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Forsmark site investigation

Hydraulic interference test

Boreholes KFM04A, HFM10, HFM13, HFM19 and HFK252

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June 2005

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Abstract

An interference test was performed in order to increase the understanding of the hydraulic conditions in the north-western part of the candidate area in Forsmark. Previous observations indicate a hydraulic connection between the deep telescopic borehole KFM04A and the percussion boreholes HFM13 and HFM19. The interpreted deformation zone A2 is assumed to connect the boreholes hydraulically. The primary aim of the conducted interference test was to verify the assumed hydraulic connection and to document the relationship between different geologic structures in the area. The deformation zone, A2, is currently interpreted to intersect KFM04A in the interval 169–242 m along the borehole.

The interference test was performed by pumping in KFM04A. The pumping was performed in a section bounded by a packer at 169 m along the borehole and by the bottom of the borehole. The pumping section included the interval which was believed to be intersected by the interpreted deformation zone A2. The presumptive pressure responses were registered in observation boreholes HFM10, HFM13 and HFM19. Furthermore, pressure responses were registered in an old borehole, HFK252, which like HFM10 is located outside the candidate area. The boreholes HFM10 and HFK252 were included in the interference test in order to find if any hydraulic responses would be observed also to the west of the interpreted extension of zone A2.

The interference test verified the assumed hydraulic connection between KFM04A and the boreholes HFM10, HFM13 and HFM19. In addition, a distinct response was recorded in borehole HFK252. The largest drawdown, c 1.4 m, was obtained in HFM10: 100–150 m. The total drawdown in HFK252 was about 0.18 m and a drawdown of 0.01 m was reached approximately 2 h after the start of pumping.

In HFM13, section 100–150 m, a stronger response was observed than in the other sections of the borehole. The weakest responses were found in HFM19 where, furthermore, no obvious differences in pressure response were found between the different sections of the borehole.

It is, however, unlikely that any of the responses, with the possible exception of the response in HFK252, have been transmitted directly via the interpreted deformation zone A2. The pressure responses in HFM10 and HFK252 may have been transmitted via other zones or fractures intersecting the pumping borehole above the pumped section, somewhere in the interval 109–168 m along the borehole where a drawdown of c 1.6 m was generated.

Sammanfattning

Ett interferenstest genomfördes för att öka förståelsen för de hydrauliska sambanden i nordvästra delen av kandidatområdet i Forsmark. Tidigare observationer indikerar att det finns en hydraulisk kontakt mellan kärnborrhål KFM04A och hammarborrhål HFM13 och HFM19. Den tolkade deformationszonen A2 antas skapa en hydraulisk förbindelse mellan borrhålen. Det primära syftet med testet var att verifiera den förmodade hydrauliska förbindelsen och att dokumentera förhållanden mellan olika geologiska strukturer i området. Deformationszon A2 skär KFM04A i intervallet 169–242 m borrhålslängd.

Interferenstestet utfördes genom att en tryckavsänkning skapades i KFM04A. Pumpning utfördes i en sektion som begränsades av en manschett på 169 m och av borrhålsbotten. Pumpsektionen innehöll det avsnitt där deformationszon A2 tolkats skära borrhålet. Eventuella tryckresponser registrerades i HFM10, HFM13 och HFM19. Dessutom registrerades grundvattennivån i ett gammalt borrhål, HFK252, som likt HFM10 ligger utanför kandidatområdet. Borrhålen HFM10 och HFK252 inkluderades i interferenstestet för att undersöka om hydrauliska responser kunde observeras även väster om den utsträckning som zon A2 för närvarande tolkats ha.

Interferenstestet verifierade den förmodade hydrauliska kontakten mellan KFM04A och borrhålen HFM10, HFM13 och HFM19. Dessutom registrerades en tydlig tryckrespons i borrhål HFK252. Den största avsänkningen erhölls i HFM10: 100–150 m med ca 1,4 m. Den totala avsänkningen i HFK252 var ungefär 0,18 m och en avsänkning på 0,01 m uppnåddes ca två timmar efter pumpstart.

I HFM13 visade sektionen 100–150 m upp en större avsänkning än i övriga sektioner i borrhålet. Den svagaste tryckresponsen erhölls i HFM19 där det dessutom inte var någon skillnad i avsänkning mellan de olika sektionerna i hålet.

Det är dock osannolikt att tryckresponserna, möjligen med undantag av den i HFK252, har transporterats direkt via den tolkade deformationszonen A2. Tryckresponserna i HFM10 och HFK252 kan ha transporterats via andra zoner eller sprickor som skär pumpborrhålet ovanför den pumpade sektionen, någonstans i intervallet 109–168 m längs borrhålet där en avsänkning på ca 1,6 m erhölls.

Contents

1 Introduction

The aim of hydraulic interference tests is to get support for interpretations of geologic structures in regard to their hydraulic and geometric properties. Furthermore, an interference test may provide information about hydraulic connectivity and hydraulic boundary conditions for the tested area. Finally, interference tests make up the basis for calibration of numerical models of the area.

This report documents the results from an interference test performed in order to verify an assumed hydraulic connection between the deep core-drilled borehole KFM04A and percussion boreholes HFM13 and HFM19. In addition, pressure was registered and responses evaluated qualitatively from percussion boreholes HFM10, close to KFM04A (but outside the candidate area), and HFK252 situated outside the candidate area. The locations of the boreholes involved in the interference test together with interpreted seismic reflectors are shown in Figure 1-1.

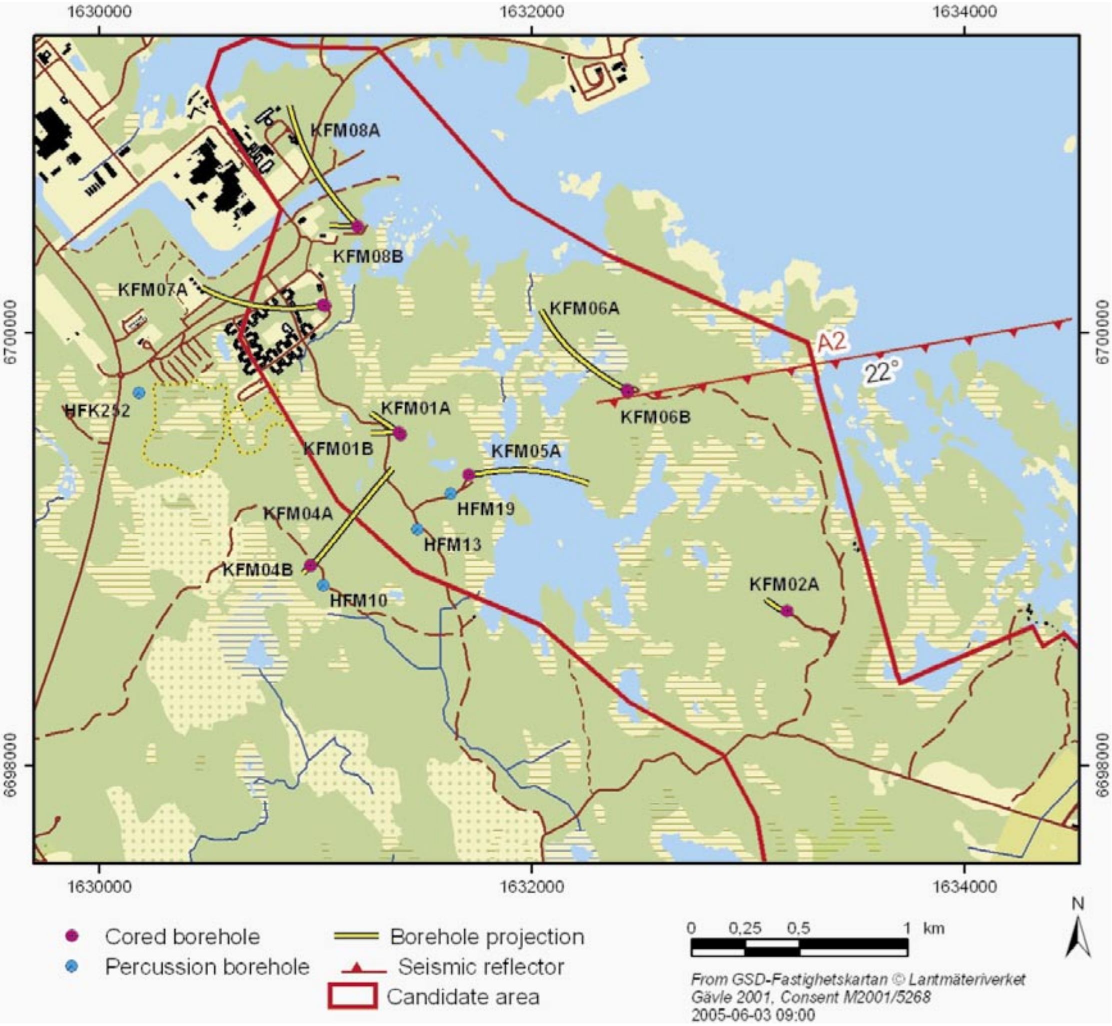

Figure 1-1. *The investigation area at Forsmark including the candidate area selected for more detailed investigations. The boreholes included in the interference test were KFM04A (pumping borehole), as well as HFM10, HFM13, HFM19 and HFK252 (observation boreholes).*

From pumping tests and flow logging, /1/, performed prior to the interference test, the total transmissivity of the pumping borehole, KFM04A, was estimated at 2.5×10^{-4} m^2/s. The transmissivities of the observation boreholes, HFM10, HFM13, HFM19 have also been evaluated previous to the interference test and were estimated at 3.11×10^{-4} m^2/s, 3.12×10^{-4} m^2/s and 3.74×10^{-4} m^2/s respectively /2, 3, 4/. HFK252, the percussion borehole outside the candidate area, has not been tested prior to this interference test.

The interference test was performed as part of the site investigation at Forsmark. The test was carried out at the end of April to the beginning of June, 2005, by Geosigma AB. The work was conducted in accordance with activity plan AP PF 400-05-035. In Table 1-1 controlling documents for the performance of this activity are listed. Both activity plan and method descriptions are internal controlling documents of SKB.

Table 1-1. Controlling documents for performance of the activity.

Activity plan	Number	Version
Undersökning av hydraulisk kontakt mellan KFM04A och HFM13 och HFM19 via deformationszon A2	AP PF 400-05-035	1.0
Method descriptions	**Number**	**Version**
Instruktion för analys av injektions- och enhålspumptester	SKB MD 320.004	1.0
Metodbeskrivning för interferenstester	SKB MD 330.003	1.0

2 Objectives

An interference test was performed in order to increase the understanding of the hydraulic conditions in the north-western part of the candidate area in Forsmark. Previous observations indicate a hydraulic connection between the deep telescopic borehole KFM04A and the percussion boreholes HFM13 and HFM19. It is the interpreted deformation zone A2 that is assumed to connect the boreholes hydraulically. The primary aim of the conducted interference test was to verify the assumed hydraulic connection and to document the relationship between different geologic structures in the area. The goal was also to find out if the interpreted deformation zone A2 reached further to the west than current interpretations indicate. The deformation zone A2 is interpreted to intersect KFM04A between 169–242 m along the borehole.

The interference test was conducted by pumping in KFM04A and monitoring possible responses in boreholes of interest, primarily HFM13 and HFM19 but also HFM10 and HFK252, situated further to the west than the interpreted extent of deformation zone A2.

3 Scope

3.1 Boreholes tested

Technical data of the boreholes tested are presented in Table 3-1. The reference point in the boreholes is always top of casing (ToC). The Swedish National coordinate system (RT90 2.5 gon V0:–15) is used in the x-y-direction together with RHB70 in the z-direction. The reported borehole diameter for boreholes HFM10, HFM13 and HFM19 in Table 3-1 refers to the final diameter of the borehole after drilling to full depth. The borehole diameter (measured as the diameter of the drill bit) may, for percussion drilled boreholes, decrease along the borehole due to worning of the drill bit. The coordinates of the boreholes at ground surface are shown in Table 3-2.

Pressure was also registered in borehole HFK252 outside the candidate area. Only limited geometrical data exist from this borehole. According to SICADA, the yield of the borehole was c 800 L/h during drilling.

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

Borehole data							
Bh ID	**Elevation of top of casing (ToC) (masl)**	**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)**
KFM04A	8.771	0–12.030	0.350	–60.080	45.240	Casing ID	2003-11-19
		12.030–107.330	0.247			Casing ID	
		107.330–107.420	0.161			Casing ID	
		107.420–108.690	0.086			Casing ID	
		108.690–1,001.420	0.077			Borehole	
HFM10	4.986	0–11.800	0.160	–68.700	92.934	Casing ID	2003-08-19
		11.800–150.000	0.139			Borehole	
HFM13	5.687	0.000–14.900	0.160	–58.845	51.194	Casing ID	2003-10-02
		14.900–175.600	0.135			Borehole	
HFM19	3.656	0–12.040	0.160	–58.103	280.915	Casing ID	2003-12-18
		12.040–185.200	0.137			Borehole	
HFK252	9.081	0–9.000	0.165	–60.101	69.112	Casing ID	2001-12-18
		9.000–80.000	0.155			Borehole	

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

Borehole data Bh ID	Northing (m)	Easting (m)
KFM04A	6698921.744	1630978.964
HFM10	6698834.785	1631037.188
HFM13	6699093.678	1631474.404
HFM19	6699257.585	1631626.925
HFK252	6699723.977	1630186.134

3.2 Tests performed

The borehole sections involved in the interference test in KFM04A are listed in Table 3-3. The times referred to in Table 3-3 are the start and stop times of data registration in the various sections. Alternatively, for the observation sections in boreholes other than KFM04A, the start and stop times refer to the start and stop times of the downloaded data files used for evaluation. The amount of data that was extracted from HMS, the Hydro Monitoring System, was adjusted to correspond to available data from the pumping borehole. HMS is registering pressure continuously. The test performance was according to the Geosigma quality plan ("Kvalitetsplan för SKB uppdrag – Undersökning av hydraulisk kontakt mellan borrhålen KFM04A och HFM13 och HFM19 via deformationszon A2, K535065, Stig Jönsson, 2005-04-15", Geosigma and SKB internal controlling document) and according to the methodology description for interference tests, SKB MD 330.003.

The interpreted points of application, see explanation below, and lengths of the borehole sections involved in the interference test together with their estimated transmissivities from previous investigations /1, 2, 3/, are presented in Table 3-4. The distances between the pumping borehole section and the observation borehole sections are shown in Table 3-5. The distances between the hydraulic points of application in the boreholes were calculated by applying ordinary trigonometrical relations.

The estimation of the points of application in the different sections of the pumping borehole and the four observation boreholes were made in one of two ways. Either, if it was obvious that some flow anomaly contributed to the greater part of the transmissivity in one section, the position of that anomaly was chosen as the point of application. Otherwise, if there was no evident part of the section that could be chosen with regard to transmissivity, the midpoint of the section was selected.

Table 3-3. Borehole sections involved in the interference test performed in KFM04A, HFM10, HFM13, HFM19 and HFK252, see Figure 1-1.

Bh ID	Test section (m)	Test type[1]	Test config	Test start date and time (YYYY-MM-DD tt:mm)	Test stop date and time (YYYY-MM-DD tt:mm)
KFM04A	0–76.5	2	Above packer	2005-04-28 12:31	2005-05-09 11:59
KFM04A	77.5–167.63	2	Between packers	2005-04-28 12:12	2005-05-09 11:51
KFM04A	168.63–1,001	1B	Below packer	2005-04-28 12:12	2005-05-09 11:51
HFM10	0–99	2	Above packer	2005-04-28 00:00	2005-05-09 22:00
HFM10	100–150	2	Below packer	2005-04-28 00:00	2005-05-09 22:00
HFM13	0–100	2	Above packer	2005-04-28 00:00	2005-05-09 22:00
HFM13	101–158	2	Between packers	2005-04-28 00:00	2005-05-09 22:00
HFM13	159–173	2	Below packer	2005-04-28 00:00	2005-05-09 22:00
HFM19	0–103	2	Above packer	2005-04-28 00:00	2005-05-09 22:00
HFM19	104–167	2	Between packers	2005-04-28 00:00	2005-05-09 22:00
HFM19	168–182	2	Below packer	2005-04-28 00:00	2005-05-09 22:00
HFK252	0–80	2	Open borehole	2005-04-28 12:10	2005-05-09 22:55

1) 1B: Pumping test-submersible pump. 2: Interference test.

Table 3-4. Points of application and lengths of the test sections as well as their estimated transmissivities from previous investigations /1, 2, 3/.

Bh ID	Test section (m)	Point of application (m along the borehole)	Section length (m)	Transmissivity (m^2/s)
KFM04A	168.6–1,001.4 [1)]	217	832.8	$2.5–10^{-4}$
HFM10	0–99.0	50	99.0	–
HFM10	100.0–150.0	118	50.0	$3.11–10^{-4}$
HFM13	0–100.0	50	100.0	–
HFM13	101.0–158.0	106	57.0	$2.11 \cdot 10^{-5}$
HFM13	159.0–173.0	162	14.0	$2.91 \cdot 10^{-4}$
HFM19	0–103.0	101	103.0	$4.02 \cdot 10^{-5}$
HFM19	104.0–167.0	150	63.0	$2.17 \cdot 10^{-5}$
HFM19	168.0–182.0	176	14.0	$2.75 \cdot 10^{-4}$
HFK252 [2)]	9.0–80.0	40	80.0	–

[1)] Reflector A2 is interpreted in the interval 169–242 m.

[2)] The borehole HFK252 has not been tested previously and no transmissivity data are thus available. The inflow during drilling was estimated at c 800 L/h.

Table 3-5. Calculated distances from the pumping borehole KFM04A to the observation borehole sections involved in the interference test.

Pumping section in KFM04A (m)	Observation sections Borehole ID	Section (m)	Distance (m)
168.6–1,001.4	HFM10	0–99.0 m	219
	HFM10	100.0–150.0	198
168.6–1,001.4	HFM13	0–100.0	482
	HFM13	101.0–158.0	496
	HFM13	159.0–173.0	517
168.6–1,001.4	HFM19	0–103.0	594
	HFM19	104.0–167.0	562
	HFM19	168.0–182.0	547
168.6–1,001.4	HFK252	0–80.0	1,128

4 Description of equipment

4.1 Overview

The temporary test system used for the interference test is described in Geosigma quality plan (“Kvalitetsplan för SKB uppdrag – Undersökning av hydraulisk kontakt mellan borrhålen KFM04A och HFM13 och HFM19 via deformationszon A2, K535065, Stig Jönsson, 2005-04-15”). The equipment in the pumping borehole, KFM04, consisted of the following parts:

- 4" submersible pump with submarine contact and hose to the ground surface,
- wire to anchor the pump,
- manual winch for hoisting the pump, mounted on the casing,
- 3 pressure transducers in the borehole,
- Tecalan hose to connect pressure transducers to the test sections,
- two packers to isolate two sections in the borehole,
- pipe string to connect packed off sections,
- aluminium rods for lowering the installation,
- flow metre at the surface,
- data logger to sample data from the flow metre and the pressure transducers,
- flow rate control valve at the surface,
- PC to visualize the data.

Much of the equipment used for the installation in KFM04A was taken from a compound test kit normally referred to as HTHB (Swedish abbreviation for Hydraulic Test System for Percussion Boreholes), and is described in SKB MD 326.001. The HTHB unit is designed to perform pumping tests in open percussion drilled boreholes under a single packer or between double packers in isolated sections of the boreholes down to a total depth of 200 m. A number of other tests can be performed with the HTHB system although they are not described here. The pumping tests can be performed with either constant hydraulic head or alternatively, with constant flow rate.

All the observation boreholes except HFK252 are connected to the SKB hydro monitoring system (HMS), where pressure is recorded continuously. In HFK252, a temporarily installed Mini-Troll pressure transducer was used to monitor the presumptive pressure response.

The estimated lower and upper practical measurement limits for the actual equipment used for the interference test, expressed in terms of specific flow (Q/s), are Q/s-L = 3×10^{-7} m^2/s and Q/s-U = 5×10^{-3} m^2/s, respectively.

4.2 Measurement sensors

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

The Mini-Troll pressure logger in the upper section of KFM04A has a measurement range of 0–686.9 kPa (70 psi) and uses 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. The specifications of the Mini-Troll transducer in HFK252 are similar.

Table 4-2 shows the type and position for each transducer used in the test. Positions are given in metres from reference point, i.e. top of casing (ToC).

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

Technical specification					
Parameter		**Unit**	**Sensor**	**Test system**	**Comments**
p-absolute (HTHB)	Output signal	mA	4–20		
	Meas range	kPa	0–1,500		
	Resolution	kPa	0.05		
	Accuracy	kPa	± 1.5 *	± 10	Depending on uncertainties of the sensor position
p-absolute (Mini-Troll)	Output signal	mA	Digital	Same as for the sensor	Mini-Troll is a combined sensor and data logger unit
	Meas range	kPa	0–686.9		
	Resolution	kPa	0.01		
	Accuracy	kPa	± 0.2 *		
Flow rate (surface)	Output signal	mA	4–20		Passive
	Meas range	L/min	1–500	1–c 165	Pumping tests
	Resolution	L/min	0.1	0.1	
	Accuracy	% o r**	± 0.5	± 0.5	

* Includes hysteresis, linearity and repeatability.

** Maximum error in % of actual reading (% o r).

Table 4-2. Type and position of sensors (from ToC) used during the interference test in KFM04A.

Borehole information				Sensors	
ID	**Test interval (m)**	**Test configuration**	**Test type**[1]	**Type**	**Position**[2] **(m b ToC)**
KFM04A	168.6–1,001.4	Below packer	1B	p-absolute (HTHB)	46 (168.6)
KFM04A	77.5–168.6	Between packers	2	p-absolute (HTHB)	46 (77.5)
KFM04A	12–76.5	Above packer	2	p-absolute (Mini-Troll)	29.3
HFM10	0–99.0 m	Above packer	2	HMS	29.8
HFM10	100.0–150.0	Below packer	2	HMS	29.8
HFM13	0–100.0	Above packer	2	HMS	29.8
HFM13	101.0–158.0	Between packers	2	HMS	29.8
HFM13	159.0–173.0	Below packer	2	HMS	29.8
HFM19	0–103.0	Above packer	2	HMS	29.8
HFM19	104.0–167.0	Between packers	2	HMS	29.8
HFM19	168.0–182.0	Below packer	2	HMS	29.8
HFK252	0–80.0	Open borehole	2	p-absolute (Mini-Troll)	–

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

2) Distances within parenthesis are the distances to actual pressure measuring point. Pressure changes are then distributed to the transducer via a water-filled Tecalan hose. Execution.

5 Execution

The test was performed in accordance with the activity plan and Geosigma quality plan as well as the methodology descriptions for interference tests, SKB MD 330.003. However, no response matrix was prepared.

5.1 Preparations

All sensors included in the test system of the pumping borehole are calibrated at the Geosigma engineering workshop in Librobäck, Uppsala. Calibration is performed on a yearly basis, or more often if needed. The last calibration of the pressure transducers P1 and P2, which were used in the pumping borehole, was conducted in April, 2004. The flow metre was calibrated in May, 2004, and the Mini-Troll transducer in borehole KFM04A was using the same calibration constants as installed by the manufacturer. Before the tests, function checks and cleaning of equipment were performed according to the activity plan.

5.2 Equipment check

An equipment check was performed at the Geosigma engineering workshop in Uppsala as well as at the site as a simple and fast test to establish the operating status of sensors and other equipment. In addition, calibration constants were implemented and checked.

To check the function of the pressure sensors, the pressure in air was recorded and found to be as expected. Submerged in water, the pressure coincided well with the total head of water, while lowering.

5.3 Procedure

The pumping test in KFM04A was carried out as a constant flow rate test followed by a pressure recovery period. The pressure interference was recorded in four percussion boreholes, HFM10, HFM13, HFM19 and HFK252. In HFK252, open borehole pressure was registered. In the other boreholes, permanent installations have been made with packers isolating different intervals of the respective boreholes. Pressure was registered in the different sections. In KFM04A two packers were installed at c 77 m and c 168 m. The section 169–1,001 m in KFM04A was the pumping section. The pump was lowered to approximately 31 m along the borehole in the upper section. The upper section was then connected to the pumping section via a string of aluminium pipe. The strategy behind the installation was to isolate the interpreted deformation zone A2 from other, shallower, conductive zones. A schematic view of the installation is presented in Figure 5-1. The flow rate in the pumping borehole was chosen based on the results from earlier pumping tests and flow logging in KFM04A. The flow rate was manually adjusted by a control valve and monitored by an electromagnetic flow metre. The data logger sampled data at a suitable frequency determined by the operator, see Table 5-3. Pumping in KFM04A was carried out using a 4" submersible pump during a period of c 120 h. The subsequent pressure recovery was measured for c 140 h.

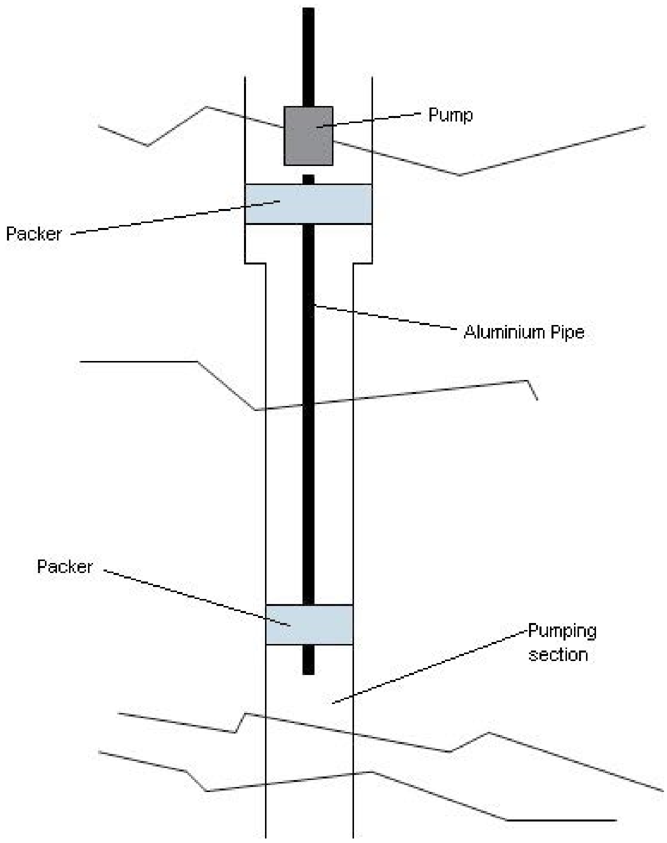

***Figure 5-1**. Schematic view of the pumping installation in borehole KFM04A.*

In KFM04A, the absolute pressure transducers connected to the HTHB-logger were attached to the pump hose 46 m below the top of casing. The transducers were connected directly to the data logger via cables. The Mini-Troll transducer measuring pressure in the upper section of KFM04A was hanging at 29.3 m below the top of casing. In observation borehole HFK252 monitoring of the pressure/water level was carried out using a Mini-Troll pressure transducer. In the other observation boreholes the hydro monitoring system was utilized for pressure registration.

Approximate sampling intervals for flow rate and pressure in the pumping borehole KFM04A are presented in Table 5-3. The Mini-Troll logger in KFM04A worked with similar logging frequencies. In HFK252 the Mini-Troll was set to logging once every 300 s.

Table 5-3. Approximate sampling intervals used for pressure registration in KFM04A during the interference test.

Time interval (s) from start/stop of pumping	Sampling interval (s)
1–500	1
501–4,500	10
> 4,500	60

5.4 Data handling

Flow and pressure data from the pumping borehole, KFM04A, were downloaded from the logger (Campbell CR 5000) to a laptop running the program PC9000 and are, already in the logger, transformed to engineering units. All files are comma-separated (*.DAT) when copied to a computer. A list of the data files from the data logger is shown in Appendix 1.

The pressure data stored in the Mini-Troll logger are downloaded to a laptop in a similar fashion as described above. The only difference is that the software used is called Win-Situ. The files produced by the logger are binary files that are converted by Win-Situ to ordinary text files.

5.5 Analyses and interpretation

No quantitative analysis has been performed for the interference test in KFM04A. However, a qualitative analysis in accordance with the methodology descriptions for interference tests, SKB MD 330.003, was conducted and is reported in Chapter 5 below.

5.6 Nonconformities

There were no deviations from the activity plan during this commission.

6 Results

6.1 Nomenclature and symbols

The nomenclature and symbols used for the results of the single-hole and interference test 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), respectively (both are SKB internal controlling documents). Additional symbols used are explained in the text.

6.2 Interference test in KFM04A

The primary aim of the interference test was to acquire a better understanding of the hydraulic conditions in the north-western part of the candidate area in Forsmark. The interference test performed was also specifically intended to confirm indications of a hydraulic connection between KFM04A and the percussion boreholes HFM13 and HFM19 via the interpreted deformation zone A2. Pressure responses were also registered in HFM10 close to the pumping borehole KFM04A and HFK252. Both HFM10 and HFK252 are situated outside the candidate area and were included in the interference test in order to check if hydraulic responses could be observed also west of the interpreted extension of zone A2.

Visual inspection of the pressure responses, presented in Figure A2-3 to A2-6 in Appendix 2, indicate that clear responses were registered in all borehole sections included in the interference test. The strength of the responses differs however. The lower section in HFM10 and borehole HFK252 are strongly affected by the pumping in KFM04A, whereas the responses in HFM13 and HFM19 are clear but much weaker. The measured drawdowns (s_p) at the end of the flow period and response time lags (dt_L) in all of the observation sections are shown in Tables 6-11 and 6-12. The response time is defined as the time lag after start of pumping until a drawdown response of 0.01 m was observed in the actual observation section or borehole.

All pressure data reported in this paper have been corrected for barometric pressure variations. This is true also for the data received from the HMS. All times presented are Swedish normal times, i.e. no adjustment for daylight saving time has been made for any reported times. There was no precipitation reported during the pumping phase of the testing period. During the recovery, however, there was a total of c 17 mm of rainfall. The precipitation during the recovery period is likely to be the explanation for the slightly higher pressure levels in most of the observation sections at the end of the recovery period in comparison to before the start of pumping.

6.2.1 Pumping borehole KFM04A

General test data for the pumping test in KFM04A are presented in Table 6-1.

Table 6-1. General test data for the pumping test in KFM04A: 169–1,001 m.

General test data				
Pumping borehole	KFM04A			
Test type[1]	Constant Rate withdrawal and recovery test			
Test section (open borehole/packed-off section)	packed-off section			
Test No	1			
Field crew	(GEOSIGMA AB)			
Test equipment system				
General comment	Interference test			
	Nomenclature	**Unit**	**Value**	
Borehole length	L	m	1,001.42	
Casing length	L_c	m	12.03	
Test section – secup	Secup	m	168.6	
Test section – seclow	Seclow	m	1,001.42	
Test section length	L_w	m	832.82	
Test section diameter[2]	$2 \times r_w$	mm	77	
Test start (start of pressure registration)		yymmdd hh:mm	050428 12:12	
Packer expanded		yymmdd hh:mm:ss	050427 20:06	
Start of flow period		yymmdd hh:mm:ss	050428 12:50	
Stop of flow period		yymmdd hh:mm:ss	050503 13:15	
Test stop (stop of pressure registration)		yymmdd hh:mm	050509 11:51	
Total flow time	t_p	min	7,226	
Total recovery time	t_F	min	8,555	
Pressure data				
Pressure in test section before start of flow period	p_i	kPa	1,383.3	
Pressure in test section before stop of flow period	p_p	kPa	1,207.6	
Pressure in test section at stop of recovery period	p_F	kPa	1,381.7	
Pressure change during flow period (p_i–p_p)	dp_p	kPa	175.7	
Flow data				
Flow rate from test section just before stop of flow period	Q_p	m^3/s	0.00087	
Mean (arithmetic) flow rate during flow period	Q_m	m^3/s	0.00095	
Total volume discharged during flow period	V_p	m^3	381	
Manual groundwater level measurements in KFM04A (168.6–1,001.4 m)	**GW level**			
Date				
YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b ToC)**	**(masl)**
2005-04-27	09:37	–1,633	7.17	2.56
2005-04-27	20:37	–973	7.17	2.56
2005-04-28	11:26	–84	7.23	2.50

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 53 L/min and the duration of the flow period was c 120 h. A constant flow rate was reached after c 15 h. The final drawdown in KFM04A was approximately 18 m. The pressure recovery was measured for about 142 h. An overview of flow and pressure responses in the different sections of KFM04A is presented in Figures A2-1 and A2-2 in Appendix 2.

A clear response to the pumping was detected in the packed off section above the pumping section, see Figure A2-2. The generated drawdown in this section was c 1.6 m which probably induced secondary pressure responses in other observation sections transmitted via zones or fractures intersecting the section, cf Section 6.2.11.

6.2.2 Observation section HFM10: 0–99 m

General test data from the observation section HFM10, 0–99 m, are presented in Table 6-2. In Figure A2-3 in Appendix 2 an overview of the pressure responses in observation borehole HFM10 is shown.

Comments on the test

A clear response to pumping was detected in this section, see Figure A2-3. The total drawdown during the flow period was c 0.72 m. A drawdown of about 0.01 m was reached approximately 2.5 h after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h.

Table 6-2. General test data from the observation section HFM10: 0–99 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	masl	2.510
Hydraulic head in test section before stop of flow period	h_p	masl	1.793
Hydraulic head in test section at stop of recovery period	h_F	masl	2.533
Hydraulic head change during flow period ($h_i - h_p$)	dh_p	masl	0.717

6.2.3 Observation section HFM10: 100–150 m

General test data from the observation section HFM10, 100–150 m, are presented in Table 6-3. In Figure A2-3 in Appendix 2 an overview of the pressure responses in observation borehole HFM10 is shown.

Comments on the test

A clear response to pumping was detected in this section, see Figure A2-3. The total drawdown during the flow period was c 1.43 m. A drawdown of about 0.01 m was reached approximately 11 minutes after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h.

Table 6-3. General test data from the observation section HFM10: 100–150 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	masl	2.986
Hydraulic head in test section before stop of flow period	h_p	masl	1.559
Hydraulic head in test section at stop of recovery period	h_F	masl	2.931
Hydraulic head change during flow period ($h_i - h_p$)	dh_p	masl	1.427

6.2.4 Observation section HFM13: 0–100 m

General test data from the observation section HFM13, 0–100 m, are presented in Table 6-4. In Figure A2-4 in Appendix 2 an overview of the pressure responses in observation borehole HFM13 is shown.

Comments on the test

A weak but unmistakable response to pumping was detected in this section, see Figure A2-4. The total drawdown during the flow period was c 0.04 m. A drawdown of about 0.01 m was reached approximately 22 h after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h.

Table 6-4. General test data from the observation section HFM13: 0–100 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	masl	2.862
Hydraulic head in test section before stop of flow period	h_p	masl	2.825
Hydraulic head in test section at stop of recovery period	h_F	masl	2.934
Hydraulic head change during flow period ($h_i - h_p$)	dh_p	masl	0.037

6.2.5 Observation section HFM13: 101–158 m

General test data from the observation section HFM13, 101–158, m are presented in Table 6-5. In Figure A2-4 an overview of the pressure responses in observation borehole HFM13 is shown.

Comments on the test

A clear response to pumping was detected in this section, see Figure A2-4. The total drawdown during the flow period was c 0.10 m. A drawdown of about 0.01 m was reached approximately 18 h after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h.

Table 6-5. General test data from the observation section HFM13: 101–158 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	masl	1.335
Hydraulic head in test section before stop of flow period	h_p	masl	1.234
Hydraulic head in test section at stop of recovery period	h_F	masl	1.381
Hydraulic head change during flow period ($h_i - h_p$)	dh_p	masl	0.101

6.2.6 Observation section HFM13: 159–173 m

General test data from the observation section HFM13, 159–173 m, are presented in Table 6-6. In Figure A2-4 an overview of the pressure responses in observation borehole HFM13 is shown.

Comments on the test

A weak but clear response to pumping was detected in this section, see Figure A2-4. The total drawdown during the flow period was c 0.04 m. A drawdown of about 0.01 m was reached approximately 14 h after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h.

Table 6-6. General test data from the observation section HFM13: 159–173 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	masl	0.612
Hydraulic head in test section before stop of flow period	h_p	masl	0.572
Hydraulic head in test section at stop of recovery period	h_F	masl	0.677
Hydraulic head change during flow period ($h_i - h_p$)	dh_p	masl	0.040

6.2.7 Observation section HFM19: 0–103 m

General test data from the observation section HFM19, 0–103 m, are presented in Table 6-7. In Figure A2-5 in Appendix 2 an overview of the pressure responses in observation borehole HFM19 is shown.

Comments on the test

A weak but clear response to pumping was detected in this section, see Figure A2-5. The total drawdown during the flow period was c 0.02 m. A drawdown of about 0.01 m was reached approximately 16 h after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h.

Table 6-7. General test data from the observation section HFM19: 0–103 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	masl	2.730
Hydraulic head in test section before stop of flow period	h_p	masl	2.709
Hydraulic head in test section at stop of recovery period	h_F	masl	2.787
Hydraulic head change during flow period ($h_i - h_p$)	dh_p	masl	0.021

6.2.8 Observation section HFM19: 104–167 m

General test data from the observation section HFM19, 104–167 m, are presented in Table 6-8. In Figure A2-5 an overview of the pressure responses in observation borehole HFM19 is shown.

Comments on the test

The response is very similar to the one in the upper section of HFM19. A weak but clear response to pumping was detected, see Figure A2-5. The total drawdown during the flow period was c 0.02 m. A drawdown of about 0.01 m was reached approximately 16 h after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h.

Table 6-8. General test data from the observation section HFM19: 104–167 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	masl	2.905
Hydraulic head in test section before stop of flow period	h_p	masl	2.884
Hydraulic head in test section at stop of recovery period	h_F	masl	2.971
Hydraulic head change during flow period ($h_i - h_p$)	dh_p	masl	0.021

6.2.9 Observation section HFM19: 168–182 m

General test data from the observation section HFM19, 168–182 m, are presented in Table 6-9. In Figure A2-5 an overview of the pressure responses in observation borehole HFM19 is shown.

Comments on the test

A very weak but clear response to pumping was detected in this section, see Figure A2-5. The total drawdown during the flow period was c 0.02 m. A drawdown of about 0.01 m was reached approximately 17 h after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h.

Table 6-9. General test data from the observation section HFM19: 168–182 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	masl	2.024
Hydraulic head in test section before stop of flow period	h_p	masl	2.009
Hydraulic head in test section at stop of recovery period	h_F	masl	2.096
Hydraulic head change during flow period ($h_i - h_p$)	dh_p	masl	0.015

6.2.10 Observation section HFK252: 0–80 m

General test data from the observation section HFK252, 0–80 m, are presented in Table 6-10. In Figure A2-6 in Appendix 2 an overview of the pressure responses in observation borehole HFK252 is shown.

Comments on the test

A clear response to pumping was detected in this borehole, see Figure A2-6. The total drawdown during the flow period was c 0.17 m. A drawdown of about 0.01 m was reached approximately 2 h after start of pumping in KFM04A. The drawdown was fully recovered after the recovery period of around 142 h. No reasonable explanation has been found for the sudden rise of pressure approximately 50 h into the flow period, which is clearly seen in Figure A2-6.

Table 6-10. General test data from the observation section HFK252: 0–80 m during the interference test in KFM04A.

Pressure data	Nomenclature	Unit	Value
Pressure in test section before start of flow period	p_i	kPa	32.94
Pressure in test section before stop of flow period	p_p	kPa	31.22
Pressure in test section at stop of recovery period	p_F	kPa	32.86
Pressure change during flow period ($p_i - p_p$)	dp_p	kPa	1.72

6.2.11 Observation section KFM04A: 109–168 m

General test data from the observation section KFM04A, 109–168 m, are presented in Table 6-11. In Figure A2-2 in Appendix 2 an overview of the pressure responses in borehole KFM04A is shown.

Comments on the test

A clear response to pumping was detected in this packed off section of the pumping borehole, see Figure A2-2. The total drawdown during the flow period was c 1.6 m. The intention of using packers to isolate the pumping section in KFM04A from more shallow parts of the borehole was to avoid transmitting pressure responses via fracture zones closer to the surface. It is obvious that a hydraulic connection existed between the pumping section and this section which led to the rather strong response. According to the difference flow logging /1/ there exist conductive fractures in this section. The generated drawdown in this section is likely to induce secondary pressure responses in other observation sections transmitted via zones or fractures intersecting this section.

Table 6-11. General test data from the observation section KFM04A: 109–168 m during the interference test in KFM04A: 169–1,001.

Pressure data	Nomenclature	Unit	Value
Pressure in test section before start of flow period	p_i	kPa	872.7
Pressure in test section before stop of flow period	p_p	kPa	856.3
Pressure in test section at stop of recovery period	p_F	kPa	869.9
Pressure change during flow period (p_i–p_p)	dp_p	kPa	16.4

6.3 Response analysis

A response analysis according to the methodology description for interference tests was made. The response time lags (dt_L) in the observation sections during pumping in KFM04A are shown in Table 6-12. The lag times were derived from the drawdown curves in the observation borehole sections at an actual drawdown of 0.01 m. It should be pointed out that some of the responses may be secondary and induced by the drawdown created in the interval above the pumped section in KFM04A.

The normalized response time with respect to the distance to the pumping borehole was calculated. This time is inversely related to the hydraulic diffusivity (T/S) of the formation. In addition, the normalized drawdown with respect to the flow rate was calculated and is presented in Table 6-13. The observation section in the pumping borehole, KFM04A: 109–169 m, is not included in the response analysis.

$dt_L[s = 0.01\ m]/r_s^2$ = normalized response time with respect to the distance r_s,

$dt_L[s = 0.01\ m]$ = time after start of pumping (s) at a drawdown s = 0.01 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 pumping flow rate,

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

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

Table 6-12. Calculated response lag times and normalized response time lags for the observation sections in HFM10, HFM13, HFM19 and HFK252 during pumping in KFM04A.

Pumping borehole	Observation borehole	Section (m)	$dt_L[s = 0.01\ m]$ (s)	r_s (m)	$dt_L[s = 0.01\ m]/r_s^2$ (s/m^2)
KFM04A	HFM10	0–99.0	8,820	219	0.1839
	HFM10	100.0–150.0	660	198	0.0168
KFM04A	HFM13	0–100.0	78,600	482	0.3383
	HFM13	101.0–158.0	65,040	496	0.2644
	HFM13	159.0–173.0	51,060	517	0.1910
KFM04A	HFM19	0–103.0	58,580	594	0.1660
	HFM19	104.0–167.0	58,800	562	0.1862
	HFM19	168.0–182.0	61,800	547	0.2065
KFM04A	HFK252	0–80.0	7,800	1,128	0.0061

Table 6-13. Drawdown and normalized drawdown for the observation sections in HFM10, HFM13, HFM19 and HFK252 during pumping in KFM04A.

Pumping borehole	Flow rate Q_p (m^3/s)	Observation borehole	Section (m)	s_p (m)	s_p/Q_p (s/m^2)
KFM04A	0.00087	HFM10	0–99.0	0.717	824.14
	0.00087	HFM10	100.0–150.0	1.427	1,640.23
KFM04A	0.00087	HFM13	0–100.0	0.037	42.53
	0.00087	HFM13	101.0–158.0	0.101	116.09
	0.00087	HFM13	159.0–173.0	0.04	45.98
KFM04A	0.00087	HFM19	0–103.0	0.021	24.14
	0.00087	HFM19	104.0–167.0	0.021	24.14
	0.00087	HFM19	168.0–182.0	0.015	17.24
KFM04A	0.00087	HFK252	0–80.0	0.175	201.72

Table 6-12 shows that the (normalized) response time lag for HFK252 was short which indicates a high hydraulic diffusivity and a good hydraulic connection between KFM04A and this borehole. It can thus be assumed that KFM04A and HFK252 are connected by the same hydraulic structure, possibly deformation zone A2.

The lower section of HFM10 is also found to have a low normalized response time lag, whereas the other observation boreholes and sections show a significantly longer response time lag indicating a weaker hydraulic connection between the pumping borehole and the observation sections in question. These results are also clearly seen in Figure 6-1, showing a response diagram where the different observation sections included in the interference test are represented by crosses. In the response diagram, observation sections represented by data points lying to the left generally indicate a better connectivity, a higher hydraulic diffusivity, in regard to the pumping borehole section than sections represented by data points further to the right and to the bottom in the diagram.

6.4 Summary of the results of the interference test

All sections included in the interference test show clear responses to pumping in KFM04A, section 169–1,001 m. Section 100–150 m in HFM10 and borehole HFK252 exhibit the strongest responses. The response diagram, Figure 6-1, indicates that the highest value of hydraulic diffusivity is found for the hydraulic connection between KFM04A, 169–1,001 m, and borehole HFK252. The responses in HFM13 and HFM19 are much weaker than in HFM10 and HFK252, but still undisputable. In HFM13, section 101–158 m was more strongly affected than the other sections in the borehole. In HFM19, the responses in the different sections were very similar.

None of the responses except the one registered in HFK252 appears to be distinct enough to be characterized as a clear zone response. Furthermore, it is unlikely, when using the current geometrical interpretation of reflector A2, that any of the responses, with the possible exception of the response in HFK252, have been transmitted directly via the interpreted deformation zone A2. The zone A2 is assumed to intersect KFM04A at 169–242 m and dip approximately towards HFM10 at 22°. Since HFM10 is only about 150 m deep it is probably not intersected by A2 based on this interpretation of the zone.

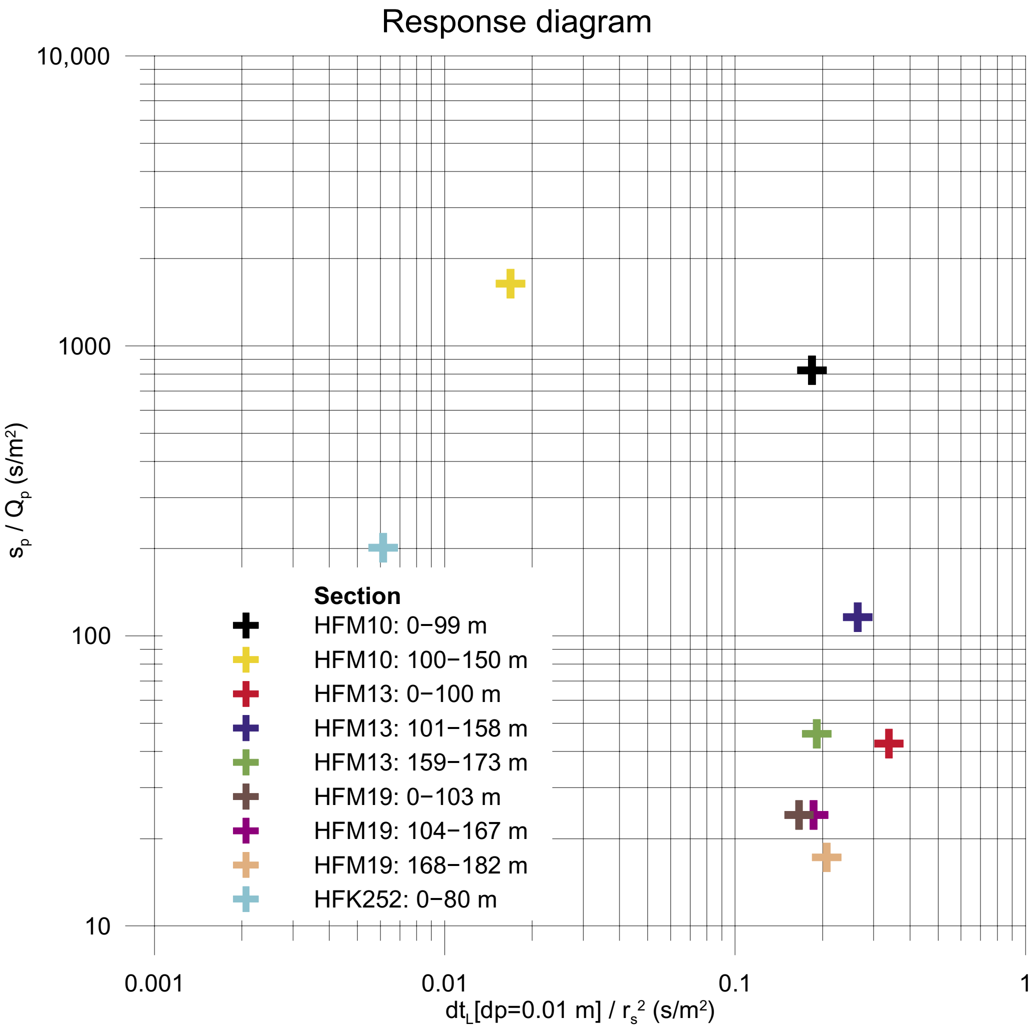

***Figure 6-1**. Response diagram.*

The relatively strong responses in HFM10 and HFK252 indicate that there is a good connection between the pumping borehole KFM04A and these boreholes in the area to the west of the interpreted extension of zone A2. It is however likely that the pressure responses in HFM10 and HFK252 have been transmitted via zones or fractures intersecting the pumping borehole above the pumping section, somewhere in the interval 109–168 m along the borehole where a drawdown of c 1.6 m was generated and not via zones or fractures intersecting the actual pumping section in KFM04A.

7 References

/1/ **Rouhiainen P, Pöllänen J, 2004.** Forsmark site investigation. Difference flow logging in borehole KFM04A. SKB P-04-190, Svensk Kärnbränslehantering AB.

/2/ **Ludvigson J-E, Källgården J, Jönsson J, 2004.** Forsmark site investigation. Pumping tests and flow logging – Boreholes HFM09 and HFM10. SKB P-04-74, Svensk Kärnbränslehantering AB.

/3/ **Ludvigson J-E, Jönsson S, Jönsson J, 2004.** Forsmark site investigation. Pumping tests and flow logging – Boreholes HFM13, HFM14 and HFM15. SKB P-04-74, Svensk Kärnbränslehantering AB.

/4/ **Ludvigson J-E, Källgården J, Hjerne C, 2004.** Forsmark site investigation. Pumping tests and flow logging – Boreholes HFM17, HFM18 and HFM19. SKB P-04-72, Svensk Kärnbränslehantering AB.

Appendix 1

List of data files

Files are named ”logger S/N”_Interferenstest_”BhID”_”secup”_”seclow”_”YYYYMMDD”_”hhmmss”. Interferenstest is just an internal marker, “logger S/N” is the loggers unique serial number, “BhID” is the name of the borehole, “secup” and “seclow” are the top and bottom of the measured section and last in the file name the datafile start time is given. The data files from the pumping borehole are a little different: Interferenstest_Pumphål is an internal marker. Pumpin and Ref_Da are parts of the original file names produced by the HTHB data logger. Ref_Da contains constants of calibration and background data. Pumpin contains data 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 (parameters)[2]	Comments
KFM04A	168.63–1,001 77.5–167.63	1B		20050428 12:12:00	20050509 11:51:00	20050426 14:21:15	20050509 11:51:19	Interferenstest_Pumphål_KFM04A_ 20050426_142115_Pumpin01.DAT	P, Q	Pressure and flow registration in KFM04A, 169–1,001 m and 78–168 m for interference.
KFM04A	168.63–1,001 77.5–167.63	1B		20050428 12:12:00	20050509 11:51:00	20050426 14:21:15	20050509 11:51:19	Interferenstest_Pumphål_KFM04A_ 20050426_142115_Ref_Da01.DAT	C, R	
KFM04A	0–76.5	–		20050428 12:31:00	20050509 11:59:00	20050428 12:31:24	20050428 13:23:54	SN13889_Interferenstest_KFM04A_ 0_76.5_20050428_123124.bin	P	Pressure response to pumping in KFM04A 169–1,001 m.
KFM04A	0–76.5	–		20050428 12:31:00	20050509 11:59:00	20050428 13:26:23	20050428 14:05:23	SN13889_Interferenstest_KFM04A_ 0_76.5_20050428_132623.bin	P	Pressure response to pumping in KFM04A 169–1,001 m.
KFM04A	0–76.5	–		20050428 12:31:00	20050509 11:59:00	20050428 14:06:40	20050509 11:59:40	SN13889_Interferenstest_KFM04A_ 0_76.5_20050428_140640.bin	P	Pressure response to pumping in KFM04A 169–1,001 m.
HFK252	0–80	2		20050428 12:10:00	20050509 22:55:00	20050428 12:10:00	20050511 11:55:00	SN11370_Interferenstest_obs_HFK252_ 20050428_121000.bin	P	Pressure response to pumping in KFM04A 169–1,001 m.

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

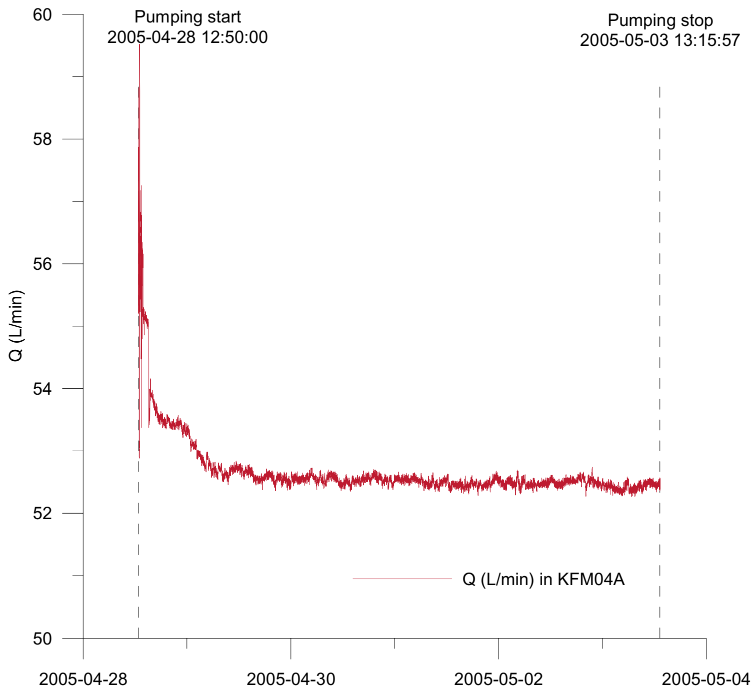

***Figure A2-1.** Linear plot of flow rate versus time in the pumping borehole KFM04A.*

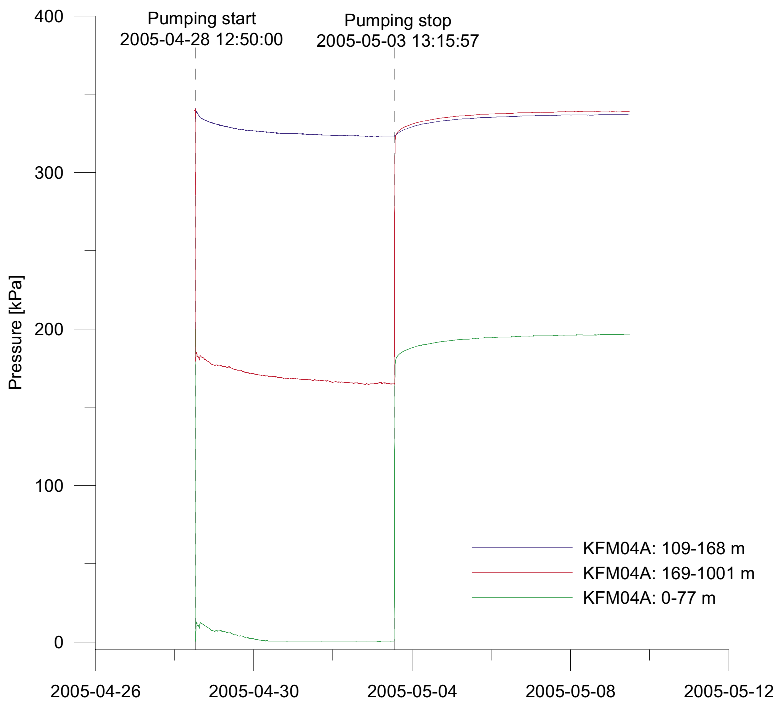

***Figure A2-2.** Linear plot of pressure versus time of all sections in KFM04A during the interference test.*

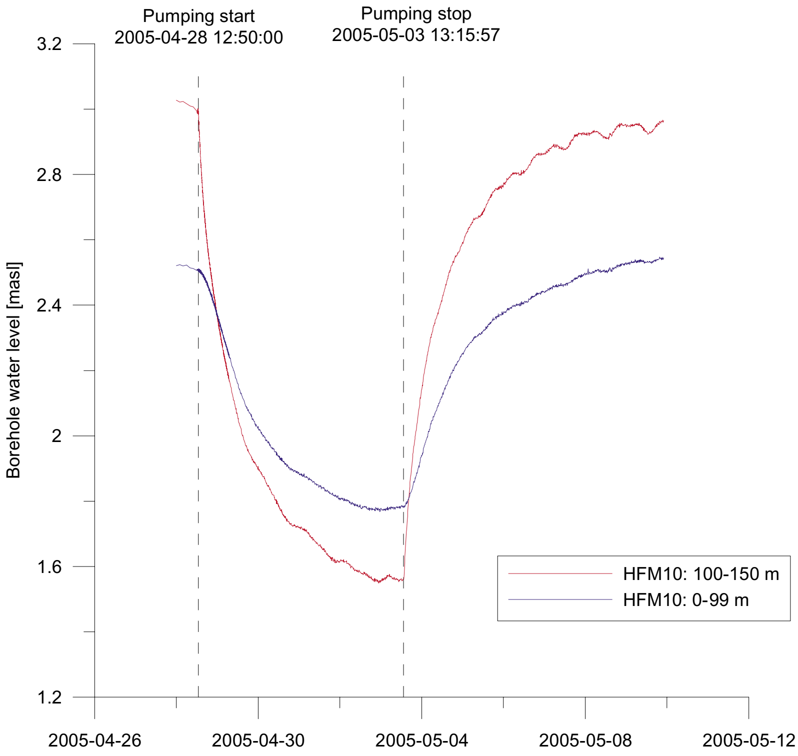

Figure A2-3. *Linear plot of hydraulic head versus time in the observation sections in HFM10 during the interference test in KFM04A.*

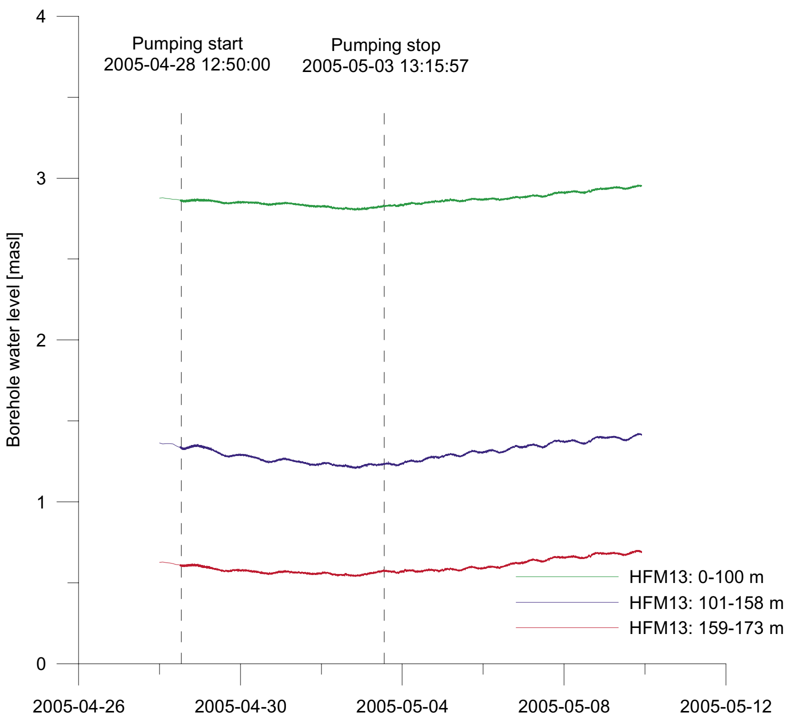

Figure A2-4. *Linear plot of hydraulic head versus time in the observation sections in HFM13 during the interference test in KFM04A.*

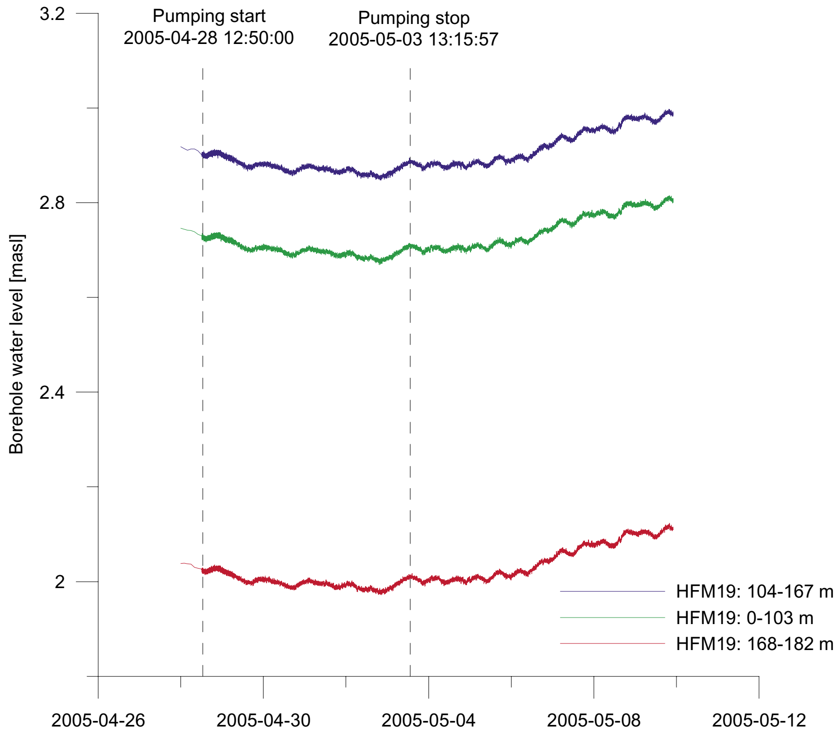

Figure A2-5. *Linear plot of hydraulic head versus time in the observation sections in HFM19 during the interference test in KFM04A.*

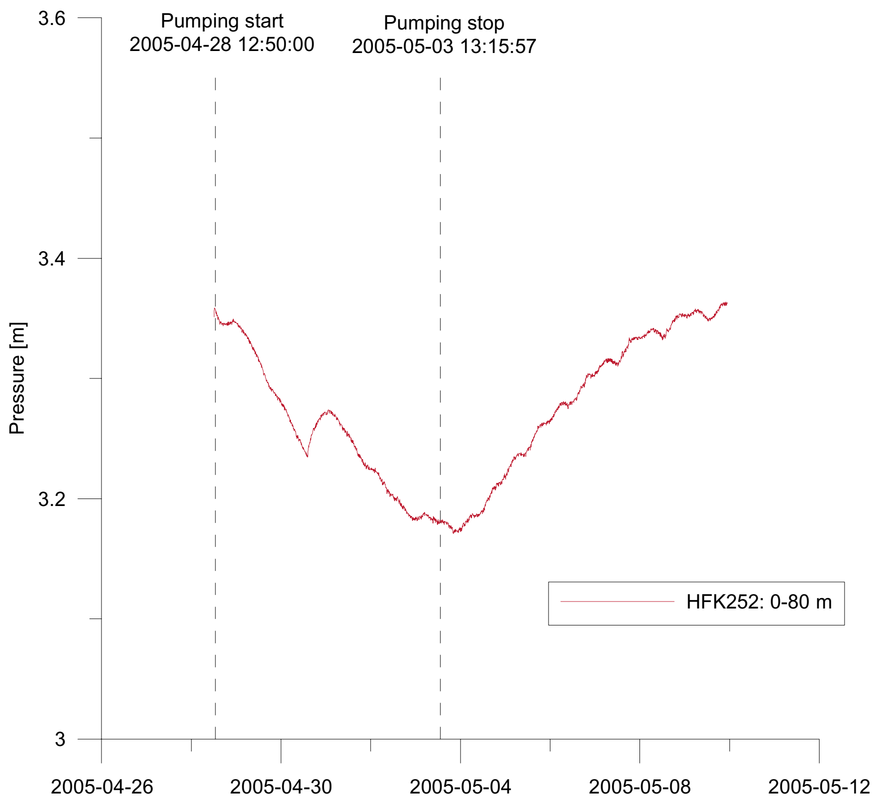

Figure A2-6. *Linear plot of pressure versus time in the observation borehole HFK252 during the interference test in KFM04A.Result tables to SICADA for the single-hole test in KFM04A (Empty cells in SICADA tables may be omitted).*

Appendix 3

Result tables to SICADA for the single-hole test in KFM04A

(Empty cells in SICADA tables may be omitted)

HY640-plu_s_hole_test_d

idcode	start_date	stop_date	secup	seclow	section_no	test_type	formation_type	start_flow_period	stop_flow_period
KFM04A	2005-04-28 12:12	2005-05-09 11:51	168.60	1,001.42		1B	1	2005-04-28 12:50:00	2005-05-03 13:15:00

flow_rate_end_qp	value_type_qp	mean_flow_rate_qm	q_measl__l	q_measl__u	tot_volume_vp	dur_flow_phase_tp	dur_rec_phase_tf
8.7000E-04	0	9.5000E-04			3.8100E+02	433,560.00	513,300.00

initial_head_hi	head_at_flow_end_hp	final_head_hf	initial_press_pi	press_at_flow_end_pp	final_press_pf	fluid_temp_tew
			1,383.30	1,207.60	1,381.70	

fluid_elcond_ecw	fluid_salinity_tdsw	fluid_salinity_tdswm	reference	comments	lp
				Pressure values are relative air pressure	

HY640-plu_s_hole_test_ed1

idcode	start_date	stop_date	secup	seclow	section_no	test_type	formation_type	lp
KFM04A	2005-04-28 12:12	2005-05-09 11:51	168.60	1,001.42		1B	1	217.00

HY645-plu_inf_test_obs_d

idcode	start_date	stop_date	secup	seclow	section_no	test_type	formation_type	start_flow_period	stop_flow_period
HFM10	2005-04-28 12:12	2005-05-09 11:51	0	99.00		2	1	2005-04-28 12:50:00	2005-05-03 13:15:00
HFM10	2005-04-28 12:12	2005-05-09 11:51	100.00	150.00		2	1	2005-04-28 12:50:00	2005-05-03 13:15:00
HFM13	2005-04-28 12:12	2005-05-09 11:51	0	100.00		2	1	2005-04-28 12:50:00	2005-05-03 13:15:00
HFM13	2005-04-28 12:12	2005-05-09 11:51	101.00	158.00		2	1	2005-04-28 12:50:00	2005-05-03 13:15:00
HFM13	2005-04-28 12:12	2005-05-09 11:51	159.00	173.00		2	1	2005-04-28 12:50:00	2005-05-03 13:15:00
HFM19	2005-04-28 12:12	2005-05-09 11:51	0	103.00		2	1	2005-04-28 12:50:00	2005-05-03 13:15:00
HFM19	2005-04-28 12:12	2005-05-09 11:51	104.00	167.00		2	1	2005-04-28 12:50:00	2005-05-03 13:15:00
HFM19	2005-04-28 12:12	2005-05-09 11:51	168.00	182.00		2	1	2005-04-28 12:50:00	2005-05-03 13:15:00

test_borehole	test_secup	test_seclow	lp	radial_distance_rs	shortest_distance_rt	time_lag_press_dtl	initial_head_hi	head_at_flow_end_hp
KFM04A	168.60	1,001.42	50.00	219.00		8,820.00	2.51	1.79
KFM04A	168.60	1,001.42	118.00	198.00		660.00	2.99	1.56
KFM04A	168.60	1,001.42	50.00	482.00		78,600.00	2.86	2.83
KFM04A	168.60	1,001.42	106.00	496.00		65,040.00	1.34	1.23
KFM04A	168.60	1,001.42	162.00	517.00		51,060.00	0.61	0.57
KFM04A	168.60	1,001.42	101.00	594.00		58,580.00	2.73	2.71
KFM04A	168.60	1,001.42	150.00	562.00		58,800.00	2.91	2.88
KFM04A	168.60	1,001.42	176.00	547.00		61,800.00	2.02	2.01

final_head_hf	initial_press_pi	press_at_flow_end_pp	final_press_pf	fluid_temp_teo	fluid_elcond_eco
2.53					
2.93					
2.93					
1.38					
0.68					
2.79					
2.97					
2.10					

fluid_salinity_tdso	fluid_salinity_tdsom	reference	comment
			dtl is for 0.01 m change
			dtl is for 0.01 m change
			dtl is for 0.01 m change
			dtl is for 0.01 m change
			dtl is for 0.01 m change
			dtl is for 0.01 m change
			dtl is for 0.01 m change
			dtl is for 0.01 m change
			dtl is for 0.01 m change
			dtl is for 0.01 m change

SICADA – description of plu_s_hole_test_d

SICADA Header	Header	Unit	Explanation
Idcode	Borehole		ID for borehole.
Secup	Borehole secup	(m)	Length coordinate along the borehole for the upper limit of the test section.
Seclow	Borehole seclow	(m)	Length coordinate along the borehole for the lower limit of the test section.
Test_type	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, 4B: Pulse test. 5A: Difference flow logging-PFL-DIFF-sequential, 5B: Difference flow logging-PFL-DIFF-overlapping. 6: Flow logging_Impeller. 7: Grain size analysis.
start_date	Date for test start	YYYY-MM-DD hh:mm	Date for the start of the pumping or injection test (YYYY-MM-DD hh:mm).
start_flow_period	Start flow/ injection	YYYY-MM-DD hh:mm:ss	Date and time for the start of the pumping or injection period (YYYY-MM-DD hh:mm:ss).
stop_flow_period	Start flow/ injection	YYYY-MM-DD hh:mm:ss	Date and time for the end of the pumping or injection period (YYYY-M-M DD hh:mm:ss).
mean_flow_rate_qm	Q_m	(m^3/s)	Arithmetic mean flow rate during flow (pumping/injection) period.
flow_rate_end_qp	Q_p	(m^3/s)	Flow rate at the end of the flow (pumping/injection) period.
value_type_qp			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	Qmeasl_L	(m^3/s)	Estimated lower measurement limit for flow rate.
q_measl_u	Qmeasl_U	(m^3/s)	Estimated upper measurement limit for flow rate.
total_volume_vp	V_p	(m^3)	Total volume pumped or injected water during the flow period.
dur_flow_phase_tp	t_p	(s)	Duration of the flow period.
dur_rec_phase_tf	t_F	(s)	Duration of the recovery period.
initial_head_hi	h_i	(m)	Hydraulic head in test section at start of the flow period.
head_at_flow_end_hp	h_p	(m)	Hydraulic head in test section at stop of the flow period.
final_head_hf	h_F	(m)	Hydraulic head in test section at stop of the recovery period.
initial_press_pi	p_i	(kPa)	Ground water pressure in test section at start of the flow period.
press_at_flow_end_pp	p_p	(kPa)	Ground water pressure in test section at stop of the flow period.
final_press_pf	p_F	(kPa)	Ground water pressure in test section at stop of the recovery period.
fluid_temp_tew	Te_w	(C°)	Measured borehole fluid temperature in the test section (representative for evaluated parameters, in general the last temperature value).
fluid_elcond_ecw	EC_w	(mS/m)	Measured electric conductivity of the borehole fluid in the test section (representative for evaluated parameters, in general the last EC value).
fluid_salinity_tdsw	TDS_w	(mg/L)	Calculated total dissolved solids of the borehole fluid in the test section, based on EC-measurement.
fluid_salinity_tdswn	TDS_{wn}	(mg/L)	Measured total dissolved solids of the borehole fluid in the test section, based on water sampling and chemical analysis.
reference	references		SKB report No for reports describing data and evaluation.
comments	comments		Short comment to data.

SICADA – description of plu_s_hole_test_ed1

SICADA Header	Header	Unit	Explanation
idcode	Borehole		ID for borehole.
secup	Borehole secup	m	Length coordinate along the borehole for the upper limit of the test section.
seclow	Borehole seclow	(m)	Length coordinate along the borehole for the lower limit of the test section.
test_type	Test type (1–7)	(–)	1A: Pumpingtest-wireline eq, 1B: Pumpingtest-submersible pump, 1C: Pumpingtest-airlift pumping. 2: Interference test, 3: Injection test. 4: Slug test, 4B: Pulse Test. 5A: Flowlogging-PFL-DIFF_sequential, 5B: Flowlogging-PFL-DIFF_overlapping. 6: Flowlogging-Impeller, 7: Grain size analysis.
formation_type	Formation type	(–)	1: Rock, 2: Soil (Superficial deposits).
seclen_class		(m)	Planned ordinary test interval during a test campaign when a great part of a borehole is tested. The test interval length might differ due to border conditions (e.g borehole end) but is still considdered to be included in the same section length class.
start_date		YYYY-MM-DD hh:mm	Date for the start of the test (YYYY-MM-DD hh:mm).
lp	L_p	(m)	Hydraulic point of application for a test section, based on the geometric midpoint of test section or the main point of transmissivity distribution in test section.
spec_capacity_q_s	Q/s	m^2/s	Specific capacity, generally estimated from Q_p, s_p or dh_p.
value_type_q_s			Code for Q/s; –1 means Q/s < lower measurement limit, 0 means measured value,–1 means Q/s > upper measurement limit.
transmissivity_tq	T_Q	m^2/s	Transmissivity, based on Q/s and a function T = f(Q/s), see e.g. (Rhén et al. 1997) p 190. The function used should be refered to in “Comments”.
transmissivity_moye	T_M	m^2/s	Transmissivity (T_M) based on (Moye, 1967).
value_type_tm			Code for T_M; –1 means T_M < lower measurement limit, 0 means measured value, –1 means T_M > upper measurement limit.
formation_width_b	b	m	Representative aquifer thickness for inferred transmissivity, generally estimated as test section length L_w.
width_of_channel_b	B	m	Inferred width of formation for evaluated TB.
tb	TB	m^3/s	Flow capacity in 1D formation of width B and transmissivity T based on transient evaluation. Considered best estimate from transient evaluation of flow period or recovery period.
l_measl_tb	TB-measl-L	m^3/s	Estimated lower measurement limit for evaluated TB.
u_measl_tb	TB-measl-L	m^3/s	Estimated upper measurement limit for evaluated TB.
sb	SB	m	Storage capacity of 1D formation of width B and storativity S based on transient evaluation. Considered best estimate from transient evaluation of flow period or recovery period.
assumed_sb	SB*	m	Assumed storage capacity of 1D formation of width B and storativity S based on transient evaluation.
leakage_factor_lf	L_f	m	Leakage factor. $L_f = (K \times b \times c_f)^{0.5}$ where K represents the aquifer conditions. c_f = b´/K´ based on 1D linear flow model. Considered best estimate from transient evaluation of flow period or recovery period.
transmissivity_tt	T_T	m^2/s	Transmissivity (T) of formation, based on 2D radial flow model. Considered best estimate from transient evaluation of flow period or recovery period.
value_type_tt			Code for T_T; –1 means T_T < lower measurement limit, 0 means measured value,–1 means T_T > upper measurement limit.
l_measl_q_s	Q/s-measl-L	m^2/s	Estimated measurement limit for evaluated T (T_T, T_Q, T_M). If estimated T equals Q/s-measl in the table actual T is considered to be equal or less than Q/s-measl.
u_measl_q_s	Q/s-measl-U	m^2/s	Estimated measurement limit for evaluated T (T_T, T_Q, T_M). If estimated T equals Q/s-measl in the table actual T is considered to be equal or grater than Q/s-measl.

SICADA Header	Header	Unit	Explanation
storativity_s	S	(–)	Storativity (Storage coefficient) of formation based on 2D radial flow model. Considered best estimate from transient evaluation of flow period or recovery period.
assumed_s	S*		Assumed storativity of formation based on 2D radial flow model.
leakage_koeff	K´/b´	(1/s)	Leakage coefficient evaluated from 2D radial flow model. K´ = hydraulic conductivity across the aquitard, b´ = water saturated thickness of aquitard (leaky formation). Considered best estimate from transient evaluation of flow period or recovery period.
hydr_kond_ksf	K_{sf}	m/s	Hydraulic conductivity of formation, based on 3D spherical flow model. Considered best estimate from transient evaluation of flow period or recovery period.
value_type_ksf			Code for K_{Sf}; –1 means K_{Sf} < lower measurement limit, 0 means measured value,–1 means K_{Sf} > upper measurement limit.
l_measl_ksf	K_S-measl-L	m/s	Estimated lower measurement limit for evaluated K_{sf}.
u_measl_ksf	K_S-measl-U	m/s	Estimated upper measurement limit for evaluated K_{sf}.
spec_storage_ss	S_{sf}	1/m	Specific storage of formation based on 3D spherical flow model. Considered best estimate from transient evaluation of flow period or recovery period.
assumed_ss	S_{sf}*	1/m	Assumed specific storage of formation based on 3D spherical flow model.
c	C	(m^3/Pa)	Wellbore storage coefficient. Considered best estimate from transient evaluation of flow period or recovery period.
cd	C_D	(–)	Dimensionless wellbore storage coefficient, $C_D = C \times \rho_w g/(2\pi\pi\ S \times r_w^2)$.
skin	ξ		Skin factor. Considered best estimate from transient evaluation of flow period or recovery period.
dt1	dt_1	s	Estimated start time after pump/injection start OR recovery start, for the period used for the evaluated parameter.
dt1	dt_2	s	Estimated stop time after pump/injection start OR recovery start, for the period used for the evaluated parameter.
dte1	dt_{e1}		Start time for evaluated parameter from start of recovery period.
dte2	dt_{e2}		Stop time for evaluated parameter from start of recovery period.
t1	t_1		Start time for evaluated parameter from start of flow period.
t2	t_2		Stop time for evaluated parameter from start of flow period.
p_horner	p*		Horner extrapolated pressure (used as an estimation of natural pressure of the test section).
transmissivity_t_nlr	T_{ILR}	m^2/s	Transmissivity, based on Non Linear Regression of the entire test sequence.
storativity_s_nlr	S_{ILR}	(–)	Storativity, based on Non Linear Regression of the entire test sequence.
c_nlr	C_{ILR}	(m^3/Pa)	Wellbore storage coefficient, based on Non Linear Regression of entire test sequence.
cd_nlr	$C_{D,ILR}$		Dimensionless wellbore storage coefficient, based on Non Linear Regression of entire test sequence.
skin_nlr	ξ_{NLR}		Skin factor, based on Non Linear Regression of entire test sequence.
transmissivity_t_grf	T_{GRF}	m^2/s	Transmissivity, based on the Generalized Radial Flow model (Baker, 1988). Considered best estimate from transient evaluation of flow period or recovery period.
storativity_s_grf	S_{GRF}	(–)	Storativity, based on Generalised Radial Flow model. Considered best estimate from transient evaluation of flow period or recovery period.
flow_dim_grf	D_{GRF}	(–)	Inferred flow dimension, based on the Generalized Radial Flow model (Barker, 1988). Considered best estimate from transient evaluation of flow period or recovery period.
comment	comment		comments on the test.

SICADA – description of plu_inf_test_obs_d

SICADA Header	Header	Unit	Explanation
idcode	ID Obs Borehole		ID for observation borehole.
secup	Borehole secup	(m)	Length coordinate along the borehole for the upper limit of observation section.
seclow	Borehole seclow	(m)	Length coordinate along the borehole for the lower limit of observation section.
start_date	Date for test start	YYYY-M M-DD hh:mm	Date for the start of the pumping/injection test (YYYY-MM-DD hh:mm).
stop_date	Date for test stop	YYYY-M M-DD hh:mm	Date for the stop of the pumping/injection test (YYYY-MM-DD hh:mm).
test_type	Test type (1–7)	(–)	1A: Pumping test-wireline eq, 1B: Pumping test-submersible pump, 1C: Pumping test-airlift pumping. 2: Interference test. 3: Injection test. 4: Slug test, 4B: Pulse test. 5A: Flowlogging-PFL-DIFF_sequential, 5B: Flowlogging-PFL-DIFF_overlapping. 6: Flowlogging Impeller. 7: Grain size analysis.
test_borehole	ID. pumped Borehole	(–)	ID for pumped or injected borehole.
test_secup	Test secup	(m)	Length coordinate along the borehole for the upper limit of pumped or injected section.
test_seclow	Test seclow	(m)	Length coordinate along the borehole for the lower limit of pumped or injected section.
start_flow_period	Start flow	YYYY-MM-DD hh:mm:ss	Time for the start of the pumping/injection period (YYYY-MM-DD hh:mm:ss).
stop_flow_period	Stop flow	YYYY-MM-DD hh:mm:ss	Time for the stop of the pumping/injection period (YYYY-MM-DD hh:mm:ss).
lp	L_p	(m)	Hydraulic point of application for a test section, based on the geometric midpoint of test section or the main point of transmissivity distribution in test section.
radial_distance_rs	r_s	(m)	Geometrical distance from point of application in test section to point of application in observation section.
shortest_distance_rt	r_t	(m)	Representative hydraulic distance from point of application in test section to point of application in observation section via inferred major conductive features. The actual structural model version shall be reported.
time_lag_press_dtl	dt_L	(s)	Time lag for pressure response to reach observation section after start/stop of pumping or injection, based on the first significant response in the observation section.
initial_head_hi	h_i	(m)	Hydraulic head in observation section at start of flow period.
head_at_flow_end_hp	h_p	(m)	Hydraulic head in observation section at stop of flow period.
final_head_hf	h_F	(m)	Hydraulic head in observation section at stop of recovery period.
initial_press_pi	p_i	(kPa)	Groundwater pressure in observation section at start of flow period.
press_at_flow_end_pp	p_p	(kPa)	Groundwater pressure in observation section at stop of flow period.
final_press_pf	p_F	(kPa)	Groundwater pressure in observation section at stop of recovery period.
fluid_temp_teo	Te_o	(C°)	Measured borehole fluid temperature in the observation section (representative for evaluated parameters).
fluid_elcond_eco	EC_o	(mS/m)	Measured electric conductivity of the borehole fluid in the observation section (representative for evaluated parameters).

SICADA Header	Header	Unit	Explanation
fluid_salinity_tdso	TDS_o	(mg/L)	Calculated total dissolved solids of the borehole fluid in the observation section, based on EC-measurement.
fluid_salinity_tdso	TDS_{om}	(mg/L)	Measured total dissolved solids of the borehole fluid in the observation section, based on water sampling and chemical analysis.
reference	References		SKB report No for reports describing data and evaluation.
comment	Comments		Short comment to the evaluated parameters (Optional).