P-06-139

Forsmark site investigation

Pumping tests and flow logging

Boreholes HFM25, HFM26

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May 2006

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ISSN 1651-4416
SKB P-06-139

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Keywords: Forsmark, Hydrogeology, Hydraulic tests, Pumping tests, Flow meter logging, Water sampling, Hydraulic parameters, Transmissivity, Flow anomaly, AP PF 400-05-121.

Abstract

The main objectives of the hydraulic tests in the percussion boreholes HFM25 and HFM26 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 borehole tests had been carried out in the actual boreholes before this campaign.

Both boreholes are drilled towards identified structure lineaments. HFM25 was drilled towards a lineament designated ZFMNE062A and HFM26 towards lineament ZFMNE0065. Thus, if possible, the aim was to identify the fracture zone or zones associated with the lineaments.

A pre-test (short capacity test) was performed to decide wether it was meaningful to make a pumping test in combination with flow logging or only a pumping test.

In borehole HFM25 the pumping capacity showed to be very low. By means of shunting back a portion of the out-pumped water to the borehole, it was possible to maintain a pumping flow rate at c 0.5 L/min (lowest possible flow rate without shunting is c 5 L/min), still causing a slow drawdown. Due to the low capacity it was decided to prolong the pre-test and measure the recovery until the next day since an ordinary 10 h pumping would not be possible.

In borehole HFM26, despite the relatively low pumping flow rate (c 9 L/min), an attempt to perform a flow logging was made. However, no flow above the measurement limit for the flow logging device could be identified along the part of the borehole that could be logged (37–180 m). A disturbance during the recovery in the pumping test, probably caused by re-infiltrating water from the pumping, brought about that only the drawdown could be evaluated.

Water sampling was performed to investigate the hydrochemistry of the groundwater in all boreholes in conjunction with the pumping tests. In HFM25 only one sample was taken during a complementary pumping performed immediately after the recovery measurements were finished.

The total borehole transmissivity of HFM25 was estimated at $3.8 \cdot 10^{-7}$ m^2/s.

In HFM26 the total transmissivity was estimated at $1.0 \cdot 10^{-5}$ m^2/s. During the logging of electric conductivity of the borehole water three possible flow anomalies were found, all below the measurement limit for the flow logging.

Sammanfattning

Det övergripande syftet med de hydrauliska testerna i hammarborrhål HFM25 och HFM26 som presenteras i denna rapport 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.

Båda borrhålen är borrade mot identifierade lineament. HFM25 borrades mot ett lineament benämnt ZFMNE062A och HFM26 mot ett lineament benämnt ZFMNE0065. Om möjligt ville man alltså karaktärisera den eller de eventuella zoner som är kopplade till lineamenten.

Ett förtest (kort kapacitetstest) skulle få utvisa om det var meningsfullt att genomföra provpumpning kombinerat med flödesloggning eller om endast pumptest skulle göras.

I HFM25 visade det sig att pumpkapaciteten var mycket låg. Med hjälp av återshuntning av pumpvatten till borrhålet kunde ett flöde på drygt 0,5 L/min upprätthållas (lägsta flöde utan shuntning är annars ca 5 L/min), fortfarande med en långsam avsänkning av nivån i borrhålet. Därför valdes att förlänga pumpningen under förtestet något och mäta återhämtning till nästföljande dag eftersom en ordinär pumpning på 10 timmar inte skulle kunna genomföras.

I HFM26 gjordes ett försök med flödesloggning trots det relativt låga flödet (ca 9 L/min). Dock identifierades inget flöde över flödessondens mätgräns längs den del av borrhålet som kunde flödesloggas (37 till 180 m). En störning av återhämtningen av pumptestet, troligtvis orsakad av återinfiltration av pumpvatten, medförde att endast pumpfasen var utvärderingsbar.

Vattenprover för undersökning av grundvattnets hydrokemiska egenskaper togs i samband med pumptesterna i borrhålen. I HFM25 togs endast ett vattenprov vid en kompletterande pumpning omedelbart efter att mätningen av återhämtningen slutförts.

Totala transmissiviteten för HFM25 uppskattades till $3,8 \cdot 10^{-7}$ m^2/s.

För HFM26 uppskattades den totala transmissiviteten till $1,0 \cdot 10^{-5}$ m^2/s. Från loggningen av vattnets elektriska konduktivitet kunde tre möjliga flödesanomalier hittas.

Contents

1 Introduction

This document reports the results of the hydraulic testing of boreholes HFM25 and HFM26 within the Forsmark site investigation. The tests were carried out as pumping tests, in HFM26 combined with flow logging. Water sampling was undertaken in both boreholes in conjunction with the tests. No other hydraulic tests had been carried out in the actual boreholes before this campaign.

Borehole HFM25 is situated between drilling site DS2 and drilling site DS6, while HFM26 is situated close to the road leading to drilling site DS3, see Figure 1-1.

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.

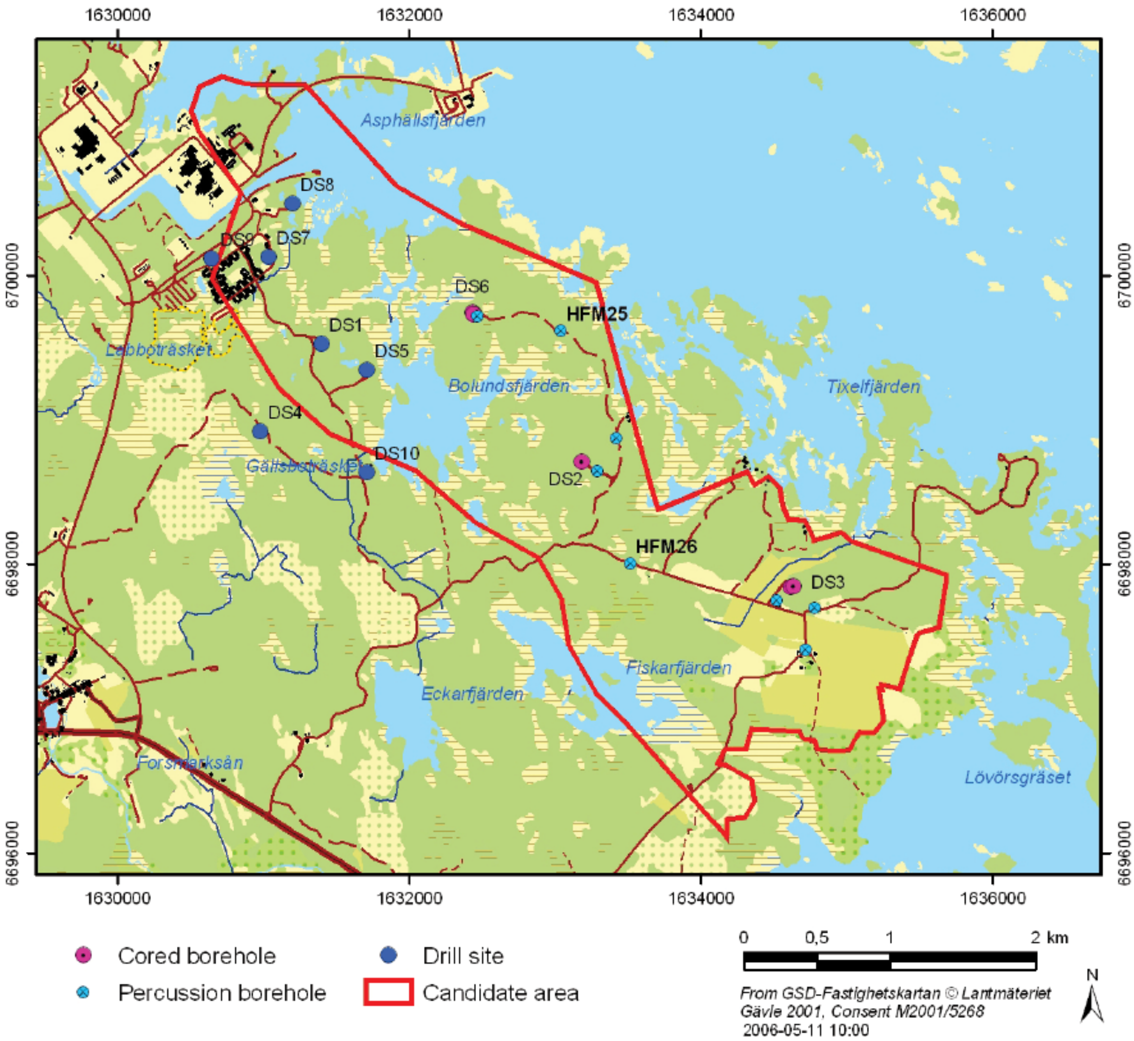


Figure 1-1. *Map showing the location of boreholes HFM25 and HFM26.*

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 descriptions	**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 HFM25 and HFM26 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.

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 below the casing. The borehole diameter decreases more or less along the borehole due to wearing of the drill bit.

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.)	Borehole length from ToC (m)	Bh-diam. (below casing) (m)	Inclin. -top of bh (from horizontal plane) (º)	Dip-Direction -top of bh (º)	Northing (m)	Easting (m)	Length (m)	Inner diam. (m)	Date (YYYY -MM-DD)
HFM25	3.86	187.5	0.140	–57.8	140.8	6,699,616	1,633,039	9.1	0.160	2005-09-08
HFM26	2.73	202.7	0.141	–53.8	112.4	6,698,009	1,633,516	12.0	0.160	2005-11-18

3.2 Tests performed

The different test types conducted in HFM25 and HFM26, 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 3-2. 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)
HFM25	9.1–187.5	1B	Open hole	2006-02-28 16:35	2006-03-01 10:32
HFM26	12.0–202.7	1B	Open hole	2006-02-09 10:15	2006-02-10 07:39
HFM26	38–180	6, L-EC, L-Te	Open hole	2006-02-09 16:23	2006-02-09 18:00

[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 Figures 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 can not be located deeper than c 80 m due to limitations in the number of pipes available.

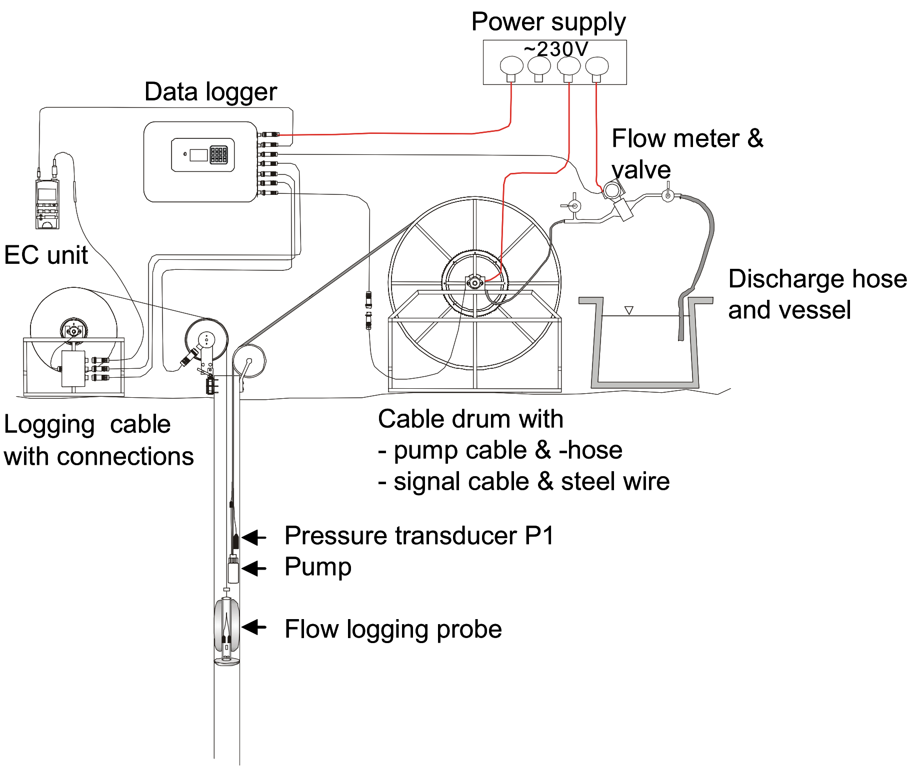


Figure 4-1. Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB. (From SKB MD 326.001, SKB internal document).

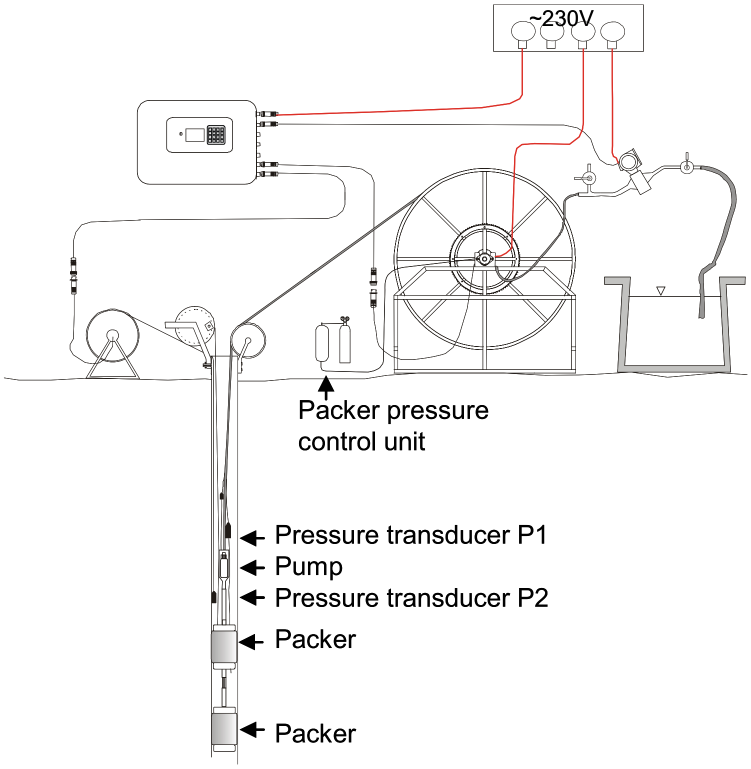


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB. (From SKB MD 326.001, SKB internal document).*

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 electro-magnetic 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).

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.

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

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

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

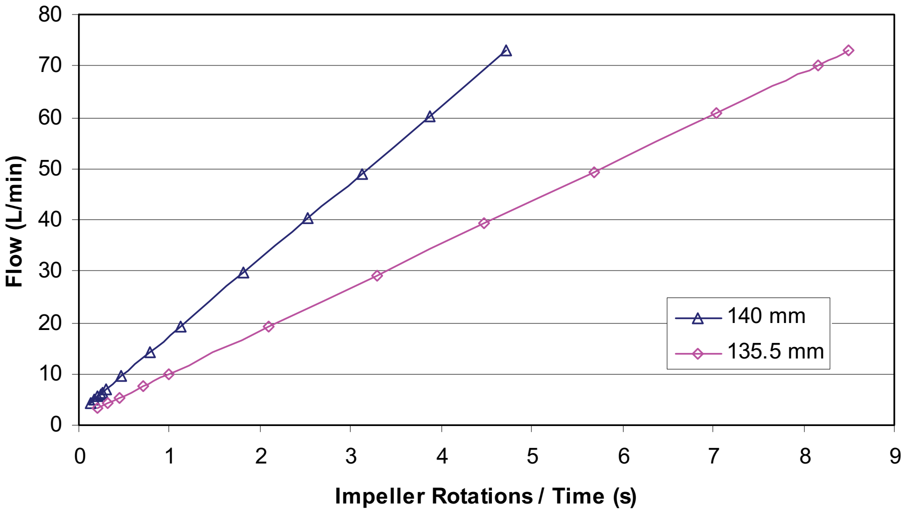


Figure 4-3. Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).

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.

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.

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

Borehole information				Sensors		Equipment affecting wellbore storage (WBS)			
ID	Test interval (m)	Test config	Test type[1)]	Type	Position (m b ToC)	Function	Position [2)] relative test section	Outer diameter (mm)	C (m^3/Pa) for test[3)]
HFM25	9.0–187.5	Open hole	1B	Pump-intake	39.4	Pump hose	In section	33.5	$2.3 \cdot 10^{-6}$
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	36.72	Signal cable	In section	8	
HFM26	12.0–202.7	Open hole	1B	Pump-intake	34.4	Pump hose	In section	33.5	$2.4 \cdot 10^{-6}$
			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	
			6	EC, Te, Q	38–180	Signal cable	In section	13.5	

[1)] 1B: Pumping test-submersible pump, 3: Injection test, 6: Flow logging–Impeller incl. EC-logging (EC-sec) and temperature logging (Te-sec)
[2)] Position of equipment that can affect wellbore storage. Position given as "In Section" or "Above Section"
[3)] Based on the casing diameter or the actual borehole diameter (Table 3-1) for open-hole tests together with the compressibility of water for the test in isolated sections, respectively (net values)

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 was 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 tests followed by a pressure recovery period. At the end of the pumping period flow logging was 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 HFM25 the flow had to be lowered successively during the test and at the end of the capacity test the flow rate was only c 0.5 L/min with nearly stable ground water level. In order to maintain enough cooling of the pump, with such a low withdrawal, it was necessary to shunt back a certain amount of the pumped water to the borehole. Due to these conditions it was not found meaningful to perform the ordinary 10 h long pumping test. Instead the recovery was prolonged to the next day and the capacity test was evaluated for the entire test sequence (not divided into drawdown and recovery). The capacity test in HFM25 was c 1.5 h long followed by a recovery of 16.5 h.

The main test in HFM26 was a c 10 h pumping test in the open hole in combination with flow logging, followed by a recovery period of c 12 h.

In general, the sampling frequency of pressure and flow during the pumping tests was according to Table 5-1. The hydraulic tests in borehole HFM26 were performed before the test in HFM25.

Table 5-1. Sampling interval 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 in HFM26, the probe was lowered almost to the bottom of the borehole. While lowering along the borehole, temperature, flow in borehole and electric conductivity data were sampled.

Flow logging was performed during the long pumping test (10 h), starting from the bottom of the hole going upwards. The logging started when the pressure in the borehole was approximately stable. The time needed to complete the flow logging survey depends on the length and character of the borehole. In general, between 3–5 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 are comma-separated (*.DAT) when copied to a computer. Data files used for transient evaluation are further converted to *.mio-files by the code Camp2mio. The operator can choose the parameters to be included in the conversion (normally pressure and discharge). Data from the flow logging are evaluated in Excel and therefore not necessarily transformed to *.mio-files. A list of 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 are 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 is 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) /3/ for constant flow rate tests with radial flow, accounting for wellbore storage and skin effects, is generally used for estimating transmissivity, storativity and skin factor for actual values on the borehole- and casing radius.

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.

AQTESOLV also includes models for discrete fractures (horizontal and vertical, respectively) intersecting the borehole, causing pseudo-linear flow.

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) /4/ 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 /2/ or alternatively, from the simulated effective casing radius. These values on C may be compared with the net values of the wellbore storage coefficient based on actual borehole geometrical data. The estimated values on C from the test data may differ from the net values due to deviations of the actual geometrical borehole data from the anticipated, e.g. regarding the borehole diameter, or presence of fractures or cavities with significant volumes.

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

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

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, eventually 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:

$T_i = Corr \cdot dQ_i / Q_p \cdot T$ (5-4)

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

$T_F(L) = Corr \cdot Q(L)/Q_p \cdot T$ (5-5)

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:

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

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

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

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

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

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

where

Corr = Q_{FT}/Q_T

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

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

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

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

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

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

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

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

Similarly, the lower measurement limit of transmissivity of a flow anomaly can be estimated using $dQ_{i\ min}$ = 1 L/min ($1.7\cdot10^{-5}$ 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 I compliance with the Activity Plan, however with the following exceptions:

- In borehole HFM25 the ordinary 10 h pumping test was not carried out due to very low flow rate. Instead the capacity test including a prolonged recovery was evaluated.

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 c10 h+12 h due to practical reasons (mainly to avoid uncontrolled pumping over-night and to eliminate the risk of freezing, theft/sabotage etc). Experience from similar tests 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.

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. In HFM25, since no 10 hours pumping test could be done, only one water sample was collected after a short pumping the day after the capacity test.

Table 6-1. Water samples collected during the pumping tests in boreholes HFM25 and HFM26 and submitted for analysis.

Bh ID	Date and time of sample	Pumped section (m)	Pumped volume (m^3)	Sample type	Sample ID no.	Remarks
HFM25	2006-03-01 10:35	9.1–187.5	0.61*	WC080	012058	Open-hole test
HFM26	2006-02-09 11:17	12.03–202.7	0.56	WC080	012056	Open-hole test
HFM26	2006-02-09 15:20	12.03–202.7	2.73	WC080	012055	Open-hole test
HFM26	2006-02-09 20:24	12.03–202.7	5.48	WC080	012049	Open-hole test

* The main portion (0.56 m^3) was pumped out during a capacity test the day before the water sampling.

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 were checked to identify possible interference on the hydraulic test data from drilling or other activities in nearby boreholes during the test periods. These records show that the drilling of KFM01D and air lift pumping in KFM01C at drill site DS1, see Figure 1-1, were in progress during the test periods for HFM26. Air lift pumping in KFM01D was finished c 2 h. before the pumping in HFM25. However, long distance to drill site DS1 and low transmissivities in the boreholes tested should infer that tests were unaffected by the drilling and pumping activities at DS1 and no obvious influence from these activities on the test results can be seen.

6.3.1 Borehole HFM25: 9.1–187.5 m

General test data for the open-hole pumping test in HFM25 are presented in Table 6-2.

The atmospheric pressure during the test period in HFM25, which is presented in Figure 6-1, varied less than 0.1 kPa, 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 has affected the groundwater levels.

Comments on test

Due to the particular conditions with a very low pumping capacity it was not possible to perform the ordinary 10 h long pumping test, and the pumping was interrupted after 87 minutes. Instead the recovery was prolonged to the next day and the capacity test was evaluated on the entire test sequence (not divided into drawdown and recovery).

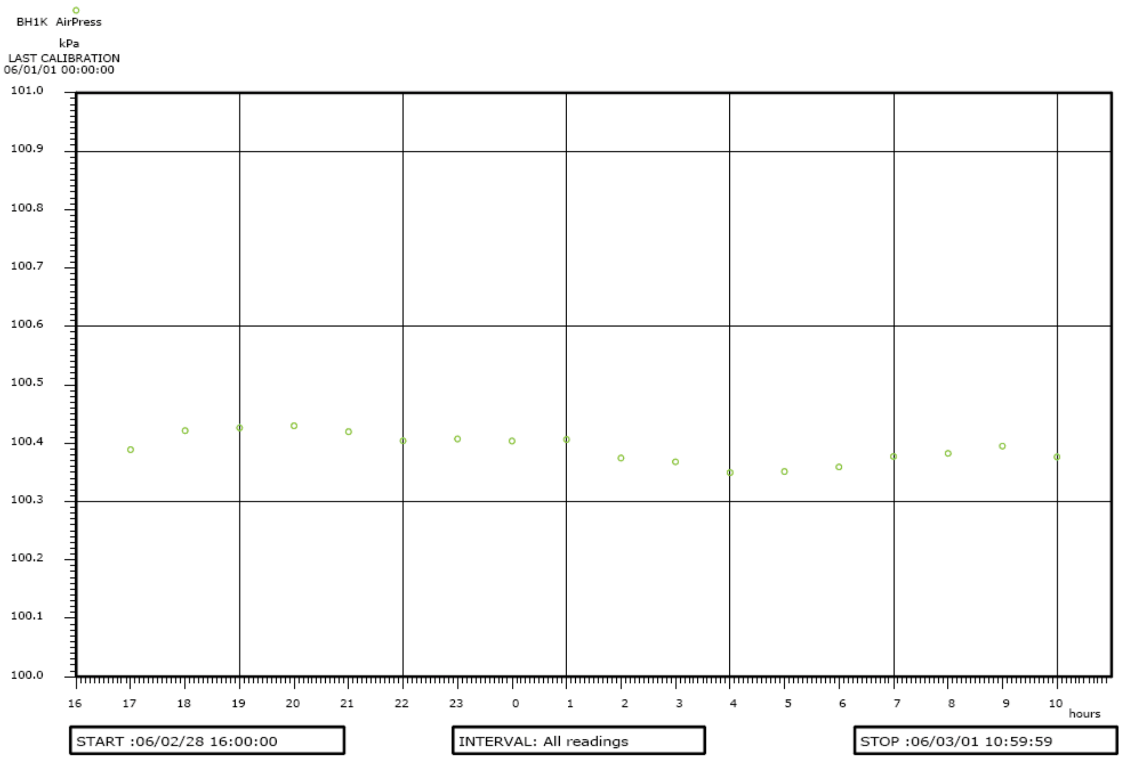


Figure 6-1. *Atmospheric pressure during the test period in HFM25.*

Table 6-2. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM25.

General test data				
Borehole	HFM25 (9.1–187.5 m)			
Test type	Capacity test and recovery.			
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			
	Nomenclature	**Unit**	**Value**	
Borehole length	L	M	187.5	
Casing length	L_c	M	9.1	
Test section – secup	Secup	M	9.1	
Test section – seclow	Seclow	M	187.5	
Test section length	L_w	M	178.4	
Test section diameter	$2 \cdot r_w$	Mm	top 139.5 bottom 138.6	
Test start (start of pressure registration)		yymmdd hh:mm	060228 16:30:09	
Packer expanded		yymmdd hh:mm:ss		
Start of flow period		yymmdd hh:mm:ss	060228 16:35:03	
Stop of flow period		yymmdd hh:mm:ss	060228 18:02:00	
Test stop (stop of pressure registration)		yymmdd hh:mm	060301 10:31:53	
Total flow time	t_p	Min	87	
Total recovery time	t_F	Min	990	

Pressure data	**Nomenclature**	**Unit**	**Value**	**GW Level (m.a.s.l.)**[2]
Absolute pressure in test section before start of flow period	p_i	kPa	373.7	1.40
Absolute pressure in test section at stop of flow period	p_p	kPa	96.6	
Absolute pressure in test section at stop of recovery period	p_F	kPa	234.2	
Maximal pressure change in test section during the flow period	dp_p	kPa	277.1	

Manual groundwater level measurements			**GW level**	
Date YYYY-MM-DD	**Time tt:mm.ss**	**Time (min)**	**(m bToC)**	**(m.a.s.l.)**
2006-02-28	13:16:00	–199	4.13	0.36
2006-02-28	16:31:00	–4	2.91	1.40

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$9.333 \cdot 10^{-6}$
Mean (arithmetic) flow rate during flow period[2]	Q_m	m^3/s	$1.08 \cdot 10^{-4}$
Total volume discharged during flow period[2]	V_p	m^3	0.56

1) From the manual measurements of groundwater level.
2) Calculated from integration of the transient flow rate curve during the flow period.

Interpreted flow regimes

Selected test diagrams according to the Instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-1–3 in Appendix 2.

As a result of the very low transmissivity, demonstrated by the very slow recovery in Figure A2-1, both the drawdown and the recovery period are dominated by wellbore storage.

Interpreted parameters

Transient evaluation of transmissivity was performed for the entire test period including both drawdown and recovery. This was done because it was difficult to obtain a stable solution when evaluating the flow- and recovery periods separately. The hydraulic parameters were more well-defined when evaluating the entire test period. The transient, quantitative interpretation of the test is presented in Figures A2-2–3 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 including wellbore storage and skin /3/.

The results are shown in the Test Summary Sheet (Table 6-8) and in Tables 6-5, 6-6 and 6-7.

6.3.2 Borehole HFM26: 12.0–202.7 m

General test data for the open-hole pumping test in HFM26 in conjunction with flow logging are presented in Table 6-3.

The atmospheric pressure during the test period in HFM26, which is presented in Figure 6-2, increased by c 1.5 kPa, i.e. only c 1% of the total drawdown of c 140 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 has affected the ground water levels.

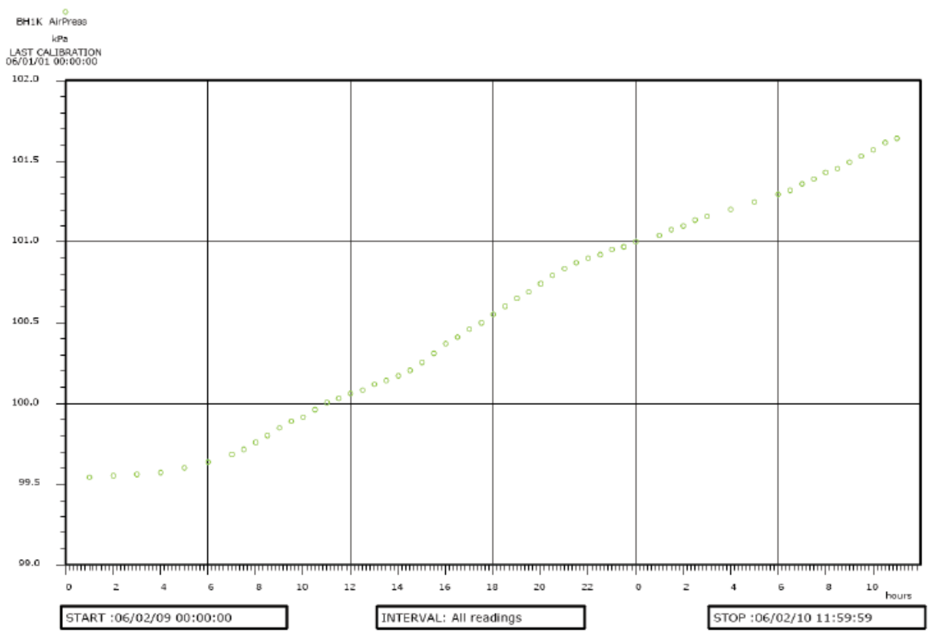


Figure 6-2. *Atmospheric pressure during the test period in HFM26.*

Table 6-3. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM26, in conjunction with flow logging.

General test data				
Borehole	HFM26 (12.0–202.7 m)			
Test type[1]	Constant rate withdrawal and recovery test			
Test section (open borehole/packed-off section):	Open borehole			
Test no.	1			
Field crew	S. Jönsson, J. Olausson and P. Fredriksson, GEOSIGMA AB			
Test equipment system	HTHB			
General comment	Single pumping borehole			
	Nomenclature	**Unit**	**Value**	
Borehole length	L	M	202.7	
Casing length	L_c	M	12.0	
Test section – secup	Secup	M	12.0	
Test section – seclow	Seclow	M	202.7	
Test section length	L_w	M	190.7	
Test section diameter	$2 \cdot r_w$	Mm	top 141.2 bottom 138.4	
Test start (start of pressure registration)		yymmdd hh:mm	060209 09:53:53	
Packer expanded		yymmdd hh:mm:ss		
Start of flow period		yymmdd hh:mm:ss	060209 10:15:02	
Stop of flow period		yymmdd hh:mm:ss	060209 20:24:00	
Test stop (stop of pressure registration)		yymmdd hh:mm	060210 07:39:21	
Total flow time	t_p	Min	609	
Total recovery time	t_F	Min	675	

Pressure data	**Nomenclature**	**Unit**	**Value**	**GW Level (m.a.s.l.)[2]**
Absolute pressure in test section before start of flow period	p_i	kPa	322.73	1.18
Absolute pressure in test section at stop of flow period	p_p	kPa	182.58	–13.65
Absolute pressure in test section at stop of recovery period	p_F	kPa	324.93	1.04
Maximal pressure change in test section during the flow period	dp_p	kPa	140.15	14.83

Manual groundwater level measurements

Date YYYY-MM-DD	**Time tt:mm:ss**	**Time (min)**	**GW level (m bToC)**	**GW level (m.a.s.l.)**
2006-02-08	09:37:00	–1,478	1.90	1.20
2006-02-08	13:00:00	–1,275	1.90	1.20
2006-02-08	16:30:00	–1,065	2.52	0.70
2006-02-09	09:55:00	–20	1.92	1.18
2006-02-09	13:51:00	216	18.41	–12.12
2006-02-09	15:30:00	315	19.28	–12.82
2006-02-09	19:31:00	556	20.27	–13.62
2006-02-09	20:11:00	596	20.31	–13.65
2006-02-10	07:36:00	1,281	2.09	1.04

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.494 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period[3]	Q_m	m^3/s	$1.500 \cdot 10^{-4}$
Total volume discharged during flow period[3]	V_p	m^3	5.48

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery or Constant drawdown withdrawal and recovery.
[2] From the manual measurements of groundwater level.
[3] Calculated from integration of the transient flow rate curve during the flow period.

Comments on test

When studying the test data a very rapid recovery compared to the drawdown is evident. One can also see a disturbance at the end of the drawdown (cf Figure A2-4). This disturbance, occurring after c 300 minutes of pumping, is partly due to reduced displacement in the borehole when the flow logging equipment is lifted. Another disturbance at the end of the drawdown period is probably caused by re-infiltration of discharged water, which also strongly influences the recovery. The surroundings are very flat and it was not possible to find a good place to let out the discharge water from the pumping.

The day before test start, a short capacity test was performed (c 85 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 10 L/min and the drawdown c 20.5 m, but slowly increasing. The actual pumping test was performed as a constant flow rate test (9 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. The drawdown in the end of the pumping test was c 14.3 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

The drawdown is dominated by wellbore storage until a disturbance is occurring at the end of the drawdown period (see above). Due to the disturbances at the end of the drawdown and during the recovery period no evaluation of the recovery was made and the evaluation of the drawdown is for the same reason restricted to the first 400 minutes.

Selected test diagrams according to the instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-4–8 in Appendix 2.

Interpreted parameters

Transient evaluation of transmissivity was performed only for the drawdown period, and the quantitative interpretation of the test is presented in Figures A2-5–6 in Appendix 2. The quantitative analysis was carried out according to the methods described in Section 5.4.1. The transmissivity was estimated by a model assuming pseudo-radial flow including wellbore storage and skin /3/.

The results are shown in the Test Summary Sheet (Table 6-9) and in Tables 6-5, 6-6 and 6-7. The analysis from the flow period was selected as representative for the test.

6.4 Flow logging

In borehole HFM25 it was not possible to achieve a pumping rate above the lower measurement limit for the flow logging equipment (c 3 L/min in a 140 mm borehole).

To achieve a reasonably high pumping rate in borehole HFM26, it was necessary to lower the pump to c 35 m borehole length, entailing that the uppermost c 37 m of the borehole could not be measured during the flow logging. The logging started at 180 m, but no flow above the lower measurement limit for the flow logging equipment was found between 37 and 180 m borehole length. The results from the simultaneous logging of temperature and electrical conductivity are presented in the following chapter.

6.4.1 Borehole HFM26

General test data for the flow logging in borehole HFM26 are presented in Table 6-4.

Table 6-4. General test data, groundwater level and flow data for the flow logging in borehole HFM26.

General test data					
Borehole	HFM26				
Test type(s)[1]	6, L-EC, L-Te				
Test section:	Open borehole				
Test no.	1				
Field crew	S. Jönsson, and P. Fredriksson, GEOSIGMA AB				
Test equipment system	HTHB				
General comments	Single pumping borehole				
	Nomenclature	**Unit**		**Value**	
Borehole length		m		202.7	
Pump position (lower level)		m		35	
Flow logged section – Secup		m		37	
Flow logged section – Seclow		m		180	
Test section diameter	2·rw	mm		top 141.2 bottom 138.4	
Start of flow period		yymmdd hh:mm		060209 10:15:02	
Start of flow logging		yymmdd hh:mm		060209 16:23	
Stop of flow logging		yymmdd hh:mm		060209 17:58	
Stop of flow period		yymmdd hh:mm		060209 20:24:00	
Groundwater level		**Nomen-clature**	**Unit**	**G.w-level (m b ToC)**	**G.w-level (m.a.s.l.)[2]**
Groundwater level in borehole, at undisturbed conditions, open hole		h_i	m	1.92	1.18
Groundwater level (steady state) in borehole, at pumping rate Q_p		h_p	m	20.31	–13.65
Drawdown during flow logging at pumping rate Q_p		s_{FL}	m		14.83
Flow data		**Nomen-clature**	**Unit**	**Flow rate**	
Pumping rate at surface		Q_p	m^3/s	$1.5 \cdot 10^{-4}$	
Corrected flow rate at Secup at pumping rate Q_p		Q_{Tcorr}	m^3/s		
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 180 m borehole length and upwards. When logging with a dummy to detect obstacles in the borehole, there were some problems to pass 180 m and therefore the flow logging probe was not lowered below this level. Since 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 37 m borehole length.

Logging results

The measured electric conductivity (EC) and temperature of the borehole fluid during the logging is presented in Figure 6-3. These variables are normally used as supporting information when interpreting flow anomalies.

Since no detectable flow was found in the logged interval (37–180 m) the accumulated inflows below 37 m must be less than the threshold value for the flow logging (c 3 L/min). According to Equation (5-11) the transmissivity below 37 m should then be less than c $3.4 \cdot 10^{-6}$ m²/s using the evaluated transmissivity for the entire borehole (T_T) from the pumping test.

From the logging of electric conductivity three possible inflow anomalies could be detected in the logged interval, one at c 179–180 m and another at c 131–132 m where the EC is increasing rather abruptly. A slightly more rapid decrease in EC between c 105 and c 110 m. than the overall decline could possibly also indicate some small inflow.

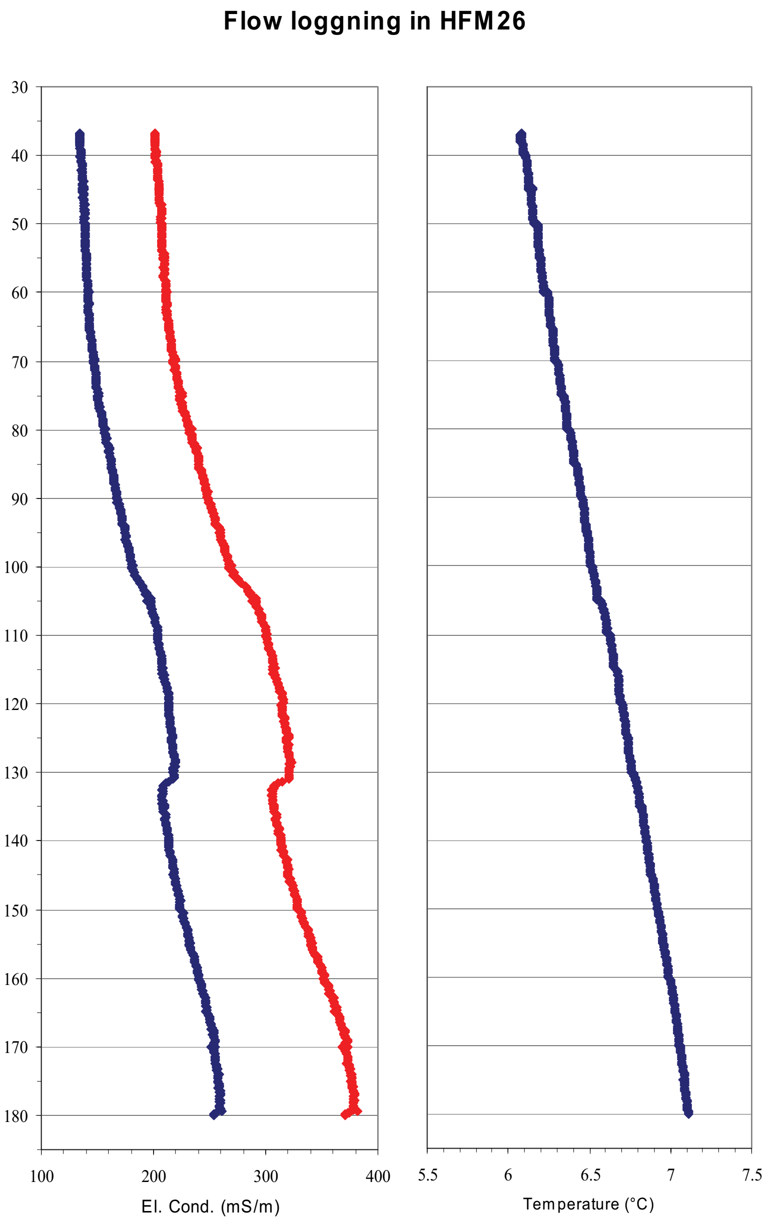


Figure 6-3. *Measured (blue) and temperature compensated (red) electrical conductivity and temperature of the borehole fluid along borehole HMF26 during flow logging.*

6.5 Summary of hydraulic tests

A compilation of measured test data from the pumping tests in the two boreholes is presented in Table 6-5. In Table 6-6 and Table 6-7, and in the test summary sheets in Tables 6-8 and 6-9, hydraulic parameters calculated from the tests in HFM25 and HFM26 are shown.

In Table 6-5, 6-6 and Table 6-7, 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 6-5. Summary of test data for the open-hole pumping tests performed with the HTHB system in boreholes HFM25 and HFM26 in the Forsmark candidate area.

Borehole ID	Section (m)	Test type[1]	p_i (kPa)	p_p (kPa)	p_F (kPa)	Q_p (m^3/s)	Q_m (m^3/s)	Vp (m^3)
HFM25	9.1–187.5	1B	373.7	96.6	234.2	$9.333\cdot10^{-6}$	$1.08\cdot10^{-4}$	0.56
HFM26	12.0–202.7	1B	322.73	182.58	324.93	$1.494\cdot10^{-4}$	$1.5\cdot10^{-4}$	5.48

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

Table 6-6. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed with the HTHB system in boreholes HFM25 and HFM26 in the Forsmark candidate area.

Borehole ID	Section (m)	Flow anomaly interval (m)	Test type[1]	Q/s (m^2/s)	T_M (m^2/s)	T_T (m^2/s)	T_i (m^2/s)	S* (–)
HFM25	9.1–187.5		1B	$3.3\cdot10^{-7}$	$4.3\cdot10^{-7}$	$3.8\cdot10^{-7}$		$4.0\cdot10^{-7}$
HFM26	12.0–202.7		1B	$1.1\cdot10^{-5}$	$1.4\cdot10^{-5}$	$1.0\cdot10^{-5}$		$2.2\cdot10^{-6}$

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

Table 6-7. Summary of calculated hydraulic parameters from the hydraulic tests performed with the HTHB system in boreholes HFM25 and HFM26 in the Forsmark candidate area.

Borehole ID	Section (m)	Test type	S* (–)	C (m^3/Pa)	ζ (–)
HFM25	9.1–187.5	1B	$4.0\cdot10^{-7}$	$2.3\cdot10^{-6}$	–0.1
HFM26	12.0–202.7	1B	$2.2\cdot10^{-6}$	$3.6\cdot10^{-6}$	–2.8

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.

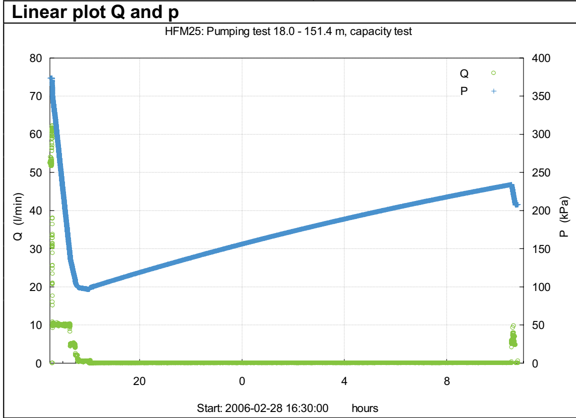
A special arrangement in HFM25, shunting back parts of the out-pumped water through a valve ahead of the flow meter at ground, made a shorter capacity test possible with a lowest flow rate at c 0.56 L/min. From the transient evaluation of this test a transmissivity lower than Q/s-L was calculated, but it should be emphasized that the accuracy of this value is less than normal for two reasons:

1. A low borehole transmissivity demands a longer test period to achieve the same precision in the determination of the flow parameters, mainly due to the prolonged influence of wellbore storage. In this case the total flow time was only 87 minutes but the recovery was 990 minutes.
2. The relative accuracy of the flow meter at surface is decreasing with decreasing flow.

Table 6-8. Test Summary Sheet for the pumping test in HFM25, Section 9.1–187.5 m.

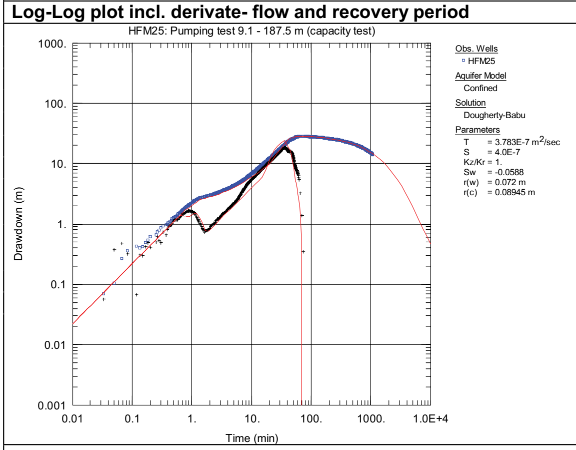
Test Summary Sheet			
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM25	Test start:	2006-02-28 16:30:09
Test section (m):	9.1-187.5	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2 \cdot r_w$ (m):	top 0.1395 bottom 0.1386	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

Linear plot Q and p



Flow period*		**Recovery period***	
Indata		**Indata**	
p_0 (kPa)	373.7		
p_i (kPa)	373.7		
p_p(kPa)	96.6	p_F (kPa)	234.2
Q_p (m^3/s)	$9.333 \cdot 10^{-6}$		
tp (min)	87	t_F (min)	990
S*	$4.0 \cdot 10^{-7}$	S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m^2/s)	$1.8 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$4.3 \cdot 10^{-7}$		
Flow regime:	WBS	Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)	$3.8 \cdot 10^{-7}$	T_w (m^2/s)	
S_w (-)		S_w (-)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$2.3 \cdot 10^{-6}$	C (m^3/Pa)	
C_D (-)		C_D (-)	
ξ (-)	-0.1	ξ (-)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Log-Log plot incl. derivate- flow and recovery period



Interpreted formation and well parameters.			
Flow regime:	WBS	C (m^3/Pa)	$2.3 \cdot 10^{-6}$
t_1 (min)		C_D (-)	
t_2 (min)		ξ (-)	-0.1
T_T (m^2/s)	$3.8 \cdot 10^{-7}$		
S (-)	$4.0 \cdot 10^{-7}$		
K_s (m/s)			
S_s (1/m)			

Comments:

Since it was difficult to get a stable solution evaluating the drawdown or the recovery alone, an evaluation for the entire test period was performed.

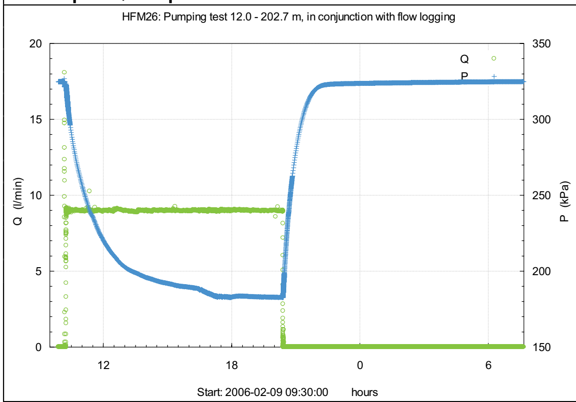
Due to the relatively short test period in relation to the low transmissivity, wellbore storage effects are dominating the pressure response for the entire test. No pseudo-radial flow regime was developed.

* The test was evaluated for the entire test period, including both drawdown and recovery.

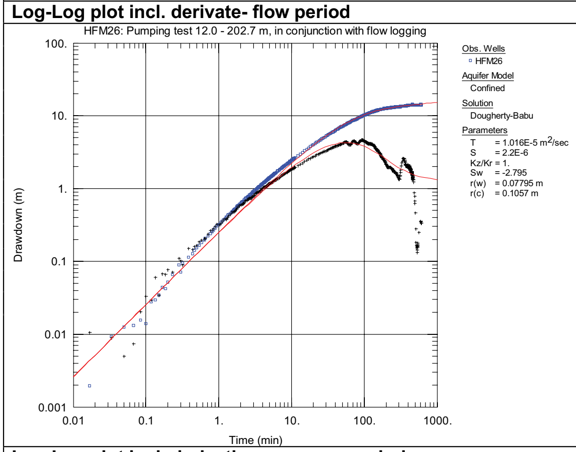
Table 6-9. Test Summary Sheet for the pumping test in HFM26, Section 12.0–202.7 m.

Test Summary Sheet			
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM26	Test start:	2006-02-09 09:53:53
Test section (m):	12.0-202.7	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2 \cdot r_w$ (m):	top 0.1412 bottom 0.1384	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

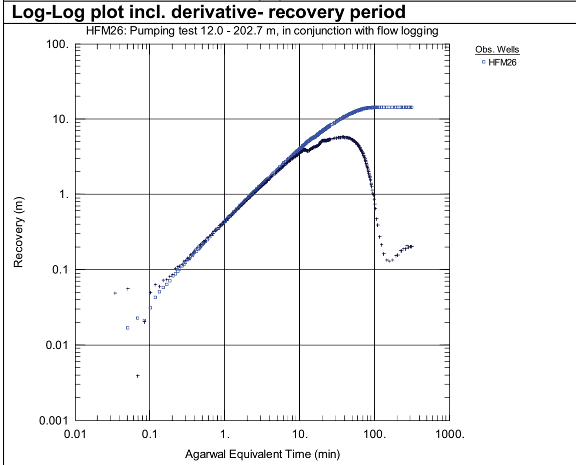
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	322.73		
p_i (kPa)	322.73		
p_p(kPa)	182.58	p_F (kPa)	324.93
Q_p (m^3/s)	$1.494 \cdot 10^{-4}$		
tp (min)	609	t_F (min)	675
S*	$1.1 \cdot 10^{-6}$	S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.2	Derivative fact.	
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->	Flow regime:	
t_1 (min)	0	dt_{e1} (min)	
t_2 (min)	200	dt_{e2} (min)	
T_w (m^2/s)	$1.0 \cdot 10^{-5}$	T_w (m^2/s)	
S_w (-)	$2.2 \cdot 10^{-6}$	S_w (-)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$3.6 \cdot 10^{-6}$	C (m^3/Pa)	
C_D (-)		C_D (-)	
ξ (-)	-2.8	ξ (-)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Interpreted formation and well parameters.			
Flow regime:	WBS->	C (m^3/Pa)	$3.6 \cdot 10^{-6}$
t_1 (min)	0	C_D (-)	
t_2 (min)	200	ξ (-)	-2.8
T_T (m^2/s)	$1.0 \cdot 10^{-5}$		
S (-)	$2.2 \cdot 10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments:
The first part of the drawdown is dominated by wellbore storage A disturbance is occurring after c. 300 min. This disturbance is partly due to reduced displacement in the borehole when the flow logging equipment is lifted. Another disturbance at the end of the drawdown period is probably caused by re-infiltration of discharged water, which also strongly influences the recovery. Therefore no evaluation of the recovery period is performed.

7 References

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

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

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

/4/ **Rehn I (ed), Gustafsson G, Stanfors R, Wikberg P, 1997.** Äspö HRL Geoscientific evaluation 1997/5. Models based on site characterization 1986–1995. SKB TR 97-06, Svensk Kärnbränslehantering AB.

Appendix 1

List of data files

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

Bh ID	Test section (m)	Test type[1]	Test no.	Test start Date, time YYYY-MM-DD tt:mm:ss	Test stop Date, time 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
HFM25	9.1–187.5	1B	1	2006-02-28 16:35:00	2006-03-01 10:47:15	2006-02-28 16:30:09	2006-03-01 10:47:15	HFM25_9.1_060228_Pumpin01.DAT	P, Q	Primarily meant to be a capacity test
						2006-02-28 13:53:11	2006-03-01 10:47:15	HFM25_9.1_060228_Ref_Da01.DAT		Reference file
HFM26	12.0–202.7	1B	1	2006-02-09 10:15:00	2006-02-10 07:39:21	2006-02-09 09:53:53	2006-02-10 07:39:21	HFM26_12.0_060209_FlowLo01.DAT	P, Q, T, EC	
						2006-02-08 09:55:01	2006-02-09 20:50:22	HFM26_12.0_060208_Ref_Da01.DAT		This reference file is valid for both tests performed in borehole HFM26
	12.0–202.7	1B	2	2006-02-08 13:20:00	2006-02-08 14:26:44	2006-02-08 13:01:11	2006-02-08 14:26:44	HFM26_12.0_060208_Pumpin01.DAT	P, Q	Kapacitetstest

[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

Test diagrams

Diagrams are presented for the following tests:

1. Pumping test in HFM25: 9.1–187.5 m
2. Pumping test in HFM26: 12.0–202.7 m

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 HFM25: 9.1–187.5 m

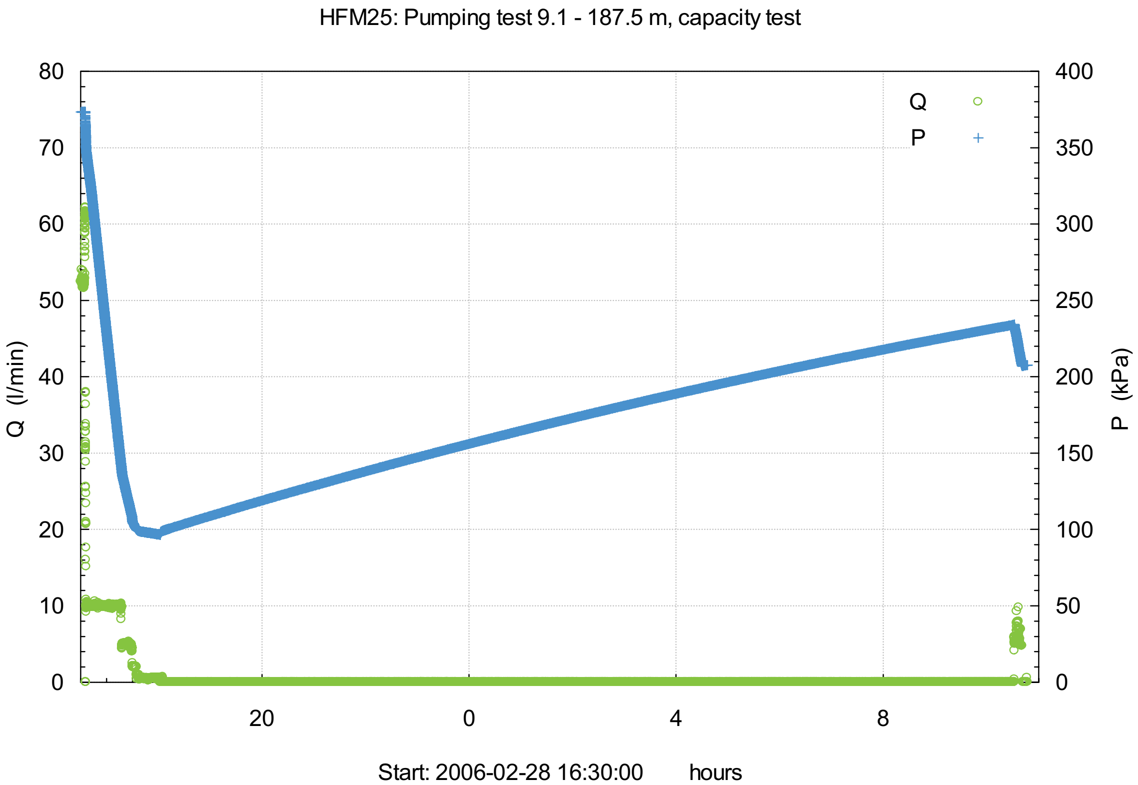


Figure A2-1. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM25 in conjunction with flow logging.*

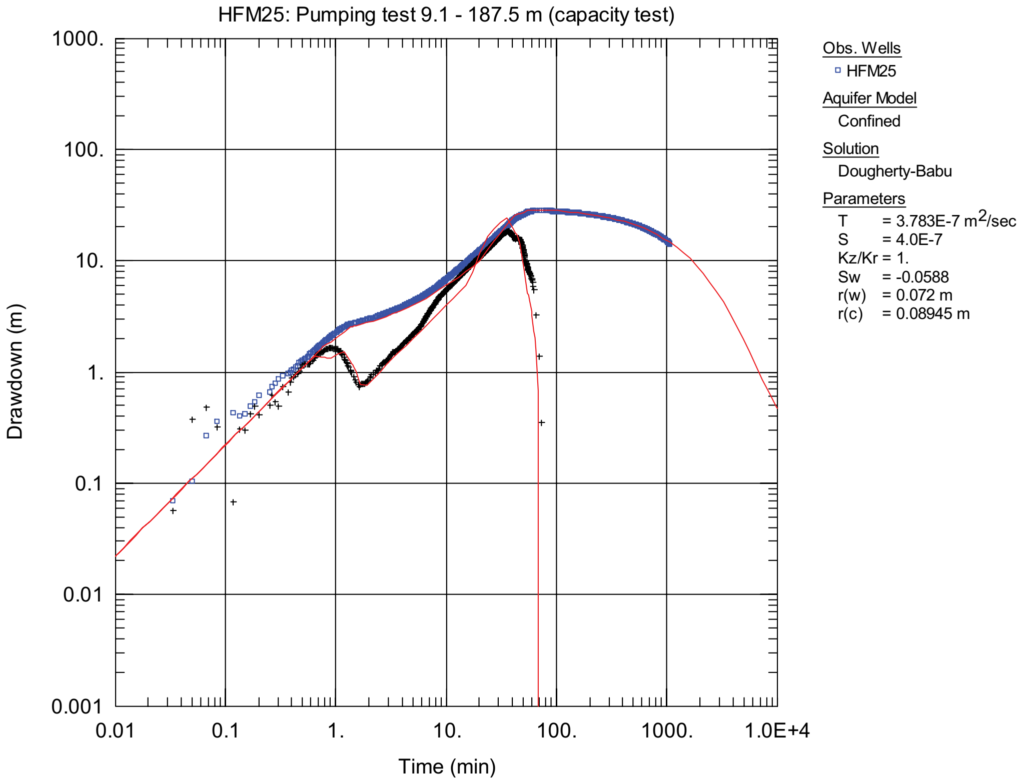


Figure A2-2. *Log-log plot of drawdown/recovery (blue □) and drawdown/recovery derivative (black +) versus time during the open-hole pumping test in HFM25.*

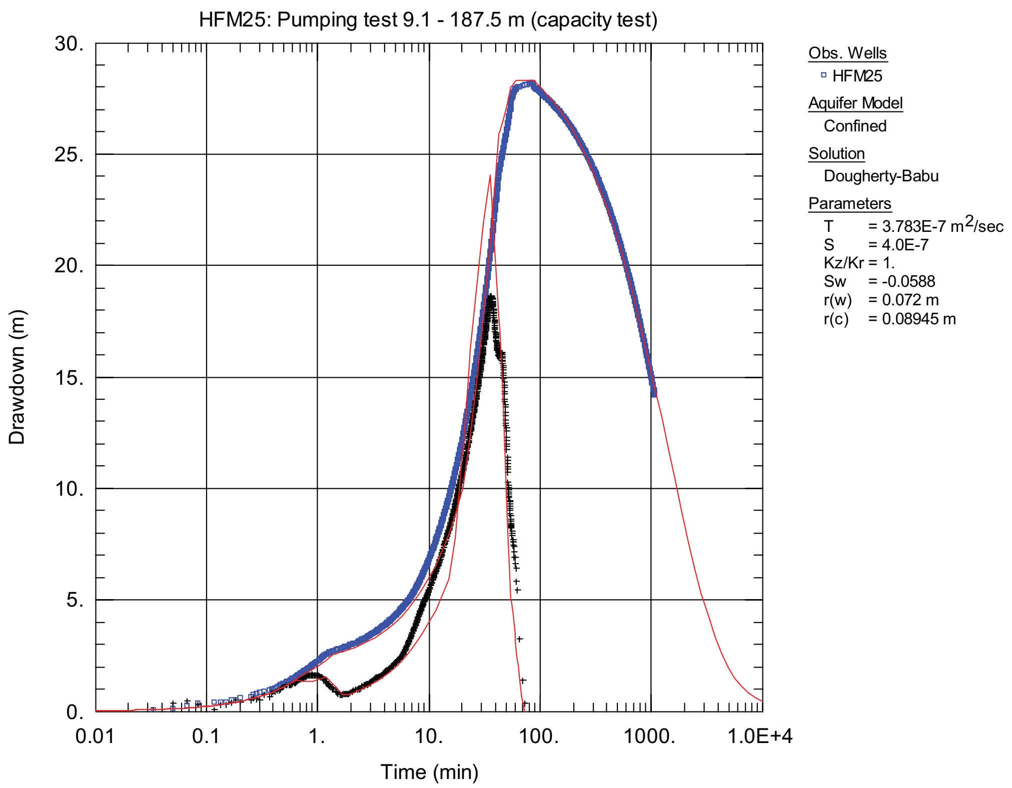


Figure A2-3. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM25.*

Pumping test in HFM26: 12.0–202.7 m

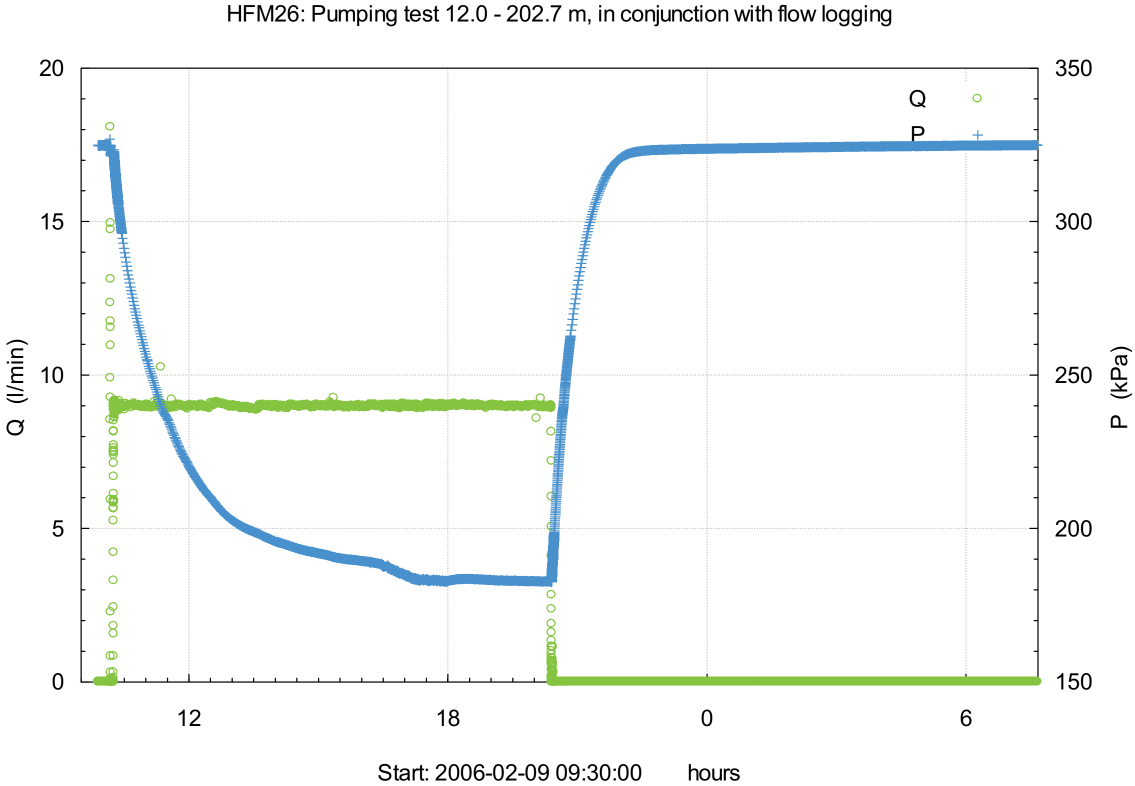


***Figure A2-4.** Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM26 in conjunction with flow logging.*

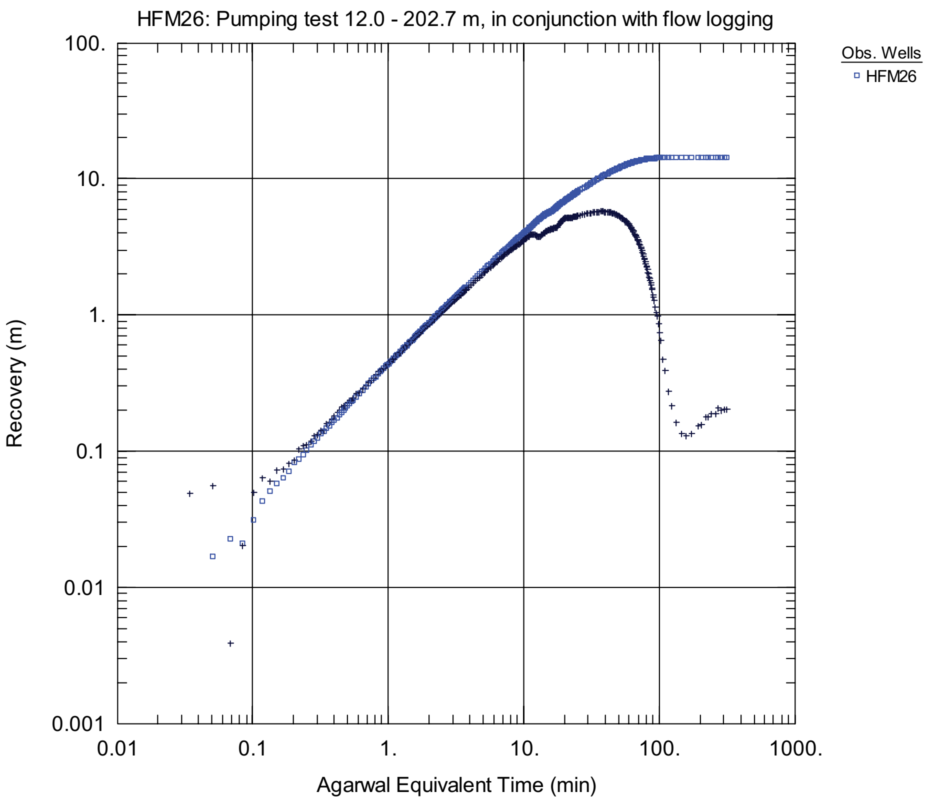


***Figure A2-5.** Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM26.*

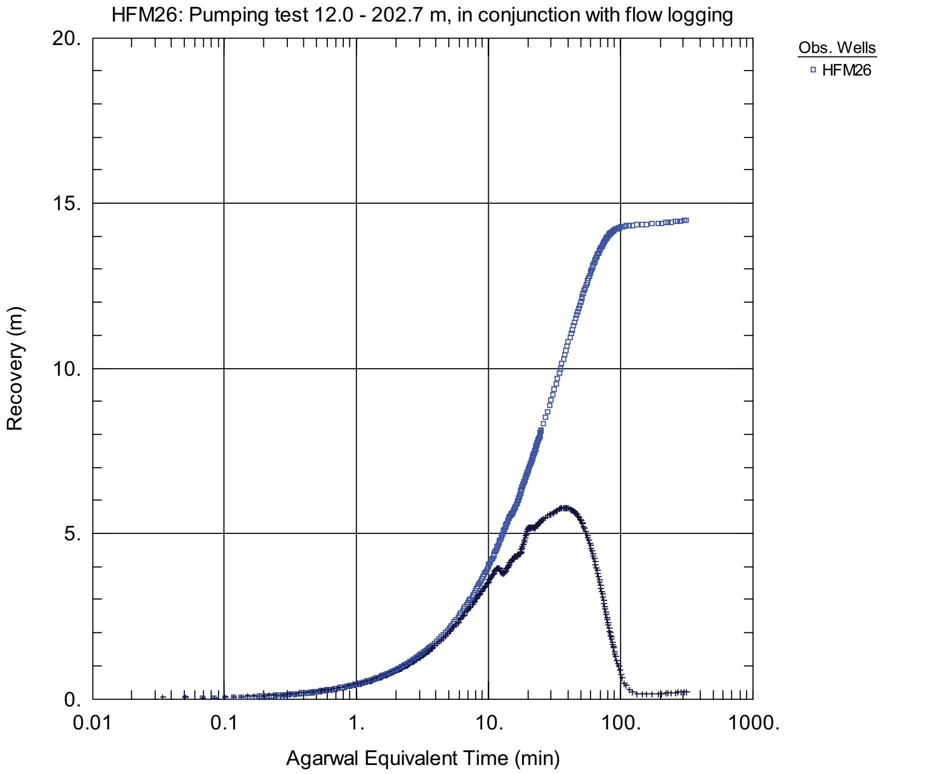


Figure A2-6. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM26.*

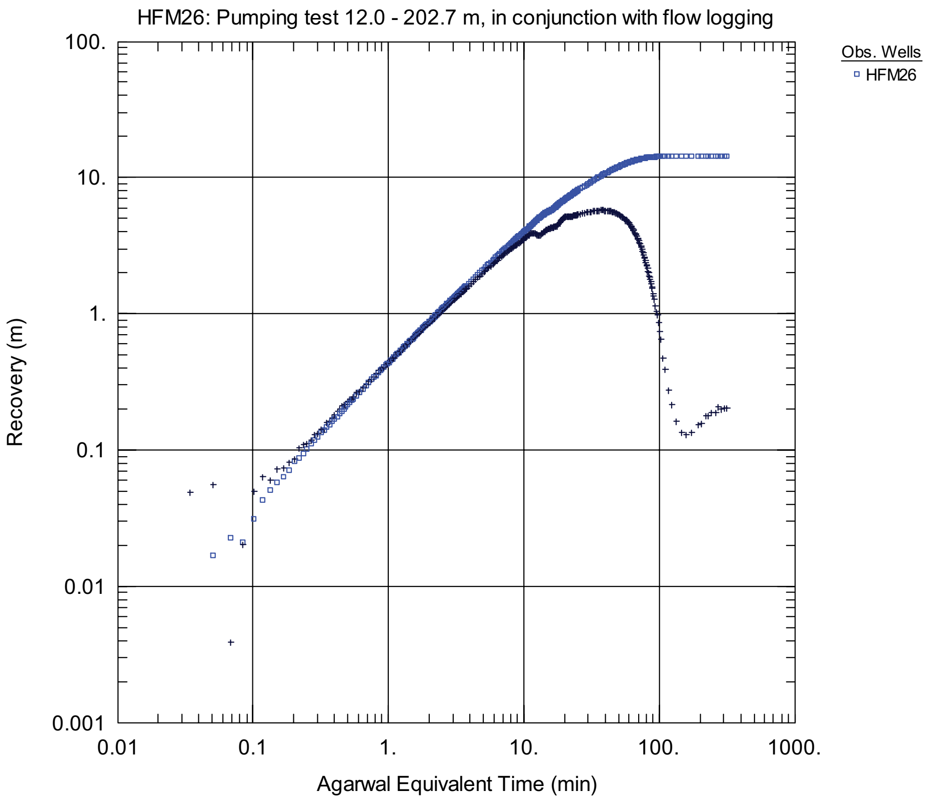


Figure A2-7. *Log-log plot of pressure recovery (blue □) and -derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM26.*

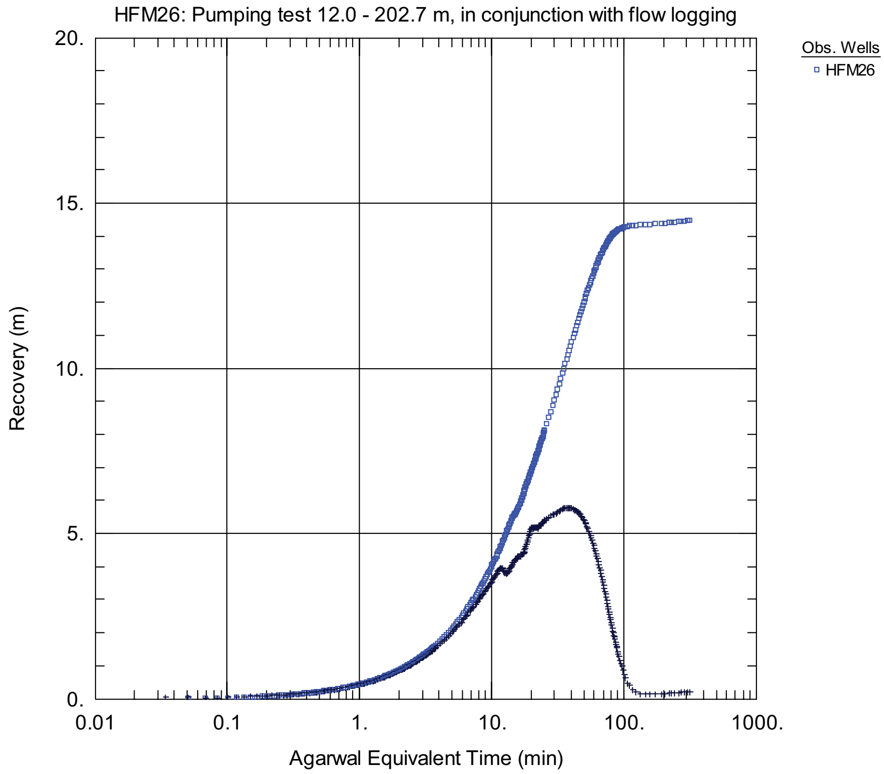


Figure A2-8. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM26.*

Appendix 3

Result tables to Sicada database

The following Result Tables are presented:

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

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

SINGLEHOLE TESTS, Pumping and injection, 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
HFM25	060228 16:30:09	060301 10:31:53	9.10	187.50		1B	1	2006-02-28 16:35:03	2006-02-28 18:02:00	9.3330E-06
HFM26	060209 09:53:53	060210 07:39:21	12.03	202.70		1B	1	2006-02-09 10:15:02	2006-02-09 20:24:00	1.4940E-04

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_volume_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	1.0800E-04	8.3333E-06	1.3333E-03	5.6000E-01	5220.00	59400.00	1.40			373.70	96.60	234.20
0	1.5000E-04	8.3333E-06	1.3333E-03	5.4800E+00	36540.00	40500.00	1.18	-13.65	1.04	322.73	182.58	324.93

cont.

(oC) fluid_temp_tew	(mS/m) fluid_elcond_ecw	(mg/l) fluid_salinity_tdsw	(mg/l) fluid_salinity_tdswm	reference	comments	(m) lp
						98.00
						107.00

Column	Datatype	Unit	Column Description
Site	CHAR		Investigation site name
Activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Project	CHAR		project code
Idcode	CHAR		Object or borehole identification code
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Section_no	INTEGER	number	Section number
test_type	CHAR		Test type code (1–7), see table description
formation_type	CHAR		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	oC	Measured section fluid temperature, see table description
fluid_elcond_ecw	FLOAT	mS/m	Measured section fluid el. conductivity,see table descr.
fluid_salinity_tdsw	FLOAT	mg/l	Total salinity of section fluid based on EC,see table descr.
fluid_salinity_tdswm	FLOAT	mg/l	Tot. section fluid salinity based on water sampling,see...
reference	CHAR		SKB report no. for reports describing data and evaluation
comments	VARCHAR		Short comment to data
error_flag	CHAR		If error_flag = “*” then an error occured and an error
in_use	CHAR		If in_use = “*” then the activity has been selected as
Sign	CHAR		Activity QA signature
Lp	FLOAT	m	Hydraulic point of application

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_ed1; Basic evaluation

idcode	start_date	stop_date	secup (m)	seclow (m)	section_no	test_type	formation_type	lp (m)	seclen_class (m)	spec_capacity_q_s (m**2/s)	value_type_q_s
HFM25	060228 16:30:09	060301 10:31:53	9.10	187.50		1B	1	98.00		3.30E-07	0
HFM26	060209 09:53:53	060210 07:39:21	12.03	202.70		1B	1	107.00		1.10E-05	0

cont.

transmissivity_tq (m**2/s)	value_type_tq	bc_tq	transmissivity_moye (m**2/s)	bc_tm	value_type_tm	hydr_cond_moye (m/s)	formation_width_b (m)	width_of_channel_b (m)	tb (m**3/s)	l_measl_tb (m**3/s)	u_measl_tb (m**3/s)	sb (m)	assumed_sb (m)	leakage_factor_lf (m)	transmissivity_tt (m**2/s)	value_type_tt	bc_tt
			4.30E-07	0	0										3.80E-07	0	1
			1.40E-05	0	0										1.10E-05	0	1

cont.

l_measl_q_s (m**2/s)	u_measl_q_s (m**2/s)	storativity_s	assumed_s	s_bc	ri (m)	ri_index	leakage_coeff (1/s)	hydr_cond_ksf (m/s)	value_type_ksf	l_measl_ksf (m/s)	u_measl_ksf (m/s)	spec_storage_ssf (1/m)	assumed_ssf (1/m)	c (m**3/pa)	cd	skin	dt1 (s)	dt2 (s)	t1 (s)	t2 (s)
2.E-07	2.E-03	4.00E-07												2.30E-06		-1.00E-01				
2.E-07	2.E-03	2.20E-06			367.42	0								3.60E-06		-2.80E+00			0.00	12000.00

cont.

dte1 (s)	dte2 (s)	p_horner (kPa)	transmissivity_t_nlr (m**2/s)	storativity_s_nlr	value_type_t_nlr	bc_t_nlr	c_nlr (m**3/pa)	cd_nlr	skin_nlr	transmissivity_t_grf (m**2/s)	value_type_t_grf	bc_t_grf	storativity_s_grf	flow_dim_grf	comment (no_unit)

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

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

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

Plu_impeller_basic_d

idcode	start_date	stop_date	secup (m)	seclow (m)	section_no	start_flowlogging (yyyymmdd)	stop_flowlogging (yyyymmdd)	l (m)	test_type	formation_type
HFM26	060209 09:53:53	060210 07:39:21	12.03	202.70		2006-02-09 16:24:17	2006-02-09 18:00:17	202.70	6	1

cont.

q_measl_l (m**3/s)	q_measl_u (m**3/s)	pump_flow_q1 (m**3/s)	pump_flow_q2 (m**3/s)	dur_flow_phase_tp1 (s)	dur_flow_phase_tp2 (s)	dur_flowlog_tfl_1 (s)	dur_flowlog_tfl_2 (s)	drawdown_s1 (m)	drawdown_s2 (m)	initial_head_ho (m.a.s.l.)	hydraulic_head_h1 (m.a.s.l.)	hydraulic_head_h2 (m.a.s.l.)	reference	comments
5.0000E-05	1.3333E-03	1.5000E-04		36540.00		5700.00		14.83		1.18	-13.65			

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

Plu_impell_mail_res

idcode	start_date	stop_date	secup (m)	seclow (m)	section_no	l (m)	cum_flow_q0 (m**3/s)	cum_flow_q1 (m**3/s)	cum_flow_q2 (m**3/s)	cum_flow_q1t (m**3/s)	cum_flow_q2t (m**3/s)	corr_cum_flow_q1c (m**3/s)	corr_cum_flow_q2c (m**3/s)
HFM26	060209 09:53:53	060210 07:39:21	12.03	202.70		37.00							

cont.

corr_cum_flow_q1tc (m**3/s)	corr_cum_flow_q2tc (m**3/s)	corr_com_flow_q1tcr (m**3/s)	corr_com_flow_q2tcr (m**3/s)	transmissivy_hole_t (m**2/s)	value_type_t	bc_t	cum_transmissivity_tf (m**2)	value_type_tf	bc_tf	l_measl_tf (m**2/s)	cum_transmissivity_tft (m**2)	value_type_tft	bc_tft	u_measl_tf (m**2/s)	reference	comments
				2.30E-06	0	1										

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