P-03-33

Forsmark site investigation

Pumping tests and flow logging

Boreholes KFM01A (0–100 m), HFM01, HFM02 and HFM03

Jan-Erik Ludvigson, Stig Jönsson, Jakob Levén
Geosigma AB

May 2003

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel 08-459 84 00
+46 8 459 84 00
Fax 08-661 57 19
+46 8 661 57 19

ISSN 1651-4416
SKB P-03-33

Forsmark site investigation

Pumping tests and flow logging

Boreholes KFM01A (0–100 m), HFM01, HFM02 and HFM03

Jan-Erik Ludvigson, Stig Jönsson, Jakob Levén
Geosigma AB

May 2003

Key words: Forsmark, hydrogeology, hydraulic tests, pumping tests, flow meter logging, water sampling, hydraulic parameters, transmissivity, flow anomaly

Abstract

Borehole KFM01A was the first 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 in a larger diameter than the diameter (76 mm) of the core drilled part.

In connection with the drill start of borehole KFM01A, six other, however more shallow boreholes, were drilled in the vicinity of KFM01A. Three of them, HFM01, HFM02 and HFM03, are percussion drilled boreholes in hard rock.

Pumping tests were performed in the percussion drilled part, 0–100 m, of KFM01A and in HFM01, HFM02 and HFM03. Water samples were collected in all boreholes in conjunction with the pumping tests. In addition, flow meter logging was performed in the latter three boreholes. In KFM01A the planned flow logging was canceled due to technical problems with the down-hole flow probe. No other borehole tests had been carried out in the actual boreholes before this campaign.

The main objectives of the hydraulic tests in the percussion boreholes were firstly, to perform a hydraulic characterization of the boreholes (e.g. to investigate the occurrence of possible sub-horizontal zones) and secondly, to investigate the groundwater chemistry. Clear evidences of probably sub-horizontally inclined fracture zones were found in three of the tested boreholes (KFM01A, HFM02 and HFM03) at shallow depths (c. 40–50 m below ground surface). The flow logging and pumping tests revealed that the zones encountered in these boreholes were very narrow (0.5–2.5 m wide) and highly conductive with estimated transmissivities in the order of $0.5–1 \cdot 10^{-3}$ m^2/s. In borehole HFM01, a more diffuse zone with an estimated transmissivity of c. $0.5–1 \cdot 10^{-4}$ m^2/s was identified in the interval c. 34–44 m.

Sammanfattning

Borrhål KFM01A var det första ca 1000 m djupa kärnborrhålet som borrades inom ramen för de pågående platsundersökningarna i Forsmarksområdet. Borrhålet är utfört som ett så kallat 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 KFM01A borrades ytterligare sex borrhål i närområdet. Tre av dessa, HFM01, HFM02 och HFM03, är hammarborrhål i berg.

Provpumpningar utfördes i den hammarborrade delen 0–100 m i KFM01A liksom i HFM01, HFM02 and HFM03. Vattenprover togs i alla borrhålen i samband med provpumpningarna. Dessutom utfördes flödesloggning i de tre senare borrhålen. I KFM01A utgick den planerade flödesloggningen pga tekniska problem med borrhålsflödessonden. 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 (t.ex. undersöka eventuell förekomst av sub-horisontella zoner) och, för det andra, att undersöka grundvattenkemin.

Tydliga tecken på sannolikt sub-horisontella zoner konstaterades i tre av de testade borrhålen (KFM01A, HFM02 och HFM03) på grunda djup (ca 40–50 m under markytan). Flödesloggningen och provpumpningarna visade att de påträffade zonerna i dessa borrhål var mycket smala (0.5–2.5 m) men högkonduktiva, med skattade transmissiviteter i storleksordningen 0.5–1· 10^{-3} m^2/s. I borrhål HFM01 identifierades en mer diffus zon med en skattad transmissivitet av 0.5–1· 10^{-4} m^2/s i intervallet ca 34–44 m.

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 KFM01A was the first 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. After a break for different types of borehole testing, this part of the borehole was reamed to a larger diameter and cased /1/. Finally, core drilling was performed below the cased part.

In connection with the drill start of borehole KFM01A, six other, however more shallow boreholes, were drilled at drillsite DS1, i.e. in the vicinity of KFM01A. Three of them, HFM01, HFM02 and HFM03, are percussion drilled boreholes in hard rock, whereas the remaining three boreholes are monitoring wells drilled through the unconsolidated overburden at drillsite DS1, 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 KFM01A is situated at drillsite DS1.

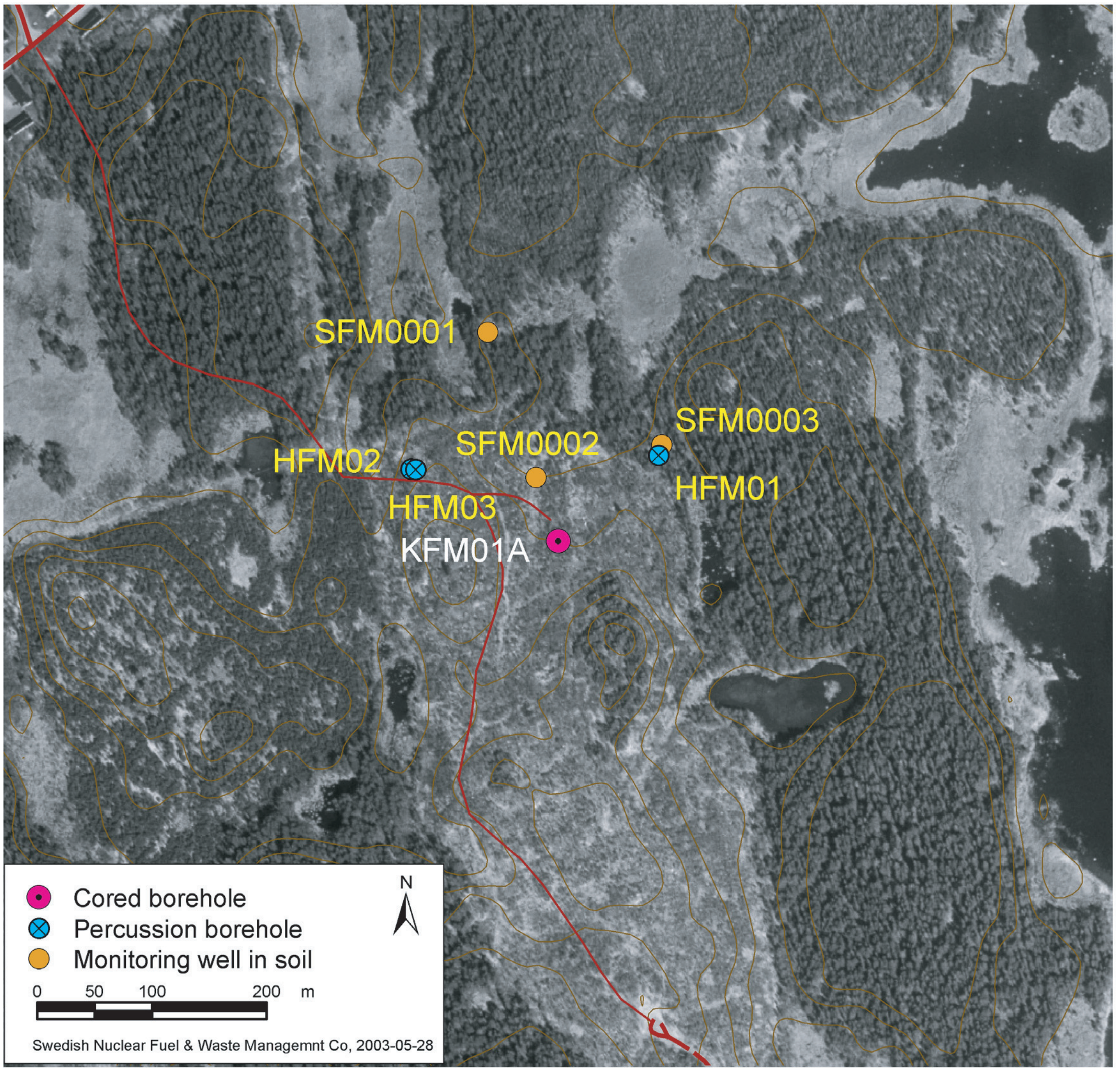


Figure 1-2. *Map showing the location of boreholes att drillsite DS1 at Forsmark.*

The first percussion borehole, HFM01, was drilled with the main objective to serve as a supply well for flushing water needed for drilling the core drilled part of KFM01A, whereas HFM02 and HFM03 were drilled primarily for groundwater level monitoring /2/. Borehole HFM03 was located close to HFM02, but drilled to a shallower depth, in order to enable the study of variations of the groundwater level in the uppermost part of the bedrock as well as the hydraulic interaction between the upper and deeper parts of the bedrock.

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

2 Objectives

The objectives of the pumping test in the interval 0–100 m in KFM01A 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 hydrochemistry of the borehole water.

The main objectives of the tests in the percussion hole HFM01 were firstly, to perform a hydraulic characterization (e.g. to reveal the occurrence of sub-horizontal fracture zones) and secondly, to investigate the water chemistry for a judgement of the potential of the borehole to serve as a supply well for flushing water during drilling of KFM01A. The same objectives also apply to boreholes HFM02 and HFM03, although these boreholes were mainly intended for groundwater level monitoring.

3 Scope

3.1 Boreholes tested

Coordinates and other data of the tested boreholes are given in Table 3-1. Northing and Easting refer to the intersection of the boreholes with the ground surface. 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 borehole diameter in Table 3-1 bears upon 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.

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

Borehole								**Casing**		**Drilling finished**
ID	**Elevation** of top of casing (ToC) (m.a.s.l.)	**Borehole length** from ToC (m)	**Bh-diam.** (below casing) (m)	**Inclin.** -top of bh (from horizontal plane) (°)	**Dip-Direction** -top of bh (from local N) (°)	**Northing**	**Easting**	**Length** (m)	**Inner diam.** (m)	**Date** (YYYY-MM-DD)
HFM01	1.73	200.20	0.140	–77.51	34.06	*6699605*	*1631485*	31.93	0.160	2002-05-03
HFM02	3.05	100.00	0.137	–87.79	6.52	*6699593*	*1631269*	25.40	0.160	2002-05-21
HFM03	3.15	26.00	0.136	–87.28	264.53	*6699593*	*1631272*	13.10	0.160	2002-05-28
KFM01A	3.125	[1] 100.57	[2] 0.164	–84.73	318.35	*6699530*	*1631397*	29.40	0.265	2002-06-10
KFM01A								[3] 100.43	[3] 0.200	

[1] Borehole length of percussion-drilled interval

[2] Borehole diameter of percussion-drilled interval at the time of the test. The borehole was subsequently reamed to 0.440 m in this interval

[3] Final borehole casing

3.2 Tests performed

The tests performed in the boreholes are listed in Table 3-2. None of the boreholes were tested previously. 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 KFM01A. Manual observations of the groundwater level in the pumped boreholes were also made during the tests.

Table 3-2. Borehole tests performed.

Bh ID	Test section (m)	Test type[1]	Test config.	Test start date and time (YYYY-MM-DD tt:mm)	Test stop date and time (YYYY-MM-DD tt:mm)
KFM01A	29.40–100.5	1B	Open hole	2002-05-24 12:08	2002-05-27 08:40
HFM01	731.93–200.20	1B	Open hole	2002-05-14 08:13	2002-05-15 08:52
HFM01	34–198	6, L-Te, L-EC	Open hole	2002-05-14 10:19	2002-05-14 15:50
HFM01	31.93–71	1B	Above packer	2002-05-16 15:46	2002-05-16 18:01
HFM01	72–200.20	1B	Below packer	2002-05-16 09:46	2002-05-16 11:12
HFM02	25.40–100.00	1B	Open hole	2002-06-04 12:08	2002-06-05 09:51
HFM02	31–100	6, L-Te, L-EC	Open hole	2002-06-04 14:34	2002-06-04 17:20
HFM03	13.10–26.00	1B	Open hole	2002-06-05 11:48	2002-06-06 08:40
HFM03	13.10–26	6, L-Te, L-EC	Open hole	2002-06-05 13:13	2002-06-05 14:37

[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 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 flow logging, sensors measuring temperature and electric conductivity as well as the down-hole flow rate are also used. The equipment on the

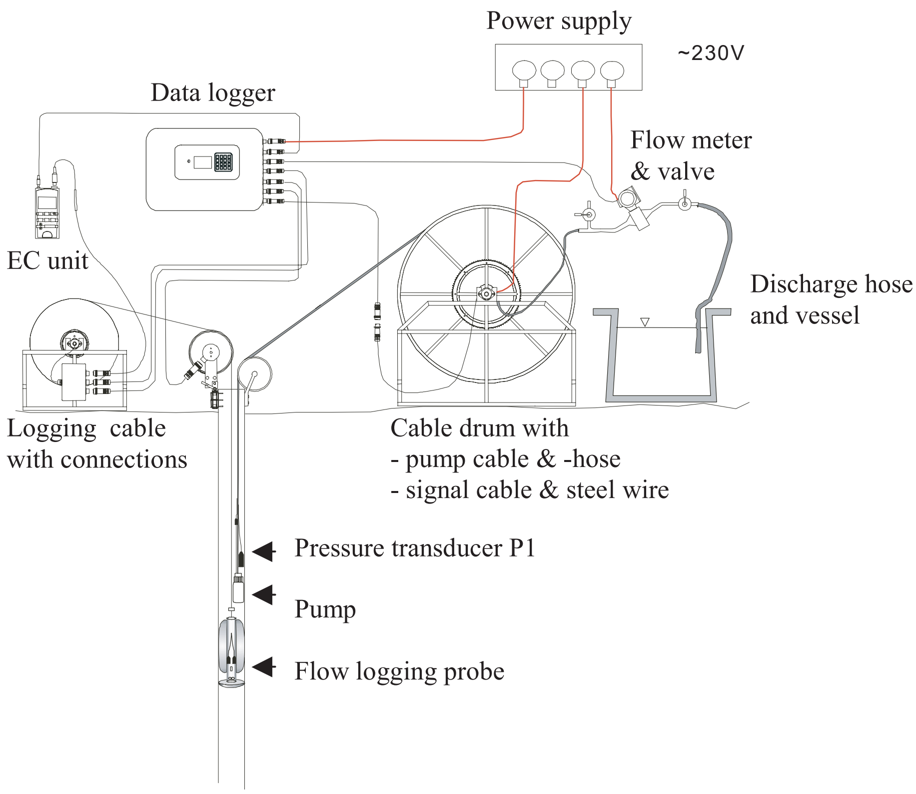


Figure 4-1. *Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB.*

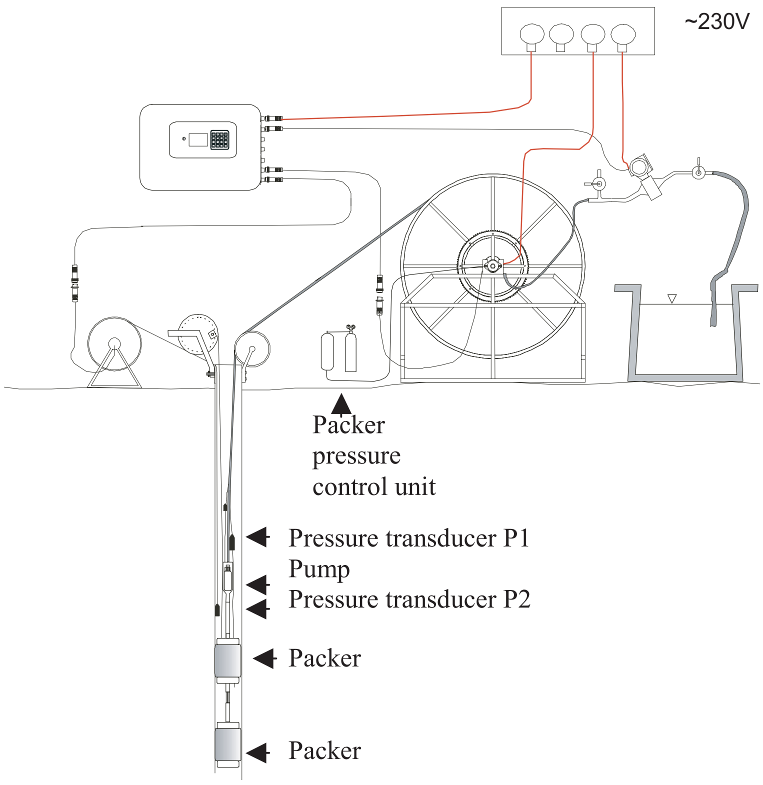


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB.*

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.

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, c.f. 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, c.f. Figure 4-3.

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

Technical specification Parameter		Unit	Sensor	HTHB system	Comments
Absolute pressure	Output signal	mA	4–20		
	Meas. range	kPa	0–1500	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

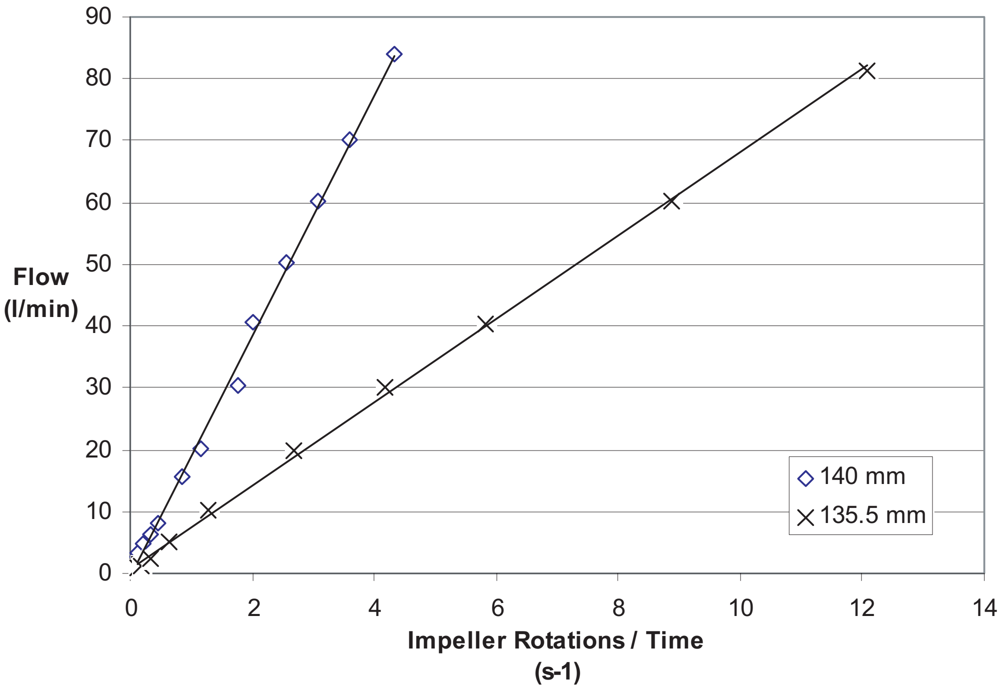


Figure 4-3. Total flow rate as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).

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 4-2 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)[3] for test
KFM01A	29.40–100.57	Open hole	1B	Pump-intake	19.5	Pump Pump hose	In Section In Section	37	$5.6 \cdot 10^{-6}$
				P (P1)	16.72	Signal cable	In Section	13.5	
HFM01	31.9–200.2	Open hole	1B	Pump-intake	29.5	Pump Pump hose	In Section In Section	37	$2.0 \cdot 10^{-6}$
			1B	P (P1)	26.72	Signal cable	In Sektion	13.5	
			6	EC-sec	34–198	Signal cable	In Section	13.5	
			6	Te-sec	34–198	Signal cable	In Section	13.5	
HFM01	31.9–71	Above a single packer	1B	Pump-intake	34.5	Pump Pump hose	In Section In Section	37	$2.0 \cdot 10^{-6}$
				P (P1)	31.72				
				P (P2)	69.66				
HFM01	71–200.2	Below a single packer	1B	Pump-intake	69.03	Pump Pump hose	Above Section Above Section	37	$9.1 \cdot 10^{-10}$
				P (P1)	65.68				
				P (P2)	65.68				
HFM02	26.1–100.1	Open hole	1B	Pump-intake	26.5	Pump Pump hose	In Section In Section	37	$2.0 \cdot 10^{-6}$
			1B	P (P1)	23.72	Signal cable	In Section	13.5	
			6	EC-sec	31–100	Signal cable	In Section	13.5	
			6	Te-sec	31–100	Signal cable	In Section	13.5	
HFM03	13.1–26.1	Open hole	1B	Pump-intake	9.5	Pump Pump hose	In Section In Section	37	$2.0 \cdot 10^{-6}$
			1B	P (P1)	6.72	Signal cable	In Section	13.5	
			6	EC-sec	13.15–26	Signal cable	In Section	13.5	
			6	Te-sec	13.15–26	Signal cable	In Section	13.5	

[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”

[3] Based on the casing diameter for the open-hole tests and the nominal borehole diameter (140 mm) together with the compressibility of water for the test in isolated section, respectively (net values)

5 Execution

The pumping tests and flow logging were performed according to Activity Plan AP PF 400-02-19 (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 HTHB are calibrated at GEOSIGMAs engineering workshop in Uppsala. Calibration is generally performed on a yearly basis, but more often if needed. If a sensor is replaced at the test site, calibration of the new sensor can be carried out in the field (except for the flow probe) or, alternatively, in the laboratory after the measurements.

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 (c.f. 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 with the total head of groundwater ($p/\rho g$). The temperature sensor showed expected values in both air and water.

The sensor for electric conductivity displayed 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 with 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. To meet this condition, the flow rate had to be slightly decreased in the early phase of a couple of tests to achieve steady-state conditions faster, e.g. in HFM01. In spite of this, the period with constant flow rate was quite dominant in all tests.

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 step length 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 some boreholes, the duration of the pumping period was changed for practical reasons. In borehole HFM01, short pumping tests (c. 0.5–1 h) were also carried out above and below a single-packer, respectively, c.f. Table 3-2. The latter tests constitute an option in the Activity Plan for a rough check of the hydraulic properties and water quality in these sections (Option 2 in Activity Plan). 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: HFM01, KFM01A, HFM02 and HFM03.

The test program performed in the boreholes was mainly according to the Activity Plan with a few exceptions (decided by the activity- and investigation leaders):

- the flow period of the test in KFM01A was prolonged to c. 21 h due to technical problems, see below
- no flow meter logging was performed in borehole KFM01A due to technical problems with the flow meter
- the flow period of the test in HFM03 was decreased to c. 5 h due to limitations of available time for testing

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

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.
- the recommended test time (3 h+3 h for flow/recovery) for tests in isolated borehole sections was decreased to c. 1 h+1 h in HFM01 due to practical reasons. These tests were performed partly to obtain a water sample and a rough estimation of the hydraulic properties of the sections and, furthermore, to confirm the results of the flow logging and as an equipment check. The test in the lower section (72–200 m) in HFM01 was further decreased to c. 0.5 h, since the flow in the section fell below the lower measurement limit of the HTHB-system, see below.

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.

In HFM01 as well as in HFM02, the flow logging started two hours after start of pumping and lasted c. 5.5 h and c. 3 h respectively, due to the shorter length of the latter borehole. In HFM03, which is only 26 m long, flow logging started about 1 hour after start of pumping and lasted c. 1.5 h.

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 select 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.

5.4 Analyses and interpretation

5.4.1 Single-hole pumping tests

As discussed in Section 5.2.1, the pumping tests were performed as constant flow rate tests, although some minor adjustments of the flow rate were made. Towards the end of the pumping tests, pseudo-radial flow occurred. Consequently, methods for single-hole, constant-flow rate tests in an equivalent porous medium were used by the standard evaluation of the tests.

Firstly, a qualitative evaluation of the actual flow regimes (pseudo-linear, pseudo-radial and pseudo-spherical flow) and possible outer boundary conditions during the tests was performed. The qualitative evaluation was made from analyses of log-log diagrams of draw-down and/or recovery data together with the corresponding pressure derivatives versus time.

From the results of the qualitative evaluation, appropriate interpretation models for the tests were selected. The quantitative interpretation of the hydraulic parameters (e.g. transmissivity and skin factor) was primarily based on the identified transient pseudo-radial flow regime during the tests in log-log and lin-log data diagrams. 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 drawdown- 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 according to Theis-Walton's and Cooper-Jacob's methods, c.f. standard textbooks. 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 /4/. The 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 wellbore 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 wellbore 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 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 in the borehole from the bottom of the hole up to a certain distance below the submersible pump. 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 estimated 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 estimated according to the methodology description for 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, estimations 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 according to the methodology description for flow logging:

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

where Q(L)=cumulative flow at borehole length L.

The lower limit of transmissivity (T_{min}) in flow logging may be estimated similar to 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). 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 DS1 at Forsmark (Figure 1-2) and submitted for analysis, see Table 6-1. The results of the water analyses are described in /3/.

Table 6-1. Data of water samples collected during the pumping tests in the boreholes at drillsite DS1 at Forsmark and submitted for analysis.

Bh ID	Date and time of sample	Pumped section (m)	Sample type	Sample ID no	Remarks
KFM01A(0–100 m)	2002-05-25 15:55	29.40–100.57	WC080	4165	Open-hole test
HFM01	2002-05-07 19:31	31.93–200.20	WC080	4112	Open-hole test
HFM01	2002-05-14 08:45	“	WC080	4113	”
HFM01	2002-05-14 11:58	“	WC080	4114	”
HFM01	2002-05-16 11:40	72–200.20	WC080	4115	Lower section
HFM01	2002-05-16 17:24	31.93–71	WC080	4116	Upper section
HFM02	2002-06-04 13:34	25.40–100.00	WC080	4169	Open-hole test
HFM02	2002-06-04 21:45	“	WC080	4170	”
HFM03	2002-05-29 12:35	13.10–26.00	WC 080	4166	Open-hole test
HFM03	2002-05-29 17:35	”	WC 080	4167	”

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.

Drilling records were checked to identify possible interference on test data from drilling in nearby boreholes. These records showed that drilling activities were not in progress during testing, except in one case, see below.

6.3.1 Borehole KFM01A: 29.40–100.57 m

General test data for the open-hole pumping test in the upper, percussion-drilled interval of borehole KFM01A are presented in Table 6-2. No flow logging was performed in this borehole due to technical problems with the measurement probe (cable breakage).

Table 6-2. General test data for the open-hole pumping test in the upper, percussion-drilled interval of borehole KFM01A.

General test data			
Borehole	KFM01A (29.40–100.57 m)		
Test type[1]	Constant Rate withdrawal and recovery test in		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	100.57
Casing length	L_c	m	29.40
Test section – Secup	Secup	m	29.40
Test section – Seclow	Seclow	m	100.57
Test section length	L_w	m	71.17
Test section diameter	$2 \cdot r_w$	mm	164
Test start (start of pressure registration)		yymmdd hh:mm	020524 12:08
Packer expanded		yymmdd hh:mm:ss	–
Start of flow period		yymmdd hh:mm:ss	020524 19:10:15
Stop of flow period		yymmdd hh:mm:ss	020525 15:57:00
Test stop (stop of pressure registration)		yymmdd hh:mm	020527 08:40
Total flow time	t_p	min	1247
Total recovery time	t_F	min	2440

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	Nomen-clature	Unit	Value
Absolute pressure in borehole before start of flow period	p_i	kPa	230.8
Absolute pressure in test section before stop of flow period	p_p	kPa	224.7
Absolute pressure in test section at stop of recovery period	p_F	kPa	235.406
Maximal pressure change during flow period	dp_p	kPa	6.1

Manual groundwater level measurements Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	GW level (m bToC)	(m a s l)
2002-05-23	12:15:00		3.52	–0.37
2002-05-24	07:48:00		3.05	0.10
2002-05-24	10:04:00		3.02	0.13
2002-05-24	12:20:00		3.05	0.10
2002-05-24	15:10:00		3.16	–0.01
2002-05-24	18:38:00		3.06	0.09

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.22 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$1.22 \cdot 10^{-3}$
Total volume discharged during flow period	V_p	m^3	91.5

Manual measurements or readings Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	Flow rate (L/min)
2002-05-24	12:23:00		73.1

Comments on the test

Several short, unsuccessful attempts to commence pumping were made before the actual test, due to problems with the flow-meter probe. This entailed that the test started from a withdrawn water level in the borehole. 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.

Interpreted flow regimes

Selected test diagrams according to the instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-1–5 in Appendix 2. The initial phase of both the flow- and recovery period indicated linear flow, manifested by a slope of approximately 1:2 in the log-log diagrams of pressure versus time. This type of response indicates flow through a high-conductive fracture towards the borehole. After a transition period, a rather well defined pseudo-radial flow regime developed between c. 200–800 min of the flow period. By the end of the test, effects of pseudo-spherical (leaky) flow occurred.

During the recovery period, the pseudo-radial flow regime was not developed. Instead, the initial linear flow period with a slope of approximately 1:2 continued. Furthermore, by the end of the recovery period, there were also indications of outer (no-flow) boundary effects. This type of response indicates flow through a high-conductive fracture with limited extension. Thus, the responses during the flow – and recovery period were not quite consistent. The reason to this discrepancy is not clear. No drilling was in progress during the test according to the drilling log.

Interpreted parameters

Quantitative analysis was in this case only made from the flow period in lin-log and log-log diagrams according to the methods described in Section 5.4.1. The transient, quantitative interpretation of the flow period of the test is shown in Figures A2-2–3 in Appendix 2. No quantitative analysis was made from the pressure recovery period in this case. The results are presented in Tables 6-15 and 6-16 and in the Test Summary Sheets below.

6.3.2 Borehole HFM01: 31.93–200.20 m

General test data for the open-hole pumping test in borehole HFM01 in conjunction with flow logging are presented in Table 6-3.

Table 6-3. General test data for the open-hole pumping test in HFM01 in conjunction with flow logging.

General test data			
Borehole	HFM01 (31.93–200.20 m)		
Testtype[1]	Constant Rate withdrawal and recovery test in		
Test section (open borehole/packed-off section):	open borehole, uncased interval		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	200.20
Casing length	L_c	m	31.93
Test section – Secup	Secup	m	31.93
Test section – Seclow	Seclow	m	200.20
Test section length	L_w	m	168.27
Test section diameter	$2 \cdot r_w$	mm	140
Test start (start of pressure registration)		yymmdd hh:mm	020514 08:11
Packer expanded		yymmdd hh:mm:ss	–
Start of flow period		yymmdd hh:mm:ss	020514 08:13:29
Stop of flow period		yymmdd hh:mm:ss	020514 18:28:10
Test stop (stop of pressure registration)		yymmdd hh:mm	020515 08:52
Total flow time	t_p	min	615
Total recovery time	t_F	min	744

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	Nomen-clature	Unit	Value
Absolute pressure in borehole before start of flow period	p_i	kPa	341.646
Absolute pressure in test section before stop of flow period	p_p	kPa	160.364
Absolute pressure in test section at stop of recovery period	p_F	kPa	340.893
Maximal pressure change during flow period	dp_p	kPa	180.529

Manual groundwater level measurements Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	GW level (m bToC)	(m a s l)
2002-05-13	13:07:20		1.06	0.70
2002-05-13	10:11:00		1.11	0.65
2002-05-13	13:07:20		1.06	0.70
2002-05-14	08:06:00	–	1.33	0.43
2002-05-14	09:12:00	59	18.63	–16.46
2002-05-14	18:23:00	610	20.36	–18.15
2002-05-15	08:50:30		1.51	0.26

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$1.00 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$9.89 \cdot 10^{-4}$
Total volume discharged during flow period	V_p	m^3	36.48

Manual measurements or readings Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	Flow rate (L/min)
2002-05-14	10:18:00		59.96

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. In the initial pumping phase, two adjustments (decreases) of the flow rate had to be made to speed up the time to steady-state conditions.

Some intermittent drilling activities (reaming and flushing of borehole KFM01A) were in progress during the flow period which may occasionally have disturbed the test data during this period.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-6–10 in Appendix 2.

Although the initial phase of the flow period was disturbed by the adjustments of the flow rate, a clear wellbore storage (WBS) dominated response prevailed during this phase. This fact indicates a lower transmissivity of HFM01 compared to the other boreholes tested in this campaign. After c. 20 min of pumping, a rather well defined pseudo-radial flow regime lasted to c. 120 min. After this time, the draw-down curve was slightly unstable which might indicate external disturbances from the drilling activities in KFM01A.

The initial response during the recovery phase confirms the early WBS-dominated flow regime from the flow period. However, a faster recovery occurred, approaching a pseudo-spherical flow regime (almost constant pressure) after c. 20 min of equivalent time.

Interpreted parameters

Quantitative analysis was only made from the flow period in lin-log and log-log diagrams according to the methods described in Section 5.4.1. The transient, quantitative interpretation of the flow period of the test is shown in Figures A2-7–8 in Appendix 2. No quantitative analysis was in this case made from the pressure recovery period.

The results are shown in Tables 6-15 and 6-16 and in the Test Summary Sheets below.

6.3.3 Borehole HFM01: 31.93–71 m

General test data for the short pumping test in the interval 31.93–71 m above a single packer in borehole HFM01 are presented in Table 6-4.

Comments on the test

The test was carried out as a pumping test with constant flow rate. Problems arose by the regulation of the flow rate. The pump was started at a slightly lower capacity than normally due to problems by overloading of the pump. The flow rate was then increased in two steps during the first c. 2 minutes. During the remaining part of test, the flow rate was slightly decreasing.

Table 6-4. General test data for the short pumping test in the interval 31.93–71 m in borehole HFM01.

General test data			
Borehole	HFM01		
Testtype[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	above a single-packer located at 71–72 m		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	200.20 (Total length)
Casing length	L_c	m	31.93
Test section – Secup	Secup	m	31.93
Test section – Seclow	Seclow	m	71
Test section length	L_w	m	39.07
Test section diameter	$2 \cdot r_w$	mm	140
Test start (start of pressure registration)		yymmdd hh:mm	020516 15:46
Packer expanded		yymmdd hh:mm:ss	020516 16:00:30
Start of flow period		yymmdd hh:mm:ss	020516 16:24:32
Stop of flow period		yymmdd hh:mm:ss	020516 17:31:00
Test stop (stop of pressure registration)		yymmdd hh:mm	020516 18:01
Total flow time	t_p	min	66.5
Total recovery time	t_F	min	30

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	Nomen-clature	Unit	Value
Absolute pressure in test section before start of flow period	p_i	kPa	388.892
Absolute pressure in section below the packer before start of flow period	p_{bi}	kPa	775.586
Absolute pressure in test section at stop of flow period	p_p	kPa	229.625
Absolute pressure in section below the packer at stop of flow period	p_{bp}	kPa	774.027
Absolute pressure in test section at stop of recovery period	p_F	kPa	387.744
Absolute pressure in section below the packer at stop of recovery period	p_{bF}	kPa	774.92
Maximal pressure change in test section during the flow period	dp_p	kPa	159.267
Maximal pressure change in section below the packer during the flow period	dp_{bp}	kPa	1.559

Manual groundwater level measurements Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	GW level (m b. ToC)	(m a s l)
2002-05-16	09:11:00		1.36	0.40
2002-05-16	15:46:00		1.33	0.43
2002-05-16	16:06:00		1.39	0.37

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$1.09 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$1.10 \cdot 10^{-3}$
Total volume discharged during flow period	V_p	m^3	4.40

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-11–15 in Appendix 2. The initial flow regime of the test was dominated by wellbore storage, similar to the previous test when the entire borehole was pumped. Both the flow- and recovery periods of the test were too short for a well-defined pseudo-radial flow regime to develop. Hence, only rough estimations of the hydraulic parameters could be made from the test by type curve matching of the flow period in the log-log diagrams. A very small pressure change occurred in the interval below the packer during the flow period, indicating good sealing by the packer and negligible hydraulic connection between the sections.

As in the previous test, a fast recovery occurred, approaching a pseudo-spherical flow regime.

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. Approximate, quantitative analyses were made from the flow period in the log-log diagram 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 Tables 6-15 and 6-16 and in the Test Summary Sheets below.

6.3.4 Borehole HFM01: 72–200.20 m

General test data for the short pumping test in the interval 72–200.20 m below a single packer in borehole HFM01 are presented in Table 6-5.

Table 6-5. General test data for the short pumping test in the interval 72–200.20 m in borehole HFM01.

General test data			
Borehole	HFM01		
Testtype[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	below a single-packer located at 71–72 m		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	200.20 (Total length)
Casing length	L_c	m	31.93
Test section – Secup	Secup	m	72
Test section – Seclow	Seclow	m	200.20
Test section length	L_w	m	128.20
Test section diameter	$2 \cdot r_w$	mm	140
Test start (start of pressure registration)		yymmdd hh:mm	020516 09:46
Packer expanded		yymmdd hh:mm:ss	020516 09:17:30
Start of flow period		yymmdd hh:mm:ss	020516 09:46:45
Stop of flow period		yymmdd hh:mm:ss	020516 10:17:41
Test stop (stop of pressure registration)		yymmdd hh:mm	020516 11:12
Total flow time	t_p	min	31
Total recovery time	t_F	min	54

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	Nomen-clature	Unit	Value
Absolute pressure in test section before start of flow period	p_i	kPa	725.236
Absolute pressure in section above the packer before start of flow period	P_{ai}	kPa	723.094
Absolute pressure in test section at stop of flow period	p_p	kPa	314.234
Absolute pressure in section above the packer at stop of flow period	P_{ap}	kPa	723.577
Absolute pressure in test section at stop of recovery period	p_F	kPa	690.512
Absolute pressure in section above the packer at stop of recovery period	P_{aF}	kPa	723.58
Maximal pressure change in test section during the flow period	dp_p	kPa	411.002
Maximal pressure change in section above the packer during the flow period	dp_{ap}	kPa	–0.483

Manual groundwater level measurements Date YYYY-MM-DD	Time tt:mm:ss	Time	GW level (m b ToC)	(m a s l)
2002-05-16	09:11:00		1.36	0.40
2002-05-16	09:33:25		1.32	0.44
2002-05-16	09:57:30	11	1.36	0.40

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$<8.33 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	–
Total volume discharged during flow period	V_p	m^3	<0.154

Manual measurements or readings Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	Flow rate (L/min)
2002-05-16	10:00:00	13	0.4*

* manual registration

Comments on the test

Due to the low-conductive test section, the duration of the test was shorter than the previous tests performed. No automatic registration of flow rate was possible, since the flow rate fell below the measurement limit. The flow rate was estimated manually by a stopwatch and vessel.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-16–20 in Appendix 2. No interpretation of flow regimes could be done from the flow period due to the low-conductive test section. The pressure recovery period was dominated by (confined) wellbore storage effects. No pseudo-radial flow period was developed. Hence, only rough estimations of the hydraulic parameters could be made from the test. A very small pressure change occurred in the interval above the packer, indicating good sealing by the packer and negligible hydraulic connection between the sections.

Interpreted parameters

No transient evaluation could be made in this case due to the low-conductive test section. Only estimations of the wellbore storage coefficient together with the specific capacity and steady-state transmissivity could be made.

The results are shown in Tables 6-15 and 6-16 and in the Test Summary Sheets below.

6.3.5 Borehole HFM02: 25.40–100.00 m

General test data for the open-hole pumping test in borehole HFM02 in conjunction with flow logging are presented in Table 6-6.

Table 6-6. General test data for the open-hole pumping test in HFM02 in conjunction with flow logging.

General test data			
Borehole	HFM02		
Testtype[1]	Constant Rate withdrawal and recovery test in		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	100.00
Casing length	L_c	m	25.40
Test section – Secup	Secup	m	25.40
Test section – Seclow	Seclow	m	100.00
Test section length	L_w	m	74.6
Test section diameter	$2 \cdot r_w$	mm	137
Test start (start of pressure registration)		yymmdd hh:mm	020604 12:08
Packer expanded		yymmdd hh:mm:ss	–
Start of flow period		yymmdd hh:mm:ss	020604 12:27:49
Stop of flow period		yymmdd hh:mm:ss	020604 22:18:05
Test stop (stop of pressure registration)		yymmdd hh:mm	020605 09:51
Total flow time	t_p	min	590
Total recovery time	t_F	min	693

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	Nomen-clature	Unit	Value
Absolute pressure in borehole before start of flow period	P_i	kPa	302.6
Absolute pressure in test section before stop of flow period	p_p	kPa	296.4
Absolute pressure in test section at stop of recovery period	p_F	kPa	302.97
Maximal pressure change during flow period	dp_p	kPa	6.2

Manual groundwater level measurements Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	GW level (m b. ToC)	(m a s l)
2002-06-03	09:53:00		2.86	0.19
2002-06-04	09:01:00		2.97	0.08
2002-06-04	11:57:30		2.92	0.13
2002-06-04	14:17:30	110	3.28	–0.23
2002-06-04	16:28:30	241	3.41	–0.36
2002-06-05	09:49:30		2.90	0.15

Flow data

Flow data	Nomenclature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.16 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$1.16 \cdot 10^{-3}$
Total volume discharged during flow period	V_p	m^3	41

Comments on the test

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

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-21–25 in Appendix 2.

The initial phase of both the flow- and recovery period displayed linear (fracture) flow, manifested by a linear response with a slope of approximately 1:2 in the log-log diagrams of pressure versus time. The response was similar to that in KFM01A described above. Between c. 100–600 min of pumping, a rather well-defined pseudo-radial flow regime developed.

During the recovery period, the pseudo-radial flow regime was not developed. Instead, the initial linear flow period with a slope of 1:2 continued with an increasing slope towards the end of the period. This fact indicates the presence of outer (no-flow) boundaries affecting the test or flow through a high-conductive fracture with limited extension.

Thus, the responses during the flow – and recovery period were not consistent. This behaviour is very similar to the responses in KFM01A during the flow- and recovery phase, respectively. The reason to this discrepancy is not clear. No drilling was in progress during the test according to the drilling log.

Interpreted parameters

Quantitative analysis was only made from the flow period in lin-log and log-log diagrams according to the methods described in Section 5.4.1.The transient, quantitative interpretation of the flow period of the test is shown in Figures A2-22–23 in Appendix 2. No quantitative analysis was made from the pressure recovery period.

The results are shown in Tables 6-15 and 6-16 and in the Test Summary Sheets below.

6.3.6 Borehole HFM03: 13.10–26.00 m

General test data for the open-hole pumping test in borehole HFM03 in conjunction with flow logging are presented in Table 6-7.

Table 6-7. General test data for the open-hole pumping test in HFM03 in conjunction with flow logging.

General test data			
Borehole	HFM03		
Testtype[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comment	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	26.00 (total length)
Casing length	L_c	m	13.10
Test section – Secup	Secup	m	13.10
Test section – Seclow	Seclow	m	26.00
Test section length	L_w	m	12.9
Test section diameter	$2 \cdot r_w$	mm	136
Test start (start of pressure registration)		yymmdd hh:mm	020605 11:48
Packer expanded		yymmdd hh:mm:ss	–
Start of flow period		yymmdd hh:mm:ss	020605 12:03:05
Stop of flow period		yymmdd hh:mm:ss	020605 17:00:01
Test stop (stop of pressure registration)		yymmdd hh:mm	020606 08:40
Total flow time	t_p	min	297
Total recovery time	t_F	min	940

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery

Pressure and groundwater level data

Pressure data	Nomen-clature	Unit	Value
Absolute pressure in borehole before start of flow period	p_i	kPa	136.6
Absolute pressure in test section before stop of flow period	p_p	kPa	125.3
Absolute pressure in test section at stop of recovery period	p_F	kPa	137.7
Maximal pressure change during flow period	dp_p	kPa	11.3

Manual groundwater level measurements Date YYYY-MM-DD	Time tt:mm:ss	Time (min)	GW level (m b. ToC)	(m a s l)
2002-06-05	10:43:00		2.93	0.22
2002-06-05	11:55:00		2.91	0.24
2002-06-05	14:42:30	159	4.01	–0.86

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$8.75 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$8.75 \cdot 10^{-4}$
Total volume discharged during flow period	V_p	m^3	15.6

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.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2-26–30 in Appendix 2.

The initial phase of both the flow- and recovery period showed linear (fracture) flow, manifested by a linear response with a slope of approximately 1:2 in the log-log diagrams of pressure versus time, c.f. the drawdown responses in KFM01A and HFM02. A pseudo-radial flow regime developed between c. 80–300 min of the flow period.

During the recovery period, an initial linear flow period with a slope of approximately 1:2 was developed. After a transition period, a pseudo-spherical flow regime developed between c. 30–100 min of equivalent time. By the end of the recovery period, apparent outer (no-flow) boundary effects were indicated. No drilling activities in neighbouring boreholes were on-going according to the drilling log.

Interpreted parameters

Quantitative analysis was made in lin-log- and log-log diagrams from both the flow- and recovery period according to the methods described in Section 5.4.1. The transient, quantitative interpretation of the flow- and recovery period of the tests is indicated Figures A2-27–30 in Appendix 2.

The results are shown in Tables 6-15 and 6-16 and in the Test Summary Sheets below.

6.4 Flow logging

6.4.1 Borehole HFM01

General test data for the flow logging in borehole HFM01are presented in Table 6-8.

Table 6-8. General test data for the flow logging in borehole HFM01.

General test data			
Borehole	HFM01		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length		m	200.20
Pump position (lower level)		m	30
Flow logged section – Secup		m	34
Flow logged section – Seclow		m	198
Test section diameter	2·rw	mm	140
Start of flow period		yymmdd hh:mm	020514 08:13
Start of flow logging		yymmdd hh:mm	020514 10:19
Stop of flow logging		yymmdd hh:mm	020514 15:50
Stop of flow period		yymmdd hh:mm	020514 18:28

[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)
Groundwater level in borehole, at undisturbed conditions, open hole	h_i	m	1.06	0.70
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m	18.76	–16.59
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m	17.7	–15.55

Flow data	Nomen-clature	Unit	Flow rate
Pumping rate at surface	Q_p	m^3/s	$1.00 \cdot 10^{-3}$
Cumulative flow rate at Secup at pumping rate Q_p	Q_T	m^3/s	$1.00 \cdot 10^{-3}$
Minimal change of borehole flow rate to detect flow anomaly	ΔQ_{Anom}	m^3/s	$1.7 \cdot 10^{-5}$
Measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$3.33 \cdot 10^{-5}$

Comments on the test

The flow logging commenced from the bottom of the hole, going upwards. The first detectable flow anomaly was found at 64 m. The step length between flow measurements was maximally 10 m in the borehole interval 65–198 m and maximally 2 m in the interval 34–65 m. The flow logging was finished off at 198 m to avoid the probe to be contaminated with possible drilling debris at the bottom of the borehole.

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 6-1. The EC-curve shown in Figure 6-1 is only relative, due to possible electronic interference from the flow-logging probe on the EC-sensor.

The results of the flow logging in borehole HFM01 are presented in Table 6-9 below. The measured inflows at the identified flow anomalies (ΔQ_i) together with their estimated percentages of the total flow are shown. In borehole HFM01 the cumulative flow rate at the top of the flow logged interval ($\Sigma\Delta Q_i$) was identical with the total flow rate (Q_p) pumped from the borehole.

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 ($\Delta Q_i/s_{FL}$). The transmissivity of the entire borehole was calculated from the transient interpretation of the pumping test during flow logging.

The dominating inflow occurs within the interval 34.5–43 m. The EC-measurements indicate that this flow anomaly may be divided into two conductive intervals by a more low-conductive layer between 39–42 m. This fact is however not supported by the flow measurements, and thus the interval 34.5–43 m is a more safe interpretation of this anomaly.

Figure 6-2 illustrates the estimated, cumulative transmissivity along the borehole from the flow logging. Since the positions of the flow anomalies in the borehole are impaired by a degree of uncertainty, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated lower measurement limit of T and the total T of the borehole are also shown in the figure, c.f. Section 5.4.2.

Table 6-9. Results of the flow logging in borehole HFM01. Q_T=cumulative flow at the top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}= drawdown during flow logging.

HFM01 Flow anomalies		Q_T=1.00 · 10^{-3} (m^3/s)	Q_p=1.00 · 10^{-3} (m^3/s)	T=6.31 · 10^{-5} (m^2/s)	s_{FL}=17.7 m	
Interval (m b ToC)	**B.h. length (m)**	**ΔQ_i (m^3/s)**	**$\Delta Q_i/Q_p$ (%)**	**T_i (m^2/s)**	**$\Delta Q_i/s_{FL}$ (m^2/s)**	**Supporting information**
34.5–43	8.5	7.07 · 10^{-4}	71	4.5 · 10^{-5}	4.0 · 10^{-5}	EC
48–50	2	8.33 · 10^{-5}	8	5.0 · 10^{-6}	4.7 · 10^{-6}	EC
60.5–63.5	3	4.33 · 10^{-5}	4	2.5 · 10^{-6}	2.4 · 10^{-6}	EC
64–64.5	0.5	1.67 · 10^{-4}	17	1.1 · 10^{-5}	9.4 · 10^{-6}	EC
Total		$\Sigma\Delta Q_i$= 1.00 · 10^{-3}	Σ100	ΣT_i= 6.3 · 10^{-5}	Σ5.7 · 10^{-5}	
Difference		Q_p–Q_T=0		–	–	

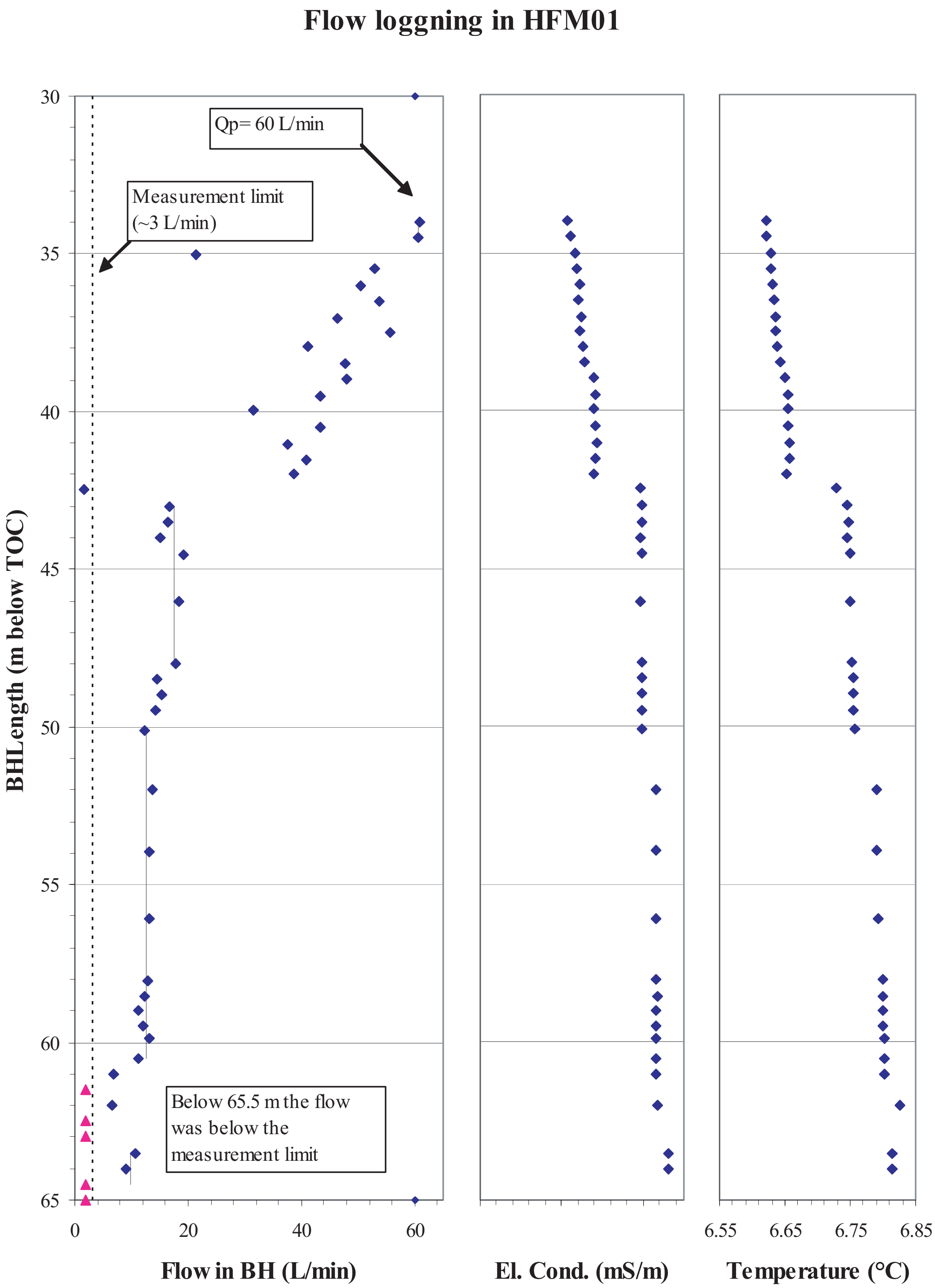


Figure 6-1. *Measured flow rate distribution along the hole during the flow logging together with the relative electric conductivity (EC) and temperature (Te) of the borehole fluid in borehole HFM01.*

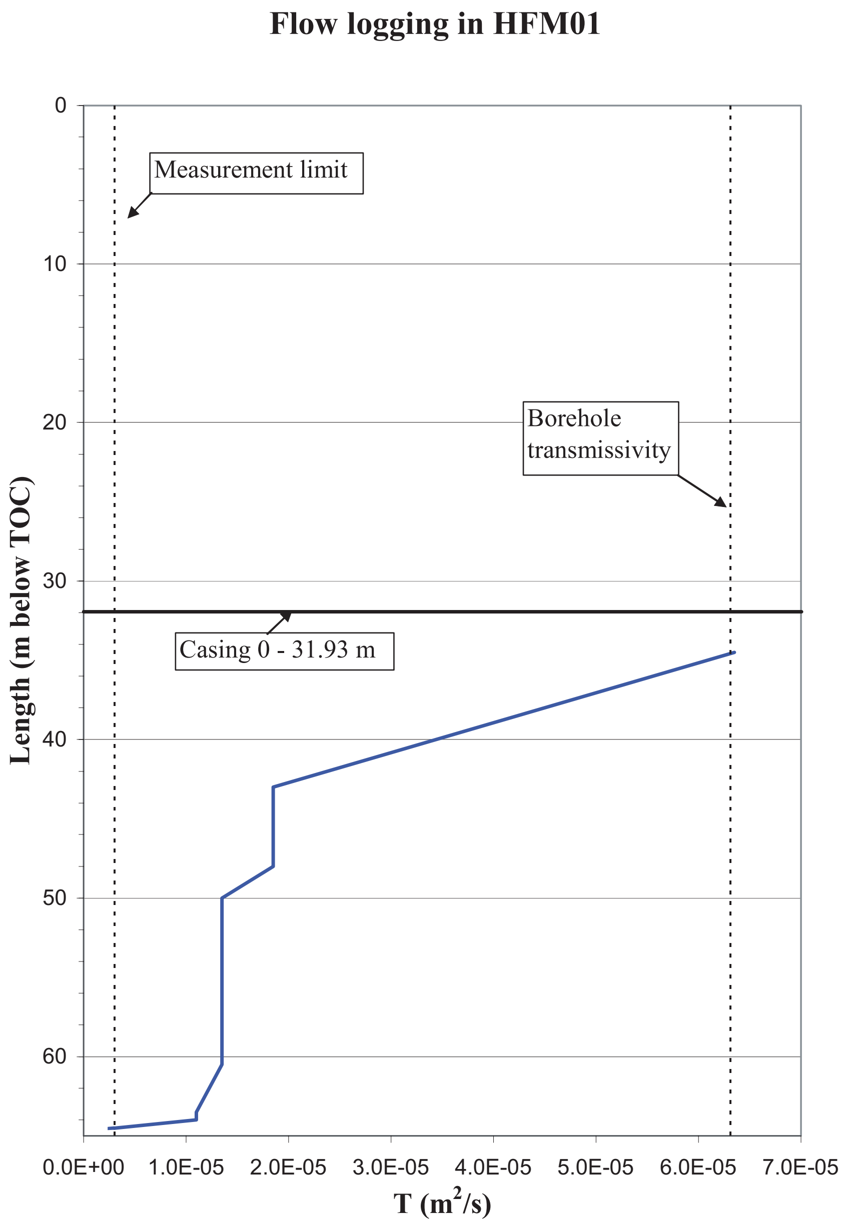


Figure 6-2. *Estimated, cumulative transmissivity along the borehole from the flow logging. Below c. 65 m the transmissivity falls below the measurement limit.*

6.4.2 Borehole HFM02

General test data for the flow logging in borehole HFM02 are presented in Table 6-10.

Table 6-10. General test data for the flow logging in borehole HFM02.

General test data			
Borehole	HFM02		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length		m	100.00
Pump position (lower level)		m	27
Flow logged section – Secup		m	31
Flow logged section – Seclow		m	100
Test section diameter	2·rw	mm	137
Start of flow period		yymmdd hh:mm	020604 12:28
Start of flow logging		yymmdd hh:mm	020604 14:34
Stop of flow logging		yymmdd hh:mm	020604 17:20
Stop of flow period		yymmdd hh:mm	020604 22:18

[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)
Groundwater level in borehole, at undisturbed conditions, open hole	h_i	m	2.92	0.15
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m	3.37	0.13
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m	0.45	–0.32

Flow data

Flow data	Nomen-clature	Unit	Flow rate
Pumping rate at surface	Q_p	m^3/s	$1.16 \cdot 10^{-3}$
Cumulative flow rate at Secup at pumping rate Q_p	Q_T	m^3/s	$1.9 \cdot 10^{-3}$ *
Minimal change of borehole flow rate to detect flow anomaly	ΔQ_{Anom}	m^3/s	$1.7 \cdot 10^{-5}$
Measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$3.33 \cdot 10^{-5}$

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

Comments on the test

The flow logging was made from the bottom of the hole, going upwards. The first detectable flow anomaly was encountered at 44.5 m (lower limit). The standard step length between flow measurements in the borehole interval 100–45 m was 5 m and 2 m in the interval 45–31 m, respectively. At each flow anomaly a step length of 0.5 m was applied.

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 possible electronic interference from the flow-logging probe on the EC-sensor.

The results of the flow logging in borehole HFM02 are presented in Table 6-11 below. Only one major flow anomaly was identified in the borehole. The measured inflow at this flow anomaly (ΔQ_i) together with the corrected inflow (ΔQ_{icorr}) due to deviation from the actual borehole diameter from the assumed diameter 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 6-11 illustrates that the cumulative flow rate at the top of the flow logged interval is higher than the pumped flow rate from the borehole, c.f. Difference. This is due to the actual borehole diameter (137 mm), which is smaller than the assumed diameter by the calibration of the flow probe (140 mm). Below, it is assumed that all flow towards the borehole occurs within the flow logged interval and that the flow difference is only due to the deviation of the borehole diameter. From the table it is clear, that the dominating inflow occurs at 42–44.5 m.

Figure 6-4 shows the estimated, cumulative transmissivity along the borehole from the flow logging. Since the positions of the flow anomalies in the borehole suffer from a degree of uncertainty, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated lower measurement limit of T and the total T of the borehole are also illustrated in the figure, c.f. Section 5.4.2.

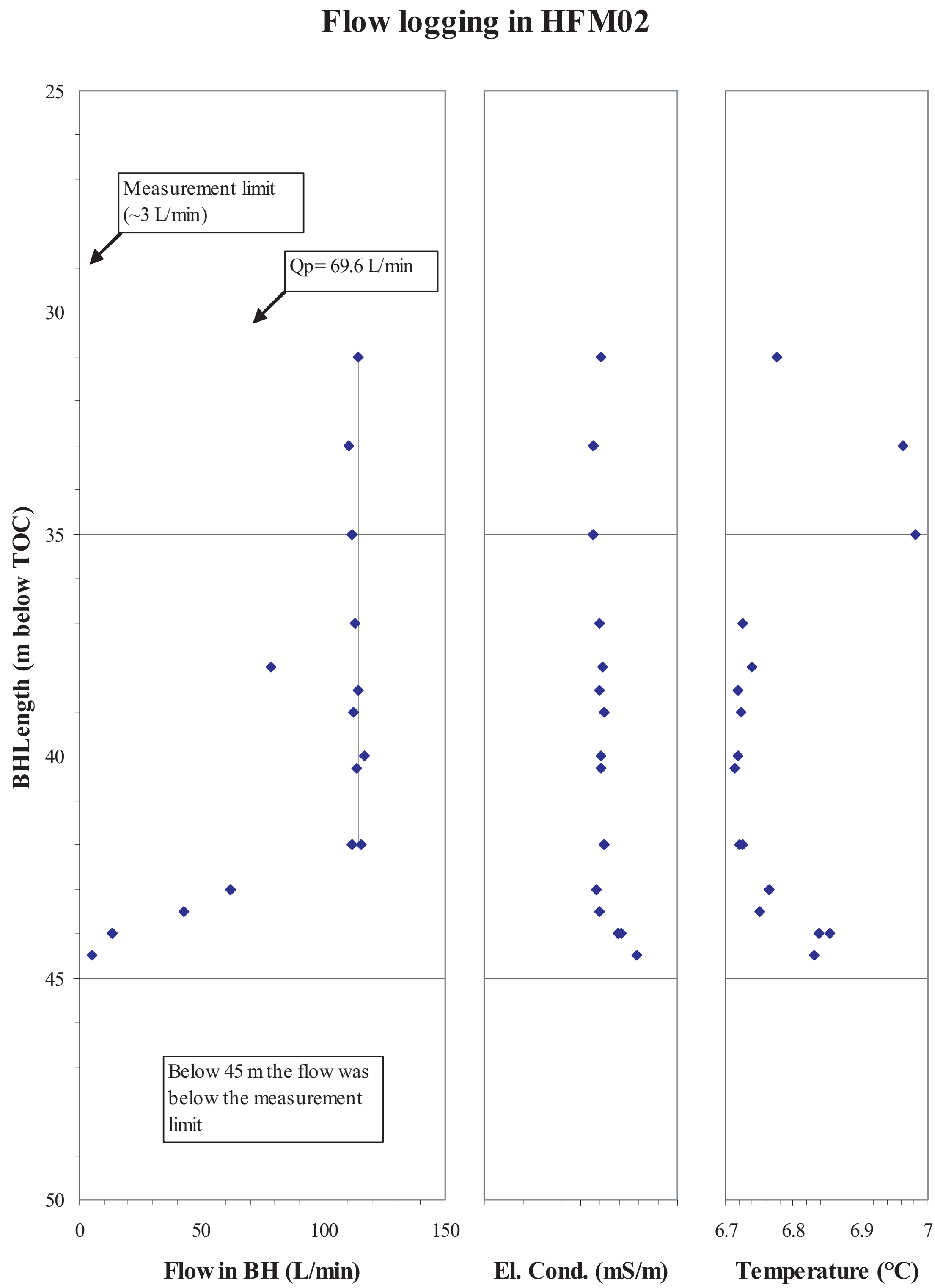


Figure 6-3. *Measured flow distribution along the hole during the flow logging, together with the relative electric conductivity (EC) and temperature (Te) of the borehole fluid in borehole HFM02.*

Table 6-11. Results of the flow logging in borehole HFM02. Q_T=cumulative flow rate at the top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}= drawdown during flow logging.

HFM02 Flow anomalies		Q_T=1.9 · 10^{-3} (m^3/s)	Q_p=1.16 · 10^{-3} (m^3/s)	T=5.9 · 10^{-4} (m^2/s)	s_{FL}=0.45 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)**	**Support inform.**
42–44.5	2.5	1.9 · 10^{-3} *	1.16 · 10^{-3} **	5.9 · 10^{-4} **	2.6 · 10^{-3} **	Te
Total		**$\Sigma\Delta Q_i$= 1.9 · 10^{-3} ***	**Σ=1.16 · 10^{-3} ****	**ΣT_i= 5.9 · 10^{-4} ****	**Σ2.6 · 10^{-3} ****	
Difference		Q_T–Q_p= 0.74 · 10^{-3}	–	–	–	

* Overestimated due to decreased borehole diameter (137 mm)

** Based on the assumption that Q_p=Q_T (all measured flow assumed to be within the flow logged interval)

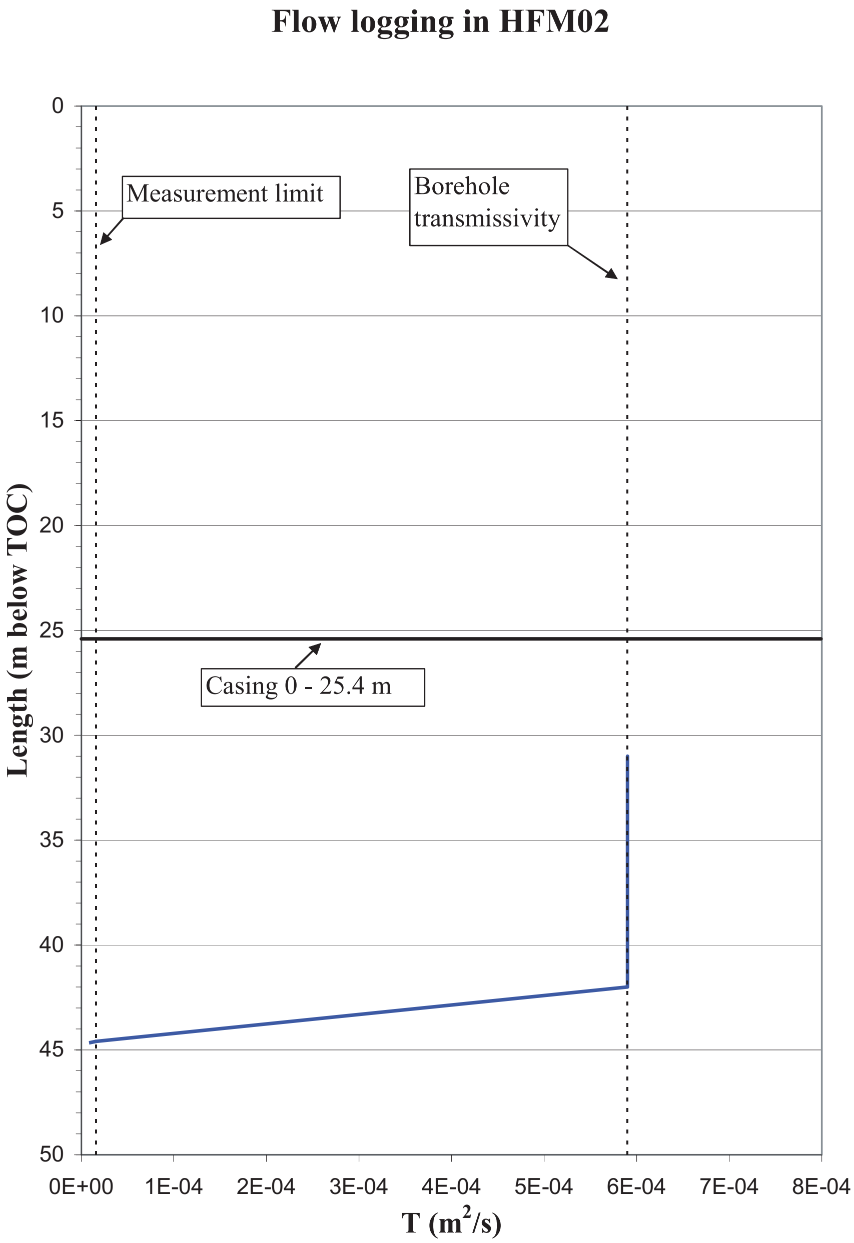


Figure 6-4. Estimated, cumulative transmissivity along the borehole from the flow logging. Below c. 45 m the transmissivity falls below the measurement limit.

6.4.3 Borehole HFM03

General test data for the flow logging in borehole HFM03 are presented in Table 6-12.

Table 6-12. General test data for the flow logging in borehole HFM03.

General test data			
Borehole	HFM03		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length		m	26.00
Pump position (lower level)		m	10
Flow logged section – Secup		m	13.15
Flow logged section – Seclow		m	26
Test section diameter	2·rw	mm	136
Start of flow period		yymmdd hh:mm	020605 12:03
Start of flow logging		yymmdd hh:mm	020605 13:13
Stop of flow logging		yymmdd hh:mm	020605 14:37
Stop of flow period		yymmdd hh:mm	020605 17:00

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)
Groundwater level in borehole, at undisturbed conditions, open hole	h_i	m	2.91	0.24
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m	3.92	–0.77
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m	1.01	2.14

Flow data

Flow data	Nomen-clature	Unit	Flow rate
Pumping rate at surface	Q_p	m^3/s	$8.75 \cdot 10^{-4}$
Cumulative flow rate at Secup at pumping rate Q_p	Q_T	m^3/s	$1.75 \cdot 10^{-3}$ *
Minimal change of borehole flow rate to detect flow anomaly	ΔQ_{Anom}	m^3/s	$1.7 \cdot 10^{-5}$
Measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$3.33 \cdot 10^{-5}$

* Incorrect value due to deviation of the actual borehole diameter (136 mm) from the assumed diameter (140 mm)

Comments on the test

The flow logging was performed from the bottom of the hole, going upwards. The first detectable flow anomaly was discovered at 22 m (lower limit). The standard step length between flow measurements was 1 m. At each flow anomaly a step length 0.5 m was applied.

Logging results

The nomenclature used for the flow logging is according to the methodology description for flow logging, c.f. Chapter 5. 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 results of the flow logging in borehole HFM03 are presented in Table 6-13 below. One major and one minor flow anomaly were identified in the borehole. The dominating inflow occurs at 21–21.5 m. The measured inflow at the identified flow anomalies (ΔQ_i), together with the corrected inflow (ΔQ_{icorr}) due to deviation from the actual borehole diameter from the assumed diameter 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 (T) was calculated from the transient interpretation of the pumping test during flow logging.

Table 6-13 illustrates that the cumulative flow at the top of the flow logged interval is higher than the pumped flow rate from the borehole, c.f. Difference. This is due to the actual borehole diameter being smaller than the assumed diameter by the flow logging (140 mm). Below, it is assumed that all flow towards the borehole occurs within the flow logged interval, and that the flow difference is only due to the deviation of the borehole diameter.

Figure 6-6 shows the estimated, cumulative transmissivity along the borehole from the flow logging. Since the positions of the flow anomalies in the borehole are impaired by a degree of uncertainty, the change in transmissivity at the anomalies is represented by sa sloping line across the anomaly. The estimated lower measurement limit of T and the total T of the borehole are also shown in the figure, c.f. Section 5.4.2.

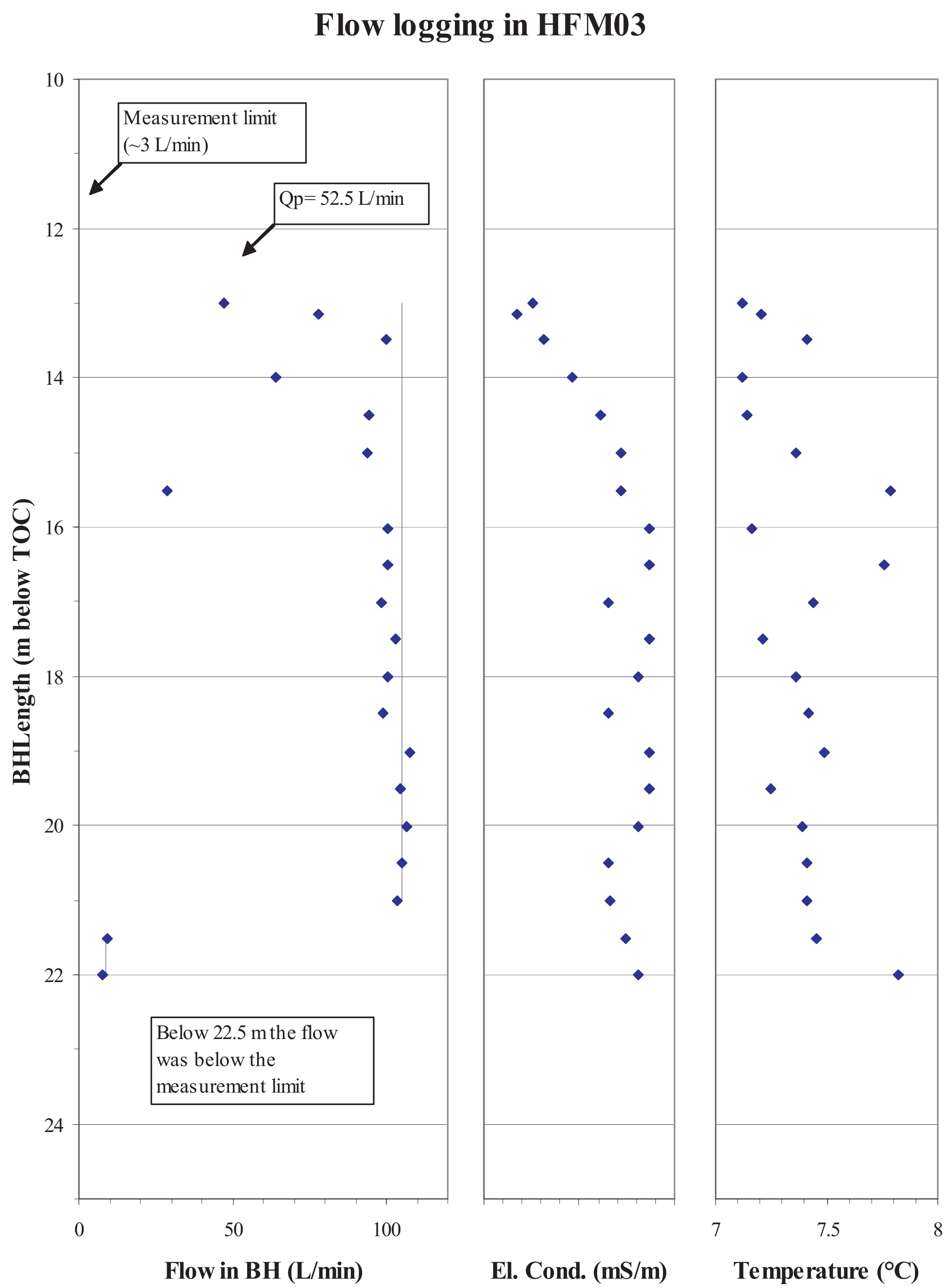


Figure 6-5. Measured flow distribution along the hole during the flow logging together. with the relative electric conductivity (EC) and temperature (Te) of the borehole fluid in borehole HFM03.

Table 6-13. Results of the flow logging in borehole HFM03. Q_T=cumulative flow rate at the top of the logged interval, Q_p=pumped flow rate from borehole, s_{FL}=total drawdown.

HFM03 Flow anomalies		Q_T=1.75 · 10^{-3} (m^3/s)	Q_p=8.75 · 10^{-4} (m^3/s)	T=4.2 · 10^{-4} (m^2/s)	s_{FL}=1.01 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)**	**Support info**
21–21.5	0.5	1.61 · 10^{-3} *	8.05 · 10^{-4} **	3.86 · 10^{-4} **	7.97 · 10^{-4} **	Te
22–22.5	0.5	1.42 · 10^{-4} *	0.71 · 10^{-4} **	3.36 · 10^{-5} **	7.03 · 10^{-5} **	
Total		$\Sigma\Delta Q_i$ =1.75 · 10^{-3} *	Σ=8.76 · 10^{-4} **	ΣT_i= 4.20 · 10^{-4}	Σ=8.67 · 10^{-4}	
Difference		Q_T–Q_p = 0.875 · 10^{-3}	–	–	–	

* Overestimated due to decreased borehole diameter (136 mm)

** Based on the assumption that Q_p= Q_T (all measured flow assumed to be within the logged interval)

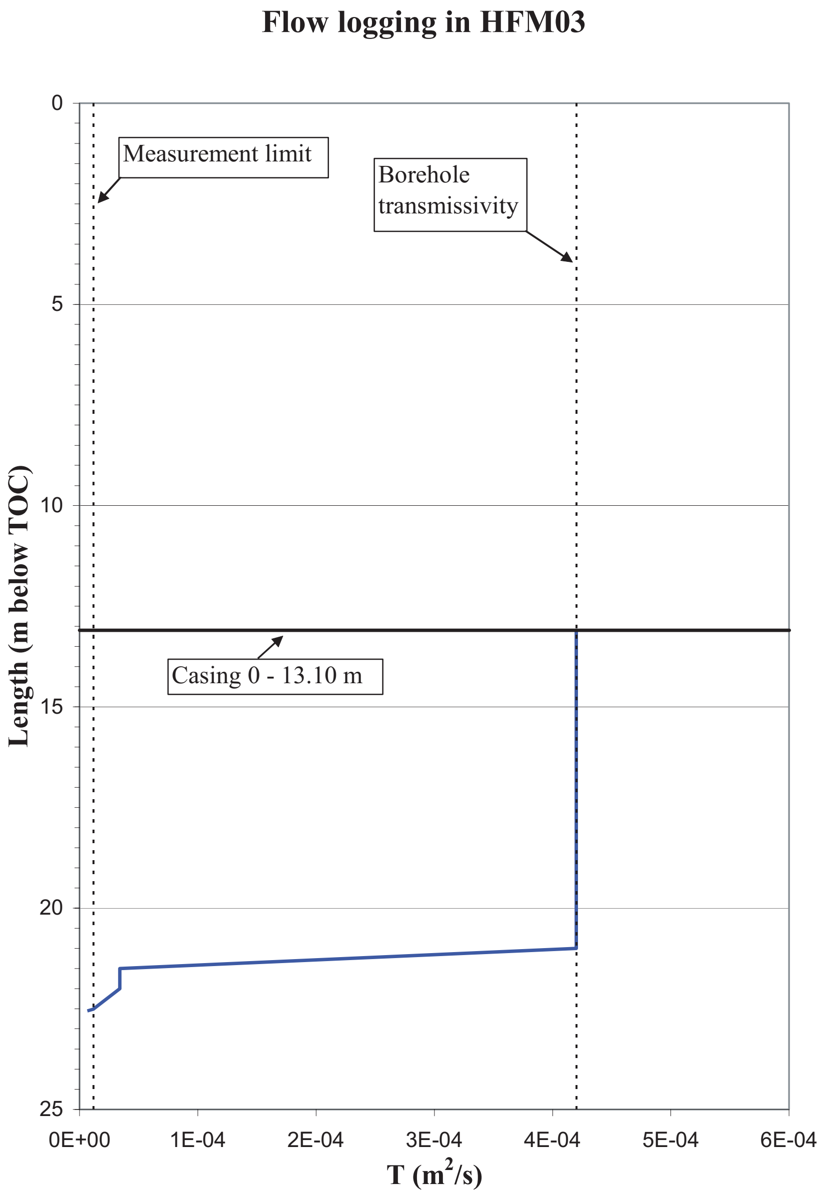


Figure 6-6. Estimated, cumulative transmissivity along the borehole from the flow logging. Below 22.5 m the transmissivity falls below the measurement limit.

6.5 Summary of hydraulic tests

A compilation of measured test data from the hydraulic tests carried out in the test campaign is presented in Table 6-14. In Table 6-15 and 6-16, calculated hydraulic parameters of the formation respectively the borehole, are shown. The results of the flow logging are displayed in Section 6.4.

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 for practical purposes (c. 50 m) in a percussion borehole, c.f. Table 4-1. These values correspond to a practical lower measurement limit of Q/s–L=2 · 10^{-6} m^2/s for pumping tests.

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

In Table 6-15, the parameter explanations are according to the methodology description for injection- and single-hole pumping tests. The parameters are also explained in the text above, except the following:

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

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

T_1 = transient transmissivity from the first 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 6-14. Summary of test data for the pumping tests performed with the HTHB-system in the Forsmark area. Section type: 1=pumped section, 2=observation section in the pumping borehole above or below the pumped section.

Borehole ID	Section (m)	Section type	p_i (kPa)	p_p (kPa)	p_F (kPa)	Q_p (m^3/s)	Q_m (m^3/s)	V_p (m^3)
KFM01A	29.40–100.57	1	230.8	224.7	235.406	1.22 · 10^{-3}	1.22 · 10^{-3}	91.5
HFM01	31.93–200.20	1	341.646	160.364	340.893	1.00 · 10^{-3}	9.89 · 10^{-4}	36.48
HFM01	31.93–71	1	388.892	229.625	387.744	1.09 · 10^{-3}	1.10 · 10^{-3}	4.40
HFM01	72–200.20	2	775.586	774.027	774.92	–	–	–
HFM01	72–200.20	1	725.236	314.234	690.512	<8.33 · 10^{-5}	–	<0.154
HFM01	31.93–71	2	723.094	723.577	723.58	–	–	–
HFM02	25.40–100.00	1	302.6	296.4	302.97	1.16 · 10^{-3}	1.16 · 10^{-3}	41
HFM03	13.10–26.00	1	136.6	125.3	137.7	8.75 · 10^{-4}	8.75 · 10^{-4}	15.6

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

Table 6-15. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed at drillsite DS1 in the Forsmark area.

Borehole ID	Section (m)	Flow anomaly interval (m)	Test type	Q/s (m^2/s)	T_M (m^2/s)	T_1 (m^2/s)	T_i (m^2/s)	S* (–)
KFM01A	29.40–100.57		1B	$2.00 \cdot 10^{-3}$	$2.30 \cdot 10^{-3}$	$8.14 \cdot 10^{-4}$		$1.0 \cdot 10^{-4}$
HFM01	31.93–200.20		1B	$5.52 \cdot 10^{-5}$	$7.10 \cdot 10^{-5}$	$6.31 \cdot 10^{-5}$		$1.0 \cdot 10^{-4}$
HFM01	34–198 (f)	34.5–43	6	$4.00 \cdot 10^{-5}$			$4.50 \cdot 10^{-5}$	
HFM01		48–50	6	$4.70 \cdot 10^{-6}$			$5.00 \cdot 10^{-6}$	
HFM01		60.5–63.5	6	$2.40 \cdot 10^{-6}$			$2.50 \cdot 10^{-6}$	
HFM01		64–64.5	6	$9.40 \cdot 10^{-6}$			$1.10 \cdot 10^{-5}$	
HFM01	31.93–71		1B	$6.78 \cdot 10^{-5}$	$6.63 \cdot 10^{-5}$	$6.67 \cdot 10^{-5}$		$1.0 \cdot 10^{-4}$
HFM01	72–200.20		1B	$<2 \cdot 10^{-6}$				
HFM02	25.40–100.00		1B	$1.88 \cdot 10^{-3}$	$2.20 \cdot 10^{-3}$	$5.91 \cdot 10^{-4}$		$1.0 \cdot 10^{-4}$
HFM02	31–100 (f)	42–44.5	6	$2.58 \cdot 10^{-3}$			$5.9 \cdot 10^{-4}$	
HFM03	13.10–26.00		1B	$7.74 \cdot 10^{-4}$	$6.84 \cdot 10^{-4}$	$4.20 \cdot 10^{-4}$		$1.0 \cdot 10^{-4}$
HFM03	13.10–26 (f)	21–21.5	6	$7.97 \cdot 10^{-4}$			$3.86 \cdot 10^{-4}$	
HFM03		22–22.5	6	$7.03 \cdot 10^{-5}$			$3.36 \cdot 10^{-5}$	

(f)=flow logged interval

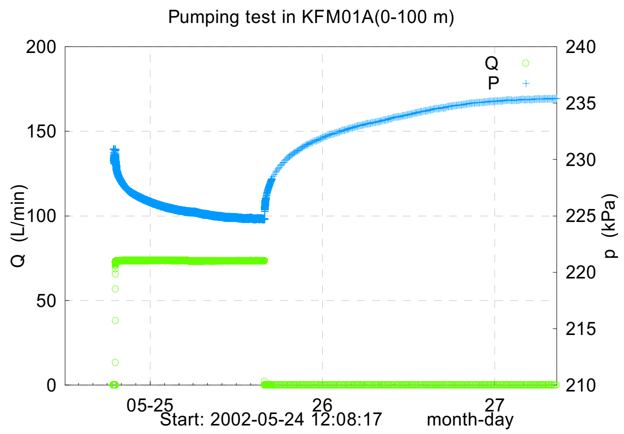
Table 6-16. Summary of calculated hydraulic parameters of the borehole from hydraulic test performed with the HTHB-system at drillsite DS1 in the Forsmark area.

Borehole ID	Section (m)	Test type	S* (–)	C(m^3/Pa)	ζ(–)
KFM01A	29.40–100.57	1B	$1.0 \cdot 10^{-4}$	–	–6.93
HFM01	31.93–200.20	1B	$1.0 \cdot 10^{-4}$	$2.28 \cdot 10^{-6}$	–0.44
HFM01	31.93–71	1B	$1.0 \cdot 10^{-4}$	$2.46 \cdot 10^{-6}$	–1.07
HFM01	72–200.20	1B	$1.0 \cdot 10^{-4}$	$3.64 \cdot 10^{-9}$	–
HFM02	25.40–100.00	1B	$1.0 \cdot 10^{-4}$		–7.16
HFM03	13.10–26.00	1B	$1.0 \cdot 10^{-4}$		–3.83

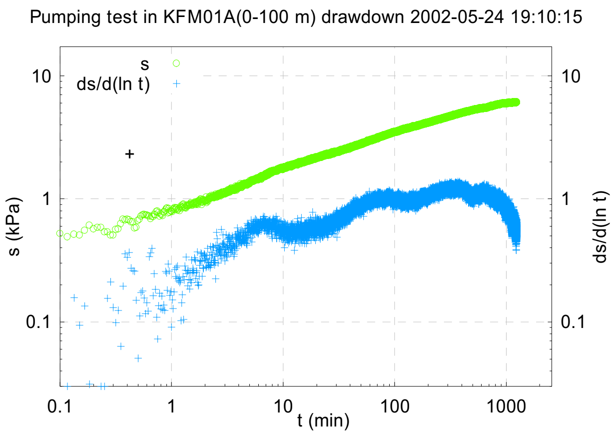
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	KFM01A	Test start:	2002-05-27 08:40
Test section (m):	29.40-100.57	Responsible for test performance:	GEOSIGMA AB J. Källgården/T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.164	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

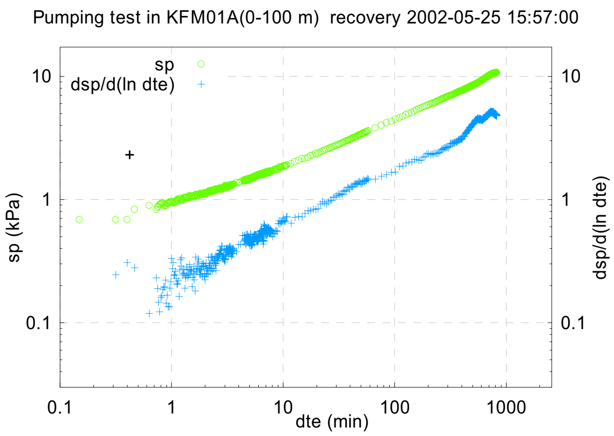
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	230.8		
p_i (kPa)	230.8		
p_p(kPa)	224.7	p_F (kPa)	340.893
Q_p (m^3/s)	$1.22 \cdot 10^{-3}$		
tp (min)	1247	t_F (s)	744
S	$1 \cdot 10^{-4}$	S	-
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$2.0 \cdot 10^{-3}$		
T_{Moye}(m^2/s)	$2.3 \cdot 10^{-3}$		
Flow regime:	PRF	Flow regime:	
t_1 (min)	200	dt_{e1} (min)	-
t_2 (min)	800	dt_{e2} (min)	-
T_w (m^2/s)	$8.14 \cdot 10^{-4}$	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)	-	C (m^3/Pa)	-
C_D (-)	-	C_D (-)	-
ξ (-)	-6.93	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)	200	C_D (-)	-
t_2 (min)	800	ξ (-)	-6.93
T_T (m^2/s)	$8.14 \cdot 10^{-4}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

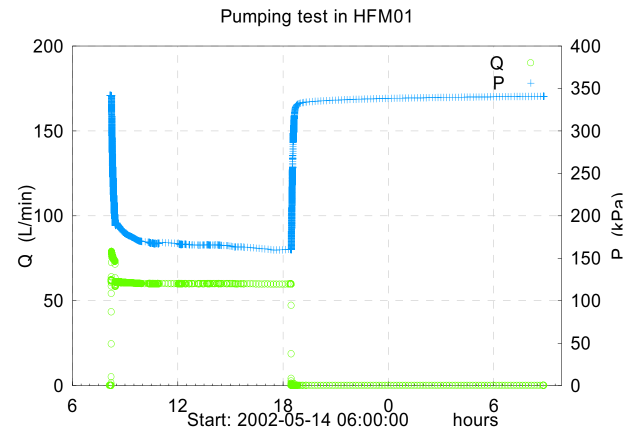
Comments: Initial linear (fracture) flow transiting to pseudo-radial flow during the flow period.

No-flow boundary effects during the recovery phase. No pseudo-radial flow was developed during this period.

Test Summary Sheet

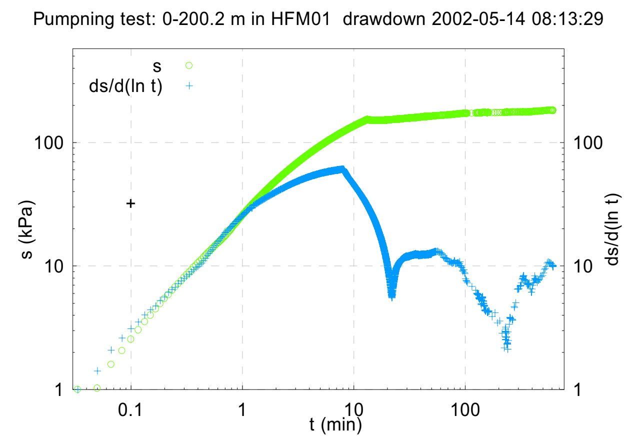
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM01	Test start:	2002-05-14 08:11
Test section (m):	31.93-200.20	Responsible for test performance:	GEOSIGMA AB J. Källgården/T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.140	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

Linear plot Q and p

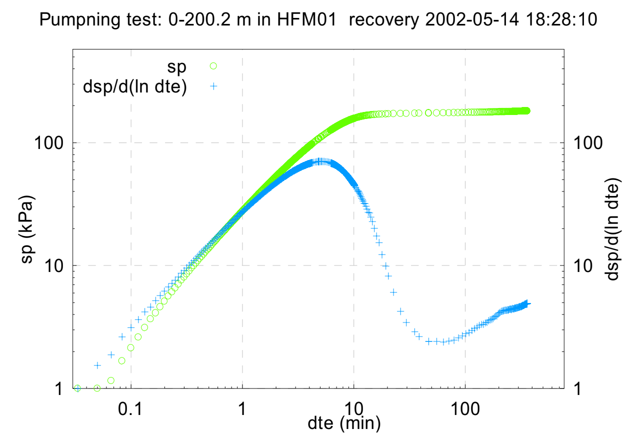


Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	341.646		
p_i (kPa)	341.646		
p_p(kPa)	160.364	p_F (kPa)	340.893
Q_p (m^3/s)	$1.00 \cdot 10^{-3}$		
tp (min)	615	t_F (s)	744
S	$1 \cdot 10^{-4}$	S	-
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.5	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$5.52 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$7.10 \cdot 10^{-5}$		
Flow regime:	PRF	Flow regime:	WBS
t_1 (min)	20	dt_{e1} (min)	0.1
t_2 (min)	120	dt_{e2} (min)	100
T_w (m^2/s)	$6.31 \cdot 10^{-5}$	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)	$2.28 \cdot 10^{-6}$	C (m^3/Pa)	$1.98 \cdot 10^{-6}$
C_D (-)		C_D (-)	-
ξ (-)	-0.44	ξ (-)	-
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



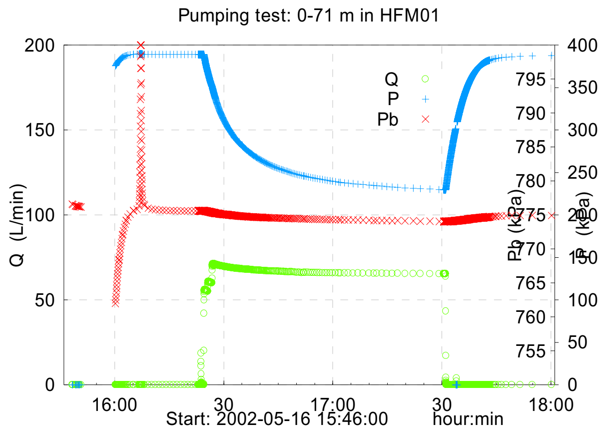
Interpreted formation and well parameters.			
Flow regime:	PRF	C (m^3/Pa)	$2.28 \cdot 10^{-6}$
t_1 (min)	20	C_D (-)	
t_2 (min)	120	ξ (-)	-0.44
T_T (m^2/s)	$6.31 \cdot 10^{-5}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Wellbore storage dominated flow transiting to pseudo-radial flow during the flow period. Fast recovery.

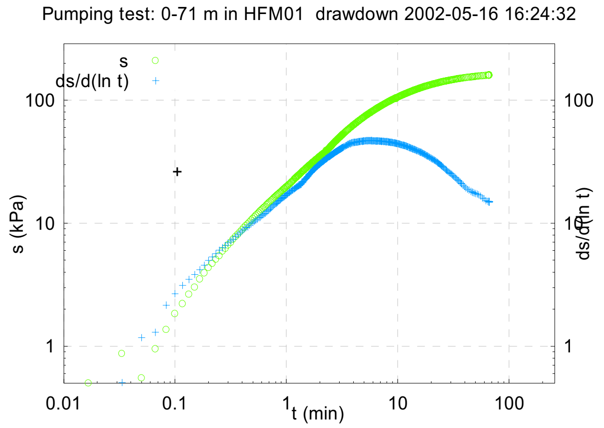
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM01	Test start:	2002-05-16 15:46
Test section (m):	29.40-71	Responsible for test performance:	GEOSIGMA AB J. Källgården/T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.140	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

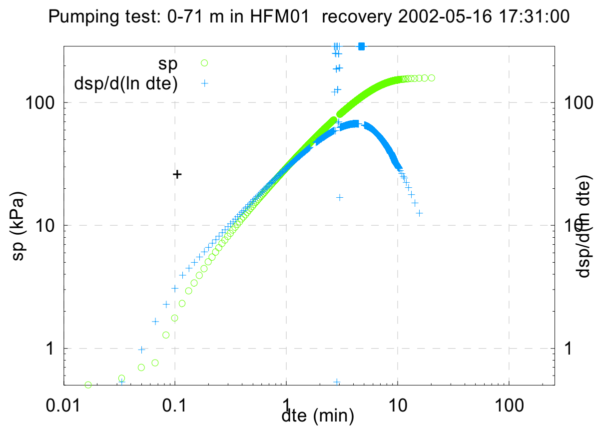
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	388.892		
p_{bi} (kPa)	775.586		
p_p(kPa)	229.625	p_F (kPa)	387.744
p_{bp} (kPa)	774.027	p_{aF} (kPa)	774.92
Q_p (m^3/s)	$1.09 \cdot 10^{-3}$		
tp (min)	66.5	t_F (min)	30
S	$1 \cdot 10^{-4}$	S	-
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.5	Derivat. fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$6.78 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$6.63 \cdot 10^{-5}$		
Flow regime:	WBS	Flow regime:	WBS
t_1 (min)	0.1	dt_{e1} (min)	-
t_2 (min)	66	dt_{e2} (min)	-
T_w (m^2/s)	$6.67 \cdot 10^{-5}$	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)	$2.46 \cdot 10^{-6}$	C (m^3/Pa)	$2.03 \cdot 10^{-6}$
C_D (-)		C_D (-)	-
ξ (-)	-1.07	ξ (-)	-
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	

Interpreted formation and well parameters

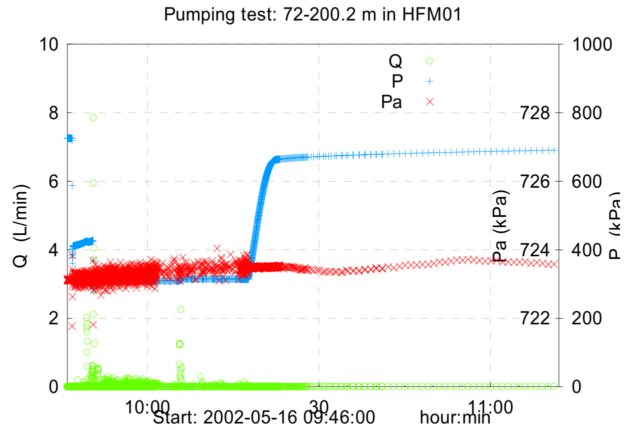
Flow regime:	WBS	C (m^3/Pa)	$2.46 \cdot 10^{-6}$
t_1 (min)	0.1	C_D (-)	
t_2 (min)	66	ξ (-)	-1.07
T_T (m^2/s)	$6.67 \cdot 10^{-5}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Wellbore storage dominated flow. Pseudo-radial flow regime not developed.

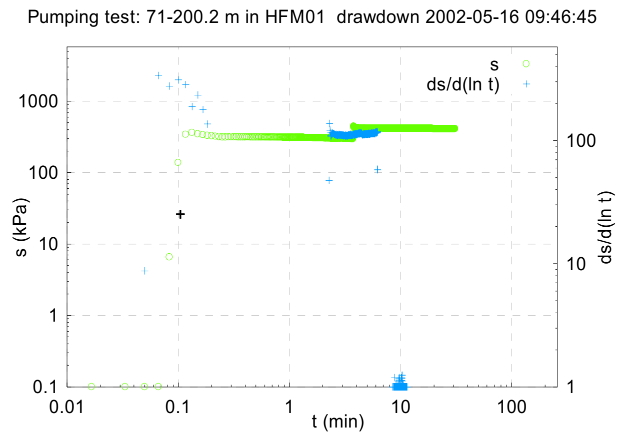
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM01	Test start:	2002-05-16 09:46
Test section (m):	72-200.20	Responsible for test performance:	GEOSIGMA AB J. Källgården/T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.140	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

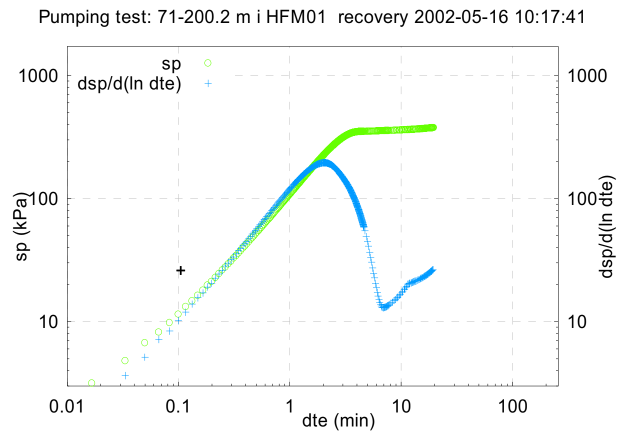
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



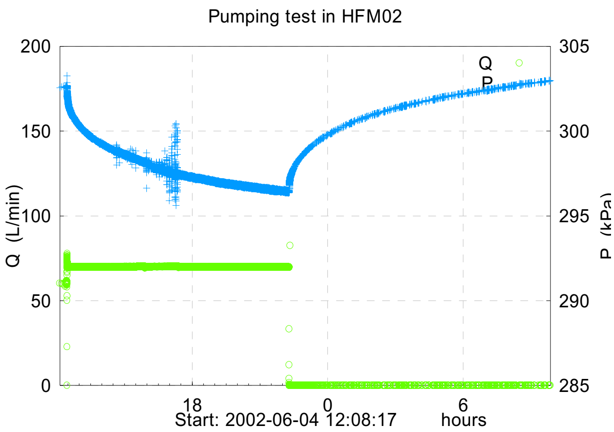
Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	725.236		
p_{ai} (kPa)	723.094		
p_p(kPa)	314.234	p_F (kPa)	690.51
p_{ap} (kPa)	723.577	p_{aF} (kPa)	723.58
Q_p (m^3/s)	$<8.33 \cdot 10^{-5}$		
tp (min)	31	t_F (min)	54
S	-	S	-
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.5	Derivat. fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$<2.0 \cdot 10^{-6}$		
T_{Moye}(m^2/s)	$<2.5 \cdot 10^{-6}$		
Flow regime:	WBS	Flow regime:	WBS
t_1 (min)		dt_{e1} (min)	-
t_2 (min)		dt_{e2} (min)	-
T_w (m^2/s)	-	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)	$3.64 \cdot 10^{-9}$
C_D (-)	-	C_D (-)	-
ξ (-)	-	ξ (-)	-
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	
Interpreted formation and well parameters			
Flow regime:	WBS	C (m^3/Pa)	$3.64 \cdot 10^{-9}$
t_1 (min)	-	C_D (-)	-
t_2 (min)	-	ξ (-)	-
T_T (m^2/s)	-		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Wellbore storage dominated flow. Flow rate below measurement limit.

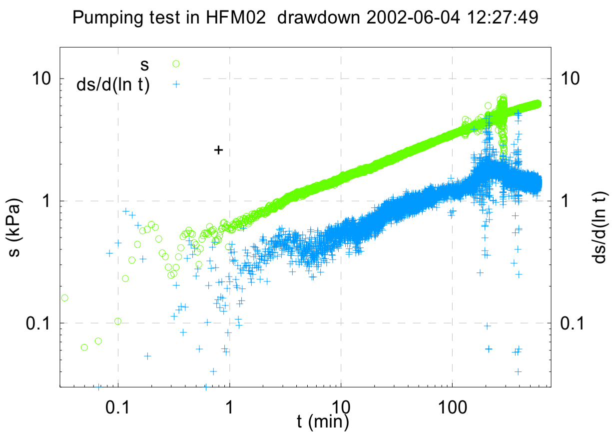
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM02	Test start:	2002-06-04 12:08
Test section (m):	25.40-100.00	Responsible for test performance:	GEOSIGMA AB J. Källgården/T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.137	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

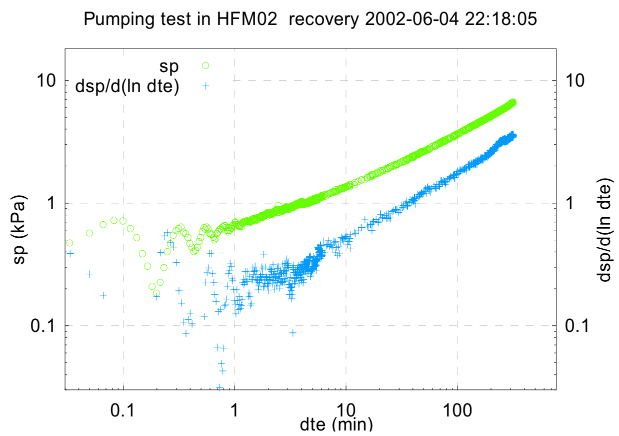
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	302.6		
p_i (kPa)	302.6		
p_p(kPa)	296.4	p_F (kPa)	302.97
Q_p (m^3/s)	$1.16 \cdot 10^{-3}$		
tp (min)	590	t_F (s)	693
S	$1 \cdot 10^{-4}$	S	-
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$1.88 \cdot 10^{-3}$		
T_{Moye}(m^2/s)	$2.20 \cdot 10^{-3}$		
Flow regime:	PRF	Flow regime:	No PRF
t_1 (min)	100	dt_{e1} (min)	-
t_2 (min)	600	dt_{e2} (min)	-
T_w (m^2/s)	$5.91 \cdot 10^{-4}$	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)	-	C (m^3/Pa)	-
C_D (-)	-	C_D (-)	-
ξ (-)	-7.16	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)	100	C_D (-)	-
t_2 (min)	600	ξ (-)	-7.16
T_T (m^2/s)	$5.91 \cdot 10^{-4}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

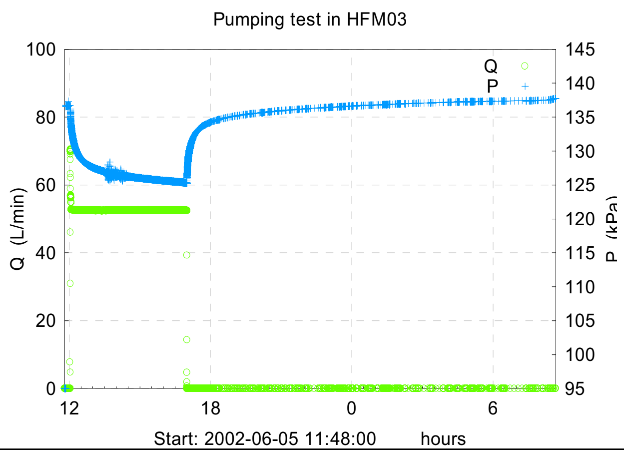
Comments: Initial linear (fracture) flow transiting to pseudo-radial flow during the flow period.

Effects of no-flow boundaries during the recovery period. No pseudo-radial flow developed during the this period.

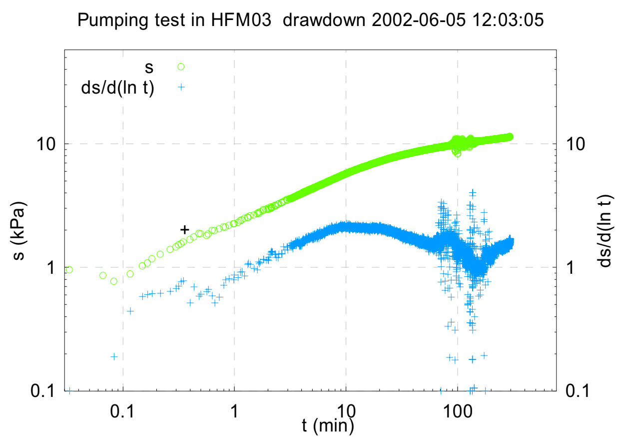
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM03	Test start:	2002-06-05 11:48
Test section (m):	13.10-26.00	Responsible for test performance:	GEOSIGMA AB J. Källgården/T. Svensson
Section diameter, $2 \cdot r_w$ (m):	0.136	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

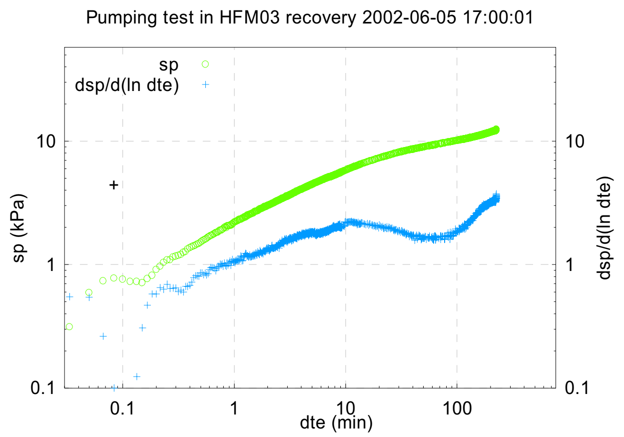
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	136.6		
p_p(kPa)	125.3	p_F (kPa)	137.7
Q_p (m^3/s)	$8.75 \cdot 10^{-4}$		
tp (min)	297	t_F (min)	940
S	$1 \cdot 10^{-4}$	S_s	-
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$7.74 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$6.84 \cdot 10^{-4}$		
Flow regime:	PRF	Flow regime:	PRF
t_1 (min)	80	dt_{e1} (min)	30
t_2 (min)	300	dt_{e2} (min)	100
T_w (m^2/s)	$5.52 \cdot 10^{-4}$	T_w (m^2/s)	$4.20 \cdot 10^{-4}$
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 (-)	-4.35	ξ (-)	-3.83
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)	-
dt_{e1} (min)	30	C_D (-)	-
dt_{e2} (min)	100	ξ (-)	-3.83
T_T (m^2/s)	$4.20 \cdot 10^{-4}$		
S (-)	-		
K_s (m/s)	-		
S_s (1/m)	-		

Comments: Initial linear (fracture) flow transiting to pseudo-radial flow both during the flow- and recovery period.

Evidences of a no-flow boundary by the end of the recovery period.

7 References

/1/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of the telescopic borehole KFM01A at drillsite DS1. SKB P-03-YY, Svensk Kärnbränslehantering AB.

/2/ **Claesson L-Å, Nilsson G, 2003.** Forsmark site investigation. Drilling of a flushing water well, HFM01, and two groundwater monitoring wells, HFM02 and HFM03, at drillsite DS1.SKB P-03-XX, Svensk Kärnbränslehantering AB.

/3/ **Nilsson A-C, 2003.** Sampling and analyses of water from percussion drilled boreholes and soil pipes at drilling area 1.Results from the percussion-drilled boreholes HFM01, HFM02, HFM03, KFM01A (0–100 m) and the soil pipes SFM0001, SFM0002 and SFM0003 (in prep.).

/4/ **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.

Appendix 1

List of test data files

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

Bh ID	Test section (m)	Test type[1]	Test no	Test start Date, time YYYY-MM-DD tt:mm:ss	Test stop Date, time YYYY-MM-DD tt:mm:ss	Datafile, start Date, time YYYY-MM-DD tt:mm:ss	Datafile, stop Date, time YYYY-MM-DD tt:mm:ss	Data files of raw and primary data	Content (param-eters)2	Comments
KFM01A	0-50	L-Te, L-EC	1	2002-05-24 09:12:40	2002-05-24 09:55	2002-05-24 08:11:13	2002-05-24 17:40:11	KFM01A_000a_020524_FlowLo00.DAT	T, EC	Teperature and Electric conductivity profiles in undisturbed bore hole. Borehole blocked at 50 m due to cavity
KFM01A	0-50		1			2002-05-21 10:07:58	2002-05-27 16:00:49	KFM01A_000a_020524_Ref_Da00.DAT	C, R	
KFM01A	50-0	L-Te, L-EC	1	2002-05-24 13:10:08	2002-05-24 13:26:30	2002-05-24 08:11:13	2002-05-24 17:40:11	KFM01A_000b_020524_FlowLo00.DAT	T, EC	Teperature and Electric conductivity profiles in disturbed bore hole.
KFM01A	50-0		1			2002-05-21 10:07:58	2002-05-27 16:00:49	KFM01A_000b_020524_Ref_Da00.DAT	C, R	
KFM01A	0-100.4	1B	1	2002-05-24 19:07:56	2002-05-27 08:42:30	2002-05-24 18:52:23	2002-05-27 08:42:32	KFM01_000_020524_Pumpin00.DAT	P, Q	
KFM01A	0-100.4		1			2002-05-21 10:07:58	2002-05-27 16:00:49	KFM01_000_020524_Ref_Da00.DAT	C, R	
HFM01	0-200.2	1B, 6, L-Te, L-EC	1	2002-05-14 08:10	2002-05-15 08:51	2002-05-13 10:07:44	2002-05-15 08:52:14	HFM01_000a_020514_FlowLo00.DAT	P, Q, T, EC	
HFM01	0-200.2		1			2002-04-29 19:15:13	2002-05-18 17:39:47	HFM01_000a_020514_Ref_Da01.DAT	C, R	
HFM01	198-34	6, L-Te, L-EC	1	2002-05-14 12:33:20.3	2002-05-14 15:49:42.5	2002-05-14 12:33:20.3	2002-05-14 15:49:42.5	HFM01_034a_020514_Spinne00.DAT	P, Q, T, Sp, EC	
HFM01	198-34		1			2002-04-29 19:15:13	2002-05-14 08:58:17	HFM01_034a_020514_Ref_Da00.DAT	C, R	
HFM01	71-200.2	1B	1	2002-05-16 09:45:00	2002-05-16 11:12:00	2002-05-15 09:39:22	2002-05-16 18:01:22	HFM01_071a_020516_Pumpin.DAT	P, Q	

HFM01	71-200.2		1			2002-04-29 19:15:13	2002-05-18 17:39:47	HFM01_071a_020516_Ref_Da00.DAT	C, R	
HFM01	0-71	1B	1	2002-051-6 15:46	2002-05-16 18:00:50	2002-05-15 09:39:22	2002-05-16 18:01:22	HFM01_000a_020516_Pumpin.DAT	P, Q	
HFM01	0-71		1			2002-04-29 19:15:13	2002-05-18 17:39:47	HFM01_000a_020516_Ref_Da00.DAT	C, R	
HFM02	31-100	L-Te, L-EC	1	2002-06-04 15:34:34	2002-06-04 17:24:07	2002-06-04 15:34:33.9	2002-06-05 14:38:07.2	HFM02_031a_020604_Spinne00.DAT	P, Q, T, Sp, EC	
HFM02	31-100		1			2002-06-04 09:44:34	2002-06-07 10:41:59	HFM02_031a_020604_Ref_Da00.DAT	C, R	
HFM02	0-100.1	1B, 6, L-Te, L-EC	1	2002-06-04 12:20:00	2002-06-05 09:51:00	2002-06-04 09:46:28	2002-06-06 19:16:10	HFM02_000b_020604_FlowLo00.DAT	P, Q, T, EC	
HFM02	0-100.1		1			2002-06-04 09:44:34	2002-06-07 10:41:59	HFM02_000b_020604_Ref_Da.DAT	C, R	
HFM03	0-26.1	1B	1	2002-05-29 12:18:00	2002-05-30 07:54:30	2002-05-29 11:12:24	2002-05-30 07:53:31	HFM03_000a_020529_Pumpin00.DAT	P, Q	Pumping test disturbed by activity in KFM01
HFM03	0-26.1		1	2002-05-29 12:18:00	2002-05-30 07:54:30	2002-05-29 10:33:43	2002-05-30 15:12:39	HFM03_000a_020529_Ref_Da00.DAT	C, R	More accurate pumping test during flowlogging 020605-020606
HFM03	26-13.15	L-Te, L-EC	1	2002-06-05 13:27:07.9	2002-06-05 14:38:07.2	2002-06-04 15:34:33.9	2002-06-05 14:38:07.2	HFM03_13,15_020605_Spinne00.DAT	P, Q, T, Sp, EC	
HFM03	26-13.15		1			2002-06-04 09:44:34	2002-06-07 10:41:59	HFM03_13,15_020605_Ref_Da00.DAT	C, R	
HFM03	0-26.1	1B, 6, L-Te, L-EC	1	2002-06-05 11:52:00	2002-06-06 08:40:00	2002-06-04 09:46:28	2002-06-06 19:16:10	HFM03_000_020605_FlowLo00.DAT	P, Q	
HFM03	0-26.1		1			2002-06-04 09:44:34	2002-06-07 10:41:59	HFM03_000_020605_Ref_Da00.DAT	C, R	

[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:

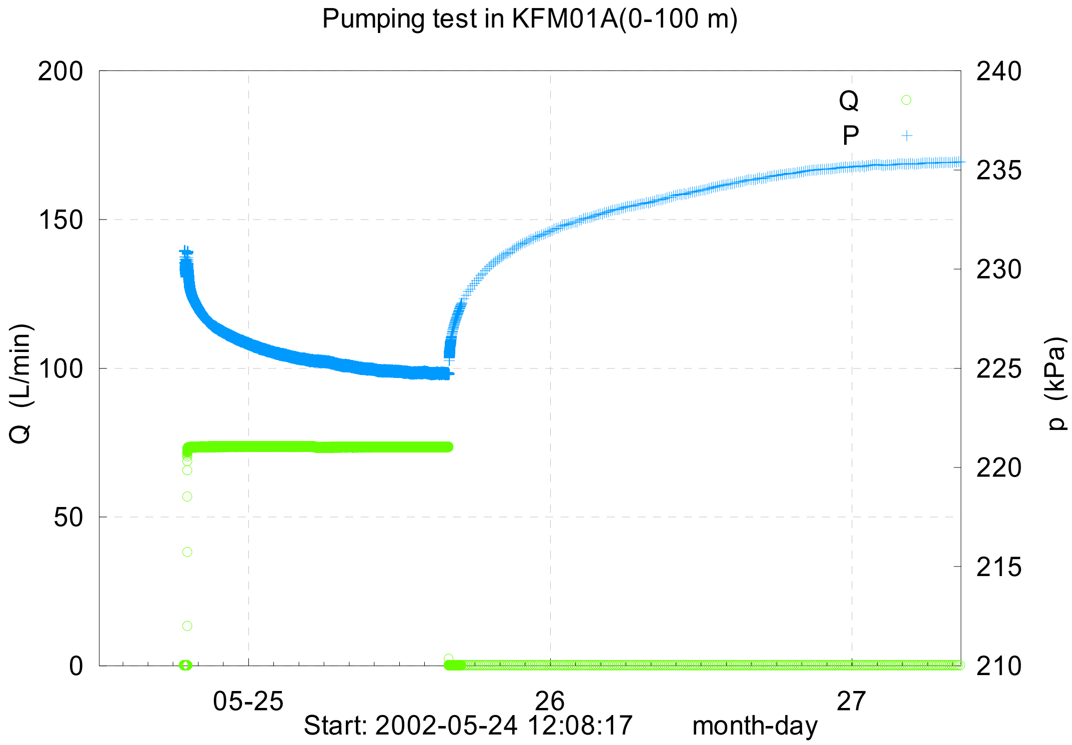


Fig A2-1. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in KFM01A(0-100 m) in conjunction with flow logging.*

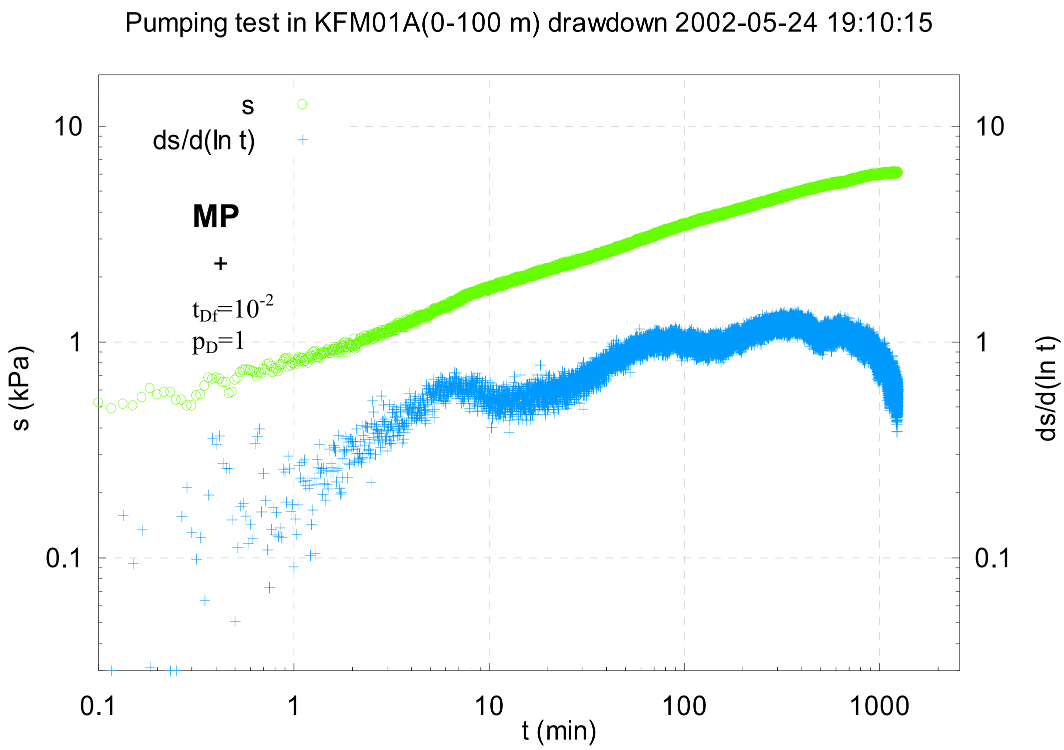


Fig A2-2. *Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the open-hole pumping test in KFM01A(0-100 m).*

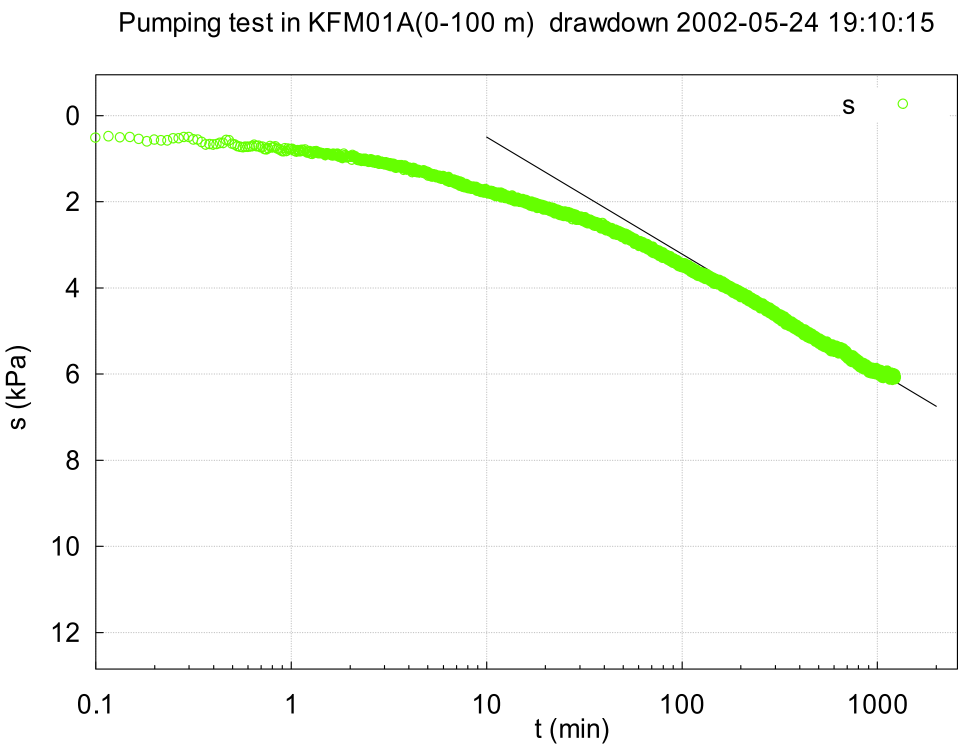


Fig A2-3. *Lin-log plot of drawdown (s) versus time (t) during the open-hole pumping test in KFM01A(0-100 m).*

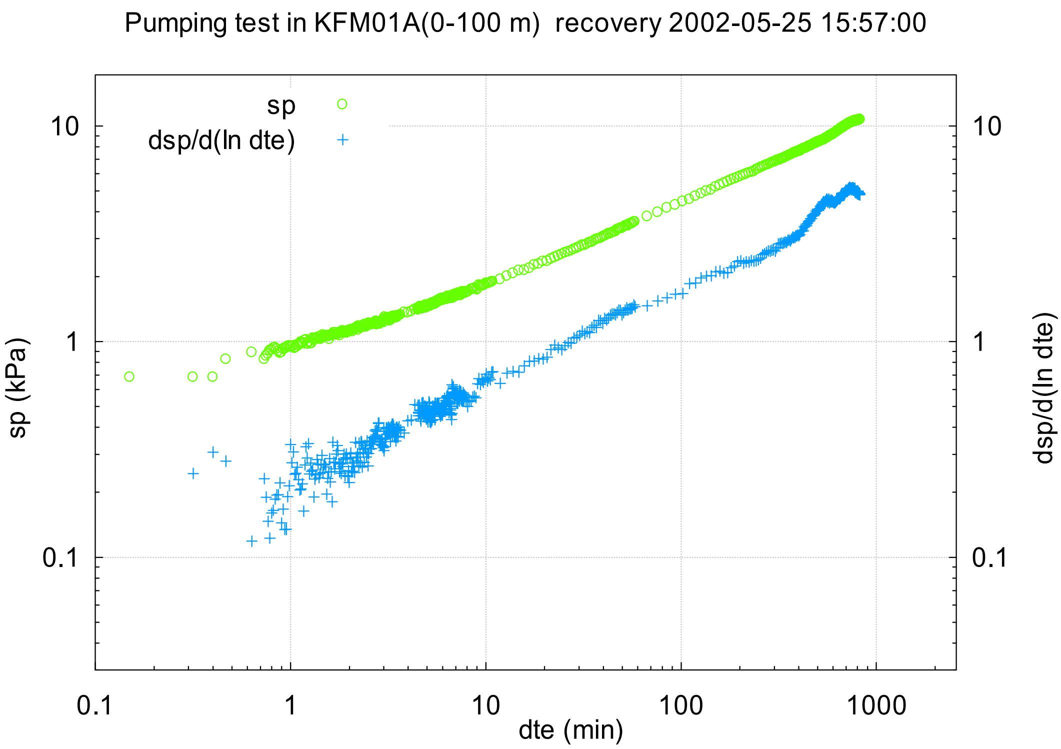


Fig A2-4. *Log-log plot of pressure recovery (sp) and - derivative, dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in KFM01A(0-100 m).*

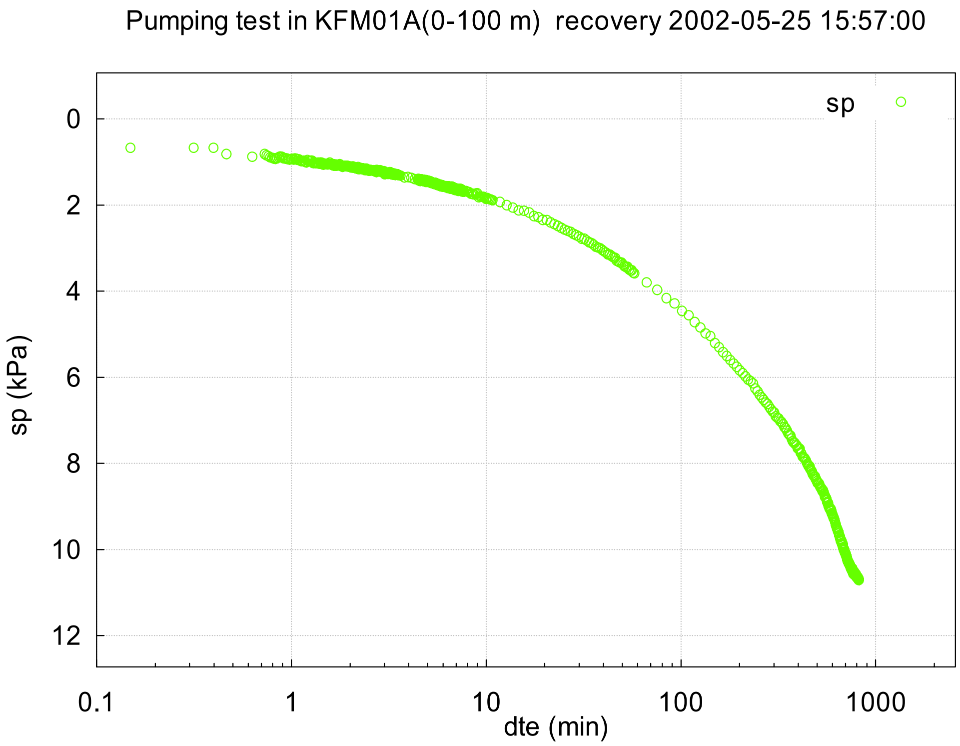


Fig A2-5. Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the open-hole pumping test in KFM01A(0-100 m).

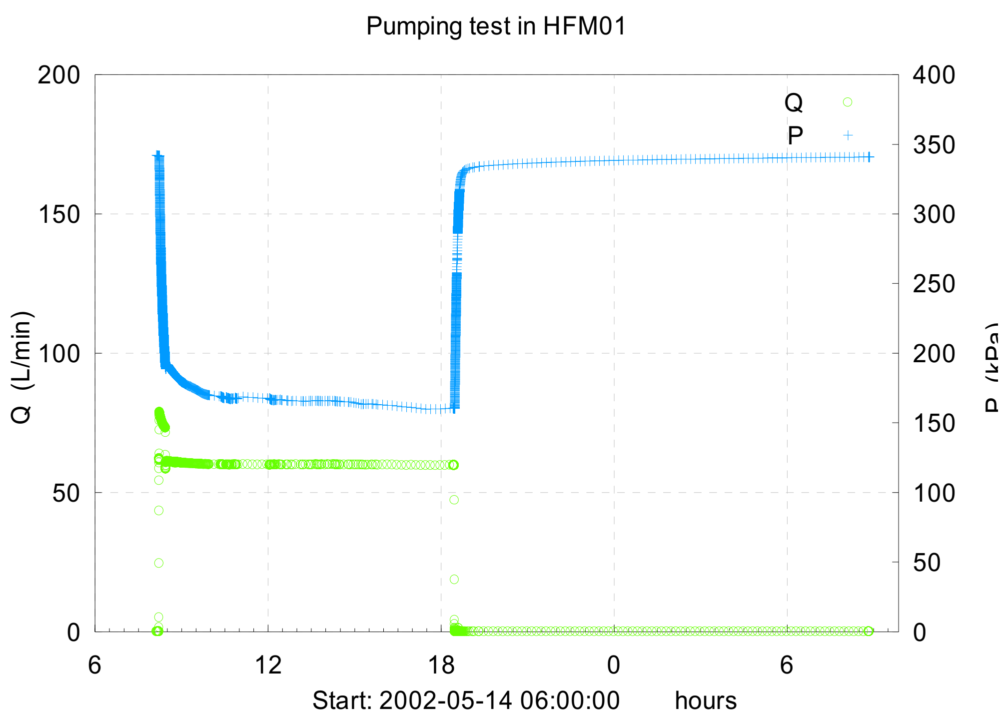


Fig A2-6. Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM01 in conjunction with flow logging.

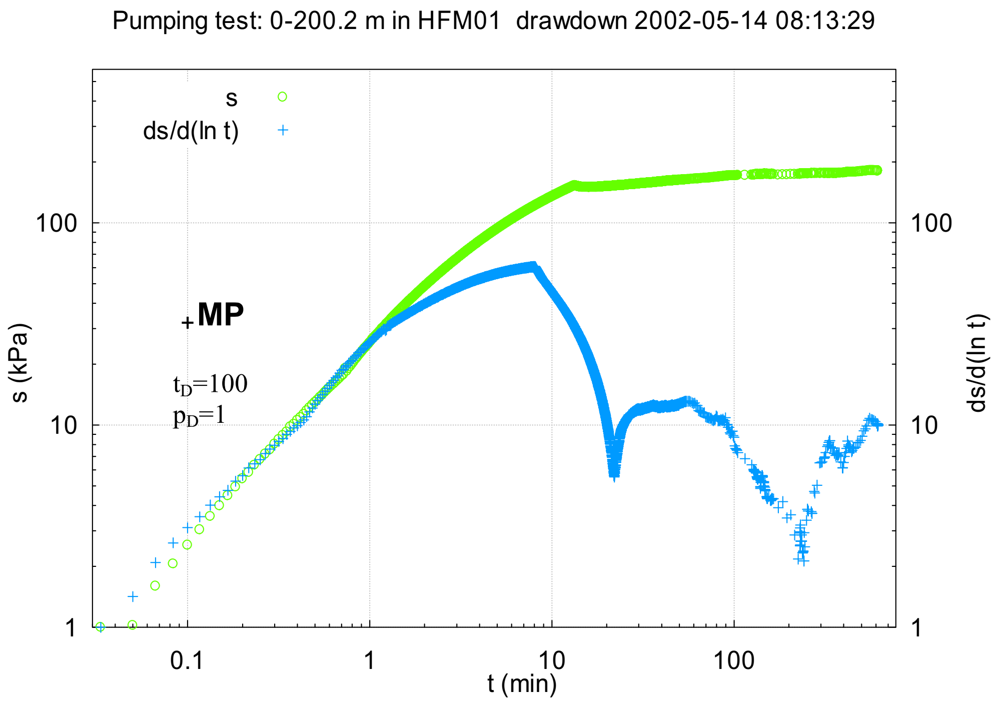


Fig A2-7. *Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the open-hole pumping test in HFM01.*

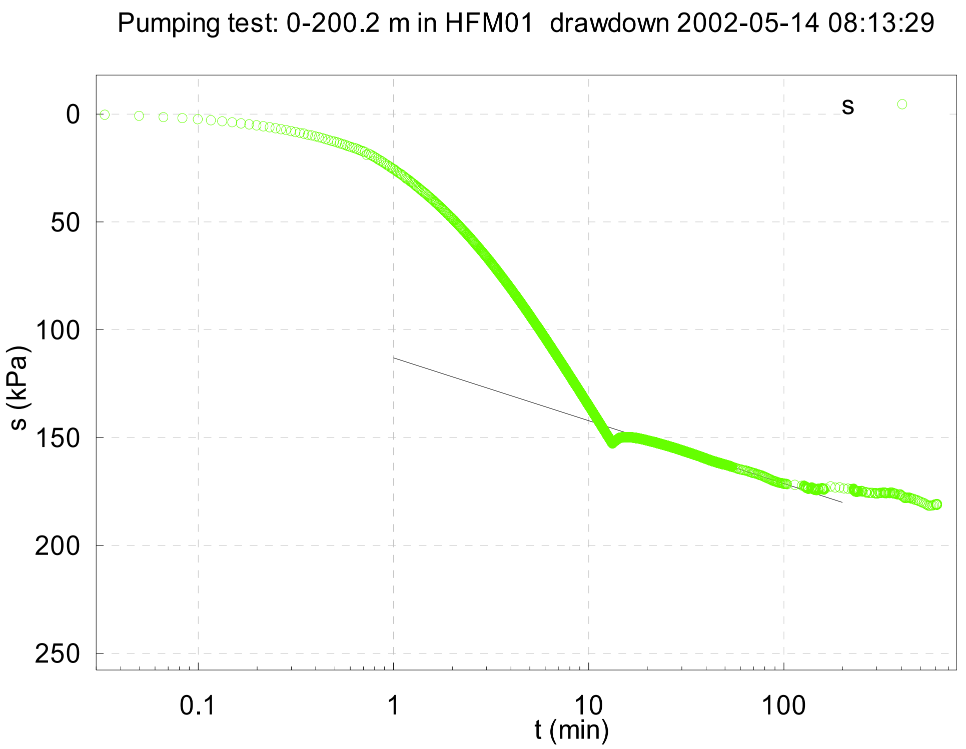


Fig A2-8. *Lin-log plot of drawdown (s) versus time (t) during the open-hole pumping test in HFM01.*

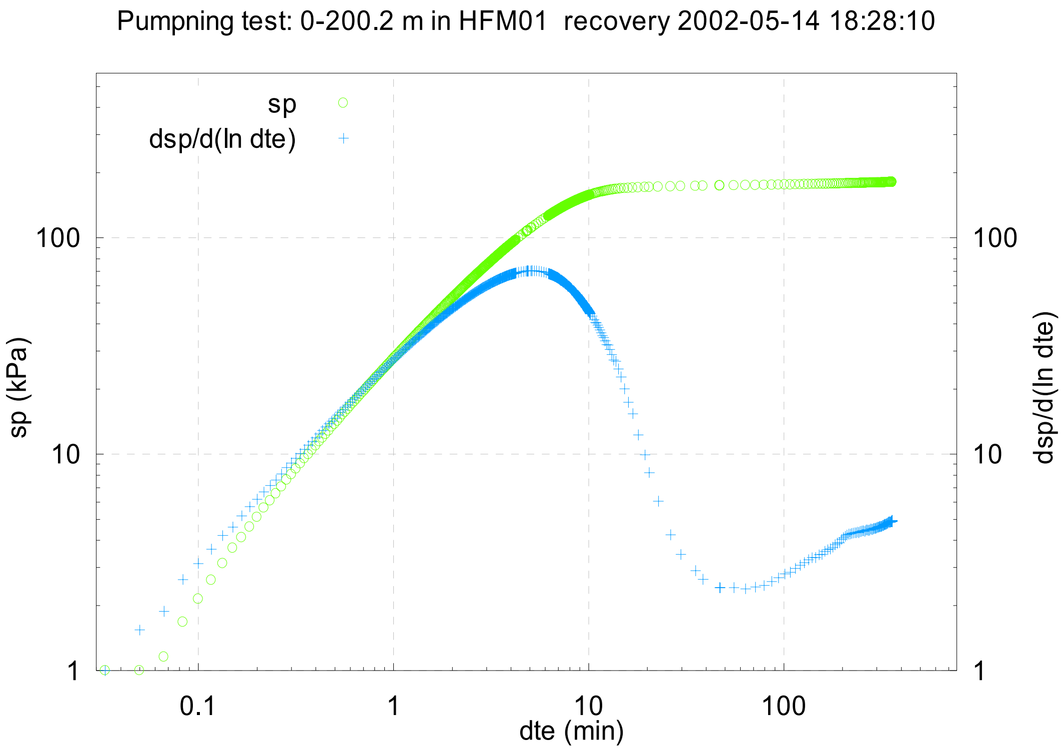


Fig A2-9. Log-log plot of pressure recovery (sp) and - derivative, dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM01.

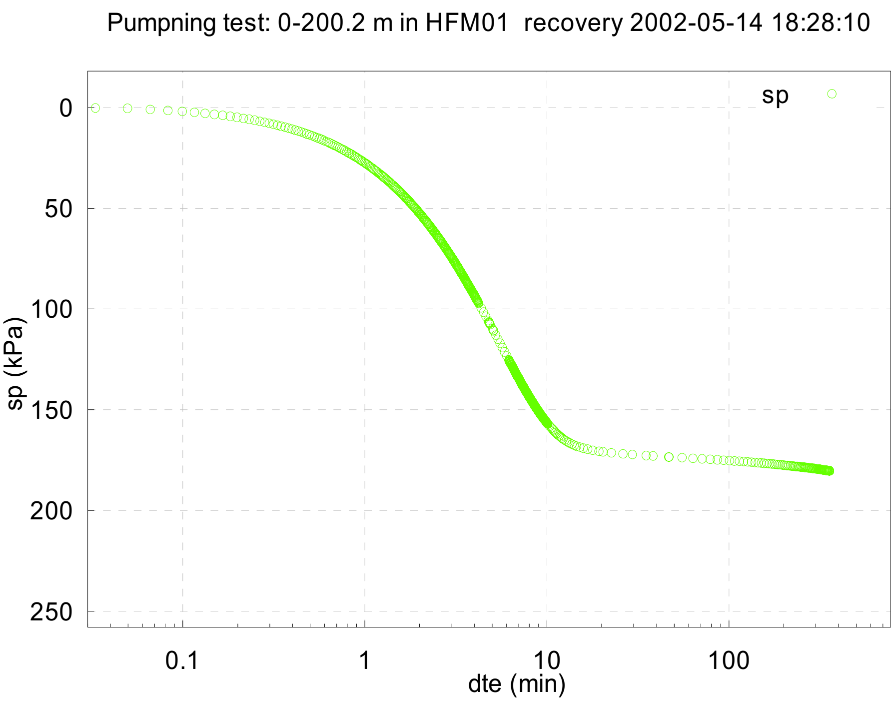


Fig A2-10. Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the open-hole pumping test in HFM01.

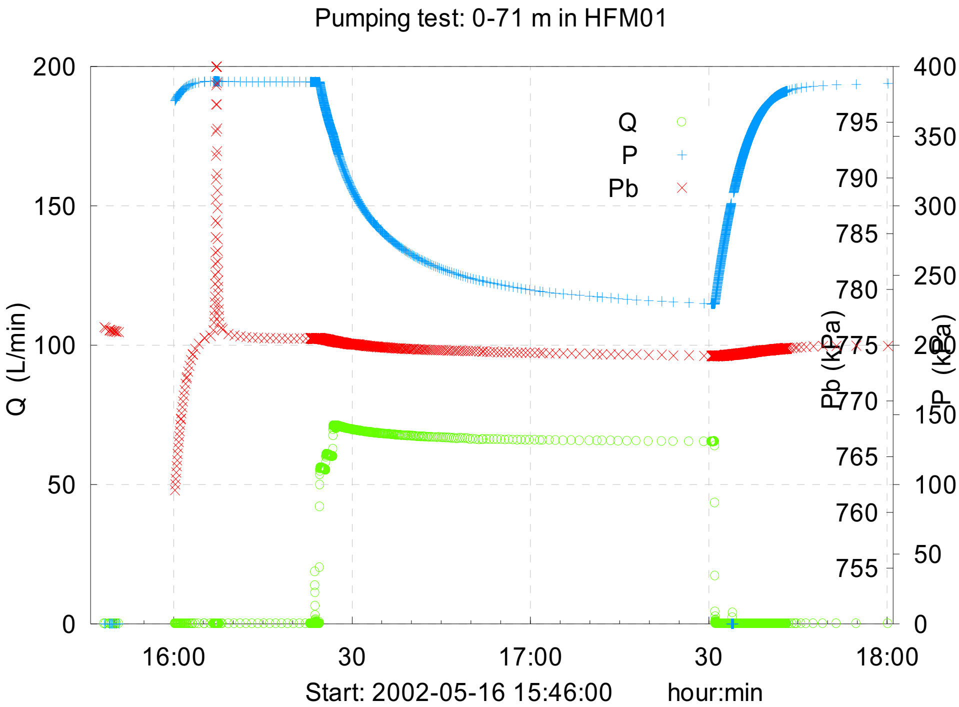


Fig A2-11. *Linear plot of flow rate (Q) and pressure (p) versus time during the pumping test in the interval 31.93-71 m in HFM01.*

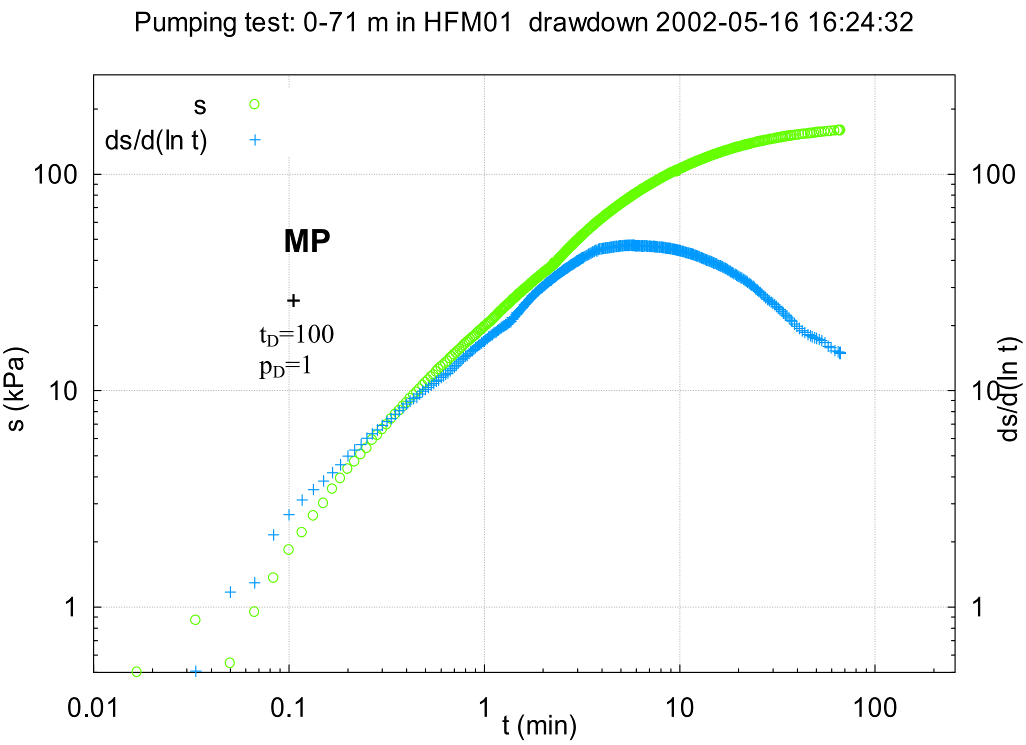


Fig A2-12. *Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the pumping test in the interval 31.93-71 m in HFM01.*

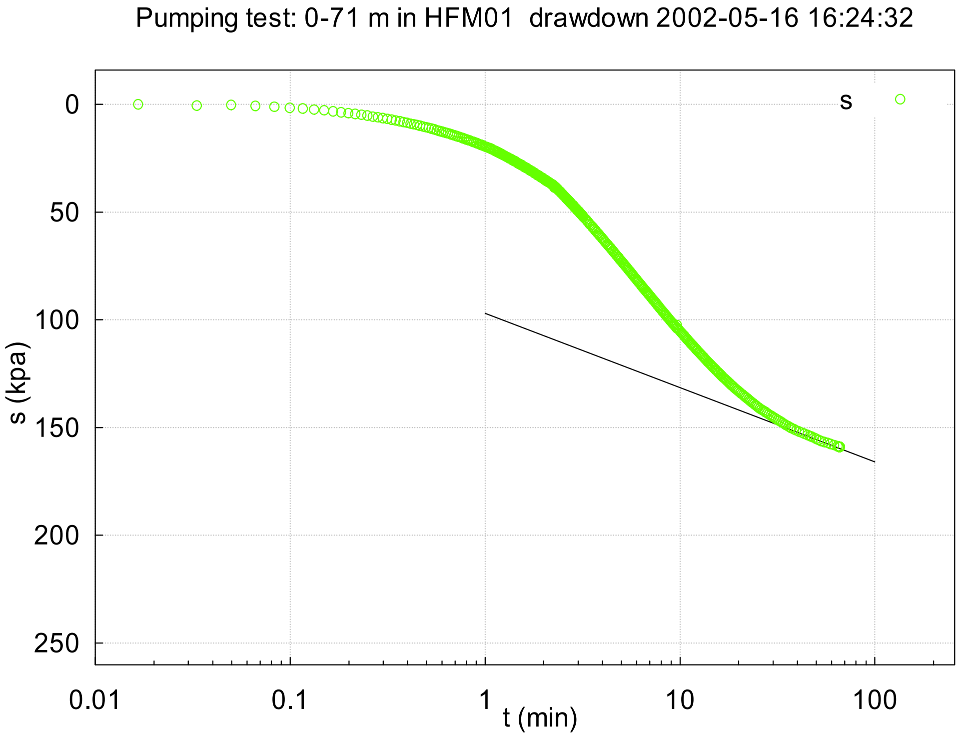


Fig A2-13. *Lin-log plot of drawdown (s) versus time (t) during the pumping test in the interval 31.93-71 m in HFM01.*

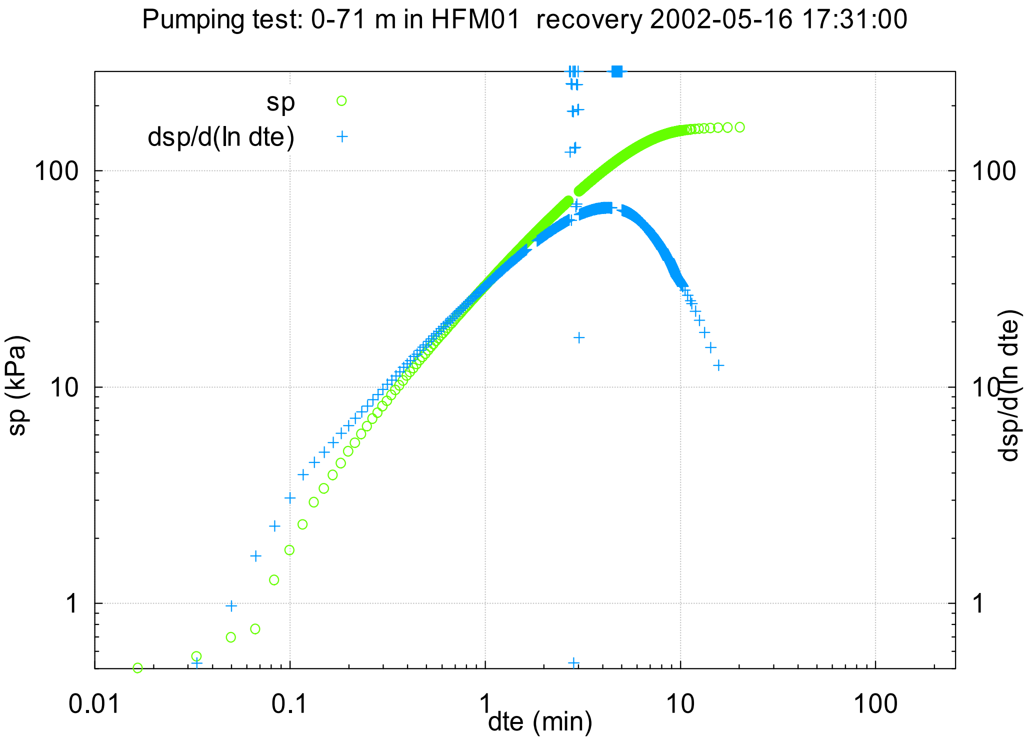


Fig A2-14. *Log-log plot of pressure recovery (sp) and - derivative, dsp/d(ln dte) versus equivalent time (dte) from the pumping test in the interval 31.93-71 m in HFM01.*

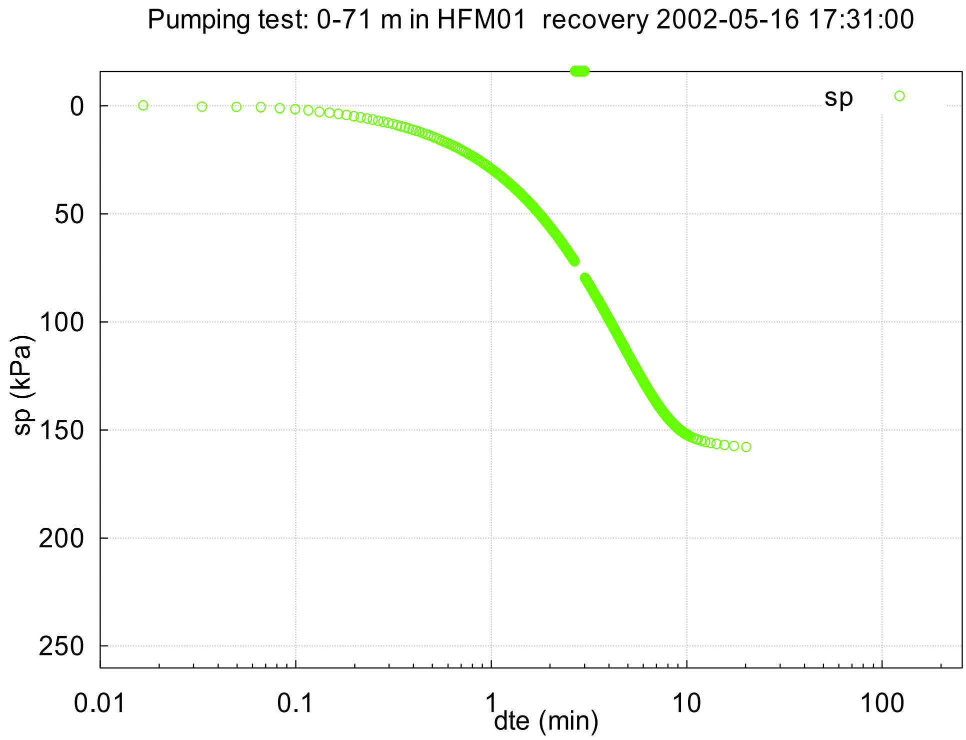


Fig A2-15. *Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the pumping test in the interval 31.93-71 m in HFM01.*

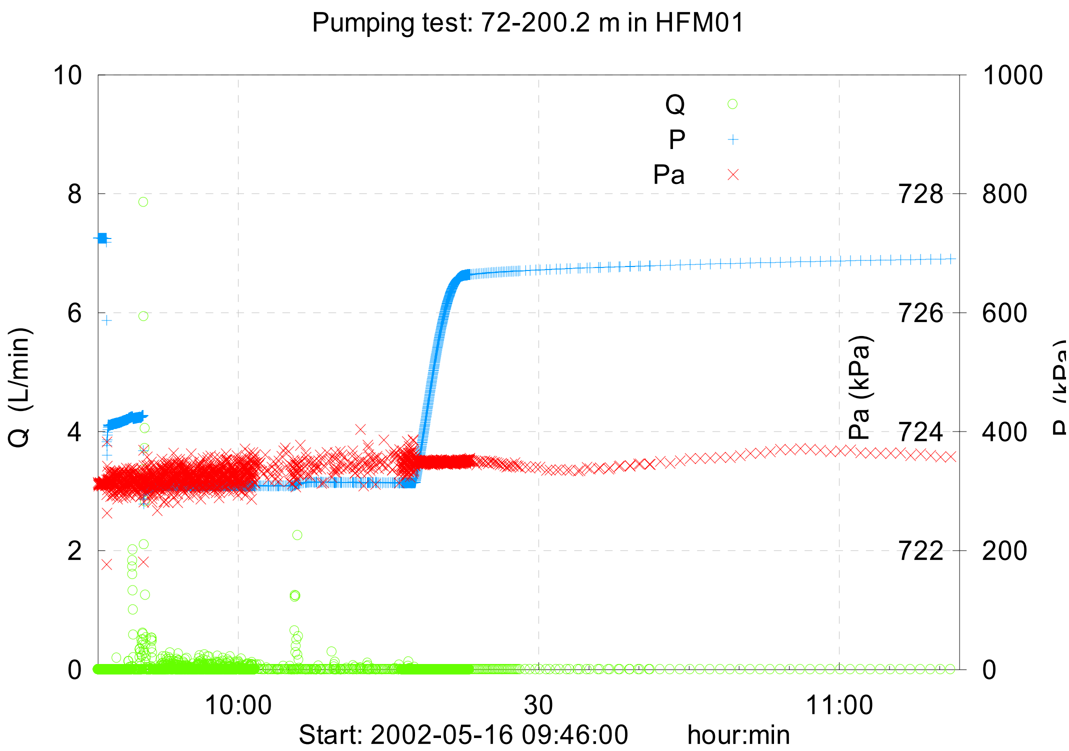


Fig A2-16. *Linear plot of flow rate (Q) and pressure (p) versus time during the pumping test in the interval 72-200.2 m in HFM01.*

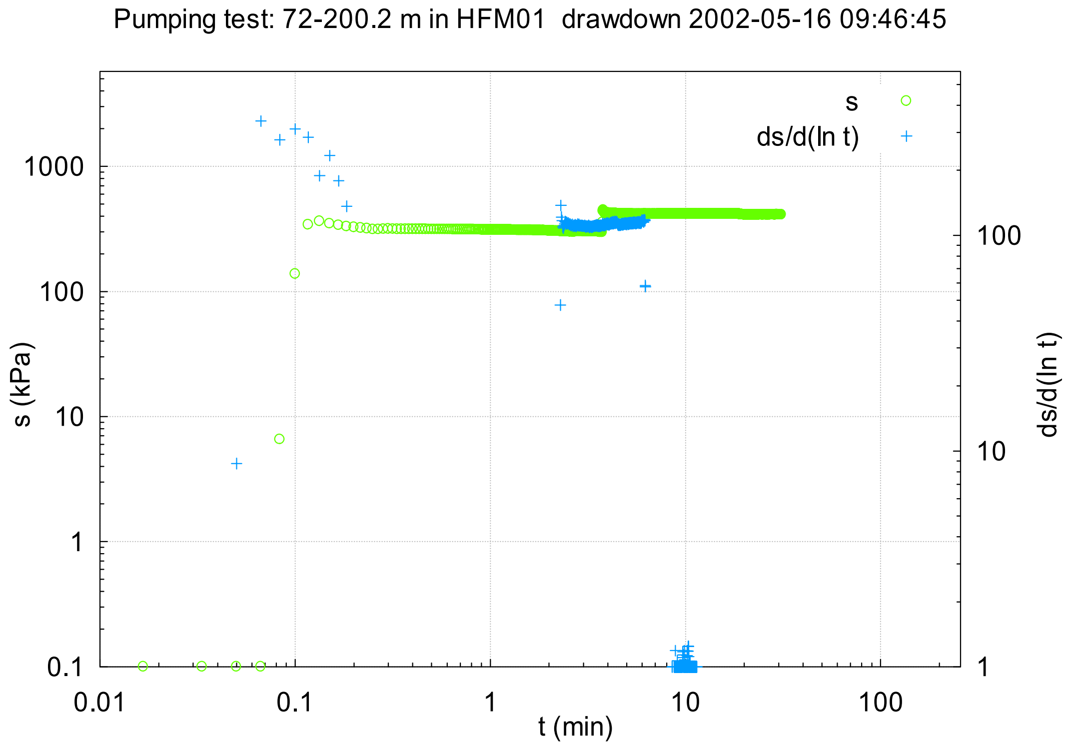


Fig A2-17. *Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the pumping test in the interval 72-200.2 m in HFM01.*

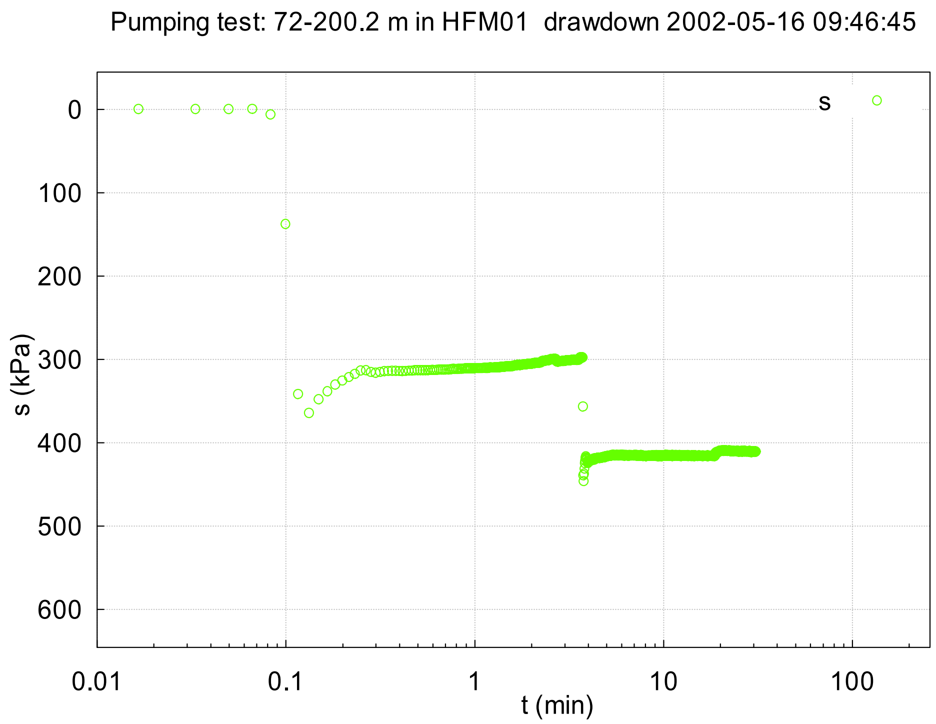


Fig A2-18. *Lin-log plot of drawdown (s) versus time (t) during the pumping test in the interval 72-200.2 m in HFM01.*

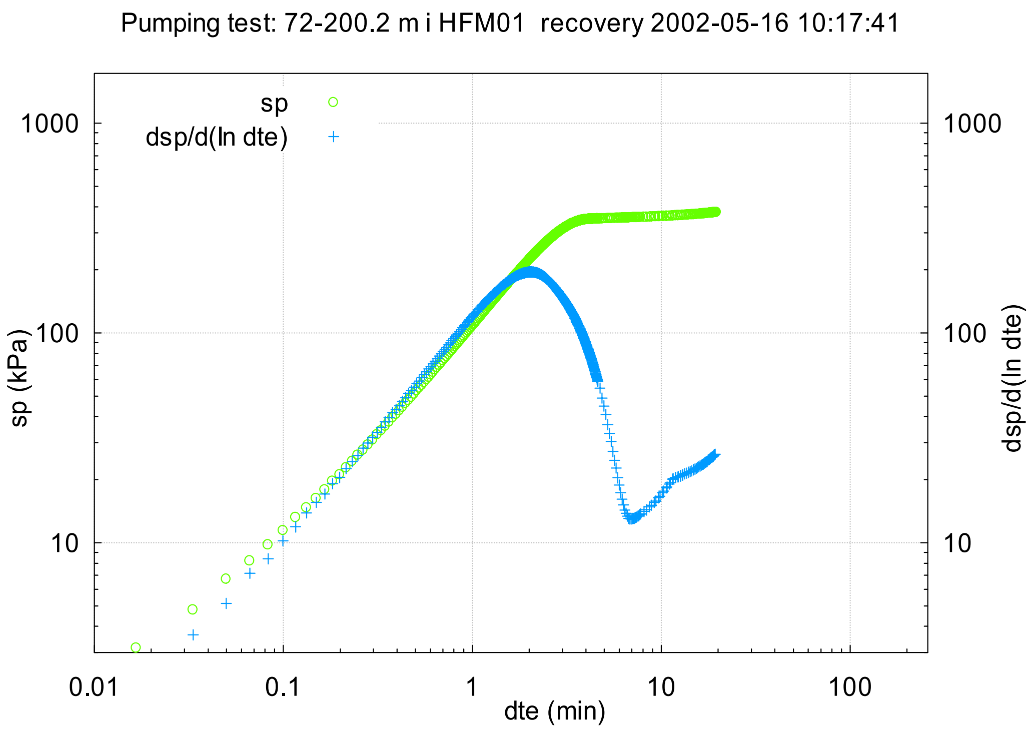


Fig A2-19. *Log-log plot of pressure recovery (sp) and - derivative, dsp/d(ln dte) versus equivalent time (dte) from the pumping test in the interval 72-200.2 m in HFM01.*

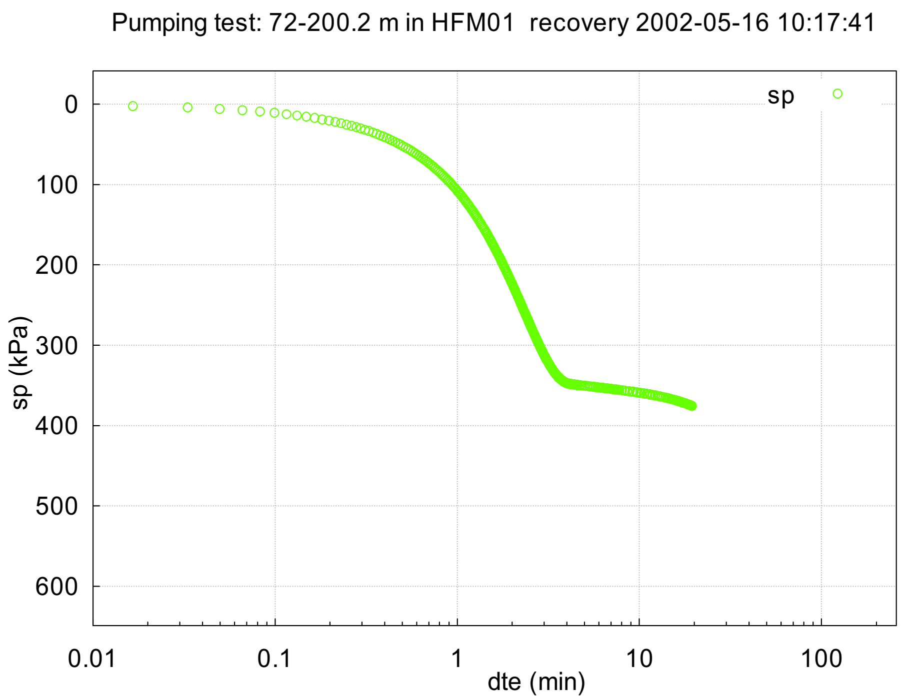


Fig A2-20. *Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the pumping test in the interval 72-200.2 m in HFM01.*

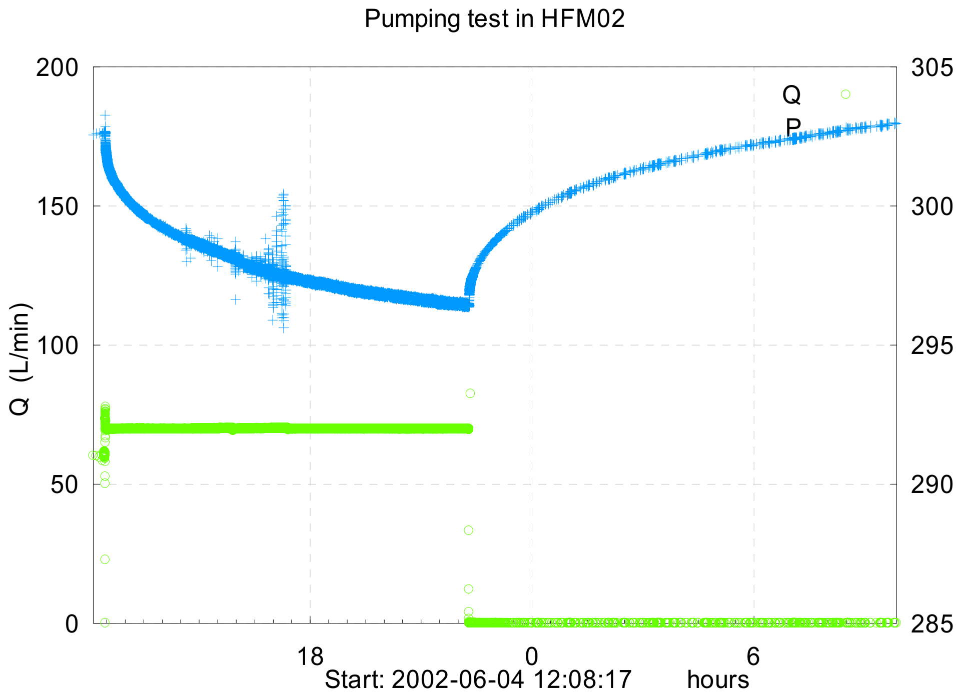


Fig A2-21. Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM02 in conjunction with flow logging.

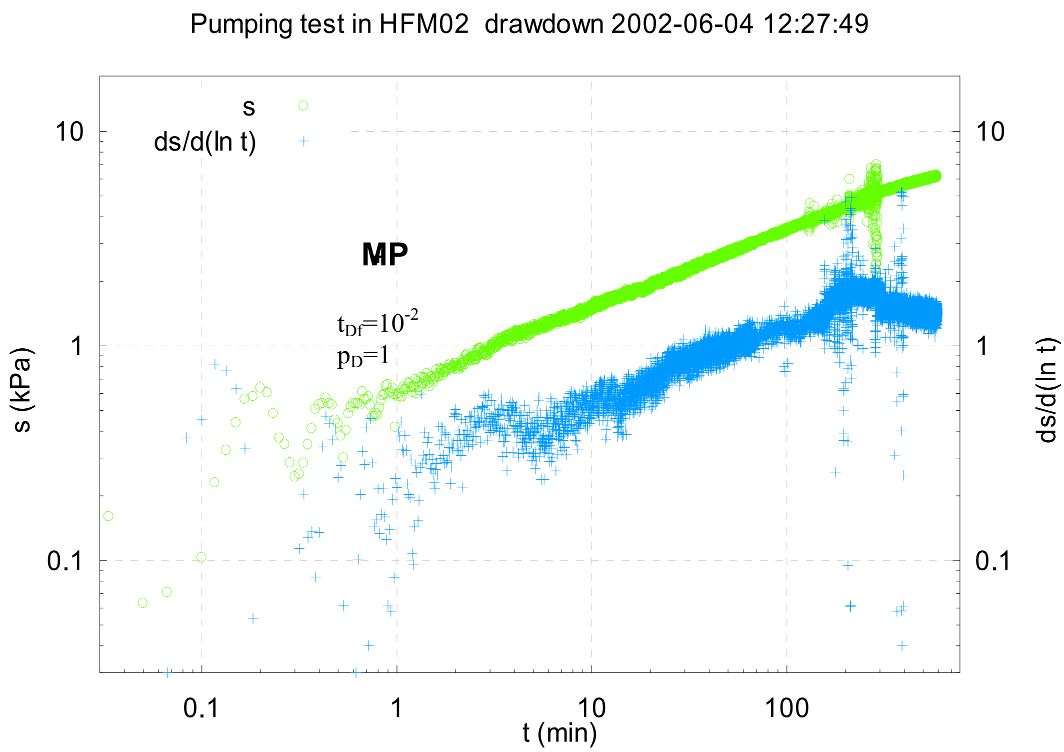


Fig A2-22. Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the open-hole pumping test in HFM02.

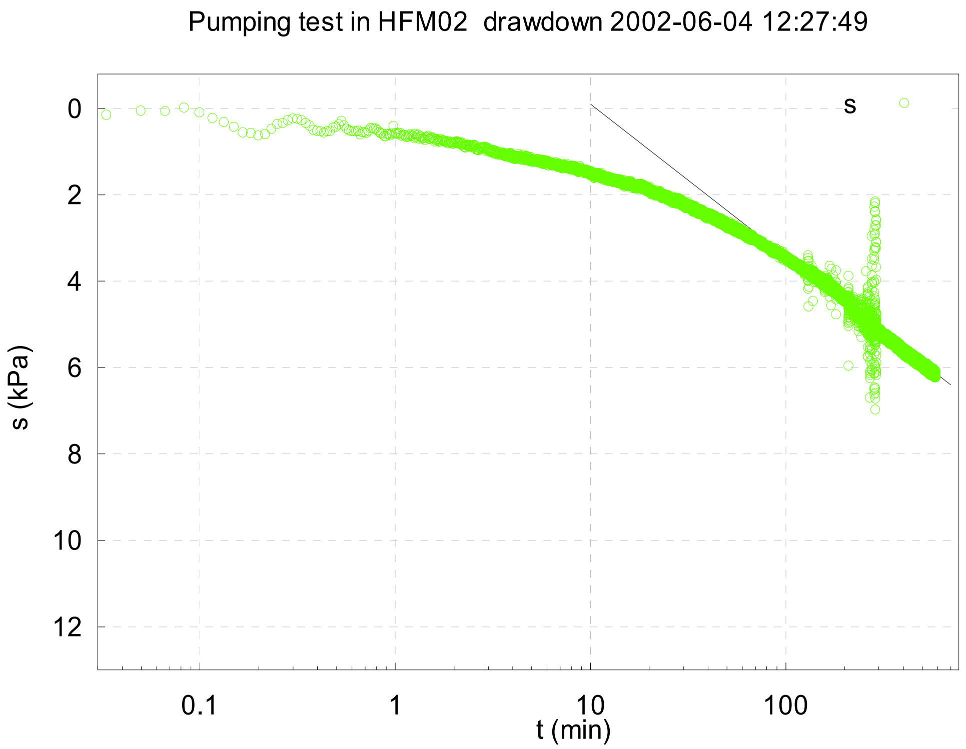


Fig A2-23. *Lin-log plot of drawdown (s) versus time (t) during the open-hole pumping test in HFM02.*

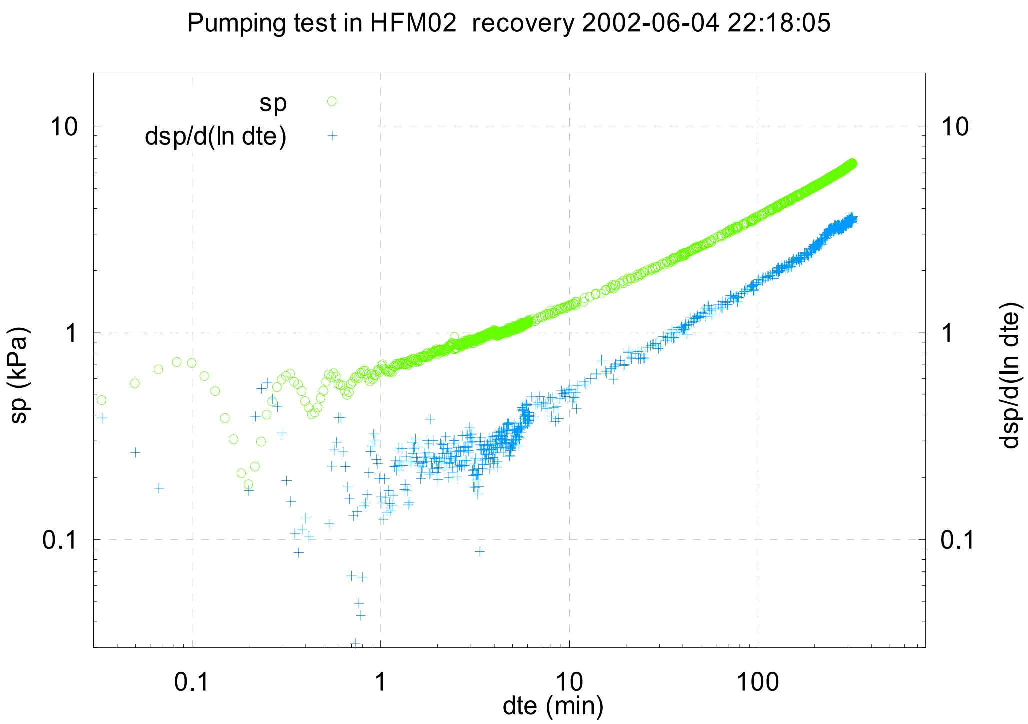


Fig A2-24. *Log-log plot of pressure recovery (sp) and - derivative, dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM02.*

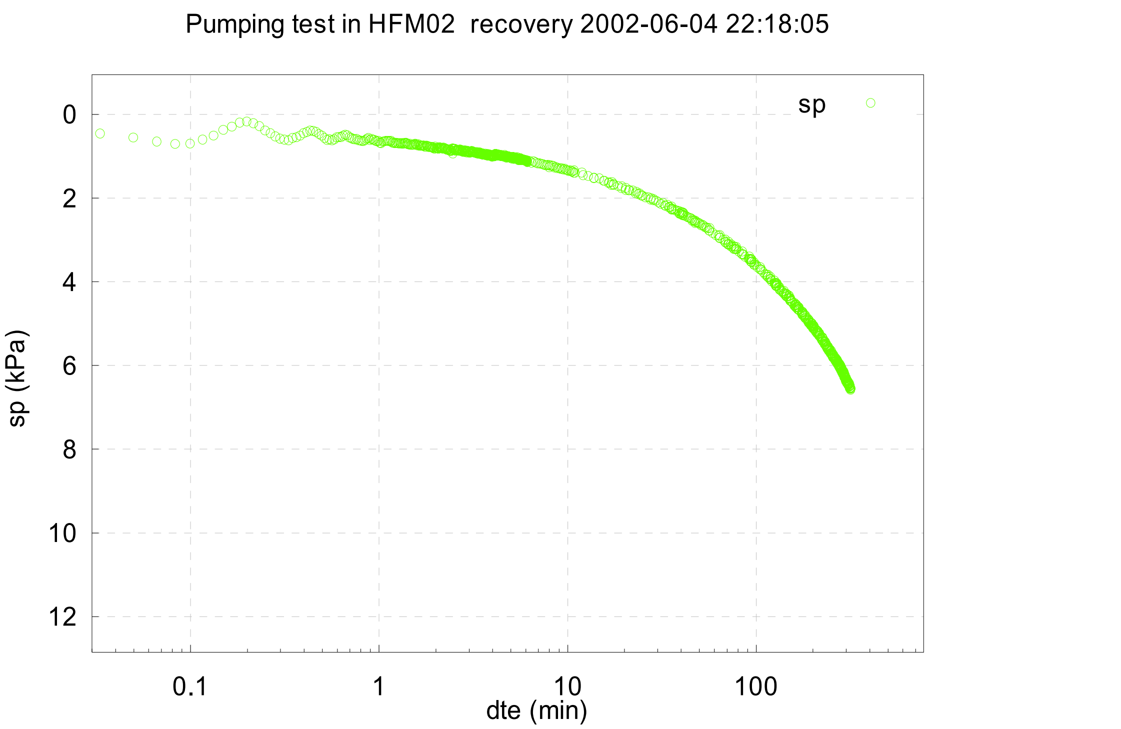


Fig A2-25. *Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the open-hole pumping test in HFM02.*

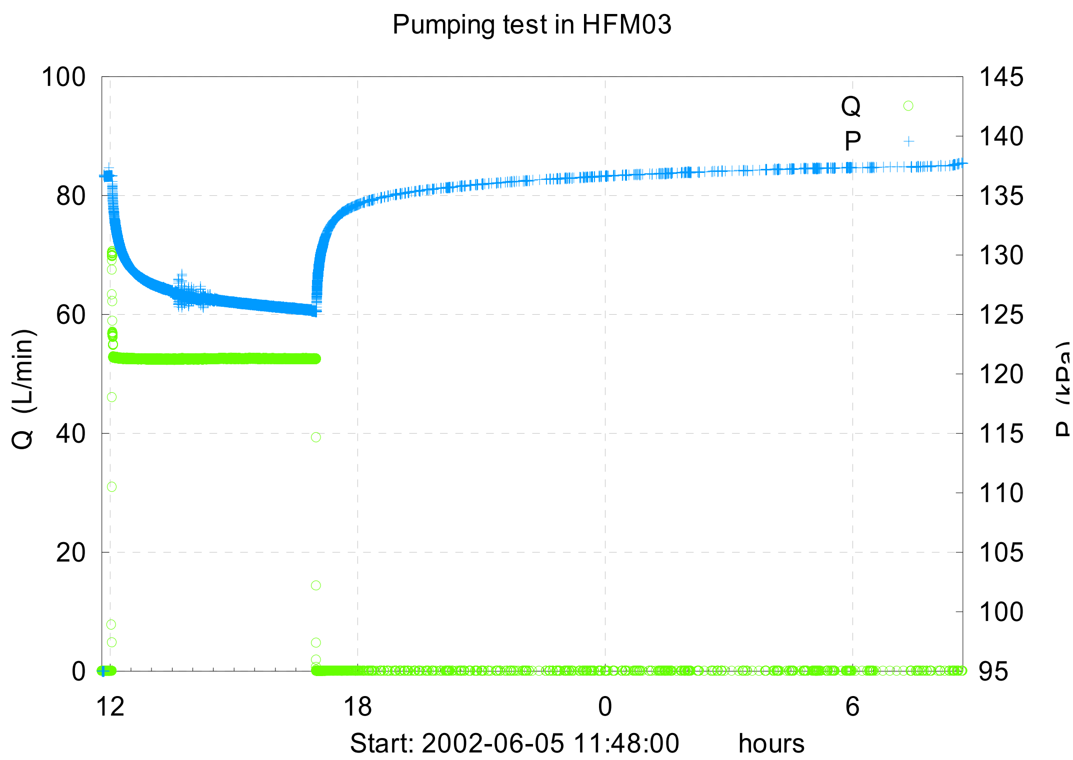


Fig A2-26. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM03 in conjunction with flow logging.*

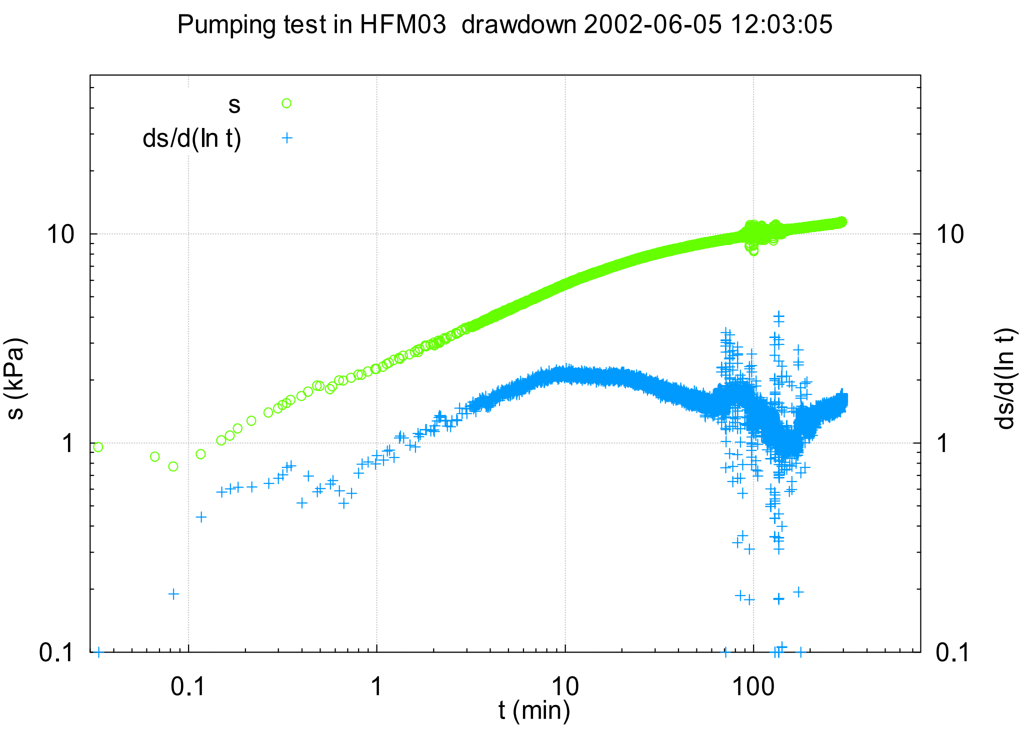


Fig A2-27. *Log-log plot of drawdown (s) and drawdown derivative, ds/d(ln t), versus time (t) during the open-hole pumping test in HFM03.*

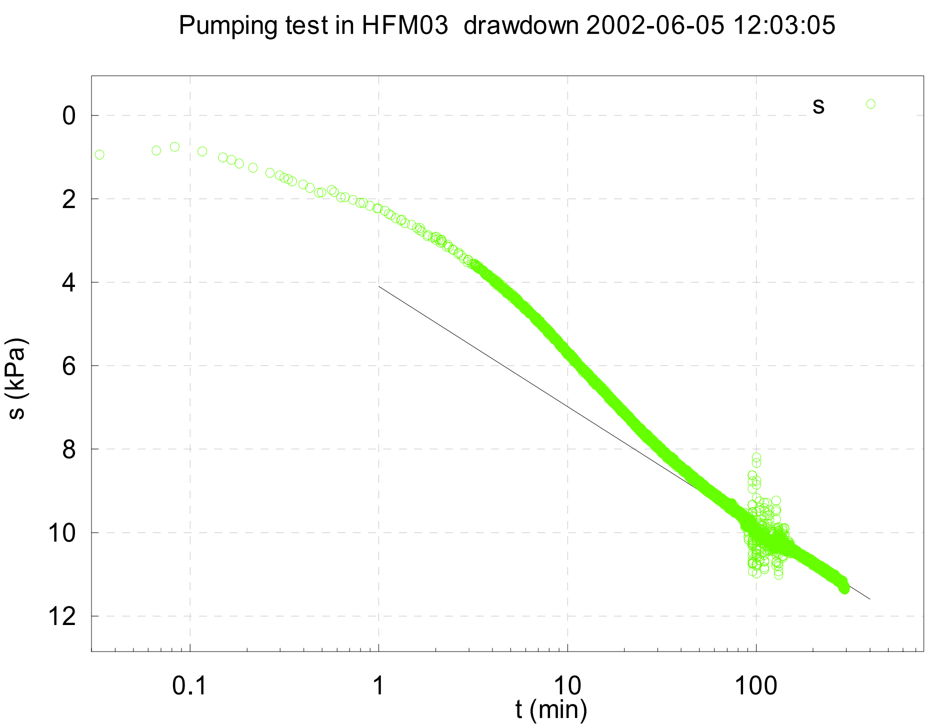


Fig A2-28. *Lin-log plot of drawdown (s) versus time (t) during the open-hole pumping test in HFM03.*

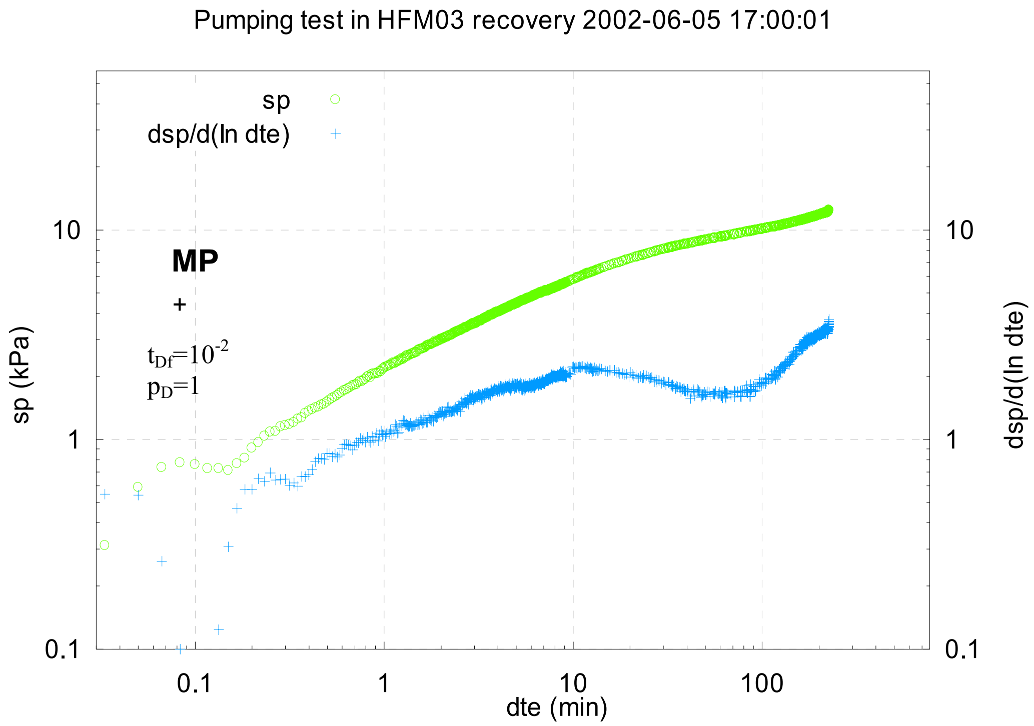


Fig A2-29. Log-log plot of pressure recovery (sp) and - derivative, dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test in HFM03.

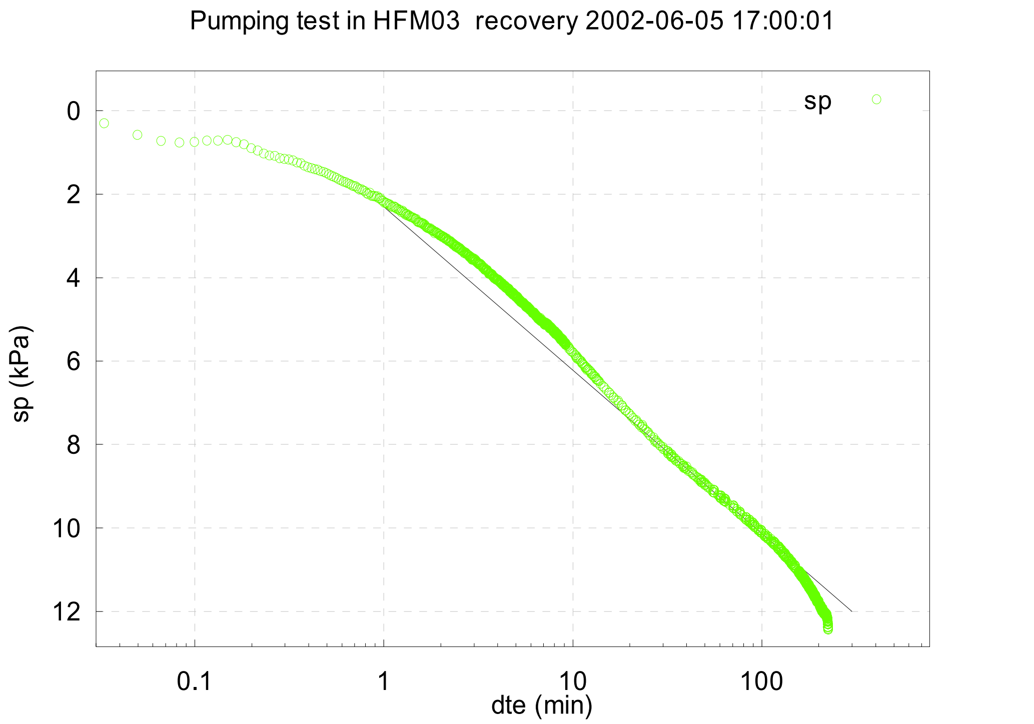


Fig A2-30. Lin-log plot of pressure recovery (sp) versus equivalent time (dte) from the open-hole pumping test in HFM03.

Appendix 3

Result tables to SICADA database

Result tables are presented for the following tests:

A. Result Table for Single hole tests at drillsite DS1 at Forsmark site nvestigation for submission to the SICADA database.

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_d; General information

Borehole	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	Start flow/ injection hhmmss	Stop flow/ injection hhmmss	Qp (m**3/s)	Value type	Q-measl-L (m**3)/s	Q-measl-U (m**3)/s	V_p (m**3)	Q_m (m**3/s)
KFM01A	29.40	100.57	1B	1	20020524 12:08	20020527 08:40	20020524 19:10:15	20020525 15:57:00	1.22E-03	0	8.33E-05	1.33E-03	91.50	
HFM01	31.93	200.20	1B	1	20020514 08:13	20020515 08:52	20020514 08:13:29	20020514 18:28:10	1.00E-03	0	8.33E-05	1.33E-03	36.48	9.89E-04
HFM01	31.93	71.00	1B	1	20020516 15:46	20020516 18:01	20020516 16:24:32	20020516 17:31:00	1.09E-03	0	8.33E-05	1.33E-03	4.40	
HFM01	72.00	200.20	1B	1	20020516 09:46	20020516 11:12	20020516 09:46:45	20020516 10:17:41		-1	8.33E-05	1.33E-03		
HFM02	25.40	100.00	1B	1	20020604 12:08	20020604 17:20	20020604 12:27:49	20020604 22:18:05	1.16E-03	0	8.33E-05	1.33E-03	41.00	
HFM03	13.10	26.00	1B	1	20020605 11:48	20020606 08:40	20020605 12:03:05	20020605 17:00:01	8.75E-04	0	8.33E-05	1.33E-03	15.60	

cont.

tp (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 (-)
74820	146400	0.09	-0.52	0.55	230.8	224.7	235.41					P-03-33	HTHB
36900	44640	0.43	-18.15	0.26	341.65	160.36	340.89					P-03-33	HTHB
3990	1800	0.43			388.89	229.62	387.74					P-03-33	HTHB
1860	3240	0.44			725.24	314.23	690.51					P-03-33	HTHB
35400	41580	0.13			302.6	296.4	302.97					P-03-33	HTHB
17820	56400	0.24			136.6	125.3	137.7					P-03-33	HTHB

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_obs

Borehole	Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YYYYMMDD hh:mm	Upper limit of observation section(m)	Lower limit of observation section (m)	p_{ai} (kPa)	p_{ap} (kPa)	p_{aF} (kPa)	p_{bi} (kPa)	p_{bp} (kPa)	p_{bF} (kPa)
KFM01A	29.40	100.57	20020524 12:08								
HFM01	31.93	200.20	20020514 08:13								
HFM01	31.93	71.00	20020516 15:46	72.00	200.20				775.59	774.03	774.92
HFM01	72.00	200.20	20020516 09:46	31.93	71.00	723.09	723.57	723.58			
HFM02	25.40	100.00	20020604 12:08								
HFM03	13.10	26.00	20020605 11:48								

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 code	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)	T_T (2D) (m^2/ s)	Q/s-measl-L (m^2/ s)	Q/s-measl-U (m^2/ s)	S (2D) (-)	S* (2D) (-)
KFM01A	29.40	100.57	20020524 12:08	2.00E-03	0		2.30E-03	71.17								8.14E-04	2.0E-06	2.0E-03		1.00E-04
HFM01	31.93	200.20	20020514 08:13	5.52E-05	0		7.10E-05	168.27								6.31E-05	2.0E-06	2.0E-03		1.00E-04
HFM01	31.93	71.00	20020516 15:46	6.78E-05	0		6.63E-05	39.07								6.67E-05	2.0E-06	2.0E-03		1.00E-04
HFM01	72.00	200.20	20020516 09:46		-1			128.2									2.0E-06	2.0E-03		
HFM02	25.40	100.00	20020604 12:08	1.88E-03	0		2.20E-03	74.6								5.91E-04	2.0E-06	2.0E-03		1.00E-04
HFM03	13.10	26.00	20020605 11:48	7.74E-04	0		6.84E-04	12.9								4.20E-04	2.0E-06	2.0E-03		1.00E-04

cont.

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 (-)
									-6.93			12000	48000	Fracture flow
						42.5	2.28E-06		-0.44			1200	7200	WBS
							2.46E-06		-1.07			6	3960	WBS
							3.64E-09							Below meas. limit
						43			-7.16			6000	36000	Fracture flow
						21			-3.83			1800	6000	Fracture flow

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 fuction 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
Borehole secup	m	Length coordinate along the borehole for the upper limit of the observation section
Borehole seclow	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

B. Result Table for Flow logging at drill site 1 at Forsmark site investigation for submission to the SICADA database

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	Date and time of flowl., stop YYYYMMDD hh:mm	Q-measl-L (m^3/s)	Q-measl-U (m^3/s)	Q_p (m^3/s)	tp (s)	t_{FL} (s)	h_0 (m a s l)	h_p (m a s l)
HFM01	34	198	6	1	2002-05-14 08:11	2002-05-14 18:28	2002-05-14 10:19	2002-05-14 15:50	5.00E-05	1.67E-03	1.00E-03	36900	19860	0.43	-18.15
HFM02	31	100	6	1	2002-06-04 12:08	2002-06-04 22:18	2002-06-04 14:34	2002-06-04 17:20	5.00E-05	1.67E-03	1.16E-03	35400	9960	0.13	
HFM03	13.1	26	6	1	2002-06-05 11:48	2002-06-05 17:00	2002-06-05 13:13	2002-06-05 14:37	5.00E-05	1.67E-03	8.75E-04	17820	5040	0.24	

cont.

s_{FL} (m)	Reference (-)	Comments (-)
17.7	P-03-33	
0.45	P-03-33	
1.01	P-03-33	

FLOWLOGG-IMPELLER TESTS plu_impell-main_res

Borehole	Borehole secup (m)	Borehole seclow (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} (m**3/s)	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)	Reference (-)	Comments (-)
HFM01	34	198								1.00E-03	1.00E-03	1.00E-03	6.31E-05	6.31E-05	2.00E-06	2.00E-03	P-03-33	bh. diam=140 mm, flow calibr.=140 mm
HFM02	31	100								1.90E-03	1.90E-03	1.16E-03	5.90E-04	5.90E-04	2.00E-06	2.00E-03	P-03-33	bh. diam=137 mm, flow calibr.=140 mm
HFM03	13.1	26								1.75E-03	1.75E-03	8.75E-04	4.20E-04	4.20E-04	2.00E-06	2.00E-03	P-03-33	bh. diam=136 mm, flow calibr.=140 mm

FLOWLOGG-IMPELLER TESTS plu_impeller_anomaly

Borehole	Borehole secup	Borehole seclow	Upper limit	Lower limit	Te_w	EC_w	TDS_w	$deltaQ_i$	$deltaQ_{icorr}$	$deltaQ_{icorr}/s_{FL}$	b_i	T_i	T_i-measl-L	T_i-measl-U	Reference	Comments
	(m)	(m)	L (m)	L (m)	(^{o} C)	(mS/m)	(mg/ L)	(m**3/s)	(m**3/s)	(m**2/s)	(m)	(m^2/ s)	(m^2/ s)	(m^2/ s)	(-)	(-)
HFM01	34	198	34.5	43				7.07E-04	7.07E-04	4.00E-05	8.5	4.50E-05			P-03-33	
HFM01			48	50				8.33E-05	8.33E-05	4.70E-06	2	5.00E-06			P-03-33	
HFM01			60.5	63.5				4.33E-05	4.33E-05	2.40E-06	3	2.50E-06			P-03-33	
HFM01			64	64.5				1.67E-04	1.67E-04	9.40E-06	0.5	1.10E-05			P-03-33	
HFM02	31	100	42	44.5				1.90E-03	1.16E-03	2.58E-03	2.5	5.90E-04			P-03-33	Assumption:Q_T=Q_p
HFM03	13.1	26	21	21.5				1.61E-03	8.05E-04	7.97E-04	0.5	3.86E-04			P-03-33	Assumption:Q_T=Q_p
HFM03			22	22.5				1.42E-04	7.10E-05	7.03E-05	0.5	3.36E-05			P-03-33	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	Lengt coordinate along the borehole for the upper limit of the logged section (Based on corrected length L)
Borehole seclow	m	Lengt 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 flowlogging start (YYYY-MM-DD hh:mm:ss)
date and time, stop	date_s	Date and time of flowlogging stop (YYYY-MM-DD hh:mm:ss)
Test type (1-7)	code_chr_2	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-comb.Sequentia, 5B: Difference flow logging-PFL-DIFF-Overlapping, 6: Flow logging-Impeller 7: Grain size analysis
Formation type	code_chr_2	1: Rock, 2: Soil (supeficial deposits)
Q-measl-L	m^3/s	Estimated lower measurement limit for borehole flow rate in flowlogging probe
Q-measl-U	m^3/s	Estimated upper measurement limit for borehole flow rate in flowlogging probe
Q_p	m^3/s	Flow rate at surface during flowlogging
tp	s	Time for the flowing phase of the test
t_{FL}	s	Duration of the flowlogging survey
s_{FL}	m	Average drawdown of the water level in open borehole during flowlogging
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 lenght)
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 flowlogging (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 lenght)

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 lenght)
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 lenght)
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 lenght)
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 lenght)
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 lenght)
$deltaQ_i$	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	text_30	SKB number for reports describing data and results
Comments	text_50	Short comment on evaluated parameters