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Forsmark site investigation

Hydraulic interference tests

Boreholes HFM11 and HFM12

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August 2004

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Abstract

The percussion boreholes HFM11 and HFM12 are drilled in a selected lineament called the Eckarfjärden zone. The two boreholes are directed towards each other with an inclination of 50° from the horizontal plane. They both penetrate the Eckarfjärden zone.

The main objectives of the hydraulic tests in the boreholes were to investigate the geometry and hydraulic characteristics of the Eckarfjärden zone.

During consecutive pumping in three sections in HFM11, pressure registrations were made in three observation sections in HFM12. These sections were selected from earlier flow logging in the two boreholes, in which a number of hydraulic anomalies were identified.

While pumping in the two deeper sections in borehole HFM11 (100–120 m and 132–152 m borehole length) clear responses were measured in the two deeper observation sections in HFM12 (61–115 m and 116–209.5 m). The hydraulic connection, with the pumping sections, could for both sections be classified as good.

The pressure responses observed in all four cases had a lag time of between 8–15 min. over a distance of between 110 and 116 m, indicating that the same hydraulic structure was involved in all responding sections. The most rapid and distinct response was obtained in section 61–115 m in borehole HFM12 while pumping in section 132–152 m in borehole HFM11.

Single-hole evaluation of the pumping tests performed in the actual sections in HFM11 showed good agreement with the results from the previous open hole pumping test performed in conjunction with flow logging in HFM11. Evaluated transmissivity from the open-hole test was approximately 25% lower than the estimated total transmissivity from the tests in the sections 35–55 m, 100–120 m and 132–152 m.

Sammanfattning

HFM11 och HFM12 är borrade i ett utvalt lineament kallat Eckarfjärdszonen. De två borrhålen är riktade mot varandra från vardera sidan av zonen med en lutning av 50 grader från horisontalplanet.

Huvudsyftet med de hydrauliska testerna i borrhålen har varit att undersöka Eckarfjärdszonens geometri och hydrauliska egenskaper.

Under tre på varandra följande pumpningar i tre sektioner i HFM11 registrerades trycken i tre observationssektioner i HFM12. Dessa sektioner valdes utgående från tidigare genomförda flödesloggningar i de två borrhålen då ett antal hydrauliska anomalier (inflödespunkter) identifierades.

Vid pumpningarna i de två djupare sektionerna i HFM11 (100–120 m och 132–152 m borrhålslängd) kunde tydliga responser mätas i de två djupare sektionerna i HFM12 (61-115 m och 116–209.5 m). Responserna för båda sektionerna kan klassificeras som ”goda”.

De tryckresponser som observerades i de fyra fallen hade en responstid på 8–15 minuter över ett avstånd som varierade mellan 110 och 116 m, vilket indikerar att samma hydrauliska struktur var inblandad i alla fallen där en respons kunde mätas. Den snabbaste och tydligaste responsen fick man i sektionen 61–115 m i borrhålet HFM12 när man pumpade i sektionen 132–152 m i HFM11.

Enhålsutvärdering av utförda pumptester i de aktuella sektionerna i HFM11 visade på god överensstämmelse med resultat från det pumptest i öppet hål som tidigare utförts i samband med flödesloggning. Uppskattad transmissivitet från det senare var ca 25 % lägre än total uppskattad transmissivitet från pumptester i sectionerna 35–55 m, 100–120 m och 132–152 m.

Contents

1 Introduction

Two boreholes, HFM11 and HFM12, were drilled in order to investigate the Eckarfjärden deforamation zone. Both boreholes, drilled inclined towards each other with their collarings on each side of the Eckafjärden zone, penetrate the zone (see Figures 1-1 and 1-2. Pumping tests and flow logging were performed in both boreholes in order to investigate inflow zones. The results from these tests, presented in /1/, indicated six different hydraulic anomalies in borehole HFM11 and two in borehole HFM12. For further characterisation of the hydraulic connections between the two boreholes, and the hydraulic properties of the Eckarfjärden zone, the interference tests documented in this report were performed by pumping in HFM11 and using HFM12 as an observation borehole.

This document reports the results gained by the hydraulic interference tests in the borehole HFM11 and HFM12, which is one of the activities performed within the site investigation at Forsmark. The work was carried out in accordance to SKB internal controlling documents, see Table 1-1. Data and results were delivered to the SKB site characterization database SICADA with field note no Forsmark 286.

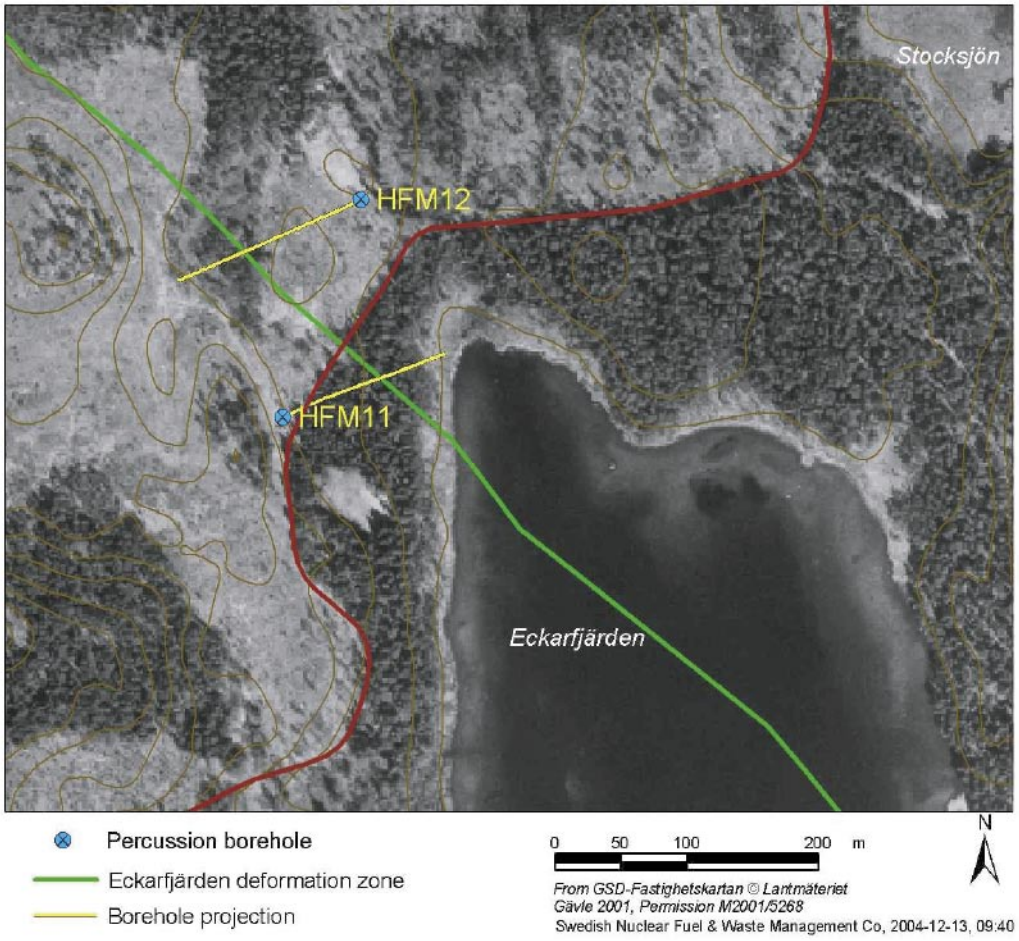


Figure 1-1. *Map showing the location of HFM11 and HFM12 at Forsmark.*

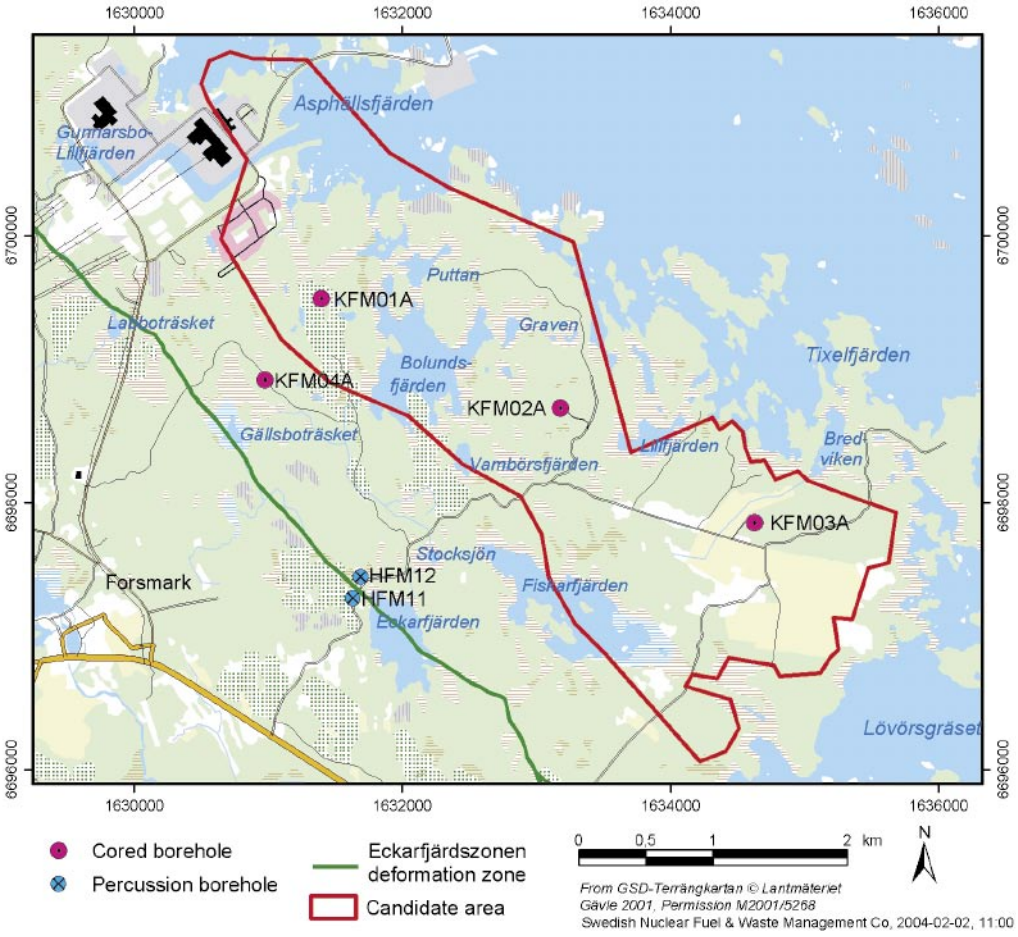


Figure 1-2. *The investigation area at Forsmark including the candidate area selected for more detailed investigations.*

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

Activity Plan	Number	Version
Hydraulic testing of the Eckarfjärd deformaition zone. Boreholes HFM11 and HFM 12.	AP PF 400-03-78	1.0
Method descriptions and instructions	**Number**	**Version**
Methodology descriptions for interference tests.	SKB MD 330.003	1.0
Instruction for analysis of injection- and single-hole pumping tests.	SKB MD 320.004	1.0
Instruktion för rengöring av borrhålsutrustning och viss markbaserad utrustning.	SKB MD 600.004	1.0

2 Objectives

Selection of pumping section intervals and observation section intervals in HFM11 and HFM12 respectively were based on flow anomalies, representing water conductive fractures or fracture zones, identified during previously performed flow logging.

The main objectives of the interference tests in HFM11 and HFM12 were to study hydraulic connections between the two boreholes, both assumed to penetrate the Eckarfjärden zone and to gain information to better understand the geometry and hydraulic properties of the water conductive structures identified in HFM11 and HFM12.

3 Scope

3.1 Boreholes tested

Technical data for the boreholes tested are presented in Table 3-1. The reference point for length measurements along the boreholes is top of casing (ToC). The Swedish National coordinate system (RT90) is used for horizontal coordinates together with RHB70 for the vertical coordinate. The reported borehole diameter in Table 3-1 refers to the diameter of the borehole at full depth. The borehole diameter (measured as the diameter of the drill bit) may decrease along the borehole due to wear of the drill bit.

The borehole coordinates at ground surface are shown in Table 3-2.

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

Borehole data Bh ID	Elevation of top of casing (ToC) (m.a.s.l.)	Borehole interval from ToC (m)	Casing/ Bh-diam. (m)	Inclination-top of bh (from horizontal plane) (°)	Dip-direction-top of borehole (from local N) (°)	Remarks	Drilling finished Date (YYYY-MM-DD)
HFM11	7.559	0.00–12.00	0.160	–50	60	Casing ID	
”		12.00–182.35	0.139			Borehole	2003-08-21
HFM12	7.025	0–14.90	0.160	–50	240	Casing ID	
”		14.90–209.50	0.135			Borehole	2003-09-16

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

Borehole data Bh ID	Northing (m)	Easting (m)
HFM11	6,697,280	1,631,634
HFM12	6,697,440	1,631,693

3.2 Tests performed

The borehole sections involved in the interference tests are listed in Table 3-3. The tests were performed in accordance with the SKB Activity plan AP PF 400-03-78 and the Geosigma quality plan 03/K 240 (SKB and Geosigma internal controlling documents) as well as the following the methodology description for interference tests, SKB MD 330.003 (SKB internal controlling document). The pumping tests in borehole HFM11 were carried out with the HTHB (HydroTestutrustning i Hammar-Borrhål) unit. Installation of packers and pressure sensors with built-in loggers in the observation borehole HFM12 was performed using equipment designed for temporary installations.

Table 3-3. Borehole tests performed in HFM11 and HFM12.

Borehole tests					
Bh ID	**Test section (m)**	**Test type[1]**	**Test config.**	**Test start date and time (YYYY-MM-DD tt:mm)**	**Test stop date andtime (YYYY-MM-DD tt:mm)**
HFM11	35–55	1B	Between packers	2003-10-28 13:32:00	2003-10-29 08:34:00
”	100–120	1B	Between packers	2003-10-29 11:37:04	2003-10-30 11:05:02
”	132–152	1B	Between packers	2003-10-30 12:25:10	2003-10-31 09:35:00
HFM12	116–209.5	2	Below packer	2003-10-28 13:32:00	2003-10-29 08:34:00
”	61–115	2	Between packers	2003-10-28 13:32:00	2003-10-29 08:34:00
”	14.9–60	2	Below packer	2003-10-28 13:32:00	2003-10-29 08:34:00
”	116–209.5	2	Below packer	2003-10-29 11:37:04	2003-10-30 11:03:00
”	61–115	2	Between packers	2003-10-29 11:37:04	2003-10-30 11:03:00
”	14.9–60	2	Below packer	2003-10-29 11:37:04	2003-10-30 11:03:00
”	116–209.5	2	Below packer	2003-10-30 12:25:10	2003-10-31 09:35:00
”	61–115	2	Between packers	2003-10-30 12:25:10	2003-10-31 09:35:00
”	14.9-60	2	Above packer	2003-10-30 12:25:10	2003-10-31 09:35:00

[1)] 1B: Pumping test-submersible pump, 2: Interference test (observation section)

The distances between the pumping sections in HFM11 and observation sections in HFM12 are shown in Table 3-4. The distances are calculated from the hydraulic point of application in each test section. These positions and the thickness of the zones are estimated from previous hydraulic single-hole tests and flow logging. The point of application with estimated thickness for the zone of interest is presented in Table 3-5.

Table 3-4. Calculated distances to the borehole sections involved in the interference tests.

Pumping section in HFM11	**Distance to point of application in observation sections in HFM12 (m)**		
	14.9–60 m	**61–115 m**	**116–209.5 m**
35–55 m	143.95	129.47	132.46
100–120 m	137.72	109.95	112.16
132–152 m	146.41	114.69	116.21

Table 3-5. Point of application in the test sections and estimated thickness of the tested zones.

Section	**Point of application (m b TOC)**	**Estimated thickness of zone* (m)**
HFM11, 35–55 m	41	4.0
HFM11, 100–120 m	109.2	2
HFM11, 132–152 m	142	4.5
HFM12, 14.9–60 m	19	15.4
HFM12, 61–115 m	111.2	2
HFM12, 116–209.5 m	123.5	0.5

*Based on identified flow anomalies during flow-logging

4 Description of equipment

4.1 Overview

The equipment used for pumping in HFM11 is referred to as HTHB (Swedish abbreviation for Hydraulic Test System for Percussion Boreholes). The HTHB unit is designed for percussion boreholes to perform pumping tests in isolated sections of the boreholes (Figure 4-1) down to a maximum depth of 200 m. A number of other tests can be performed with the HTHB system, although not described here. The pumping tests can be performed with either constant hydraulic head or alternatively, with constant flow rate.

All equipment that belongs to the HTHB is, when not in use, stored on a trailer and can be easily transported with a standard car. The equipment used in the borehole includes a submersible borehole pump with housing, expandable packers, pressure sensors and a pipe string and/or hose. A pressure transducer (P1) measures the pressure in the test section while another pressure transducer (P2) measures the pressure in the section below the test section, with which it is connected via a packer lead-through and a polyamide tube within the test section. The flow rate is manually adjusted by a control valve and monitored by an electromagnetic flow meter. A data logger samples data at a frequency determined by the operator.

The packers are normally expanded by water (nitrogen gas is used to pressurize the water) unless the depth to the groundwater level is large. In such cases, the packers are expanded by nitrogen gas.

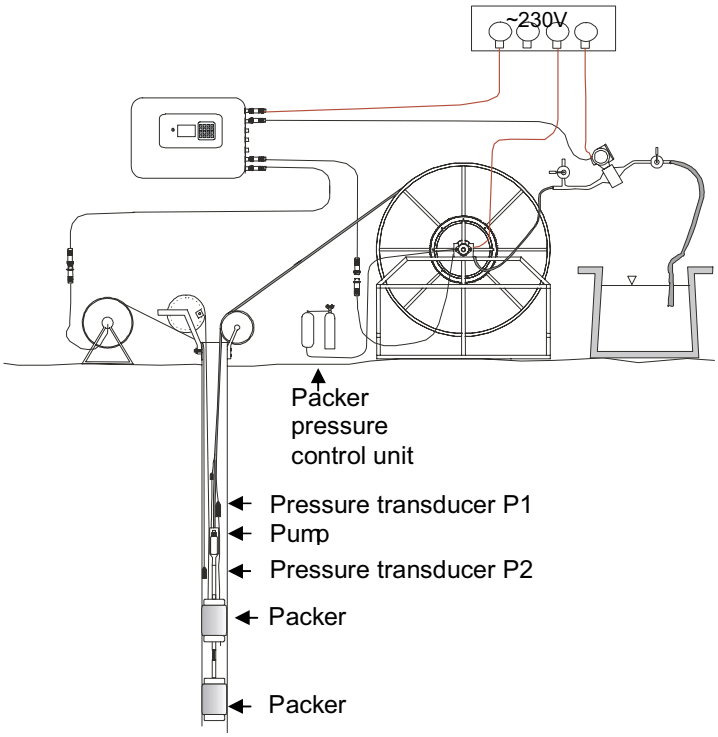


Figure 4-1. *Schematic test set-up for a pumping test in an isolated borehole section with HTHB.*

In observation borehole HFM12, two packers, expanded by nitrogen gas, were installed at 60–61 m and 115–116 m. Each section was connected by a 6/4 (outer-/ inner diameter) polyamide tube to a PEM-tube of larger diameter reaching down to approximately 15 m below top of casing. Submersible data loggers with internal pressure sensors (mini-Troll) and supported by data cables were installed in the PEM-tubes.

4.2 Measurement sensors

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

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

Technical specification Parameter		Unit	Sensor	HTHB system	Comments
Absolute pressure	Output signal	mA	4–20		
(pumping borehole)	Meas. range	kPa	0–1,500	0–1,500	
	Resolution	kPa	0.05		
	Accuracy	kPa	±1.5 (1	±10	Depending on uncertainties of the sensor position
Flow rate	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. (2	± 0.5	± 0.5	

1) Includes hysteresis, linearity and repeatability
2) Maximum error in % of actual reading (% o.r.).

The mini-Troll pressure loggers in the observations sections, have a measuring range of 0–206.8 kPa and use a 16-bit A-D converter, implying a resolution of c 0.01 kPa. The accuracy given by the manufacturer is c 0.2 kPa.

Table 4-2 shows the positions of the pressure sensors for each test. Positions are given in metres from the reference point, i.e. top of casing (ToC), lower part.

Equipment affecting the well bore storage coefficient is given in terms of diameter of the submerged item. Position is given as “in section” or “above section”. The volume of the submerged pump and the pump hose (~9 dm^3) has no influence on well bore storage of the pumping test section, because the pump is always situated above the test section.

Table 4-2. Position of sensors (from ToC) and equipment that may affect well bore storage in the pumping sections during the interference tests.

Borehole information				Sensors		Equipment in test section affecting well bore storage (WBS)		
ID	Test interval (m)	Test confi-guration	Test type[1]	Type	Position (m b ToC)	Function	Position[2] relative test section	Outer diameter (mm)
HFM11	35–55	Closed section	1B	P (P1)	29.67	Polyamide tube	In section	6
				P (P2)	28.67	Aluminum bar	In section	20
						Steel wire	In section	36
HFM11	100–120	Closed section	1B	P (P1)	94.67	Polyamide tube	In section	6
				P (P2)	93.67	Aluminum bar	In section	20
						Steel wire	In section	36
HFM11	132–152	Closed section	1B	P (P1)	125.67	Polyamide tube	In section	6
				P (P2)	124.67	Aluminum bar	In section	20
						Steel wire	In section	36

[1)] 1B: Pumping test-submersible pump, 2: Interference test (observation borehole during pumping in another borehole).
[2)] Position of equipment that can affect well bore storage. Position given as “In Section” or “Above Section” or “In borehole”.

5 Execution

5.1 Preparations

All sensors included in the HTHB system are calibrated at Geosigma engineering workshop in Librobäck, Uppsala. Calibration is performed on a yearly basis, or more often if needed. The last calibration before the tests for HTHB1 was done in March, 2003.

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

In order to check the function of the pressure sensors P1 and P2 (cf Figure 4-1), the pressure in the borehole was recorded at different levels while lowering the sensors. The pressures recorded by the sensors coincided well with the total head of water ($p/\rho g$). The mini-Troll loggers in the observation borehole were checked in the same way and the function was found to be good.

The flow meter was checked by measuring the time needed to fill a vessel with known volume during pumping. The agreement between the flow meter and the manually measured flow was good.

5.2 Procedure

The pumping tests in HFM11 were carried out as constant flow rate tests followed by a pressure recovery period. The pressure interference was recorded in the three sections in HFM12 during both the flow and recovery period.

The flow rates in the pumping sections were chosen based upon the results from previous pumping tests and flow logging in HFM11. The pumping periods were approximately 4h and recovery was measured over the following night. See Table 3-3 for pumping- and observation sections involved in the interference tests. For description of pressure registration procedure for pumping- and observation sections see section 4.1.

Approximate sampling interval for flow rate and pressure in the pumping borehole HFM11 is presented in Table 5-1. The pressure in the observation sections in borehole HFM12 was recorded with an interval of 30 s. Event triggered logging for a pressure change of 0.05 kPa was also used in the observation sections in HFM12.

Table 5-1. Approximate sampling interval used for pressure registration in HFM11 during the interference 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

During the interference tests, manual measurements of the groundwater levels were performed in the PEM hoses connected to the observation sections in HFM12 as well as in the section above the pumping section in HFM11.

5.3 Data handling

Data are downloaded from the HTHB-logger (Campbell CR 5000) to a laptop with the program PC9000. Data from the logger is in engineering units and comma-separated in the file (*.DAT) 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). A list of the data files from the data logger is shown in Appendix 1.

Processed data files (*.mio-files) from the hydraulic tests with pressure versus time data were converted to drawdown- and recovery files by the code PUMPKONV and plotted in different diagrams listed in the Instruction for analysis of injection- and single-hole pumping tests (SKB MD 320.004, SKB internal document) by the code SKB-plot and the software AQTESOLV.

5.4 Analyses and interpretation

As discussed in Section 5.2.1 the interference tests were performed as constant flow rate test. Methods assuming two dimensional flow for constant-flow tests in an equivalent porous medium were used for the analyses and interpretation of the tests.

A qualitative evaluation of actual flow regimes (pseudo-linear, pseudo-radial and pseudo-spherical flow, respectively) and possible outer boundary conditions during the tests was firstly performed. The qualitative evaluation was made from analyses of log-log diagrams of drawdown and/or recovery data together with the corresponding pressure derivatives versus time. In particular, pseudo-radial flow is reflected by a constant (horizontal) derivative in the diagrams whereas no-flow- and constant head boundaries are reflected by an increase and decrease of the derivative, respectively.

The quantitative, transient interpretation of the hydraulic parameters (transmissivity and storativity from the observation boreholes together with the skin factor from the pumping sections) was primarily based on the identified pseudo-radial flow regime during the tests in log-log and lin-log data diagrams. For tests with strong indications of a flow regime of lower dimension (i.e. fracture response), corresponding type curves were used as a complement to the standard evaluation methods for radial flow in the analyses.

The transient analysis was performed using a special version of the test analysis software AQTESOLV that enables both visual and automatic type curve matching. Thus, the quantitative transient evaluation is performed as an iterative process of manual type curve matching and non-linear regression.

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

The transient analysis of responses in the pumping sections dominated by wellbore storage was made according to the single-hole methods described in /1/. The estimation of the borehole storage coefficient, in appropriate pumping tests, was based on the early response with 1:1 slope.

After transient analysis of each test, the different estimates of transmissivity (Moye, pseudo-radial flow regimes during flow and recovery period respectively, fracture responses etc) for that test were checked and one of them was chosen to be the best representative of transmissivity. For single-hole tests, the interpreted parameters represent the surrounding rock formation. Interference tests provide information of the rock formation (i.e. dominating fracture zones) in between the actual pumping section and the observation section as well for the rock formation surrounding the observation section. The judged best evaluation of T is denoted T_T. For tests approaching a pseudo-spherical or pseudo-stationary flow by the end of the test, i.e. no transient evaluation assuming a two dimensional flow regime was possible, the steady-state evaluation according to Moye was considered the best estimate of T.

5.5 Nonconformities

No deviations from the Activity plan were made.

6 Results

6.1 Nomenclature, symbols and result presentation

The nomenclature and symbols used for the results of the interference tests are according to the Instruction for analysis of single-hole injection- and pumping tests (SKB MD 320.004), and the methodology description for interference tests (SKB MD 330.003). Additional symbols used are explained in the text.

Below, the results of the single-hole and interference tests are presented test by test. No corrections of measured data, e.g. for changes of the barometric pressure, tidal fluctuations or natural trends etc have been made by the analysis of the data due to the short duration of tests. The drawdown and recovery is calculated as the difference from the pressure before the flow period and at stop of the flow period respectively.

A summary of test data from the interference tests is presented in Table 6-15.

A summary of the responses together with calculated parameters from the interference tests are displayed in Table 6-16. Test diagrams are presented in Appendix 2. Also a Test Summary Sheet for each conducted test is provided in Section 6.6.

6.2 Response analysis in the observation borehole sections

6.2.1 Overview

The selection of pumping sections in HFM11 and observation sections in HFM12 was based on the flow anomalies (i.e. fractures/fracture zones) identified during the previously conducted flow logging. A simple initial qualitative analysis of the hydraulic connection between selected pumping sections in borehole HFM11 and the observation sections in HFM12 can be made by analysis of the transmissivities assigned to the flow anomalies in pumping- and observation sections respectively. In Table 6-1, drawdown during test and total transmissivity of identified flow anomalies in each section are presented.

Table 6-1. Transmissivity in selected pumping sections in borehole HFM11 and observation sections in borehole HFM12 based on anomalies identified during previously conducted flow logging.

Pumping borehole	Q_p (m^3/s)	Observation borehole	Section (m)	r_s (m)	s_p (m)	ΣT_i(m^2/s)
HFM11	$2.03 \cdot 10^{-4}$		35.0–55.0		7.30	$2.25 \cdot 10^{-5}$
		HFM12	14.9–60.0	144.0	–	–
			61.0–115.0	129.5	–	$1.36 \cdot 10^{-6}$
			116.0–209.5	132.5	–	$6.51 \cdot 10^{-6}$
HFM11	$2.50 \cdot 10^{-4}$		100.0–120.0		33.9	$1.03 \cdot 10^{-5}$
		HFM12	14.9–60.0	137.7	–	–
			61.0–115.0	110.0	0.92	$1.36 \cdot 10^{-6}$
			116.0–209.5	112.2	0.48	$6.51 \cdot 10^{-6}$
HFM11	$5.77 \cdot 10^{-4}$		132.0–152.0		37.4	$1.77. \cdot 10^{-5}$
		HFM12	14.9–60.0	146.4	–	–
			61.0–115.0	114.7	2.21	$1.36 \cdot 10^{-6}$
			116.0–209.5	116.2	1.76	$6.51 \cdot 10^{-6}$

6.2.2 Respons analysis

A simplified response analysis according to SKB MD 330.003 was made in this case due to the few observation boreholes/sections. The response time lags (dt_L) in the observation sections during the interference tests in HFM11 and HFM12 are shown in Table 6-2a. The time lags were in this case derived from the drawdown curves in the observation borehole at an actual drawdown of 0.01 m.

The normalised response time with respect to the distance to the pumping borehole (Index 1) was calculated, see Table 6-2a. The normalised response time is inversely related to the hydraulic diffusivity (T/S) of the formation. The distances between the boreholes are shown in Table 3-4. In addition, the normalized drawdown with respect to the flow rate (Index 2) was calculated in Table 6-2b.

$dt_L[s=0.1\ m] / r_s^2$ = normalised response time with respect to the distance r_s

$dt_L[s=0.1\ m]$ = time after start of pumping (s) at a drawdown s=0.1 m in the observation section

r_s = 3D-distance between the hydraulic point of application (hydr. p.a.) in the pumping borehole and observation borehole (m)

s_p/Q_p = normalized drawdown with respect to the flow rate

s_p = drawdown at stop of pumping in the actual observation borehole (m)

Q_p = flow rate by the end of the flow period (m^3/s)

Table 6-2a shows that the normalised response times calculated for the two lower observation sections in HFM12 differ a little between the interference tests in the two lower pumping sections in HFM11 (sections 100–120 m and 132–152 m). The lower values associated with pumping in section 132–152 are suggesting a slightly higher hydraulic diffusivity (T/S) in the assumed fracture zone connecting the lower section in HFM11 (132–152 m) observation sections in HFM12. The top section in HFM11 (35–55 m) does not seem to have a direct hydraulic connection with the observation borehole HFM12. Weak responses in the two lower sections are indicating an indirect connection through the rock mass or single fractures.

Table 6-2b shows that the normalised drawdowns are similar in the responding observation sections. The size of normalised drawdown in observation section 61–115 m is the same, regardless of which of the two lower sections in HFM11 is being pumped. The bottom observation section in HFM12 (116–209.5 m) may be slightly better connected with the lowest section in HFM11 (132–152 m).

Table 6-2a. Calculated response time lags and normalised response times for the observation section s in HFM12 during pumping in selected sections in HFM11.

Pumping borehole	Observation borehole	Section (m)	Hydr. p.a. (m)	dt_L[s=0.01 m] (min)	r_s (m)	dt_L[s=0.1 m]/r_s^2 (s/m²)
HFM11 35.0–55.0 m	HFM12	14.9–60	19	no response	144.0	–
		61–115	11.2	weak resp.	129.5	–
		116–209.5	123.5	weak resp.	132.5	–
HFM11 100.0–120.0 m	HFM12	14.9–60	19	no response	137.7	–
		61–115	11.2	11	110.0	0.055
		116–209.5	123.5	15	112.2	0.071
HFM11 132.0–152.0 m	HFM12	14.9–60	19	no response	146.4	–
		61–115	11.2	8	114.7	0.036
		116–209.5	123.5	10	116.2	0.044

Table 6-2b. Drawdown and normalised drawdown for the observation sections in HFM12 during pumping in selected sections in HFM11.

Pumping borehole	Q_p (m³/s)	Observation borehole	Section (m)	r_s (m)	s_p (m)	s_p/Q_p (s/m²)
HFM11 35.0–55.0 m	$2.03 \cdot 10^{-4}$	HFM12	14.9–60.0	144.0	–	–
			61.0–115.0	129.5	–	–
			116.0–209.5	132.5	–	–
HFM11 100.0–120.0 m	$2.50 \cdot 10^{-4}$	HFM12	14.9–60.0	137.7	–	–
			61.0–115.0	110.0	0.92	$3.7 \cdot 10^{-3}$
			116.0–209.5	112.2	0.48	$1.9 \cdot 10^{-3}$
HFM11 132.0–152.0 m	$5.77 \cdot 10^{-4}$	HFM12	14.9–60.0	146.4	–	–
			61.0–115.0	114.7	2.21	$3.8 \cdot 10^{-3}$
			116.0–209.5	116.2	1.76	$3.1 \cdot 10^{-3}$

6.3 Interference test while pumping in HFM11: 35–55 m

Test diagrams of drawdown and recovery in section 35–55 m in the pumping borehole HFM11 and the responses in the sections 14.9–60 m, 61–115 m and 116–209.5 m in the observation borehole HFM12 are presented in Appendix A2:1.

6.3.1 Pumping section HFM11: 35–55 m

General test data for the pumping test in HFM11, section 35–55 m, are presented in Table 6-3.

Comments on the test

The test was performed as a constant-flow rate pumping test. The flow rate was c 12.2 L/min and the duration of the flow period was c 4 h. The final drawdown was 7.30 m. Air in the pump hose entailed initial problems in the flow regulation and selection of an appropriate constant flow rate. Constant flow rate was obtained after c 7 min.

Recovery was measured for c 15 h, but only the first 4 h were used for transient evaluation of transmissivity. After 4 h, approximately 95% of the maximal pressure change during the flow period had recovered.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2:1-1 to A2:1-5 in Appendix 2:1.

For the flow period, a pseudo-radial flow regime is indicated from c 1,000 s to c 8,000 s. After 8,000 s, there is weak indication of transition into pseudo-sperical flow.

During recovery, a first pseudo-radial flow period is indicated from c 15–50 s. The first period of pseudo-radial flow is followed by a transition to a second pseudo-radial flow regime or, alternatively, a flow regime of lower dimension, indicating a boundary.

Interpreted parameters

Transient, quantitative interpretation of the flow- and recovery period of the test is shown in log-log and lin-log diagrams in Appendix A2:1, Figures A2:1-2 to A2:1-5. Quantitative analysis was made both from the flow- and recovery period according to the methods described in Section 5.4. The results are shown in the Test Summary Sheets and in Table 6-14 in Section 6.5.4 and Table 6-15 in Section 6.6. The most representative transient parameter estimation is chosen from the interpretation of the flow period due to a longer and more well-defined pseudo-radial flow regime. See Table 6-16 for parameter values.

Table 6-3. General test data for the pumping test in HFM11: 35–55 m.

General test data			
Pumping borehole	HFM11 (35–55 m)		
Test type[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	packed off section		
Test No	1		
Field crew	T. Svensson, D. Segerbäck (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comment	Interference test		
	Nomenclature	**Unit**	**Value**
Borehole length	L	m	182.35
Casing length	L_c	m	12.00
Test section- secup	Secup	m	35.00
Test section- seclow	Seclow	m	55.00
Test section length	L_w	m	20.00
Test section diameter[2]	$2 \cdot r_w$	mm	140
Test start (start of pressure registration)		yymmdd hh:mm	031028 13:54
Packer expanded		yymmdd hh:mm:ss	031028 11:50 ca
Start of flow period		yymmdd hh:mm:ss	031028 14:07:41
Stop of flow period		yymmdd hh:mm:ss	031028 18:17:27
Test stop (stop of pressure registration)		yymmdd hh:mm	031029 08:34
Total flow time	t_p	min	249.8
Total recovery time	t_F	min	895.6
Pressure data			
Absolute pressure in test section before start of flow period	p_i	kPa	310.0
Absolute pressure in test section before stop of flow period	p_p	kPa	238.4
Absolute pressure in test section at stop of recovery period	p_F	kPa	310.2
Maximal pressure change during flow period	dp_p	kPa	71.6
Flow data			
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$2.03 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$2.08 \cdot 10^{-4}$
Total volume discharged during flow period	V_p	m^3	3.1

Manual groundwater level measurements in HFM11 (0–34 m, i.e. above pumping section)			**GW level**	
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**
2003-10-28	11:53	–135	1.95	6.07
2003-10-28	13:35	–33	1.80	6.18
2003-10-28	14:02	-6	1.44	6.46
2003-10-28	14:30	22	1.45	6.45
2003-10-28	15:00	52	1.53	6.39
2003-10-28	15:30	82	1.61	6.33
2003-10-28	15:53	105	1.69	6.26
2003-10-28	17:37	209	2.01	6.02
2003-10-28	18:15	247	2.13	5.93

[1)] Constant Head injection and recovery or Constant Rate withdrawal and recovery [2)] Nominal diameter

6.3.2 Observation section HFM12: 14.9–60.0 m

General test data from the observation section HFM12: 14.9–60.0 m are presented in Table 6-4.

Table 6-4. General test data from the observation section HFM12: 14.9–60 m.

Pressure data			Nomenclature	Unit	Value	GW level (m a s l)
Absolute pressure in test section before start of flow period			pi	kPa	165.7	6.22
Absolute pressure in test section before stop of flow period			pp	kPa	165.8	6.23
Absolute pressure in test section at stop of recovery period			pF	kPa	166.1	6.26
Maximal pressure change during flow period			dpp	kPa	–	–
Manual groundwater level measurements			**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**		
2003-10-27	18:55		0.98	6.27		
2003-10-28	09:50	–258	1.05	6.22		
2003-10-28	13:50	–18	1.05	6.22		

Comments on the test

No significant response to the pumping in section 35–55 m in HFM11 was detected. Variations in hydraulic head were less than ± 0.025 m. The variations were not correlated to pumping in HFM11 section 35–55 m.

Interpreted flow regimes

Figure A2:1-6 in Appendix 2 shows the minor variations in hydraulic head. Flow regime interpretation was not possible.

Interpreted parameters

Transient parameter interpretation is not possible.

6.3.3 Observation section HFM12: 61–115 m

General test data from the observation section HFM12: 61–115 m are presented in Table 6-5.

Table 6-5. General test data from the observation section HFM12: 61–115 m.

Pressure data			Nomenclature	Unit	Value	GW level (m a s l)
Absolute pressure in test section before start of flow period			pi	kPa	163.2	5.97
Absolute pressure in test section before stop of flow period			pp	kPa	162.0	5.85
Absolute pressure in test section at stop of recovery period			pF	kPa	162.8	5.93
Maximal pressure change during flow period			dpp	kPa	1.2	
Manual groundwater level measurements			**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**		
2003-10-27	18:55		1.37	5.98		
2003-10-28	09:50	–258	1.10	6.18		
2003-10-28	13:50	–18	1.38	5.97		

Comments on the test

The response was delayed by c 60 min to the pumping in section 35–55 m in HFM11. The final drawdown was c 0.13 m. The drawdown continued to increase c 3,000 s after stop of flow period and the total recovery was c 0.015 m during the first 4 h.

Interpreted flow regimes

Selected test diagrams are presented in Appendix 2, Figures A2:1-7 to A2:1-11. Flow regime interpretation was not possible.

Interpreted parameters

Transient parameter interpretation was not possible.

6.3.4 Observation section HFM12: 116–209.5 m

General test data from the observation section HFM12: 116–209.5 m are presented in Table 6-6.

Table 6-6. General test data from the observation section HFM12: 116–209.5 m.

Pressure data			Nomenclature	Unit	Value	GW level (m a s l)
Absolute pressure in test section before start of flow period			pi	kPa	169.9	6.61
Absolute pressure in test section before stop of flow period			pp	kPa	169.3	6.55
Absolute pressure in test section at stop of recovery period			pF	kPa	169.5	6.57
Maximal pressure change during flow period			dpp	kPa	0.6	
Manual groundwater level measurements			**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**		
2003-10-27	18:55		0.57	6.59		
2003-10-28	09:50	–258	0.12	6.93		
2003-10-28	13:50	–18	0.54	6.61		

Comments on the test

The pressure response time lag was c 3,600 s to the pumping in HFM11:35–55 m. A weak response of c 0.06 m maximum drawdown after c 4 h pumping occurred. During the recovery period, the pressure decreased during the first c 6,000 s by 0.025 m followed by a recovery of c 0.01 m. Hence, no significant recovery correlated to the pumping in HFM11, section 35–55 m, could be identified. The total recovery registered after more than 14 h was less than 0.05 m.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2:1-12 to A2:1-14 in Appendix 2. Flow regime interpretation was not possible.

Interpreted parameters

Transient parameter interpretation was not possible.

6.4 Interference test in HFM11: 100–120 m

Test diagrams of drawdown and recovery in section 100–120 m in the pumping borehole HFM11 and the responses in sections 14.9–60 m, 61–115 m and 116–209.5 m in observation borehole HFM12, are presented in Appendix A2:2.

6.4.1 Pumping section HFM11: 100–120 m

General test data for the pump test in section HFM11:100–120 m are presented in Table 6-7.

Table 6-7. General test data for the pumping test in HFM11: 100–120 m.

General test data				
Pumping borehole	HFM11 (100–120 m)			
Test type[1]	Constant Rate withdrawal and recovery test			
Test section (open borehole/packed-off section):	packed off section			
Test No	1			
Field crew	T. Svensson, D. Segerbäck (GEOSIGMA AB)			
Test equipment system	HTHB1			
General comment	Interference test			
	Nomenclature	**Unit**		**Value**
Borehole length	L	m		182.35
Casing length	L_c	m		12.00
Test section- secup	Secup	m		100.00
Test section- seclow	Seclow	m		120.00
Test section length	L_w	m		20.00
Test section diameter[2]	$2 \cdot r_w$	mm		140
Test start (start of pressure registration)		yymmdd hh:mm		031029 11:37
Packer expanded		yymmdd hh:mm:ss		031029 11:40:00
Start of flow period		yymmdd hh:mm:ss		031029 13:00:04
Stop of flow period		yymmdd hh:mm:ss		031029 17:05:14
Test stop (stop of pressure registration)		yymmdd hh:mm		031030 11:05
Total flow time	t_p	min		245.2
Total recovery time	t_F	min		1,079.8
Pressure data				
Absolute pressure in test section before start of flow period	p_i	kPa		627.2
Absolute pressure in test section before stop of flow period	p_p	kPa		294.5
Absolute pressure in test section at stop of recovery period	p_F	kPa		622.7
Maximal pressure change during flow period	dp_p	kPa		332.7
Flow data				
Flow rate from test section just before stop of flow period	Q_p	m^3/s		$2.50 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s		$2.49 \cdot 10^{-4}$
Total volume discharged during flow period	V_p	m^3		3.7
Manual groundwater level measurements in HFM11 (0–99 m, i.e. above pumping section)			**GW level**	
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**
2003-10-29	11:01		1.43	6.46
2003-10-29	12:58	–2	1.61	6.33
2003-10-29	16:56	236	1.64	6.30

[1)] Constant Head injection and recovery or Constant Rate withdrawal and recovery
[2)] Nominal diameter

Comments on the test

The test was performed as a constant-flow rate pumping test. The flow rate was c 15.0 L/min and the duration of the flow period was c 4 h. Recovery was measured for 18 h, but only the first 4 h were used in the recovery diagrams.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2:2-1 to A2:2-5 in Appendix 2.

For the flow period, the noisy derivative makes identification of flow regimes impossible. For the recovery period, a pseudo-spherical flow regime is indicated from c 20 s to c 500 s.

Interpreted parameters

Transient, quantitative interpretation of the flow- and recovery period of the test using models assuming pseudo-radial flow regime is not considered representative in this case, although such an interpretation was attempted on the flow period. This interpretation provided an apparent high value of the skin factor, which indicates a flow regime of higher dimension than two, see A2:2-1 to A2:2-5 in Appendix 2. Thus, the steady-state evaluation with Moye's formula was considered the most representative in this case. See Table 6-16 for parameter values.

6.4.2 Observation section HFM12: 14.9–60 m

General test data from the observation section HFM12: 14.9–60 m are presented in Table 6-8.

Table 6-8. General test data from the observation section HFM12: 14.9–60 m.

Pressure data			**Nomenclature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in test section before start of flow period			pi	kPa	166.1	6.20
Absolute pressure in test section before stop of flow period			pp	kPa	166.0	6.19
Absolute pressure in test section at stop of recovery period			pF	kPa	165.9	6.18
Maximal pressure change during flow period			dpp	kPa	0.1	
Manual groundwater level measurements			**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**		
2003-10-29	08:20	–280	1.08	6.20		
2003-10-30	10:52	1,312	1.06	6.21		

Comments on the test

No indication of a hydraulic connection between the pumping section 100–120 m in borehole HFM11 and section 14.9–60 m in borehole HFM12 was obtained. Drawdown continues to increase throughout the recovery period, see Appendix 2, Figures A2:2-6 to A2:2-8.

Interpreted flow regimes

No flow regime interpretation is possible.

Interpreted parameters

No parameter interpretation is possible.

6.4.3 Observation section HFM12: 61–115 m

General test data from the observation section HFM12: 61–115 m are presented in Table 6-9.

Table 6-9. General test data from the observation section HFM12: 61–115 m.

Pressure data			**Nomenclature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in test section before start of flow period			pi	kPa	163.1	5.87
Absolute pressure in test section before stop of flow period			pp	kPa	154.3	4.97
Absolute pressure in test section at stop of recovery period			pF	kPa	162.2	5.77
Maximal pressure change during flow period			dpp	kPa	8.8	
Manual groundwater level measurements			**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**		
2003-10-29	08:20	–280	1.51	5.87		
2003-10-30	10:52	1,312	1.55	5.84		

Comments on the test

A response of c 0.9 m to the pumping in HFM11, section 100–120 m, was observed with a pressure response time lag of c 11 min.

Interpreted flow regimes

Selected test diagrams are presented in Appendix 2, Figures A2:2-9 to A2:2-13.

During the drawdown period, a pseudo-radial flow regime is indicated from c 6,000 s to c 11,000 s. Indication of pseudo-radial flow during recovery is weaker due to irregular derivative.

Interpreted parameters

Quantitative transient analysis was made both from the flow- and recovery period. The most representative transient parameter estimation is chosen from the Cooper-Jacob solution of the flow period due to a more pronounced period of pseudo-radial flow regime. See Table 6-16 for parameter values.

6.4.4 Observation section HFM12: 116–209.5 m

General test data from the observation section HFM12: 116–209.5 m are presented in Table 6-10.

Table 6-10. General test data from the observation section HFM12: 116–209.5 m.

Pressure data			**Nomenclature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in test section before start of flow period			pi	kPa	169.9	6.53
Absolute pressure in test section before stop of flow period			pp	kPa	165.2	6.05
Absolute pressure in test section at stop of recovery period			pF	kPa	169.4	6.48
Maximal pressure change during flow period			dpp	kPa	4.7	
Manual groundwater level measurements						
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**GW level (m b. ToC)**	**(m a s l)**		
2003-10-29	08:20	–280	0.65	6.53		
2003-10-30	10:52	1,312	0.65	6.53		

Comments on the test

A weak response with a total drawdown of c 0.5 m was observed with a pressure response time lag of c 15 min.

Interpreted flow regimes

Selected test diagrams are presented in Appendix 2, Figures A2:2-14 to A2:2-18.

A pseudo-radial flow regime is indicated from c 5,000 s to c 9,000 s during drawdown. A less pronounced pseudo-radial flow regime was also indicated during the recovery period, see Figure A2:2-18.

Interpreted parameters

Quantitative transient analysis was made both from the flow and recovery period.The analysis from the recovery period was only considered as a support to the transient evaluation on the drawdown period. Most representative transient parameter estimation is chosen from the Cooper-Jacob solution of the flow period. See Section 6-6, Table 6-16, and Test Summary Sheet for presentation of parameter values.

6.5 Interference test in HFM11: 132–152 m

Test diagrams of drawdown and recovery in section 132–152 m in the pumping borehole HFM11 and the responses in sections 14.9–60 m, 61–115 m and 116–209.5 m in observation borehole HFM12, are presented in Appendix A2:3.

6.5.1 Pumping section HFM11: 132–152 m

General test data for the pump test in section HFM11:132–152 m are presented in Table 6-11.

Comments on the test

The test was performed as a constant-flow rate pumping test. The flow rate was c 35 L/min and the duration of the flow period was 4 h and 20 min. Recovery was measured for c 15 h, although only the first c 4 h were used for transient evaluation.

A pressure response of c 90 kPa was observed in the section below the pumping section, see Figure A2:3-1 in Appendix 2. In addition, a drawdown of c 0.6 m was observed in the section above the pumping section.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2:3-1 to A2:3-5 in Appendix 2.

For the flow period, a well-defined pseudo-radial flow regime is indicated from c 1,000 s to c 10,000 s.

A pseudo-radial flow regime is also indicated from c 120 s to c 1,500 s during the recovery period.

Interpreted parameters

Quantitative analysis was made both from the flow- and recovery period. Most representative estimation of transmissivity is based on the drawdown period due to a longer and more pronounced period of a pseudo-radial flow regime. Parameter values are presented in Section 6-6, Table 6-16 and Test Summary Sheet.

Table 6-11. General test data for the pumping test in HFM11: 132–152 m.

General test data			
Pumping borehole	HFM11 (132–152 m)		
Test type[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	packed off section		
Test No	1		
Field crew	T. Svensson, P. Askling (GEOSIGMA AB)		
Test equipment system	HTHB1		
General comment	Interference test		
	Nomenclature	**Unit**	**Value**
Borehole length	L	m	182.35
Casing length	L_c	m	12.00
Test section – secup	Secup	m	132.00
Test section – seclow	Seclow	m	152.00
Test section length	L_w	m	20.00
Test section diameter[2]	$2 \cdot r_w$	mm	140
Test start (start of pressure registration)		yymmdd hh:mm	031030 12:25
Packer expanded		yymmdd hh:mm:ss	031030 12:30
Start of flow period		yymmdd hh:mm:ss	031030 13:36:11
Stop of flow period		yymmdd hh:mm:ss	031030 17:57:02
Test stop (stop of pressure registration)		yymmdd hh:mm	031031 09:35
Total flow time	t_p	min	260.9
Total recovery time	t_F	min	938.0
Pressure data			
Absolute pressure in test section before start of flow period	p_i	kPa	848.6
Absolute pressure in test section before stop of flow period	p_p	kPa	481.6
Absolute pressure in test section at stop of recovery period	p_F	kPa	845.3
Maximal pressure change during flow period	dp_p	kPa	367.0
Flow data			
Flow rate from test section just before stop of flow period	Q_p	m^3/s	$5.77 \cdot 10^{-4}$
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	$5.76 \cdot 10^{-4}$
Total volume discharged during flow period	V_p	m^3	9.0

Manual groundwater level measurements in HFM11 (0–99 m, i.e. above pumping section)		**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Date YYYY-MM-DD**	**Time tt:mm**		**Date YYYY-MM-DD**
2003-10-30	13:51	2003-10-30	13:51		2003-10-30
2003-10-30	15:21	2003-10-30	15:21		2003-10-30
2003-10-30	16:25	2003-10-30	16:25		2003-10-30
2003-10-30	17:48	2003-10-30	17:48		2003-10-30
2003-10-31	09:22	2003-10-31	09:22		2003-10-31

[1)] Constant Head injection and recovery or Constant Rate withdrawal and recovery
[2)] Nominal diameter

6.5.2 Observation section HFM12: 14.9–60 m

General test data from the observation section HFM12: 14.9–60 m are presented in Table 6-12.

Table 6-12. General test data from the observation section HFM12: 14.9–60 m.

Pressure data			Nomenclature	Unit	Value	GW level (m a s l)
Absolute pressure in test section before start of flow period			pi	kPa	165.8	6.21
Absolute pressure in test section before stop of flow period			pp	kPa	166.3	6.26
Absolute pressure in test section at stop of recovery period			pF	kPa	165.5	6.18
Maximal pressure change during flow period			dpp	kPa	0.8	
Manual groundwater level measurements			**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**		
2003-10-30	10:52	164	1.06	6.21		
2003-10-31	15:20	1,544	1.03	6.24		

Comments to the test

No indication of hydraulic connection between the pumping section 132–152 m in borehole HFM11 and section 14.9–60 m in observation borehole HFM12 was observed.

Interpreted flow regimes

No flow regime interpretation is possible. See Figure A2:3-6 in Appendix 2 for pressure response overview.

Interpreted parameters

No parameter interpretation is possible.

6.5.3 Observation section HFM12: 61–115 m

General test data from the observation section HFM12: 61–115 m are presented in Table 6-13.

Table 6-13. General test data from the observation section HFM12: 61–115 m.

Pressure data			Nomenclature	Unit	Value	GW level (m a s l)
Absolute pressure in test section before start of flow period			pi	kPa	163.1	5.84
Absolute pressure in test section before stop of flow period			pp	kPa	141.4	3.62
Absolute pressure in test section at stop of recovery period			pF	kPa	160.4	5.56
Maximal pressure change during flow period			dpp	kPa	21.7	
Manual groundwater level measurements			**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**		
2003-10-30	10:52	164	1.55	5.84		
2003-10-31	15:20	1,544	1.63	5.78		

Comments to the test

A pronounced response with a total drawdown of c 2.2 m and a pressure response time lag of c 8 min was observed.

Interpreted flow regimes

Selected test diagrams are presented in Figures A2:3-7 to A2:3-11 in Appendix 2.

No distinct period of pseudo-radial flow regime developed during the flow period. A short period of pseudo-radial flow is interpreted from 3,000 s to 5,000 s. After 5,000 s there is an indication of pseudo-linear flow. The recovery period data show a very similar behaviour compared to the drawdown period.

Interpreted parameters

In spite of only weak indications of pseudo-radial flow, a transient evaluation was considered relevant. The most representative transient parameter estimation is chosen from the Cooper-Jacob solution of the flow period. See Test Summary Sheet and Table 6-16 in Section 6-6 for parameter values.

6.5.4 Observation section HFM12: 116–209.5 m

General test data from the observation section HFM12: 116–209.5 m is presented in Table 6-14.

Table 6-14. General test data from the observation section HFM12: 116–209.5 m.

Pressure data			**Nomenclature**	**Unit**	**Value**	**GW level (m a s l)**
Absolute pressure in test section before start of flow period			pi	kPa	170.0	6.53
Absolute pressure in test section before stop of flow period			pp	kPa	152.7	4.77
Absolute pressure in test section at stop of recovery period			pF	kPa	166.4	6.16
Maximal pressure change during flow period			dpp	kPa	17.3	
Manual groundwater level measurements			**GW level**			
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m a s l)**		
2003-10-30	10:52	164	0.65	6.53		
2003-10-31	15:20	1,544	1.78	5.66		

Comments on the test

A clear response with a drawdown of c 1.8 m was observed. The response was very similar to the response in the observation section 61–115 m, which may indicate a hydraulic connection between the two observation sections. Suspicions of connections between the two observation sections, and not "separate" connections with the pumping section, are supported by the fact that the pressure response time lag is shorter in observation section 61–115 m, even though estimated transmissivity is almost five times higher in observation section 116–209.5 m (transmissivity from flow logging).

Interpreted flow regimes

Test diagrams are presented in Figures A2:3-12 to A2:316 in Appendix 2.

Note the similarity in shape of pressure response and pressure response derivative with the observation section above (61–115 m).

Interpreted parameters

No transient parameter interpretation was made in this section.

6.6 Summary of interference tests

A compilation of measured test data from the interference tests in HFM11:32–52, 100–120 and 132–152 m is shown in Table 6-15. In Tables 6-16 and 6-17 calculated hydraulic parameters of the formation and borehole from the tests, respectively, are shown.

The lower and upper practical measurement limit for the HTHB system, expressed in terms of specific flow (Q/s), is Q/s–L=$2 \cdot 10^{-6}$ m^2/s and Q/s–U=$2 \cdot 10^{-3}$ m^2/s for pumping tests.

Table 6-15. Summary of test data for the interference tests performed in percussion boreholes HFM11 and HFM12.

Pumping borehole ID	Borehole ID	Section (m)	Test type[1)]	pi (kPa)	pp (kPa)	pF (kPa)	Qp (m^3/s)	Qm (m^3/s)	Vp (m^3)
HFM11	HFM11	35–55	1B	310.0	238.4	310.2	$2.03 \cdot 10^{-4}$	$2.08 \cdot 10^{-4}$	3.1
	HFM12	116–209.5	2	169.9	169.3	169.5			
	HFM12	61–115	2	163.2	162.0	162.8			
	HFM12	14.9–60	2	165.7	165.8	166.1			
HFM11	HFM11	100–120	1B	627.2	294.5	622.7	$2.50 \cdot 10^{-4}$	$2.49 \cdot 10^{-4}$	3.7
	HFM12	116–209.5	2	169.9	165.2	169.4			
	HFM12	61–115	2	163.1	154.3	162.2			
	HFM12	14.9–60	2	166.1	166.0	165.9			
HFM11	HFM11	132–152	1B	848.6	481.6	845.3	$5.77 \cdot 10^{-4}$	$5.76 \cdot 10^{-4}$	9.0
	HFM12	116–209.5	2	170.0	152.7	166.4			
	HFM12	61–115	2	163.1	141.4	160.4			
	HFM12	14.9–60	2	165.8	166.3	165.5			

1B: Pumping test-submersible pump, 2: Interference test (observation borehole during pumping in another borehole)

Table 6-16. Summary of calculated hydraulic parameters of the formation from the interference tests in HFM11 and HFM12 in the Forsmark area.

Pumping borehole ID	Observation borehole ID	Section (m)	Test type	Q/s (m^2/s)	Tmoye (m^2/s)	T_T (m^2/s)	S (–)	S* (–)	Comments
HFM11		35–55	1B	$2.78 \cdot 10^{-5}$	$2.64 \cdot 10^{-5}$	$2.30 \cdot 10^{-5}$	–	$5 \cdot 10^{-5}$	
	HFM12	116–209.5	2	–	–	–	–	–	Weak response
	HFM12	61–115	2	–	–	–	–	–	Weak response
	HFM12	14.9–60	2	–	–	–	–	–	No response
HFM11		100–120	1B	$7.37 \cdot 10^{-6}$	$6.99 \cdot 10^{-5}$	$1.85 \cdot 10^{-5}$	–	$5 \cdot 10^{-5}$	
	HFM12	116–209.5	2	–	–	$8.94 \cdot 10^{-5}$	$2.85 \cdot 10^{-5}$	–	
	HFM12	61–115	2	–	–	$5.88 \cdot 10^{-5}$	$1.16 \cdot 10^{-5}$	–	
	HFM12	14.9–60	2	–	–	–	–	–	
HFM11		132–152	1B	$2.78 \cdot 10^{-5}$	$1.46 \cdot 10^{-5}$	$1.66 \cdot 10^{-5}$	–	$5 \cdot 10^{-5}$	
	HFM12	116–209.5	2	–	–	–	–	–	
	HFM12	61–115	2	–	–	$5.90 \cdot 10^{-5}$	$1.13 \cdot 10^{-5}$	–	
	HFM12	14.9–60	2	–	–	–	–	–	

Q/s = specific flow for the pumping borehole.
T = transmissivity from transient evaluation.
S = storativity from transient evaluation.
S* = sumed storativity by the estimation of the skin factor.

Table 6-17. Summary of calculated hydraulic parameters of the pumping sections from the interference tests in HFM11 and HFM12 in the Forsmark area.

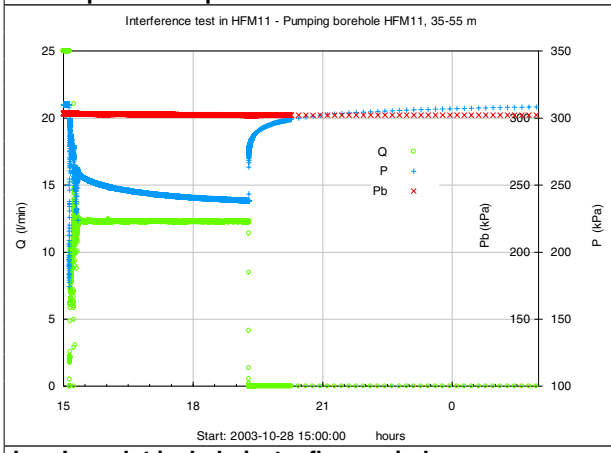
Borehole ID	Section (m)	Test type	S* (–)	C[1)] (m^3/Pa)	ζ (–)
HFM11	35–55	1B	$5.0 \cdot 10^{-5}$	$1.35 \cdot 10^{-10}$	–2.3
HFM11	100–120	1B	$5.0 \cdot 10^{-5}$	$1.35 \cdot 10^{-10}$	8.3
HFM11	132–152	1B	$5.0 \cdot 10^{-5}$	$1.35 \cdot 10^{-10}$	–0.63

[1)] Theoretical value presented. No unique C-value evaluation from transient data possible.
C = wellbore storage coefficient
ζ = skin factor

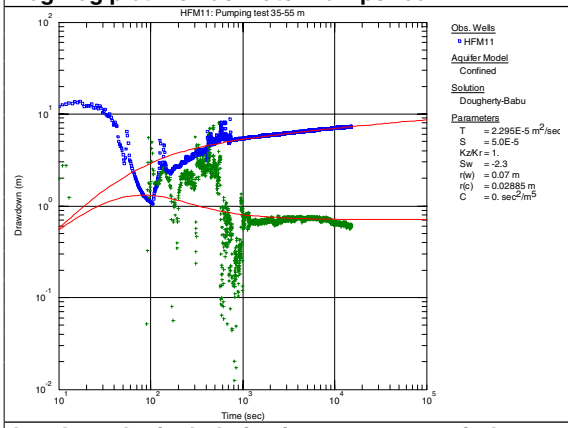
Test Summary Sheet – Pumping section HFM11:35–55 m

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM11	Test start:	20031028
Test section (m):	35–55	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

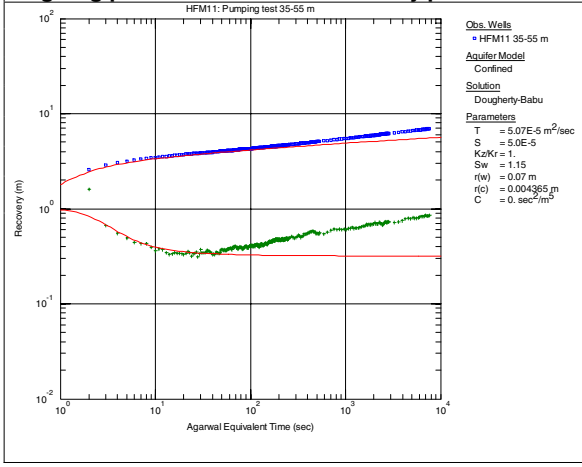
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	310		
p_p(kPa)	238.4	p_F (kPa)	310.2
Q_p (m^3/s)	$2.03 \cdot 10^{-4}$		
tp (min)	249.8	t_F (min)	
S*	$5.0 \cdot 10^{-5}$	S*	$5.0 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.	0.3	Derivative fact.	
Results		**Results**	
Q/s (m^2/s)	$2.78 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$2.64 \cdot 10^{-5}$		
Flow regime:	PRF	Flow regime:	
t_1 (min)	1,500	dt_{e1} (min)	
t_2 (min)	8,000	dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)	–2.3	ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

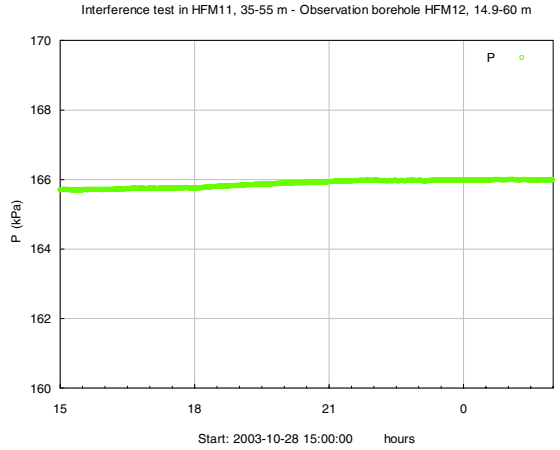
Interpreted formation and well parameters.

Flow regime:	PRF	C (m^3/Pa)	
t_1 (min)	1,500	C_D (–)	
t_2 (min)	8,000	ξ (–)	–2.3
T_T (m^2/s)	$2.30 \cdot 10^{-5}$		
S (–)			
K_s (m/s)			
S_s (1/m)			

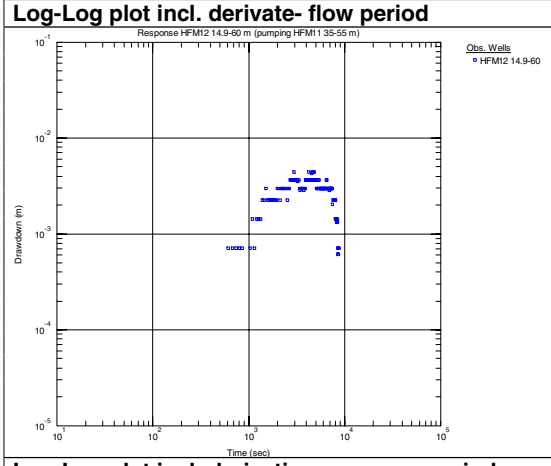
Comments: Air in the pump hose lead to initial problems in flow regulation and descicion of appropriate constant flow rate. Flow equal to final flow after c 7 min.

Test Summary Sheet – Observation section HFM12:14.9–60 m (while pumping in HFM11:35–55 m)			
Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031028
Test section (m):	14.9–60	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

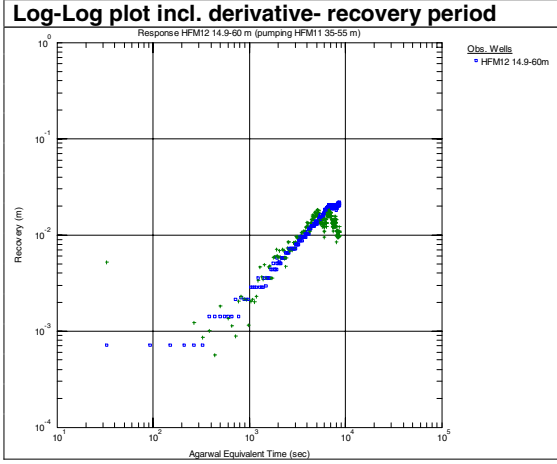
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	165.7		
p_p(kPa)	165.8	p_F (kPa)	166.1
Q_p (m^3/s)			
tp (min)		t_F (min)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

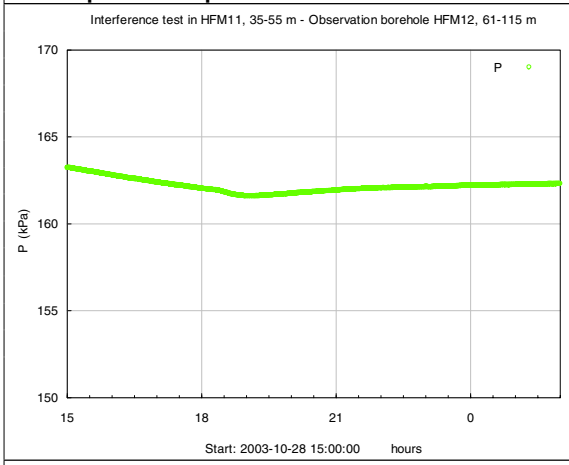
Interpreted formation and well parameters.

Flow regime:		C (m^3/Pa)	
t_1 (min)		C_D (–)	
t_2 (min)		ξ (–)	
T_T (m^2/s)			
S (–)			
K_s (m/s)			
S_s (1/m)			

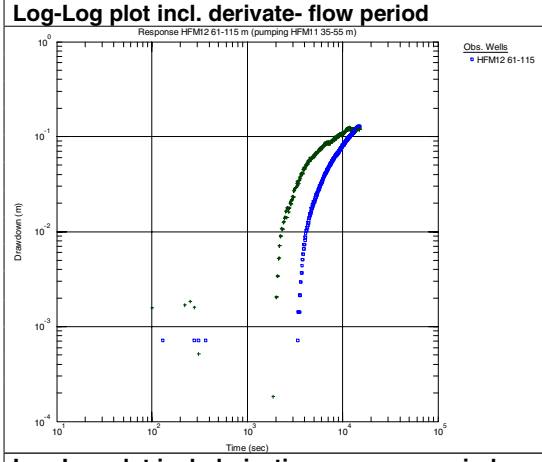
No significant pressure response.

Test Summary Sheet – Observation section HFM12:61 – 115 m (while pumping in HFM11:35–55 m)			
Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031028
Test section (m):	61–115	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

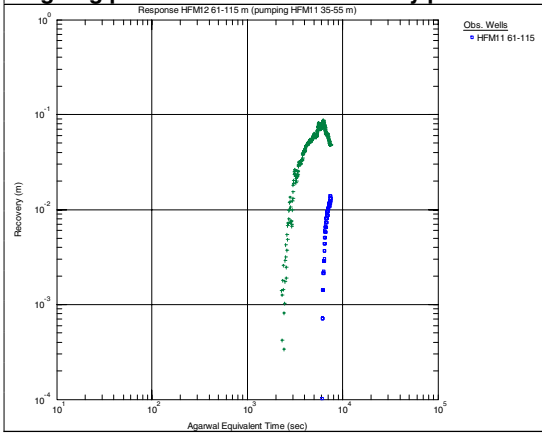
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	163.2		
p_p(kPa)	162.0	p_F (kPa)	162.8
Q_p (m^3/s)			
tp (min)		t_F (s)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

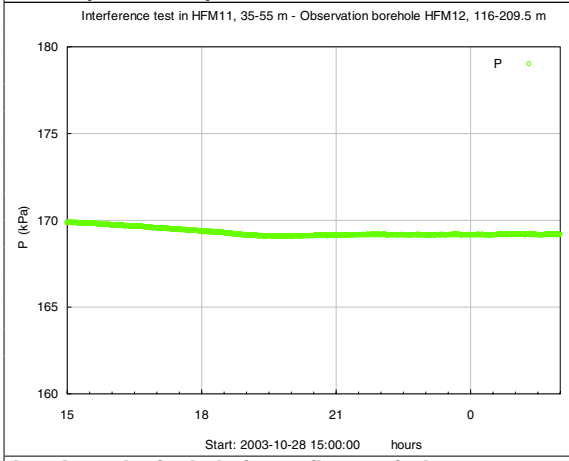
Interpreted formation and well parameters.

Flow regime:		C (m^3/Pa)	
t_1 (min)		C_D (–)	
t_2 (min)		ξ (–)	
T_T (m^2/s)			
S (–)			
K_s (m/s)			
S_s (1/m)			

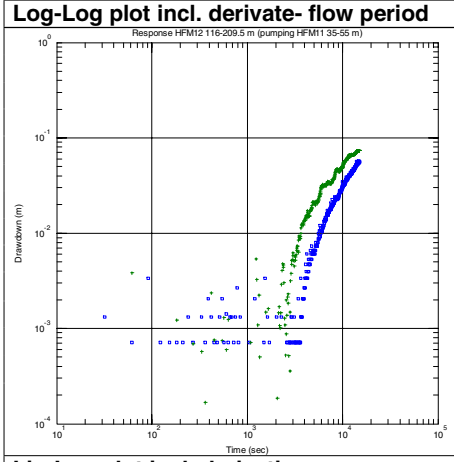
Weak response.
No transient interpretation.

Test Summary Sheet – Observation section HFM12:116 – 209.5 m (while pumping in HFM11:35–55 m)			
Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031028
Test section (m):	61–115	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

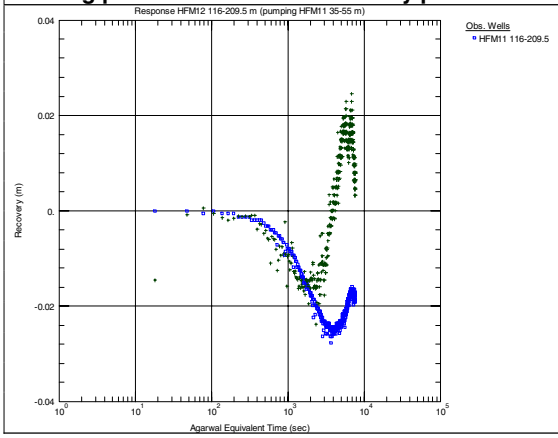
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Lin-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	169.9		
p_p(kPa)	169.3	p_F (kPa)	169.5
Q_p (m^3/s)			
tp (min)		t_F (s)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

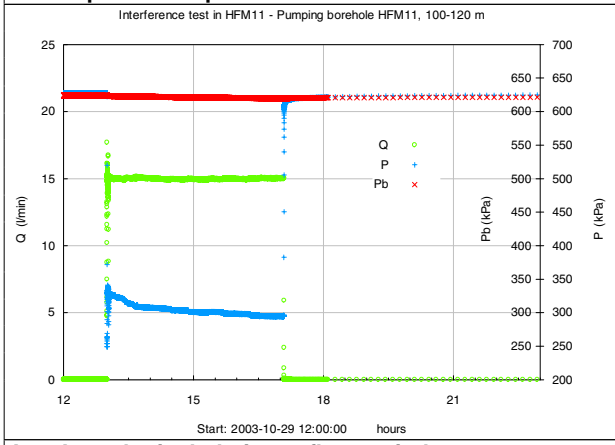
Interpreted formation and well parameters.			
Flow regime:		C (m^3/Pa)	
t_1 (min)		C_D (–)	
t_2 (min)		ξ (–)	
T_T (m^2/s)			
S (–)			
K_s (m/s)			
S_s (1/m)			

No significant response.
Lin log plot of recovery period due to "negative" recovery, i.e. decreasing pressure in observation section after pump stop.

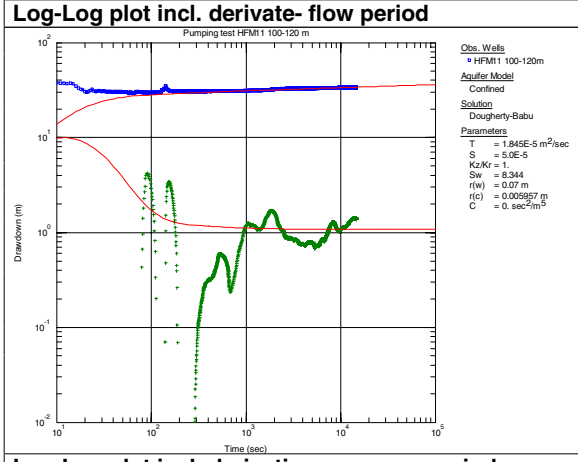
Test Summary Sheet – Pumping section HFM11:100–120 m

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM11	Test start:	20031029
Test section (m):	100–120	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

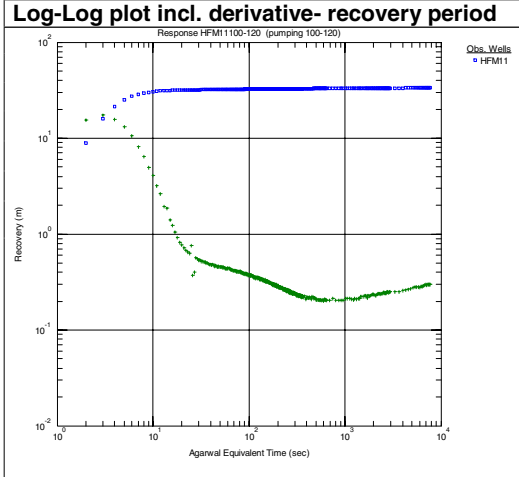
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	627.2		
p_p(kPa)	294.5	p_F (kPa)	622.7
Q_p (m^3/s)	$2.50\cdot10^{-4}$		
tp (min)	245.2	t_F (min)	1079.8
S*	$5.0\cdot10^{-5}$	S*	$5.0\cdot10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)	$7.37\cdot10^{-6}$		
T_{Moye}(m^2/s)	$6.99\cdot10^{-6}$		
Flow regime:	PRF/PSF	Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

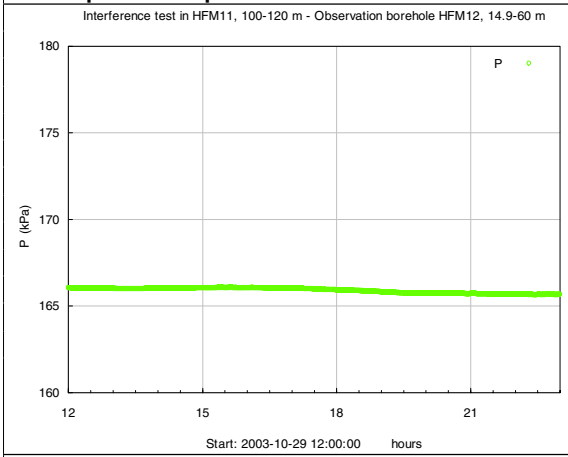
Interpreted formation and well parameters.

Flow regime:	PRF/PSF	C (m^3/Pa)	
t_1 (min)	41.7	C_D (–)	
t_2 (min)	233.3	ξ (–)	8.3
T_T (m^2/s)	$1.85\cdot10^{-5}$		
S (–)			
K_s (m/s)			
S_s (1/m)			

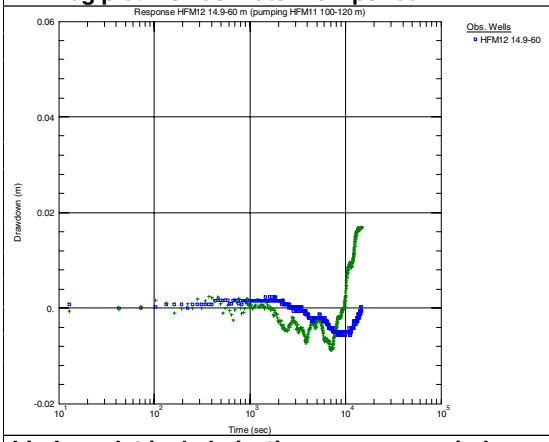
Comments:

Test Summary Sheet – Observation section HFM12:14.9–60 m (while pumping in HFM11:100–120 m)			
Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031029
Test section (m):	14.9–60	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

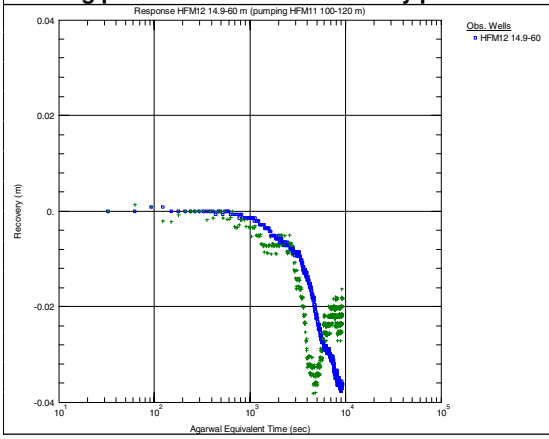
Linear plot Q and p



Lin-Log plot incl. derivate- flow period



Lin-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	166.1		
p_p(kPa)	166.0	p_F (kPa)	165.9
Q_p (m^3/s)			
tp (min)		t_F (s)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

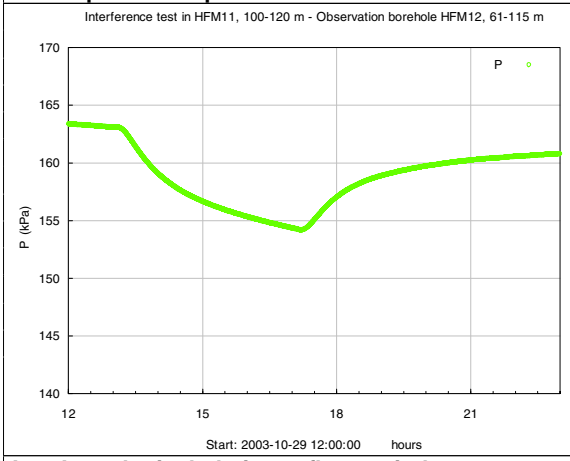
Interpreted formation and well parameters.			
Flow regime:		C (m^3/Pa)	
t_1 (min)		C_D (–)	
t_2 (min)		ξ (–)	
T_T (m^2/s)			
S (–)			
K_s (m/s)			
S_s (1/m)			

No significant response.
Lin-log plot of drawdown and recovery period due to negative values, i.e. increasing pressure during pumping and decreasing pressure in observation section after pump stop.

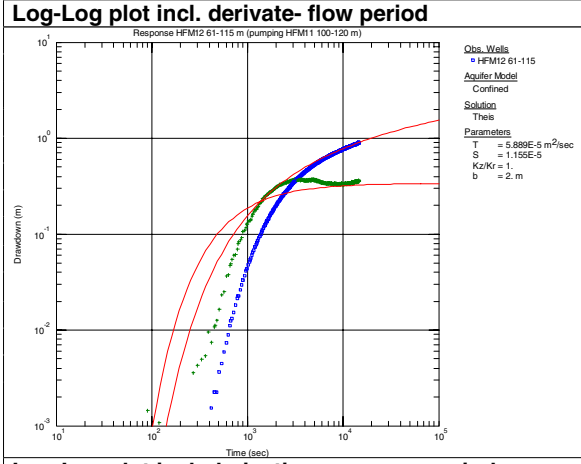
Test Summary Sheet – Observation section HFM12:61–115m (while pumping in HFM11:100–120 m)

Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031029
Test section (m):	61–115	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

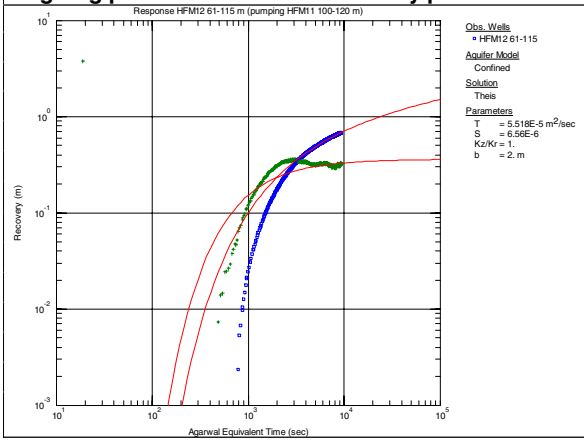
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	163.1		
p_p(kPa)	154.3	p_F (kPa)	162.2
Q_p (m^3/s)			
tp (min)		t_F (s)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

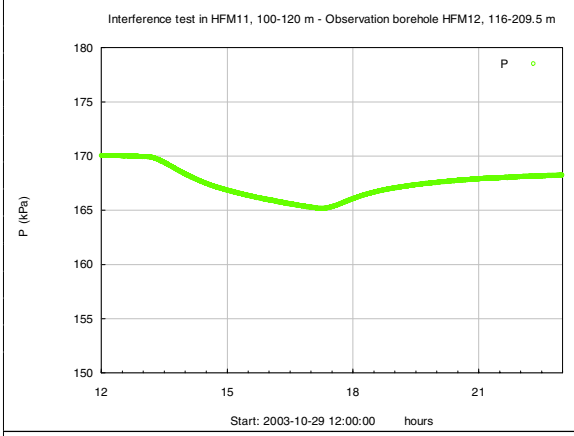
Interpreted formation and well parameters.

Flow regime:		C (m^3/Pa)	
t_1 (min)	100	C_D (–)	
t_2 (min)	183.3	ξ (–)	
T_T (m^2/s)	$5.88 \cdot 10^{-5}$		
S (–)	$1.16 \cdot 10^{-5}$		
K_s (m/s)			
S_s (1/m)			

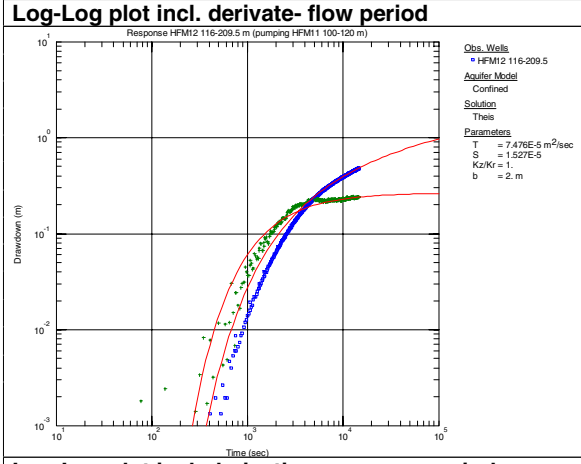
uncertainty larger than normal due to u>0.01 in Cooper-Jacob solution.

Test Summary Sheet – Observation section HFM12:116–209.5 m (while pumping in HFM11:100–120 m)			
Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031029
Test section (m):	61–115	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

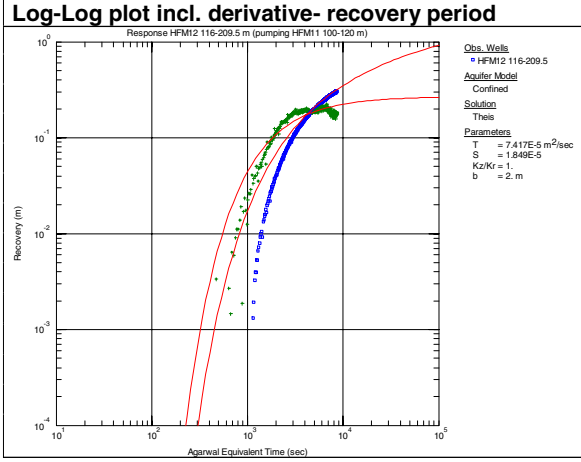
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	169.9		
p_p(kPa)	165.2	p_F (kPa)	169.4
Q_p (m^3/s)			
tp (min)		t_F (s)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters.

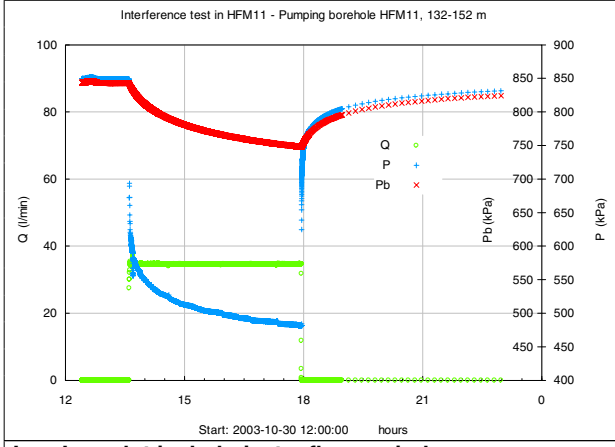
Flow regime:		C (m^3/Pa)	
t_1 (min)	83.3	C_D (–)	
t_2 (min)	150	ξ (–)	
T_T (m^2/s)	$8.94 \cdot 10^{-5}$		
S (–)	$2.85 \cdot 10^{-5}$		
K_s (m/s)			
S_s (1/m)			

uncertainty larger than normal due to u>0.01 in Cooper-Jacob solution.

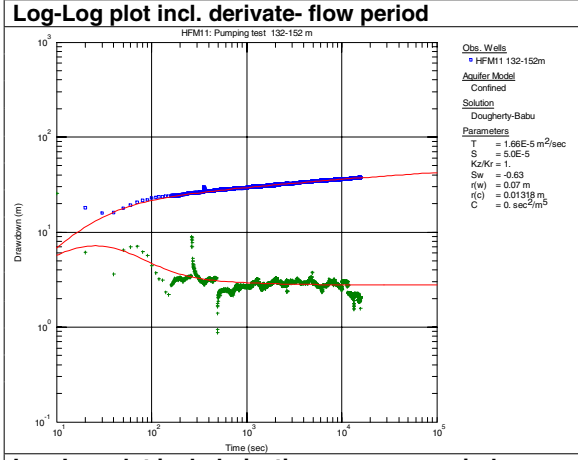
Test Summary Sheet – Pumping section HFM11:132–152 m

Project:	PLU	Test type:	1B
Area:	Forsmark	Test no:	1
Borehole ID:	HFM11	Test start:	20031030
Test section (m):	132–152	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

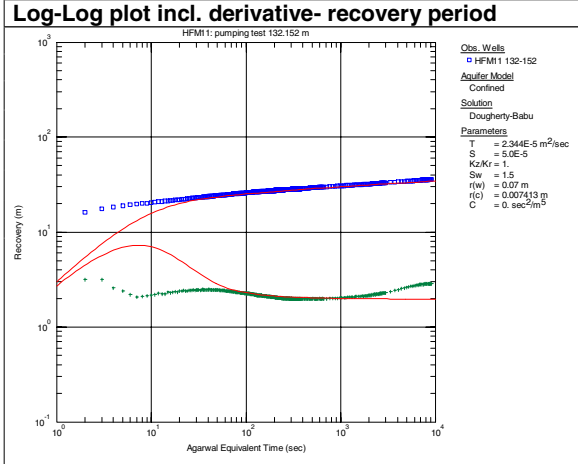
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	848.6		
p_p(kPa)	481.6	p_F (kPa)	845.3
Q_p (m^3/s)	$5.77 \cdot 10^{-4}$		
tp (min)	260.9	t_F (min)	938.0
S*	$5.0 \cdot 10^{-5}$	S*	$5.0 \cdot 10^{-5}$
EC_w (mS/m)			
Te_w(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)	$1.54 \cdot 10^{-5}$		
T_{Moye}(m^2/s)	$1.46 \cdot 10^{-5}$		
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

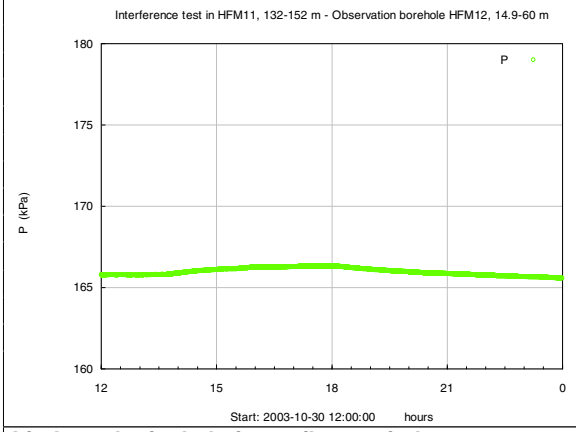
Interpreted formation and well parameters.

Flow regime:	PRF	C (m^3/Pa)	
t_1 (min)	16.7	C_D (–)	
t_2 (min)	166.7	ξ (–)	–0.63
T_T (m^2/s)	$1.66 \cdot 10^{-5}$		
S (–)			
K_s (m/s)			
S_s (1/m)			

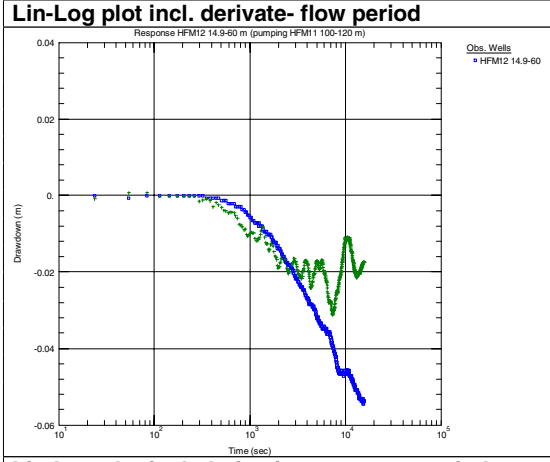
Comments:

Test Summary Sheet – Observation section HFM12:14.9–60 m (while pumping in HFM11:132–152 m)			
Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031030
Test section (m):	14.9–60	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

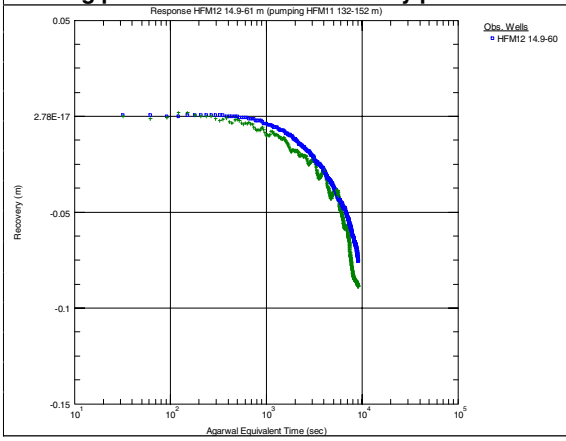
Linear plot Q and p



Lin-Log plot incl. derivate- flow period



Lin-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	165.8		
p_p(kPa)	166.3	p_F (kPa)	165.5
Q_p (m^3/s)			
tp (min)		t_F (s)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

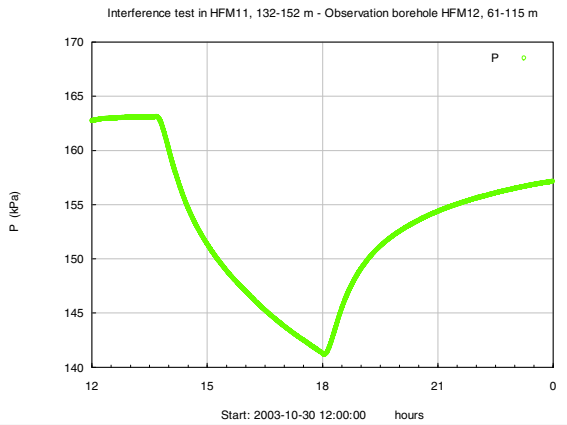
Interpreted formation and well parameters.

Flow regime:		C (m^3/Pa)	
t_1 (min)		C_D (–)	
t_2 (min)		ξ (–)	
T_T (m^2/s)			
S (–)			
K_s (m/s)			
S_s (1/m)			

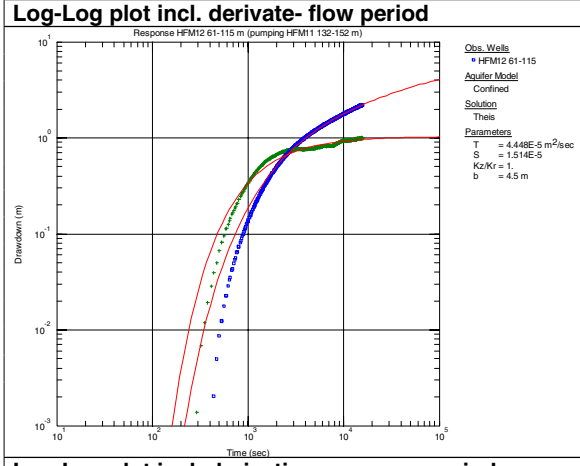
No significant response.
Lin-log plot of drawdown and recovery period due to negative values, i.e. increasing pressure during pumping and decreasing pressure in observation section after pump stop.

Test Summary Sheet – Observation section HFM12:61–115 m (while pumping in HFM11:132–152 m)			
Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031030
Test section (m):	61–115	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

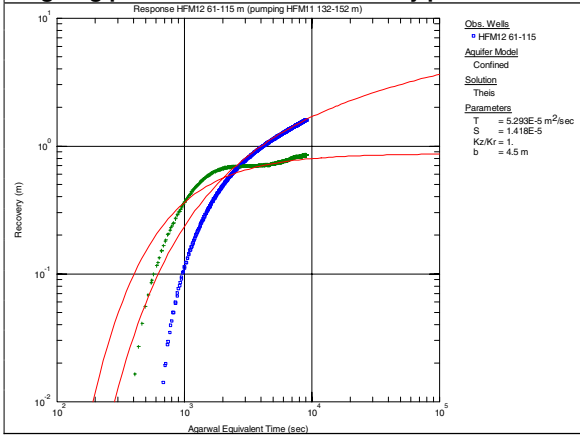
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	163.1		
p_p(kPa)	141.4	p_F (kPa)	160.4
Q_p (m^3/s)			
tp (min)		t_F (s)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters.

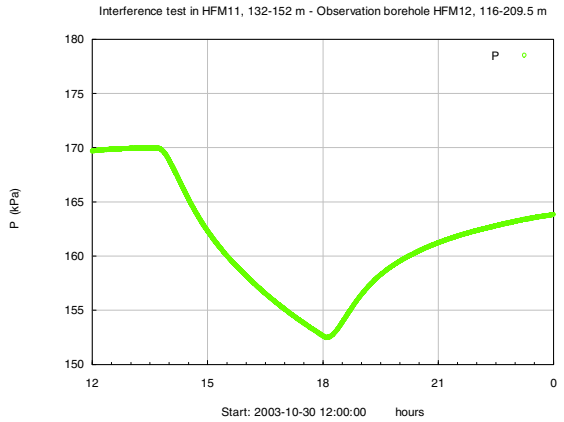
Flow regime:		C (m^3/Pa)	
t_1 (min)	50.0	C_D (–)	
t_2 (min)	83.3	ξ (–)	
T_T (m^2/s)	$5.9 \cdot 10^{-5}$		
S (–)	$1{,}13 \cdot 10^{-5}$		
K_s (m/s)			
S_s (1/m)			

Uncertainty larger than normal due to u > 0.01 in Cooper-Jacob solution.

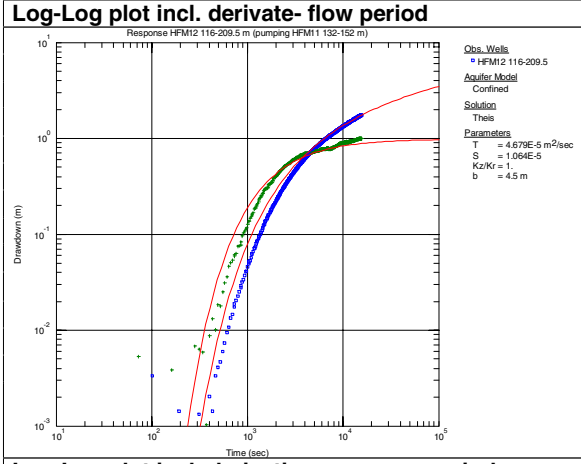
Test Summary Sheet – Observation section HFM12:116–209.5 m (while pumping in HFM11:132–152 m)

Project:	PLU	Test type:	2
Area:	Forsmark	Test no:	1
Borehole ID:	HFM12	Test start:	20031030
Test section (m):	116–209.5	Responsible for test performance:	GEOSIGMA AB Tomas Svensson
Section diameter, 2·rw (m):	0.140 (nominal)	Responsible for test evaluation:	GEOSIGMA AB J-E Ludvigson

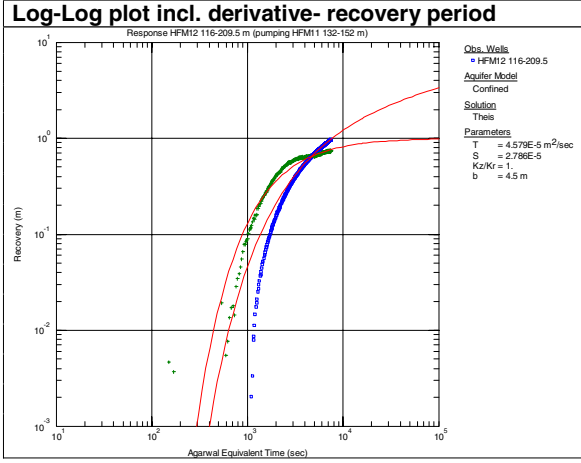
Linear plot Q and p



Log-Log plot incl. derivate- flow period



Log-Log plot incl. derivative- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa)			
p_i (kPa)	170.0		
p_p(kPa)	152.7	p_F (kPa)	166.4
Q_p (m^3/s)			
tp (min)		t_F(min)	
S*		S*	
Ecw (mS/m)			
Tew(gr C)			
Derivative fact.		Derivative fact.	
Results		**Results**	
Q/s (m^2/s)			
T_{Moye}(m^2/s)			
Flow regime:		Flow regime:	
t_1 (min)		dt_{e1} (min)	
t_2 (min)		dt_{e2} (min)	
T_w (m^2/s)		T_w (m^2/s)	
S_w (–)		S_w (–)	
K_{sw} (m/s)		K_{sw} (m/s)	
S_{sw} (1/m)		S_{sw} (1/m)	
C (m^3/Pa)		C (m^3/Pa)	
C_D (–)		C_D (–)	
ξ (–)		ξ (–)	
T_{GRF}(m^2/s)		T_{GRF}(m^2/s)	
S_{GRF}(–)		S_{GRF}(–)	
D_{GRF} (–)		D_{GRF} (–)	

Interpreted formation and well parameters.

Flow regime:		C (m^3/Pa)	
t_1 (min)		C_D (–)	
t_2 (min)		ξ (–)	
T_T (m^2/s)			
S (–)			
K_s (m/s)			
S_s (1/m)			

7 References

/1/ **Almén K-E et al. 1986.** Hydraulic testing in crystalline rock. A comparative study of single-hole test methods. SKB TR 86-27, Svensk Kärnbränslehantering AB.

List of test data files

Appendix 1

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, etc) after ”secup” to separate identical names. XX can be one of five alternatives: Ref_Da containing constants of calibration and background data, FlowLo containing data from pumping test in combination with flow logging. Spinne contains data from spinner measurements; Inject contains data from injection test and Pumpin from pumping tests (no combined flow logging).

Bh ID	Test section (m)	Test type[1]	Test no	Test start Date, time YYYY-MM-DD tt:mm:ss	Test stop Date, time YYYY-MM-DD tt:mm:ss	Datafile, start Date, time YYYY-MM-DD tt:mm:ss	Datafile, stop Date, time YYYY-MM-DD tt:mm:ss	Data files of raw and primary data	Content (parame-ters)2	Comments
HFM11	35–55	1B		2003-10-28 13:32:00	2003-10-29 09:13:00	2003-10-28 11:55:35	2003-10-29 09:13:06	HFM11_035_031028_Pumpin00.DAT	P, Q	Pressure registration in HFM12 for interference / TSv
HFM11						2003-09-29 22:19:10	2003-10-29 09:13:13	HFM11_035_031028_Ref_Da00.DAT		
HFM11	100–120	1B		2003-10-29 11:37:04	2003-10-30 11:05:02	2003-10-28 11:55:35	2003-10-30 11:14:58	HFM11_100_031029_Pumpin00.DAT	P, Q	Pressure registration in HFM12 for interference / TSv
HFM11						2003-09-29 22:19:10	2003-10-30 11:15:06	HFM11_100_031029_Ref_Da00.DAT		
HFM11	132–152	1B		2003-10-30 12:25:10	2003-10-31 09:35:00	2003-10-30 12:25:10	2003-10-31 09:35:00	HFM11_132_031030_Pumpin00.DAT	P, Q	Pressure registration in HFM12 for interference / TSv
HFM11						2003-09-29 22:19:10	2003-10-31 09:35:08	HFM11_132_031030_Ref_Da00.DAT		
HFM12	14.9–60	2		2003-10-28 13:50:00	2003-10-29 08:34:00	2003-10-28 13:47:00	2003-10-29 08:48:00	HFM12_000_031028_interference.DAT	P	Response to pumping HFM11 35–55 m/TSv
HFM12	61–115	2		2003-10-28 13:50:00	2003-10-29 08:34:00	2003-10-28 13:52:23	2003-10-29 08:34:23	HFM12_061_031028_interference.DAT	P	Response to pumping HFM11 35–55 m/TSv
HFM12	116–195	2		2003-10-28 13:50:00	2003-10-29 08:34:00	2003-10-28 13:49:45	2003-10-29 08:40:15	HFM12_116_031028_interference.DAT	P	Response to pumping HFM11 35–55 m/TSv
HFM12	14.9–60	2		2003-10-29 11:37:04	2003-10-30 11:03:00	2003-10-29 08:49:17	2003-10-30 10:03:47	HFM12_000_031029_interference.DAT	P	Response to pumping HFM11 100–120 m/TSv
HFM12	61–115	2		2003-10-29 11:37:04	2003-10-30 11:03:00	2003-10-29 08:35:58	2003-10-30 10:47:58	HFM12_061_031029_interference.DAT	P	Response to pumping HFM11 100–120 m/TSv
HFM12	116–195	2		2003-10-29 11:37:04	2003-10-30 11:03:00	2003-10-29 08:42:52	2003-10-30 10:43:52	HFM12_116_031029_interference.DAT	P	Response to pumping HFM11 100–120 m/TSv
HFM12	14.9–60	2		2003-10-30 12:25:10	2003-10-31 09:35:00	2003-10-30 10:09:05	2003-10-31 20:10:35	HFM12_000_031030_interference.DAT	P	Response to pumping HFM11 132-152 m/TSv
HFM12	61–115	2		2003-10-30 12:25:10	2003-10-31 09:35:00	2003-10-30 10:51:32	2003-10-31 20:15:02	HFM12_061_031030_interference.DAT	P	Response to pumping HFM11 132-152 m/TSv
HFM12	116–195	2		2003-10-30 12:25:10	2003-10-31 09:35:00	2003-10-30 10:45:23	2003-10-31 20:19:53	HFM12_116_031030_interference.DAT	P	Response to pumping HFM11 132-152 m/TSv

[1)] 1B: Pumping test-submersible pump, 2: Interference test (observation borehole during pumping in another borehole)

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

Appendix 2

Test diagrams

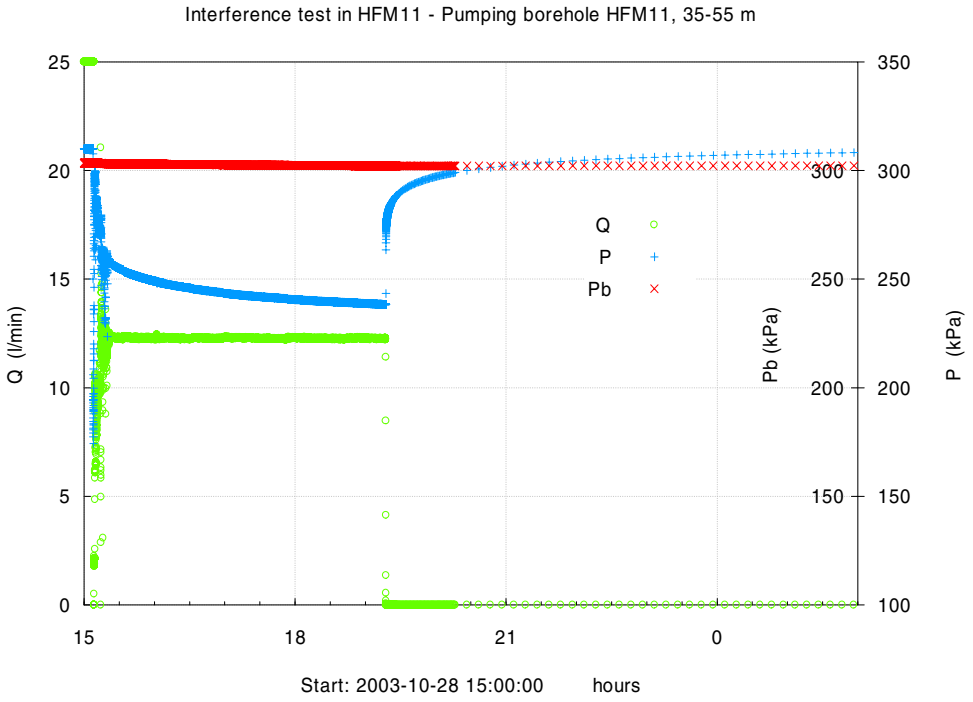


Figure A2:1-1. *Linear plot of flow rate (Q), pressure in test section (P) and pressure in section below test section (Pb) versus time in the pumping section HFM11: 35–55 m.*

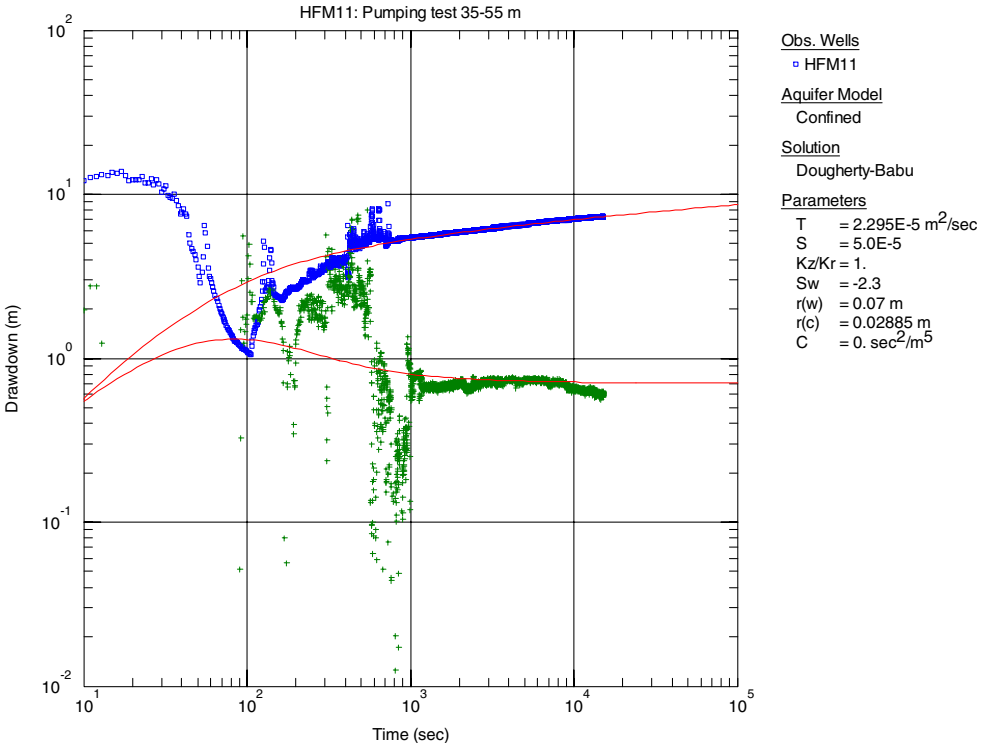


Figure A2:1-2. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time during pumping test in HFM11, section 35–55 m.*

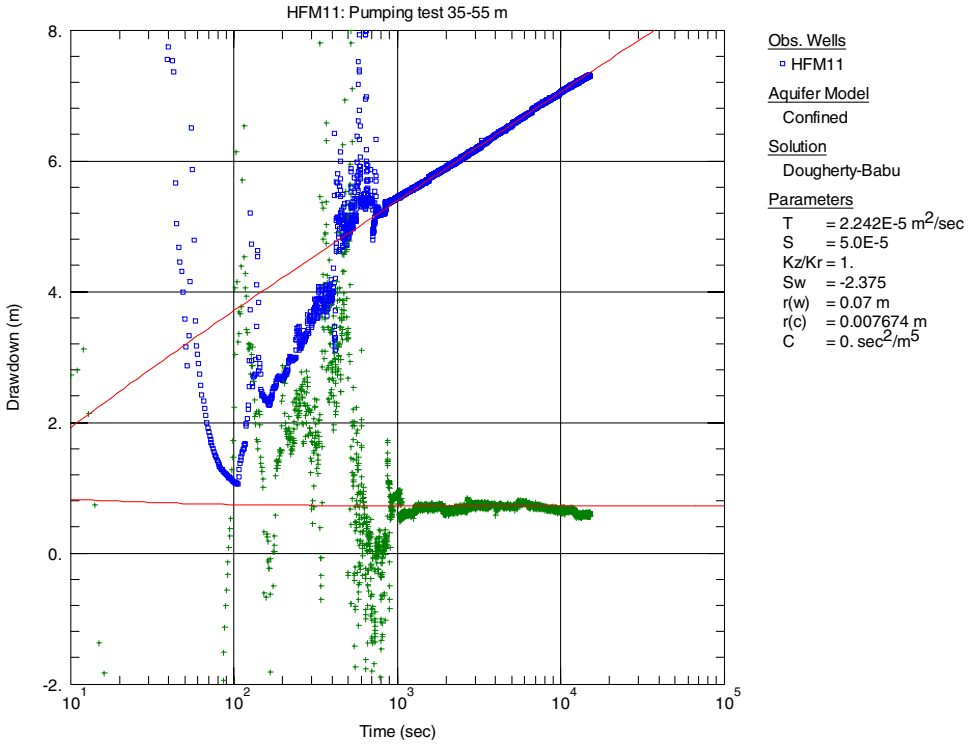


Figure A2:1-3. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time during the pumping test in HFM11, section 35–55 m.*

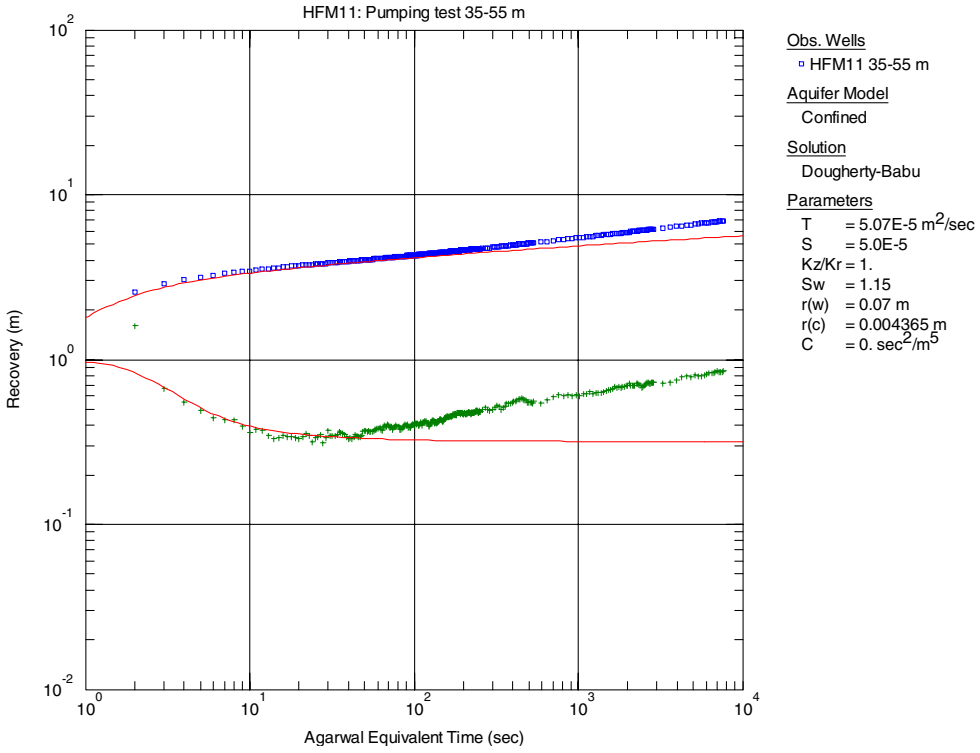


Figure A2:1-4. *Log-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in HFM11, section 35–55 m.*

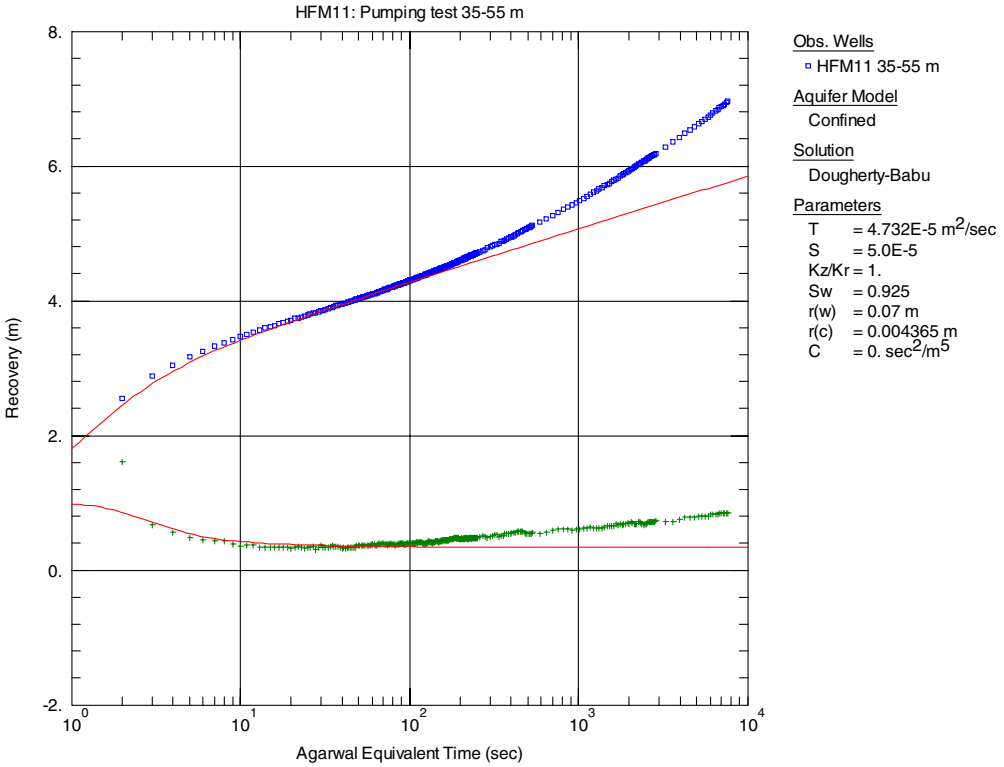


Figure A2:1-5. *Lin-log plot of pressure recovery (blue squares) and derivative of pressure recovery (green crosses) versus equivalent time in HFM11 section 35–55 m.*

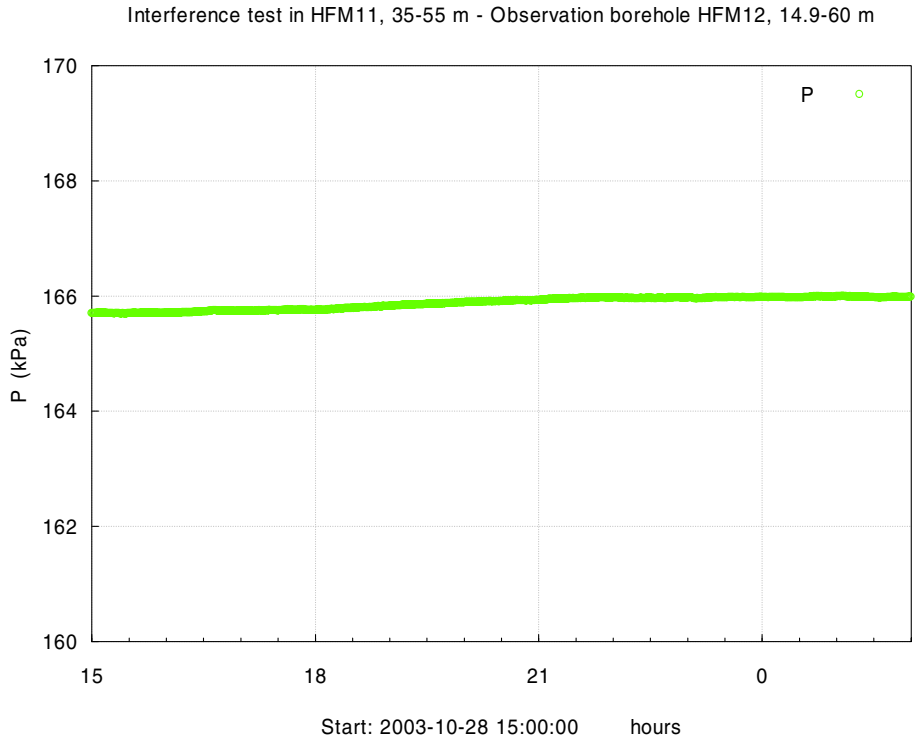


Figure A2:1-6. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 14.9–60 m, during pumping in HFM11, section 35–55 m.*

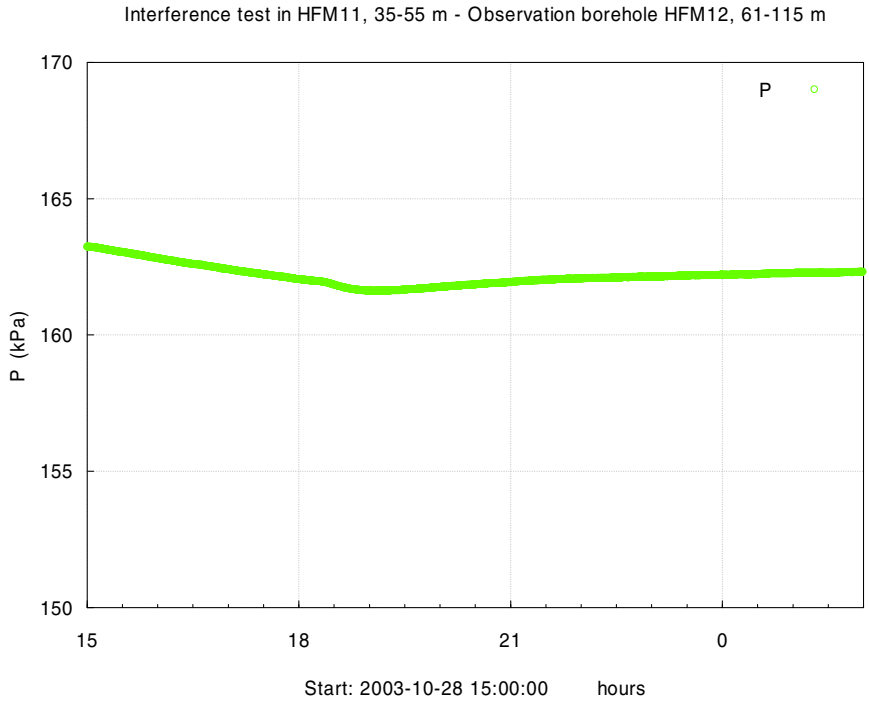


Figure A2:1-7. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 35–55 m.*

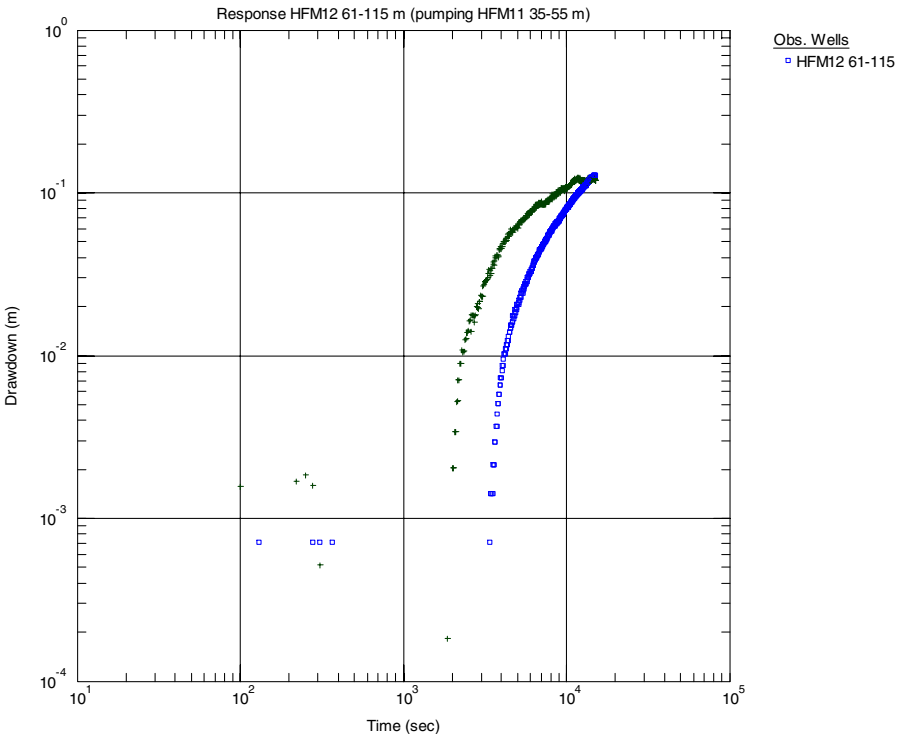


Figure A2:1-8. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 35–55 m.*

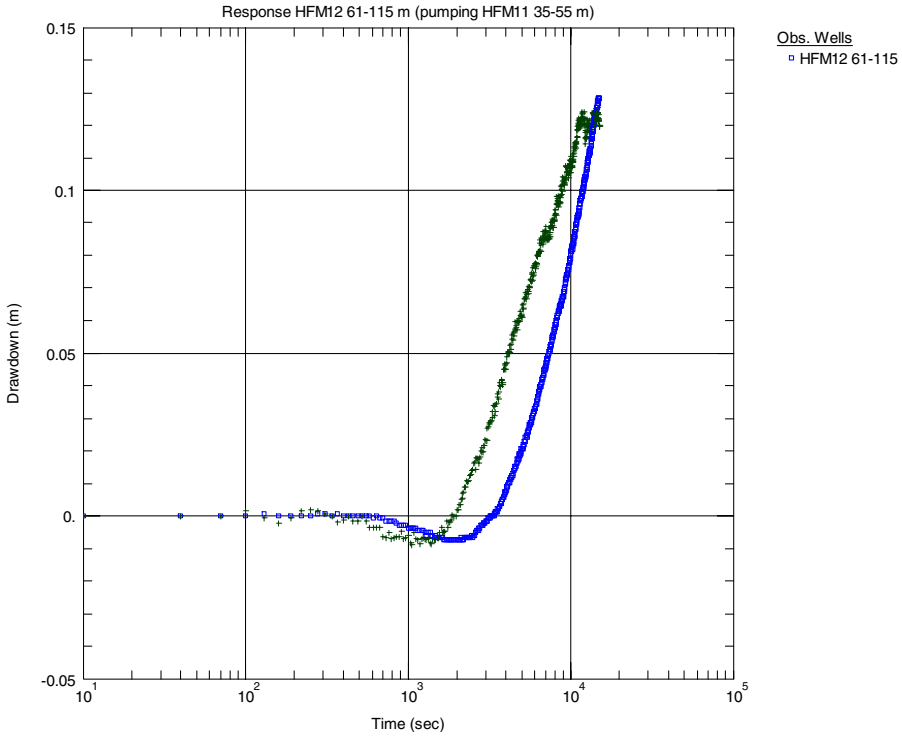


Figure A2:1-9. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 61–115, m during pumping in HFM11, section 35–55 m.*

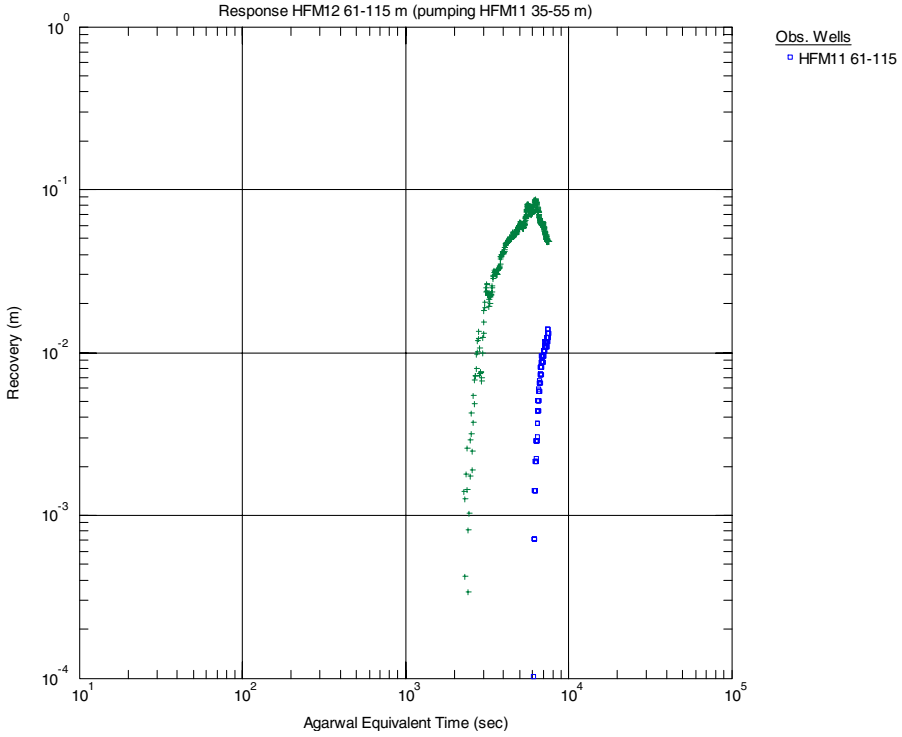


Figure A2:1-10. *Log-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 35–55 m.*

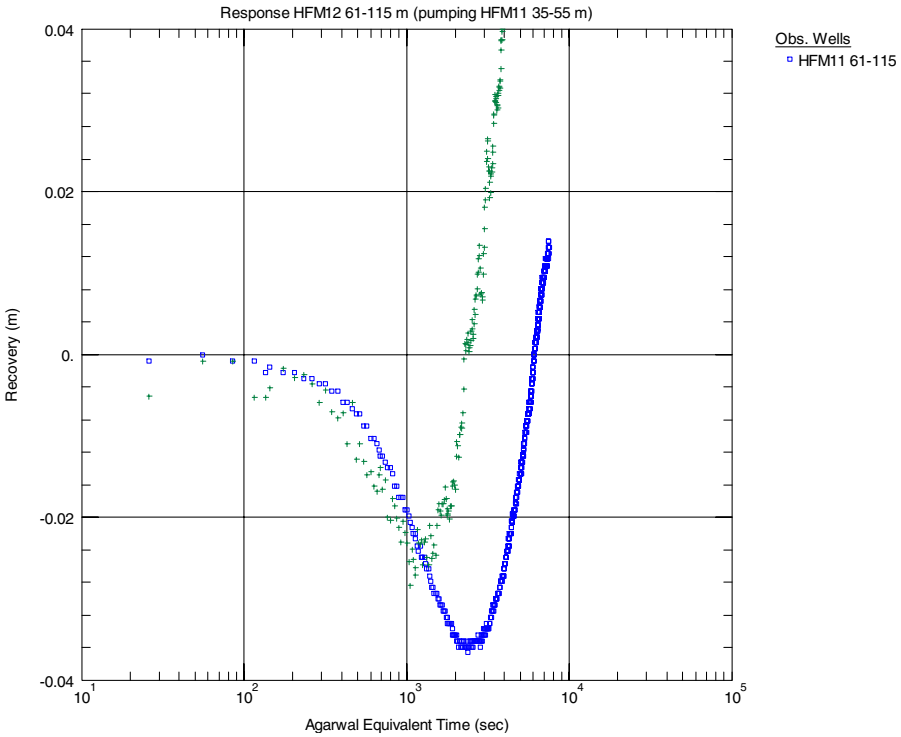


Figure A2:1-11. *Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 35–55 m.*

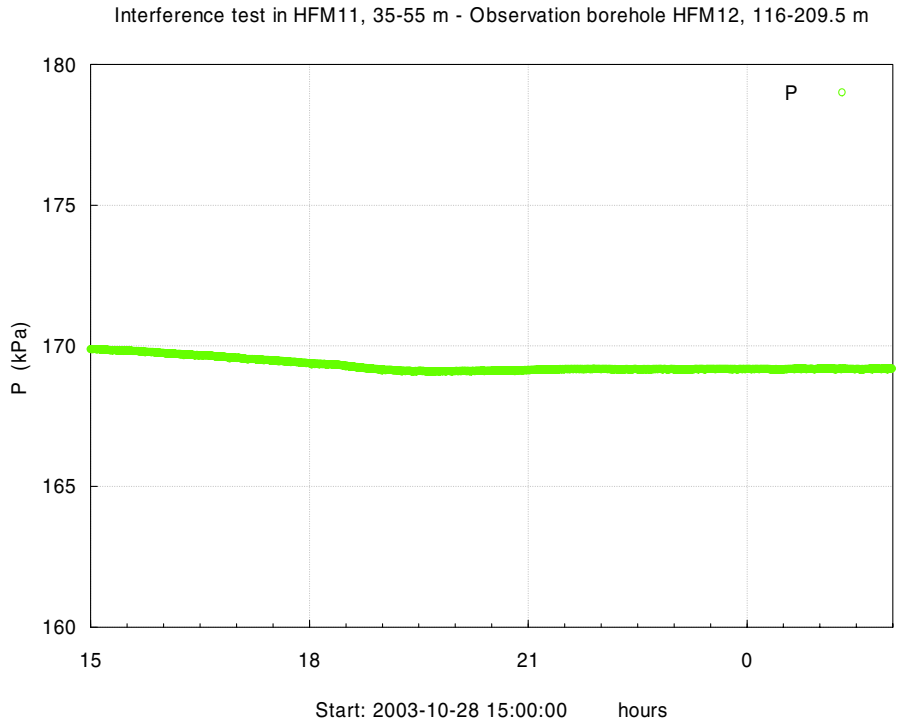


Figure A2:1-12. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 35–55 m.*

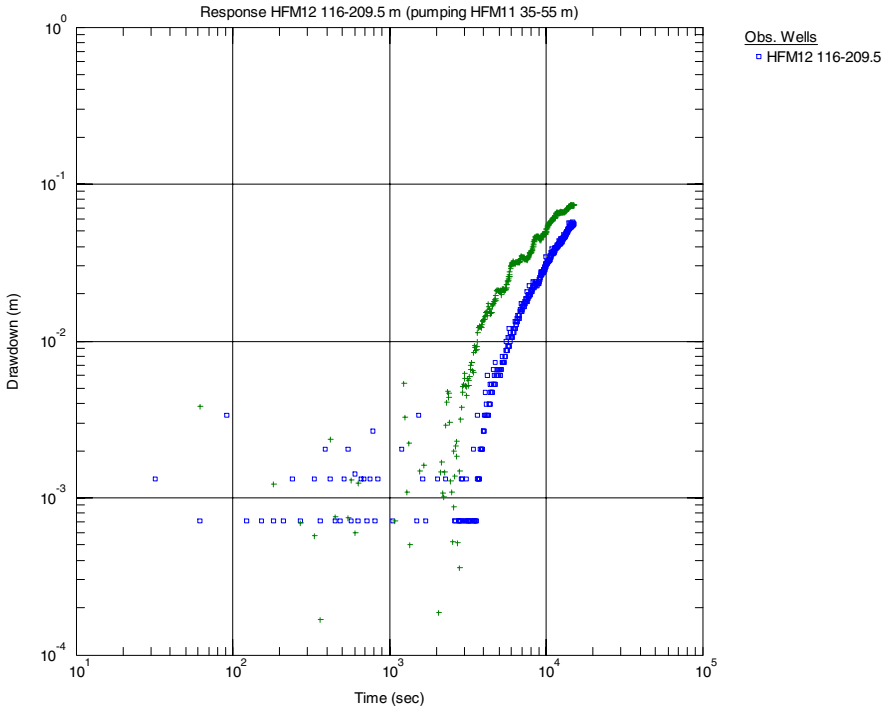


Figure A2:1-13. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 35–55 m.*

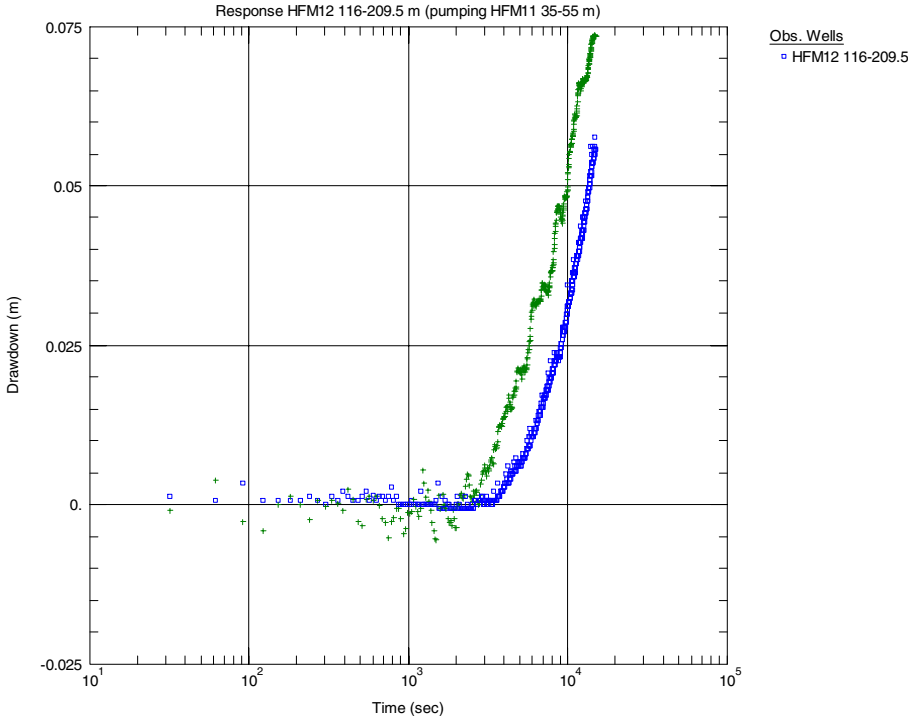


Figure A2:1-14. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 35–55 m.*

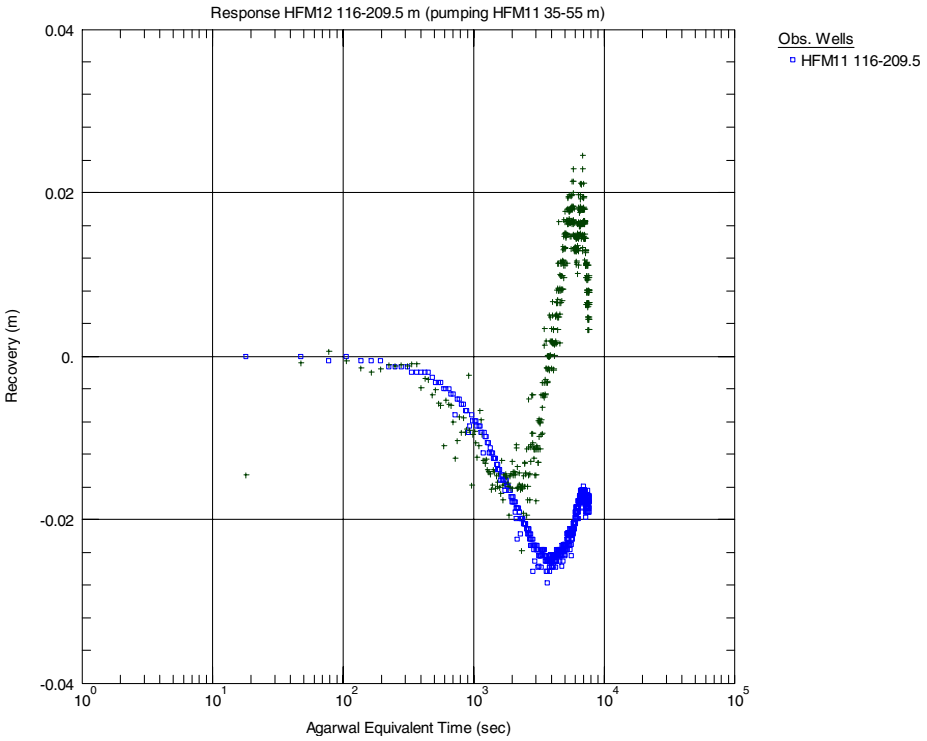


Figure A2:1-15. *Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 35–55 m.*

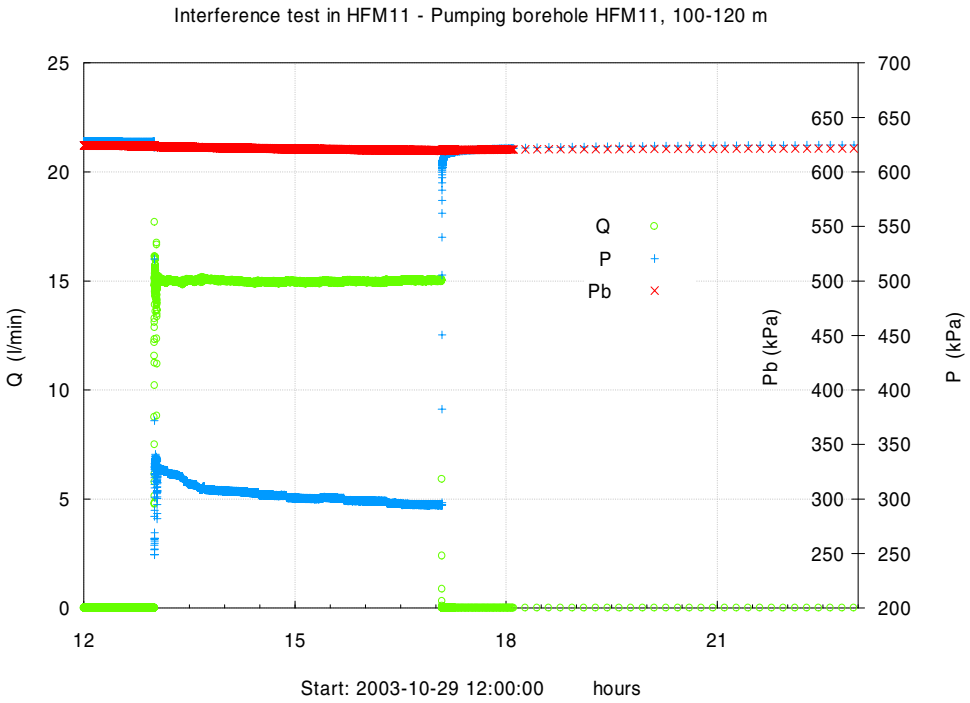


Figure A2:2-1. *Linear plot of flow rate (Q), pressure in test section (P) and pressure in section below test section (P_b) versus time in the pumping section HFM11: 100–120 m.*

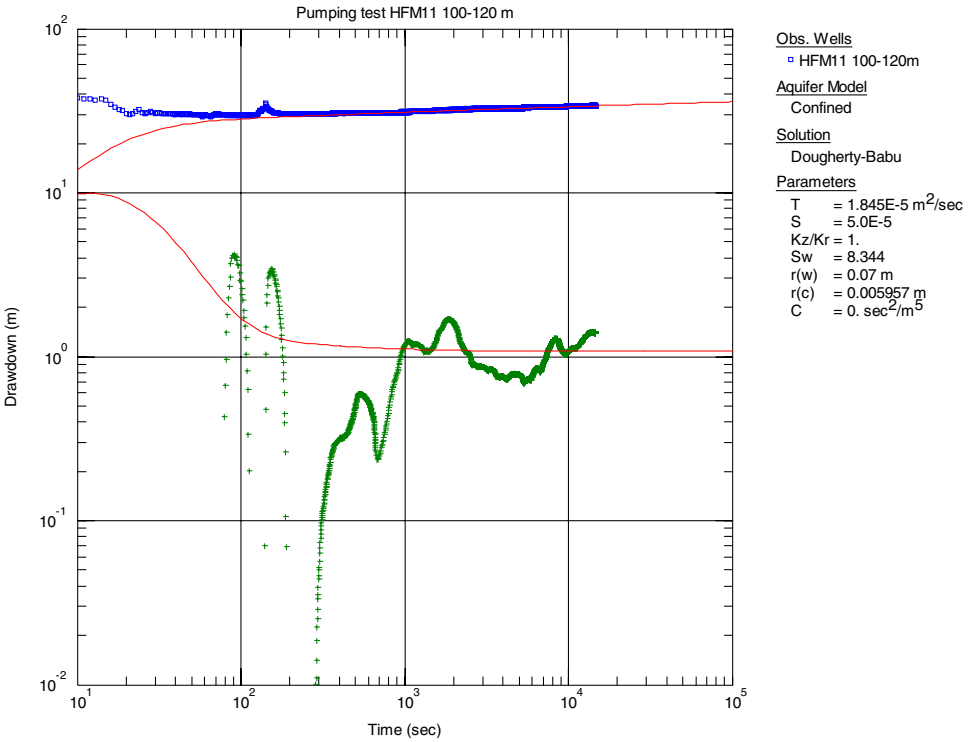


Figure A2:2-2.. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time during pumping test in HFM11, section 100–120 m.*

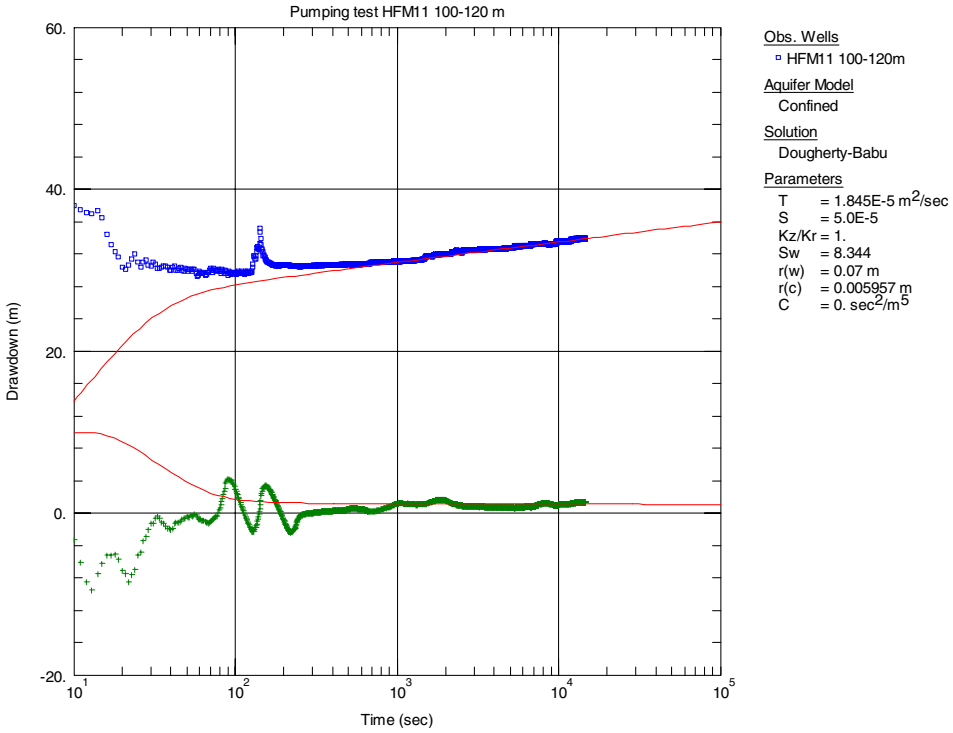


Figure A2:2-3. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time during pumping test in HFM11, section 100–120 m.*

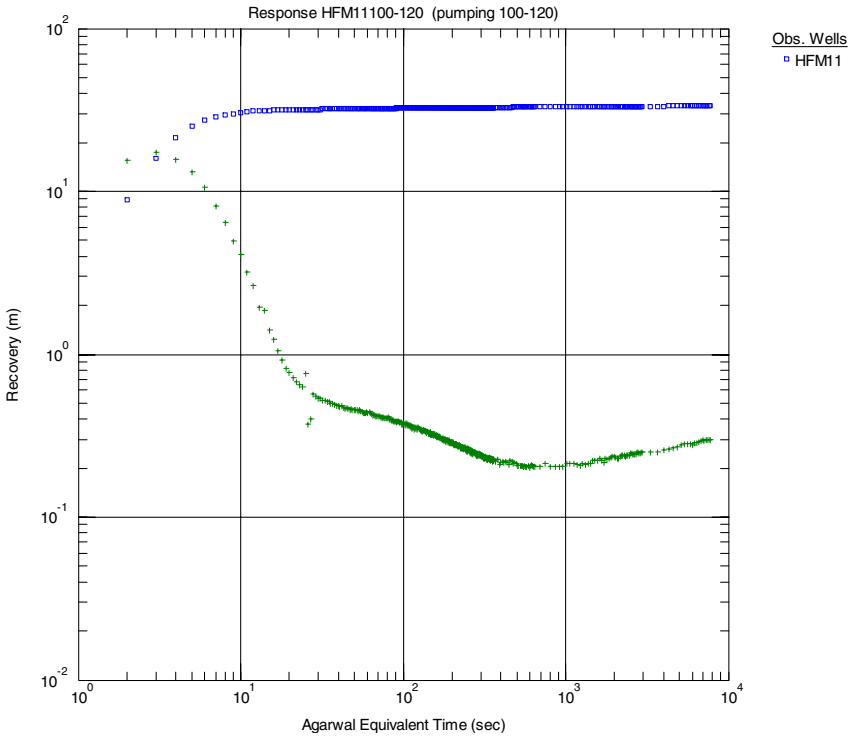


Figure A2:2-4. *Log-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time during pumping test in HFM11, section 100–120 m.*

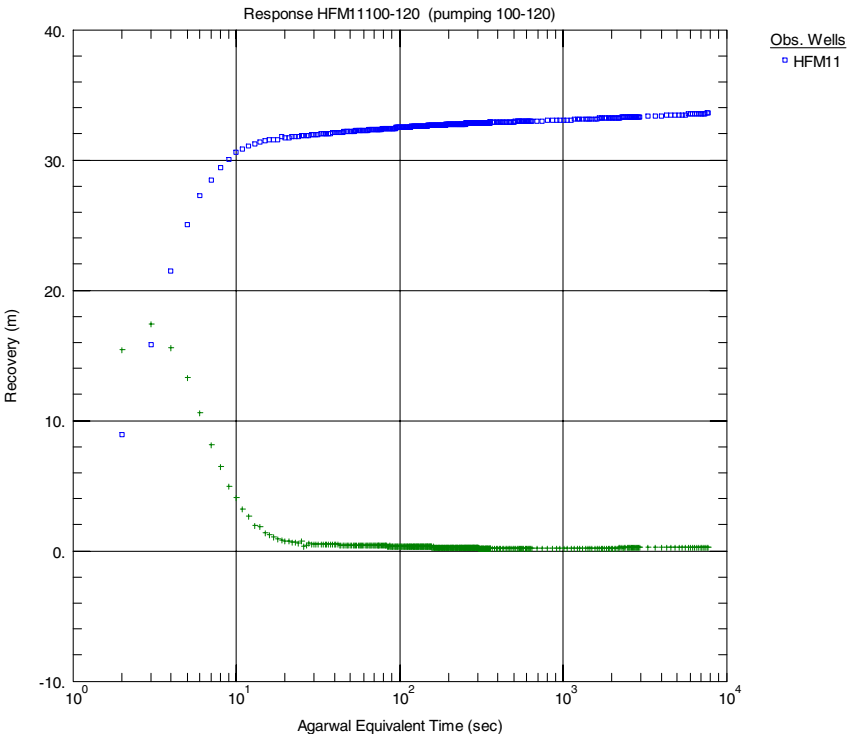


Figure A2:2-5. *Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time during pumping test in HFM11, section 100–120 m.*

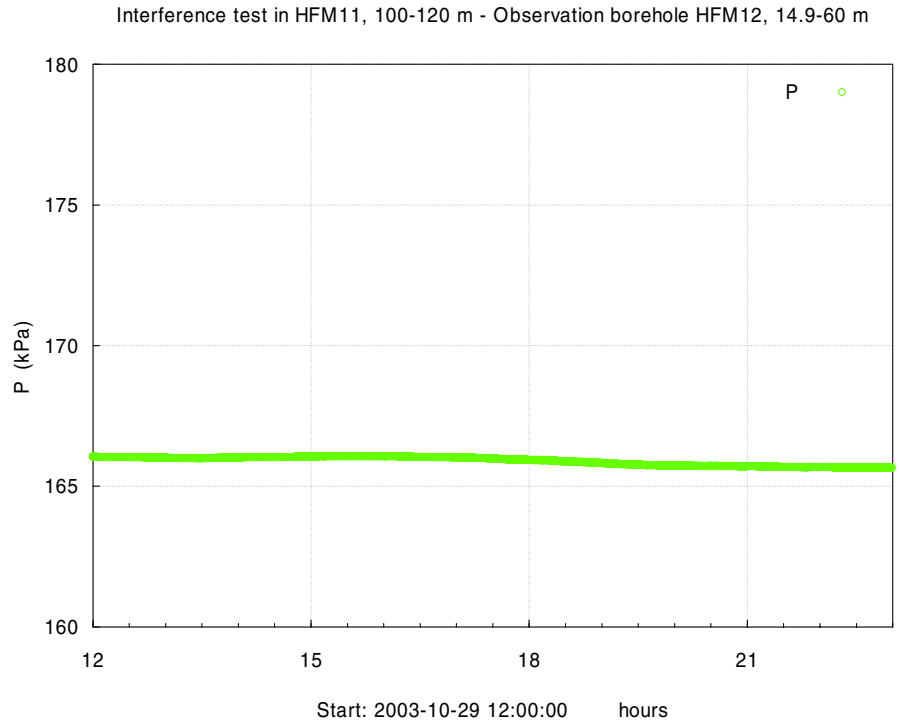


Figure A2:2-6. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 14.9–60 m, during pumping in HFM11, section 100–120 m.*

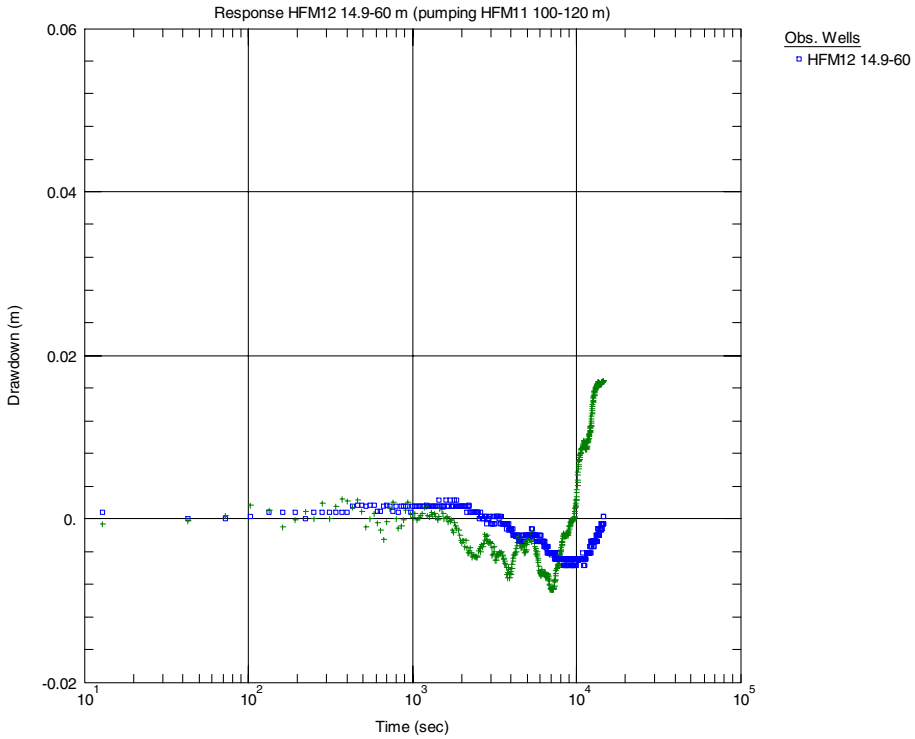


Figure A2:2-7. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 14.9–60 m, during pumping in HFM11, section 100–120 m.*

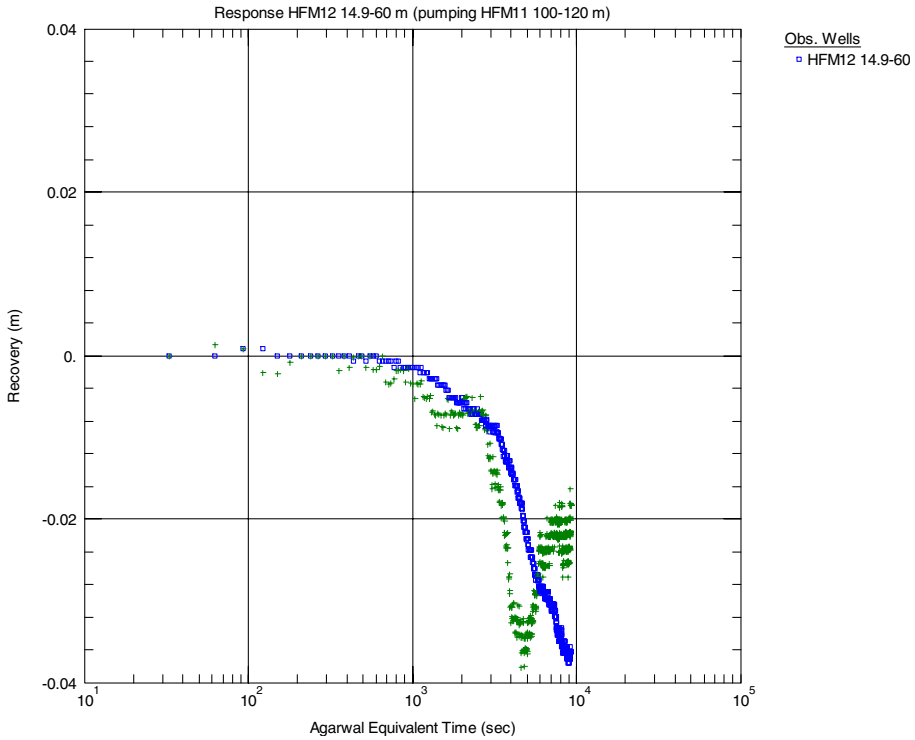


Figure A2:2-8*. Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 14.9–60 m, during pumping in HFM11, section 100–120 m.*

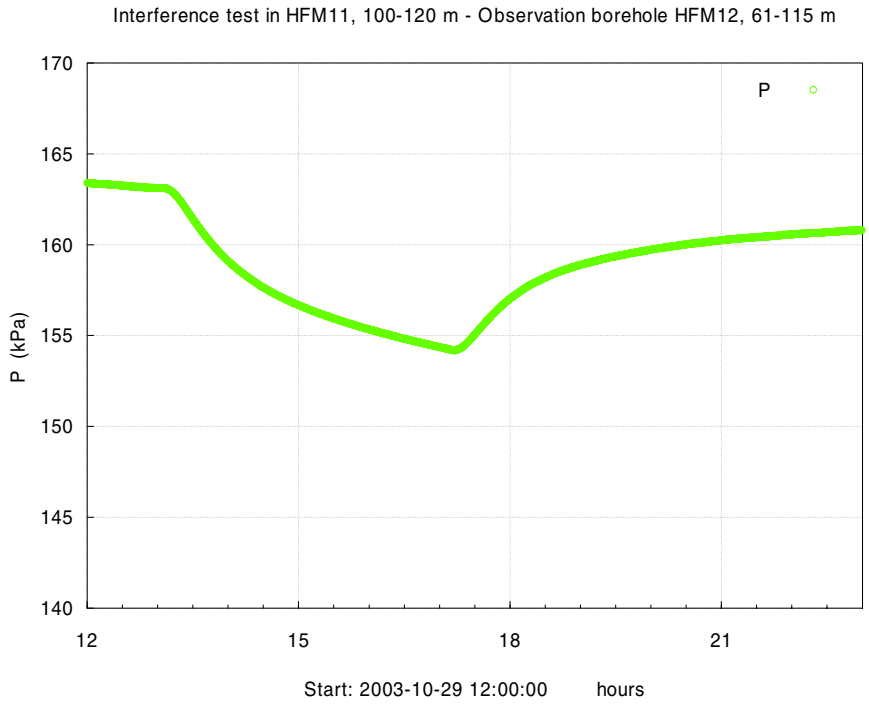


Figure A2:2-9. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 100–120 m.*

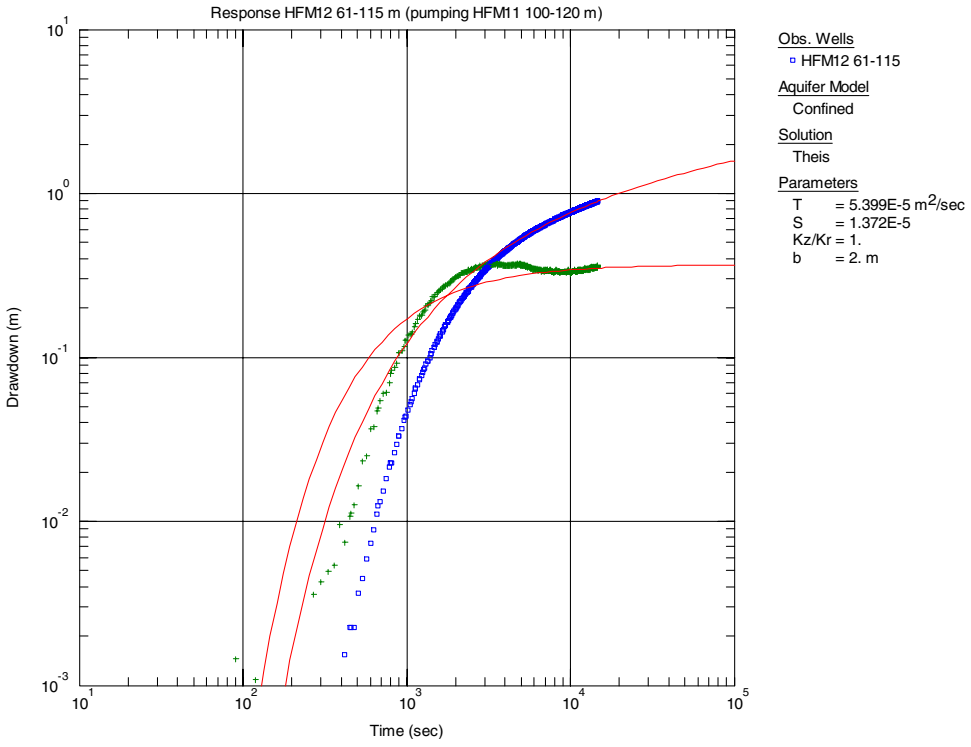


Figure A2:2-10. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 100–120 m.*

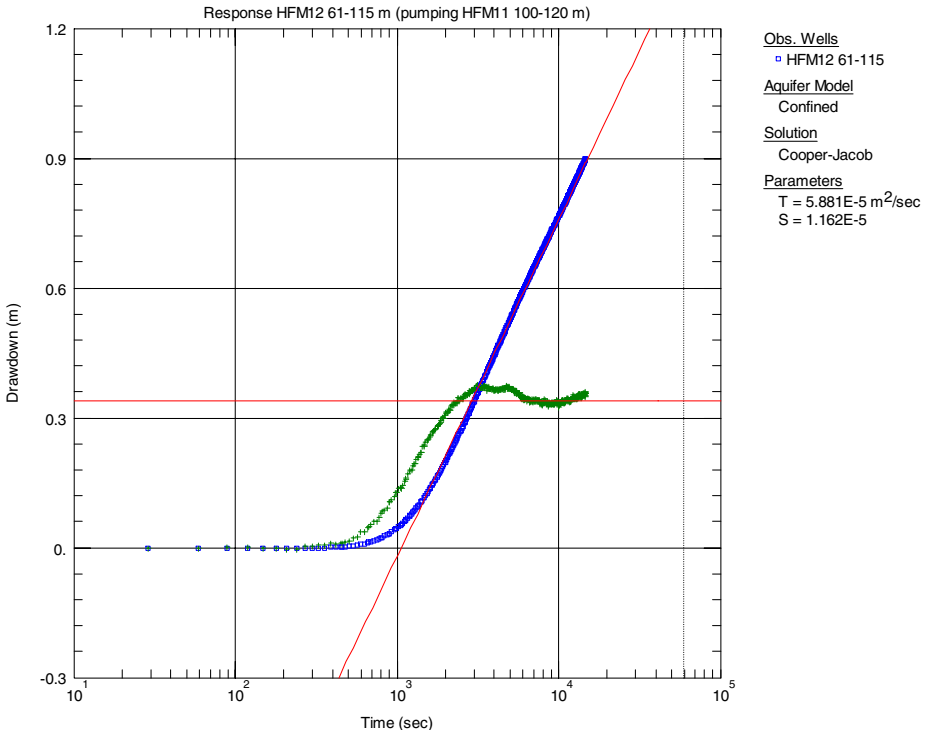


Figure A2:2-11. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 100–120 m.*

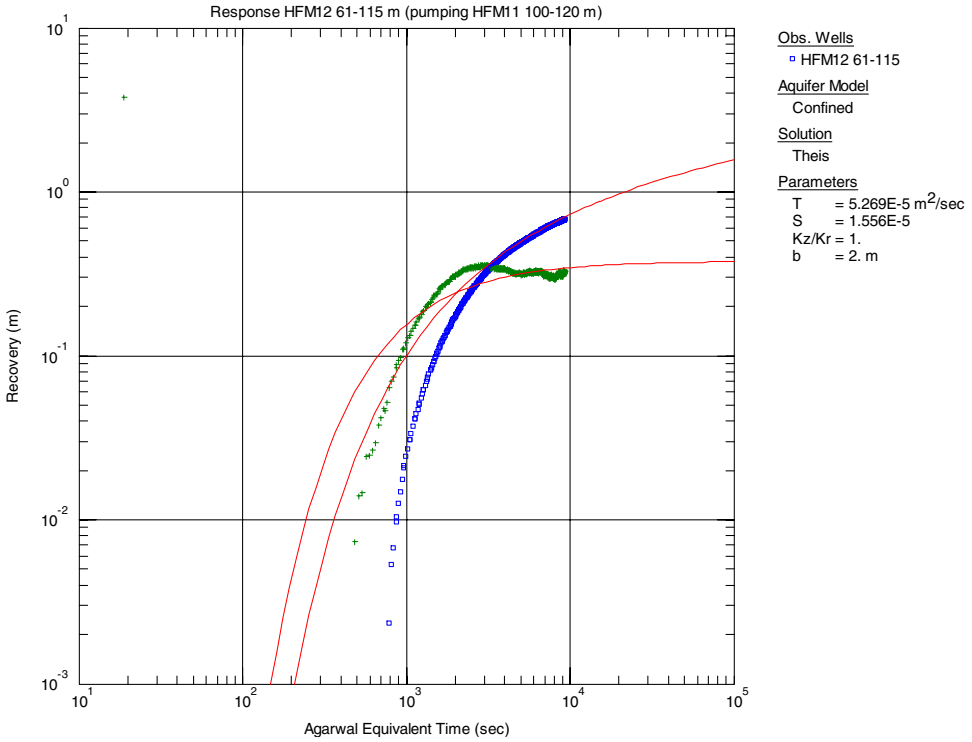


Figure A2:2-12. *Log-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 100–120 m.*

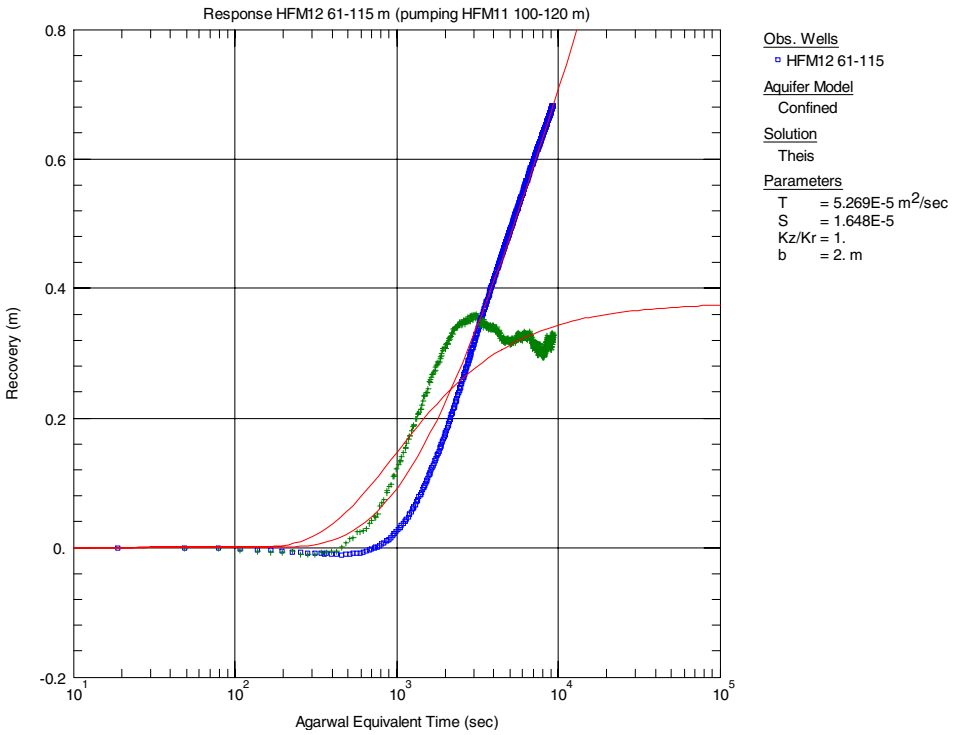


Figure A2:2-13. *Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 100–120 m.*

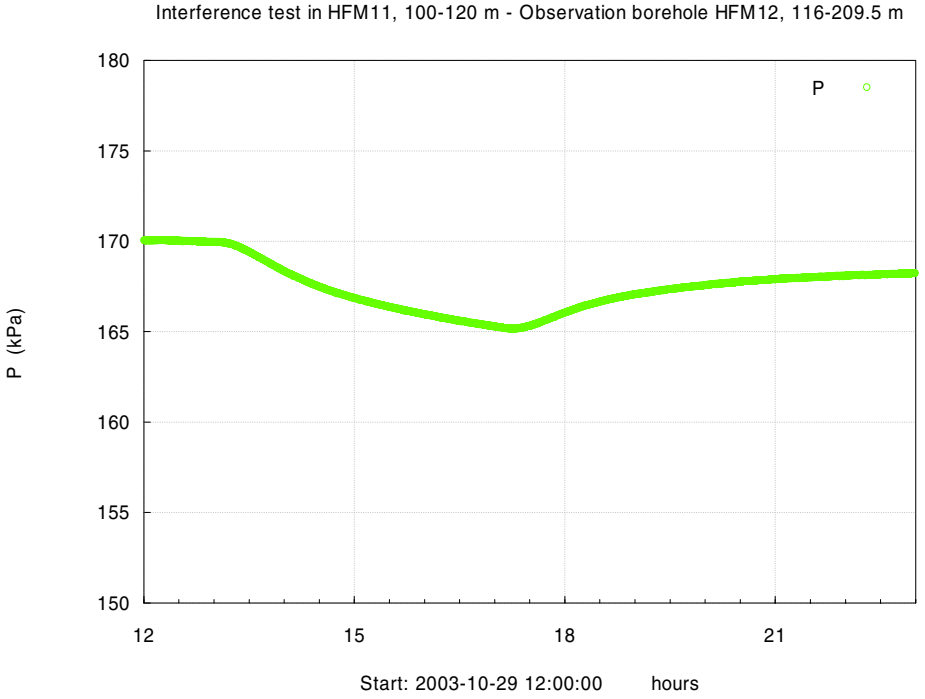


Figure A2:2-14. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 100–120 m.*

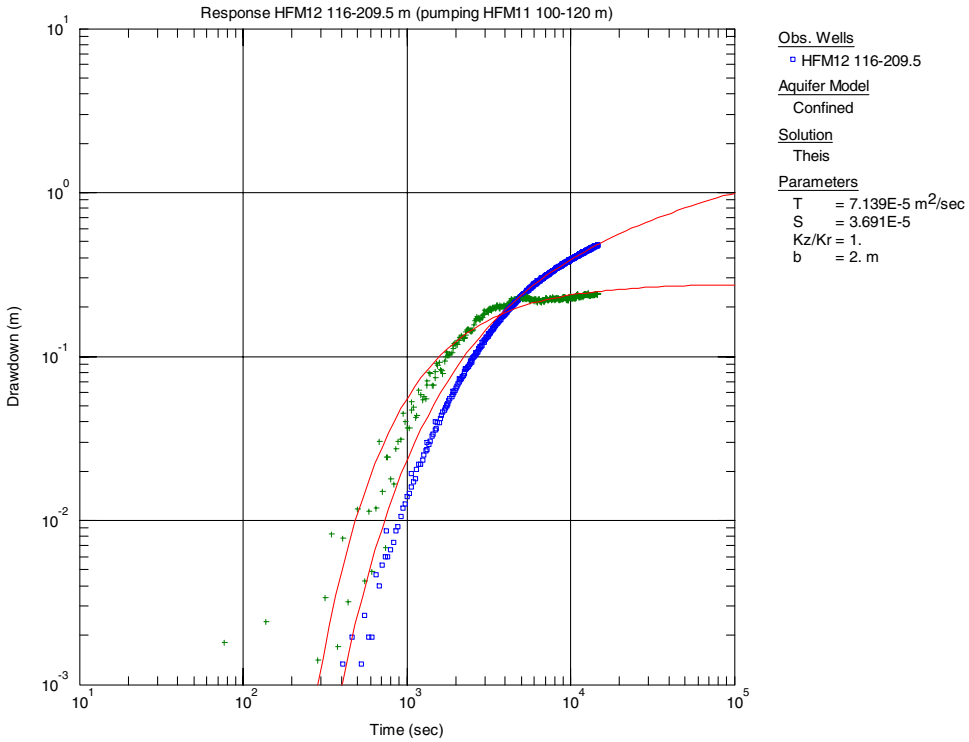


Figure A2:2-15. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 100–120 m.*

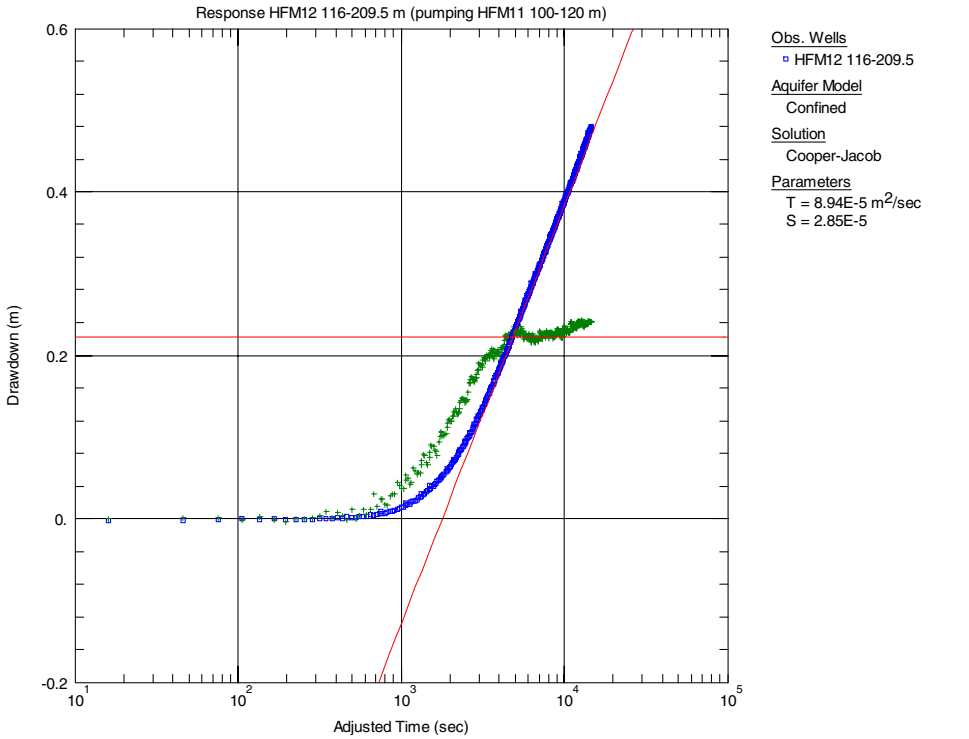


Figure A2:2-16. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 100–120 m.*

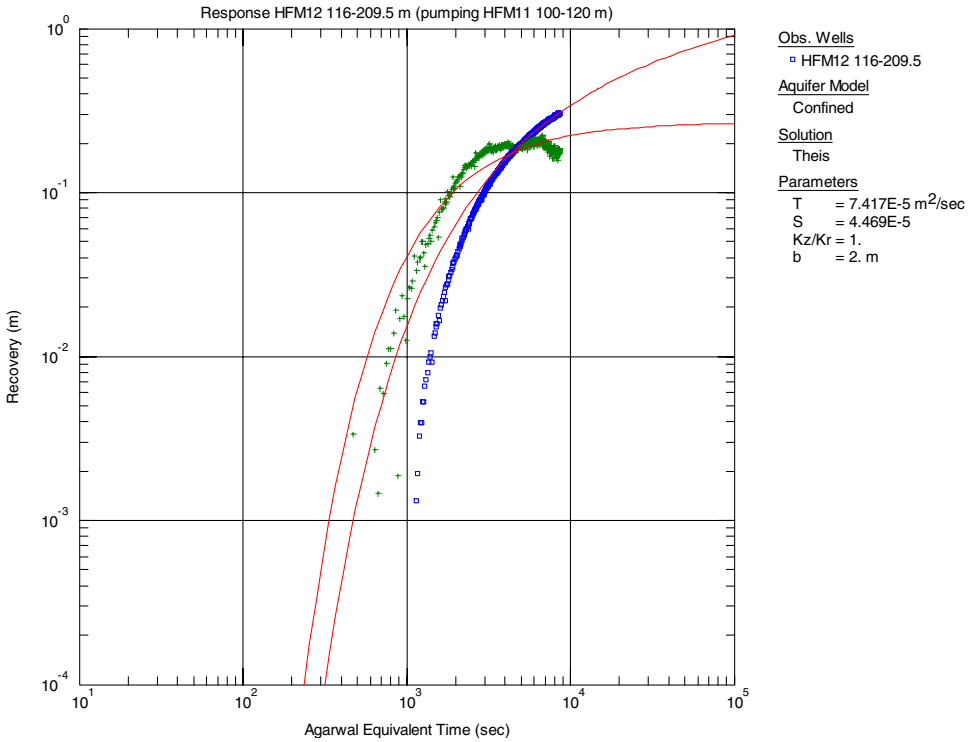


Figure A2:2-17. *Log-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 100–120 m.*

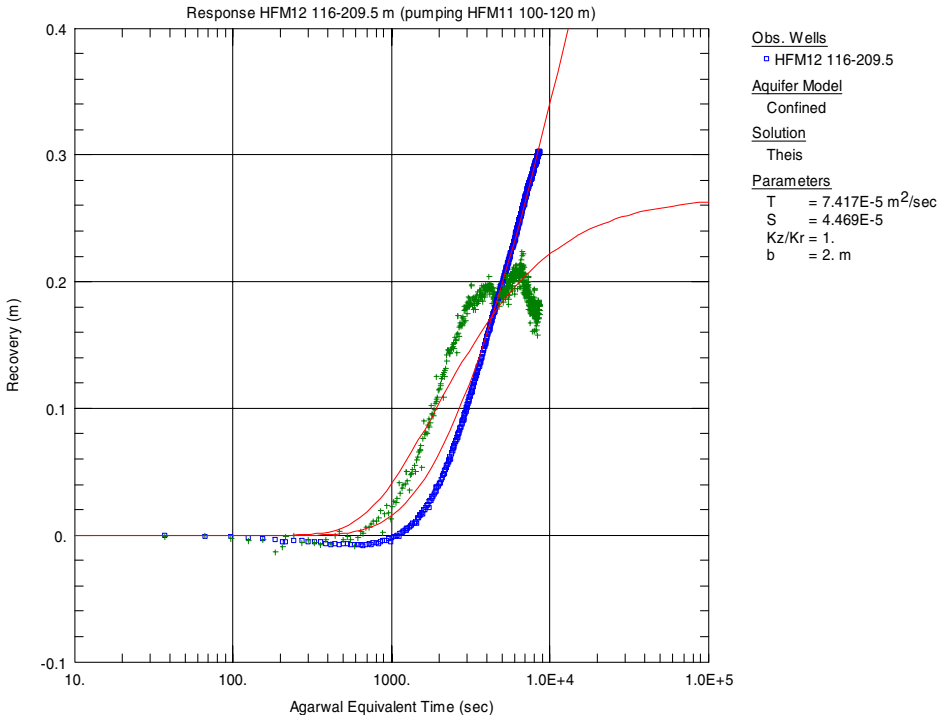


Figure A2:2-18. *Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 100–120 m.*

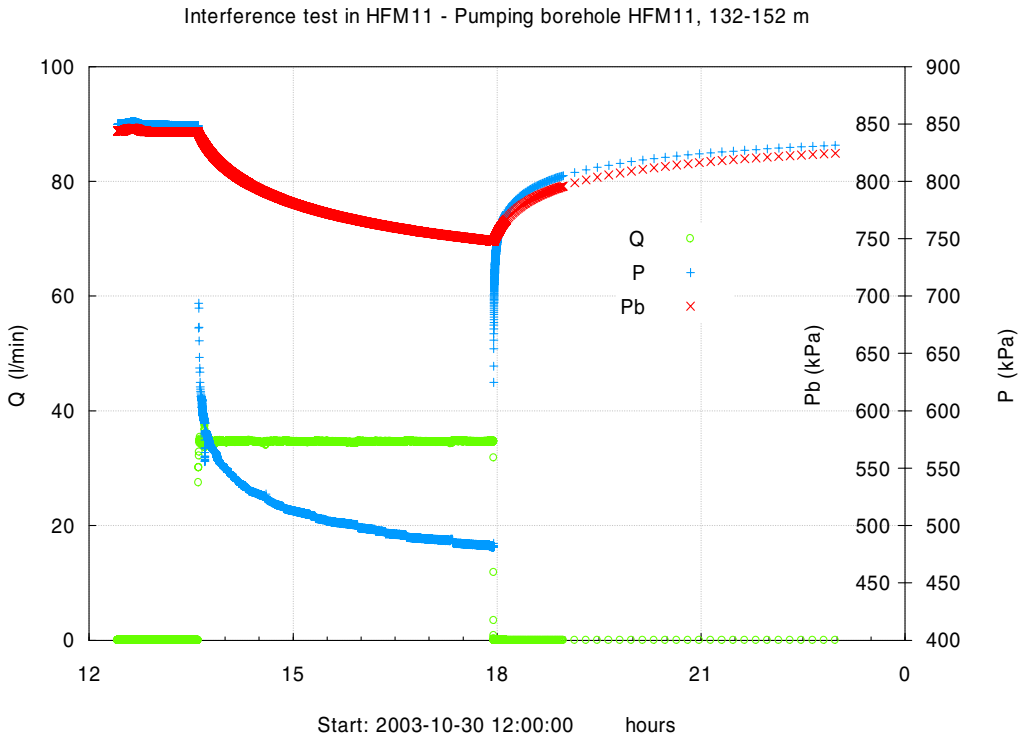


Figure A2:3-1. *Linear plot of flow rate (Q), pressure in test section (P) and pressure in section below test section (P_b) versus time in the pumping section HFM11: 132–152 m.*

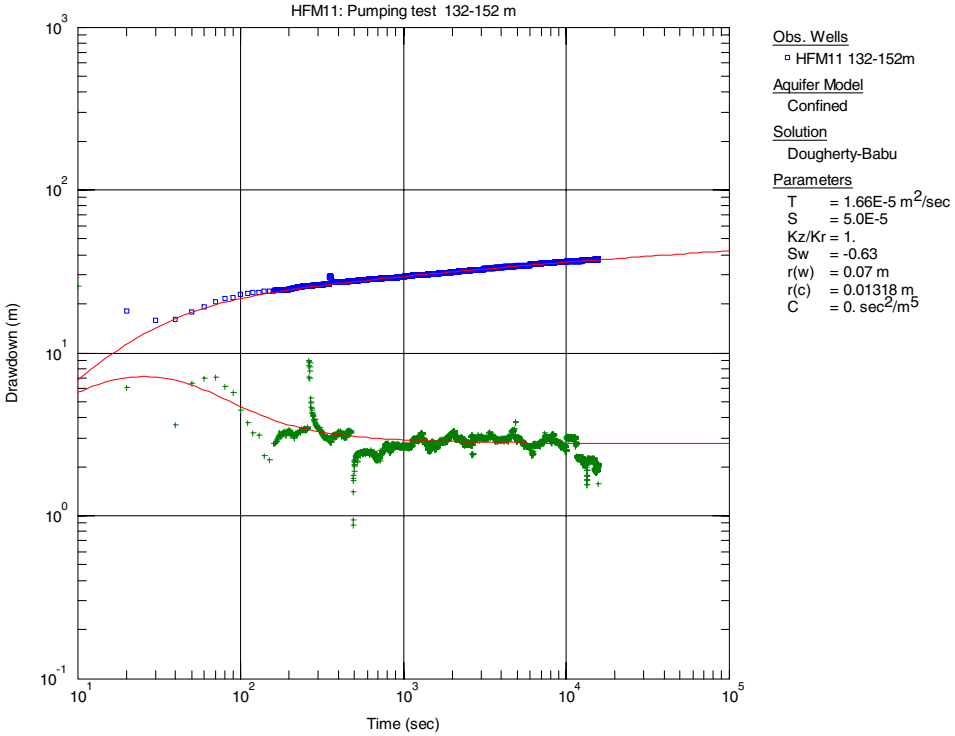


Figure A2:3-2. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time during pumping test in HFM11, section 132–152 m.*

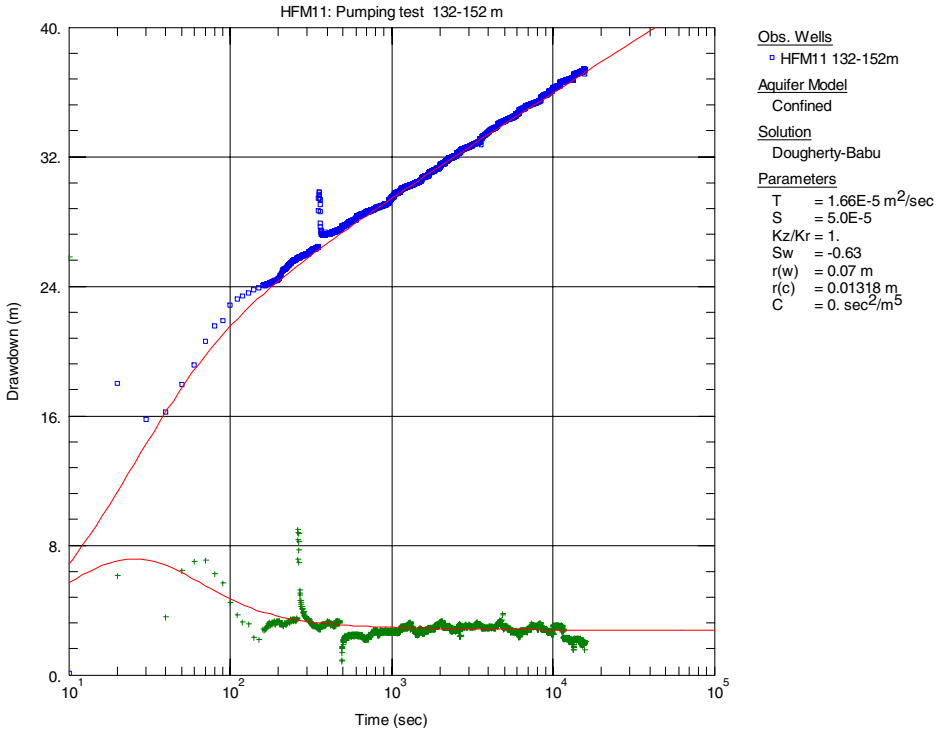


Figure A2:3-3. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time during pumping test in HFM11, section 132–152 m.*

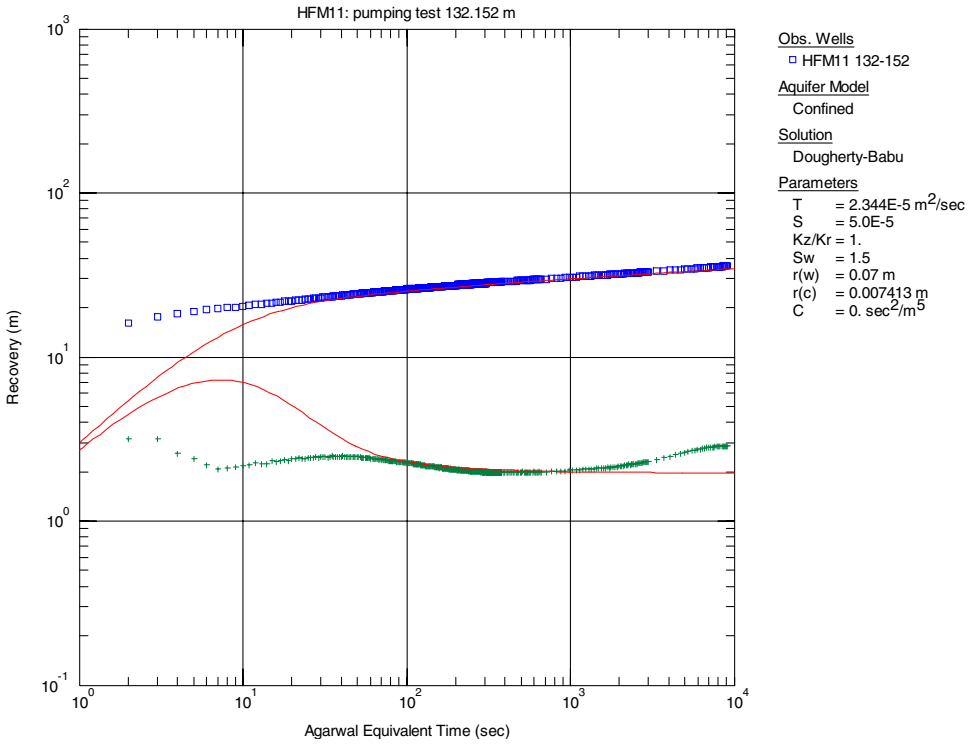


Figure A2:3-4. *Log-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time during pumping test in HFM11, section 132–152 m.*

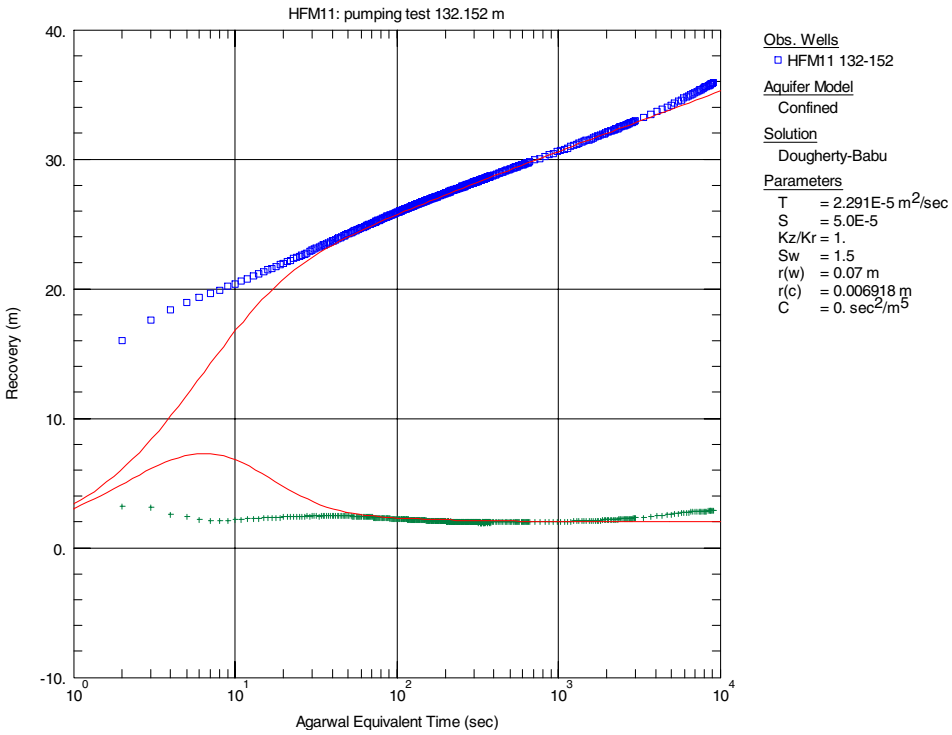


Figure A2:3-5. *Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time during pumping test in HFM11, section 132–152 m.*

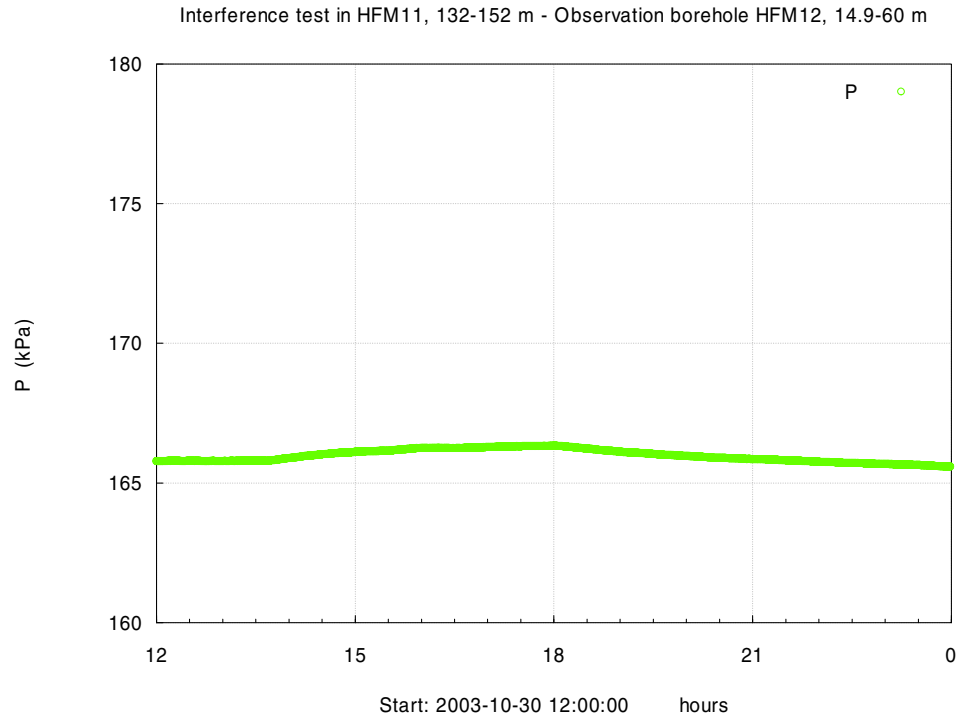


Figure A2:3-6. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 14.9–60 m, during pumping in HFM11, section 132–152 m.*

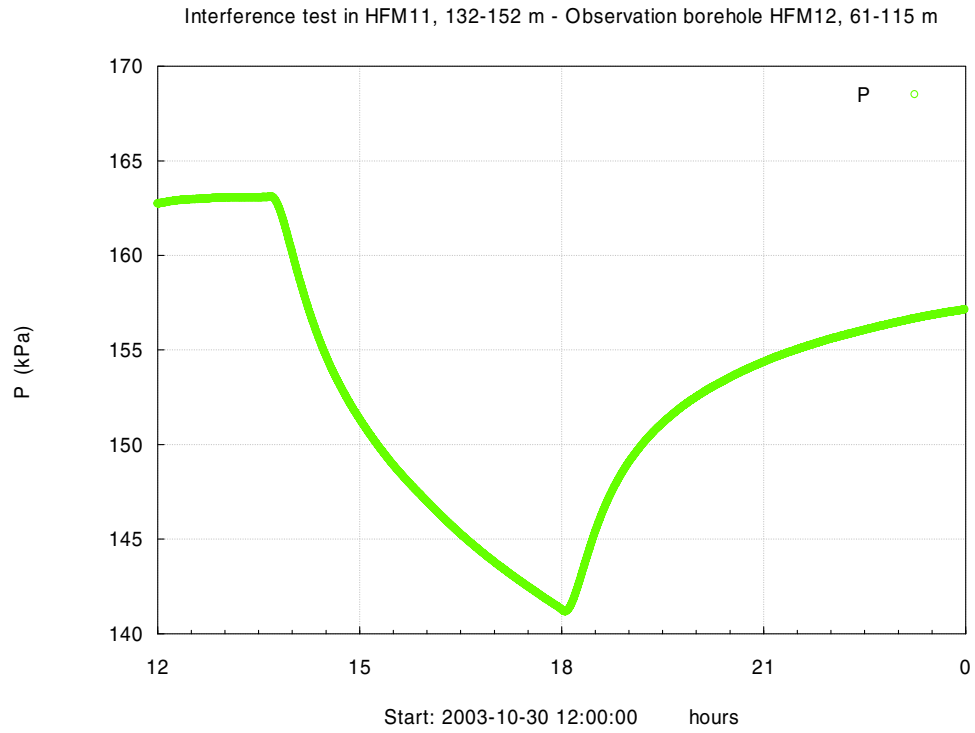


Figure A2:3-7. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 132–152 m.*

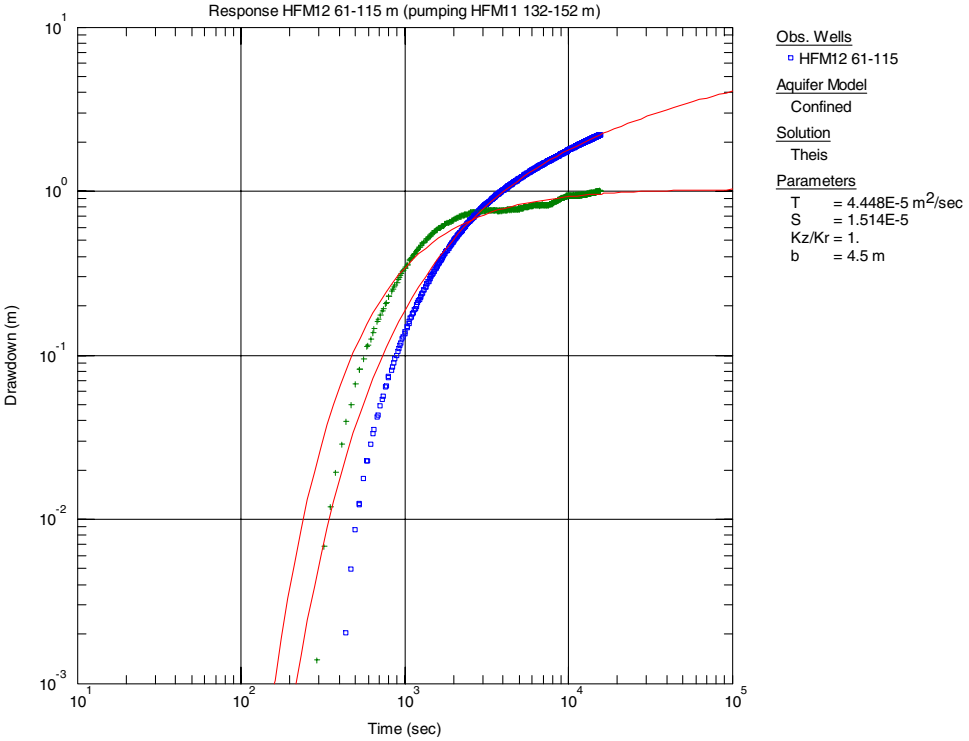


Figure A2:3-8. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 132–152 m.*

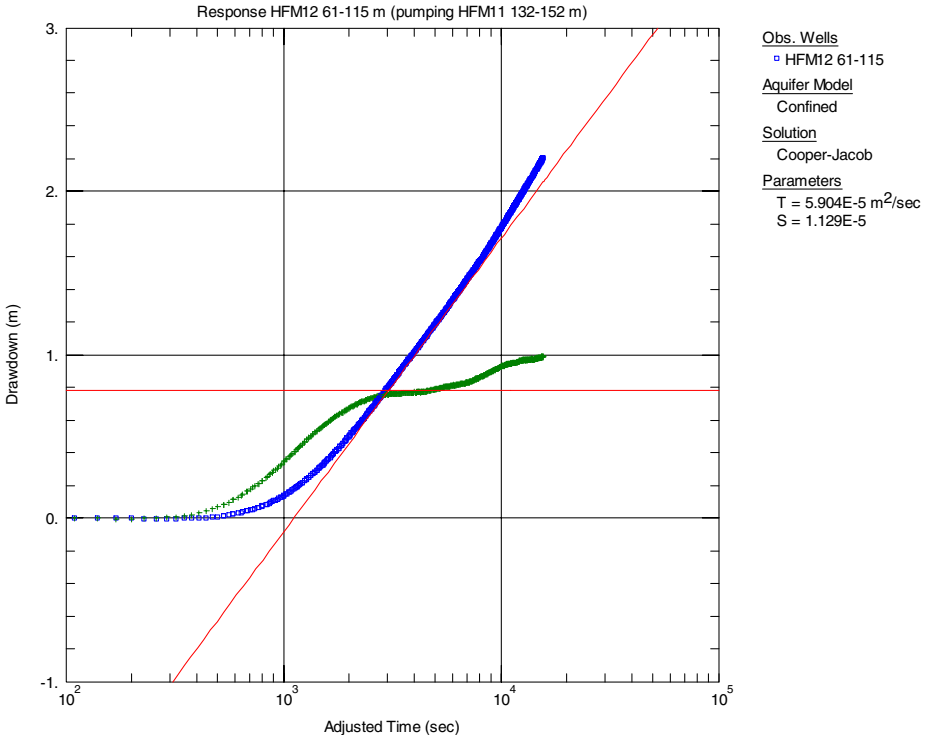


Figure A2:3-9. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 132–152 m.*

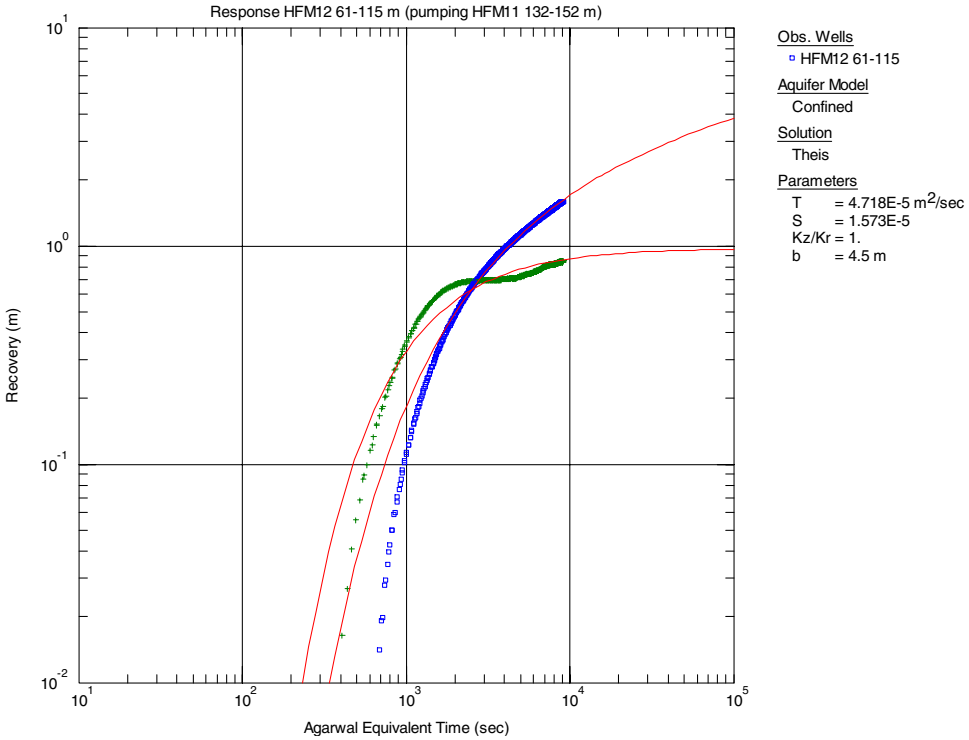


Figure A2:3-10. *Log-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 132–152 m.*

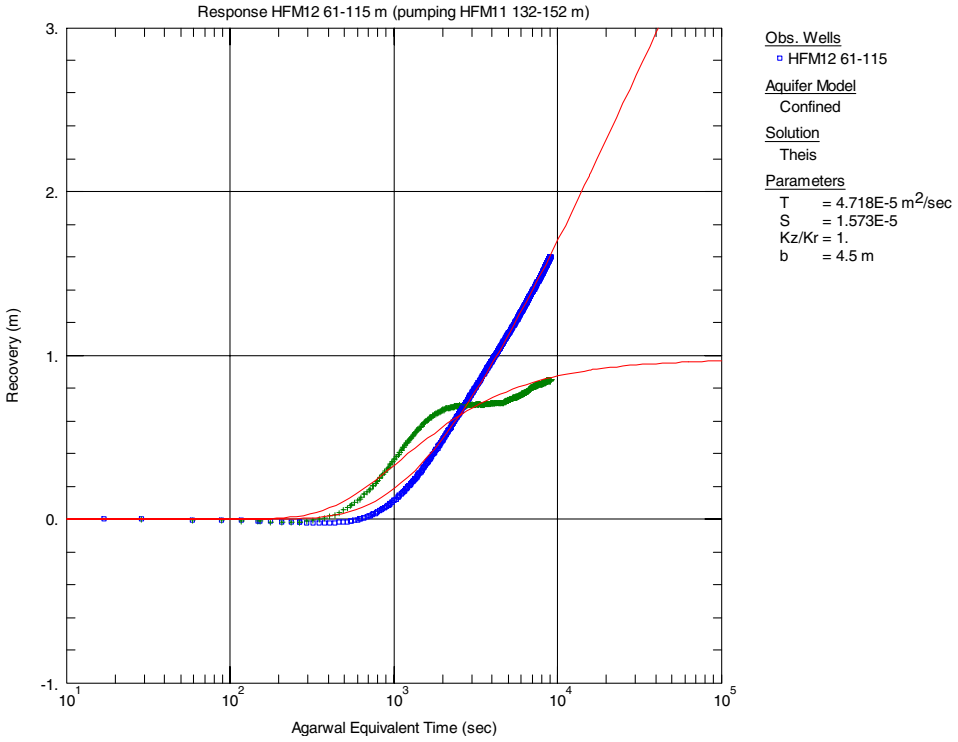


Figure A2:3-11. *Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 61–115 m, during pumping in HFM11, section 132–152 m.*

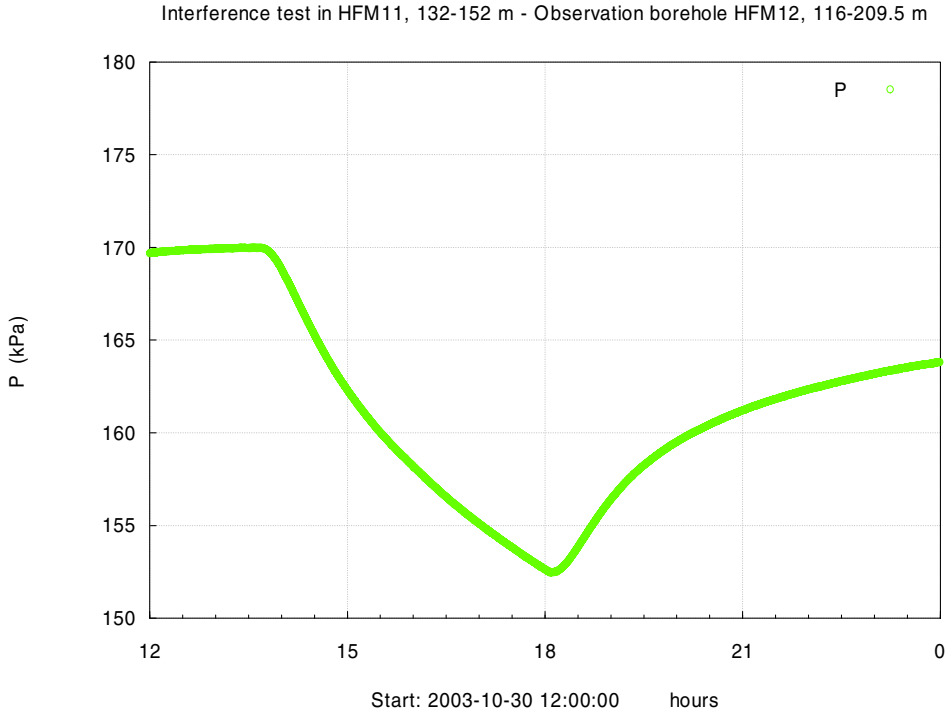


Figure A2:3-12. *Linear plot of pressure (P) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 132–152 m.*

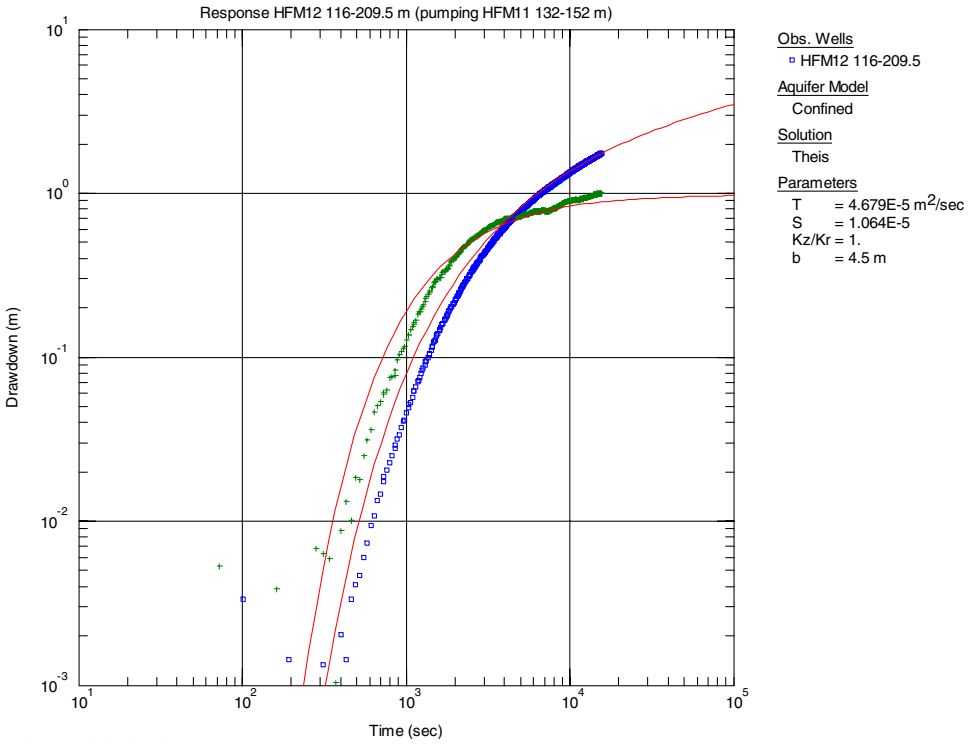


Figure A2:3-13. *Log-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 132–152 m.*

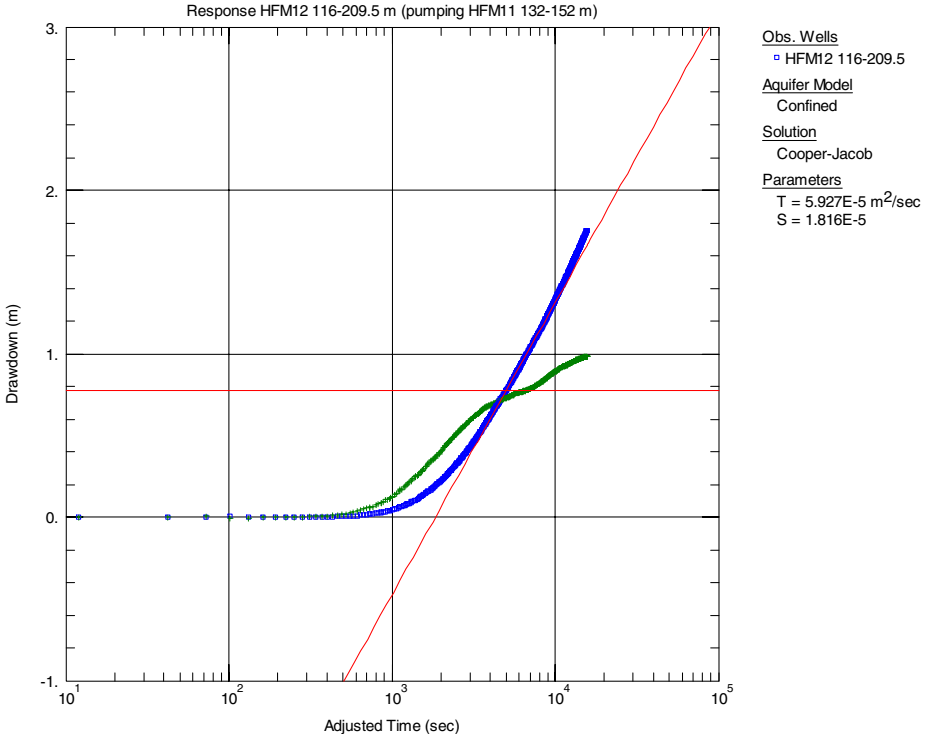


Figure A2:3-14. *Lin-log plot of drawdown (blue squares) and drawdown derivative (green crosses) versus time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 132–152 m.*

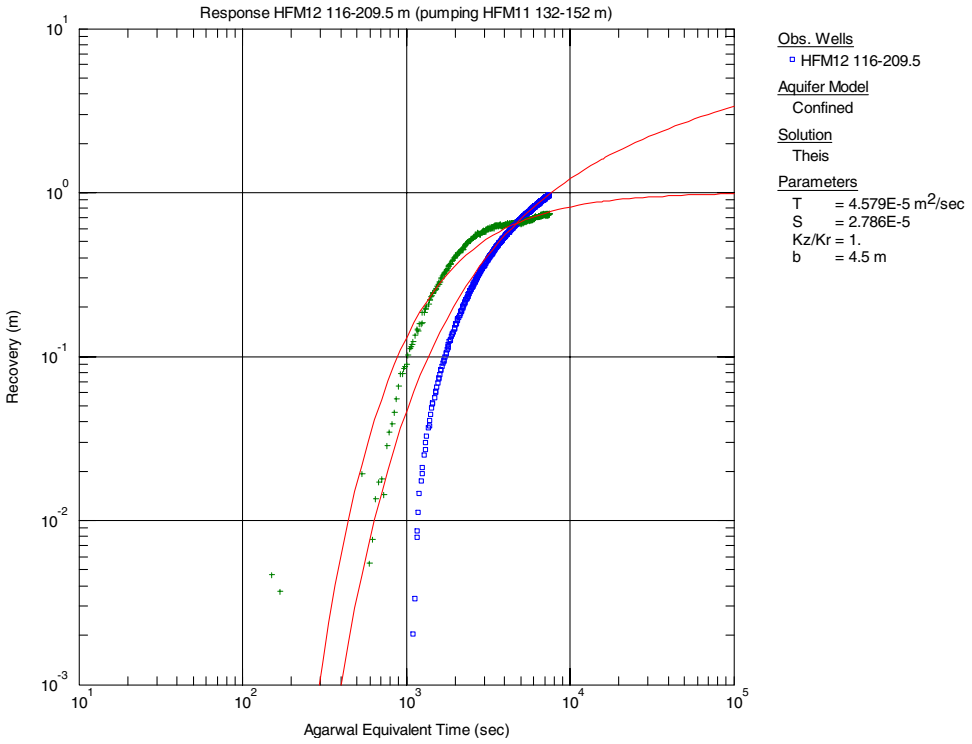


Figure A2:3-15. *Log-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 132–152 m.*

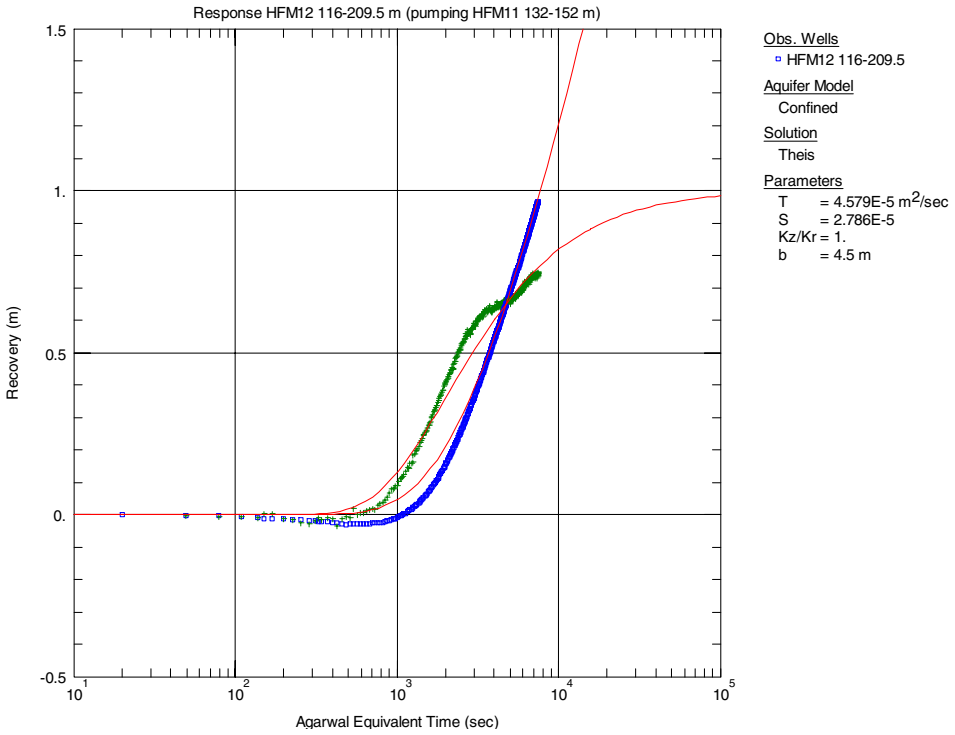


Figure A2:3-16. *Lin-log plot of pressure recovery (blue squares) and pressure recovery derivative (green crosses) versus equivalent time in observation borehole HFM12, section 116–209.5 m, during pumping in HFM11, section 132–152 m.*

Appendix 3

Result tables from Sicada

A. Result table to SICADA for single-hole test during the interference tests in HFM11 and HFM12.

Singlehole tests, pumping and injection, s_hole_test_d; General information

Borehole	Borehole secup (m)	Borehole seclow (m)	Test type (1–6)	Formation type (–)	Date and time for test, start YYYYMMDD hh:mm	Date and time for test, stop YYYYMMDD hh:mm	Date and time for flow, start YYYYMMDD hh:mm:ss	Date and time for flow, stop YYYYMMDD hh:mm:ss	Qp (m**3/s)
HFM11	35.00	55.00	1B	1	20031028 13:54	20031029 08:34	2003-10-28 14:07:41	2003-10-28 18:17:27	2.03E–04
HFM11	100.00	120.00	1B	1	20031029 11:37	20031030 11:05	2003-10-29 13:00:04	2003-10-29 17:05:14	2.50E–04
HFM11	132.00	152.00	1B	1	20031030 12:25	20031031 09:25	2003-10-30 13:36:11	2003-10-30 17:57:02	5.77E–04

cont.

Value type	Q-measl-L (m**3)/s	Q-measl-U (m**3)/s	V_p (m**3)	Q_m (m**3/s)	tp (s)	t_F (s)	h_i (m a sl)	h_p (m a sl)	h_F (m a sl)	p_i (m)	p_p (m)	p_F (m)
0	8.33E–05	1.33E–03	3.1	2.076E–04	14,986	53,736.00				310.0	238.4	310.20
0	8.33E–05	1.33E–03	3.7	2.4939E–04	14,710	64,788.00				627.2	294.5	622.70
0	8.33E–05	1.33E–03	9.0	5.7600E–04	15,651	56,280.00				848.57	481.6	845.3

cont.

Te_w (°C)	EC_w (mS/m)	TDS_w (mg/ L)	TDS_{wm} (mg/ L)	Reference	Comments (–)

Singlehole tests, pumping and injection, s_hole_test_ed1; Basic evaluation

Borehole	Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YYYYMMDD hh:mm	Q/s (m^2/ s)	Value code	T_Q (m^2/ s)	T_M (m^2/ s)	b (m)	B (m)	TB (1D) (m^3/ s)	TB-measl-L (1D) (m^3/ s)	TB-measl-U (1D) (m^3/ s)	SB (1D) (m)
HFM11	35.00	55.00	20031028 13:54	2.78E–05	0		2.64E–05	20					
HFM11	100.00	120.00	20031029 11:37	7.37E–06	0		6.99E–06	20					
HFM11	132.00	152.00	20031030 12:25	1.54E–05	0		1.46E–05	20					

cont.

SB* (1D) (m)	L_f (1D) (m)	T_T (2D) (m^2/ s)	Q/s-measl-L (m^2/ s)	Q/s-measl-U (m^2/ s)	S (2D) (–)	S* (2D) (–)	K´/b´ (2D) (1/s)	K_S (3D) (m/s)	K_S-measl-L (3D) (m/s)	K_S-measl-U (3D) (m/s)	S_S (3D) (1/m)	S_S* (3D) (1/m)	L_p (m)
		2.30E–05	2.0E–06	2.0E–03		5.00E–05							41
		6.99E–06	2.0E–06	2.0E–03		5.00E–05							109
		1.66E–05	2.0E–06	2.0E–03		5.00E–05							142

cont.

C (m**3/Pa)	C_D (–)	ξ (2D) (–)	ω (–)	λ (–)	t_1 (s)	t_2 (s)	Comments (–)
		–2.3			1,500	8,000	PRF
							PRF/PSF
		–0.63			1,000	10,000	PRF

SICADA – description of s_hole_test_d

PLU interference tests, Observation section data

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

Header	Unit	Explanation
TB	m3/s	1D model for evaluation of formation properties. T=transmissivity, B=width of formation
TB-measl-L	m2/s	Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or less than TB-measlim
TB-measl-L	m2/s	Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or greater than TB-measlim
SB	m	1D model for evaluation of formation properties. S= Storativity, B=width of formation
SB*	m	1D model for evaluation of formation properties. Assumed SB. S= Storativity, B=width of formation
L_f	m	1D model for evaluation of Leakage factor
T_T	m2/s	2D model for evaluation of formation properties. T=transmissivity
T-measl-L	m2/s	Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or less than T-measlim
T-measl-U	m2/s	Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or grater than T-measlim
S	(–)	2D model for evaluation of formation properties. S= Storativity
S*	(–)	2D model for evaluation of formation properties. Assumed S. S= Storativity
K´/b´	(1/s)	2D model for evaluation of leakage coefficient. K´= hydraulic conductivity in direction of leaking flow for the aquitard, b´= Saturated thickness of aquitard (leaking formation)
K_S	m/s	3D model for evaluation of formation properties. K=Hydraulic conductivity
K_S-measl-L	m/s	Estimated measurement limit for evaluated KS. If estimated KS equals KS-measlim in the table actual KS is considered to be equal or less than KS-measlim
K_S-measl-U	m/s	Estimated measurement limit for evaluated KS. If estimated KS equals KS-measlim in the table actual KS is considered to be equal or greater than KS-measlim
S_S	1/m	3D model for evaluation of formation properties. Ss=Specific Storage
S_S*	1/m	3D model for evaluation of formation properties. Assumed Ss. Ss=Specific Storage
L_p	m	Hydraulic point of appication, based on hydraulic conductivity distribution (if available) or the midpoint of the borehole test section
C	(m3/Pa)	Wellbore storage coefficient
C_D	(–)	Dimensionless wellbore storage coefficient
ξ	(–)	Skin factor
ω	(–)	Storativity ratio
λ	(–)	Interporosity flow coefficient
dt_1	s	Estimated start time after pump/injection start OR recovery start, for the period used for the evaluated parameter
dt_2	s	Estimated stop time after pump/injection start OR recovery start, for the period used for the evaluated parameter
Borehole secup	m	Length coordinate along the borehole for the upper limit of the observation section
Borehole seclow	m	Length coordinate along the borehole for the lower limit of the observation section
p_{ai}	kPa	Initial formation pressure of the observation section, which is located above the test section in the borehole
p_{ap}	kPa	Final pressure at the end of the pumping/injection period in the observation section, which is located above the test section in the borehole
p_{aF}	kPa	Final pressure at the end of the recovery period in the observation section, which is located above the test section in the borehole
p_{bi}	kPa	Initial formation pressure of the observation section, which is located below the test section in the borehole
p_{bp}	kPa	Final pressure at the end of the pumping/injection period in the observation section, which is located below the test section in the borehole
p_{bF}	kPa	Final pressure at the end of the recovery period in the observation section, which is located below the test section in the borehole
References		SKB report No for reports describing data and evaluation

B. Result table to SICADA from the interference tests in HFM11 and HFM12

Interference tests – observation sections: plu_inf_test_obs_general data

ID Obs. Borehole	Borehole secup (m)	Borehole seclow (m)	Test type (1–7)	Formation type (–)	ID Pumped Borehole	Test secup	Test seclow	Date and time for test, start YY-MM-DD hh:mm	Date and time for test, stop YY-MM-DD hh:mm	Date and time for flow, start hh:mm:ss	Date and time for flow, stop hh:mm:ss
HFM12	14.90	60.00	2	1	HFM11	35.00	55.00	20031028 13:54	20031029 08:34	2003-10-28 14:07:41	2003-10-28 18:17:27
HFM12	61.00	115.00	2	1	HFM11	35.00	55.00	20031028 13:54	20031029 08:34	2003-10-28 14:07:41	2003-10-28 18:17:27
HFM12	116.00	209.50	2	1	HFM11	35.00	55.00	20031028 13:54	20031029 08:34	2003-10-28 14:07:41	2003-10-28 18:17:27
HFM12	14.90	60.00	2	1	HFM11	100.00	120.00	20031029 11:37	20031030 11:05	2003-10-29 13:00:04	2003-10-29 17:05:14
HFM12	61.00	115.00	2	1	HFM11	100.00	120.00	20031029 11:37	20031030 11:05	2003-10-29 13:00:04	2003-10-29 17:05:14
HFM12	116.00	209.50	2	1	HFM11	100.00	120.00	20031029 11:37	20031030 11:05	2003-10-29 13:00:04	2003-10-29 17:05:14
HFM12	14.90	60.00	2	1	HFM11	132.00	152.00	20031030 12:25	20031031 09:25	2003-10-30 13:36:11	2003-10-30 17:57:02
HFM12	61.00	115.00	2	1	HFM11	132.00	152.00	20031030 12:25	20031031 09:25	2003-10-30 13:36:11	2003-10-30 17:57:02
HFM12	116.00	209.50	2	1	HFM11	132.00	152.00	20031030 12:25	20031031 09:25	2003-10-30 13:36:11	2003-10-30 17:57:02

cont

Lp (m)	r_s (m)	r_t (m)	dt_L (s)	h_i (m)	h_p (m)	h_F m)	p_i (kPa)	p_p (kPa)	p_F (kPa)	Te_o (° C)	EC_o (mS/m)	TDS_o (mg/ L)	TDS_{om} (mg/ L)	Refe-rence	Comments (-)
19	143.95		–				165.7	165.8	166.1						
111	129.47		11,890				163.2	162.0	162.8						dtL at dP=1kPa
123.5	132.46		–				169.9	169.3	169.5						
19	137.72		–				166.1	166.0	165.9						
111	109.95		1,480				163.1	154.3	162.2						dtL at dP=1kPa
123.5	112.16		2,597				169.9	165.2	169.4						dtL at dP=1kPa
19	146.41		–				165.8	166.3	165.5						
111	114.69		907				163.1	141.4	160.4						dtL at dP=1kPa
123.5	116.21		1,386				170.0	152.7	166.4						dtL at dP=1kPa

Interference tests – observation sections: plu_inf_test_obs_evaluated data

ID Obs. Borehole	Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YY-MM-DD hh:mm	Date and time for test, stop YY-MM-DD hh:mm	ID Pumped Borehole	Test secup	Test seclow	b (m)	B (m)	TB_o (1D) (m^3/ s)	TB-measl-L (1D) (m^3/ s)	T_o (2D) (m^2/ s)	T-measl-L (2D) (m^2/ s)
HFM12	14.90	60.00	20031028 13:54	20031029 08:34	HFM11	35.00	55.00	45.1				–	2.00E–06
HFM12	61.00	115.00	20031028 13:54	20031029 08:34	HFM11	35.00	55.00	54				–	2.00E–06
HFM12	116.00	209.50	20031028 13:54	20031029 08:34	HFM11	35.00	55.00	93.5				–	2.00E–06
HFM12	14.90	60.00	20031029 11:37	20031030 11:05	HFM11	100.00	120.00	45.1				–	2.00E–06
HFM12	61.00	115.00	20031029 11:37	20031030 11:05	HFM11	100.00	120.00	54				5.88E–05	2.00E–06
HFM12	116.00	209.50	20031029 11:37	20031030 11:05	HFM11	100.00	120.00	93.5				8.94E–05	2.00E–06
HFM12	14.90	60.00	20031030 12:25	20031031 09:25	HFM11	132.00	152.00	45.1				–	2.00E–06
HFM12	61.00	115.00	20031030 12:25	20031031 09:25	HFM11	132.00	152.00	54				5.90E–05	2.00E–06
HFM12	116.00	209.50	20031030 12:25	20031031 09:25	HFM11	132.00	152.00	93.5				–	2.00E–06

cont

T-measl-U (2D) (m^2/ s)	S_o (2D) (–)	K'/b'_o (2D) (1/s)	K_{so} (3D) (m/s)	K_S-measl-L (3D) (m/s)	K_S-measl-U (3D) (m/s)	S_{so} (3D) (1/m)	t_1 or dt_1 (s)	t_2 or dt_2 (s)	Comments (–)
2.00E–03	–								
2.00E–03	–								
2.00E–03	–								
2.00E–03	–								
2.00E–03	1.16E–05						6,000	11,000	uncertainty larger than normal due to u>0.01 in Cooper-Jacob solution
2.00E–03	2.85E–05						5,000	9,000	uncertainty larger than normal due to u>0.01 in Cooper-Jacob solution
2.00E–03	–								
2.00E–03	1.13E–05						3,000	5,000	uncertainty larger than normal due to u>0.01 in Cooper-Jacob solution
2.00E–03	–								

SICADA – description of plu_inf_test_obs

PLU interference tests, Observation section data

Header	Unit	Explanation
ID Obs Borehole		ID for observation borehole.
Borehole secup	m	Length coordinate along the borehole for the upper limit of observation section.
Borehole seclow	(m)	Length coordinate along the borehole for the lower limit of observation section.
Date for test start	Date	Date for the start of the pumping/injection test (YYYY-MM-DD hh:mm).
Date for test stop	Date	Date for the stop of the pumping/injection test (YYYY-MM-DD hh:mm).
Test type (1–7)	(–)	1A: Pumping test – wireline eq, 1B:Pumping test-submersible pump, 1C: Pumpingtest-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging-PFL-DIFF-sequential, 5B: Difference flow logging-PFL-DIFF-overlapping, 6:Flow logging_Impeller,7:Grain size analysis.
ID. pumped Borehole	(–)	ID for pumped or injected borehole.
Test secup	(m)	Length coordinate along the borehole for the upper limit of pumped or injected section.
Test seclow	(m)	Length coordinate along the borehole for the lower limit of pumped or injected section.
Start flow		Time for the start of the pumping/injection period (YYYY-MM-DD hh:mm:ss).
Stop flow		Time for the stop of the pumping/injection period (YYYY-MM-DD hh:mm:ss).
Hydr. p. a. (L_p)	m	Hydraulic point of application. Based on the hydraulic conductivity distribution (if available) or the midpoint of the borehole section.
r_s	m	Radial distance from point of application of T (or K)-distribution (or mid-point) of test section to point of applicationT(or K)-distribution (or mid-point) of obsevation section.
r_t	m	Shortest distance from point of application of T (or K)-distribution (or mid-point) of test section to point of applicationT(or K)-distribution (or mid-point) of obsevation section via interptered major conductive features. In the “Comments” the Model version X.Y used shall be reported.
dt_L	s	Time lag for pressure response to reach observation well after stop pumping/injecting, based on a reponse of 0.1m in the observation section.
h_i	m	Initial formation hydraulic head. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
h_p	m	Final hydraulic head at the end of the pumping/injection period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
h_F	m	Final hydraulic head at the end of the recovery period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z=0 m.
p_i	kPa	Initial formation pressure.
p_p	kPa	Final pressure at the end of the pumping/injection period.
p_F	kPa	Final pressure at the end of the recovery period.
Te_o	gr C	Fluid temperature in formation at obsevation section.

Header	Unit	Explanation
EC_o	mS/m	Electrical conductivity of the fluid in formation at observation section.
TDS_o	mg/L	Total salinity of the fluid in formation at observation section based on EC.
TDS_{om}	mg/L	Total salinity of the fluid in formation at observation section based on water sample and chemical analysis.
b	m	b: Interpreted formation thickness or section lengthrepresentative for evaluated T ot TB.
B	m	B: Interpreted witdth of a formation with evaluated TB.
TB_o	m3/s	TB_o: 1D model for evaluation of formation properties. T=transmissivity, B=width of formation.
TB-measl-L	m2/s	Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or less than TB-measlim.
TB-measl-U	m2/s	Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or greater than TB-measlim.
SB_o	m	SB_o: 1D model for evaluation of formation properties. S= Storativity, B=width of formation.
Lf_0	m	1D model for evaluation of Leakage factor.
Tt_0	m2/s	2D model for evaluation of formation properties. T=transmissivity.
T-measl-L	m2/s	Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or less than T-measlim.
T-measl-U	m2/s	Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or greater than T-measlim.
S_o	(–)	2D model for evaluation of formation properties. S= Storativity.
K'/b'_0	(1/s)	2D model for evaluation of leakage coefficient. K´= hydraulic conductivity in direction of leaking flow for the aquitard, b´= Saturated thickness of aquitard (leaking formation).
K_{S0}	m/s	3D model for evaluation of formation properties. K=Hydraulic conductivity.
K_S-measl-L	m/s	Estimated measurement limit for evaluated K_S. If estimated K_S equals K_S-measlim in the table actual K_S is considered to be equal or less than K_S-measlim.
K_S-measl-U	m/s	Estimated measurement limit for evaluated K_S. If estimated K_S equals K_S-measlim in the table actual K_S is considered to be equal or greater than K_S-measlim.
S_{S0}	1/m	3D model for evaluation of formation properties. Ss=Specific Storage.
dt_1	s	Estimated start time after pump/injection start OR recovery start, for the period used for the evaluated parameter.
dt2	s	Estimated stop time after pump/injection start OR recovery start, for the period used for the evaluated parameter.
References		SKB report No for reports describing data and evaluation.
Comments		Short comment to the evaluated parameters (Optional).

Index o Observation borehole or observation section (o short for observation).