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Boreholes KFM02A (0–100 m), HFM04 and HFM05

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May 2003

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Abstract

Borehole KFM02A was the second deep (c 1000 m) cored borehole drilled within the frame of on-going site investigations in the Forsmark area. The borehole is telescopic drilled, implying that the upper part, 0–100 m, is percussion drilled with a larger diameter than the diameter of the core drilled part (76 mm).

In connection with the drill start of borehole KFM02A, four other, however more shallow boreholes, were drilled in the vicinity of KFM02A. Two of them, HFM04 and HFM05, are percussion drilled boreholes in hard rock.

Pumping tests were performed in the percussion drilled part, 0–100 m, of KFM02A and in HFM04 and HFM05. Water samples were collected in all boreholes in conjunction with the pumping tests. No other borehole tests had been carried out in the actual boreholes prior to this campaign.

The main objectives of the hydraulic tests in the percussion boreholes were firstly, to perform a hydraulic characterization of the boreholes and secondly, for HFM04 and HFM05, to investigate the groundwater chemistry.

From the flow logging, one high-transmissivity zone was identified in all three of the tested boreholes at depths ranging from c 60 m to c 150 m below ground surface. The flow logging showed that the zones encountered in these boreholes were narrow (2–6 m wide) and highly conductive with estimated transmissivities in the order of $1–5 \cdot 10^{-4}$ m^2/s.

In borehole HFM05 and KFM02A(0–100 m) two pseudo-radial flow regimes, i.e. with a flow dimension close to 2, were identified, possibly representing the hydraulic properties of the zone close to the borehole and at larger distances from the borehole, respectively.

Sammanfattning

Borrhål KFM02A var det andra ca 1000 m djupa kärnborrhålet som borrades inom ramen för de pågående platsundersökningarna i Forsmarksområdet. Borrhålet är utfört som ett s k teleskopborrhål, vilket innebär att avsnittet 0–100 m är hammarborrat med grövre dimension än det kärnborrade avsnittet mellan 100 och 1000 m, som håller diametern 76 mm.

I samband med borrstarten för KFM02A borrades ytterligare fyra borrhål i närområdet. Två av dessa, HFM04 och HFM05, är hammarborrhål i berg.

Provpumpning och flödesloggning utfördes i KFM02A (0–100 m), HFM04 och HFM05. Vattenprover togs i alla borrhålen i samband med provpumpningarna. Inga andra borrhålstester hade utförts i de aktuella borrhålen före denna kampanj.

De huvudsakliga syftena med de hydrauliska testerna i hammarborrhålen var, för det första, att utföra en hydraulisk karaktärisering av borrhålen och, för det andra, att undersöka grundvattenkemin.

Från flödesloggningen identifierades en högtransmissiv zon i alla tre borrhålen på djup varierande mellan ca 60–150 m under markytan. Flödesloggningen visade att de påträffade zonerna i dessa borrhål var smala (ca 2–6 m) och högtransmissiva. Transmissiviteten skattades till i storleksordningen $1–5 \cdot 10^{-4}$ m^2/s.

I borrhålen HFM05 och KFM02A (0–100 m) identifierades två perioder med pseudo-radiellt flöde, dvs med en flödesdimension nära 2, som möjligen kan representera de hydrauliska egenskaperna av zonen nära borrhålet respektive på längre avstånd från detta.

Contents

1 Introduction

The initial phase of the on-going site investigations in the Forsmark area includes drilling and multi-disciplinary investigations of three c 1000 m deep cored boreholes, see Figure 1-1. Of these, borehole KFM02A was the second one to be completed. The borehole is telescopic drilled, implying that the upper part, 0–100 m, is percussion drilled with a larger diameter than that of the core drilled part, which is 76 mm. The percussion drilled interval was drilled in two steps. The first step resulted in a borehole diameter of c 165 mm. A large inflow, c 650–700 L/min, was observed during drilling at 79.6 m. After a break for different types of borehole testing, this part of the borehole was reamed to a larger diameter and cased. Finally, core drilling was performed below the cased part.

In connection with the drill start of borehole KFM02A, four other, however more shallow boreholes, were drilled at drillsite DS2, i.e. in the vicinity of KFM02A. Two of them, HFM04 and HFM05, are percussion drilled boreholes in hard rock, whereas the remaining two boreholes are monitoring wells drilled through the unconsolidated overburden at drillsite DS2, see Figure 1-2.

Figure 1-1. The investigation area at Forsmark including the candidate area selected for more detailed investigations. The drillsites for the earliest drilled deep cored boreholes are marked with blue dots. Borehole KFM02A is situated at drillsite DS2.

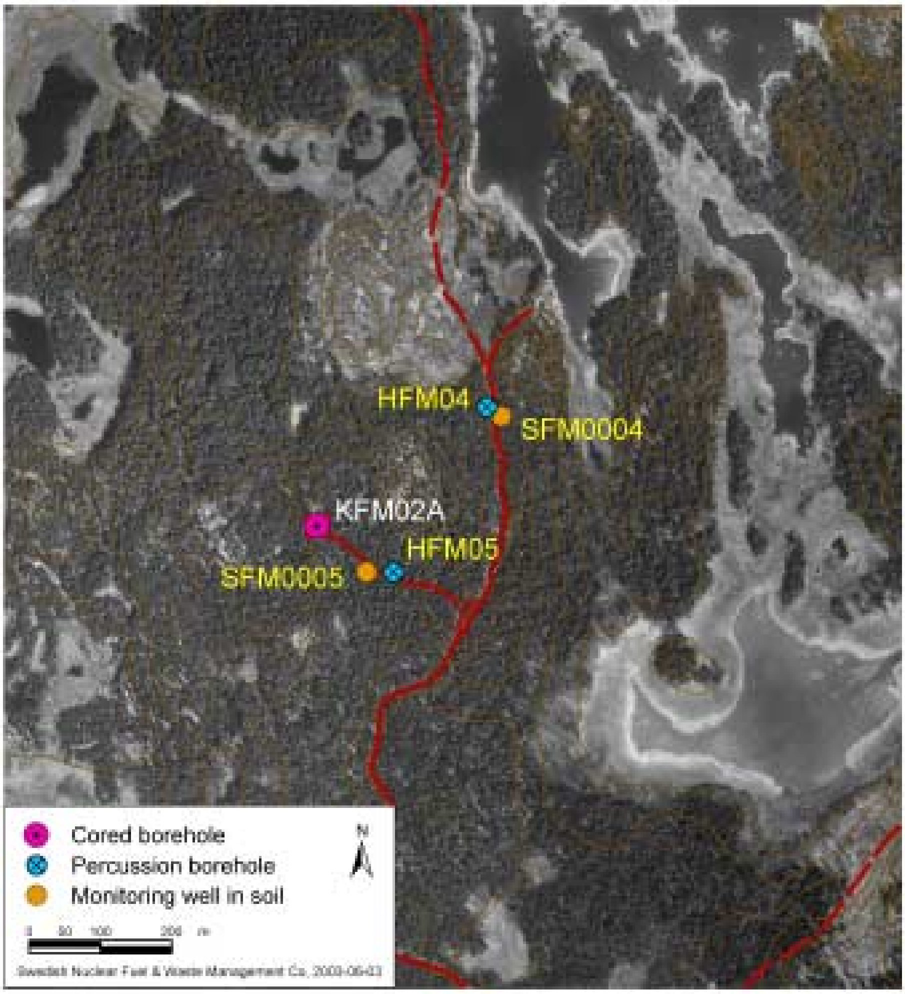


Figure 1-2. *Map showing the location of boreholes att drillsite DS2 at Forsmark.*

Boreholes HFM04 and HFM05 were drilled with the purpose that one of them would be suitable to serve as a supply well for the flushing water needed for drilling the cored part of borehole KFM02A, whereas the other would be used for groundwater level monitoring /1/. Furthermore, the groundwater chemistry was to be investigated in both boreholes.

In HFM04 an inflow of c 17 L/min was encountered during drilling at 6.8 m and some moisture observed at 78 m. Fractures were indicated at 62–65 m, however not connected with groundwater inflow during drilling. From the entire interval 12–130 m, the inflow was estimated at c 2.2 L/min during a recovery test during drilling. In HFM05, an inflow of c 40 L/min was estimated at c 155 m during drilling.

This report presents results from pumping tests and flow logging in boreholes KFM02A (0–100 m), HFM04 and HFM05, performed with a specially designed equipment system, the HTHB test system. Water samples were collected during pumping. The results of the chemical investigations are reported in /2/.

No other borehole tests had been carried out in the actual boreholes before the campaign described in this report.

2 Objectives

Pumping tests, flow logging and groundwater sampling were performed in KFM02A (0–100 m) and in HFM04 and HFM05. The objectives of the pumping test in the interval 0–100 m in KFM02A (more exactly 12.0–100.4 m) were to characterize the hydraulic properties of the rock formation penetrated by the borehole, before installation of a borehole casing, and furthermore to investigate the hydrogeochemical character of the borehole water.

The main objectives of the tests in the percussion holes HFM04 and HFM05 were firstly, to obtain a hydraulic characterization (e.g. to reveal the occurrence of possible sub-horizontal fracture zones) and secondly, to investigate the water chemistry, partially for a general hydrogeochemical characterization, partally for a judgement of the potential of either borehole to serve as a supply well for flushing water during drilling of KFM02A.

3 Scope

3.1 Boreholes tested

Pertinent data on the tested boreholes are given in Table 3-1. The reference point in the boreholes is always top of casing (ToC). The Swedish National coordinate system (RT90 2.5 g W) is used to indicate position in the x-y-plane together with RHB70 in the z-direction. The reported borehole diameters in Table 3-1 refer to the final diameter of the boreholes after drilling to full depth. The borehole diameter (measured as the diameter of the drill bit) usually decreases c 1–2 mm/100 m along the borehole in the type of rock prevailing at Forsmark, due to successively increased wear of the drill bit.

The coordinates of the boreholes and other borehole data are shown in Table 3-2. Northing and Easting refer to the intersection of the boreholes with the ground surface.

Table 3-1. Technical data of the boreholes tested. (From SICADA).

Borehole data							
Bh ID	**Elevation of top of casing (ToC) (m.a.s.l.)**	**Borehole interval from ToC (m)**	**Casing/ Bh-diam. (m)**	**Inclination- top of bh (from horizontal plane) (°)**	**Dip-direction- top of borehole (from local N) (°)**	**Remarks**	**Drilling finished Date (YYYY-MM-DD)**
KFM02A	7.353	0-100.40 [1)]	0.200 [2)]	-85.385	275.764	Casing ID	
”			0.165 [3)]			borehole	2002-11-26
HFM04	3.873	-0.22-2.72	0.244	-84.257	336.875	Casing ID	
		0.00-12.10	0.160			Casing ID	
		12.10-221.70	0.138			borehole	2002-12-03
HFM05	7.672	0-11.85	0.160	-84.961	335.589	Casing ID	
”		11.85-11.87	0.146			Casing ID	
”		11.87-101.3	0.136			borehole	
”		101.3-200.10	0.134			borehole	2002-12-16

1) Borehole length of percussion-drilled interval
2) Final borehole casing
3) Borehole diameter of percussion-drilled interval at the time of the test

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

Borehole data		
Bh ID	**Northing (m)**	**Easting (m)**
KFM02A	6698712.501	1633182.863
HFM04	6698878.968	1633420.733
HFM05	6698647.275	1633289.721

3.2 Tests performed

None of the boreholes were tested prior to the test campaign described in this report. The tests performed in the boreholes are listed in Table 3-3. In conjunction with the flow logging, temperature- and electric conductivity logging of the borehole water was also performed.

During the pumping tests, water samples were collected and submitted for analysis, see Section 6.2. Of primary interest was to decide if the borehole water was of sufficient quality to be used as flushing water for drilling of the cored part of borehole KFM02A.

Manual observations of the groundwater level in the pumped boreholes were also made during the tests as a back-up for the automatic registrations.

Table 3-3. Borehole tests performed.

Borehole tests				
Bh ID	**Test section (m)**	**Test type[1]**	**Test start date and time (YYYY-MM-DD tt:mm)**	**Test stop date and time (YYYY-MM-DD tt:mm)**
KFM02A	12.00-100.40	1B	2002-11-29 09:18	2002-12-02 09:03
”	22-100	6, L-Te, L-EC	2002-11-29 13:38	2002-11-29 15:47
HFM04	12.10-221.70	1B	2002-12-10 10:00	2002-12-11 10:10
”	35-210	6, L-Te, L-EC	2002-12-10 17:55	2002-12-10 19:00
HFM05	11.87-200.10	1B	2002-12-19 08:00	2002-12-20 10:00
”	28-195	6, L-Te, L-EC	2002-12-19 14:36	2002-12-19 17:30

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

4 Description of equipment

4.1 Overview

The equipment used for these tests is referred to as HTHB (Swedish abbreviation for Hydraulic Test System for Percussion Boreholes), which is described in SKB MD 326.001-15, Version 1.0 (Mätsystembeskrivning för HTHB-utrustning. Handhavandedel).

The HTHB-unit is designed for percussion boreholes to perform pumping- and injection tests, either in open boreholes (or above a single packer), see Figure 4-1, or in isolated sections of the boreholes (Figure 4-2) down to a total depth of 200 m. With the HTHB-unit, it is also possible to perform a impeller flow logging survey along the borehole during an open-hole pumping test (Figure 4-1). The pumping tests can be performed with either a constant hydraulic head or, alternatively, with a constant flow rate. For injection tests, the deepest position of the upper packer is limited to c 80 m below ToC.

All equipment included in the HTHB-system is, when not in use, stored on a trailer and can easily be transported with a standard car. The down the hole-equipment consists of a submersible borehole pump with housing, expandable packers, pressure sensors and a pipe string and/or hose. During impeller flow logging, sensors measuring temperature and electric conductivity as well as the down-hole flow rate are also used. The equipment on the ground includes a control valve for manual adjustment of the total flow/injection rate, which is 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 to pressurize the water) unless the depth to the groundwater level is large. In such cases, the packers are expanded by nitrogen gas. A folding pool is used to collect and store the discharged water from the borehole for subsequent use in injection tests.

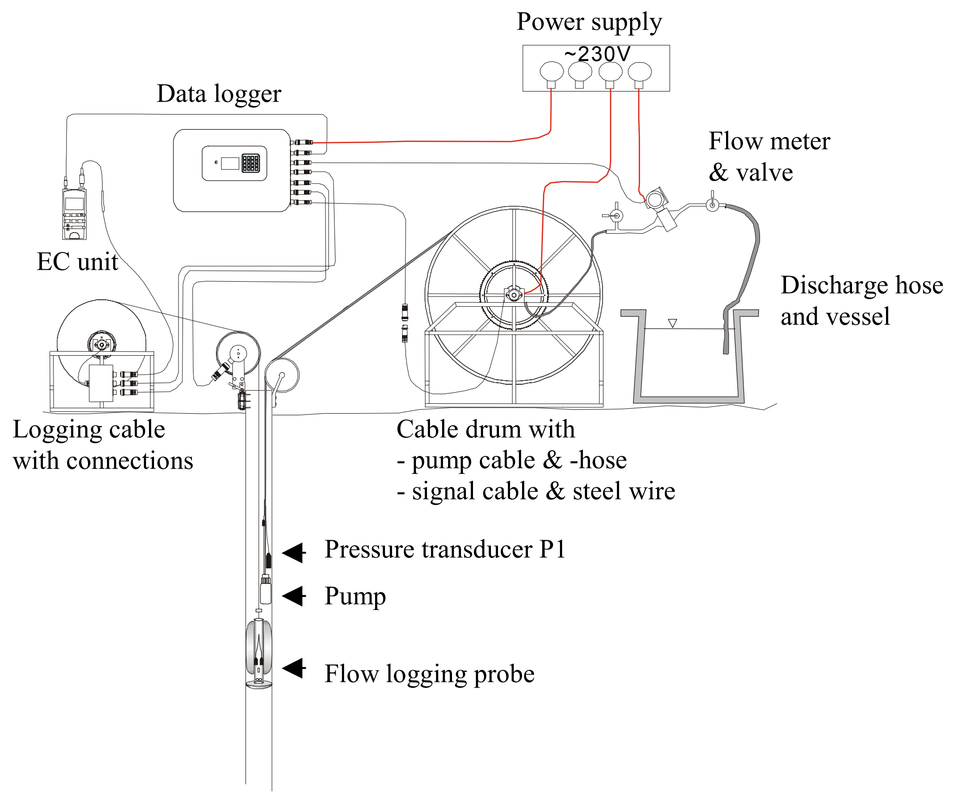


Figure 4-1. *Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB.*

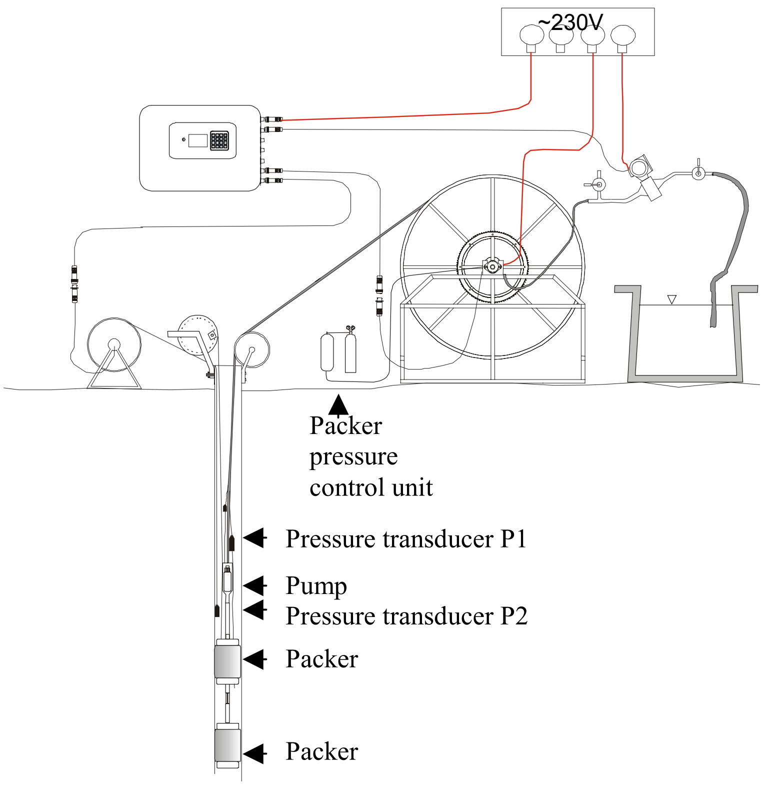


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB.*

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 the borehole inclination may also affect the accuracy of measured data.

The flow-logging probe is calibrated for different borehole diameters (e.g. different pipe diameters), i.e. 111.3, 135.5, 140 and 160 mm. During calibration the probe is installed in a vertically orientated pipe and a water flow is pumped through. Spinner rotations and the total discharge are measured. Calibration gives excellent correlation ($R^2 > 0.99$) between total discharge and the number of spinner rotations. The calibration also clearly demonstrates the sensitivity of the probe in relation to deviations in the borehole diameter, cf Figure 4-3.

The recorded flow at each position during flow logging was found to be rather insensitive to the measurement time (50, 100, 200 s), provided that sufficient stabilisation time is allowed to a change in flow. The stabilisation time may be up to 30 s at flow rates close to the lower measurement limit, whereas this time is almost instantaneous at high flow rates.

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	0–1500	0–1500	
	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	0–50000	0–50000	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
	Accuracy***	% o.r.**		± 20	and 100 s sampling time
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 repeatibility
** Maximum error in % of actual reading (% o.r.).
*** Applicable to boreholes with a borehole diameter of 140 mm and 100 s sampling time
**** For injection tests the minimal flow rate is 1 L/min

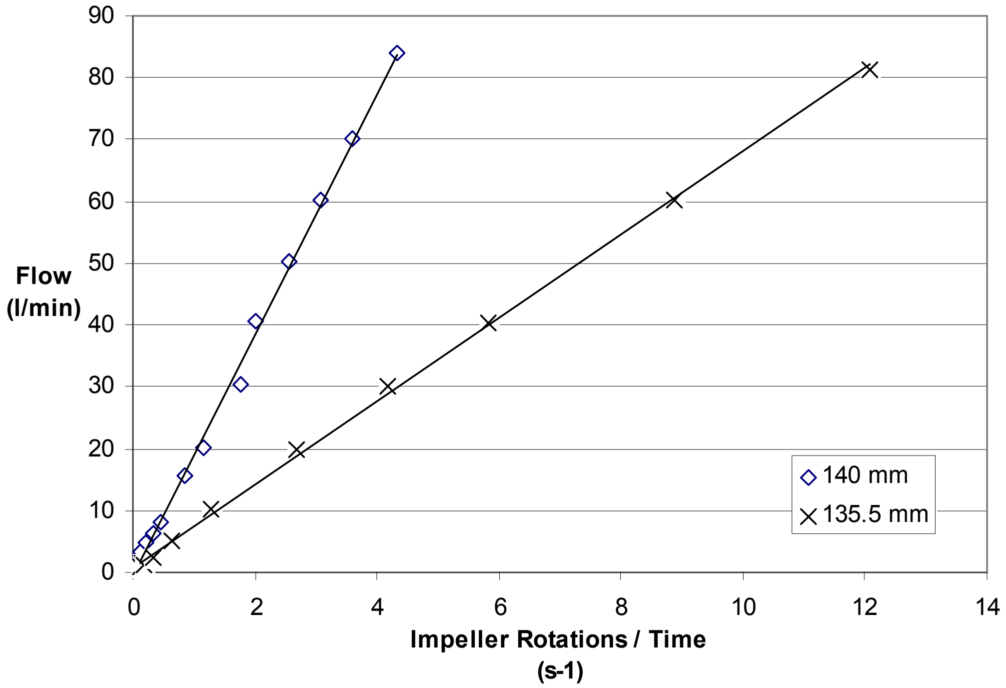


Figure 4-3. *Total flow rate as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).*

Table 4-2 lists the position of sensors for each test. The following types of sensors are used: pressure (p), temperature (Te), electric conductivity (EC) together with the (lower) level of the submersible pump (Pump). Positions are given in metre 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 the submerged component. Position is given as “in section” or “above section”. The volume of the submerged pump (~ 4 dm^3) is in most cases of minor importance.

In addition, the theoretical wellbore storage coefficient, C, for the actual test configurations and the geometrical data of the boreholes (Table 3-1) have been calculated, see Section 5.4.1. These values on C may be compared with the estimated ones from the test interpretations described in Chapter 6.

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

Borehole information				Sensors		Equipment affecting wellbore storage (WBS)			
ID	Test interval (m)	Test config	Test type[1]	Type	Position (m b ToC)	Function	Position[2] relative test section	Outer diameter (mm)	C (m^3/Pa) for actual test[3)]
KFM02A	12-100.4	Open hole	1B	Pump-intake	17.5	Pump	In borehole		$3.2\cdot10^{-6}$
						Pump hose	In borehole	33.5	(based on the casing diameter of 200 mm)
			1B	P (P1)	14.72	Pump cable	In borehole	14.5	
			6	EC, Te, Q	22-100	Signal cable	In borehole	8	
						Signal cable	In borehole	13.5	
						Tecalan hose	In borehole	6	
						Steel wire	In borehole	6	
HFM04	12-221.7	Open hole	1B	Pump-intake	30.95	Pump	In borehole		$2.0\cdot10^{-6}$
						Pump hose	In borehole	33.5	(based on the casing diameter of 160 mm)
			1B	P (P1)	28.17	Pump cable	In borehole	14.5	
			6	EC, Te, Q	35-210	Signal cable	In borehole	8	
						Signal cable	In borehole	13.5	
						Tecalan hose	In borehole	6	
						Steel wire	In borehole	6	
HFM05	12-200.1	Open hole	1B	Pump-intake	24.5	Pump	In borehole		$2.0\cdot10^{-6}$
						Pump hose	In borehole	33.5	(based on the casing diameter of 160 mm)
			1B	P (P1)	21.22	Pump cable	In borehole	14.5	
			6	EC, Te, Q	28-195	Signal cable	In borehole	8	
						Signal cable	In borehole	13.5	
						Tecalan hose	In borehole	6	
						Steel wire	In borehole	6	

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

2) Position of equipment that can affect wellbore storage. Position given as “In Section” or “Above Section” or “In borehole”

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

5 Execution

The pumping tests and flow logging were performed according to Activity Plan AP PF 400-02-39 (SKB internal controlling document) in accordance with the methodology descriptions for single-hole pumping tests, SKB MD 321.003, Version 1.0 (Metodbeskrivning för hydrauliska enhålspumptester), and flow logging, SKB MD 322.009, Version 1.0 (Metodbeskrivning för flödesloggning).

5.1 Preparations

All sensors included in the HTHB-system are calibrated at GEOSIGMAs engineering workshop in Librobäck, Uppsala. Calibration is performed on a yearly basis, or more often if needed. The last calibration before the tests for HTHB1 (the first of two manufactured HTHB-systems) was done in April, 2002. Calibration protocol was submitted in the delivery of raw data after the test campaign.

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

To check the function of the pressure sensors P1 and P2 (cf. Figures 4-1 and 4-2), the pressure in air was recorded and found to be as expected. Submerged in water while lowering, P1 coincided well to the total head of water ($p/\rho g$). The temperature sensor showed expected values in both air and water.

The sensor for electric conductivity showed a zero value in air. The impeller used in the flow logging equipment worked well as indicated by the rotation on the logger while lowering. The measuring wheel (used to check the position of the flow logging probe) and the sensor attached to it indicated a length that corresponded well to the pre-measured cable length.

5.2 Procedure

5.2.1 Overview

The pumping tests were mainly carried out as single-hole, constant flow rate tests, followed by a pressure recovery period. The intention was to obtain approximately steady-state conditions during the flow logging.

The flow logging was performed while pumping. Discrete flow measurements were made at fixed step lengths (10 m), starting from the bottom and moving the flow probe upwards along the borehole. When the first detectable flow anomaly was indicated, the flow probe was lowered 10 m, and repeated measurements with a shorter step length (2 m) were made to locate the position of the flow anomaly more exactly. Finally, a step length of 0.5 m was used to determine the detailed position of the anomaly. After characterization of the first anomaly, the flow logging continued with a length increment of 2 m, until the next flow anomaly was encountered. The flow logging survey was terminated at a short distance below the submersible pump in the borehole.

5.2.2 Details

Single-hole pumping tests

Prior to the tests, function checks and cleaning of equipment, as well as time synchronisation of clocks and data loggers were performed according to the Activity Plan. Short flow capacity tests were carried out to identify an appropriate flow rate for the tests. All pumping tests and flow meter loggings were carried out after completion of the boreholes at full drilling depths, using the HTHB-unit. The pumped water from the boreholes was discharged on the ground, sloping downhill from the pumping borehole.

The main test in each borehole was a c 10 h long pumping test in the open hole in combination with flow logging, followed by a recovery period of c 12 h. In borehole KFM02A (12.0–100.4 m), the duration of the recovery period was increased over the weekend for practical reasons. In general, the sampling frequency of pressure during the pumping tests was according to Table 5-1.The hydraulic tests in the boreholes were performed in the following order of time: KFM02A (12.0–100.4 m), HFM04 and HFM05.

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

- the recommended test time (24 h + 24 h for flow/recovery) for the longer 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 also indicates that c 10 h of pumping and 12 h of recovery in general is sufficient to estimate the hydraulic properties of the borehole regarding, e.g. wellbore storage effects and other disturbing factors.

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

Time interval (s) from start/stop of pumping	Sampling frequency (s)
1-300	1
301-600	10
601-3600	60
>3600	600

Flow logging

Before start of flow logging, the probe was lowered to the bottom of the borehole (max. speed = 0.5 m/s), simultaneously as temperature- and electric conductivity data were sampled. The probe was halted (15 s) at every two metres for data sampling with an interval of 5 s.

Flow logging was performed during the long pumping test (10 h), starting from the bottom of the hole, going upwards. The logging was started at approximately stable pressure conditions. The time needed to complete the flow logging survey depends on the length and character of the borehole. In general, between 3–7 hours are needed for a percussion borehole of 100–200 m length.

5.3 Data handling

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

Processed data files (*.mio-files) from the hydraulic tests with pressure versus time data were converted to drawdown- and recovery files by the code PUMPKONV and plotted in different diagrams listed in the methodology instruction for analysis of injection- and single-hole pumping tests, SKB MD 320.004, Version 1.0, (Metodinstruktion analys av injektions- och enhålspumptester) by the code SKB-plot.

By the conversion to drawdown- and recovery files, different values were applied on the filter coefficient (step length) by the calculation of the pressure derivative to investigate the effect of this coefficient on the derivative. It is desired to achieve maximal smoothing of the derivative without altering the original shape of the data.

5.4 Analyses and interpretation

5.4.1 Single-hole pumping tests

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

From the results of the qualitative evaluation, appropriate interpretation models for the tests were selected. In most cases, a certain period with pseudo-radial flow could be identified during the pumping tests. Consequently, methods for single-hole, constant-flow rate tests in an equivalent porous medium were used by the standard evaluation of the tests. For tests indicating a fractured- or borehole storage dominated response, corresponding type curves were used by the analyses.

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

The transient analysis of tests dominated by wellbore storage was made according to the single-hole methods described in /3/. Estimation of the borehole storage coefficient C in appropriate pumping tests was based on the early borehole response with 1:1 slope in a log-log diagram. These values on C may be compared with the well-bore storage coefficient calculated below, based on actual borehole geometrical data and assumed fluid properties (net values). The estimated values on C from the test data may differ from the net values due to deviations of the actual geometrical borehole properties from the anticipated, e.g. borehole diameter. Furthermore, the effective compressibility is usually higher than the water compressibility in an isolated section due to e.g. packer compliance, resulting in a higher C-value.

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

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

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

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

r_{we} = borehole radius where the changes of the groundwater level occur (either r_w or r_c)
r_w = nominal borehole radius (m)
r_c = inner radius of the borehole casing (m)
ρ = density of water (kg/m^3)
g = acceleration of gravity (m/s^2)
L_w = section length (m)
c_w = compressibility of water (Pa^{-1}).

5.4.2 Flow logging

The measured parameters during the flow meter logging (flow, temperature and electric conductivity of the borehole fluid) are firstly plotted versus borehole length. From these plots, flow anomalies were identified along the borehole, i.e. borehole intervals over which (in this case) changes of flow rates exceeding c 1 L/min occur. The magnitude of the inflow at the flow anomaly is determined by the actual change in flow rate over the interval. In some cases, the flow changes are accompanied by corresponding changes in temperature and/or electric conductivity of the fluid.

Flow logging can only be carried out up to a certain distance below the submersible pump (when logging from the bottom of the hole upwards). 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 in this part. Such superficial inflows may be identified by comparing the cumulative flow at the top of the flow-logged interval (Q_T) with the discharged flow rate (Q_p) from the hole at the surface during the flow logging. If the latter flow rate is significantly higher than the cumulative flow rate, one or several inflow zones are likely to exist above the flow-logged interval.

The transmissivity (T) of the entire borehole was calculated from the analysis of the pumping test during flow logging. The cumulative transmissivity at the top of the flow-logged interval ($T_{FT}=\Sigma T_i$) was then calculated according to the methodology description for Impeller flow logging, SKB MD 322.009, (assuming zero natural flow in the borehole):

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

If $Q_T < Q_p$, one or several flow anomalies may be located above the flow-logged interval. In such cases, the (order of magnitude) of the transmissivity of these anomalies may be estimated from Equation (5-3).

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

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

For comparison, estimates of the transmissivities of the identified flow anomalies were also made from the specific flows, simply by dividing the measured inflow (ΔQ_i) at the anomaly by the drawdown (s_{FL}) in the hole during the flow logging (assuming negligible head losses). The sum of the specific flows may then be compared with the total transmissivity (and specific flow) of the borehole.

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

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

where Q(L)=cumulative flow at borehole length L.
The lower limit of transmissivity (T_{min}) in flow logging may be estimated in a similar way as Equation (5-3):

$$T_{min} = T \cdot Q_{min} / Q_p \qquad (5\text{-}6)$$

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.

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 methodology instruction for analysis of single-hole injection- and pumping tests, SKB MD 320.004, Version 1.0 (Metodinstruktion för analys av injektions- och enhålspumptester), and the methodology description for impeller flow logging, SKB MD 322.009, Version 1.0 (Metodbeskrivning för flödesloggning), cf Section 3.2. Additional symbols used are explained in the text.

6.2 Water sampling

Water samples were collected during the pumping tests in the boreholes at drillsite DS2 at Forsmark (Figure 1-2) and submitted for analysis, see Table 6-1. The results of the water analyses are described in /2/.

Table 6-1. Data of water samples collected during the pumping tests in the boreholes at drillsite DS2 at Forsmark and submitted for analysis.

Bh ID	Date and time of sample	Pumped section (m)	Pumped volume (m^3)	Sample type	Sample ID no	Remarks
KFM02A(0-100 m)	2002-11-29 10:00	12.00-100.40	1.95	WC080	4398	Open-hole test
HFM04	2002-12-10 11:45	12.10-221.70	1.0	WC080	4399	Open-hole test
	2002-12-10 15:15	“	6.0	WC080	4400	Open-hole test
	2002-12-10 20:28	“	15.5	WC080	4401	Open-hole test
HFM05	2002-12-19 11:40	11.87-200.10	3.4	WC080	4433	Open-hole test
“	2002-12-19 15:50	“	19.6	WC080	4434	Open-hole test
“	2002-12-19 20:30	“	37.8	WC 080	4435	Open-hole test

6.3 Single-hole pumping tests

Below, the results of the pumping tests are presented test by test. Corrections of measured data, e.g. for changes of the barometric pressure or tidal fluctuations, were not made by the data analysis. No such data, nor data on air temperature or precipitation were available during the test periods in point. However, in single-hole tests such corrections are generally not necessary for an adequate data analysis, unless very small drawdowns are applied in the boreholes. Furthermore, no subtractions of the barometric pressure from the measured absolute pressure were made, since the pressure differences, e.g. drawdown, are used by the evaluation of the tests.

Drilling records were checked to identify possible interference on test data from drilling in nearby boreholes. These records showed that no drilling activities were in progress during testing, except in one case, see below.

The lower measurement limit for the HTHB-system, presented in the tables below, is expressed in terms of specific flow (Q/s). The lower limit is based on the minimal flow rate Q, for which the system is designed (5 L/min) and an estimated maximal allowed drawdown for practical purposes (c 50 m) in a percussion borehole. These values correspond to a lower measurement limit of Q/s–L=$2\cdot10^{-6}$ m^2/s.

6.3.1 Borehole KFM02A (12.0–100.4 m)

General test data for the open-hole pumping test in the upper, percussion-drilled interval of borehole KFM02A are presented in Table 6-2. Flow logging was performed during this test.

Table 6-2. General test data for the open-hole pumping test in the upper, percussion-drilled interval of borehole KFM02A in conjunction with flow logging.

General test data			
Borehole	KFM02A		
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, T. Svensson (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comment	Single hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	100.4
Casing length	L_c	m	12.03
Test section- secup	Secup	m	12.0
Test section- seclow	Seclow	m	100.4
Test section length	L_w	m	88.4
Test section diameter	$2\cdot r_w$	mm	165
Test start (start of pressure registration)		yymmdd hh:mm	021129 09:18
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	021129 09:30
Stop of flow period		yymmdd hh:mm:ss	021129 19:34
Test stop (stop of pressure registration)		yymmdd hh:mm	021202 09:03
Total flow time	t_p	min	604
Total recovery time	t_F	min	809

1: Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in borehole before start of flow period	p_i	kPa	184.2	1.15
Absolute pressure in test section before stop of flow period	p_p	kPa	163.8	-0.93
Absolute pressure in test section at stop of recovery period	p_F	kPa	184.1	1.14
Maximal pressure change during flow period	dp_p	kPa	20.4	

Manual groundwater level measurements in KFM02A (12.0-100.4 m)			**GW level**	
Date YYYY-MM-DD	**Time tt:mm:ss**	**Time (min)**	**(m b. ToC)**	**(m a s l)**
2002-11-27	15:03:00		6.58	0.79
2002-11-28	10.33.00		6.32	1.05
2002-11-29	09:00.00	-30	6.22	1.15
2002-12-02	08:55:00		6.06	1.31

Flow data

Flow data	**Nomen-clature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.09 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$1.09 \cdot 10^{-3}$
Total volume discharged during flow period	V_p	m^3	39.35

Comments on the test

The test was carried out as a pumping test with a constant flow rate with the intention to achieve (approximately) steady-state conditions during the flow logging. The actual drawdown was slightly increasing during the flow logging.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-1–5 in Appendix 2. The initial phase of both the flow- and recovery period indicate pseudo-linear flow from the pressure versus time diagrams in Figures A2-2 and A2-4, respectively. Furthermore, the drawdown derivate indicates two periods with apparent pseudo-radial flow at c 4–60 min respectively 300–600 min (end of the flow period) during the flow period. The first period can be assumed to represent the near-region around the borehole, which is dominated by flow in a high-conductive fracture or narrow fracture zone towards the borehole.

The second period may correspond to a larger region around the borehole, representing more averaged hydraulic properties of the rock on a larger scale. Thus, the rock behaves as an apparent double-permeability system with two regions of different hydraulic parameters, represented by the two pseudo-radial flow periods. An alternative geometrical interpretation to the observed drawdown response, although more theoretical, would be the presence of a linear hydraulic no-flow boundary within the radius of influence with significantly different hydraulic properties on each side of the boundary.

The response during the recovery period basically confirms the drawdown response, although the flow regimes are not as well-defined. After an initial pseudo-linear flow, a short pseudo-radial flow regime developed between c 10–30 min, cf Figure A2-4. Then the recovery increases, indicating the presence of an apparent no-flow boundary as during drawdown. An apparent late pseudo-radial flow regime seems to occur by the end of the recovery period. However, this regime is disturbed by probable tidal effects during the long recovery period. No drilling was in progress during the test according to the drilling log.

Interpreted parameters

Transient, quantitative interpretation of the flow- and recovery periods of the test is shown in lin-log and log-log diagrams in Figures A2-2–3 and A2-3–4, respectively. Quantitative analysis was applied both on the flow- and recovery period, according to the methods described in Section 5.4.1. However, from the recovery period, only hydraulic parameters from the first pseudo-radial flow period were calculated. The results are shown in the Test Summary Sheets and in Table 6-13 and 6-14 in Section 6.5.

6.3.2 Borehole HFM04

General test data for the open-hole pumping test in the interval 12–221.7 m in borehole HFM04 in conjunction with flow logging are presented in Table 6-3.

Comments on the test

The intention was to perform the pumping test with a constant flow rate to achieve (approximately) steady-state conditions during the flow logging. This strategy failed because the borehole characteristics (i.e. inflow conditions) had changed since the short capacity test after drilling, probably due to insufficient clear pumping of the borehole prior to the capacity test, entailing that the apparent transmissivity of the borehole had increased significantly since the capacity test, cf Table 6-4.

The flow rate was increased twice during the pumping test to obtain a sufficient drawdown, cf Figure A2-6 in Appendix 2. As a consequence of the flow rate increase, the specific capacity of the borehole decreased slightly during the test, possibly indicating increased head losses in the conductive fracture(s) intersecting the borehole and/or limitations of the extent of the fracture(s).

Table 6-3. General test data for the open-hole pumping test in HFM04 in conjunction with flow logging.

General test data			
Borehole	HFM04		
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, P. Askling (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comment	Single-hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	221
Casing length	L_c	m	12
Test section- secup	Secup	m	12
Test section- seclow	Seclow	m	221.7
Test section length	L_w	m	209.7
Test section diameter	$2 \cdot r_w$	mm	140
Test start (start of pressure registration)		yymmdd hh:mm	021210 10:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	021210 10:43:00
Stop of flow period		yymmdd hh:mm:ss	021210 20:47:00
Test stop (stop of pressure registration)		yymmdd hh:mm	021211 10:10
Total flow time	t_p	min	604
Total recovery time	t_F	min	803

1: Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in borehole before start of flow period	p_i	kPa	346.0	0.80
Absolute pressure in test section before stop of flow period	p_p	kPa	292.7	-4.64
Absolute pressure in test section at stop of recovery period	p_F	kPa	346.5	0.85
Maximal pressure change during flow period	dp_p	kPa	53.4	

Manual groundwater level measurements			**GW level**	
Date YYYY-MM-DD	**Time tt:mm:ss**	**Time (min)**	**(m b. ToC)**	**(m a s l)**
2002-12-10	09:54:00		3.04	0.85
2002-12-10	10:25:00		3.03	0.86
2002-12-10	10:41:00	-2	3.09	0.80
2002-12-10	13:45:00	182	6.12	-2.22
2002-12-10	13:50:00	187	6.42	-2.51
2002-12-10	16:01:30	318.5	7.79	-3.88
2002-12-10	20:38:00	595	8.61	-4.69

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$4.93 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$4.03 \cdot 10^{-4}$
Total volume discharged during flow period	V_p	m^3	14.6

Table 6-4. Estimated specific capacity from the capacity test and pumping test, respectively in borehole HFM04.

Test	Duration (min)	Flow rate (L/min)	Drawdown s_w (m)	Specific capacity Q/s_w (m^2/s)
Capacity test	30	24	20	$2.0 \cdot 10^{-5}$
Pumping test, step 1	30	12	0.85	$2.4 \cdot 10^{-4}$
D:o, step 2	150	20.5	1.8	$1.9 \cdot 10^{-4}$
D:o, step 3	420	30	5.4	$9.3 \cdot 10^{-5}$

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-6–10 in Appendix 2. A short period of pseudo-linear flow occurred during the initial phase of the flow period, indicating flow from a dominating fracture towards the borehole, cf Figure A2-7. A short period with pseudo-radial flow occurred after c 1 min of pumping, followed by a pseudo-spherical flow (leakage). The flow rate was then increased in two steps. After that, no well-defined period with pseudo-radial flow developed during the flow period.

The initial response during the recovery phase was dominated by wellbore storage effects, cf Figure A2-9. The behaviour during the recovery period was different from that during the flow period, and no well-defined period with pseudo-radial flow occurred.

Interpreted parameters

The transient, quantitative interpretation of the flow- and recovery period of the test is demonstrated in Figures A2-7–8 in Appendix 2. Quantitative analysis was made from the first step of the flow period in lin-log and log-log diagrams according to the methods described in Section 5.4.1. No well-defined period with pseudo-radial flow occurred during the later steps of the flow period. Therefore, the calculated hydraulic parameters from this test are impaired with some uncertainty.

No quantitative analysis was made from the pressure recovery period, since no well-defined pseudo-radial flow period was developed during this period. The results are shown in the Test Summary Sheets and Table 6-13 and 6-14 in Section 6-5.

6.3.3 Borehole HFM05

General test data for the open-hole pumping test in the interval 12–200.1 m in borehole HFM05 are presented in Table 6-5.

Table 6-5. General test data for the pumping test in conjunction with the flow logging in borehole HFM05.

General test data			
Borehole	HFM05		
Test type[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	T. Svensson, P. Askling (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comment	Single-hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	200.1
Casing length	L_c	m	12
Test section- secup	Secup	m	12
Test section- seclow	Seclow	m	200.1
Test section length	L_w	m	188.1
Test section diameter	$2 \cdot r_w$	mm	136
Test start (start of pressure registration)		yymmdd hh:mm	021219 08:00
Packer expanded		yymmdd hh:mm:ss	-
Start of flow period		yymmdd hh:mm:ss	021219 10:48:00
Stop of flow period		yymmdd hh:mm:ss	021219 20:48:00
Test stop (stop of pressure registration)		yymmdd hh:mm	021220 10:00
Total flow time	t_p	min	600
Total recovery time	t_F	min	792

1: Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in borehole before start of flow period	p_i	kPa	241.2	0.44
Absolute pressure in test section before stop of flow period	p_p	kPa	195.5	-4.22
Pressure in test section at stop of recovery period	p_F	kPa	237.3	-0.01
Maximal pressure change during flow period	dp_p	kPa	45.7	

Manual groundwater level measurements			GW level	
Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	(m b. ToC)	(m a s l)
2002-12-18	10:35:00		7.18	0.52
2002-12-18	13:00:00		7.17	0.53
2002-12-18	16:35:00		7.16	0.54
2002-12-19	10:09:00	-39	7.26	0.44
2002-12-19	11:00:30	12.5	10.81	-3.10
2002-12-19	11:50:00	62	11.16	-3.44
2002-12-19	13:14:00	146	11.36	-3.64
2002-12-19	15:40:00	292	11.60	-3.88
2002-12-19	20:46:00	598	11.87	-4.15
2002-12-20	09:43:00		7.45	0.52

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.08 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$1.08 \cdot 10^{-3}$
Total volume discharged during flow period	V_p	m^3	39

Comments on the test

The test was carried out as a pumping test with constant flow rate, followed by a recovery period. The drawdown was slightly decreasing during the flow logging. The temperature sensor used during flow logging belongs to the HTHB2-system, since the ordinary sensor in HTHB1 was not in function. The corresponding calibration constants for the actual sensor connected to the HTHB2-system was used.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-11–15 in Appendix 2. The initial flow regime during the flow period was dominated by wellbore storage, cf Figure A2-12. After that, the drawdown derivative indicated two periods of approximate pseudo-radial flow, cf the test in KFM02A (12.0–100.4 m). The first period lasted between c 30–80 min and the second between c 300–600 min (end of the flow period). The first period can be assumed to represent the near-region around the borehole, dominated by flow in a high-conductive fracture or narrow fracture zone towards the borehole. The second period may correspond to a larger region around the borehole, representing more averaged hydraulic properties of the rock on a larger scale.

An alternative geometrical interpretation of the observed drawdown response, although more theoretical, would be the presence of a linear hydraulic no-flow boundary within the radius of influence with significantly different hydraulic properties on each side of the boundary. The first and second periods of pseudo-radial flow would then correspond to the flow conditions before respectively after the hypothetical no-flow boundary.

As in the previous test, a rapid recovery with effects of wellbore storage occurred, with no well-defined pseudo-radial flow regime. The recovery derivative indicated effects of a no-flow boundary by the end of the recovery period, cf Figure A2-14.

Interpreted parameters

The transient, quantitative interpretation of the flow- and recovery period of the test is shown in Figures A2-12–15 in Appendix 2. Quantitative analyses were made from the flow period in lin-log and log-log diagrams according to the methods described in Section 5.4.1. From the recovery period, only an estimation of the wellbore storage coefficient was made. The results are shown in the Test Summary Sheets and in Table 6-13 and 6-14 in Section 6-5.

6.4 Flow logging

6.4.1 Borehole KFM02A (12.0–100.4 m)

General test data for the flow logging in borehole KFM02A (12.0–100.4 m) are presented in Table 6-6.

Table 6-6. General test data for the flow logging in borehole KFM02A (12.0–100.4 m).

General test data			
Borehole	KFM02A(0-100 m)		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB1		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length		m	100.4
Pump position (lower level)		m	18
Flow logged section - Secup		m	22
Flow logged section - Seclow		m	100
Test section diameter	2·rw	mm	165
Start of flow period		yymmdd hh:mm	021129 09:30
Start of flow logging		yymmdd hh:mm	021129 13:38
Stop of flow logging		yymmdd hh:mm	021129 15:47
Stop of flow period		yymmdd hh:mm	021129 19:34

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

Groundwater level and flow data

Groundwater level	**Nomen-clature**	**Unit**	**G.w-level (m b ToC)**	**G.w-level (m a s l)**
Level in borehole, at undisturbed conditions , open hole	h_i	m	6.22	1.15
Level (steady state) in borehole, at pumping rate Q_p	h_p	m	-	-0.63
Final drawdown during flow logging	s_{FL}	m	1.78	

Flow data	**Nomen-clature**	**Unit**	**Flow rate**
Pumping rate from borehole at surface	Q_p	m^3/s	$1.09 \cdot 10^{-3}$
Cumulative flow rate at Secup at pumping rate Q_p	Q_T	m^3/s	$6.47 \cdot 10^{-4}$
Measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$6.67 \cdot 10^{-5}$
Minimal change of borehole flow rate to detect flow anomaly	ΔQ_{Anom}	m^3/s	$1.7 \cdot 10^{-5}$

Comments on the test

The flow logging started close to the bottom of the hole and continued upwards. The first detectable flow anomaly was found at 81 m. The step length between flow measurements was maximally 10 m in the borehole interval 81–100 m and maximally 2 m in the interval 22–81 m.

The measured electric conductivity was not temperature-compensated due to large uncertainties in absolute values. The measured maximal borehole flow rate at the top of the flow logged interval was only c 63% of the total flow rate pumped from the borehole at the surface. The most probable reason to this discrepancy is that the calibration of the flow probe was based on 160 mm diameter, whereas the borehole diameter was c 165 mm.

Logging results

The nomenclature used for the flow logging is according to the method description for flow logging. The measured flow distribution along the hole during the flow logging, together with the relative electric conductivity (EC) and temperature (Te) of the borehole fluid is presented in Figure 6-1. The EC-curve shown in Figure 6-1 is only relative due to probable electronic interference between the flow-logging probe and the EC-sensor.

The results of the flow logging in borehole KFM02A (12.0–100.4 m) are presented in Table 6-7 below. Only one major flow anomaly was identified. The measured inflow at the identified flow anomaly (ΔQ_i), together with the corrected inflow (ΔQ_{icorr}) due to deviation from the actual borehole diameter from the assumed one by the flow calibration is shown. The cumulative transmissivity (T_{FT}) at the top of the flow-logged borehole interval was calculated from Equation (5-3) and the transmissivity of individual flow anomalies (T_i) from Equation (5-4). An estimation of the transmissivity of the interpreted flow anomaly was also made by the specific flow ($\Delta Q_{icorr}/s_{FL}$). The transmissivity of the entire borehole was calculated from the transient interpretation of the pumping test during flow logging.

Table 6-7. Results of the flow logging in borehole KFM02A (12.0–100.4 m). Q_T=cumulative flow on top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}= drawdown during flow logging.

KFM02A Flow anom.		Q_T=6.47·10^{-4} (m^3/s)	Q_p=1.09·10^{-3} (m^3/s)	T =3.98·10^{-4} (m^2/s)	s_{FL}=1.78 m	
Interval (m) (from ToC)	**B.h. length (m)**	**ΔQ_i (m^3/s)**	**ΔQ_{icorr} (m^3/s)**	**T_i (m^2/s)**	**$\Delta Q_{icorr}/s_{FL}$ (m^2/s)**	**Supporting information**
79.5-81.5	2	6.67·10^{-4} *	1.09·10^{-3} **	3.98·10^{-4} **	6.12·10^{-4} **	Te, EC
Total		**Σ= 6.67·10^{-4} ***	**Σ= 1.09·10^{-3}****	**Σ= 3.98·10^{-4} ****	**Σ =6.12·10^{-4} ****	
Difference		Q_p-Q_T=4.43·10^{-4}				

* Probably underestimated flow due to non-representative calibration of the flow probe based on 160 mm diameter. The actual borehole diameter was 165 mm.

** The corrected flow is based on the assumption that all inflow occurs within the flow logged interval, i.e Q_T= Q_p=$\Sigma\Delta Q_{icorr}$ and that the difference in flow is only due to the borehole diameter.

As Table 6-7 demonstrates, only c 61% of the total flow at the surface was measured within the flow logged interval. The major part of the flow is concentrated to the interval 79.5–81.5 m. The true flow yielding interval may be narrower (c 79.5–80 m). However, possible cavities within the interval may result in uncertainties regarding the exact inflow levels.

As discussed above, the difference between the cumulative flow rate on top of the logged interval (Q_T) and the discharged flow rate from the borehole (Q_p) is most likely due to uncertainties in the calibration of the flow probe. Based on observations during drilling, this explanation is considered as more likely than the possibility that additional flow anomaly(ies), not covered by the flow logging, would be present between the casing shoe at c 12 m and the top of the logged interval (22 m).

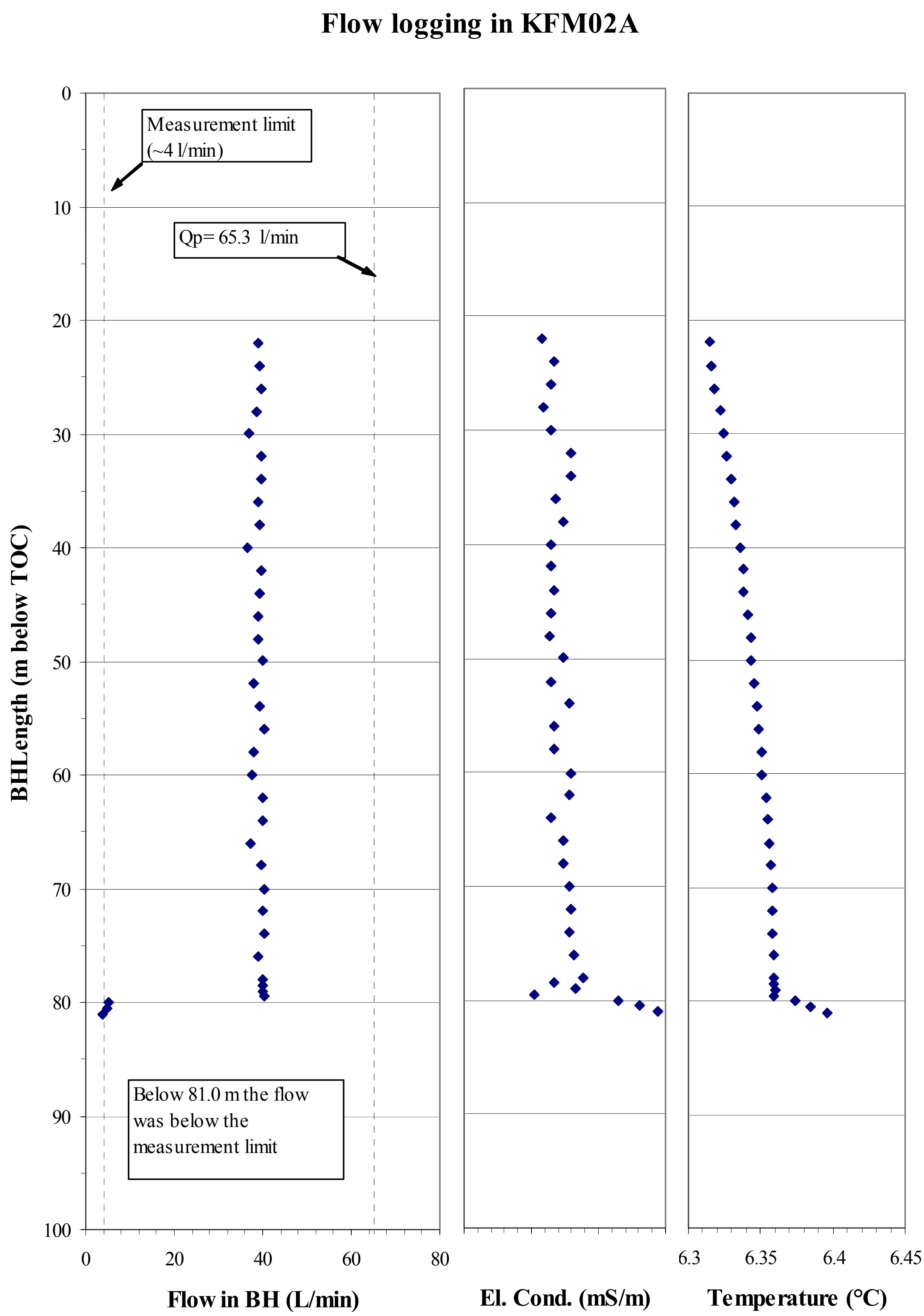


***Figure 6-1.** Measured flow distribution along borehole KFM02A (12.0–100.4 m) during the flow logging, together with the (temperature-compensated) relative electric conductivity (EC) and temperature (Te) of the borehole fluid.*

Figure 6-2 illustrates the cumulative transmissivity $T_F(L)$ along the borehole length (L), calculated from the flow logging using Equation (5-5). Since the width of the flow anomaly in the borehole is not exactly identified, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated lower limit of T and the total T of the borehole are also demonstrated in the figure, cf Section 5.4.2.

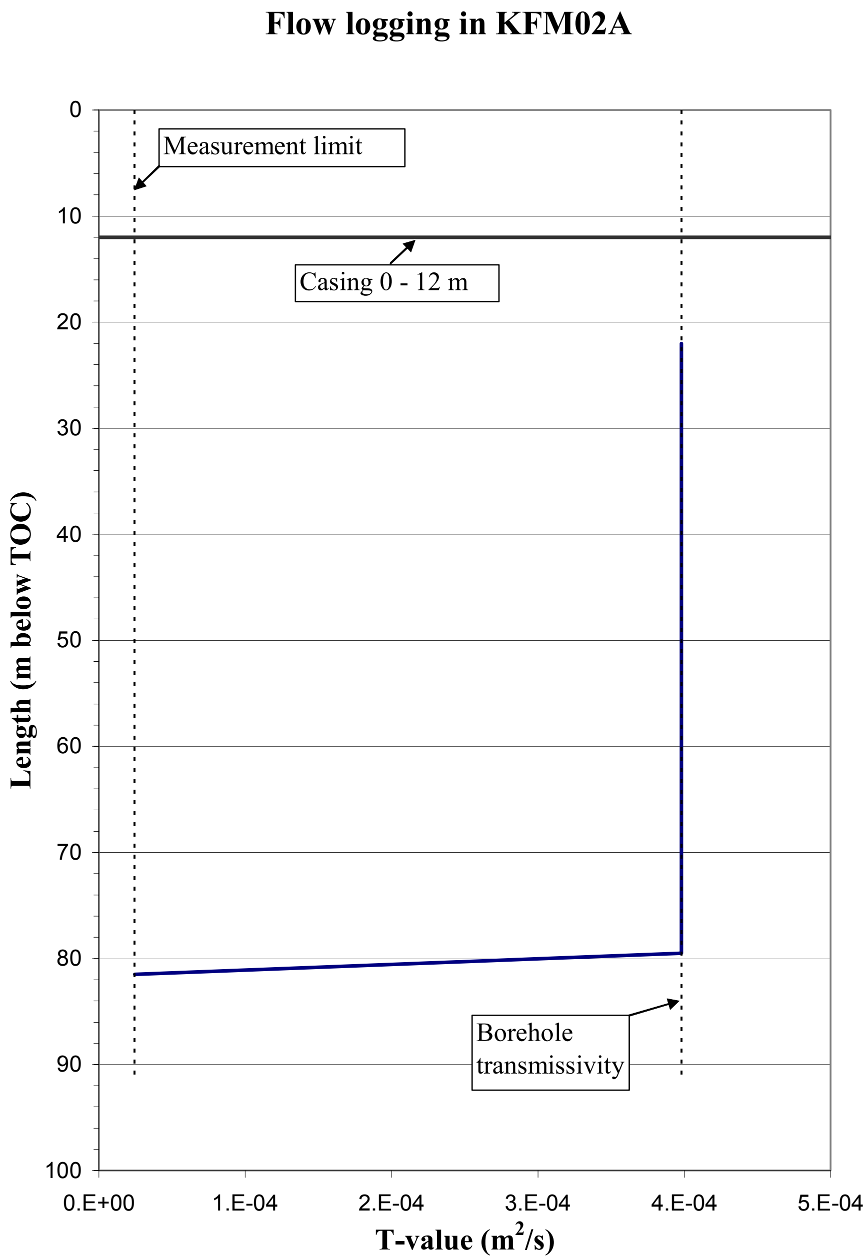


Figure 6-2. *Calculated, cumulative transmissivity along the flow-logged interval of borehole KFM02A (12.0–100.4 m). Below c 81.5 m, the borehole transmissivity fell below the measurement limit. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.4.2 Borehole HFM04

General test data for the flow logging in borehole HFM04 are presented in Table 6-8.

Table 6-8. General test data for the flow logging in borehole HFM04.

General test data			
Borehole	HFM04		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	S. Jönsson, T. Svensson (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length		m	221
Pump position (lower level)		m	31.45
Flow logged section - Secup		m	35
Flow logged section - Seclow		m	210
Test section diameter	2·rw	mm	140
Start of flow period		yymmdd hh:mm	021210 10:43
Start of flow logging		yymmdd hh:mm	021210 17:55
Stop of flow logging		yymmdd hh:mm	021210 19:00
Stop of flow period		yymmdd hh:mm	021210 20:47

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

Groundwater level data

Groundwater level	Nomen-clature	Unit	G.w-level (m b ToC)	G.w-level (m a s l)
Level in borehole, at undisturbed conditions , open hole	h_i	m		0.80
Level (steady state) in borehole, at pumping rate Q_p	h_p	m		-4.64
Drawdown during flow logging	s_{FL}	m	5.10	

Flow data

Flow data	Nomen-clature	Unit	Flow rate
Pumping rate from borehole at surface	Q_p	m^3/s	$4.93\cdot10^{-4}$
Cumulative flow rate at Secup at pumping rate Q_p	Q_T	m^3/s	$5.58\cdot10^{-4}$ *
Measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$5.0\cdot10^{-5}$
Minimal change of borehole flow rate to detect flow anomaly	ΔQ_{Anom}	m^3/s	$1.7\cdot10^{-5}$

* Incorrect value due to deviation of the actual borehole diameter from the assumed diameter (140 mm)

Comments on the test

The flow logging was performed in the upward direction, starting from the bottom of the hole. The first detectable flow anomaly was indicated at 63.5 m (lower limit). The length increment between the flow measurements was maximally 10 m in the borehole interval 63.5–210 m, and maximally 2 m within the interval 35–63.5 m. At each flow anomaly a step length 0.5 m was used.

The measured electric conductivity was not temperature-compensated due to large uncertainties in the absolute values. The measured maximal borehole flow rate on top of the flow logged interval exceeded the total flow rate pumped from the borehole at the surface. The most probable reason to this discrepancy is deviations between the true borehole diameter, which is 138 mm at the bottom of the borehole, and the diameter assumed by the calibration of the flow probe, 140 mm.

Logging results

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured flow distribution along the hole during the flow logging, together with the relative electric conductivity (EC) and temperature (Te) of the borehole fluid is presented in Figure 6-3. The EC-curve shown in Figure 6-3 is only relative due to probable electronic interference between the flow-logging probe and the EC-sensor.

As can be concluded from Figure 6-3, almost the entire inflow to the borehole is concentrated to the interval 60–63.5 m. The true flow yielding interval may be narrower (c 60–62 m), but possible cavities in the interval may result in uncertainties regarding the exact inflow levels. The flow yielding interval corresponds to the section (62–65 m) where fractures, however non-flowing, were observed during drilling, cf Chapter 1.

The results of the flow logging in borehole HFM04 are presented in Table 6-9 below. Only one major flow anomaly was identified in the borehole. The measured inflow at the identified flow anomaly (ΔQ_i), together with the corrected inflow (ΔQ_{icorr}) due to deviation of the actual borehole diameter from the assumed diameter by the flow calibration is demonstrated.

The cumulative transmissivity (T_{FT}) on top of the flow-logged borehole interval was calculated from Equation (5-3), and the estimated transmissivity of individual flow anomalies (T_i) from Equation (5-4). An estimation of the transmissivity of the interpreted flow anomaly was also made by the specific flow ($\Delta Q_{icorr}/s_{FL}$). The transmissivity of the entire borehole was calculated from the transient interpretation of the pumping test during flow logging.

Table 6-9. Results of the flow logging in borehole HFM04. Q_T=cumulative flow on top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}= drawdown during flow logging.

HFM04 Flow anomalies		$Q_T=5.57 \cdot 10^{-4}$ (m^3/s)	$Q_p=4.93 \cdot 10^{-4}$ (m^3/s)	$T=7.87 \cdot 10^{-5}$ (m^2/s)	s_{FL}=5.1 m	
Interval (m bToC)	**B.h. length (m)**	**ΔQ_i (m^3/s)**	**ΔQ_{icorr} (m^3/s)**	**T_i (m^2/s)**	**$\Delta Q_{icorr}/s_{FL}$ (m^2/s)**	**Supporting information**
60-63.5	3.5	$5.58 \cdot 10^{-4}$ *	$4.93 \cdot 10^{-4}$ **	$7.87 \cdot 10^{-5}$ **	$9.67 \cdot 10^{-5}$ **	Te , EC
Total		**$\Sigma = 5.58 \cdot 10^{-4}$ ***	**$\Sigma = 4.93 \cdot 10^{-4}$ ****	**$\Sigma T_i = 7.87 \cdot 10^{-5}$ ****	**$\Sigma = 9.67 \cdot 10^{-5}$ ****	
Difference		$Q_T - Q_p = 0.64 \cdot 10^{-4}$		-	-	

* Overestimated due to assumed decreasing borehole diameter along the hole.

** The corrected flow is based on the assumption that all inflow occurs within the flow logged interval, i.e $Q_T = Q_p = \Sigma \Delta Q_{icorr}$ and that the difference in flow is only due to the borehole diameter.

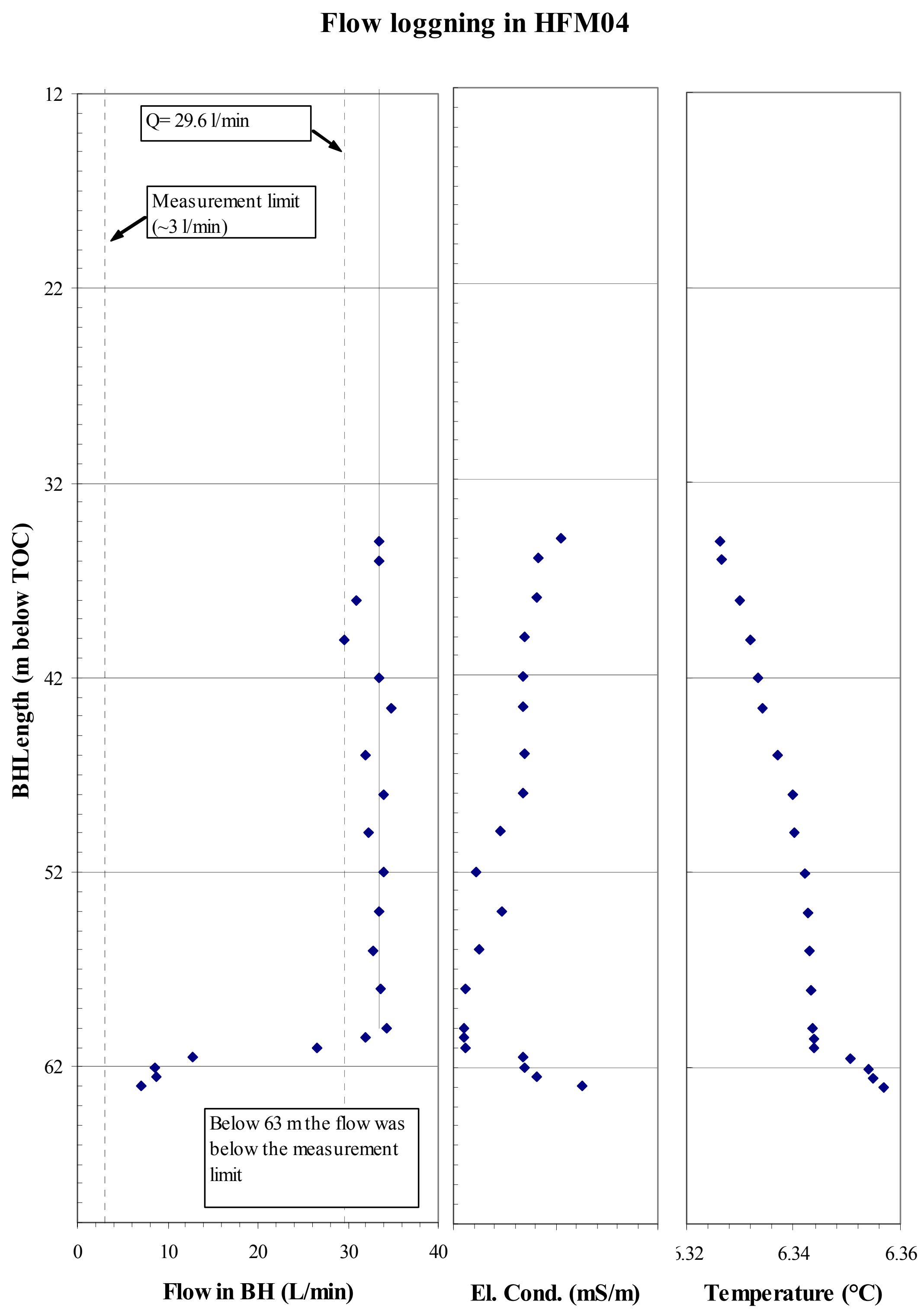


Figure 6-3. *Measured flow distribution along borehole HFM04 during the flow logging together with the relative electric conductivity (EC) and temperature (Te) of the borehole fluid.*

Figure 6-4 illustrates the cumulative transmissivity $T_F(L)$ along the borehole length (L), calculated from the flow logging using Equation (5-3). Since the detailed positions of the flow anomalies in the borehole are not known the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated lower limit of T and the total T of the borehole are also illustrated in the figure, cf Section 5.4.2.

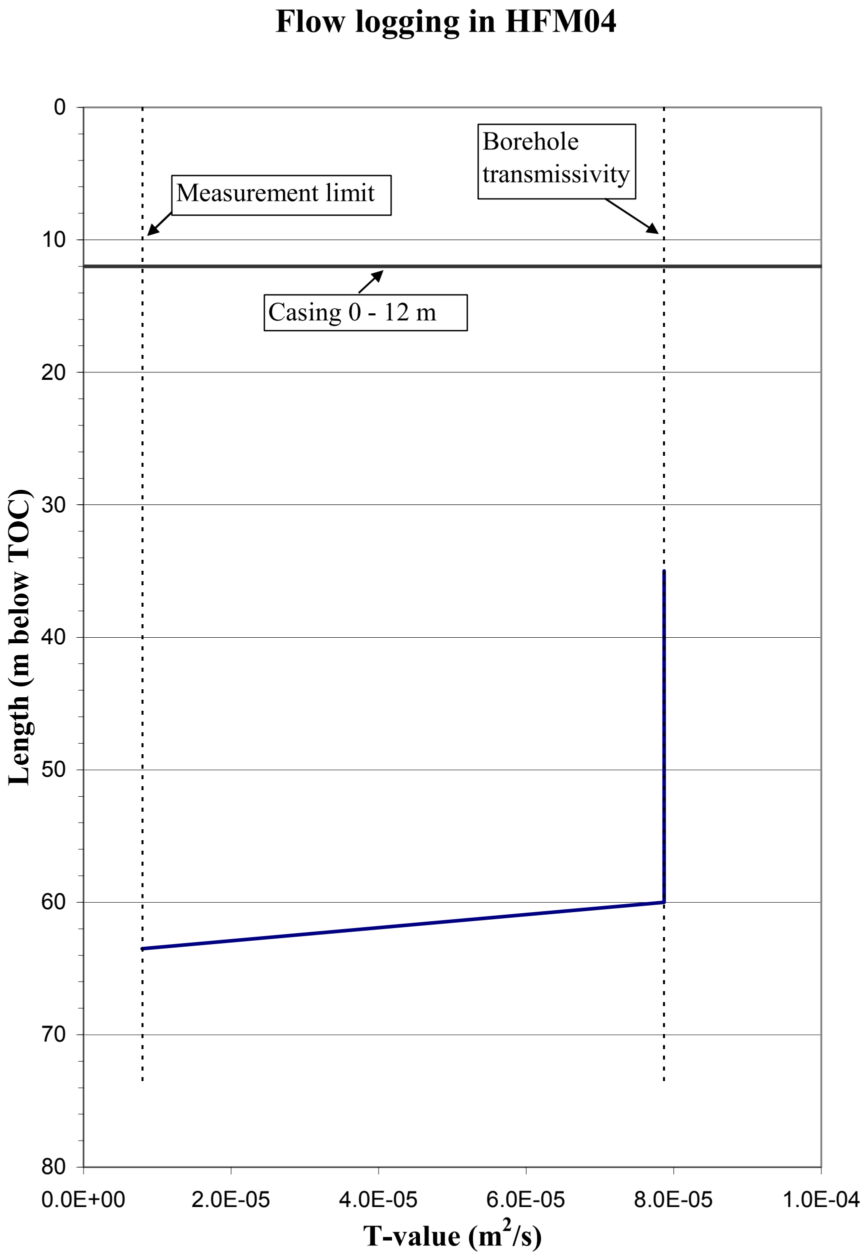


Figure 6-4. *Calculated, cumulative transmissivity along the flow-logged interval of borehole HFM04. Below c 63 m, the borehole transmissivity fell below the measurement limit. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.4.3 Borehole HFM05

General test data for the flow logging in borehole HFM05 are presented in Table 6-10.

Table 6-10. General test data for the flow logging in borehole HFM05.

General test data			
Borehole	HFM05		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	T, Svensson, P. Askling (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length		m	200.1
Pump position (lower level)		m	25.0
Flow logged section - Secup		m	28
Flow logged section - Seclow		m	195
Test section diameter	2·rw	mm	136
Start of flow period		yymmdd hh:mm	021219 10:48
Start of flow logging		yymmdd hh:mm	021219 14:36
Stop of flow logging		yymmdd hh:mm	021219 17:30
Stop of flow period		yymmdd hh:mm	021219 20:48

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

Groundwater level data

Groundwater level	**Nomen-clature**	**Unit**	**G.w-level (m b ToC)**	**G.w-level (m a s l)**
Level in borehole, at undisturbed conditions , open hole	h_i	m		0.44
Level (steady state) in borehole, at pumping rate Q_p	h_p	m		-4.22
Drawdown during flow logging	s_{FL}	m	4.30	

Flow data

Flow data	**Nomen-clature**	**Unit**	**Flow rate**
Pumping rate from borehole at surface	Q_p	m^3/s	$1.08 \cdot 10^{-3}$
Cumulative flow rate at Secup at pumping rate Q_p	Q_T	m^3/s	$1.81 \cdot 10^{-3}$ *
Measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$5.0 \cdot 10^{-5}$
Minimal change of borehole flow rate to detect flow anomaly	ΔQ_{Anom}	m^3/s	$1.7 \cdot 10^{-5}$

* Incorrect value due to deviation of the actual borehole diameter from the assumed diameter (140 mm)

Comments on test

The flow logging started close to the bottom of the borehole and continued in the upward direction. The first detectable flow anomaly was encountered at 156 m (lower limit). The length increment between flow measurements was maximally 10 m in the borehole interval 156–195 m and maximally 2 m in the interval 28–156 m. At each flow anomaly, the step length 0.5 m was applied.

The measured electric conductivity was not temperature-compensated, due to large uncertainties in the absolute values. The measured maximal borehole flow rate on top of the flow logged interval exceeded the total flow rate pumped from the borehole at the surface. The most probable reason to this discrepancy is deviations between the true borehole diameter along the hole (136 mm at the bottom of the borehole) and the diameter assumed by the calibration of the flow probe (140 mm diameter).

The standard step length between the flow measurements was 1 m. At each flow anomaly, the step length was decreased to 0.5 m.

Logging results

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured flow distribution along the hole during the flow logging, together with the relative electric conductivity (EC) and temperature (Te) of the borehole fluid, is presented in Figure 6-5. The EC-curve shown in Figure 6-5 is only relative, due to probable electronic interference between the flow-logging probe and the EC-sensor.

Figure 6-5 clearly demonstrates, that almost the entire inflow to the borehole is concentrated to the interval 150.5–156.5 m. The true flow-yielding interval may be narrower, but possible cavities in the interval may result in uncertainties of the exact inflow levels.

The results of the flow logging in borehole HFM05 are presented in Table 6-11 below. Only one major flow anomaly was identified in the borehole. The measured inflow at the identified flow anomaly (ΔQ_i), together with the corrected inflow (ΔQ_{icorr}) due to deviation from the true borehole diameter from the assumed diameter by the flow calibration is displayed.

The cumulative transmissivity (T_{FT}) on top of the flow-logged borehole interval was calculated from Equation (5-3), and the transmissivity of individual flow anomalies (T_i) from Equation (5-4). An estimation of the transmissivity of the interpreted flow anomaly was also made by the specific flow ($\Delta Q_{icorr}/s_{FL}$). The transmissivity of the entire borehole was calculated from the transient interpretation of the pumping test during flow logging.

Table 6-11. Results of the flow logging in borehole HFM05. Q_T=cumulative flow on top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}= drawdown during flow logging.

HFM05 Flow anomalies		$Q_T=1.81\cdot10^{-3}$ (m^3/s)	$Q_p=1.08\cdot10^{-3}$ (m^3/s)	$T=3.96\cdot10^{-4}$ (m^2/s)	s_{FL}=4.30 m	
Interval (m b ToC	**B.h. length (m)**	**ΔQ_i (m^3/s)**	**ΔQ_{icorr} (m^3/s)**	**T_i (m^2/s)**	**$\Delta Q_{icorr}/s_{FL}$ (m^2/s)**	**Supporting information**
150.5-156.5	6	$2.40\cdot10^{-3}$ *	$1.08\cdot10^{-3}$**	$3.96\cdot10^{-4}$ **	$2.51\cdot10^{-4}$ *	Te
Total		**$\Sigma\Delta Q_i=2.40\cdot10^{-3}$**	**$\Sigma\ 1.08\cdot10^{-3}$**	**$\Sigma T_i= 3.96\cdot10^{-4}$**	**$\Sigma=2.51\cdot10^{-4}$**	
Difference		$Q_T-Q_p = 0.73\cdot10^{-3}$		-	-	

* Overestimated due to decreased borehole diameter (136 mm).

** The corrected flow is based on the assumption that all inflow occurs within the flow logged interval, i.e $Q_T= Q_p=\Sigma\Delta Q_{icorr}$ and that the difference in flow is only due to the borehole diameter.

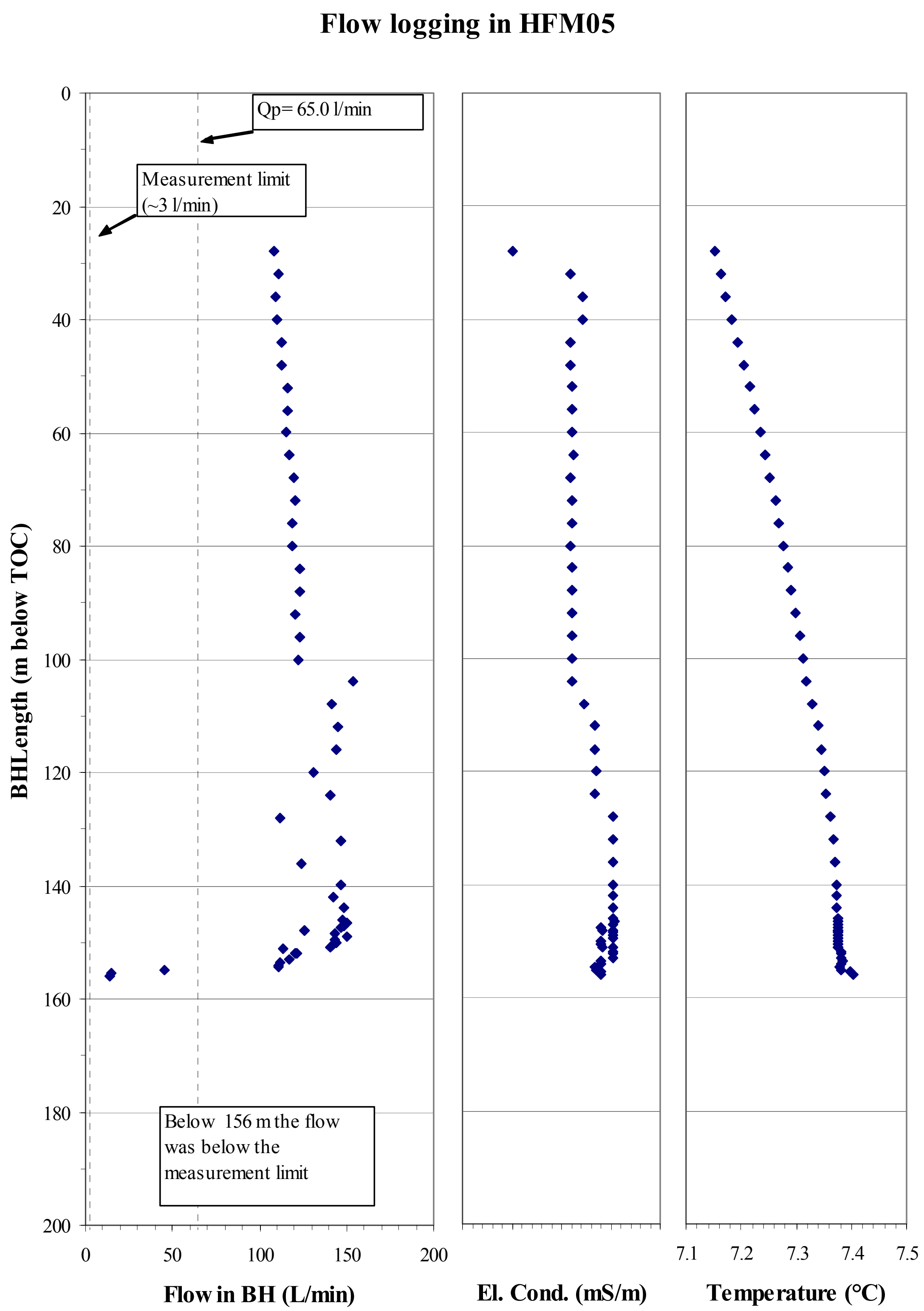


Figure 6-5. *Measured flow distribution along borehole HFM05 during the flow logging, together with the relative electric conductivity (EC) and temperature (Te) of the borehole fluid.*

Figure 6-6 illustrates the cumulative transmissivity $T_F(L)$ along the borehole length (L), calculated from the flow logging using Equation (5-3). Since the detailed positions of the flow anomalies in the borehole are not known, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated lower limit of T and the total T of the borehole are also shown in the figure, cf Section 5.4.2.

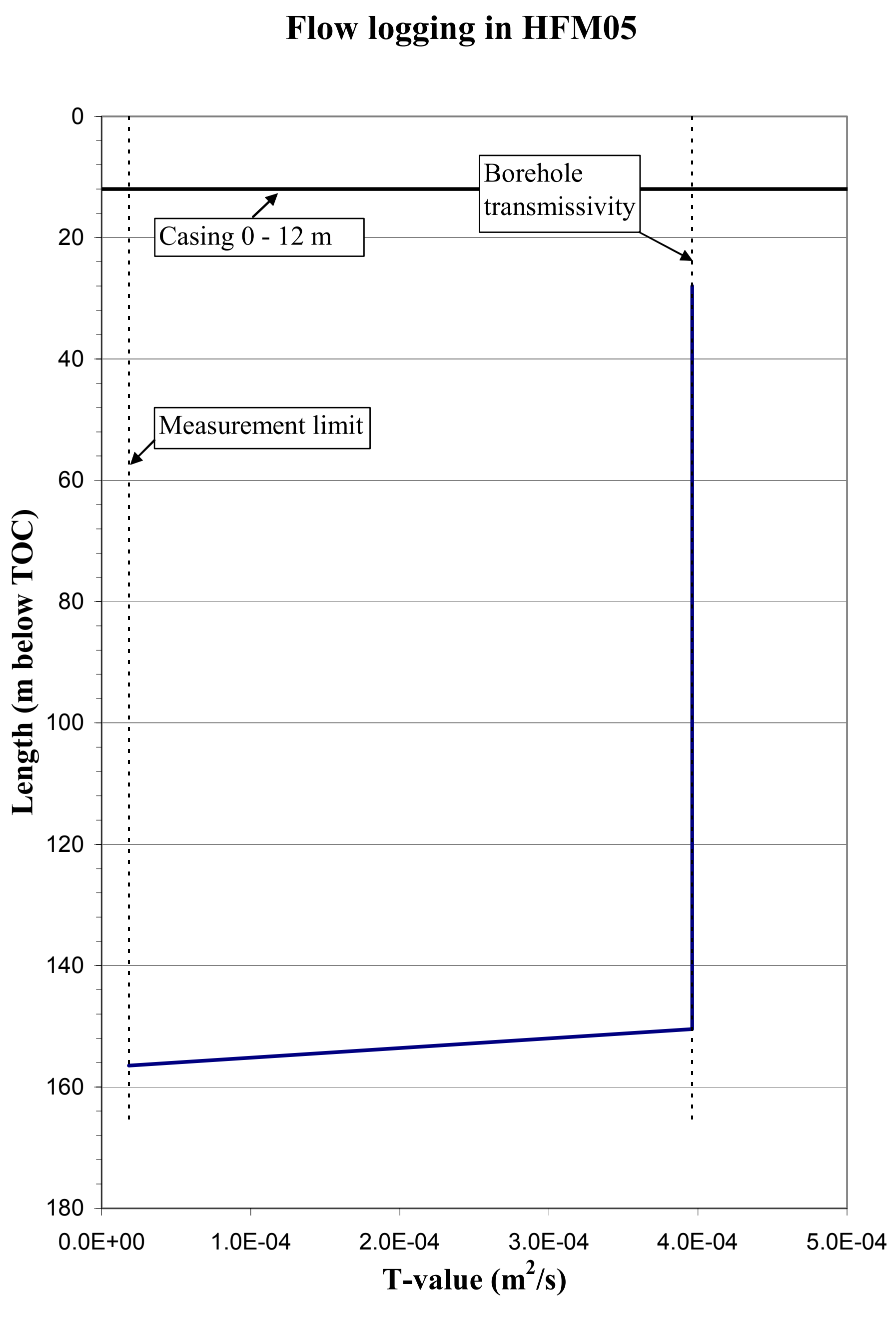


Figure 6-6. *Calculated, cumulative transmissivity along the flow-logged interval of borehole HFM05. Below c 156.5 m, the borehole transmissivity fell below the measurement limit. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.5 Summary of hydraulic tests

The results of the flow logging were presented in Section 6.4. A compilation of measured test data from the hydraulic tests carried out in the test campaign is given in Table 6-12, whereas the calculated hydraulic parameters of the formation respectively the borehole are shown in Tables 6-13 and 6-14.

The lower measurement limit for the HTHB-system, presented in the tables below, is expressed in terms of specific flow (Q/s). For pumping tests, the practical lower limit is based on the minimal flow rate Q, for which the system is designed (5 L/min), and an estimated maximal allowed drawdown in a percussion borehole for practical purposes, (c 50 m), cf Table 4-1. These values correspond to a practical lower measurement limit of Q/s–L=$2\cdot10^{-6}$ m^2/s of the pumping tests.

Similarly, the practical, upper measurement limit of the HTHB-system is estimated from the maximal flow rate (c 80 L/min) and a minimal drawdown of c 0.5 m, which is considered significant in relation to e.g. background fluctuations of the pressure prior to and during the test. These values correspond to an estimated, practical upper measurement limit of Q/s–U=$2\cdot10^{-3}$ m^2/s for both pumping tests and injection tests.

In Tables 6-13 and 6-14, the parameter explanations are according to the methodology instruction for analysis of injection tests and single-hole pumping tests. The parameters are also explained in the text above, except the following parameters:

T_M = Steady-state transmissivity calculated from Moye's formula
T_1 = Transient transmissivity from the first pseudo-radial flow regime
T_2 = Transient transmissivity from the second pseudo-radial flow regime
T_i = Estimated transmissivity of flow anomaly
S* = Assumed value on storativity used in single-hole tests for calculation of the skin factor
C = Wellbore storage coefficient
ζ = Skin factor

Table 6-12. Summary of test data for the hydraulic tests performed in boreholes at drillsite DS2 in the Forsmark 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)
KFM02A	12.00-100.40	1B	184.20	163.80	184.10	$1.09\cdot10^{-3}$	$1.09\cdot10^{-3}$	39.4
HFM04	12.10-221.70	1B	346.00	292.70	346.50	$4.93\cdot10^{-4}$	$4.03\cdot10^{-4}$	14.6
HFM05	11.87-200.10	1B	241.20	195.50	237.30	$1.08\cdot10^{-3}$	$1.08\cdot10^{-3}$	39.0

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

Table 6-13. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed at drillsite DS2 in the Forsmark area.

Borehole ID	Section (m)	Flow Anomaly interval (m)	Test type	Q/s (m^2/s)	T_{Moye} (m^2/s)	T_1 (m^2/s)	T_2 (m^2/s)	T_i (m^2/s)	S* (-)
KFM02A	12.00-100.40		1B	$5.33 \cdot 10^{-4}$	$6.17 \cdot 10^{-4}$	$3.98 \cdot 10^{-4}$	$2.12 \cdot 10^{-4}$		$5.0 \cdot 10^{-5}$
KFM02A	22-100	79.5-81.5	6					$3.98 \cdot 10^{-4}$	
HFM04	12.10-221.70		1B	$9.13 \cdot 10^{-5}$	$1.09 \cdot 10^{-4}$	$7.87 \cdot 10^{-5}$	-		$5.0 \cdot 10^{-5}$
HFM04	35-210	60.0-63.5	6					$7.87 \cdot 10^{-5}$	
HFM05	11.87-200.10		1B	$2.32 \cdot 10^{-4}$	$3.10 \cdot 10^{-4}$	$3.96 \cdot 10^{-4}$	$2.08 \cdot 10^{-4}$		$5.0 \cdot 10^{-5}$
HFM05	28-195	150.5-156.5	6					$3.96 \cdot 10^{-4}$	

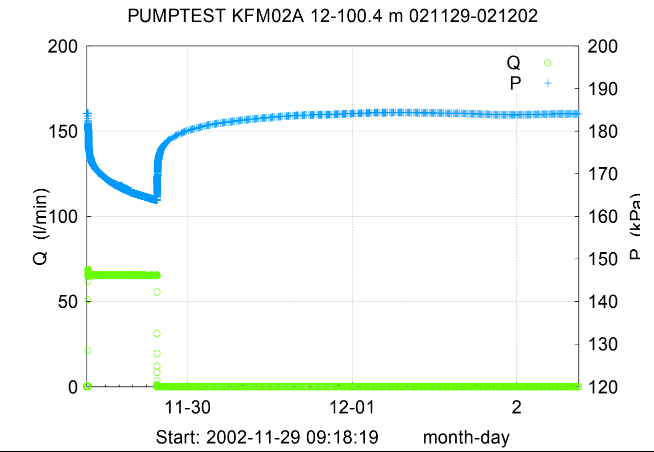
Table 6-14. Summary of calculated hydraulic parameters of the borehole from hydraulic test performed in boreholes within drillsite DS2 in the Forsmark area.

Borehole ID	Section (m)	Test type	S* (-)	C (m^3/Pa)	ζ (-)
KFM02A	12.00-100.40	1B	$5 \cdot 10^{-5}$	-	-4.97
HFM04	12.10-221.70	1B	$5 \cdot 10^{-5}$	$2.40 \cdot 10^{-6}$	-4.31
HFM05	11.87-200.10	1B	$5 \cdot 10^{-5}$	$2.38 \cdot 10^{-6}$	0.50

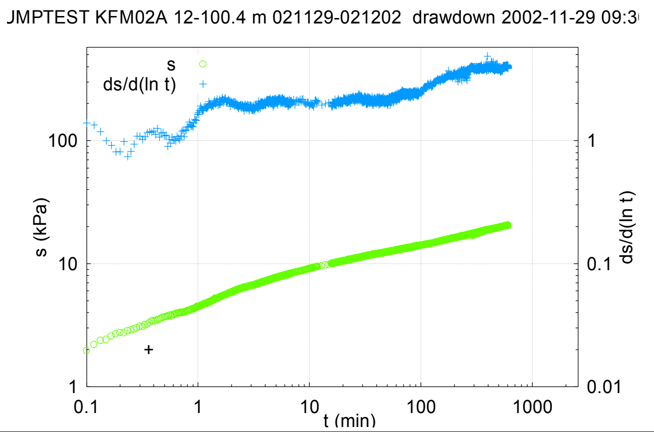
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	KFM02A (12.0-100.4 m)	Test start:	2002-11-29 09:18
Test section (m):	12.00-100.40	Responsible for test performance:	GEOSIGMA AB S. Jönsson/T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.165	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

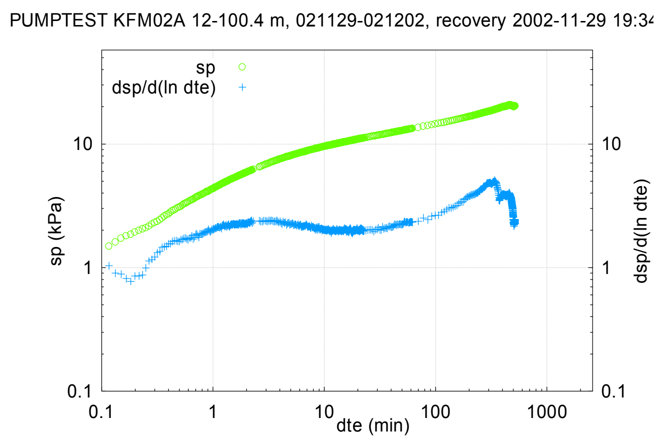
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	184.2		
p_i (kPa)	184.2		
p_p(kPa)	163.8	p_F (kPa)	184.1
Q_p (m^3/s)	$1.09 \cdot 10^{-3}$		
tp (min)	604	t_F (min)	809
S*	$5 \cdot 10^{-5}$	S*	$5 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$5.33 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$6.17 \cdot 10^{-4}$		
Flow regime:	PRF	Flow regime:	PRF
t_1 (min)	4	dt_{e1} (min)	10
t_2 (min)	60	dt_{e2} (min)	30
T_w (m^2/s)	$3.98 \cdot 10^{-4}$	T_w (m^2/s)	$4.34 \cdot 10^{-4}$
S_w (-)	-	S_w (-)	-
K_{sw} (m/s)	-	K_{sw} (m/s)	-
S_{sw} (1/m)	-	S_{sw} (1/m)	-
C (m^3/Pa)	-	C (m^3/Pa)	-
C_D (-)	-	C_D (-)	-
ξ (-)	-4.97	ξ (-)	-
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Interpreted formation and well parameters.

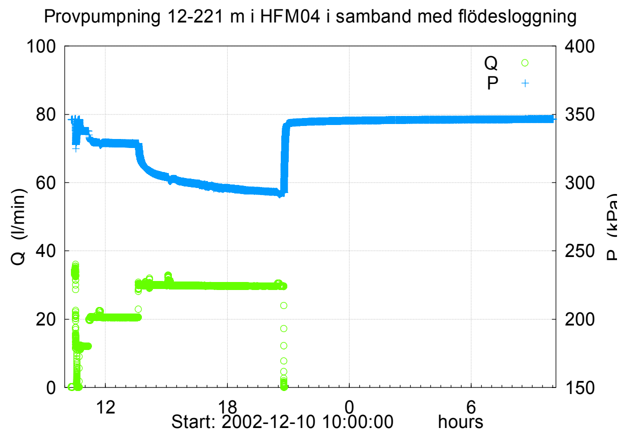
Flow regime:	PRF	C (m^3/Pa)	-
t_1 (min)	4	C_D (-)	-
t_2 (min)	60	ξ (-)	-4.77
T_T (m^2/s)	$3.98 \cdot 10^{-4}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Initial linear (fracture) flow transiting to a first pseudo-radial flow during both the flow- and recovery period. A second pseudo-radial flow developed later.

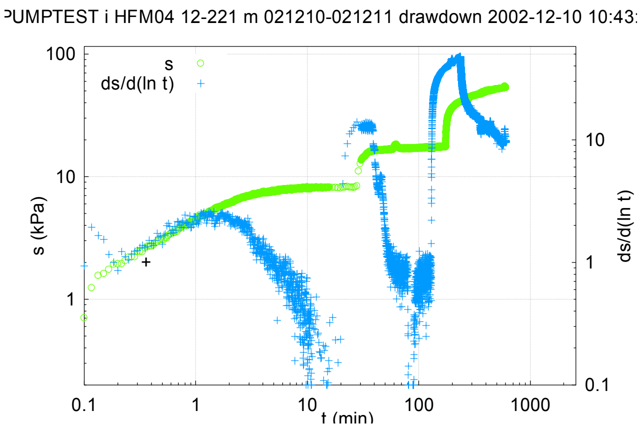
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM04	Test start:	2002-12-10 10:00
Test section (m):	12.10-221.70	Responsible for test performance:	GEOSIGMA AB S. Jönsson/P. Askling
Section diameter, $2 \cdot r_w$ (m):	0.140	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

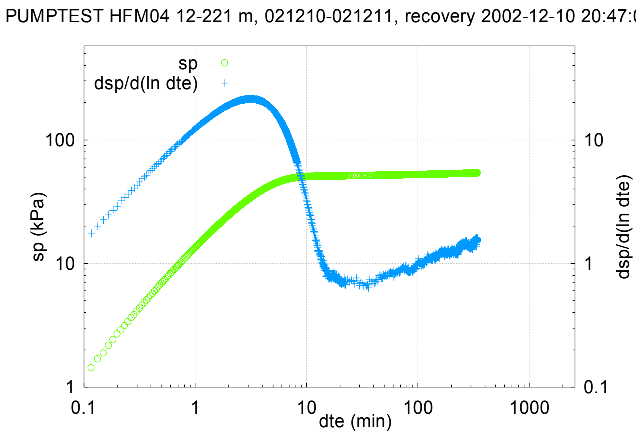
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	346.0		
p_i (kPa)	346.0		
p_p(kPa)	292.7	p_F (kPa)	346.5
Q_p (m^3/s)	$4.93 \cdot 10^{-4}$		
tp (min)	604	t_F (s)	803
S*	$5 \cdot 10^{-5}$	S*	-
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$9.13 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$1.09 \cdot 10^{-4}$		
Flow regime:	PRF	Flow regime:	WBS
t_1 (min)	1	dt_{e1} (min)	0.05
t_2 (min)	3	dt_{e2} (min)	2
T_w (m^2/s)	$7.87 \cdot 10^{-5}$	T_w (m^2/s)	-
S_w (-)	-	S_w (-)	-
K_{sw} (m/s)	-	K_{sw} (m/s)	-
S_{sw} (1/m)	-	S_{sw} (1/m)	-
C (m^3/Pa)	-	C (m^3/Pa)	$2.40 \cdot 10^{-6}$
C_D (-)	-	C_D (-)	-
ξ (-)	-4.31	ξ (-)	-
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

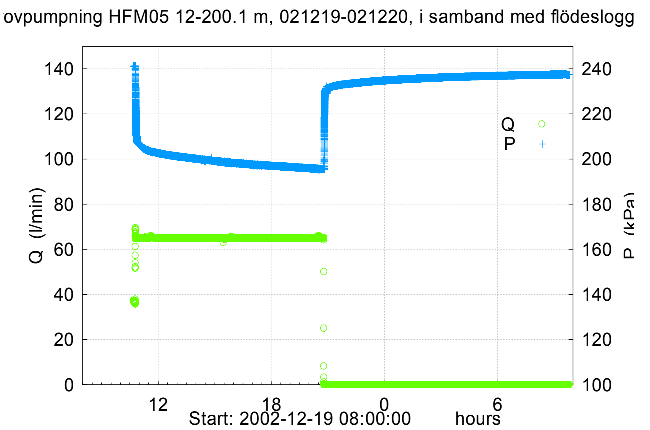
Interpreted formation and well parameters.			
Flow regime:	PRF	C (m^3/Pa)	$2.40 \cdot 10^{-6}$
t_1 (min)	1	C_D (-)	
t_2 (min)	3	ξ (-)	-4.31
T_T (m^2/s)	$7.87 \cdot 10^{-5}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: The flow rate was increased in two steps due to the fact that the hydraulic parameters of the formation had improved significantly between the short capacity test and this test. A short pseudo-radial flow period developed but no well-defined such period was developed during the later steps of the pumping. Wellbore storage effects occurred during the recovery period but no well-defined pseudo-radial flow period developed during recovery.

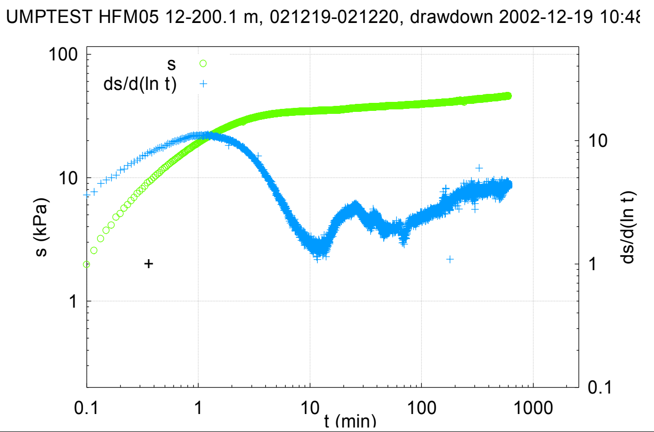
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM05	Test start:	2002-12-19 08:00
Test section (m):	11.87-200.10	Responsible for test performance:	GEOSIGMA AB T. Svensson/P. Askling
Section diameter, $2 \cdot r_w$ (m):	0.136	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

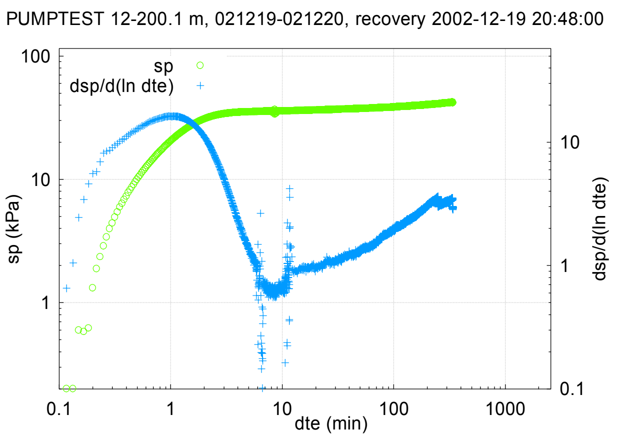
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	241.2		
p_i (kPa)	241.2		
p_p(kPa)	195.5	p_F (kPa)	237.3
Q_p (m^3/s)	$1.08 \cdot 10^{-3}$		
tp (min)	600	t_F (min)	792
S*	$5 \cdot 10^{-5}$	S*	$5 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$2.32 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$3.10 \cdot 10^{-4}$		
Flow regime:	PRF	Flow regime:	WBS
t_1 (min)	30	dt_{e1} (min)	-
t_2 (min)	80	dt_{e2} (min)	-
T_w (m^2/s)	$3.96 \cdot 10^{-4}$	T_w (m^2/s)	-
S_w (-)	-	S_w (-)	-
K_{sw} (m/s)	-	K_{sw} (m/s)	-
S_{sw} (1/m)	-	S_{sw} (1/m)	-
C (m^3/Pa)	$2.38 \cdot 10^{-6}$	C (m^3/Pa)	-
C_D (-)	-	C_D (-)	-
ξ (-)	0.5	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:	PRF	C (m^3/Pa)	-
t_1 (min)	30	C_D (-)	-
t_2 (min)	80	ξ (-)	0.5
T_T (m^2/s)	$3.96 \cdot 10^{-4}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Initial linear (fracture) flow transiting to a first pseudo-radial flow during both the flow- and recovery period. A second pseudo-radial flow developed later. No well-defined pseudo-radial flow regime developed during the recovery period. Possible effects of no-flow boundaries were indicated by the end of the recovery.

7 References

/1/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of a flushing water well, HFM05, and one groundwater monitoring well, HFM04, at drillsite DS2. SKB P-03-51, Svensk Kärnbränslehantering AB.

/2/ **Nilsson A-C, 2003.** Sampling and analyses of water from percussion drilled boreholes in hard rock and stand pipes at drillsite DS2. Results from the percussion-drilled boreholes HFM04, HFM05, KFM02A (borehole section 0–100 m) and the stand pipes SFM0004 and SFM0005 (in prep).

/3/ **Almén K-E, Andersson J-E, Carlsson L, Hansson K, Larsson N-Å, 1986.** Hydraulic testing in crystalline rock. A comparative study of single-hole test methods. Technical Report 86-27, Svensk Kärnbränslehantering AB.

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 (parameters)2	Comments
HFM04	63-35	6 L-EC L-T		2002-12-10 17:55:50	2002-12-10 19:00:50	2002-11-29 13:38:24	2002-12-10 19:00:50	HFM04_000_021210_Spinne01.dat	P, Q, T, Sp, EC	
HFM04	0-210	?				02-11-28 10:41:36	02-12-11 10:02:26	HFM04_000a_021210_FlowLo01.dat	P, Q, T, EC	Data from undisturbed bh and from sections where no flowdata has been collected
HFM04						02-11-28 09:03:02	02-12-10 21:10:27	HFM04_000a_021210_Ref_Da01.dat		
HFM04	0-221	1B, 6 L-EC, L-T		02-12-10 10:29:43	02-12-11 10:01:26	02-11-28 10:41:36	02-12-11 10:02:26	HFM04_000b_021210_FlowLo01.DAT	P, Q, T, EC	
HFM04						02-11-28 09:03:02	02-12-10 21:10:27	HFM04_000b_021210_Ref_Da01.DAT	P, Q, T, Sp, EC	
HFM05	156-28	6, L-EC L-T		2002-12-19 14:36:16	2002-12-19 17:30:36	2002-12-19 14:36:16	2002-12-19 17:30:36	HFM05_000_021219_Spinne01.DAT	P, Q, T, EC	
HFM05	0-195					2002-12-18 12:38:27	2002-12-20 09:49:21	HFM05_000a_021219_FlowLo00.DAT	P, Q, T, EC	Data from undisturbed bh and from sections where no flowdata has been collected
HFM05						2002-12-18 11:17:09	2002-12-20 09:49:21	HFM05_000a_021219_Ref_Da01.DAT		
HFM05	0-200,1	1B, 6 L-EC, L-T		2002-12-19 10:48:02	2002-12-20 09:49:20	2002-12-18 12:38:27	2002-12-20 09:49:21	HFM05_000b_021219_FlowLo00.DAT	P, Q, T, EC	
HFM05						2002-12-18 11:17:09	2002-12-20 09:49:21	HFM05_000b_021219_Ref_Da01.DAT		

Bh ID	Test section (m)	Test type[1]	Test no	Test start Date, time YYYY-MM-DD tt:mm:ss	Test stop Date, time YYYY-MM-DD tt:mm:ss	Datafile, start Date, time YYYY-MM-DD tt:mm:ss	Datafile, stop Date, time YYYY-MM-DD tt:mm:ss	Data files of raw and primary data	Content (parameters)2	Comments
HFM05	0-200,1	1B		2002-12-18 16:39:47	2002-12-19 09:44:25	2002-12-18 16:39:47	2002-12-19 09:44:25	HFM05_000_021218_Pumpin00.DAT	P,Q	Capacity test before flow logging. Pumpingdata and pressuredata collected.
HFM05				2002-12-18 11:17:09	2002-12-20 09:49:21			HFM05_000_021218_Ref_Da01.DAT		
KFM02	0-100,4	1B, 6 L-EC, L-T		021129 09:18:19	021202 09:03:20	021128 10:41:36	021202 09:03:20	KFM02A_000a_021129_FlowLo00.DAT	P,Q,T,EC	
KFM02						021128 09:03:02	021129 19:57:38	KFM02A_000a_021129_Ref_Da00.DAT		
KFM02										
KFM02	81-22	6 L-EC L-T		02-11-29 13:38:24	02-11-29 15:47:15	02-11-29 13:38:24	02-11-29 15:47:15	KFM02A_000_021129_Spinne00.DAT	P, Q, T, Sp, EC	
KFM02						021128 10:41:36	021202 09:03:20	KFM02A_000b_021129_FlowLo00.DAT	P,Q,T,EC	Data from undisturbed bh and from sections where no flowdata has been collected
KFM02						021128 09:03:02	021129 19:57:38	KFM02A_000b_021129_Ref_Da00.DAT		

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

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

Appendix 2

Test diagrams

Diagrams are presented for the following tests: Page

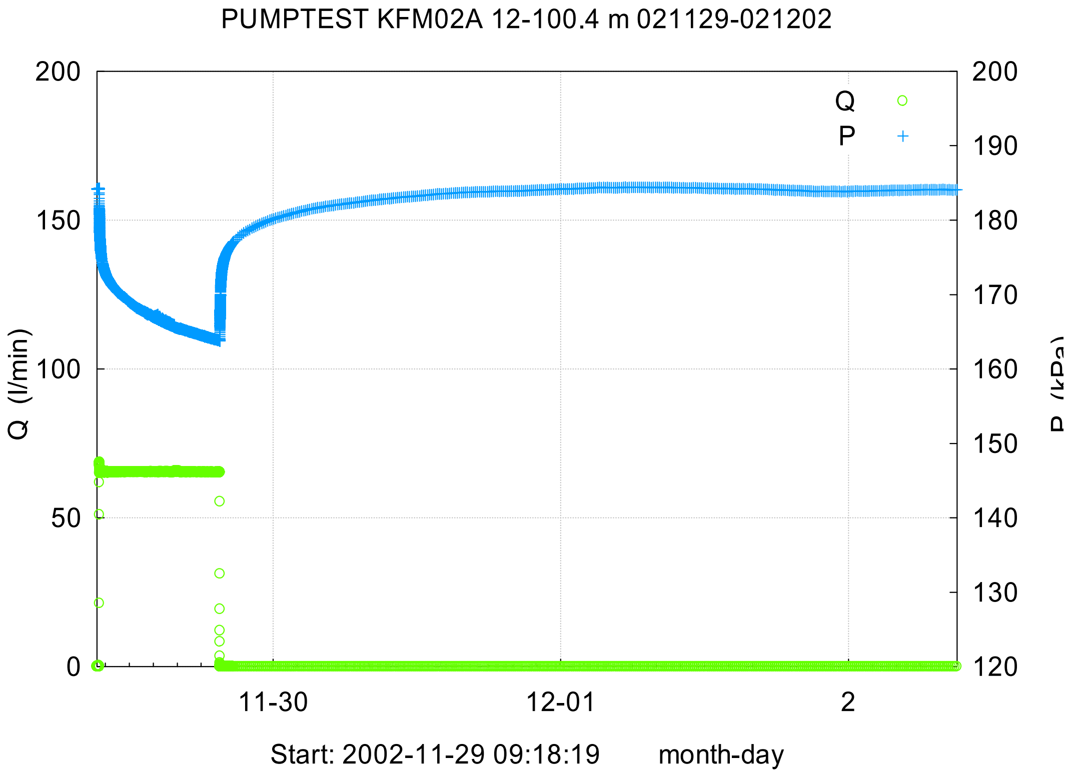


Figure A2-1. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in KFM02A (12.0–100.4 m) in conjunction with flow logging.*

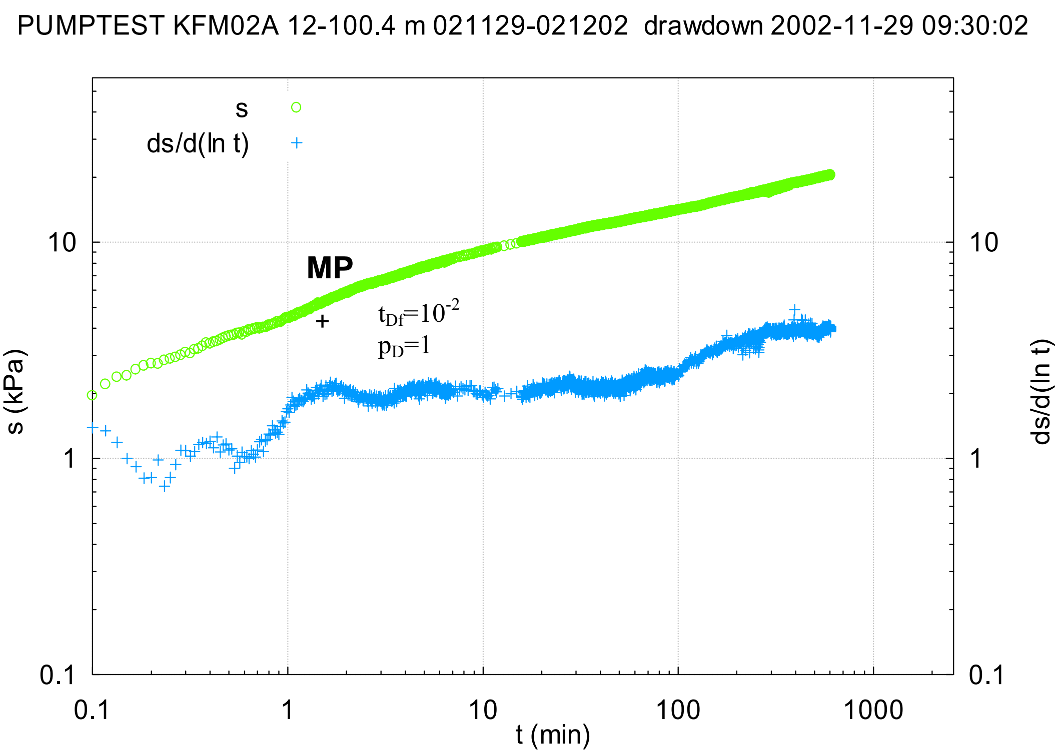


Figure A2-2. *Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the open-hole pumping test in KFM02A (12.0–100.4 m).*

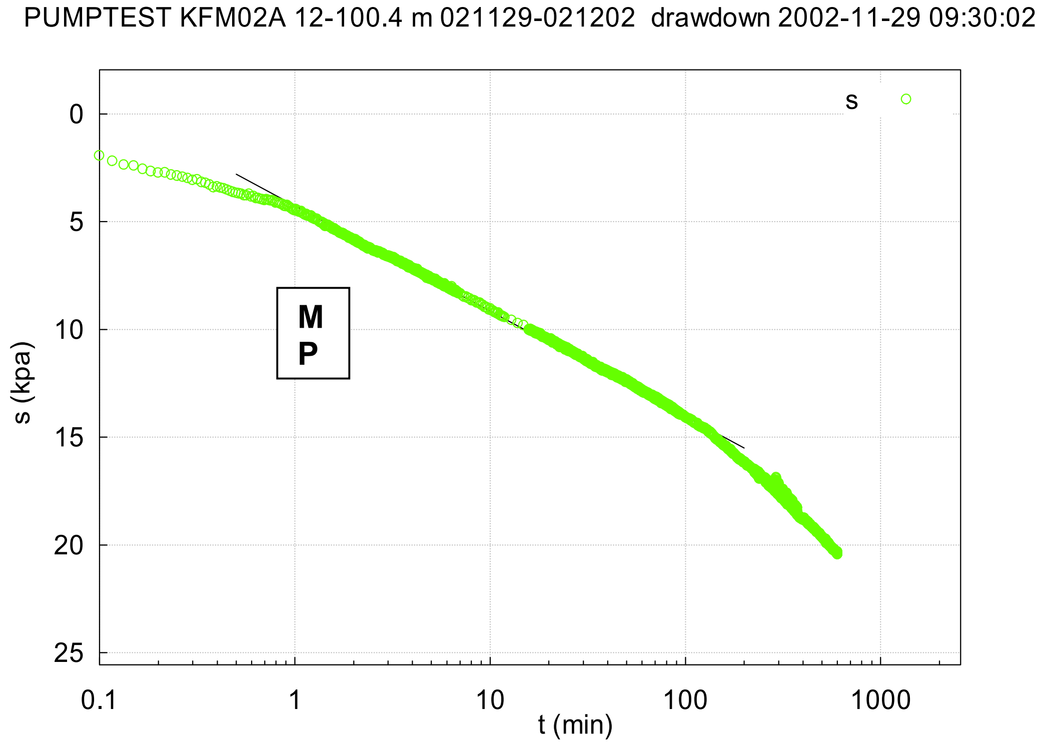


Figure A2-3. *Lin-log plot of drawdown (s) versus time (t) during the open-hole pumping test in KFM02A (12.0–100.4 m).*

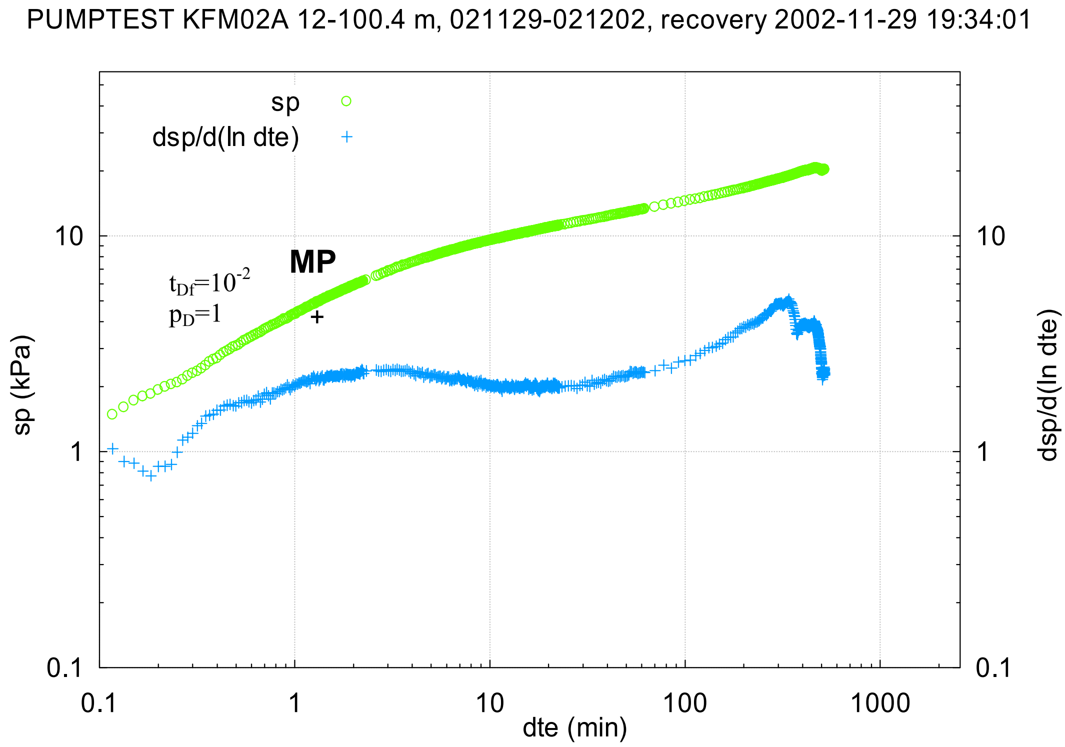


Figure A2-4. *Log-log plot of pressure recovery (sp) and – derivative, dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in KFM02A (12.0–100.4 m).*

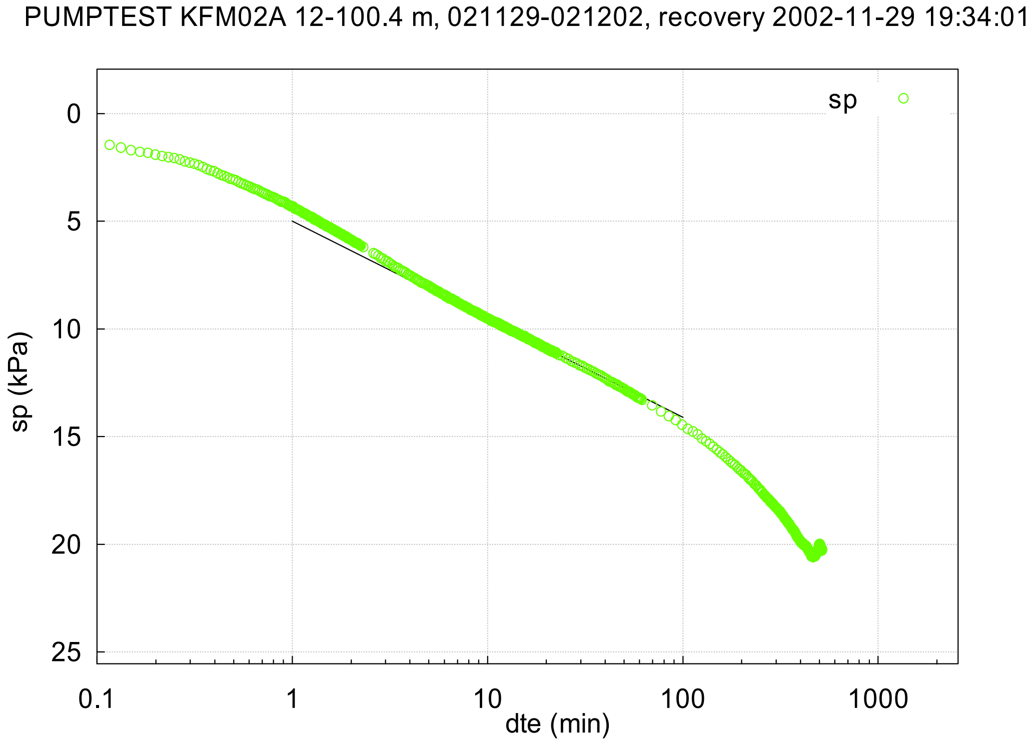


Figure A2-5. *Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the open-hole pumping test in KFM02A (12.0–100.4 m).*

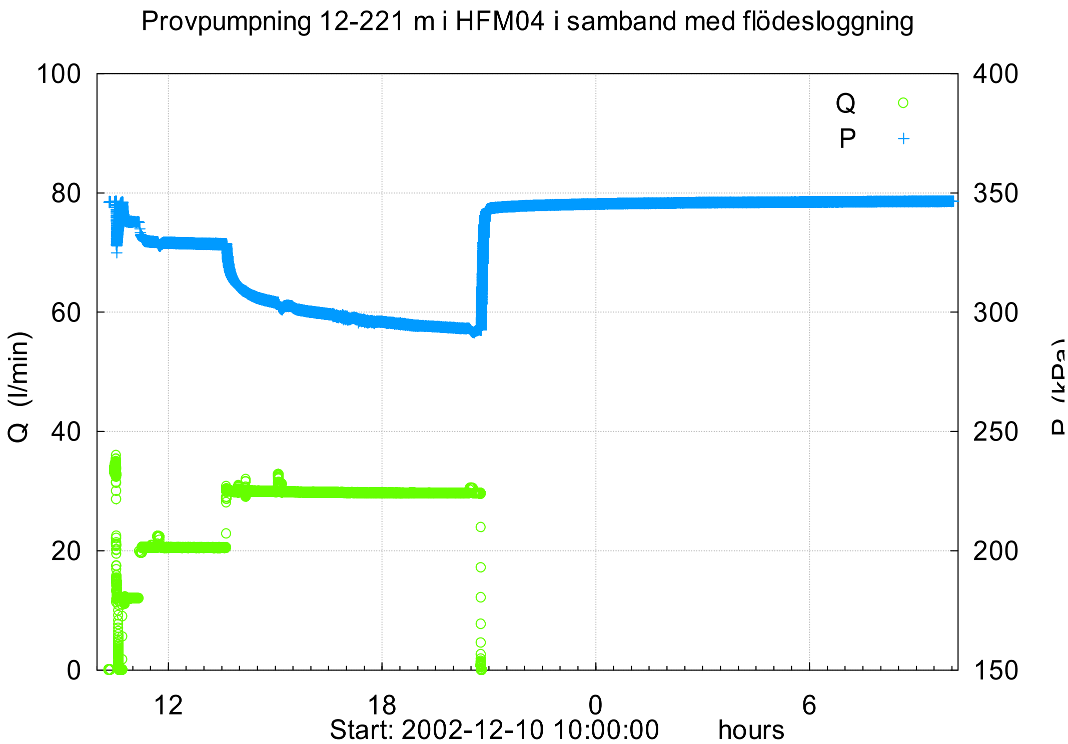


Figure A2-6. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM04 in conjunction with flow logging.*

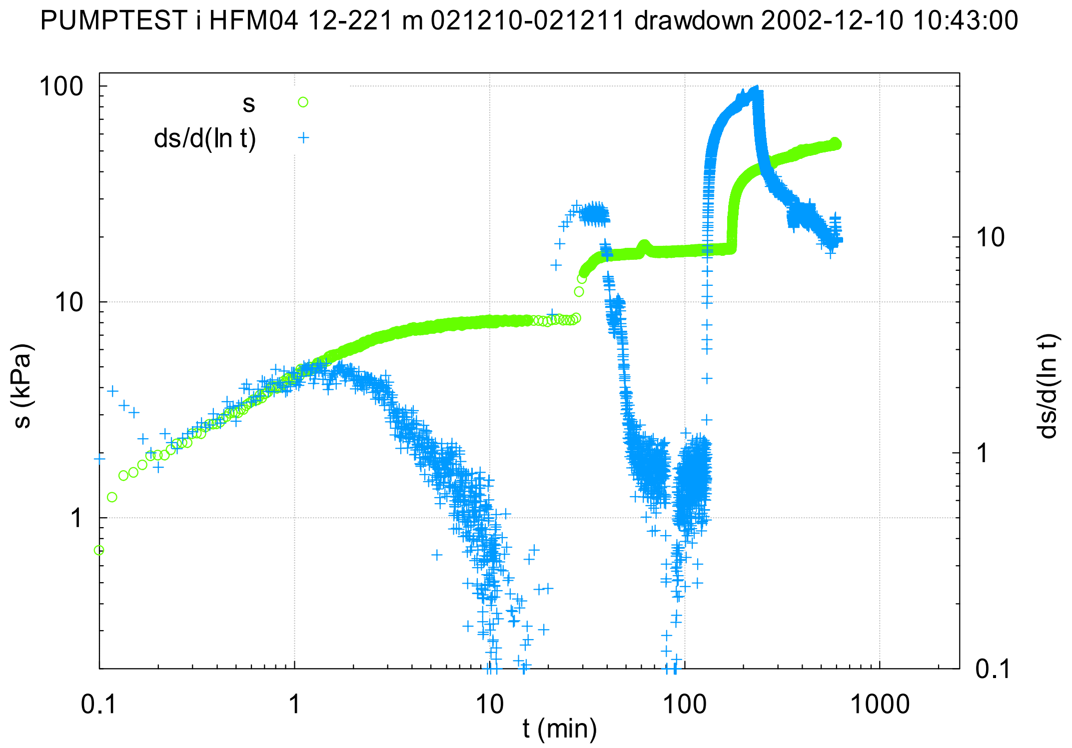


Figure A2-7. *Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the open-hole pumping test in HFM04.*

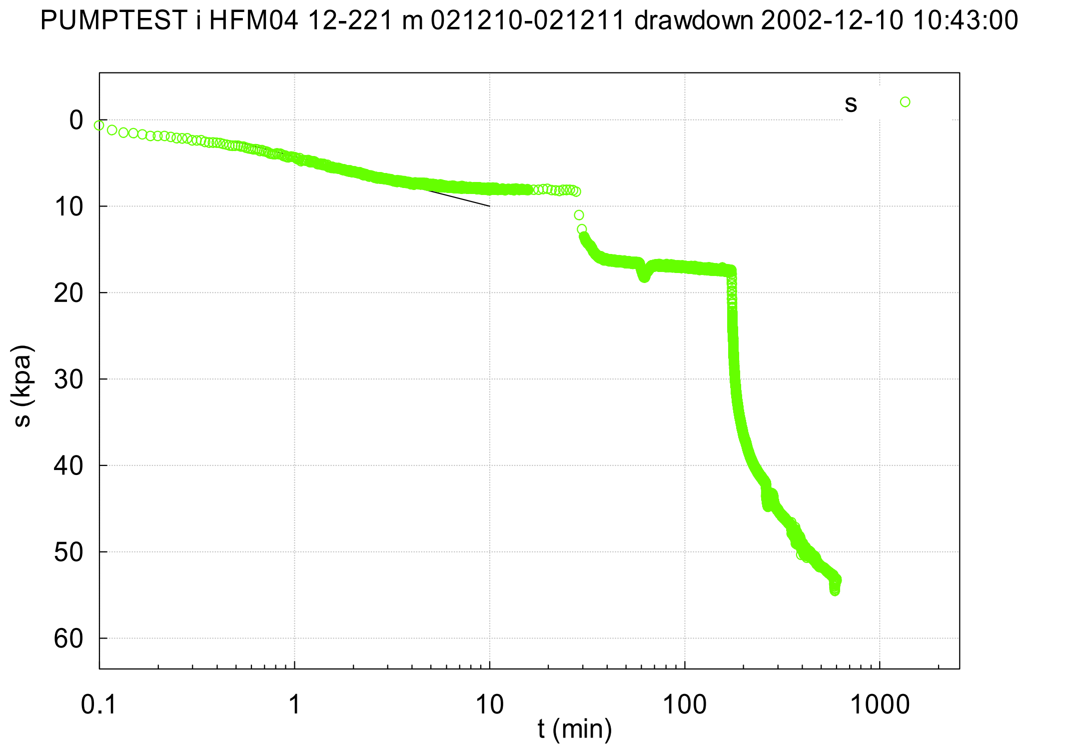


Figure A2-8. *Lin-log plot of drawdown (s) versus time (t) during the open-hole pumping test in HFM04.*

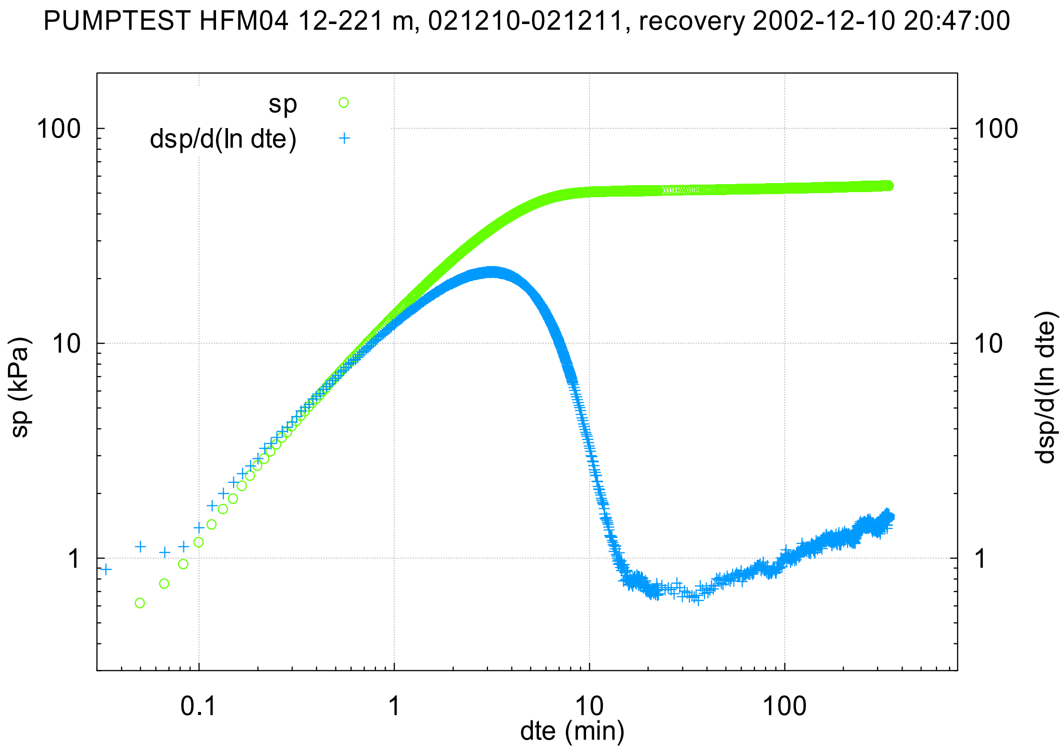


Figure A2-9. *Log-log plot of pressure recovery (sp) and – derivative, dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM04.*

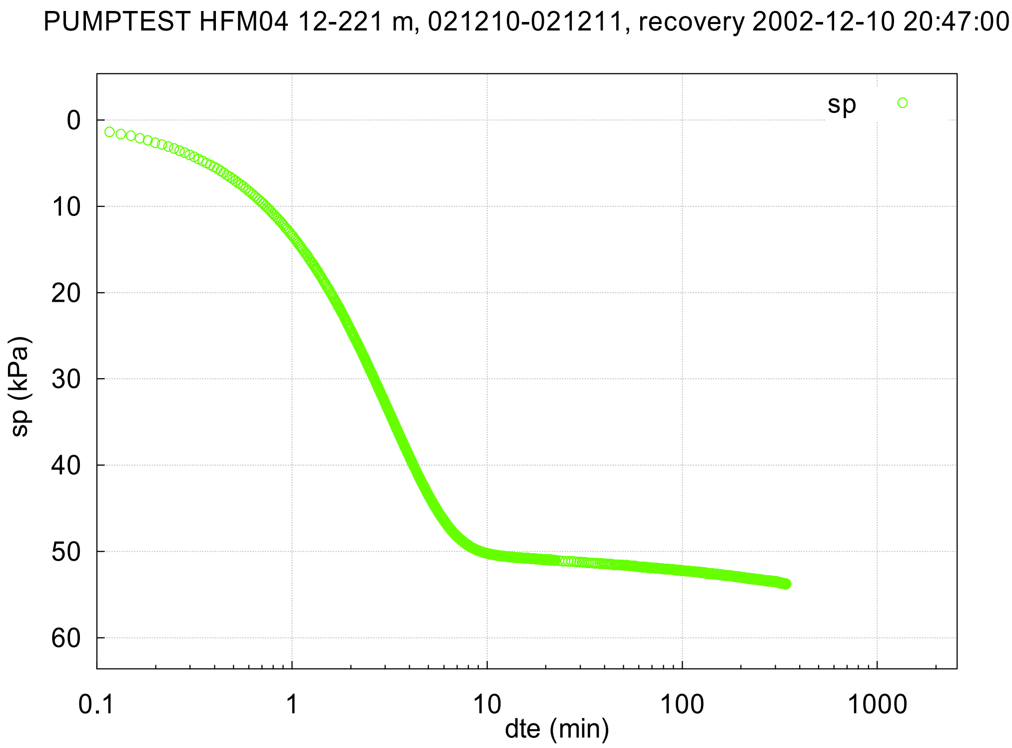


Figure A2-10. *Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the open-hole pumping test in HFM04.*

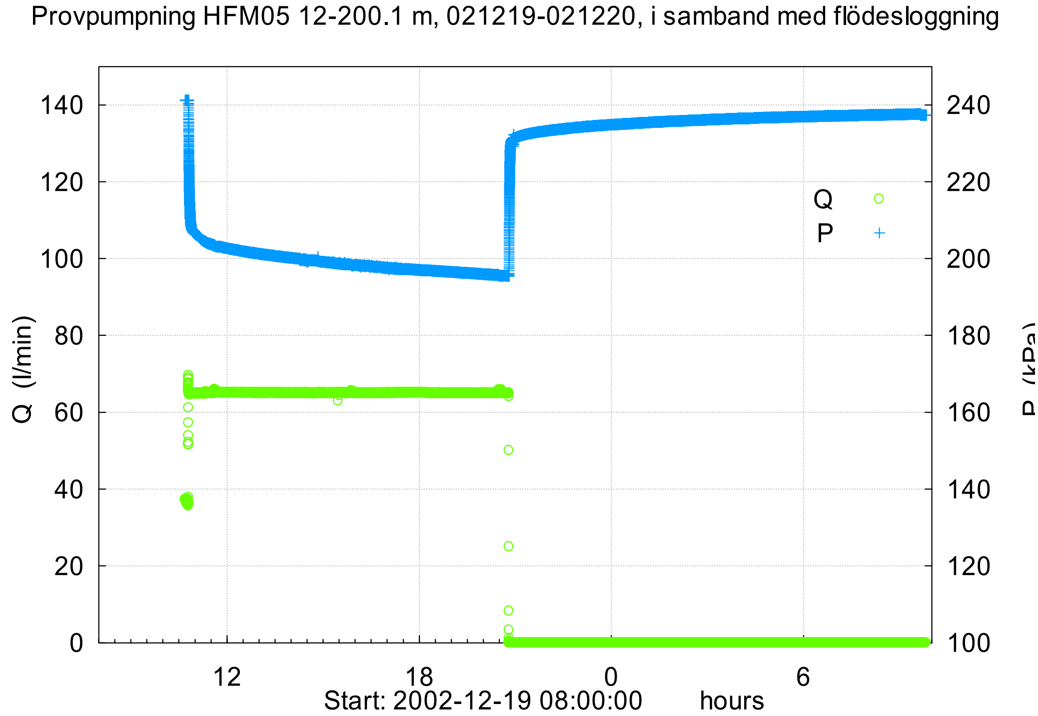


Figure A2-11. *Linear plot of flow rate (Q) and pressure (p) versus time during the pumping test in the interval 31.93–71 m in HFM05.*

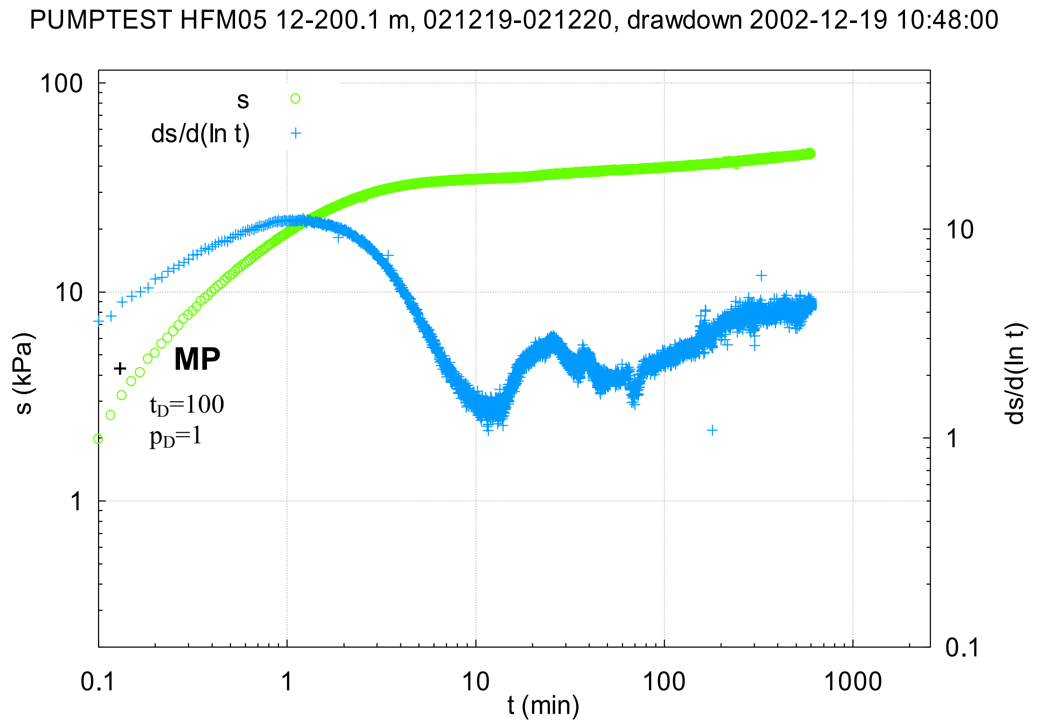


Figure A2-12. *Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the pumping test in the interval 31.93–71 m in HFM05.*

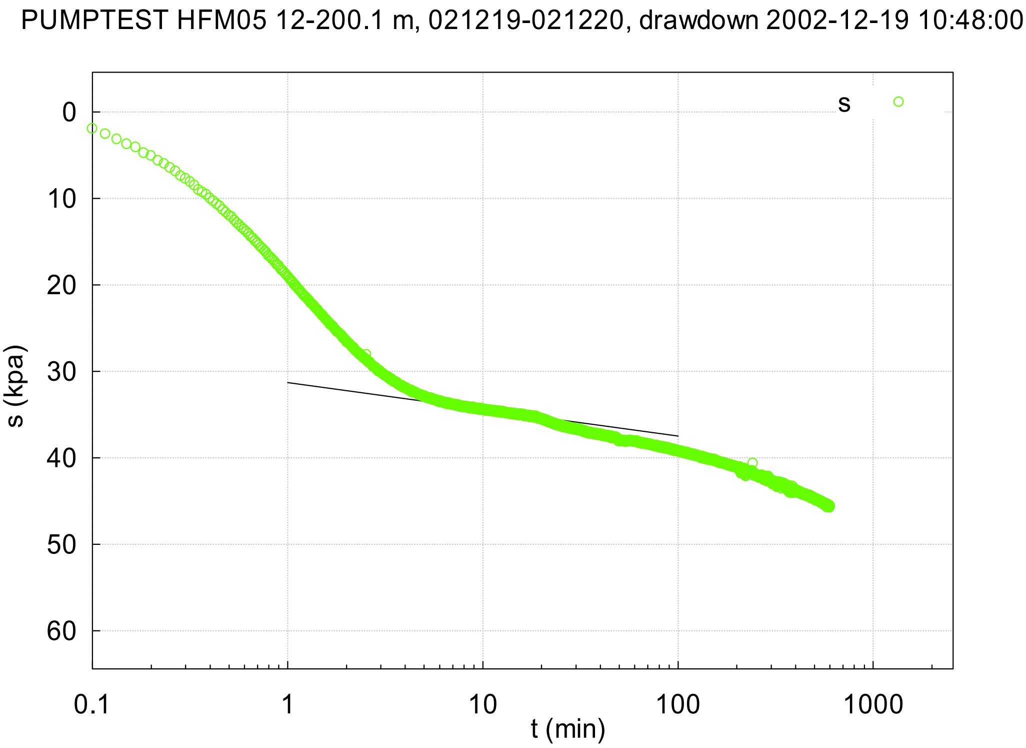


Figure A2-13. *Lin-log plot of drawdown (s) versus time (t) during the pumping test in the interval 31.93–71 m in HFM05.*

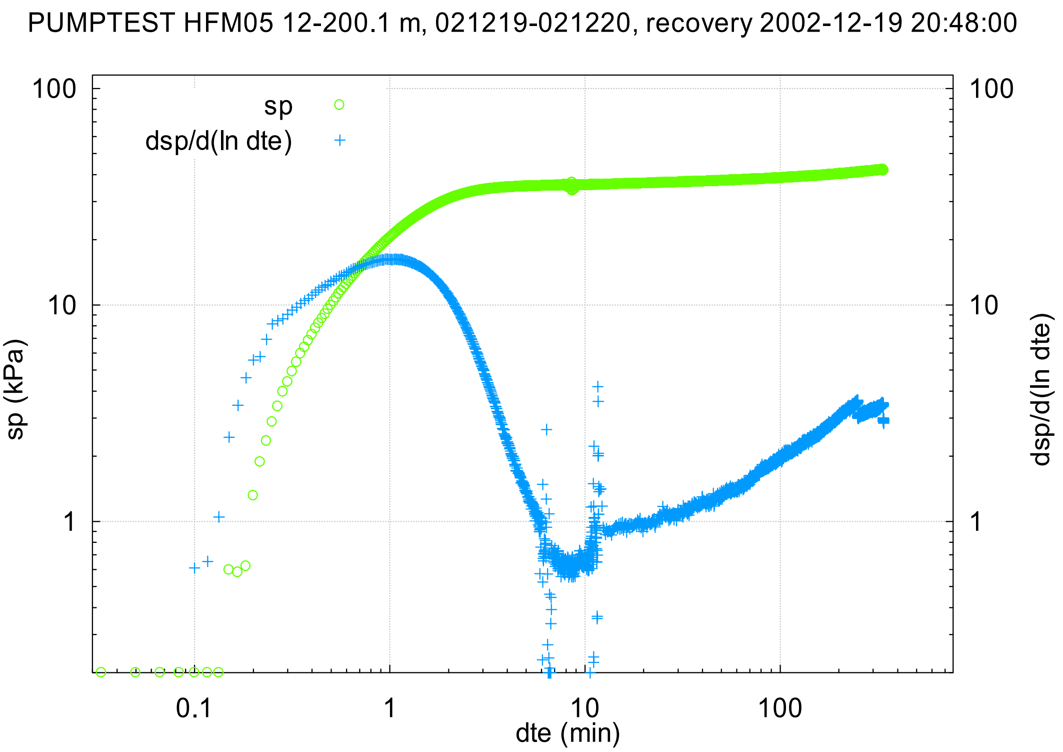


Figure A2-14. *Log-log plot of pressure recovery (sp) and – derivative, dsp/d(ln dte) versus equivalent time (dte) from the pumping test in the interval 31.93–71 m in HFM05.*

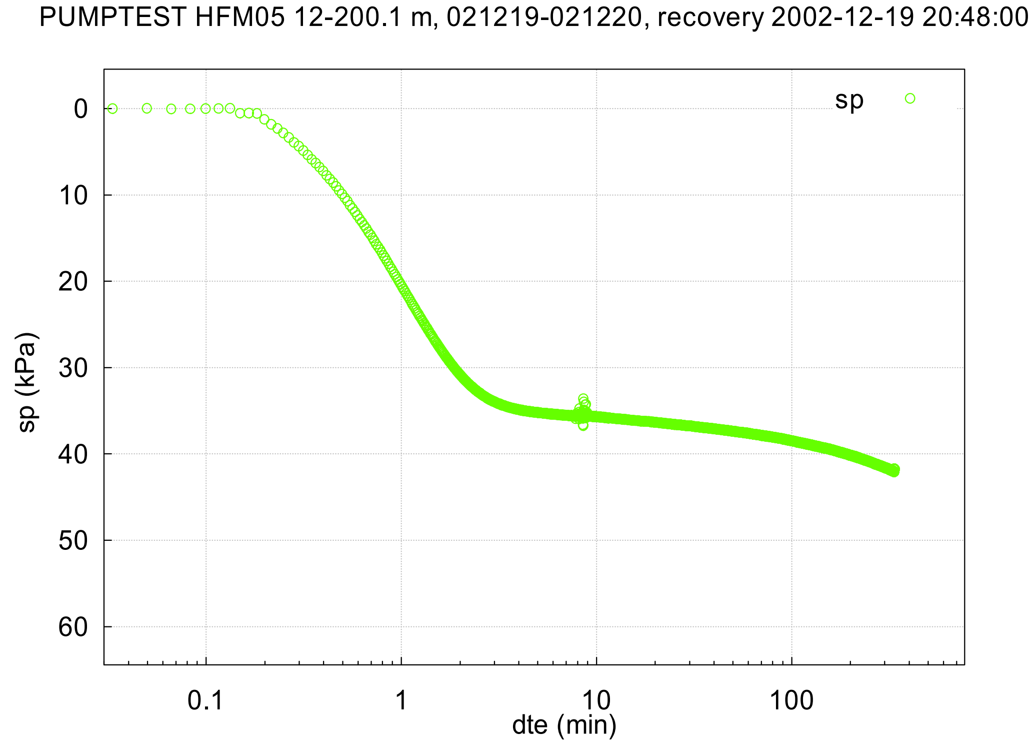


Figure A2-15. *Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the pumping test in the interval 31.93–71 m in HFM05.*

Appendix 3

Result tables to Sicada database

The following result tables are presented:

A. Result Table for Single hole tests at drillsite DS2 at Forsmark for submission to SICADA

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_d; General information

Borehole idcode	Borehole secup (m)	Borehole seclow (m)	Test type (1-6)	Formation type (-)	Date and time for test, start YYYYMMDD hh:mm	Date and time for test, stop YYYYMMDD hh:mm	Date and time for flow period, start YYYYMMDD hh:mm:ss	Date and time for flow period, stop YYYYMMDD hh:mm:ss	Qp (m**3/s)	Value type (-1, 0 or 1)	Q-measl-L (m**3)/s	Q-measl-U (m**3)/s	V_p (m**3)	Q_m (m**3/s)
KFM02A	12.00	100.40	1B	1	20021129 09:18	20021202 09:03	20021129 09:30:00	20021129 19:34:00	1.09E-03	0	8.3E-05	1.3E-03	39.4	1.09E-03
HFM04	12.00	221.70	1B	1	20021210 10:00	20021211 10:10	20021210 10:43:00	20021210 20:47:00	4.93E-04	0	8.3E-05	1.3E-03	14.6	4.03E-04
HFM05	12.00	200.10	1B	1	20021219 08:00	20021220 10:00	20021219 10:48:00	20021219 20:48:00	1.08E-03	0	8.3E-05	1.3E-03	39.0	1.08E-03

cont.

t_p (s)	t_F (s)	h_i (m a sl)	h_p (m a sl)	h_F (m a sl)	p_i (kPa)	p_p (kPa)	p_F (kPa)	Te_w (°C)	EC_w (mS/m)	TDS_w (mg/ L)	TDS_{wm} (mg/ L)	Reference	Comments (-)
36240	48540	0.79	-1.27	0.78	184.20	163.80	184.10					P-03-34	
36240	48180	0.80	-4.64		346.00	292.70	346.50					P-03-34	
36000	47520	0.44	-4.22	-0.01	241.20	195.50	237.30					P-03-34	

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_ed1; Basic evaluation

Borehole	Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YYYYMMDD hh:mm	Q/s (m^2/s)	Value type (-1, 0 or 1)	T_Q (m^2/ s)	T_M (m^2/ s)	b (m)	B (m)	TB (1D) (m^3/ s)	TB-measl-L (1D) (m^3/ s)	TB-measl-U (1D) (m^3/ s)	SB (1D) (m)	SB* (1D) (m)	L_f (1D) (m)
KFM02A	12.00	100.40	20021129 09:18	5.33E-04	0		6.17E-04	88.4							
HFM04	12.00	221.70	20021210 10:00	9.13E-05	0		1.09E-04	209.7							
HFM05	12.00	200.10	20021219 08:00	2.32E-04	0		3.10E-04	188.1							

cont.

T_T (2D) (m^2/ s)	Value type (-1, 0 or 1)	Q/s-measl-L (m^2/ s)	Q/s-measl-U (m^2/ s)	S (2D) (-)	S* (2D) (-)	K´/b´ (2D) (1/s)	K_S (3D) (m/s)	K_S-measl-L (3D) (m/s)	K_S-measl-U (3D) (m/s)	S_S (3D) (1/m)	S_S* (3D) (1/m)	L_p (m)	C (m**3/Pa)	C_D (-)	ξ (2D) (-)	ω (-)	λ (-)	t_1 (s)	t_2 (s)	Comments (-)
3.98E-04	0	2.0E-06	2.0E-03		5.00E-05										-4.97			60	6000	
7.87E-05	0	2.0E-06	2.0E-03		5.00E-05								2.40E-06		-4.31			40	180	
3.96E-04	0	2.0E-06	2.0E-03		5.00E-05								2.38E-06		0.5			600	7200	

Header	Unit	*Explanation*
Borehole		ID for borehole
Borehole secup	m	Length coordinate along the borehole for the upper limit of the test section
Borehole seclow	m	Length coordinate along the borehole for the lower limit of the test section
Test type (1- 7)	(-)	1A: Pumping test - wireline eq., 1B:Pumping test-submersible pump, 1C: Pumpingtest-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging-PFL-DIFF-sequential, 5B: Difference flow logging-PFL-DIFF-overlapping, 6:Flow logging_Impeller,7:Grain size analysis
Date for test start		Date for the start of the pumping or injection test (YYYYMMDD hh:mm)
Start flow / injection		Date and time for the start of the pumping or injection period (YYMMDD hh:mm:ss)
Start flow / injection		Date and time for the end of the pumping or injection period (YYMMDD hh:mm:ss)
Q_m	m^3/s	Arithmetic mean flow rate of the pumping/injection period.
Q_p	m^3/s	Flow rate at the end of the pumping/injection period.
Value type	-	Code for Q_p-value; -1 means Q_p<lower measurement limit, 0 means measured value, 1 means Q_p> upper measurement value of flowrate
Q-measl_L	m^3/s	Estimated lower measurement limit for flow rate
Q-measl_U	m^3/s	Estimated upper measurement limit for flow rate
V_p	m^3	Total volume pumped (positive) or injected (negative) water during the flow period.
t_p	s	Time for the flowing phase of the test
t_F	s	Time for the recovery phase of the test
h_i	m	Initial formation hydraulic head. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
h_p	m	Final hydraulic head at the end of the pumping/injection period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
h_F	m	Final hydraulic head at the end of the recovery period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
p_i	kPa	Initial formation pressure.
p_p	kPa	Final pressure at the end of the pumping/injection period.
p_F	kPa	Final pressure at the end of the recovery period.
Te_w	gr C	Fluid temperature in the test section representative for the evaluated parameters
EC_w	mS/m	Electrical conductivity of the fluid in the test section representative for the evaluated parameters
TDS_w	mg/L	Total salinity of the fluid in formation at test section based on EC.
TDS_{wn}	mg/L	Total salinity of the fluid in formation at test section based on water sampling and chemical analysis.
Sec.type,	(-)	Test section (pumping or injection) is labeled 1 and all observation sections are labeled 2
Q/s	m2/s	Specific capacity, based on Qp and s=abs(pi-pp). Only given for test section (label 1) in interference test.
T_Q	m2/s	Transmissivity based on specific capacity and a a function for T=f(Q/s). The function used should be refered in "Comments"
T_M	m2/s	Transmissivity based on Moye (1967)

b	m	Interpreted formation thickness representative for evaluated T ot TB.
B	m	Interpreted witdth of a formation with evaluated TB
TB	m3/s	1D model for evaluation of formation properties. T=transmissivity, B=width of formation
TB-measl-L	m2/s	Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or less than TB-measlim
TB-measl-L	m2/s	Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or greater than TB-measlim
SB	m	1D model for evaluation of formation properties. S= Storativity, B=width of formation
SB*	m	1D model for evaluation of formation properties. Assumed SB. S= Storativity, B=width of formation
L_f	m	1D model for evaluation of Leakage factor
T_T	m2/s	2D model for evaluation of formation properties. T=transmissivity
T-measl-L	m2/s	Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or less than T-measlim
T-measl-U	m2/s	Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or grater than T-measlim
S	(-)	2D model for evaluation of formation properties. S= Storativity
S*	(-)	2D model for evaluation of formation properties. Assumed S. S= Storativity
K´/b´	(1/s)	2D model for evaluation of leakage coefficient. K´= hydraulic conductivity in direction of leaking flow for the aquitard, b´= Saturated thickness of aquitard (leaking formation)
K_S	m/s	3D model for evaluation of formation properties. K=Hydraulic conductivity
K_S-measl-L	m/s	Estimated measurement limit for evaluated KS. If estimated KS equals KS-measlim in the table actual KS is considered to be equal or less than KS-measlim
K_S-measl-U	m/s	Estimated measurement limit for evaluated KS. If estimated KS equals KS-measlim in the table actual KS is considered to be equal or greater than KS-measlim
S_S	1/m	3D model for evaluation of formation properties. Ss=Specific Storage
S_S*	1/m	3D model for evaluation of formation properties. Assumed Ss. Ss=Specific Storage
L_p	m	Hydraulic point of appication, based on hydraulic conductivity distribution (if available) or the midpoint of the borehole test section
C	(m3/Pa)	Wellbore storage coefficient
C_D	(-)	Dimensionless wellbore storage coefficient
ξ	(-)	Skin factor
ω	(-)	Storativity ratio
λ	(-)	Interporosity flow coefficient
dt_1	s	Estimated start time after pump/injection start OR recovery start, for the period used for the evaluated parameter
dt_2	s	Estimated stop time after pump/injection start OR recovery start, for the period used for the evaluated parameter
	m	Length coordinate along the borehole for the upper limit of the observation section
	m	Length coordinate along the borehole for the lower limit of the observation section
p_{ai}	kPa	Initial formation pressure of the observation section, which is located above the test section in the borehole
p_{ap}	kPa	Final pressure at the end of the pumping/injection period in the observation section, which is located above the test section in the borehole
p_{aF}	kPa	Final pressure at the end of the recovery period in the observation section, which is located above the test section in the borehole
p_{bi}	kPa	Initial formation pressure of the observation section, which is located below the test section in the borehole

p_{bp}	kPa	Final pressure at the end of the pumping/injection period in the observation section, which is located below the test section in the borehole
p_{bF}	kPa	Final pressure at the end of the recovery period in the observation section, which is located below the test section in the borehole
References		SKB report No for reports describing data and evaluation
Index w		Active borehole or borehole section

B. Result Table for Flow logging at drillsite DS2 at Forsmark for submission to SICADA

FLOWLOGG-IMPELLER TESTS-plu_impeller_basic

Borehole	Borehole secup (m)	Borehole seclow (m)	Test type (1-7)	Formation type (-)	Date and time of test, start YYYYMMDD hh:mm	Date and time of stop of flow period YYYYMMDD hh:mm	Date and time of flowl., start YYYYMMDD hh:mm:ss	Date and time of flowl., stop YYYYMMDD hh:mm:ss	Q-measl-L (m^3/s)	Q-measl-U (m^3/s)	Q_p (m^3/s)
KFM02A	22.00	100.00	6	1	2002-11-29 09:18	2002-12-02 09:03	2002-11-29 13:38	2002-11-29 15:47	6.7E-05	1.7E-03	1.09E-03
HFM04	35.00	210.00	6	1	2002-12-10 10:00	2002-12-11 10:10	2002-12-10 17:55	2002-12-10 19:00	5.0E-05	1.7E-03	4.93E-04
HFM05	28.00	195.00	6	1	2002-12-19 08:00	2002-12-20 10:00	2002-12-19 14:36	2002-12-19 17:30	5.0E-05	1.7E-03	1.08E-03

cont.

tp (s)	t_{FL} (s)	h_0 (m a s l)	h_p (m a s l)	s_{FL} (m)	Reference (-)	Comments (-)
36240	7740	1.15	-0.63	1.78	P-03-34	
36240	3900	0.80	-4.64	5.10	P-03-34	
36000	10440	0.44	-4.22	4.30	P-03-34	

plu_impell-main_res

Borehole ID	Borehole secup (m)	Borehole seclow (m)	L Corrected (m)	Te_{w0} (°C)	EC_{w0} (mS/m)	TDS_{w0} (mg/L)	Q_0 (m**3/s)	Te_w (°C)	EC_w (mS/m)	TDS_w (mg/L)	Q_{1T} (m**3/s)	Q_T (m**3/s)	Q_{Tcorr}	T Entire hole (m^2/s)	T_{FT} (m^2/s)	T_F-measl-L (m^2/s)	T_F-measl-U (m^2/s)
KFM02A	22.00	100.00									6.47E-04	6.47E-04	1.09E-03	3.98E-04	3.98E-04	2.0E-06	2.0E-03
HFM04	35.00	210.00									5.57E-04	5.57E-04	4.93E-04	7.87E-05	7.87E-05	2.0E-06	2.0E-03
HFM05	28.00	195.00									1.81E-03	1.81E-03	1.08E-03	3.96E-04	3.96E-04	2.0E-06	2.0E-03

cont.

Reference (-)	Comments (-)
P-03-34	Final bh. diam=165 mm, flow calibration=160 mm
P-03-34	Final bh. diam=140 mm, flow calibration=140 mm
P-03-34	Final bh. diam=136 mm, flow calibration=140 mm

FLOWLOGG-IMPELLER TESTS plu_impeller_anomaly

Borehole	Borehole secup (m)	Borehole seclow (m)	Upper limit L (m)	Lower limit L (m)	Te_w (°C)	EC_w (mS/m)	TDS_w (mg/L)	$deltaQ_i$ (m**3/s)	$deltaQ_{icorr}$ (m**3/s)	$deltaQ_{icorr}/s_{FL}$ (m**2/s)	b_i (m)	T_i (m^2/s)	T_i-measl-L (m^2/s)	T_i-measl-U (m^2/s)	Reference (-)	Comments (-)
KFM02A	22.00	100.00	79.5	81.5				6.67E-04	1.09E-03	6.12E-04	2	3.98E-04			R-03-34	Assumption:Q_T=Q_p
HFM04	35.00	210.00	60	63.5				5.58E-04	4.93E-04	9.67E-05	3.5	7.87E-05			R-03-34	Assumption:Q_T=Q_p
HFM05	28.00	195.00	150.5	156.5				2.40E-03	1.08E-03	2.51E-04	6	3.96E-04			R-03-34	Assumption:Q_T=Q_p

Header	Unit	Description
Date/time test start	date	Date for the stop of the test (YYYY-MM-DD hh:mm)
Date/time test stop	date	Date for the stop of the test (YYYY-MM-DD hh:mm)
Borehole	idcode	Object or borehole identification code
Borehole secup	m	Length coordinate along the borehole for the upper limit of the logged section (Based on corrected length L)
Borehole seclow	m	Length coordinate along the borehole for the lower limit of the logged section. (Based on corrected length L)
date and time, start	date_s	Date and time of flow logging start (YYYY-MM-DD hh:mm:ss)
date and time, stop	date_s	Date and time of flow logging stop (YYYY-MM-DD hh:mm:ss)
Test type (1-7)		1A: Pumping test - wireline eq., 1B:Pumping test-submersible pump, 1C: Pumpingtest-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging-PFL-DIFF- Sequential, 5B: Difference flow logging-PFL-DIFF-Overlapping, 6: Flow logging-Impeller 7: Grain size analysis
Formation type		1: Rock, 2: Soil (supeficial deposits)
Q-measl-L	m^3/s	Estimated lower measurement limit for borehole flow rate in flow logging probe
Q-measl-U	m^3/s	Estimated upper measurement limit for borehole flow rate in flow logging probe
Q_p	m^3/s	Flow rate at surface during flow logging
tp	s	Time for the flowing phase of the test
t_{FL}	s	Duration of the flow logging survey
s_{FL}	m	Average drawdown of the water level in open borehole during flow logging
h_0	masl	Initial hydraulic head. Measured as water level in open borehole with reference level in the local coordinates system with z=0 m.
h_p	masl	Stabilised hydraulic head during first pumping period. Measured as water level in open borehole with reference level in the local coordinates system with z=0 m.
L , Corrected	m	Corrected length to point considered representative for measured value
Q	m**3/s	Cumulative flow rate:Q1-Qo. Position for measurement is related to L (corrected length)
Q_0	m^3/s	Natural (undisturbed) measured cummulative flow rate. Position for measurement is related to L (corrected length)
Q_1	m^3/s	Cumulative flow rate during pumping. Position for measurement is related to L (corrected length)
Q_{1T}	m^3/s	Cummulative flow rate:Q_1 at the top of measured interval
Q_T	m^3/s	Cummulative flow rate:Q at the top of measured interval
$Q_T$corr	m^3/s	Cummulative flow rate:QTat the top of measured interval, based on corrected borehole diameter
T(Entire hole)	m**2/s	Evaluated transmissivity for the entire hole section that is considered representative for the flow logging (also reported in data file for single-hole interpretation)
T_F	m**2	Cumulative transmissivity based on impeller measurement. 2D model for evaluation of formation properties of the test section. T_F = Óti = T*(Q_T/Q_p)
T_{FT}	m**2	Cumulative transmissivity of the entire measured interval, based on impeller measurement
T_F-measl-L	m**2/s	Estimated lower measurement limit for evaluated T_F. If estimated T_F equals T-measlim in the table, the actual T_F is considered to be equal or less than T_F - measlim
T_F-measl-U	m**2/s	Estimated upper measurement limit for evaluated T_F. If estimated T_F equals T-measlim in the table, the actual T_F is considered to be equal or greater than T_F - measlim
Te_{w0}	gr C	Natural (undisturbed) fluid temperature in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected length)
EC_{w0}	mS/m	Natural (undisturbed) electrical conductivity of the fluid in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected length)
TDS_{w0}	mg/L	Natural (undisturbed) total salinity of the fluid in the test section representative for the evaluated parameters based on EC. Position for measurement is related to L (corrected length)
Upper limit	m	Corrected length coordinate along the borehole for the upper limit of the flow anomaly
Lower limit	m	Corrected length coordinate along the borehole for the lower limit of the flow anomaly

Te_w	centigrade	Natural (undisturbed) fluid temperature in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected length)
EC_w	mS/m	Natural (undisturbed) electrical conductivity of the fluid in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected length)
TDS_w	mg/L	Natural (undisturbed) total salinity of the fluid in the test section representative for the evaluated parameters based on EC. Position for measurement is related to L (corrected length)
deltaQ$_i$	m**3/s	deltaQi : Flow rate of interpreted flow anomaly i
deltaQ$_{icorr}$	m**3/s	deltaQicorr : Flow rate of interpreted flow anomaly calculated with corrected borehole diameter.
deltaQ$_i$/S_{FL}	m**2/s	deltaQi/s_{FL}: Specific capacity of interpreted flow anomaly
b_i	m	Interpreted formation thickness representative for evaluated Ti of anomaly i.
T_i	m**2/s	Evaluated transmissivity of flow anomaly i considered representative for the flow logging
T_i-measlim-L	m**2/s	Estimated lower measurement limit for evaluated $T_{i.}$ If estimated T_i equals T-measlim in the table actual T_i is considered to be equal or less thanT_i-measlim
T_i-measlim-L	m**2/s	Estimated upper measurement limit for evaluated $T_{i.}$ If estimated T_i equals T_i-measlim in the table actual T_i is considered to be equal or greater thanT_i-measlim
Reference		SKB number for reports describing data and results
Comments		Short comment on evaluated parameters