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Forsmark site investigation

Pumping tests and flow logging boreholes HFM23, HFM27 and HFM28

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September 2006

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Abstract

The main objectives of the hydraulic tests in the percussion boreholes HFM23, HFM27 and HFM28 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.

Boreholes HFM23 and HFM28 were drilled to provide flushing water to the core drilling at drill site 9. None of the boreholes, though, had enough flow capacity for this purpose. HFM27 was drilled towards a deformation zone, possibly associated with a lineament designated ZFMNE0061. The intention was to intersect the zone at a borehole length of 100–120 m.

In each borehole a short capacity test was performed to decide whether it was meaningful to make a subsequent pumping test in combination with flow logging or only a pumping test and to decide a suitable pumping flow rate for the pumping test.

In boreholes HFM23 and HFM28 the pumping capacity showed to be rather low, at the limit for flow logging with the HTHB equipment, and therefore no flow logging was performed in HFM28. Flow logging in HFM23 did not result in any measurable flow in the logged interval (31–80 m). In HFM27 the flow logging resulted in four detected flow anomalies.

Water sampling was performed to investigate the hydrochemistry of the groundwater in all boreholes in conjunction with the pumping tests.

The total borehole transmissivity of HFM23 was estimated at $4.3 \cdot 10^{-6}$ m^2/s. During the logging of electric conductivity and temperature two possible flow anomalies could be seen as sudden changes in the electric conductivity.

The total borehole transmissivity of HFM27 was estimated at $8.3 \cdot 10^{-5}$ m^2/s. Four hydraulically conductive parts were found during the flow logging.

In HFM28 the total transmissivity was estimated at $9.0 \cdot 10^{-6}$ m^2/s.

Sammanfattning

Det övergripande syftet med de hydrauliska testerna i hammarborrhålen HFM23, HFM27 och HFM28 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.

Borrhålen HFM23 och HFM28 borrades för att förse kärnborrningen vid borrplats 9 med spolvatten. Inget av borrhålen hade dock tillräcklig kapacitet för detta syfte. HFM27 borrades mot en deformationszon som eventuellt är kopplad till lineamentet ZFMNE0061. Avsikten var att korsa zonen vid 100–120 m borrhålslängd.

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.

I HFM23 och HFM28 visades sig kapaciteten vara ganska låg, på gränsen till vad som krävs för flödesloggning med HTHB-utrustningen, och därför gjordes ingen flödesloggning i HFM28. Flödesloggningen i HFM23 resulterade inte i något mätbart flöde i det loggade intervallet (31–80 m). I HFM27 resulterade flödesloggningen i fyra detekterade flödesanomalier.

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

Den totala transmissiviteten för HFM23 uppskattades till $4{,}3 \cdot 10^{-6}$ m^2/s. Under loggningen av vattnets elektriska konduktivitet och temperatur kunde man se två möjliga flödesanomalier som plötsliga förändringar i den elektriska konduktiviteten.

I HFM27 uppskattades den totala transmissiviteten till $8{,}3 \cdot 10^{-5}$ m^2/s. Fyra hydrauliskt konduktiva partier hittades under flödesloggningen.

I borrhålet HFM28 uppskattades den totala transmissiviteten till $9{,}0 \cdot 10^{-6}$ m^2/s.

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1 Introduction

This document reports the results of the hydraulic testing of boreholes HFM23, HFM27 and HFM28 within the Forsmark site investigation. The tests were carried out as pumping tests, in HFM23 and HFM27 combined with flow logging. Water sampling was undertaken in the boreholes in conjunction with the tests. No other hydraulic tests had been carried out in the actual boreholes before this campaign.

Borehole HFM23 and HFM28 is situated close to drill site DS9 and HFM27 c. 150 m from drill site DS1 close to the road leading to the drill site, see Figure 1-1.

All time notations in this report are made according to Swedish Summer Time (SSUT), UTC +2 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.

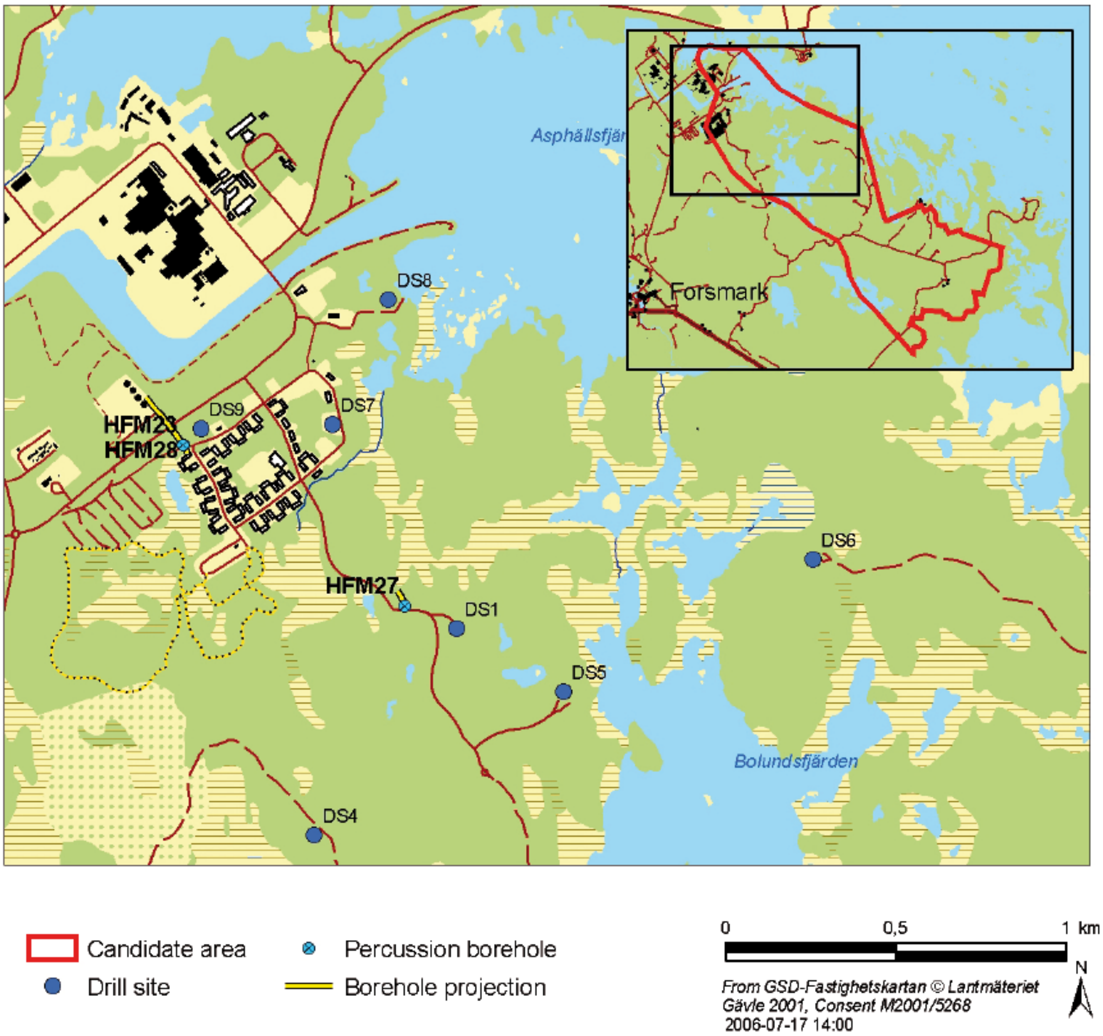


Figure 1-1. *Map showing the location of boreholes HFM23, HFM27 and HFM28.*

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

Activity plan	Number	Version
Hydrotester och vattenprovtagning i hammarborrhålen HFM23, HFM24, HFM25, HFM26, HFM27, HFM28 och HFM32	AP PF 400-05-121	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 objectives of the pumping tests and flow logging in boreholes HFM23, HFM27 and HFM28 were to investigate the hydraulic properties of the penetrated rock volumes, for example by identifying the position and hydraulic character of major inflows (which may represent e.g. sub-horizontal fracture zones). Furthermore, the aim was also to investigate the hydrochemical properties of the groundwater.

Prior to the pumping tests hydraulic fracturing was performed in both boreholes, Claesson and Nilsson (2006) /1/. In HFM28, hydraulic fracturing was performed at three levels, c. 30 m, c. 50 m and c. 75 m. The packer was inflated to c. 360 bars overpressure, whereupon water was pressed into the borehole section between the packer and the borehole bottom (150.50 m). With the packer at the 30 m level a pressure decrease was observed, but in the other sections no significant pressure changes were observed.

In HFM23, hydraulic fracturing was performed at two levels, c. 30 m and c. 38 m. No pressure decrease was observed during water injection, but when water was pressed into the respective sections in HFM23, an overflow in HFM28 was observed.

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								Casing		Drilling finished
ID	Elevation of top of casing (ToC) (m a s l)	Bh length from ToC (m)	Bh diam. (below casing) (m)	Inclin. –top of bh (from horizontal plane) (°)	Dip-Direction –top of bh (°)	Northing (m)	Easting (m)	Length (m)	Inner diam. (m)	Date (YYYY-MM-DD)
HFM23	4.25	211.5	0.1370	–58.48	324.35	6700068	1630595	20.80	0.160	2005-09-01
HFM27	2.45	127.5	0.1405	–67.83	337.26	6699595	1631246	12.03	0.160	2005-11-10
HFM28	4.27	151.2	0.1383	–84.76	146.78	6700069	1630597	12.10	0.160	2005-09-14

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)
HFM23	20.8–211.5	1B	Open hole	2006-03-20 08:56	2006-03-21 08:11
HFM23	31.0–80.0	6, L-EC, L-Te	Open hole	2006-03-20 15:02	2006-03-20 15:57
HFM27	12.0–127.5	1B	Open hole	2006-03-06 10:09	2006-03-07 07:29
HFM27	12.0–125.0	6, L-EC, L-Te	Open hole	2006-03-06 16:25	2006-03-06 19:38
HFM28	12.1–151.2	1B	Open hole	2006-03-15 08:07	2006-03-16 09:25

[1] 1B: Pumping test-submersible pump, 3: Injection test, 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 ($p/\rho g$). 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. The impeller used in the flow logging equipment worked well as indicated by the rotation read on the data logger while lowering. 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).

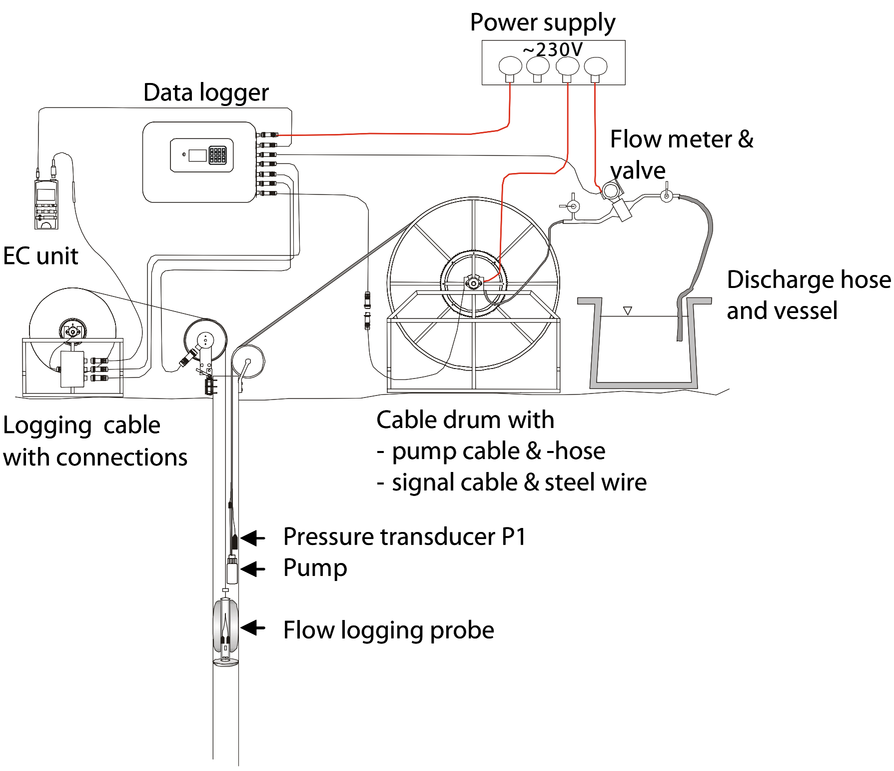


Figure 4-1. *Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB. (From SKB MD 326.001, SKB internal document).*

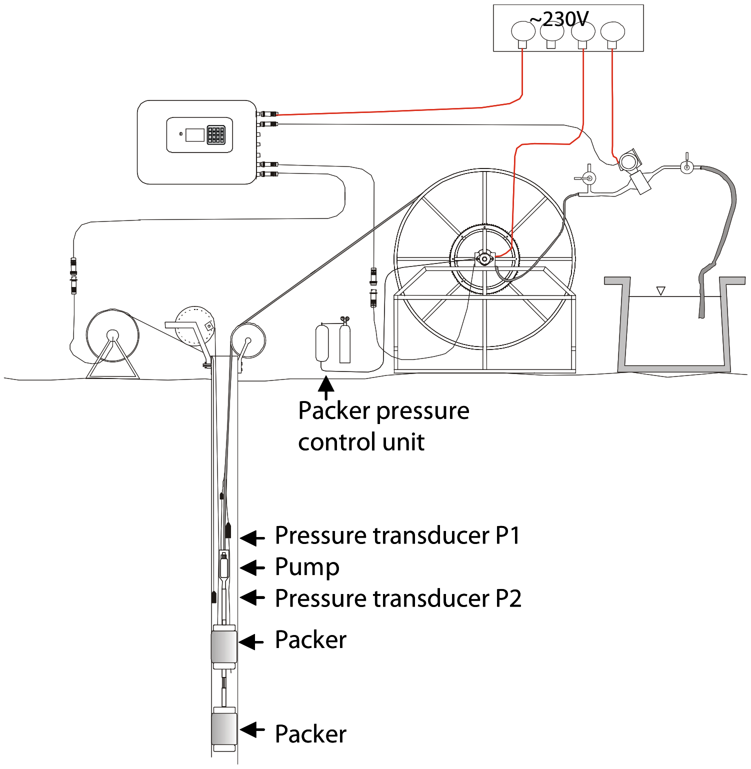


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB. (From SKB MD 326.001, SKB internal document.)*

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.

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.

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.

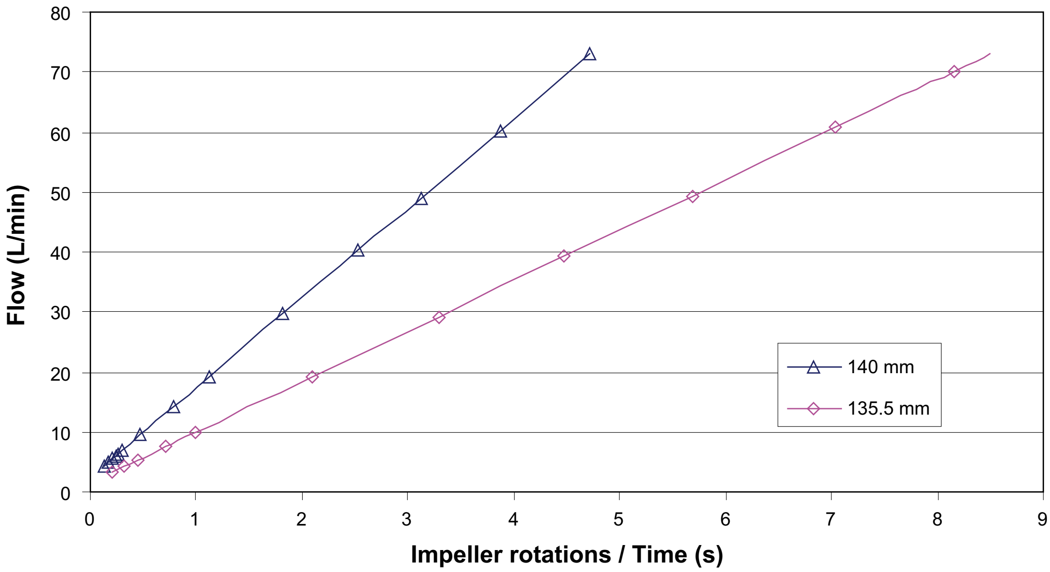


Figure 4-3. *Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).*

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

Technical specification Parameter		Unit	Sensor	HTHB system	Comments
Absolute pressure	Output signal	mA	4–20		
	Meas. range	kPa	0–1,500	0–1,500	
	Resolution	kPa	0.05		
	Accuracy	kPa	±1.5 *	±10	Depending on uncertainties of the sensor position
Temperature	Output signal	mA	4–20		
	Meas. range	°C	0–50	0–50	
	Resolution	°C	0.1		
	Accuracy	°C	± 0.6	±0.6	
Electric conductivity	Output signal	V	0–2		
	Meas. range	mS/m	0–50,000	0–50,000	With conductivity meter
	Resolution	% o.r.**		1	
	Accuracy	% o.r.**		± 10	
Flow (Spinner)	Output signal	Pulses/s	c. 0.1–c. 15		
	Meas. range	L/min		2–100	115 mm borehole diameter
				3–100	140 mm borehole diameter
				4–100	165 mm borehole diameter
	Resolution***	L/min		0.2	140 mm borehole diameter and 100 s sampling time
	Accuracy***	% o.r.**		± 20	
Flow (surface)	Output signal	mA	4–20		Passive
	Meas. range	L/min	1–150	5–c. 80****	Pumping tests
	Resolution	L/min	0.1	0.1	
	Accuracy	% o.r.**	± 0.5	± 0.5	

* Includes hysteresis, linearity and repeatability.

** Maximum error in % of actual reading (% o.r.).

*** Applicable to boreholes with a borehole diameter of 140 mm and 100 s sampling time.

**** By special arrangements it is possible to lower the lower limit to ca 0.5 L/min.

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				**Pump/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] **(m^3/Pa)**
HFM23	20.8–211.5	Open hole	1B	Pump (intake)	27.4	Pump hose	In section	33.5	$2.3·10^{-6}$
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	24.7	Signal cable	In section	8	
			6	EC, Te, Q	31.0–80.0	Signal cable	In section	13.5	
HFM27	12.0–127.5	Open hole	1B	Pump (intake)	8.9	Pump hose	In section	33.5	$2.1·10^{-6}$
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	6.2	Signal cable	In section	8	
			6	EC, Te, Q	12.0–125.0	Signal cable	In section	13.5	
HFM28	12.1–151.2	Open hole	1B	Pump (intake)	34.4	Pump hose	In section	33.5	$1.9·10^{-6}$
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	31.72	Signal cable	In section	8	

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

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

[3] Based on the casing diameter or the actual borehole diameter for open-hole tests together with the compressibility of water for the test in isolated sections, respectively (net values). (In these cases no drawdown below the casing occurred).

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 September 2005. 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 breakage in the signal cable to the electric conductivity sensor during the latest calibration, the calibration constants achieved during the former calibration in April 2004 were used for the repaired 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 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 HFM23 and in HFM27 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. 11 hours. In HFM28 no flow logging was made since the capacity of the borehole was considered to be too low for such a test. The pumping and recovery periods were c. 10 hours and c. 15 hours respectively.

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 hole 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.

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. The operator can choose the parameters to be included in the conversion (normally pressure and discharge). Data from the flow logging are evaluated in Excel and therefore not necessarily transformed to *.mio-files. A list of 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 provide 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 flow 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 /2/ and /3/ 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 which 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) /4/ 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. 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.

$$S = 0.0007 \cdot T^{0.5} \tag{5-1}$$

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 /3/ 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:

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

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 probe, corrections of the measured borehole flow rates may 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:

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

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

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

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:

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

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

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

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

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

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 times:

- The recommended test time (24 h+24 h for drawdown/recovery) for the longer pumping tests during flow logging 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.
- No flow logging was performed in HFM28 due to low yielding capacity.

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 nearby boreholes during the test periods. Reported activities are presented in Table 6-2.

No obvious influence from these activities on the test results can be seen. The activity most close to a tested borehole is the hydraulic injection tests in KFM09B. However, these tests have a short duration and normally a limited spatial influence.

6.3.1 Borehole HFM23: 20.8–211.5 m

General test data for the open-hole pumping test in HFM23 are presented in Table 6-3.

The atmospheric pressure during the test period in HFM23, which is presented in Figure 6-1, varied less than 0.2 kPa, and thus the effect of atmospheric pressure variations on the test results is considered negligible. Since the temperature was below 0°C, no snow melting or rain have affected the groundwater levels.

Table 6-1. Water samples collected during the pumping tests in boreholes HFM23, HFM27 and HFM28 and submitted for analysis.

Bh ID	Date and time of sample	Pumped section (m)	Pumped volume (m^3)	Sample type	Sample ID no	Remarks
HFM23	2006-03-20 10:10	20.8–211.5	0.6	WC080	012054	Open-hole test
HFM23	2006-03-20 14:09	20.8–211.5	3.0	WC080	012053	Open-hole test
HFM23	2006-03-20 19:00	20.8–211.5	5.9	WC080	012050	Open-hole test
HFM27	2006-03-06 11:05	12.0–127.5	2.3	WC080	012061	Open-hole test
HFM27	2006-03-06 15:13	12.0–127.5	14.7	WC080	012060	Open-hole test
HFM27	2006-03-06 20:15	12.0–127.5	29.8	WC080	012057	Open-hole test
HFM28	2006-03-15 09:17	12.1–151.2	0.3	WC080	012052	Open-hole test
HFM28	2006-03-15 13:16	12.1–151.2	1.5	WC080	012037	Open-hole test
HFM28	2006-03-15 17:50	12.1–151.2	3.0	WC080	012051	Open-hole test

Table 6-2. Activities at the PLU site that might have influenced the hydraulic tests in boreholes HFM23, HFM27 and HFM28.

Borehole ID	Test period	Ongoing activities
HFM23	2006-03-06 – 2003-03-07	Drilling at DS8; flushing water from HFM22. Drilling at DS6; flushing water from HFM05. Hydraulic injection tests in KFM09B. Hydraulic injection tests in KFM09B.
HFM27	2006-03-15 – 2003-03-16	Drilling at DS8; flushing water from HFM22.
HFM28	2006-03-20 – 2003-03-21	Drilling at DS8; flushing water from HFM22. Rinse pumping at KFM06C and drilling start at DS10 from 2003-03-21.

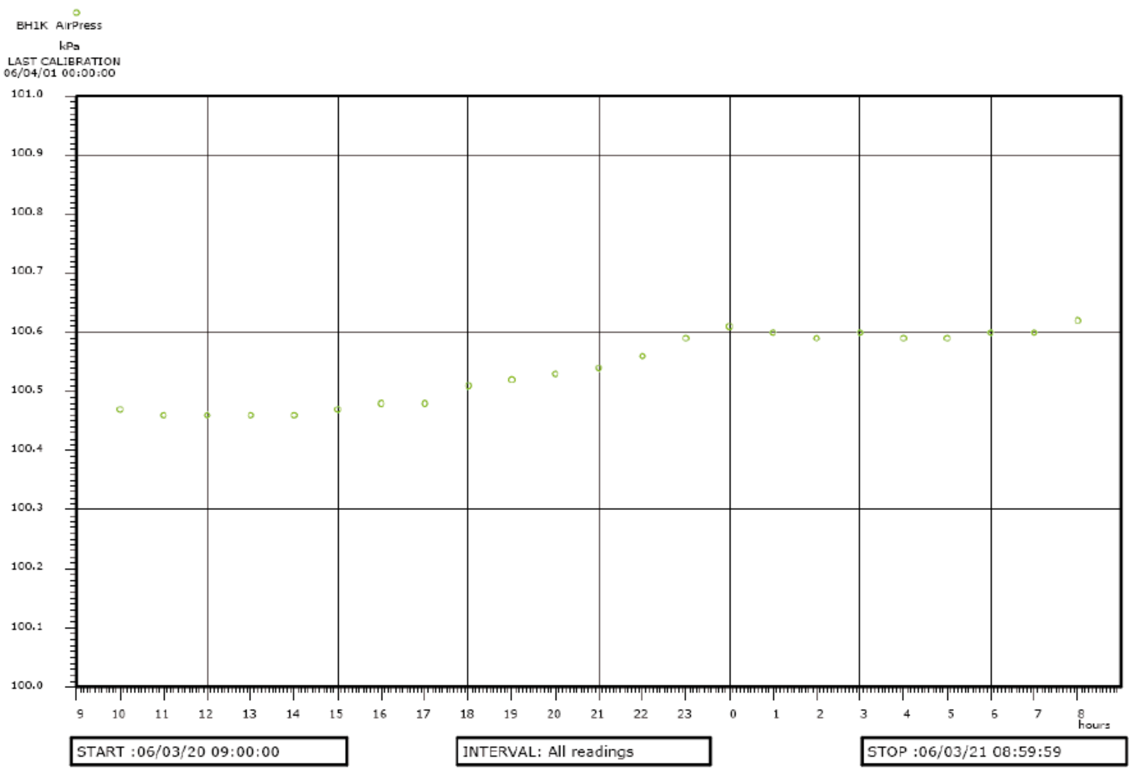


***Figure 6-1.** Atmospheric pressure during the test period in HFM23.*

Table 6-3. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM23.

General test data				
Borehole	HFM23 (20.8–211.5 m)			
Test type	Constant rate withdrawal and recovery test			
Test section (open borehole/packed-off section)	Open borehole			
Test no	1			
Field crew	J. Olausson and P. Fredriksson, GEOSIGMA AB			
Test equipment system	HTHB			
General comment	Single pumping borehole			
	Nomen-clature	**Unit**	**Value**	
Borehole length	L	m	211.5	
Casing length	L_c	m	20.8	
Test section – secup	Secup	m	20.8	
Test section – seclow	Seclow	m	211.5	
Test section length	L_w	m	190.7	
Test section diameter	$2 \cdot r_w$	mm	top 137.0 bottom 135.1	
Test start (start of pressure registration)		yymmdd hh:mm:ss	060320 08:56:13	
Packer expanded		yymmdd hh:mm:ss		
Start of flow period		yymmdd hh:mm:ss	060320 09:13:02	
Stop of flow period		yymmdd hh:mm:ss	060320 19:12:02	
Test stop (stop of pressure registration)		yymmdd hh:mm:ss	060321 08:11:38	
Total flow time	t_p	Min	599	
Total recovery time	t_F	Min	780	

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l)** [1]
Absolute pressure in test section before start of flow period	p_i	kPa	273.6	1.51
Absolute pressure in test section at stop of flow period	p_p	kPa	126.2	
Absolute pressure in test section at stop of recovery period	p_F	kPa	267.3	0.84
Maximal pressure change in test section during the flow period	dp_p	kPa	147.4	

Manual groundwater level measurements **Date YYYY-MM-DD**	**Time tt:mm:ss**	**Time (min)**	**GW level (m b ToC)**	**(m a s l)**
2006-03-16	09:45:00	–5,728	3.51	1.26
2006-03-16	13:36:00	–4,057	3.54	1.23
2006-03-17	14:31:00	–4,002	3.49	1.27
2006-03-17	14:52:00	–3,981	3.30	1.44
2006-03-20	08:53:00	–17	3.22	1.51
2006-03-21	08:08:00	1,375	4.00	0.84

Flow data	**Nomen-clature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.65 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period [2]	Q_m	m^3/s	$1.66 \cdot 10^{-4}$
Total volume discharged during flow period [2]	V_p	m^3	5.97

[1] From the manual measurements of groundwater level. Manual levelling were not possible during pumping.

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

Comments on test

Four days before test start, a short capacity test was performed (c. 96 min). The capacity test was conducted with varying flow rate, during observation of the drawdown response. By the end of the capacity test, the flow rate was c. 20 L/min and the drawdown c. 13.5 m. The actual pumping test was performed as a constant flow rate test (c. 10 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. The drawdown after 96 minutes pumping of the pumping test was c. 9.0 m and at the end of the c. 10 hours pumping period c. 15 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.

Interpreted flow regimes

Selected test diagrams according to the Instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2:1–5 in Appendix 2.

The variations during the first minute of the drawdown depend on a too high flow rate during the first 30 seconds, before the desired rate is reached. The flow rate adjustments are well modelled by the evaluation software.

As a result of the low transmissivity, both the drawdown and the recovery period are dominated by wellbore storage. A transition to pseudo-radial flow (PRF) may be seen after c. 100 minutes during the drawdown. The first part of the recovery response supports the drawdown response but the PRF is not clearly developed and the water level seems to stabilize on a slightly lower level than before start of pumping. This fact may possibly be due to hydraulic boundary effects, for example due to restrictions in the extension of the fracture system.

Interpreted parameters

Transient evaluation of transmissivity was performed for both the flow- and recovery period and the transient, quantitative interpretation is presented in Figures A2:2–5 in Appendix 2. The quantitative analysis was performed according to the methods described in Section 5.4.1. The transmissivity was estimated by a model assuming pseudo-radial flow /4/ on both the flow- and recovery period. The representative transmissivity (i.e. T_T) is considered from the transient evaluation of the drawdown period assuming pseudo-radial flow including wellbore storage and skin. The agreement between the drawdown and the recovery period regarding transmissivity and skin factor is good.

The results are shown in the test summary sheet (Table 6-12) and in Tables 6-9, 6-10 and 6-11.

6.3.2 Borehole HFM27: 12.0–127.5 m

General test data for the open-hole pumping test in HFM27 in conjunction with flow logging are presented in Table 6-4.

The atmospheric pressure during the test period in HFM27, which is presented in Figure 6-2, increased by c. 0.7 kPa, i.e. only c. 2% of the total drawdown of c. 30 kPa in the borehole during the test, and thus the effect of atmospheric pressure variations on the test results is considered negligible. Since the temperature was well below 0°C, no snow melting or rain have affected the groundwater levels.

Table 6-4. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM27, in conjunction with flow logging.

General test data			
Borehole	HFM27 (12.0–127.5 m)		
Test type	Constant rate withdrawal and recovery test		
Test section (open borehole/packed-off section)	Open borehole		
Test no	1		
Field crew	S. Jönsson, Pirkka-Tapio Tammela, GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	mm	127.5
Casing length	L_c	m	12.0
Test section – secup	Secup	m	12.0
Test section – seclow	Seclow	m	127.5
Test section length	L_w	m	115.5
Test section diameter	$2 \cdot r_w$	mm	top 140.5 bottom 138.6
Test start (start of pressure registration)		yymmdd hh:mm:ss	060306 10:09:08
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	060306 10:18:00
Stop of flow period		yymmdd hh:mm:ss	060306 20:25:02
Test stop (stop of pressure registration)		yymmdd hh:mm:ss	060307 07:29:54
Total flow time	t_p	Min	607
Total recovery time	t_F	Min	665

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l) 1)**
Absolute pressure in test section before start of flow period	p_i	kPa	135.3	0.59
Absolute pressure in test section at stop of flow period	p_p	kPa	104.9	
Absolute pressure in test section at stop of recovery period	p_F	kPa	132.1	0.24
Maximal pressure change in test section during the flow period	dp_p	kPa	30.4	

Manual groundwater level measurements **Date YYYY-MM-DD**	**Time tt:mm:ss**	**Time (min)**	**GW level (m b ToC)**	**(m a s l)**
2006-03-02	14:12:00	–5,526	2.46	0.17
2006-03-02	15:29:00	–5,449	2.44	0.19
2006-03-03	09:40:00	–4,358	2.26	0.36
2006-03-03	11:30:00	–4,248	4.52	–1.74
2006-03-06	10:06:00	–12	2.01	0.59
2006-03-06	11:10:00	52	3.58	–0.87
2006-03-06	12:29:00	131	4.29	–1.52
2006-03-06	14:21:00	243	4.77	–1.97
2006-03-06	15:21:00	303	4.93	–2.12
2006-03-06	20:27:00	609	5.05	–2.23
2006-03-07	07:23:00	1,265	2.39	0.24

Flow data	**Nomen-clature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$8.30 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period 2)	Q_m	m^3/s	$8.32 \cdot 10^{-4}$
Total volume discharged during flow period 2)	V_p	m^3	30.29

1) From the manual measurements of groundwater level. Manual levelling were not possible during pumping.

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

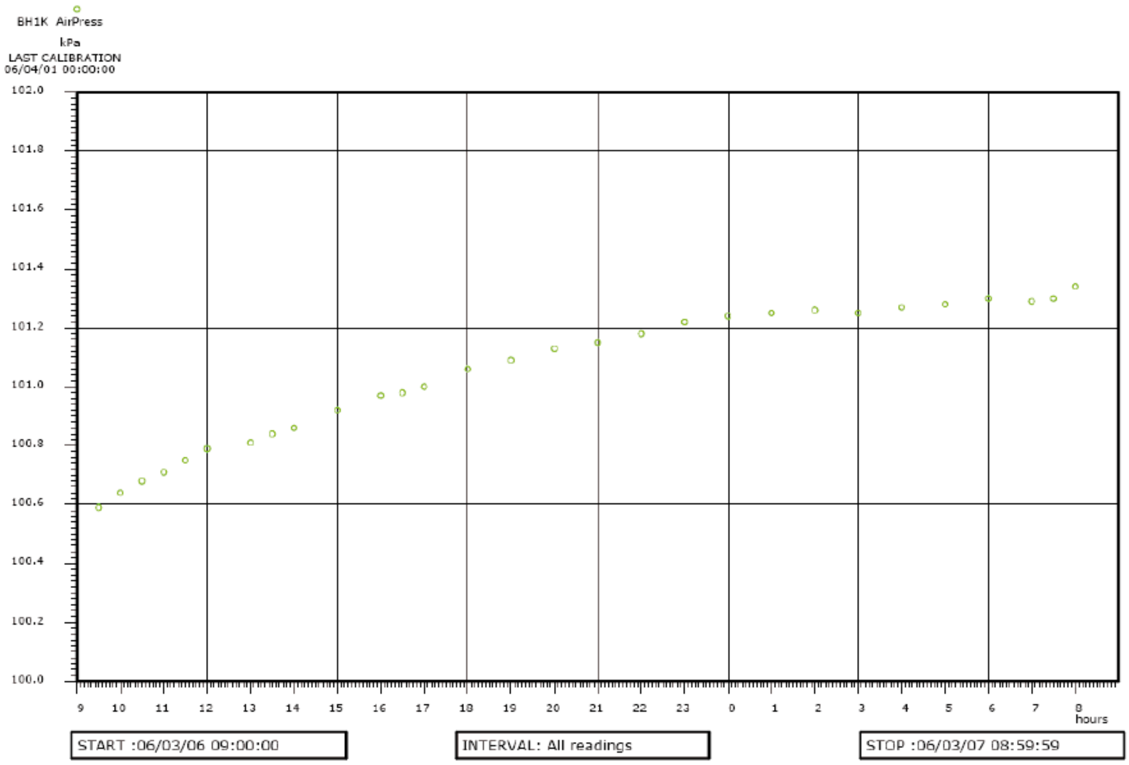


Figure 6-2. *Atmospheric pressure during the test period in HFM27.*

Comments on test

A few days before test start, a short capacity test was performed (c. 100 min). The capacity test was conducted with varying flow rate, 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. 1.9 m. The actual pumping test was performed as a constant flow rate test (50 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. The drawdown after 100 minutes pumping of the pumping test was c. 1.9 m and the drawdown at the end of the pumping test was c. 3.1 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.

Interpreted flow regimes

Transient evaluation of transmissivity was performed for both the flow- and recovery period. Selected test diagrams according to the Instruction for analysis of injection- and single-hole pumping tests are presented in Figures A2:6–10 in Appendix 2.

The early response in both the drawdown and the recovery period indicates a pseudo-linear flow regime, during drawdown followed by a dominating pseudo-radial flow after c. 100 minutes. The first part of the recovery response supports the drawdown response but the PRF is not clearly developed and the water level seems to stabilize on a slightly lower level than before start of pumping. This fact may possibly be due to hydraulic boundary effects, for example due to restrictions in the extension of the fracture system.

Interpreted parameters

A model by Gringarten-Ramey /6/ for a horizontal single fracture, which gives a more accurate fit in the early phase with pseudo-linear flow, is applied. Type curve matching with this model provides values on K, S_s and L_f, where L_f is the theoretical fracture length. The test section length is used to convert K and S_s to T and S respectively. The model does not provide values for wellbore skin.

The results are shown in the test summary sheet (Table 6-13) and in Tables 6-9, 6-10 and 6-11. The analysis from the flow period was selected as representative for the test.

6.3.3 Borehole HFM28: 12.1–151.2 m

General test data for the open-hole pumping test in HFM28 are presented in Table 6-5.

The atmospheric pressure during the test period in HFM28, which is presented in Figure 6-3, varied less than 0.2 kPa, and thus the effect of atmospheric pressure variations on the test results is considered negligible. Since the temperature was below 0°C, no snow melting or rain have affected the groundwater levels.

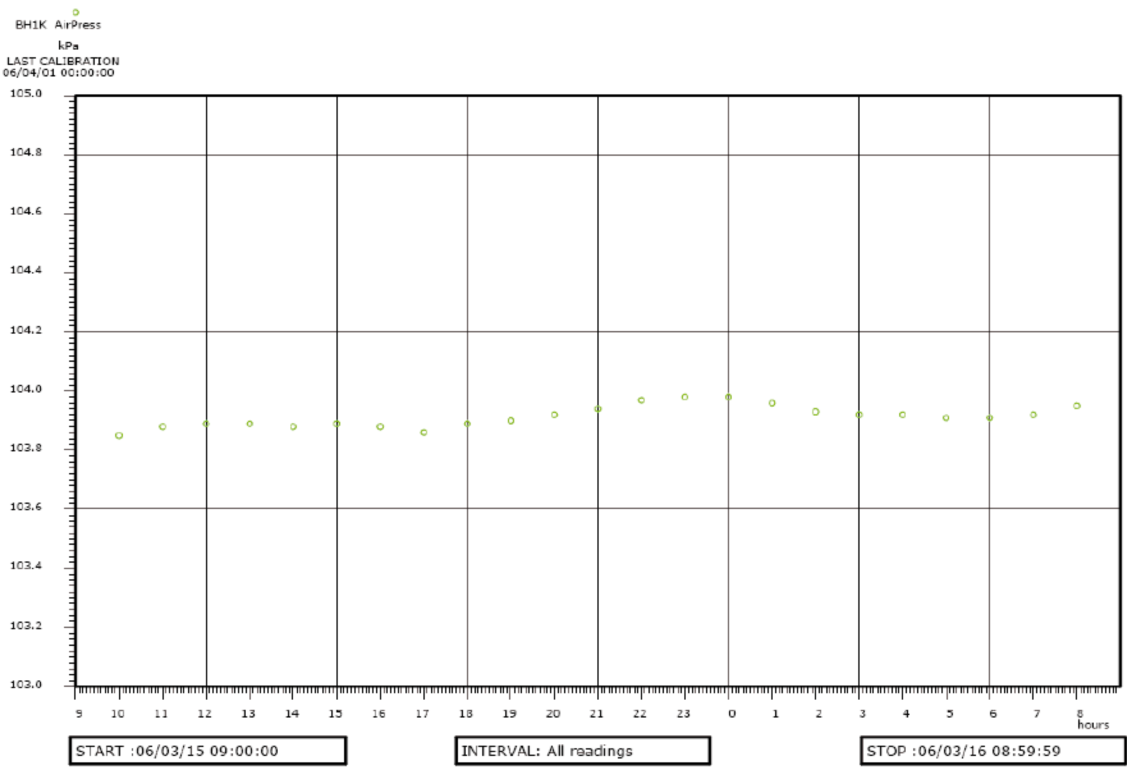


Figure 6-3. *Atmospheric pressure during the test period in HFM28.*

Table 6-5. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM28.

General test data				
Borehole	HFM28 (12.1–151.2 m)			
Test type	Constant rate withdrawal and recovery test			
Test section (open borehole/packed-off section)	Open borehole			
Test no	1			
Field crew	J. Olausson and P. Fredriksson, GEOSIGMA AB			
Test equipment system	HTHB			
General comment	Single pumping borehole			
	Nomen-clature	**Unit**	**Value**	
Borehole length	L	m	151.2	
Casing length	L_c	m	12.1	
Test section – secup	Secup	m	12.1	
Test section – seclow	Seclow	m	151.2	
Test section length	L_w	m	139.1	
Test section diameter	$2 \cdot r_w$	mm	top 138.3 bottom 135.1	
Test start (start of pressure registration)		yymmdd hh:mm:ss	060315 08:06:50	
Packer expanded		yymmdd hh:mm:ss		
Start of flow period		yymmdd hh:mm:ss	060315 08:17:55	
Stop of flow period		yymmdd hh:mm:ss	060315 18:16:01	
Test stop (stop of pressure registration)		yymmdd hh:mm:ss	060316 09:25:44	
Total flow time	t_p	Min	598	
Total recovery time	t_F	Min	910	

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l)** [1)]
Absolute pressure in test section before start of flow period	p_i	kPa	429.8	1.51
Absolute pressure in test section at stop of flow period	p_p	kPa	341.1	–7.74
Absolute pressure in test section at stop of recovery period	p_F	kPa	429.6	1.27
Maximal pressure change in test section during the flow period	dp_p	kPa	88.7	9.25

Manual groundwater level measurements **Date YYYY-MM-DD**	**Time tt:mm:ss**	**Time (min)**	**GW level (m b ToC)**	**(m a s l)**
2006-03-14	15:56:00	–982	3.16	1.12
2006-03-14	17:15:00	–903	3.03	1.25
2006-03-14	17:31:00	–887	2.57	1.71
2006-03-15	08:03:00	–15	2.77	1.51
2006-03-15	08:34:00	16	5.66	–1.37
2006-03-15	09:24:00	66	9.09	–4.79
2006-03-15	10:48:00	150	10.51	–6.20
2006-03-15	14:35:00	377	11.57	–7.26
2006-03-15	18:13:00	595	12.06	–7.74
2006-03-16	09:25:00	1,507	3.01	1.27

Flow data	**Nomen-clature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$8.30 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period [2]	Q_m	m^3/s	$8.33 \cdot 10^{-5}$
Total volume discharged during flow period [2]	V_p	m^3	2.99

[1)] From the manual measurements of groundwater level. Manual levelling were not possible during pumping.

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

Comments on test

The day before test start, a short capacity test was performed (c. 94 min). The capacity test was conducted with varying flow rate, during observation of the drawdown response. By the end of the capacity test, the flow rate was c. 5 L/min and the drawdown c. 8.6 m, indicating a relatively low capacity. The flow was considered too low to allow for a meaningful flow logging and therefore only a pumping test (constant flow rate, c. 5 L/min) in the open borehole was performed. The drawdown after 94 minutes pumping of the pumping test was c. 6.8 m and at the end of the c. 10 hours pumping period c. 9 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.

Interpreted flow regimes

Selected test diagrams according to the Instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2:11–15 in Appendix 2.

Initially, both the drawdown and the recovery period are dominated by wellbore storage. A transition to approximate pseudo-radial flow may be seen after c. 200 minutes during the drawdown. At the end of the recovery period small fluctuations in the pressure seems to influence the response.

Interpreted parameters

Transient evaluation of transmissivity was performed for both the flow- and recovery period and the transient, quantitative interpretation is presented in Figures A2:12–15 in Appendix 2. The quantitative analysis was performed according to the methods described in Section 5.4.1. The transmissivity was estimated by a model assuming pseudo-radial flow /4/ on both the flow- and recovery period. The representative transmissivity (i.e. T_T) is considered from the transient evaluation of the flow period assuming pseudo-radial flow including wellbore storage and skin. The agreement between the drawdown and the recovery period regarding transmissivity is good. The skin factor is not well defined by the recovery response, probably due to the deviating appearance at the end of this period. Therefore, the skin factor is held the same as obtained during the drawdown when analysing the recovery.

The results are shown in the test summary sheet (Table 6-14) and in Tables 6-9, 6-10 and 6-11.

6.4 Flow logging

A complete flow logging was made in borehole HFM27.

In borehole HFM28 the flow capacity was considered too low to allow a meaningful flow logging.

In HFM23 flow logging was performed but no flow above the lower measurement limit for the flow logging equipment could be found (c. 3 L/min in a 140 mm borehole). Therefore, only the simultaneous logging of temperature and electrical conductivity are presented in the following chapter.

6.4.1 Borehole HFM23

General test data for the flow logging in borehole HFM23 are presented in Table 6-6.

Table 6-6. General test data, groundwater level and flow data for the flow logging in borehole HFM23.

General test data				
Borehole	HFM23			
Test type(s) [1]	6, L-EC, L-Te			
Test section	Open borehole			
Test no	1			
Field crew	J. Olausson and P. Fredriksson, GEOSIGMA AB			
Test equipment system	HTHB			
General comments	Single pumping borehole			
	Nomenclature	**Unit**	**Value**	
Borehole length		m	211.5	
Pump position (lower level)		m	28.0	
Flow logged section – Secup		m	31.0	
Flow logged section – Seclow		m	80.0	
Test section diameter	$2 \cdot r_w$	mm	top 137.0 bottom 135.1	
Start of flow period		yymmdd hh:mm	060320 09:13	
Start of flow logging		yymmdd hh:mm	060320 15:02	
Stop of flow logging		yymmdd hh:mm	060320 15:58	
Stop of flow period		yymmdd hh:mm	060320 19:12	

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	3.22	1.51
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m		
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m		

Flow data	**Nomenclature**	**Unit**	**Flow rate**
Pumping rate at surface	Q_p	m³/s	$1.65 \cdot 10^{-4}$
Corrected flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m³/s	
Threshold value for borehole flow rate during flow logging	Q_{Measl}	m³/s	$5 \cdot 10^{-5}$
Minimal change of borehole flow rate to detect flow anomaly	dQ_{Anom}	m³/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.

Comments on test

Since the inclination of the borehole HFM23 decreases towards depth it was not possible to lower the flow logging device below c. 80 m. 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 at c. 31 m borehole length.

Logging results

The measured electric conductivity (EC) and temperature of the borehole fluid during the logging are presented in Figure 6-4. These variables are normally used as supporting information when interpreting flow anomalies.

Since no detectable flow was found in the logged interval (31–80 m) the accumulated inflows below 31 m must be less than the threshold value for the flow logging (c. 3 L/min). According to Equation (5-11) the transmissivity below 31 m should then be less than c. $1.3 \cdot 10^{-6}$ m²/s using the evaluated transmissivity for the entire borehole (T_T) from the pumping test.

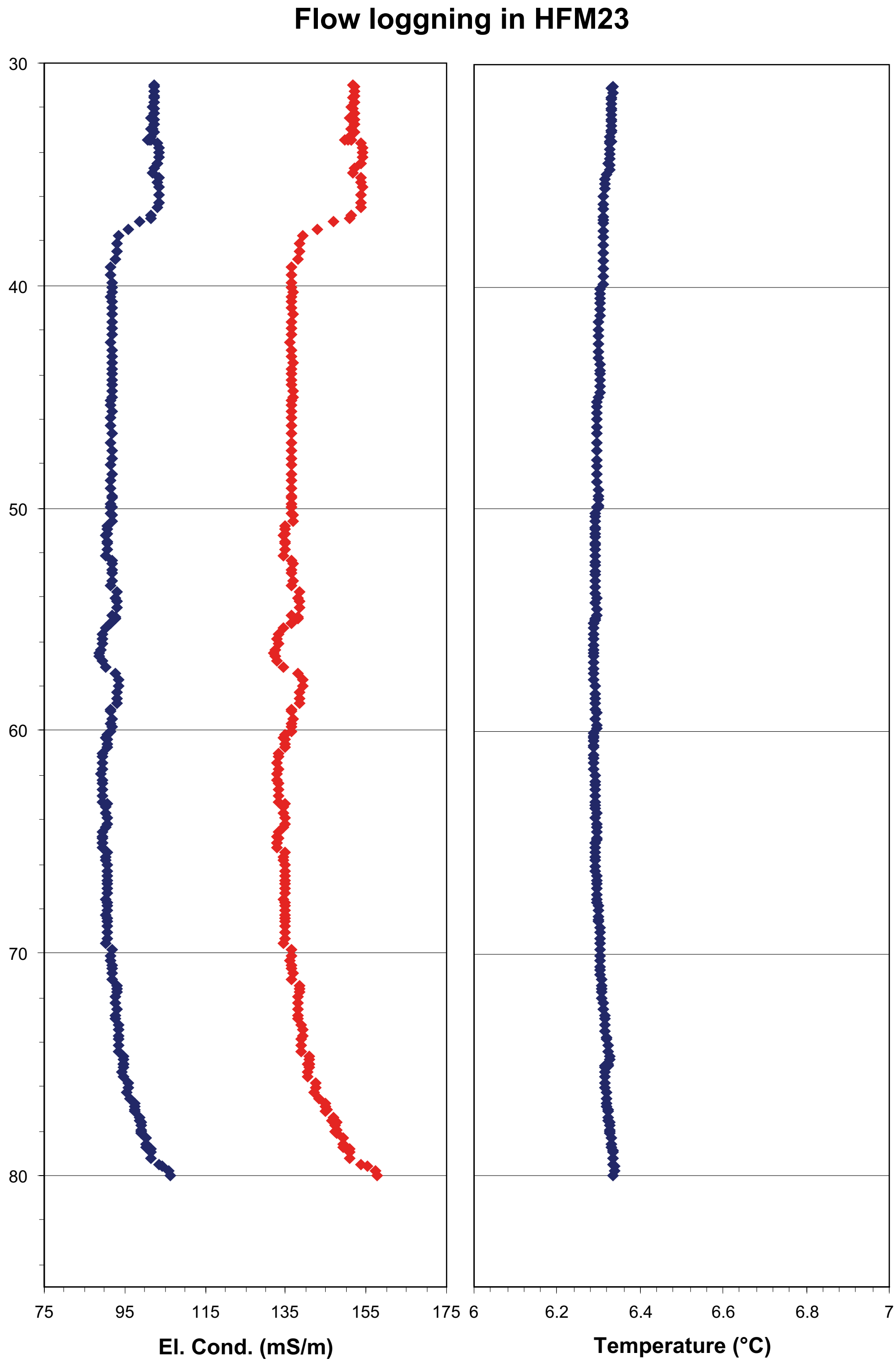


Figure 6-4. *Measured (blue) and temperature compensated (red) electrical conductivity and temperature of the borehole fluid along borehole HMF23 during flow logging.*

From the logging of electric conductivity two possible inflow anomalies could be detected in the logged interval, one at c. 36–38 m and another at c. 55–57 m where the EC is changing rather abruptly.

6.4.2 Borehole HFM27

General test data for the flow logging in borehole HFM27 are presented in Table 6-7.

Table 6-7. General test data, groundwater level and flow data for the flow logging in borehole HFM27.

General test data				
Borehole	HFM27			
Test type(s) [1]	6, L-EC, L-Te			
Test section	Open borehole			
Test no	1			
Field crew	S. Jönsson, and Pirkka-Taio Tammela, GEOSIGMA AB			
Test equipment system	HTHB			
General comments	Single pumping borehole			
	Nomenclature	**Unit**	**Value**	
Borehole length		m	127.5	
Pump position (lower level)		m	9.5	
Flow logged section – Secup		m	12.0	
Flow logged section – Seclow		m	125.0	
Test section diameter	$2{\cdot}r_w$	mm	top 140.5 bottom 138.6	
Start of flow period		yymmdd hh:mm	060306 10:18	
Start of flow logging		yymmdd hh:mm	060306 16:25	
Stop of flow logging		yymmdd hh:mm	060306 19:47	
Stop of flow period		yymmdd hh:mm	060306 20:25	
Groundwater level	**Nomen-clature**	**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	2.01	0.59
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m		
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m		
Flow data	**Nomen-clature**	**Unit**	**Flow rate**	
Pumping rate at surface	Q_p	m^3/s	$8.30{\cdot}10^{-4}$	
Corrected flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m^3/s	$8.30{\cdot}10^{-4}$	
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.

Comments on test

The flow logging was made from the bottom of the hole and upwards. The step length between flow logging measurements was maximally 5 m (below first measurable flow). Above first measurable flow (115 m), the step length was 2 m up to 105 m borehole length. Between 105 and 54 m the step length was kept at 5 m since no measurable flow was measured in this interval and in order to shorten the test time. Shorter test time implies more equal conditions all over the flow logging test.

The 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 electric conductivity (EC) and temperature of the borehole fluid are presented in Figure 6-5.

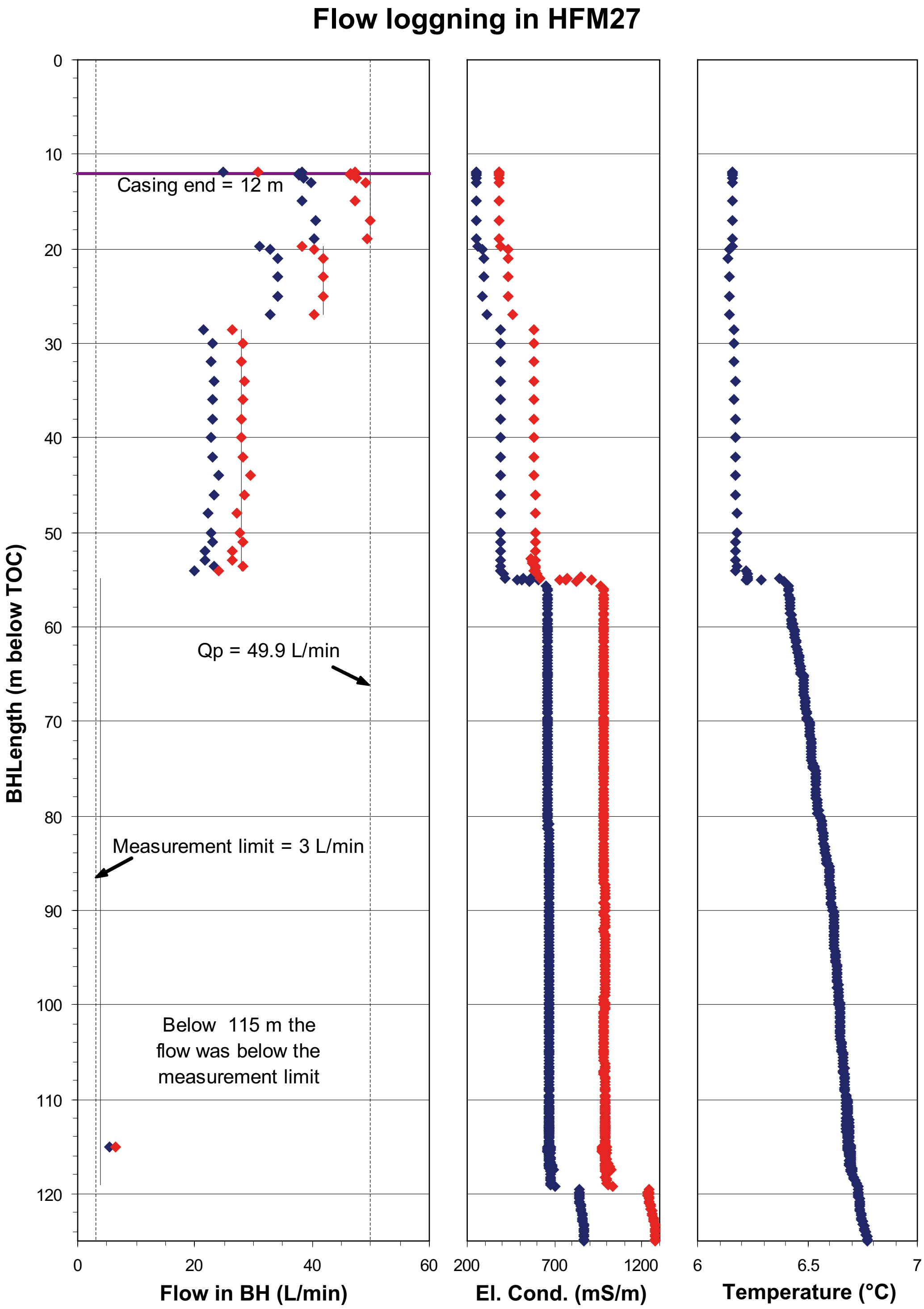


***Figure 6-5.** Measured (blue) and corrected (red) inflow distribution together with measured (blue) and temperature compensated (red) electrical conductivity and temperature of the borehole fluid along borehole HMF27 during flow logging. (Totally logged interval.)*

The figure presents measured borehole flow rates with calibration constants for a 140 mm pipe (according to the drilling record the borehole diameter in the upper part is 140.5 mm) together with 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 possible to extend the flow logging to slightly above the end of the casing and therefore method 1 is used.

Figure 6-5 shows three detected inflows between 12.1 and 54 m. All inflows are supported by both the EC- and the temperature measurements. The small deep inflow, below 115 m, could only be measured once with no interruptions in the rotation of the spinner (at 115 m borehole length) over the standard sampling period of 100 seconds. It was obvious from observations of the spinner rotations during the measurements below and above this level that the flow in the borehole was close to the measurement limit; the spinner sometimes rotated shorter or longer time but did not rotate during the whole sampling period. The clear change in electric conductivity at c. 119 m indicates that the small inflow is located at this level. One reason why the threshold value for the borehole flow measurements seems to be somewhat higher than the laboratory value is probably that the borehole has an inclination of ca 68° (the calibration is made in a vertical pipe).

The results of the flow logging in borehole HFM27 are presented in Table 6-8. 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 ($T_F(L)$) at the top of the flow-logged borehole interval 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 in conjunction with the flow logging (cf. Section 6.3.2). An estimation of the transmissivity of the interpreted flow anomalies was also made by calculating the specific flows (dQ_i/s_{FL}).

Figure 6-6 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.

Table 6-8. Results of the flow logging in borehole HFM27. Q_{Tcorr} = corrected cumulative flow at the top of the logged interval, T = transmissivity from the pumping test, s_{FL} = drawdown during flow logging and Q_p = pumped flow rate from borehole.

Flow anomalies		$Q_{Tcorr} = 8.3 \cdot 10^{-4}$ (m³/s)	$T = 8.3 \cdot 10^{-5}$ (m²/s)	s_{FL} = 3.10 m	$Q_p = 8.3 \cdot 10^{-4}$ (m³/s)	
Interval (m b ToC)	**Bh length (m)**	**dQ_{icorr} (m³/s)**	**T_i (m²/s)**	**dQ_{icorr}/s_{FL} (m²/s)**	**dQ_{icorr}/Q_p (%)**	**Supporting information**
19.3–19.8	0.5	$1.3 \cdot 10^{-04}$	$1.3 \cdot 10^{-05}$	$4.2 \cdot 10^{-05}$	15.7	EC, Temp
27.0–28.5	1.5	$2.3 \cdot 10^{-04}$	$2.3 \cdot 10^{-05}$	$7.5 \cdot 10^{-05}$	28.1	EC, Temp
54.0–54.8	0.8	$4.0 \cdot 10^{-04}$	$4.0 \cdot 10^{-05}$	$1.3 \cdot 10^{-04}$	48.2	EC, Temp
119.0–119.5	0.5	$6.7 \cdot 10^{-05}$	$6.7 \cdot 10^{-06}$	$2.2 \cdot 10^{-05}$	8.0	EC, Temp
Total		$8.3 \cdot 10^{-04}$	$8.3 \cdot 10^{-05}$	$1.9 \cdot 10^{-4}$	100.0	
Difference		$Q_p - Q_{Tcorr} = 0$	–	–		

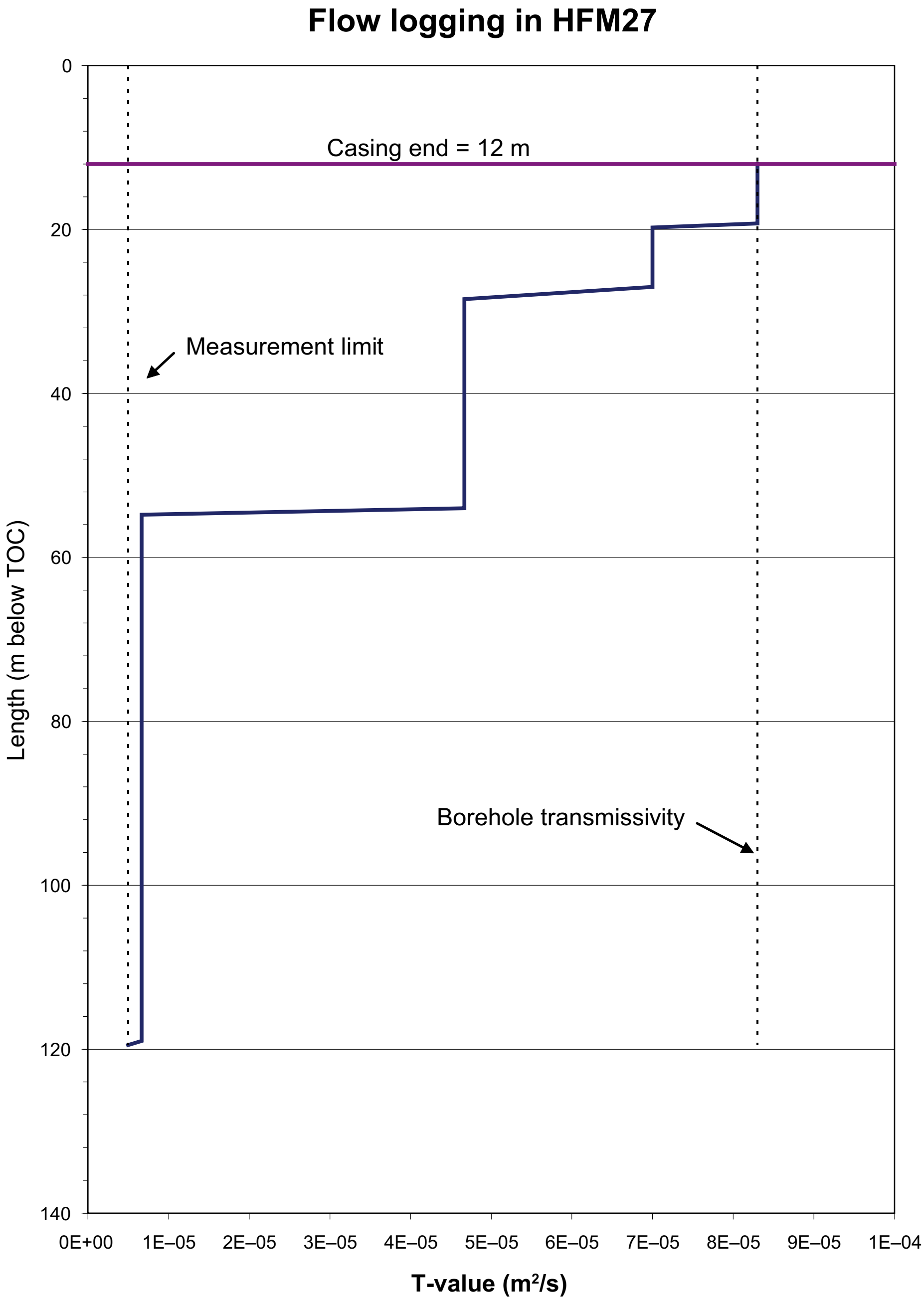


Figure 6-6. *Calculated, cumulative transmissivity along the flow logged interval of borehole HFM27. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.5 Summary of hydraulic tests

A compilation of measured test data from the pumping tests in the three boreholes is presented in Table 6-9. In Table 6-10, Table 6-11, and in the test summary sheets in Tables 6-12, 6-13 and 6-14, hydraulic parameters calculated from the tests are shown.

In Tables 6-9, 6-10 and 6-11, 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 corrected specific flow 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 6-9. Summary of test data for the open-hole pumping tests performed with the HTHB system in boreholes HFM23, HFM27 and HFM28 in the Forsmark candidate area.

Borehole ID	Section (m)	Test type [1]	pi (kPa)	pp (kPa)	pF (kPa)	Qp (m³/s)	Qm (m³/s)	Vp (m³)
HFM23	20.8–211.5	1B, 6	273.6	126.2	267.3	$1.65 \cdot 10^{-4}$	$1.66 \cdot 10^{-4}$	5.97
HFM27	12.0–127.5	1B, 6	135.3	104.9	132.1	$8.30 \cdot 10^{-4}$	$8.32 \cdot 10^{-4}$	30.29
HFM28	12.1–151.2	1B	429.8	341.1	429.6	$8.30 \cdot 10^{-5}$	$8.33 \cdot 10^{-5}$	2.99

[1)] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller.

Table 6-10. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed with the HTHB system in boreholes HFM23, HFM27 and HFM28 in the Forsmark candidate area.

Borehole ID	Section (m)	Flow anomaly interval (m)	Test type [1)]	Q/s (m²/s)	T_M (m²/s)	T_T (m²/s)	T_i (m²/s)
HFM23	20.8–211.5		1B	$1.1 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$	$4.3 \cdot 10^{-6}$	
HFM27	12.0–127.5		1B	$2.7 \cdot 10^{-4}$	$3.3 \cdot 10^{-4}$	$8.3 \cdot 10^{-5}$	
HFM27	12.0–125.0 (f)	19.3–19.8	6	$4.3 \cdot 10^{-05}$			$1.3 \cdot 10^{-05}$
HFM27	12.0–125.0 (f)	27.0–28.5	6	$7.5 \cdot 10^{-05}$			$2.3 \cdot 10^{-05}$
HFM27	12.0–125.0 (f)	54.0–54.8	6	$1.3 \cdot 10^{-04}$			$4.0 \cdot 10^{-05}$
HFM27	12.0–125.0 (f)	119.0–119.5	6	$2.2 \cdot 10^{-05}$			$6.7 \cdot 10^{-06}$
HFM28	12.1–151.2		1B	$9.2 \cdot 10^{-6}$	$1.2 \cdot 10^{-5}$	$9.0 \cdot 10^{-6}$	

[1)] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller.

Table 6-11. Summary of calculated hydraulic parameters from the hydraulic tests performed with the HTHB system in boreholes HFM23, HFM27 and HFM28 in the Forsmark candidate area.

Borehole ID	Section (m)	Test type [1)]	S* (–)	C [2)] (m³/Pa)	ζ (–)
HFM23	20.8–211.5	1B	$1.5 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	–6.4
HFM27	12.0–127.5	1B	$6.4 \cdot 10^{-6}$	$2.1 \cdot 10^{-6}$	[3)]
HFM28	12.1–151.2	1B	$2.1 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	–3.1

[1)] 1B: Pumping test-submersible pump.

[2)] When the fictive casing radius r(c) can be obtained from the parameter estimation using the Dougherty-Babu model in Aqtesolv software. C is calculated according to Equation 5-2. Otherwise the geometrical value of C is presented.

[3)] The model used for HFM27 does not provide wellbore skin (see Section 6.3.2).

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.

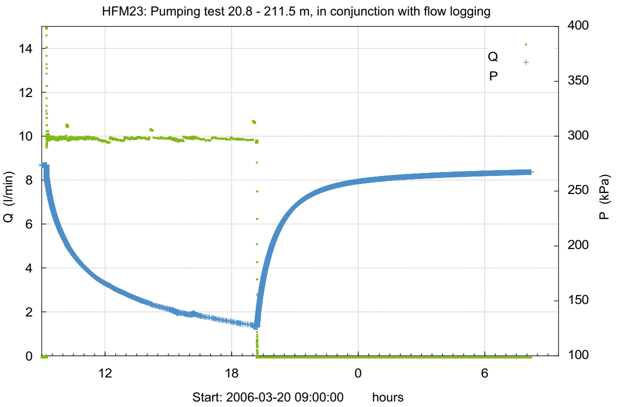
Similarly, the practical, upper measurement limit of the HTHB-system is estimated from the maximal flow rate (c. 80 L/min) and a minimal drawdown of c. 0.5 m, which is considered significant in relation to e.g. background fluctuations of the pressure before and during the test. These values correspond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

Table 6-12. Test summary sheet for the pumping test in HFM23, section 20.8–211.5 m.

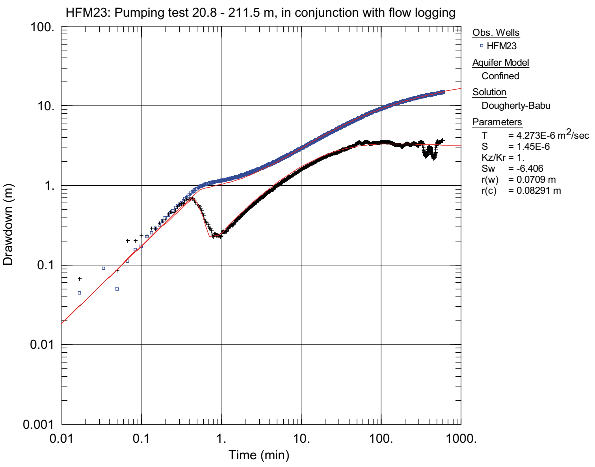
Test summary sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM23	Test start:	2006-03-20 08:56:13
Test section (m):	20.8–211.5	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2 \cdot r_w$ (m):	top 0.137 bottom 0.1351	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

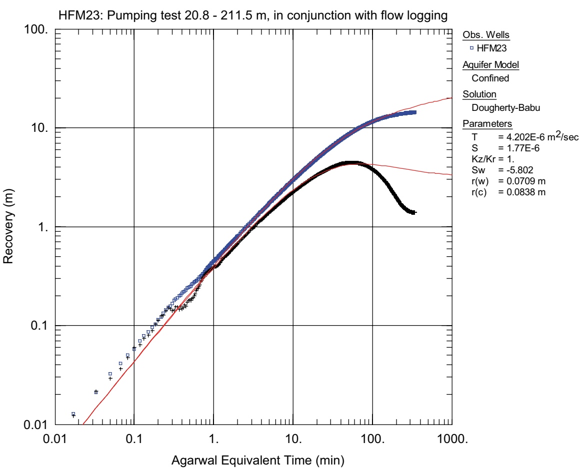
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period*		**Recovery period***	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	273.6		
p_p (kPa)	126.2	p_F (kPa)	267.3
Q_p (m^3/s)	$1.65 \cdot 10^{-4}$		
tp (min)	599	t_F (min)	780
S*	$1.5 \cdot 10^{-6}$	S*	$1.8 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w (gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m^2/s)	$1.1 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$1.4 \cdot 10^{-5}$		
Flow regime:	WBS->PRF	Flow regime:	WBS
t_1 (min)	100	dt_{e1} (min)	
t_2 (min)	599	dt_{e2} (min)	
T_w (m^2/s)	$4.3 \cdot 10^{-6}$	T_w (m^2/s)	$4.2 \cdot 10^{-6}$
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$2.3 \cdot 10^{-6}$	C (m^3/Pa)	$2.3 \cdot 10^{-6}$
C_D (–)		C_D (–)	
ξ (–)	–6.4	ξ (–)	–5.8
T_{GRF} (m^2/s)		T_{GRF} (m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters

Flow regime:	PRF	C (m^3/Pa)	$2.3 \cdot 10^{-6}$
t_1 (min)	100	C_D (–)	
t_2 (min)	599	ξ (–)	–6.4
T_T (m^2/s)	$4.3 \cdot 10^{-6}$		
S (–)	$1.5 \cdot 10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments: During the drawdown initial wellbore storage effects are transitioning to a pseudo-radial flow regime after c. 100 min. The small disturbances on the derivative after c. 60 and c. 300 min and at the very end of the drawdown are a result of disturbed flow rate in connection to water sampling.

The recovery is not reaching the original level prevailing before start of pumping, indicating flow restrictions in the fracture system in the periphery of the influence area.

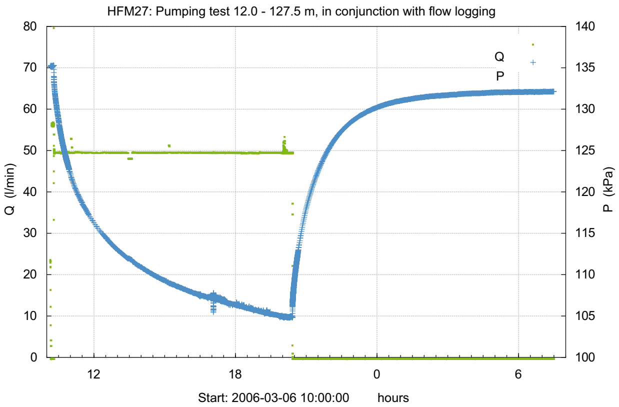
The results from the drawdown period are chosen as the most representative for the borehole.

Table 6-13. Test summary sheet for the pumping test in HFM27, section 12.0–127.5 m.

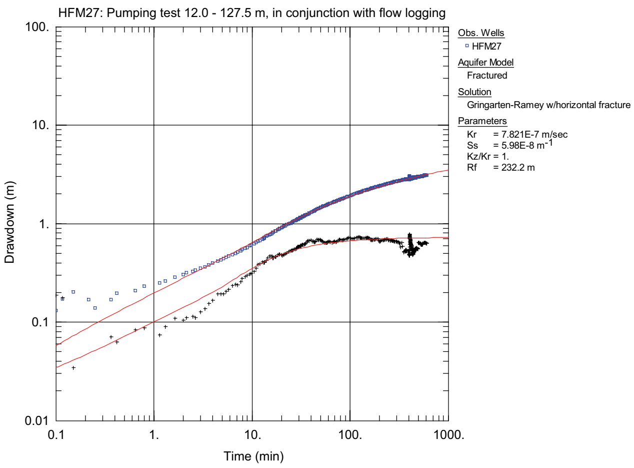
Test summary sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM27	Test start:	2006-03-06 10:09:08
Test section (m):	12.0–127.5	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2 \cdot r_w$ (m):	top 0.1405 bottom 0.1386	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

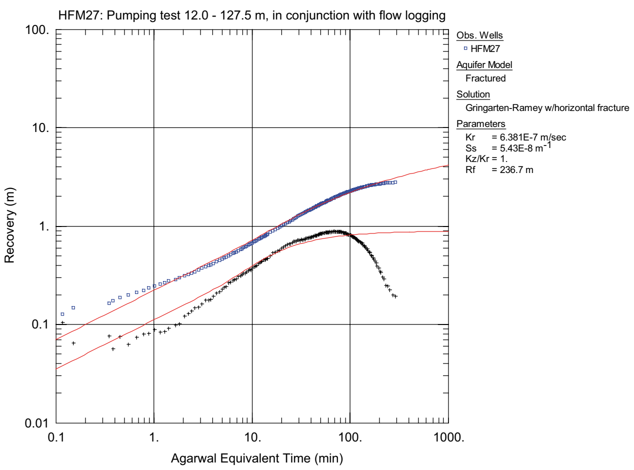
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	135.3		
p_p (kPa)	104.9	p_F (kPa)	132.1
Q_p (m³/s)	$8.3 \cdot 10^{-4}$		
tp (min)	607	t_F (min)	665
S*	$6.4 \cdot 10^{-6}$	S*	$5.8 \cdot 10^{-6}$
EC_w (mS/m)			
Te_w (gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m²/s)	$1.1 \cdot 10^{-5}$		
T_{Moye} (m²/s)	$3.3 \cdot 10^{-4}$		
Flow regime:	WBS->PRF	Flow regime:	WBS
t_1 (min)	100	dt_{e1} (min)	
t_2 (min)	607	dt_{e2} (min)	
T_w (m²/s)	$8.3 \cdot 10^{-5}$	T_w (m²/s)	$6.8 \cdot 10^{-5}$
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m³/Pa)	$2.1 \cdot 10^{-6}$	C (m³/Pa)	$2.1 \cdot 10^{-6}$
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF} (m²/s)		T_{GRF} (m²/s)	
S_{GRF} (–)		S_{GRF} (–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters

Flow regime:	WBS->PRF	C (m³/Pa)	$2.1 \cdot 10^{-6}$
t_1 (min)	100	C_D (–)	
t_2 (min)	607	ξ (–)	
T_T (m²/s)	$8.3 \cdot 10^{-5}$		
S (–)	$6.4 \cdot 10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments: A model by Gringarten and Ramey /6/ for a horizontal fracture results in a better fit than the generally used Dougherty-Babu model in this case, especially during the early phases. The model does not provide values on wellbore skin.

During the drawdown, pseudo-linear flow is transitioning to a pseudo-radial flow regime after c. 100 min.

The recovery is not reaching the original level prevailing before start of pumping, indicating flow restrictions in the fracture system in the periphery of the influence area.

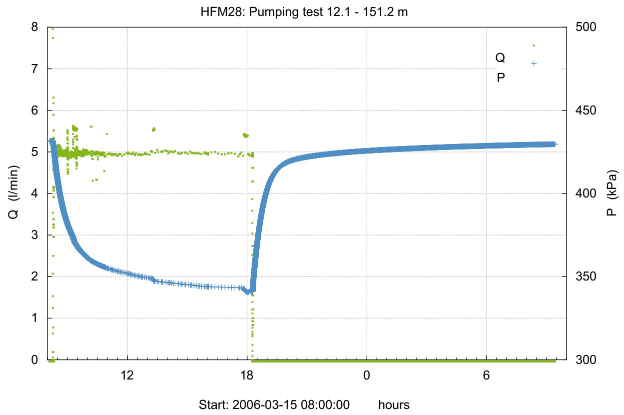
The results from the drawdown period are chosen as the most representative for the borehole.

Table 6-14. Test summary sheet for the pumping test in HFM28, section 12.1–151.2 m.

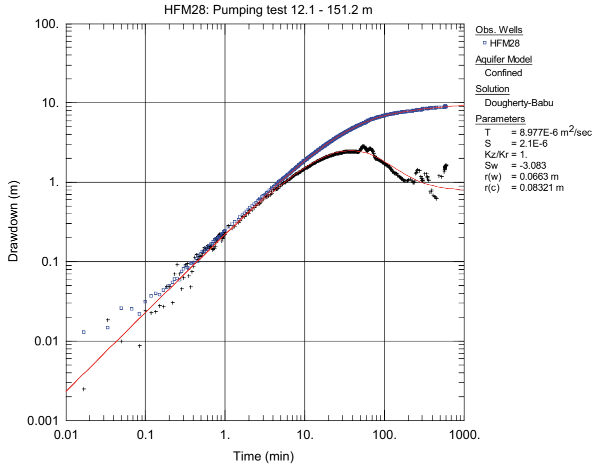
Test summary sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM28	Test start:	2006-03-15 08:06:50
Test section (m):	12.1–151.2	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2\cdot r_w$ (m):	top 0.1383 bottom 0.1351	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

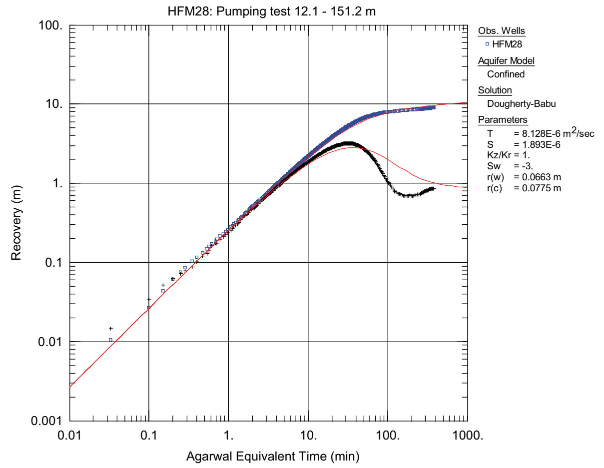
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	429.8		
p_p (kPa)	341.1	p_F (kPa)	429.6
Q_p (m³/s)	$8.30\cdot10^{-5}$		
tp (min)	598	t_F (min)	910
S*	$2.1\cdot10^{-6}$	S*	$1.9\cdot10^{-6}$
EC_w (mS/m)			
Te_w (gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m²/s)	$9.2\cdot10^{-6}$		
T_{Moye} (m²/s)	$1.2\cdot10^{-5}$		
Flow regime:	WBS->PRF	Flow regime:	WBS->(PRF)
t_1 (min)	200	dt_{e1} (min)	
t_2 (min)	598	dt_{e2} (min)	
T_w (m²/s)	$9.0\cdot10^{-6}$	T_w (m²/s)	$8.1\cdot10^{-6}$
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m³/Pa)	$2.2\cdot10^{-6}$	C (m³/Pa)	$1.9\cdot10^{-6}$
C_D (–)		C_D (–)	
ξ (–)	–3.1	ξ (–)	–3.0
T_{GRF} (m²/s)		T_{GRF} (m²/s)	
S_{GRF} (–)		S_{GRF} (–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters

Flow regime:	WBS->PRF	C (m³/Pa)	$2.2\cdot10^{-6}$
t_1 (min)	200	C_D (–)	
t_2 (min)	598	ξ (–)	–3.1
T_T (m²/s)	$9.0\cdot10^{-6}$		
S (–)	$2.2\cdot10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments: During the drawdown initial wellbore storage effects are transitioning to an approximate pseudo-radial flow regime after c. 200 minutes. The disturbances on the derivative after c. 60 and c. 300 minutes and at the very end of the drawdown are a result of disturbed flow rate in connection to water sampling.

The initial phase of the recovery is dominated by wellbore storage effects followed by a transition, possibly to pseudo-radial flow, at the very end of the recovery period.

The results from the drawdown period are chosen as the most representative for the borehole.

7 References

/1/ **Claesson L-Å, Nilsson G, 2006.** Drilling of monitoring wells HFM23 and HFM28 at drill site DS9 as well as HFM24 and SFM0080 at drill site DS10. SKB P-05-278, Svensk Kärnbränslehantering AB.

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

/3/ **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. Tekniskt Dokument TD-01-63, Svensk Kärnbränslehantering AB.

/4/ **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.

/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.

/6/ **Gringarten A C, Ramey H J, 1974.** Unsteady state pressure distribution created by a well with a single horizontal fracture, partial penetration or restricted entry. Soc. Petrol. Engrs. J, pp 413–426.

Appendix 1

List of 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
HFM23	20.8–211.5	1B	2006-03-20 09:13.02	2006-03-21 08:11:38	2006-03-17 13:25:26	2006-03-21 08:11:38	HFM23_20.8_060320_FlowLo03.DAT	P, Q, T, EC	Also includes data from logging in undisturbed borehole
					2006-03-16 10:09:08	2006-03-21 08:11:38	HFM23_20.8_060316_Ref_Da03.DAT		Reference file
		1B	2006-03-16 13:41:00	2006-03-16 15:17:58	2006-03-14 16:21:33	2006-03-16 15:17:58	HFM23_20.8_060316_Pumpin03.DAT	P, Q	Capacity test
HFM27	12.0–127.5		2006-03-02 13:15:59	2006-03-02 16:51:19	2006-03-02 13:15:59	2006-03-02 16:51:19	HFM27_12.0_060302_FlowLo01.DAT	P, Q, T, EC	Logging in undisturbed borehole
		1B	2006-03-03 09:51:00	2006-03-03 11:33:17	2006-03-03 09:44:28	2006-03-03 11:33:17	HFM27_12.0_060303_Pumpin01.DAT	P, Q	Capacity test
		1B	2006-03-06 10:18.00	2006-03-07 07:29:54	2006-03-06 10:09:08	2006-03-07 07:29:54	HFM27_12.0_060306_FlowLo04.DAT	P, Q, T, EC	
		6, L-EC, L-T	2006-03-06 16:38:31	2006-03-06 19:46:48	2006-03-06 16:38:31	2006-03-06 19:46:48	HFM27_12.0_060306_Spinne04.DAT	P, Q, T, EC, SP	
					2006-03-02 12:40:55	2006-03-06 20:39:55	HFM27_12.0_060302_Ref_Da04.DAT		Reference file
HFM28			2006-03-15 08:16:01	2006-03-16 09:25:44	2006-03-14 16:21:33	2006-03-16 09:25:44	HFM28_12.1_060314_Pumpin02.DAT	P, Q	Also includes data from a capacity test starting 060314 17:35:00
					2006-03-14 16:09:41	2006-03-15 18:28:45	HFM28_12.1_060314_Ref_Da02.DAT		

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

Test diagrams

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).

Pumping test in HFM23: 20.8–211.5 m

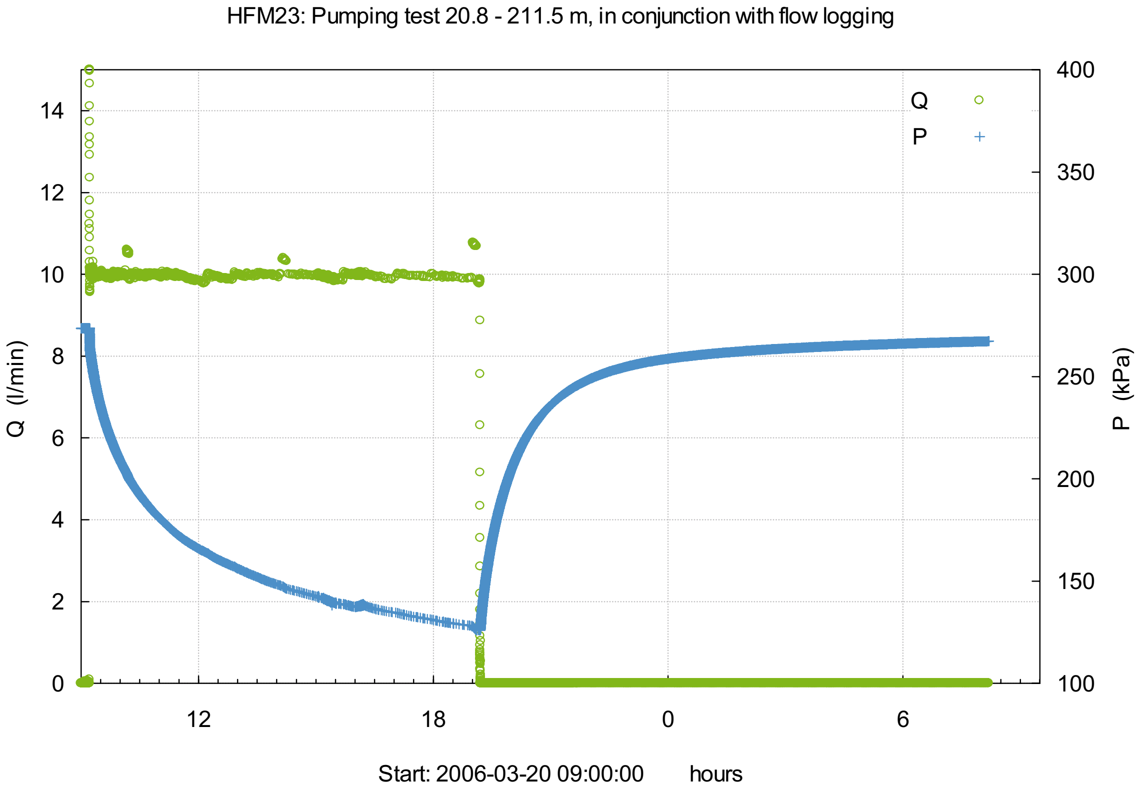


Figure A2-1. *Linear plot of flow rate (Q) and pressure (P) versus time during the open-hole pumping test in HFM23 in conjunction with flow logging.*

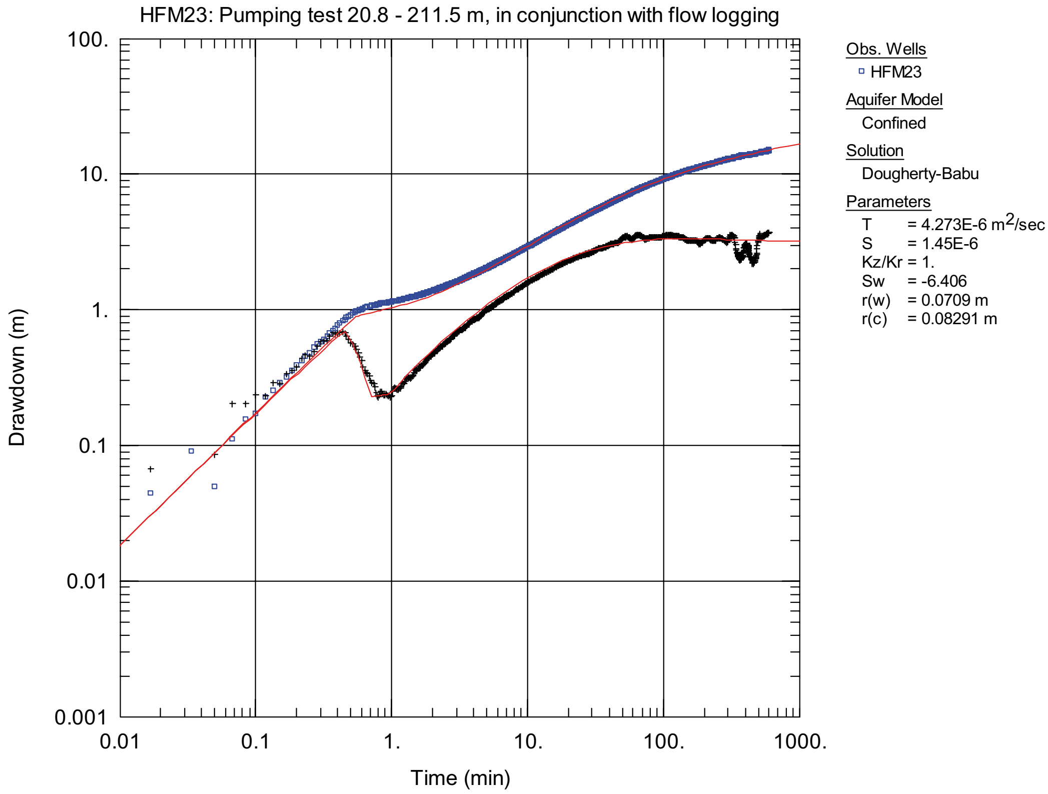


Figure A2-2. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM23.*

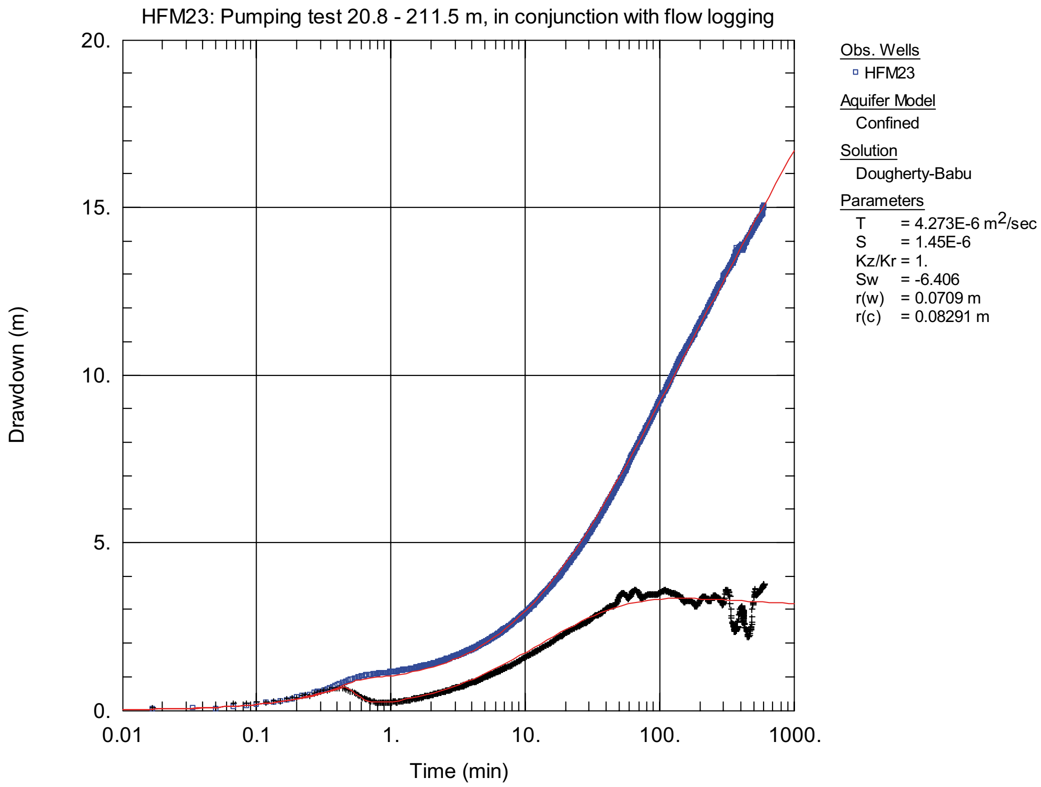


Figure A2-3. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM23.*

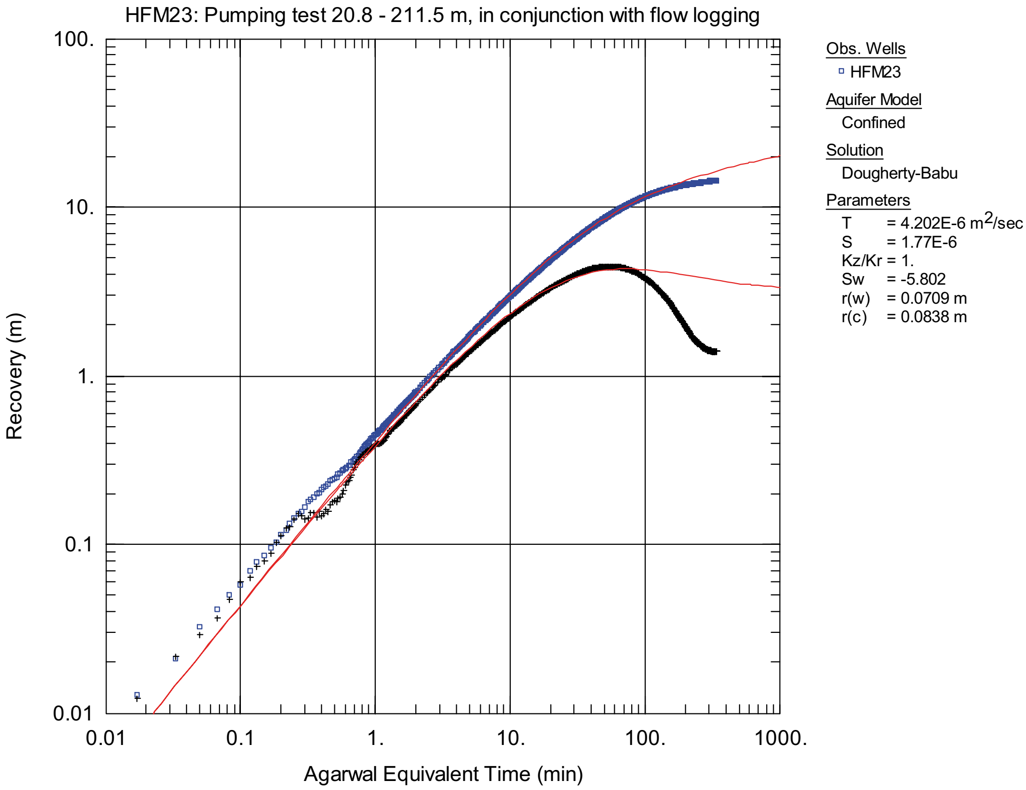


Figure A2-4. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM23.*

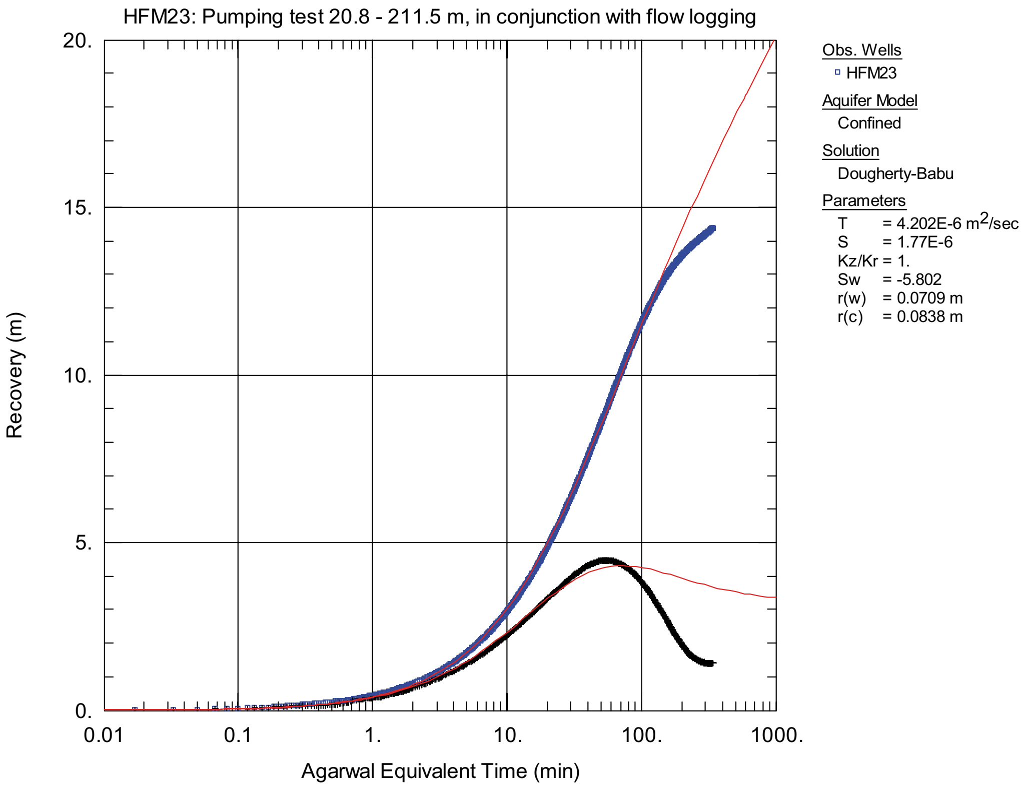


Figure A2-5. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM23.*

Pumping test in HFM27: 12.0–127.5 m

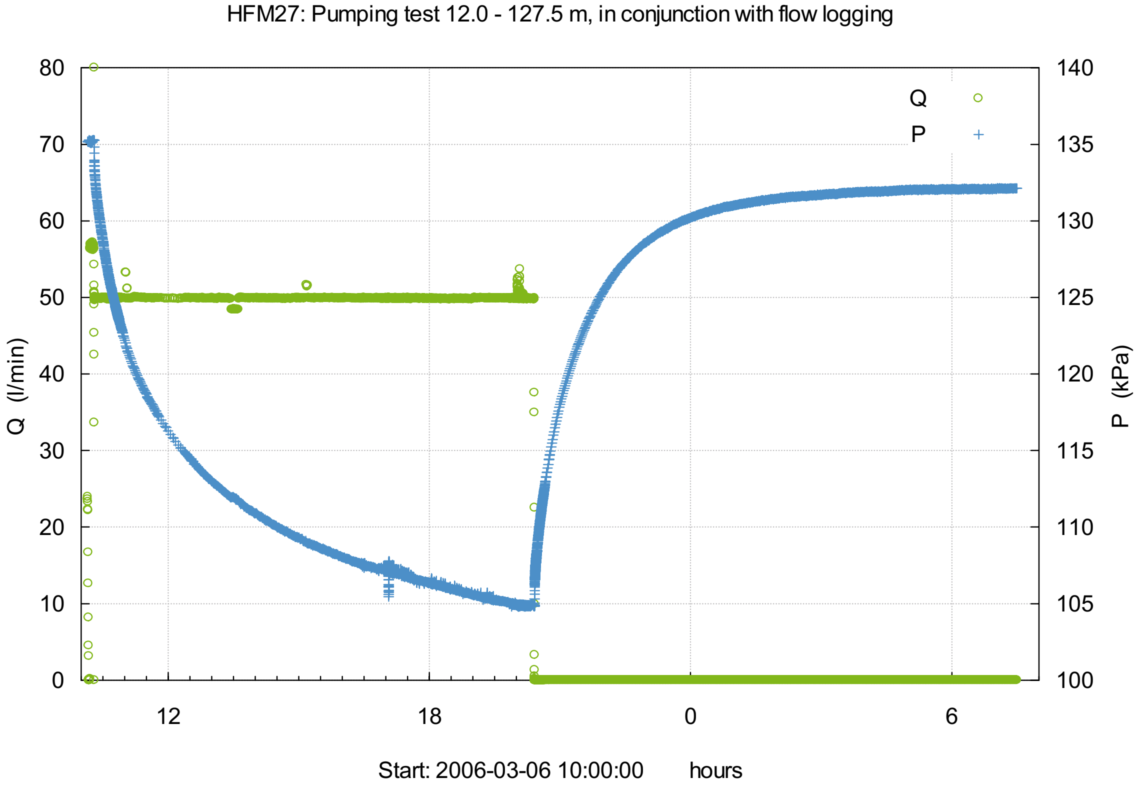


Figure A2-6. *Linear plot of flow rate (Q) and pressure (P) versus time during the open-hole pumping test in HFM27 in conjunction with flow logging.*

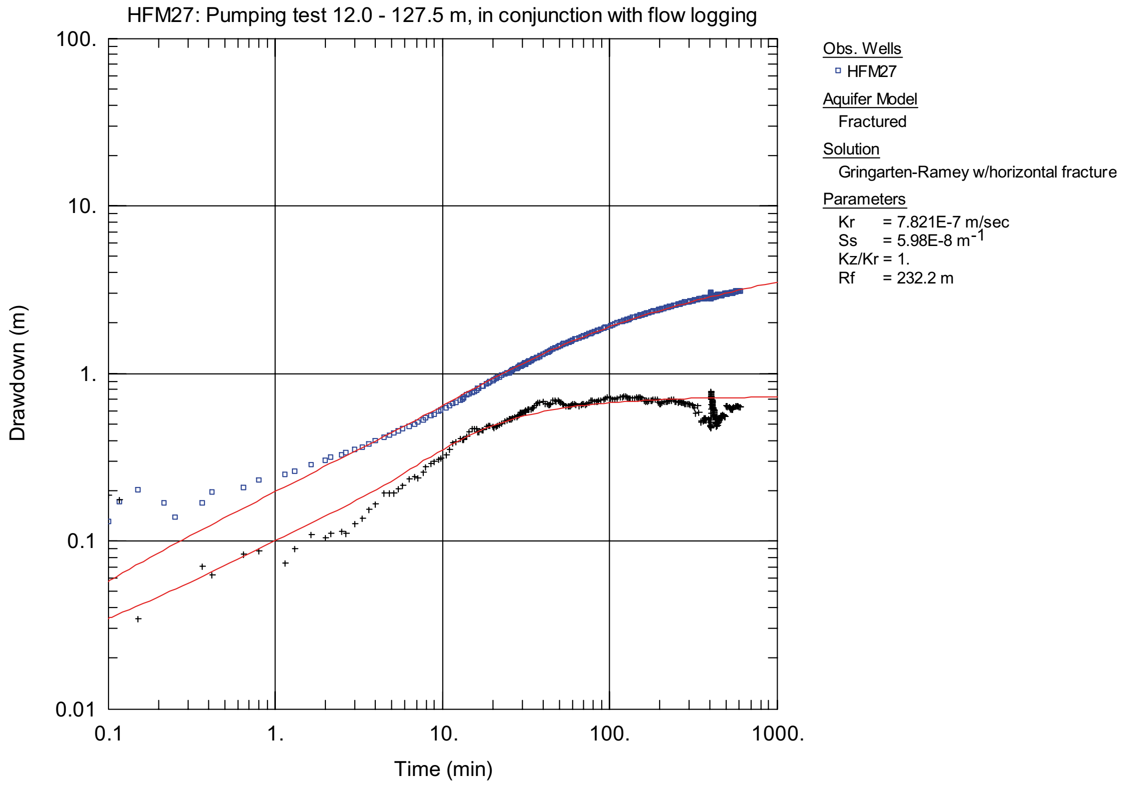


***Figure A2-7.** Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM27.*

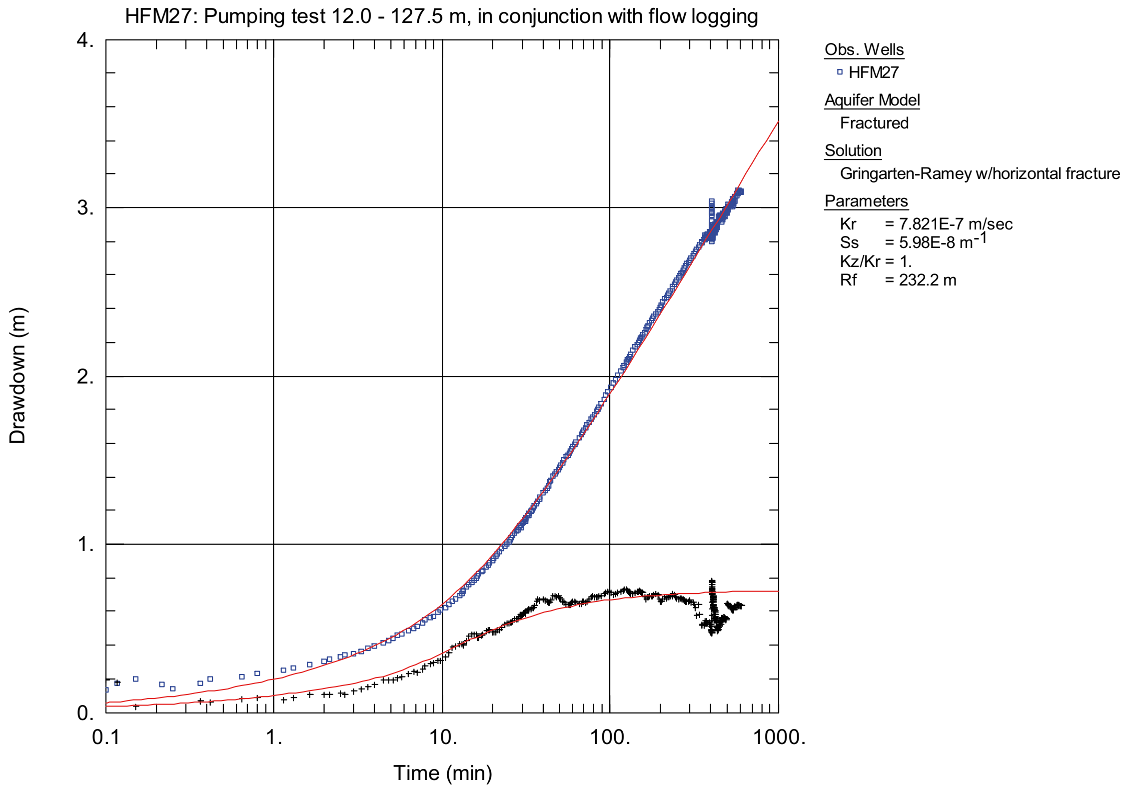


***Figure A2-8.** Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM27.*

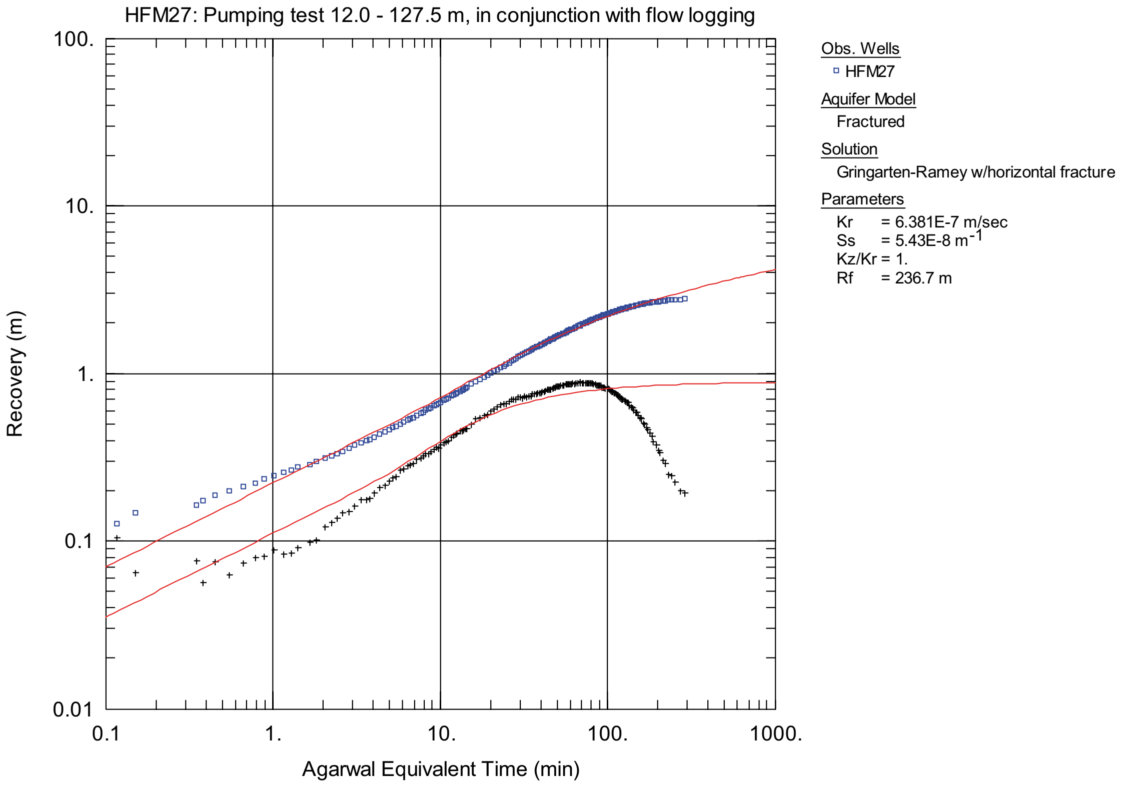


Figure A2-9. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM27.*

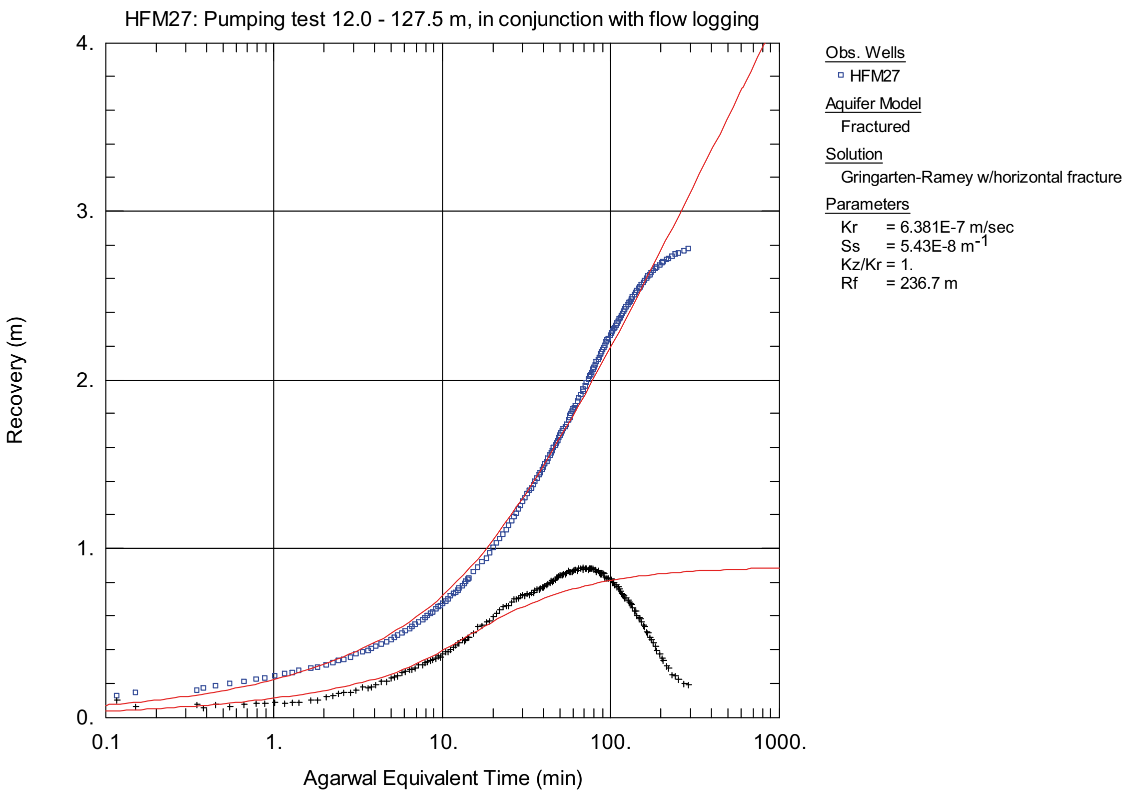


Figure A2-10. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM27.*

Pumping test in HFM28: 12.1–151.2 m

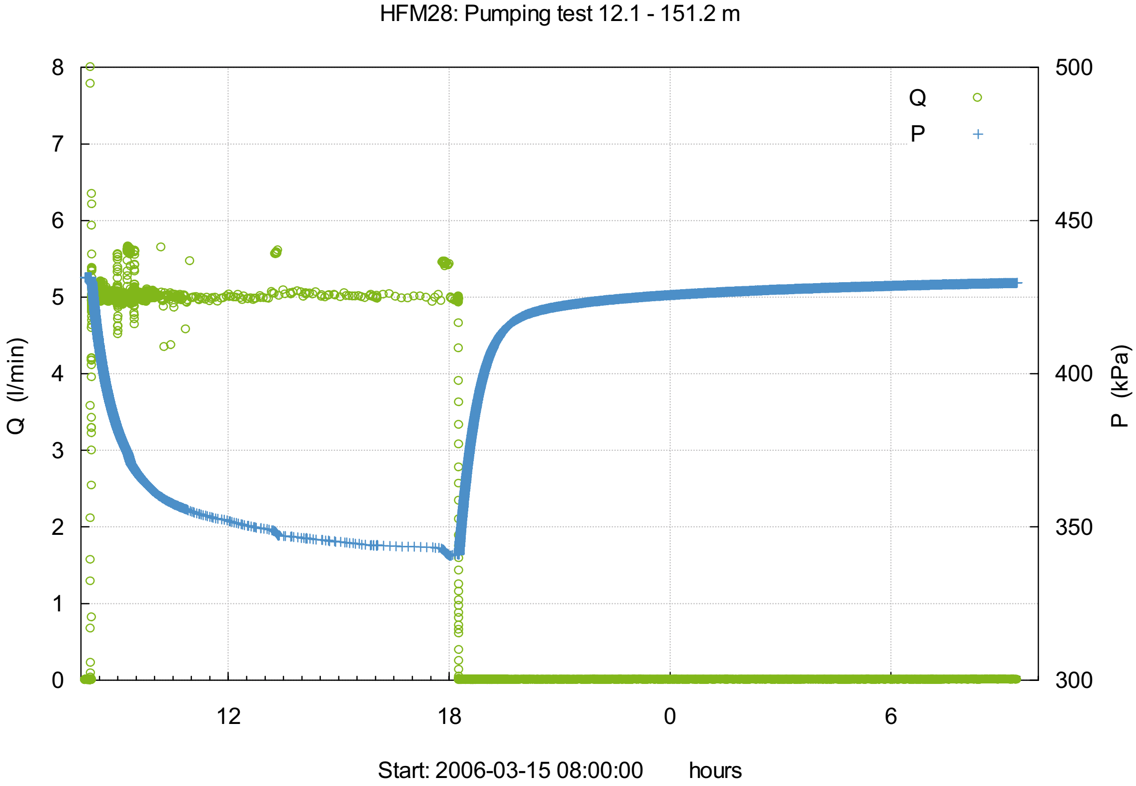


Figure A2-11. *Linear plot of flow rate (Q) and pressure (P) versus time during the open-hole pumping test in HFM28.*

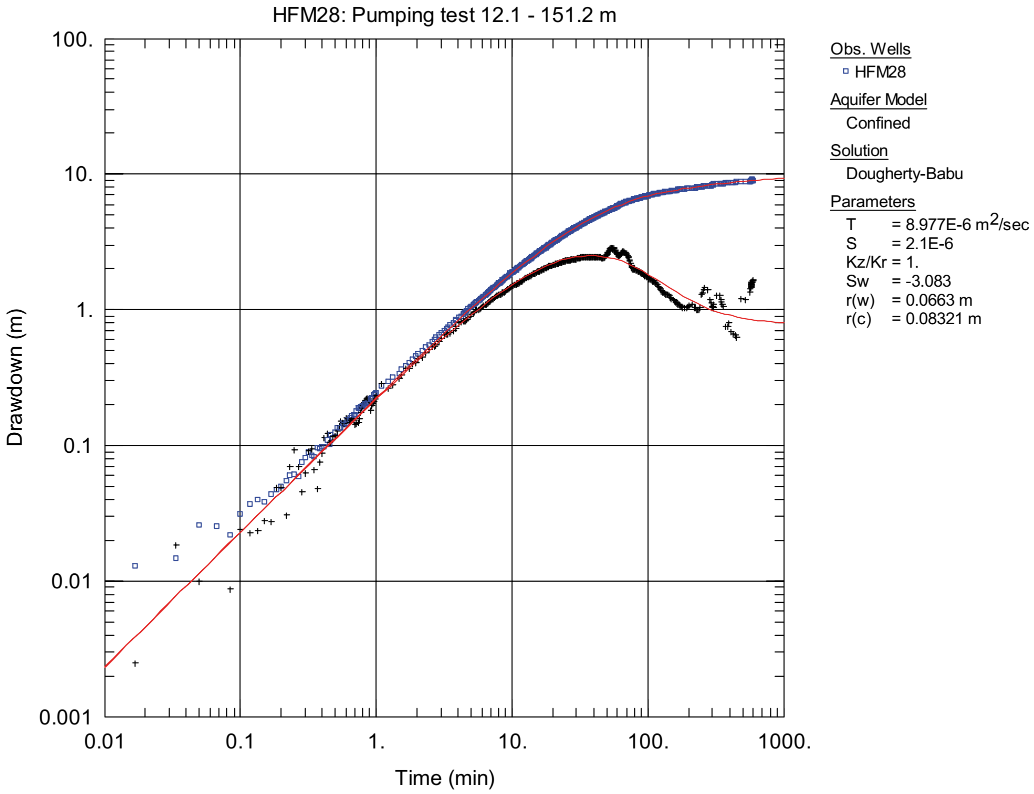


Figure A2-12. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM28.*

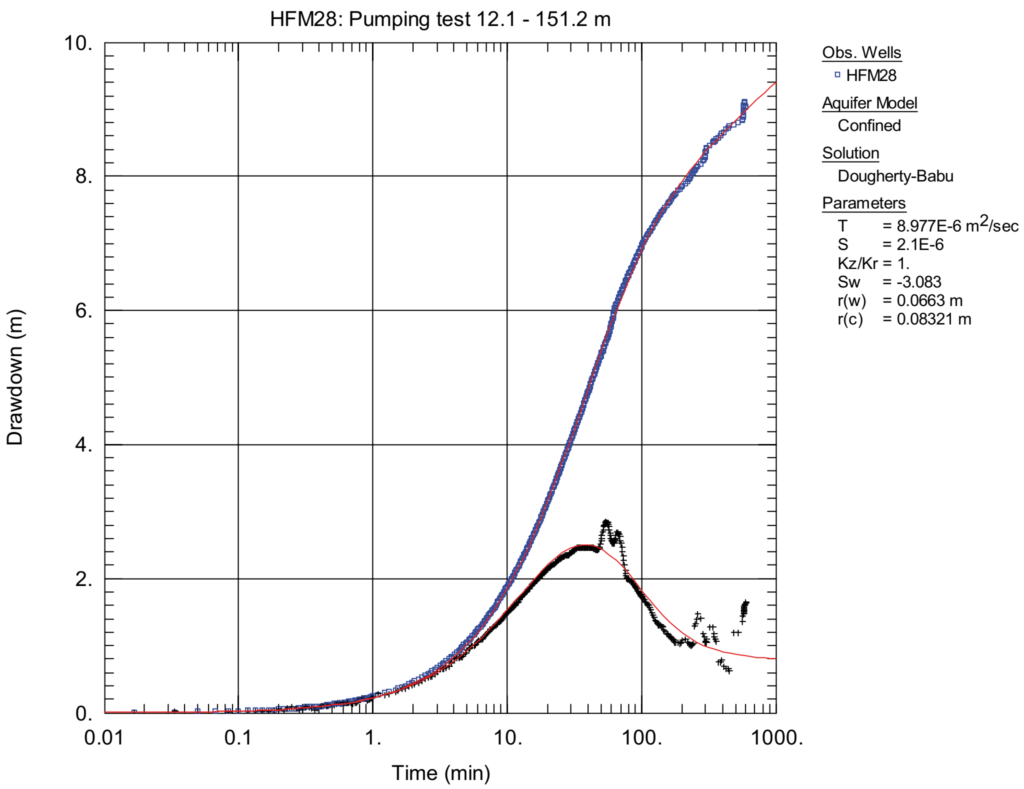


Figure A2-13. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM28.*

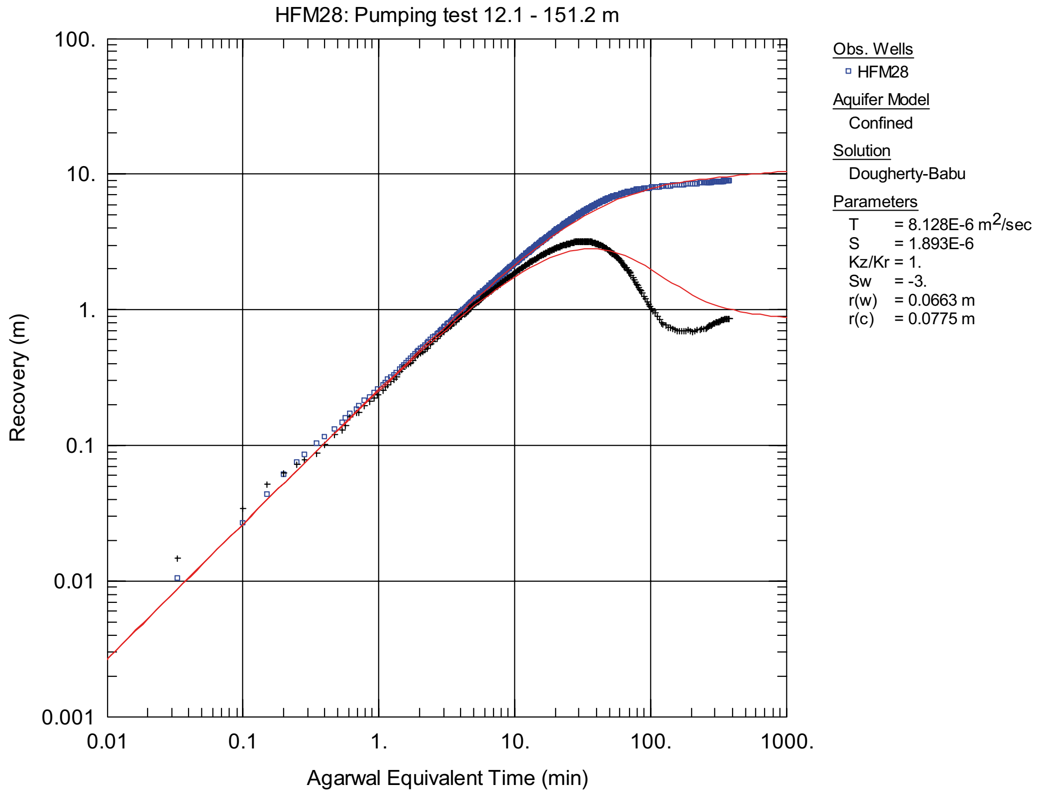


Figure A2-14. *Log-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM28.*

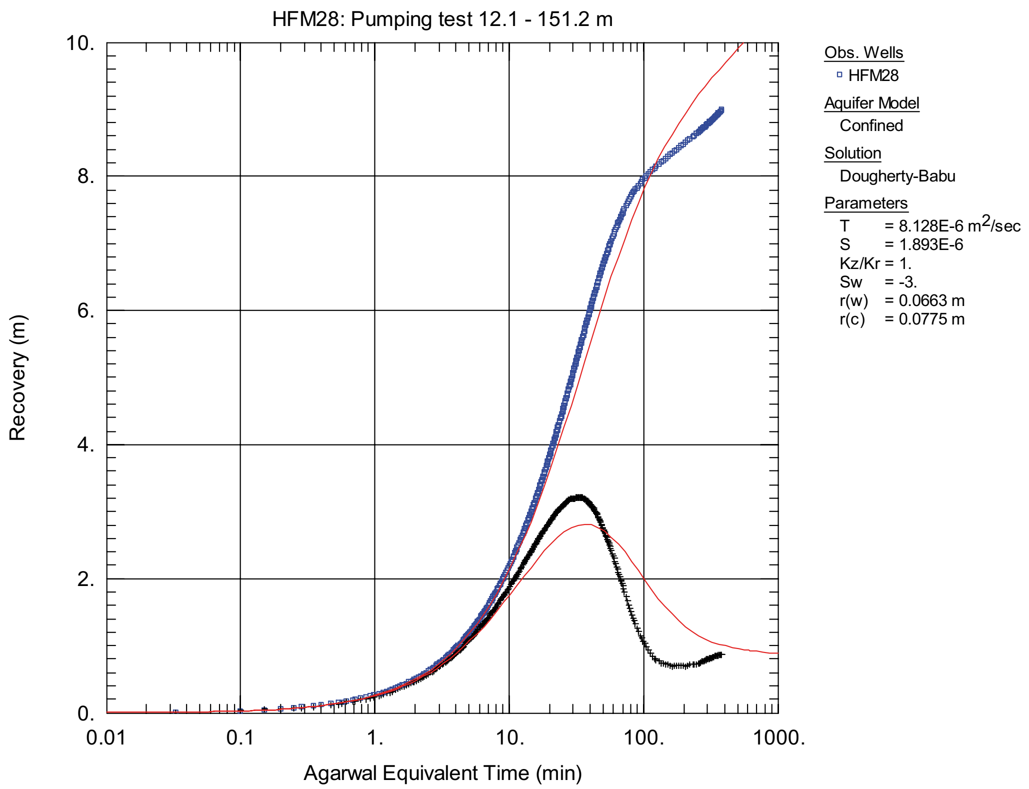


Figure A2-15. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) versus equivalent time (dte) from the open-hole pumping test in HFM28.*

Appendix 3

Result tables to Sicada database

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	(m) secup	(m) seclow	section_ no	test_ type	formation_ type	(yyyymmdd) start_flow_period	(yyyymmdd) stop_flow_period	(m^3/s) flow_rate_end_qp
HFM23	060320 08:56:13	060321 08:11:38	20.80	211.50		1B	1	060320 09:13:02	060320 19:12:02	1.65E-04
HFM27	060306 10:09:08	060307 07:29:54	12.00	127.50		1B	1	060306 10:18:00	060306 20:25:02	8.30E-04
HFM28	060315 08:06:50	060316 09:25:44	12.10	151.20		1B	1	060315 08:17:55	060315 18:16:01	8.30E-05

cont.

value_ type_qp	(m^3/s) mean_flow_ rate_qm	(m^3/s) q_measl__l	(m^3/s) q_measl__u	(m^3) tot_vol- ume_vp	(s) dur_flow_ phase_tp	(s) dur_rec_ phase_tf	(m) initial_ head_hi	(m) head_at_ flow_end_hp	(m) final_ head_hf	(kPa) initial_ press_pi	(kPa) press_at_ flow_end_pp	(kPa) final_press_ pf
0	1.66E-04	8.33E-05	1.33E-03	5.97E+00	35940	46800	1.51	-13.51	0.84	273.6	126.2	267.3
0	8.32E-04	8.33E-05	1.33E-03	3.03E+01	36420	39900	0.59	-2.50	0.24	135.3	104.9	132.1
0	8.33E-05	8.33E-05	1.33E-03	2.99E+00	35880	54600	1.51	-7.52	1.27	429.8	341.1	429.6

cont.

(°C) fluid_temp_ tew	(mS/m) fluid_elcond_ ecw	(mg/l) fluid_salinity_ tdsw	(mg/l) fluid_salinity_ tdswm	reference	comments	(m) lp
						116
						40
						82

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.limit1: >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	Ground water pressure at the end of the recovery period
fluid_temp_tew	FLOAT	°C	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	(m) secup	(m) seclow	section_no	test_ type	formation_ type	(m) lp	(m) seclen_ class	(m²/s) spec_ capacity_q_s	value_ type_ q_s	(m²/s) transmissivity_ tq	value_ type_ tq	bc_ tq
HFM23	060320 08:56:13	060321 08:11:38	20.8	211.5		1B	1	116		1.1E-05	0			
HFM27	060306 10:09:08	060307 07:29:54	12.0	127.5		1B	1	40		2.7E-04	0			
HFM28	060315 08:06:50	060316 09:25:44	12.1	151.2		1B	1	82		9.2E-06	0			

cont.

(m²/s) transmissivity_ moye	bc_ tm	value_ type_tm	(m/s) hydr_cond_ moye	(m) formation_ width_b	(m) width_of_ channel_b	(m³/s) tb	(m³/s) l_measl_ tb	(m³/s) u_ measl_tb	(m) sb	(m) assumed_ sb	(m) leakage_ factor_lf	(m²/s) transmissivity_ tt	value_ type_tt	bc_ tt	(m²/s) l_measl_ q_s	(m²/s) u_measl_ q_s
1.4E-05	0	0								4.3E-06	0	1			2.E-06	2.E-03
3.3E-04	0	0								8.3E-05	0	1			2.E-06	2.E-03
1.2E-05	0	0								9.0E-06	0	1			2.E-06	2.E-03

cont.

storativity_ s	assumed_ s	s_ bc	(m) ri	ri_ index	(1/s) leakage_ coeff	(m/s) hydr_ cond_ksf	value_ type_ ksf	(m/s) l_measl_ ksf	(m/s) u_measl_ ksf	(1/m) spec_ storage_ssf	(1/m) assumed_ ssf	(m³/pa) c	cd	skin	(s) dt1	(s) dt2	(s) t1	(s) t2
1.5E-06			481.47	0								2.20E-06		-6.4E+00			6000.00	35940.00
6.4E-06			1030.89	0								2.10E-06					6000.00	36420.00
2.1E-06			588.21	0								2.20E-06		3.1E+00			12000.00	35880.00

cont.

(s) dte1	(s) dte2	(kPa) p_horner	(m²/s) transmissivity_ t_nlr	storativity_ s_nlr	value_ type_t_ nlr	bc_t_ nlr	(m³/pa) c_nlr	cd_ nlr	skin_ nlr	(m²/s) transmissivity_ t_grf	value_ type_t_ grf	bc_ t_ grf	storativity_ s_grf	flow_ dim_grf	(no_unit) comment

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	(m) secup	(m) seclow	section_no	(yyyymmdd) start_flowlogging	(yyyymmdd) stop_flowlogging	(m) l	test_type	formation_ type	(m³/s) q_measl_l
HFM23	2006-03-20 15:02	2006-03-20 15:58	31.00	80.00		2006-03-20 15:02:00	2006-03-20 15:58:00	211.50	6	1	5.0000E-05
HFM27	2006-03-06 16:25	2006-03-06 19:47	12.00	125.00		2006-03-06 16:25:00	2006-03-06 19:47:00	125.00	6	1	5.0000E-05

cont.

(m³/s) q_measl_u	(m³/s) pump_ flow_q1	(m³/s) pump_ flow_q2	(s) dur_flow_ phase_tp1	(s) dur_flow_ phase_tp2	(s) dur_flowlog_ tfl_1	(s) dur_flowlog_ tfl_2	(m) drawdown_ s1	(m) drawdown_ s2	(m a s l) initial_ head_ho	(m a s l) hydraulic_ head_h1	(m a s l) hydraulic_ head_h2	reference	comments
1.3333E-03	1.65E-04		35940.00		3360.00		15.02		1.51	-13.51			
1.3333E-03	8.30E-04		36420.00		12120.00		3.10		0.59	-2.51			

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 desc
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	(m) secup	(m) seclow	section_no	(m) l	(m³/s) cum_ flow_q0	(m³/s) cum_ flow_q1	(m³/s) cum_ flow_q2	(m³/s) cum_ flow_q1t	(m³/s) cum_ flow_q2t	(m³/s) corr_cum_ flow_q1c	(m³/s) corr_cum_ flow_q2c	(m³/s) corr_cum_ flow_q1tc
HFM23	2006-03-20 15:02	2006-03-20 15:58	31.00	80.00		211.50								
HFM27	2006-03-06 16:25	2006-03-06 19:47	12.00	125.00		127.50								

cont.

(m³/s) corr_cum_ flow_q2tc	(m³/s) corr_com_ flow_q1tcr	(m³/s) corr_com_ flow_q2tcr	(m²/s) transmissitivy_ hole_t	value_ type_t	bc_ t	(m²) cum_ transmissivity_tf	value_ type_tf	bc_ tf	(m²/s) l_measl_tf	(m²) cum_ transmissivity_tft	value_ type_ tft	bc_ tft	(m²/s) u_ measl_tf	reference	comments
			4.3E-06	0	1										
	8.3000E-04		8.3E-05	0	1				1.67E-06	8.3E-05	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 table descr
corr_cum_flow_q2c	FLOAT	m^3/s	Corrected cumulative flow q2 at pump flow Q2, see table descr
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	(m) secup	(m) seclow	section_ no	(m) l_a_upper	(m) l_a_lower	(°C) fluid_ temp_tea	(mS/m) fluid_ elcond_eca	(mg/l) fluid_salinity_ tdsa	(m^3/s) dq1	(m^3/s) dq2
HFM27	2006-03-06 16:25	2006-03-06 19:47	12.00	125.00		19.30	19.80					
HFM27	2006-03-06 16:25	2006-03-06 19:47	12.00	125.00		27.00	28.50					
HFM27	2006-03-06 16:25	2006-03-06 19:47	12.00	125.00		54.00	54.80					
HFM27	2006-03-06 16:25	2006-03-06 19:47	12.00	125.00		119.00	119.50					

cont.

(m) r_wa	(m^3/s) dq1_ corrected	(m^3/s) dq2_ corrected	(m^2/s) spec_cap_ dq1c_s1	(m^2/s) spec_cap_ dq2c_s2	value_ type_ dq1_s1	value_ type_dq2_ s2	(m) ba	(m^2/s) transmissivity_ tfa	value_ type_ tfa	bc_ tfa	(m^2/s) l_measl_tfa	(m^2/s) u_measl_tfa	comments
0.07	1.3E-04		4.2E-05		0		0.3	1.3E-05	0	1	1.67E-06	8.30E-05	
0.07	2.3E-04		7.5E-05		0		1.5	2.3E-05	0	1	1.67E-06	8.30E-05	
0.07	4.0E-04		1.3E-04		0		0.8	4.0E-05	0	1	1.67E-06	8.30E-05	
0.07	6.7E-05		2.2E-05		0		0.5	6.7E-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	°C	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 Q1 or head h1
dq2	FLOAT	m^3/s	Flow rate of inferred flow anomaly at pump flow Q2 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 descr
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