just north of drill site 8 to, if possible, find sections of the ”porous granite” which has been encountered for instance in the core borehole KFM08C. A further purpose with HFM38 was to characterize possible crush zones and to investigate their connections with the porous granite.

In each borehole a short capacity test was performed to decide whether it was meaningful to make a pumping test in combination with flow logging or only a pumping test and to decide a suitable pumping flow rate for the pumping test. Since the flow rate capacity in all three boreholes was high enough, flow logging was performed in all boreholes.

Water samples were collected in all boreholes in conjunction with the pumping tests to investigate the hydrochemistry of the groundwater.

The total borehole transmissivity of HFM36 was estimated at $2.4 \cdot 10^{-5}$ m^2/s and five flow anomalies were found during the flow logging.

The total borehole transmissivity of HFM37 was estimated at $9.4 \cdot 10^{-6}$ m^2/s. Due to low transmissity the pumping flow rate (c. 5 L/min) was just above the measurement limit (c. 3 L/min) of the flow logging equipment. Flow logging in the borehole did not result in any measurable flow in the logged borehole interval, below the pump.

In HFM38 the total transmissivity was estimated at $1.3 \cdot 10^{-4}$ m^2/s. During the flow logging two flow anomalies were detected.

Sammanfattning

Det övergripande syftet med de hydrauliska testerna i hammarborrhålen HFM36, HFM37 och HFM38 var att undersöka de hydrauliska egenskaperna (t ex förekomst och hydraulisk transmissivitet av enskilda hydrauliska ledare) och vattenkemin i borrhålen. Före dessa mätinsatser hade inga andra hydrauliska tester genomförts i borrhålen.

HFM36 borras vid borrplatsen BP12 för att säkerställa spolvattenförsörjning till borrningen av ett kärnborrhål på denna borrplats. Syftet med HFM37 är att karaktärisera Forsmarkszonen i ett ytligt snitt samt att erhålla ett moniteringsborrhål inför kärnborrningen av borrhålet KFM12. HFM38 borras vid kylvattenkanalen strax norr om BP8 för att, om möjligt, finna sektioner av den ”porösa granit” som påträffats bland annat i kärnborrhål KFM08C. Ytterligare ett syfte med HFM38 är att karaktärisera möjliga krosszoner och att kartlägga deras eventuella samband med den porösa graniten.

Ett kort kapacitetstest gjordes i varje borrhål för att utvisa om det var meningsfullt att genomföra en provpumpning kombinerad med flödesloggning eller om endast pumptest skulle göras samt för att fastställa ett lämpligt pumpflöde för pumptestet. Eftersom flödeskapaciteten var god i alla tre borrhålen kunde flödesloggning genomföras i samtliga.

Vattenprover för undersökning av grundvattnets hydrokemiska egenskaper togs i samband med pumptesterna i borrhålen.

Den totala transmissiviteten för HFM36 uppskattades till $2{,}4\cdot10^{-5}$ m^2/s och fem flödesanomalier detekterades.

I HFM37 uppskattades den totala transmissiviteten till $9{,}4\cdot10^{-6}$ m^2/s. På grund av låg transmissivitet var pumpflödet (ca 5 L/min) precis över flödesloggningutrustningens mätgräns (ca 3 L/min). Flödesloggningen i borrhålet resulterade inte i några detekterade flöden i det flödesloggade borhålsintervallet, nedanför pumpen.

I borrhålet HFM38 uppskattades den totala transmissiviteten till $1{,}3\cdot10^{-4}$ m^2/s. Under flödesloggningen fann man två flödesanomalier.

Contents

1 Introduction

This document reports the results of the hydraulic testing of boreholes HFM36, HFM37 and HFM38 within the Forsmark site investigation. The tests were carried out as pumping tests combined with flow logging. Water sampling was undertaken in conjunction with the tests. No other hydraulic tests had been carried out in the actual boreholes before this campaign.

The boreholes HFM36 and HFM37 are situated southeast of Forsmark village. Borehole HFM38 is situated close to the cooling water channel east of the Forsmark nuclear power plant, see Figure 1-1.

All time notations in this report are made according to Swedish Winter Time (SWUT), UTC +1 h.

The work was carried out in accordance to SKB internal controlling documents; see Table 1-1. Data and results were delivered to the SKB site characterization database SICADA, where they are traceable by the Activity Plan number.

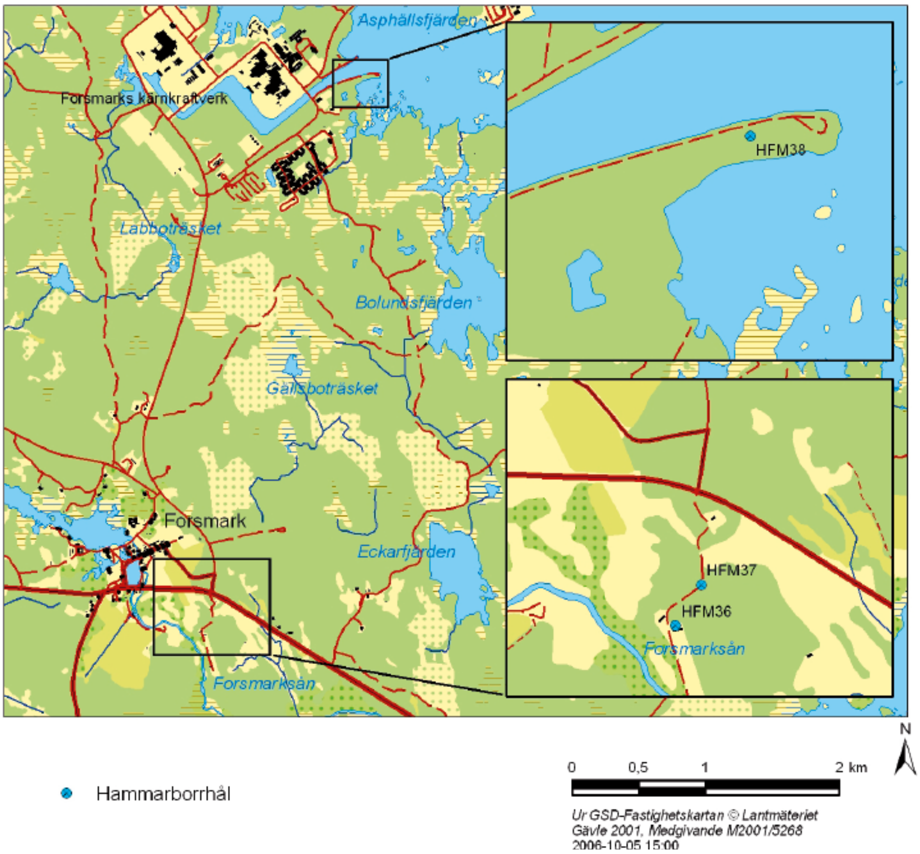


Figure 1-1. *Map showing the location of boreholes HFM36, HFM37 and HFM38.*

Table 1-1. SKB Internal controlling documents for performance of the activity.

Activity Plan	Number	Version
Hydrotester och vattenprovtagning i hammarborrhålen HFM36, HFM37 och HFM38	AP PF 400-06-086	1.0
Method documents	**Number**	**Version**
Metodbeskrivning för hydrauliska enhålspumptester	SKB MD 321.003	1.0
Metodbeskrivning för flödesloggning	SKB MD 322.009	1.0
Instruktion för analys av injektions- och enhålspumptester	SKB MD 320.004	1.0
Mätsystembeskrivning för HydroTestutrustning för HammarBorrhål. HTHB	SKB MD 326.001	3.0

2 Objectives

The objective of the pumping tests and flow logging in boreholes HFM36, HFM37 and HFM38 was to investigate the hydraulic properties of the penetrated rock volumes, by analysing the pumping test and identify the position and hydraulic character of major inflows (which may represent e.g. sub-horizontal fracture zones). Furthermore, another aim was to investigate the hydrochemical properties of the groundwater.

3 Scope

3.1 Boreholes tested

Technical data of the boreholes tested are displayed in Table 3-1. The reference point in the boreholes is always top of casing (ToC). The Swedish National coordinate system (RT90 2.5 gon W) is used in the x-y-plane together with RHB70 in the z-direction. Northing and Easting refer to the top of the boreholes at top of casing. The borehole diameter in Table 3-1, measured as the diameter of the drill bit, refers to the initial diameter just below the casing. The borehole diameter decreases more or less along the borehole due to wearing of the drill bit.

3.2 Tests performed

The different test types conducted in the boreholes, as well as the test periods, are presented in Table 3-2.

During the pumping tests, water samples were collected and submitted for analysis, see Section 6.2. During the tests, manual observations of the groundwater level in the pumped boreholes were also made

Table 3-1. Selected technical data of the boreholes tested (from SICADA).

Borehole ID	Elevation of top of casing (ToC) (m.a.s.l.)	Borehole length from ToC (m)	Bh-diam. (below casing) [1] (m)	Inclin. -top of bh (from horizontal plane) (º)	Dip-direction -top of bh (º)	Northing (m)	Easting (m)	Casing Length (m)	Inner diam. (m)	Drilling finished Date (YYYY-MM-DD)
HFM36	8.4	152.6	0.1375	–58.91	256.61	6696504	1630082	12.1	0.160	2006-09-04
HFM37	11.4	191.8	0.1410	–59.15	41.35	6696592	1630137	9.1	0.160	2006-08-16
HFM38	2.2	200.8	0.1410	–54.45	93.62	6700701	1631302	9.1	0.160	2006-06-22

[1] Measured as the diameter of the drill bit.

Table 3-2. Borehole tests performed.

Bh ID	Test section (m)	Test type [1]	Test config	Test start date and time (YYYY-MM-DD tt:mm)	Test stop date and time (YYYY-MM-DD tt:mm)
HFM36	12.1–152.6	1B	Open hole	2006-11-23 08:08	2006-11-24 08:16
HFM36	22.5–140.0	6, L-EC, L-Te	Open hole	2006-11-23 15:10	2006-11-23 17:35
HFM37	9.1–191.8	1B	Open hole	2006-11-21 08:18	2006-11-22 07:11
HFM37	15.5–186.1	6, L-EC, L-Te	Open hole	2006-11-21 16:17	2006-11-21 17:35
HFM38	9.1–200.8	1B	Open hole	2006-11-15 08:21	2006-11-16 09:24
HFM38	21.0–193.0	6, L-EC, L-Te	Open hole	2006-11-15 16:32	2006-11-15 19:22

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

3.3 Equipment check

Prior to the tests, an equipment check was performed to establish the operating status of sensors and other equipment. In addition, calibration constants were implemented and checked. To check the function of the pressure sensor P1 (cf. Figure 4-1), the pressure in air was recorded and found to be as expected. Submerged in the water while lowering, measured pressure coincided well with the total head of water (p/ρg). The temperature sensor displayed expected values in both air and water.

The sensor for electric conductivity displayed a zero value in air and a reasonable value in borehole water.

During the logging in HFM38, some rubbish was stuck in the impeller, causing it to rotate slower. When lowering the probe the number of revolutions per meter for the impeller was only c. a third of normal, indicating that the equipment was not in the best condition. All visible dirt was removed but the impeller was still rotating slower, possibly because of some remaining dirt. After the tests in HFM38 an additional calibration of the impeller was made. This calibration showed that the impeller was working correctly with only insignificant differences compared to earlier calibration.

In the boreholes HFM37 and HFM36 the impeller used in the flow logging equipment worked well, as indicated by the number of rotations read on the data logger while lowering the flow logging probe in the boreholes.

The measuring wheel (used to measure the position of the flow logging probe) and the sensor attached to it indicated a length that corresponded well to the pre-measured length marks on the signal cable.

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) and is described in the user manual of the measurement system.

The HTHB unit is designed to perform pumping- and injection tests in open percussion drilled boreholes (Figure 4-1), and in isolated sections of the boreholes (Figure 4-2) down to a total depth (borehole length) 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). For injection tests, however, the upper packer cannot be located deeper than c. 80 m due to limitations in the number of pipes available.

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

The packers are normally expanded by water (nitrogen gas is used for pressurization) unless the depth to the groundwater level is large, or the risk of freezing makes the use of water unsuitable. 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 (if required).

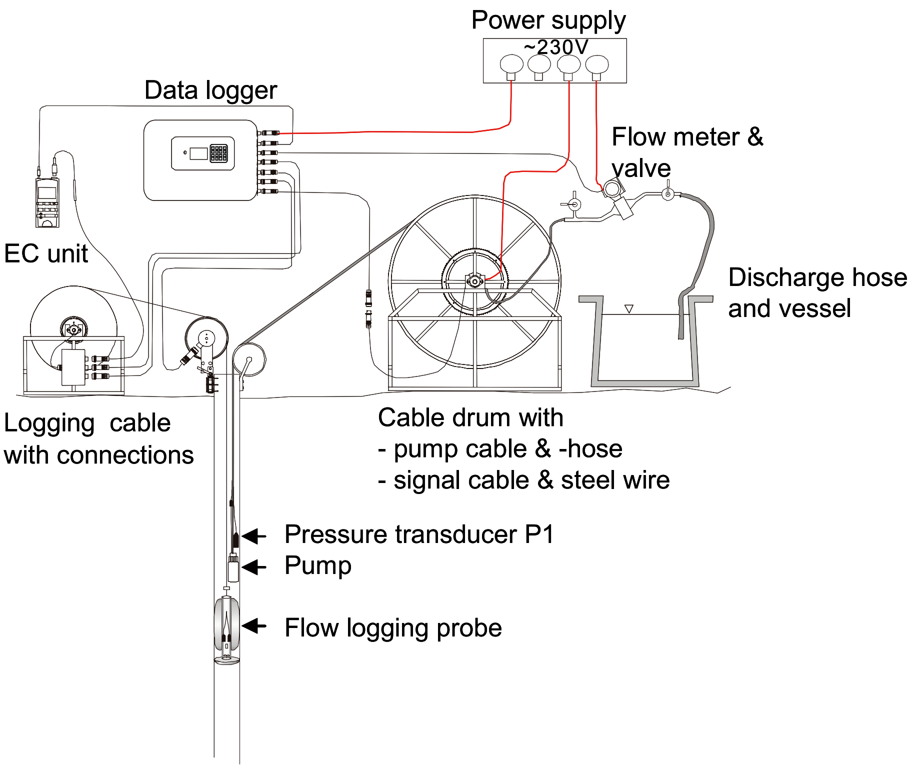


Figure 4-1. *Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB. (From SKB MD 326.001, SKB internal document).*

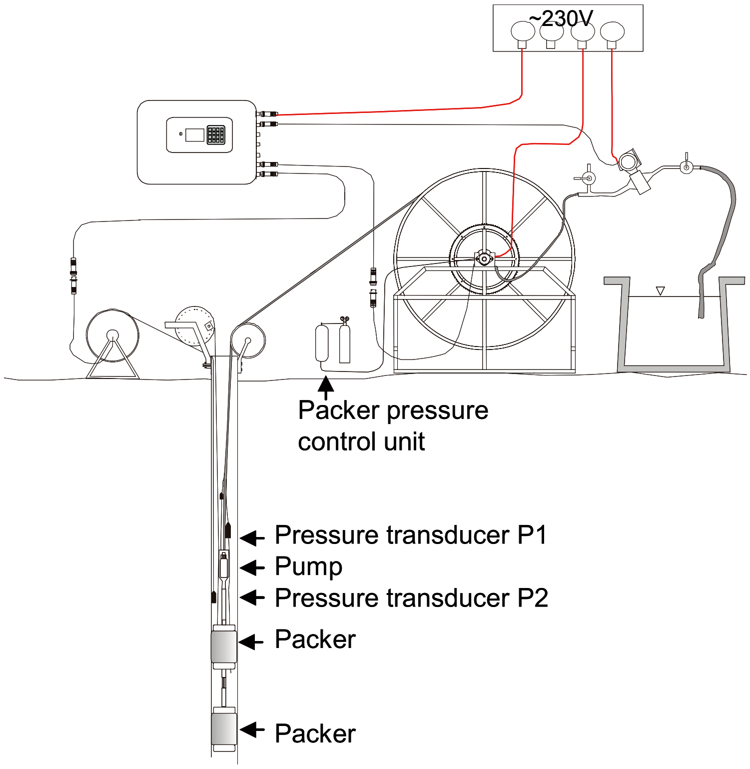


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB. (From SKB MD 326.001, SKB internal document).*

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	

Technical specification Parameter		Unit	Sensor	HTHB system	Comments
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 determinations of the borehole inclination may also affect the accuracy of measured data.

The flow logging probe is calibrated for different borehole diameters (in reality different pipe diameters), i.e. 111.3, 135.5, 140 and 162 mm. During calibration the probe is installed in a vertically orientated pipe and a water flow is pumped through. The spinner rotations and total discharge are measured. Calibration gives excellent correlation ($R^2 > 0.99$) between total discharge and the number of spinner rotations. The calibration also clearly demonstrates how sensible the probe is to deviations in the borehole diameter, cf. Figure 4-3.

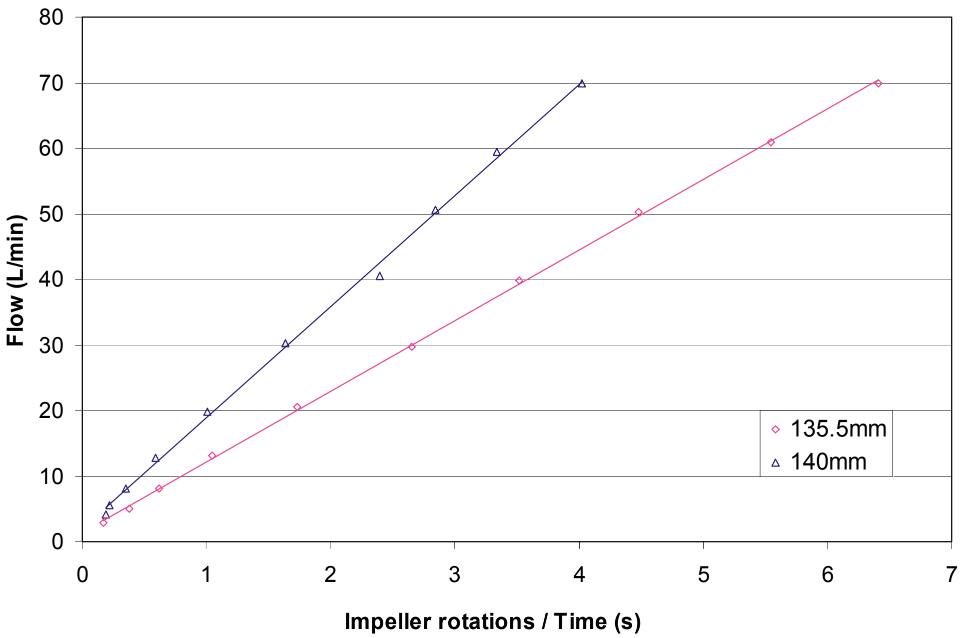


Figure 4-3. *Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).*

The stabilisation time may be up to 30 s at flows close to the lower measurement limit, whereas the stabilisation is almost instantaneous at high flows.

Table 4-2 presents the position of sensors for each test together with the level of the pump-intake of the submersible pump. The following types of sensors are used: pressure (P), temperature (Te), electric conductivity (EC). Positions are given in metres from the reference point, i.e. top of casing (ToC), lower part. The sensors measuring temperature and electric conductivity are located 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 submerged item. Position is given as "in section" or "above section". The volume of the submerged pump (~ 4 dm^3) is not involved in the wellbore storage since the groundwater level always is kept above the top of the pump in open boreholes.

In addition, the theoretical wellbore storage coefficient C for the actual test configurations and geometrical data of the boreholes were calculated, see Section 5.4.1. These values on C may be compared with the estimated ones from the test interpretations described in Chapter 6.

For tests where the change of water level occurs below the casing, two different values of the theoretical wellbore storage coefficient C can be estimated. One is based on the casing diameter and the other one is based on the actual borehole diameter below the casing.

Table 4-2. Position of sensors (from ToC) and of equipment that may affect wellbore 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 [3] (m3/Pa)
HFM36	12.1–152.6	Open hole	1B	Pump-intake	19.6	Pump hose	In section	33.5	1.58 10–6
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	16.7	Signal cable	In section	8	
			6	EC, Te, Q	22.5–140.0	Signal cable	In section	13.5	
HFM37	9.1–191.8	Open hole	1B	Pump-intake	14.0	Pump hose	In section	33.5	1.67 10–6
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	11.2	Signal cable	In section	8	
			6	EC, Te, Q	15.5–186.1	Signal cable	In section	13.5	
HFM38	9.1–200.8	Open hole	1B	Pump-intake	17.5	Pump hose	In section	33.5	1.56 10–6
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	14.7	Signal cable	In section	8	
			6	EC, Te, Q	21.0–194.5	Signal cable	In section	13.5	

[1] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller incl. EC-logging (EC-sec) and temperature logging (Te-sec).

[2] Position of equipment that can affect wellbore storage. Position given as "In Section" or "Above Section".

[3] Based on the actual borehole diameter (Table 3-1) together with the compressibility of water. The wellbore storage coefficient based on the casing diameter is $2.01 \cdot 10^{-6}$ m^3/Pa for all three boreholes.

5 Execution

5.1 Preparations

All sensors included in the HTHB system are calibrated at the Geosigma engineering service station in Uppsala. Calibration is generally performed on a yearly basis, but more often if needed. The latest calibration was performed in October–November 2006. If a sensor is replaced at the test site, calibration of the new sensor can be carried out in the field (except the flow probe) or alternatively, in the laboratory after the measurements. Due to a lack of calibration fluids, the calibration constants achieved during the calibration in April 2004 were used for the conductivity sensor.

Functioning checks of the equipment used in the present test campaign were made prior to each hydraulic test. The results from the functioning checks are presented in Section 3.3.

Before the tests, cleaning of equipment as well as time synchronisation of clocks and data loggers were performed according to the Activity Plan.

5.2 Procedure

5.2.1 Overview

The main pumping test is always preceded by a shorter capacity test (the day before) to determine a proper pumping flow rate. During the capacity test the flow rate is changed considering the obtained response.

The main pumping is normally carried out as a single-hole, constant flow rate test followed by a pressure recovery period. At the end of the pumping period flow logging is performed.

Before flow logging is started, the intention is to achieve approximately steady-state conditions in the borehole. The flow logging is performed with discrete flow measurements made at fixed step lengths (5 m until the first flow anomaly is found and 2 m thereafter), starting from the bottom and upwards along the borehole. When a detectable flow anomaly is found, the flow logging probe is lowered and repeated measurements with a shorter step length (0.5 m) are made to determine a more correct position of the anomaly. The flow logging survey is terminated a short distance below the submersible pump in the borehole.

5.2.2 Details

Single-hole pumping tests

In HFM36, HFM37 and HFM38 the main test consisted of c. 10 h pumping in the open borehole in combination with flow logging at the end of the pumping period, followed by a recovery period of c. 12 hours.

In general, the sampling frequency of pressure and flow during the pumping tests was according to Table 5-1, which corresponds to a predefined measurement sequence on the data logger. Sometimes, for practical reasons, the interval is shortened during certain periods of the test.

Table 5-1. Standard sampling intervals used for pressure registration during the pumping tests.

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

Flow logging

Prior to the start of the flow logging, the probe is lowered almost to the bottom of the borehole. While lowering along the borehole, temperature, flow and electric conductivity data are sampled.

Flow logging is performed during the 10 hours pumping test, starting from the bottom of the borehole going upwards. The logging starts when the pressure in the borehole is approximately stable. The time needed to complete the flow logging survey depends on the length and character of the borehole. In general, between 3–5 hours is normal for a percussion borehole of 100–200 m length, cf. Section 6.4.

During the flow logging in borehole HFM38 some problems with the spinner occurred. A flow anomaly indicating a borehole flow rate of c. 20 L/min was detected at c. 187–188 m borehole length. However, when the flow logging probe was lifted further, the flow rate decreased to c. 6 L/min. Thereafter the flow rate remained at almost the same value until a flow anomaly at c. 29 m indicated an inflow of c. 15 L/min. Because of the malfunctioning spinner (see also Section 3.3) the results achieved when using the normal procedure described in Section 5.2.1 was not considered good enough to be used for evaluation of flow anomalies in the borehole.

An alternative way to measure flow changes along the borehole is to continuously lower the flow logging probe slowly from the top to the bottom of the borehole, i.e. in the reverse direction to the borehole flow. An advantage with this method is that the lower measuring limit could be reduced since the impeller is always in motion due to the lowering. A disadvantage is that the collected data will be more scattered. A continuous lowering of the flow logging probe was performed in all three boreholes but used for evaluation of flow anomalies only for borehole HFM38, due to the problems when logging according to the standard flow logging method, mentioned above (see further Section 6.4.3).

5.3 Data handling

Data are downloaded from the logger (Campbell CR 5000) to a laptop with the program PC9000 and are, already in the logger, transformed to engineering units. All files (*.DAT) are comma-separated when copied to a computer. Data files used for transient evaluation are further converted to *.mio-files by the code Camp2mio. Data from the flow logging are evaluated in Excel and therefore not necessarily transformed to *.mio-files. A list of all data files from the logger is presented in Appendix 1.

Processed data files (*.mio-files) are used to create linear plots of pressure and flow versus time with the code SKBPLOT and evaluation plots with the software AQTESOLV, according to the Instruction for analysis of injection- and single-hole pumping tests (SKB MD 320.004, SKB internal document).

5.4 Analyses and interpretation

This section provides a comprehensive general description of the procedure used when analysing data from the hydraulic tests carried out with the HTHB equipment.

5.4.1 Single-hole pumping tests

Firstly, a qualitative evaluation of the actual flow regimes (wellbore storage, pseudo-linear, pseudo-radial or pseudo-spherical flow) and possible outer boundary conditions during the hydraulic tests is performed. The qualitative evaluation is made from analyses of log-log diagrams of drawdown and/or recovery data together with the corresponding derivatives versus time. In particular, pseudo-radial flow (2D) is reflected by a constant (horizontal) derivative in the diagrams. Pseudo-linear and pseudo-spherical flows are reflected by a slope of the derivative of 0.5 and –0.5, respectively, in a log-log diagram. Apparent no-flow- and constant head boundaries are reflected by a rapid increase and decrease of the derivative, respectively.

From the results of the qualitative evaluation, appropriate interpretation models for the quantitative evaluation of the tests are selected. In general, a certain period with pseudo-radial flow can be identified during the pumping tests. Consequently, methods for single-hole, constant-flow rate or constant drawdown tests for radial flow in a porous medium described in Almén K-E et al. 1986 /1/ and Morosini M et al. 2001 /2/ are generally used by the evaluation of the tests. For tests indicating a fractured- or borehole storage dominated response, corresponding type curve solutions are used by the routine analyses.

If possible, transient analysis is applied on both the drawdown- and recovery phase of the tests. The recovery data are plotted versus Agarwal equivalent time. Transient analysis of drawdown- and recovery data are made in both log-log and lin-log diagrams as described in the Instruction (SKB MD 320.004). In addition, a preliminary steady-state analysis (e.g. Moye's formula) is made for all tests for comparison.

The transient analysis was performed using a special version of the aquifer test analysis software AQTESOLV that enables both visual and automatic type curve matching with different analytical solutions for a variety of aquifer types and flow conditions. The evaluation is performed as an iterative process of type curve matching and non-linear regression on the test data. For the flow period as well as the recovery period of the constant flow rate tests, a model presented by Dougherty-Babu (1984) /3/ for constant flow rate tests with radial flow, accounting for wellbore storage and skin effects, is generally used for estimating transmissivity, storativity and skin factor for actual values on the borehole- and casing radius. AQTESOLV also includes other models, for example a model for discrete fractures (horizontal and vertical, respectively) intersecting the borehole, causing pseudo-linear flow. In addition, a model for pseudo-spherical flow in a leaky aquifer by Moench (1985) /4/ is included. If found advantageous, others than the Dougherty-Babu model may be used in a specific case.

The effective casing radius may be estimated from the regression analysis for tests affected by wellbore storage. The wellbore storage coefficient can be calculated from the simulated effective casing radius, see below. The effective wellbore radius concept is used to account for negative skin factors.

Rather than assuming a fixed value of the storativity of $1 \cdot 10^{-6}$ by the analysis according to the instruction SKB MD 320.004, an empirical regression relationship between storativity and transmissivity, Equation 5-1 (Rhén et al. 1997) /5/ is used. Firstly, the transmissivity and skin factor are obtained by type curve matching on the data curve using a fixed storativity value of 10^{-6}. From the transmissivity value obtained, the storativity is then calculated according to Equation 5-1 and the type curve matching is repeated.

$$S = 0.0007 \cdot T^{0.5} \qquad (5\text{-}1)$$

S = storativity (–)

T = transmissivity (m^2/s)

In most cases the change of storativity does not significantly alter the calculated transmissivity by the new type curve matching. Instead, the estimated skin factor, which is strongly correlated to the storativity, is altered correspondingly.

The nomenclature used for the simulations with the AQTESOLV code is presented in the beginning of Appendix 2.

Estimations of the borehole storage coefficient, C, based on actual borehole geometrical data (net values) according to Equation (5-2), are presented in Table 4-2. The borehole storage coefficient may also be estimated from the early test response with 1:1 slope in a log-log diagram /2/ or alternatively, from the simulated effective casing radius. These values on C may be compared with the net values of the wellbore storage coefficient based on actual borehole geometrical data. The estimated values on C from the test data may differ from the net values due to deviations of the actual geometrical borehole data from the anticipated, e.g. regarding the borehole diameter, or presence of fractures or cavities with significant volumes.

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

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

r_{we} = borehole radius where the changes of the groundwater level occur (either r_w or r_c) or alternatively, the simulated effective casing radius r(c)

r_w = nominal borehole radius (m)

r_c = inner radius of the borehole casing (m)

r(c) = simulated effective casing radius (m)

ρ = density of water (kg/m^3)

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

5.4.2 Flow logging

The measured parameters during flow logging (flow, temperature and electric conductivity of the borehole fluid) are firstly plotted versus borehole length. From these plots, flow anomalies are identified along the borehole, i.e. borehole intervals over which changes of flow exceeding c. 1 L/min occur. The size of the inflow at a flow anomaly is determined by the actual change in flow rate across the anomaly. In most cases, the flow changes are accompanied by changes in temperature and/or electric conductivity of the fluid. If the actual borehole diameter differs from the one assumed by the calibration of the flow logging probe, corrections of the measured borehole flow rates might be necessary, cf. Figure 4-3.

Flow logging can be carried out from the borehole bottom up to a certain distance below the submersible pump (c. 2.5 m). The remaining part of the borehole (i.e. from the pump to the casing) cannot be flow-logged, although high inflow zones may sometimes be located here. Such superficial inflows may be identified by comparing the flow at the top of the flow-logged interval (Q_T) with the discharged flow rate (Q_p) measured at the surface during the flow logging. If the latter flow rate is significantly higher, one or several inflow zones are likely to exist above the flow-logged interval. However, one must be careful when interpreting absolute flow values measured by the flow logging probe since it is very sensitive to the actual borehole diameter. The probe is calibrated in a tube with a certain diameter (see Section 4.2) but the actual borehole diameter, measured as the diameter of the drill bit, is most often deviating from the nominal diameter. Furthermore, the borehole diameter is normally somewhat larger than the diameter of the drill bit, depending, among other things, on the rock type. The diameter is also decreasing towards depth, due to successive wearing of the drill bit.

To account for varying diameter along the borehole, one may utilize the logging in the undisturbed borehole when lowering the flow logging probe before pumping. Under the assumption of a linear relationship between borehole diameter and gain in the calibration function, transforming counts per seconds from the flow sensor to engineering units (L/min), and using known borehole diameters at two or more borehole lengths, one can obtain a relationship between gain and borehole length in the actual borehole. This relationship is then used for correction of the measured flow along the borehole.

Since the absolute value of the borehole diameter is uncertain and the measured borehole flow to some degree probably also depends on borehole inclination, it is often necessary to make a final correction to achieve correspondence between the measured borehole flow at the top of the flow logged interval and the pumped flow measured at surface. To make these corrections, all significant flow anomalies between the top of the flow logged interval and the casing must also be quantified. Therefore, it may be necessary to supplement the flow logging with injection or pumping tests above the highest logged level in the borehole, unless it is possible to carry out the flow logging to the casing. Alternatively, if other information (e.g. BIPS logging or drilling information) clearly shows that no inflow occurs in this part of the borehole, no supplementary tests are necessary.

Depending on if supplementary tests are carried out, two different methods are employed for estimating the transmissivity of individual flow anomalies in the flow logged interval of the borehole. In both cases the transmissivity of the entire borehole (T) is estimated from the transient analysis of the pumping test.

Method 1

If no significant inflow occurs above the flow logged interval, the corrected logged flow at a certain length, $Q(L)_{corr}$, can be calculated according to:

$$Q(L)_{corr} = Corr \cdot Q(L) \qquad (5\text{-}3)$$

where

$Corr = Q_P/Q_T$

$Q(L)$ = measured flow at a certain length L in the borehole, if necessary corrected for varying borehole diameter

Q_P = pumped flow from the borehole

Q_T = measured flow at the top of the logged interval

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

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

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

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

Method 2

If additional hydraulic tests show that there exist significant flow anomalies above the flow logged interval, the transmissivity T_A for the non flow logged interval is estimated from these tests. In this case the resulting transmissivity of the flow-logged interval (T_{FT}) is calculated according to:

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

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

The resulting flow at the top of the flow logged interval Q_{FT} may be calculated from:

$Q_{FT} = Q_P \cdot T_{FT}/T$ (5-7)

and the corrected flow $Q(L)_{corr}$ from:

$Q(L)_{corr} = Corr \cdot Q(L)$ (5-8)

where

Corr = Q_{FT}/Q_T

Q(L) = measured flow at a certain length L in the borehole, if necessary corrected for varying borehole diameter

The transmissivity of an individual flow anomaly (T_i) is calculated from the relative contribution of the anomaly to the total flow at the top of the flow logged interval (dQ_i/ Q_T) and the calculated transmissivity of the entire flow-logged interval (T_{FT}) according to:

$T_i = Corr \cdot dQ_i/Q_T \cdot T_{FT}$ (5-9)

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

$T_F(L) = Corr \cdot Q(L)/Q_T \cdot T_{FT}$ (5-10)

The threshold value of transmissivity (T_{min}) in flow logging may be estimated in a similar way:

$T_{min} = T \cdot Q_{min}/Q_p$ (5-11)

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.

Similarly, the lower measurement limit of transmissivity of a flow anomaly can be estimated using $dQ_{i\,min}$ = 1 L/min ($1.7 \cdot 10^{-5}$ m^3/s) which is considered as the minimal change in borehole flow rate to identify a flow anomaly. The upper measurement limit of transmissivity of a flow anomaly corresponds to the transmissivity of the entire borehole.

5.5 Nonconformities

The hydraulic test program was mainly performed in compliance with the Activity Plan, however with the following exceptions:

- Compared to the Methodology Description for single-hole pumping tests (SKB MD 321.003), a deviation was made regarding the recommended test time (24 h + 24 h for drawdown + recovery). For the longer pumping tests during flow logging the test time was decreased to c. 10 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 in other boreholes indicates that c. 10 h of pumping and 12 h of recovery in general is sufficient to estimate the hydraulic properties of the borehole regarding e.g. wellbore storage effects and other disturbing factors.
- In borehole HFM38 a malfunctioning impeller made the results from the normal flow logging procedure, with discrete flow measurements at fixed distances along the borehole, impossible to evaluate. Instead the results from a complementary measurement during continuous lowering of the flow logging probe could be used to evaluate flow anomalies in the borehole. (See Sections 3.3 and 5.2.2.)

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, Version 1.0, and the methodology description for impeller flow logging, SKB MD 322.009, Version 1.0. Additional symbols used are explained in the text. The nomenclature for the analyses of the pumping tests by the AQTESOLV code is presented in Appendix 2.

6.2 Water sampling

Water samples were taken during the pumping tests in the boreholes and submitted for analysis, see Table 6-1. The results are presented within the scope of another activity.

6.3 Single-hole pumping tests

Below, the results of the single-hole pumping tests are presented test by test. The atmospheric pressure and precipitation were monitored at the site during the testing periods. However, no corrections of measured data, e.g. for changes of the atmospheric pressure or tidal fluctuations, have been made before the analysis of the data. For the actual type of single-hole tests such corrections are generally not needed considering the relatively short test time and large drawdown applied in the boreholes. However, for longer tests with a small drawdown applied, such corrections may be necessary.

Drilling records and other activities were checked to identify possible interference on the hydraulic test data from activities in boreholes within the investigation area during the test periods. Reported activities are presented in Table 6-2. In this case the distances between the tested boreholes HFM36, HFM37 and HFM38 and disturbing activities are several kilometres.

Table 6-1. Water samples collected during the pumping tests in boreholes HFM36, HFM37 and HFM38 and submitted for analysis.

Bh ID	Date and time of sample	Pumped section (m)	Pumped volume (m³)	Sample type	Sample ID no	Remarks
HFM36	2006-11 23 09:09	12.1–152.6	2.3	WC080	012548	Open-hole test
HFM36	2006-11-23 12:54	12.1–152.6	11.2	WC080	012549	Open-hole test
HFM36	2006-11-23 18:08	12.1–152.6	23.6	WC080	012550	Open-hole test
HFM37	2006-11-21 09:50	9.1–191.8	0.4	WC080	012545	Open-hole test
HFM37	2006-11-21 13:55	9.1–191.8	1.8	WC080	012546	Open-hole test
HFM37	2006-11-21 18:47	9.1–191.8	3.2	WC080	012547	Open-hole test
HFM38	2006-11-14 10:43	9.1–200.8	4.6	WC080	012533	Open-hole test
HFM38	2006-11-14 14:35	9.1–200.8	18.5	WC080	012534	Open-hole test
HFM38	2006-11-14 19:25	9.1–200.8	35.7	WC080	012535	Open-hole test

Table 6-2. Activities at the PLU site that might have influenced the hydraulic tests in boreholes HFM36, HFM37 and HFM38.

Borehole ID	Test period	Ongoing activities
HFM36	2006-11-23–2006-11-24	Drilling of borehole KFM02B. Flushing water from HFM05.
HFM37	2006-11-21–2006-11-22	Drilling of borehole KFM02B. Flushing water from HFM05. Nitrogen blowing in KFM11A.
HFM38	2006-11-15–2006-11-16	Drilling of borehole KFM02B. Flushing water from HFM05. Drilling of borehole KFM11A. Flushing water from HFM33.

No obvious influence on the test results from other activities could be seen.

6.3.1 Borehole HFM36: 12.1–152.6 m

General test data for the open-hole pumping test in HFM36 are presented in Table 6-3.

The atmospheric pressure during the test period in HFM36, which is presented in Figure 6-1, varied less than 0.65 kPa, i.e. only c. 0.6% of the total drawdown, and thus the effect of atmospheric pressure variations on the test results is considered negligible. A small rainfall, less than 4 mm, during the night and day before the test does not seem to have affected the groundwater levels.

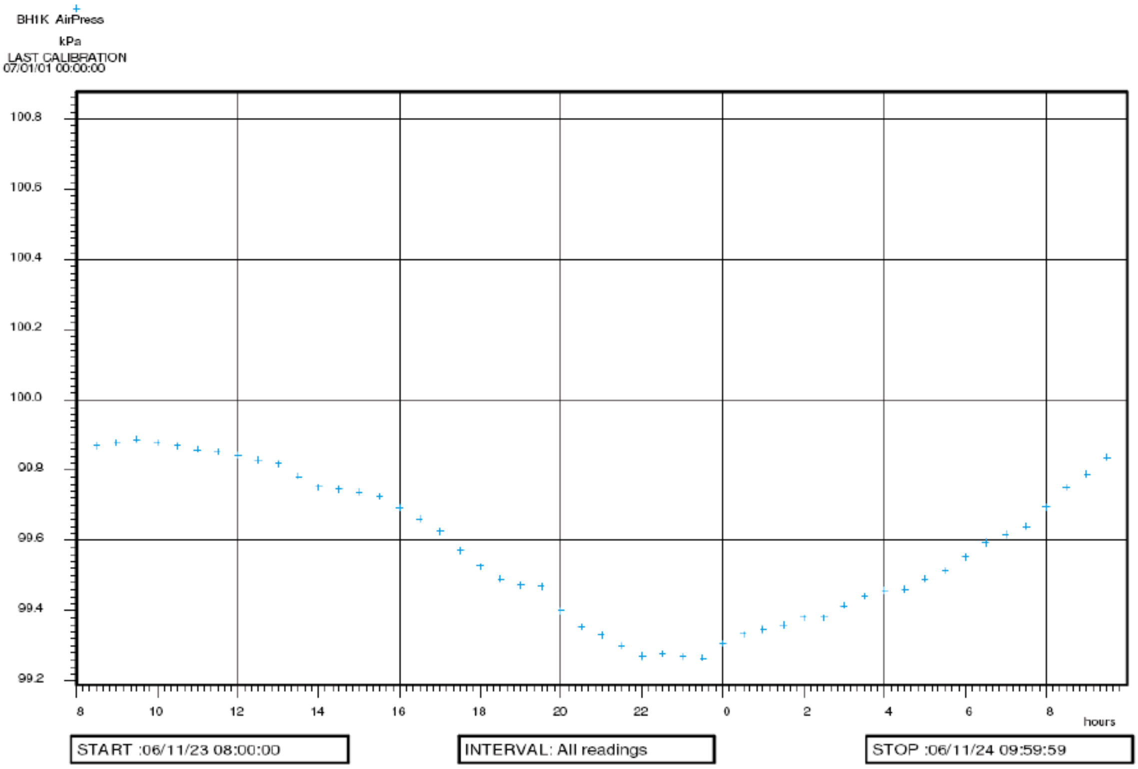


Figure 6-1. *Atmospheric pressure during the test period in HFM36.*

Table 6-3. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM36.

General test data				
Borehole	HFM36 (12.1–152.6 m)			
Test type	Constant rate withdrawal and recovery test			
Test section (open borehole/packed-off section):	Open borehole			
Test No	1			
Field crew	J. Harrström, E. Gustavsson and K. Gokall-Norman, GEOSIGMA AB			
Test equipment system	HTHB			
General comment	Single pumping borehole			
	Nomenclature	**Unit**	**Value**	
Borehole length	L	m	152.6	
Casing length	L_c	m	12.1	
Test section – secup	Secup	m	12.1	
Test section – seclow	Seclow	m	152.6	
Test section length	L_w	m	140.5	
Test section diameter	$2 \cdot r_w$	mm	top 137.5 bottom 136.8	
Test start (start of pressure registration)		yymmdd hh:mm:ss	061123 08:08:01	
Packer expanded		yymmdd hh:mm:ss		
Start of flow period		yymmdd hh:mm:ss	061123 08:12:03	
Stop of flow period		yymmdd hh:mm:ss	061123 18:13:02	
Test stop (stop of pressure registration)		yymmdd hh:mm:ss	061124 08:16:20	
Total flow time	t_p	Min	601	
Total recovery time	t_F	Min	843	

Pressure data	Nomenclature	Unit	Value	GW level (m.a.s.l.) [1]
Absolute pressure in test section before start of flow period	p_i	kPa	214.2	6.36
Absolute pressure in test section at stop of flow period	p_p	kPa	108.6	[3]
Absolute pressure in test section at stop of recovery period	p_F	kPa	211.4	6.05
Maximal pressure change in test section during the flow period	dp_p	kPa	105.3	[3]

Manual groundwater level measurements Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	GW level (m b ToC)	(m.a.s.l.)
2006-11-22	10:18:00	–1,310	2.44	6.33
2006-11-22	12:50:00	–1,158	2.30	6.45
2006-11-23	08:08:00	–4	2.40	6.36
2006-11-24	08:22:00	1,454	2.77	6.05

Flow data	Nomenclature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$6.61 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period [2]	Q_m	m^3/s	$6.58 \cdot 10^{-4}$
Total volume discharged during flow period [2]	V_p	m^3	23.74

[1] From the manual measurements of groundwater level.

[2] Calculated from integration of the transient flow rate curve during the flow period.

[3] Manual levelling was not possible.

Comments on test

The day before test start, a short capacity test was performed (c. 68 min). The capacity test was conducted with the flow rate increasing in steps, during observation of the drawdown response. By the end of the capacity test, the flow rate was c. 60 L/min and the drawdown c. 9.4 m. The actual pumping test was performed as a constant flow rate test (c. 39.5 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. After c. 65 minutes of pumping the drawdown was c. 6.8 m and at the end of the 10 hours pumping period c. 10.7 m.

A comparison of the results from the capacity test and the pumping test shows good consistence. Discrepancies between the two may indicate changes in the borehole skin zone due to pumping.

Interpreted flow regimes

Selected test diagrams according to the Instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-1 to A2-7 in Appendix 2.

During the flow period, initial wellbore storage effects are indicated during the first c. 0.1 min transitioning to a pseudo-linear flow regime until c. 2 min. After a transition period, a pseudo-radial flow regime can be seen during c. 40–300 min. After c. 300 min a transition to a pseudo-spherical flow regime approaching an apparent constant head boundary by the end of the flow period is indicated.

After c. 150 min of the flow period the water level in the open borehole is assumed to pass below the lower end of the casing at a drawdown of c. 8.3 m. This is suggested by the borehole data in Table 3-1 and the initial position of the water level in Table 6-3.

During the first c. 0.5 min of the recovery period, wellbore storage effects are also indicated. After c. 2.5 min the water level returns back into the lower end of the casing which causes a distortion and a temporary flattening out of the pressure derivative. After a transition period, an approximate pseudo-radial flow regime can be seen from c. 40 min to the end of the recovery period.

Interpreted parameters

Transient evaluation of transmissivity was performed for both the flow- and recovery period according to the methods described in Section 5.4.1. The transient analyses are presented in Figures A2-2 to A2-5 in Appendix 2. The transmissivity and skin factor were estimated by a standard model assuming pseudo-radial flow including wellbore storage and skin /3/ for both the flow and recovery period. The strongly negative value estimated on the skin factor may suggest the presence of a dominating fracture in the test section. Thus, a model for an equivalent horizontal fracture intersecting the test section was also used for the analysis of the flow period (Figures A2-6 to A2-7). The estimated transmissivity values of the rock were similar from both models.

By the analysis of the recovery period the same value on the effective casing radius r_c as obtained from the flow period was used since the intermediate part of the recovery period is disturbed by the transition of the water level into the cased interval of the borehole.

The representative transmissivity (T_T) is considered from the transient evaluation of the flow period. The agreement between the flow and the recovery period regarding transmissivity and skin factor is good.

The results are shown in the Test Summary Sheet (Table 6-14) and in Tables 6-11, 6-12 and 6-13.

6.3.2 Borehole HFM37: 9.1–191.8 m

General test data for the open-hole pumping test in HFM37 in conjunction with flow logging are presented in Table 6-4.

Table 6-4. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM37.

General test data	
Borehole	HFM37 (9.1–191.8 m)
Test type	Constant rate withdrawal and recovery test
Test section (open borehole/packed-off section):	Open borehole
Test No	1
Field crew	J. Harrström, E. Gustavsson and K. Gokall-Norman, GEOSIGMA AB
Test equipment system	HTHB
General comment	Single pumping borehole

	Nomenclature	**Unit**	**Value**
Borehole length	L	m	191.8
Casing length	L_c	m	9.1
Test section – secup	Secup	m	9.1
Test section – seclow	Seclow	m	191.8
Test section length	L_w	m	182.7
Test section diameter	$2 \cdot r_w$	mm	top 141.0 bottom 138.5
Test start (start of pressure registration)		yymmdd hh:mm:ss	061121 08:18:15
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	061121 08:51:04
Stop of flow period		yymmdd hh:mm:ss	061121 18:57:02
Test stop (stop of pressure registration)		yymmdd hh:mm:ss	061122 07:11:17
Total flow time	t_p	Min	606
Total recovery time	t_F	Min	734

Pressure data	**Nomenclature**	**Unit**	**Value**	**GW level (m.a.s.l.) [1]**
Absolute pressure in test section before start of flow period	p_i	kPa	175.6	9.72
Absolute pressure in test section at stop of flow period	p_p	kPa	107.2	[3]
Absolute pressure in test section at stop of recovery period	p_F	kPa	167.0	8.68[4]
Maximal pressure change in test section during the flow period	dp_p	kPa	68.4	[3]

Manual groundwater level measurements			**GW level**	
Date YYYY-MM-DD	**Time tt:mm:ss**	**Time (min)**	**(m b ToC)**	**(m.a.s.l.)**
2006-11-20	10:25:00	–1,346	2.30	9.42
2006-11-20	16:30:00	–981	2.30	9.42
2006-11-21	08:33:00	–18	1.95	9.72
2006-11-22	08:11:00	1,400	3.16	8.68
2006-11-22	08:57:00	1,446	2.98	8.83

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$8.25 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period [2]	Q_m	m^3/s	$9.01 \cdot 10^{-5}$
Total volume discharged during flow period [2]	V_p	m^3	3.28

[1] From the manual measurements of groundwater level.

[2] Calculated from integration of the transient flow rate curve during the flow period.

[3] Manual levelling was not possible.

[4] Levelled one hour after test stop.

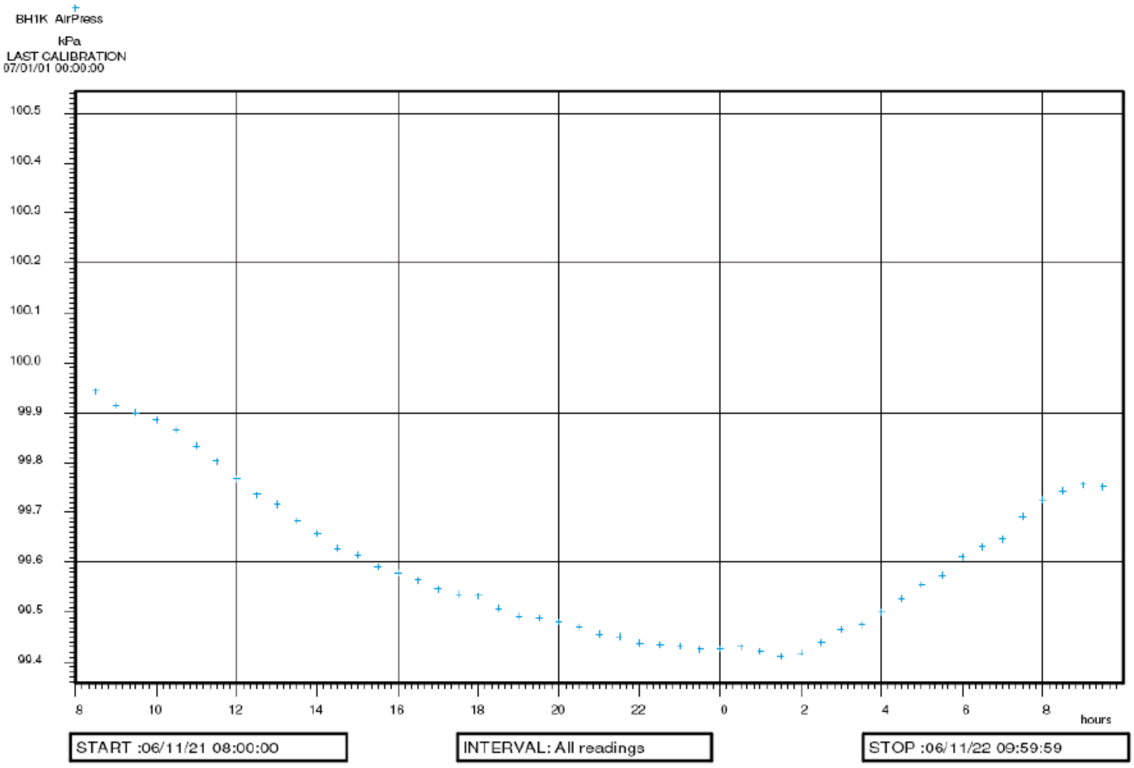


Figure 6-2. *Atmospheric pressure during the test period in HFM37.*

The atmospheric pressure during the test period in HFM37, presented in Figure 6-2, varied 0.55 kPa, i.e. only c. 0.8% of the total drawdown of c. 69.4 kPa in the borehole during the test. There was a small rainfall, less than 2.5 mm, during the test. However, it does not seem to have affected the test.

Comments on test

The day before test start, a short capacity test was performed (c. 65 min). The capacity test was conducted with the flow rate increasing in steps, during observation of the drawdown response. By the end of the capacity test, the flow rate was c. 7.5 L/min and the drawdown c. 6.8 m. The actual pumping test was performed as a constant flow rate test (5.3 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. After 65 minutes of pumping the drawdown was c. 6.0 m and at the end of the pumping test c. 7.1 m.

A comparison of the results from the capacity test and the pumping test shows good coincidence. Discrepancies between the two may indicate changes in the borehole skin zone due to pumping.

During the pumping, since the drawdown became larger than expected, another pressure transducer was lowered into the borehole. The first pressure transducer is attached to the pump hose and could not be lowered to another position. The pressure data were compensated for this action.

Interpreted flow regimes

Selected test diagrams according to the Instruction for analysis of injection- and single-hole pumping tests are presented in Figures A2-8 to A2-12 in Appendix 2.

The somewhat disturbed appearance at the end of the flow period is caused by lowering and lifting the flow logging equipment, resulting in water level changes in the borehole. These changes were transformed to apparent flow rate changes. The corrected flow rate for these changes Q_{corr} is used in the evaluation of the test.

Although the beginning of the flow period is disturbed, wellbore storage effects are assumed to dominate the first c. 2 min of the period. An approximate pseudo-radial flow regime seems to start after c. 200 minutes of the flow period but is masked by the apparent changes in flow rate after this time.

After c. 67 min of the flow period the water level in the open borehole is assumed to pass below the lower end of the casing into the cored borehole interval at a drawdown of c. 6.1 m. This is suggested by the borehole data for HFM37 in Table 3-1 and the initial position of the water level in Table 6-4.

During the recovery period, wellbore storage effects dominate during the first c. 2 min. After c. 5 min the water level returns back into the lower end of the casing which causes a distortion and a temporary flattening out of the pressure derivative. After a transition period, an approximate pseudo-radial flow regime can be seen from c. 200 min to the end of the recovery period.

Interpreted parameters

Transient evaluation of transmissivity was performed for both the flow- and recovery period according to the methods described in Section 5.4.1. The transient analyses are presented in Figures A2-9 to A2-12 in Appendix 2. The transmissivity and skin factor were estimated by a standard model assuming pseudo-radial flow including wellbore storage and skin /3/ for both the flow and recovery period.

By the analysis of the recovery period the same value on the effective casing radius r_c as obtained from the flow period was used, since the early part of the recovery period is disturbed by the transition of the water level into the cased interval of the borehole.

The representative transmissivity (T_T) is considered from the transient evaluation of the recovery period due to the apparent changes in flow rate by the end of the flow period. The agreement between the flow and the recovery period regarding transmissivity and skin factor is good.

The results are shown in the Test Summary Sheet (Table 6-15) and in Tables 6-11, 6-12 and 6-13.

6.3.3 Borehole HFM38: 9.1–200.8 m

General test data for the open-hole pumping test in HFM38 are presented in Table 6-5.

The atmospheric pressure during the test period in HFM38, presented in Figure 6-3, varied less than 0.5 kPa, i.e. less than 1% of the total drawdown of 54 kPa. Thus, the effect of atmospheric pressure variations on the test results is considered negligible. A rainfall, about 11 mm, the day before the pumping does not seem to affected the test.

Table 6-5. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM38.

General test data			
Borehole	HFM38 (9.1–200.8 m)		
Test type	Constant rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	Open borehole		
Test No	1		
Field crew	J. Harrström, J. Florberger and E. Walger, GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomenclature	**Unit**	**Value**
Borehole length	L	m	200.8
Casing length	L_c	m	9.1
Test section – secup	Secup	m	9.1
Test section – seclow	Seclow	m	200.8
Test section length	L_w	m	191.7
Test section diameter	$2 \cdot r_w$	mm	top 141.0 bottom 136.0
Test start (start of pressure registration)		yymmdd hh:mm:ss	061115 08:21:00
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	061115 09:50:07
Stop of flow period		yymmdd hh:mm:ss	061115 20:24:32
Test stop (stop of pressure registration)		yymmdd hh:mm:ss	061116 09:24:07
Total flow time	t_p	Min	634
Total recovery time	t_F	Min	780

Pressure data	**Nomenclature**	**Unit**	**Value**	**GW level (m.a.s.l.)** [1]
Absolute pressure in test section before start of flow period	p_i	kPa	195.6	0.37
Absolute pressure in test section at stop of flow period	p_p	kPa	138.5	–5.56
Absolute pressure in test section at stop of recovery period	p_F	kPa	196.3	0.34
Maximal pressure change in test section during the flow period	dp_p	kPa	57.1	5.93

Manual groundwater level measurements **Date** **YYYY-MM-DD**	**Time** **tt:mm:ss**	**Time** **(min)**	**GW level** **(m b ToC)**	**(m.a.s.l.)**
2006-11-13	10:44:00	–2,826	2.27	0.35
2006-11-13	15:40:00	–2,530	2.22	0.39
2006-11-14	08:42:00	–1,508	2.22	0.39
2006-11-15	08:11:00	–99	2.25	0.37
2006-11-15	20:23:00	633	9.48	–5.56
2006-11-16	09:22:00	1,412	2.28	0.34

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$9.89 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period [2]	Q_m	m^3/s	$9.90 \cdot 10^{-4}$
Total volume discharged during flow period [2]	V_p	m^3	37.66

[1] From the manual measurements of groundwater level.

[2] Calculated from integration of the transient flow rate curve during the flow period.

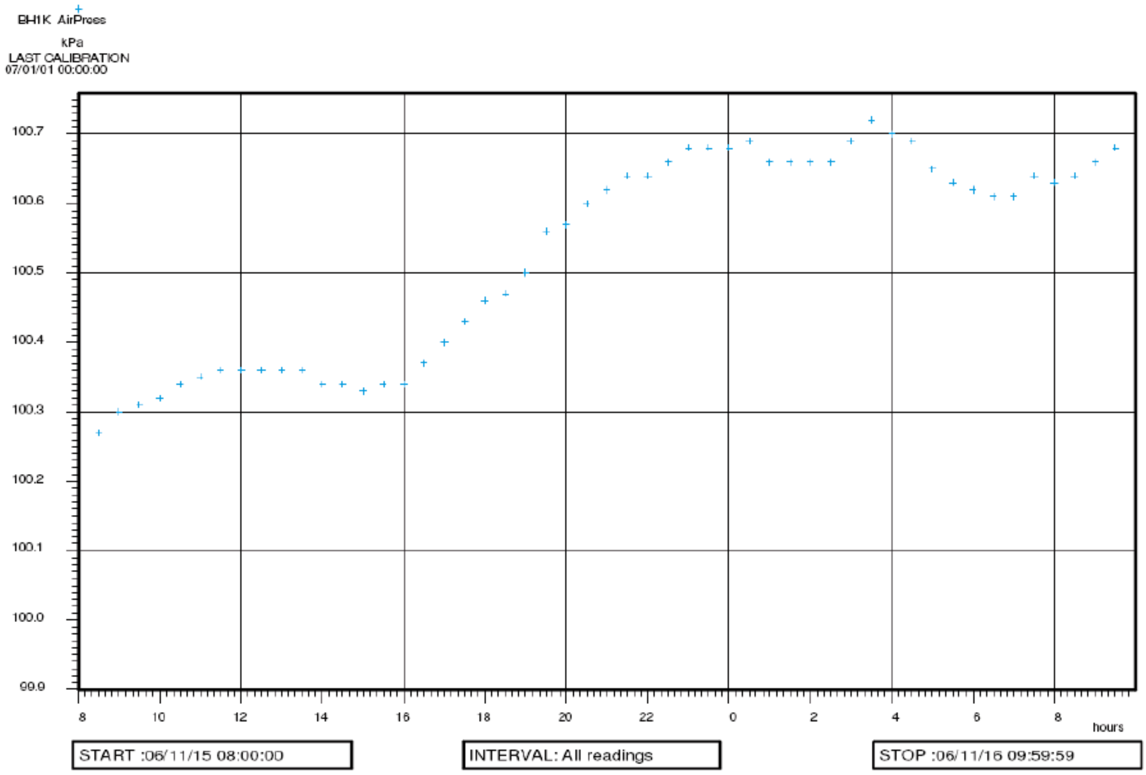


Figure 6-3. *Atmospheric pressure during the test period in HFM38.*

Comments on test

The day before test start, a short capacity test was performed (c. 108 min). The capacity test was conducted by increasing the flow rate in steps, during observation of the drawdown response. By the end of the capacity test, the flow rate was c. 58.8 L/min and the drawdown 5.5 m. The drawdown after 110 minutes of pumping of the 10 hours pumping test, at a flow rate of c. 59 L/min, was 5.6 m and at the end of the test 5.8 m. The results from the capacity test and the pumping test show good agreement. Discrepancies between the two may indicate changes in the borehole skin zone due to pumping.

Interpreted flow regimes

Selected test diagrams according to the Instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-13 to A2-17 in Appendix 2.

Initially, both the drawdown and recovery periods are influenced by wellbore storage. After c. 20 minutes a transition to a pseudo-spherical flow regime (leaky aquifer) can be observed during both periods. By the end of the test, small fluctuations of the water level, caused by lowering the flow logging equipment in the borehole, can be observed.

At the end of the flow period the water level in the borehole can be assumed to be located slightly below (c. 0.43 m) the casing. Thus, after c. 50 min of the flow period the water level in the open borehole is assumed to pass below the lower end of the casing at a drawdown of c. 5.5 m. This is suggested by the borehole data for HFM38 in Table 3-1 and the initial position of the water level in Table 6-5.

After c. 0.2 min of the recovery period the water level returns back into the lower end of the casing which caused a small change of the pressure derivative in this case.

Interpreted parameters

Transient evaluation of transmissivity was performed for both the flow- and recovery period and the quantitative interpretation is presented in Figures A2-14 to A2-17 in Appendix 2. The quantitative analysis was made according to the methods described in Section 5.4.1. Transient evaluation was accomplished by a model assuming pseudo-spherical flow /4/ for both the flow- and recovery period. By the transient evaluation with this model, the lower semi-confining layer was considered impermeable implying that the parameters r/B'' and β'' in AQTESOLV are zero. The representative transmissivity (T_T) is considered from the transient evaluation assuming pseudo-spherical flow including wellbore storage and skin. The agreement between the flow and the recovery period regarding transmissivity and skin factor is good.

The results are shown in the Test Summary Sheet (Table 6-16) and in Tables 6-11, 6-12 and 6-13. The analysis from the flow period was selected as representative for the test.

6.4 Flow logging

6.4.1 Borehole HFM36

General test data for the flow logging in borehole HFM36 are presented in Table 6-6.

Table 6-6. General test data, groundwater level and flow data for the flow logging in borehole HFM36.

General test data	
Borehole	HFM36
Test type(s) [1]	6, L-EC, L-Te
Test section:	Open borehole
Test No	1
Field crew	J. Harrström and E. Gustavsson, GEOSIGMA AB
Test equipment system	HTHB
General comments	Single pumping borehole

	Nomenclature	**Unit**	**Value**
Borehole length		m	152.6
Pump position (lower level)		m	20
Flow logged section – secup		m	22.5
Flow logged section – seclow		m	140.0
Test section diameter	2·rw	mm	top 137.5 bottom 136.8
Start of flow period		yymmdd hh:mm	061123 08:12
Start of flow logging		yymmdd hh:mm	061123 15:10
Stop of flow logging		yymmdd hh:mm	061123 17:35
Stop of flow period		yymmdd hh:mm	061123 18:13

Groundwater level	**Nomenclature**	**Unit**	**GW level (m b ToC)**	**GW level (m.a.s.l.) [2]**
Groundwater level in borehole, at undisturbed conditions, open hole	h_i	m	2.40	6.36
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m	[3]	[3]
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m	10.73	

Flow data	**Nomenclature**	**Unit**	**Flow rate**
Pumping rate at surface	Q_p	m^3 /s	$6.61\cdot10^{-4}$
Corrected flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m^3 /s	$6.61\cdot10^{-4}$
Threshold value for borehole flow rate during flow logging	Q_{Measl}	m^3 /s	$5\cdot10^{-5}$
Minimal change of borehole flow rate to detect flow anomaly	dQ_{Anom}	m^3 /s	$1.7\cdot10^{-5}$

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

2) Calculated from the manual measurements of groundwater level.

3) Manual levelling was not possible.

Comments on test

The flow logging was made from 140 m borehole length and upwards. The step length between flow logging measurements was maximally 5 m (below first measurable flow). Above first measurable flow (65 m), the step length was maximally 2 m, and decreased to 0.5 m when a flow anomaly was encountered.

The simultaneously measured electric conductivity and temperature are used as supporting information when interpreting flow anomalies.

Logging results

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured flow distribution along the borehole during the flow logging together with the electric conductivity (EC) and temperature of the borehole fluid are presented in Figure 6-4. The figure presents measured borehole flow rates with calibration constants for a 140 mm pipe and corrected borehole flow rates. The correction is performed in two steps according to the method described in Section 5.4.2. In this case, it was not possible to extend the flow logging to the lower end of the casing. However, during drilling no water inflow was recorded above c. 27.8 m and therefore no flow anomalies were assumed to exist above the highest logged level (22.5 m). Consequently, method 1 was used to evaluate the flow logging measurements.

Figure 6-4 shows five detected inflows between 27 and 65 m and that all five inflows are supported by changes in the EC measurements. Three anomalies were also supported by small changes in borehole water temperature.

Above the first detected inflow at c. 65 m, borehole flow could not be measured at all spinner locations, indicating that the borehole flow rate was close to the measurement limit. Therefore the location of the deepest flow anomaly is uncertain. A change in temperature at c. 88.5 m indicates an inflow at this location. Results from borehole TV (BIPS) does not contradict such an interpretation since the rock is partly fractured at this borehole length.

The results of the flow logging in borehole HFM36 are presented in Table 6-7 below. The corrected measured inflow at the identified flow anomalies (dQ_{icorr}) and their estimated percentage of the total flow is shown. The transmissivity of individual flow anomalies (T_i) was calculated from Equation (5-4) using the corrected flow values (se above) and the cumulative transmissivity ($T_F(L)$) from Equation (5-5). The borehole transmissivity is taken from the transient evaluation of the flow period of the pumping test (cf. Section 6.3.1), performed in conjunction with the flow logging. An estimation of the transmissivity of the interpreted flow anomaly was also made by calculating the specific flow (dQ_i/s_{FL}).

Table 6-7. Results of the flow logging in borehole HFM36. T=transmissivity from the pumping test, s_{FL}= drawdown during flow logging and Q_p=pumped flow rate from borehole.

Flow anomalies			$T=2.4\cdot10^{-5}$ (m^2/s)	s_{FL}= 10.7 m	$Q_p=6.61\cdot10^{-4}$ (m^3/s)	
Interval (m b ToC)	B.h. length (m)	dQ_{icorr} (m^3/s)	T_i (m^2/s)	dQ_{icorr}/s_{FL} (m^2/s)	dQ_{icorr}/Q_p (%)	Supporting information
27.0–27.5	0.5	$1.3\cdot10^{-4}$	$4.7\cdot10^{-6}$	$1.2\cdot10^{-5}$	19.6	EC, Temp
32.0–32.5	0.5	$1.3\cdot10^{-4}$	$4.7\cdot10^{-6}$	$1.2\cdot10^{-5}$	19.7	EC, Temp
40.0–41.0	1	$5.2\cdot10^{-5}$	$1.9\cdot10^{-6}$	$4.8\cdot10^{-6}$	7.8	EC, Temp
50.5–51.0	0.5	$2.8\cdot10^{-4}$	$1.0\cdot10^{-5}$	$2.6\cdot10^{-5}$	42.6	EC
88.0–88.5	0.5	$6.8\cdot10^{-5}$	$2.5\cdot10^{-6}$	$6.3\cdot10^{-6}$	10.3	EC
Total		**$6.6\cdot10^{-4}$**	**$2.4\cdot10^{-5}$**	**$6.2\cdot10^{-5}$**	**100**	

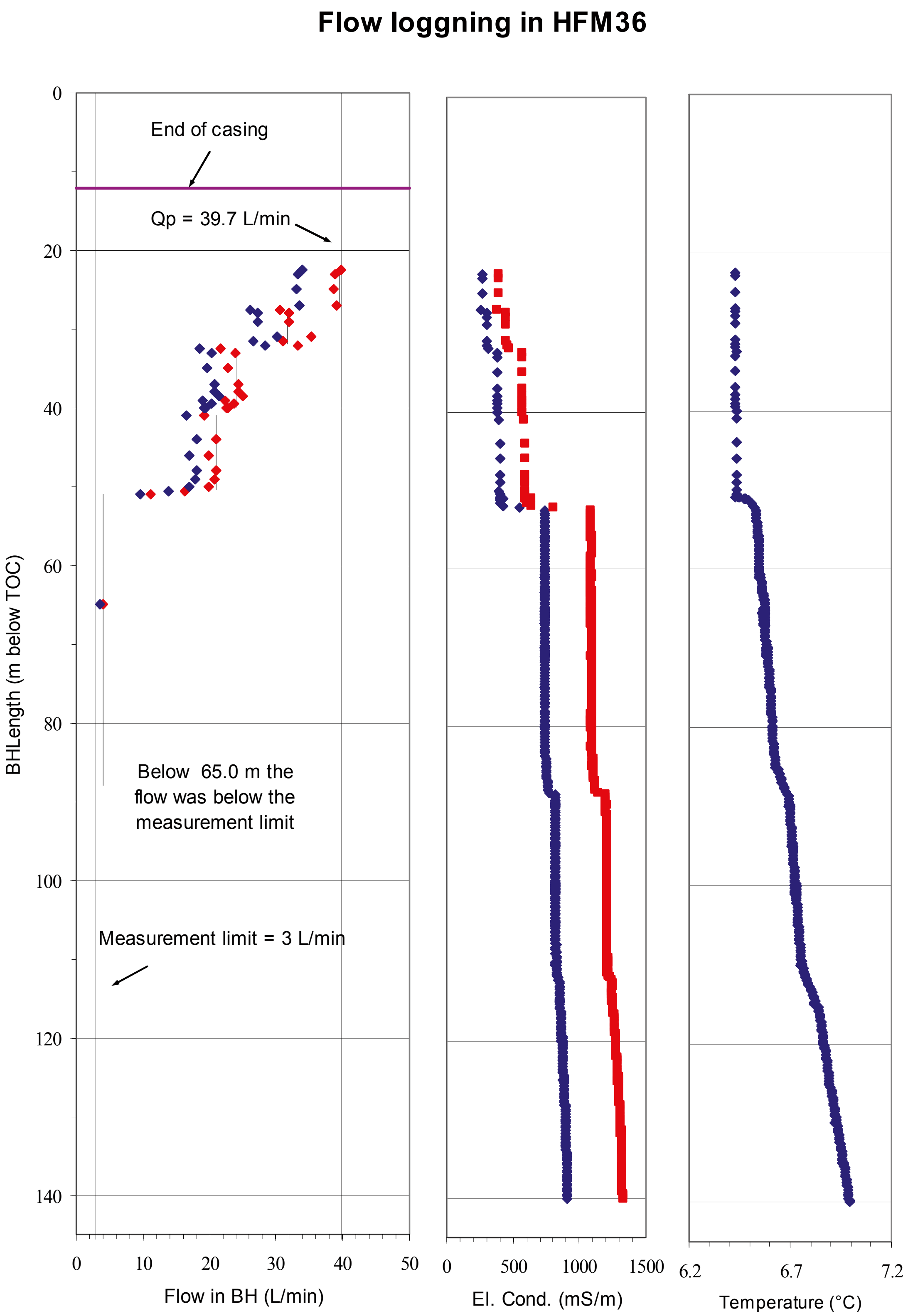


Figure 6-4. Measured (blue) and corrected (red) inflow distribution together with measured (blue) and temperature compensated (red) electrical conductivity and temperature of the borehole fluid along borehole HMF36 during flow logging.

Figure 6-5 presents the cumulative transmissivity $T_F(L)$ along the borehole length (L) from the flow logging calculated from Equation (5-5). Since the width of the flow anomaly in the borehole is not known in detail, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated threshold value of T and the total transmissivity of the borehole are also presented in the figure, cf. Section 5.4.2.

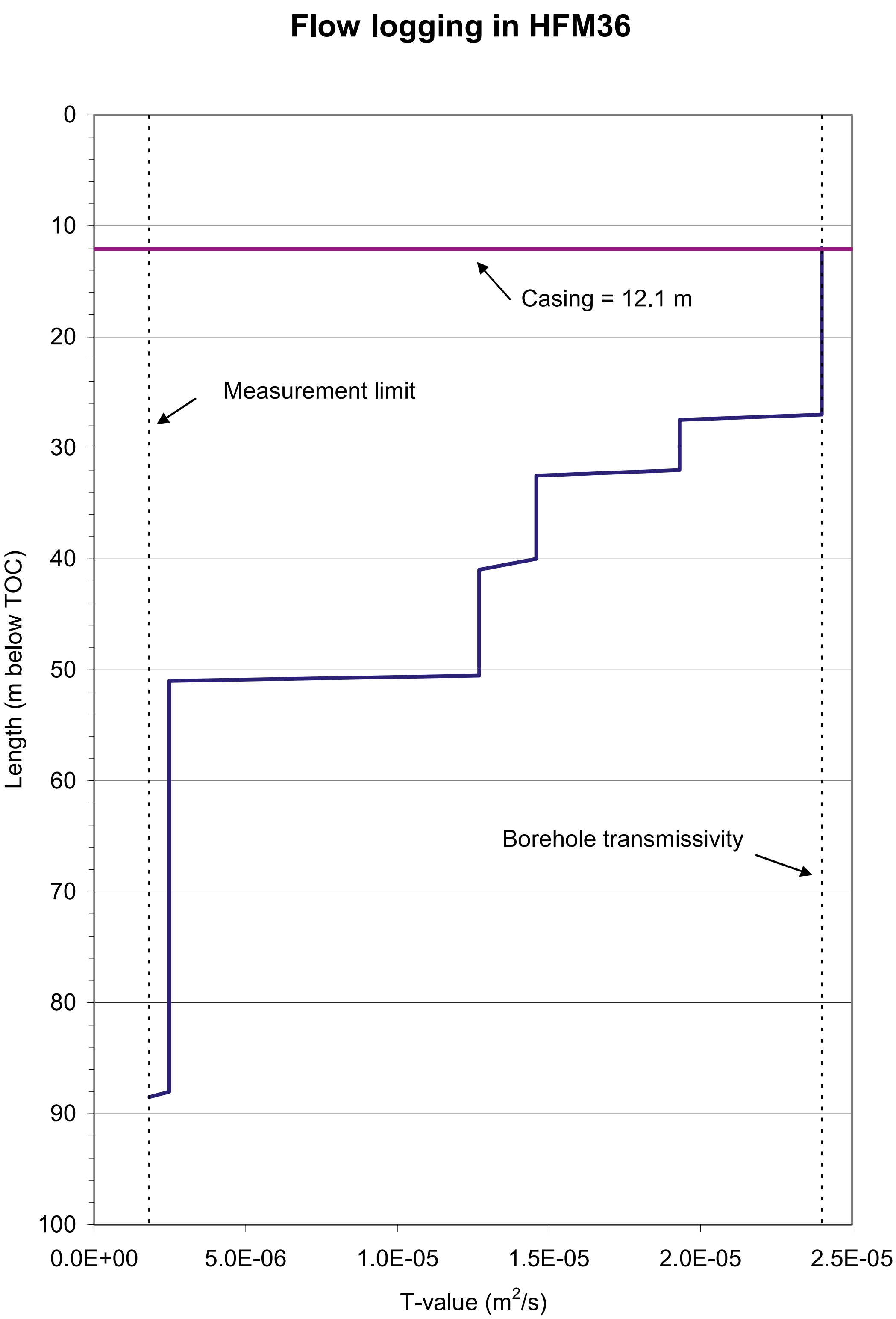


Figure 6-5. *Calculated, cumulative transmissivity along the flow logged interval of borehole HFM36. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.4.2 Borehole HFM37

In HFM37 flow logging was performed but no flow above the lower measurement limit (c. 3 L/min in a 140 mm borehole) for the flow logging equipment could be found. Therefore, only the simultaneous logging of temperature and electrical conductivity are presented below.

General test data for the flow logging in borehole HFM37 are presented in Table 6-8.

Comments on test

As no measurable flow was encountered, the step length between flow logging measurements was 5 m all the way up to the top of the logged interval.

Table 6-8. General test data, groundwater level and flow data for the flow logging in borehole HFM37.

General test data				
Borehole	HFM37			
Test type(s) [1)]	6, L-EC, L-Te			
Test section:	Open borehole			
Test No	1			
Field crew	J. Harrström and E. Gustavsson, GEOSIGMA AB			
Test equipment system	HTHB			
General comments	Single pumping borehole			
	Nomenclature	**Unit**	**Value**	
Borehole length		m	191.8	
Pump position (lower level)		m	14.5	
Flow logged section – secup		m	15.5	
Flow logged section – seclow		m	186.1	
Test section diameter	2·rw	mm	top 141.0 bottom 138.5	
Start of flow period		yymmdd hh:mm	061121 08:51	
Start of flow logging		yymmdd hh:mm	061121 16:17	
Stop of flow logging		yymmdd hh:mm	061121 17:35	
Stop of flow period		yymmdd hh:mm	061121 18:57	
Groundwater level	**Nomenclature**	**Unit**	**GW level (m b ToC)**	**GW level (m.a.s.l.)** [2]
Groundwater level in borehole, at undisturbed conditions, open hole	h_i	m	1.95	9.72
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m	[3)]	[3)]
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m	6.67	
Flow data	**Nomenclature**	**Unit**	**Flow rate**	
Pumping rate at surface	Q_p	m^3 /s	$8.25 \cdot 10^{-5}$	
Corrected flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m^3 /s	$8.25 \cdot 10^{-5}$	
Threshold value for borehole flow rate during flow logging	Q_{Measl}	m^3 /s	$5 \cdot 10^{-5}$	
Minimal change of borehole flow rate to detect flow anomaly	dQ_{Anom}	m^3 /s	$1.7 \cdot 10^{-5}$	

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

[2)] Calculated from the manual measurements of groundwater level.

[3)] Manual levelling was not possible.

Logging results

The measured electric conductivity (EC) and temperature of the borehole fluid during the logging are presented in Figure 6-6. These variables are normally used as supporting information when interpreting flow anomalies.

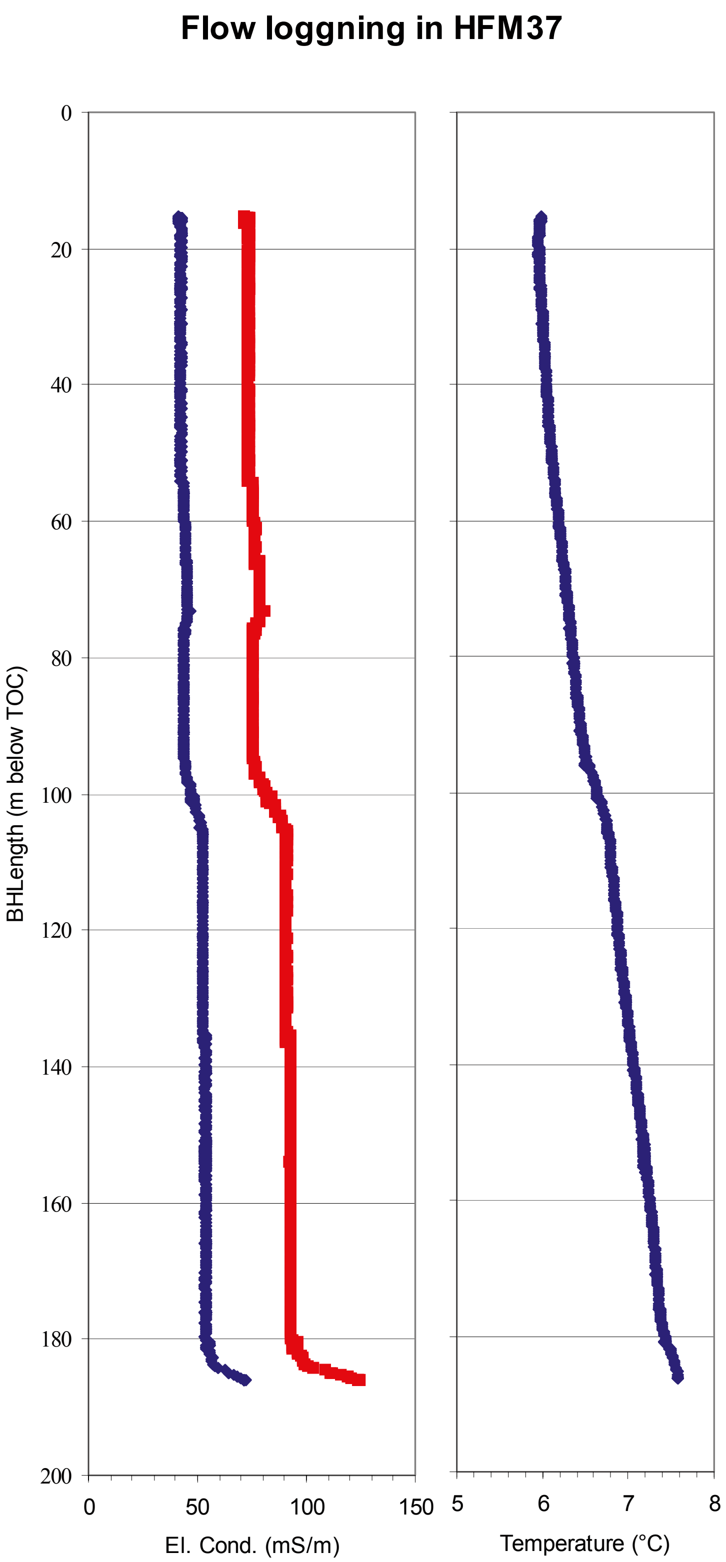


***Figure 6-6.** Measured (blue) and temperature compensated (red) electrical conductivity and temperature of the borehole fluid along borehole HMF37 during flow logging.*

Since no detectable flow was found in the logged interval (15.5–186.1 m) the accumulated inflows below 15.5 m must be less than the threshold value for the flow logging (c. 3 L/min). According to Equation (5-11) the transmissivity below 15.5 m should then be less than c. $6.27 \cdot 10^{-6}$ m^2/s using the evaluated transmissivity for the entire borehole (T_T) from the pumping test.

From the logging of electric conductivity and temperature two possible inflow anomalies could be detected in the logged interval, one at c. 95–105 m and another at c. 180–185 m.

6.4.3 Borehole HFM38

General test data for the flow logging in borehole HFM38 are presented in Table 6-9.

Table 6-9. General test data, groundwater level and flow data for the flow logging in borehole HFM38.

General test data				
Borehole	HFM38			
Test type(s) [1]	6, L-EC, L-Te			
Test section:	Open borehole			
Test No	1			
Field crew	J. Florberger and J. Harrström, GEOSIGMA AB			
Test equipment system	HTHB			
General comments	Single pumping borehole			
	Nomenclature	**Unit**	**Value**	
Borehole length		m	200.8	
Pump position (lower level)		m	18.0	
Flow logged section – secup		m	21.0	
Flow logged section – seclow		m	194.5	
Test section diameter	2·rw	mm	top 141.0 bottom 136.0	
Start of flow period		yymmdd hh:mm	061115 09:50	
Start of flow logging		yymmdd hh:mm	061115 16:32	
Stop of flow logging		yymmdd hh:mm	061115 19:22	
Stop of flow period		yymmdd hh:mm	061115 20:24	
Groundwater level	**Nomenclature**	**Unit**	**GW level (m b ToC)**	**GW level (m.a.s.l.) [2]**
Groundwater level in borehole, at undisturbed conditions, open hole	h_i	m	2.25	0.37
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m	9.48	–5.56
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m	5.93	5.93
Flow data	**Nomenclature**	**Unit**	**Flow rate**	
Pumping rate at surface	Q_p	m^3 /s	$9.89 \cdot 10^{-4}$	
Corrected flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m^3 /s	$9.89 \cdot 10^{-4}$	
Threshold value for borehole flow rate during flow logging	Q_{Measl}	m^3 /s	– [3]	
Minimal change of borehole flow rate to detect flow anomaly	dQ_{Anom}	m^3 /s	– [3]	

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

[2] Calculated from the manual measurements of groundwater level.

[3] Due to a defective impeller in the flow logging device an alternative method with continuous lowering of the probe was used. The threshold value and the detection flow rate should then be almost the same, however not determined for this method.

Comments on test

Depending on a malfunctioning impeller in the flow logging probe the results from the ordinary flow logging procedure, lifting the probe in fixed steps from the bottom to the top of the borehole, could not be used to interpret the magnitude of flow anomalies. Instead an alternative method with continuous lowering of the flow logging probe was used (see Sections 3.3 and 5.2.2). A disadvantage with this method is that the results will be more scattered, to a certain degree though, compensated by the fact that many more values are collected.

The logged electric conductivity and temperature are used as supporting information when interpreting flow anomalies.

Logging results

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured flow distribution along the borehole during the flow logging together with the electric conductivity (EC) and temperature of the borehole fluid are presented in Figure 6-7.

The method for correction of borehole flow rates due to decreasing borehole diameter with depth was made in a slightly different way than normally but with the principles as described in Section 5.4.2. In this case, it was not possible to extend the flow logging to the lower end of the casing. However, during drilling no water inflow was recorded above c. 32.2 m and therefore no flow anomalies were assumed to exist above the highest logged level (21 m). Consequently, method 1 was used to evaluate the flow logging measurements.

Figure 6-7 shows two detected inflows in the flow logged interval between 21.0 and 194.5 m borehole length. Both inflows are supported by changes in electric conductivity.

The results of the flow logging in borehole HFM38 are presented in Table 6-10 below. The corrected measured inflow at the identified flow anomalies (dQ_{icorr}) and their estimated percentage of the total flow is shown. The transmissivity of individual flow anomalies (T_i) was calculated from Equation (5-4) using the corrected flow values (see above) and the cumulative transmissivity ($T_F(L)$) from Equation (5-5). The transmissivity for the entire borehole used in Equation (5-4) and (5-5) was taken from the transient evaluation of the flow period of the pumping test (cf. Section 6.3.3). An estimation of the transmissivity of the interpreted flow anomalies was also made by calculating the specific flows (dQ_i/S_{FL}).

Figure 6-8 presents the cumulative transmissivity $T_F(L)$ along the borehole length (L) from the flow logging, calculated from Equation (5-5). Since the width of the flow anomaly in the borehole is not known in detail, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated total transmissivity of the borehole is also presented in the figure, cf. Section 5.4.2.

Table 6-10. Results of the flow logging in borehole HFM38. T=transmissivity for the flow logged interval calculated from the pumping test, s_{FL}= drawdown during flow logging and Q_{FT}=calculated flow at the top of the flow logged interval.

Flow anomalies			$T=1.3\cdot10^{-4}$ (m²/s)	s_{FL}= 5.8 m	$Q_{FT}=9.9\cdot10^{-4}$ (m³/s)	
Interval (m b ToC)	B.h. length (m)	dQ_{icorr} (m³/s)	T_i (m²/s)	dQ_{icorr}/s_{FL} (m²/s)	dQ_{icorr}/Q_p (%)	Supporting information
28.5–29.7	1.2	$6.2\cdot10^{-4}$	$8.3\cdot10^{-5}$	$1.2\cdot10^{-4}$	62.6	EC
188.5–187.3	1.2	$3.7\cdot10^{-4}$	$4.8\cdot10^{-5}$	$6.3\cdot10^{-5}$	37.4	EC
Total		$\mathbf{9.9\cdot10^{-4}}$	$\mathbf{1.3\cdot10^{-4}}$	$\mathbf{1.7\cdot10^{-4}}$	**100**	

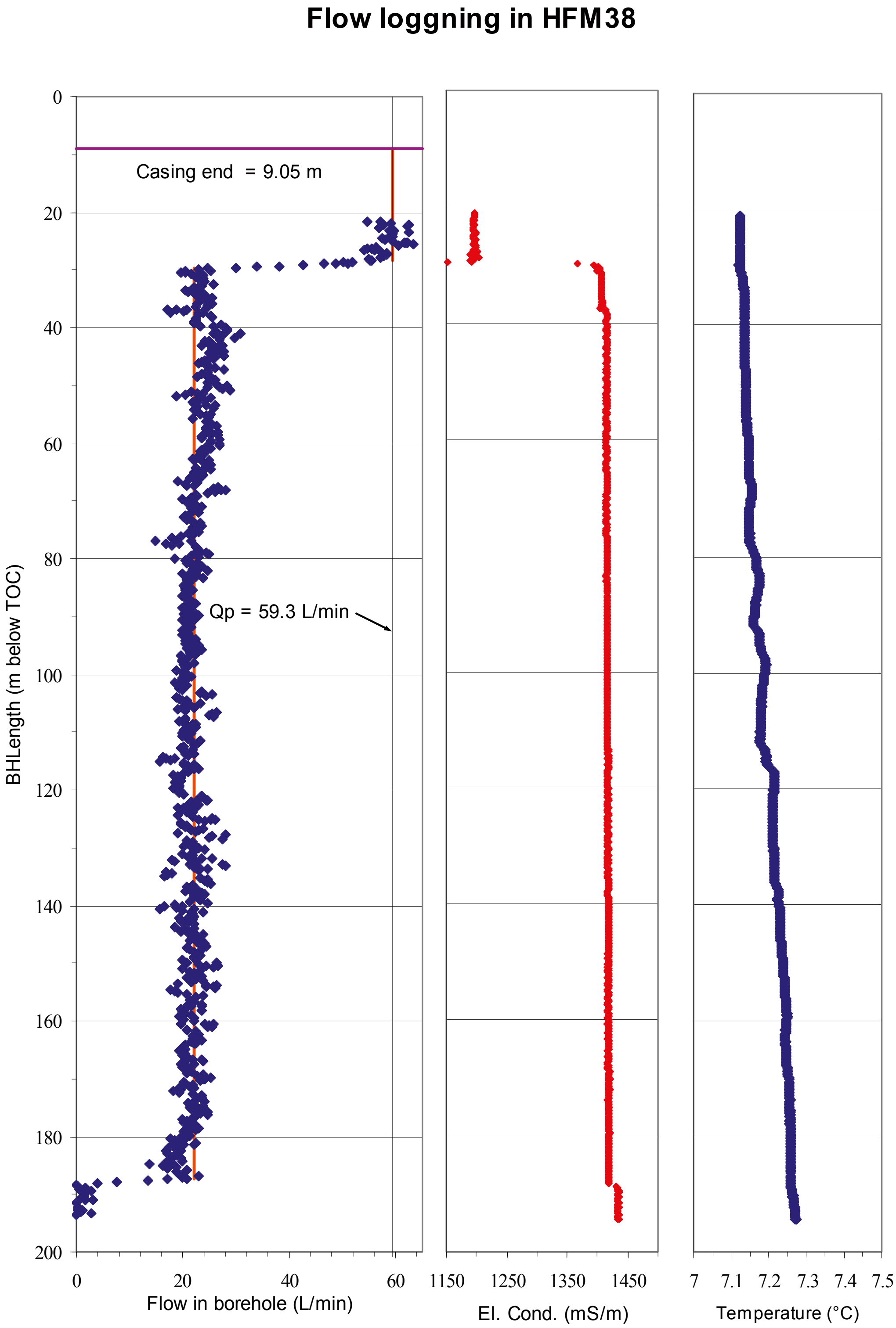


Figure 6-7. *Corrected inflow distribution together with temperature compensated electrical conductivity and temperature of the borehole fluid along borehole HMF38 during flow logging.*

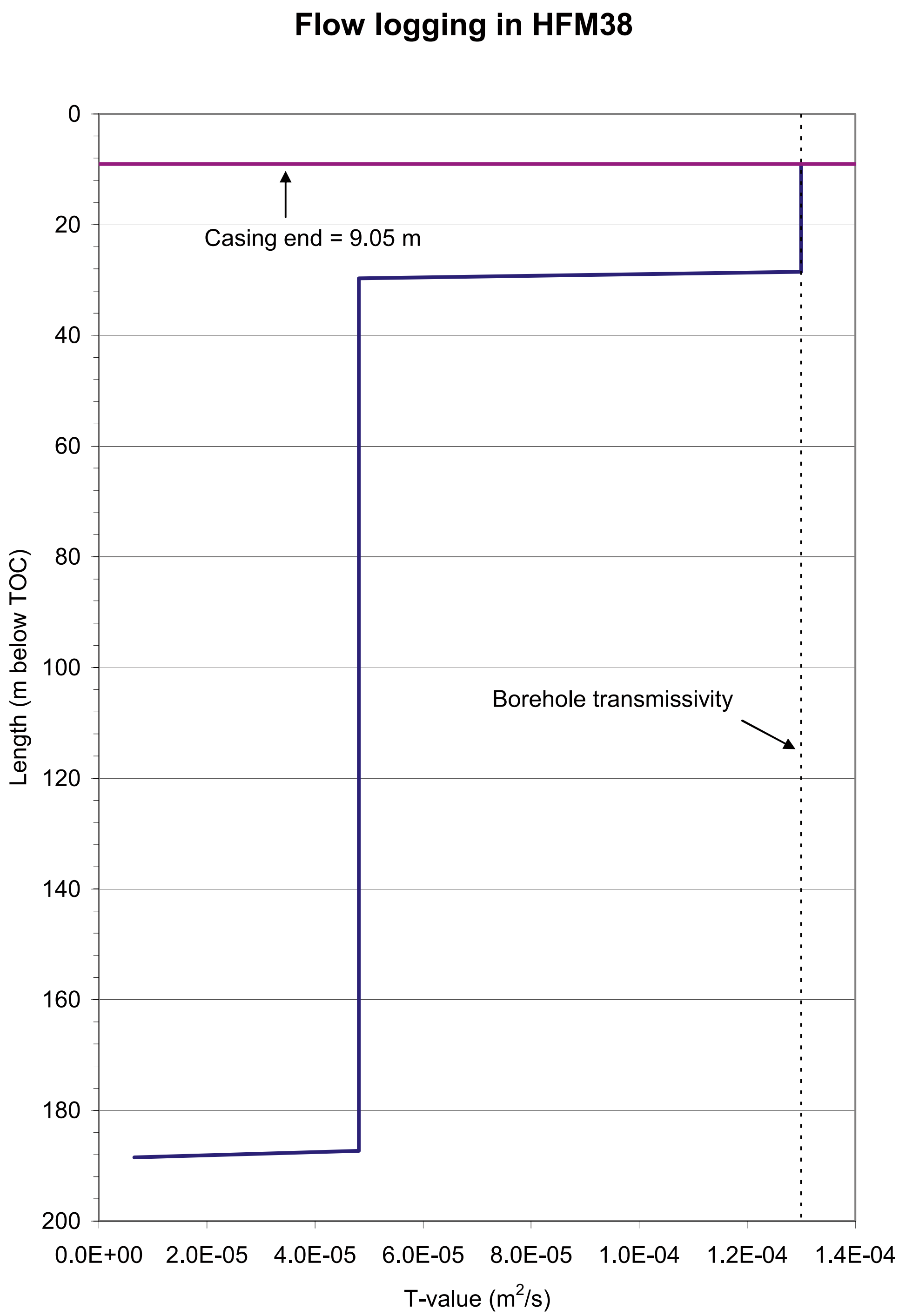


Figure 6-8. *Calculated, cumulative transmissivity along the flow logged interval of borehole HFM38. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.5 Summary of hydraulic tests

A compilation of measured test data from the pumping tests in the three boreholes is presented in Table 6-11. In Tables 6-12, 6-13, and in the test summary sheets in Tables 6-14, 6-15 and 6-16 hydraulic parameters calculated from the tests are shown.

In Tables 6-11, 6-12 and 6-13, the parameter explanations are according to the instruction for injection- and single-hole pumping tests. The parameters are also explained in the text above, except the following:

Q/s = specific flow for the borehole and flow anomalies (for the latter ones, the specific flow, corrected for the borehole diameter, is listed)

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

T_T = judged best estimate of transmissivity (from transient evaluation of hydraulic test or from Moye's formula)

T_i = estimated transmissivity of flow anomaly

S* = assumed value on storativity used in single-hole tests

C = wellbore storage coefficient

ζ = skin factor

Table 6-11. Summary of test data for the open-hole pumping tests performed with the HTHB system in boreholes HFM36, HFM37 and HFM38 in the Forsmark investigation area.

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)
HFM36	12.1–152.6	1B, 6	214.2	108.6	211.4	$6.61 \cdot 10^{-4}$	$6.58 \cdot 10^{-4}$	23.74
HFM37	9.1–191.8	1B, 6	175.6	107.2	167.0	$8.25 \cdot 10^{-5}$	$9.01 \cdot 10^{-5}$	3.28
HFM38	9.1–200.8	1B, 6	195.6	138.5	196.3	$9.89 \cdot 10^{-4}$	$9.90 \cdot 10^{-4}$	37.66

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

Table 6-12. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed with the HTHB system in boreholes HFM36, HFM37 and HFM38 in the Forsmark investigation area.

Borehole ID	Section (m)	Flow anomaly interval (m)	Test type [1]	Q/s (m^2/s)	T_M (m^2/s)	T_T (m^2/s)	T_i (m^2/s)
HFM36	12.1–152.6		1B	$6.2 \cdot 10^{-5}$	$7.9 \cdot 10^{-5}$	$2.4 \cdot 10^{-5}$	
HFM36	22.5–140.0 (f)	27.0–27.5	6	$1.2 \cdot 10^{-5}$			$4.7 \cdot 10^{-6}$
HFM36	22.5–140.0 (f)	32.0–32.5	6	$1.2 \cdot 10^{-5}$			$4.7 \cdot 10^{-6}$
HFM36	22.5–140.0 (f)	40.0–41.0	6	$4.8 \cdot 10^{-6}$			$2.0 \cdot 10^{-6}$
HFM36	22.5–140.0 (f)	50.5–51.0	6	$2.6 \cdot 10^{-5}$			$1.0 \cdot 10^{-5}$
HFM36	22.5–140.0 (f)	88.0–88.5	6	$6.3 \cdot 10^{-6}$			$2.5 \cdot 10^{-6}$
HFM37	9.1–191.8		1B	$1.2 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$	$9.4 \cdot 10^{-6}$	
HFM38	9.1–200.8		1B	$1.7 \cdot 10^{-4}$	$2.3 \cdot 10^{-4}$	$1.3 \cdot 10^{-4}$	
HFM38	21.0–194.5 (f)	28.5–29.7	6	$1.1 \cdot 10^{-4}$			$8.2 \cdot 10^{-5}$
HFM38	21.0–194.5 (f)	187.3–188.5	6	$6.3 \cdot 10^{-5}$			$4.8 \cdot 10^{-5}$

[1)] 1B: Pumping test-submersible pump, 6: Flow logging–Impeller.
(f) Flowlogged interval.

Table 6-13. Summary of calculated hydraulic parameters from the hydraulic tests performed with the HTHB system in boreholes HFM36, HFM37 and HFM38 in the Forsmark investigation area.

Borehole ID	Section (m)	Test type[1)]	S* (–)	C [2)] (m^3/Pa)	ζ (–)
HFM36	12.1–152.6	1B	$3.8 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$	–6.7
HFM37	9.1–191.8	1B	$2.2 \cdot 10^{-6}$	$2.1 \cdot 10^{-6}$	–3.8
HFM38	9.1–200.8	1B	$7.9 \cdot 10^{-6}$	$3.6 \cdot 10^{-6}$	–4.0

1) 1B: Pumping test-submersible pump.

2) When the fictive casing radius r(c) can be obtained from the parameter estimation in the transient analyses, C is calculated according to Equation 5-2. Otherwise the geometrical value of C is presented.

Appendix 3 includes the result tables delivered to the database SICADA. The lower measurement limit for the pumping tests with the HTHB system, presented in the result tables, is expressed in terms of specific flow (Q/s). For pumping tests, the practical lower limit is based on the minimum flow rate for which the system is designed (5 L/min) and an estimated maximum allowed drawdown for practical purposes (c. 50 m) in a percussion borehole, cf. Table 4-1. These values correspond to a practical lower measurement limit (Q/s-L) of $2 \cdot 10^{-6}$ m^2/s of the pumping tests.

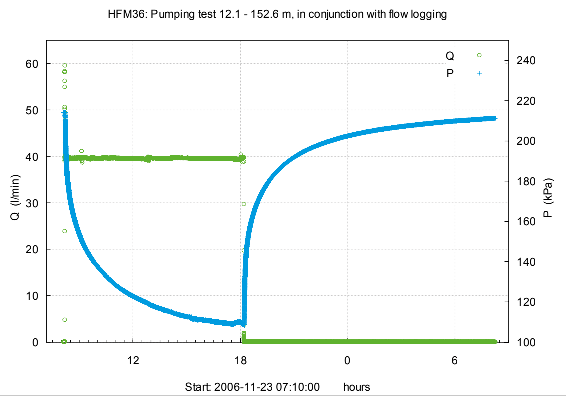
Similarly, the practical, upper measurement limit of the HTHB-system is estimated from the maximal flow rate (c. 80 L/min) and a minimal drawdown of c. 0.5 m, which is considered significant in relation to e.g. background fluctuations of the pressure before and during the test. These values correspond to an estimated, practical upper measurement limit (Q/s-U) of $2 \cdot 10^{-3}$ m^2/s for pumping tests.

Table 6-14. Test Summary Sheet for the pumping test in HFM36, section 12.1–152.6 m.

Test Summary Sheet

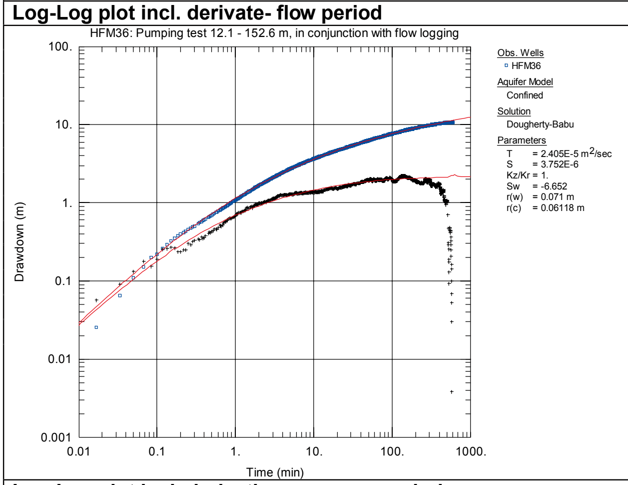
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM36	Test start:	2006-11-23 08:12:03
Test section (m):	12.1-152.6	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2 \cdot r_w$ (m):	top 0.1375 bottom 0.1368	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

Linear plot Q and p

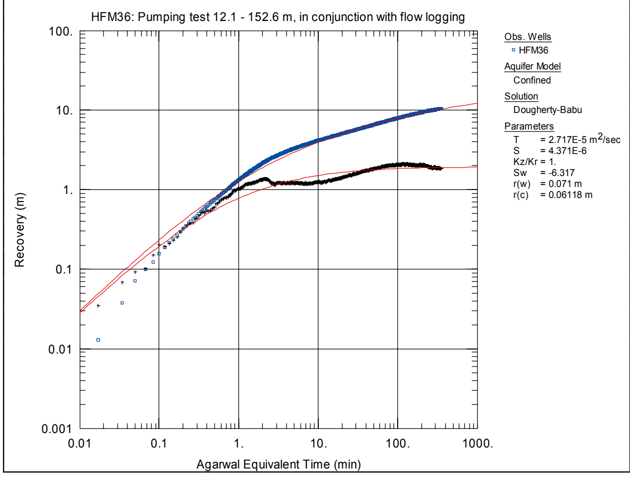


Flow period*		Recovery period*	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	214.2		
p_p(kPa)	108.6	p_F (kPa)	211.4
Q_p (m^3/s)	$6.6 \cdot 10^{-4}$		
tp (min)	601	t_F (min)	843
S*	$3.8 \cdot 10^{-6}$	S*	$4.4 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.1	Derivative fact.	0.1
Results		**Results**	
Q/s (m^2/s)	$6.1 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$7.87 \cdot 10^{-5}$		
Flow regime:	WBS->PRF	Flow regime:	WBS->PRF
t_1 (min)	40	dt_{e1} (min)	40
t_2 (min)	300	dt_{e2} (min)	300
T_w (m^2/s)	$2.4 \cdot 10^{-5}$	T_w (m^2/s)	$2.7 \cdot 10^{-5}$
S_w (-)		S_w (-)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$1.20 \cdot 10^{-6}$	C (m^3/Pa)	$1.20 \cdot 10^{-6}$
C_D (-)		C_D (-)	
ξ (-)	-6.7	ξ (-)	-6.3
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:	WBS->PRF	C (m^3/Pa)	$1.2 \cdot 10^{-6}$
t_1 (min)	40	C_D (-)	
t_2 (min)	300	ξ (-)	-6.7
T_T (m^2/s)	$2.4 \cdot 10^{-5}$		
S* (-)	$3.8 \cdot 10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments:

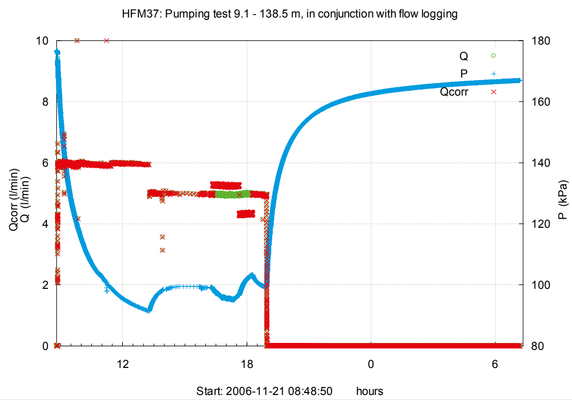
After initial wellbore storage effects and pseudo-linear flow, pseudo-radial flow prevails between c. 40-300 min during both the drawdown and the recovery period. After c. 300 min of the flow period there is a transition to pseudo-spherical flow and an apparent constant head boundary at the end.

The results from the flow period are chosen as the most representative for the test section.

Table 6-15. Test Summary Sheet for the pumping test in HFM37 section 9.1–191.8 m.

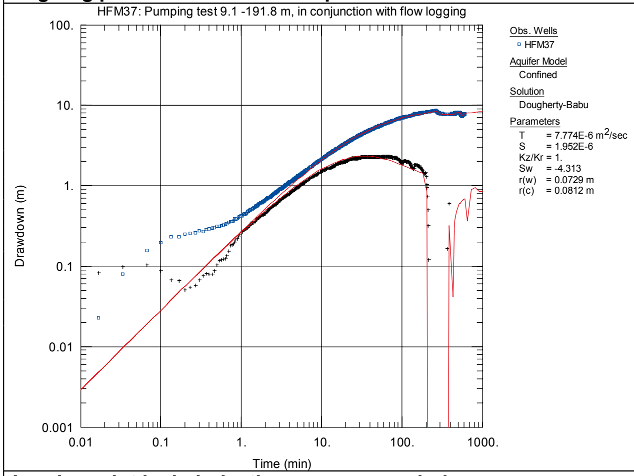
Test Summary Sheet			
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM37	Test start:	2006-11-21 08:51:04
Test section (m):	9.1-191.8	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2\cdot r_w$ (m):	top 0.1410 bottom 0.1385	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

Linear plot Q and p



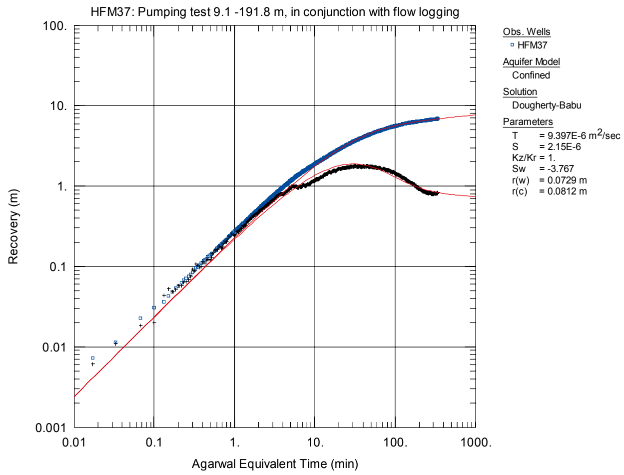
Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	175.6		
p_p(kPa)	107.1	p_F (kPa)	167.0
Q_p (m^3/s)	$8.3\cdot10^{-5}$		
tp (min)	606	t_F (min)	737
S*	$2.0\cdot10^{-6}$	S*	$2.2\cdot10^{-6}$
EC_w (mS/m)			
Te_w (gr C)			
Derivative fact.	0.3	Derivative fact.	0.1
Results		**Results**	
Q/s (m^2/s)	$1.2\cdot10^{-5}$		
T_{Moye}(m^2/s)	$1.5\cdot10^{-5}$		

Log-Log plot incl. derivate- flow period



Flow period		Recovery period	
Flow regime:	WBS->PRF	Flow regime:	WBS->PRF
t_1 (min)	200	dt_{e1} (min)	200
t_2 (min)		dt_{e2} (min)	300
T_w (m^2/s)	$7.8\cdot10^{-6}$	T_w (m^2/s)	$9.4\cdot10^{-6}$
S_w (-)		S_w (-)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$2.1\cdot10^{-6}$	C (m^3/Pa)	$2.1\cdot10^{-6}$
C_D (-)		C_D (-)	
ξ (-)	-4.3	ξ (-)	-3.8
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.			
Flow regime:	WBS->PRF	C (m^3/Pa)	$2.1\cdot10^{-6}$
t_1 (min)	200	C_D (-)	
t_2 (min)	300	ξ (-)	-3.8
T_T (m^2/s)	$9.4\cdot10^{-6}$		
S* (-)	$2.2\cdot10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments:

Initially, both the drawdown and recovery periods are influenced by wellbore storage. A period of approximate pseudo-radial flow regime may be interpreted between c. 200 – 300 min during the recovery period.

The results from the recovery period are chosen as the most representative.

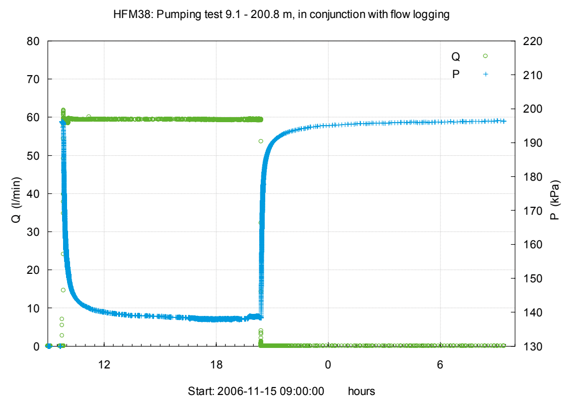
The somewhat disturbed appearance at the end of the flow period is caused by lowering and lifting the flow logging equipment, resulting in water level changes in the borehole. Q_{corr} used in the evaluation is the corrected flow rate for these occurrences.

Table 6-16. Test Summary Sheet for the pumping test in HFM38, section 9.1–200.8 m.

Test Summary Sheet

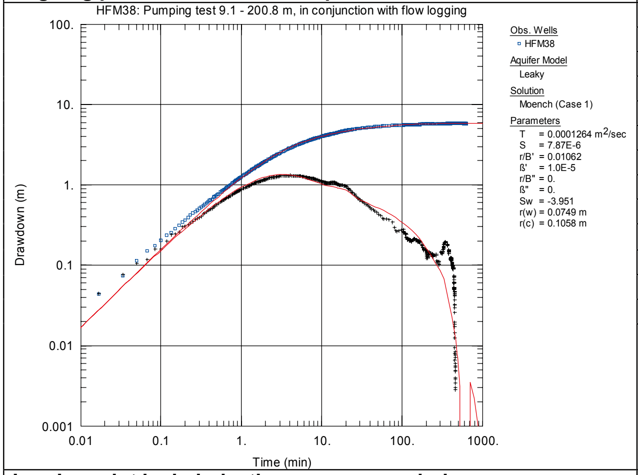
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM38	Test start:	2006-11-15 09:50:07
Test section (m):	9.1-200.8	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2 \cdot r_w$ (m):	top 0.1410 bottom 0.1360	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

Linear plot Q and p

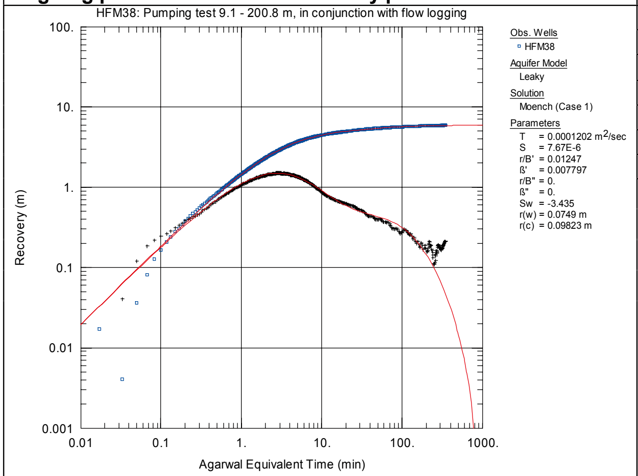


Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	195.6		
p_p(kPa)	138.5	p_F (kPa)	196.3
Q_p (m^3/s)	$9.89 \cdot 10^{-4}$		
tp (min)	634	t_F (min)	780
S*	$7.9 \cdot 10^{-6}$	S*	$7.7 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.2
Results		**Results**	
Q/s (m^2/s)	$1.7 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$2.3 \cdot 10^{-4}$		
Flow regime:	WBS->PSF	Flow regime:	WBS->PSF
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)	$1.3 \cdot 10^{-4}$	T_w (m^2/s)	$1.2 \cdot 10^{-4}$
S_w (-)		S_w (-)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$3.6 \cdot 10^{-6}$	C (m^3/Pa)	$3.1 \cdot 10^{-6}$
C_D (-)		C_D (-)	
ξ (-)	-4.0	ξ (-)	-3.4
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:	WBS->PSF	C (m^3/Pa)	$3.6 \cdot 10^{-6}$
t_1 (min)		C_D (-)	
t_2 (min)		ξ (-)	-4.0
T_T (m^2/s)	$1.3 \cdot 10^{-4}$		
S* (-)	$7.9 \cdot 10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments:

Initially both the drawdown and recovery periods are influenced by wellbore storage. After c. 20 minutes a transition to a pseudo-spherical flow regime can be observed.

The results from the drawdown are chosen as the most representative.

7 References

/1/ **Almén K-E, Andersson J-E, Carlsson L, Hansson K, Larsson N-Å, 1986.** Hydraulic testing in crystalline rock. A comparative study of single-hole test methods. SKB Technical Report 86-27, Svensk Kärnbränslehantering AB.

/2/ **Morosini M, Almén K-E, Follin S, Hansson K, Ludvigson J-E, Rhén I, 2001.** Metoder och utrustningar för hydrauliska enhålstester. Metod och programaspekter för geovetenskapliga platsundersökningar. SKB Tekniskt Dokument TD-01-63, Svensk Kärnbränslehantering AB.

/3/ **Dougherty D E, Babu D K, 1984.** Flow to a partially penetrating well in a double-porosity reservoir, Water Resour. Res., 20 (8), 1116–1122.

/4/ **Moench A F, 1985.** Transient Flow to a Large-Diameter Well in an Aquifer With Storative Semiconfining Layers. Water Resour. Res., 21 (8), 1121–1131.

/5/ **Rhén I (ed), Gustafson G, Stanfors R, Wikberg P, 1997.** Äspö HRL – Geoscientific evaluation 1997/5. Models based on site characterization 1986–1995. SKB TR 97-06, 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 start Date, time YYYY-MM-DD tt:mm:ss	Test stop Date, time YYYY-MM-DD tt:mm:ss	Datafile, start Date, time YYYY-MM-DD tt:mm:ss	Datafile, stop Date, time YYYY-MM-DD tt:mm:ss	Data files of raw and primary data	Content (parameters)[2]	Comments
HFM36	12.1–152.6	1B	2006-11-23 08:08:01	2006-11-24 08:16:20	2006-11-13 15:26:27	2006-11-24 08:16:20	HFM36_12.06_061122_ FlowLo02.DAT	P, Q, T, EC	
HFM36					2006-11-20 13:10:50	2006-11-23 18:21:21	HFM36_12.06_061122_ Ref_Da02.DAT		Reference file
HFM36	22.5–140.0	6, L-EC, L-T	2006-11-23 15:42:07	2006-11-23 17:35:09	2006-11-23 15:42:07	2006-11-23 17:35:09	HFM36_12.06_061122_ Spinne02.DAT	P, Q, T, EC, SP	
HFM36	12.1–152.6	1B	2006-11-22 12:55:09	2006-11-23 08:07:54	2006-11-22 12:52:30	2006-11-23 08:07:54	HFM36_12.06_061123_ Pumpin02.DAT	P, Q	Capacity test
HFM37	9.1–191.8	1B	2006-11-21 08:18:15	2006-11-22 07:11:17	2006-11-20 13:10:50	2006-11-22 07:11:17	HFM37_061120_9.07_ FlowLo02.DAT	P, Q, T, EC	
HFM37					2006-11-20 13:10:50	2006-11-22 07:11:17	HFM37_061120_9.07_ Ref_Da02.DAT		Reference file
HFM37	9.1–191.8	1B	2006-11-20 16:48:45	2006-11-21 08:18:14	2006-11-20 16:45:09	2006-11-21 08:18:14	HFM37_061120_9.07_ Pumpin02.DAT	P, Q	Capacity test
HFM38	9.0–200.8	1B	2006-11-15 08:21:00	2006-11-16 09:24:07	2006-11-13 15:26:27	2006-11-16 09:24:07	HFM38_9.05_061113_ FlowLo06.DAT	P, Q, T, EC	
HFM38					2005-06-30 12:46:00	2006-11-16 09:24:07	HFM38_9.05_061113_ Ref_Da06.DAT		Reference file
HFM38	21.0–193.0	6, L-EC, L-T	2006-11-15 16:40:07	2006-11-15 19:22:09	2006-11-14 16:46:07	2006-11-15 19:22:09	HFM36_9.05_061114_ Spinne06.DAT	P, Q, T, EC, SP	
HFM38	9.1–200.8	1B	2006-11-13 17:12:08	2006-11-14 01:47	2006-11-13 17:04	2006-11-14 01:47	HFM38_9.05_061113_ Pumpin06.DAT	P,Q	Capacity test

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.

Appendix 2

Diagram of test responses

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

K_Z/K_r = ratio of hydraulic conductivities in the vertical and radial direction (set to 1)

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

K_r = hydraulic conductivity, radial direction (m/s)

S_s = specific storage (1/m)

R_f = fracture radius (m)

Dimensionless parameters (Moench, 1985 /4/)

$r/B' = \gamma' = r_w\, (K'/K \cdot b \cdot b')^{1/2}$

$\beta' = \gamma'/4 \cdot (\sigma')^{1/2}$

$\sigma' = (S_s' \cdot b') / (S_s \cdot b)$

K = hydraulic conductivity of aquifer (m/s)

K' = hydraulic conductivity of semiconfining layer (m/s)

S_s = specific storage of aquifer (1/m)

S_s' = specific storage of semiconfining layer (1/m)

b = thickness of aquifer (m)

b' = thickness of semiconfining layer (m)

r_w = borehole radius (m)

Pumping test in HFM36: 12.1–152.6 m

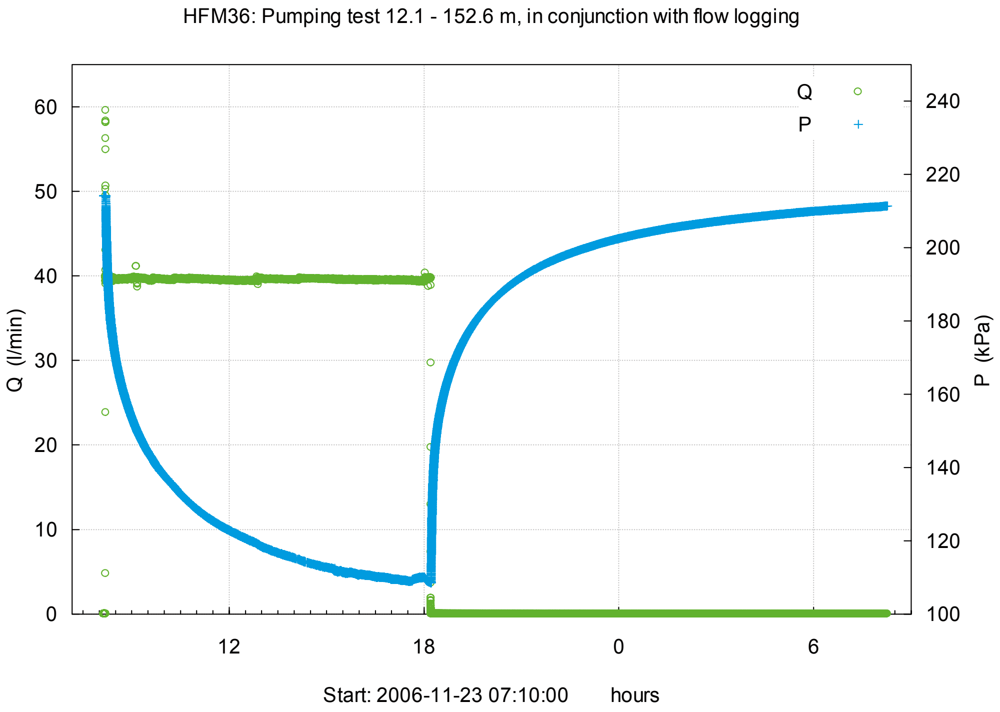


Figure A2-1. Linear plot of flow rate (Q) and pressure (P) versus time during the open-hole pumping test in HFM36 in conjunction with flow logging.

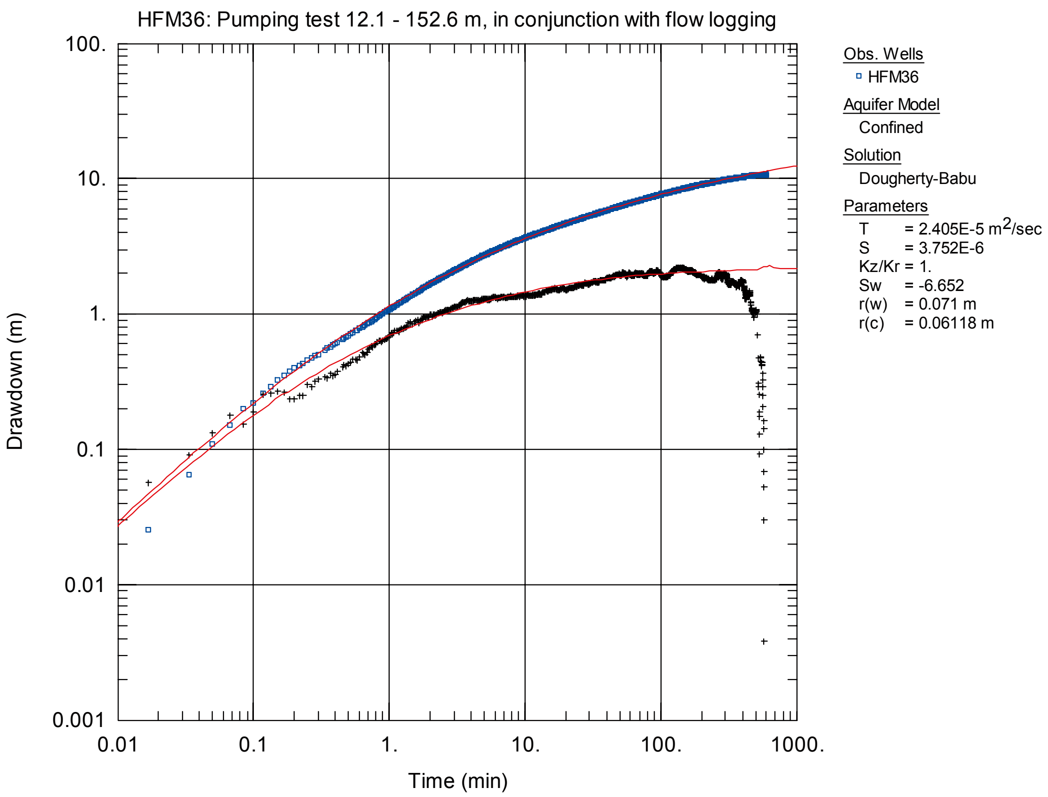


Figure A2-2. Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM36.

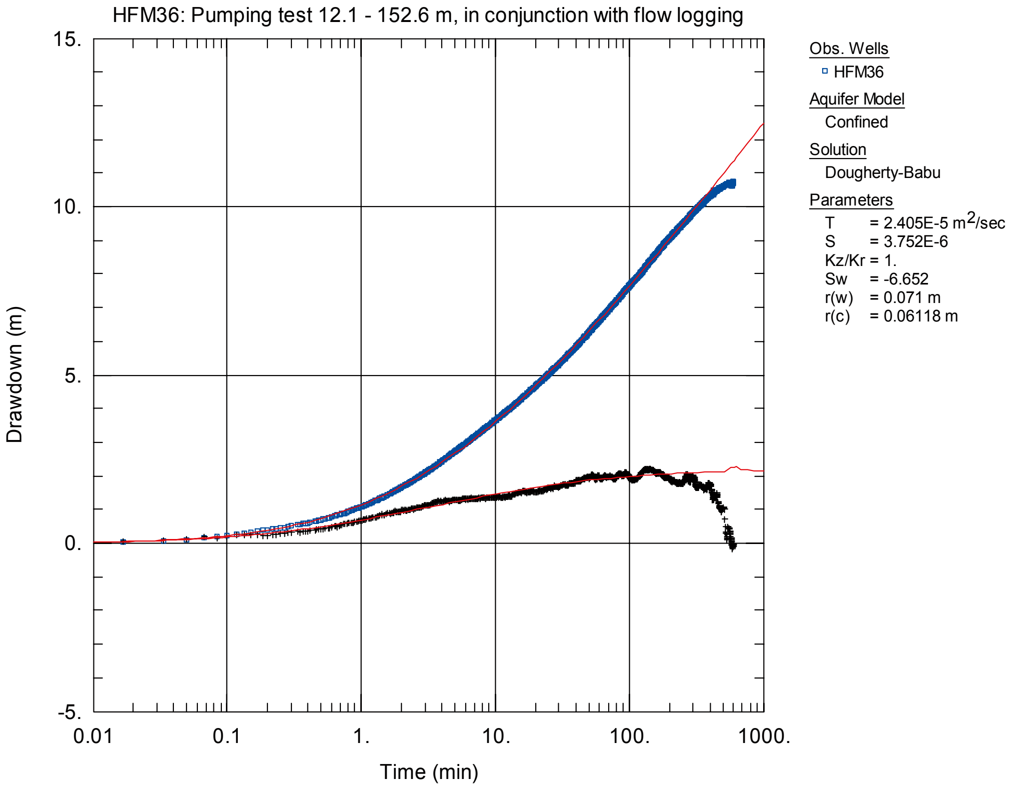


Figure A2-3. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM36.*

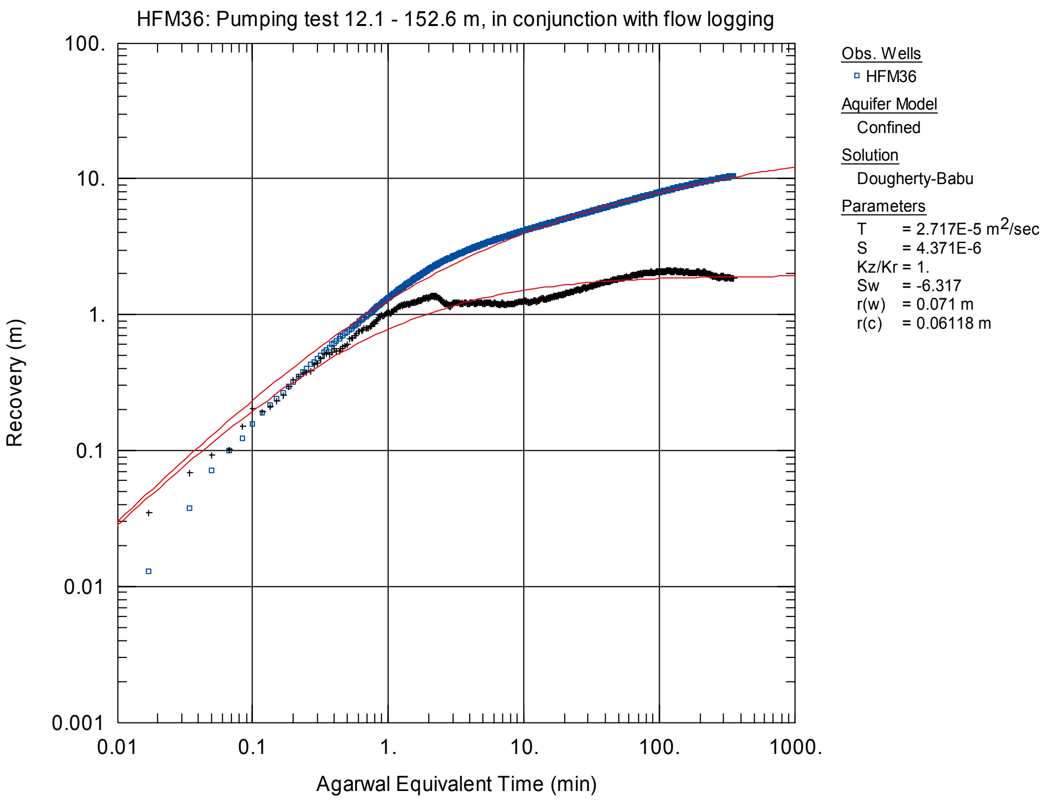


Figure A2-4. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM36.*

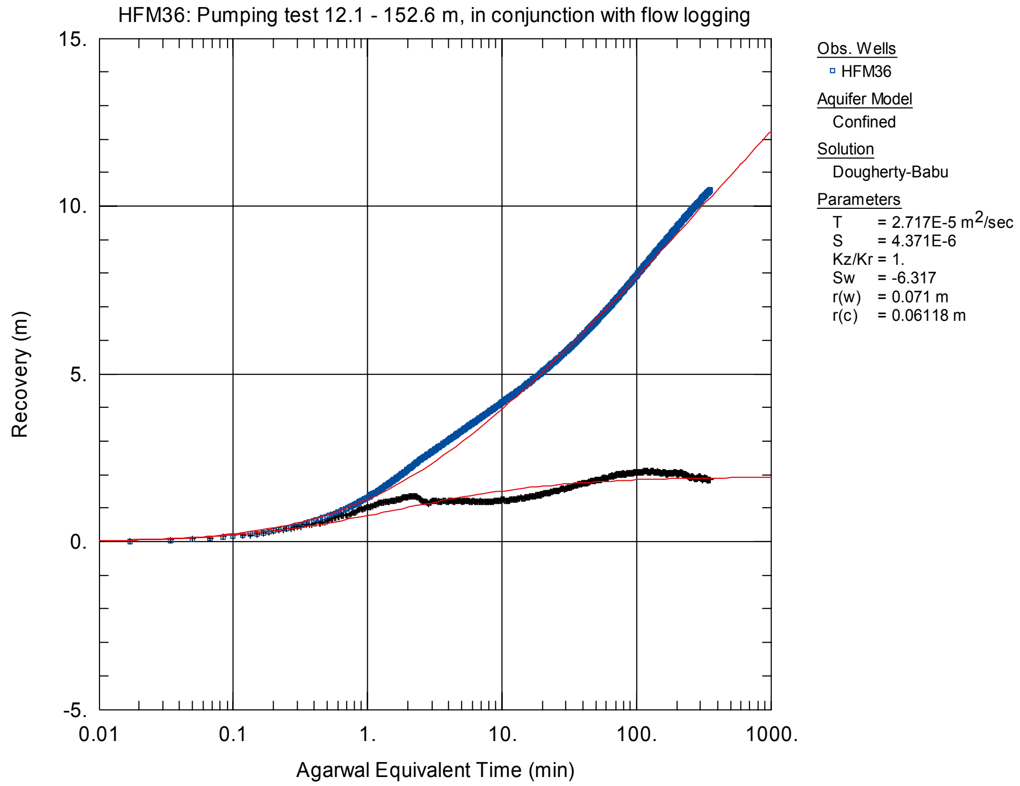


Figure A2-5. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM36.*

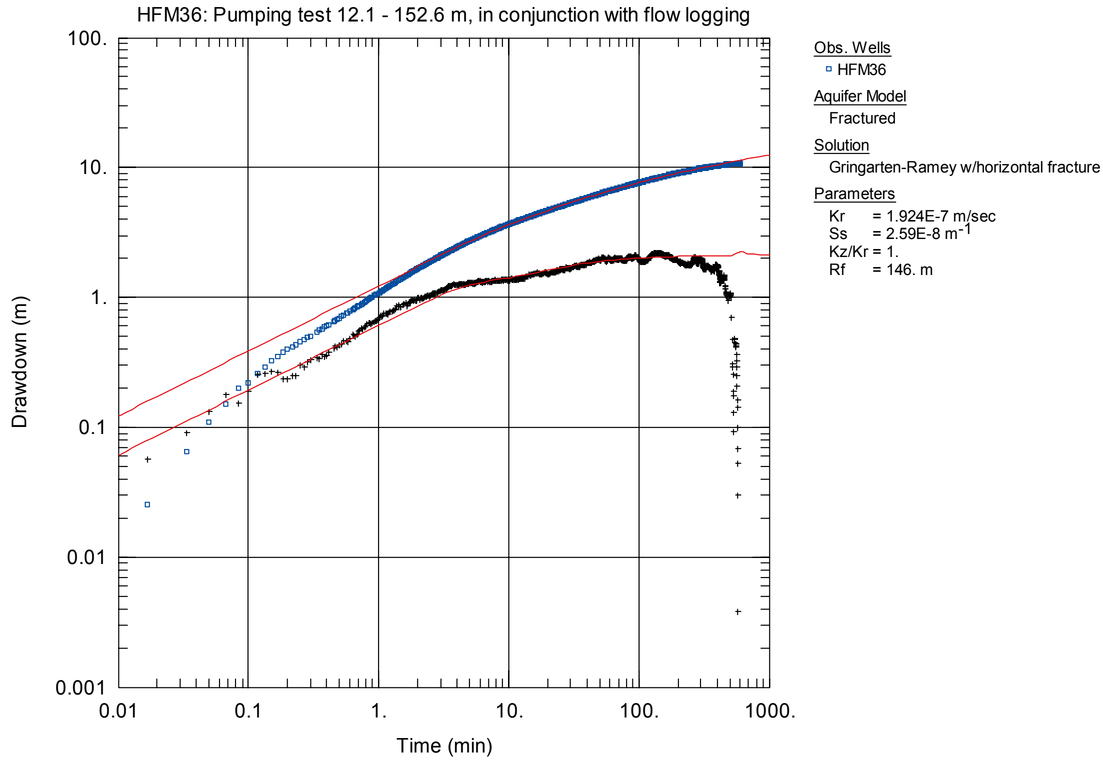


Figure A2-6. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM36. Alternative model for a single horizontal fracture.*

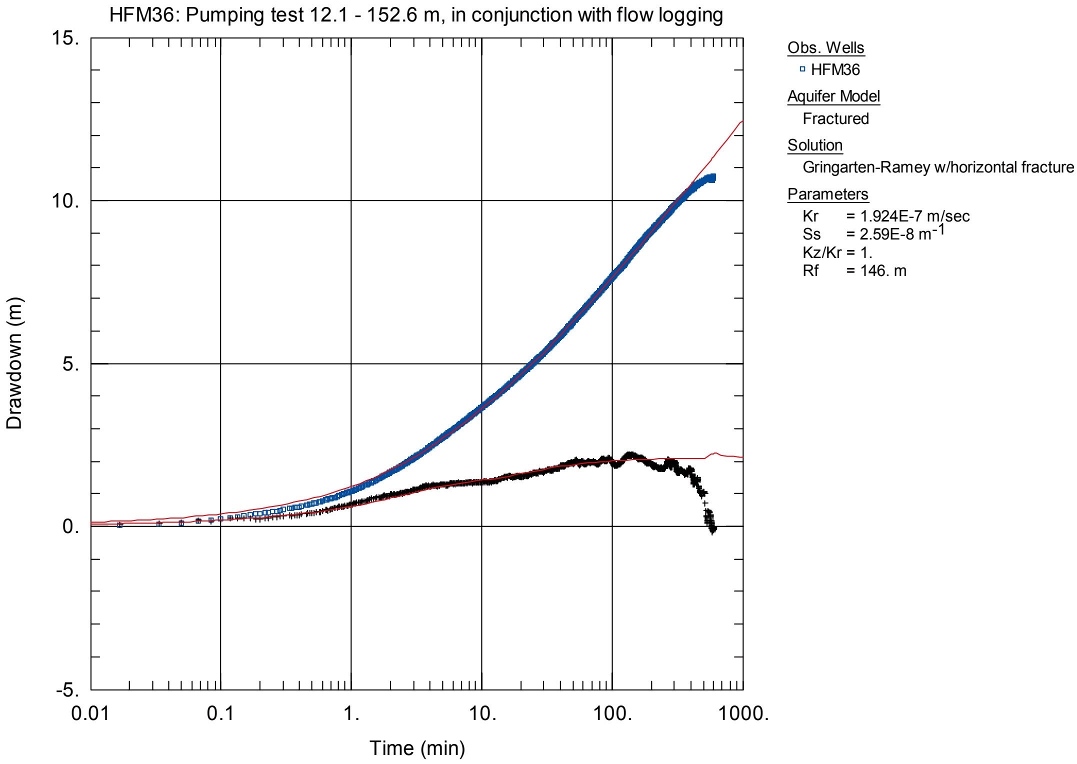


Figure A2-7. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM36. Alternative model for a single horizontal fracture.*

Pumping test in HFM37: 9.1–191.8 m

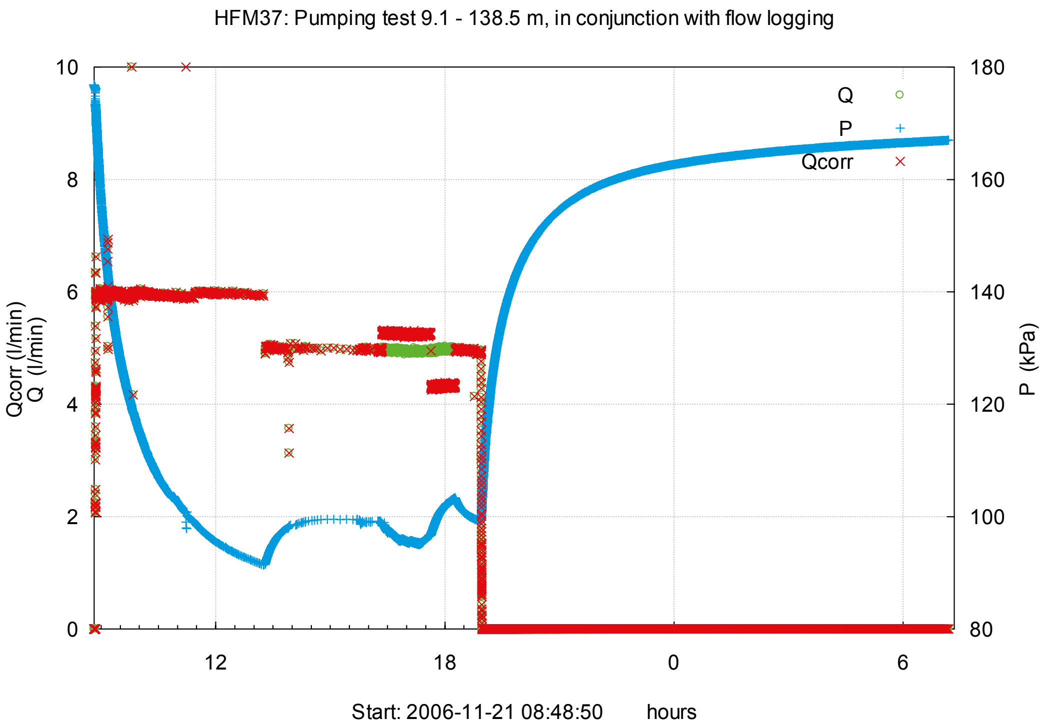


Figure A2-8. *Linear plot of flow rate (Q), corrected flow rate (Qcorr) and pressure (P) versus time during the open-hole pumping test in HFM37 in conjunction with flow logging.*

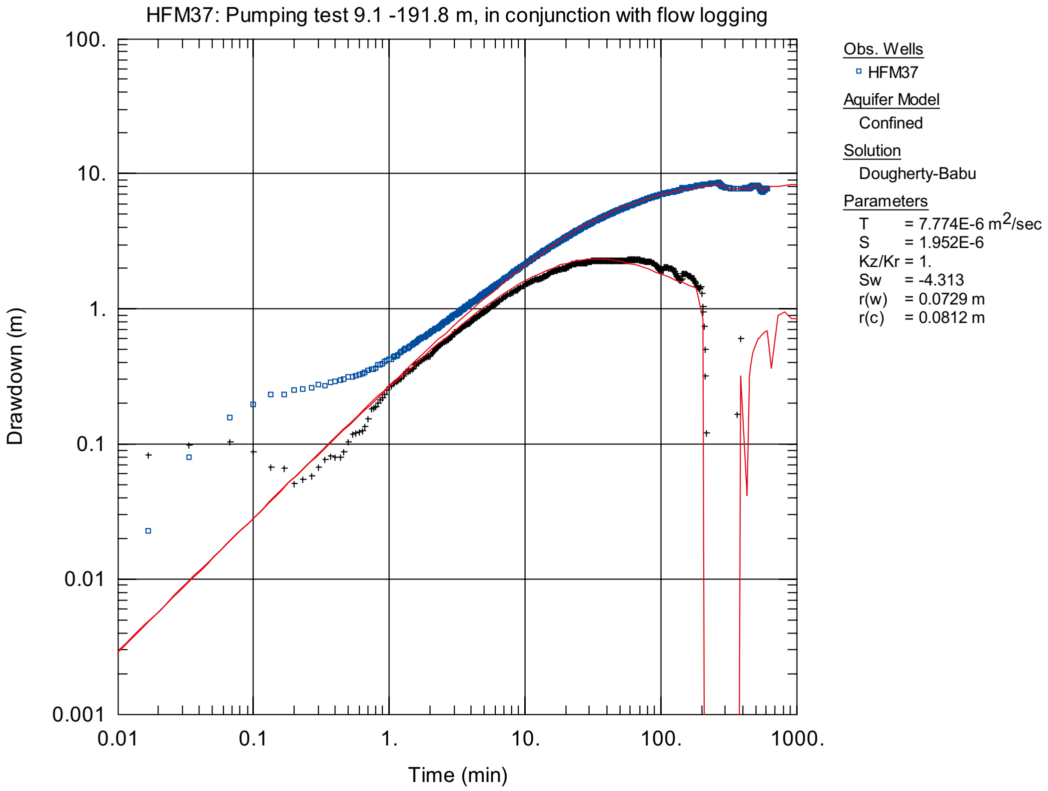


Figure A2-9. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM37.*

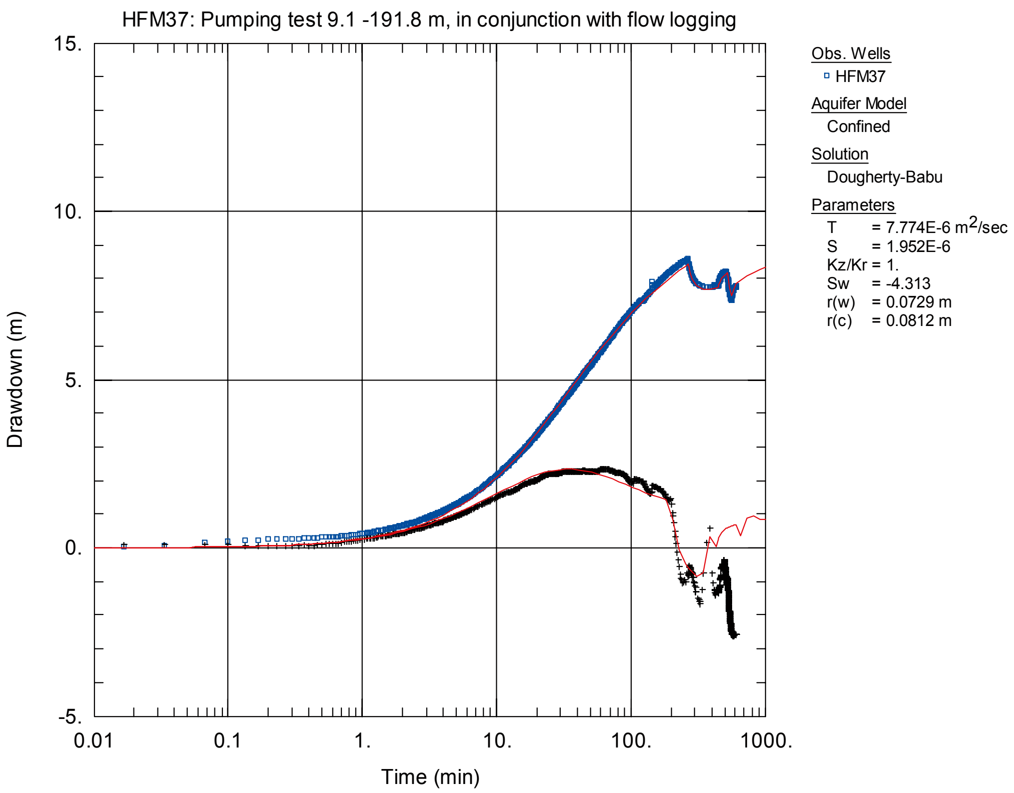


Figure A2-10. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM37.*

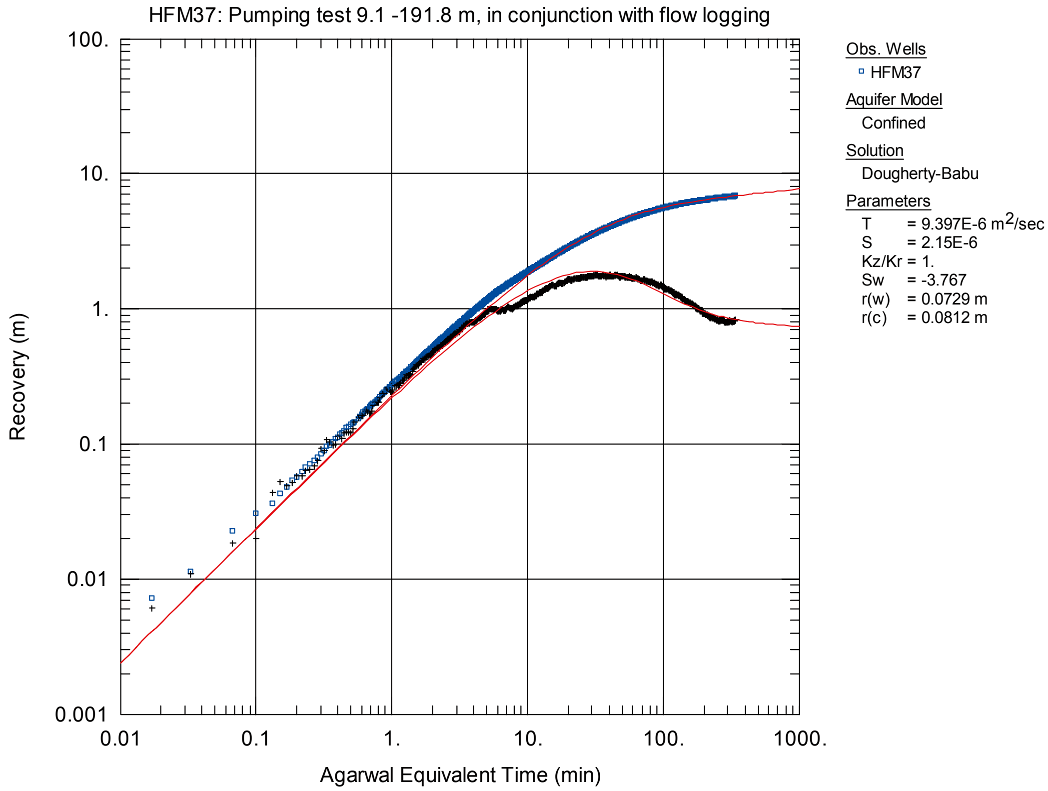


Figure A2-11. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM37.*

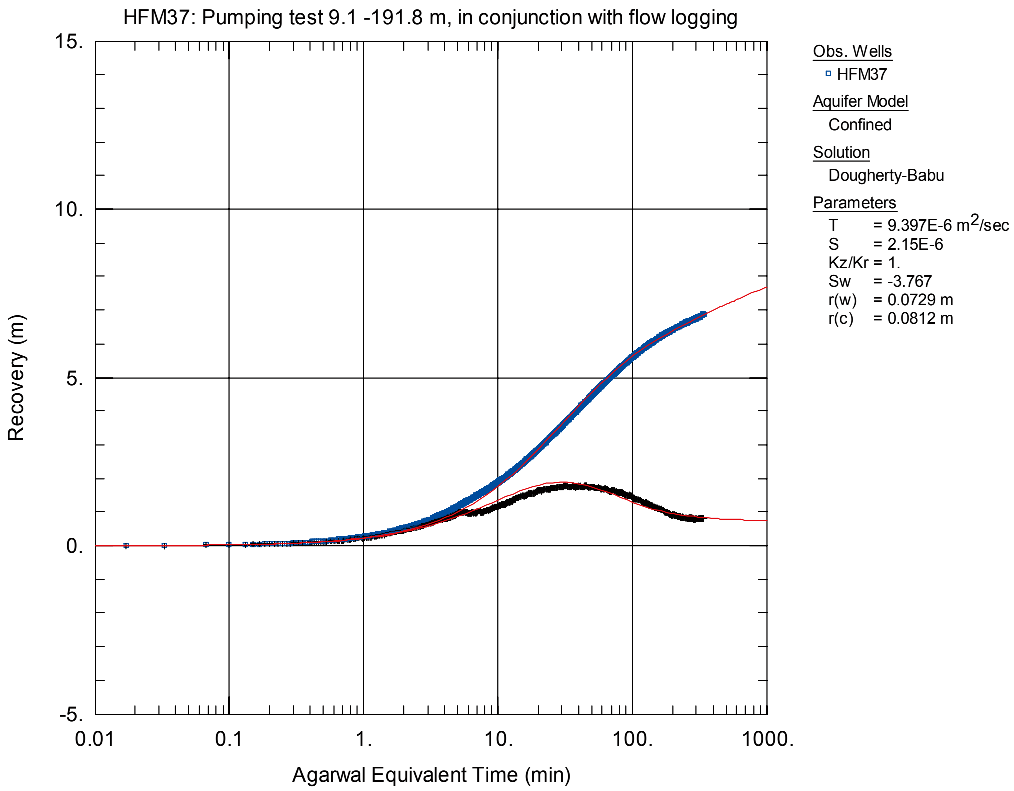


Figure A2-12. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM37.*

Pumping test in HFM38: 9.1–200.8 m

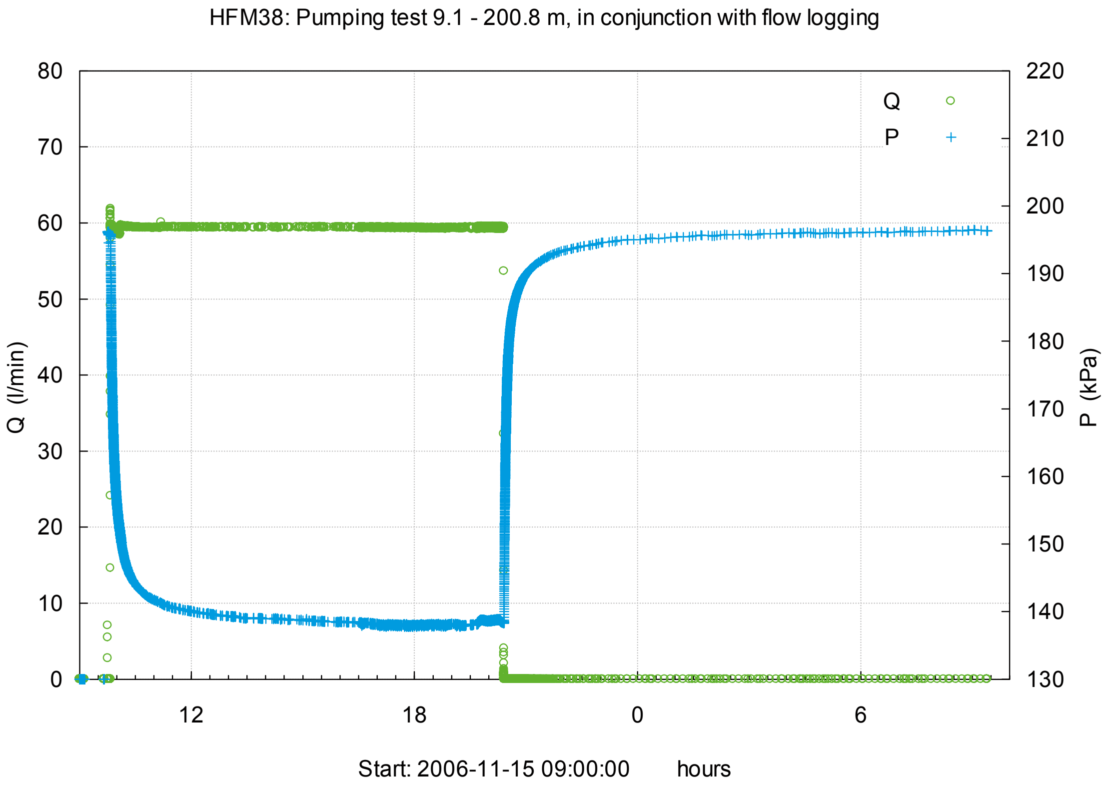


Figure A2-13. Linear plot of flow rate (Q) and pressure (P) versus time during the open-hole pumping test in HFM38.

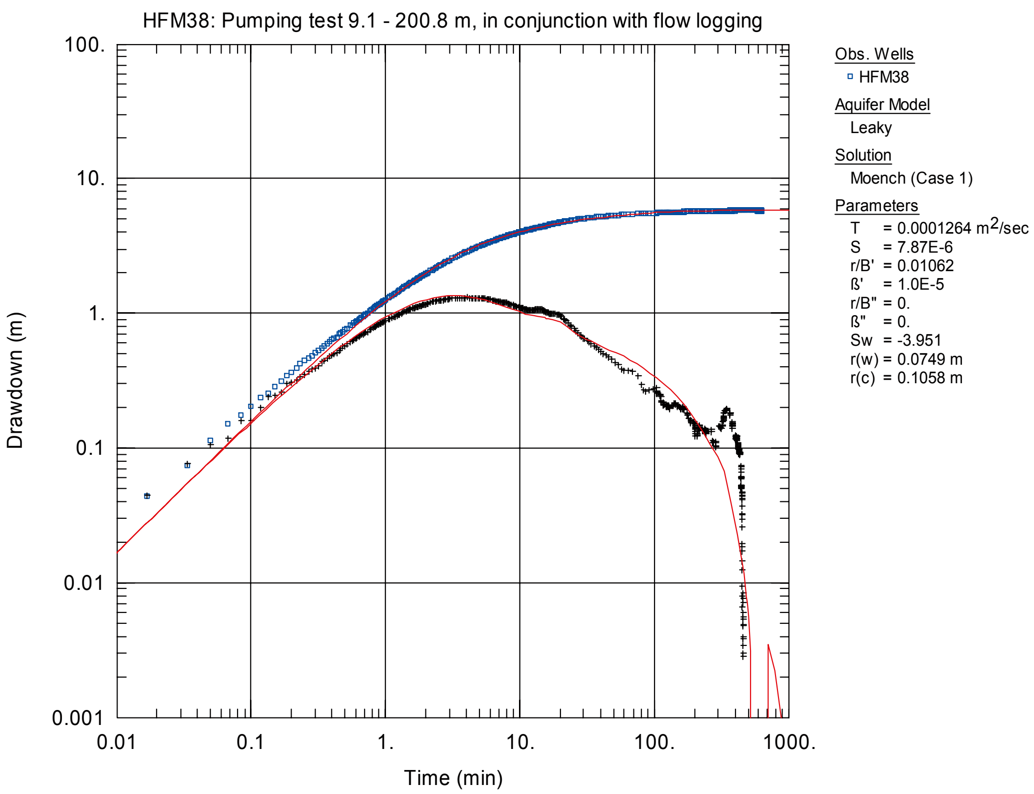


Figure A2-14. Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM38.

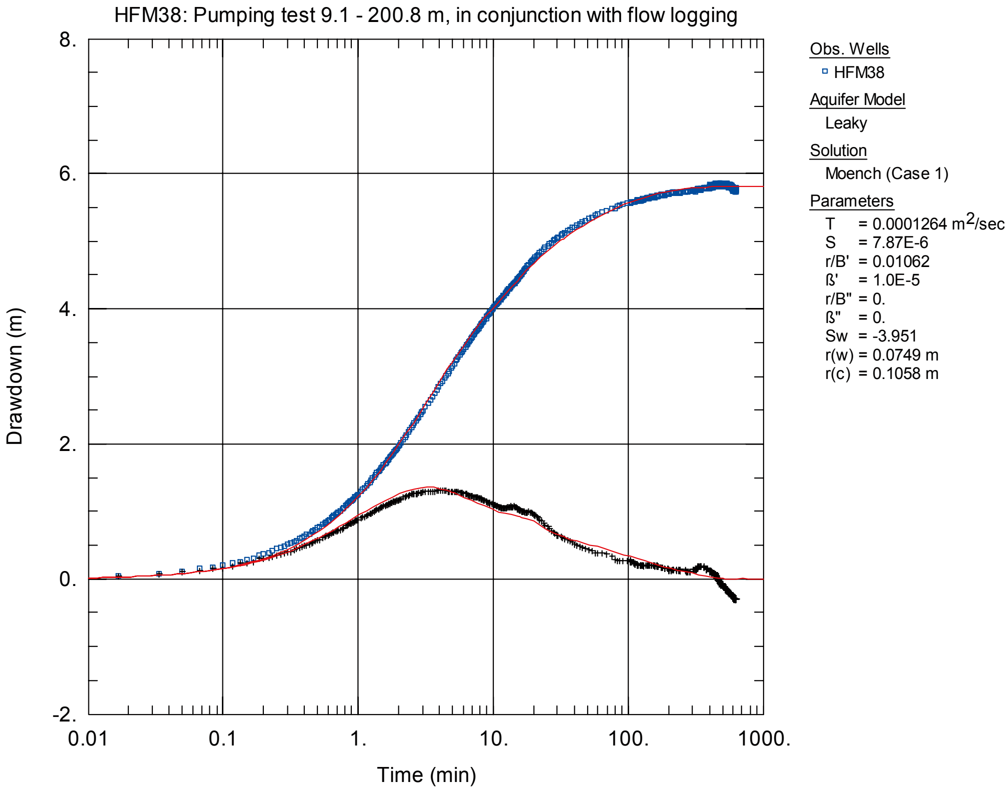


Figure A2-15. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM38.*

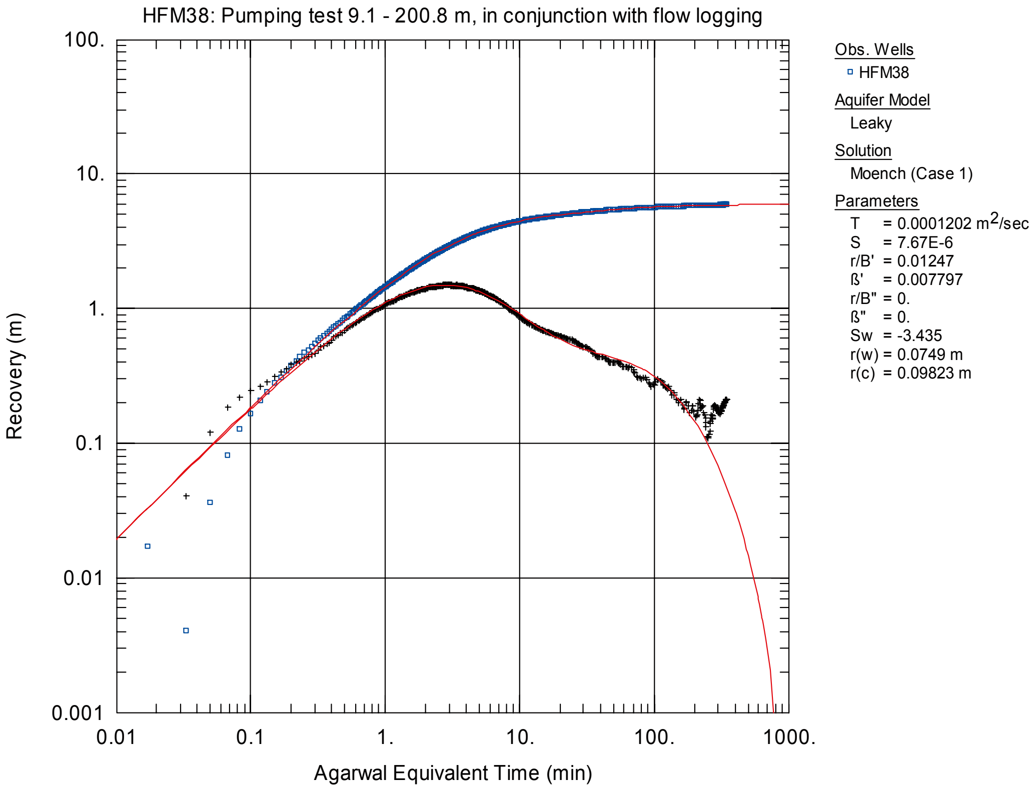


Figure A2-16. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM38.*

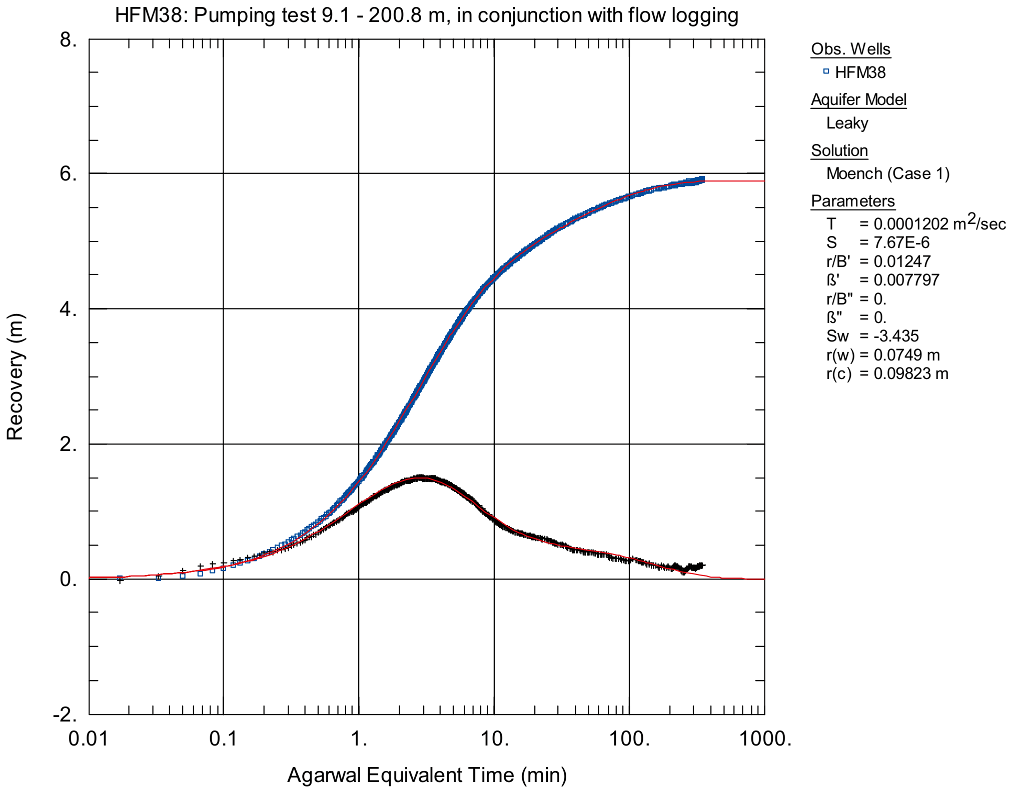


Figure A2-17. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM38.*

Appendix 3

Result tables to the data base Sicada

A. Result Table for Single-hole tests for submission to the Sicada database

SINGLEHOLE TESTS, Pumping and injection, plu_s_hole_test_d; General information.

idcode	start_date	stop_date	secup (m)	seclow (m)	sec-tion_no	test_ type	forma-tion_type	start_flow_period (yyyymmdd)	stop_flow_period (yyyymmdd)	flow_rate_end_ qp (m**3/s)	value_ type_qp
HFM36	061123 08:12:03	061124 08:16:20	12.0	152.6		1B	1	061123 08:12:03	061123 18:13:02	6.61E–04	0
HFM37	061121 08:51:04	061122 07:11:17	9.1	191.8		1B	1	061121 08:51:04	061121 18:57:02	8.25E–05	0
HFM38	061115 09:50:07	061116 09:24:07	9.1	200.8		1B	1	061115 09:50:07	061115 20:24:32	9.89E–04	0

cont.

mean_flow_rate_ qm (m**3/s)	q_measl__l (m**3/s)	q_measl__u (m**3/s)	tot_volume_ vp (m**3)	dur_flow_ phase_tp (s)	dur_rec_ phase_tf (s)	initial_ head_hi (m)	head_at_flow_ end_hp (m)	final_head_ hf (m)	initial_press_ pi (kPa)	press_at_flow_ end_pp (kPa)	final_press_ pf (kPa)
6.58E–04	8.33E–05	1.33E–03	2.37E+01	36,060	50,580	6.36		6.1	214	109	211
9.01E–05	8.33E–05	1.33E–03	3.28E+00	36,360	44,040	9.72		8.7	176	107	167
9.90E–04	8.33E–05	1.33E–03	3.77E+01	38,040	46,800	0.37	–6	0.3	196	139	196

cont.

fluid_temp_ tew (oC)	fluid_elcond_ ecw (mS/m)	fluid_salinity_ tdsw (mg/l)	fluid_salinity_ tdswm (mg/l)	reference	comments	lp (m)
						50
						91
						80

Column	Datatype	Unit	Column description
Site	CHAR		Investigation site name
Activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Project	CHAR		project code
Idcode	CHAR		Object or borehole identification code
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Section_no	INTEGER	number	Section number
test_type	CHAR		Test type code (1–7), see table description
formation_type	CHAR		1: Rock, 2: Soil (superficial deposits)
start_flow_period	DATE	yyyymmdd	Date & time of pumping/injection start (YYYY-MM-DD hh:mm:ss)
stop_flow_period	DATE	yyyymmdd	Date & time of pumping/injection stop (YYYY-MM-DD hh:mm:ss)
flow_rate_end_qp	FLOAT	m**3/s	Flow rate at the end of the flowing period
value_type_qp	CHAR		0:true value, –1 < lower meas.limit 1: > upper meas.limit
mean_flow_rate_qm	FLOAT	m**3/s	Arithmetic mean flow rate during flow period
q_measl__l	FLOAT	m**3/s	Estimated lower measurement limit of flow rate
q_measl__u	FLOAT	m**3/s	Estimated upper measurement limit of flow rate
tot_volume_vp	FLOAT	m**3	Total volume of pumped or injected water
dur_flow_phase_tp	FLOAT	s	Duration of the flowing period of the test
dur_rec_phase_tf	FLOAT	s	Duration of the recovery period of the test
initial_head_hi	FLOAT	m	Hydraulic head in test section at start of the flow period
head_at_flow_end_hp	FLOAT	m	Hydraulic head in test section at stop of the flow period.
final_head_hf	FLOAT	m	Hydraulic head in test section at stop of recovery period.
initial_press_pi	FLOAT	kPa	Groundwater pressure in test section at start of flow period
press_at_flow_end_pp	FLOAT	kPa	Groundwater pressure in test section at stop of flow period.
final_press_pf	FLOAT	kPa	Groundwater pressure at the end of the recovery period.
fluid_temp_tew	FLOAT	oC	Measured section fluid temperature, see table description
fluid_elcond_ecw	FLOAT	mS/m	Measured section fluid el. conductivity,see table descr.
fluid_salinity_tdsw	FLOAT	mg/l	Total salinity of section fluid based on EC,see table descr.
fluid_salinity_tdswm	FLOAT	mg/l	Tot. section fluid salinity based on water sampling,see...
reference	CHAR		SKB report No for reports describing data and evaluation
comments	VARCHAR		Short comment to data
error_flag	CHAR		If error_flag = "*" then an error occured and an error
in_use	CHAR		If in_use = "*" then the activity has been selected as
Sign	CHAR		Activity QA signature
Lp	FLOAT	m	Hydraulic point of application

SINGLEHOLE TESTS, Pumping and injection, plu_s_hole_test_ed1; Basic evaluation.

idcode	start_date	stop_date	secup (m)	seclow (m)	section_ no	test_ type	formation_ type	lp (m)	seclen_ class (m)	spec_capacity_ q_s m**2/s)	value_ type_q_s	transmissiv- ity_tq (m**2/s)	value_ type_tq	bc_ tq	transmissivity_ moye (m**2/s)
HFM36	061123 08:12:03	061124 08:16:20	12.0	152.6		1B	1	50	6.1E–05	0					7.9E–05
HFM37	061121 08:51:04	061122 07:11:17	9.1	191.8		1B	1	91	1.2E–05	0					1.5E–05
HFM38	061115 09:50:07	061116 09:24:07	9.1	200.8		1B	1	80	1.7E–04	0					2.3E–04

cont.

bc_ tm	value_ type_tm	hydr_cond_ moye (m/s)	formation_ width_b (m)	width_of_ channel_b (m)	tb (m**3/s)	l_measl_tb (m**3/s)	u_measl_tb (m**3/s)	sb (m)	assumed_ sb (m)	leakage_ factor_lf (m)	transmissivity_ tt (m**2/s)	value_ type_tt	bc_ tt	l_measl_q_ s (m**2/s)	u_measl_q_ s (m**2/s)
0	0										2.4E–05	0	1	2.E–06	2.E–03
0	0										9.4E–06	0	1	2.E–06	2.E–03
0	0										1.3E–04	0	1	2.E–06	2.E–03

cont.

storativity_ s	assumed_ s	s_bc	ri (m)	ri_ index	leakage_ coeff (1/s)	hydr_cond_ ksf (m/s)	value_ type_ksf	l_measl_ ksf (m/s)	u_measl_ ksf (m/s)	spec_stor- age_ssf (1/m)	assumed_ ssf (1/m)	c (m**3/pa)	cd	skin	dt1 (s)	dt2 (s)	t1 (s)
3.8E–06			505.76	0								1.20E–06		–6.7			2,400
2.2E–06			591.23	0								2.10E–06		–3.8			12,000
7.9E–06			1,186.78	0								3.60E–06		–4.0			

cont.

t2 (s)	dte1 (s)	dte2 (s)	p_horner (kPa)	transmissivity_ t_nlr (m**2/s)	storativity_ s_nlr	value_ type_t_nlr	bc_t_ nlr	c_nlr (m**3/pa)	cd_ nlr	skin_ nlr	transmissivity_ t_grf (m**2/s)	value_ type_t_grf	bc_t_ grf	storativity_ s_grf	flow_ dim_grf	comment (no_unit)
18,000	2,400.00	18,000.00														
	12,000.00	18,000.00														

Column	Datatype	Unit	Column description
Site	CHAR		Investigation site name
Activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Project	CHAR		project code
Idcode	CHAR		Object or borehole identification code
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Section_no	INTEGER	number	Section number
test_type	CHAR		Test type code (1–7), see table description!
formation_type	CHAR		Formation type code. 1: Rock, 2: Soil (superficial deposits)
Lp	FLOAT	m	Hydraulic point of application for test section, see descr.
seclen_class	FLOAT	m	Planned ordinary test interval during test campaign.
spec_capacity_q_s	FLOAT	m**2/s	Specific capacity (Q/s) of test section, see table descript.
value_type_q_s	CHAR		0:true value, –1: Q/s < lower meas.limit, 1:Q/s > upper meas.limit
transmissivity_tq	FLOAT	m**2/s	Tranmissivity based on Q/s, see table description
value_type_tq	CHAR		0:true value, –1: TQ < lower meas.limit, 1:TQ > upper meas.limit.
bc_tq	CHAR		Best choice code. 1 means TQ is best choice of T, else 0
transmissivity_moye	FLOAT	m**2/s	Transmissivity,TM, based on /Moye 1967/
bc_tm	CHAR		Best choice code. 1 means Tmoye is best choice of T, else 0
value_type_tm	CHAR		0:true value, –1: TM < lower meas.limit, 1:TM > upper meas.limit.
hydr_cond_moye	FLOAT	m/s	K_M: Hydraulic conductivity based on /Moye 1967/
formation_width_b	FLOAT	m	b:Aquifer thickness repr. for T(generally b=Lw), see descr.
width_of_channel_b	FLOAT	m	B:Inferred width of formation for evaluated TB
Tb	FLOAT	m**3/s	TB:Flow capacity in 1D formation of T & width B, see descr.
l_measl_tb	FLOAT	m**3/s	Estimated lower meas. limit for evaluated TB,see description
u_measl_tb	FLOAT	m**3/s	Estimated upper meas. limit of evaluated TB,see description
Sb	FLOAT	m	SB:S=storativity,B=width of formation,1D model,see descript.
assumed_sb	FLOAT	m	SB* : Assumed SB,S=storativity,B=width of formation,see...
Leakage_factor_lf	FLOAT	m	Lf:1D model for evaluation of Leakage factor
transmissivity_tt	FLOAT	m**2/s	TT:Transmissivity of formation, 2D radial flow model,see...
value_type_tt	CHAR		0:true value, –1: TT < lower meas.limit, 1: TT > upper meas.limit,
bc_tt	CHAR		Best choice code. 1 means TT is best choice of T, else 0
l_measl_q_s	FLOAT	m**2/s	Estimated lower meas. limit for evaluated TT,see table descr
u_measl_q_s	FLOAT	m**2/s	Estimated upper meas. limit for evaluated TT,see description
storativity_s	FLOAT		S:Storativity of formation based on 2D rad flow,see descr.
assumed_s	FLOAT		Assumed Storativity,2D model evaluation,see table descr.
s_bc	FLOAT		Best choice of S (Storativity), see descr.
Ri	FLOAT	m	Radius of influence
ri_index	CHAR		ri index=index of radius of influence : –1, 0 or 1, see descr.
Leakage_coeff	FLOAT	1/s	K'/b':2D rad flow model evaluation of leakage coeff,see desc
hydr_cond_ksf	FLOAT	m/s	Ksf:3D model evaluation of hydraulic conductivity,see desc.
value_type_ksf	CHAR		0:true value, –1: Ksf < lower meas.limit, 1: Ksf > upper meas.limit,
l_measl_ksf	FLOAT	m/s	Estimated lower meas.limit for evaluated Ksf,see table desc.
u_measl_ksf	FLOAT	m/s	Estimated upper meas.limit for evaluated Ksf,see table descr
spec_storage_ssf	FLOAT	1/m	Ssf:Specific storage,3D model evaluation,see table descr.
assumed_ssf	FLOAT	1/m	Ssf*:Assumed Spec.storage,3D model evaluation,see table des.
C	FLOAT	m**3/pa	C: Wellbore storage coefficient; flow or recovery period
Cd	FLOAT		CD: Dimensionless wellbore storage coefficient

Column	Datatype	Unit	Column description
Skin	FLOAT		Skin factor;best estimate of flow/recovery period,see descr.
dt1	FLOAT	s	Estimated start time of evaluation, see table description
dt2	FLOAT	s	Estimated stop time of evaluation. see table description
t1	FLOAT	s	Start time for evaluated parameter from start flow period
t2	FLOAT	s	Stop time for evaluated parameter from start of flow period
dte1	FLOAT	s	Start time for evaluated parameter from start of recovery
dte2	FLOAT	s	Stop time for evaluated parameter from start of recovery
p_horner	FLOAT	kPa	p*:Horner extrapolated pressure, see table description
transmissivity_t_nlr	FLOAT	m**2/s	T_NLR Transmissivity based on None Linear Regression...
storativity_s_nlr	FLOAT		S_NLR=storativity based on None Linear Regression,see..
value_type_t_nlr	CHAR		0:true value, –1: T_NLR < lower meas.limit, 1: > upper meas.limit
bc_t_nlr	CHAR		Best choice code. 1 means T_NLR is best choice of T, else 0
c_nlr	FLOAT	m**3/pa	Wellbore storage coefficient, based on NLR, see descr.
cd_nlr	FLOAT		Dimensionless wellbore storage constant, see table descrip.
skin_nlr	FLOAT		Skin factor based on Non Linear Regression,see desc.
transmissivity_t_grf	FLOAT	m**2/s	T_GRF:Transmissivity based on Genelized Radial Flow,see...
value_type_t_grf	CHAR		0:true value, –1: T_GRF < lower meas.limit, 1: > upper meas.limit
bc_t_grf	CHAR		Best choice code. 1 means T_GRF is best choice of T, else 0
storativity_s_grf	FLOAT		S_GRF:Storativity based on Generalized Radial Flow, see des.
flow_dim_grf	FLOAT		Inferred flow dimesion based on Generalized Rad. Flow model
comment	VARCHAR	no_unit	Short comment to the evaluated parameters
error_flag	CHAR		If error_flag = “*” then an error occured and an error
in_use	CHAR		If in_use = “*” then the activity has been selected as
Sign	CHAR		Activity QA signature

B. Result Table for Flow logging at the Forsmark site investigation for submission to the Sicada database

Plu_impeller_basic_d.

idcode	start_date	stop_date	secup (m)	seclow (m)	section_ no	start_flowlogging (yyyymmdd)	stop_flowlogging (yyyymmdd)	l (m)	test_ type	formation_ type	q_measl_l (m**3/s)	q_measl_u (m**3/s)
HFM36	061123 08:12:03	061124 08:16:20	22.5	140.0		2006-11-23 15:42:07	2006-11-23 17:35:09	152.6	6	1	5.0000E–05	1.3333E–03
HFM37	061121 08:51:04	061122 07:11:17	15.5	186.1		2006-11-21 16:17:00	2006-11-21 17:35:00	191.8	6	1	5.0000E–05	1.3333E–03
HFM38	061115 09:50:07	061116 09:24:07	21.0	194.5		2006-11-15 16:40:08	2006-11-15 19:22:09	200.8	6	1	5.0000E–05	1.3333E–03

cont.

pump_flow_ q1 (m**3/s)	pump_flow_ q2 (m**3/s)	dur_flow_ phase_tp1 (s)	dur_flow_ phase_tp2 (s)	dur_flow- log_tfl_1 (s)	dur_flow- log_tfl_2 (s)	drawdown_ s1 (m)	drawdown_ s2 (m)	initial_head_ ho (m.a.s.l.)	hydraulic_head_ h1 (m.a.s.l.)	hydraulic_head_ h2 (m.a.s.l.)	reference	comments
6.61E–04		36,060		6,782		10.73		6.36	–4.37			
8.25E–05		36,360		4,680		6.97		9.72	2.75			
9.89E–04		38,040		9,721		5.93		0.37	–5.56			

Column	Datatype	Unit	Column description
Site	CHAR		Investigation site name
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Sign	CHAR		Activity QA signature
start_flowlogging	DATE	yyyymmdd	Date and time of flowlogging start (YYYY-MM-DD hh:mm:ss)
stop_flowlogging	DATE	yyyymmdd	Date and time of flowlogging stop (YYYY-MM-DD hh:mm:ss)
L	FLOAT	m	Corrected borehole length during logging, see table descr.
test_type	CHAR		Type of test,(1– 7); see table description
formation_type	CHAR		1: Rock, 2: Soil (supeficial deposits)
q_measl_l	FLOAT	m**3/s	Estimated lower measurement limit of borehole flow,see des.
q_measl_u	FLOAT	m**3/s	Estimated upper measurement limit of borehole flow,see desc.
pump_flow_q1	FLOAT	m**3/s	Flow rate at surface during flow logging period 1
pump_flow_q2	FLOAT	m**3/s	Flow rate at surface during flow logging period 2
dur_flow_phase_tp1	FLOAT	s	Duration of flow period 1
dur_flow_phase_tp2	FLOAT	s	Duration of flow period 2
dur_flowlog_tfl_1	FLOAT	s	Duration of the flowlogging survey 1
dur_flowlog_tfl_2	FLOAT	s	Duration of the flowlogging survey 2
drawdown_s1	FLOAT	m	Representative drawdown in borehole during flowlog period 1
drawdown_s2	FLOAT	m	Representative drawdown in borehole during flowlog period 2
initial_head_ho	FLOAT	m.a.s.l.	Initial hydraulic head (open borehole),see table description
hydraulic_head_h1	FLOAT	m.a.s.l.	Represen. hydr.head during flow period 1,see table descr.
hydraulic_head_h2	FLOAT	m.a.s.l.	Represen. hydr.head during flow period 2,see table descr.
reference	CHAR		SKB report number for reports describing data & evaluation
comments	VARCHAR		Short comment to the evaluated parameters (optional))

Plu_impell_main_res.

idcode	start_date	stop_date	secup (m)	seclow (m)	section_ no	l (m)	cum_flow_ q0 (m**3/s)	cum_flow_ q1 (m**3/s)	cum_flow_ q2 (m**3/s)	cum_flow_ q1t (m**3/s)	cum_flow_ q2t (m**3/s)	corr_cum_flow_ q1c (m**3/s)	corr_cum_flow_ q2c (m**3/s)	corr_cum_flow_ q1tc (m**3/s)
HFM36	061123 08:12:03	061124 08:16:20	22.5	140.0		152.6								
HFM37	061121 08:51:04	061122 07:11:17	15.5	186.1		191.8								
HFM38	061115 09:50:07	061116 09:24:07	21.0	194.5		200.8								

cont.

corr_cum_flow_ q2tc (m**3/s)	corr_com_flow_ q1tcr (m**3/s)	corr_com_flow_ q2tcr (m**3/s)	transmissitivy_ hole_t (m**2/s)	value_ type_t	bc_t	cum_transmis- sivity_tf (m**2)	value_ type_tf	bc_ tf	l_measl_tf (m**2/s)	cum_transmis- sivity_tft (m**2)	value_ type_tft	bc_ tft	u_measl_ tf (m**2/s)	reference	comments
	6.6E–04		2.4E–05	0	1				1.67E–06	2.4E–05	0	1			
			9.4E–06	0	1				1.67E–06						
	9.9E–04		1.3E–04	0	1				1.67E–06	1.3E–04	0	1			

Column	Datatype	Unit	Column description
Site	CHAR		Investigation site name
Activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Project	CHAR		project code
Idcode	CHAR		Object or borehole identification code
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Section_no	INTEGER	number	Section number
L	FLOAT	m	Corrected borehole length
cum_flow_q0	FLOAT	m**3/s	Undisturbed cumulative flow rate, see table description
cum_flow_q1	FLOAT	m**3/s	Cumulative flow rate at pumping flow Q1/head h1,see descr.
cum_flow_q2	FLOAT	m**3/s	Cumulative flow rate at pumping flow Q2/head h2, see descr.
cum_flow_q1t	FLOAT	m**3/s	Cumulative flow at the top of measured interval,pump flow Q1
cum_flow_q2t	FLOAT	m**3/s	Cumulative flow at the top of measured interval,pump flow Q2
corr_cum_flow_q1c	FLOAT	m**3/s	Corrected cumulative flow q1 at pump flow Q1,see tabledescr.
corr_cum_flow_q2c	FLOAT	m**3/s	Corrected cumulative flow q2 at pump flow Q2,see tabledescr.
corr_cum_flow_q1tc	FLOAT	m**3/s	Corrected cumulative flow q1T at pump flow Q1,see...
corr_cum_flow_q2tc	FLOAT	m**3/s	Corrected cumulative flow q2T at pump flow Q2,see...
corr_com_flow_q1tcr	FLOAT	m**3/s	Corrected q1Tc for estimated borehole radius (rwa)
corr_com_flow_q2tcr	FLOAT	m**3/s	Corrected q2Tc for estimated borehole radius (rwa)
transmissitivy_hole_t	FLOAT	m**2/s	T: Transmissivity of the entire hole, see table description
value_type_t	CHAR		0:true value, –1: T < lower meas.limit, 1: T > upper meas.limit
bc_t	CHAR		Best choice code: 1 means T is best transm. choice, else 0
cum_transmissivity_tf	FLOAT	m**2	T_F: Cumulative transmissivity, see table description
value_type_tf	CHAR		0:true value, –1: TF < lower meas.limit, 1: TF > upper meas.limit
bc_tf	CHAR		Best choice code: 1 means TF is best transm. choice, else 0
l_measl_tf	FLOAT	m**2/s	Lower measurement limit of T_F,see table description
cum_transmissivity_tft	FLOAT	m**2	T_FT: Cumulative transmissivity, see table description
value_type_tft	CHAR		0:true value, –1: TFT < lower meas.limit, 1: TFT > upper meas.limit
bc_tft	CHAR		Best choice code: 1 means TFT is best transm. choice,else 0
u_measl_tf	FLOAT	m**2/s	Upper measurement limit of T_F, see table description
reference	CHAR		SKB number for reports describing data and results
comments	CHAR		Short comment to evaluated data (optional)
error_flag	CHAR		If error_flag = “*” then an error occured and an error
in_use	CHAR		If in_use = “*” then the activity has been selected as
Sign	CHAR		Activity QA signature

Plu_impeller_anomaly.

idcode	start_date	stop_date	secup (m)	seclow (m)	section_ no	l_a_upper (m)	l_a_lower (m)	fluid_temp_ tea (oC)	fluid_elcond_ eca (mS/m)	fluid_salinity_ tdsa (mg/l)	dq1 (m**3/s)	dq2 (m**3/s)	r_wa (m)
HFM36	061123 08:12:03	061124 08:16:20	22.5	140.0		27.0	27.5						0.069
HFM36	061123 08:12:03	061124 08:16:20	22.5	140.0		32.0	32.5						0.069
HFM36	061123 08:12:03	061124 08:16:20	22.5	140.0		40.0	41.0						0.069
HFM36	061123 08:12:03	061124 08:16:20	22.5	140.0		50.5	51.0						0.069
HFM36	061123 08:12:03	061124 08:16:20	22.5	140.0		88.0	88.5						0.069
HFM38	061115 09:50:07	061116 09:24:07	21.0	194.5		28.5	29.7						0.071
HFM38	061115 09:50:07	061116 09:24:07	21.0	194.5		187.3	188.5						0.071

cont.

dq1_corrected (m**3/s)	dq2_corrected (m**3/s)	spec_cap_dq1c_ s1 (m**2/s)	spec_cap_dq2c_ s2 (m**2/s)	value_type_ dq1_s1	value_type_ dq2_s2	ba (m)	transmissivity_ tfa (m**2/s)	value_ type_tfa	bc_tfa	l_measl_tfa (m**2/s)	u_measl_tfa (m**2/s)	comments
1.3E–04		1.2E–05		0		0.5	4.7E–06	0	1	1.67E–06	8.30E–05	
1.3E–04		1.2E–05		0		0.5	4.7E–06	0	1	1.67E–06	8.30E–05	
5.2E–05		4.8E–06		0		1.0	1.9E–06	0	1	1.67E–06	8.30E–05	
2.8E–04		2.6E–05		0		0.5	1.0E–05	0	1	1.67E–06	8.30E–05	
6.8E–05		6.3E–06		0		0.5	2.5E–06	0	1	1.67E–06	8.30E–05	
6.2E–04		1.1E–04		0		1.2	8.2E–05	0	1	1.67E–06	8.30E–05	
3.7E–04		6.3E–05		0		1.2	4.8E–05	0	1	1.67E–06	8.30E–05	

Column	Datatype	Unit	Column description
site	CHAR		Investigation site name
activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
project	CHAR		project code
idcode	CHAR		Object or borehole identification code
secup	FLOAT	m	Upper section limit (m)
seclow	FLOAT	m	Lower section limit (m)
section_no	INTEGER	number	Section number
l_a_upper	FLOAT	m	Borehole length to upper limit of inferred flow anomaly
l_a_lower	FLOAT	m	Borehole length to lower limit of inferred flow anomaly
fluid_temp_tea	FLOAT	oC	Measured borehole fluid temperature at inferred anomaly.
fluid_elcond_eca	FLOAT	mS/m	Measured fluid el conductivity of borehole fluid at anomaly
fluid_salinity_tdsa	FLOAT	mg/l	Calculated total dissolved solids of fluid at anomaly, see.
dq1	FLOAT	m**3/s	Flow rate of inferred flow anomaly at pump flow Q1or head h1
dq2	FLOAT	m**3/s	Flow rate of inferred flow anomaly at pump flowQ2 or head h2
r_wa	FLOAT	m	Estimated borehole radius
dq1_corrected	FLOAT	m**3/s	Corrected flow rate of anomaly at pump flow Q1 or see descr.
dq2_corrected	FLOAT	m**3/s	Corrected flow rate of anomaly at pump flow Q2, or see descr
spec_cap_dq1c_s1	FLOAT	m**2/s	dq1/s1.Spec. capacity of anomaly at pump flow Q1 or.. ,see
spec_cap_dq2c_s2	FLOAT	m**2/s	dq2/s2.Spec. capacity of anomaly at pump flow Q2 or.,see des
value_type_dq1_s1	CHAR		0:true value, –1: < lower meas.limit, 1: > upper meas.limit.
value_type_dq2_s2	CHAR		0:true value, –1: < lower meas.limit, 1: > upper meas.limit.
ba	FLOAT	m	Representative thickness of anomaly for TFa,see description
transmissivity_tfa	FLOAT	m**2/s	Transmissivity of inferred flow anomaly.
value_type_tfa	CHAR		0:true value, –1: TFa < lower meas.limit, 1: TFa > upper meas. limit.
bc_tfa	CHAR		Best choice code.1 means TFa is best choice of T, else 0
l_measl_tfa	FLOAT	m**2/s	Lower measurement limit of TFa, see table description
u_measl_tfa	FLOAT	m**2/s	Upper measurement limit of TFa, see table description
comments	CHAR		Short comment on evaluated parameters
error_flag	CHAR		If error_flag = "*" then an error occured and an error
in_use	CHAR		If in_use = "*" then the activity has been selected as
sign	CHAR		Activity QA signature