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Forsmark site investigation

Hydraulic interference test

Boreholes KFM02A and KFM03A

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April 2006

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Abstract

An interference test was performed in order to increase the understanding of the hydraulic conditions in the south-eastern part of the candidate area in Forsmark. The purpose of the conducted interference test was to document a possible hydraulic connection between the boreholes KFM02A and KFM03A. A fracture system that has been interpreted to belong to deformation zone A3 was believed to make up the presumptive hydraulic connection.

A3 is one of several low-angle (c 25°) deformation zones in the candidate area dipping towards south-east. Previous hydraulic single hole tests indicate that the transmissivity of the zone decreases with increasing depth. In KFM02A, zone A3 is interpreted to intersect the borehole at 160–184 m along the borehole in which interval the transmissivity is c $3 \cdot 10^{-6}$ m^2/s. In KFM03A zone A3 is interpreted to intersect the borehole as deep as 803–816 m, where the transmissivity has decreased to c $3 \cdot 10^{-8}$ m^2/s.

The interference test was performed by pumping in KFM02A. The presumptive pressure responses were registered in different sections of observation borehole KFM03A. In the pumping borehole the drawdown at the end of the flow period was c 9 m and the final flow rate was about 110 L/min. During the entire interference test, all pressure data from KFM03A exhibit an oscillating behaviour due to tidal effects, also called earth tides.

Only three of eight packed off sections in KFM03A, i.e. 351.5–401.5 m, 472.5–632.5 m and 633.5–650.0 m, responded to the pumping in KFM02A. The strongest interference was detected in section 633.5–650.0 m and the weakest in section 351.5–401.5 m. The total drawdown in section 633.5–650.0 m was approximately 0.4 m. However, no pressure response was registered in the packed off section which includes the interval 803–816 m, where deformation zone A3 is believed to intersect KFM03A.

None of the responses, with the possible exception of KFM03A: 633.5–650.0 m, are considered as distinct enough to be characterized as clear zone responses considering the very long distances between the boreholes. It is therefore uncertain if any of the responses is associated with deformation zone A3 with the interpreted orientation of the zone in this borehole.

Sammanfattning

Ett interferenstest genomfördes för att öka förståelsen för de hydrauliska sambanden i den sydöstra delen av kandidatområdet i Forsmark. Syftet med det utförda interferenstestet var att dokumentera om det finns en hydraulisk kontakt mellan kärnborrhål KFM02A och KFM03A. Ett spricksystem som tolkats tillhöra deformationszon A3 antogs utgöra den förmodade hydrauliska kontakten mellan hålen.

A3 är en av flera observerade flacka (ca 25°) deformationszoner som stupar mot sydost. Hydrauliska enhålstester har tidigare indikerat att zonens transmissivitet har ett djupavtagande. I KFM02A är A3 tolkad att skära borrhålet på mellan 160–184 m djup vilket intervall har en transmissivitet på ca $3 \cdot 10^{-6}$ m^2/s. I KFM03A tolkas zon A3 skära borrhålet mellan 803–816 m. Transmissiviteten har då sjunkit till ca $3 \cdot 10^{-8}$ m^2/s.

Interferenstestet utfördes genom pumpning i KFM02A och presumtiva tryckresponser registrerades i olika sektioner i observationsborrhål KFM03A. I pumpborrhålet var avsänkningen vid slutet av flödesperioden ca 9 m och det slutliga pumpflödet ungefär 110 L/min. Under hela interferenstestet uppvisar alla tryckdata från KFM03A ett oscillerande beteende beroende på s k tidaleffekter.

Bara tre av åtta avgränsade sektioner in KFM03A, 351,5–401.5 m, 472,5–632,5 m, och 633,5–650,0 m, uppvisade tryckresponser från pumpningen i KFM02A. Den tydligaste interferensen uppmättes i sektion 633,5–650,5 m och den svagaste responsen detekterades i sektion 351,5–401,5 m. Den totala avsänkningen i sektion 633,5–650,0 m var ca 0,4 m. Ingen respons registrerades emellertid i den isolerade sektion som innehåller borrhålsavsnitt 803–816 m där deformationszon A3 tros skära KFM03A.

Ingen av responserna, möjligen med undantag av KFM03A: 633,5–650,0 m kan betraktas som tillräckligt stark för att karaktäriseras som tydlig zonrespons med beaktande av de mycket långa avstånden mellan borrhålen. Det är därför osäkert om någon av responserna kan hänföras till deformationszon A3 med den tolkade orienteringen av zonen i detta borrhål.

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.

From pumping tests and flow logging, /1/, performed prior to the interference test, the total transmissivity of the pumping borehole, KFM02A, was estimated at $2.5 \cdot 10^{-4}$ m^2/s. The total transmissivity of observation borehole KFM03A has also been evaluated previously and was estimated at c $2.0 \cdot 10^{-4}$ m^2/s, /2/. This report documents the results from the interference test performed in order to find out whether there exists a hydraulic connection between the deep core-drilled boreholes KFM02A and KFM03A, via deformation zone A3. The locations of the boreholes involved in the interference test together with the seismic reflector interpreted as deformation zone A3 are shown in Figure 1-1.

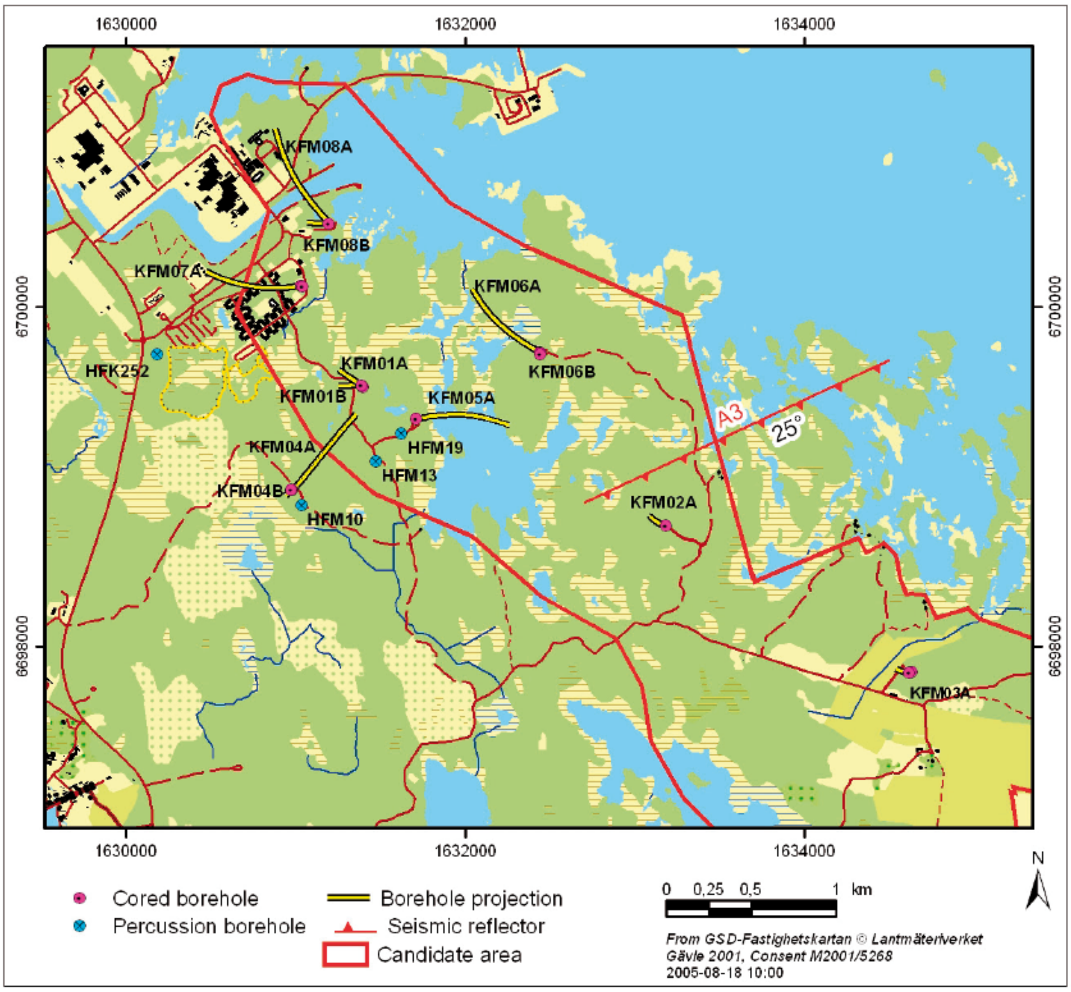

Figure 1-1. Boreholes and the seismic reflector A3 within the investigation area at Forsmark including the candidate area selected for more detailed investigations.

This document reports the results gained from the hydraulic interference test between the cored boreholes KFM02A and KFM03A. The interference test was performed within the site investigation at Forsmark. The test was carried out in May of 2005, by Geosigma AB. The work was conducted in accordance with activity plan AP PF 400-05-050. In Table 1-1, the controlling documents for the performance of this activity are listed. Both the activity plan and method descriptions are internal controlling documents of SKB.

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

Activity plan	Number	Version
Undersökning av hydraulisk kontakt mellan KFM02A och KFM03A via deformationszon A3	AP PF 400-05-050	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 south-eastern part of the candidate area at Forsmark. The primary aim of the interference test was to document the possible existence of a hydraulic connection between the cored boreholes KFM02A and KFM03A. The presumptive pressure response was believed to be transmitted via deformation zone A3.

A3 is one of several low-angle (c 25°) deformation zones dipping towards south-east. Previous hydraulic single-hole tests indicate that the transmissivity of the zone decreases with depth. In KFM02A, zone A3 is interpreted to intersect the borehole at 160–184 m along the borehole, where the approximate transmissivity is c $3 \cdot 10^{-6}$ m^2/s. Deformation zone A3 is interpreted to intersect borehole KFM03A at 803–816 m where the transmissivity has decreased to c $3 \cdot 10^{-8}$ m^2/s.

To verify the assumed hydraulic connection between the boreholes, an interference test was conducted by pumping in KFM02A and monitoring possible responses in different sections of KFM03A.

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 2.5gon V0:–15) is used in the x-y-direction together with RHB70 in the z-direction. The coordinates of the boreholes at ground surface are shown in Table 3-2.

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

Borehole data							
Bh ID	**Elevation of top of casing (ToC) (m.a.s.l.)**	**Borehole interval from ToC (m)**	**Casing/ Bh-diam. (m)**	**Inclination-top of bh (from horizontal plane) (°)**	**Dip-direction-top of borehole (from local N) (°)**	**Remarks**	**Drilling finished Date (YYYY-MM-DD)**
KFM02A	7.353	0.000–2,390	0.440	–85,385	275,764	Borehole	2003-03-12
”		2,390–11,800	0.358			Borehole	
”		11,800–100,350	0.251			Borehole	
”		100,350–100,420	0.164			Borehole	
”		100,420–102.000	0.086			Borehole	
”		102,000–1,002,440	0.077			Borehole	
”		0.000–100,140	0.200			Casing ID	
”		0.100–11,800	0.265			Casing ID	
KFM03A	8.285	0.000–11,960	0.200	–85.747	271,523	Casing ID	2003-06-23
”		11,960–100,290	0.196			Borehole	
”		100,290–100,340	0.163			Borehole	
”		100,340–102,050	0.086			Borehole	
”		102,050–1,001,190	0.077			Borehole	

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

Borehole data		
Bh ID	**Northing (m)**	**Easting (m)**
KFM02A	6698712.501	1633182.863
KFM03A	6697852.096	1634630.737

3.2 Tests performed

The borehole sections involved in the interference test in KFM02A 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 KFM03A, 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 and to get enough data for a sufficiently long recovery period for the evaluation. 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 KFM02A och KFM03A via deformationszon A3, K535078, Stig Jönsson, 2005-05-16", 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/ and /3/, are presented in Table 3-4. The estimated transmissivities of the observation sections in KFM03A are derived from the injection tests /2/. The results of the injection tests in KFM03A are consistent with the results of the difference flow logging in this borehole, /4/. The distances between the pumping borehole and the observation borehole sections are shown in Table 3-5. The distances between the hydraulic points of application in the boreholes were calculated.

Two different points of application was used for the pumping borehole KFM02A. The reason for this was that the first point, at 115 m along the borehole, had the greatest value of transmissivity and was the natural selection. The other estimate of point of application, at 172 m along the borehole, however, was the assumed position of the interpreted deformation zone A3.

The estimation of the points of application in the different sections of the pumping borehole and the observation borehole sections respectively was made in one of two ways. Either, if it was obvious that a certain flow anomaly contributed to the major part of the transmissivity in one section, the position of that anomaly was chosen as the point of application.

Table 3-3. Borehole sections involved in the interference test between KFM02A and KFM03A, 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)
KFM02A	102.0–1,002.4	1B	Open borehole	2005-05-17 14:18	2005-05-25 11:14
KFM03A	969.5–994.5	2	Between packers	2005-05-17 00:00	2005-06-03 23:00
"	820.5–968.5	2	Between packers	2005-05-17 00:00	2005-06-03 23:00
"	651.0–819.5	2	Between packers	2005-05-17 00:00	2005-06-03 23:00
"	633.5–650.0	2	Between packers	2005-05-17 00:00	2005-06-03 23:00
"	472.5–632.5	2	Between packers	2005-05-17 00:00	2005-06-03 23:00
"	402.5–471.5	2	Between packers	2005-05-17 00:00	2005-06-03 23:00
"	351.5–401.5	2	Between packers	2005-05-17 00:00	2005-06-03 23:00
"	0–350.5	2	Above packer	2005-05-17 00:00	2005-06-03 23:00

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/ and /4/.

Bh ID	Test section (m)	Point of application (m below TOC)	Section length (m)	Transmissivity (m^2/s)
KFM02A	102.0–1,002.4	115	900.4	2.5·10–4
KFM02A	102.0–1,002.4	172	900.4	2.5·10–4
KFM03A	969.5–994.5	989	25.0	5.7·10–7
”	820.5–968.5	944	148.0	8.7·10–7
”	651.0–819.5	809	168.5	4.7·10–8
”	633.5–650.0	644	16.5	7.5·10–7
”	472.5–632.5	512	160.0	5.8·10–8
”	402.5–471.5	454	69.0	2.3·10–6
”	351.5–401.5	389	50.0	1.8·10–4
”	0–350.5	119	350.0	3.3·10–7

Table 3-5.NCalculated distances from the pumping borehole KFM02A to the observation borehole sections involved in the interference test.

Pumping section in KFM02A (m)	Observation sections		Distance (m) to	
	Borehole ID	Section (m)	KFM02A@115 m	KFM02A@172 m
102.0–1,002.4	KFM03A	969.5–994.5	1,827	1,804
”	KFM03A	820.5–968.5	1,811	1,790
”	KFM03A	651.0–819.5	1,769	1,751
”	KFM03A	633.5–650.0	1,728	1,716
”	KFM03A	472.5–632.5	1,706	1,697
”	KFM03A	402.5–471.5	1,699	1,692
”	KFM03A	351.5–401.5	1,692	1,688
”	KFM03A	0–350.5	1,686	1,691

Alternatively, if no evident part of the section could be chosen with regard to transmissivity, either the midpoint of the section was selected or, if several parts of the section have comparable values of transmissivity, a point of balance calculation was made to estimate the point of application.

3.3 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.

4 Description of equipment

4.1 Overview

The temporary test system used for the interference test is described in the Geosigma Quality Plan and the equipment in the pumping borehole, KFM02A, 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,
- 1 pressure transducer in the borehole,
- flow meter at the surface,
- data logger to sample data from the flow meter and the pressure transducer,
- flow rate control valve at the surface,
- PC to visualize the data.

Much of the equipment used for the installation in KFM02A were 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 for percussion boreholes to perform pumping tests in open 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 sections in borehole KFM03A are connected to the SKB hydro monitoring system (HMS), where pressure is recorded continuously.

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=$3\cdot10^{-7}$ m^2/s and Q/s-U=$5\cdot10^{-3}$ 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.

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

The test performance was in accordance with the Activity plan and the Geosigma Quality Plan as well as the methodology descriptions for interference tests, SKB MD 330.003. However, no response matrix was prepared due to the few responding observation sections.

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
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 KFM02A.

Borehole information ID	Test interval (m)	Test configuration	Test type[1)]	Sensors Type	Position (m b ToC)
KFM02A	100.14–1,002.44	Open borehole	1B	p-absolute (HTHB)	30.0
KFM03A	0–350.5	Above packer	2	HMS	39.3
KFM03A	351.5–401.5	Between packers	2	HMS	39.3
KFM03A	402.5–471.5	Between packers	2	HMS	39.3
KFM03A	472.5–632.5	Between packers	2	HMS	39.3
KFM03A	633.5–650.0	Between packers	2	HMS	39.3
KFM03A	651.0–819.5	Between packers	2	HMS	39.3
KFM03A	820.5–968.5	Between packers	2	HMS	39.3
KFM03A	969.5–994.5	Between packers	2	HMS	39.3

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

5 Execution

5.1 Preparations

All sensors included in the test system of the pumping borehole are calibrated at the Geosigma engineering workshop in Libroback, Uppsala. Calibration is performed on a yearly basis, or more often if needed. The last calibration of the pressure transducer P2, which was used in the pumping borehole, was conducted in April, 2004. The flow meter was calibrated in May, 2004. Before the tests, function checks and cleaning of equipment were performed according to the Activity Plan.

5.2 Procedure

The pumping test in KFM02A was carried out as a constant flow rate test followed by a pressure recovery period. The pressure interference was recorded in several sections of KFM03A, a cored borehole which is connected to the HMS (Hydro Monitoring System). The flow rate in the pumping borehole was chosen, based on the results from earlier pumping tests and flow logging in KFM02A. The limiting factor concerning maximum flow rate for this test, however, was the capacity of a drainage pump on the ground surface. This pump was installed to transport water from a sedimentation container on the surface to the sea. The discharged water from the borehole was pumped into the container. The flow rate was manually adjusted by a control valve and monitored by an electromagnetic flow meter. The data logger sampled data at a suitable frequency determined by the operator, see Table 5-3. Pumping in KFM02A was carried out using a 4" submersible pump during a period of c 190 h. The subsequent pressure recovery was measured for c 230 h.

In KFM02A, the absolute pressure transducer connected to the HTHB-logger was attached to the pump hose 30 m below the top of casing. The transducers were connected directly to the data logger via cables. In observation borehole KFM03A the hydro monitoring system was utilized for pressure registration.

Approximate sampling intervals for flow rate and pressure in the pumping borehole KFM02A are presented in Table 5-3. In the observation borehole, the standard sampling frequency used for the HMS was 30 min throughout the test. In addition, a sample was taken whenever there was a level change of 0.1 m or more since the last sample.

Table 5-3. Approximate sampling intervals used for pressure registration in KFM02A during the interference test.

Time interval (s) from start/stop of pumping [1)]	Sampling interval (s)
1–600	1
601–5,400	10
5,401–7,000	60
>7,001	300

[1)] The frequency was not changed before stop of pumping.

5.3 Data handling

Flow and pressure data from the pumping borehole, KFM02A, were downloaded from the logger (Campbell CR 5 000) 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.

5.4 Analyses and interpretation

No quantitative analysis has been performed for the interference test in KFM02A. 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. The response analysis was somewhat simplified due to the low number of observation sections during the test.

5.5 Nonconformities

- During the first day of pumping in KFM02A, the intended flow rate could not be held. The reason was that a drainage pump on the ground surface, installed to transport the water from a sedimentation container to the sea, had insufficient capacity.
- Pumping activities in the area had lowered the water table in borehole KFM02A prior to the start of pumping. Therefore the actual drawdown must be considered larger than the measured drawdown.

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) cf Table 1-1. Additional symbols used are explained in the text.

6.2 Interference test in KFM02A

The primary aim of the interference test was to document a possible hydraulic connection between the cored boreholes KFM02A and KFM03A. A fracture zone, interpreted to belong to deformation zone A3 was believed to make up the presumptive hydraulic connection. Visual inspection of the pressure responses, presented in Figure A2-3 and A2-4, indicates that significant responses were registered in two or possibly three sections of KFM03A. All other observation sections listed in Table 3-3 were unaffected during the time of the interference test. The measured drawdowns (s_p) at the end of the flow period and response time lags (dt_L) in the responding observation sections are shown in Tables 6-10 and 6-11. 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.

The pressure in all of the observation sections of KFM03A was displaying an oscillating behaviour. This phenomenon is believed to be caused by tidal effects, also called earth tides, and has been investigated to some extent previously in /3/. In Figure A2-3, the sea water level in Kallrigafjärden outside the investigation area is included. Inspection of Figure A2-3 shows that the pressure in the observation borehole sections is correlated to the sea water level which in turn is correlated to other less specific tidal effects that influence the pressure in the observation sections.

All pressure data reported in this document have been corrected for barometric pressure. This also includes 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.

During the interference test, approximately 10 mm of precipitation was reported in the vicinity of the boreholes included in the test. The rainfall was evenly distributed over the testing period and no signs of the rain influencing the test results have been discovered.

6.2.1 Pumping borehole KFM02A

General test data for the pumping test in KFM02A are presented in Table 6-1.

Table 6-1. General test data for the pumping test in KFM02A: 102–1,002 m.

General test data			
Pumping borehole	KFM02A		
Test type[1]	Constant Rate withdrawal and recovery test		
Test section (open borehole/packed-off section):	open borehole		
Test No	1		
Field crew	(GEOSIGMA AB)		
Test equipment system			
General comment	Interference test		
	Nomenclature	**Unit**	**Value**
Borehole length	L	m	1,002.44
Casing length	L_c	m	102.00
Test section- secup	Secup	m	102.00
Test section- seclow	Seclow	m	1,002.44
Test section length	L_w	m	900.44
Test section diameter[2]	$2 \cdot r_w$	mm	77
Test start (start of pressure registration)		yymmdd hh:mm	050517 00:00
Packer expanded		yymmdd hh:mm:ss	
Start of flow period		yymmdd hh:mm:ss	050517 15:20
Stop of flow period		yymmdd hh:mm:ss	050525 11:09
Test stop (stop of pressure registration)		yymmdd hh:mm	050603 23:00
Total flow time	t_p	min	11,269
Total recovery time	t_F	min	13,671
Pressure data			
Pressure in test section before start of flow period	p_i	kPa	917.5
Pressure in test section before stop of flow period	p_p	kPa	828.0
Pressure in test section at stop of recovery period	p_F	kPa	[3]
Pressure change during flow period (p_i - p_p)	d_{pp}	kPa	89.5
Flow data			
Flow rate from test section just before stop of flow period	Q_p	m^3 /s	0.001865
Mean (arithmetic) flow rate during flow period	Q_m	m^3 /s	0.00188
Total volume discharged during flow period	V_p	m^3	1,190

Manual groundwater level measurements in KFM02A (102.0–1,002.4 m)			**GW level**	
Date YYYY-MM-DD	**Time tt:mm**	**Time (min)**	**(m b. ToC)**	**(m.a.s.l.)**
2005-05-17	10:25	–295	7.98	–0.60
2005-05-18	15:00	1,420	11.30	–3.91
2005-05-18	15:15	1,435	15.10	–7.70

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

2) Nominal diameter.

3) Pressure in pumping borehole was only measured until pumping stop.

Comments on the test

The test was performed as a constant-flow rate pumping test. The flow rate was c 112 L/min and the duration of the flow period was c 188 h. A constant flow rate was reached after c 24 h. In the beginning, the flow rate had to be adjusted so as not to become higher than the capacity of a drainage pump on the ground surface, pumping water from a sedimentation container to the sea. The drainage pump was exchanged on the second day of pumping and the intended flow rate was reached. The final drawdown in KFM02A was approximately 9 m. Pumping activities in the area had, however, lowered the water table in borehole KFM02A before the start of pumping. Therefore the actual drawdown must be considered larger than the measured drawdown. Ground water level measurements conducted in 2004 suggest that the water table may normally be positioned roughly 1 to 1.5 m above the actual starting level prior to the start of pumping. The pressure recovery was measured for about 228 h in the observation boreholes, but since no quantitative evaluation was planned, no recovery measurements were made in KFM02A. An overview of flow rate and pressure responses in KFM02A is presented in Figures A2-1 and A2-2.

6.2.2 Observation section KFM03A: 0.0–350.5 m

General test data from the observation section KFM03A, 0.0–350.5 m, are presented in Table 6-2. In Figures A2-3 and A2-4 in Appendix 2 an overview of the pressure responses in observation borehole KFM03A is shown.

Table 6-2. General test data from the observation section KFM03A: 0.0–350.5 m during the interference test in KFM02A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	m	1,030.36
Hydraulic head in test section before stop of flow period	h_p	m	1,030.26
Hydraulic head in test section at stop of recovery period	h_F	m	1,030.18
Hydraulic head change during flow period (h_i - h_p)	dh_p	m	0.10

Comments on the test

The hydraulic head was slightly decreasing throughout the entire test period. However, it is unlikely that this section is influenced by the pumping in KFM02A. The pressure in the observation section is showing an oscillating behaviour, see Figure A2-4. This is believed to be natural fluctuations, mainly caused by so called tidal effects which, in part, have been studied previously in /3/. The maximum change in hydraulic head during the flow period is c 0.30 m. This is, however, due to the periodic behaviour of the pressure, mentioned above. The actual drawdown during the flow period is c 0.10 m when comparing measured levels at the start and stop of the flow period, respectively. Both these measurements were made at an approximate trough in the cycle of the pressure oscillation.

6.2.3 Observation section KFM03A: 351.5–401.5 m

General test data from the observation section KFM03A, 351.5–401.5 m, are presented in Table 6-3. In Figures A2-3 and A2-4 an overview of the pressure responses in observation borehole KFM03A is shown.

Table 6-3. General test data from the observation section KFM03A: 351.5–401.5 m during the interference test in KFM02A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	m	1,029.82
Hydraulic head in test section before stop of flow period	h_p	m	1,029.70
Hydraulic head in test section at stop of recovery period	h_F	m	1,029.79
Hydraulic head change during flow period (h_i - h_p)	dh_p	m	0.12

Comments on the test

This section indicates a weak response to pumping in KFM03A. The pressure in the test section demonstrates an oscillating behaviour, see Figure A2-3. Like for the previous section this is believed to be natural fluctuations, mainly caused by so called tidal effects which, in part, have been studied previously in /3/. The maximum change in hydraulic head during the flow period is c 0.16 m. This is, however, due to the periodic behaviour of the pressure, mentioned above. The actual drawdown during the flow period is c 0.12 m when comparing measured levels at the start and stop of the flow period, respectively. Both these measurements were made at an approximate trough in the cycle of the pressure oscillation. A drawdown of about 0.01 m was reached approximately 24 h after start of pumping in KFM02A. The exact time is hard to derive due to the interference from tidal effects. The drawdown was fully recovered after the recovery period of c 228 h.

6.2.4 Observation section KFM03A: 402.5–471.5 m

General test data from the observation section KFM03A, 402.5–471.5 m, are presented in Table 6-4. In Figures A2-3 and A2-4 an overview of the pressure responses in observation borehole KFM03A is shown.

Table 6-4. General test data from the observation section KFM03A: 402.5–471.5 m during the interference test in KFM02A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	m	1,030.15
Hydraulic head in test section before stop of flow period	h_p	m	1,030.64
Hydraulic head in test section at stop of recovery period	h_F	m	1,030.77
Hydraulic head change during flow period (h_i - h_p)	dh_p	m	–0.49

Comments on the test

No response to pumping was detected in this section. The hydraulic head of the section is increasing throughout the test. The reason for this is not clear. The hydraulic head of the section is displaying an oscillating behaviour, see Figure A2-4. This is believed to be caused by tidal effects, see above.

6.2.5 Observation section KFM03A: 472.5–632.5 m

General test data from the observation section KFM03A, 472.5–632.5 m, are presented in Table 6-5. An overview of the pressure responses in observation borehole KFM03A is given in Figures A2-3 and A2-4.

Table 6-5. General test data from the observation section KFM03A: 472.5–632.5 m during the interference test in KFM02A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	m	1,030.08
Hydraulic head in test section before stop of flow period	h_p	m	1,029.90
Hydraulic head in test section at stop of recovery period	h_F	m	1,030.02
Hydraulic head change during flow period (h_i - h_p)	dh_p	m	0.18

Comments on the test

A clear response to pumping in KFM02A was detected in this section, see Figure A2-3. Also in this section the pressure is showing an oscillating behaviour. The maximum change in hydraulic head during the flow period is c 0.29 m. This is, however, due to the periodic behaviour of the pressure, mentioned above. The actual drawdown during the flow period is c 0.18 m when comparing measured levels at the start and stop of the flow period, respectively. Both these measurements were made at an approximate trough in the cycle of the pressure oscillation. A drawdown of about 0.01 m was reached approximately 17 h after start of pumping in KFM02A. The drawdown was not quite recovered after the recovery period of c 228 h. The exact amount of recovery is, however, difficult to establish due to the oscillating pressure.

6.2.6 Observation section KFM03A: 633.5–650.0 m

General test data from the observation section KFM03A, 633.5–650.0 m, are presented in Table 6-6. See Figures A2-3 and A2-4 for an overview of the pressure responses in observation borehole KFM03A.

Table 6-6. General test data from the observation section KFM03A: 633.5–650.0 m during the interference test in KFM02A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	m	1,029.94
Hydraulic head in test section before stop of flow period	h_p	m	1,029.54
Hydraulic head in test section at stop of recovery period	h_F	m	1,029.81
Hydraulic head change during flow period (h_i - h_p)	dh_p	m	0.40

Comments on the test

This section exhibits the strongest pressure response to pumping of all sections in KFM03A, Figure A2-3. Also here the pressure in the test section is showing an oscillating behaviour which is believed to mainly be caused by tidal effects. The maximum change in hydraulic head during the flow period is c 0.52 m. This is, however, due to the periodic behaviour of the pressure, mentioned above. The actual drawdown during the flow period is c 0.40 m when comparing measured levels at the start and stop of the flow period, respectively. Both these measurements were made at an approximate trough in the cycle of the pressure oscillation. A drawdown of about 0.01 m was reached approximately 17 h after start of pumping in KFM02A. The drawdown was not quite recovered after the recovery period of c 228 h. The exact amount of recovery is, however, difficult to establish due to the oscillating pressure.

6.2.7 Observation section KFM03A: 651.0–819.5 m

General test data from the observation section KFM03A, 651.0–819.5 m, are presented in Table 6-7. In Figures A2-3 and A2-4 an overview of the pressure responses in observation borehole KFM03A is shown.

Table 6-7. General test data from the observation section KFM03A: 651.0–819.5 m during the interference test in KFM02A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	m	1,029.41
Hydraulic head in test section before stop of flow period	h_p	m	1,029.50
Hydraulic head in test section at stop of recovery period	h_F	m	1,029.58
Hydraulic head change during flow period (h_i - h_p)	dh_p	m	0.09

Comments on the test

No response to pumping was detected in this section. The hydraulic head of the section was slightly increasing during the test. The oscillating behaviour displayed in Figure A2-4 is believed to be caused by tidal effects which, in part, have been studied previously in /3/.

6.2.8 Observation section KFM03A: 820.5–968.5 m

General test data from the observation section KFM03A, 820.5–968.5 m, are presented in Table 6-8. See Figures A2-3 and A2-4 for an overview of the pressure responses in observation borehole KFM03A.

Table 6-8. General test data from the observation section KFM03A: 820.5–968.5 m during the interference test in KFM02A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	m	1,025.33
Hydraulic head in test section before stop of flow period	h_p	m	1,025.37
Hydraulic head in test section at stop of recovery period	h_F	m	1,025.47
Hydraulic head change during flow period (h_i - h_p)	dh_p	m	0.04

Comments on the test

No response to pumping was detected in this section. The hydraulic head of the section was slightly increasing during the test. The oscillating behaviour displayed in Figure A2-4 is believed to be caused by tidal effects. See also the sections above.

6.2.9 Observation section KFM03A: 969.5–994.5 m

General test data from the observation section KFM03A, 969.5–994.5 m, are presented in Table 6-9. In Figures A2-3 and A2-4 an overview of the pressure responses in observation borehole KFM03A is shown.

Table 6-9. General test data from the observation section KFM03A: 969.5–994.5 m during the interference test in KFM02A.

Pressure data	Nomenclature	Unit	Value
Hydraulic head in test section before start of flow period	h_i	m	1,027.36
Hydraulic head in test section before stop of flow period	h_p	m	1,027.45
Hydraulic head in test section at stop of recovery period	h_F	m	1,027.54
Hydraulic head change during flow period (h_i - h_p)	dh_p	m	–0.09

Comments on the test

No response to pumping was detected in this section. The hydraulic head of the section was slightly increasing during the test. The oscillating behaviour displayed in Figure A2-4 is also here believed to be caused by natural fluctuations, mainly so called tidal effects.

6.3 Response analysis

A simplified response analysis according to the methodology description for interference tests was made in this case due to the few observation sections. The response time lags (dt_L) in the observation sections during pumping in KFM02A are shown in Table 6-10. The lag times were derived from the drawdown curves in the observation borehole sections at an actual drawdown of 0.01 m. Because of the oscillating behaviour of the measured pressure in the observation borehole, it was difficult to determine the exact time to reach a 0.01 m drawdown. It was possible, however, to make an approximate estimate from the drawdown curves. Only observation sections in which a judged pressure response was recorded are included in the response analysis.

The normalised response time with respect to the distance to the pumping borehole was then 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 6-11. The presented numbers are calculated using the point of application at 172 m along the borehole in KFM02A, which was the assumed position of the interpreted deformation zone A3. Calculations were also made using the other point of application at 115 m along the borehole. The resulting difference was minute and is not presented here.

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

The (normalized) response time lags for all three sections in KFM03A where a response was detected must be considered as rough estimates. The reason for this is, as mentioned above, the difficulty to make an estimate of that parameter due to the oscillating pressure. In addition, the distances to the observation sections are very long.

The three sections in KFM03A included in the response analysis all respond in a similar way to pumping in KFM02A. The largest drawdown was observed in section 633.5–650.0 m and the weakest response in section 351.5–401.5, which is also indicated in Figure 6-1. This figure is showing a response diagram where the different observation sections included in the response analysis 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 compared to sections represented by data points further to the right in the diagram. However, the position of data points representing observation sections at very large distances may be uncertain.

Table 6-10. Calculated response lag times and normalized response time lags for the observation sections in KFM03A during pumping in KFM02A.

Pumping borehole	Observation borehole	Section (m)	dt_L[s=0.01 m] (s)	r_s (m)	dt_L[s=0.01 m]/rs^2 (s/m2)
KFM02A	KFM03A	351.5–401.5	86,400	1,688	0.0303
”	KFM03A	472.5–632.5	61,200	1,697	0.0213
”	KFM03A	633.5–650.0	61,200	1,716	0.0208

Table 6-11. Drawdown and normalized drawdown for the observation sections in KFM03A during pumping in KFM02A.

Pumping borehole	Flow rate Qp (m3/s)	Observation borehole	Section (m)	sp (m)	sp/Qp (s/m2)
KFM02A	0.001865	KFM03A	351.5–401.5	0.12	64.34
”	0.001865	KFM03A	472.5–632.5	0.18	96.51
”	0.001865	KFM03A	633.5–650.0	0.40	214.48

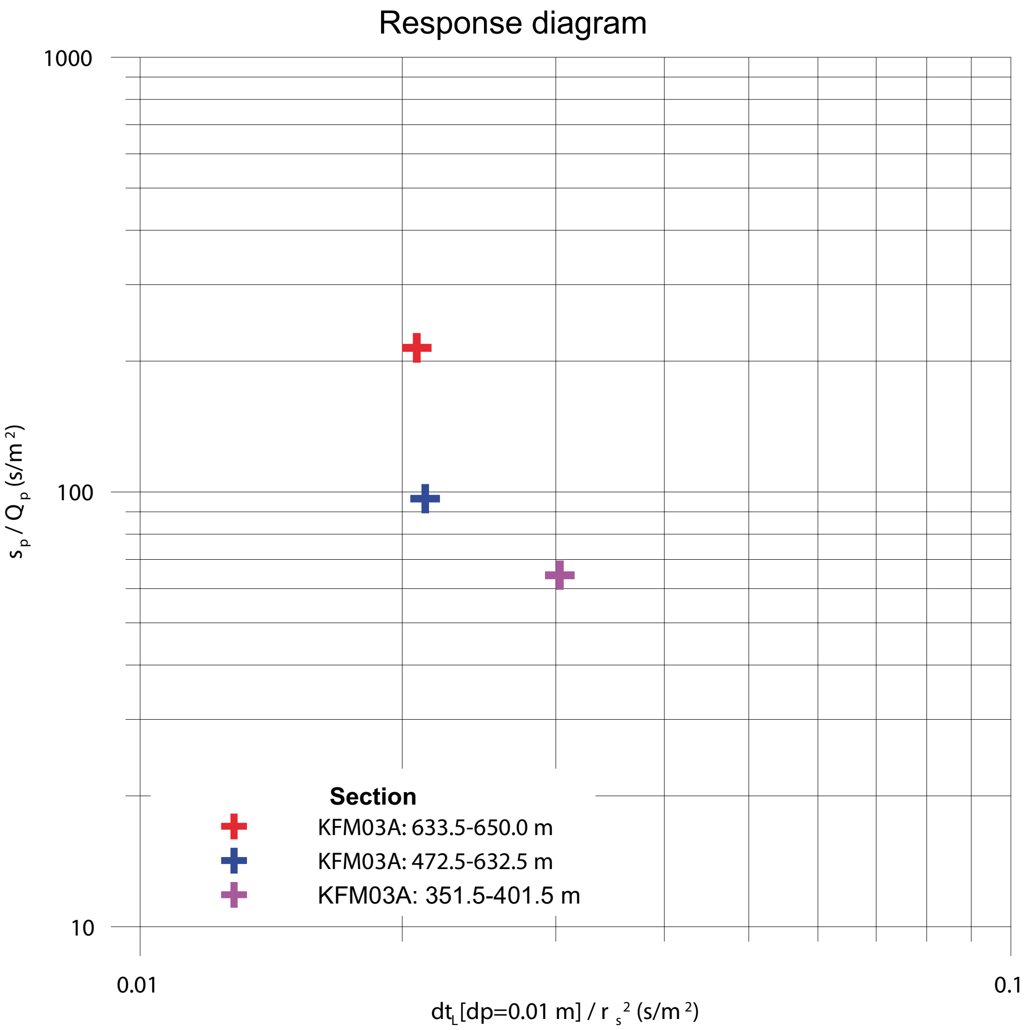

***Figure 6-1**. Response diagram of the observation sections in KFM03A from the interference test in KFM02A.*

6.4 Summary of the results of the interference test

Only three of the eight packed off sections in KFM03A, 351.5–401.5 m, 472.5–632.5 m and 633.5–650.0 m, responded to pumping in KFM02A. The strongest interference was detected in section 633.5–650.0 m and the weakest response was measured in section 351.5–401.5 m. The interference test was performed mainly to find any presumptive hydraulic connection between boreholes KFM02A and KFM03A via what has been interpreted as deformation zone A3. It is believed that A3 intersects KFM03A at 803–816 m along the borehole. The observation section containing this interval, 651.0–819.5 m, did however not show any response to pumping in KFM02A during the actual flow period. It should be noted that section 633.5–650.0, where the strongest response was registered, is adjacent to the section containing the interval with the assumed intersection of A3.

None of the responses, with the possible exception of KFM03A: 633.5–650.0 m, are considered as distinct enough to be characterized as clear zone responses considering the very long distances involved and the relatively short duration of the interference test. It is therefore uncertain if any of the responses has been transported via the interpreted deformation zone A3.

7 References

/1/ **Rouhiainen P, Pöllänen J, 2004.** Forsmark site investigation. Difference flow logging in borehole KFM02A. SKB P-04-188, Svensk Kärnbränslehantering AB.

/2/ **Källgården J, Ludvigson J-E, Hjerne C, 2004.** Forsmark site investigation. Single-hole injection tests in borehole KFM03A. SKB P-04-194, Svensk Kärnbränslehantering AB.

/3/ **Ludvigson J-E, Jönsson S, Levén J, 2004.** Forsmark site investigation. Hydraulic evaluation of pumping activities prior to hydro-geochemical sampling in borehole KFM03A – Comparison with results from difference flow logging. SKB P-04-96, Svensk Kärnbränslehantering AB.

/4/ **Pöllänen J, Sokolnicki M, 2004.** Forsmark site investigation. Difference flow logging in borehole KFM03A. SKB P-04-189, Svensk Kärnbränslehantering AB.

List of data files

Files are named: Interferenstest_Pumphål_”BhID”_”YYYYMMDD”_”hhmm”_”File Type”. Interferenstest_Pumphål is just an internal marker. “BhID” is the name of the borehole, datafile start time is given. 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
KFM02A	102–1,002	1B		20050517 00:00:00	20050603 23:00:00	20050426 14:21:15	20050526 07:14:50	Interferenstest_Pumphål_ KFM02A_20050426_1421_ Pumpin00.DAT	P, Q	Pressure and flow registration in KFM02A for interference.
KFM02A	102–1,002	1B		20050517 00:00:00	20050603 23:00:00	20050426 14:21:15	20050526 07:14:50	Interferenstest_Pumphål_ KFM02A_20050426_1421_Ref_ Da00.DAT	C, R	

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

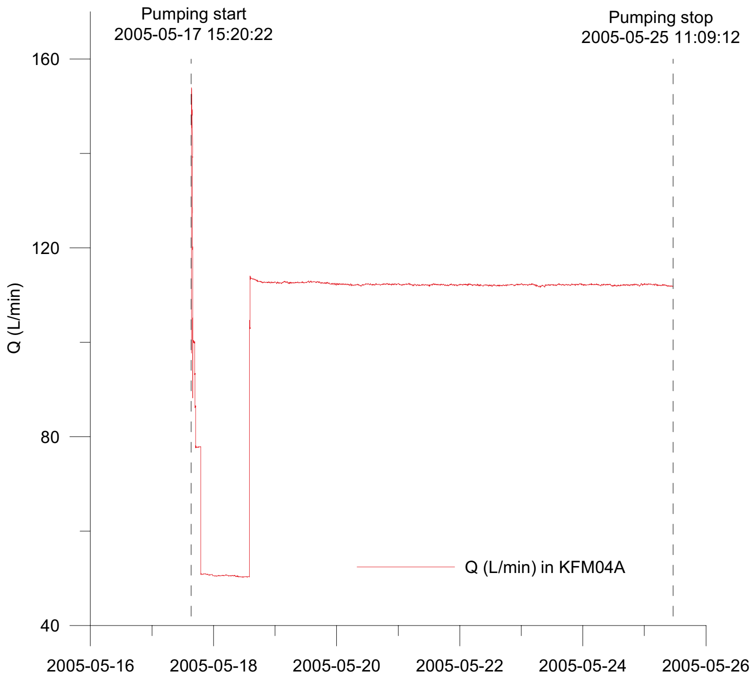

Figure A2-1. *Linear plot of flow rate versus time in the pumping borehole KFM02A.*

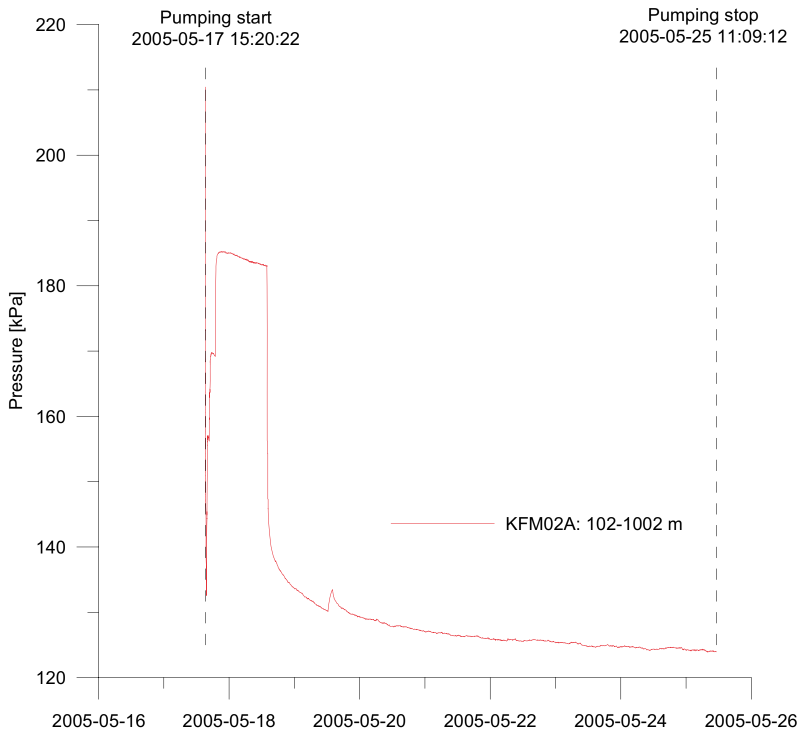

Figure A2-2. *Linear plot of pressure versus time in the pumping borehole KFM02A during the interference test.*

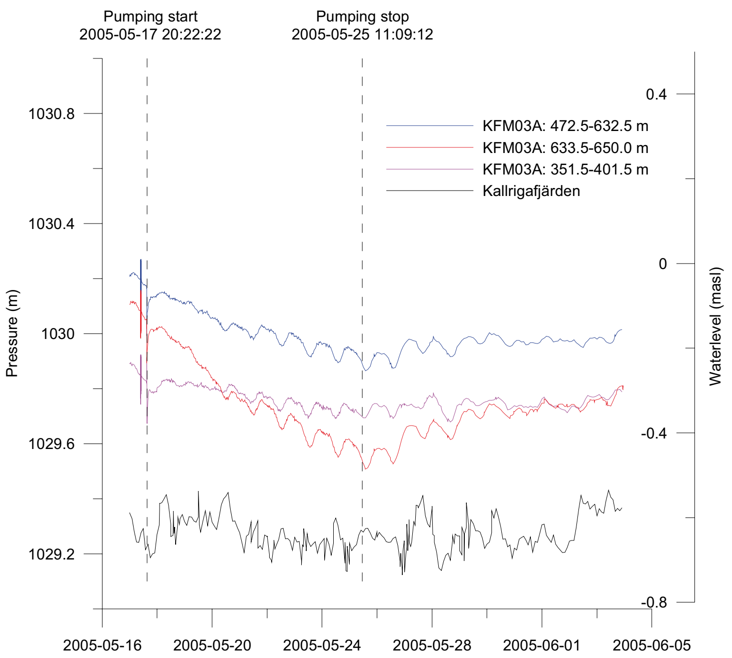

Figure A2-3. *Linear plot of pressure versus time of all sections in KFM03A displaying a response during the interference test. Also included is the sea water level in Kallrigafjärden during the time of the interference test.*

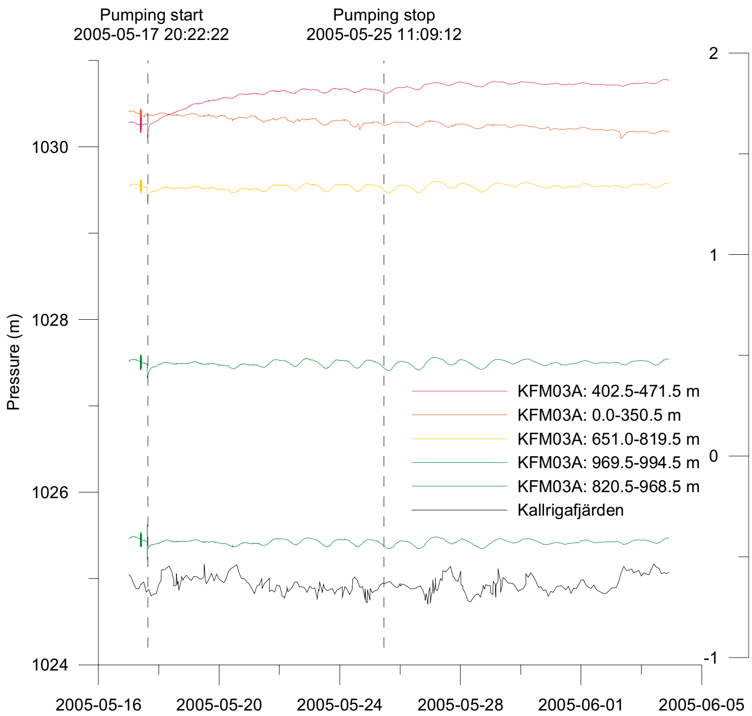

Figure A2-4. *Linear plot of hydraulic head versus time in the observation sections in KFM03A not showing signs of pressure response during the interference test in KFM02A. Also included is the sea water level in Kallrigafjärden during the time of the interference test.*

SICADA tables

Result tables to SICADA for the single-hole test in KFM02A (Empty cells in SICADA tables may be omitted)

plu_s_hole_test_d

idcode	start_date	stop_date	secup	seclow	section_no	test_typ	formation_type	start_flow_period	stop_flow_period
KFM02A	2005-05-17 00:00	2005-06-03 23:00	0.00	1002.4		1B	1	2005-05-17 15:20:00	2005-05-25 11 09 00

cont.

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
1.8650E-03	0	1.8800E-03			1.1900E+03	676140.00	820260.00

cont.

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
			917.5	828.00		

cont.

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

SICADA – description of plu_s_hole_test_d

PLU Injection and Pumping tests. General information

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.

plu_s_hole_test_ed1

idcode	start_date	stop_date	secup	seclow	section_no	test_type	formation_type	lp
KFM02A	2005-05-17 00:00	2005-06-03 23:00	0	1002.4		1B	1	172

SICADA - description of plu_s_hole_test_ed1

PLU Single hole tests, pumping and injection. Basic evaluation

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 considered 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) s. 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.

SICADA Header	Header	Unit	Explanation
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.
ri_index	ri-index		ri-index= 0: Pressure response indicates that the size of the hydraulic feature is greater than radius of influence based on time for last pressure response measured (tp=t2). Size of hydraulic feature greater than radius of influence based on t2. ri-index= 1: Pressure response indicates that the hydraulic feature assigned the representative transmissivity is connected to hydraulic feature with less transmissivity or barrier boundary. Size of hydraulic feature estimated as radius of influence based on t2. (Size of feature somewhat under estimated using t2- but error considered as small.). ri-index= –1: Pressure response indicates that the hydraulic feature assigned the representative transmissivity is connected to hydraulic feature with greater transmissivity or a constant head boundary. Size of hydraulic feature estimated as radius of influence based on t2. (Size of feature somewhat under estimated using t2- but error considered as small.)
bc_s	S-BC		Calculated by using S if S=value or S=f(T) if S*=value.
leakage_factor_lf	L_f	m	Leakage factor. $L_f = (K \cdot b \cdot c_f)^{0.5}$ 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.
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.

SICADA Header	Header	Unit	Explanation
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, $C_D = C \cdot \rho_w g / (2\pi \cdot S \cdot r_w^2)$.
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	dte_1		Start time for evaluated parameter from start of recovery period.
dte2	dte_2		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.

plu_inf_test_obs_d

idcode	start_date	stop_date	secup	seclow	section_no	test_type	formation_type	start_flow_period	stop_flow_period
KFM03A	2005-05-17 00:00	2005-06-03 23:00	0.00	350.5		2	1	2005-05-17 15:20:00	2005-05-25 11:09:00
KFM03A	2005-05-17 00:00	2005-06-03 23:00	351.50	401.5		2	1	2005-05-17 15:20:00	2005-05-25 11:09:00
KFM03A	2005-05-17 00:00	2005-06-03 23:00	402.50	471.5		2	1	2005-05-17 15:20:00	2005-05-25 11:09:00
KFM03A	2005-05-17 00:00	2005-06-03 23:00	472.50	632.5		2	1	2005-05-17 15:20:00	2005-05-25 11:09:00
KFM03A	2005-05-17 00:00	2005-06-03 23:00	633.50	650.0		2	1	2005-05-17 15:20:00	2005-05-25 11:09:00
KFM03A	2005-05-17 00:00	2005-06-03 23:00	651.00	819.5		2	1	2005-05-17 15:20:00	2005-05-25 11:09:00
KFM03A	2005-05-17 00:00	2005-06-03 23:00	820.50	968.5		2	1	2005-05-17 15:20:00	2005-05-25 11:09:00
KFM03A	2005-05-17 00:00	2005-06-03 23:00	969.50	994.5		2	1	2005-05-17 15:20:00	2005-05-25 11:09:00

cont.

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
KFM02A	0	1002.44	119.00	1691.00			1030.36	1030.26
KFM02A	0	1002.44	389.00	1688.00		86400.00	1029.82	1029.70
KFM02A	0	1002.44	454.00	1692.00			1030.15	1030.64
KFM02A	0	1002.44	512.00	1697.00		61200.00	1030.08	1029.90
KFM02A	0	1002.44	644.00	1716.00		61200.00	1029.94	1029.54
KFM02A	0	1002.44	809.00	1751.00			1029.41	1029.50
KFM02A	0	1002.44	944.00	1790.00			1025.33	1025.37
KFM02A	0	1002.44	989.00	1804.00			1027.36	1027.45

cont.

final_head_h f	initial_press_pi	press_at_flow_end_pp	final_press_p	f fluid_temp_teo	fluid_elcond_eco
1030.18					
1029.79					
1030.77					
1030.02					
1029.81					
1029.58					
1025.47					
1027.54					

cont.

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

SICADA - description of plu_inf_test_obs_d

PLU interference tests, Observation section data

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).

SICADA Header	Header	Unit	Explanation
lp	Lp	(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	rs	(m)	Geometrical distance from point of application in test section to point of application in observation section.
shortest_distance_rt	rt	(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	dtL	(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	hi	(m)	Hydraulic head in observation section at start of flow period.
head_at_flow_end_hp	hp	(m)	Hydraulic head in observation section at stop of flow period.
final_head_hf	hF	(m)	Hydraulic head in observation section at stop of recovery period.
initial_press_pi	pi	(kPa)	Groundwater pressure in observation section at start of flow period.
press_at_flow_end_pp	pp	(kPa)	Groundwater pressure in observation section at stop of flow period.
final_press_pf	pF	(kPa)	Groundwater pressure in observation section at stop of recovery period.
fluid_temp_teo	Teo	(Co)	Measured borehole fluid temperature in the observation section (representative for evaluated parameters).
fluid_elcond_eco	ECo	(mS/m)	Measured electric conductivity of the borehole fluid in the observation section (representative for evaluated parameters).
fluid_salinity_tdso	TDSo	(mg/L)	Calculated total dissolved solids of the borehole fluid in the observation section, based on EC-measurement.
fluid_salinity_tdso	TDSom	(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).
Index o			Observation borehole or observation section (o short for observation).