P-04-135

Forsmark site investigation

Hydraulic interferences during the drilling of borehole KFM01B

Boreholes HFM01, HFM02, HFM03 and KFM01A

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Geosigma AB

February 2004

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Keywords: Forsmark, KFM01, Hydrogeology, Hydraulic tests, Drilling, Interference tests, Transmissivity, Storativity, AP PF 400-03-49.

Abstract

During the first part of the drilling (0–235 m) of borehole KFM01B (starting in July 2003) observations were made in the nearby surrounding boreholes. Observations were made by monitoring the pressure in boreholes KFM01A, HFM01, HFM02 and HFM03. In borehole KFM01A three sections were isolated by two packers, and the pressure was monitored in each section.

The main aim of monitoring the pressure in the surrounding boreholes during drilling of KFM01B was to investigate the hydraulic connectivity between the boreholes.

During drilling of KFM01B a high water pressure was used and small but clear responses of increasing pressure were recorded in the observation boreholes HFM01, HFM02, HFM03 and in KFM01A (section 1 and 2).

An interpretation was made for the observed pressure responses in the percussion boreholes HFM01–03 using the existing information from previous hydraulic tests in the area. The interpretation made in this report is that the body of the estimated water loss during the drilling of KFM01B exits through the fracture zone intersecting at c 20–40 m. That is, the findings discussed in this report do not contradict the result reported previously.

Sammanfattning

Under den första delen (0–235 meter) av borrningen av KFM01B (startade i juli 2003) lagrades tryckdata från omkringliggande borrhål. Observationer gjordes i hammarborrhål HFM01–03 samt i kärnborrhål KFM01A. I KFM01A sektionerades tre sektioner med två manschetter och tryck loggades i alla tre sektionerna.

Avsikten med loggningen var att vidare undersöka den hydrauliska kontakten mellan borrhålen i området.

Under borrningen observerades tydliga tryckökningar i alla hammarborrhål samt i de två understa sektionerna i KFM01A (sektion 1 och 2).

Ett försök till tolkning av uppmätta tryckresponser gjordes genom att utnyttja befintlig hydraulisk information från tidigare tester i området. Slutsatsen från tolkningen är att huvuddelen av flödet (spolvattenförlusten) lämnar KFM01B via sprickzonen som skär borrhålet på ca 20–40 m djup. Resultatet från denna rapport sammanfaller därmed med tidigare resultat från området.

Contents

1 Introduction

During the first part of the drilling of borehole KFM01B (starting in July 2003) observations were made in the nearby surrounding boreholes. Observations were made by monitoring the pressure in boreholes KFM01A, HFM01, HFM02 and HFM03 (see Figure 1-1). In borehole KFM01A three sections were defined by two packers and the pressure was monitored in each section. In the percussion boreholes the pressure was measured in open boreholes.

The work was carried out in compliance with the SKB internal controlling document AP PF 400-03-49. Pressure data used in this report can be extracted from the SKB database HMS.

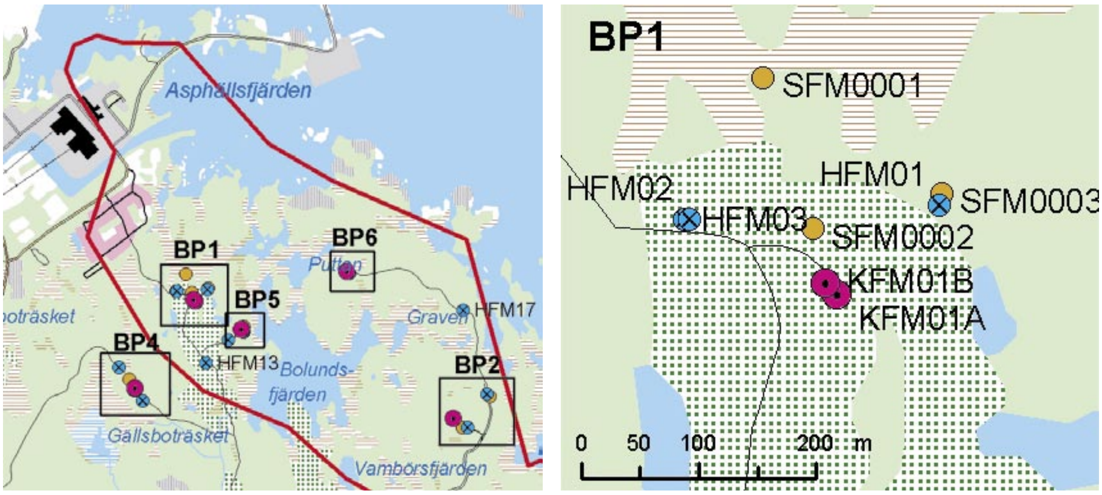


Figure 1-1. *Part of the investigation area at Forsmark including the candidate area selected for more detailed investigations. The enlargement to the right shows the borehole surrounding KFM01B at the drilling site DS1.*

2 Objectives and scope

The main aim of monitoring the pressure in the surrounding boreholes during drilling of KFM01B was to investigate the hydraulic connectivity between borehole KFM01B (source) and HFM01–03 respectively KFM01A (observation boreholes).

A second objective was to explain the flooding of borehole KFM01A (section 3) during the drilling of KFM01B.

The field work was governed by the drilling of KFM01B, which means that the testing conditions were not optimised from a hydraulic point of view. The extracted data were however found to be sufficient and of interest.

2.1 Observation boreholes

Technical data of the boreholes tested are shown in Table 2-1 and Table 2-2. The reference point in the boreholes is always the centre of top of casing (ToC). The Swedish National coordinate system (RT90) is used in the x-y-direction together with RHB70 in the z-direction. Northing and Easting refer to the position of the top of the boreholes at the ground surface (ToC). The borehole diameter in Table 2-1 refers to the final diameter of the drill bit after drilling to full depth.

Table 2-1. Technical data of percussion boreholes HFM01–03 (from SICADA).

Borehole								Casing		Drilling finished
ID	Elevation of top of casing (ToC) (m.a.s.l.)	Borehole length from ToC (m)	Bh-diam (below casing) (m)	Inclin – top of bh (from horizontal plane) (°)	Dip-direction – top of bh (from local N) (°)	Northing	Easting	Length (m)	Inner diam (m)	Date (YYYY-MM-DD)
HFM01	1.73	200.20	0.140	–77.51	34.06	6699605	1631485	31.93	0.160	2002-05-03
HFM02	3.05	100.00	0.137	–87.79	6.52	6699593	1631269	25.40	0.160	2002-05-21
HFM03	3.15	26.00	0.136	–87.28	264.53	6699593	1631272	13.10	0.160	2002-05-28

Table 2-2. Technical data of the borehole KFM01A (from SICADA).

Borhole length (m)	1,001.450				
Drilling period (s)	**From Date**	**To Date**	**Secup (m)**	**Seclow (m)**	**Drilling Type**
	2002-05-07	2002-06-10	0.000	100.570	Percussion drilling
	2002-06-25	2002-10-28	100.570	1,001.490	Core drilling
Starting point coordinate	**Length (m)**	**Northing (m)**	**Easting (m)**	**Elevation**	**Coord System**
	0.000	6699529.813	1631397.160	3.125	RT90-RHB70

Angles	Length (m)	Bearing	Inclination (– = down)	
	0.000	318.352	–84.734	
Borehole diameter	**Secup (m)**	**Seclow (m)**	**Hole diam (m)**	
	0.000	12.000	0.440	
	12.000	29.400	0.358	
	29.400	100.480	0.251	
	100.480	100.520	0.164	
	100.520	102.130	0.086	
	102.130	1,001.450	0.076	
Core diameter	**Secup (m)**	**Seclow (m)**	**Core diam (m)**	
	100.520	101.080	0.072	
	101.080	1,001.450	0.051	
Casing diameter	**Secup (m)**	**Seclow (m)**	**Case In (m)**	**Case Out (m)**
	0.000	29.400	0.265	0.273
	0.000	100.400	0.200	0.208
	97.330	97.330	0.195	0.199
	101.990	101.990	0.080	0.084

Figure 2-1 present a schematic drawing of a cross section with the boreholes at the drilling site DS1. The fractures position are only approximate but support the observed hydraulic responses.

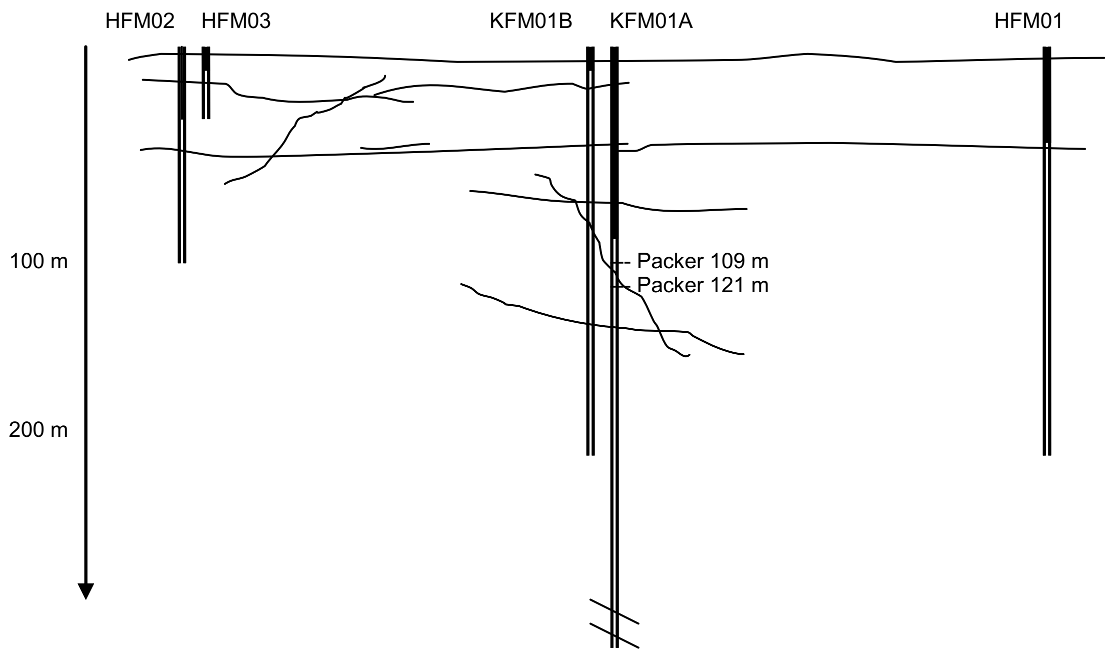


Figure 2-1. *Schematic cross-section over boreholes HFM01–03 and KFM01A respectively KFM01B and assumed fractures.*

3 Description of equipment

3.1 Pressure measurements

To monitor the water pressure, pressure sensors with built in data loggers, named mini-Troll, were used (Table 3-2).

In KFM01A, two packers were installed at lengths according to Table 3-1. The packers were inflated with an antifreeze agent and pressurised by nitrogen (~1.8 MPa). An installation drawing is attached in Appendix 1. Three mini-Troll loggers were installed inside 15 metre long PEM-hoses at the fixed depth of 10.0 m below top of casing. Two PEM-hoses were hydraulically connected to section 1 and 2 with a 8/6 mm Tecalan hose and the third PEM-hose had its open lower end in the upper part of the borehole (hydraulically connected to section 3).

Table 3-1. Measurement sections and packer positions in KFM01A in metre from top of casing (TOC) to the upper end of packer. Length of packer is about one metre.

Section number	Interval (m)	Packer position (upper end)
3	102–109*	109
2	110–121	121
1	122–1,000	

* Borehole casing from 0–101.99 m.

In the three percussion boreholes, which were all open, i.e. non-sectioned, the mini-Troll loggers were installed without a covering PEM-hose.

Table 3-2. Technical data of mini-Troll.

General:	
Dimensions	18.3 mm OD, 295.9 mm long
Wetted materials	316 stainless steel, polyurethane (cable)
Sensors:	
Ranges/Accuracy's	21 m (206.8 kPa)/± 0.1% FS, ± 0.05% @ 15°C
Resolution	16-bit A-D converter: 1 mm (0.00531% FS) for a 21 m sensor
Pressure rating	2 x range/3 x burst (11 m = 3 x range/5 x burst)
Operating temperature	–5°C to 50°C
Other:	
Measurement schedules	Linear (500 millisecond minimum), linear average, event, or logarithmic (300 millisecond minimum)
Processor	Motorola HC11
Real-time clock accuracy	± 4 min/yr over operating temp. range: ± 2 min/yr from 0°C to 40°C
Memory	1 MB flash
Filter	316 L stainless steel
Thermal stabilization time	30 min to 1 hr to within 0.1% of full scale, 1.5 to 2 hr to within 0.05% of full scale

4 Test performance

Drilling of the first part of KFM01B started late in July 2003 and prevailed during August (Figure 4-1).

The water pressure in the observation boreholes (HFM01–03 and KFM01A) was monitored with pressure sensors with built in data loggers. A default scan time of 60 s was used together with an event condition of 0.05 kPa. (~ 0.5 cm). Data were extracted from loggers to a laptop computer on a regular basis. All observation data are stored in the HMS-database.

High water pressure (3–7 MPa) was used on the drill bit during drilling in order to remove drilling debris. The high pressure in combination with water loss to the formation may generate strong responses of increasing pressure in the surrounding boreholes.

Between the drilling periods, two overnight (12 hour) pumping tests were performed in KFM01B using the wireline pump equipment (MP1-pump). No other hydraulic events in the immediate surroundings during the drilling periods caused groundwater level disturbance.

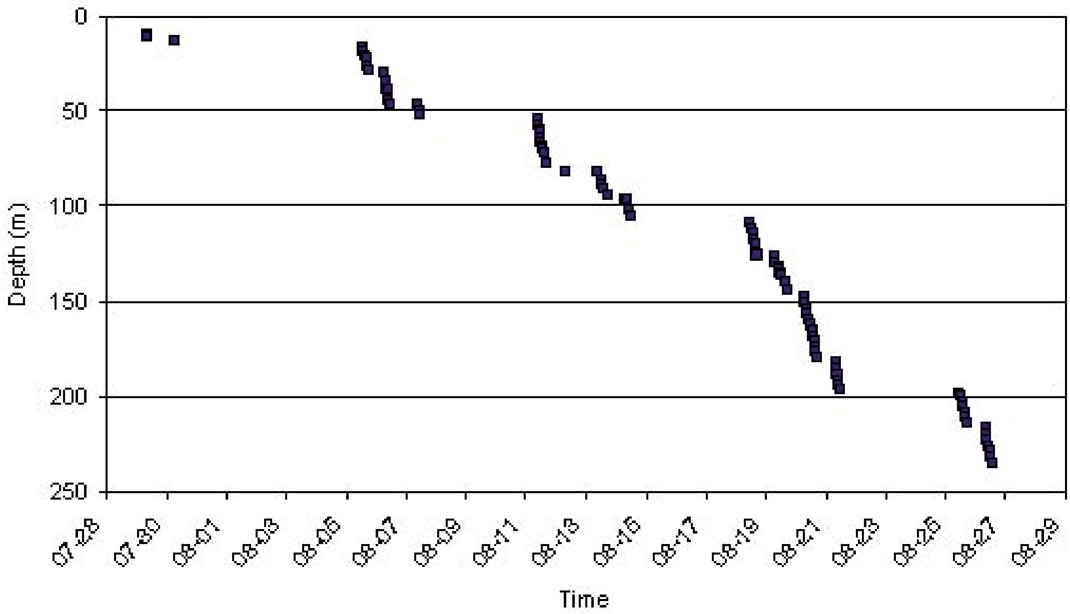


Figure 4-1. *Drilling activity in KFM01B (2003-07-29 to 2003-08-26).*

5 Results

5.1 Qualitative analysis

During drilling of KFM01B, a high water pressure was applied on the drill bit and responses of increasing pressure can be seen in the observation boreholes HFM01, HFM02, HFM03 and in KFM01A (section 1 and 2), see Figure 5-1, 5-2 and 5-3. A rough estimation of the water loss during drilling is 15–20 L/min, which is about 50% of the total water flow rate. The responses seen in section 3 in KFM01A are artificial and depending on water leakage from section 2 (see explanation in 5.3).

Initial drilling (0–46 m) 2003-07-29 to 2003-08-06

When the drilling reached about 20 m the first responses (pressure spikes) were observed in HFM01–03 (Figure 5-1). The pressure increased between 1 and 2 kPa in all boreholes. However, since the logging did not start until drilling had reached almost 20 m it cannot be excluded that responses occurred even earlier, i.e., above 20 m.

Figure 5-2 shows a decreasing pressure trend in all sections in KFM01A. The trend is assumed to be natural. In section 1 and 2, deviations from the trend were observed when the drilling reached about 14 m (2003-07-30). This could indicate a hydraulic connection between KFM01A and KFM01B. However, at the time a rainfall occurred and considering the weak indication the interpretation of the connection is very uncertain.

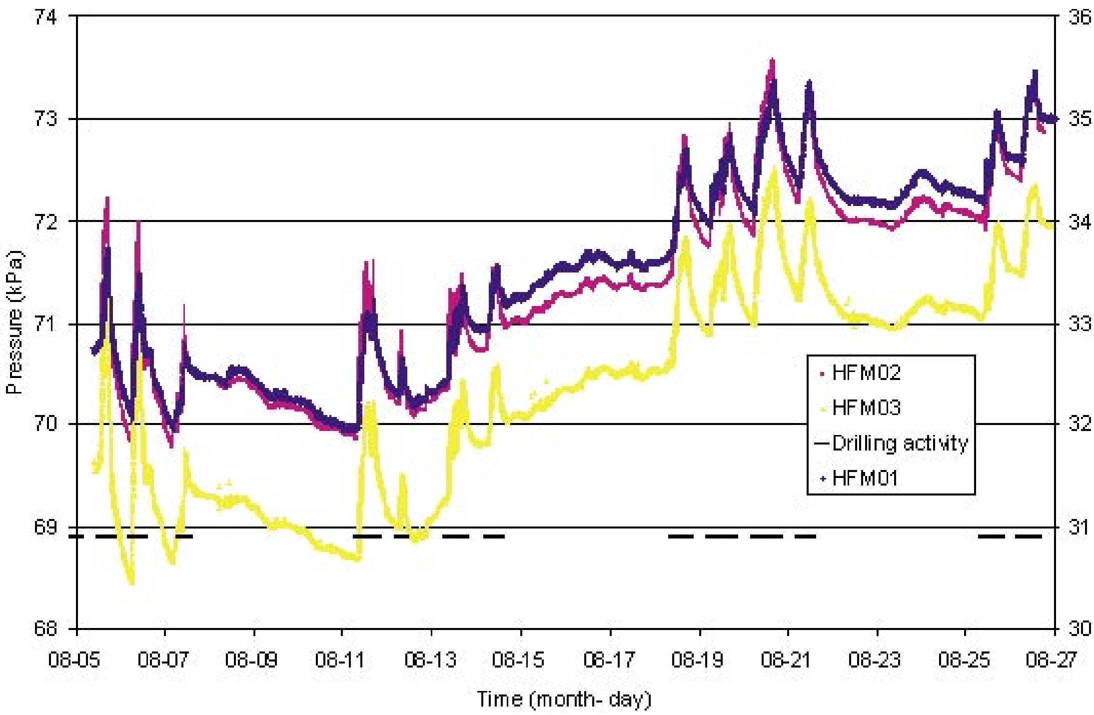


Figure 5-1. *Pressure responses in HFM01–03 during drilling of KFM01B (drilling period 17–235 m).*

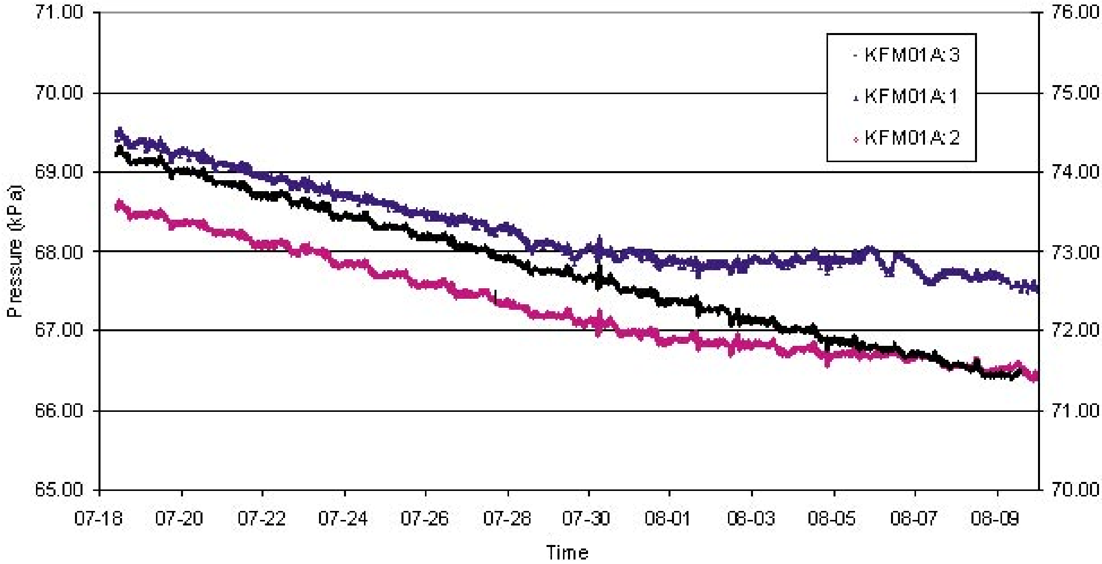


Figure 5-2. *Pressure responses in KFM01A (section 1–3) during drilling of KFM01B (drilling period 0–53 m).*

When the drilling had reached 29 m (2003-08-05) an overnight (12 hour) pumping test was carried out in KFM01B using an MP1-pump and with an average flow rate of 8.6 L/min. A weak response (less then 0.3 kPa drawdown) was observed in KFM01A, section 1 (Figure 5-2). This indicates a weak connectivity. However, not as evident as expected due to the prevailing drilling, i.e. the pressure spikes observed in the surrounding percussion boreholes were not seen in KFM01A.

In HFM01–03 the responses of pumping coincide with recovery after the disturbance due to the drilling activity. Therefore no effects from pumping are identified.

Responses (pressure spikes) observed in HFM01–03 thereafter, all coincide with the drilling activity.

Drilling (46–72 m) 2003-08-06 to 2003-08-11

When the drilling had reached 46 m (2003-08-06) an overnight (12 hour) pumping test was again carried out using the wireline-probe. The pumping test was performed in the section 34.7–46.2 m with an average flow rate of 4.7 L/min. A weak response (less then 0.4 kPa drawdown) was again observed in KFM01A, section 1 (Figure 5-2). In HFM01–03 the responses of pumping coincide with recovery after the disturbance due to drilling (Figure 5-1). Therefore possible effects from pumping cannot be identified.

Drilling (72–235 m) 2003-08-11 to 2003-08-26

When drilling had reached 72 m (2003-08-11) the first obvious responses of an increasing pressure occurred in the two lowest sections in KFM01A (Figure 5-3). The strongest response is observed in section 2 (2 kPa) followed by section 1 (1 kPa).

Clear responses (pressure spikes) were thereafter observed in KFM01A (section 1 and 2), all of which coincide with the drilling activity (Figure 5-3). From 2003-08-18 also section 3 displays distinct responses. These responses are, however, most probably artificial, see Chapter 5.3.

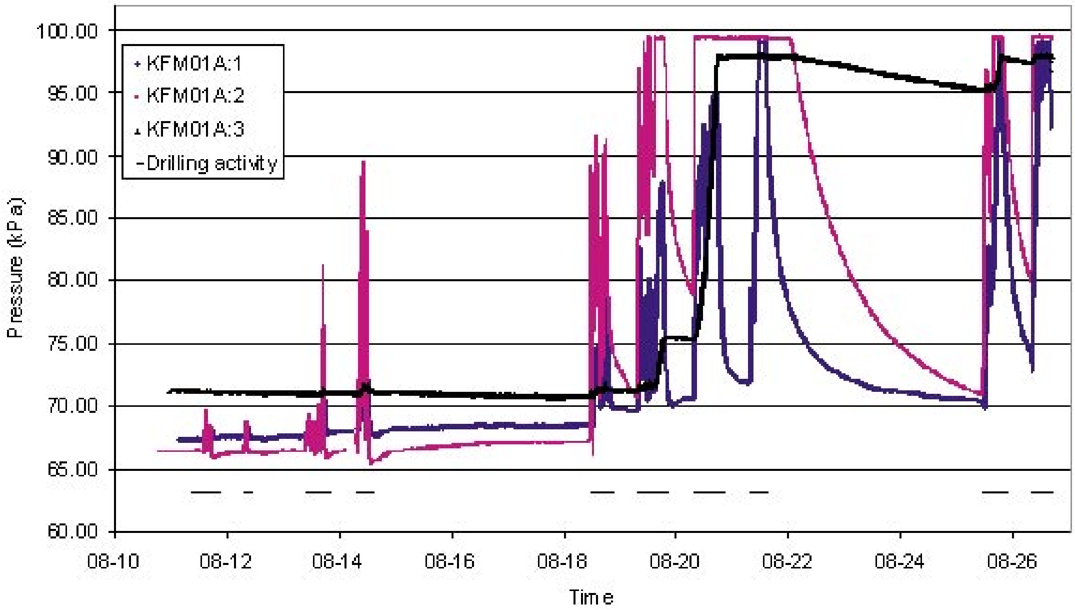


Figure 5-3. *Pressure responses in KFM01A (section 1–3) during drilling of KFM01B (drilling period 53–235 m).*

5.2 Quantitative analysis

In the percussion boreholes HFM01–03, the responses from the pumping tests in KFM01B (using the MP1-pump) were strongly affected by the recovery from the drilling period. This leads to a very difficult interpretation of data. Transient analysis is instead made on recovery data after a selected drilling period. Transmissivity (T) and storativity (S) are calculated using the slope of recovery data plotted in a lin-log diagram (Cooper-Jacob's method). The results are to be regarded as very approximate and rather as an attempt to see if the method can be applied under these circumstances.

$T = 0.183 \times Q/\Delta s$

$S = 135 \times T \times t_0/r^2$

Q	Injection flow rate in (m^3/s).
Δs	Pressure decrease over one time decade (m).
t_0	Time in the intersection between the extrapolated straight line (drawdown) and the starting pressure (min).
r	Spherical distance from observation borehole to drilling position (m).

The flow rate used in the calculation is the same as the observed water loss during drilling (c 15 L/min). Considering the existing information from previous hydraulic tests in the area /1/, it is likely to assume that the major part of the water loss during the drilling of KFM01B exits through the fracture zone intersecting KFM01B at c 20–45 m. The same zone also intersects with the percussion boreholes HFM01–03. Consequently, the flow rate causing the responses in KFM01A:1–2 is very small and difficult to estimate.

Figure 5-4 shows the drilling period chosen for evaluation of responses in the percussion boreholes HFM01–03. Se Appendix 3 for all diagrams. The response is by no means optimal for quantitative interpretation. It is e.g. difficult/uncertain to establish the exact time for stop of drilling. The method used this time is to choose the peak pressure value and plot the subsequent data. As injection flow rate, a rough estimation made by the drillers is used (~ 15 L/min), corresponding to the water loss to the formation during drilling. As can be seen in Figure 5-5, the recovery is quite small, about 0.1 m.

Due to the difficulty to estimate a representative flow rate corresponding to the responses in KFM01A:1–2, no values for transmissivity and storativity are calculated. A hydraulic connection between KFM01B and section 1 and 2 in KFM01A is however documented.

The results are shown in Table 5-1. In the column “Comments” the T-values from earlier interference tests in the area are listed in order to determine the quality of the test method used in this report. The transmissivities for the percussion boreholes HFM01–03, estimated in this report correspond very well with the results from previous tests preformed in the area.

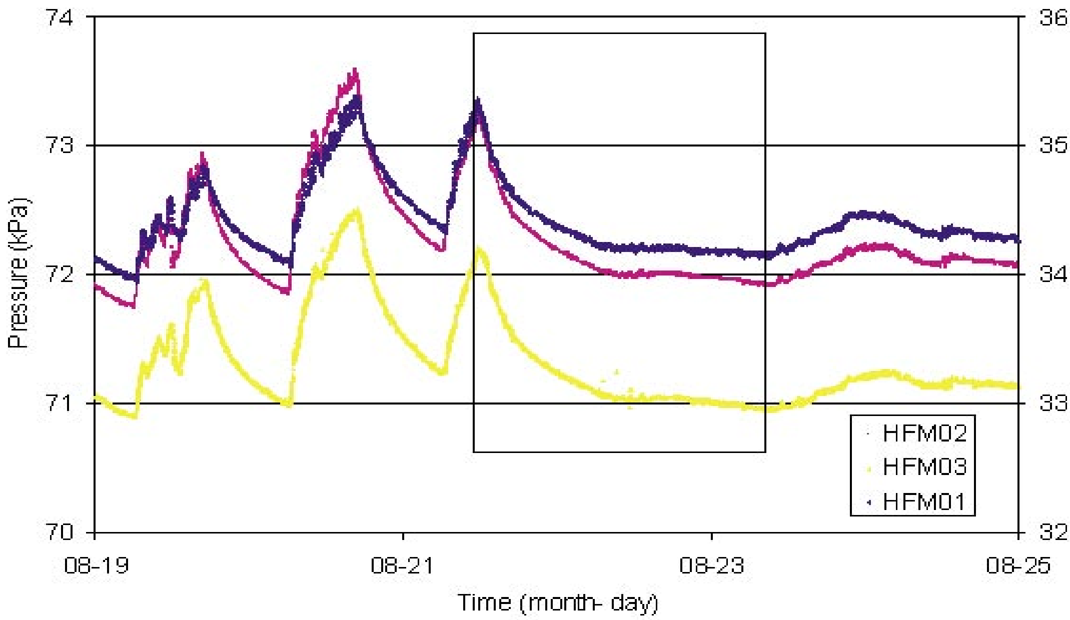


***Figure 5-4.** Pressure responses in HFM01–03 during the drilling of KFM01B. The selected area is used for quantitative comparison.*

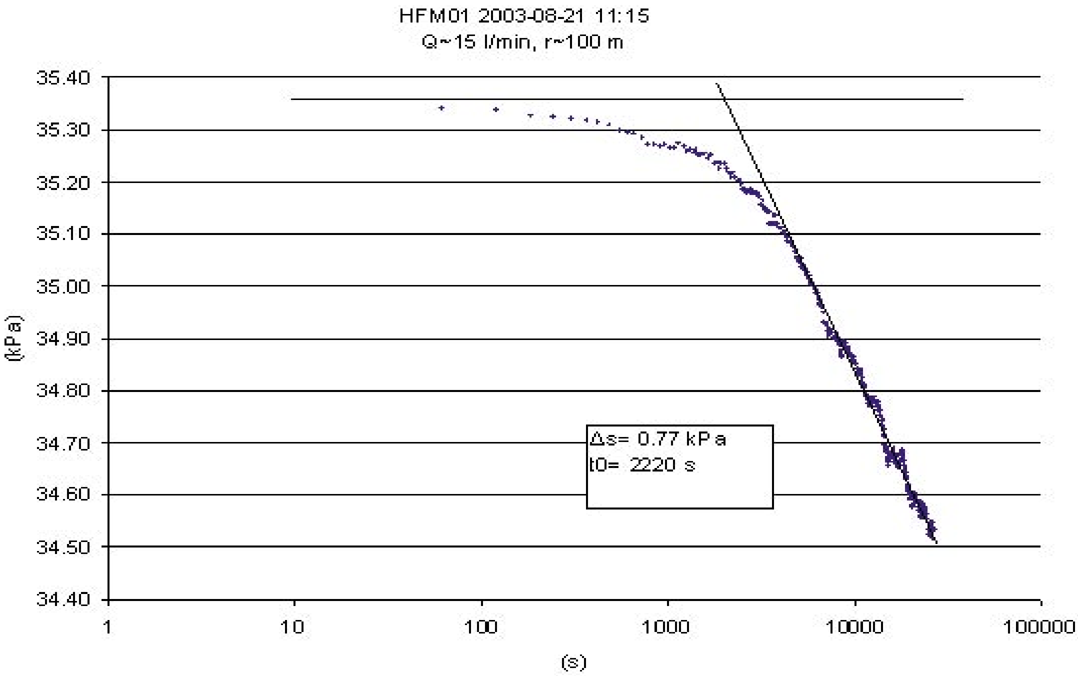


Figure 5-5. *Example of recovery response in HFM01 after a period of drilling.*

Table 5-1. Summary of estimated hydraulic parameters from the responses at drilling site DS1 during drilling of KFM01B.

Pumping/ Injection borehole ID	Observation Borehole ID	Section (m)	Test type (–)	Distance, (m)	T (m^2/s)	S (–)	Comments
KFM01B	HFM01	31.93–200.20		117	6.1×10^{-4}	2.3×10^{-4}	T = 5.31×10^{-4} in earlier interference test
KFM01B	HFM02	25.40–100.00		130	5.9×10^{-4}	1.4×10^{-4}	T = 5.26×10^{-4} in earlier interference test
KFM01B	HFM03	13.10–26.00		127	5.9×10^{-4}	2.2×10^{-4}	T = 5.26×10^{-4} in earlier interference test
KFM01B	KFM01A:3	102–109			–	–	No response in section
KFM01B	KFM01A:2	110–121		60	not evaluated	not evaluated	T = 8×10^{-8} with PSS injection tests
KFM01B	KFM01A:1	122–1,000		80	not evaluated	not evaluated	T = 1.3×10^{-7} with PSS injection tests

T = Transmissivity from transient evaluation.

S = Storativity from transient evaluation.

5.3 Comments on the artificial response in KFM01A:3

The responses observed in KFM01A, section 3, do not resemble the responses in the two lower sections. This indicates that the response is somehow artificial.

The hypothesis is that water from section 2 (and sometimes also from section 1) has flooded the PEM-hose and leaked into the borehole (section 3). See drawing of installation of packers, Appendix 1.

Section 3 is short, the casing ends at 102 m and a packer is placed at 109 m (Table 3-1), and is assumed to have a very low hydraulic conductivity (very few fractures are seen with BIPS). Earlier injection tests performed with the Pipe String System (PSS) show that the section 105.5–110.5 m has a transmissivity of about 3E–9 m^2/s.

According to pressure data in KFM01A, section 2, water pressure has during several periods reached the upper limit of the pressure sensor. That will correspond to a water level of 10 m above the pressure sensor. Since the pressure sensor was placed 10 m below the reference point (top of casing), the PEM-hose is then flooded if the pressure in section 2 increases further (this is also observed during data extraction 2003-08-26 16:00).

Figure 5-6 shows the pressure in the sections 1–3 in KFM01A during 24 hours. As can be seen the pressure in section 3 starts to increase when section 2 has reached its upper limit, and it then takes about nine hours for section 3 to reach the upper limit (e.g for the water to reach top of casing). The "upper limit values" in section 2 and 3 differ about 1.5 kPa, which is explained by the fact that the PEM-hoses ends about 0.16 m above top of casing (see Appendix 1).

From the increased water level in section 3, together with the borehole diameter and the given time, the total flow rate needed to verify the hypothesis can be calculated.

The casing diameter in the upper part of KFM01A is 0.265 m (Table 3-1). The increase of pressure in section 3 corresponds to about 2.25 m of water. Together it gives a total volume of 0.124 m^3, indicating a flow rate through the 8/6 mm Tecalan hose of 0.23 L/min, allowing a time of nine hours. The pressure loss due to friction in the 100 m Tecalan hose from section 2 would be about 7 kPa (standard nomogram produced by GEOTEC).

Considering the discussion above, the hypothesis, that the PEM-hose from section 2 has flooded and leaked into the borehole (section 3), seems verified

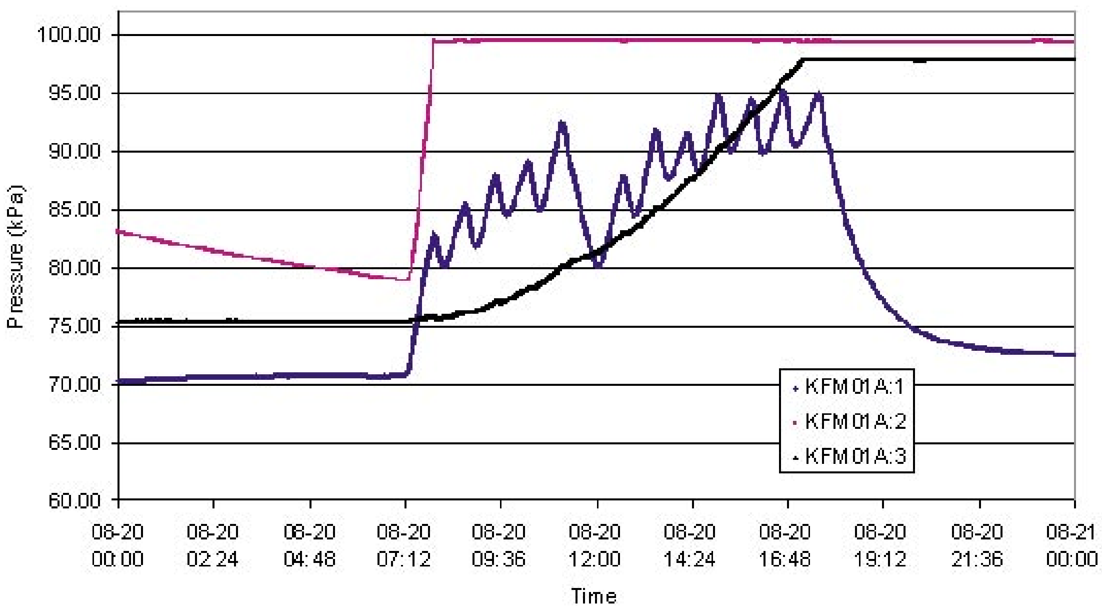


Figure 5-6. *Water pressure in the section 1–3 in KFM01A during 24 hours (2003-08-20 to 2003-08-21).*

6 Conclusions

During the drilling of KFM01B, water with a high pressure and flow rate was injected. The responses in the surrounding percussion boreholes were clear, but overall rather weak (about 1 kPa). Responses from the pumping tests that were performed after a day of drilling could therefore not be identified, due to the strong pressure recovery after drilling that occurred contemporarily.

The qualitative analysis is considered to be the most valuable in this report. A clear hydraulic connection between KFM01B and the percussion boreholes HFM01–03 was observed when the drilling reached the depth of c 20 m. At a drilling depth of c 72 m, a clear hydraulic connection between KFM01B and the two lower sections in KFM01A was revealed.

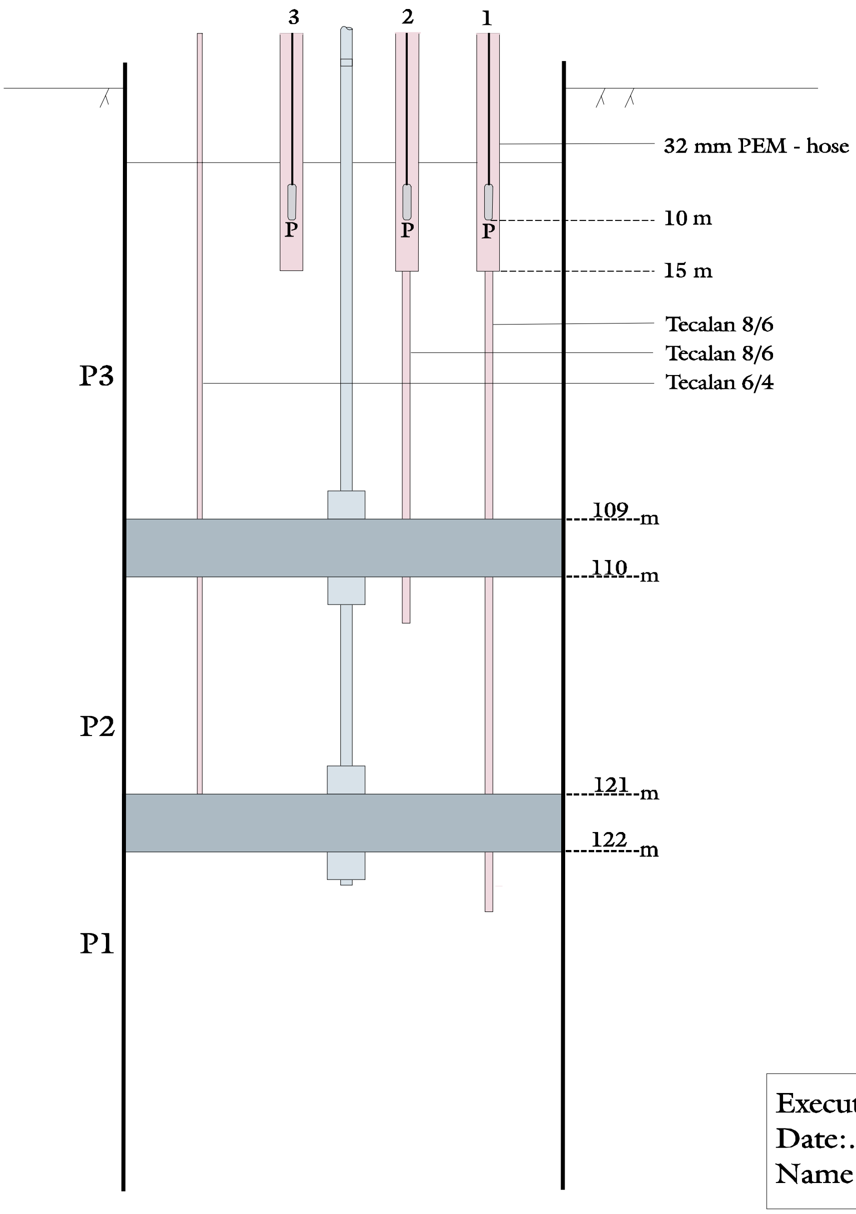
Due to the rather weak responses and uncertainties regarding details in drilling activity, the quantitative analysis in this report is considered to be merely a rough estimation. The results can be regarded as an attempt to test if the method is applicable under these circumstances. However, the result shows a good agreement with earlier interference tests performed in the area.

7 References

/1/ **SKB, 2003.** Hydraulic interference tests, Boreholes HFM01, HFM02 and HFM03. SKB P-03-35, Svensk Kärnbränslehantering AB.

Installation of packers in KFM01A

INSTALLATION OF PACKERS CORE BOREHOLES	Bh-name: KFM01A	Casing length: 101,45
INSTALLATION DRAWING/ ACTIVITY RECORD	Bh-diameter: 76 mm	Length outside casing:
	Bh-length: 1001,45	
	Bh-inclination:	
	Packer inflation pressure:	
	Packer inflation time:	
	Remarks:	



Executed:
Date:
Name:

Appendix 2

Core drilling record KFM01B

Activity Id	Idcode	Start Date	Bhlen (m)	Sub Start Date	Sub Stop Date
12981636	KFM01B	2003-07-29 09:17	9.40	2003-07-29 09:17	2003-07-29 09:17
12981636	KFM01B	2003-07-29 09:17	10.48	2003-07-29 09:17	2003-07-29 09:17
12981636	KFM01B	2003-07-29 09:17	11.69	2003-07-29 09:17	2003-07-29 12:18
12981636	KFM01B	2003-07-29 09:17	13.54	2003-07-30 07:00	2003-07-30 07:00
12981636	KFM01B	2003-07-29 09:17	17.00	2003-08-05 13:07	2003-07-30 13:07
12981636	KFM01B	2003-07-29 09:17	18.81	2003-08-05 14:10	2003-08-05 14:24
12981636	KFM01B	2003-07-29 09:17	20.81	2003-08-05 15:12	2003-08-05 15:24
12981636	KFM01B	2003-07-29 09:17	21.27	2003-08-05 15:44	2003-08-05 15:50
12981636	KFM01B	2003-07-29 09:17	26.42	2003-08-05 16:49	2003-08-05 17:23
12981636	KFM01B	2003-07-29 09:17	29.34	2003-08-05 17:33	2003-08-05 18:00
12981636	KFM01B	2003-07-29 09:17	30.10	2003-08-06 07:17	2003-08-06 07:25
12981636	KFM01B	2003-07-29 09:17	35.17	2003-08-06 08:14	2003-08-06 08:38
12981636	KFM01B	2003-07-29 09:17	38.15	2003-08-06 08:46	2003-08-06 09:11
12981636	KFM01B	2003-07-29 09:17	38.78	2003-08-06 09:19	2003-08-06 09:25
12981636	KFM01B	2003-07-29 09:17	43.75	2003-08-06 10:04	2003-08-06 10:19
12981636	KFM01B	2003-07-29 09:17	46.24	2003-08-06 10:33	2003-08-06 10:52
12981636	KFM01B	2003-07-29 09:17	47.00	2003-08-07 09:38	2003-08-07 09:52
12981636	KFM01B	2003-07-29 09:17	49.39	2003-08-07 10:52	2003-08-07 11:10
12981636	KFM01B	2003-07-29 09:17	51.73	2003-08-07 11:24	2003-08-07 11:36
12981636	KFM01B	2003-07-29 09:17	54.68	2003-08-11 09:11	2003-08-11 09:38
12981636	KFM01B	2003-07-29 09:17	57.68	2003-08-11 09:51	2003-08-11 10:24
12981636	KFM01B	2003-07-29 09:17	60.45	2003-08-11 10:37	2003-08-11 11:04
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12981636	KFM01B	2003-07-29 09:17	125.58	2003-08-18 17:08	2003-08-18 17:34
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12981636	KFM01B	2003-07-29 09:17	135.94	2003-08-19 12:49	2003-08-19 12:52
12981636	KFM01B	2003-07-29 09:17	139.63	2003-08-19 15:49	2003-08-19 15:58
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12981636	KFM01B	2003-07-29 09:17	208.70	2003-08-25 15:46	2003-08-25 16:09
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12981636	KFM01B	2003-07-29 09:17	15.56	2003-07-30 07:00	2003-07-30 14:00
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12981636	KFM01B	2003-07-29 09:17	13.62	2003-07-30 07:00	2003-07-30 07:00
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12981636	KFM01B	2003-07-29 09:17	11.00	2003-07-29 09:17	2003-07-29 09:17
12981636	KFM01B	2003-07-29 09:17	13.43	2003-07-30 07:00	2003-07-30 07:00
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Diagrams for transient analysis

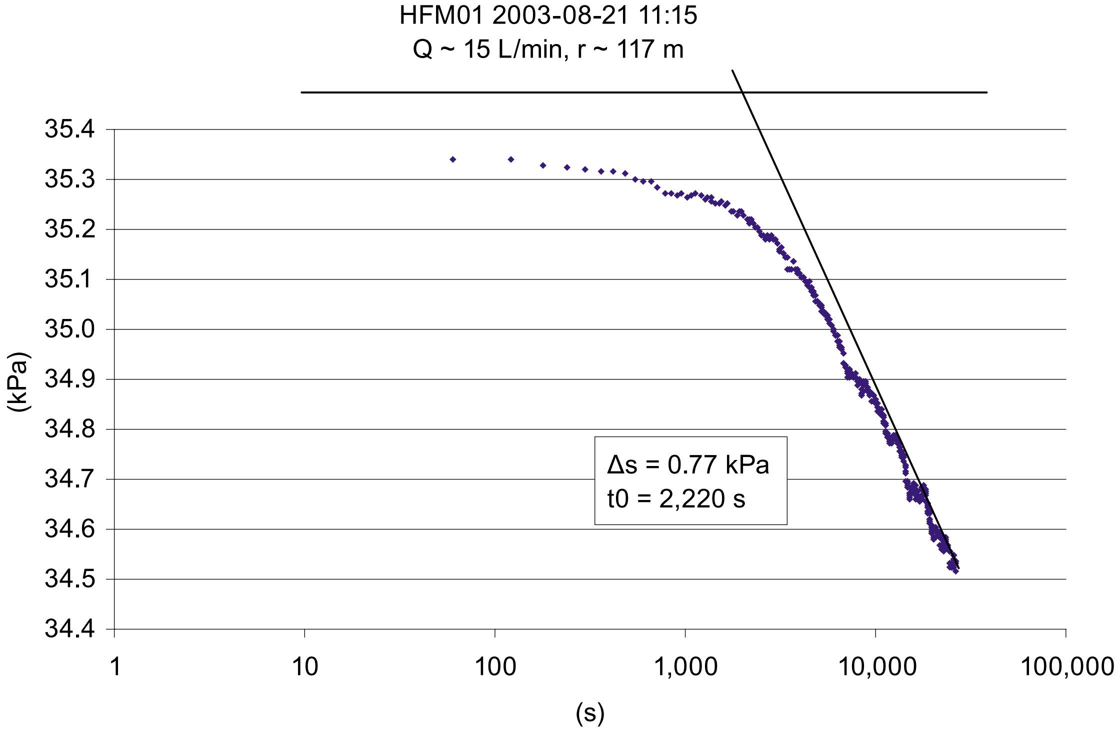

Figure A3-1. Drawdown in HFM01.

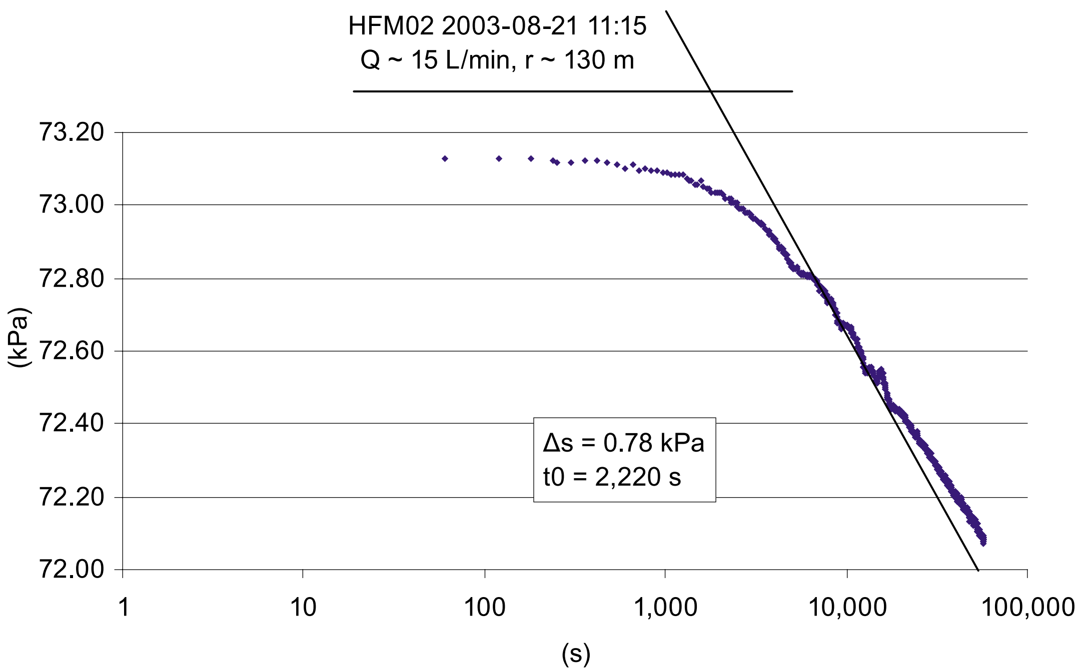

Figure A3-2. Drawdown in HFM02.

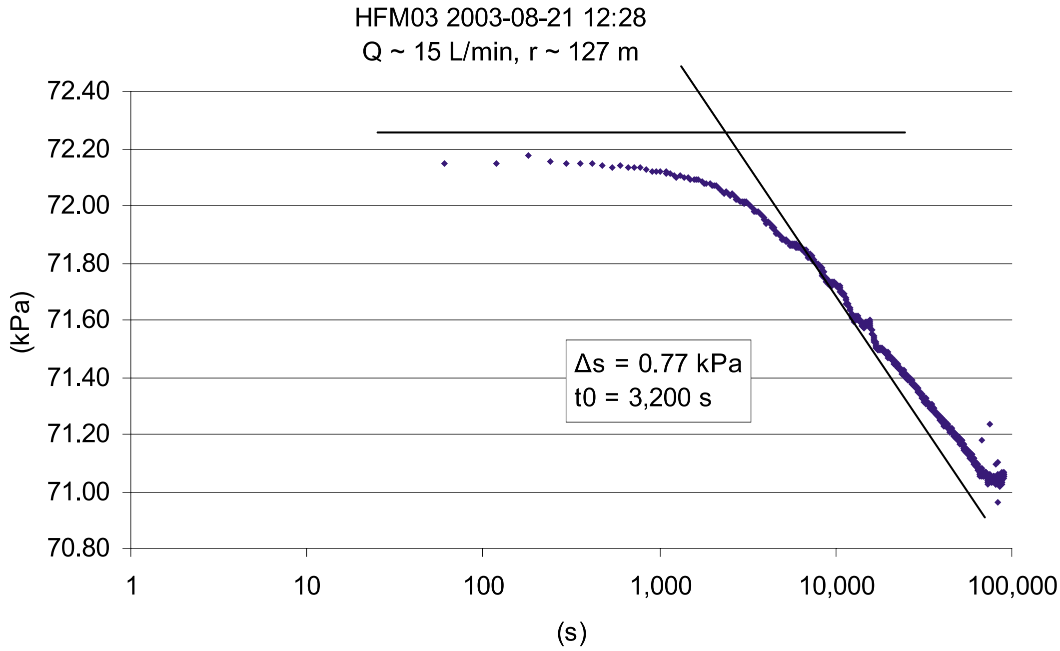

Figure A3-3. *Drawdown in HFM03.*