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Forsmark site investigation

Pumping tests and flow logging

Boreholes HFM13, HFM14 and HFM15

Jan-Erik Ludvigson, Stig Jönsson, Janette Jönsson
Geosigma AB

May 2004

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

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Abstract

The percussion drilled borehole HFM13 is drilled c 350 m SW of KFM05A with an inclination of 60° with the purpose to investigate possible hydraulic connection between HFM13 and drilling site DS5. The percussion drilled boreholes HFM14 and HFM15 are drilled at drilling site DS5 with the purpose to serve as supply wells during drilling of KFM05A. HFM14 is drilled with an inclination of 60° and HFM15 with an inclination of 45°.

Pumping tests were performed in all three boreholes together with flow logging in HFM13 and HFM15 during November 2003. In HFM14, flow logging was not performed since cavities and fractures below the casing could damage the equipment. In order to confirm the results from the flow logging in HFM13 a short injection test was performed in the upper part of the borehole that could not be measured during the flow logging.

Water sampling was undertaken in all boreholes in conjunction with the pumping tests. 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 HFM13–15 were to investigate the hydraulic characteristics and water chemistry of the boreholes.

In HFM13 two conductive sections were identified with a transmissivity ranging from c $2 \cdot 10^{-5}$ m^2/s to c $3 \cdot 10^{-4}$ m^2/s. The total transmissivity of borehole HFM13 was estimated to $3.1 \cdot 10^{-4}$ m^2/s. The total transmissivity of borehole HFM14 was estimated to $4.7 \cdot 10^{-4}$ m^2/s. In HFM15, four conductive parts were encountered with transmissivities ranging from c $6 \cdot 10^{-5}$ m^2/s to c$1 \cdot 10^{-4}$ m^2/s. The total transmissivity of borehole HFM15 was estimated to $3.2 \cdot 10^{-4}$ m^2/s.

The flow logging showed that these high transmissive sections are narrow, in HFM13 between 1.0–1.5 m wide and in HFM15 between 0.5–1.0 m wide. Since no flow logging was performed in HFM14, no information about the hydraulic intervals is available.

Sammanfattning

Hammarborrhålet HFM13 är borrad ca 350 m SV om borrplats 5 med syfte att undersöka eventuell hydraulisk förbindelse mellan HFM13 och borrplats 5. Hammarborrhålen HFM14 och HFM15 är borrade på borrplats 5 med syftet att användas som spolvatten-brunnar vid borrningen av KFM05A.

Pumptester utfördes i alla tre borrhålen tillsammans med flödesloggning i HFM13 och HFM15. I HFM14 utfördes ingen flödesloggning eftersom det bedömdes att det fanns risk för att utrustningen kunde skadas eller fastna på grund av kaviteter och sprickor belägna strax under casingen. För att bekräfta resultaten från flödesloggningen i HFM13 gjordes en kort injektionstest i den övre delen av borrhålet som inte flödesloggats.

Vattenprover togs i alla borrhålen i samband med pumptesterna. Inga andra tester hade gjorts i borrhålen innan pumptesterna.

De huvudsakliga syftena med de hydrauliska testerna i hammarborrhålen HFM13–15 var att undersöka de hydrauliska och vattenkemiska förhållandena för borrhålen.

I HFM13 påträffades två hydrauliska partier med transmissiviteter mellan ca $2 \cdot 10^{-5}$ m^2/s to ca $3 \cdot 10^{-4}$ m^2/s. Totala transmissiviteten i HFM13 uppskattades till $3.1 \cdot 10^{-4}$ m^2/s. Den totala transmissiviteten i HFM14 uppskattades till $4.7 \cdot 10^{-4}$ m^2/s. I HFM15 påträffades fyra konduktiva sektioner med transmissiviteter mellan ca $6 \cdot 10^{-5}$ m^2/s to ca $1 \cdot 10^{-4}$ m^2/s. Den totala transmissiviten i HFM15 uppskattades till $3.2 \cdot 10^{-4}$ m^2/s.

Flödesloggningen visade att dessa högkonduktiva sektioner är smala, i HFM13 från 1.0 till 1.5 m och i HFM15 från 0.5 till 1.0 m. Eftersom ingen flödesloggning gjordes i HFM14 finns ingen information om hydrualiska zoner i detta borrhål.

Contents

1 Introduction

Three percussion drilled boreholes are drilled in the vicinity of drilling site DS5 see Figure 1-1 and 1-2. HFM13 is drilled c 350 m SW of KFM05A with the purpose to investigate possible hydraulic connection between HFM13 and drilling site DS5 as described in /1/ and /2/. HFM14 and HFM15 which are inclined 60° and 45° respectively from the horizontal plane are drilled at drill site 5.

Pumping tests were performed to investigate hydraulic connection between the actual boreholes and possible connection to the core drilled boreholes. In Figure 1-2 the detailed location of boreholes HFM13-15 is displayed. The location of HFM16 is also shown since activities in this borehole during the test period in HFM13-15 might have affected the test response in HFM14. In addition, flow logging was performed in HFM13 and HFM15 but not in HFM14 due to cavities and fractures below casing that prevented equipment from being lowered in the borehole without risks of damaging the equipment. Water sampling was conducted in all three boreholes in conjunction with the tests. No other borehole tests had been carried out in the actual boreholes before this campaign.

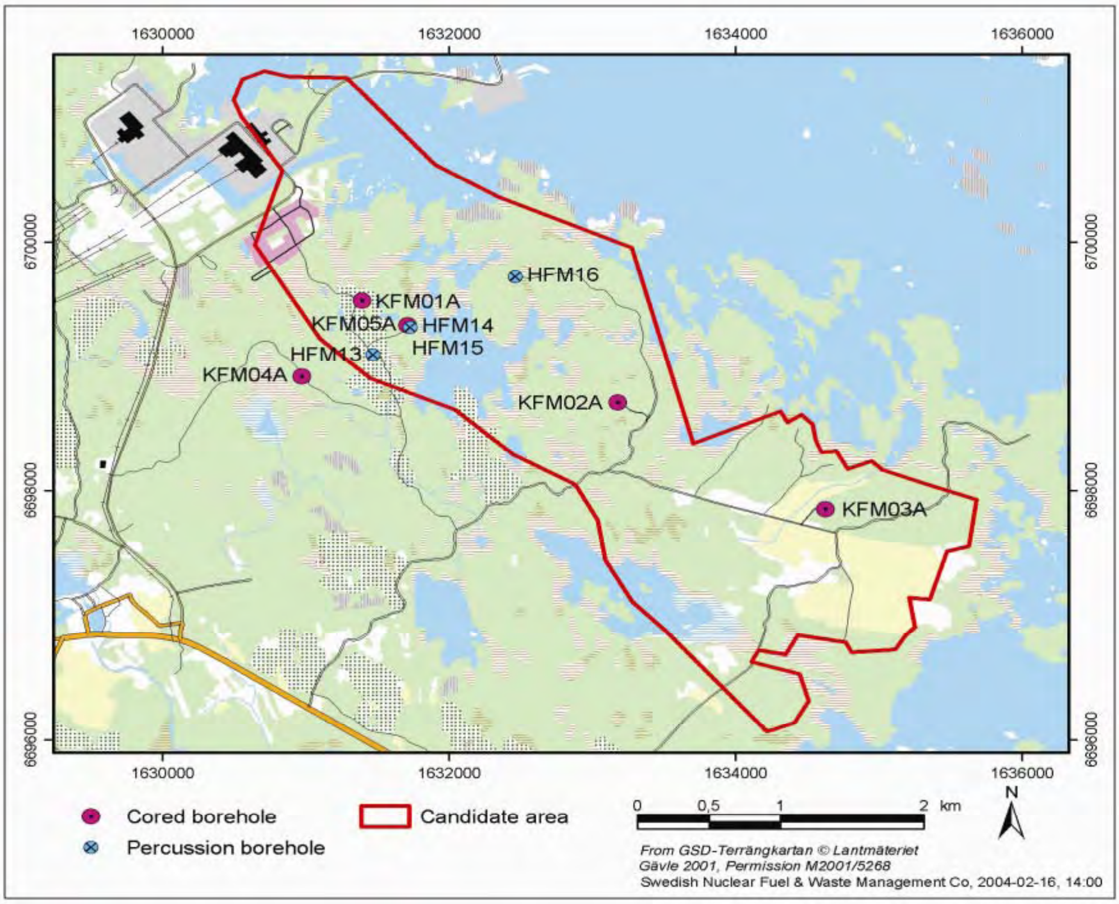


Figure 1-1. *The investigation area at Forsmark including the candidate area selected for more detailed investigations.*

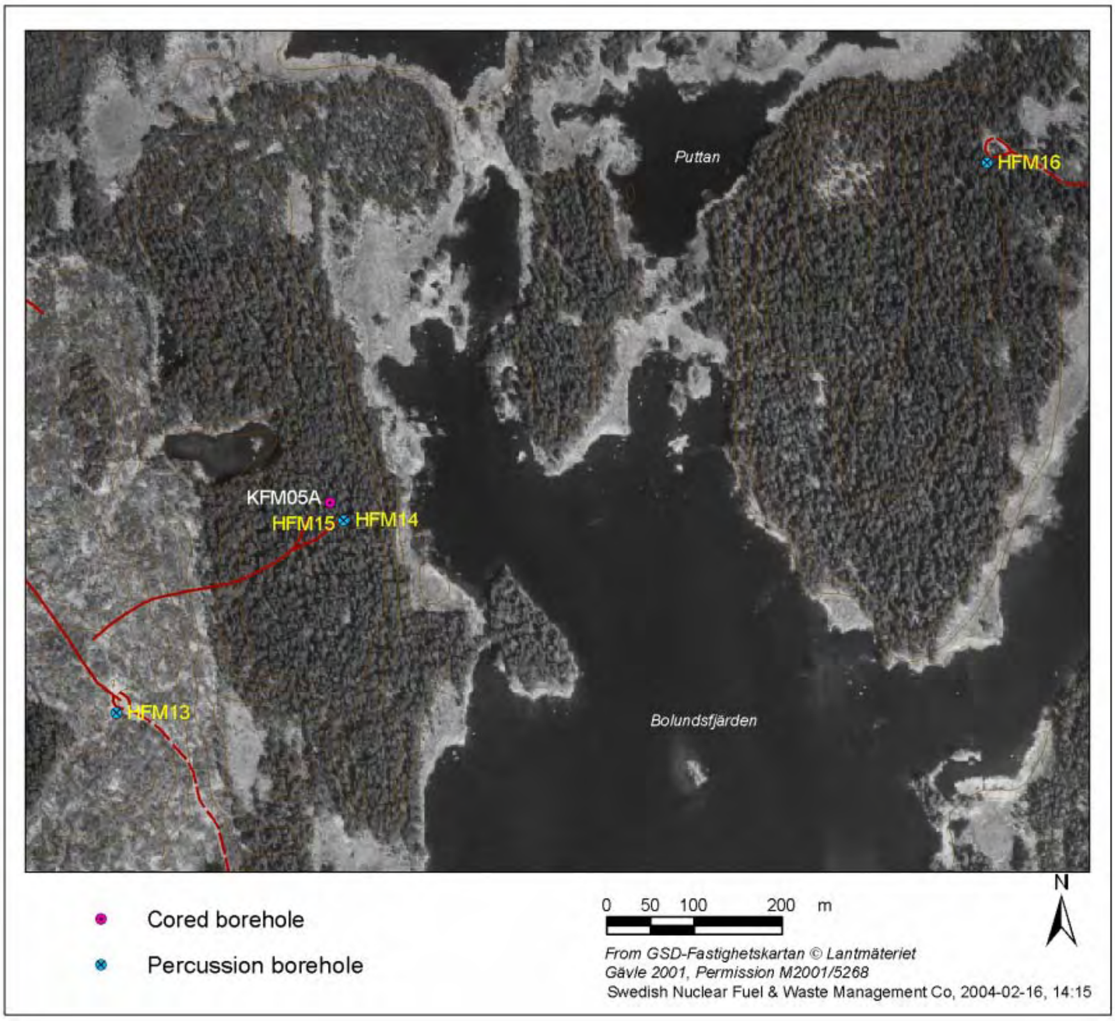


Figure 1-2*. Map showing the location of HFM13, HFM14, HFM15 and HFM16 at Forsmark.*

This document reports the results gained by the *Hydraulic testing of boreholes HFM13, HFM14 and HFM15*. The activity is performed within the Forsmak site investigation. The work was carried out in accordance to SKB internal controlling documents, see Table 1-1. Data and results were delivered to the SKB site characterization database SICADA with field note number: Forsmark 254.

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

Activity Plan	Number	Version
Hydraulic testing and water sampling in HFM13, HFM14 and HFM15	AP PF 400-03-95	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hydrauliska enhålspumptester	SKB MD 321.003	1.0
Metodbeskrivning för flödesloggning.	SKB MD 322.009	1.0
Mätsystembeskrivning för HydroTestutrustning för Hammarborrhål. HTHB	SKB MD 326.001	1.0
Metodbeskrivning för injektionstester	SKB MD 323.001	1.0

2 Objectives

The main objectives of the single-hole pumping tests and flow logging in HFM13, 14 and 15 were to:

- Identify the position and size of inflow sections in the boreholes.
- Estimate the transmissivity of flow anomalies and of the entire boreholes.
- Study the water chemistry of the boreholes.

3 Scope

3.1 Boreholes tested

Selected technical data of the boreholes tested are displayed in Table 3-1. The reference point in the boreholes is always top of casing (ToC). The Swedish National coordinate system (RT90 2.5 gon W) is used in the x-y-direction together with RHB70 in the z-direction. The reported borehole diameter along the borehole is shown in Table 3-1. The borehole diameter (measured as the diameter of the drill bit) may change along the borehole due to wearing of the drill bit or change of drill bit.

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

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

Borehole data							
Bh ID	**Elevation of top of casing (ToC) (m.a.s.l.)**	**Borehole interval from ToC (m)**	**Casing/ Bh-diam. (m)**	**Inclination-top of bh (from horizontal plane) (°)**	**Dip-direction-top of borehole (from local N) (°)**	**Remarks**	**Drilling finished Date (YYYY-MM-DD)**
HFM13	5.687	0–14.9	0.160	–58.845	51.194	Casing ID *	2003-10-02
		14.9–101.0	0.138			borehole	
		101.0–152.4	0.137			borehole	
		152.4–175.6	0.135			borehole	
HFM14	3.912	0.00–3.1	0.158	–59.810	331.748	Casing ID *	2003-10-09
		3.1–101.3	0.138			borehole	
		101.3–150.5	0.136			borehole	
HFM15	3.878	0.00–6.00	0.160	–43.700	314.305	Casing ID *	2003-10-15
		6.00–99.5	0.139			borehole	

* Casing ID=inner diameter of casing

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

Borehole data		
Bh ID	**Northing (m)**	**Easting (m)**
HFM13	6699093.678	1631474.404
HFM14	6699313.139	1631734.586
HFM15	6699312.444	1631733.081

3.2 Tests performed

Table 3-3. Borehole tests performed.

Borehole tests				
Bh ID	**Test section (m)**	**Test type[1]**	**Test start date and time (YYYY-MM-DD tt:mm)**	Test stop date and time (YYYY-MM-DD tt:mm)
HFM13	14.9–175.6	1B	2003-11-17 08:11:07	2003-11-18 09:36:24
	18.5–162	6, L-Te, L-EC	2003-11-17 13:05:30	2003-11-17 17:00:48
	14.9–18.5	3	2003-11-18 18:45:55	2003-11-18 19:54:38
HFM14	3.1–150.5	1B	2003-11-05 08:27:24	2003-11-06 11:10:48
HFM15	6.0–99.5	1B	2003-11-12 08:00:00	2003-11-13 10:27:32
	19–95	6, L-Te, L-EC	2003-11-12 15:22:07	2003-11-12 18:40:28

1) 1B: Pumping test-submersible pump, 2: Interference test, 3: Injection test, 6: Flow logging–Impeller, L-EC: EC-logging, L-Te: temperature logging,

During the pumping tests, water samples were collected and analysed /6/. Manual observations of the groundwater level in the pumped boreholes were also made during the tests.

3.3 Equipment check

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

To check the function of the pressure sensors P1 and P2 (cf Figures 4-1 and 4-2), the pressure in air was recorded and found to be as expected. Submerged in water while lowering, P1 coincided with the total head of water (p/ρg). 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 to the premeasured cable length.

4 Description of equipment

4.1 Overview

The equipment used in these tests is referred to as HTHB (Swedish abbreviation for Hydraulic Test System for Percussion Boreholes). The HTHB unit is designed for percussion boreholes to perform pumping- and injection tests in open boreholes (or above a single packer), see Figure 4-1 and 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 constant hydraulic head or, alternatively, with constant flow rate. For injection tests, however, the upper packer can not be located deeper than c 80 m due to limitations in the number of pipes available.

All equipment that belongs to the HTHB is, when not in use, stored on a trailer and can be easily transported with a standard car. The equipment used in the borehole includes 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 down-hole flow rate are also employed. At the top of the borehole the total flow/injection rate is manually adjusted by a control valve and monitored by an electromagnetic flow meter. A data logger samples data at a frequency determined by the operator.

The packers are normally expanded by water (nitrogen gas is used to pressurize the water) unless the depth to the groundwater level is large. In such cases, the packers are expanded by nitrogen gas. A folding pool is used to collect and store the discharged water from the borehole for subsequent use in injection tests.

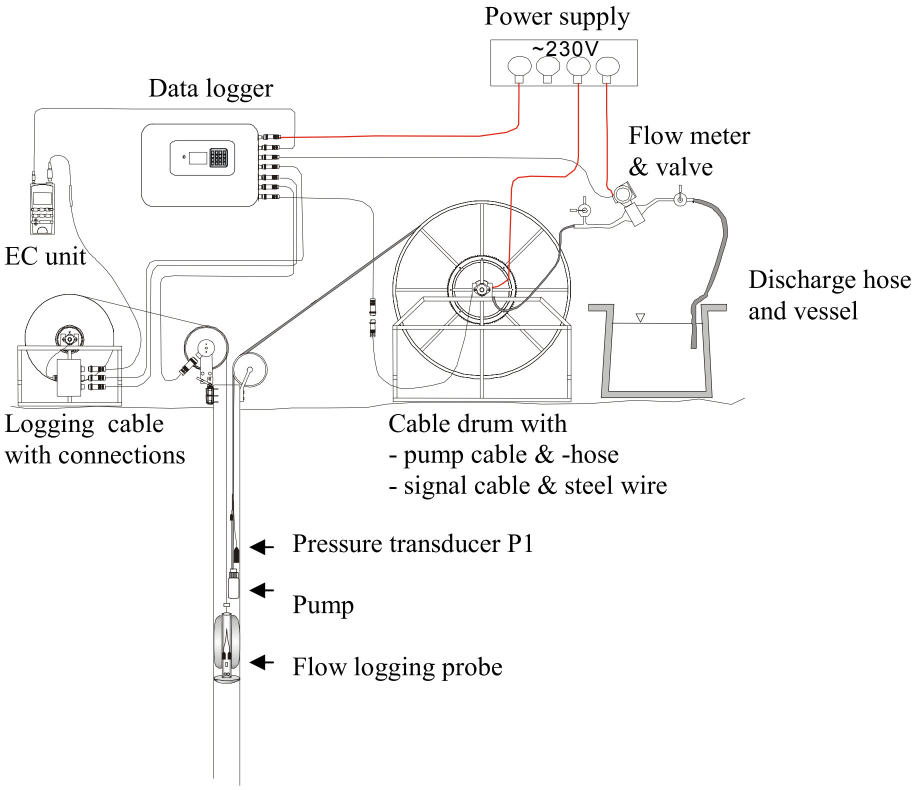


***Figure 4-1**. Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB. (SKB internal document: SKB MD 362.001)*

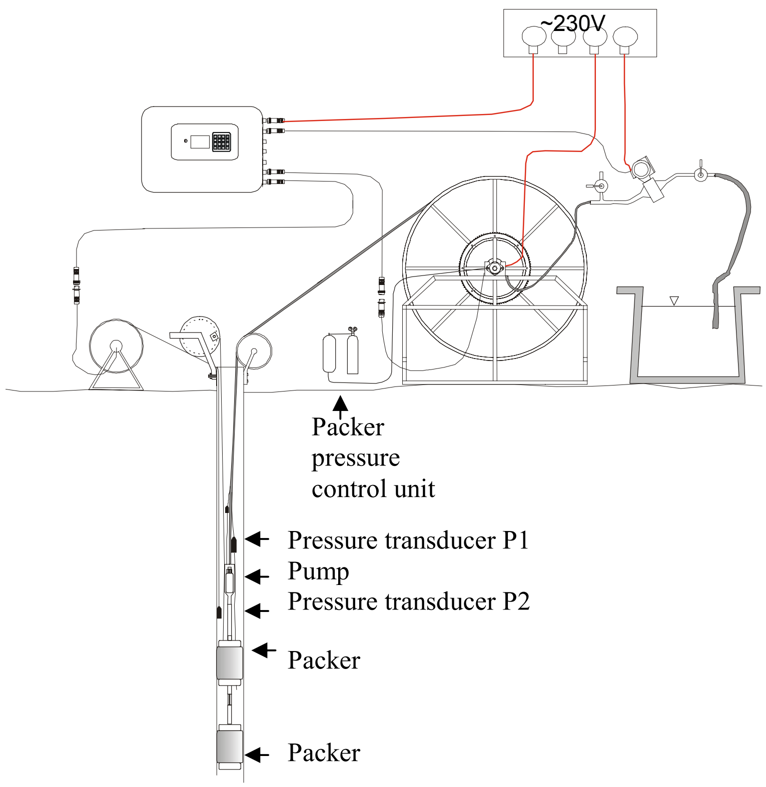


***Figure 4-2.** Schematic test set-up for a pumping test in an isolated borehole section with HTHB. Additional equipment details are described in Figure 4-1. (SKB internal document: SKB MD 362.001)*

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.

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		
	Accur<acy	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 and 100 s sampling time
	Accuracy***	% o.r.**		±20	
Flow (surface)	Output signal	mA	4–20		Passive
	Meas. range	L/min	1–150	5-c. 80****	Pumping tests
	Resolution	L/min	0.1	0.1	
	Accuracy	% o.r.**	±0.5	±0.5	

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

Errors in reported borehole data (diameter etc) may significantly increase the error in measured data. For example, the flow logging probe is very sensitive to variations in the borehole diameter, cf Figure 4-3. Borehole deviation and uncertainties in the borehole inclination may also affect the accuracy of measured data.

The flow-logging probe is calibrated for different borehole diameters (in reality 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 how sensible the probe is to deviations in the borehole diameter, cf Figure 4-3.

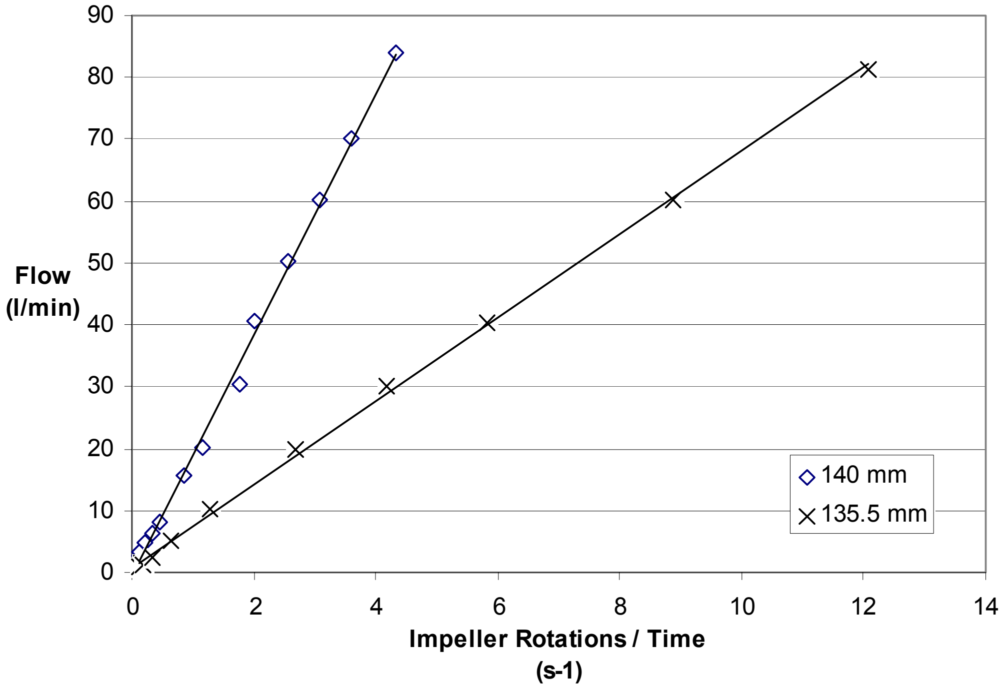


***Figure 4-3**. Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).*

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

Table 4-2 presents the position of sensors for each test. The following 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 placed 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 item. 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 4-1) 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 configuration**	**Test type[1]**	**Type**	**Position (m b ToC)**	**Function**	**Position[2] relative test section**	**Outer diameter (mm)**	**C (m^3/Pa) for actual test[3)]**
HFM13	14.9–175.6	Open hole	1B	Pump-intake	14.2	Pump	In borehole		$2.0\cdot10^{-6}$
						Pump hose	In borehole	33.5	(based on the casing diameter of 160 mm)
						Pump cable	In borehole	14.5	
		Open-hole	1B		11.52	Signal cable	In borehole	8	
	18.5–162	closed section	6	P (P1)	18.5–162	Signal cable	In borehole	13.5	
				EC, Te, Q		Tecalan hose	In borehole	6	
	14.9–18.5		3		9.02	Steel wire	In borehole	6	
				P (P2)					
HFM14	3.1–150.5	Open hole	1B	Pump-intake	16.4	Pump	In borehole		$1.5\cdot10^{-6}$
						Pump hose	In borehole	33.5	(based on the borehole diameter of 138 mm)
						Pump cable	In borehole	14.5	
						Signal cable	In borehole	8	
						Signal cable	In borehole	13.5	
						Tecalan hose	In borehole	6	
						Steel wire	In borehole	6	
HFM15	6.0–99.5	Open hole	1B	Pump-intake	14.4	Pump	In borehole		$1.5\cdot10^{-6}$
						Pump hose	In borehole	33.5	(based on the borehole diameter of 139 mm)
						Pump cable	In borehole	14.5	
			1B		11.72	Signal cable	In borehole	8	
	19–95		6	P (P1)	19–89	Signal cable	In borehole	13.5	
				EC, Te, Q		Tecalan hose	In borehole	6	
						Steel wire	In borehole	6	

1) 1B:Pumping test-submersible pump, 6: Flow logging–Impeller incl. EC-logging (EC-sec) and temperature logging (Te-sec), 3:Injection test.
2) Position of equipment that can affect wellbore storage. Position given as “In Section” or “Above Section” or “In borehole”
3) Based on the actual borehole diameter or casing diameter for open-hole tests (net values)

5 Execution

5.1 Preparations

All sensors included in the HTHB system were calibrated at Geosigma engineering workshop in Librobäck, Uppsala. Calibration is performed on a yearly basis, or more often if needed. Last calibration of spinner and flow meter was performed in March 2003, sensor for electrical conductivity in May 2003, wheel for length measurements in June 2003 and pressure sensors together with temperature sensor in November 2003.

Before the tests, functioning checks and cleaning of equipment together with time synchronisation of clocks and data loggers were performed according to the Activity Plan. No errors were detected during these checks.

5.2 Procedure

5.2.1 Overview

The pumping tests were carried out as single-hole, constant flow rate tests in HFM13, 14 and 15 followed by a pressure recovery period. The pumping phase was in all three boreholes followed by a recovery phase. The intention was to obtain approximately steady-state conditions in the borehole during the flow logging.

The flow logging was performed while pumping. The flow measurements were performed from the bottom and upwards along the borehole. The position of the anomaly is determined with an accuracy of c 0.5m. After the first anomaly was measured at the bottom of the borehole 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 test, in HFM15 a short flow capacity tests were carried out to select an appropriate flow rate for the tests. Capacity test was not performed in HFM14 due to the problems caused by the cavities and fractures below the casing. Neither in HFM13 was a capacity test performed. The drilling records indicated high inflows in the borehole. This information was considered sufficient for the choice of an appropriated flow rate for the pumping tests. All pumping tests and flow meter logging were performed after the boreholes were drilled to full depth, 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 borehole in combination with flow logging, followed by a recovery period of c 12 h. In general, the sampling frequency of pressure during the pumping tests was according to Table 5-1. The single-hole hydraulic tests in the boreholes were performed in the following order of time: HFM14, HFM15 and HFM13.

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

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

Flow logging

Before start of the flow logging, the probe was lowered to the bottom of the borehole. While lowering along the borehole (max. speed=0.5 m/s), temperature- and electric conductivity data were sampled. The probe was halted (15 s) at every two metres to sample data with a sampling 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 started when the pressure in the borehole was approximately stable. The time needed to complete the flow logging survey depends on the length and character of the borehole. In general, between 3–7 hours is normal for a percussion borehole of 100–200 m length. In HFM13 the flow logging lasted c 4h and in HFM15 c 3.5 h.

Flow logging can only be carried out up to a certain distance below the submersible pump (when logging is performed from the bottom of the borehole and upward). The remaining part of the borehole (i.e. from the pump to the casing shoe) can not be flow-logged, although high capacity 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. In order to check such superficial flow anomalies, short injection tests are sometimes carried out by the HTHB system in c 5 m long sections above the flow logged interval.

5.3 Data handling

Data are downloaded from the logger (Campbell CR 5000) to a laptop with the program PC9000 and are, already in the logger, transformed to engineering units. All files are comma-separated (*.DAT) when copied to a computer. Data files used for transient evaluation are further converted to *.mio-files by the code Camp2mio. The operator can choose the parameters to be included in the conversion (normally pressure and discharge). Data from the flow logging are evaluated in Excel and therefore not necessarily transformed to *.mio-files. A list of the data files from the data logger is shown 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 Instruction for analysis of injection- and single-hole pumping tests (SKB MD 320.004) 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 test was perfomed as a constant flow rate test followd by pressure recovery periods. Firstly, a qualitative evaluation of actual flow regimes (wellbore storage, pseudo-linear, pseudo-radial and pseudo-spherical flow, respectively) and possible outer boundary conditions during the tests was performed. The qualitative evaluation was made from analyses of log-log diagrams of drawdown and/or recovery data together with the corresponding pressure derivatives versus time. In particular, pseudo-radial flow is reflected by a constant (horizontal) derivative in the diagrams. Pseudo-linear and pseudo-spherical flow is reflected by a slope of the derivative of 0.5 and –0.5, respectively in a log-log diagram. No-flow- and constant head boundaries are reflected by a rapid increase and decrease of the derivative, respectively.

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

If possible, transient analysis was applied on both the drawdown- and recovery phase of the tests. The recovery data were plotted versus equivalent time. Transient analysis of drawdown- and recovery data was generally made in both log-log and lin-log diagrams as described in the above Instruction and in /3/ and /4/. In addition, a preliminary steady-state analysis (e.g. Moye's formula) was used for all tests for comparison.

The transient analysis was performed using a special version of the aquifer test analysis software AQTESOLV which enables both visual and automatic type curve matching with different analytical solutions for a variety of aquifer types and flow conditions. The evaluation is carried out as an iterative process of type curve matching and non-linear regression on the test data. For the flow period as well as the recovery period of the actual tests, a model presented by Dougherty-Babu (1984) /5/ for constant flow rate tests with radial flow, accounting for wellbore storage and skin effects, was generally used for estimating transmissivity, storativity and skin factor for actual values on the borehole- and casing radius. The software also includes models for discrete fractures intersecting the borehole causing pseudo-linear flow.

The effective casing radius may also be estimated by the regression analysis. The wellbore storage coefficient can be calculated from the actual or simulated effective casing radius, see below. The model uses the effective wellbore radius concept to account for negative skin factors. AQTESOLV also includes models for discrete fractures (horizontal and vertical, respectively) intersecting the borehole, causing pseudo-linear flow.

Rather than assuming a fixed value of the storativity of $1 \cdot 10^{-6}$ by the analysis according to the instruction SKB MD 320.004 (SKB internal document) the storativity was estimated from each test by type curve matching. This is considered justified in this case since all tests were performed in the upper part of the bedrock in which part higher storativity sometimes may be relevant. The nomenclature used for the simulations with the AQTESOLV code is presented in the beginning of Appendix 2.

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

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

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

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

5.4.2 Flow logging

The measured parameters during the flow logging (flow, temperature and electric conductivity of the borehole fluid) were firstly plotted versus borehole length. From these plots, flow anomalies were identified along the borehole, i.e. borehole intervals over which changes of flow higher than c 1 L/min, in this case, 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. If the actual borehole diameter differs from the one assumed by the calibration of the flow probe, corrections of the borehole flow rate may be nessesary, cf Figure 4-3.

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

$$T_{FT} = \Sigma T_i = T \cdot Q_T/Q_p \qquad (5\text{-}2)$$

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 (dQ_i) at the anomaly and the calculated transmissivity of the entire borehole (T) according to /2/:

$$T_i = T \cdot dQ_i/Q_p \qquad (5\text{-}3)$$

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

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

$$T_F (L) = T \cdot Q(L)/Q_p \qquad (5\text{-}4)$$

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):

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

In a 140 mm borehole, Q_{min} = 3 L/min ($5 \cdot 10^{-5}$ m^3/s, see Table 4-1, whereas Q_p is the actual flow rate during flow logging. The upper measurement limit of borehole transmissivity is estimated from Equation. (5-5) with Q_{max} = 100 L/min ($1.7 \cdot 10^{-3}$ m^3/s), cf Table 4-1.

Similarly the lower measurement limit of transmissivity of a flow anomaly can be estimated from Equation. (5-3) using dQ_i (min) = 1 L/min ($1.7 \cdot 10^{-5}$ m^3/s) which is considered as the minimal change in borehole flow rate to identify a flow anomaly. The upper measurement limit of transmissivity of a flow anomaly is estimated from Equation. (5-3) with Q_{max} = 100 L/min.

5.5 Nonconformities

The test program performed in the boreholes was mainly according to the Activity Plan. Compared to the Methodology Description for single-hole pumping tests SKB internal document SKB MD 321.003 Version 1.0, some deviations were made regarding the recommended test times:

The recommended test time (24 h+24 h for drawdown/recovery) for the longer tests during flow logging was decreased to c10 h +12 h due to practical reasons (mainly to avoid uncontrolled pumping over-night and to eliminate the risk of freezing, theft/sabotage etc.). Experience from similar tests 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.

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 SKB internal documents: Instruction for analysis of single-hole injection- and pumping tests (SKB MD 320.004), Version 1.0 and Methodology description for flow logging (SKB MD 322.009), Version 1.0 cf Section 3.2. Additional symbols used are explained in the text. The nomenclature for the analyses by the AQTESOLV code is presented in Appendix 2.

6.2 Water sampling

The water samples collected during the pumping tests in the boreholes and submitted for analysis are listed in Table 6-1. The analyses are presented in /6/.

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

Bh ID	Date and time of sample	Pumped section (m)	Pumped volume (m^3)	Sample type	Sample ID no	Remarks
HFM13	2003-11-17 10:31	14.9–175.6	7.7	WC080	8130	Open-hole test
	2003-11-17 14.30	14.9–175.6	24	WC080	8129	Open-hole test
	2003-11-17 17:56	14.9–175.6	36	WC080	8128	Open-hole test
HFM14	2003-11-05 10:24	3.1–150.5	5.4	WC080	8095	Open-hole test
	2003-11-05 15:09	3.1–150.5	18	WC080	8094	Open-hole test
	2003-11-05 18:40	3.1–150.5	36	WC080	8093	Open-hole test
HFM15	2003-11-12 09:10	6–99.5	1.8	WC080	8125	Open-hole test
	2003-11-12 15:00	6–99.5	23	WC080	8126	Open-hole test
	2003-11-12 18:30	6–99.5	35	WC080	8127	Open-hole test

6.3 Single-hole pumping tests

Below, the results of the pumping tests are presented test by test. The barometric pressure and precipitation was monitored at the site during the testing periods. No corrections of measured data, e.g. for changes of the barometric pressure or tidal fluctuations, have been made prior to the analysis of the data. For the actual single-hole tests such corrections are generally not needed considering the rather short test time and relatively large drawdown applied in the boreholes. However, for longer tests with a small drawdown applied, such corrections may be necessary.

Drilling records were checked to identify possible interference on the hydraulic test data from drilling or other activities in nearby boreholes during the test periods. These records showed that some drilling and/or pumping activities were in progress at drilling site DS1 (KFM01B), at drilling site DS6 (HFM16) and at drilling site DS4 (air-lift pumping in KFM04) during the actual test periods, cf Table 6-2. Especially the hydraulic tests in boreholes HFM14 and HFM15 were probably affected by the activities in HFM16 and KFM01B, respectively.

Table 6-2. Activities in nearby boreholes during the hydraulic test periods in HFM13–15. (From SICADA)

Hydraulic tests Pumping Bh ID	Hydraulic test period (drd+rec)	Reported drilling activity in borehole interval	Time period
HFM13	20031117 08:11 to 20031118 09:36	KFM01B: Drilling of c 440–452 m	20031117 12:27 to 18:05
		KFM01B: Drilling of c 452–	20031118 08:05 to c 14
		KFM04A: Air lift pumping	20031106 to 20031124
HFM14	20031105 08:27 to 20031106 11:11	HFM16: Pumping in 0–12 m +rec.	20031105 during daytime
		HFM16: Drilling, water at c 41.2 m	20031106 07:45 to c 14
		KFM01B: Drilling at c 410 m	20031106 c 09–09:30
HFM15	20031112 08:40 to 20031113 10:27	KFM01B: Drilling at c 414 m	20031112 c 12
		KFM04A: Air-lift pumping	20031106 to 20031124

6.3.1 Borehole HFM13

General test data for the open-hole pumping test in borehole HFM13 in conjunction with flow logging are presented in Table 6-3.

Table 6-3. General test data for the open-hole pumping test in HFM13 in conjunction with flow logging.

General test data			
Borehole	HFM13		
Test type[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	Open borehole		
Test No	1		
Field crew	J. Jönsson, c Hjerne (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comment	Single hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	175.6
Casing length	L_c	m	14.9
Test section – secup	Secup	m	14.9
Test section – seclow	Seclow	m	175.6
Test section length	L_w	m	160.7
Test section diameter	$2 \cdot r_w$	mm	top 138 bottom 135
Test start (start of pressure registration)		yymmdd hh:mm:ss	031117 08:11:07
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	031117 08:21:01
Stop of flow period		yymmdd hh:mm:ss	031117 18:21:34
Test stop (stop of pressure registration)		yymmdd hh:mm:ss	031118 09:36:24
Total flow time	t_p	min	600
Total recovery time	t_F	min	938.4

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

Pressure and groundwater level data

Pressure data	Nomen-clature	Unit	Value	GW level (m a s l)
Absolute pressure in borehole before start of flow period	p_i	kPa	146.3	0.507
Absolute pressure in test section before stop of flow period	p_p	kPa	116.2	–2.58
Absolute pressure in test section at stop of recovery period	p_F	kPa	142.8	0.47
Pressure change by the end of flow period	dp_p	kPa	30.1	3.09 *

Calculated from manual groundwater level measurements.

Manual groundwater level measurements in HFM13			GW level	
Date YYYY-MM-DD	Time tt:mm.ss	Time (min)	(m b. ToC)	(m a s l)
2003-11-14	11:20		5.98	0.51
2003-11-14	15:37		5.99	0.50
2003-11-17	08:15		5.98	0.51
2003-11-17	17:52		9.55	–2.58
2003-11-18	09:30		5.45	0.47
2003-11-18	15:09		6.20	0.32
2003-11-18	18:47		6.08	0.42

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.05 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$1.04 \cdot 10^{-3}$
Total volume discharged during flow period	V_p	m^3	63.4

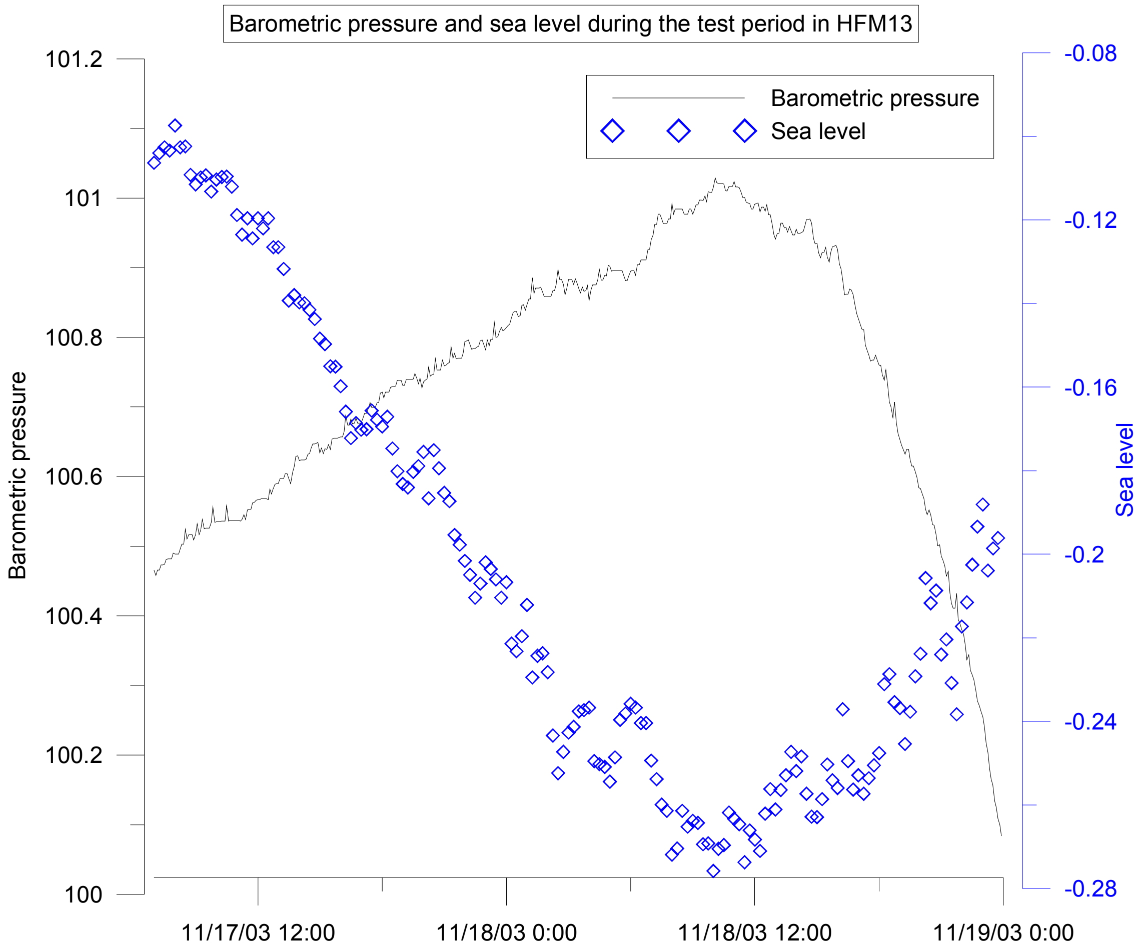


***Figure 6-1**. Barometric pressure during the test period in HFM13*

Comments on the test

The pumping test was performed as a constant flow rate test with the intention to achieve (approximately) steady-state conditions during the flow logging. No capacity test was made before the pumping test. The drilling record indicated high inflow of groundwater during drilling of the borehole.

The barometric pressure during the test period in HFM13 is presented in Figure 6-1. The barometric pressure increased during the pumping and recovery period and decreased during the injection test.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2:1–5 in Appendix 2. The initial phase of both the flow- and recovery period indicated wellbore storage effects from the pressure versus time diagrams in Figures A2:2 and-4, respectively. After initial wellbore storage effect the drawdown derivate indicates a period with apparent pseudo-radial flow from c 2–200 min. Pressure disturbance occurred at c 1 min and c 50 min during drawdown. The reasons to these are unknown. The response during the recovery period basically confirms the drawdown response. After initial wellbore storage effects, pseudo-radial flow occurred from c 10 min cf Figure A2:4. The reported drilling activities in KFM01B (Table 6-2) seem not to have disturbed the test responses.

Interpreted parameters

Transient, quantitative interpretation of the flow- and recovery period of the test is presented in lin-log and log-log diagrams in Figures A2:2–3 and 4–5, respectively in Appendix 2. Quantitative analysis was made from both the flow- and recovery period according to the methods described in Section 5.4.1. The results are exposed in the Test Summary Sheets and in Table 6-16, 6-17 and 6-18 in Section 6.5.

6.3.2 Borehole HFM14

General test data for the open-hole pumping test in borehole HFM14 in conjunction with flow logging are presented in Table 6-5.

Table 6-5. General test data for the open-hole pumping test in HFM14.

General test data			
Borehole	HFM14		
Test type[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	Open borehole		
Test No	1		
Field crew	J. Jönsson, C. Hjerne (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comment	Single hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	150.4
Casing length	L_c	m	3.0
Test section – secup	Secup	m	3.0
Test section – seclow	Seclow	m	150.4
Test section length	L_w	m	147.4
Test section diameter	$2 \cdot r_w$	mm	top 138 bottom 135
Test start (start of pressure registration)		yymmdd hh:mm	031105 08:27:24
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	031105 08:48:04
Stop of flow period		yymmdd hh:mm:ss	031105 18:55:13
Test stop (stop of pressure registration)		yymmdd hh:mm	031106 11:10:48
Total flow time	t_p	min	601.2
Total recovery time	t_F	min	975.7

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

Pressure and groundwater level data

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in borehole before start of flow period	p_i	kPa	181.7	0.202
Absolute pressure in test section before stop of flow period	p_p	kPa	173.3	–0.568
Absolute pressure in test section at stop of recovery period	p_F	kPa	182	3.763 *
Pressure change by the end of flow period	dp_p	kPa	8.4	0.77 **

* Calculated value from pressure data
** Calculated from manual groundwater level measurements.

Manual groundwater level measurements in HFM14			**GW level**	
Date YYYY-MM-DD	**Time tt:mm.ss**	**Time (min)**	**(m b. ToC)**	**(m a s l)**
2003-11-03	13:18		4.07	0.392
2003-11-05	08:27		4.28	0.202
2003-11-05	09:14		4.84	–0.288
2003-11-05	17:23		5.17	–0.568

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$9.9 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$9.9 \cdot 10^{-4}$
Total volume discharged during flow period	V_p	m^3	36

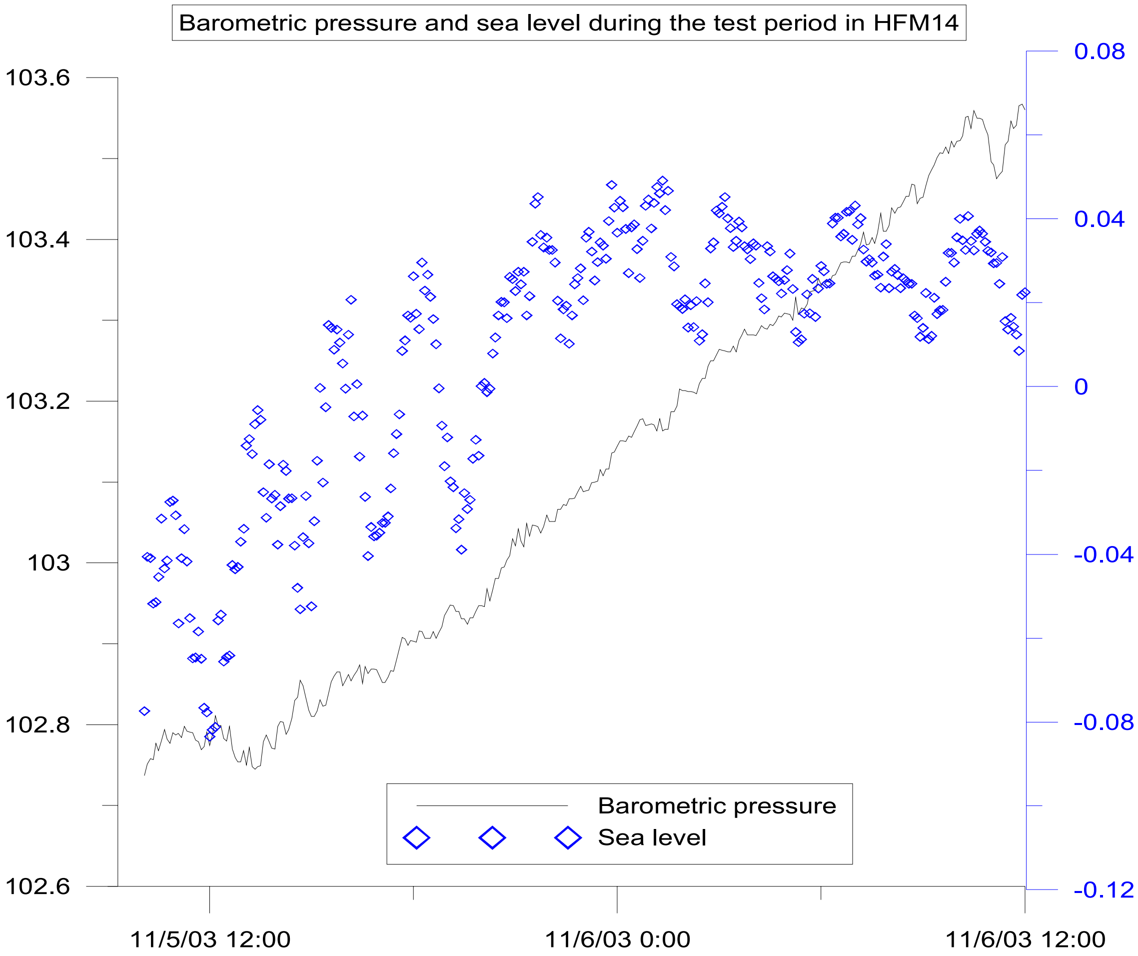


***Figure 6-2.** Barometric pressure during the test period in HFM14.*

Comments on the test

The pumping test was performed as a constant flow rate test with the intention to achieve (approximately) steady-state conditions. No capacity test before the pumping test was made. The drilling record indicated high inflow of groundwater during drilling of the borehole. No precipitation was measured during the test period. The barometric pressure during the test period in HFM14 is shown in Figure 6-2. The barometric pressure increased during both the injection phase and the recovery phase.

The flow period is strongly disturbed by external effects, probably due to the drilling activites in borehole HFM16, cf Table 6-2.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2:6–10 in Appendix 2. The initial phase of both the flow- and recovery period indicate pseudo-linear flow from the pressure versus time diagrams in Figures A2:7 and: 9, respectively. The flow period is then distorted. After initial pseudo-linear flow the recovery derivate indicates a period with apparent pseudo-radial flow from c 100 min. By the end of the recovery period some minor disturbances occur, possibly caused by drilling activies in HFM16.

Interpreted parameters

No evalualtion was made on the flow period due to the disturbances. The transient interpretation of the recovery period of the test is exposed in lin-log and log-log diagrams in Figures A2:9–10 according to the methods described in Section 5.4.1. The simulated curves do not match the test data perfectly during the initial fracture-dominated phase since a bilinear flow regime (slope 1:4) is indicated. The results are displayed in the Test Summary Sheets and in Table 6-16, 6-17 and 6-18 in Section 6.5.

6.3.3 Borehole HFM15

General test data for the open-hole pumping test in borehole HFM15 in conjunction with flow logging are presented in Table 6-7.

Table 6-7. General test data for the open-hole pumping test in HFM15 in conjunction with flow logging.

General test data			
Borehole	HFM15		
Test type[1]	Constant Pressure withdrawal and recovery test		
Test section (open borehole/packed-off section):	Open borehole		
Test No	1		
Field crew	J. Jönsson, C. Hjerne (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comment	Single-hole test		
	Nomen-clature	**Unit**	**Value**
Borehole length	L	m	99.5
Casing length	L_c	m	6.0
Test section – secup	Secup	m	6.0
Test section – seclow	Seclow	m	99.5
Test section length	L_w	m	93.5
Test section diameter	$2·r_w$	mm	top 139 bottom 138
Test start (start of pressure registration)		yymmdd hh:mm	031111 10:36:02
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	031112 08:40:00
Stop of flow period		yymmdd hh:mm:ss	031112 18:46:03
Test stop (stop of pressure registration)		yymmdd hh:mm	031113 10:27:32
Total flow time	t_p	min	626
Total recovery time	t_F	min	941.5

1) Constant Pressure withdrawal and recovery of Constant pressure withdrawal and recovery.

Pressure and groundwater level data

Pressure data	Nomen-clature	Unit	Value	GW level (m a s l)
Absolute pressure in borehole before start of flow period	p_i	kPa	144.6	–0.052
Absolute pressure in test section before stop of flow period	p_p	kPa	134.5	–1.092
Absolute pressure in test section at stop of recovery period	p_F	kPa	144.4	–0.072
Pressure change by the end of flow period	dp_p	kPa	10.1	1.14 *

* Calculated from manual groundwater level measurements.

Manual groundwater level measurements			GW level	
Date YYYY-MM-DD	Time tt:mm.ss	Time (min)	(m b. ToC)	(m a s l)
2003-11-11	10:37		5.70	–0.152
2003-11-11	14:11		5.75	–0.192
2003-11-12	08:30		5.56	–0.052
2003-11-12	18:43		7.03	–1.092
2003-11-13	09:22		5.58	–0.072

Flow data

Flow data	Nomen-clature	Unit	Value
Flow rate from test section just before stop of flowing	Q_p	m^3/s	$9.92\ 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$9.55\ 10^{-4}$
Total volume discharged during flow period	V_p	m^3	36.1

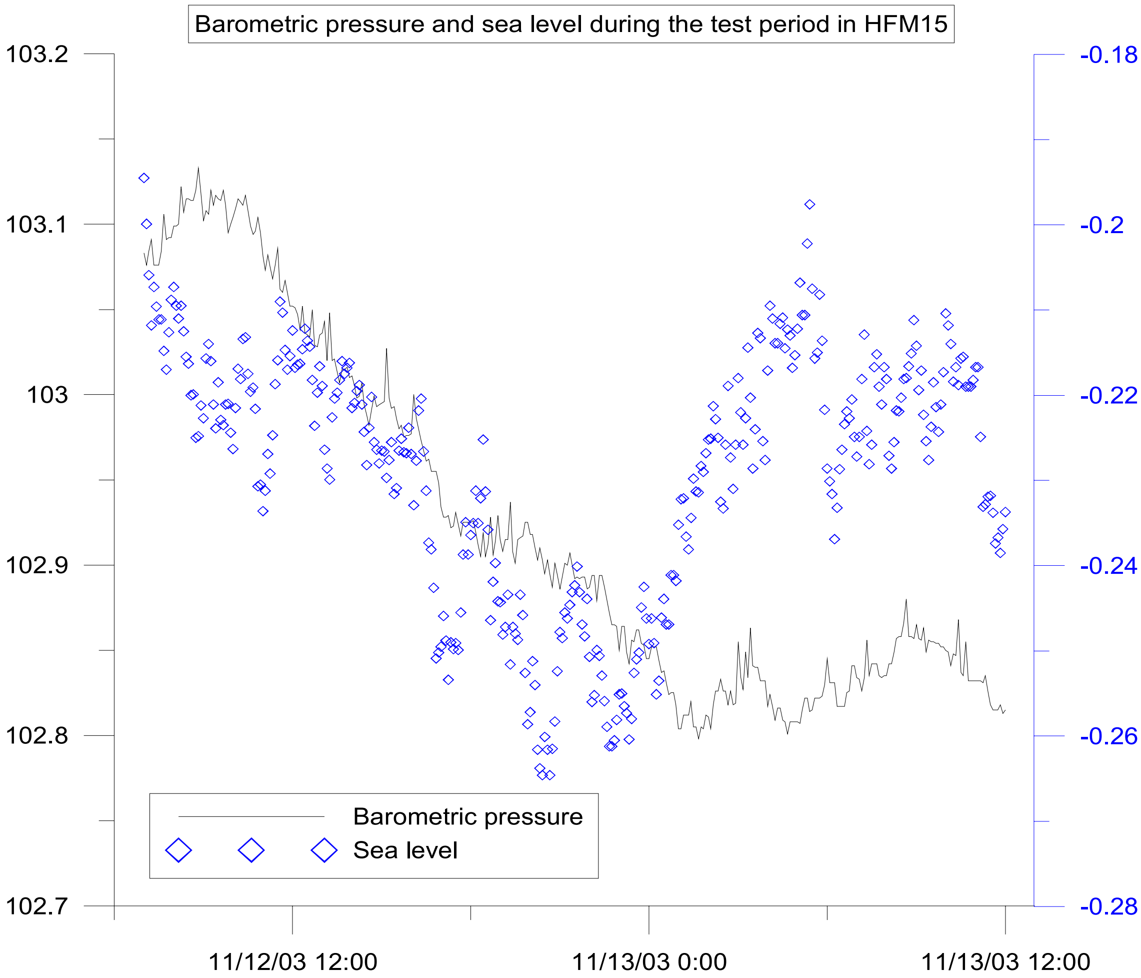


Figure 6-3. *Barometric pressure during the test period in HFM15.*

Comments on the test

The pumping test was performed as a constant flow rate test in order to achieve (approximately) steady-state conditions during the flow logging. A comparison of flow rate and drawdown from the capacity test and the pumping test is shown in Table 6-8. The barometric pressure during the test period in HFM15 is shown in Figure 6-3. The barometric pressure decreased during the injection phase and most of the recovery phase. At the end of the recovery phase the barometric pressure was fairly constant.

Table 6-8. Estimated specific capacity from the capacity test and pumping test in borehole HFM15.

Test	Duration (min)	Flow rate (L/min)	Drawdown s_w (m)	Specific capacity Q/s_w (m^2/s)
Capacity test	15.5	64.9	5.7	$1.9 \cdot 10^{-4}$
Pumping test	626	59.4	1.01	$9.82\ 10^{-4}$

Table 6-8 indicates that the specific capacity had increased significantly between the capacity test and the pumping test. This fact indicates that the hydraulic borehole conditions were improved after the capacity test, possibly due to clearing of the borehole from drilling debris and flushing water.

The flow period was probably affected by the drilling activities in borehole KFM01B, cf Table 6-2.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2:11–15 in Appendix 2. Pseudo-linear flow occurred in the beginning of both the flow and recovery period. After c 80 min during the flow period a pseudo-radial flow period is indicated. After c 200 min disturbances occurred, probably due to the drilling activites in KFM01B. The recovery period shows a consistent response to the flow period. After initial pseudo-linear flow, pseudo-radial flow is indicated after c 50 min.

Interpreted parameters

The transient, quantitative interpretation of the flow- and recovery period of the test is displayed in Figures A2:12–13 and 14–15, respectively in Appendix 2 according to the methods described in Section 5.4.1. The simulated curves do not match the test data perfectly during the initial fracture-dominated phase since a bilinear flow regime (slope 1:4) is indicated. The results are presented in the Test Summary Sheets and in Table 6-16, 6-17 and 6-18 in Section 6.5.

6.4 Flow logging

6.4.1 Borehole HFM13

General test data for the flow logging in borehole HFM13 are presented in Table 6-9.

Table 6-9. General test data for the flow logging in borehole HFM13.

General test data			
Borehole	HFM13		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	GEOSIGMA AB		
Test equipment system	HTHB1		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length		m	175.6
Pump position (lower level)		m	14.8
Flow logged section – Secup		m	18.5
Flow logged section – Seclow		m	162
Test section diameter	$2 \cdot r_w$	mm	top 135 bottom 138
Start of flow period		yymmdd hh:mm	031117 08:21:01
Start of flow logging		yymmdd hh:mm	031117 13:05:30
Stop of flow logging		yymmdd hh:mm	031117 17:00:48
Stop of flow period		yymmdd hh:mm	031117 18:21:34

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

Pressure, groundwater level and flow data

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GWL (masl)**
Absolute pressure in borehole before start of flow period	p_i	kPa	146.7	0.51
Absolute pressure in test section before stop of flow period	p_p	kPa	116.2	–2.58
Absolute pressure in test section at stop of recovery period	p_F	kPa	142.8	0.47
Pressure drawdown during flow logging	dp_p	kPa	30.1	3.09
Groundwater level	**Nomen-clature**	**Unit**	**G.w-level (m b ToC)**	**G.w-level (m a s l)**
Level in borehole, at undisturbed conditions , open hole	h_i	m	5.98	0.51
Level (steady state) in borehole, at pumping rate Q_p	h_p	m	9.55	–2.58
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m	3.00	
Flow data	**Nomen-clature**	**Unit**	**Flow rate**	
Pumping rate at surface	Q_p	m^3/s	$1.05 \cdot 10^{-3}$	
Corrected cumulative flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m^3/s	$1.061 \cdot 10^{-3}$	
Lower measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$5 \cdot 10^{-5}$	
Minimal change in borehole flow rate to detect flow anomaly	dQ_{anom}	m^3/s	$1.7 \cdot 10^{-5}$	

Comments on the test

The flow logging was made from the bottom of the borehole and upwards. The first detectable flow anomaly was found at 163.5 m. The step length between flow measurements was maximally 2 m in the borehole interval 162–18.5 m.

The measured electric conductivity is temperature-compensated. The measured cumulative borehole flow rate (Q_{FT}) at the top of the flow logged interval was only c 46% of the total flow rate (Q_p) pumped from the borehole at the surface. An injection test was performed in the interval 14.9–18.5 m. The test indicated that the section had a transmissivity below the measurement limit.

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 together with the temperature-compensated electric conductivity (EC) and temperature (Te) of the borehole fluid is presented in Figure 6-4.

It was concluded that the discrepancy between Q_{FT} and Q_p is due to the calibration constants used for the flow probe. The calibration constants used in HFM13 was based on 135.5 mm borehole diameter. Since the calibration constants used in this case correspond to a smaller diameter than the actual borehole diameter in the upper part of the borehole, the flow rate tends to be under-estimated. The cumulative flow rate is corrected for the discrepancy in diameters. By the correction, Q_T and Q_p is assumed to be equal and the corrected flow rate is plotted besides the uncorrected values in the graph below.

The cumulative transmissivity (T_{FT}) at the top of the flow-logged borehole interval was calculated from Equation. (5-2) and the transmissivity of individual flow anomalies (T_i) from Equation. (5-3). An estimation of the transmissivity of the interpreted flow anomaly was also made by the specific flow (dQ_{icorr}/s_{FL}). The transmissivity of the entire borehole was calculated from the transient interpretation of the pumping test during flow logging.

The results of the flow logging in borehole HFM13 are presented in Table 6-10 below. Two flow anomalies were identified in the borehole. The measured inflow at the identified flow anomaly (dQ_i) together with the corrected inflow (dQ_{icorr}) is presented. The largest inflow is from the interval 162.5–163.5 m.

After the correction of the borehole flow the total flow at the surface (Q_p) is distributed within the flow logged interval (ΣdQ_{icorr}). It is thus assumed that there is no flow anomaly above the flow logged interval, cf the injection test presented below.

Table 6-10. Results of the flow logging in borehole HFM13. Q_{Tcorr}=cumulative flow at the top of the logged interval, corrected due to the deviation of the actual borehole diameter from the one used by the calibration. Q_p=pumped flow rate from borehole, s_{FL}=drawdown during flow logging. T=transmissivity from the pumping test.

HFM13 Flow anom.		$Q_{Tcorr}=1.06 \cdot 10^{-3}$ (m³/s)	$Q_p=1.06 \cdot 10^{-3}$ (m³/s)	$T=3.12 \cdot 10^{-4}$ (m²/s)	s_{FL}=3.00 m	
Interval (m) (from ToC)	**B.h. length (m)**	**dQ_i (m^3/s)**	**dQ_{icorr} * (m^3/s)**	**T_i (m^2/s)**	**dQ_{icorr}/s_{FL} (m^2/s)**	**Supporting information**
105.5–106	0.5	$2.97 \cdot 10^{-5}$	$7.17 \cdot 10^{-5}$	$2.11 \cdot 10^{-5}$	$2.32 \cdot 10^{-5}$	EC, T
162.5–163.5	1	$5.66 \cdot 10^{-4}$	$9.87 \cdot 10^{-4}$	$2.91 \cdot 10^{-4}$	$3.19 \cdot 10^{-4}$	EC, T
Total		**$\Sigma=5.96 \cdot 10^{-4}$**	**$\Sigma=1.06 \cdot 10^{-3}$**	**$\Sigma=3.12 \cdot 10^{-4}$**	**$\Sigma=3.43 \cdot 10^{-4}$**	
Difference		$Q_p - Q_{Tcorr}=0$				

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

Injection test

To confirm the result from the flow logging, an injection test was performed in the uppermost part of the borehole. Water collected from the borehole during pumping was injected in a borehole section between two packers. The measured section was between 14.9–18.5 m i.e. 3.6 m long. The low injection rate in this section indicates that there is no flow anomaly in this section. The results from the injection test are shown in Table 6-11 below. Only a steady-state evaluation of the transmissivity by Moye's formula was made.

Table 6-11. Results of the injection test in section 14.9–18.5 m in borehole HFM13 in conjunction with flow logging.

Injection test	Nomen-clature	Unit	Value
Injection rate at surface	Q_p	m³/s	$<1.86 \cdot 10^{-5}$
Absolute pressure in borehole before start of flow period	p_i	kPa	126.67
Absolute pressure in test section before stop of flow period	p_p	kPa	384.57
Absolute pressure in test section at stop of recovery period	p_F	kPa	122.67
Pressure change by the end of flow period	dp_p	kPa	257.9
Specific flow rate	Q_p/dp_p	m²/s	$<7.1 \cdot 10^{-7}$
Transmissivity (Moye)	T_M	m²/s	$<5.0 \cdot 10^{-7}$

Summary of results

Table 6-12 presents a summary of the results from the pumping test and corrected results from the flow logging together with the results of the injection test. The results in Table 6-12 are consistent and demonstrate that the entire transmissivity of the borehole is located within the flow-logged interval.

Table 6-12. Compilation of results from the different hydraulic tests performed in borehole HFM13.

Test type	Interval (m)	Specific flow Q/s (m^2/s)	T (m^2/s)
Flow logging	18.5–162	$3.43 \cdot 10^{-4}$	$3.12 \cdot 10^{-4}$
Pumping test	14.9–175.6	$9.82\ 10^{-4}$	$3.12 \cdot 10^{-4}$
Injection test	14.9–18.5	$<7.1 \cdot 10^{-7}$	$<5.0 \cdot 10^{-7}$

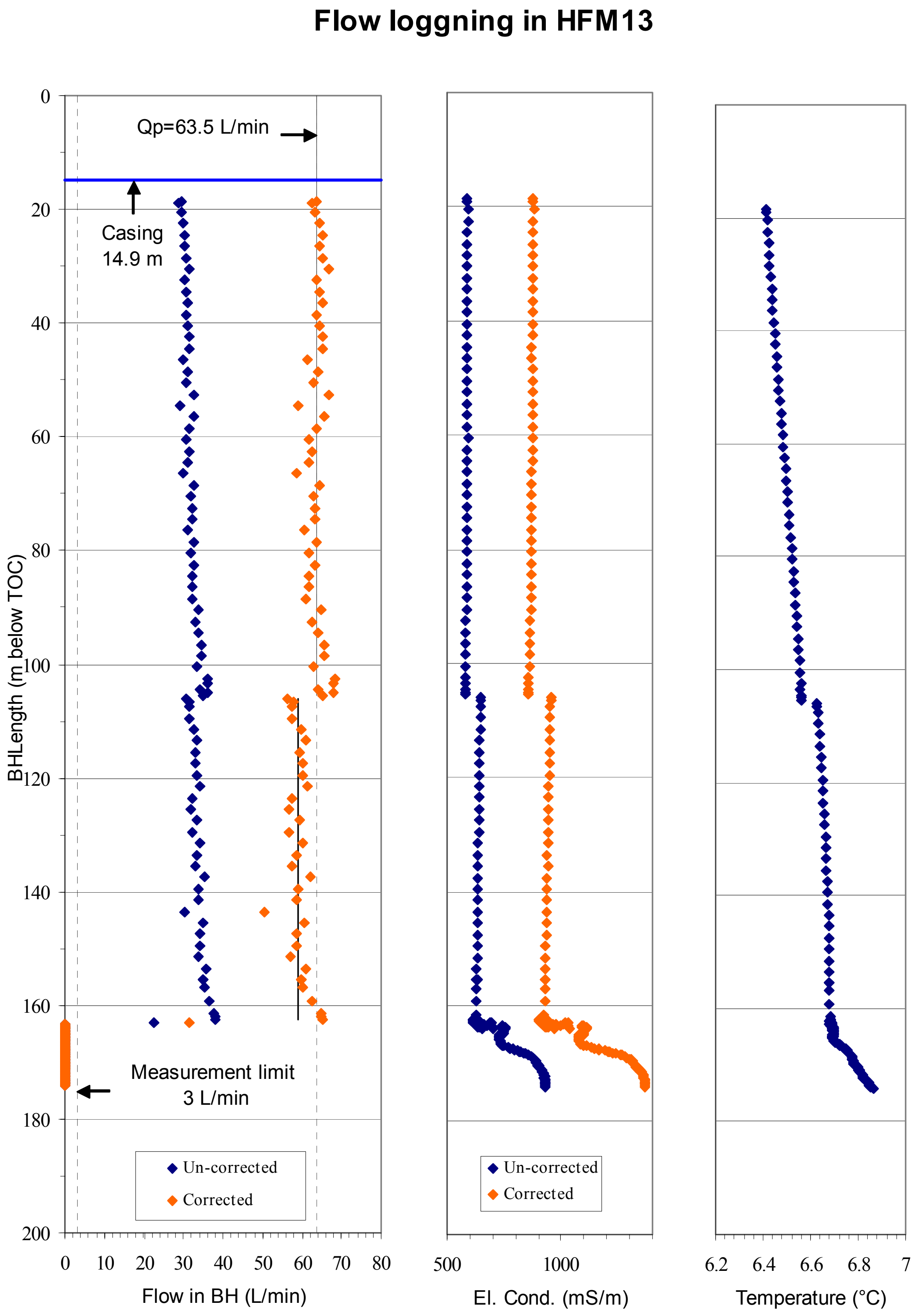


Figure 6-4. Measured (blue) and corrected (red) inflow distribution together with the electric conductivity (EC) and temperature (Te) distribution of the borehole fluid along borehole HMF13 during flow logging. The inflow values are corrected due to deviation from the actual borehole diameter from the assumed one. Below 163 m the flow rate was below the measurement limit.

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

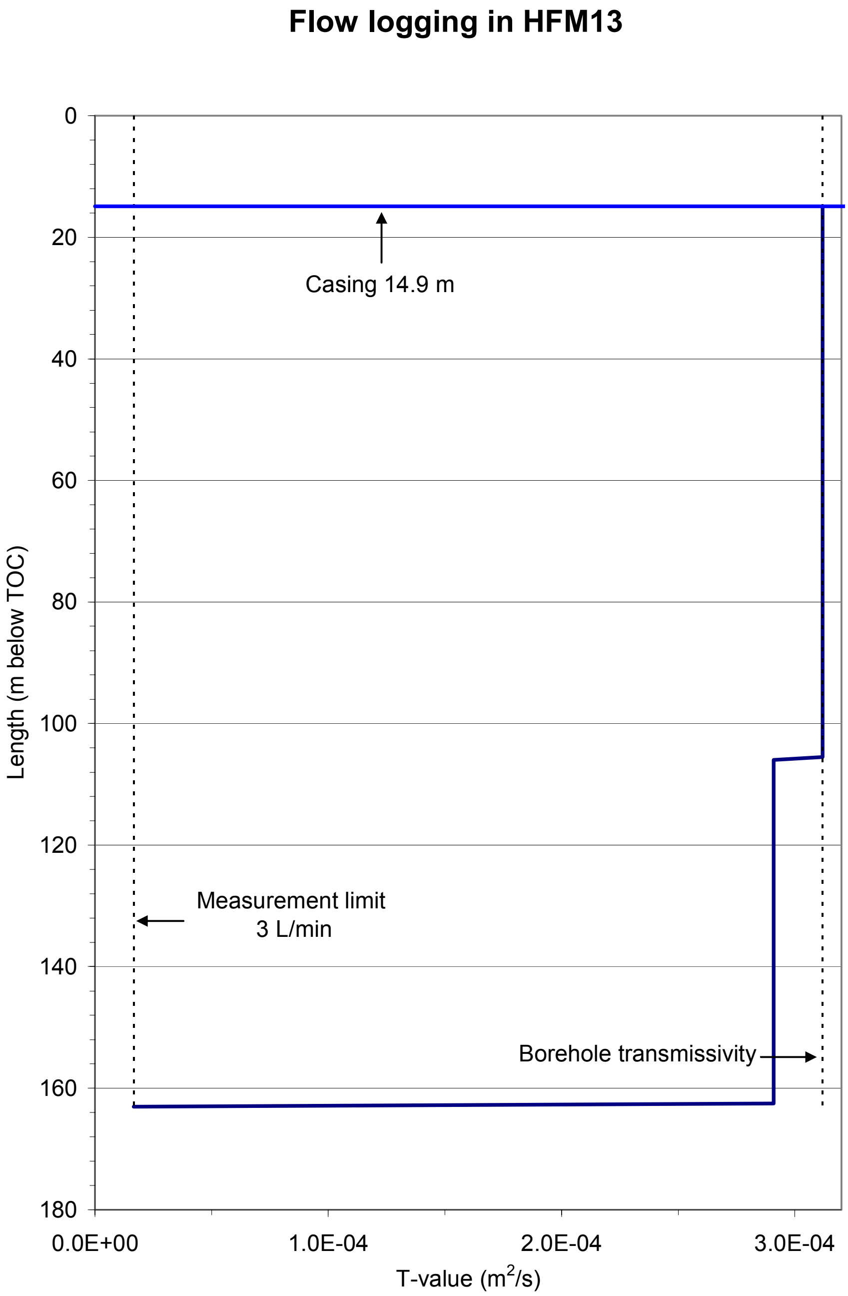


***Figure 6-5**. Calculated, cumulative transmissivity along the flow-logged interval of borehole HFM13. Below c 163.5 m, the borehole transmissivity fell below the measurement limit. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.4.2 Borehole HFM15

General test data for the flow logging in borehole HFM15 are presented in Table 6-13.

Table 6-13. General test data for the flow logging in borehole HFM15.

General test data			
Borehole	HFM15		
Test type(s)[1]	6, L-EC, L-Te		
Test section:	Open borehole		
Test No	1		
Field crew	J. Jönsson, C. Hjerne (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comments	Single pumping borehole		
	Nomen-clature	**Unit**	**Value**
Borehole length		m	99.5
Pump position (lower level)		m	15
Flow logged section – Secup		m	19
Flow logged section – Seclow		m	95
Test section diameter	$2 \cdot r_w$	mm	top 139 bottom 138
Start of flow period		yymmdd hh:mm	031112 08:19:59
Start of flow logging		yymmdd hh:mm	031112 15:10:00
Stop of flow logging		yymmdd hh:mm	031112 18:40:28
Stop of flow period		yymmdd hh:mm	031112 18:46:03

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

Pressure, groundwater level and flow data

Pressure data	**Nomen-clature**	**Unit**	**Value**	**GWL (masl)**
Absolute pressure in borehole before start of flow period	p_i	kPa	144.6	1.682
Absolute pressure in test section before stop of flow period	p_p	kPa	134.5	3.152
Absolute pressure in test section at stop of recovery period	p_F	kPa	144.3	1.702
Pressure drawdown during flow logging	dp_p	kPa	10.1	4.83

Groundwater level	**Nomen-clature**	**Unit**	**G.w-level (m b ToC)**	**G.w-level (m a s l)**
Level in borehole, at undisturbed conditions , open hole	h_i	m	5.70	–0.052
Level (steady state) in borehole, at pumping rate Q_p	h_p	m	7.03	–1.092
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m	1.01	

Flow data	**Nomen-clature**	**Unit**	**Flow rate**
Pumping rate at surface	Q_p	m^3/s	$9.92 \cdot 10^{-4}$
Corrected cumulative flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m^3/s	$9.92 \cdot 10^{-4}$
Lower measurement limit for flow rate during flow logging	Q_{Measl}	m^3/s	$5 \cdot 10^{-5}$
Minimal rate in borehole flow rate to detect flow anomaly	dQ_{anom}	m^3/s	$1.7 \cdot 10^{-5}$

Comments on the test

The flow logging was made from the bottom of the hole upwards. The first detectable flow anomaly was at 89 m (lower limit). The step length between flow measurements was maximally 2 m. At each flow anomaly a step length 0.5-m was used.

Logging results

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured cumulative borehole flow rate at the top of the flow logged interval (Q_T) was higher than the total flow rate pumped from the borehole (Q_p) at the surface. This discrepancy is most likely due to the choice of calibration constants for the flow probe. The calibration constants used in HFM15 was based on 140 mm diameter. Since the calibration constants used are larger than the actual borehole diameter in the upper part of the borehole, the flow rate tends to be over-estimated. The cumulative flow rate is corrected for the discrepancy in diameters so that Q_T is assumed equal to Q_p.

The measured and corrected flow distribution along the borehole during flow logging together with the measured and temperature-corrected electric conductivity (EC) and temperature (Te) distribution of the borehole fluid is presented in Figure 6-6.

As can be seen from Figure 6-6 almost all inflow to the borehole is concentrated to the interval 60–63.5 m. This interval may be narrower (c. 60–62 m) but potential cavities in the interval may result in uncertainties of the exact inflow levels. The interval corresponds to the interval (62–65 m) where (non-flowing) fractures were observed during drilling.

The results of the flow logging in borehole HFM15 are presented in Table 6-14 below. Four flow anomalies were identified in the borehole. The measured inflow at the identified flow anomaly (dQ_i) together with the corrected inflow (dQ_{icorr}) is presented.

The cumulative transmissivity (T_{FT}) at the top of the flow-logged borehole interval was calculated from Equation. (5-2) and the estimated transmissivity of individual flow anomalies (T_i) from Equation. (5-3). An estimation of the transmissivity of the interpreted flow anomaly was also made by the specific flow (dQ_{icorr}/s_{FL}). The transmissivity of the entire borehole was calculated from the transient interpretation of the pumping test during flow logging.

Table 6-14. Results of the flow logging in borehole HFM15. Q_{Tcorr}=cumulative flow at the top of the logged interval, corrected due to the deviation of the actual borehole diameter from the one used by the calibration. Q_p=pumped flow rate from borehole, s_{FL}=drawdown during flow logging. T=transmissivity from the pumping test.

HFM15 Flow anomalies		$Q_{Tcorr}=9.92\cdot10^{-4}$ (m^3/s)	$Q_p=9.92\cdot10^{-4}$ (m^3/s)	$T=3.19\cdot10^{-4}$ (m^2/s)	s_{FL}=1.01 m	
Interval (m bToC)	**B.h. length (m)**	**dQ_i (m^3/s)**	**$dQ_{i\ corr}$ * (m^3/s)**	**T_i (m^2/s)**	**$dQ_{i\ corr}/s_{FL}$ (m^2/s)**	**Supporting information**
22.9–24.5	1.51	$2.39\cdot10^{-4}$	$2.13\cdot10^{-4}$	$6.88\cdot10^{-5}$	$1.97\cdot10^{-4}$	EC & T
67–68.5	1.5	$2.85\cdot10^{-4}$	$2.56\cdot10^{-4}$	$8.24\cdot10^{-5}$	$2.32\cdot10^{-4}$	EC & T
71.9–74.5	1	$2.28\cdot10^{-4}$	$2.04\cdot10^{-4}$	$6.58\cdot10^{-5}$	$1.86\cdot10^{-4}$	EC & T
88.0–89.0	1	$3.53\cdot10^{-4}$	$3.16\cdot10^{-4}$	$1.02\cdot10^{-4}$	$2.87\cdot10^{-4}$	EC & T
Total		**$\Sigma=11.05\cdot10^{-4}$**	**$\Sigma=9.89\cdot10^{-4}$**	**$\Sigma=3.19\cdot10^{-4}$**	**$=8.99\cdot10^{-4}$**	
Difference		$Q_{Tcorr} - Q_p=0$				

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

Summary of results

Table 6-15 displays an overview of the results from the tests performed in the borehole. The results in Table 6-15 are consistent and show that the entire transmissivity is located within the flow-logged interval.

Table 6-15. Compilation of results from the pumping test and corrected results from the flow logging in borehole HFM15.

Test type	**Interval (m)**	**Specific flow Q/s (m^2/s)**	**T (m^2/s)**
Flow logging	19–95	$8.99\cdot10^{-4}$	$3.19\cdot10^{-4}$
Pumping test	6.0–99.5	$9.8\ 10^{-4}$	$3.19\cdot10^{-4}$

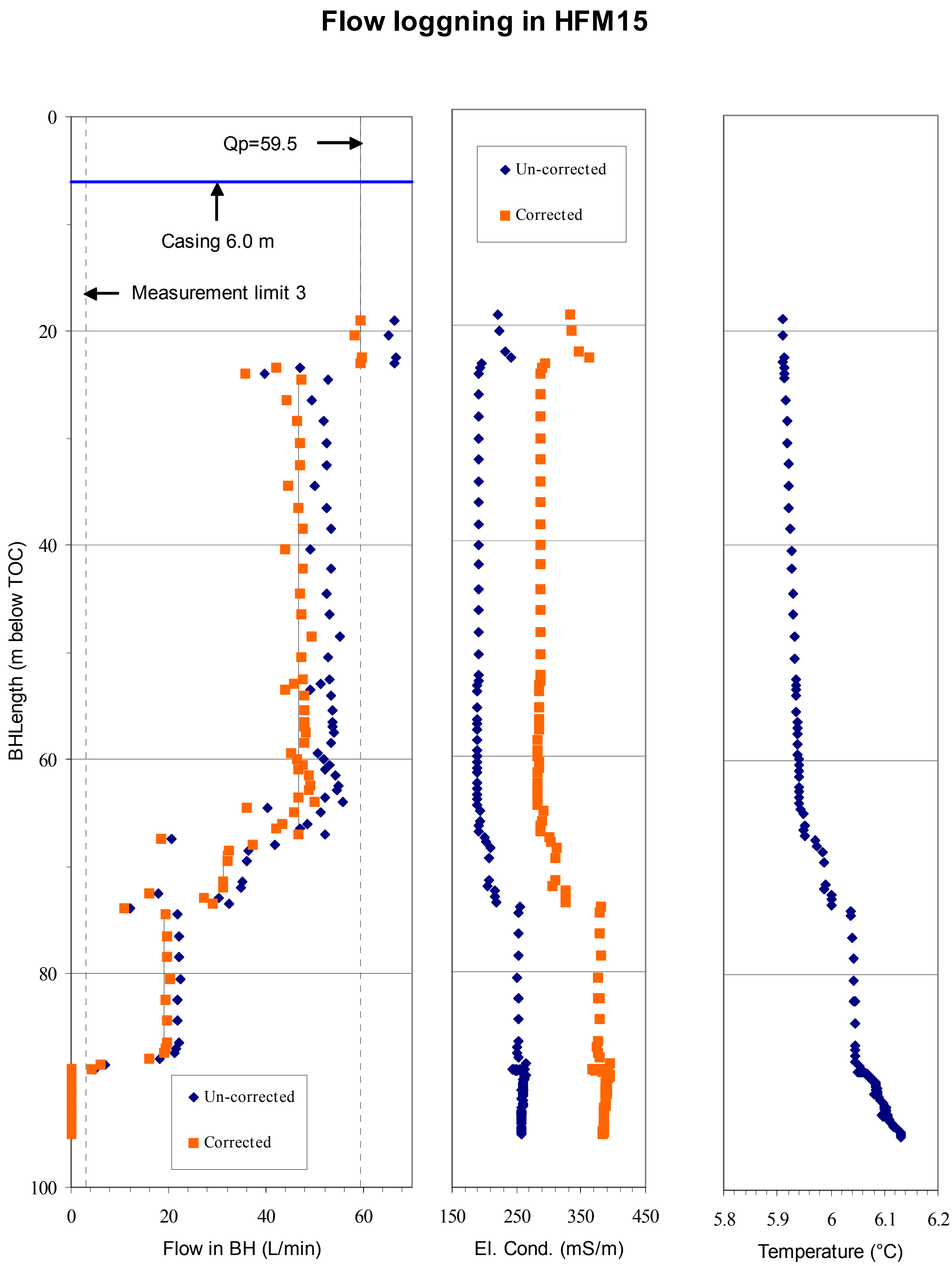


Figure 6-6*. Measured (blue) and corrected (red) inflow distribution together with the electric conductivity (EC) and temperature (Te) distribution of the borehole fluid along borehole HMF15 during flow logging. The inflow values are corrected due to deviation from the actual borehole diameter from the assumed one. Below c 89 m the inflow was below the measurement limit.*

Figure 6-7 shows the calculated, cumulative transmissivity T_F (L) along the borehole length (L) from the flow logging from Equation. (5-4). Since the detailed positions of the flow anomalies in the borehole are not known the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated lower limit of T and the total T of the borehole are also shown in the figure, cf Section 5.4.2.

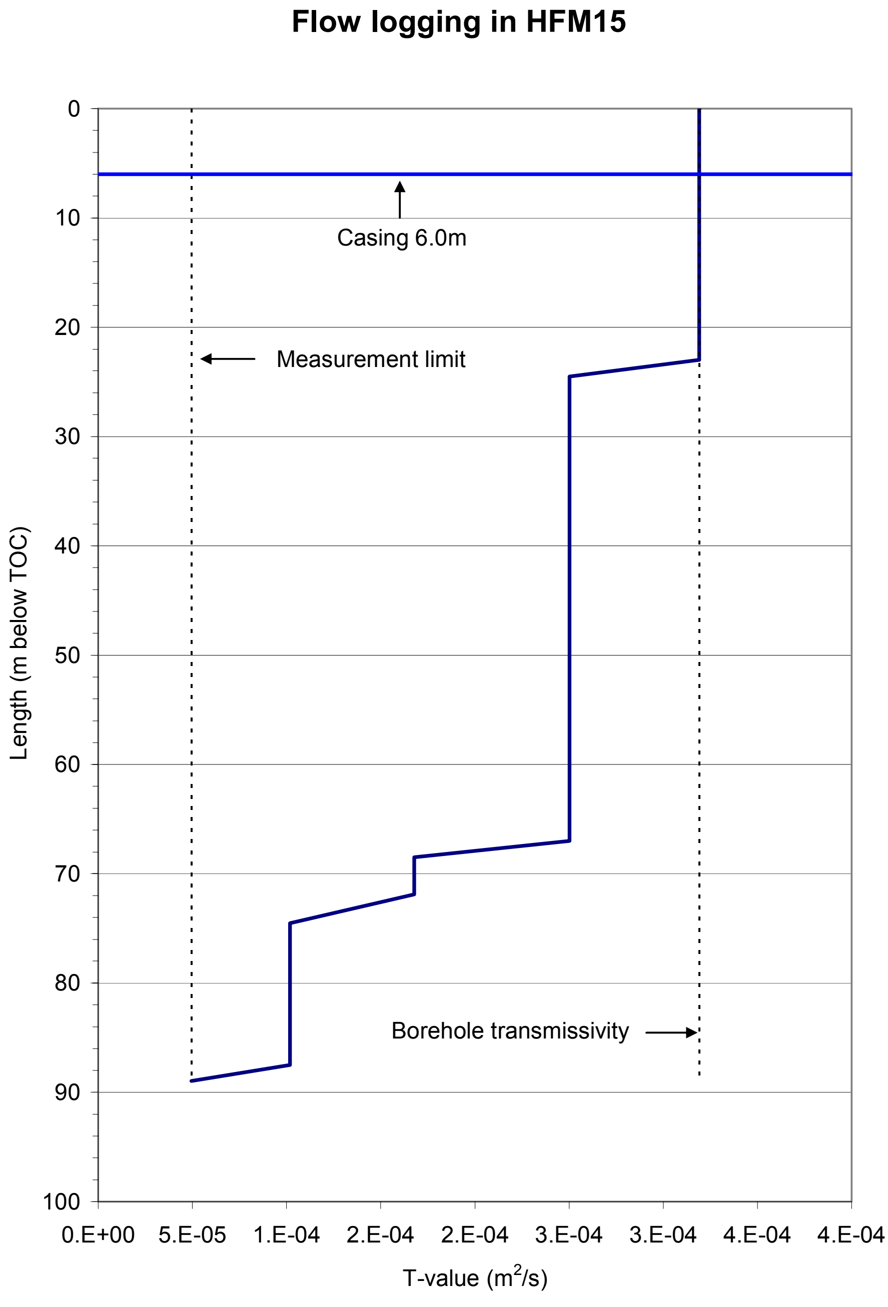


***Figure 6-7**. Calculated, cumulative transmissivity along the flow-logged interval of borehole HFM15. Below c 89 m, the borehole transmissivity fell below the measurement limit. The total borehole transmissivity was calculated from the pumping test during flow logging.*

6.5 Summary of hydraulic tests

A compilation of measured test data from the pumping tests carried out in the test campaign is shown in Table 6-16. In Table 6-17 and 6-18 hydraulic parameters calculated from the tests are displayed. The results of the flow logging are presented 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 practical purposes estimated maximal allowed drawdown for (c 50 m) in a percussion borehole, cf Table 4-1. These values correspond to a practical lower measurement limit of Q/s-L = $2 \cdot 10^{-6}$ m^2/s of the pumping tests.

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

In Table 6-16 to 6-18, the parameter explanations are according to the Instruction for analysis of injection tests and single-hole pumping tests. The parameters are also explained in the text above, except the following:

T_M = steady-state transmissivity calculated from Moye's formula
T_T = representative transmissivity from the pumping test
T_i = estimated transmissivity of flow anomaly from flow logging
C = wellbore storage coefficient
ζ = skin factor

Table 6-16. Summary of test data from the pumping tests performed in boreholes at HFM13, 14 and 15 in the Forsmark area.

Borehole ID	Section (m)	Test type[1)]	p_i (kPa)	p_p (kPa)	p_F (kPa)	Q_p (m^3/s)	Q_m (m^3/s)	V_p (m^3)
HFM13	14.9–175.6	1B	146.3	116.2	142.8	$1.05 \cdot 10^{-3}$	$1.04 \cdot 10^{-3}$	63.4
HFM14	3–150.4	1B	181.7	173.3	182	$9.9 \cdot 10^{-4}$	$9.9 \cdot 10^{-4}$	36
HFM15	6–99.5	1B	144.6	134.5	144.4	$9.92 \cdot 10^{-4}$	$9.55 \cdot 10^{-4}$	36.1

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

Table 6-17. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed in boreholes HFM13–15 in the Forsmark area.

Borehole ID	Section (m)	Flow Anomaly interval (m)	Test type[1]	Q/s (m^2/s)	T_M (m^2/s)	T_T (m^2/s)	T_i (m^2/s)	S (–)
HFM13	14.9–175.6		1B	$3.50\cdot10^{-4}$	$4.49\cdot10^{-4}$	$3.12\cdot10^{-4}$		$1.38\cdot10^{-6}$
HFM13	18.5–162	105.5–106	6	$2.32\cdot10^{-5}$			$2.11\cdot10^{-5}$	
HFM13		162.5–163.5	6	$3.19\cdot10^{-4}$			$2.91\cdot10^{-4}$	
HFM14	3.1–150.4		1B	$1.18\cdot10^{-3}$	$1.50\cdot10^{-3}$	$4.67\cdot10^{-4}$		$1.37\cdot10^{-4}$
HFM15	6.0–99.5		1B	$9.82\cdot10^{-4}$	$1.17\cdot10^{-3}$	$3.19\cdot10^{-4}$		$3.48\cdot10^{-4}$
HFM15		22.9–24.5	6	$1.97\cdot10^{-4}$			$6.88\cdot10^{-5}$	
HFM15		67–68.5	6	$2.32\cdot10^{-4}$			$8.24\cdot10^{-5}$	
HFM15		71.9–74.5	6	$1.86\cdot10^{-4}$			$6.58\cdot10^{-5}$	
HFM15		88.0–89.0	6	$2.87\cdot10^{-4}$			$1.02\cdot10^{-4}$	

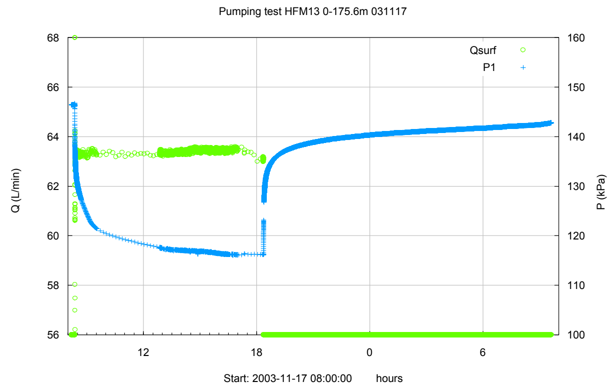
[1)] 1B: Pumping test-submersible pump, 6: Flow logging–Impeller. L-EC: EC-logging, L-Te: temperature logging.

Table 6-18. Summary of calculated hydraulic parameters of the borehole from hydraulic test performed in boreholes within Drill Site 2 in the Forsmark area.

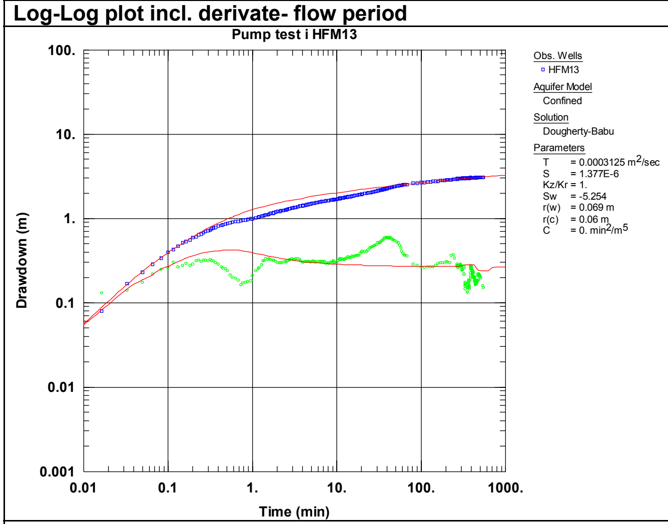
Borehole ID	Section (m)	Test type	C (m^3/Pa)	ζ (–)
HFM13	14.9–175.6	1B	$1.47\cdot10^{-6}$	–5.3
HFM14	3.1–150.4	1B		–6.0
HFM15	6.0–99.5	1B		–6.0

Test Summary Sheet			
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM13	Test start:	2003-11-17 08:11:07
Test section (m):	14.9–175.6	Responsible for test performance:	GEOSIGMA AB J. Jönsson, C. Hjerne
Section diameter, $2 \cdot r_w$ (m):	top 0.138 bottom 0.135	Responsible for test evaluation:	GEOSIGMA AB J-E. Ludvigson

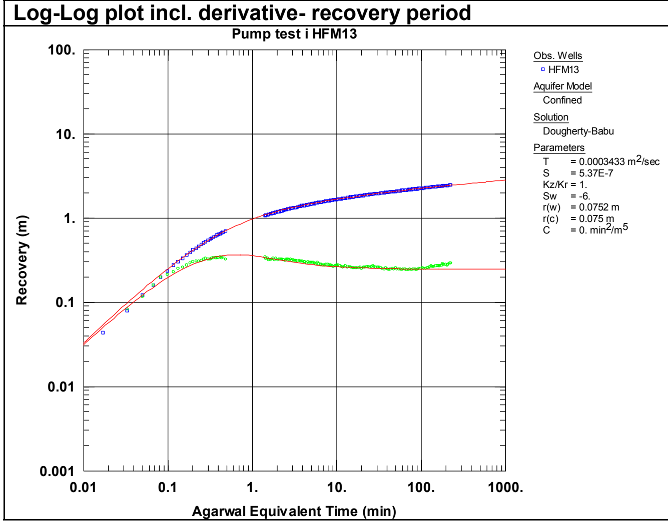
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	146.5		
p_i (kPa)	146.5		
p_p(kPa)	116.2	p_F (kPa)	142.7
Q_p (m^3/s)	$1.05 \cdot 10^{-3}$		
tp (min)	600	t_F (min)	938.4
S*		S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.2	Derivative fact.	0.2
Results		**Results**	
Q/s (m^2/s)	$3.5 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$4.49 \cdot 10^{-4}$		
Flow regime:	PRF	Flow regime:	PRF
t_1 (min)	2	dt_{e1} (min)	10
t_2 (min)	200	dt_{e2} (min)	300
T_w (m^2/s)	$3.12 \cdot 10^{-4}$	T_w (m^2/s)	$3.43 \cdot 10^{-4}$
S_w (–)	$1.38 \cdot 10^{-6}$	S_w (–)	$5.37 \cdot 10^{-7}$
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$1.47 \cdot 10^{-6}$	C (m^3/Pa)	$2.52 \cdot 10^{-6}$
C_D (–)		C_D (–)	
ξ (–)	–5.3	ξ (–)	–6.00
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

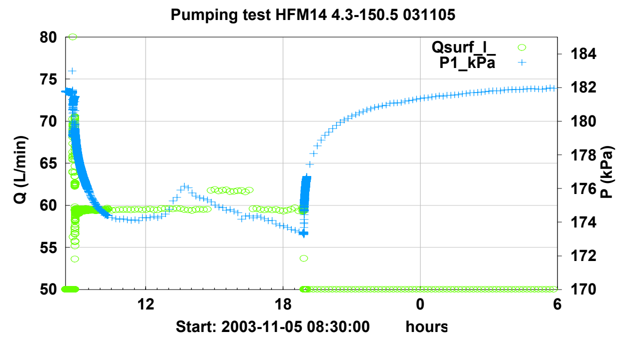
Interpreted formation and well parameters.			
Flow regime:	PRF	C (m^3/Pa)	$1.47 \cdot 10^{-6}$
t_1 (min)	2	C_D (–)	
t_2 (min)	200	ξ (–)	–5.3
T_T (m^2/s)	$3.12 \cdot 10^{-4}$		
S (–)	$1.38 \cdot 10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments: Initial wellbore storage transiting to pseudo-radial flow during both the flow- and recovery period. The flow period are probably affected by a few minor external effects

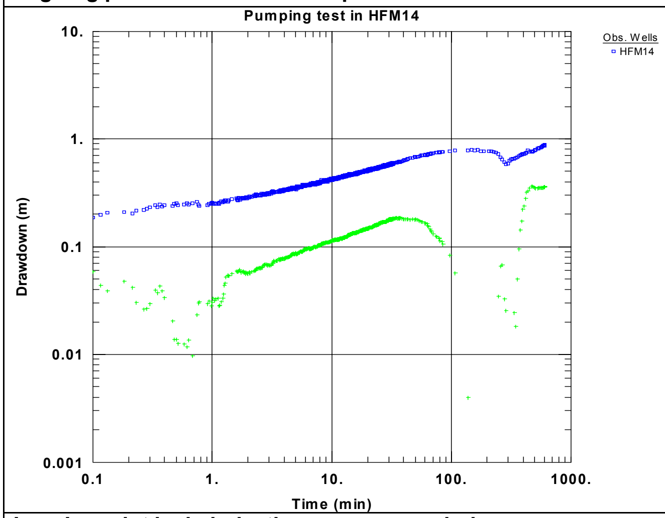
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM14	Test start:	2003-11-05 08:27:24
Test section (m):	3.1–150.5	Responsible for test performance:	GEOSIGMA AB J. Jönsson, C. Hjerne
Section diameter, $2 \cdot r_w$ (m):	top 0.138 bottom 0.135	Responsible for test evaluation:	GEOSIGMA AB J-E. Ludvigson

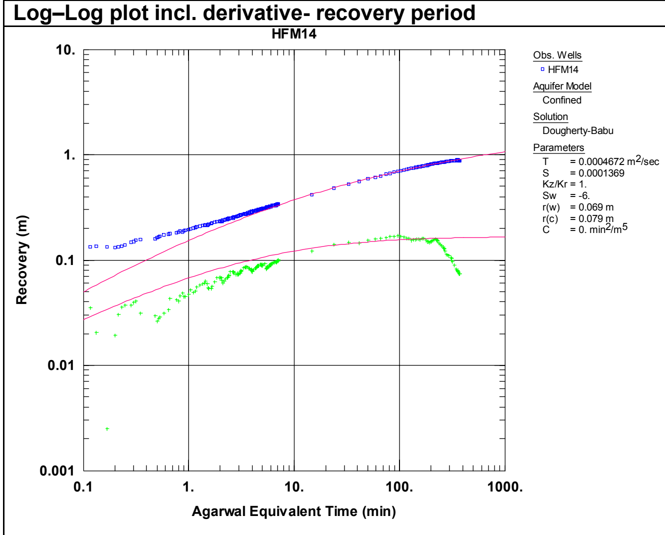
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log–Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	181.7		
p_i (kPa)	181.7		
p_p(kPa)	173.3	p_F (kPa)	182
Q_p (m^3/s)	$9.9 \cdot 10^{-4}$		
tp (min)	601.2	t_F (s)	975.7
S*		S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.5	Derivative fact.	0.3
Results		**Results**	
Q/s (m^2/s)	$1.18 \cdot 10^{-3}$		
T_{Moye} (m^2/s)	$1.50 \cdot 10^{-3}$		
Flow regime:		Flow regime:	PRF
t_1 (min)		dt_{e1} (min)	50
t_2 (min)		dt_{e2} (min)	200
T_w (m^2/s)	–	T_w (m^2/s)	$4.67 \cdot 10^{-4}$
S_w (–)	–	S_w (–)	$1.37 \cdot 10^{-4}$
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 (–)	–	ξ (–)	–6.00
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters.

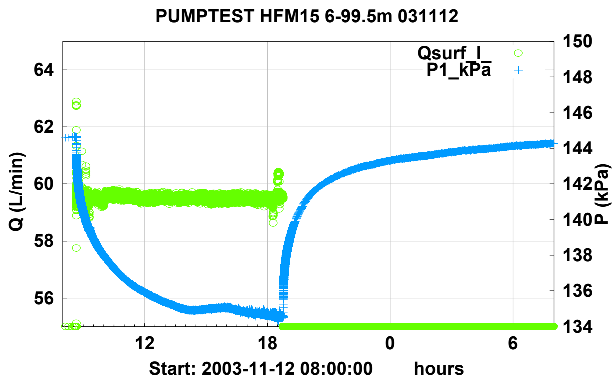
Flow regime:	PRF	C (m^3/Pa)	
t_1 (min)	50	C_D (–)	
t_2 (min)	200	ξ (–)	–6.00
T_T (m^2/s)	$4.67 \cdot 10^{-4}$		
S (–)	$1.37 \cdot 10^{-4}$		
K_s (m/s)	–		
S_s (1/m)	–		

Comments: Pseudo-linear flow occurred during the initial phase of both the flow- and recovery period. The flow perid was then distorted by external effects from c 100 min, possibly by activities in borehole HFM16.
During the recovery period pseudo-radial flow was indicated from c 50 min.

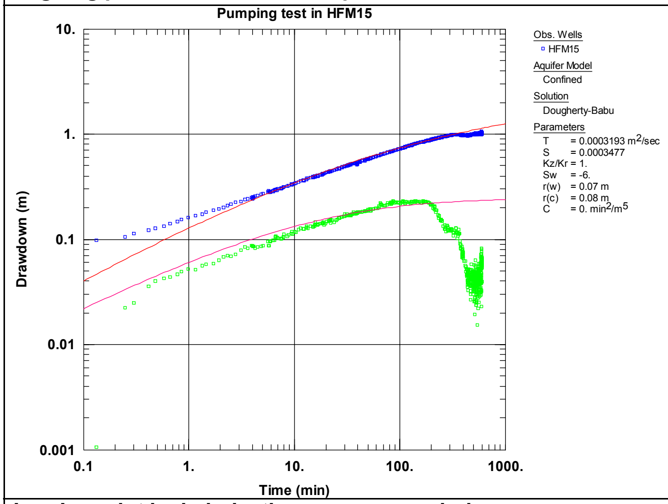
Test Summary Sheet

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM15	Test start:	2003-11-11 10:36:02
Test section (m):	6–99.5	Responsible for test performance:	GEOSIGMA AB J. Jönsson, C. Hjerne
Section diameter, $2 \cdot r_w$ (m):	top 0.139 bottom 0.138	Responsible for test evaluation:	GEOSIGMA AB J-E. Ludvigson

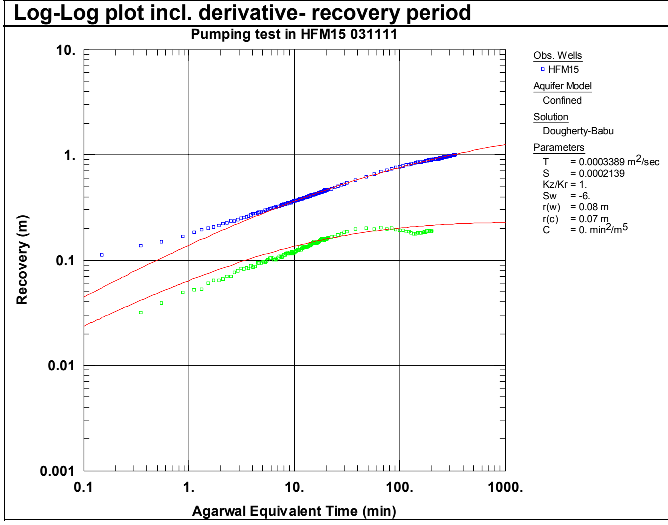
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	144.6		
p_i (kPa)	144.6		
p_p(kPa)	134.5	p_F (kPa)	144.3
Q_p (m^3/s)	$9.90 \cdot 10^{-4}$		
tp (min)	626	t_F (s)	941.5
S*		S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.5	Derivative fact.	0.5
Results		**Results**	
Q/s (m^2/s)	$9.82 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$1.17 \cdot 10^{-3}$		
Flow regime:	PRF	Flow regime:	PRF
t_1 (min)	80	dt_{e1} (min)	50
t_2 (min)	200	dt_{e2} (min)	200
T_w (m^2/s)	$3.19 \cdot 10^{-4}$	T_w (m^2/s)	$3.39 \cdot 10^{-4}$
S_w (–)	$3.48 \cdot 10^{-4}$	S_w (–)	$2.14 \cdot 10^{-4}$
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 (–)	–6.0	ξ (–)	–6.0
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)	80	C_D (–)	
t_2 (min)	200	ξ (–)	–6.0
T_T (m^2/s)	$3.19 \cdot 10^{-4}$		
S (–)	$3.48 \cdot 10^{-4}$		
K_s (m/s)			
S_s (1/m)			

Comments: Pseudo-linear flow cccurred in the beginning of both the flow- and recovery period transiting to pseudo-radial. The flow period is probably distorted by drilling activities in borehole KFM01B from c 200 min.

7 References

/1/ **Claesson L-Å, Nilsson G, 2003a.** Forsmark site investigation. Drilling of six percussion drillholes on different lineaments, HFM11–13 and HFM17–19. SKB P-04-XX, Svensk Kärnbränslehantering AB. In prep.

/2/ **Claesson L-Å, Nilsson G, 2003b.** Forsmark site investigation. Drilling of two groundwater monitoring wells, HFM14 and HFM15 and one groundwater monitoring well SFM0058 in soil at drilsite DS5. SKB P-04-XX, Svensk Kärnbränslehantering AB. In prep.

/3/ **Morosini, M, Almén K-E, Follin S, Hansson K, Ludvigson J-E and Rhén I, 2001.** Metoder och utrustningar för hydrauliska enhålstester. Metod och programaspekter för geovetenskapliga platsundersökningar. Tekniskt Dokument TD-01-63, Svensk Kärnbränslehantering AB.

/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.

/5/ **Dougherty, D E and D K Babu, 1984.** Flow to a partially penetrating well in a double-porosity reservoir, Water Resour. Res, 20 (8), 1116–1122.

/6/ **Nilsson D, 2004.** Sampling and analyses of groundwater in percussion drilled boreholes. Results from the percussion-drilled boreholes HFM09 to HFM19 and the percussion drilled parts of KFM05A and KFM06A.

Appendix 1

List of data files

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

Bh ID	**Test section** (m)	**Test type**[1]	**Test no**	**Test start Date, time** YYYY-MM-DD tt:mm:ss	Test stop Date, time YYYY-MM-DD tt:mm:ss	**Datafile, start Date, time** YYYY-MM-DD tt:mm:ss	Data file, stop Date, time YYYY-MM-DD tt:mm:ss	**Data files of raw and primary data**	**Content (parameters)**[2]	**Comments**
HFM13	0-175.6	1B	1	2003-11-17 08:11:07	2003-11-18 09:36:24	2003-11-17 08:11:07	2003-11-18 09:36:24	HFM13_000_031117_FlowLo00.DAT	P, Q, T, EC	
		1B	1			2003-11-17 08:08:59	2003-11-19 11:27:58	HFM13_000_031117_Ref_Da00.DAT		
	18.5 - 174	6 L-EC L-T	1	2003-11-17 13:05:30	2003-11-17 17:00:48	2003-11-17 13:05:30	2003-11-17 17:00:48	HFM13_18.5_031117_Spinne00.DAT	P, Q, T, EC, SP	
		6 L-EC L-T	1			2003-11-17 08:08:59	2003-11-19 11:27:58	HFM13_18.5_031117_Ref_Da00.DAT		
	14.9 -18.5	3	1	2003-11-18 18:45:55	2003-11-18 19:54:38	2003-11-18 14:02:08	2003-11-18 19:54:38	HFM13_14.5_031118_Inject00.DAT	P, Q	
						2003-11-17 08:08:59	2003-11-19 11:27:58	HFM13_14.5_031118_Ref_Da00.DAT		
HFM14	0-150.5	1B	1	2003-11-05 08:27:24	2003-11-06 11:10:48	2003-10-30 13:25:10	2003-11-06 11:10:50	HFM14_000_031105_Pumpin00.DAT	P, Q	
						2003-09-29 22:19:10	2003-11-06 11:10:55	HFM14_000_031105_Ref_Da00.DAT		
HFM15	0-99.5	1B	1	2003-11-12 08:00:00	2003-11-13 10:27:32	2003-10-01 11:03:38	2003-11-13 10:27:32	HFM15_000_031111_FlowLo00.DAT	P, Q, T, EC	En kapacitetstest genomfördes 03-11-11 med pumpstart kl. 14:19:30 /SJ
						2003-09-29 22:19:10	2003-11-13 10:27:38	HFM15_000_031111_Ref_Da00.DAT		
	19 – 95	6	1	2003-11-12 15:27:07	2003-11-12 18:40:28	2003-10-02 13:51:30	2003-11-12 18:40:28	HFM15_019_031112_Spinne00.DAT	P, Q, T, EC, SP	

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	Data file, stop Date, time YYYY-MM-DD tt:mm:ss	**Data files of raw and primary data**	**Content (parameters)**[2]	**Comments**
						2003-09-29 22:19:10	2003-11-13 10:27:38	HFM15_019_031112_Ref_Da00.DAT		

1: 1A: Pumping test-wire-line equipment, 1B: Pumping test-submersible pump, 1C: Pumping test-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging-PFL-DIFF_sequential, 5B: Difference flow logging-PFL-DIFF_overlapping, 6: Flow logging-Impeller, Logging-EC: L-EC, Logging temperature: L-T, Logging single point resistance: L-SPR
2: P=Pressure, Q=Flow, Te=Temperature, EC=El. conductivity. SPR=Single Point Resistance, C=Calibration file, R=Reference file, Sp=Spinner rotations

Appendix 2

Test diagrams

Diagrams are presented for the following tests:

1. Pumping test in HFM13 14.9-175.6 m

2. Pumping test in HFM14 3.0-150.4 m

3. Pumping test in HFM15 6.0-99.5

Nomenclature:

T = transmissivity (m^2/s)

S = storativity (-)

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

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

C = well loss constant (set to 0)

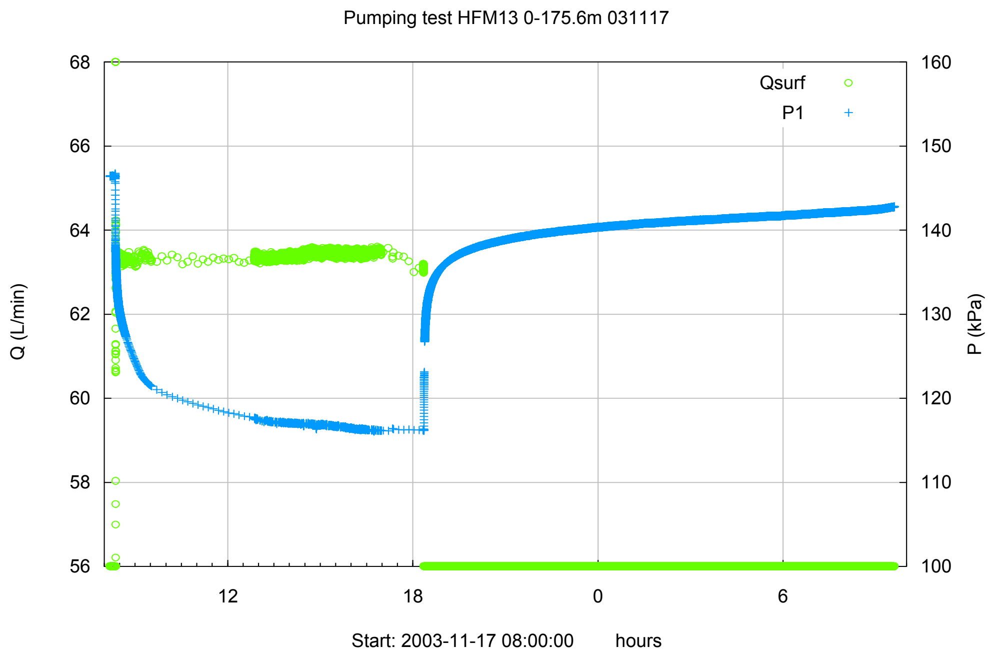


Figure A2:1*. Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM13 in conjunction with flow logging.*

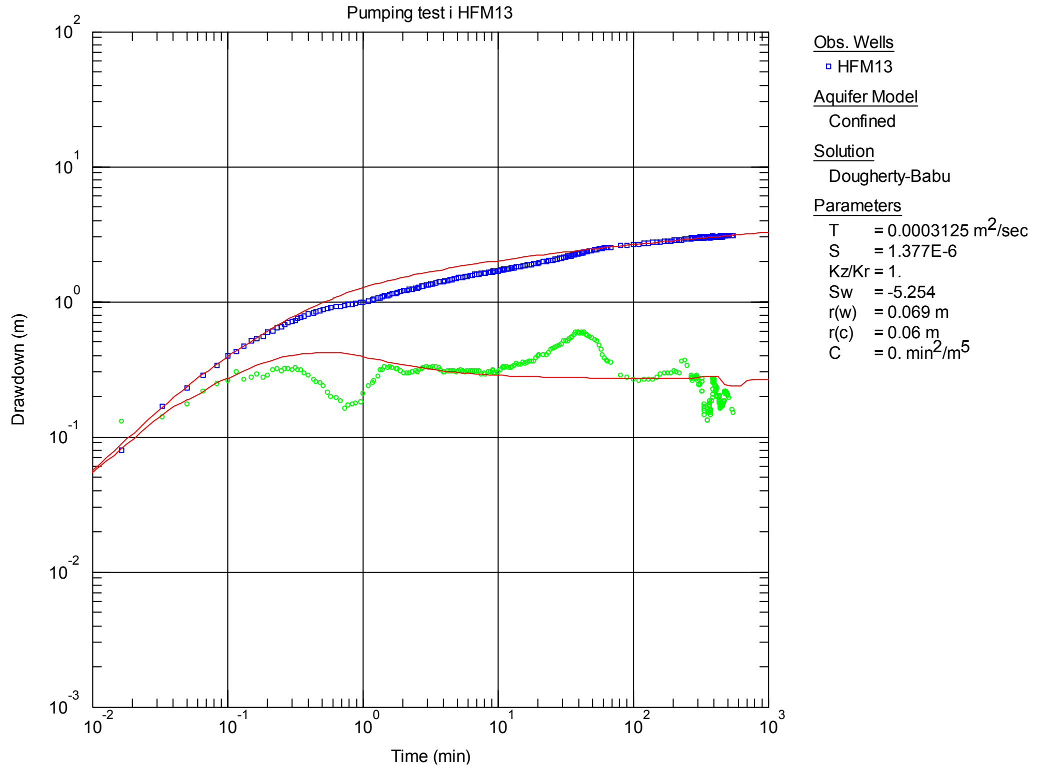


Figure A2:2*. Log-log plot of drawdown (blue) and drawdown derivative (green) versus time together with simulated curves (red) during the pumping test in HFM13.*

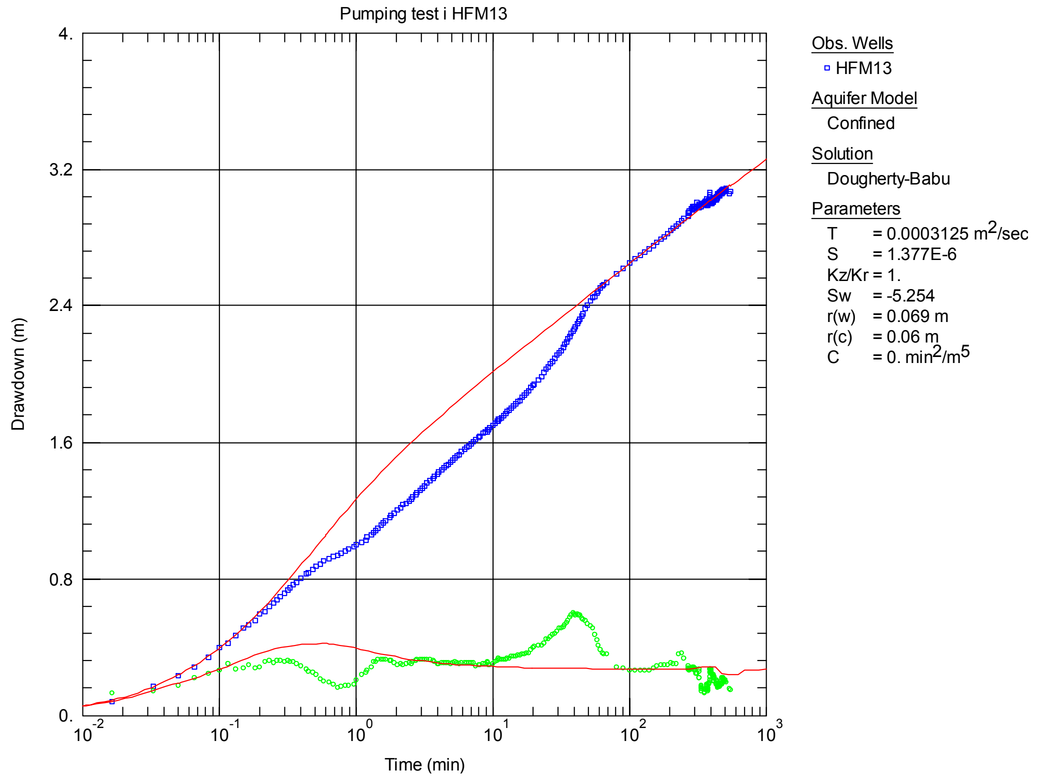


Figure A2:3*. Lin-log plot of drawdown (blue) and drawdown derivative (green) versus time together with simulated curves (red) during the pumping test in HFM13.*

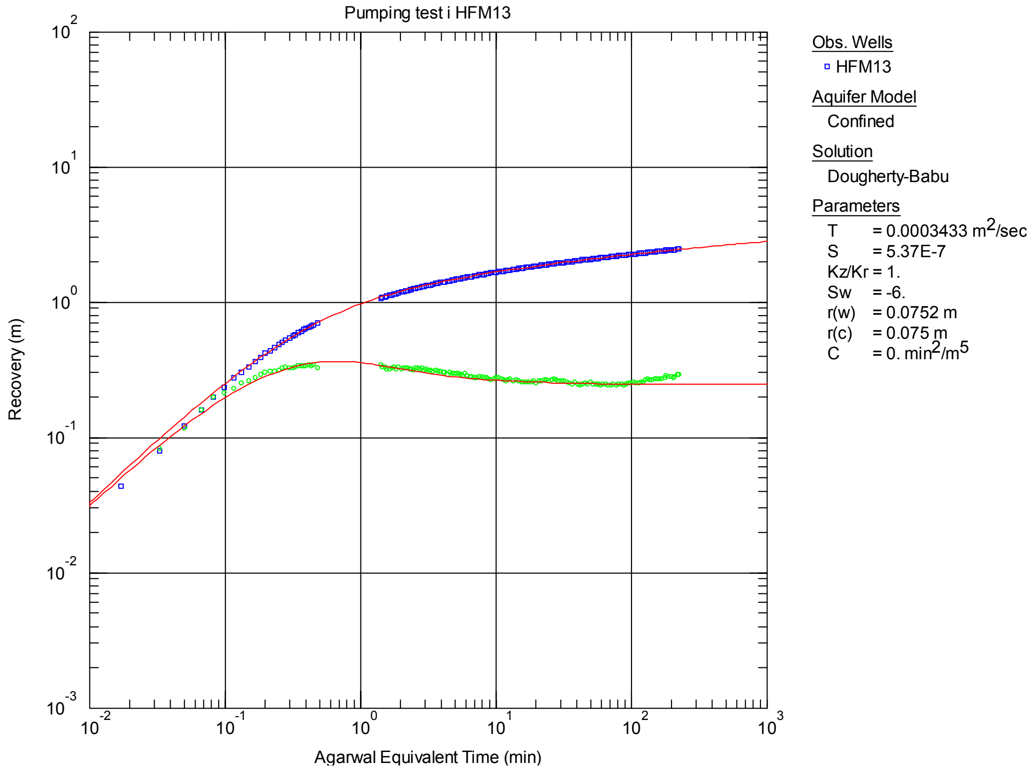


Figure A2:4. *Log-log plot of pressure recovery (blue) and derivative (green) versus equivalent time together with simulated curves (red) during the pumping test in HFM13.*

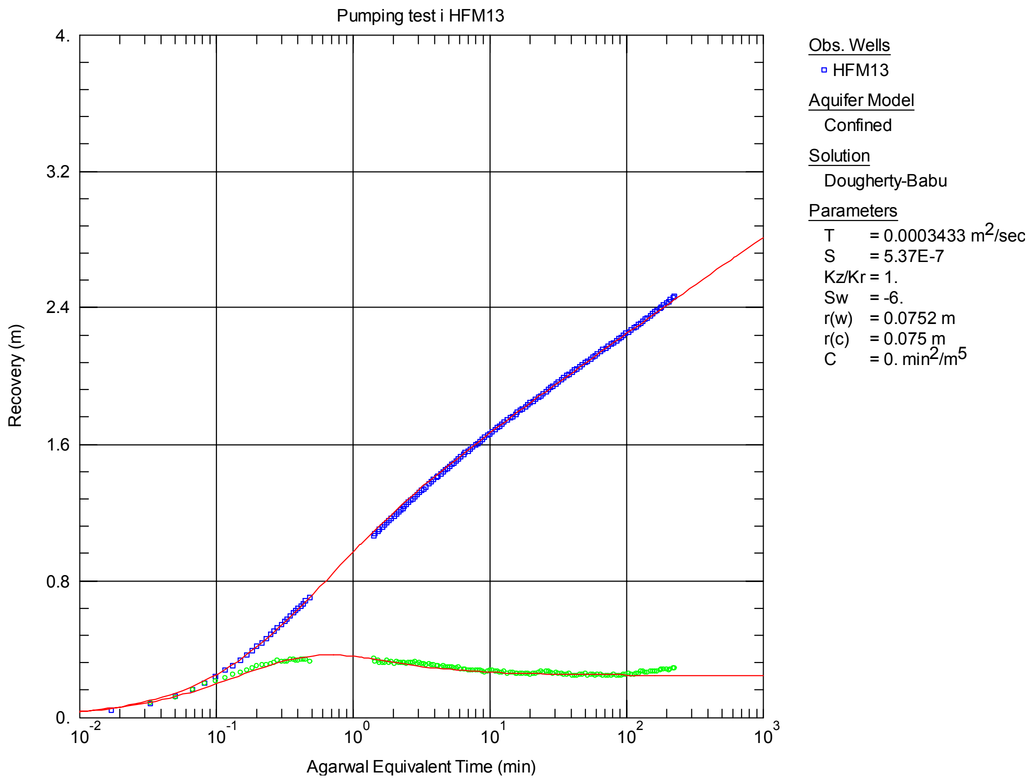


Figure A2:5. *Lin-log plot of pressure recovery (blue) and derivative (green) versus equivalent time together with simulated curves (red) during the pumping test in HFM13.*

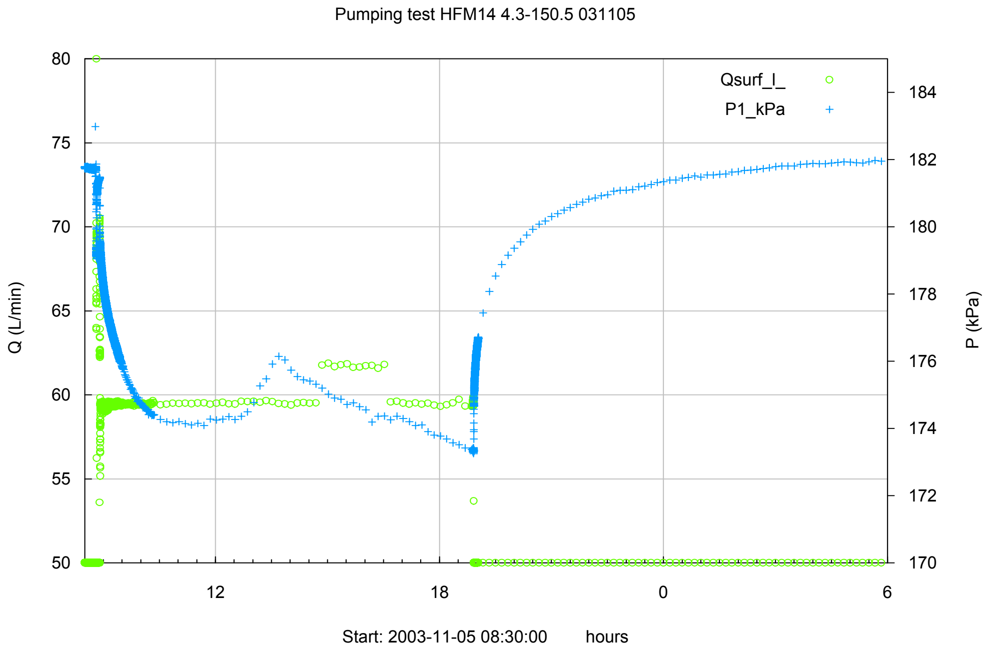


Figure A2:6. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM14 in conjunction with flow logging.*

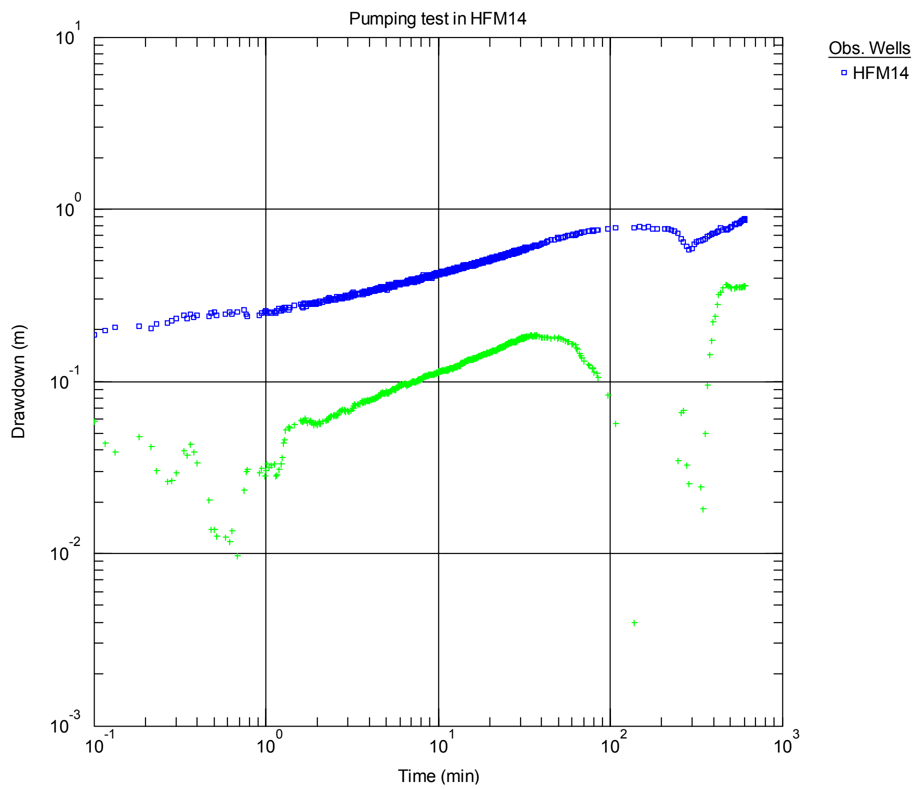


Figure A2:7*. Log-log plot of drawdown (blue) and drawdown derivative (green) versus time during the pumping test in HFM14.*

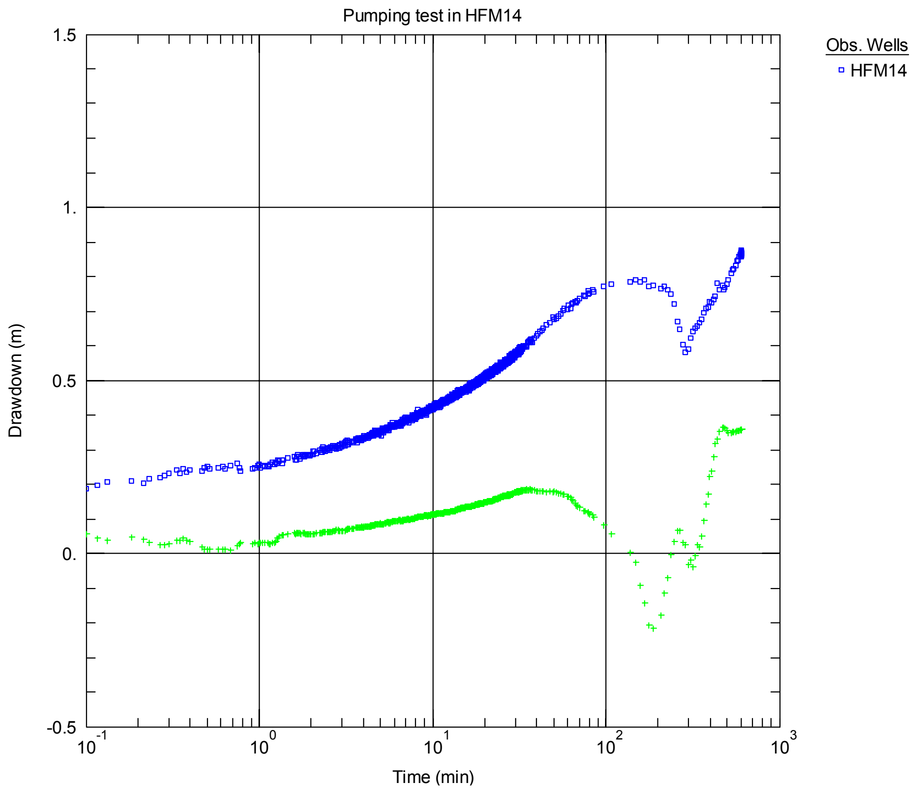


Figure A2:8. *Lin-log plot of drawdown (blue) and drawdown derivative (green) versus time during the pumping test in HFM14.*

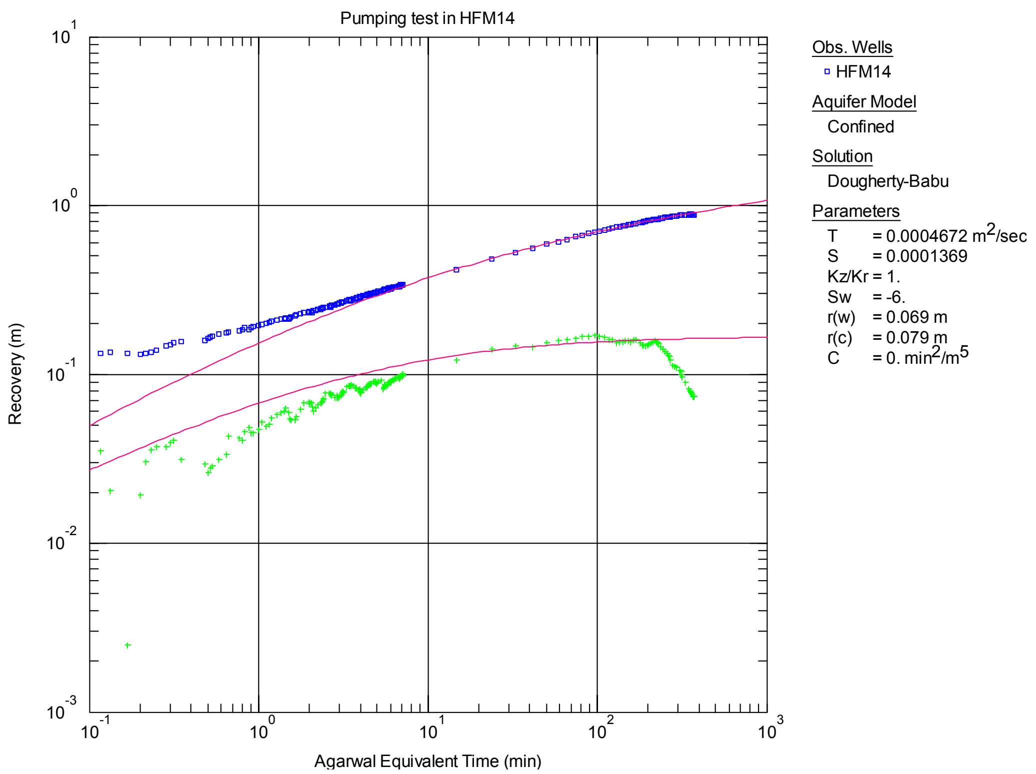


Figure A2:9*. Log-log plot of pressure recovery (blue) and derivative (green) versus equivalent time together with simulated curves (red) during the pumping test in HFM14.*

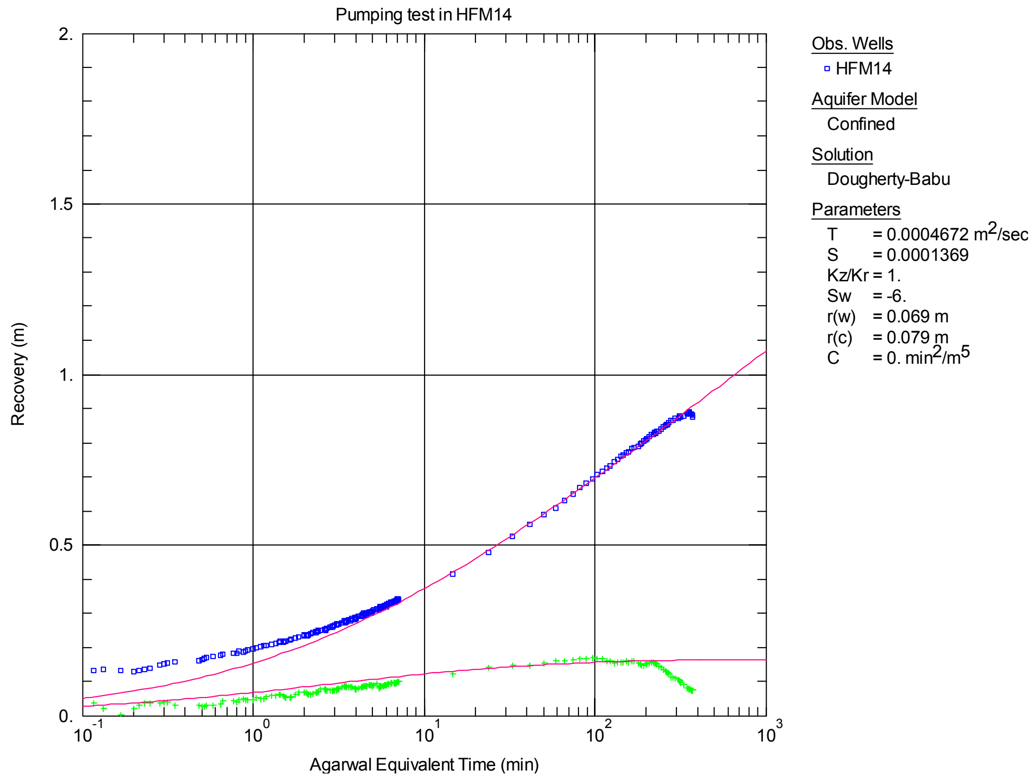


Figure A2:10. *Lin-log plot of pressure recovery (blue) and derivative (green) versus equivalent time together with simulated curves (red) during the pumping test in HFM14.*

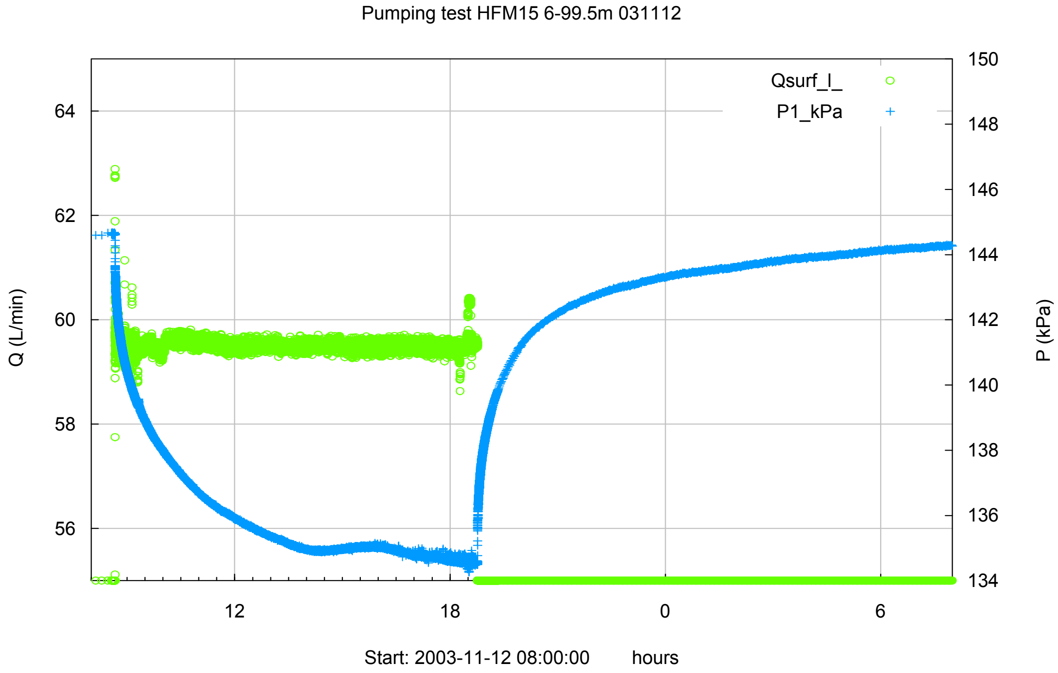


***Figure A2:11**. Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM15 in conjunction with flow logging.*

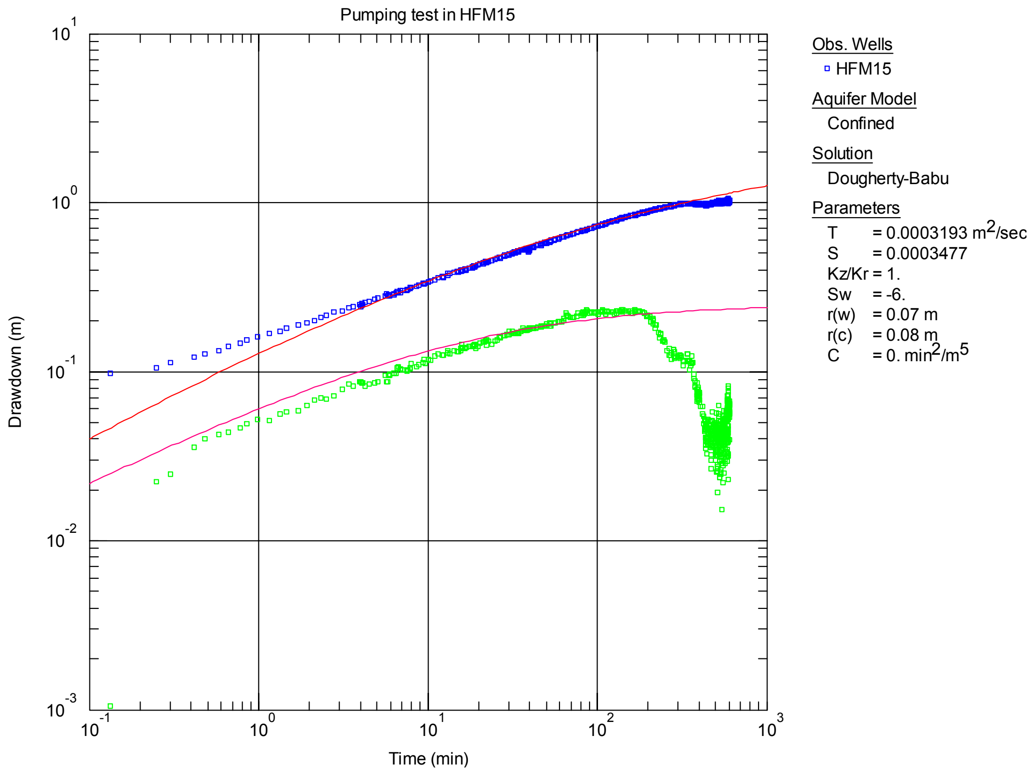


***Figure A2:12**. Log-log plot of drawdown (blue) and drawdown derivative (green) versus time together with simulated curves (red) during the pumping test in HFM15.*

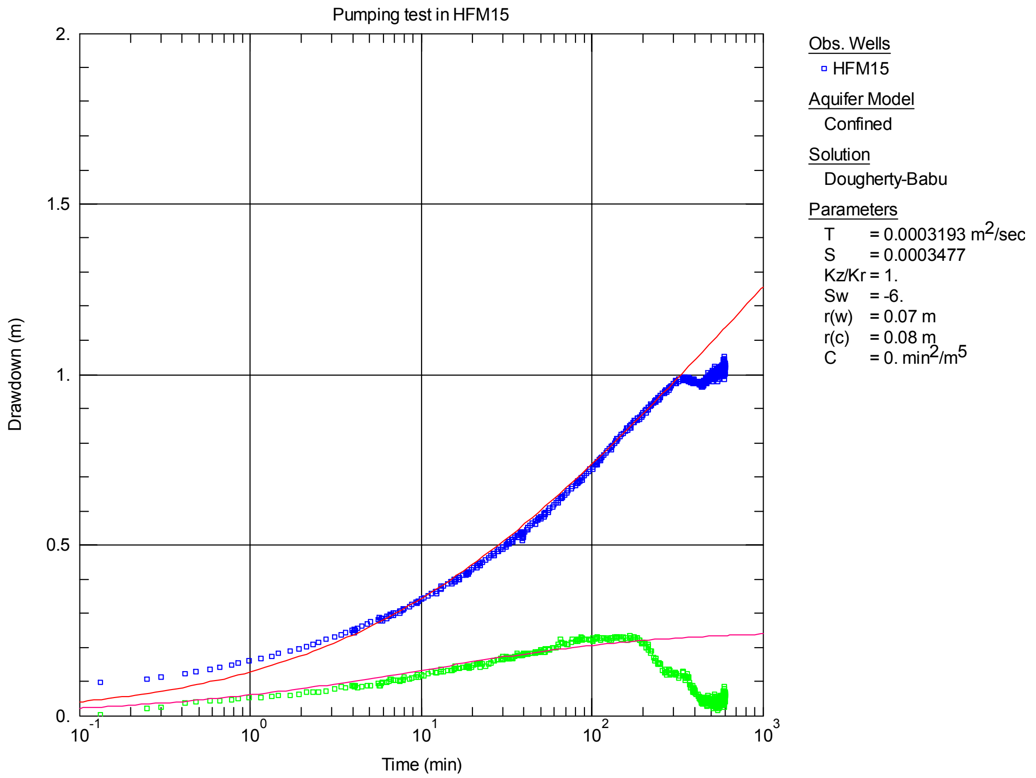


Figure A2:13 *Lin-log plot of drawdown (blue) and drawdown derivative (green) versus time together with simulated curves (red) during the pumping test in HFM15.*

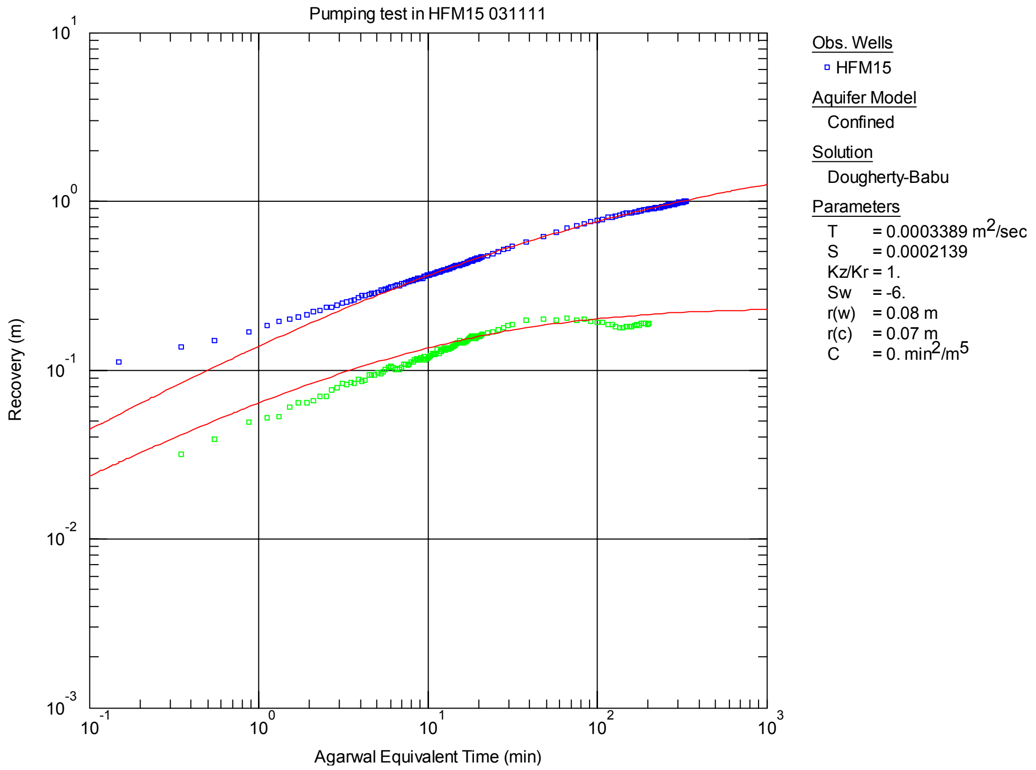


Figure A2:14*. Log-log plot of pressure recovery (blue) and derivative (green) versus equivalent time together with simulated curves (red) during the pumping test in HFM15.*

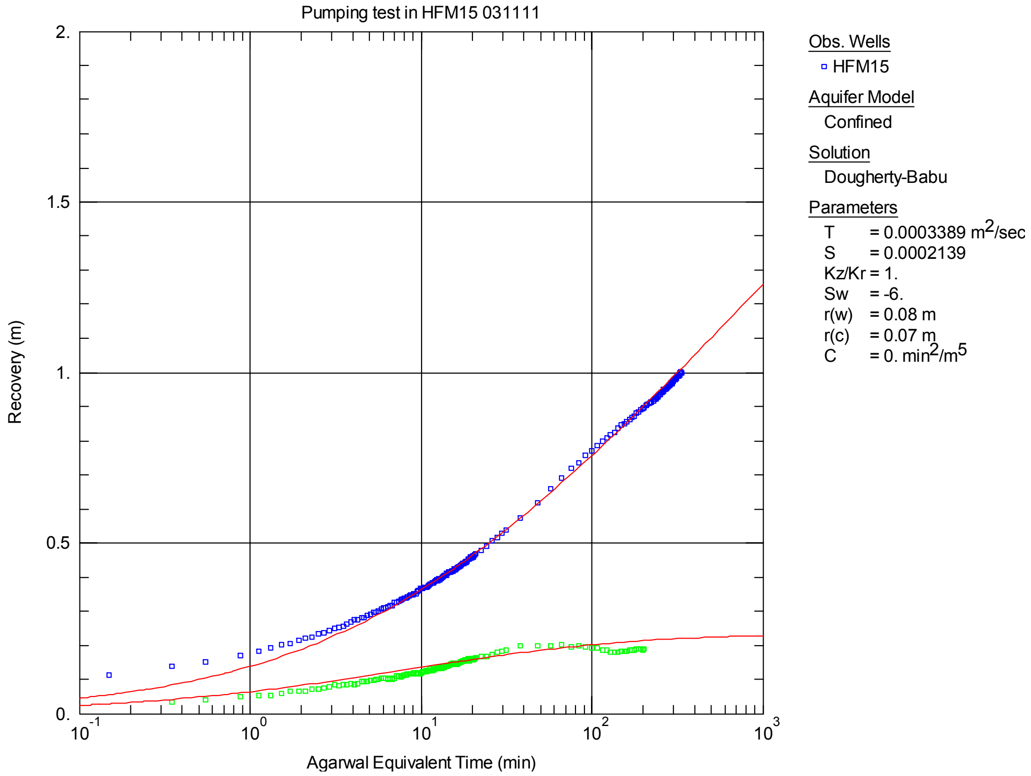


Figure A2:15. *Lin-log plot of pressure recovery (blue) and derivative (green) versus equivalent time together with simulated curves (red) during the pumping test in HFM15.*

Appendix 3

Result tables to Sicada

The following Result Tables are presented:

1. Result Tables for Single-hole pumping and injection tests

2. Result Tables for flow meter logging

A. Result Table for Single-hole tests in boreholes HFM13-15 at Forsmark for submission to Sicada

SINGLE HOLE TESTS, Pumping and injection, s_hole_test_d; General information

Borehole idcode	Borehole secup (m)	Borehole seclow (m)	Test type (1-6)	Formation type (-)	Date and time for test, start YYYYMMDD hh:mm	Date and time for test, stop YYYYMMDD hh:mm	Date and time for flow period, start YYYYMMDD hh:mm:ss	Date and time for flow period, stop YYYYMMDD hh:mm:ss	Qp (m**3/s)	Value type (-1, 0 or 1)	Q-measl-L (m**3)/s	Q-measl-U (m**3)/s	V_p (m**3)
HFM13	14.90	175.60	1B	1	20031117 08:11	20031118 09:36	20031117 08:21:01	20031117 18:21:34	1.05E-03	0	8.3E-05	1.3E-03	63.4
HFM13	14.90	18.50	3	1	20031118 18:45	20031118 19:54	20031118 19:20:07	20031118 19:35:01		-1	1.7E-05	1.3E-03	0.0185
HFM14	3.00	150.40	1B	1	20031105 08:27	20031106 11:10	20031105 08:48:04	20031105 18:55:13	9.90E-04	0	8.3E-05	1.3E-03	36.0
HFM15	6.00	99.5	1B	1	20031111 10:36	20031113 10:27	20031112 08:40:00	20031112 18:46:03	9.92E-04	0	8.30E-05	1.30E-03	36.1

cont.

Q_m (m**3/s)	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 (-)
1.04E-03	36000	56304	0.51	-2.58	0.47	146.3	116.2	142.8					P-04	
1.86E-05	894	1177				126.4	383.8	122.7					P-04	
9.90E-04	36072	58542	0.20	-0.57		181.7	173.3	182.0					P-04	
9.55E-04	37560	56490	-0.052	-1.092	-0.072	144.6	134.5	144.4					P-04	

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_ed1; Basic evaluation

Borehole	Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YYYYMMDD hh:mm	Q/s (m^2/s)	Value type (-1, 0 or 1)	T_Q (m^2/ s)	T_M (m^2/ s)	b (m)	B (m)	TB (1D) (m^3/ s)	TB-me (1D) (m^3/ s)	TB-meas (1D) (m^3/ s)	SB (1D) (m)	SB* (1D) (m)	L_f (1D) (m)	T_T (2D) (m^2/ s)	Value type (-1, 0 or 1)
HFM13	14.90	175.60	20031117 08:11	3.5E-04	0		4.49E-04	160.9								3.12E-04	0
HFM13	14.90	18.50	20031118 18:45		-1			3.6									-1
HFM14	3.10	150.50	20031105 08:27	1.18E-03	0		1.50E-03	147.4								4.67E-04	0
HFM15	6.00	99.50	20031111 10:36	9.82E-04	0		1.17E-03	93.5								3.19E-04	0

cont.

Q/s-measl-L (m²/ s)	**Q/s-measl-U** (m²/ s)	**S (2D)** (-)	**S* (2D)** (-)	**K´/b´ (2D)** (1/s)	**K_S (3D)** (m/s)	**K_S-measl-L (3D)** (m/s)	**K_S-measl-U (3D)** (m/s)	**S_S (3D)** (1/m)	**S_S* (3D)** (1/m)	**L_p** (m)	**C** (m**3/Pa)	**C_D** (-)	**ξ (2D)** (-)	**ω** (-)	**λ** (-)	**t_1** (s)	**t_2** (s)	**Comments** (-)
2.0E-06	2.0E-03		1.38E-06								1.47E-06		-5.3			120	12000	
8.0E-07	2.0E-03																	
2.0E-06	2.0E-03		1.37E-04										-6			3000	12000	
2.0E-06	2.0E-03		3.48E-04										-6			4800	12000	

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 - wire line eq, 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,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 flow rate
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.

Appendix 3:1

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 Q_p and s=abs (p_i-p_p). Only given for test section (label 1) in interference test.
T_Q	m2/s	Transmissivity based on specific capacity and a function for T=f (Q/s). The function used should be referred in "Comments"
T_M	m2/s	Transmissivity based on Moye (1967)
b	m	Interpreted formation thickness representative for evaluated T or TB.
B	m	Interpreted width 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
80 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 application, based on hydraulic conductivity distribution (if available) or the midpoint of the borehole test section
C	(m3/Pa)	Wellbore storage coefficient
C_D	(-)	Dimensionless wellbore storage coefficient
ξ	(-)	Skin factor

ω	(-)	Storativity ratio
λ	(-)	Interporosity flow coefficient
dt_1	s	Estimated start time after pump/injection start OR recovery start, for the period used for the evaluated parameter
dt_2	s	Estimated stop time after pump/injection start OR recovery start, for the period used for the evaluated parameter
	m	Length coordinate along the borehole for the upper limit of the observation section
	m	Length coordinate along the borehole for the lower limit of the observation section
p_{ai}	kPa	Initial formation pressure of the observation section, which is located above the test section in the borehole
p_{ap}	kPa	Final pressure at the end of the pumping/injection period in the observation section, which is located above the test section in the borehole
p_{aF}	kPa	Final pressure at the end of the recovery period in the observation section, which is located above the test section in the borehole
p_{bi}	kPa	Initial formation pressure of the observation section, which is located below the test section in the borehole
p_{bp}	kPa	Final pressure at the end of the pumping/injection period in the observation section, which is located below the test section in the borehole
p_{bF}	kPa	Final pressure at the end of the recovery period in the observation section, which is located below the test section in the borehole
References		SKB report No for reports describing data and evaluation
Index w		Active borehole or borehole section

B. Result Table for Flow logging in boreholes HFM13-15 at Forsmark for submission to Sicada

FLOWLOGG-IMPELLER TESTS-plu_impeller_basic

Borehole	Borehole secup (m)	Borehole seclow (m)	Test type (1-7)	Formation type (-)	Date and time of test start YYYYMMDD hh:mm	Date and time of test stop YYYYMMDD hh:mm	Date and time of flowl., start YYYYMMDD hh:mm:ss	Date and time of flowl., stop YYYYMMDD hh:mm:ss
HFM13	18.50	162.00	6	1	20031117 13:05	20031117 17:00	20031117 13:05:30	20031117 17:00:48
HFM15	19	95	6	1	20031111 10:36	20031113 10:27	20031112 15:10:00	20031112 18:40:28

cont.

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)	s_{FL} (m)	Reference (-)	Comments (-)
5.0E-05	1.7E-03	1.05E-03	36000	14175	0.51	-2.58	3.00		
5.0E-05	1.7E-03	9.90E-04	37560	12028	1.822	3.152	1.01		

FLOWLOGG-IMPELLER TESTS plu_impell-main_res

Borehole	Borehole secup (m)	Borehole seclow (m)	L Corrected (m)	Te_{w0} (°C)	EC_{w0} (mS/m)	TDS_{w0} (mg/ L)	Q_0 (m**3/s	Te_w (°C)	EC_w (mS/m)	TDS_w (mg/ L)	Q_{1T} (m**3/s)	Q_T (m**3/s)	Q_{Tcorr}	T Entire hole (m^2/ s)	T_{FT} (m^2/ s)
HFM13	18.50	162.00									4.90E-04	4.90E-04	1.06E-03	3.12E-04	3.12E-04
HFM15	19	95									1.10E-03	1.10E-03	9.92E-04	3.19E-04	3.19E-04

cont.

T_F-measl-L (m²/s)	T_F-measl-U (m²/s)	Reference (-)	Comments (-)
2.0E-06	2.0E-03		
2.0E-06	2.0E-03		

FLOWLOGG-IMPELLER TESTS plu_impeller_anomaly

Borehol	Borehole secup (m)	Borehole seclow (m)	Upper limit L (m)	Lower limit L (m)	Te_w (°C)	EC_w (mS/m)	TDS_w (mg/ L)	$deltaQ_i$ (m**3/s)	$deltaQ_{icorr}$ (m**3/s)	$deltaQ_{icorr}/s_{FL}$ (m**2/s)	b_i (m)	T_i (m²/ s)	T_i-measl-L (m²/ s)	T_i-measl-U (m²/ s)	Reference (-)	Comments (-)
HFM13	18.50	162.00	105.5	106				2.97E-05	7.17E-05	2.32E-05	0.5	2.11E-05	5.6E-06	4.4E-04		
			162.5	163.5				5.66E-04	9.87E-04	3.19E-04	1	2.91E-04	5.6E-06	4.4E-04		
HFM15	19	95	22.9	24.5				2.39E-04	2.13E-04	1.97E-04	1.51	6.88E-05	1.6E-05	1.3E-03		
			67	68.5				2.85E-04	2.56E-04	2.32E-04	1.5	8.24E-05	1.6E-05	1.3E-03		
			71.9	74.5				2.28E-04	2.04E-04	1.86E-04	1	6.58E-05	1.6E-05	1.3E-03		
			87.99	88.97				3.53E-04	3.16E-04	2.87E-04	0.98	1.02E-04	1.6E-05	1.3E-03		

Header	Unit	Description
Date/time test start	date	Date for the stop of the test (YYYY-MM-DD hh:mm)
Date/time test stop	date	Date for the stop of the test (YYYY-MM-DD hh:mm)
Borehole	idcode	Object or borehole identification code
Borehole secup	m	Length coordinate along the borehole for the upper limit of the logged section (Based on corrected length L)
Borehole seclow	m	Length coordinates along the borehole for the lower limit of the logged section. (Based on corrected length L)
date and time, start	date_s	Date and time of flow logging start (YYYY-MM-DD hh:mm:ss)
date and time, stop	date_s	Date and time of flow logging stop (YYYY-MM-DD hh:mm:ss)
Test type (1-7)		1A: Pumping test - wire line eq, 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-comb.Sequentia, 5B: Difference flow logging-PFL-DIFF-Overlapping, 6: Flow logging-Impeller 7: Grain size analysis
Formation type		1: Rock, 2: Soil (superficial deposits)
Q-measl-L	m^3/s	Estimated lower measurement limit for borehole flow rate in flow logging probe
Q-measl-U	m^3/s	Estimated upper measurement limit for borehole flow rate in flow logging probe
Q_p	m^3/s	Flow rate at surface during flow logging
t_p	s	Time for the flowing phase of the test
t_{FL}	s	Duration of the flow logging survey
s_{FL}	m	Average drawdown of the water level in open borehole during flow logging
h_0	masl	Initial hydraulic head. Measured as water level in open borehole with reference level in the local coordinates system with z=0 m.
h_p	masl	Stabilized 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 cumulative flow rate. Position for measurement is related to L (corrected length)
Q_1	m^3/s	Cumulative flow rate during pumping. Position for measurement is related to L (corrected length)
Q_{1T}	m^3/s	Cumulative flow rate:Q_1 at the top of measured interval
Q_T	m^3/s	Cumulative flow rate: Q at the top of measured interval
Q_{Tcorr}	m^3/s	Cumulative flow rate: QT at the top of measured interval, based on corrected borehole diameter
T(Entire hole)	m**2/s	Evaluated transmissivity for the entire hole section that is considered representative for the flow logging (also reported in data file for single-hole interpretation)
T_F	m**2	Cumulative transmissivity based on impeller measurement. 2D model for evaluation of formation properties of the test section. $T_{F=}$Óti=T*(Q_T/Q_p)

T_{FT}	m**2	Cumulative transmissivity of the entire measured interval, based on impeller measurement
T_F-measl-L	m**2/s	Estimated lower measurement limit for evaluated T_F. If estimated T_F equals T-measlim in the table, the actual T_F is considered to be equal or less than T_F - measlim
T_F-measl-U	m**2/s	Estimated upper measurement limit for evaluated T_F. If estimated T_F equals T-measlim in the table, the actual T_F is considered to be equal or greater than T_F - measlim
Te_{w0}	gr C	Natural (undisturbed) fluid temperature in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected length)
EC_{w0}	mS/m	Natural (undisturbed) electrical conductivity of the fluid in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected length)
TDS_{w0}	mg/L	Natural (undisturbed) total salinity of the fluid in the test section representative for the evaluated parameters based on EC. Position for measurement is related to L (corrected length)
Upper limit	m	Corrected length coordinate along the borehole for the upper limit of the flow anomaly
Lower limit	m	Corrected length coordinate along the borehole for the lower limit of the flow anomaly
Te_w	centigrade	Natural (undisturbed) fluid temperature in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected length)
EC_w	mS/m	Natural (undisturbed) electrical conductivity of the fluid in the test section representative for the evaluated parameters. Position for measurement is related to L (corrected length)
TDS_w	mg/L	Natural (undisturbed) total salinity of the fluid in the test section representative for the evaluated parameters based on EC. Position for measurement is related to L (corrected length)
$deltaQ_i$	m**3/s	deltaQi : Flow rate of interpreted flow anomaly i
$deltaQ_{icorr}$	m**3/s	deltaQicorr: Flow rate of interpreted flow anomaly calculated with corrected borehole diameter.
$deltaQ_i/S_{FL}$	m**2/s	$deltaQi/s_{FL}$: Specific capacity of interpreted flow anomaly
b_i	m	Interpreted formation thickness representative for evaluated Ti of anomaly i.
T_i	m**2/s	Evaluated transmissivity of flow anomaly i considered representative for the flow logging
T_i-measlim-L	m**2/s	Estimated lower measurement limit for evaluated $T_{i.}$ If estimated T_i equals T-measlim in the table actual T_i is considered to be equal or less than T_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 than T_i-measlim
Reference		SKB number for reports describing data and results
Comments		Short comment on evaluated parameters