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Forsmark site investigation

Pumping tests and flow logging

Boreholes HFM29, HFM30 and HFM31

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Abstract

The main objectives of the hydraulic tests in the percussion boreholes HFM29 and HFM30 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. In borehole HFM31 no measurements were conducted, since the measurements during the drilling indicated a very low transmissivity.

Two of the boreholes are drilled towards identified structure lineaments. HFM29 was drilled towards a lineament designated MFM0123 and the aim was to intersect a supposed deformation zone. HFM30 was drilled towards lineament MFM0017 to if possible, characterize the zone or zones causing the lineament. HFM31 was drilled towards the reflection seismic reflector designated B8 (ZFMNE1193).

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

In borehole HFM29, the flow capacity showed to be very low. By means of shunting back a portion of the discharged 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 flow 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 HFM30 a pumping test in conjunction with flow logging was performed all the way up to the casing (18 m borehole length). Hence, there are no inflows above the highest position for flow logging, and no complementary pumping- or injection tests were necessary.

Water sampling was performed to investigate the hydrochemistry of the groundwater in both boreholes in conjunction with the pumping tests. In HFM29 only two samples were collected due to the short pumping time (4 h).

The total borehole transmissivity of HFM29 was estimated at 6.8×10^{-8} m^2/s.

In HFM30 the total transmissivity was estimated at 1.3×10^{-4} m^2/s. During the flow logging six flow anomalies were found in the interval 18.0–195.5 m. Most anomalies were confirmed also by changes in electric conductivityand/or temperature. The flow anomaly contributing most to the total inflow to the borehole was encountered at borehole length 119.0–120.0 m, and represents c 30% of the total borehole transmissivity.

Sammanfattning

Det övergripande syftet med de hydrauliska testerna i hammarborrhål HFM29 och HFM30 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. I borrhål HFM31 genomfördes inga mätningar eftersom mätningarna i samband med borrningen visade att transmissiviteten var väldigt låg.

Två av borrhålen är borrade i syfte att undersöka lineament. HFM29 borrades mot ett lineament benämnt MFM0123 och syftet är att genomskära en förmodad deformations-zon. HFM30 borrades mot ett lineament benämnt MFM0017 för att om möjligt karakterisera den eller de zoner som orsakar lineamenten. Borrhål HFM31 borrades mot den reflektionsseismiska reflektorn B8 (ZFMNE1193).

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

I HFM29 visade det sig att pumpkapaciteten var mycket låg. Med hjälp av återshuntning av pumpvatten till borrhålet kunde ett flöde på knappt 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 HFM30 genomfördes pumptest i kombination med flödesloggning. Loggningen kunde genomföras ända upp till foderrörets nederkant, vilket visar att det inte finns inflöden ovan-för den högsta flödesloggade punkten. Därför var det inte nödvändigt att genoföra några kompletterande pump- eller injektionstester.

Vattenprover för undersökning av grundvattnets hydrokemiska egenskaper togs i samband med pumptesterna i båda borrhålen. I HFM29 togs endast två vattenprover på grund av den kortare pumptiden (4 h).

Totala transmissiviteten för HFM29 uppskattades $6,8 \times 10^{-8}$ m^2/s.

För HFM30 uppskattades den totala transmissiviteten till $1,3 \times 10^{-4}$ m^2/s. Från flödes-loggningen kunde sex flödesanomalier i intervallet 18,0–195,5 m identifieras. De flesta flödesanomalierna bekräftades även av förändringar i elektrisk konduktivitet och/eller temperatur. Flödesanomalin som bidrar till största delen av det totala inflödet till borrhålet påträffades i intervallet 119,0–120,0 m, och står för ca 30 % av borrhålets totala transmissivitet

Contents

1 Introduction

This document reports the results of the hydraulic testing of boreholes HFM29 and HFM30 within the Forsmark site investigation. Although planned to be performed (cf the Activity Plan, Table 1-1) no measurements were conducted in borehole HFM31 since measurements during the drilling indicated a very low transmissivity.

The tests were carried out as pumping tests, in HFM30 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.

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

Boreholes HFM29 and HFM30 are situated along the road between drill site DS10 and drill site DS2, and HFM31 is situated west of reactor no. 3, outside the candidate area, see Figure 1-1.

Figure 1-1. Map showing the location of all percussion drilled boreholes within the Forsmark area including the candidate area selected for more detailed investigations. The location of boreholes HFM29, HFM30 and HFM30 are indicated by the arrows.

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.

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

Activity Plan	Number	Version
Hydrotester och vattenprovtagning i hammarborrhålen HFM29, HFM30, och HFM31	AP PF 400-06-036	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 HFM29 and HFM30 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) 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.

3.2 Tests performed

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

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

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

Borehole ID	Elevation of top of casing (ToC) (m.a.s.l.)	Borehole length from ToC (m)	Bh-diam. (below casing) (m)	Inclin. -top of bh (from horizontal plane) (°)	Dip-direction -top of bh (°)	Northing (m)	Easting (m)	Casing Length (m)	Casing Inner diam. (m)	Drilling finished Date (YYYY-MM-DD)
HFM29	4.47	199.7	0.1410	–58.57	29.95	6698019	1632503	9.03	0.160	2005-12-19
HFM30	3.13	200.8	0.1403	–55.50	28.81	6697931	1631820	18.03	0.160	2006-05-11

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)
HFM29	9.0–199.7	1B	Open hole	2006-05-15 13:06	2006-05-16 07:55
HFM30	18.0–200.8	1B	Open hole	2006-05-17 09:00	2006-05-18 07:41
HFM30	18.0–195.5	6, L-EC, L-Te	Open hole	2006-05-17 15:24	2006-05-17 19:55

[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/ρg). The temperature sensor displayed expected values in both air and water.

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

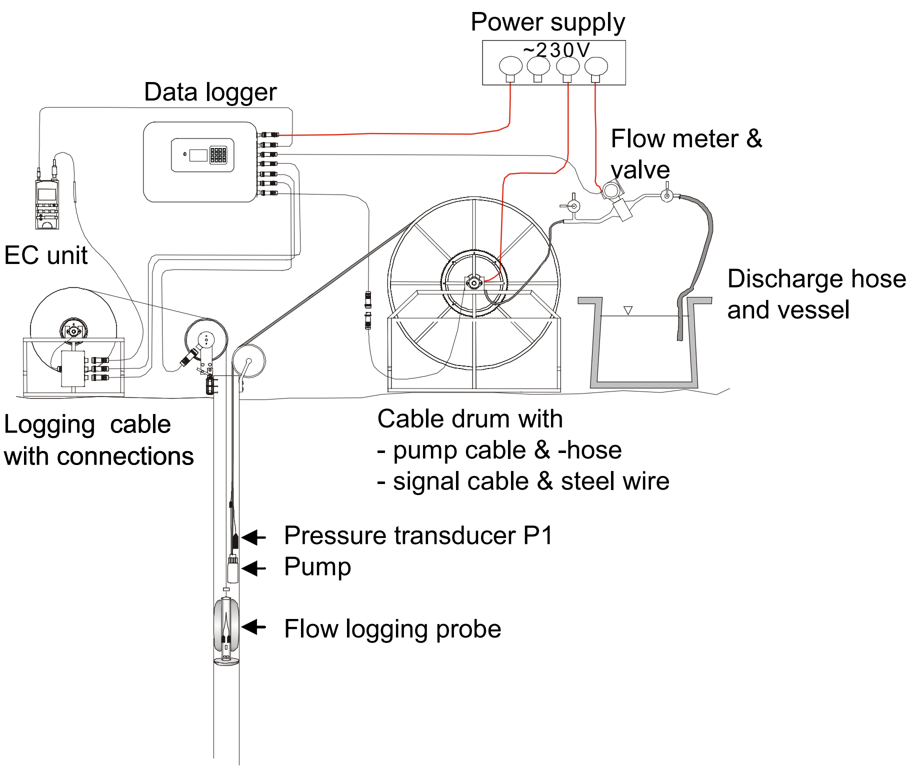


Figure 4-1. *Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB. (From SKB MD 326.001, SKB internal document).*

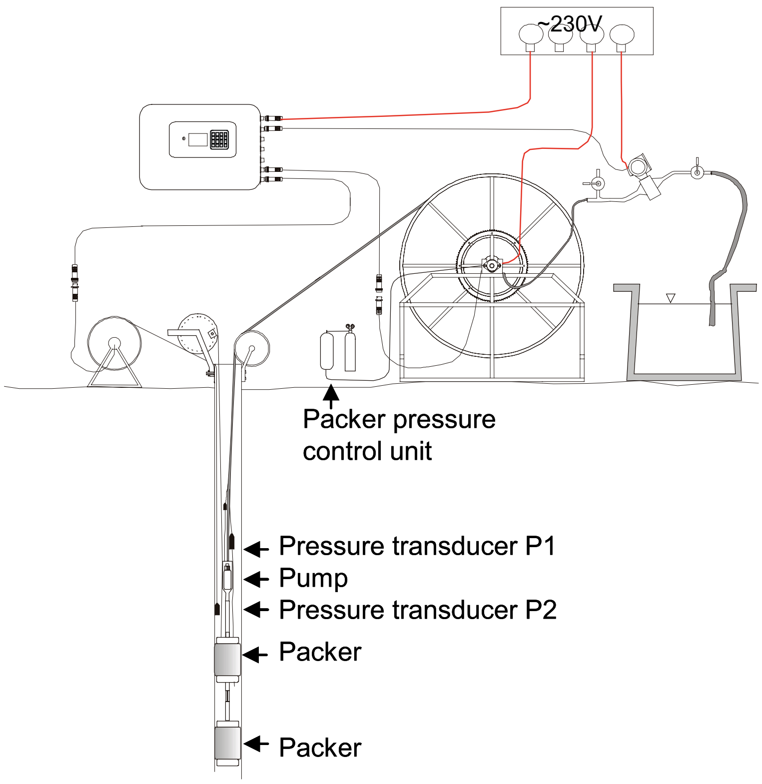


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB. (From SKB MD 326.001, SKB internal document).*

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.

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 c 0.5 L/min.

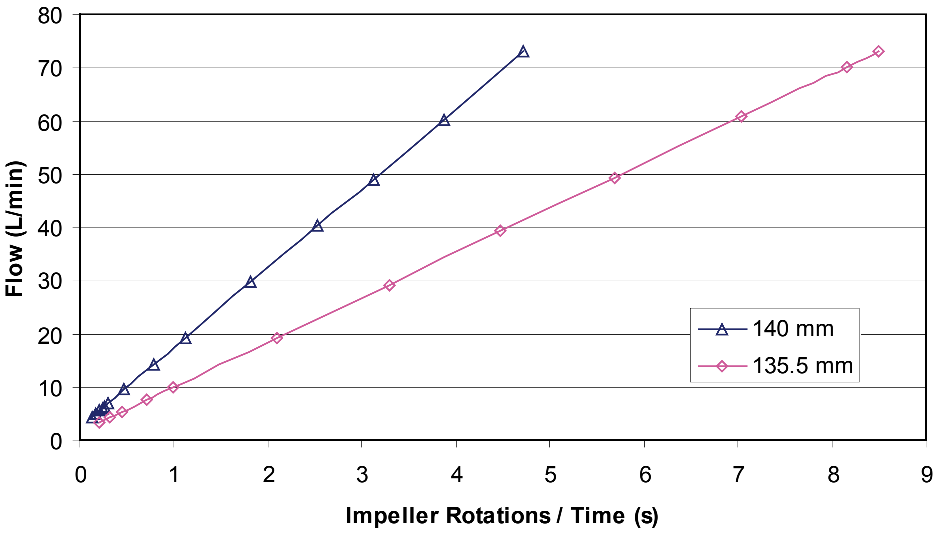


Figure 4-3. *Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).*

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

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

Equipment affecting the wellbore storage coefficient is given in terms of diameter of submerged item. Position is given as "in section" or "above section". The volume of the submerged pump (~ 4 dm^3) is not involved in the wellbore storage since the groundwater level always is kept above the top of the pump in open boreholes.

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

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

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

Borehole information				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 (m^3/Pa)
HFM29	9.0–199.7	Open hole	1B	Pump (intake)	39.4	Pump hose	In section	33.5	1.9×10^{-6} 3)
			1B			Pump cable	In section	14.5	1.6×10^{-6} 4)
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	36.72	Signal cable	In section	8	
HFM30	18.0–200.8	Open hole	1B	Pump (intake)	14.4	Pump hose	In section	33.5	1.9×10^{-6} 3)
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	11.72	Signal cable	In section	8	
			6	EC, Te, Q	18.0–195.5	Signal cable	In section	13.5	

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 (Table 3-1) for open-hole tests together with the compressibility of water for the test in isolated sections, respectively (net values).

4) Based on actual borehole diameter below casing (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 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 HFM30 the main test consisted of c 11 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 HFM29 no flow logging was made since the capacity of the borehole was considered to be too low for such a test. The pumping and the recovery periods were c 4 hours and c 14 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 pre-defined 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 test.

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 in borehole and electric conductivity data are sampled.

Flow logging is performed during the long pumping test (11 h), 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 provides a comprehensive general description of the procedure used when analysing data from the hydraulic tests carried out with the HTHB equipment.

5.4.1 Single-hole pumping tests

Firstly, a qualitative evaluation of the actual flow regimes (wellbore storage, pseudo-linear, pseudo-radial or pseudo-spherical flow) and possible outer boundary conditions during the hydraulic tests is performed. The qualitative evaluation is made from analyses of log-log diagrams of drawdown and/or recovery data together with the corresponding derivatives versus time. In particular, pseudo-radial flow (2D) is reflected by a constant (horizontal) derivative in the diagrams. Pseudo-linear and pseudo-spherical 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 (Almén et al.) /1/ and (Morosini et al.) /2/ are generally used by the evaluation of the tests. For tests indicating a fractured- or borehole storage dominated response, corresponding type curve solutions are used by the routine analyses.

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

The transient analysis was performed using a special version of the aquifer test analysis software AQTESOLV 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. AQTESOLV also includes models 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 1×10^{-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.

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

S = storativity (–)

T = transmissivity (m^2/s)

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

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

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

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

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

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

r_w = nominal borehole radius (m)

r_c = inner radius of the borehole casing (m)

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

ρ = density of water (kg/m^3)

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

5.4.2 Flow logging

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

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

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:

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

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

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

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:

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

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

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

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:

$$T_i = Corr \times dQ_i / Q_T \times T_{FT} \qquad (5\text{-}10)$$

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

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

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

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

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 (1.7×10^{-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:

- It was not possible to perform the flow logging in borehole HFM29, due to the low flow rate used for pumping. Instead, the pre-test was prolonged and the recovery was measured until the next day.
- The transient evaluation of the pumping test in HFM29 was made for the whole period instead of making one transient evaluation of the flow period and one of the recovery period as prescribed in the instruction for analysis of single-hole injection- and pumping tests, SKB MD 320.004, Version 1.0.
- The test in HFM30 was meant to be performed as a constant flow rate test. However, to avoid a too large drawdown, the flow rate was lowered after c 235 minutes of pumping.
- No measurements were conducted in borehole HFM31 since the measurements during the drilling indicated a very low transmissivity.

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.

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. In HFM29, since no 10 hours pumping test could be done, only two water samples were collected, one after c 90 minutes of pumping and one shortly before the stop of pumping.

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. No such disturbing activities were going on in the area close to the tested boreholes HFM29 and HFM30 during the test periods.

Table 6-1. Water samples collected during the pumping tests in boreholes HFM29 and HFM30 and submitted for analysis.

Bh ID	Date and time of sample	Pumped section (m)	Pumped volume (m^3)	Sample type	Sample ID no	Remarks
HFM29	2006-05-15 15:10	9.0-199.7	0.4	WC080	012255	Open-hole test
HFM29	2006-05-15 17:20	9.0-199.7	0.5	WC080	012257	Open-hole test
HFM30	2006-05-17 10:05	18.0-200.8	3.6	WC080	012256	Open-hole test
HFM30	2006-05-17 14:04	18.0-200.8	18.4	WC080	012258	Open-hole test
HFM30	2006-05-17 20:04	18.0-200.8	38.1	WC080	012259	Open-hole test

6.3.1 Borehole HFM29: 9.0–199.7 m

General test data for the open-hole pumping test in HFM29 are presented in Table 6-2.

The atmospheric pressure during the test period in HFM29, which is presented in Figure 6-1, varied less than 0.2 kPa, i.e. less than 0.1% of the total drawdown of 292 kPa in the borehole during the test, and thus the effect of atmospheric pressure variations on the test results is considered negligible. The precipitation during the measurement period and the days just before was very small and it is not likely that it has affected the ground water levels.

Comments on test

The pumping test was planned to be performed as a constant flow rate test during c 10 h with the intention to achieve (approximately) steady-state conditions by the end of the flow period. However, since the flow capacity turned out to be very low 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. An attempt to decrease the flow rate to achieve a constant pressure instead of constant flow rate was made. However, the drawdown continued to increase even though the flow rate was lowered to only 0.5 L/min. The low pumping rate was possible to achieve by a special arrangement shunting back parts of the discharged water through a valve ahead of the flow meter at the surface. After 238 minutes pumping the drawdown was c 30 m and the test had to be interrupted.

Interpreted flow regimes

Selected test diagrams according to the Instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2:1-4 in Appendix 2.

Since neither the flow rate, nor the pressure could be kept constant during the flow period the interpretation of flow regimes becomes difficult. The deviating appearance during the first minute of the flow period depends on a too high flow rate during the first 30 seconds, before the desired value is reached. The varying flow rate is well modelled by the test evaluation program.

As a result of the low transmissivity, both the flow and the recovery periods are dominated by wellbore storage. 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.

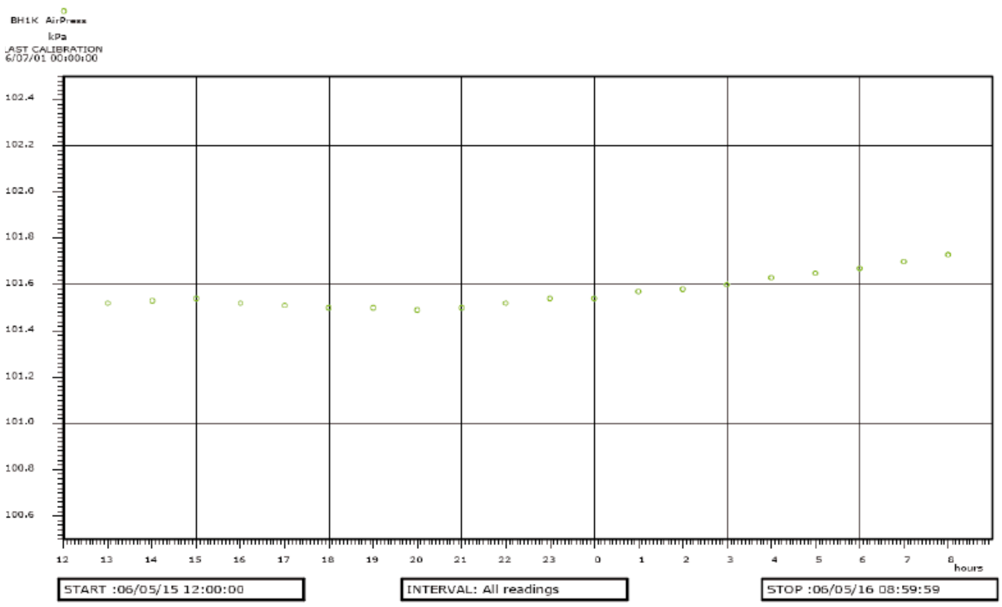


Figure 6-1. *Atmospheric pressure during the test period in HFM29.*

Table 6-2. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM29.

General test data			
Borehole	HFM29 (9.0–199.7 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 and E. Walger, GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomenclature	Unit	Value
Borehole length	L	M	199.7
Casing length	L_c	M	9.0
Test section- secup	Secup	M	9.0
Test section- seclow	Seclow	M	199.7
Test section length	L_w	M	190.7
Test section diameter	$2 \times r_w$	Mm	top 141.0 bottom 138.1
Test start (start of pressure registration)		yymmdd hh:mm	060515 13:06.34
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	060515 13:37
Stop of flow period		yymmdd hh:mm:ss	060515 17:35.01
Test stop (stop of pressure registration)		yymmdd hh:mm	060516 07:55.07
Total flow time	t_p	Min	238
Total recovery time	t_F	Min	860

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	391.4	2.91
Absolute pressure in test section at stop of flow period	p_p	kPa	99.6	
Absolute pressure in test section at stop of recovery period	p_F	kPa	143.4	–22.59
Maximal pressure change in test section during the flow period	dp_p	kPa	291.8	

Manual groundwater level measurements			**GW level**	
Date YYYY-MM-DD	**Time tt:mm:ss**	**Time (min)**	**(m bToC)**	**(m.a.s.l.)**
2006-05-15	09:28:00	–249	3.03	1.87
2006-05-15	10:25:00	–192	3.55	1.42
2006-05-15	11:24:00	–133	1.57	3.12
2006-05-15	13:18:00	–19	1.82	2.91
2006-05-16	07:43:00	1,086	31.56	–22.59

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	8.33×10^{-6}
Mean (arithmetic) flow rate during flow period [2]	Q_m	m^3/s	3.29×10^{-5}
Total volume discharged during flow period [2]	V_p	m^3	0.47

1) From the manual measurements of groundwater level. Manual leveling was not possible during pumping.

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

Interpreted parameters

The quantitative analysis was performed according to the methods described in Section 5.4.1, with the exception that the evaluation was made on the flow- and recovery periods together.

Since it was difficult to get an unambiguous solution when evaluating the flow and the recovery alone, evaluation of the entire test period was performed. The transient, quantitative interpretation is presented in Figures A2:3-4 in Appendix 2. The transmissivity was estimated by a model assuming pseudo-radial flow /3/, preceded by wellbore storage, and skin on both the flow- and recovery period. The representative transmissivity (i.e. T_T) is considered from the transient evaluation assuming pseudo-radial flow including wellbore storage and skin.

The results are shown in the Test Summary Sheet (Table 6-9) and in Tables 6-6, 6-7 and 6-8.

6.3.2 Borehole HFM30: 18.0–200.8 m

General test data for the open-hole pumping test in HFM30 in conjunction with flow logging are presented in Table 6-3.

The atmospheric pressure during the test period in HFM30, which is presented in Figure 6-2, varied by c 0.4 kPa, i.e. only c 0.5% of the total drawdown of c 72 kPa in the borehole during the test, and thus the effect of atmospheric pressure variations on the test results is considered negligible. The precipitation during the measurement period and the days just before was very small and it is not likely that it has affected the ground water levels.

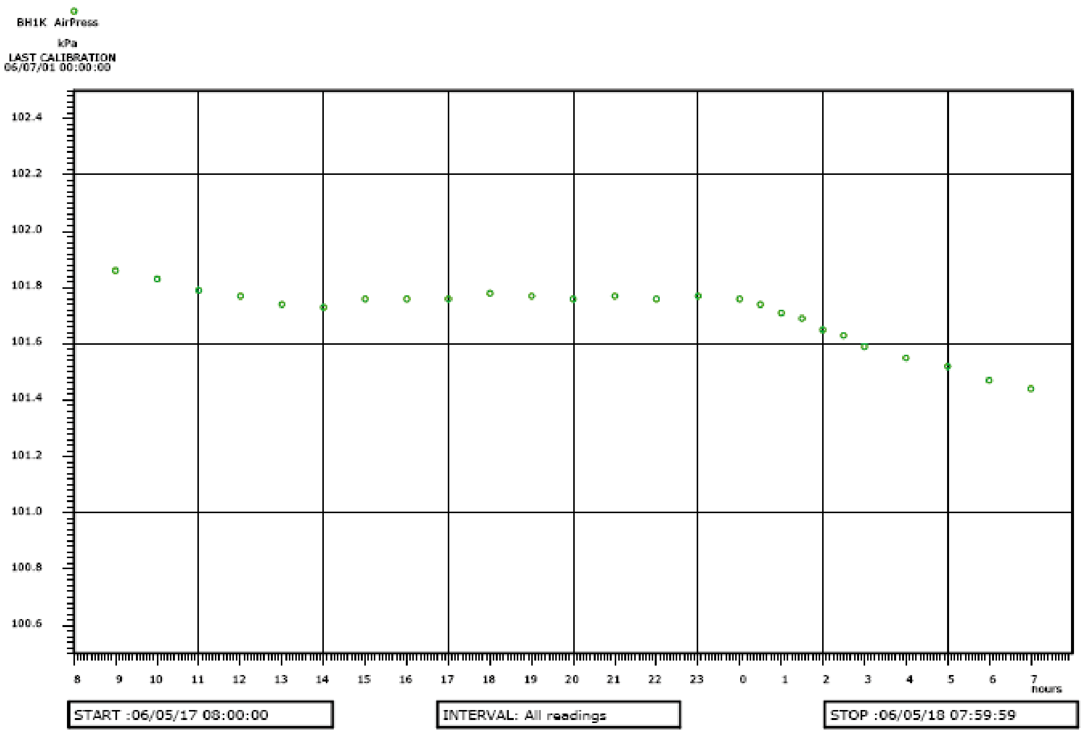


Figure 6-2. *Atmospheric pressure during the test period in HFM30.*

Table 6-3. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM30, in conjunction with flow logging.

General test data			
Borehole	HFM30 (18.0–200.8 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, E. Walger, GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	M	200.8
Casing length	L_c	M	18.0
Test section- secup	Secup	M	18.0
Test section- seclow	Seclow	M	200.8
Test section length	L_w	M	182.8
Test section diameter	$2 \times r_w$	Mm	top 140.3, bottom 138.7
Test start (start of pressure registration)		yymmdd hh:mm	060517 09:00:15
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	060517 09:10
Stop of flow period		yymmdd hh:mm:ss	060517 20:12
Test stop (stop of pressure registration)		yymmdd hh:mm	060518 07:41:15
Total flow time	t_p	Min	662
Total recovery time	t_F	Min	689

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW Level (m.a.s.l.) [2]**
Absolute pressure in test section before start of flow period	p_i	kPa	184.79	2.31
Absolute pressure in test section at stop of flow period	p_p	kPa	112.74	–5.10
Absolute pressure in test section at stop of recovery period	p_F	kPa	173.88	1.2
Maximal pressure change in test section during the flow period	dp_p	kPa	32.05	
Manual groundwater level measurements	GW level			

Date YYYY-MM-DD	**Time tt:mm:ss**	**Time (min)**	**(m bToC)**	**(m.a.s.l.)**
2006-05-16	12:20:00	–1,250	0.71	2.54
2006-05-16	14:42:00	–1,108	0.71	2.54
2006-05-16	15:56:00	–1,034	0.71	2.54
2006-05-16	16:05:00	–1,025	2.23	1.28
2006-05-16	16:46:00	–984	6.83	–2.53
2006-05-17	08:48:00	–22	0.99	2.31
2006-05-17	10:47:00	97	8.48	–3.90
2006-05-17	13:50:00	280	8.68	–4.07
2006-05-17	15:11:00	361	8.98	–4.32
2006-05-17	20:09:00	659	9.93	–5.10
2006-05-18	07:37:00	1,347	2.32	1.20

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	9.13×10^{-4}
Mean (arithmetic) flow rate during flow period [3]	Q_m	m^3/s	9.73×10^{-4}
Total volume discharged during flow period [3]	V_p	m^3	38.63

[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

The day before test start, a short capacity test was performed (c 60 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 5.1 m. The actual pumping test was performed as a constant flow rate test (65 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. However, the flow rate had to be decreased to c 55 L/min after 235 minutes pumping to avoid a too large drawdown. The drawdown after 60 minutes pumping was c 5.7 m and the drawdown at the end of the pumping test was c 7.3 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

Selected test diagrams according to the Instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2:5–9 in Appendix 2.

The first period of the flow period is dominated by wellbore storage. A transition to pseudo-radial flow takes place after c 10 minutes. The increasing derivative at end of the period represents an apparent negative hydraulic boundary. The recovery period shows the same transition into a pseudo-radial flow regime after the initial period of c 10 minutes dominated by wellbore storage. After c 50 minutes of the recovery period apparent negative hydraulic boundary effects, for example due to restrictions in the extension of the fracture system, can be seen.

Interpreted parameters

The transmissivity was estimated by a model assuming pseudo-radial flow /3/ including wellbore storage and skin on both the flow- and recovery period. The representative transmissivity (i.e. T_T) is considered from the transient evaluation assuming pseudo-radial flow including wellbore storage and skin. The agreement between the flow and the recovery periods regarding transmissivity is good. The quantitative interpretation of the test is presented in Figures A2:6-9 in Appendix 2. The quantitative analysis was carried out according to the methods described in Section 5.4.1.

The results are shown in the Test Summary Sheet (Table 6-10) and in Tables 6-6, 6-7 and 6-8. The analysis from the flow period was selected as representative for the test.

6.4 Flow logging

In borehole HFM29 the flow capacity was considered too low to allow for a meaningful flow logging. In HFM30 flow logging was performed and results from the flow logging and the simultaneous logging of temperature and electrical conductivity are presented in the following Chapter.

6.4.1 Borehole HFM30

General test data for the flow logging in borehole HFM30 are presented in Table 6-4.

Table 6-4. General test data, groundwater level and flow data for the flow logging in borehole HFM30.

General test data				
Borehole	HFM30			
Test type(s) [1]	6, L–EC, L–Te			
Test section:	Open borehole			
Test No	1			
Field crew	S. Jönsson, and E. Walger, GEOSIGMA AB			
Test equipment system	HTHB			
General comments	Single pumping borehole			
	Nomenclature	**Unit**	**Value**	
Borehole length		m	200.8	
Pump position (lower level)		m	15	
Flow logged section – Secup		m	18.0	
Flow logged section – Seclow		m	195.5	
Test section diameter	2·rw	mm	top 140.3 bottom 138.7	
Start of flow period		yymmdd hh:mm	060517 09:10	
Start of flow logging		yymmdd hh:mm	060517 15:25	
Stop of flow logging		yymmdd hh:mm	060517 19:55	
Stop of flow period		yymmdd hh:mm	060517 20:12:00	

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	0.71	2.54
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m	9.93	–5.10
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m		7.64

Flow data	**Nomen-clature**	**Unit**	**Flow rate**
Pumping rate at surface	Q_p	m^3 /s	9.13×10^{-4}
Corrected flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m^3 /s	9.13×10^{-4}
Threshold value for borehole flow rate during flow logging	Q_{Measl}	m^3 /s	5×10^{-5}
Minimal change of borehole flow rate to detect flow anomaly	dQ_{Anom}	m^3 /s	1.7×10^{-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 195.5 m borehole length and upward. The step length between flow logging measurements was maximally 5 m. Since a measurable flow was encountered already at the first position of the logging probe, the step length between flow logging measurements was intended to be dedcreased to maximally 2 m. However, in order to shorten the measurement time, the interval between the measurements was increased to 5 m at some positions above 132 m on the way up to the top of the logged interval at c 18 m borehole length. The flow logging could be performed all the way up to the casing (18.0 m below ToC) which means that there are no inflows above the highest flow logged position. Hence, no additional pumping- or injection tests were performed and the calculations of transmissivitiy of the detected flow anomalies are made according to Method 1 described in Section 5.4.2.

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.

Figure 6-3 present 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 140.3 mm) together with corrected borehole flow rates. The correction is performed in two steps. Firstly the calibration constants used are corrected for variations of the diameter along the borehole using information from the logging in the undisturbed borehole as described in Section 5.4.2. Secondly, if necessary, a scaling to achieve conformance between measured borehole flow at the top of the flow logged interval and the pumped flow rate measured by the flow meter at surface is performed. The correction is performed under the assumption of no inflow above the highest position for flow logging. In this case, it was possible to extend the flow logging to slightly above the end of the casing.

The difference between the highest flow rate measured at the top of the flow logged interval in the borehole and the total pumped flow measured at the surface may be explained by the borehole diameter in the uppermost part of the borehole being greater than the diameter of the pipe used for calibration. Probably also the inclination of the borehole (c 56°), deviating from 90°, has some influence on the flow measured in the borehole.

Figure 6-4 shows six detected inflows between 18.0 and 199.5 m. The first definable flow was encountered at 195.5 where the flow logging started. Since it is not possible to say where below 195.5 m the inflow actually occurs. The entire interval from the bottom of the borehole to 195.5m is therefore regarded as an anomaly. Obviously this anomaly can not be supported by the EC- or the temperature measurements. All other inflows, except the one at 190.0–191.5 m are supported by the temperature measurements. For two of the flow anomalies clear change of electric conductivity (EC) can also be seen.

The results of the flow logging in borehole HFM30 are presented in Table 6-5 below. The measured inflow at the identified flow anomalies (dQ_i) and their estimated percentage of the total flow is shown. The cumulative transmissivity (T_{FT}) at the top of the flow-logged borehole interval was calculated from Equation (5-4) and the transmissivity of individual flow anomalies (T_i) from Equation (5-5) using the corrected flow values (se above). The transmissivity for the entire borehole used in Equation (5-5) was taken from the transient evaluation of the pumping test in conjunction with the flow logging (cf Section 6.3.1). An estimation of the transmissivity of the interpreted flow anomalies was also made by calculating the specific flows (dQ_i/s_{FL}).

Table 6-5. Results of the flow logging in borehole HFM30. Q_{Tcorr}=corrected cumulative flow at the top of the logged interval. Q_p=pumped flow rate from borehole, s_{FL}= drawdown during flow logging. T=transmissivity from the pumping test.

HFM30 Flow anomalies		**Q_{Tcorr} =9.13×10⁻⁴ (m³/s)**	**T_{FT} = T = 1.35×10⁻⁴ (m²/s)**	**s_{FL}= 7.34 m**	**Q_p=9.13×10⁻⁴ (m³/s)**	
Interval (m b ToC)	**B.h. length (m)**	**dQ_{icorr} ¹ (m³/s)**	**T_i (m²/s)**	**dQ_{icorr}/s_{FL} (m²/s)**	**dQ_{icorr}/Q_p (%)**	**Supporting information**
67.0–72.0	5	4.667E-05	6.90E-06	6.358E-06	5.11	Temp
119.0–120.0	1	2.750E-04	4.06E-05	3.747E-05	30.11	EC, Temp
136.0–136.5	0.5	1.667E-04	2.46E-05	2.271E-05	18.25	EC, Temp
159.0–159.5	0.5	1.250E-04	1.85E-05	1.703E-05	13.69	Temp
190.0–191.5	1.5	5.833E-05	8.62E-06	7.947E-06	6.39	
195.5–200.8	5.25	2.417E-04	3.57E-05	3.292E-05	26.46	–
Total		**9.13×10⁻⁴**	**1.35×10⁻⁴**	**1.24×10⁻⁴**	**100**	
Difference		Q_p-Q_{Tcorr}=0	–	–		

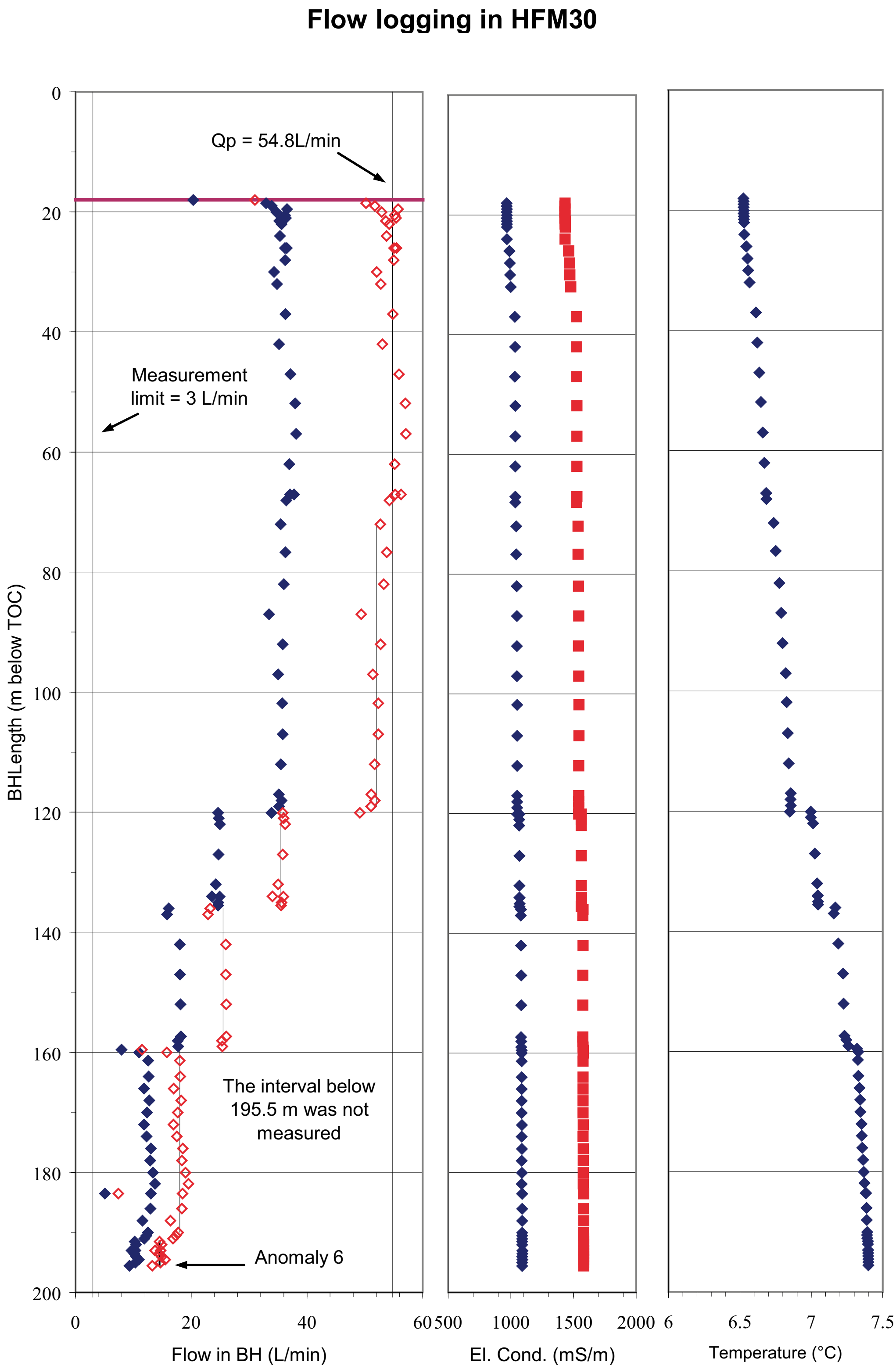


Figure 6-3. *Measured (blue) and corrected (red) inflow distribution together with measured (blue) and temperature compensated (red) electrical conductivity and temperature of the borehole fluid along borehole HMF30 during flow logging. (Total logged interval.)*

Figure 6-4 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 indicated in the Figure, cf Section 5.4.2.

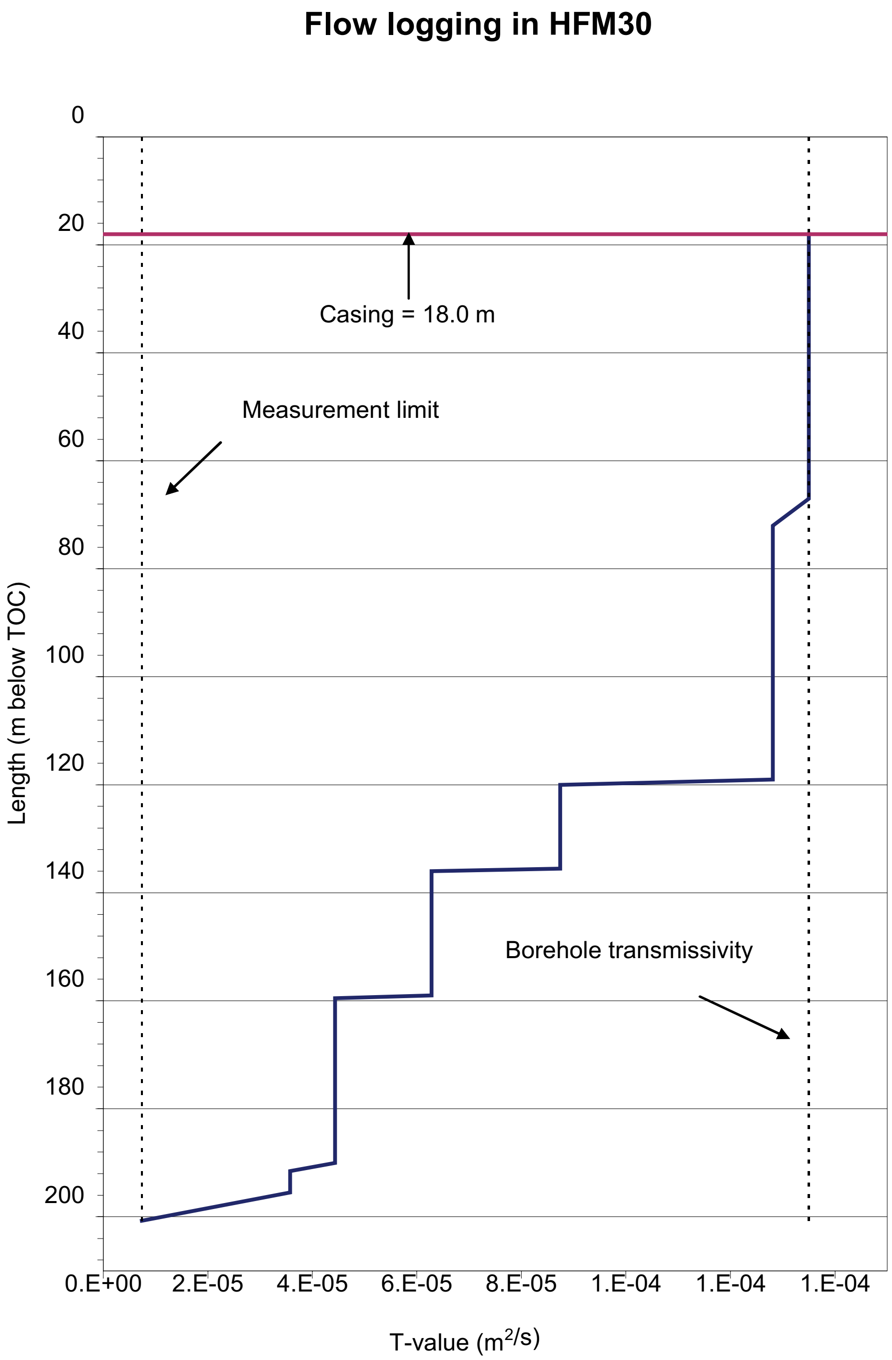


Figure 6-4. *Calculated, cumulative transmissivity along the flow logged interval of borehole HFM30. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.5 Summary of hydraulic tests

A compilation of measured test data from the pumping tests in the two boreholes is presented in Table 6-6. In Table 6-7 and Table 6-8, and in the test summary sheets in Tables 6-9 and 6-10, hydraulic parameters calculated from the tests in HFM29 and HFM30 are shown.

In Table 6-6, 6-7 and Table 6-8, 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 6-6. Summary of test data for the open-hole pumping tests performed with the HTHB system in boreholes HFM29 and HFM30 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)	V_p (m^3)
HFM29	9.0–199.7	1B	391.41	96.57	143.35	8.333×10^{-6}	3.3×10^{-5}	0.47
HFM30	18.0–200.8	1B	184.79	112.74	173.88	9.133×10^{-4}	9.7×10^{-4}	38.63

[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 of the formation from the hydraulic tests performed with the HTHB system in boreholes HFM29 and HFM30 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* (–)
HFM29	9.0–199.7		1B	2.80×10^{-7}	3.60×10^{-7}	6.81×10^{-8}		1.83×10^{-7}
HFM30	18.0–200.8		1B	1.24×10^{-4}	1.58×10^{-4}	1.35×10^{-4}		8.12×10^{-6}
HFM30	18.0–195.5 (f)	67.0–72.0	6	6.36×10^{-6}			6.90×10^{-6}	
HFM30	18.0–195.5 (f)	119.0–120.0	6	3.75×10^{-5}			4.06×10^{-5}	
HFM30	18.0–195.5 (f)	136.0–136.5	6	2.27×10^{-5}			2.46×10^{-5}	
HFM30	18.0–195.5 (f)	159.0–159.5	6	1.70×10^{-5}			1.85×10^{-5}	
HFM30	18.0–195.5 (f)	190.0–191.5	6	7.95×10^{-6}			8.62×10^{-6}	
HFM30	18.0–195.5 (f)	195.5–200.8	6	3.29×10^{-5}			3.57×10^{-5}	2.2×10^{-6}

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

Table 6-8. Summary of calculated hydraulic parameters from the hydraulic tests performed with the HTHB system in boreholes HFM29 and HFM30 in the Forsmark candidate area.

Borehole ID	Section (m)	Test type [1)]	S* (–)	C (m^3/Pa) [2)]	ζ (–)
HFM29	9.0–199.7	1B	$1.8 \cdot 10^{-7}$	$1.7 \cdot 10^{-6}$	–2.0
HFM30	18.0–200.8	1B	$8.1 \cdot 10^{-6}$	$1.9 \cdot 10^{-6}$	–4.0

[1)] 1B: Pumping test submersible pump

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

Appendix 3 includes the result Tables delivered to the database SICADA. The lower measurement limit for the pumping tests with the HTHB system, presented in the result Tables, is expressed in terms of specific flow (Q/s). For pumping tests, the practical lower limit is based on the minimum flow rate for which the system is designed (5 L/min) and an estimated maximum allowed drawdown for practical purposes (c 50 m) in a percussion borehole, cf Table 4-1. These values correspond to a practical lower measurement limit (Q/s–L) of 2×10^{-6} m^2/s of the pumping tests. Using a special arrangement makes it possible to lower the minimum flow rate to c 0.5 L/min. This corresponds to a lower measurement limit for Q/s of c 2×10^{-7} m^2/s.

Similarly, the practical, upper measurement limit of the HTHB-system is estimated from the maximum flow rate (c 80 L/min) and a minimum 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 $2 \times 10^{-3\hat{}}$ m^2/s for pumping tests.

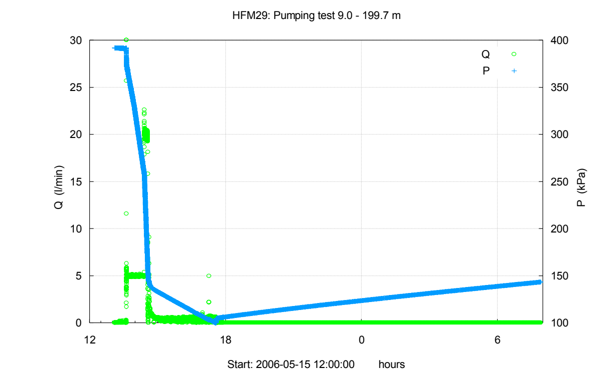
A special arrangement in HFM29, shunting back parts of the discharged water through a valve ahead of the flow meter at the surface, made a shorter capacity test possible with a lowest flow rate at c 0.5 L/min. From the transient evaluation of this test a transmissivity lower than the standard Q/s–L was calculated. 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 238 minutes but the recovery was 860 minutes.
2. The relative accuracy of the flow meter at surface is decreasing with decreasing flow.

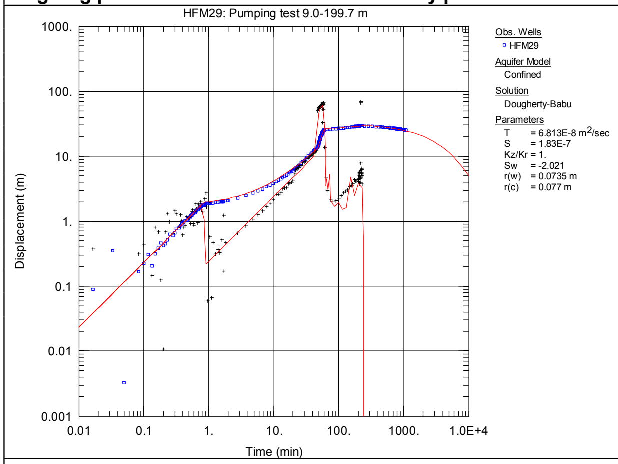
Table 6-9. Test Summary Sheet for the pumping test in HFM29, section 9.0–199.7 m.

Test Summary Sheet			
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM29	Test start:	2006-05-15 13:06:34
Test section (m):	9.0-199.7	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2 \cdot r_w$ (m):	top 0.1410 bottom 0.1381	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

Linear plot Q and p



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



Flow period*		Recovery period*	
Indata		**Indata**	
p_0 (kPa)	391.8		
p_i (kPa)	391.4		
p_p(kPa)	99.6	p_F (kPa)	143.4
Q_p (m^3/s)	$8.33 \cdot 10^{-6}$		
tp (min)	238	t_F (min)	860
S*	$1.8 \cdot 10^{-7}$	S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.1	Derivative fact.	
Results			
Q/s (m^2/s)	$2.8 \cdot 10^{-7}$		
T_{Moye}(m^2/s)	$3.6 \cdot 10^{-7}$		
Flow regime:	WBS	Flow regime:	
t_1 (min)	0.5	dt_{e1} (min)	
t_2 (min)	1000	dt_{e2} (min)	
T_w (m^2/s)	$6.8 \cdot 10^{-8}$	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)	$1.7 \cdot 10^{-6}$	C (m^3/Pa)	
C_D (-)		C_D (-)	
ξ (-)	-2.0	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)	$1.7 \cdot 10^{-6}$
t_1 (min)	0.5	C_D (-)	
t_2 (min)	1000	ξ (-)	-2.0
T_T (m^2/s)	$6.8 \cdot 10^{-8}$		
S (-)	$1.8 \cdot 10^{-7}$		
K_s (m/s)			
S_s (1/m)			

Comments:

Since it was difficult to get an unambiguous solution when evaluating the flow and the recovery periods alone, 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.

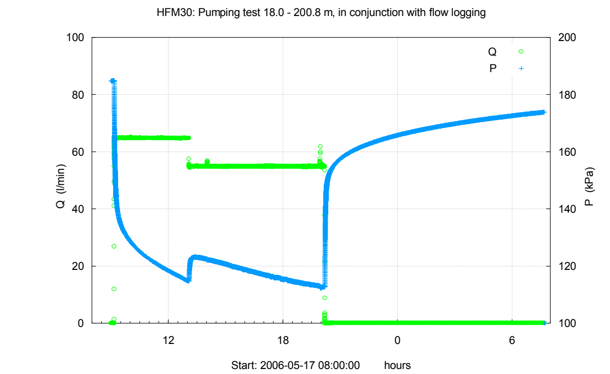
* The test was evaluated for the entire test period, including both drawdown and recovery.

Table 6-10. Test Summary Sheet for the pumping test in HFM30, section 18.0–200.8 m.

Test Summary Sheet

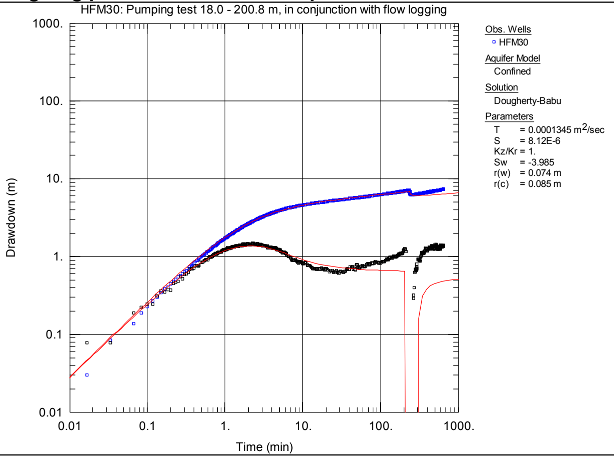
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM30	Test start:	2006-05-16 09:00:15
Test section (m):	18.0-200.8	Responsible for test performance:	Geosigma AB S. Jönsson
Section diameter, $2 \cdot r_w$ (m):	top 0.1403 bottom 0.1387	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

Linear plot Q and p

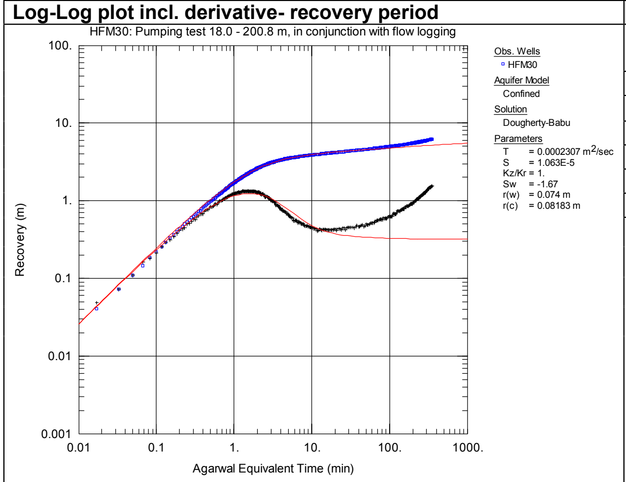


Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	184.74		
p_i (kPa)	184.79		
p_p(kPa)	112.74	p_F (kPa)	173.88
Q_p (m^3/s)	$9.133 \cdot 10^{-4}$		
tp (min)	662	t_F (min)	689
S*	$8.1 \cdot 10^{-6}$	S*	$1.1 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.1	Derivative fact.	0.1
Results		**Results**	
Q/s (m^2/s)	$1.2 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$1.6 \cdot 10^{-4}$		
Flow regime:	WBS->PRF ->NFB	Flow regime:	WBS-> PRF-> NFB
t_1 (min)	0	dt_{e1} (min)	662
t_2 (min)	180	dt_{e2} (min)	740
T_w (m^2/s)	$1.3 \cdot 10^{-4}$	T_w (m^2/s)	$2.3 \cdot 10^{-4}$
S_w (-)		S_w (-)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$1.9 \cdot 10^{-6}$	C (m^3/Pa)	$1.9 \cdot 10^{-6}$
C_D (-)		C_D (-)	
ξ (-)	-4.0	ξ (-)	-1.7
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.

Flow regime:	WBS-> PRF->NFB	C (m^3/Pa)	$1.9 \cdot 10^{-6}$
t_1 (min)	0	C_D (-)	
t_2 (min)	180	ξ (-)	-4.0
T_T (m^2/s)	$1.3 \cdot 10^{-4}$		
S (-)	$8.1 \cdot 10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments:

The first part of the drawdown is dominated by wellbore storage. After c. 10 minutes of the drawdown period there is a transition into a short period of pseudo-radial flow followed by an apparent no flow boundary

Also the recovery period is dominated by WBS during the first c. 10 minutes followed by a pseudo-radial flow regime. This is followed by an increase of the derivative probably reflecting an apparent negative hydraulic boundary,

Transient evaluations of both the drawdown and the recovery period are consistent regarding both flow regimes and transmissivity. The transient evaluation of the flow period is regarded as the most representative.

7 References

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

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

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

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

Appendix 1

List of test data files

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

Bh ID	Test section (m)	Test type[1]	Test 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 (para-meters)[2]	Comments
HFM29	9.0–199.7	1B	1	060515 13:37:00	060516 07:55:07	060515 13:06:34	060516 07:55:07	HFM29_9.0_060515_Pumpin00.DAT	P, Q	Primarily meant to be a capacity test
						060515 10:48:52	060515 17:55:08	HFM29_9.0_060515_Ref_Da00.DAT		Reference file
HFM30	18.0–200.8	1B	2	060517 09:10:04	060518 07:42:15	060516 13:56:09	060518 07:42:15	HFM30_18.0_060516_FlowLo04.DAT	P, Q, T, EC	
						060516 13:43:53	060517 20:34:16	HFM30_18.0_060516_Ref_Da04.DAT		This reference file is valid for both tests performed in borehole HFM30
	18.0–200.8	6	1	060517 15:24:53	060517 19:55:29	060517 15:24:53	060517 19:55:29	HFM30_18.0_060517_Spinne04.DAT	P, Q, T, EC, SP	
	18.0–200.8	1B	1	060516 15:48:03	060516 16:48:08	060516 15:44:49	060516 16:49:10	HFM30_18.0_060516_Pumpin00.DAT		Capacity test

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

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

Diagram of test responses

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

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

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

Pumping test in HFM29: 9.0–199.7 m

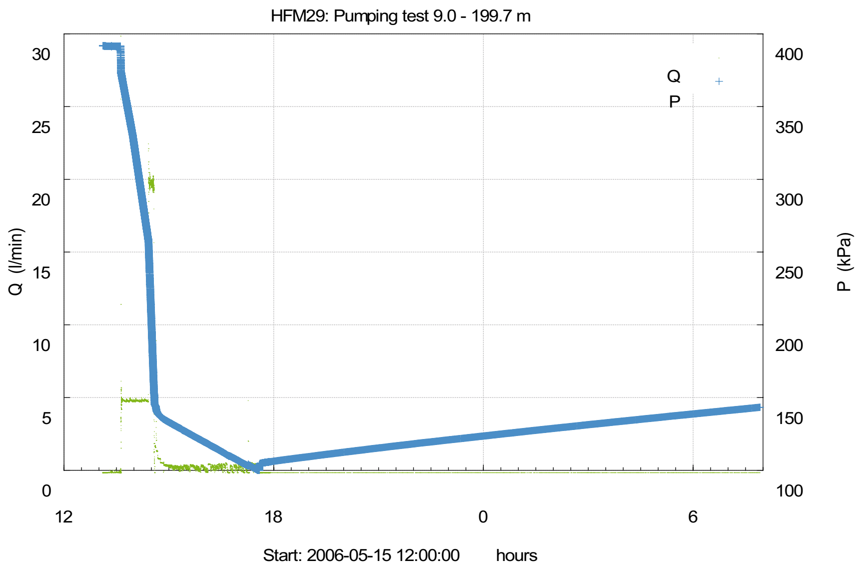


Figure A2-1. *Linear plot of flow rate (Q) and pressure (P) versus time during the open-hole pumping test in HFM29.*

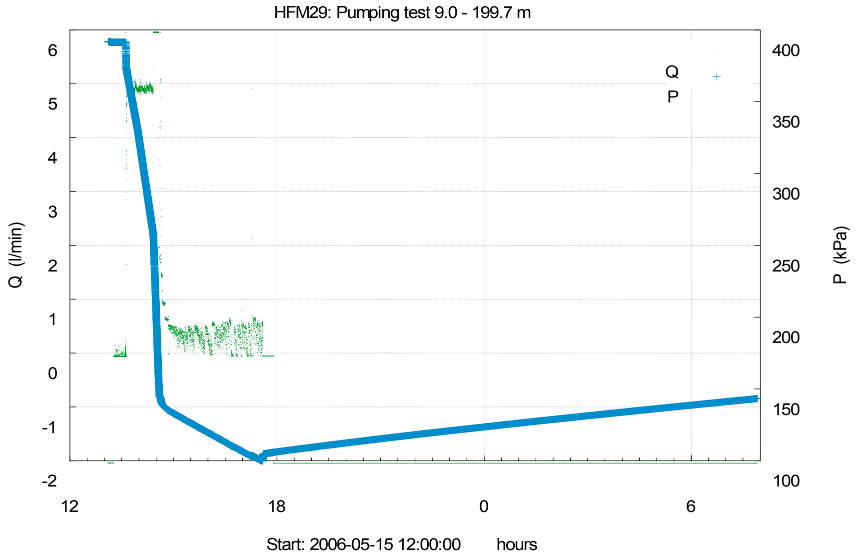


Figure A2-2. *Linear plot of flow rate (Q) and pressure (P) versus time, with a more detailed scale for the flow rate (Q), during the open-hole pumping test in HFM29.*

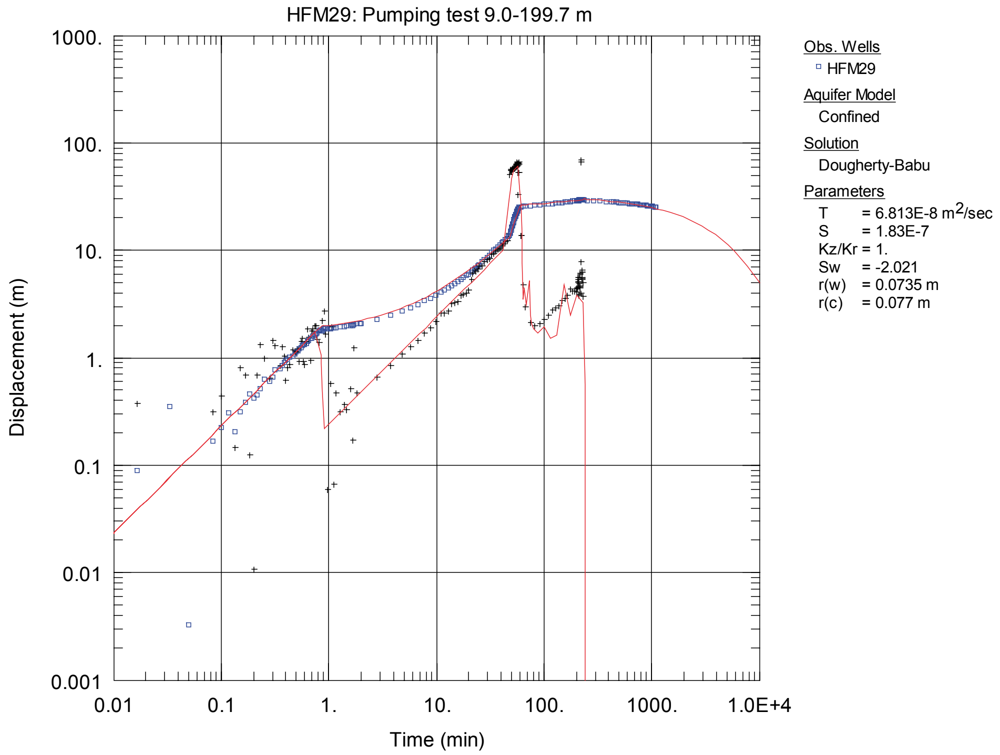


Figure A2-3. *Log-log plot of drawdown and recovery (blue □) and drawdown and recovery derivative (black +) versus time during the open-hole pumping test in HFM29.*

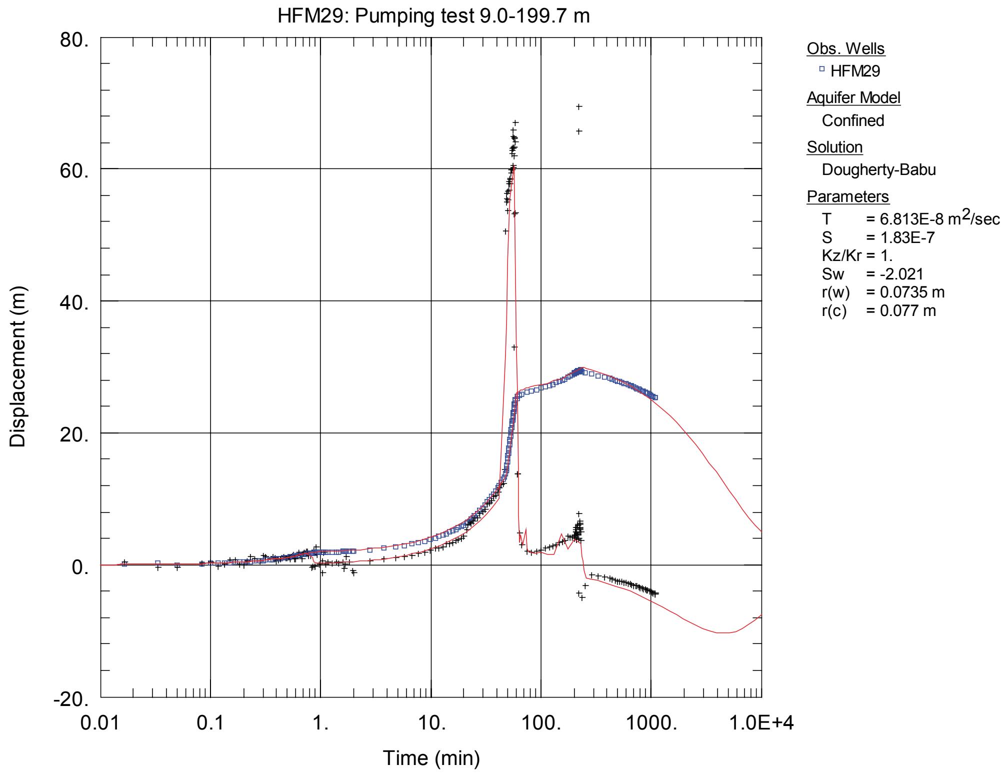


Figure A2-4. Lin-log plot of drawdown and recovery (blue □) and drawdown and recovery derivative (black +) versus time during the open-hole pumping test in HFM29.

Pumping test in HFM30: 18.0–200.8 m

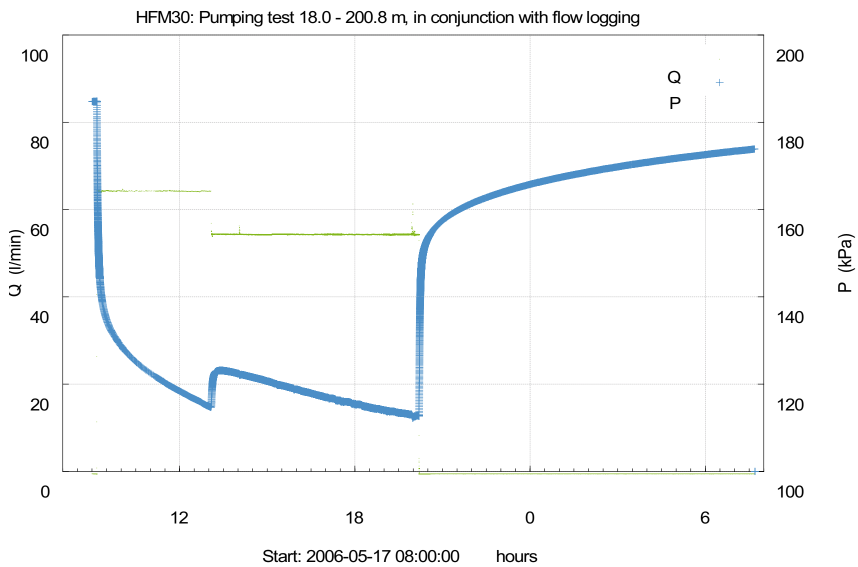


Figure A2-5. Linear plot of flow rate (Q) and pressure (P) versus time during the open-hole pumping test in HFM30 in conjunction with flow logging.

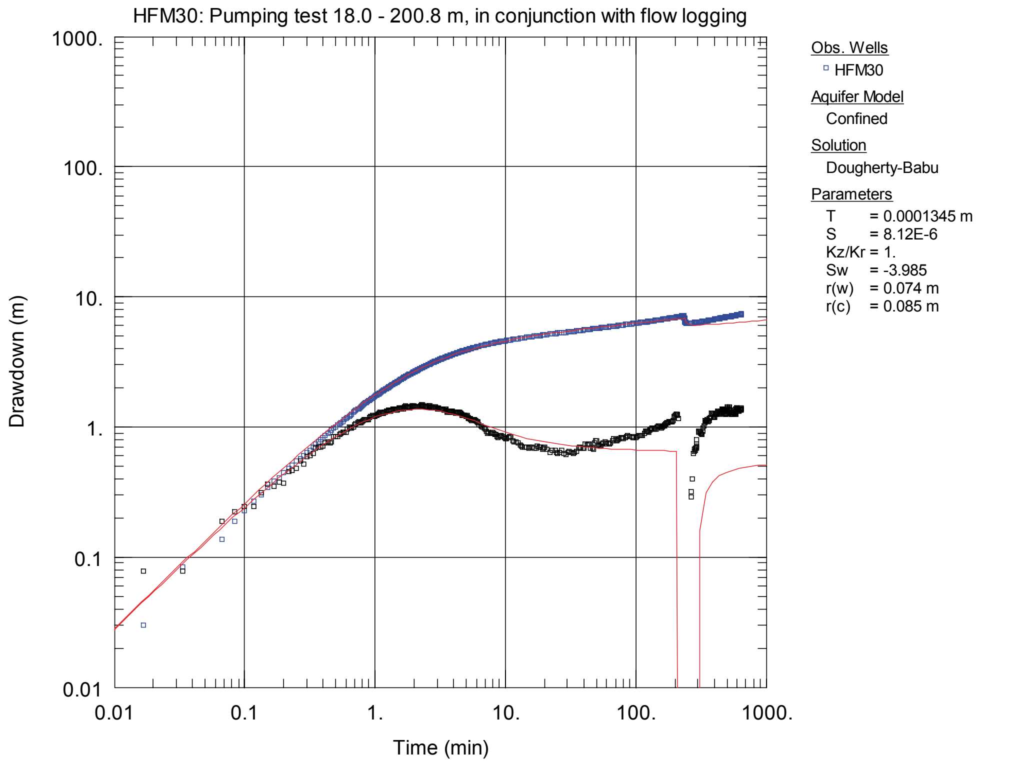


Figure A2-6. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM30.*

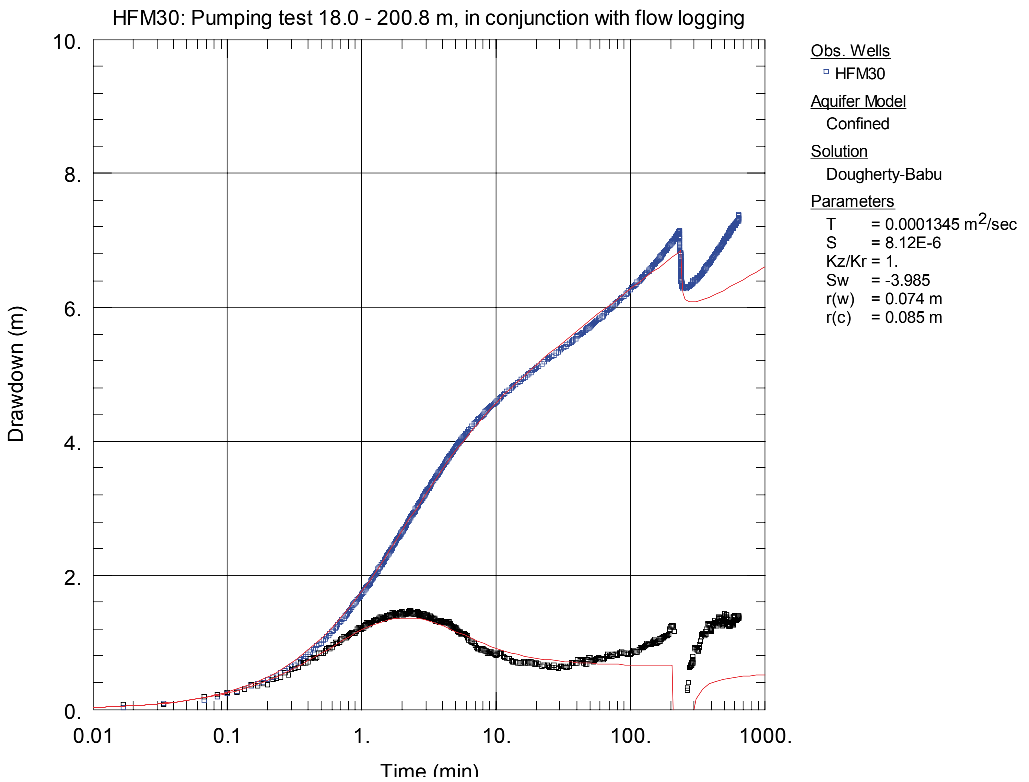


Figure A2-7. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM30.*

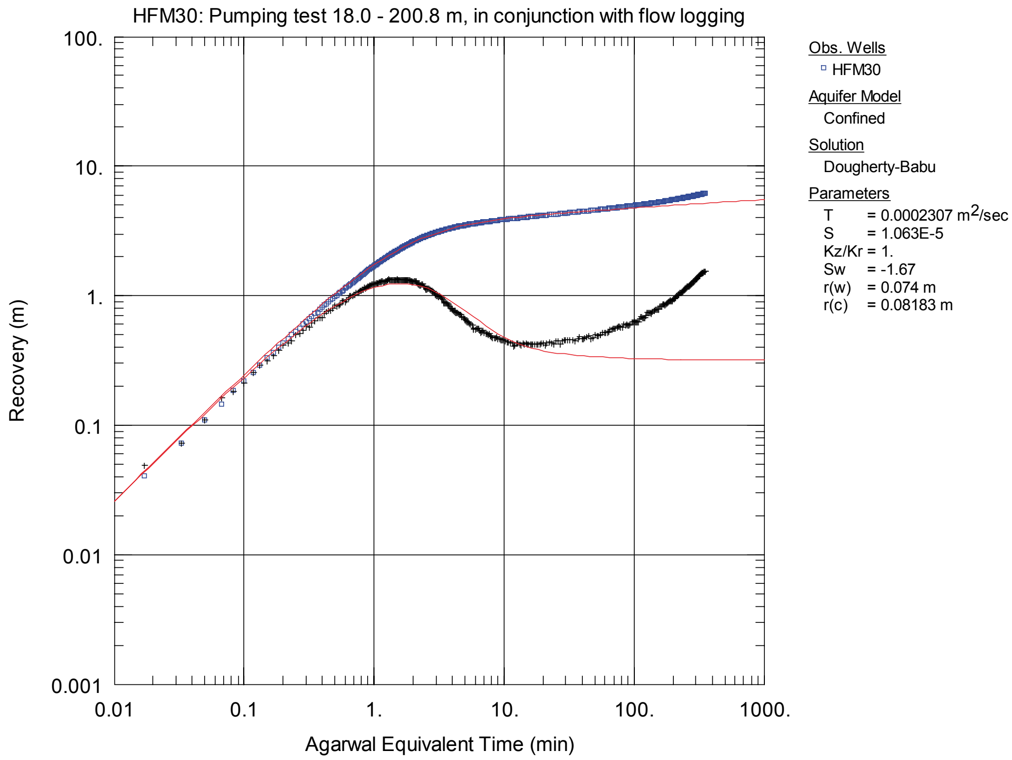


Figure A2-8. *Log-log plot of pressure recovery (blue □) and -derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM30.*

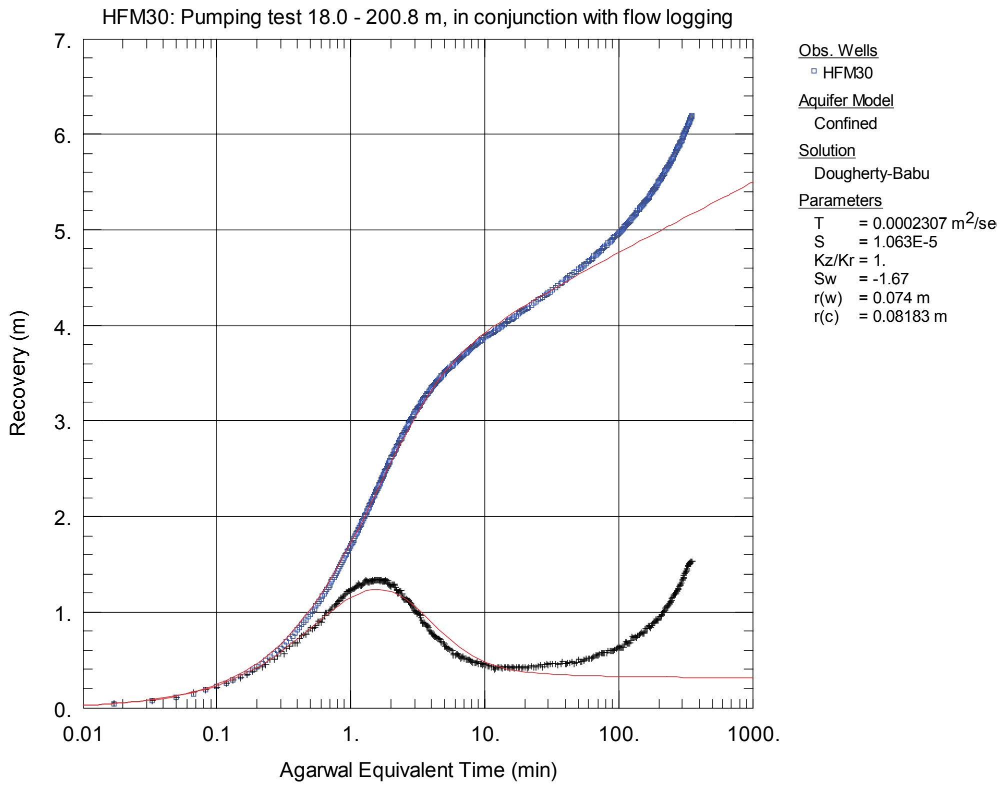


Figure A2-9. *Lin-log plot of pressure recovery (blue □) and -derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM30.*

Appendix 3

Result tables to the data base Sicada

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

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

idcode	start_date	stop_date	secup (m)	seclow (m)	section_no	test_type (yyyymmdd)	formation_type (yyyymmdd)	start_flow_period (m**3/s)	stop_flow_period	flow_rate_ end_qp
HFM29	060515 13:06:34	060516 07:55:07	9.03	199.70		1B	1	2006-05-15 13:37	2006-05-15 17:35	8.33E-06
HFM30	060517 09:00:15	060518 07:41:15	18.03	200.75		1B	1	2006-05-17 09:10	2006-05-17 20:12	9.13E-04

cont.

value_type_qp	mean_flow_ rate_qm (m**3/s)	q_measl__l (m**3/s)	q_measl__u (m**3/s)	tot_volume_ vp (m**3)	dur_flow_ phase_tp (s)	dur_rec_ phase_tf (s)	initial_ head_hi (m)	head_at_flow_ end_hp (m)	final_ head_hf (m)	initial_ press_pi (kPa)	press_at_ flow_end_pp (kPa)	final_ press_ pf (kPa)
0	3.29E-05	8.33E-05	1.33E-03	4.71E-01	14,280	65,866	2.91		–22.59	391.41	99.57	143.35
0	9.73E-04	8.33E-05	1.33E-03	3.86E+01	39,719	41,355	2.31	–5.10	1.20	184.79	112.74	173.88

cont.

fluid_temp_ tew (°C)	fluid_elcond_ ecw (mS/m)	fluid_salin- ity_tdsw (mg/l)	fluid_salin- ity_tdswm (mg/l)	reference	comments	lp (m)
						104
						120

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 and time of pumping/injection start (YYYY-MM-DD hh:mm:ss)
stop_flow_period	DATE	yyyymmdd	Date and 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, s_hole_test_ed1; Basic evaluation.

idcode	start_date	stop_date	secup (m)	seclow (m)	section _no	test_ type	forma-tion_type	lp (m)	seclen_ class (m)	spec_capacity _q_s (m**2/s)	value_ type_q_s	transmissiv-ity_tq (m**2/s)	value_type_tq
HFM29	060515 13:06:34	060516 07:55:07	9.03	199.70		1B	1	104		2.80E-07	0		
HFM30	060517 09:00:15	060518 07:41:15	18.03	200.75		1B	1	120		1.24E-04	0		

cont.

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	l_measl_tb (m**3/s)	u_ measl_tb (m**3/s)	sb (m)	assumed_ sb (m)	leakage_ factor_lf (m)	transmis-sivity_tt (m**2/s)	value_ type_tt	bc_ tt	l_measl_q_ s (m**2/s)
	3.60E-07	0	0										6.81E-08	0	1	2.E-06
	1.58E-04	0	0										1.35E-04	0	1	2.E-06

cont.

u_measl_ q_s m**2/s)	stora-tiv-ity_s	assumed _s	s_bc	ri (m)	ri_ index	leakge_ coeff (1/s)	hydr_ cond _ksf (m/s)	value_ type_ ksf	l_measl_ ksf (m/s)	u_measl _ksf (m/s)	spec_stor-age_ssf (1/m)	assumed _ssf (1/m)	c (m**3/ pa)	cd	skin	dt1 (s)	dt2 (s)	t1 (s)	t2 (s)
2.E-03		1.80E-07											1.70E-06		–2.02E+00				
2.E-03		8.10E-06		650.38	1								1.90E-06		–3.99E+00			0.00	11,280.00

cont.

dte1 (s)	dte2 (s)	p_horner (kPa)	transmis-sivity_t_nlr (m**2/s)	storativ-ity_s_nlr	value_ type_t_nlr	bc_t_nlr	c_nlr (m**3/pa)	cd_nlr	skin_ nlr	transmis-sivity_t_grf (m**2/s)	value_ type_t_grf	bc_t_grf	storativ-ity_s_grf	flow_ dim_grf	comment (no_unit)
39,720.00	44,400.00														

Column	Datatype	Unit	Column description
Site	CHAR		Investigation site name
Activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Project	CHAR		project code
Idcode	CHAR		Object or borehole identification code
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Section_no	INTEGER	number	Section number
test_type	CHAR		Test type code (1-7), see table description!
formation_type	CHAR		Formation type code. 1: Rock, 2: Soil (superficial deposits)
Lp	FLOAT	m	Hydraulic point of application for test section, see descr.
seclen_class	FLOAT	m	Planned ordinary test interval during test campaign.
spec_capacity_q_s	FLOAT	m**2/s	Specific capacity (Q/s) of test section, see table descript.
value_type_q_s	CHAR		0:true value,–1:Q/s<lower meas.limit,1:Q/s>upper meas.limit
transmissivity_tq	FLOAT	m**2/s	Tranmissivity based on Q/s, see table description
value_type_tq	CHAR		0:true value,–1:TQ<lower meas.limit,1:TQ>upper meas.limit.
bc_tq	CHAR		Best choice code. 1 means TQ is best choice of T, else 0
transmissivity_moye	FLOAT	m**2/s	Transmissivity,TM, based on Moye (1967)
bc_tm	CHAR		Best choice code. 1 means Tmoye is best choice of T, else 0
value_type_tm	CHAR		0:true value,–1:TM<lower meas.limit,1:TM>upper meas.limit.
hydr_cond_moye	FLOAT	m/s	K_M: Hydraulic conductivity based on Moye (1967)
formation_width_b	FLOAT	m	b:Aquifer thickness repr. for T(generally b=Lw) ,see descr.
width_of_channel_b	FLOAT	m	B:Inferred width of formation for evaluated TB
Tb	FLOAT	m**3/s	TB:Flow capacity in 1D formation of T and 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 descr.
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 descr
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
Skin	FLOAT		Skin factor;best estimate of flow/recovery period,see descr.

Column	Datatype	Unit	Column description
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
HFM30	2006-05-17 09:00	2006-05-18 07:41	18.03	195.50		2006-05-17 15:24:53	2006-05-17 19:55:30	200.75	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_flow-log_tfl_1 (s)	dur_flow-log_tfl_2 (s)	draw-down_s1 (m)	draw-down_s2 (m)	initial_ head_ho (m.a.s.l.)	hydrau-lic_head_h1 (m.a.s.l.)	hydraulic_ head_h2 (m.a.s.l.)	refer-ence	com-ments
5.0000E-05	1.3333E-03	9.13E-04		39,719.00		16,237.00		7.34		2.31	–5.10			

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 and evaluation
comments	VARCHAR		Short comment to the evaluated parameters (optional))

Plu_impell_main_res.

idcode	start_date	stop_date	secup (m)	seclow (m)	section_no	l (m)	cum_ flow_q0 (m**3/s)	cum_ flow_q1 (m**3/s)	cum_ flow_q2 (m**3/s)	cum_ flow_q1t (m**3/s)	cum_flow_ q2t (m**3/s)	corr_cum_ flow_q1c (m**3/s)	corr_cum_ flow_q2c (m**3/s)	corr_cum_ flow_q1tc (m**3/s)
HFM30	2006-05-17 15:24	2006-05-17 19:55	18.03	195.50		200.75								

cont.

corr_cum_ flow_q2tc (m**3/s)	corr_com_ flow_q1tcr (m**3/s)	corr_com_ flow_q2tcr (m**3/s)	transmissi- tivy_hole_t	value_ type_t	bc_t	cum_transmis- sivity_tf (m**2/s)	value_type_ tf	bc_tf	l_measl_tf (m**2/s)	cum_trans- missivity_ tft (m**2)	value_ type_tft	bc_tft	u_measl_tf (m**2)	refer- ence	com- ments
	9.1333E-04		1.35E-04	0	1		0	1	1.69E-06	1.35E-04	0	1			

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

Plu_impeller_anomaly.

idcode	start_date	stop_date	secup (m)	seclow (m)	sec-tion_no	l_a_upper (m)	l_a_lower (m)	fluid_temp_tea (°C)	fluid_elcond_eca (mS/m)	fluid_salin-ity_tdsa (mg/l)	dq1 (m**3/s)	dq2 (m**3/s)
HFM30	2006-05-17 15:24	2006-05-17 19:55	18.03	200.75		67.00	72.00					
HFM30	2006-05-17 15:24	2006-05-17 19:55	18.03	200.75		119.00	120.00					
HFM30	2006-05-17 15:24	2006-05-17 19:55	18.03	200.75		136.00	136.50					
HFM30	2006-05-17 15:24	2006-05-17 19:55	18.03	200.75		159.00	159.50					
HFM30	2006-05-17 15:24	2006-05-17 19:55	18.03	200.75		190.00	191.00					
HFM30	2006-05-17 15:24	2006-05-17 19:55	18.03	200.75		195.50	200.75					

cont.

r_wa (m)	dq1_corrected (m**3/s)	dq2_corrected (m**3/s)	spec_cap_dq1c_s1 (m**2/s)	spec_cap_dq2c_s2 (m**2/s)	value_type_dq1_s1	value_type_dq2_s2	ba (m)	transmissiv-ity_tfa (m**2/s)	value_type_tfa	bc_tfa	l_measl_tfa (m**2/s)	u_measl_tfa (m**2/s)	comments
0.07	4.67E-05		6.36E-06		0		5.0	6.90E-06	0	1	1.67E-06	8.30E-05	
0.07	2.75E-04		3.75E-05		0		1.0	4.06E-05	0	1	1.67E-06	8.30E-05	
0.07	1.67E-04		2.27E-05		0		0.5	2.46E-05	0	1	1.67E-06	8.30E-05	
0.07	1.25E-04		1.70E-05		0		0.5	1.85E-05	0	1	1.67E-06	8.30E-05	
0.07	5.83E-05		7.95E-06		0		1.0	8.62E-06	0	1	1.67E-06	8.30E-05	
0.07	2.42E-04		3.29E-05		0		5.3	3.57E-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)
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 Q1or head h1
dq2	FLOAT	m**3/s	Flow rate of inferred flow anomaly at pump flowQ2 or head h2
r_wa	FLOAT	m	Estimated borehole radius
dq1_corrected	FLOAT	m**3/s	Corrected flow rate of anomaly at pump flow Q1 or see descr.
dq2_corrected	FLOAT	m**3/s	Corrected flow rate of anomaly at pump flow Q2, or see descr
spec_cap_dq1c_s1	FLOAT	m**2/s	dq1/s1.Spec. capacity of anomaly at pump flow Q1 or ..,see
spec_cap_dq2c_s2	FLOAT	m**2/s	dq2/s2.Spec. capacity of anomaly at pump flow Q2 or.,see des
value_type_dq1_s1	CHAR		0:true value,–1:<lower meas.limit,1:>upper meas.limit.
value_type_dq2_s2	CHAR		0:true value,–1:<lower meas.limit,1:>upper meas.limit.
ba	FLOAT	m	Representative thickness of anomaly for TFa,see description
transmissivity_tfa	FLOAT	m**2/s	Transmissivity of inferred flow anomaly.
value_type_tfa	CHAR		0:true value,–1:TFa<lower meas.limit,1:TFa>upper meas.limit.
bc_tfa	CHAR		Best choice code.1 means TFa is best choice of T, else 0
l_measl_tfa	FLOAT	m**2/s	Lower measurement limit of TFa, see table description
u_measl_tfa	FLOAT	m**2/s	Upper measurement limit of TFa, see table description
comments	CHAR		Short comment on evaluated parameters
error_flag	CHAR		If error_flag = “*” then an error occured and an error
in_use	CHAR		If in_use = “*” then the activity has been selected as
sign	CHAR		Activity QA signature