P-06-140

Forsmark site investigation

Pumping tests and flow logging in borehole HFM14 and pumping test in KFM05A (0–114 m)

Anna Lindquist, Jan-Erik Ludvigson
Geosigma AB

June 2006

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

ISSN 1651-4416
SKB P-06-140

Forsmark site investigation

Pumping tests and flow logging in borehole HFM14 and pumping test in KFM05A (0–114 m)

Anna Lindquist, Jan-Erik Ludvigson
Geosigma AB

June 2006

Keywords: Forsmark, Hydrogeology, Hydraulic tests, Pumping tests, Flow meter logging, Water sampling, Hydraulic parameters, Transmissivity, Flow anomaly, AP PF 400-05-125.

This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the authors and do not necessarily coincide with those of the client.

A pdf version of this document can be downloaded from www.skb.se

Abstract

The percussion drilled borehole HFM14 is situated at drill site DS5 and was drilled with the purpose to serve as one of the supply wells during core-drilling of KFM05A. HFM14 is drilled with an inclination of 60°. The deep core-drilled borehole KFM05A is also inclined c. 60° from the horizontal plane. Different hydraulic tests (e.g. injection tests /1/ and difference flow logging /2/) have already been performed in the core drilled borehole KFM05A, and it is now equipped for long time hydro monitoring. A packer separates the section 0–114 m from the rest of the borehole. An inner casing has been installed in the interval 97–110 m (borehole length), but the casing is perforated in the interval 108.85–109.40 m. This means that the actual tested section is 108.85–114.0 m.

The main objectives of the hydraulic tests in the percussion borehole HFM14 were to investigate the occurrence and hydraulic characteristics of transmissive rock structures as well as the hydrogeochemical characteristics of the groundwater. The main aim of the pumping test in KFM05A was to test the capacity of the upper section (0–114 m) to find out if it can be used as a pumping well in a planned interference test.

A pumping test has previously been conducted in HFM14, but no flow logging was performed, due to the potential risk of fractures and cavities below the casing damaging the equipment /3/. A longer casing has been installed since then, which now makes flow logging possible.

Pumping tests were performed in borehole HFM14 in conjunction with flow logging. In order to supplement the results from the flow logging, a pumping test above a single packer was conducted in the upper part of the borehole (i.e. above the highest position for flow logging). Water sampling was performed in conjunction with the main pumping test.

The total borehole transmissivity of HFM14 was estimated at $5.7\cdot10^{-4}$ m^2/s. The pumping test in the interval 6.0–14.0 m resulted in a transmissivity of the section of $9.0\cdot10^{-6}$ m^2/s. Hence, the flow logged interval 14.0–145.0 m has an estimated transmissivity of c. $5.6\cdot10^{-4}$ m^2/s. The flow logging indicated four conductive sections; at c. 20.5–21.5 m with a transmissivity of $2.5\cdot10^{-4}$ m^2/s, at c. 49.5–50.0 m with a transmissivity of $9.9\cdot10^{-5}$ m^2/s, at 67.5–68.5 m with a transmissivity of $8.2\cdot10^{-5}$ m^2/s and at c. 100.0–102.0 m with a transmissivity of $1.2\cdot10^{-4}$ m^2/s. The transmissivity of the section 108.85–114.0 m in borehole KFM05A was estimated at $4.1\cdot10^{-4}$ m^2/s.

Sammanfattning

Det hammarborrade borrhålet HFM14 ligger vid borrplats BP5 och borrades primärt för att användas som spolvattenbrunn vid kärnborrningen av KFM05A. Borrhål HFM14 är borrat med en lutning av 60° från horisontalplanet. Även det djupa kärnborrhålet KFM05A (1 002,07 m långt) lutar ca 60° från horisontalplanet. Olika hydrauliska tester (t ex injektionstester /1/ och differensflödesloggning /2/) har redan genomförts i detta hål, och hålet är nu instrumenterat med utrustning för långtidsmonitering. En manschett skiljer den övre, testade sektionen (0–114 m) från resten av borrhålet. Ett foderrör har installerats ned till borrhålslängd 110 m, men foderröret är perforerat i intervallet 108,85–109,40 m. Detta innebär att den testade sektionen sträcker sig från borrhålslängd 108,85 m till 114,0 m.

Det huvudsakliga syftet med de hydrauliska testerna i hammarborrhål HFM14 som presenteras i denna rapport var att undersöka förekomsten av och de hydrauliska egenskaperna, liksom grundvattenkemin hos transmissiva strukturer som borrhålet penetrerar. För pumpningen i KFM05A var syftet att kapacitetsbestämma den översta sektionen (0–114 m) för att avgöra om denna kan fungera som pumpbrunn i ett senare interferenstest.

Ett pumptest har tidigare genomförts i HFM14, men ingen flödesloggning kunde genomföras på grund av kaviteter och sprickor nedanför foderröret som riskerade att förstöra utrustningen /3/. Ett längre foderrör har nu installerats, vilket gör det möjligt att genomföra flödesloggning.

Inom den aktivitet som presenteras i denna rapport utfördes pumptester i kombination med flödesloggning i HFM14. För att komplettera resultatet från flödesloggningen utfördes ett pumptest ovanför en enkelmanschett i den övre delen av HFM14 (dvs ovan den högsta flödesloggade punkten). Vattenprover för undersökning av grundvattnets hydrokemiska egenskaper togs i samband med det huvudsakliga, längre pumptestet i borrhål HFM14.

Totala transmissiviteten för HFM14 uppskattades till $5{,}7 \cdot 10^{-4}$ m^2/s. Pumptestet ovanför enkelmanschetten, 6,0–14,0 m, resulterade i en transmissivitet för sektionen på $9{,}0 \cdot 10^{-6}$ m^2/s. Det flödesloggade intervallet har därför en transmissivitet av $5{,}6 \cdot 10^{-4}$ m^2/s. Flödesloggningen indikerade fyra konduktiva avsnitt; vid ca 20,5–21,5 m djup med en uppmätt transmissivitet på $2{,}5 \cdot 10^{-4}$ m^2/s, vid ca 49,5–50,0 m med uppmätt transmissivitet på $9{,}9 \cdot 10^{-5}$ m^2/s, vid ca 67,5–68,5 m med uppmätt transmissivitet på $8{,}2 \cdot 10^{-5}$ m^2/s och vid ca 100,0–102,0 m med en transmissivitet på $1{,}2 \cdot 10^{-4}$ m^2/s. Transmissiviteten för sektionen 108,85–114,0 m i KFM05A uppskattades till $4{,}1 \cdot 10^{-4}$ m^2/s.

Contents

1 Introduction

This document reports the results of hydraulic testing in borehole HFM14 and the upper section (0–114 m) of KFM05A within the Forsmark site investigation. The borehole KFM05A is cased to borehole length 110.0 m, but the casing interval 108.85–109.40 m is perforated. This means that the actual tested section is 108.85–114.0 m. In this report the tested section in KFM05A is referred to as 108.85–114.0 m.

A pumping test combined with flow logging was carried out in HFM14. Water sampling was undertaken in conjunction with the pumping test. In addition, a shorter pumping test was performed above a packer at 14–15 m in borehole HFM14 to quantify the transmissivity above the flow logged interval. In KFM05A only a short pumping test was conducted in the upper section (0–114 m). Both HFM14 and KFM05A have been investigated prior to this field campaign /1/, /2/ and /3/.

The two boreholes are situated at drill site DS5, see Figure 1-1.

The work was carried out in accordance to SKB internal controlling documents; see Table 1-1. Data and results were delivered to the SKB site characterization database SICADA, where they are traceable by the Activity Plan number.

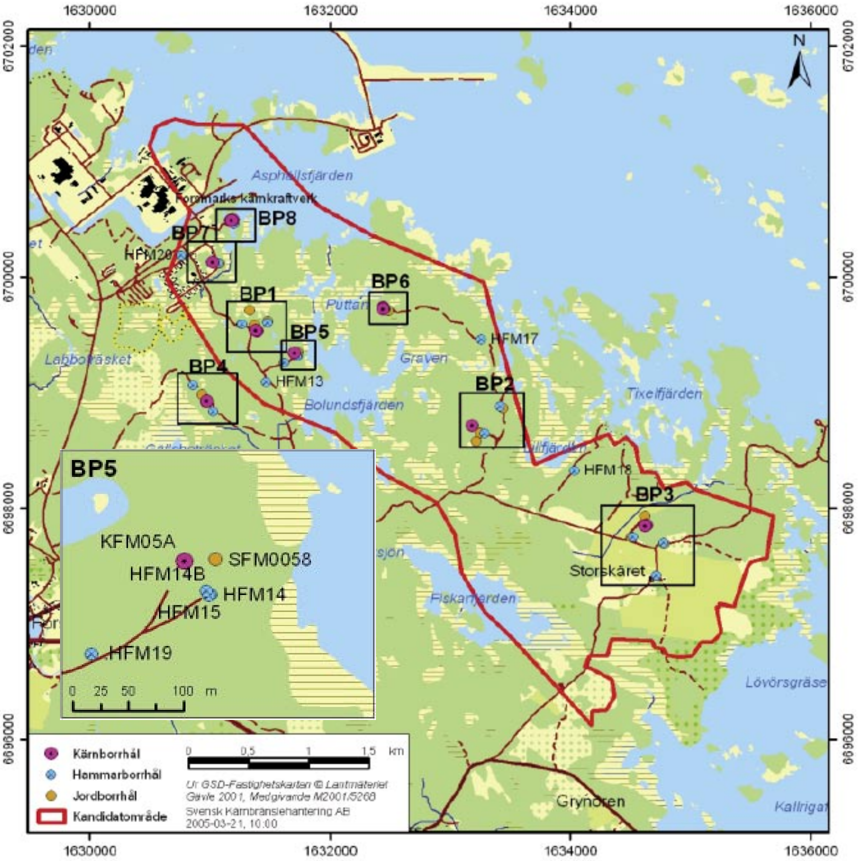


Figure 1-1. *Map showing the location of boreholes HFM14 and KFM05A as well as all the other boreholes at DS5.*

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

Activity Plan	Number	Version
Provpumpning i borrhål KFM05A (0–114 m) samt provpumpning och vattenprovtagning i borrhål HFM14	AP PF 400-05-125	1.0
Method descriptions	**Number**	**Version**
Metodbeskrivning för hydrauliska enhålspumptester	SKB MD 321.003	1.0
Metodbeskrivning för flödesloggning	SKB MD 322.009	1.0
Instruktion för analys av injektions- och enhålspumptester	SKB MD 320.004	1.0
Mätsystembeskrivning för HydroTestutrustning för HammarBorrhål. HTHB	SKB MD 326.001	3.0

2 Objectives

The objectives of the pumping tests and flow logging in borehole HFM14 were to investigate the hydraulic properties of the penetrated rock volumes, for example by identifying the position and hydraulic character of major inflows (which may represent e.g. sub-horizontal fracture zones). Furthermore, the aim was also to investigate the hydrochemical properties of the groundwater. The test in KFM05A was conducted as a shorter pumping test without flow logging and the aim was to test whether the upper section (0–114 m) can be used as a pumping well in a later interference test.

3 Scope

3.1 Boreholes tested

Technical data of the boreholes tested are displayed in Table 3-1. The reference point in the boreholes is always top of casing (ToC). The Swedish National coordinate system (RT90 2.5 gon W) is used in the x-y-plane together with RHB70 in the z-direction. Northing and Easting refer to the top of the boreholes at top of casing. The borehole diameter in Table 3-1, measured as the diameter of the drill bit, refers to the initial diameter below the casing of the boreholes. The borehole diameter decreases more or less along the borehole due to wearing of the drill bit.

3.2 Tests performed

The different test types conducted in boreholes HFM14 and KFM05A as well as the test periods are presented in Table 3-2. The test in KFM05A was performed in the upper section 0–114 m, but the actual tested borehole interval is from 108.85–114.0 m, since the borehole is cased to 110.0 m, with a perforated interval from 108.85–109.40 m.

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

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

Borehole								Casing		Drilling finished
ID	Elevation of top of casing (ToC) (m.a.s.l.)	Borehole length from ToC (m)	Bh-diam. (below casing) (m)	Inclin. -top of bh (from horizontal plane) (°)	Dip-Direction -top of bh (°)	Northing (m)	Easting (m)	Length (m)	Inner diam. (m)	Date (YYYY-MM-DD)
HFM14	3.91	150.5	0.138	–59.81	331.75	6699313	1631734	6.0	0.160	2003-10-09
KFM05A	5.53	114 (1,002.7)	0.077	–59.80	80.90	6699344	1631710	110.0[1)]	0.086[2)]	2004-04-20

[1)] The casing is perforated in the interval 108.85–109.40 m.

[2)] KFM05A is a telescopic borehole with a varying casing diameter, however the major part of the casing has this diameter.

Table 3-2. Borehole tests performed.

Bh ID	Test section (m)	Test type [1]	Test config.	Test start date and time (YYYY-MM-DD tt:mm)	Test stop date and time (YYYY-MM-DD tt:mm)
HFM14	6.0–150.0	1B	Open hole	060404 09:31:29	060405 08:16:45
HFM14	14.0–145.0	6, L-Te, L-EC	Open hole	060404 16:38:18	060404 19:58:44
HFM14	6.0–14.0	1B	Above packer	060405 10:11:15	060406 09:20:13
KFM05A [2)]	108.85–114.0 (0–114)	1B	Open hole	060406 13:42:00	060407 08:56:58

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

[2)] The borehole is cased to 110.0 m, but the interval 108.85–109.40 is perforated.

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 the water while lowering, measured pressure coincided well with the total head of water ($p/\rho g$). The temperature sensor displayed expected values in both air and water.

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

4 Description of equipment

4.1 Overview

The equipment used in these tests is referred to as HTHB (Swedish abbreviation for Hydraulic Test System for Percussion Boreholes) and is described in the user manual of the measurement system.

The HTHB unit is designed to perform pumping- and injection tests in open percussion drilled boreholes (Figure 4-1), and in isolated sections of the boreholes (Figure 4-2) down to a total depth (borehole length) of 200 m. With the HTHB unit, it is also possible to perform a flow logging survey along the borehole during an open-hole pumping test (Figure 4-1). The pumping tests can be performed with either a constant hydraulic head or, alternatively, with a constant flow rate. For injection tests, however, the upper packer cannot be located deeper than c. 80 m due to limitations in the number of pipes available.

All equipment that belongs to the HTHB system is, when not in use, stored on a trailer and can easily be transported by a standard car. The borehole equipment includes a submersible borehole pump with housing, expandable packers, pressure sensors and a pipe string and/or hose. During flow logging, the sensors measuring temperature and electric conductivity as well as down-hole flow rate are also employed. At the top of the borehole, the total flow/injection rate is manually adjusted by a control valve and monitored by an electromagnetic flow meter. A data logger samples data at a frequency determined by the operator.

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

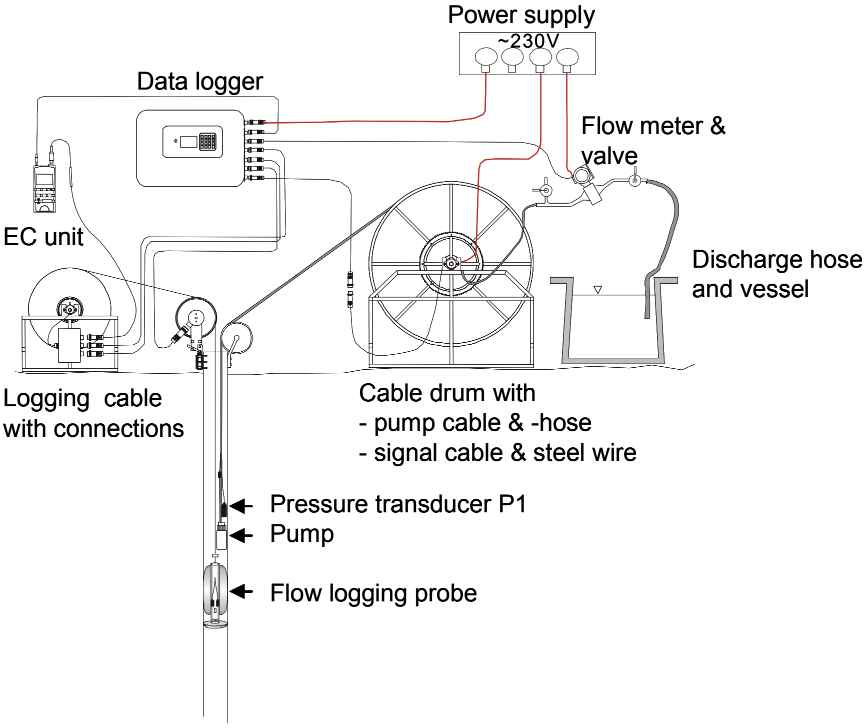


Figure 4-1. Schematic test set-up for a pumping test in an open borehole in combination with flow logging with HTHB. (From SKB MD 326.001, SKB internal document).

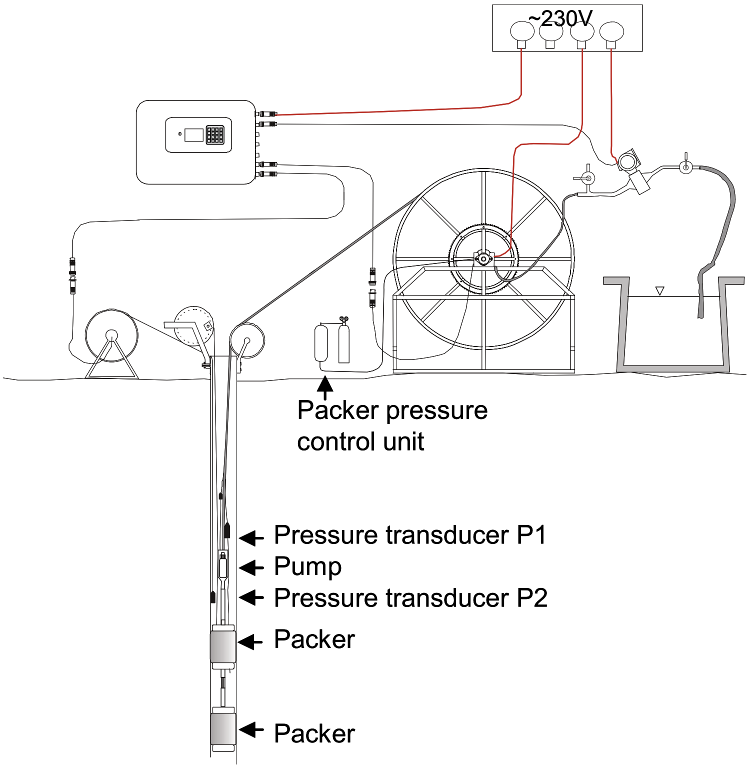


Figure 4-2. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB. (From SKB MD 326.001, SKB internal document).*

4.2 Measurement sensors

Technical data of the sensors used together with estimated data specifications of the HTHB test system for pumping tests and flow logging are given in Table 4-1.

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

The flow logging probe is calibrated for different borehole diameters (in reality different pipe diameters), i.e. 111.3, 135.5, 140 and 162 mm. During calibration the probe is installed in a vertically orientated pipe and a water flow is pumped through. The spinner rotations and total discharge are measured. Calibration gives excellent correlation ($R^2 > 0.99$) between total discharge and the number of spinner rotations. The calibration also clearly demonstrates how sensible the probe is to deviations in the borehole diameter, cf. Figure 4-3.

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

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

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

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

* Includes hysteresis, linearity and repeatability.
** Maximum error in % of actual reading (% o.r.).
*** Applicable to boreholes with a borehole diameter of 140 mm and 100 s sampling time.

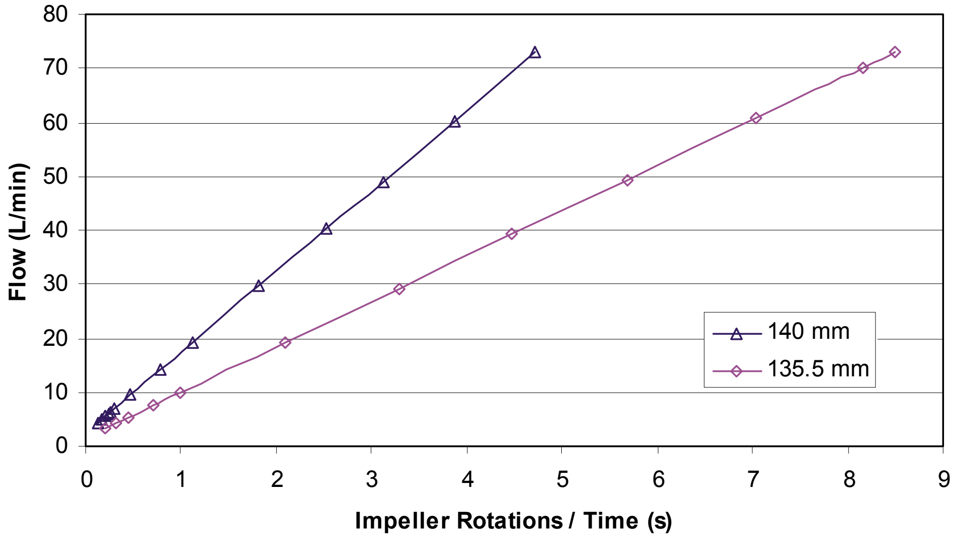


Figure 4-3. Total flow as a function of impeller rotations for two borehole diameters (140 and 135.5 mm).

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

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

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

Borehole information				Sensors		Equipment affecting wellbore storage (WBS)			
ID	Test interval (m)	Test config	Test type 1)	Type	Position (m b ToC)	Function	Position 2) relative test section	Outer diameter (mm)	C (m^3/Pa) for test3)
HFM14	6.0–150.5	Open hole	1B	Pump-intake	10.4	Pump hose	In section	33.5	$1.9 \cdot 10^{-6}$
			1B			Pump cable	In section	14.5	
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	7.72	Signal cable	In section	8	
			6	EC, Te, Q	140–145.0	Signal cable	In section	13.5	
HFM14	6.0–14.0	Above packer	1B	Pump-intake	11.4	Pump hose	In section	33.5	$1.9 \cdot 10^{-6}$
			1B			Pump cable	In section	14.5	$1.4 \cdot 10^{-6}$ 4)
			1B			Steel wire	In section	5	
			1B			Polyamide tube	In section	6	
			1B	P (P1)	8.72	Signal cable	In section	8	
			1B	P (P2)	13.12	Signal cable	In section	8	
			1B			Steel wire	In section	6	
			1B			Aluminum rod	In section	20	

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

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

3) Based on the casing diameter or the actual borehole diameter (Table 3-1) for open-hole tests together with the compressibility of water for the test in isolated sections, respectively (net values).

4) Value of C based on borehole diameter below casing.

5 Execution

5.1 Preparations

All sensors included in the HTHB system are calibrated at the Geosigma engineering service station in Uppsala. Calibration is generally performed on a yearly basis, but more often if needed. The latest calibration was performed in September 2005. If a sensor is replaced at the test site, calibration of the new sensor can be carried out in the field (except the flow probe) or alternatively, in the laboratory after the measurements. Due to a breakage in the signal cable to the electric conductivity sensor during the latest calibration the calibration constants achieved during the former calibration in April 2004 were used for the repaired sensor.

Functioning checks of the equipment used in the present test campaign were made prior to each hydraulic test. The results from the functioning checks are presented in Section 3.3.

Before the tests, cleaning of equipment as well as time synchronisation of clocks and data loggers was performed according to the Activity Plan.

5.2 Procedure

5.2.1 Overview

The main pumping test in HFM14 was carried out as a single-hole, constant flow rate test followed by a pressure recovery period. At the end of the pumping period flow logging was performed. A second pumping test above a single packer at 14–15 m was made in HFM14 to achieve the transmissivity above the highest position of the flow logging probe. The test in KFM05A was carried out in the same way as the main pumping test in HFM14, but the pumping time was shorter and no flow logging was performed.

Before flow logging is started, the intention is to achieve approximately steady-state conditions in the borehole.

The flow logging is performed with discrete flow measurements made at fixed step lengths (5 m until the first flow anomaly is found and 2 m thereafter), starting from the bottom and upwards along the borehole. When a detectable flow anomaly is found, the flow probe is lowered and repeated measurements with a shorter step length (0.5 m) are made to determine a more correct position of the anomaly. The flow logging survey is terminated a short distance below the submersible pump in the borehole.

5.2.2 Details

Single-hole pumping tests

Before the pumping tests, short flow capacity tests were carried out to select an appropriate flow rate or an appropriate drawdown for the tests. The pumped water from both HFM14 and KFM05A was discharged on the ground, sloping downhill from the borehole.

The main test in HFM14 borehole was a c. 10 h pumping test in the open hole in combination with flow logging, followed by a recovery period of c. 12 h. The pumping test above a packer in HFM14 was 3.5 h long, followed by a recovery of c. 15 h (during the night). The pumping time for the test in KFM05A was c. 3 h and the pressure recovery was registered over night.

In general, the sampling frequency of pressure and flow during the pumping tests is according to Table 5-1. The hydraulic tests in borehole HFM14 were performed before the test in KFM05A.

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

Time interval (s) from start/stop of pumping	Sampling interval (s)
1–300	1
301–600	10
601–3,600	60
> 3,600	600

Flow logging

Prior to the start of the flow logging, the probe was lowered to the bottom of the borehole. While lowering along the borehole, temperature- and electric conductivity data were sampled.

Flow logging was performed during the long pumping test (10 h), starting from the bottom of the hole going upwards. The logging started when the pressure in the borehole was approximately stable. The time needed to complete the flow logging survey depends on the length and character of the borehole. In general, between 3–5 hours is a normal period for a percussion borehole of 100–200 m length, cf. Section 6.4.

5.3 Data handling

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

Processed data files (*.mio-files) are used to create linear plots of pressure and flow versus time with the code SKBPLOT and evaluation plots with the software AQTESOLV, according to the Instruction for analysis of injection- and single-hole pumping tests (SKB MD 320.004, SKB internal document).

5.4 Analyses and interpretation

This section provide a comprehensive general description of the procedure used when analysing data from the hydraulic tests carried out with the HTHB equipment.

5.4.1 Single-hole pumping tests

Firstly, a qualitative evaluation of the actual flow regimes (wellbore storage, pseudo-linear, pseudo-radial or pseudo-spherical flow) and possible outer boundary conditions during the hydraulic tests are performed. The qualitative evaluation is made from analyses of log-log diagrams of drawdown and/or recovery data together with the corresponding derivatives versus time. In particular, pseudo-radial flow (2D) is reflected by a constant (horizontal) derivative in the diagrams. Pseudo-linear and pseudo-spherical flow are reflected by a slope of the derivative of 0.5 and -0.5, respectively in a log-log diagram. Apparent no-flow- and constant head boundaries are reflected by a rapid increase and decrease of the derivative, respectively.

From the results of the qualitative evaluation, appropriate interpretation models for the quantitative evaluation of the tests are selected. In general, a certain period with pseudo-radial flow can be identified during the pumping tests. Consequently, methods for single-hole, constant-flow rate or constant drawdown tests for radial flow in a porous medium described in /4/ and /5/ are generally used by the evaluation of the tests. For tests indicating a fractured- or borehole storage dominated response, corresponding type curve solutions is used by the routine analyses.

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

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

The effective casing radius may be estimated from the regression analysis for tests affected by wellbore storage. The wellbore storage coefficient can be calculated from the simulated effective casing radius, see below. The effective wellbore radius concept is used to account for negative skin factors.

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

Rather than assuming a fixed value of the storativity of $1\cdot10^{-6}$ by the analysis according to the instruction SKB MD 320.004, an empirical regression relationship between storativity and transmissivity, Equation 5-1 (Rhén et al. 1997) /6/ is used. Firstly, the transmissivity and skin factor are obtained by type curve matching on the data curve using a fixed storativity value of 10^{-6}. From the transmissivity value obtained, the storativity is then calculated according to Equation 5-1 and the type curve matching is repeated.

$$S = 0.0007\cdot T^{0.5} \tag{5-1}$$

S = storativity (–)

T = transmissivity (m^2/s)

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

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

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

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

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

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

r_w = nominal borehole radius (m)

r_c = inner radius of the borehole casing (m)

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

ρ = density of water (kg/m^3)

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

5.4.2 Flow logging

The measured parameters during flow logging (flow, temperature and electric conductivity of the borehole fluid) are firstly plotted versus borehole length. From these plots, flow anomalies are identified along the borehole, i.e. borehole intervals over which changes of flow exceeding c. 1 L/min occur. The size of the inflow at a flow anomaly is determined by the actual change in flow rate across the anomaly. In most cases, the flow changes are accompanied by changes in temperature and/or electric conductivity of the fluid. If the actual borehole diameter differs from the one assumed by the calibration of the flow probe, corrections of the measured borehole flow rates may be necessary, cf. Figure 4-3.

Flow logging can be carried out from the borehole bottom up to a certain distance below the submersible pump (c. 2.5 m). The remaining part of the borehole (i.e. from the pump to the casing) cannot be flow-logged although high inflow zones may sometimes be located here. Such superficial inflows may be identified by comparing the flow at the top of the flow-logged interval (Q_T) with the discharged flow rate (Q_p) measured at the surface during the flow logging. If the latter flow rate is significantly higher, one or several inflow zones are likely to exist above the flow-logged interval. However, one must be careful when interpreting absolute flow values measured by the flow logging probe since it is very sensitive to the actual borehole diameter. The probe is calibrated in a tube with a certain diameter (see Section 4.2) but the actual borehole diameter, measured as the diameter of the drill bit, is most often deviating from the nominal diameter. Furthermore, the borehole diameter is normally somewhat larger than the diameter of the drill bit, depending, among other things, on the rock type. The diameter is also decreasing towards depth, due to successive wearing of the drill bit.

To account for varying diameter along the borehole, one may utilize the logging in the undisturbed borehole when lowering the flow logging probe before pumping. Under the assumption of a linear relationship between borehole diameter and gain in the calibration function, transforming counts per seconds from the flow sensor to engineering units (L/min), and using known borehole diameters at two or more borehole lengths, one can obtain a relationship between gain and borehole length in the actual borehole. This relationship is then used for correction of the measured flow along the borehole.

Since the absolute value of the borehole diameter is uncertain and the measured borehole flow to some degree probably also depends on borehole inclination, it is often necessary to make a final correction to achieve correspondence between the measured borehole flow at the top of the flow logged interval and the pumped flow measured at surface. To make these corrections, all significant flow anomalies between the top of the flow logged interval and the casing must also be quantified. Therefore, it may be necessary to supplement the flow logging with injection or pumping tests above the highest logged level in the borehole, unless it is possible to carry out the flow logging to the casing. Alternatively, if other information (e.g. BIPS logging or drilling information) clearly shows that no inflow occurs in this part of the borehole no supplementary tests are necessary.

Depending on if supplementary tests are carried out two different methods are employed for estimating the transmissivity of individual flow anomalies in the flow logged interval of the borehole. In both cases the transmissivity of the entire borehole (T) is estimated from the transient analysis of the pumping test.

Method 1

If no significant inflow occurs above the flow logged interval, the corrected logged flow at a certain length, $Q(L)_{corr}$, can be calculated according to:

$$Q(L)_{corr} = Corr \cdot Q(L) \tag{5-3}$$

where

Corr = Q_P/Q_T

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

Q_P = pumped flow from the borehole

Q_T = measured flow at the top of the logged interval

The transmissivity of an individual flow anomaly (T_i) is calculated from the measured inflow (dQ_i) at the anomaly, the discharge Q_p and the calculated transmissivity of the entire borehole (T) according to:

$$T_i = Corr \cdot dQ_i/Q_p \cdot T \tag{5-4}$$

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

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

Method 2

If additional hydraulic tests show that there exist significant flow anomalies above the flow logged interval, the transmissivity T_A for the non flow logged interval is estimated from these tests. In this case the resulting transmissivity of the flow-logged interval (T_{FT}) is calculated according to:

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

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

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

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

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

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

where

Corr = Q_{FT}/Q_T

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

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

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

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

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

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

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

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

Similarly, the lower measurement limit of transmissivity of a flow anomaly can be estimated using $dQ_{i\,min}$ = 1 L/min ($1.7 \cdot 10^{-5}$ 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 corresponds to the transmissivity of the entire borehole.

5.5 Nonconformities

The hydraulic test program was mainly performed in compliance with to the Activity Plan, however with the following exceptions:

- The discharged water pumped from HFM14 infiltrated in a hollow next to the borehole and it started to flow back into the borehole through hydraulic connections after c. 2.5 h of pumping. This prolonged the time to achieve steady-state conditions in the borehole somewhat (see Section 6.3.1). However, the water collected in the hollow was emptied, and after this all the pumped water was discharged further away from the borehole. Before the start of the flow logging, approximate steady-state conditions prevailed.
- The pumping test above the single packer in HFM14 initially indicated a high transmissivity, hence the flow rate was increased. This, however, led to a rapidly decreasing pressure, and the flow rate had to be lowered again. The low flow rate then used for the rest of the test was not sufficient to obtain a decreasing or stable pressure. Instead the pressure increased with a constant rate for the remaining 3 h of pumping. Transient evaluation was however possible.

- Manual water level measurements were only performed prior to and after the pumping in KFM05A. Since the borehole is equipped for long time monitoring, it was impossible to get the probe down when the pump with hose also were installed in the hole.

Compared to the Methodology Description for single-hole pumping tests (SKB MD 321.003), a deviation was made regarding the recommended test times:

- The recommended test time (24 h + 24 h for drawdown/recovery) for the longer pumping tests during flow logging was decreased to c.10 h +12 h due to practical reasons (mainly to avoid uncontrolled pumping over-night and to eliminate the risk of freezing, theft/sabotage etc.). Experience from similar tests in other boreholes indicates that c. 10 h of pumping and 12 h of recovery in general is sufficient to estimate the hydraulic properties of the borehole regarding e.g. wellbore storage effects and other disturbing factors.

6 Results

6.1 Nomenclature and symbols

The nomenclature and symbols used for the results of the pumping tests and flow logging are according to the instruction for analysis of single-hole injection- and pumping tests, SKB MD 320.004, Version 1.0, and the methodology description for impeller flow logging, SKB MD 322.009, Version 1.0. Additional symbols used are explained in the text. The nomenclature for the analyses of the pumping tests by the AQTESOLV code is presented in Appendix 2.

6.2 Water sampling

Water samples were taken during the pumping tests in the boreholes and submitted for analysis, see Table 6-1.

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

6.3 Single hole pumping tests

6.3.1 Borehole HFM14: 6.0–150.5 m

General test data for the open-hole pumping test in HFM14 in conjunction with flow logging are presented in Table 6-2.

The atmospheric pressure during the test period in HFM14 is presented in Figure 6-1. The atmospheric pressure varied c. 0.3 kPa, i.e. only about c. 1.7% of the total drawdown of c. 1.81 m in the borehole during the test, and thus the effect of atmospheric pressure variations on the test results is considered as negligible.

Table 6-1. Water samples collected during the pumping tests in boreholes HFM14 submitted for analysis.

Bh ID	Date and time of sample	Pumped section (m)	Pumped volume (m^3)	Sample type	Sample ID no	Remarks
HFM14	2006-04-04 09:42	6.0–150.5	0.8	WC080	012220	Open-hole test
HFM14	2006-04-04 16:00	6.0–150.5	26.5	WC080	012219	Open-hole test
HFM14	2006-04-04 20:00	6.0–150.5	43.25	WC080	012221	Open-hole test

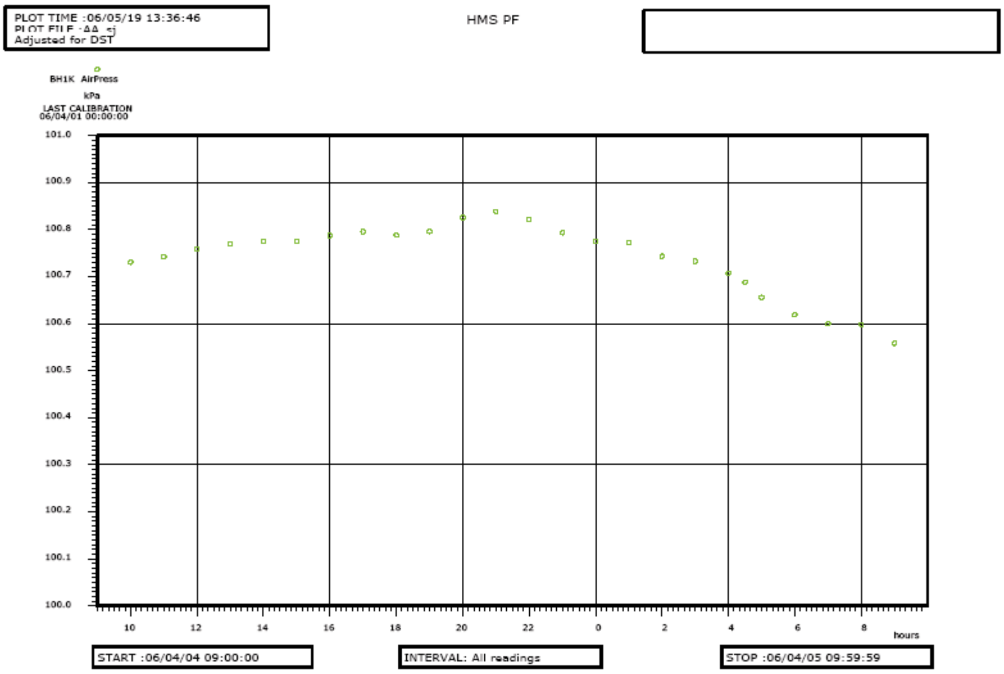


Figure 6-1. *Atmospheric pressure during the main pump test period in HFM14.*

Comments on test

The day before test start, a short capacity test was performed (c. 15 min). By the end of the capacity test, the flow rate was c. 70 L/min and the drawdown c. 1.15 m. The actual pumping test was performed as a constant flow rate test (68.0 L/min) with the intention to achieve (approximately) steady-state conditions during the flow logging. A comparison of the results from the capacity test and pumping test is presented in Table 6-3. Discrepancies between the two may indicate changes in the borehole skin zone due to pumping. Table 6-3 shows a good consistency in specific capacity from the short capacity test and the main pumping test indicating stable borehole conditions.

After c. 150 minutes of pumping with constant flow rate, the pressure in the borehole started to increase. The explanation was that the discharged water somehow got hydraulically connected to the borehole. When the discharge hose was moved further away, and the pool produced by the discharged water was emptied by a pump and discharged further away, the pressure started to decrease again. After another 8 h of pumping the conditions in the borehole were approximately stable and flow logging could be carried out as planned.

Interpreted flow regimes

Selected test diagrams according to the Instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-1 until A2-7 in Appendix 2.

During the drawdown period a pseudo-radial flow regime is identified after c. 5 minutes lasting until 130 minutes, when the drawdown starts to decrease (see explanation above and Figures A2-1, A2-2 and A2-3). The transient evaluation is only made on this part of the drawdown curve. The recovery period shows two pseudo-radial flow regimes, the first from c. 2 minutes to c. 20 minutes, and the second from c. 40 min to the end of the period (see Figures A2-4 until A2-7).

Table 6-2. General test data, pressure, groundwater level and flow data for the open-hole pumping test in borehole HFM14, in conjunction with flow logging.

General test data	
Borehole	HFM14 (6.0–150.5 m)
Test type [1]	Constant rate withdrawal and recovery test
Test section (open borehole/packed-off section):	Open borehole
Test No	1
Field crew	A. Lindquist and C. Hjerne, GEOSIGMA AB
Test equipment system	HTHB
General comment	Single pumping borehole

	Nomenclature	**Unit**	**Value**
Borehole length	L	M	150.5
Casing length	L_c	M	6.0
Test section – secup	Secup	M	6.0
Test section – seclow	Seclow	M	150.5
Test section length	L_w	M	144.5
Test section diameter	$2 \cdot r_w$	Mm	top 138.0 bottom 136.0
Test start (start of pressure registration)		yymmdd hh:mm	060404 09:29
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	060404 09:31:29
Stop of flow period		yymmdd hh:mm:ss	060404 20:06:50
Test stop (stop of pressure registration)		yymmdd hh:mm	060405 08:16
Total flow time	t_p	Min	636
Total recovery time	t_F	Min	730

Pressure data	**Nomenclature**	**Unit**	**Value**	**GW Level (m.a.s.l.) [2]**
Absolute pressure in test section before start of flow period	p_i	kPa	129.88	0.69
Absolute pressure in test section at stop of flow period	p_p	kPa	112.13	–1.13
Absolute pressure in test section at stop of recovery period	p_F	kPa	127.85	0.51
Maximal pressure change in test section during the flow period	dp_p	kPa	17.75	

Manual groundwater level measurements			**GW level**	
Date YYYY-MM-DD	**Time tt:mm.ss**	**Time (min)**	**(m bToC)**	**(m.a.s.l.)**
060403	10:18:00	–1,393.5	3.66	0.75
060404	09:20:00	–11.5	3.73	0.69
060404	10:37:00	65.5	5.33	–0.70
060404	12:44:00	192.5	4.84	–0.27
060404	14:17:00	285.5	5.28	–0.65
060404	15:57:00	385.5	5.59	–0.92
060404	19:58:00	626.5	5.83	–1.13
060405	08:08:00	1,346.5	3.93	0.51
060406	10:58:00	2,956.5	3.93	0.51

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.13 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period [3]	Q_m	m^3/s	$1.13 \cdot 10^{-3}$
Total volume discharged during flow period [3]	V_p	m^3	43.25

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

[2] From the manual measurements of groundwater level.

[3] Calculated from integration of the transient flow rate curve during the flow period.

Table 6-3. Estimated specific capacity from the capacity test and pumping test in borehole HFM14: 6.0–150.5 m.

Test	Duration (min)	Flow rate, Qp (L/min)	Drawdown, sw = pi-pp (m)	Specific capacity, Qp/sw (m²/s)
Short capacity test	16	70.15	1.15	$1.02 \cdot 10^{-3}$
Pumping test 1)	16	68.15	1.10	$1.03 \cdot 10^{-3}$
	636	68.00	1.81	$6.26 \cdot 10^{-4}$

[1] The values on the second row represent the first 16 minutes of the main pumping test

Interpreted parameters

Transient evaluation of transmissivity was performed for both the flow- and recovery period and the interpretation of the test is presented in Figures A2-2 until A2-5 in Appendix 2. The quantitative analysis was performed according to the methods described in Section 5.4.1. The transmissivity was estimated by a model assuming pseudo-radial flow /5/ on both the flow- and recovery period. The evaluation on the first PRF during the recovery period is considered as more representative of the hydraulic condition close to the borehole, whereas the second PRF is assumed to represent the condition further away from the borehole. The representative transmissivity (i.e. T_T) is considered to be from the transient evaluation of the flow period. The agreement between the drawdown and the recovery period regarding transmissivity and skin factor is rather good.

The results are shown in the Test Summary Sheet (Table 6-13) and in Tables 6-11 and 6-12 in Section 6.5. The analysis from the flow period was selected as representative for the test.

6.3.2 Borehole HFM14: 6.0–14.0 m

General test data for the pumping test above a packer at 14–15 m in HFM14 are presented in Table 6-4.

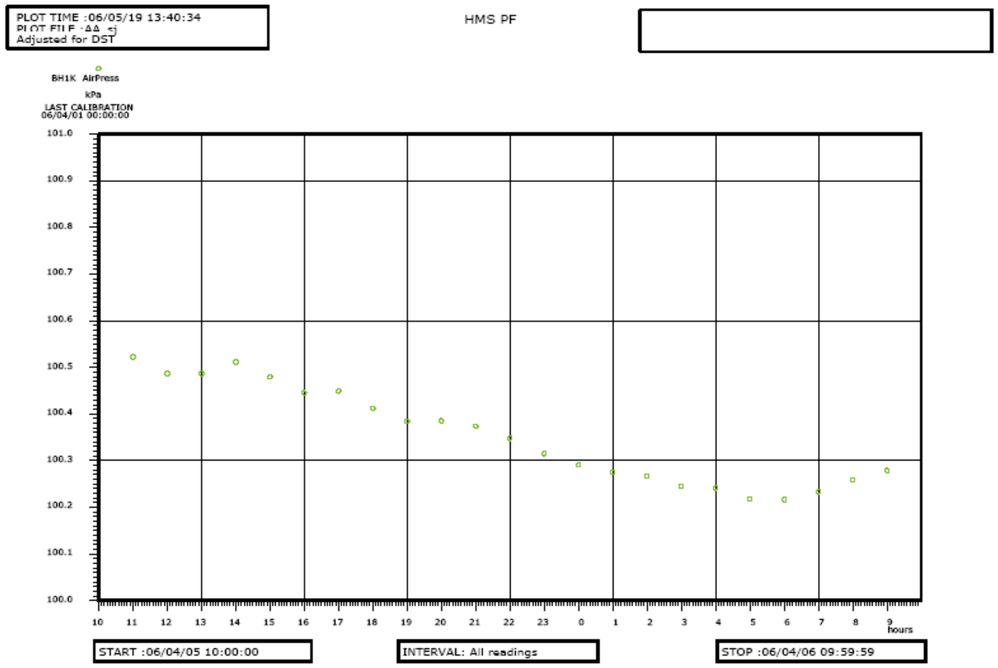


Figure 6-2. Atmospheric pressure during the pump test above a single packer in borehole HFM14.

The atmospheric pressure during the test period is presented in Figure 6-2. The atmospheric pressure varied c. 0.2 kPa, i.e. only c. 0.9% of the drawdown, at the end of the flow period, of c. 2.28 m in the borehole during the test, and thus the effect of atmospheric pressure variations on drawdown is considered as negligible.

Table 6-4. General test data, pressure, groundwater level and flow data for the pumping test above a packer at 14–15 m in borehole HFM14.

General test data	
Borehole	HFM14 (6.0–14.0 m)
Test type [1]	Constant rate withdrawal and recovery test
Test section (open borehole/packed-off section):	Open borehole
Test No	1
Field crew	A. Lindquist, C. Hjerne GEOSIGMA AB
Test equipment system	HTHB
General comment	Single pumping borehole

	Nomenclature	**Unit**	**Value**
Borehole length	L	m	150.5
Casing length	L_c	m	6.0
Test section – secup	Secup	m	6.0
Test section – seclow	Seclow	m	14.0
Test section length	L_w	m	8.0
Test section diameter [2]	$2 \cdot r_w$	mm	138.0
Test start (start of pressure registration)		yymmdd hh:mm	060405 10:10
Packer expanded		yymmdd hh:mm:ss	060405 10:11:15
Start of flow period		yymmdd hh:mm:ss	060405 10:33:49
Stop of flow period		yymmdd hh:mm:ss	060405 13:59:27
Test stop (stop of pressure registration)		yymmdd hh:mm	060406 09:20
Total flow time	t_p	min	205
Total recovery time	t_F	min	1,160

Pressure data	**Nomenclature**	**Unit**	**Value**	**GW Level (m.a.s.l.)**
Absolute pressure in test section before start of flow period	p_i	kPa	138.20	0.51
Absolute pressure in test section at stop of flow period	p_p	kPa	115.77	
Absolute pressure in test section at stop of recovery period	p_F	kPa	136.77	
Maximal pressure change in test section during the flow period [3]	dp_p	kPa	41.09	
Pressure in test section at stop of flow period		kPa	22.43	

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$3.33 \cdot 10^{-5}$
Mean (arithmetic) flow rate during flow period [2]	Q_m	m^3/s	$4.94 \cdot 10^{-5}$
Total volume discharged during flow period [2]	V_p	m^3	0.607

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

[2] Calculated from integration of the transient flow rate curve.

[3] The maximal pressure change did not occur at the end of the flow period, but early during the flow period.

Comments on test

The flow logging in conjunction with the pumping test indicated that additional flow anomalies could be present in the upper section 6.0–14.0 m, but the pumping test showed that the transmissivity was lower than indicated by the flow logging probe. The test was supposed to be performed as a constant rate pumping test with a constant flow rate of 10 L/min. Since only a small drawdown followed when starting the pump, the flow rate was increased to 20 L/min after c. 2 minutes of pumping. The drawdown was then rapidly increasing, and in order to avoid a too large drawdown (the pressure sensor must be kept below the water surface) the flow rate had to be decreased again, this time to 2 L/min. This flow rate was then kept constant during the rest of the pumping. However the pressure was increasing slowly during the rest of the 3 h pumping period (see Figure A2-8). The test was evaluated with variable pumping rates, and a value of transmissivity was estimated. However, the interpretation of flow regimes as well as the qualitative evaluation of the test are very uncertain.

A pressure sensor was placed below the packer in order to detect any pressure interference with the section below the pumped section. In case of interference the transmissivity of the tested section might be overestimated. No sign of interference was though discovered.

Interpreted flow regimes

Selected test diagrams according to the instruction for analysis of injection – and single-hole pumping tests are presented in Figures A2-8 until A2-12 in Appendix 2.

No flow regimes can be identified from the drawdown period. The recovery period only indicates wellbore storage.

Interpreted parameters

The transient, quantitative interpretation of the flow- and recovery period of the test is presented in Figures A2-9 until A2-12 in Appendix 2. Quantitative analysis was applied both on the flow- and recovery period according to the methods described in Section 5.4.1.

The transmissivity was estimated by a model assuming pseudo-radial flow together with skin and wellbore storage /5/ on both the flow and the recovery period. The transient evaluation on the flow period is uncertain due to the changes in flow rate. No unambiguous transient evaluation is possible from the recovery period. An example of possible transient evaluation is shown in Appendix 2.

The results are exposed in the Test Summary Sheet (Table 6-14) in Table 6-11as well as in Table 6-12 in Section 6.5. The analysis from the flow period was selected as the representative one.

6.3.4 Borehole KFM05A: 108.85–114.0 m

General test data for the pumping test in the upper section (0–114 m) in KFM05A, above the single packer installed, are presented in Table 6-5.

The aim of the test in KFM05A was to make rough estimation of the transmissivity without making any transient evaluations of either the drawdown period, or the recovery period. The variations of atmospheric pressure during the test period and snow melting possibly affecting the ground water levels are therefore neglected.

Comments on test

The test was performed as a constant rate pumping test with a flow rate of 67.3 L/min during approximately 3 h. The pressure recovery was registered overnight.

Interpreted flow regimes

No transient evaluation was made on this pumping test, hence no flow regimes were identified. The linear plot of pressure and flow rate versus time is presented in Figure A2-13 in Appendix 2.

Table 6-5. General test data, pressure, groundwater level and flow data for the pumping test in borehole KFM05A.

General test data	
Borehole	KFM05A (108.85–114.0 m)
Test type [1]	Constant rate withdrawal and recovery test
Test section (open borehole/packed-off section):	Open borehole
Test No	1
Field crew	A. Lindquist, P. Fredriksson GEOSIGMA AB
Test equipment system	HTHB
General comment	Single pumping borehole

	Nomenclature	**Unit**	**Value**
Borehole length[3]	L	m	114.0 m (1,002.71 m)
Casing length	L_c	m	110.0
Test section – secup	Secup	m	108.85
Test section – seclow	Seclow	m	114.0
Test section length	L_w	m	5.15
Test section diameter [2]	$2 \cdot r_w$	mm	Inside casing 86.0 Below casing 77.3
Test start (start of pressure registration)		yymmdd hh:mm	060406 13:32
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	060406 13:42:02
Stop of flow period		yymmdd hh:mm:ss	060406 16:57:19
Test stop (stop of pressure registration)		yymmdd hh:mm	060407 08:56
Total flow time	t_p	min	195
Total recovery time	t_F	min	959

Pressure data	**Nomenclature**	**Unit**	**Value**	**GW Level (m.a.s.l.)**
Absolute pressure in test section before start of flow period	p_i	kPa	229.16	0.22
Absolute pressure in test section at stop of flow period	p_p	kPa	211.01	
Absolute pressure in test section at stop of recovery period	p_F	kPa	228.25	0.21
Maximal pressure change in test section during the flow period	dp_p	kPa	18.15	

Flow data	**Nomenclature**	**Unit**	**Value**
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$1.12 \cdot 10^{-3}$
Mean (arithmetic) flow rate during flow period [2]	Q_m	m^3/s	$1.12 \cdot 10^{-3}$
Total volume discharged during flow period [2]	V_p	m^3	13.04

[1] Constant Head injection and recovery or Constant Rate withdrawal and recovery or Constant drawdown withdrawal and recovery.
[2] Calculated from integration of the transient flow rate curve.
[3] The borehole is actually c. 1,000 m long, but a packer is installed isolating the upper 114 m.

Interpreted parameters

A steady-state evaluation of the pumping test was made using Moye's formula. The estimated transmissivity depends on whether it is assumed that the transmissivity is dominated by the perforated part of the casing (108.85–109.40 m), or that the entire non-cased borehole section from 108.85 until 114.0 m contributes to the measured transmissivity. The true value of transmissivity is probably somewhere between these two calculated values. The measured section has two different borehole diameters, one at the cased interval and a smaller one below the cased part. Also the specific flow Q_p/s is calculated. The values calculated by Moye's formula overestimate the transmissivity, T_M, since it assumes stationary conditions, which are not likely to prevail after only 3 h of pumping. In addition the skin factor in the perforated interval is likely to be negative due to large fractures in the interval, which further leads to an overestimation of T_M in relation to transient evaluation. A summary of different stationary evaluation of transmissivity is found in Table 6-6 below. The result is also presented in the Test Summary Sheet (Table 6-15).

According to the difference flow logging /2/ performed earlier in KFM05A the main inflow to the borehole occurs in the fractured interval 108.85–109.40 m. Hence, evaluation one in Table 6-6 above is considered as the representative value of transmissivity.

6.4 Flow logging

6.4.1 Borehole HFM14

General test data for the flow logging in borehole HFM14 are presented in Table 6-7. The estimation of the different flow anomalies in the flow logged interval is made according to Method 2 described in Section 5.4.2.

Comments on test

The flow logging was made from the bottom of the hole and upwards. The step length between flow logging measurements was maximally 5 m in the borehole interval 145.0–100 m (below the first measurable flow). Above 100 m, the step length was at most 2 m.

The measured electric conductivity and temperature are used as supporting information when interpreting flow anomalies.

Table 6-6. Different stationary evaluations of the pumping test in KFM05A: 0–114 m.

Evaluation	Diameter of section (m)	Assumed section length (m)	TM (m^2/s)	Specific flow, Qp/s (m^2/s)	Comments
1	0.086	0.55	4.06E–04	7.19E–04	Assuming only the perforated part of the casing contributes to the transmissivity
2	0.086	4.55	6.48E–04	7.19E–04	Assuming the same diameter (0.086 m) in the whole section, and that the non-cased borehole interval below 110.0 m as well as the perforated interval contributes to the transmissivity.
3	0.0773	4.55	6.60E–04	7.19E–04	Assuming the same diameter (0.0773 m) in the whole section, and that the non-cased borehole interval below 110.0 m as well as the perforated interval contributes to the transmissivity.

Logging results

The nomenclature used for the flow logging is according to the methodology description for flow logging. The measured flow distribution along the hole during the flow logging together with the electric conductivity (EC) and temperature of the borehole fluid is presented in Figure 6-3.

Table 6-7. General test data, groundwater level and flow data for the flow logging in borehole HM14.

General test data				
Borehole	HFM14			
Test type(s) [1]	6, L-EC, L-Te			
Test section:	Open borehole			
Test No	1			
Field crew	A. Lindquist, C. Hjerne GEOSIGMA AB			
Test equipment system	HTHB			
General comments	Single pumping borehole			
	Nomenclature	**Unit**	**Value**	
Borehole length		m	150.5	
Pump position (lower level)		m	11.0	
Flow logged section – Secup		m	14.0	
Flow logged section – Seclow		m	145.0	
Test section diameter	2·rw	mm	top 138.0 bottom 136.0	
Start of flow period		yymmdd hh:mm	060404 09:31	
Start of flow logging		yymmdd hh:mm	060404 16:10	
Stop of flow logging		yymmdd hh:mm	060404 19:58	
Stop of flow period		yymmdd hh:mm	060404 20:06	
Groundwater level	**Nomenclature**	**Unit**	**G.w-level (m b ToC)**	**G.w-level (m.a.s.l.) [2]**
Groundwater level in borehole, at undisturbed conditions, open hole	h_i	m	3.73	0.69
Groundwater level (steady state) in borehole, at pumping rate Q_p	h_p	m	5.83	–1.13
Drawdown during flow logging at pumping rate Q_p	s_{FL}	m		1.82
Flow data	**Nomenclature**	**Unit**	**Flow rate**	
Pumping rate at surface	Q_p	m^3/s	$1.137\cdot10^{-3}$	
Corrected cumulative flow rate at Secup at pumping rate Q_p	Q_{Tcorr}	m^3/s	$1.03\cdot10^{-3}$	
Threshold value for borehole flow rate during flow logging	Q_{Measl}	m^3/s	$5\cdot10^{-5}$	
Minimal change of borehole flow rate to detect flow anomaly	dQ_{Anom}	m^3/s	$1.7\cdot10^{-5}$	

1) 6: Flow logging-Impeller, L-EC: EC-logging, L-TE: temperature logging
2) Calculated from the manual measurements of groundwater level

In this case flow logging could only be performed up to 14.0 m below ToC whereas the casing starts at 6.0 m below ToC. Comparison of the pumped flow from the borehole and the cumulative flow measured by the flow logging probe at 14.0 m indicated that there was an inflow above 14.0 m. Hence a pumping test above a single packer was conducted above 14.0 m and the estimated transmissivity from this test was subtracted from the total borehole transmissivity to obtain the transmissivity of the flow logged interval.

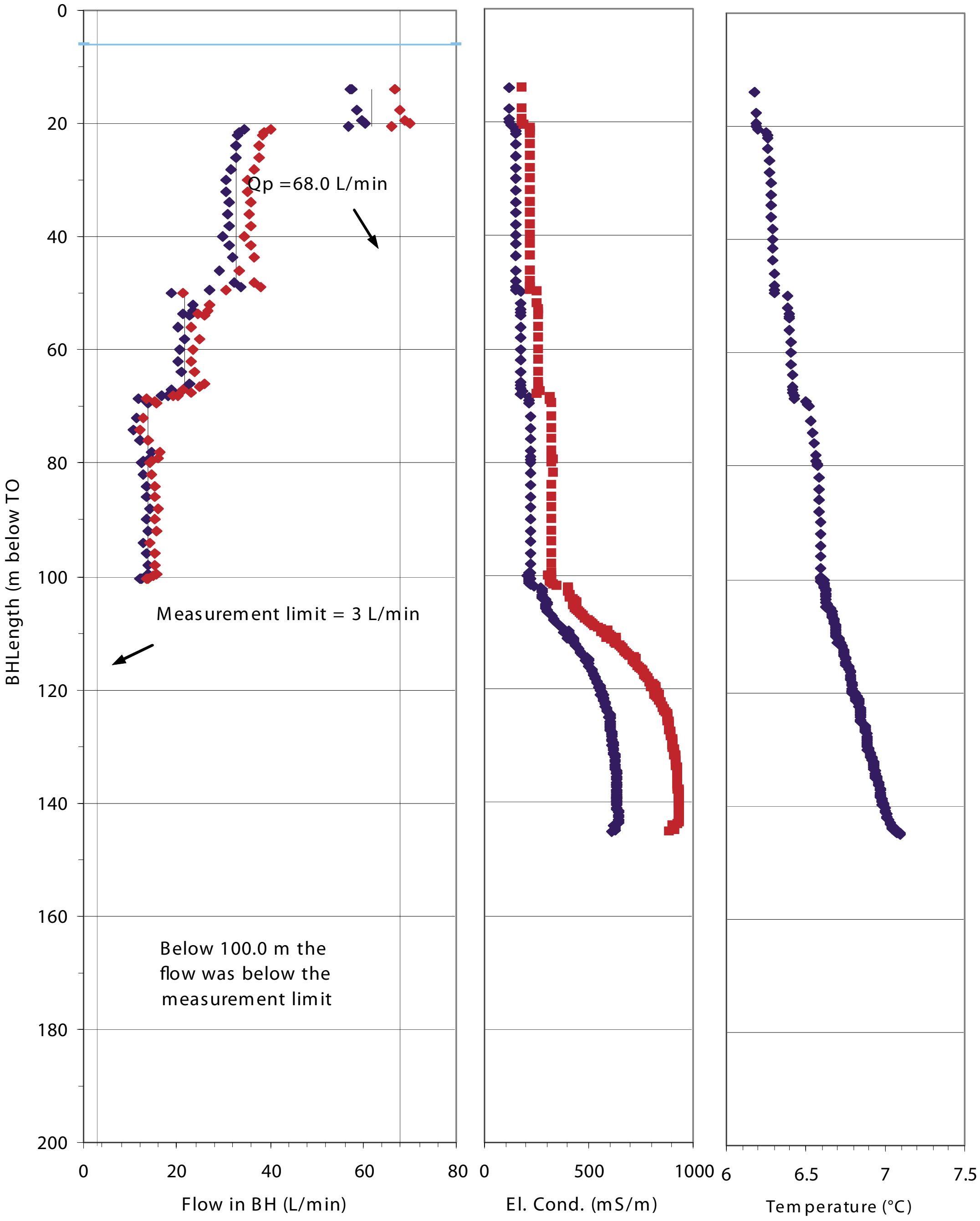


Figure 6-3. *Measured (blue) and corrected (red) inflow distribution together with measured (blue) and temperature compensated (red) electrical conductivity and temperature of the borehole fluid along borehole HMF14 during flow logging. (Total logged interval.)*

The figures present the measured borehole flow rates using calibration constants for a 140 mm pipe (according to the drilling record the borehole diameter in the upper part is 138.0 mm) and corrected borehole flow rates. The correction is performed in two steps. Firstly the calibration constants used are corrected for variations of the diameter along the borehole using information from the logging in the undisturbed borehole as described in Section 5.4.2. Secondly, if necessary, a scaling to achieve conformance between measured borehole flow at the top of the flow logged interval and the pumped flow rate measured by the flow meter at surface is performed. To calculate the correct flow rate at the top of the flow logged interval, the relationship between Q_p measured by the flow meter at the surface and the transmissivity of the entire borehole was used to calculate Q_{Tcorr}, cf Section 5.4.2.

Probably also the inclination of the borehole (ca 60°), deviating from 90°, has some influence on the flow measured in the borehole.

Figure 6-3 shows four detected inflows between 14 m and 102 m. All inflows are supported by the EC-measurements. For three of the flow anomalies a clear change in temperature can also be seen.

The results of the flow logging in borehole HFM14 are presented in Table 6-8 below. The measured inflow at the identified flow anomalies (dQ_i) and their estimated percentage of the total flow is shown. The cumulative transmissivity (T_{FT}) at the top of the flow-logged borehole interval was calculated from Equation (5-7) and the transmissivity of individual flow anomalies (T_i) from Equation (5-10) using the corrected flow values (se above). The transmissivity for the entire borehole used in Equation (5-7) was taken from the transient evaluation of the flow period of the pumping test in conjunction with the flow logging, and T_A is the transmissivity estimated from the pumping test above a single packer. (cf. Section 6.3.2). An estimation of the transmissivity of the interpreted flow anomalies was also made by calculating the specific flows (dQ_i/s_{FL}).

Summary of results

Table 6-9 presents a summary of the results from the pumping test in conjunction with flow logging, the pumping test above the single packer and the corrected results from the flow logging.

Table 6-8. Results of the flow logging in borehole HFM14. Q_{Tcorr} = corrected cumulative flow at the top of the logged interval. Q_p = pumped flow rate from borehole, s_{FL} = drawdown during flow logging. T = transmissivity from the pumping test, T_A = transmissivity from the pumping test above the flow logged interval (see Table 6-9).

HFM14 Flow anomalies Interval (m b ToC)	B.h. length (m)	$Q_{Tcorr} = 1.12 \cdot 10^{-3}$ (m³/s) dQ_{icorr} 1 (m³/s)	$T_{FT} = (T–T_A) =$ $5.57 \cdot 10^{-4}$ (m²/s) T_i (m²/s)	s_{FL} = 1.81 m dQ_{icorr}/s_{FL} (m²/s)	$Q_p = 1.13 \cdot 10^{-3}$ (m³/s) dQ_{icorr}/Q_p (%)	Supporting information
20.5–21.5	1	5.033E–04	2.51E–04	2.781E–04	45.14	EC, Temp
49.0–50.0	1	1.983E–04	9.91E–05	1.096E–04	17.79	EC, Temp
67.5–68.5	1	1.642E–04	8.20E–05	9.070E–05	14.72	EC, Temp
100.0–102.0	2	2.492E–04	1.24E–04	1.377E–04	22.35	EC, Temp?
Total		1.12·10–3	5.57·10–4	6.16·10–4	100	
Difference		$Q_p–Q_{Tcorr} = 1.76 \cdot 10^{-5}$	–	–		

Table 6-9. Compilation of results from the different hydraulic tests performed in borehole HFM14.

Test type	Interval (m)	Specific flow Q/s (m²/s) 1)	T (m²/s)
Flow logging	14.0–145.0	$6.16 \cdot 10^{-4}$	$5.57 \cdot 10^{-4}$
Pumping test	6.0–150.5	$6.26 \cdot 10^{-4}$	$5.66 \cdot 10^{-4}$
Pumping test above single packer	6.0–14.0	$1.46 \cdot 10^{-5}$	$8.99 \cdot 10^{-5}$

1) Due to the test performance explained in Section 6.2.2, the specific flow and transmissivity are uncertain for the pumping test above a single packer

Figure 6-4 presents the cumulative transmissivity $T_F(L)$ along the borehole length (L) from the flow logging calculated from Equation (5-11). Since the width of the flow anomaly in the borehole is not known in detail, the change in transmissivity at the anomalies is represented by a sloping line across the anomaly. The estimated threshold value of T and the total transmissivity of the borehole are also indicated in the figure, cf. Section 5.4.2.

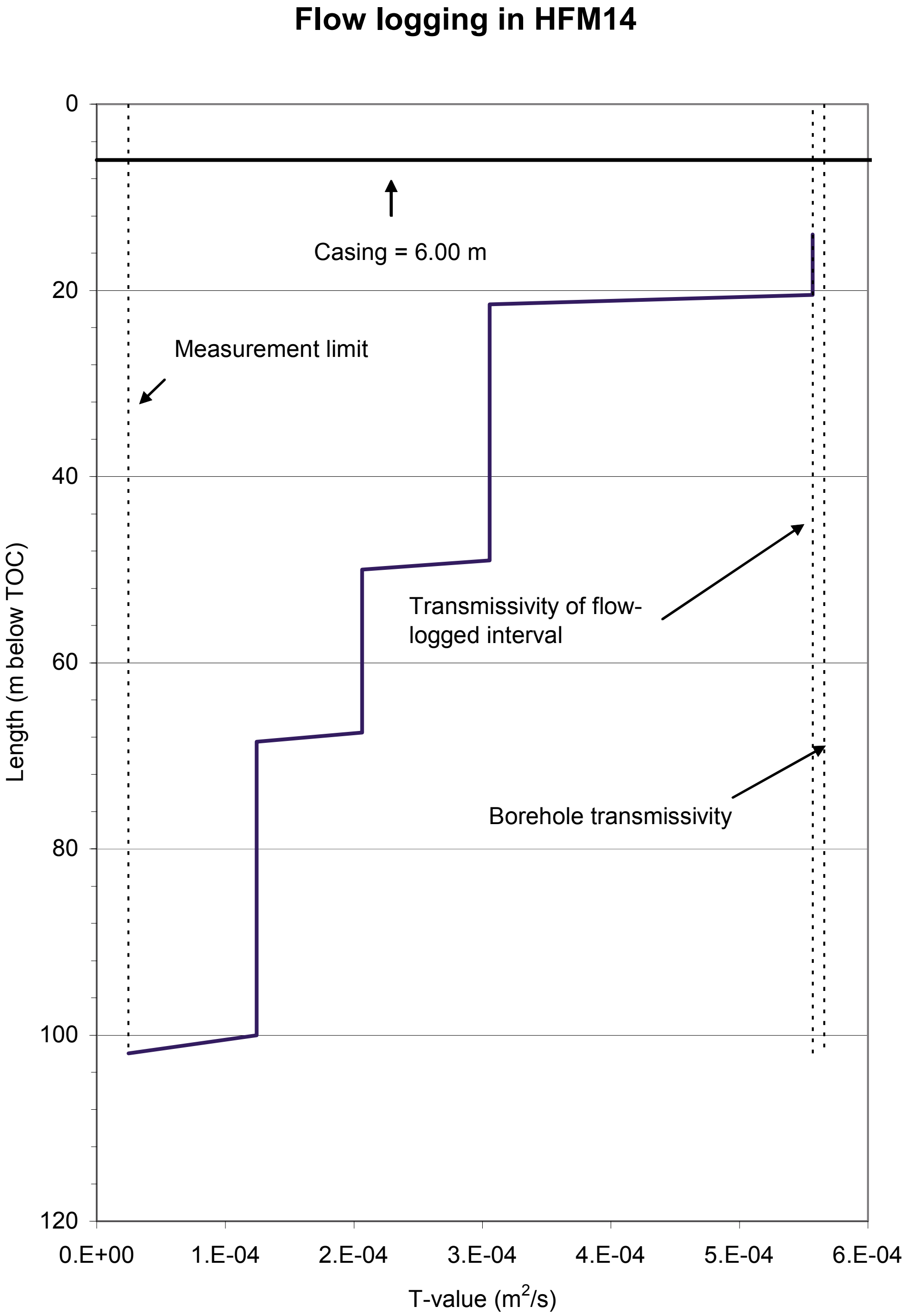


Figure 6-4. *Calculated, cumulative transmissivity along the flow logged interval of borehole HFM14. The total borehole transmissivity was calculated from the pumping test during flow logging, and the transmissivity of the flow logged interval was calculated subtracting the transmissivity from the non flow-logged interval from the borehole total transmissivity.*

6.5 Summary of hydraulic tests

A compilation of measured test data from the pumping tests carried out in the test campaigns is presented in Table 6-10. In Table 6-11 and Table 6-12, and in the test summary sheets in Tables 6-13, 6-14 and 6-15 hydraulic parameters calculated from the tests in HFM14 and KFM05A are shown.

In Table 6-11 and Table 6-12, the parameter explanations are according to the instruction for injection- and single-hole pumping tests. The parameters are also explained in the text above, except the following:

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

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

T_T = judged best estimate of transmissivity (from transient evaluation of hydraulic test or from Moye's formula)

T_i = estimated transmissivity of flow anomaly

S* = assumed value on storativity used in single-hole tests

C = wellbore storage coefficient

ζ = skin factor

Table 6-10. Summary of test data for the open-hole pumping tests performed with the HTHB system in boreholes HFM14 and KFM05A in the Forsmark candidate area.

Borehole ID	Section (m)	Test type [1]	p_i (kPa)	p_p (kPa)	p_F (kPa)	Q_p (m^3/s)	Q_m (m^3/s)	V_p (m^3)
HFM14	6.0–150.5	1B	129.88	112.3	127.85	$1.13 \cdot 10^{-3}$	$1.13 \cdot 10^{-3}$	43.25
HFM14	6.0–14.0	1B	138.20	115.77	136.77	$3.33 \cdot 10^{-5}$	$4.94 \cdot 10^{-5}$	0.607
KFM05A	108.85–114.0	1B	229.16	211.01	228.25	$1.12 \cdot 10^{-3}$	$1.12 \cdot 10^{-3}$	13.04

1) 1B: Pumping test-submersible pump.

Table 6-11. Summary of calculated hydraulic parameters of the formation from the hydraulic tests performed with the HTHB system in borehole HFM14 and KFM05A in the Forsmark candidate area.

Borehole ID	Section (m)	Flow Anomaly interval (m)	Test type [1]	Q/s (m^2/s)	T_M (m^2/s)	T_T (m^2/s)	T_i (m^2/s)	S* (–)
HFM14	6.0–150.5		1B	$6.24 \cdot 10^{-4}$	$8.62 \cdot 10^{-4}$	$5.66 \cdot 10^{-4}$		$1.67 \cdot 10^{-5}$
HFM14	6.0–145.0 (f)	20.5–21.5	6	2.781E–04			2.51E–04	
HFM14	6.0–145.0 (f)	49.0–50.0	6	1.096E–04			9.91E–05	
HFM14	6.0–145.0 (f)	67.5–68.5	6	9.070E–05			8.20E–05	
HFM14	6.0–145.0 (f)	100.0–102.0	6	1.377E–04			1.24E–04	
HFM14	6.0–14.0		1B	$1.46 \cdot 10^{-5}$	$1.34 \cdot 10^{-5}$	$8.99 \cdot 10^{-6}$		$2.10 \cdot 10^{-6}$
KFM05A [2]	108.85–114.0		1B	$7.19 \cdot 10^{-4}$	$4.06 \cdot 10^{-4}$			$1.41 \cdot 10^{-5}$

(f) = flow logged interval.

1) 1B: Pumping test-submersible pump, 6: Flow logging–Impeller.

2) S* is estimated from the steady-state transmissivity.

Table 6-12. Summary of calculated hydraulic parameters of the formation from hydraulic tests performed with the HTHB system in boreholes HFM14 and KFM05A in the Forsmark candidate area.

Borehole ID	Section (m)	Test type	S* (–)	C (m^3/Pa)	ζ (–)
HFM14	6.0–150.5	1B	$1.67\cdot10^{-5}$	$1.9\cdot10^{-6}$	–4.69
HFM14	6.0–14.0	1B	$2.10\cdot10^{-6}$	$1.9\cdot10^{-6}$	–3.64
KFM05A 1)	108.85–114.0	1B	–	–	–

1) Only steady-state evaluation is performed from this test.

Appendix 3 includes the result tables delivered to the database SICADA. The lower measurement limit for the HTHB system is expressed in terms of specific flow (Q/s). For pumping tests, the practical lower limit is based on the minimum flow rate Q, for which the system is designed (5 L/min) and an estimated maximum allowed drawdown for practical purposes (c. 50 m) in a percussion borehole, cf. Table 4-1. These values correspond to a practical lower measurement limit of $Q/s\text{-}L=2\cdot10^{-6}$ m^2/s of the pumping tests.

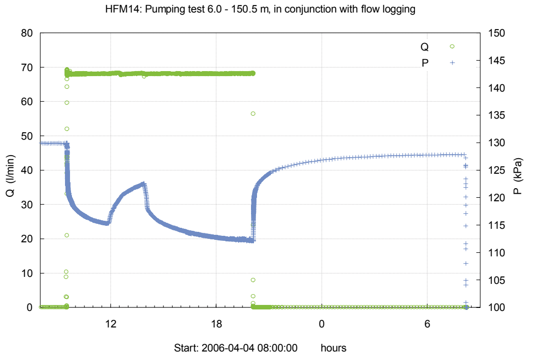
Similarly, the practical, upper measurement limit of the HTHB-system is estimated from the maximal flow rate (c. 80 L/min) and a minimal drawdown of c. 0.5 m, which is considered significant in relation to e.g. background fluctuations of the pressure before and during the test. These values correspond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

Table 6-13. Test Summary Sheet for the pumping test in HFM14, section 6.0–150.5 m.

Test Summary Sheet

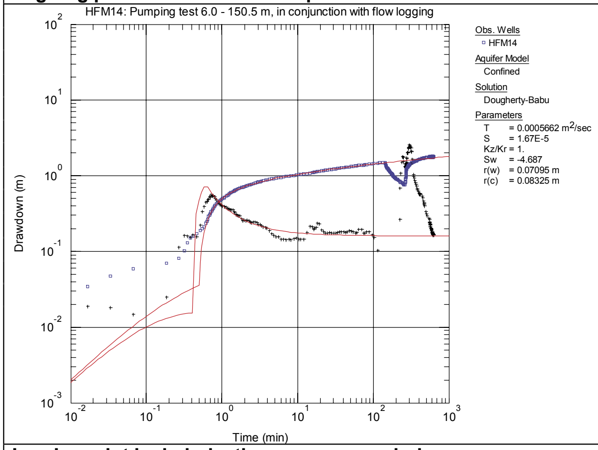
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM14	Test start:	2006-04-04 09:29:00
Test section (m):	6.0-150.5	Responsible for test performance:	Geosigma AB A. Lindquist
Section diameter, $2 \cdot r_w$ (m):	top 0.138 bottom 0.136	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

Linear plot Q and p

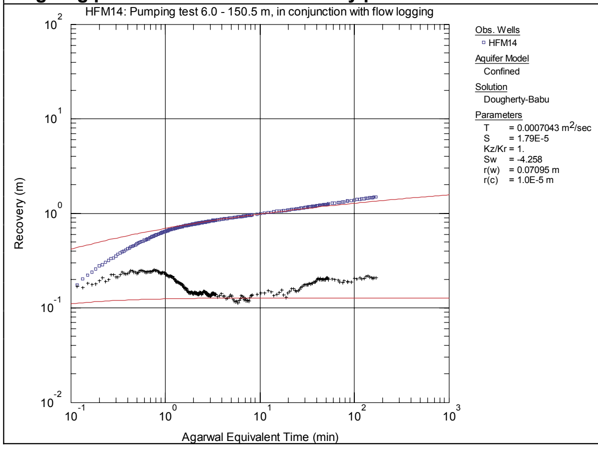


Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)	129.88		
p_i (kPa)	129.88		
p_p(kPa)	112.13	p_F (kPa)	127.85
Q_p (m^3/s)	$1.13 \cdot 10^{-3}$		
tp (min)	636	t_F (min)	730
S*	$1.67 \cdot 10^{-5}$	S*	$1.79 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)	$6.24 \cdot 10^{-4}$		
T_{Moye}(m^2/s)	$8.6 \cdot 10^{-4}$		
Flow regime:	WBS->PRF	Flow regime:	WBS->PRF
t_1 (min)	2	dt_{e1} (min)	0.1
t_2 (min)	100	dt_{e2} (min)	170
T_w (m^2/s)	$5.7 \cdot 10^{-4}$	T_w (m^2/s)	$7.0 \cdot 10^{-4}$
S_w (-)		S_w (-)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$1.9 \cdot 10^{-6}$	C (m^3/Pa)	
C_D (-)		C_D (-)	
ξ (-)	-4.69	ξ (-)	-4.26
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Interpreted formation and well parameters.

Flow regime:	PRF	C (m^3/Pa)	$1.9 \cdot 10^{-6}$
t_1 (min)	2	C_D (-)	
t_2 (min)	100	ξ (-)	-4.69
T_T (m^2/s)	$5.7 \cdot 10^{-4}$		
S (-)	$1.7 \cdot 10^{-5}$		
K_s (m/s)			
S_s (1/m)			

Comments:

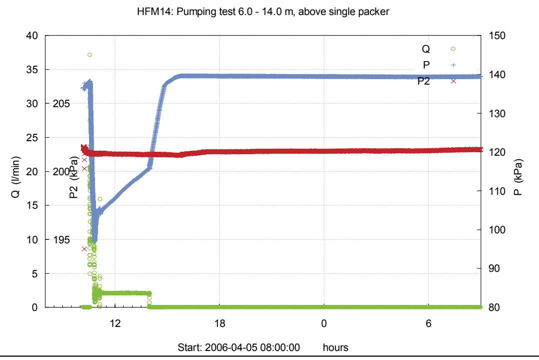
Transient evaluation is only made on the first c.100 minutes of the test, before the pressure started to increase in the borehole due to a hydraulic connection with the discharged water.

Both the drawdown and the recovery period show signs of WBS transitioning to a PRF. The recovery period shows two pseudo-radial flow regimes, the first from c. 2 minutes to c. 20 minutes, and the second from c. 40 min to the end of the period

Table 6-14. Test Summary Sheet for the pumping test in HFM14, section 6.0–14.0 m.

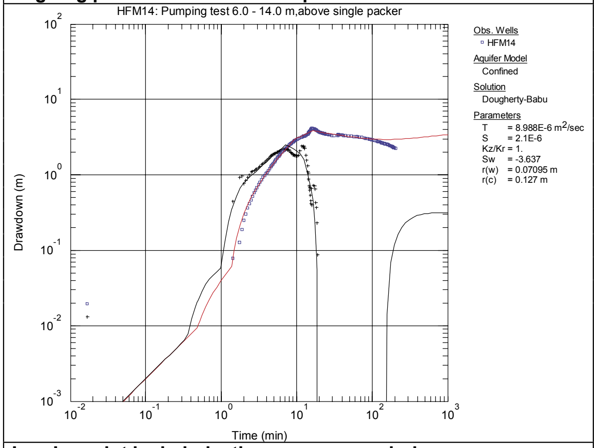
Test Summary Sheet			
Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM14	Test start:	2006-04-05 10:10:00
Test section (m):	6.0-14.0	Responsible for test performance:	Geosigma AB A. Lindquist
Section diameter, $2 \cdot r_w$ (m):	0.138	Responsible for test evaluation:	Geosigma AB J-E Ludvigson

Linear plot Q and p



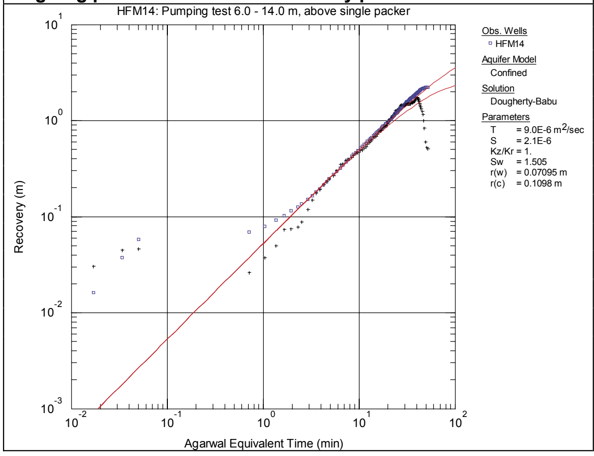
Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)	136.43		
p_i (kPa)	138.20		
p_p(kPa)	115.77	p_F (kPa)	136.77
Q_p (m^3/s)	$3.33 \cdot 10^{-5}$		
tp (min)	205	t_F (min)	1160
S*	$2.1 \cdot 10^{-6}$	S*	
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)	$1.5 \cdot 10^{-5}$		

Log-Log plot incl. derivate- flow period



T_{Moye}(m^2/s)	$1.30 \cdot 10^{-5}$		
Flow regime:		Flow regime:	
t_1 (min)	2	dt_{e1} (min)	
t_2 (min)	110	dt_{e2} (min)	
T_w (m^2/s)	$9.0 \cdot 10^{-6}$	T_w (m^2/s)	
S_w (-)		S_w (-)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)	$4.6 \cdot 10^{-6}$	C (m^3/Pa)	
C_D (-)		C_D (-)	
ξ (-)	-3.64	ξ (-)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(-)		S_{GRF}(-)	
D_{GRF} (-)		D_{GRF} (-)	

Log-Log plot incl. derivative- recovery period



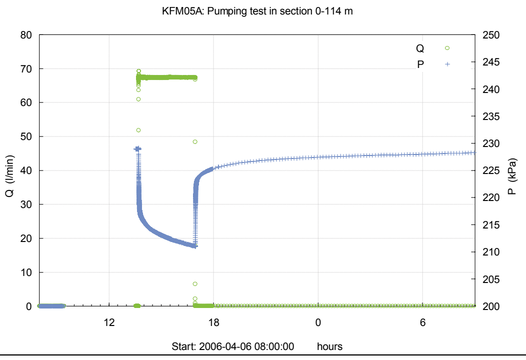
Interpreted formation and well parameters.			
Flow regime:		C (m^3/Pa)	$1.9 \cdot 10^{-6}$
t_1 (min)	2	C_D (-)	
t_2 (min)	110	ξ (-)	-3.64
T_T (m^2/s)	$9.0 \cdot 10^{-6}$		
S (-)	$2.1 \cdot 10^{-6}$		
K_s (m/s)			
S_s (1/m)			

Comments:

Since the flow was highly varying, and the drawdown was decreasing during the major pumping time, the identification of flow regimes from the drawdown period is very difficult. In addition the transient evaluation is uncertain.

The recovery period only shows WBS and no unambiguous transient evaluation can be made from the period. However, by visual matching an approximate fit can be obtained supporting the values of T, ξ and r(c) from the flow period.

Table 6-15. Test Summary Sheet for the pumping test in KFM05A, section 108.85–114.0 m.

Test Summary Sheet					
Project:	PLU	Test type:	1B		
Area:	Forsmark	Test no:	1		
Borehole ID:	KFM05A	Test start:	2006-04-06 13:32:00		
Test section (m):	108.85-114.0 (0-114)	Responsible for test performance:	Geosigma AB A. Lindquist		
Section diameter, $2 \cdot r_w$ (m):	108.85-109.4: 0.086 below 110.10: 0.0773	Responsible for test evaluation:	Geosigma AB J-E Ludvigson		
Linear plot Q and p		**Flow period**		**Recovery period**	
		**Indata**			
		p_0 (kPa)	229.16		
		p_i (kPa)	229.16		
		p_p(kPa)	211.01	p_F (kPa)	228.25
		Q_p (m^3/s)	$1.12 \cdot 10^{-3}$		
		tp (min)	195	t_F (min)	959
		S*	$3.4 \cdot 10^{-6}$	S*	
		EC_w (mS/m)			
		Te_w(gr C)			
		Derivative fact.		Derivative fact.	
		Results		**Results**	
		Q/s (m^2/s)	$7.19 \cdot 10^{-4}$		
		T_{Moye}(m^2/s)	$4.06 \cdot 10^{-4}$		
		Comments: The test is only evaluated using the steady-state evaluation, using Moye's formula according to different assumptions of the borehole radius and length of the test section.			

7 References

/1/ **Gokall-Norman K, Ludvigson J-E, Hjerne C, 2005.** Single-hole injection tests in borehole KFM05A. Forsmark site investigation. SKB P-05-56. Svensk kärnbränslehantering AB.

/2/ **Pöllänen J, Sokolnicki M, Rouhiainen P, 2004.** Difference flow logging in borehole KFM05A. Forsmark site investigation. SKB P-04-191. Svensk kärnbränslehantering AB.

/3/ **Ludvigson J-E, Jönsson S, Jönsson J, 2004.** Pumping tests and flow logging. Boreholes HFM13, HFM14 and HFM15. Forsmark site investigation. SKB P-04-71. Svensk kärnbränslehantering AB.

/4/ **Morosini M, Almén K-E, Follin S, Hansson K, Ludvigson J-E, Rhén I, 2001.** Metoder och utrustningar för hydrauliska enhålstester. Metod och programaspekter för geovetenskapliga platsundersökningar. Tekniskt Dokument TD-01-63, Svensk Kärnbränslehantering AB.

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

/6/ **Rehn I (ed), Gustafsson G, Stanfors R, Wikberg P, 1997.** Äspö HRL – Geoscientific evaluation 1997/5. Models based on site characterization 1986–1995. SKB TR 97-06, Svensk kärnbränslehantering AB.

Appendix 1

List of data files

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

Sektion (m – m)	**Test typ***	**Start (yymmdd hh: mm)**	**Stopp (yymmdd hh: mm)**	**Test Start (yymmdd hh: mm:ss)**	**Test Stopp (yymmdd hh: mm:ss)**	**Fil (bhnamn_secup_yymmdd_XX)**	**Parametrar (P,Q,T,Sp, EC)**	**Kommentar/ Signatur**
6.0–150.5	PT	060403 13:13:58	060405 08:16:45	060404 09:31:29	060405 08:16:45	HFM14_6.0_060404_FlowLo00.DAT	P, Q, T, EC	
		050630 12:46:00	060405 10:20:48			HFM14_6.0_060403_Ref_Da00.DAT		This reference file is valid for all tests performed in HFM14.
14.0–145.0	SP	060404 16:38:18	060404 19:58:44	060404 16:38:18	060404 19:58:44	HFM14_6.0_060404_Spinne00.DAT	P, Q, T, EC, SP	
6.0–14.0	PT	060405 10:07:54	060406 09:20:13	060405 10:11:15	060406 09:20:13	HFM14_6.0_060405_Pumpin00.DAT	P, Q	Pumping test above single packer
6.0–150.5	PT	060403 13:13:58	060404 12:56:45	060403 15:05:31	060403 15:21:42	HFM14_6.0_060403_FlowLo00.DAT	P, Q, T, EC	Capacity test

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

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

Diagram of test responses

Test diagrams

Nomenclature in AQTESOLV:

T = transmissivity (m^2/s)

S = storativity (–)

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

S_w = skin factor

r(w) = borehole radius (m)

r(c) = effective casing radius (m)

Pumping test in HFM14: 6.0–150.5 m

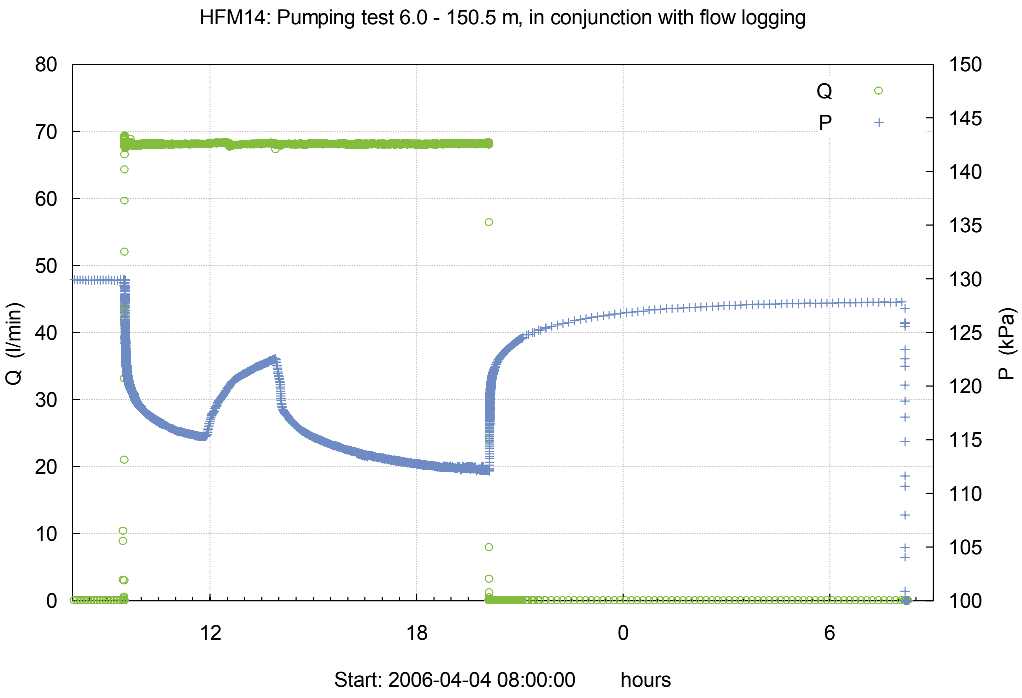


Figure A2-1. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test in HFM14 in conjunction with flow logging.*

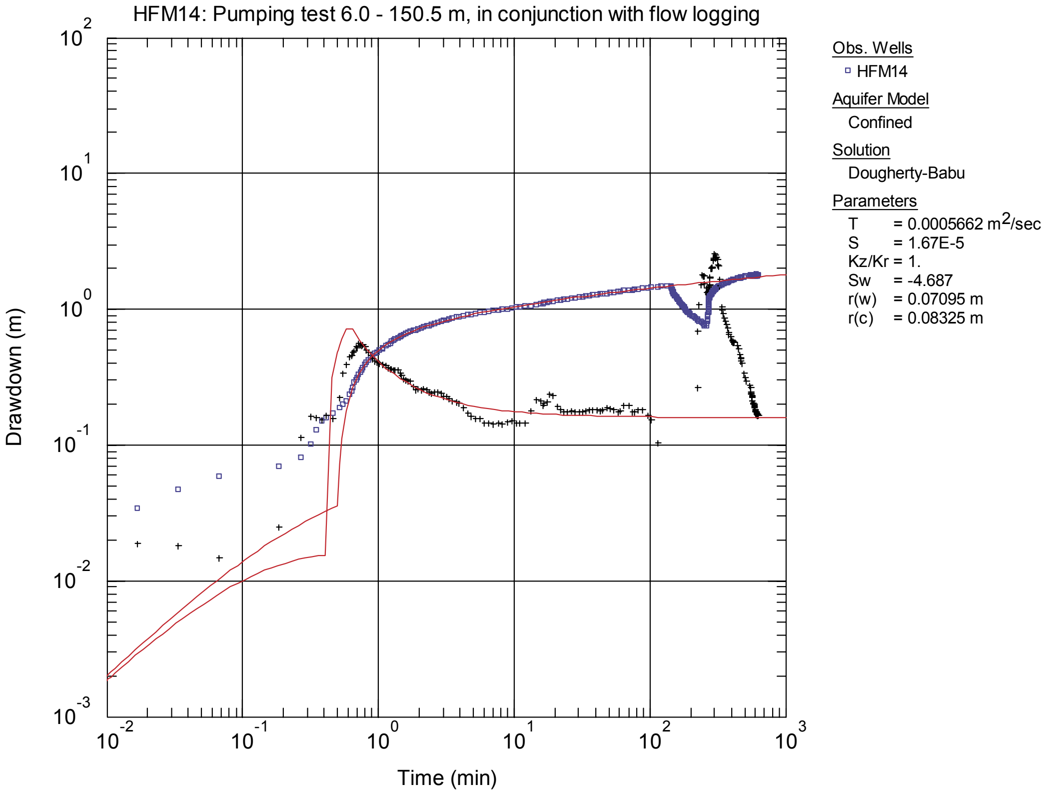


Figure A2-2. Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM14.

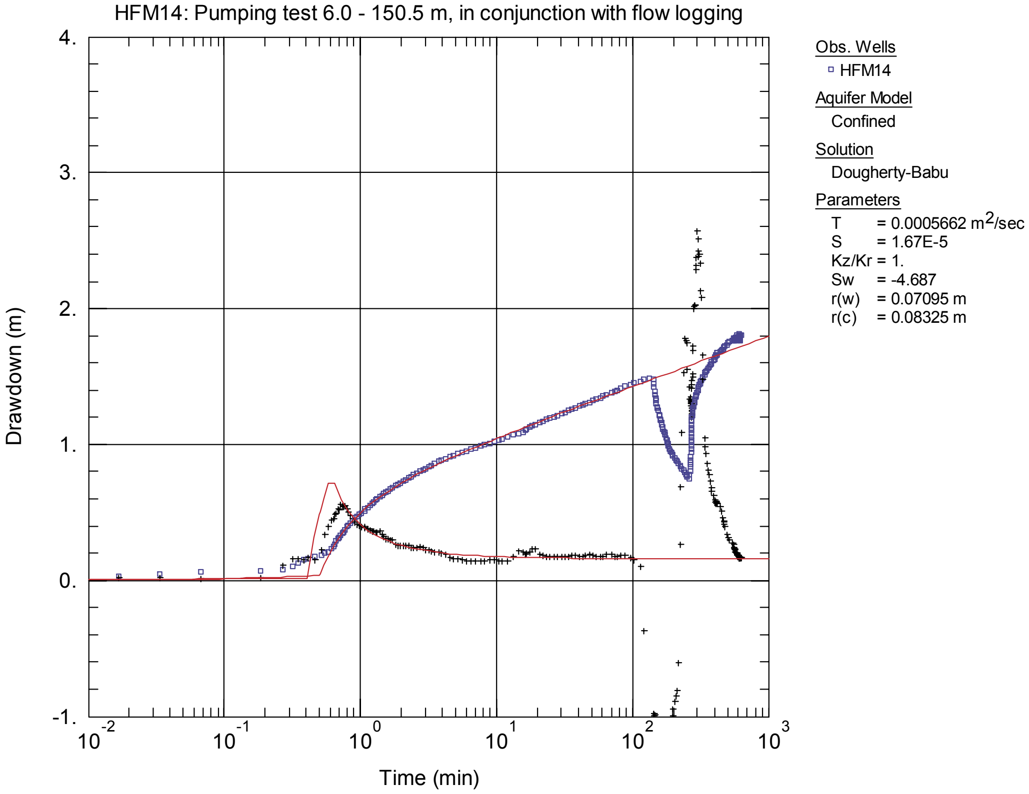


Figure A2-3. Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test in HFM14.

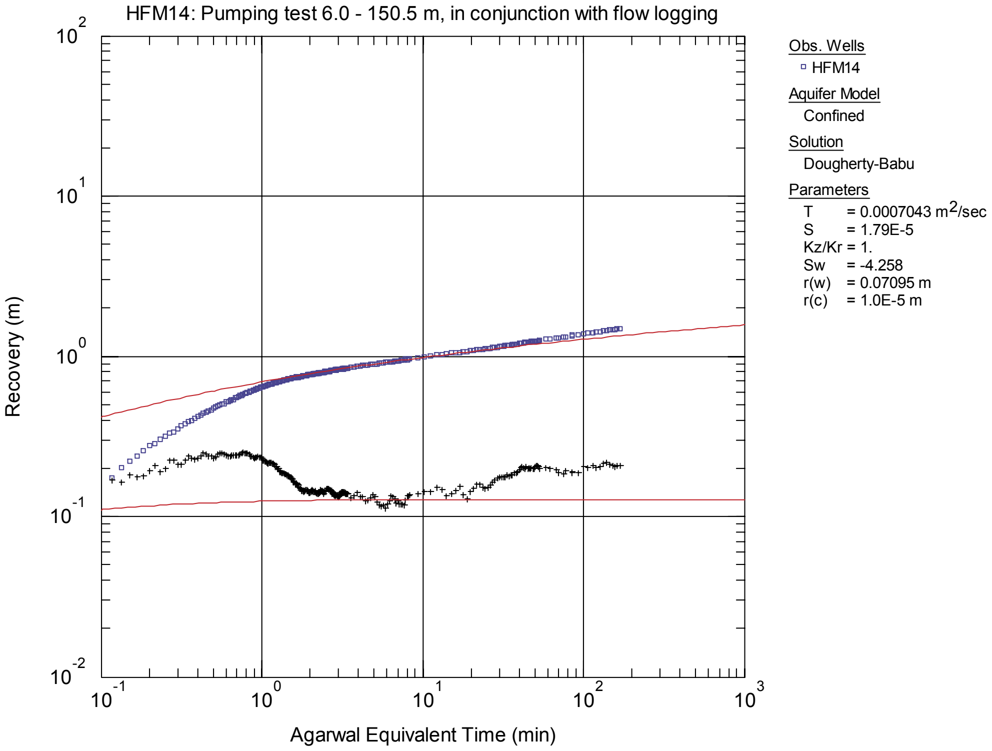


Figure A2-4. *Log-log plot of pressure recovery (blue □) and derivative (black +) dsp/d(ln dte) versus equivalent time (dte), showing fit to the first PRF, from the open-hole pumping test in HFM14.*

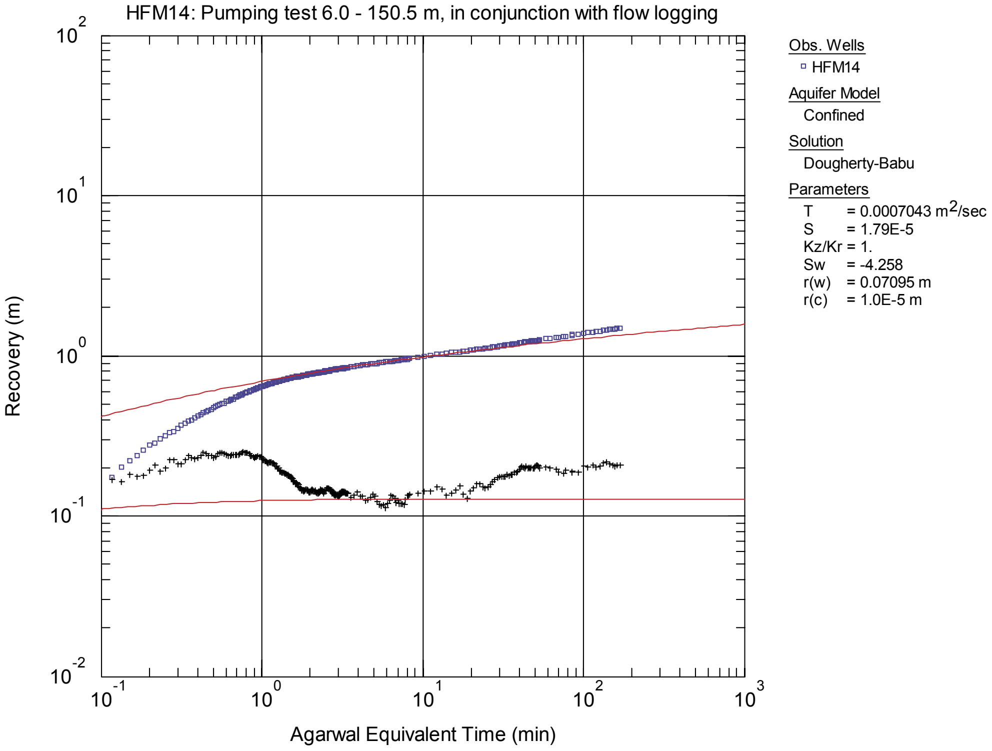


Figure A2-5. *Lin-log plot of pressure recovery (blue □) and derivative (black +) dsp/d(ln dte) versus equivalent time (dte), showing fit to the first PRF, from the open-hole pumping test in HFM14.*

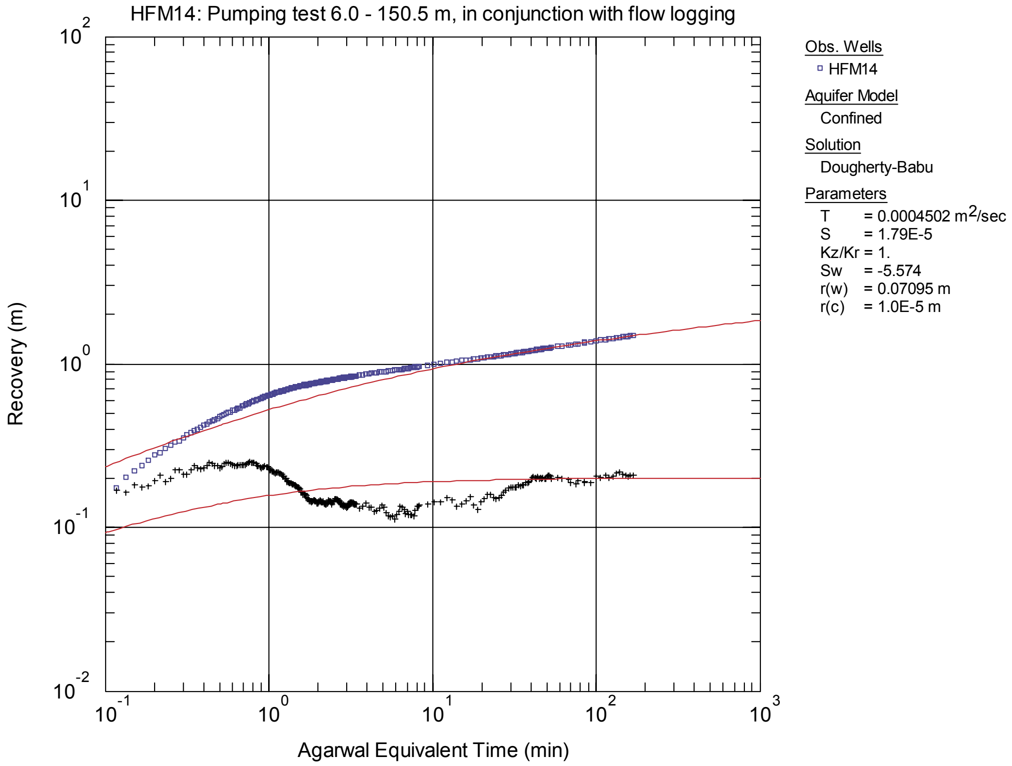


Figure A2-6. *Log-log plot of pressure recovery (blue □) and derivative (black +) dsp/d(ln dte) versus equivalent time (dte), showing fit to the second PRF, from the open-hole pumping test in HFM14.*

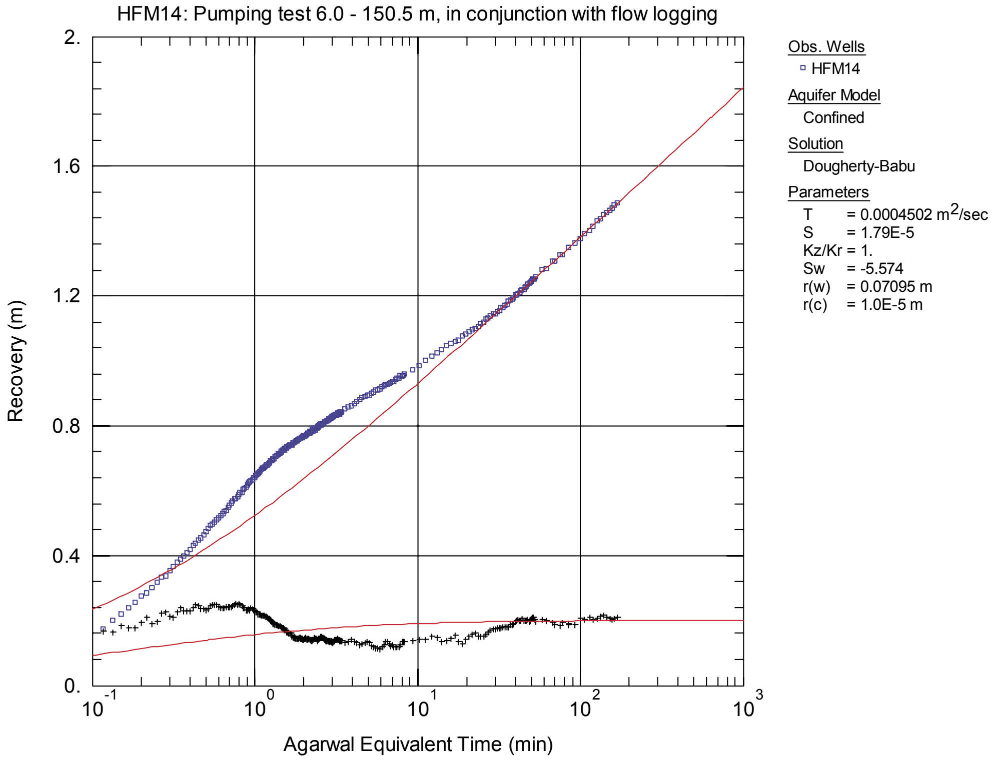


Figure A2-7. *Lin-log plot of pressure recovery (blue □) and derivative (black +) dsp/d(ln dte) versus equivalent time (dte), showing fit to the second PRF, from the open-hole pumping test in HFM14.*

Pumping test in HFM14: 6.0–14.0 m

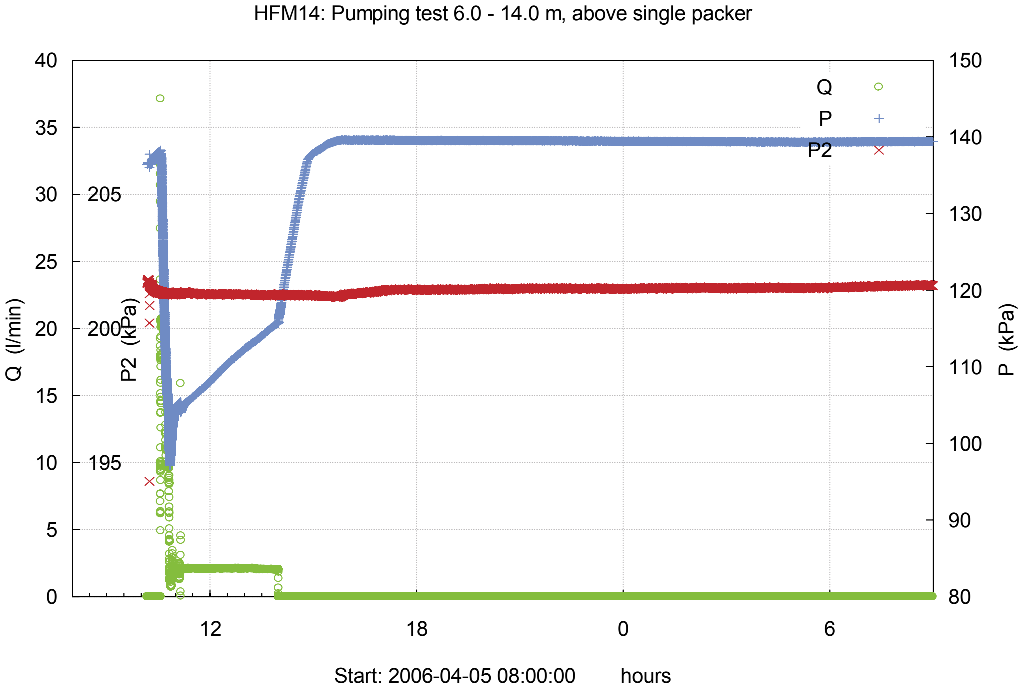


Figure A2-8. *Linear plot of flow rate (Q) and pressure (p) versus time during the open-hole pumping test above a single packer in HFM14.*

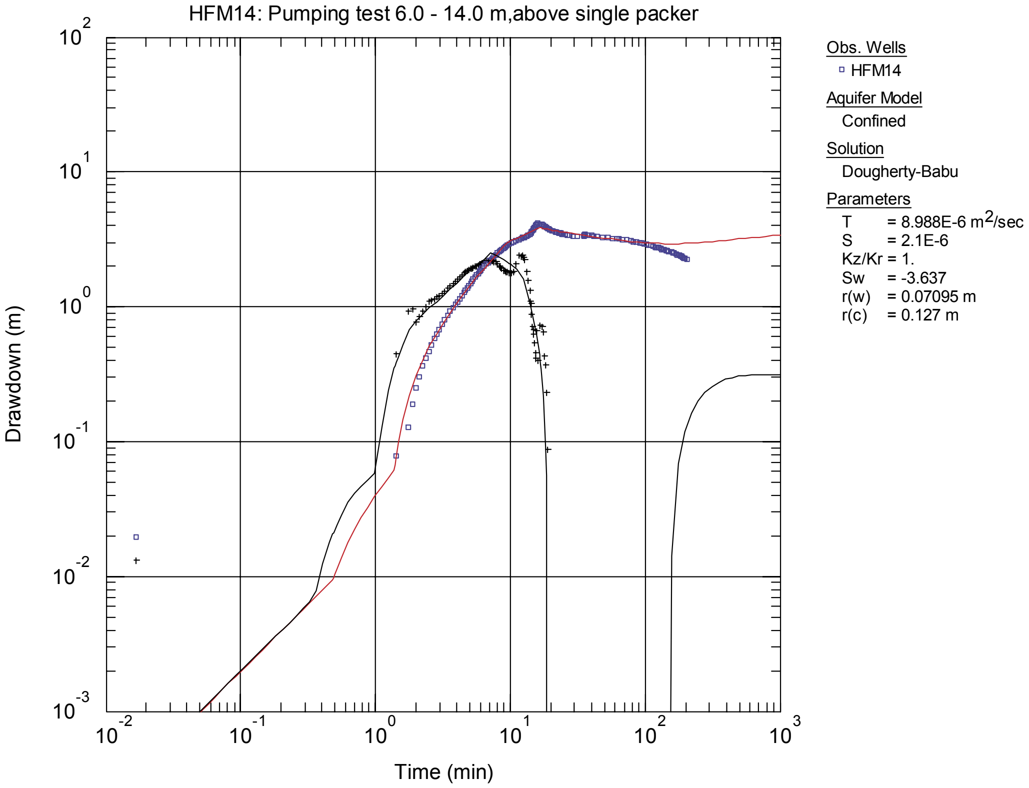


Figure A2-9. *Log-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test above a single packer in HFM14.*

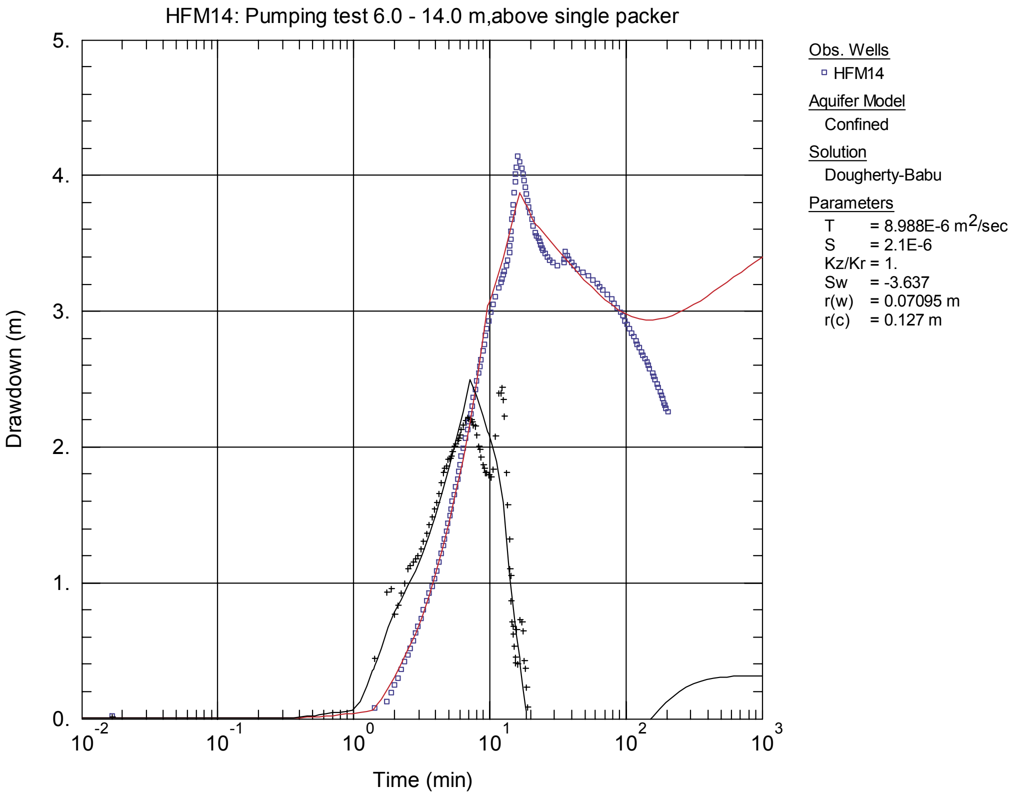


Figure A2-10. *Lin-log plot of drawdown (blue □) and drawdown derivative (black +) versus time during the open-hole pumping test above a single packer in HFM14.*

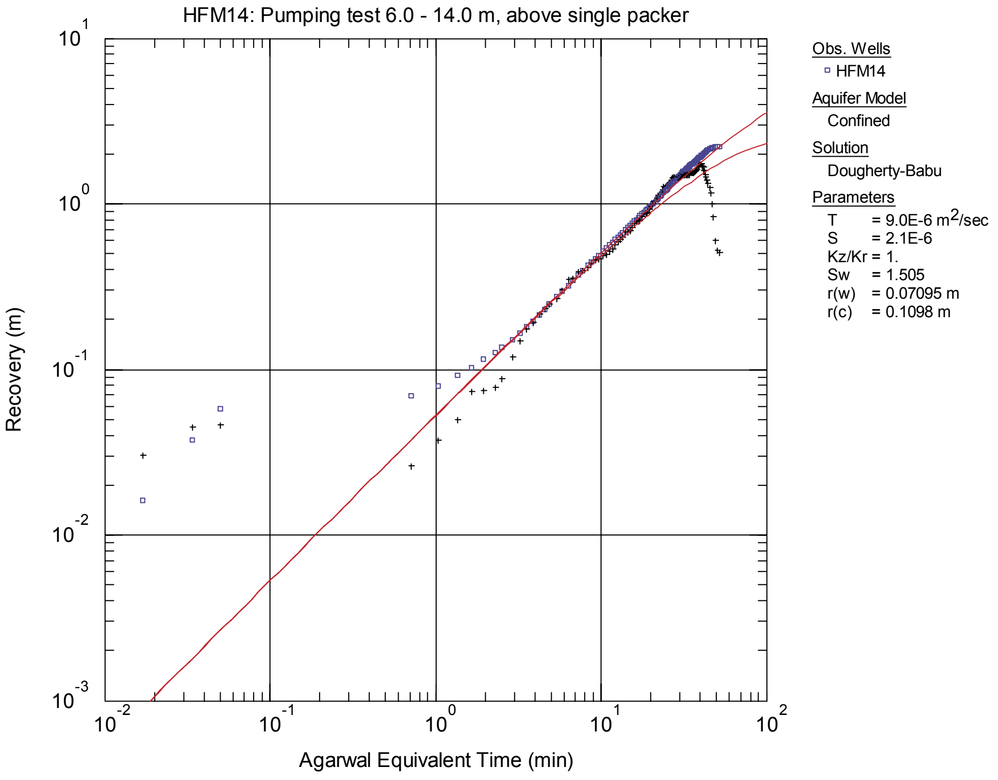


Figure A2-11. *Log-log plot of pressure recovery (blue □) and derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from the open-hole pumping test above a single packer in HFM14.*

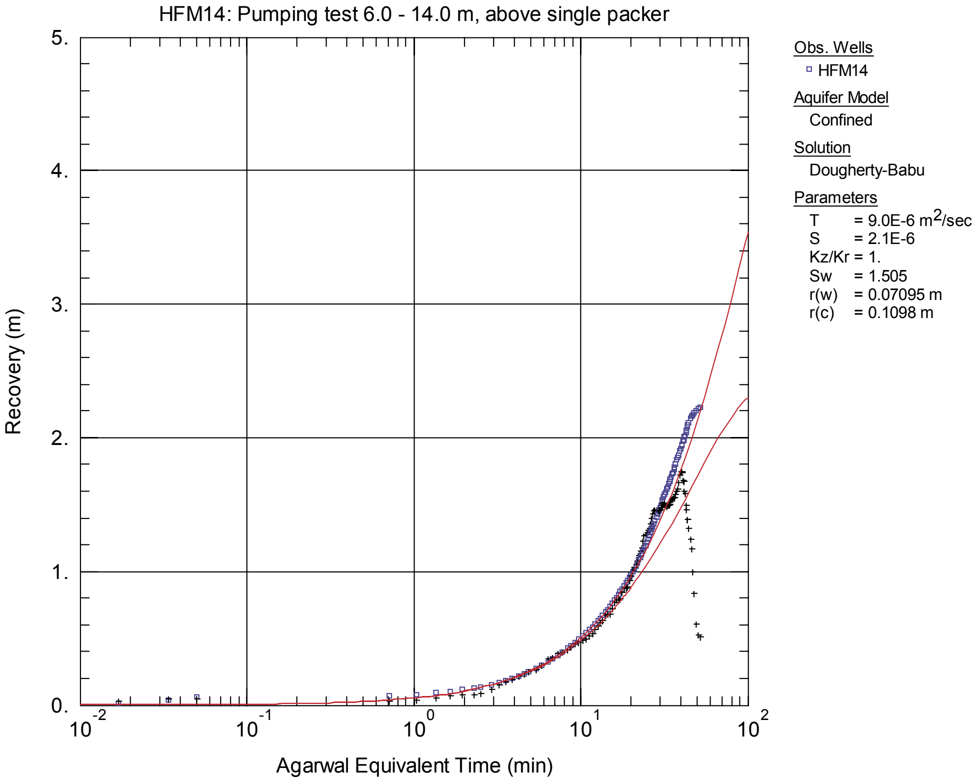


Figure A2-12. *Lin-log plot of pressure recovery (blue □) and derivative (black +) dsp/d(ln dte) versus equivalent time (dte) from open-hole pumping test above a single packer in HFM14.*

Pumping test in KFM05A: 0–114 m

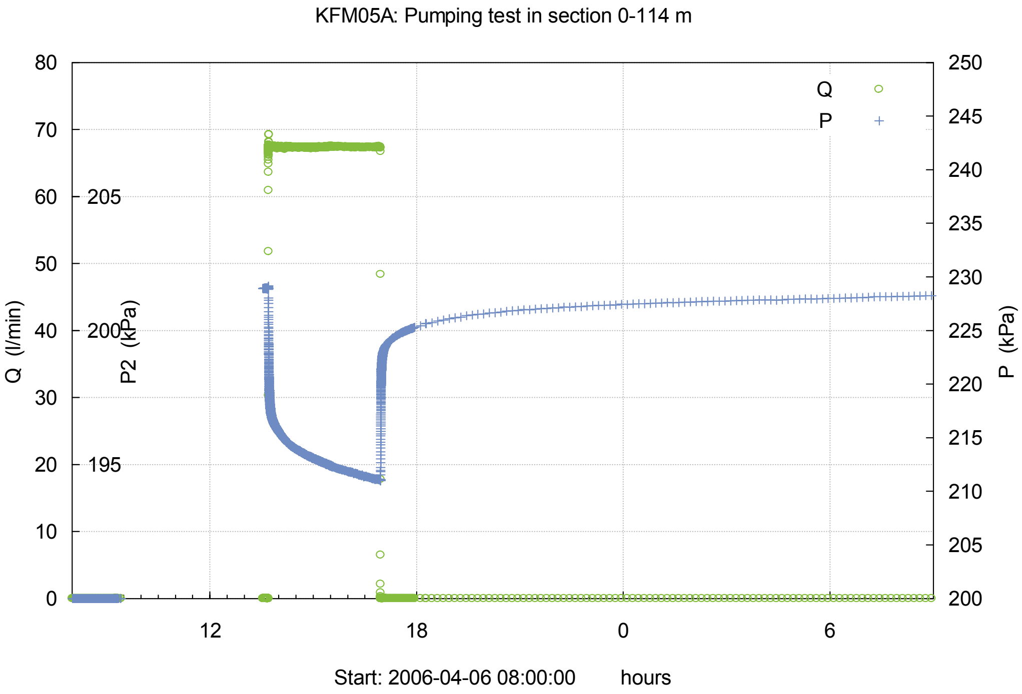


Figure A2-13. *Linear plot of flow rate (Q), pressure in test section (P) and pressure above test section (Pa) versus time during the pumping test in KFM05A.*

Result tables to Sicada database

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

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

idcode	start_date	stop_date	(m) secup	(m) seclow	section_ no	test_ type	forma- tion_type	(yyyymmdd) start_flow_period	(yyyymmdd) stop_flow_period	(m**3/s) flow_rate_ end_qp
HFM14	060404 09:29:00	060505 08:15:45	6.00	150.50		1B	1	2006-04-04 09:31:29	2006-04-04 20:06:50	1.1300E–03
HFM14	060405 10:10.00	060406 09:20:00	6.00	14.00		1B	1	2006-04-05 10:33:49	2006-04-05 13:59:27	3.3300E–05
KFM05A	060406 13:32.00	060407 08:56:00	0.00	114.00		1B	1	2006-04-06 13:42:02	2006-04-06 16:57:19	1.1200E–03

cont.

value_ type_qp	(m**3/s) mean_flow_ rate_qm	(m**3/s) q_measl__l	(m**3/s) q_measl__u	(m**3) tot_vol- ume_vp	(s) dur_flow_ phase_tp	(s) dur_rec_ phase_tf	(m) initial_ head_hi	(m) head_at_ flow_end_hp	(m) final_ head_hf	(kPa) initial_ press_pi	(kPa) press_at_ flow_end_pp	(kPa) final_ press_pf
0	1.1300E–03	8.3333E–05	1.3333E–03	4.3250E+01	38,160.00	43,800.00	0.69	–1.13	0.51	129.88	112.13	127.85
0	4.9400E–05	8.3333E–05	1.3333E–03	6.0700E–01	12,300.00	69,600.00	0.51		0.51	138.20	115.77	136.77
0	1.1200E–03	8.3333E–05	1.3333E–03	1.3040E+01	11,700.00	57,540.00	0.22		0.21	229.16	211.01	228.25

cont.

(oC) fluid_el- cond_ecw	(mS/m) fluid_ temp_tew	(mg/l) fluid_salin- ity_tdsw	(mg/l) fluid_salin- ity_tdswm	referencs	comments	(m) lp
						70.00
						10.00
						109.10

Column	Datatype	Unit	Column description
Site	CHAR		Investigation site name
Activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Project	CHAR		project code
Idcode	CHAR		Object or borehole identification code
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Section_no	INTEGER	number	Section number
test_type	CHAR		Test type code (1–7), see table description
formation_type	CHAR		1: Rock, 2: Soil (superficial deposits)
start_flow_period	DATE	yyyymmdd	Date and time of pumping/injection start (YYYY-MM-DD hh:mm:ss)
stop_flow_period	DATE	yyyymmdd	Date and time of pumping/injection stop (YYYY-MM-DD hh:mm:ss)
flow_rate_end_qp	FLOAT	m**3/s	Flow rate at the end of the flowing period
value_type_qp	CHAR		0:true value,–1<lower meas.limit1: > upper meas.limit
mean_flow_rate_qm	FLOAT	m**3/s	Arithmetic mean flow rate during flow period
q_measl__l	FLOAT	m**3/s	Estimated lower measurement limit of flow rate
q_measl__u	FLOAT	m**3/s	Estimated upper measurement limit of flow rate
tot_volume_vp	FLOAT	m**3	Total volume of pumped or injected water
dur_flow_phase_tp	FLOAT	s	Duration of the flowing period of the test
dur_rec_phase_tf	FLOAT	s	Duration of the recovery period of the test
initial_head_hi	FLOAT	m	Hydraulic head in test section at start of the flow period
head_at_flow_end_hp	FLOAT	m	Hydraulic head in test section at stop of the flow period.
final_head_hf	FLOAT	m	Hydraulic head in test section at stop of recovery period.
initial_press_pi	FLOAT	kPa	Groundwater pressure in test section at start of flow period
press_at_flow_end_pp	FLOAT	kPa	Groundwater pressure in test section at stop of flow period.
final_press_pf	FLOAT	kPa	Ground water pressure at the end of the recovery period.
fluid_temp_tew	FLOAT	oC	Measured section fluid temperature, see table description
fluid_elcond_ecw	FLOAT	mS/m	Measured section fluid el. conductivity, see table descr.
fluid_salinity_tdsw	FLOAT	mg/l	Total salinity of section fluid based on EC, see table descr.
fluid_salinity_tdswm	FLOAT	mg/l	Tot. section fluid salinity based on water sampling, see...
reference	CHAR		SKB report No for reports describing data and evaluation
comments	VARCHAR		Short comment to data
error_flag	CHAR		If error_flag = "*" then an error occured and an error
in_use	CHAR		If in_use = "*" then the activity has been selected as
Sign	CHAR		Activity QA signature
Lp	FLOAT	m	Hydraulic point of application

SINGLEHOLE TESTS, Pumping and injection, s_hole_test_ed1; Basic evaluation.

idcode	start_date	stop_date	(m) secup	(m) seclow	section_ no	test_ type	formation_ type	(m) lp	(m) seclen_ class	(m**2/s) spec_capac- ity_q_s	value_type_ q_s
HFM14	060404 09:29:00	060505 08:15:45	6.00	150.50		1B	1	70.00		6.26E–04	0
HFM14	060405 10:10.00	060406 09:20:00	6.00	14.00		1B	1	10.00		1.46E–05	0
KFM05A	060406 13:32.00	060407 08:56:00	0.00	114.00		1B	1	109.10		7.19E–04	0

cont.

(m**2/s) transmis- sivity_tq	value_ type_tq	bc_ tq	(m**2/s) transmissiv- ity_moye	bc_ tm	value_ type_tm	(m/s) hydr_cond_ moye	(m) formation_ width_b	(m) width_of_ channel_b	(m**3/s) tb	(m**3/s) l_mea- sl_tb	(m**3/s) u_mea- sl_tb	(m) sb	(m) assumed_ sb	(m) leakage_ factor_lf	(m**2/s) transmis- sivity_tt	value_ type_tt	bc_tt
			8.62E–04	0	0										5.66E–04	0	1
			1.34E–05	0	0										8.99E–06	0	1
			4.06E–04	0	0												0

cont.

(m**2/s) l_measl_ q_s	(m**2/s) u_measl_ q_s	(m) storativ- ity_s	(1/s) as- sumed_s	(m/s) s_bc	(m/s) ri	(m/s) ri_in- dex	(1/m) leakage_ coeff	(1/m) hydr_ cond_ksf	(m**3/pa) value_ type_ksf	(s) l_measl_ ksf	(s) u_measl_ ksf	(s) spec_stor- age_ssf	(s) assumed_ ssf	c	cd	skin	dt1	dt2	t1	t2
2.E–06	2.E–03	1.67E–06			2,139.03	0								1.90E–06		–4.69E+00			120.00	6,000.00
2.E–06	2.E–03	2.01E–06			257.69									1.90E–06		–3.64E+00			120.00	6,600.00
2.E–06	2.E–03																			

cont.

(s) dte1	(s) dte2	(kPa) p_ horner	(m**2/s) transmissiv- ity_t_nlr	storativ- ity_s_nlr	value_type_ t_nlr	bc_t_nlr	(m**3/pa) c_nlr	cd_nlr	skin_ nlr	(m**2/s) transmissiv- ity_t_grf	value_ type_t_grf	bc_t_ grf	storativ- ity_s_grf	flow_dim_ grf	(no_unit) comment
1,800.00	45,600.00														
900.00	12,000.00														
480.005	400.00														

Column	Datatype	Unit	Column description
Site	CHAR		Investigation site name
Activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Project	CHAR		project code
Idcode	CHAR		Object or borehole identification code
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Section_no	INTEGER	number	Section number
test_type	CHAR		Test type code (1–7), see table description!
formation_type	CHAR		Formation type code. 1: Rock, 2: Soil (superficial deposits)
Lp	FLOAT	m	Hydraulic point of application for test section, see descr.
seclen_class	FLOAT	m	Planned ordinary test interval during test campaign.
spec_capacity_q_s	FLOAT	m**2/s	Specific capacity (Q/s) of test section, see table descript.
value_type_q_s	CHAR		0:true value,–1:Q/s<lower meas.limit,1:Q/s > upper meas.limit
transmissivity_tq	FLOAT	m**2/s	Tranmissivity based on Q/s, see table description
value_type_tq	CHAR		0:true value,–1:TQ<lower meas.limit,1:TQ > upper meas.limit.
bc_tq	CHAR		Best choice code. 1 means TQ is best choice of T, else 0
transmissivity_moye	FLOAT	m**2/s	Transmissivity,TM, based on Moye (1967)
bc_tm	CHAR		Best choice code. 1 means Tmoye is best choice of T, else 0
value_type_tm	CHAR		0:true value,–1:TM<lower meas.limit,1:TM > upper meas.limit.
hydr_cond_moye	FLOAT	m/s	K_M: Hydraulic conductivity based on Moye (1967)
formation_width_b	FLOAT	m	b:Aquifer thickness repr. for T(generally b=Lw), see descr.
width_of_channel_b	FLOAT	m	B:Inferred width of formation for evaluated TB
Tb	FLOAT	m**3/s	TB:Flow capacity in 1D formation of T and width B, see descr.
l_measl_tb	FLOAT	m**3/s	Estimated lower meas. limit for evaluated TB, see description
u_measl_tb	FLOAT	m**3/s	Estimated upper meas. limit of evaluated TB, see description
Sb	FLOAT	m	SB: S = storativity,B = width of formation,1D model, see descript.
assumed_sb	FLOAT	m	SB*: Assumed SB, s = storativity, B = width of formation, see...
Leakage_factor_lf	FLOAT	m	Lf:1D model for evaluation of Leakage factor
transmissivity_tt	FLOAT	m**2/s	TT:Transmissivity of formation, 2D radial flow model, see...
value_type_tt	CHAR		0:true value,–1:TT<lower meas.limit,1:TT > upper meas.limit,
bc_tt	CHAR		Best choice code. 1 means TT is best choice of T, else 0
l_measl_q_s	FLOAT	m**2/s	Estimated lower meas. limit for evaluated TT, see table descr
u_measl_q_s	FLOAT	m**2/s	Estimated upper meas. limit for evaluated TT, see description
storativity_s	FLOAT		S:Storativity of formation based on 2D rad flow, see descr.
assumed_s	FLOAT		Assumed Storativity,2D model evaluation, see table descr.
s_bc	FLOAT		Best choice of S (Storativity), see descr.
Ri	FLOAT	m	Radius of influence
ri_index	CHAR		ri index = index of radius of influence: –1,0 or 1, see descr.
Leakage_coeff	FLOAT	1/s	K'/b':2D rad flow model evaluation of leakage coeff, see desc
hydr_cond_ksf	FLOAT	m/s	Ksf:3D model evaluation of hydraulic conductivity, see desc.
value_type_ksf	CHAR		0:true value,–1:Ksf < lower meas.limit,1:Ksf > upper meas.limit,
l_measl_ksf	FLOAT	m/s	Estimated lower meas.limit for evaluated Ksf, see table desc.
u_measl_ksf	FLOAT	m/s	Estimated upper meas.limit for evaluated Ksf, see table descr
spec_storage_ssf	FLOAT	1/m	Ssf:Specific storage,3D model evaluation, see table descr.
assumed_ssf	FLOAT	1/m	Ssf*:Assumed Spec.storage,3D model evaluation, see table des.

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

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

Plu_impeller_basic_d.

idcode	start_date	stop_date	(m) secup	(m) seclow	section_no	(yyyymmdd) start_flowlogging	(yyyymmdd) stop_flowlogging	(m) l	test_type	formation_type
HFM14	2006-04-04 09:29	2006-04-05 08:16	14.00	145.50		2006-04-04 16:10:00	2006-04-04 19:58:00	150.50	6	1

cont.

(m**3/s) q_measl_l	(m**3/s) q_measl_u	(m**3/s) pump_flow_q1	(m**3/s) pump_flow_q2	(s) dur_flow_phase_tp1	(s) dur_flow_phase_tp2	(s) dur_flow-log_tfl_1	(s) dur_flow-log_tfl_2	(m) drawdown_s1	(m) drawdown_s2	(m.a.s.l.) initial_head_ho	(m.a.s.l.) hydraulic_head_h1	(m.a.s.l.) hydraulic_head_h2	reference	comments
5.0000E–05	1.3333E–03	1.1300E–03		38,160.00		13,680.00		1.81		0.69	–1.13			

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

Plu_impell_mail_res.

idcode	start_date	stop_date	(m) secup	(m) seclow	section_ no	(m) l	(m**3/s) cum_flow_ q0	(m**3/s) cum_flow_ q1	(m**3/s) cum_flow_ q2	(m**3/s) cum_flow_ q1	(m**3/s) tcum_ flow_q2t	(m**3/s) corr_cum_ flow_q1c	(m**3/s) corr_cum_ flow_q2c	(m**3/s) corr_cum_ flow_q1tc
HFM14	2006-04-04 16:10	2006-04-04 19:58	14.00	145.50		21.50								
HFM14	2006-04-04 16:10	2006-04-04 19:58	14.00	145.50		20.50								

cont.

(m**3/s) corr_cum_ flow_q2tc	(m**3/s) corr_com_ flow_q1tcr	(m**3/s) corr_com_ flow_q2tcr	(m**2/s) transmissi- tivy_hole_t	value_ type_t	bc_t	(m**2) cum_trans- missivity_tf	value_ type_tf	bc_tf	(m**2/s) l_measl_tf	(m**2) cum_trans- missivity_tft	value_type_tft	bc_tft	(m**2/s) u_mea- sl_tf	reference	comments
	1.1150E–03		5.66E–04	0	1					1.69E–06	5.57000E–04	0	1		
	1.1150E–03		5.66E–04	0	1					1.69E–06	5.57000E–04	0	1		

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

plu_impeller_anomaly.

idcode	start_date	stop_date	(m) secup	(m) seclow	section_no	(m) l_a_upper	(m) l_a_lower	(oC) fluid_temp_tea	(mS/m) fluid_elcond_eca	(mg/l) fluid_salinity_tdsa	(m**3/s) dq1	(m**3/s) dq2
HFM14	2006-04-04 16:38	2006-04-04 19:58	14.00	145.50		20.50	21.50					
HFM14	2006-04-04 16:38	2006-04-04 19:58	14.00	145.50		49.00	50.00					
HFM14	2006-04-04 16:38	2006-04-04 19:58	14.00	145.50		67.50	68.50					
HFM14	2006-04-04 16:38	2006-04-04 19:58	14.00	145.50		100.00	102.00					

cont.

(m**3/s) dq2	(m) r_wa	(m**3/s) dq1_corrected	(m**3/s) dq2_corrected	(m**2/s) spec_cap_dq1c_s1	(m**2/s) spec_cap_dq2c_s2	value_type_dq1_s1	value_type_dq2_s2	(m) ba	(m**2/s) transmissivity_tfa	value_type_tfa	bc_tfa	(m**2/s) l_measl_tfa	(m**2/s) u_measl_tfa	comments
		5.033E–04		2.781E–04		0			2.51E–04	0		1.69E–06		
		1.983E–04		1.096E–04		0			9.91E–05	0		1.69E–06		
		1.642E–04		9.070E–05		0			8.20E–05	0		1.69E–06		
		2.492E–04		1.377E–04		0			1.24E–04	0		1.69E–06		

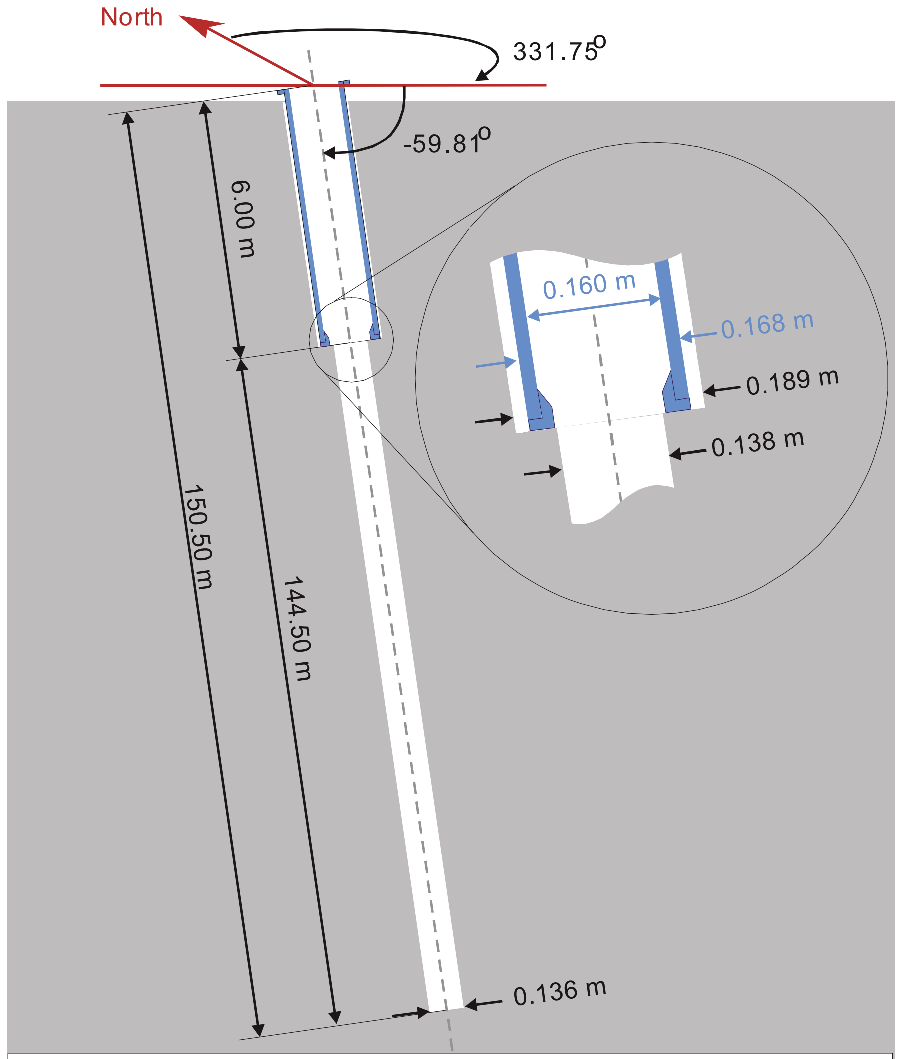
Column	Datatype	Unit	Column description
Site	CHAR		Investigation site name
Activity_type	CHAR		Activity type code
start_date	DATE		Date (yymmdd hh:mm:ss)
stop_date	DATE		Date (yymmdd hh:mm:ss)
Project	CHAR		project code
Idcode	CHAR		Object or borehole identification code
Secup	FLOAT	m	Upper section limit (m)
Seclow	FLOAT	m	Lower section limit (m)
Section_no	INTEGER	number	Section number
l_a_upper	FLOAT	m	Borehole length to upper limit of inferred flow anomaly
l_a_lower	FLOAT	m	Borehole length to lower limit of inferred flow anomaly
fluid_temp_tea	FLOAT	oC	Measured borehole fluid temperature at inferred anomaly.
fluid_elcond_eca	FLOAT	mS/m	Measured fluid el conductivity of borehole fluid at anomaly
fluid_salinity_tdsa	FLOAT	mg/l	Calculated total dissolved solids of fluid at anomaly, see.
dq1	FLOAT	m**3/s	Flow rate of inferred flow anomaly at pump flow Q1or head h1
dq2	FLOAT	m**3/s	Flow rate of inferred flow anomaly at pump flowQ2 or head h2
r_wa	FLOAT	m	Estimated borehole radius
dq1_corrected	FLOAT	m**3/s	Corrected flow rate of anomaly at pump flow Q1 or see descr.
dq2_corrected	FLOAT	m**3/s	Corrected flow rate of anomaly at pump flow Q2, or see descr
spec_cap_dq1c_s1	FLOAT	m**2/s	dq1/s1.Spec. capacity of anomaly at pump flow Q1 or, see
spec_cap_dq2c_s2	FLOAT	m**2/s	dq2/s2.Spec. capacity of anomaly at pump flow Q2 or, see des
value_type_dq1_s1	CHAR		0:true value,–1: < lower meas.limit,1: > upper meas.limit.
value_type_dq2_s2	CHAR		0:true value,–1: < lower meas.limit,1: > upper meas.limit.
Ba	FLOAT	m	Representative thickness of anomaly for TFa, see description
transmissivity_tfa	FLOAT	m**2/s	Transmissivity of inferred flow anomaly.
value_type_tfa	CHAR		0:true value,–1:TFa < lower meas.limit,1:TFa > upper meas.limit.
bc_tfa	CHAR		Best choice code.1 means TFa is best choice of T, else 0
l_measl_tfa	FLOAT	m**2/s	Lower measurement limit of TFa, see table description
u_measl_tfa	FLOAT	m**2/s	Upper measurement limit of TFa, see table description
comments	CHAR		Short comment on evaluated parameters
error_flag	CHAR		If error_flag = “*” then an error occured and an error
in_use	CHAR		If in_use = “*” then the activity has been selected as
Sign	CHAR		Activity QA signature

Appendix 4

Technical data of boreholes HFM14 and KFM05A

Technical data

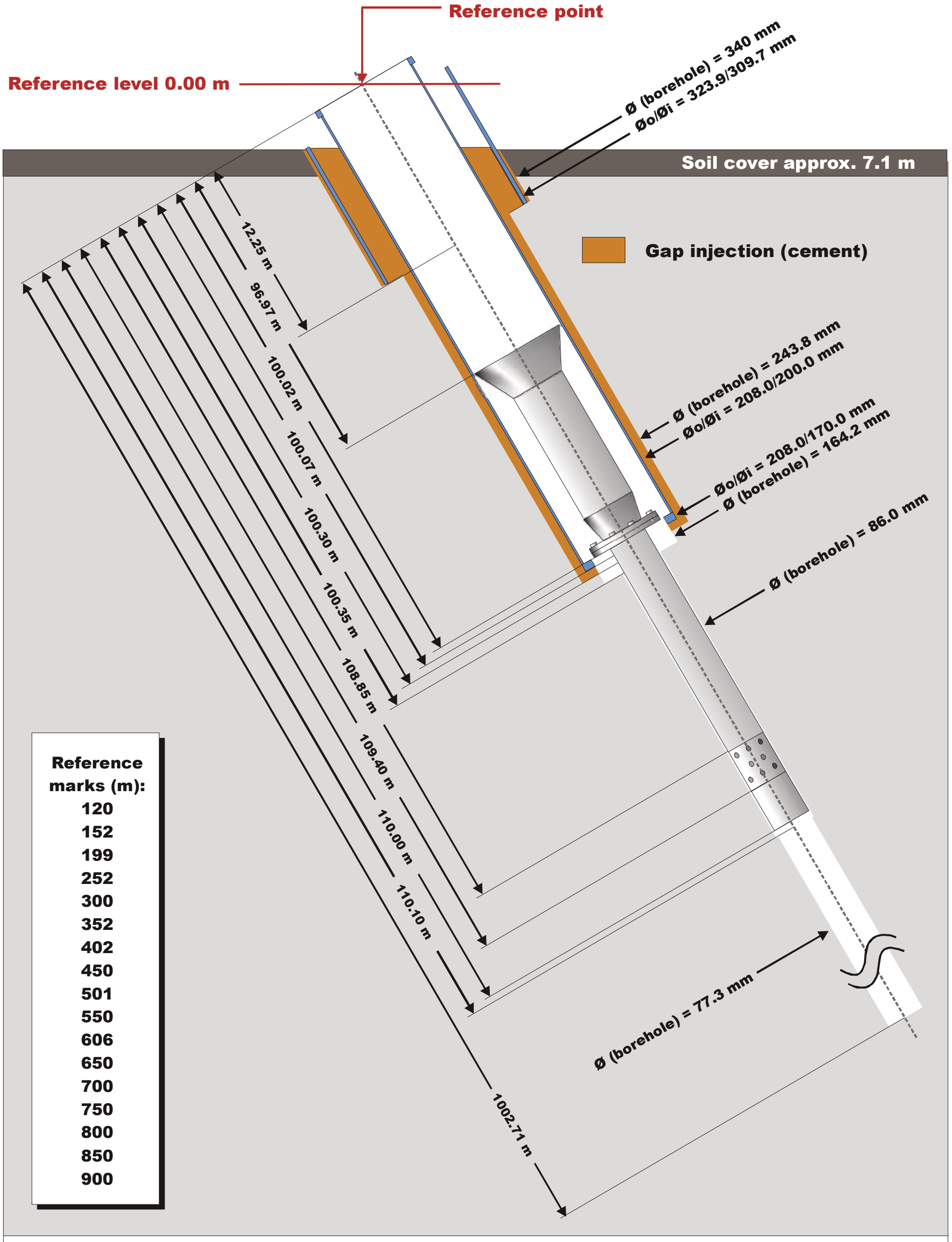
Borehole HFM14



Drilling reference point			
Northing:	6699313.14	(m),	RT90 2,5 gon V 0:-15
Easting:	1631734.59	(m),	RT90 2,5 gon V 0:-15
Elevation:	3.91	(m.a.s.l.),	RHB 70
Drilling period			
Drilling start date:	2003-10-06		
Drilling stop date:	2003-10-09		

Technical data

Borehole KFM05A



Drilling reference point

Northing: 6699344.85 (m), RT90 2,5 gon V 0:-15
Easting: 1631710.80 (m), RT90 2,5 gon V 0:-15
Elevation: 5.53 (m), RHB 70

Orientation

Bearing (degrees): 80.90°
Inclination (degrees): -59.80°

Borehole

Length: 1002.71 m

Percussion drilling period

Drilling start date: 2003-11-23
Drilling stop date: 2003-12-16

Core drilling period

Drilling start date: 2004-01-27
Drilling stop date: 2004-04-20