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## Hydraulic interference test

### Boreholes HFM18 and KFM03A

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December 2004

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*Keywords:* Forsmark, Hydrogeology, Hydraulic tests, Pumping tests, Single-hole tests, Interference tests, Hydraulic parameters, Transmissivity, Storativity, AP PF 400-04-65.

# Abstract

An interference test was performed in order to verify an assumed hydraulic connection between previously identified major flow anomalies in percussion borehole HFM18 and a fractured zone at c 389 m in the deep telescopic borehole KFM03A. The identified zones in the boreholes are assumed to belong to the same major geologic structure (seismic reflector A4).

The interference test was performed by pumping in the open borehole HFM18. The presumptive pressure response was registered in observation borehole KFM03A where a double packer system was installed to isolate section 386–391 m in which the primary pressure response was anticipated. In addition, the pressure was registered in the borehole intervals above and below this section in KFM03A as well as in the private well F3:38 at Lillfjärden.

The interference test verified the assumed hydraulic connection between HFM18 and KFM03A: 386–391 m, most likely via a high-transmissive fracture zone. A clear pressure response was obtained in the latter section c 45 min after start of pumping. The distance to the pumping borehole HFM18 is c 840 m. The maximum drawdown in the observation section KFM03A: 386–391 m was 0.72 m. From the pressure interference in this section, the transmissivity was estimated at $5 \times 10^{-4}$ $m^2/s$ and the storativity at $2 \times 10^{-5}$.

Also in the borehole interval KFM03A: 392–1,001 m a clear pressure response was obtained c 140 min after start of pumping. The maximum drawdown in this interval was c 0.5 m. The distance to the pumping borehole HFM18 to this section is c 865 m. However, no clear pressure response was obtained in the open borehole interval KFM03A: 12–385 m, i e the section including the ground water level in the borehole.

Finally, a good pressure response was also obtained in the private well F3:38 at Lillfjärden which indicates that this well might be intersected by the same fracture zone between HFM18 and KFM03A.

# Sammanfattning

Ett interferenstest genomfördes för att verifiera en förmodad hydraulisk kontakt mellan tidigare identifierade större flödesanomalier i hammarborrhål HFM18 och vid ca 389 m i kärnborrhål KFM03A. De identifierade zonerna i respektive borrhål antas båda tillhöra samma större geologiska struktur (seismisk reflektor A4).

Interferenstesten utfördes genom pumpning i öppet hål i HFM18. Den förväntade tryckresponsen registrerades i observationsborrhål KFM03A där ett dubbelmanschett-system installerades för att isolera sektionen 386–391 m i vilken den primära tryck-responsen förväntades. Dessutom registrerades trycket i sektionerna över och under denna sektion i KFM03A samt i den privata brunnen F3:38 vid Lillfjärden.

Interferenstesten verifierade den förmodade hydrauliska kontakten mellan HFM18 och KFM03A: 386–391 m, sannolikt via en hög-transmissiv sprickzon. En tydlig tryckrespons erhölls i den senare sektionen ca 45 min efter pumpstart. Avståndet till pumphålet HFM18 är ca 840 m. Den maximala avsänkningen i observationssektionen var 0,72 m. Från interferensen i denna sektion skattades transmissiviteten till $5 \times 10^{-4}$ $m^2/s$ och storativiteten till ca $2 \times 10^{-5}$.

Även i borrhålsintervallet KFM03A: 392–1 001 m erhölls en tydlig respons efter c 140 min efter pumpstart. Den maximala avsänkningen i denna sektion var ca 0,5 m. Avståndet till pumphålet HFM18 till denna sektion är ca 865 m. Däremot erhölls ingen tydlig respons i det öppna borrhålsintervallet KFM03A: 12–385 m, dvs sektionen upp till grundvattenytan i borrhålet.

Slutligen erhölls god respons i den privata brunnen F3:38 vid Lillfjärden vilket tyder på att eventuellt också denna brunn penetrerar sprickzonen mellan HFM18 och KFM03A.

# Contents

# 1 Introduction

The aim of hydraulic interference tests is to get support for interpretations of hydraulic 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 in borehole HFM18 /1/ prior to the interference test, the total transmissivity of the borehole was estimated at $1.6 \times 10^{-4}$ $m^2/s$. Three separate flow anomalies were identified at c 36.5–38 m, 46.0–46.5 m and 48.0–48.5 m. This report documents the results from the interference test performed in order to verify an assumed hydraulic connection between HFM18 and the cored, subvertical borehole KFM03A at c 388 m (possibly the seismic reflector A4). Pressure measurements were also made in the private well F3:38 at Lillfjärden which possibly also might intersect the same fracture zone. This well is c 6 m deep and drilled in hard rock /2/. The locations of the boreholes involved in the interference test together with interpreted seismic reflectors are shown in Figure 1-1.

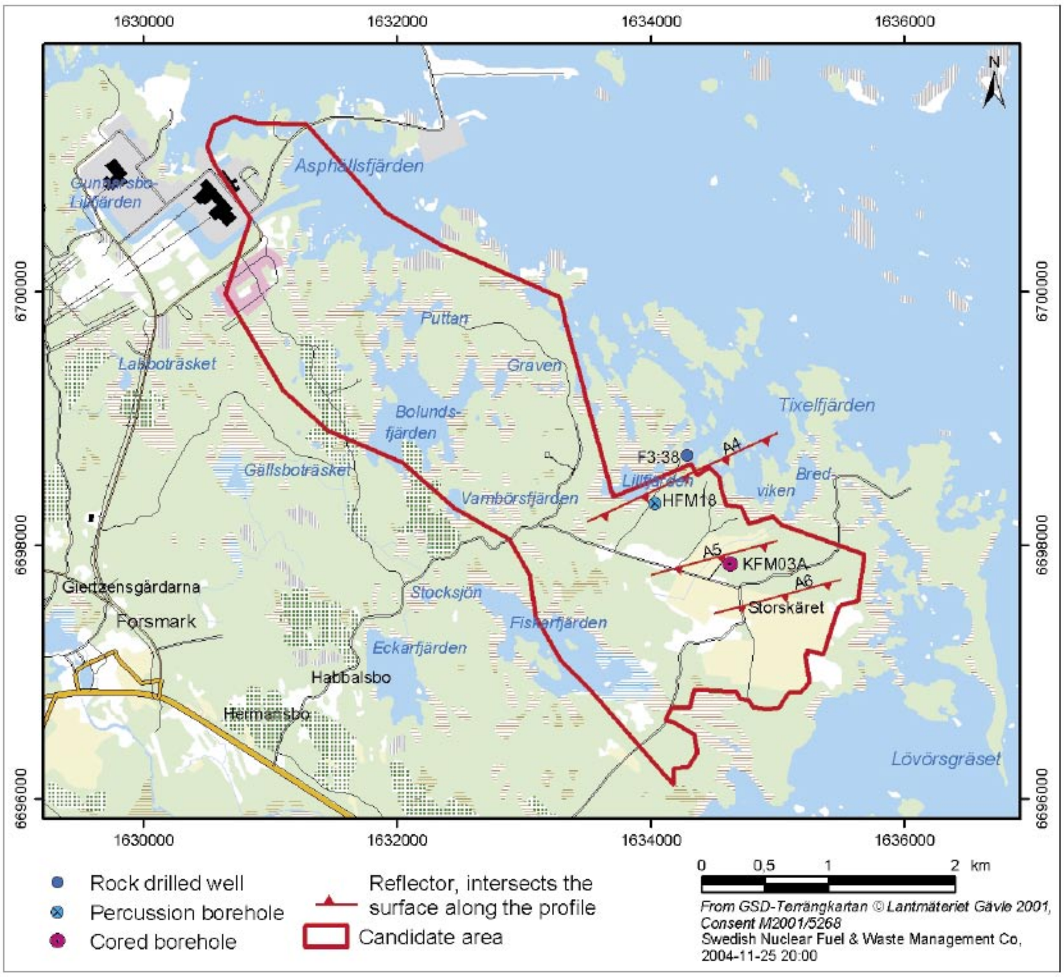



*__Figure 1-1.__ The investigation area at Forsmark including the candidate area selected for more detailed investigations together with the three boreholes involved in this interference test and interpreted seismic reflectors. F3:38 is a private well at Lillfjärden.*

This document reports the results gained by the hydraulic interference test between HFM18 and KFM03A, which is one of the activities performed within the site investigation at Forsmark. The test was carried out at the end of June to the beginning of July, 2004, by Geosigma AB. The work was conducted in accordance with activity plan AP PF 400-04-65. In Table 1-1 controlling documents for performing this activity are listed. Both activity plan and method descriptions are SKB's internal controlling documents.

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

| Activity plan | Number | Version |
|---|---|---|
| Undersökning av hydrulisk kontakt mellan HFM18 och KFM03A (389 m) | AP PF 400-04-65 | 1.0 |
| **Method descriptions** | **Number** | **Version** |
| Metodbeskrivning för interferenstester | SKB MD 330.003 | 1.0 |

# 2 Objectives

The main objectives of the interference test in HFM18 were to investigate the assumed hydraulic connection between boreholes HFM18 and KFM03A and, if existing, to estimate the transmissivity of the hydraulic structure connecting the boreholes. There were reasons to believe that the very conductive flow anomalies in borehole HFM18 at c 37 m and in KFM03A at c 389 m along the borehole may be hydraulically connected by a fracture zone (seismic reflector A4).

To verify the assumed hydraulic connection between the boreholes, an interference test was conducted by pumping in HFM18 and monitoring possible responses in KFM03A.

Figure 1-1 indicates that the seismic reflector A4 is outcropping at the ground surface slightly to the south-east of the private well F3:38. However, the interpreted orientation of the assumed fracture zone is associated with a degree of uncertainty. Pressure measurements were therefore made also in this well during the interference test in order to investigate the possible existence of a hydraulic connection with reflector A4.

# 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) is used in the x-y-direction together with RHB70 in the z-direction. The reported borehole diameter for borehole HFM18 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 worn drill bit. The coordinates of the boreholes at ground surface are shown in Table 3-2.

The private well at Lillfjärden (denoted F3:38 in the well inventory report /2/) is denoted PFM000010 in Sicada. Only limited geometrical data exist from this well.

**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 bore-hole (from local N) (°)** | **Remarks** | **Drilling finished Date (YYYY-MM-DD)** |
| HFM18 | 5.039 | 0.00–9.00 | 0.160 | –59.35 | 313.29 | Casing ID | |
| ” | | 9.00–180.65 | 0.140 | | | Borehole | 2003-12-16 |
| 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 | |
| PFM000010 (F3:38) | | 0–6 | | | | | |

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

| Borehole data | | |
|---|---|---|
| **Bh ID** | **Northing (m)** | **Easting (m)** |
| HFM18 | 6,698,326.858 | 1,634,037.374 |
| KFM03A | 6,697,852.096 | 1,634,630.737 |
| PFM000010 (F3:38) | 6,698,705 | 1,634,288 |

## 3.2 Tests performed

The borehole sections involved in the interference test in HFM18 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. The test performance was according to the Geosigma quality plan ("Kvalitetsplan för SKB uppdrag – Interferenstest mellan borrhålen HFM18 och KFM03A, K 304255, Stig Jönsson, 2004-06-23", 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/ and /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. The distance between the pumping borehole section and the private well F3:38 at Lillfjärden was estimated at c 460 m from maps.

In HFM18, the point of application was estimated from a point of balance calculation considering the contribution from three different flow anomalies identified from the previous hydraulic single-hole pumping tests and flow logging /1/. In the observation borehole sections in KFM03A, the points of application were selected from the identified flow anomalies during the difference flow logging in borehole KFM03A, /4/.

**Table 3-3. Borehole sections involved in the interference test performed in HFM18 and KFM03A. F3:38 is a private well at Lillfjärden, 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) |
|---|---|---|---|---|---|
| HFM18 | 9.00–180.65 | 1B | Open borehole | 2004-06-30 15:48 | 2004-07-05 09:57 |
| KFM03A | 11.96–385 | 2 | Above packer | 2004-06-30 15:16 | 2004-07-05 12:36 |
| KFM03A | 386–391 | 2 | Between packers | 2004-06-30 15:14 | 2004-07-05 12:34 |
| KFM03A | 392–1,001.19 | 2 | Below packer | 2004-06-30 15:12 | 2004-07-05 12:32 |
| F3:38 | 0–6 | 2 | Open borehole | 2004-06-29 09:30 | 2004-07-09 13:42 |

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/ and /3/.**

| Bh ID | Test section (m) | Point of application (m below TOC) | Section length (m) | Transmissivity ($m^2/s$) |
|---|---|---|---|---|
| HFM18 | 9.00–180.65 | 42.2 | 171 | $1.62\times10^{-4}$ |
| KFM03A | 102.05–385* | 380.8 | 373 | $5.1\times10^{-6}$ |
| KFM03A | 386–391 | 388.6 | 5 | $1.71\times10^{-4}$ |
| KFM03A | 392–1,001.19 | 451.3 | 610 | $4.6\times10^{-6}$ |
| F3:38 | 0–6 | | | |

* The open borehole interval 11.96–102.05 is not tested previously and no transmissivity data are thus available for this interval.

**Table 3-5. Calculated distances from the pumping borehole HFM18 to the observation borehole sections involved in the interference test.**

| Pumping section in HFM18 (m) | Observation sections in KFM03A (m) | | | F3:38 |
|---|---|---|---|---|
| 9.00–180.65 | 11.96–385 | 386–391 | 392–1,001.19 | 0–6 |
| Distance | 836.7 | 840.1 | 864.4 | 460 |

## 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 tests is described in Activity Plan AP PF 400-04-65 (SKB internal controlling document). The equipment in the pumping borehole, HFM18, 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,
- pressure transducer in the borehole,
- flow meter at the surface,
- ata logger to sample data from the flow meter and the pressure transducer,
- flow rate control valve at the surface,
- PC to visualize the data.

The winch used to lower the pump in HFM18 and the pressure transducer were taken from a compound test kit normally referred to as HTHB (Swedish abbreviation for Hydraulic Test System for Percussion Boreholes). Other parts of the equipment, for example the data logger, flow meter and flow rate control valve very much resemble the equipment included in HTHB and are 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.

In the observation borehole KFM03A, the PSS (Pipe String System), described in SKB MD 345.101, was used to lower and install the five metre test section at 386–391 m along the borehole. The test section was isolated by packers and the pressure was measured below, within and above the test section. The monitoring of pressure/water level in KFM03A was carried out using mini-Trolls, a combined pressure transducer and data logger. Three of these were lowered approximately 10–20 m into the borehole, cf Table 4-2. The relative pressure transducers measuring pressure within and below the isolated section respectively, were connected to the measurement points by water-filled Tecalan hoses. (A relative pressure transducer measures the groundwater pressure subtracted by the barometric pressure). The mini-Troll transducers are fitted with cables leading up to the surface where transferring of data into a laptop PC can be conveniently executed at any time. As a backup, the pressure transducers normally used together with the PSS, were also installed and connected to the data acquisition system built into the PSS.

In the private well F3:38 at Lillfjärden, the absolute pressure was monitored by a Mini-Troll sensor.

## 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 4-1. 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<br>Parameter | | Unit | Sensor | Test system | Comments |
|---|---|---|---|---|---|
| p-absolute | Output signal | mA | 4–20 | | |
| (HTHB) | Meas. range | kPa | 0–1,500 | | |
| | Resolution | kPa | 0.05 | | |
| | Accuracy | kPa | ± 1.5 * | ± 10 | Depending on uncertainties of the sensor position |
| p-relative | Output signal | mA | Digital | Same as for the sensor | Mini-Troll is a combined sensor and data logger unit |
| (Mini-Troll) | Meas. range | kPa | 0–206.8 | | |
| | 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.).

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

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

Equipment affecting the wellbore storage coefficient is given in terms of diameter of the submerged item. Position is given as "in section" or "above section" where "section" refers to the isolated test section.

**Table 4-2. Type and position of sensors (from ToC) and equipment that may affect wellbore storage in the pumping borehole and observation sections during the interference test in HFM18.**

| Borehole information | | | | Sensors | | Equipment in test section affecting wellbore storage (WBS) | | |
|---|---|---|---|---|---|---|---|---|
| ID | Test interval (m) | Test configuration | Test type[1] | Type | Position[2)] (m b ToC) | Function | Position[3] relative test section | Outer diameter (mm) |
| HFM18 | 9–180 | Open borehole | 1B | p-absolute (HTHB) | 38.3 | Transducer cable | In borehole | 8 |
| | | | | | 39.0 | Pump hose | In borehole In borehole | 40 |
| | | | | | 39.0 | Steel wire | | 6 |
| | | | | | 39.0–40.9 | Pump | In borehole | 95 |
| KFM03A | 12–385 | Above packers | 2 | p- absolute (Mini-Troll) | | Transducer cable | Above section | 9.1 |
| | | | | | | 2xTecalan hose | Above section | 6 |
| | | | | | | Aluminium pipe | Above section | 33 |
| | | | | | | 2xHydraulic hose | Above section | 11.7 |
| KFM03A | 386–391 | Between packers | 2 | p-relative (Mini-Troll) | 18.0 (386) | Transducer cable | In section | 9.1 |
| | | | | | | Tecalan hose | In section | 6 |
| | | | | | | Aluminium pipe | | 33 |
| KFM03A | 392–1,001 | Below packers | 2 | p-relative (Mini-Troll) | 18.8 (392) | | Below section | |
| F3:38 | 0–6 | Open borehole | 2 | p-absolute (Mini-Troll) | | Transducer cable | In borehole | 9.1 |

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

# 5 Execution

The test performance was 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 or response diagrams were prepared due to the few observation sections available.

## 5.1 Preparations

All sensors included in the test system are calibrated at Geosigma engineering workshop in Librobäck, Uppsala. Calibration is performed on a yearly basis, or more often if needed. The last calibration 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, and the mini-Troll transducers used in the observation borehole KFM03A are 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 Procedure

The pumping test in HFM18 was carried out as a constant flow rate test followed by a pressure recovery period. The pressure interference was recorded in three sections in KFM03A (below, above and between packers) during both the flow- and recovery period. The flow rate in the pumping borehole was chosen based on the results from earlier pumping tests and flow logging in HFM18. 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 5-1. Pumping in HFM18 was carried out using a 4" submersible pump during a period of c 48 h. The subsequent pressure recovery was measured over the weekend.

In HFM18, the absolute pressure transducer was attached to the pump hose c 0.70 m above the pump. The transducer was connected directly to the data logger via a cable. In observation borehole KFM03A monitoring of the pressure/water level was carried out using mini-Troll pressure transducers. For the isolated test section and the section below the packers, the pressure changes were transmitted via water-filled Tecalan hoses to the transducers attached to the pipe string c 15 m below top of casing.

Approximate sampling intervals for flow rate and pressure in the pumping borehole HFM18 are presented in Table 5-1. The mini-Troll pressure loggers in observation borehole KFM03A were logging pressure with an interval of 300 s with an additional condition to log as frequently as every 10 s if a pressure difference of at least 0.1 kPa between two consecutive scans occurred. Prior to and after the interference test, manual measurements of groundwater levels were performed in the observation borehole KFM03A as well as in the pumping borehole HFM18.

**Table 5-1. Approximate sampling intervals used for pressure registration in HFM18 during the interference test.**

| Time interval (s) from start/stop of pumping | Sampling interval (s) |
|---|---|
| 1–500 | 1 |
| 501–800 | 10 |
| 801–3,800 | 60 |
| > 3,800 | 600 |

## 5.3 Data handling

Flow and pressure data from the pumping borehole, HFM18, 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 loggers 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.

The produced logger files from both boreholes were imported into the evaluation software Aqtesolv and plotted in different diagrams listed in the Instruction for analysis of injection- and single-hole pumping tests (SKB MD 320.004).

## 5.4 Analyses and interpretation

As discussed in Section 5.2, the interference test was performed as a constant flow rate test. Methods for constant-flow tests in an equivalent porous medium were used by the analyses and interpretation of the tests. The responses in the observation borehole KFM03A as well as in the pumping borehole were analysed.

Firstly, a qualitative evaluation of actual flow regimes (pseudo-linear, pseudo-radial and pseudo-spherical flow, respectively) and possible outer boundary conditions during the test was performed. The qualitative evaluation was made from analyses of log-log diagrams of drawdown and/or recovery data together with the corresponding pressure derivatives versus time. In particular, pseudo-radial flow is reflected by a constant (horizontal) derivative in the diagrams, whereas apparent no-flow- and constant head boundaries are reflected by a steep increase/decrease of the derivative, respectively. Different values were applied on the filter coefficient (step length) by the calculation of the pressure derivative to investigate the effect of this coefficient on the derivative. It is desired to achieve maximal smoothing of the derivative without altering the original shape of the data.

The quantitative, transient interpretation of the hydraulic parameters in the observation borehole KFM03A (transmissivity and storativity) was primarily based on the identified pseudo-radial flow regime during the test in log-log and lin-log data diagrams.

The transient analyses were performed using a special version of the test analysis software AQTESOLV that enables both visual and automatic type curve matching. Thus, the quantitative transient evaluation is performed as an iterative process of type curve matching and automatic non-linear regression. For the evaluation of the interference test in HFM18, models described in /5/ and /6/ were used.

When possible, transient analysis was made both on the drawdown- and recovery phase of the test. The recovery data were plotted versus equivalent time. The analysis of the drawdown- and recovery data was made both in log-log and lin-log diagrams according to standard methods described in the above instruction in the previous section.

Transmissivity and storativity were estimated from the transient analysis of both the flow- and recovery period. However, one of those analyses was judged to provide the most representative values of transmissivity and storativity for the formation.

# 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 HFM18–KFM03A

The primary aim of the interference test was to confirm a possible hydraulic connection between HFM18 and KFM03A along the structure possibly representing a fracture zone identified in KFM03A: 386–391 m, /3/ and /4/. The pressure was also registered above and below the isolated observation section in KFM03A, i.e. within the intervals 12–385 m and 392–1,001.19 m, respectively, cf Figure 6-1. In addition, pressure registrations were made in the private well F3:38 at Lillfjärden. Visual inspection of the pressure responses in Figure 6-1 shows that significant responses were registered in the two lower observation sections in borehole KFM03A, whereas the upper section was virtually unaffected by the pumping (or only slightly affected). The measured drawdown ($s_p$) at the end of the flow period and response time lags ($dt_L$) in the observation sections in KFM03A and in the private well F3:38 are shown in Table 6-1. 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.

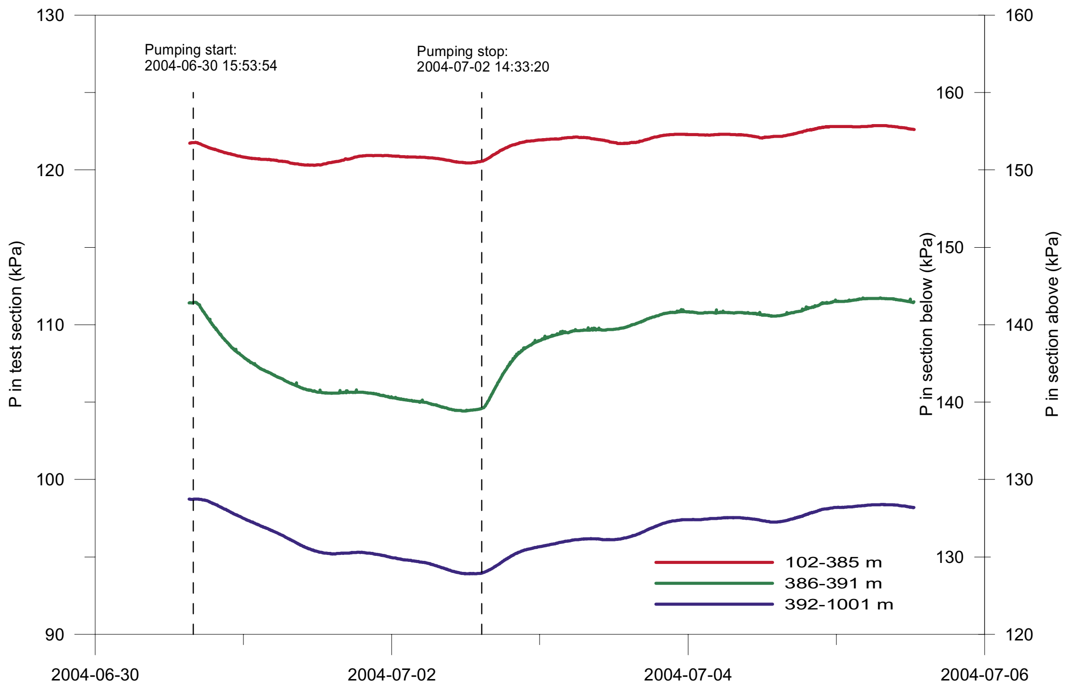



***Figure 6-1.*** *Pressure response in observation borehole KFM03A during pumping in HFM18.*

**Table 6-1. Drawdown in the pumping borehole HFM18, in the observation sections in KFM03A, and the private well F3:38 during the interference test in HFM18.**

| Pumping borehole | Flow rate $Q_p$ ($m^3/s$) | Observation borehole | Section (m) | $s_p$ (m) | $dt_L$[s = 0.01 m] (sec) |
|---|---|---|---|---|---|
| HFM18 | 0.0021 | | | 29.8 | – |
| | | KFM03A | 11.96–385 | – | no response |
| | | KFM03A | 386–391 | 0.70 | 2,700 |
| | | KFM03A | 392–1,001.19 | 0.49 | 8,300 |
| | | F3:38 | 0–6 | 0.35 | 2,800 |

The atmospheric pressure and precipitation during the test is shown in Figure A2-11 in Appendix 2. Registered data in the upper section (ground water level) in KFM03A and in the private well F3:38 have not been corrected for variations in the atmospheric pressure during the test. However, the atmospheric pressure was rather stable and only decreased c 0.4 kPa during the flow period of the test. In the two lower sections in KFM03A relative pressure transducers were used and thus no corrections are needed.

The pressure data in all sections of observation borehole KFM03A were heavily affected by a diurnal superimposed oscillation. This phenomenon has been observed during previous tests in borehole KFM03A /7/. In /7/, a very good correlation between observed oscillations in KFM03A and the sea water level with an approximate response time lag of four (4) hours was identified. A comparison with sea water level data to registered pressure data during the interference test in HFM18 (Figure 6-2) indicates that the sea water level is the dominating external effect. Figure 6-2 shows the influence of the sea water level at Kallrigafjärden on the measured pressure responses in section 386–391 m in KFM03A during pumping in HFM18.

### 6.2.1 Pumping borehole HFM18

General test data for the open-hole pumping test in HFM18 are presented in Table 6-2.

#### *Comments on the test*

The test was performed as a constant-flow rate pumping test. The flow rate was c 126 L/min and the duration of the flow period was c 47 h. A constant flow rate was reached after c 2 hours. The final drawdown in HFM18 was approximately 29.8 m. The pressure recovery was measured for c 67 h.

The estimated total transmissivity at the entire borehole from the previous pumping test conducted in conjunction with flow logging was $1.6 \times 10^{-4}$ $m^2/s$ /1/. When deciding the position of the borehole pump, consideration was taken into the positions of the dominating flow anomalies identified during flow logging and the desired, maximum drawdown in the pumping borehole. Based on previous pumping tests and a short capacity test conducted with the actual test equipment in HFM18, the appropriate flow rate to be applied during the pumping test was estimated at c 150 L/min, a value that was fallen slightly short of during the interference test.

**Table 6-2. General test data for the pumping test in HFM18: 9–180 m.**

| | | | |
|---|---|---|---|
| **General test data** | | | |
| Pumping borehole | HFM18 | | |
| 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 | 180.65 |
| Casing length | $L_c$ | m | 9.0 |
| Test section – secup | Secup | m | 9.0 |
| Test section – seclow | Seclow | m | 180.65 |
| Test section length | $L_w$ | m | 171.65 |
| Test section diameter[2] | $2 \times r_w$ | mm | 140 |
| Test start (start of pressure registration) | | yymmdd hh:mm | 040630 15:48 |
| Packer expanded | | yymmdd hh:mm:ss | – |
| Start of flow period | | yymmdd hh:mm:ss | 040630 15:53:54 |
| Stop of flow period | | yymmdd hh:mm:ss | 040702 14:33:20 |
| Test stop (stop of pressure registration) | | yymmdd hh:mm | 040705 09:57 |
| Total flow time | $t_p$ | min | 2,803 |
| Total recovery time | $t_F$ | min | 4,044 |
| **Pressure data** | | | |
| Absolute pressure in test section before start of flow period | $p_i$ | kPa | 373.4 |
| Absolute pressure in test section before stop of flow period | $p_p$ | kPa | 98.1 |
| Absolute pressure in test section at stop of recovery period | $p_F$ | kPa | 374.7 |
| Maximal pressure change during flow period | $dp_p$ | kPa | 276.8[3)] |
| **Flow data** | | | |
| Flow rate from test section just before stop of flow period | $Q_p$ | $m^3/s$ | 0.0021 |
| Mean (arithmetic) flow rate during flow period | $Q_m$ | $m^3/s$ | 0.0021 |
| Total volume discharged during flow period | $V_p$ | $m^3$ | 359 |

| Manual groundwater level measurements in HFM18 (9.0–180.7 m) | | | GW level | |
|---|---|---|---|---|
| **Date YYYY-MM-DD** | **Time tt:mm** | **Time (min)** | **(m b. ToC)** | **(m a s l)** |
| 2004-06-28 | 09:30 | | 5.41 | 0.38 |
| 2004-06-30 | 15:39 | | 5.42 | 0.37 |

[1)] Constant Head injection and recovery or Constant Rate withdrawal and recovery.
[2)] Nominal diameter.
[3)]Actual maximum pressure change is estimated to be about 18 kPa larger. See comments in text for more information.

The pressure transducer was located c 0.7 m above the borehole pump. Unfortunately, the actual drawdown in the borehole slightly exceeded the assumed value which resulted in the pressure transducer hanging in air after c 1,500 s of the flow period of the test, cf Figure A2-1 to A2–3. However, extrapolation of data together with the specific test configuration enables a rough estimate of the actual, total drawdown.

The final drawdown in HFM18 is assumed to be c 1.8 m larger than indicated by the pressure transducer, i.e. 29.8 m. By the transient evaluation of the recovery period, the final drawdown was corrected with this amount. The reference pressure of recovery, $p_p$, was thus assigned the estimated total drawdown of 29.8 m.

Selected test diagrams for HFM18 are presented in Figures A2-1 to A2-5 in Appendix 2.

### *Interpreted flow regimes*

During the flow period, WBS is indicated during the first c 100 s followed by a transition period. The latter period was interrupted at c 1,500 s due to the water level in the borehole beeing lowered below the pressure transducer, which was located at c 28 m below the reference point (see "Comments on the test" for detailed explanation). After c 1,500 s, pressure data do thus not represent the actual drawdown in the borehole, and no flow regime interpretation is possible for this part of the curve.

The first part of the recovery period is also slightly uncertain due to possible errors in the estimated final pressure during the flow period ($p_p$). However, a short period of WBS appears. From c 100 s, a transition period followed by pseudo-spherical (leaky) flow is indicated. By the end of the recovery period effects of apparent hydraulic boundaries are implied. There was no indication of pseudo-radial flow during the recovery period.

### *Interpreted parameters*

Due to reasons explained above, only an approximate transient interpretation of the flow period was possible, based on the first c 1,500 s. This interpretation is considered as very uncertain. For the recovery period, a transient interpretation was made. The wellbore storage coefficient, C, and skin factor, ζ, were estimated from the simulated effective casing radius and the effective borehole radius, respectively. The representative hydraulic parameters were chosen from the transient evaluation of the recovery period.

The results are presented in Table 6-7. A summary of test data and of the results is found in the Test Summary Sheet below.

## 6.2.2 Observation section KFM03A: 386–391 m

General test data from the isolated observation section KFM03A: 386–391 m are presented in Table 6-3.

### *Comments on the test*

The pressure response showed a periodic trend of oscillating pressure during both the flow- and recovery period. This fact is believed to be a result of fluctuations of the adjacent sea water level, see Section 6.2. These effects have been more thoroughly investigated previously in /7/. Figure 6-2 shows the correlation between the pressure in observation borehole KFM03A and the sea water level in Kallrigafjärden. The lag time in KFM03A to pressure changes of the sea water level is approximately 4 h. The sea water level data are extracted from the Hydro Monitoring System (HMS) database for the Forsmark site investigation area. Selected test diagrams for observation section KFM03A: 386–391 m are presented in Figures A2-6 to A2-10 in Appendix 2.

**Table 6-3. General test data from the observation section KFM03A: 386–391 m during the interference test in HFM18.**

| Pressure data | Nomenclature | Unit | Value |
|---|---|---|---|
| Absolute pressure in test section before start of flow period | $p_i$ | kPa | 3,862.47 |
| Absolute pressure in test section before stop of flow period | $p_p$ | kPa | 3,855.15 |
| Absolute pressure in test section at stop of recovery period | $p_F$ | kPa | 3,862.79 |
| Maximum pressure change during flow period | $dp_p$ | kPa | 7.028 |

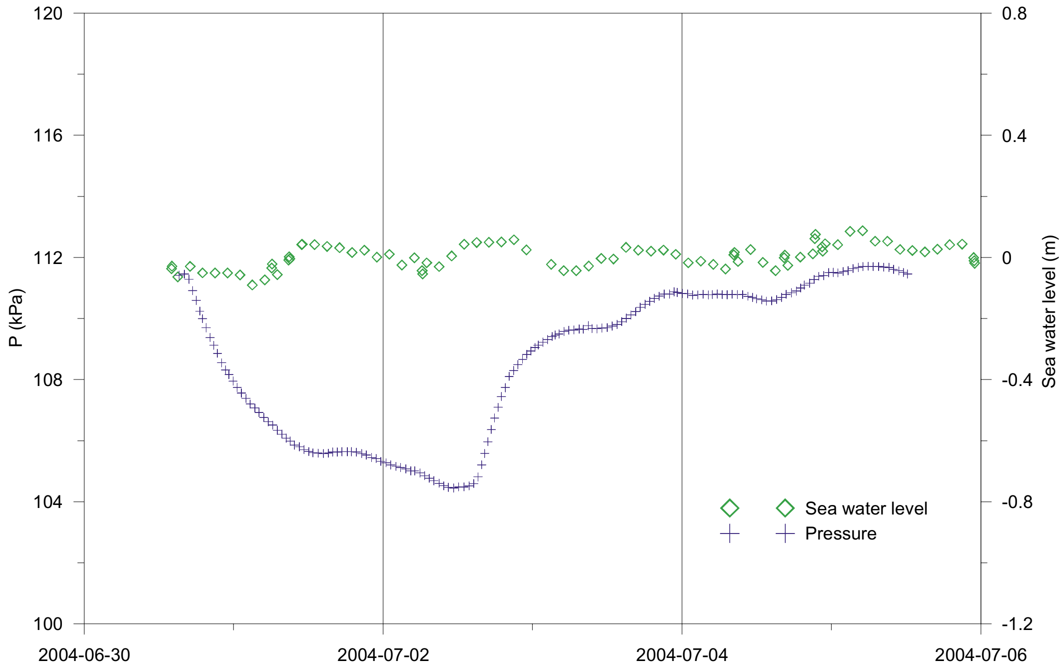



***Figure 6-2.*** *Correlation between the sea water level in Kallrigafjärden and the pressure response in the observation section KFM03A: 386–391 m during pumping in HFM18.*

### *Interpreted flow regimes*

Due to the pressure oscillations discussed in the previous section, the pressure in the section is disturbed, both during the flow- and recovery period. However, an apparent pseudo-radial flow regime transiting to pseudo-spherical flow is indicated during the flow period. The plateau in pressure data at c 70,000 s (c 19 h) is most likely caused by changes of the sea water level as can be seen in Figure 6-2 during 2004-07-01.

Natural oscillations probably caused by changes of the sea water level complicate the interpretation of flow regimes, during the recovery period as well. By the interpretation of flow regimes natural pressure oscillations must be filtered out firstly. This procedure enables an identification of an apparent pseudo-radial flow regime from c 40,000 s to 100,000 s during the recovery period.

The superimposed pressure oscillation primarily caused by the change in sea water level complicates identification of other external effects that might influence the responses during the interference test. Actual characteristics of the rock may also be over-shadowed and hard to separate from the oscillations. This fact increases the uncertainty in the flow regime interpretation in this case.

### *Interpreted parameters*

Transient evaluation of transmissivity and storativity was performed for both the flow- and recovery period using a model for pseudo-radial, transiting to leaky flow by the end of the test. Good agreement was obtained of the interpreted parameters between the flow- and recovery period. The representative hydraulic parameters were chosen from the transient evaluation of the first part (t < 70,000 s) of the flow period since this part is relatively unaffected by variations of the sea water level, cf Figure 6-2.

The results are presented in Table 6-8. A summary of test data and results is found in the Test Summary Sheet below.

### 6.2.3 Private well F3:38 at Lillfjärden

The absolute pressure was registered in the private well F3:38 at Lillfjärden, see Figure 1-1, during pumping in borehole HFM18. The pressure in the well (Figure 6-3) shows a clear response to the pumping, although disturbed by changes in the sea water level and probably also by rain 2004-07-02 and 2004-07-04 (see Figure A2-11 in Appendix 2). The correlation between pressure (water level) in the well and the sea water level was demonstrated in an earlier report /7/ where a time lag of approximately 4 hours between changes in the sea water level and the response in the well was found.

Since the atmospheric pressure changes were small during the observation period, no subtraction of the atmospheric pressure from the absolute pressure recorded in the well has been performed. The atmospheric pressure is plotted with the same resolution as the pressure in the private well F3:38 in Figure 6-3.

### 6.2.4 Response analysis

A simplified response analysis according to the methodology description for interference tests was made in this case due to the few observation boreholes/sections. The response time lags ($dt_L$) in the observation sections during pumping in HFM18 are shown in Table 6-4. The lag times were derived from the drawdown curves in the observation borehole sections at an actual drawdown of 0.01 m. Only the isolated test section (386–391 m), where a first change in pressure is registered after c 30 min, was evaluated quantitatively. The response time lag for the isolated test section (386–391 m) was c 45 min and c 140 min for the section below (392–1,001 m).

The normalised response time with respect to the distance to the pumping borehole (Index 1) 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 (Index 2) was calculated in Table 6-5.

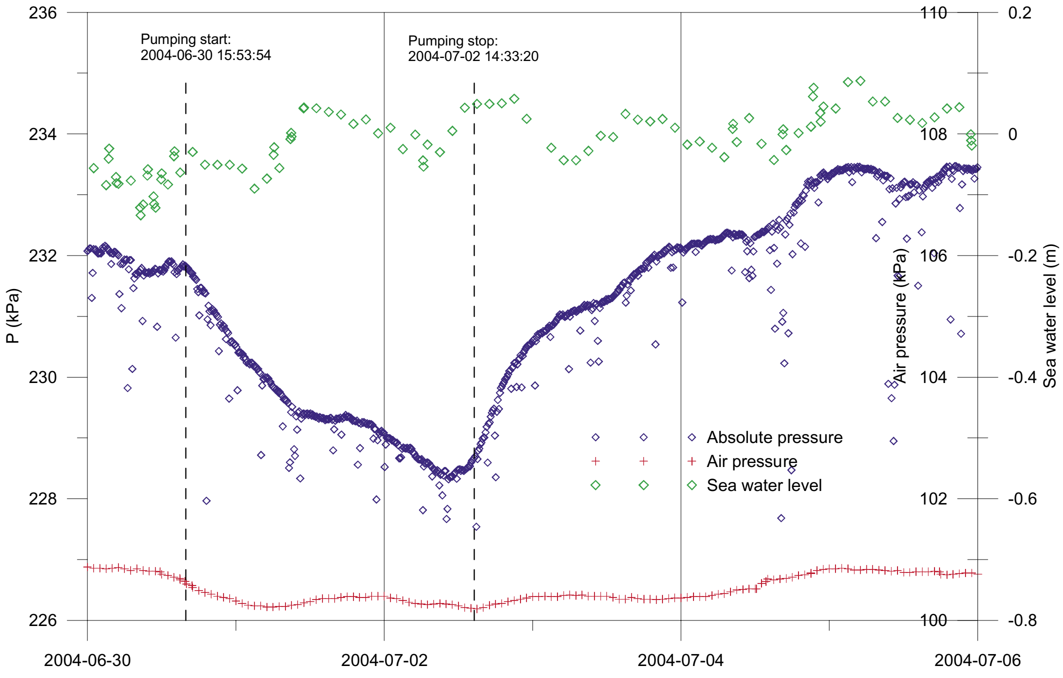



***Figure 6-3.*** *Response in the private well Lillfjärden F3:38 while pumping in borehole HFM18.*

$dt_{L[s = 0.01\ m]}/r_s^2$ = normalised 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 ($m^3/s$)

Tables 6-4 and 6-5 show that the (normalized) response time lag for the observation section KFM03A: 386–391 m was very short which indicates a high hydraulic diffusivity and a very good hydraulic connection between HFM18 and this section. It can thus be assumed that the fracture zone intersecting KFM03A at c 389 m also intersects HFM18. This fracture zone probably corresponds to the interpreted seismic reflector A4, see Figure 1-1. Good responses were also obtained in the borehole interval below the observation section in KFM03A and in the private well F3:38, also indicating good hydraulic connections with HFM18.

**Table 6-4. Calculated response lag times and normalised response time lags for the observation sections in KFM03A and the private well F3:38 during pumping in HFM18.**

| Pumping borehole | Observation borehole | Section (m) | $dt_L$[s = 0.01 m] (s) | $r_s$ (m) | $dt_L$[s = 0.01 m]/$r_s^2$ ($s/m^2$) |
|---|---|---|---|---|---|
| HFM18 | KFM03A | 11.96–385 | no response | 836.7 | – |
| | KFM03A | 386–391 | 2,700 | 840.1 | 0.004 |
| | KFM03A | 392–1,001.19 | 8,300 | 864.4 | 0.011 |
| | F3:38 | 0–6 | 2,800 | 461 | 0.013 |

**Table 6-5. Drawdown and normalised drawdown for the observation sections in KFM03A and the private well F3:38 during pumping in HFM18.**

| Pumping borehole | Flow rate $Q_p$ ($m^3/s$) | Observation borehole | Section (m) | $s_p$ (m) | $s_p/Q_p$ ($s/m^2$) |
|---|---|---|---|---|---|
| HFM18 | 0.0021 | KFM03A | 11.96–385 | – | – |
| | | KFM03A | 386–391 | 0.72 | $3.41\times10^2$ |
| | | KFM03A | 392–1,001.19 | 0.49 | $2.33\times10^2$ |
| | | F3:38 | 0–6 | 0.35 | $1.67\times10^2$ |

## 6.3 Summary of the results of the interference test

A compilation of measured test data from the combined single-hole and interference test in HFM18 is shown in Table 6-6. In Tables 6-7 and 6-8, calculated hydraulic parameters from the single-hole test and interference test in HFM18, respectively, are shown.

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.

**Table 6-6. Summary of test data from the interference test in borehole HFM18 in the Forsmark area.**

| Pumping borehole ID | Observation borehole ID | Section (m) | Test type[1)] | $p_i$ (kPa) | $p_p$ (kPa) | $p_F$ (kPa) | $Q_p$ ($m^3/s$) | $Q_m$ ($m^3/s$) | $V_p$ ($m^3$) |
|---|---|---|---|---|---|---|---|---|---|
| HFM18 | HFM18 | 9.0–180.65 | 1B | 373.4 | 98.1[2] | 374.7 | 0.0021 | 0.0021 | 359 |
| | KFM03A | 386–391 | 2 | 3,862.47 | 3,855.15 | 3,862.79 | – | – | – |

[1)] 1B: Pumping test-submersible pump, 2: Interference test (observation borehole).
[2)] See comments in Section 6.3.1.

**Table 6-7. Summary of calculated hydraulic parameters from the single-hole test in HFM18 in the Forsmark area.**

| Pumping borehole ID | Section (m) | Test type | Q/s ($m^2/s$) | $T_M$ ($m^2/s$) | $T_T$ ($m^2/s$) | ζ (–) | C ($m^3/Pa$) | S* (–) |
|---|---|---|---|---|---|---|---|---|
| HFM18 | 9.0–180.65 | 1B | $7.05\times10^{-5}$ | $9.09\times10^{-5}$ | $6.00\times10^{-5}$ | –2.65 | $1.8\times10^{-6}$ | $2.0\times10^{-5}$ |

**Table 6-8. Summary of calculated hydraulic parameters from the interference test in HFM18 in the Forsmark area.**

| Pumping borehole ID | Observation borehole ID | Section (m) | Test type | $T_o$ ($m^2/s$) | $S_o$ (–) | K*/b' ($s^{-1}$ ) |
|---|---|---|---|---|---|---|
| HFM18 | KFM03A | 386–391 | 2 | $5.24\times10^{-4}$ | $1.95\times10^{-5}$ | $2.38\times10^{-11}$ |

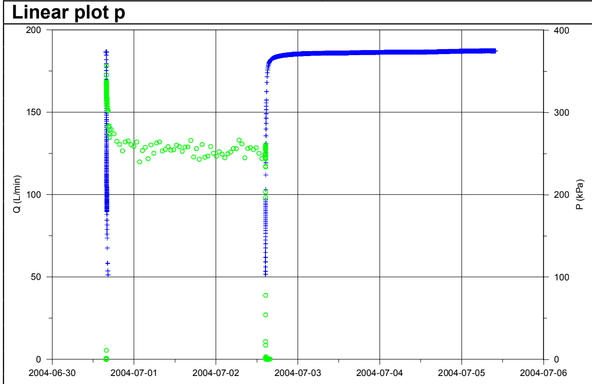
Q/s = specific flow for the pumping/injection borehole,
$T_M$ = transmissivity from stationary evaluation of single-hole test,
$T_T$ = transmissivity from transient evaluation of single-hole test,
$T_o$ = transmissivity from transient evaluation of interference test,
$S_o$ = storativity from transient evaluation of interference test,
S* = assumed storativity in the pumping/injection borehole,
K'/b' = leakage coefficient from transient evaluation of interference test,
C = wellbore storage coefficient,
ζ = skin factor.

Single-hole tests indicate that the zone has somewhat better hydraulic properties close to KFM03A than in the proximity of HFM18, see Table 6-7 and 3-4. This is confirmed by the interference test. There is a good agreement between values of transmissivity from the single-hole test in the actual observation section in KFM03A and the interference test. The difference in calculated transmissivity between $T_T$ in Table 6-7 and $T_o$ in Table 6-8 is assumed to be an effect of the heterogeneity of the rock.

## Test Summary Sheet - Pumping section HFM18: 9.0-180.65 m

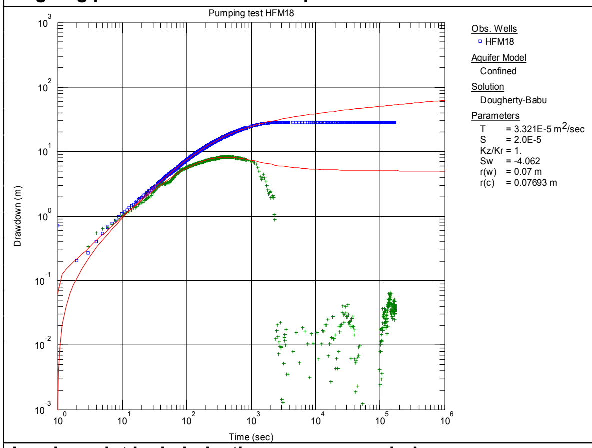
| | | | |
|---|---|---|---|
| Project: | PLU | Test type: | 1B |
| Area: | Forsmark | Test no: | 1 |
| Borehole ID: | HFM18 | Test start: | 2004-06-30 15:48 |
| Test section (m): | 9.0-180 | Responsible for test performance: | GEOSIGMA AB<br>Kristoffer Gokall-Norman |
| Section diameter, 2·rw (m): | 0.140 (nominal) | Responsible for test evaluation: | GEOSIGMA AB<br>J-E Ludvigson |
| | | | |

**Linear plot p**

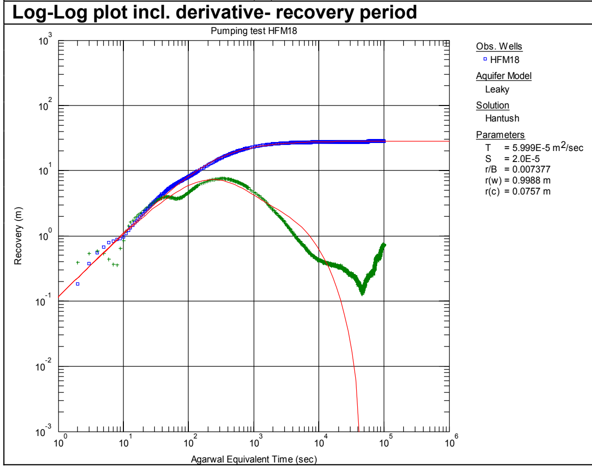



| **Flow period** | | **Recovery period** | |
|---|---|---|---|
| **Indata** | | **Indata** | |
| $p_0$ (kPa) | | | |
| $p_i$ (kPa ) | 373.4 | | |
| $p_p$(kPa) | 98.1 | $p_F$ (kPa ) | 374.7 |
| $Q_p$ ($m^3$/s) | 0.0021 | | |
| tp (s) | 168 180 | $t_F$ (s) | 242 640 |
| S* | $2.0 \cdot 10^{-5}$ | S* | $2.0 \cdot 10^{-5}$ |
| $EC_w$ (mS/m) | | | |
| $Te_w$(gr C) | | | |
| Derivative fact. | 0.2 | Derivative fact. | 0.2 |
| | | | |
| | | | |
| **Results** | | **Results** | |
| Q/s ($m^2$/s) | $7.05 \cdot 10^{-5}$ | | |
| $T_{Moye}$($m^2$/s) | $9.09 \cdot 10^{-5}$ | | |
| Flow regime: | WBS→ | Flow regime: | WBS→PSF |
| $t_1$ (s) | 0 | $dt_{e1}$ (s) | 0 |
| $t_2$ (s) | 84000 | $dt_{e2}$ (s) | 600 000 |
| $T_w$ ($m^2$/s) | $3.34 \cdot 10^{-5}$ | $T_w$ ($m^2$/s) | $6.00 \cdot 10^{-5}$ |
| $S_w$ (-) | | $S_w$ (-) | |
| $K_{sw}$ (m/s) | | $K_{sw}$ (m/s) | |
| $S_{sw}$ (1/m) | | $S_{sw}$ (1/m) | |
| C ($m^3$/Pa) | $1.90 \cdot 10^{-6}$ | C ($m^3$/Pa) | $1.80 \cdot 10^{-6}$ |
| $C_D$ (-) | | $C_D$ (-) | |
| ξ (-) | -4.05 | ξ (-) | -2.65 |
| | | | |
| $T_{GRF}$($m^2$/s) | | $T_{GRF}$($m^2$/s) | |
| $S_{GRF}$(-) | | $S_{GRF}$(-) | |
| $D_{GRF}$ (-) | | $D_{GRF}$ (-) | |

**Log-Log plot incl. derivate- flow period**




**Log-Log plot incl. derivative- recovery period**

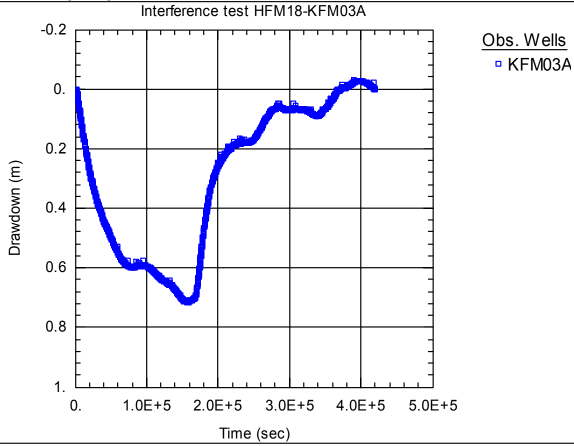



| **Interpreted formation and well parameters.** | | | |
|---|---|---|---|
| Flow regime: | PSF | C ($m^3$/Pa) | $1.80 \cdot 10^{-6}$ |
| $t_1$ (s) | 0 | $C_D$ (-) | |
| $t_2$ (s) | 600 000 | ξ (-) | -2.65 |
| $T_T$ ($m^2$/s) | $6.00 \cdot 10^{-5}$ | | |
| S (-) | | | |
| $K_s$ (m/s) | | | |
| $S_s$ (1/m) | | | |

**Comments**: During the last part of the flow period the water level fell below the position of the pressure transducer due to higher drawdown than expected. For comments about the final drawdown $p_p$, see Section 6.3.1. Only an approximate evaluation was made from the flow period.
During the recovery period, initial WBS transiting to pseudo-spherical (leaky) flow was observed.

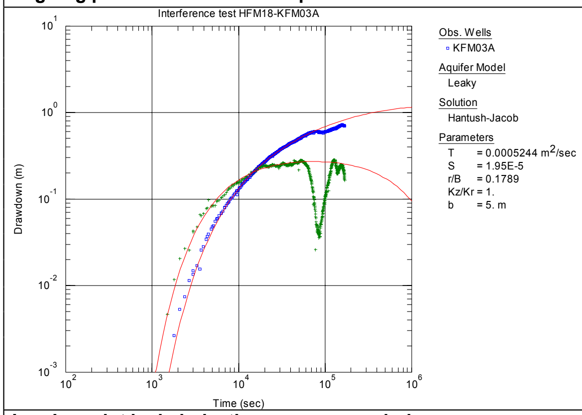
| Test Summary Sheet – Observation section KFM03A: 386-391 m (while pumping in HFM18) | | | |
|---|---|---|---|
| Project: | PLU | Test type: | 2 |
| Area: | Forsmark | Test no: | 1 |
| Borehole ID: | KFM03A | Test start: | 2004-06-30 15:48 |
| Test section (m): | 386-391 | Responsible for test performance: | GEOSIGMA AB |
| Section diameter, 2·rw (m): | 0.077 | Responsible for test evaluation: | GEOSIGMA AB<br>J-E Ludvigson |

**Linear plot p**

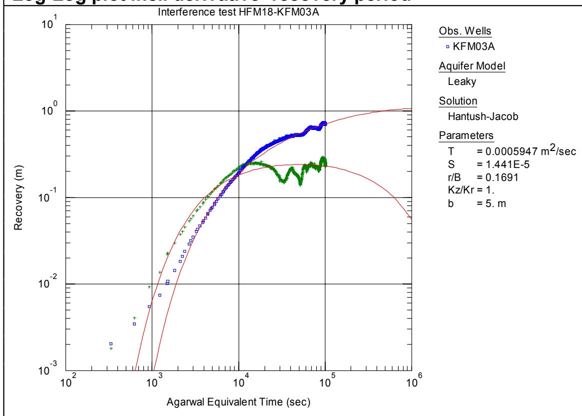



| Flow period | | Recovery period | |
|---|---|---|---|
| **Indata** | | **Indata** | |
| $p_0$ (kPa) | | | |
| $p_i$ (kPa ) | 3862.47 | | |
| $p_p$(kPa) | 3855.15 | $p_F$ (kPa ) | 3862.79 |
| $Q_p$ ($m^3$/s) | | | |
| tp (s) | | $t_F$ (s) | |
| S* | - | S* | - |
| Ecw (mS/m) | | | |
| Tew(gr C) | | | |
| Derivative fact. | 0.2 | Derivative fact. | 0.2 |
| | | | |
| | | | |
| **Results** | | **Results** | |
| Q/s ($m^2$/s) | | | |
| $T_{Moye}$($m^2$/s) | | | |
| Flow regime: | PRF | Flow regime: | PRF |
| $t_1$ (s) | 1500 | $dt_{e1}$ (s) | 1000 |
| $t_2$ (s) | 70000 | $dt_{e2}$ (s) | 100000 |
| $T_o$ ($m^2$/s) | $5.24 \cdot 10^{-4}$ | $T_o$ ($m^2$/s) | $5.95 \cdot 10^{-4}$ |
| $S_o$ (-) | $1.95 \cdot 10^{-5}$ | $S_o$ (-) | $1.44 \cdot 10^{-5}$ |
| K'/b' ($s^{-1}$) | $2.38 \cdot 10^{-11}$ | K'/b' ($s^{-1}$) | $2.41 \cdot 10^{-11}$ |
| $K_{sw}$ (m/s) | | $K_{sw}$ (m/s) | |
| $S_{sw}$ (1/m) | | $S_{sw}$ (1/m) | |
| C ($m^3$/Pa) | | C ($m^3$/Pa) | |
| $C_D$ (-) | | $C_D$ (-) | |
| ξ (-) | | ξ (-) | |
| $T_{GRF}$($m^2$/s) | | $T_{GRF}$($m^2$/s) | |
| $S_{GRF}$(-) | | $S_{GRF}$(-) | |
| $D_{GRF}$ (-) | | $D_{GRF}$ (-) | |

**Log-Log plot incl. derivate- flow period**




**Log-Log plot incl. derivative- recovery period**




| Interpreted formation and well parameters. | | | |
|---|---|---|---|
| Flow regime: | PRF | $K_s$ (m/s) | |
| $t_1$ (s) | 1500 | $S_s$ (1/m) | |
| $t_2$ (s) | 70000 | C ($m^3$/Pa) | |
| $T_o$ ($m^2$/s) | $5.24 \cdot 10^{-4}$ | $C_D$ (-) | |
| $S_o$ (-) | $1.95 \cdot 10^{-5}$ | ξ (-) | |
| K'/b' ($s^{-1}$) | $2.38 \cdot 10^{-11}$ | | |

**Comments:** Pressure data in the observation section was heavily affected by a diurnal superimposed pressure oscillation assumed to be introduced by fluctuations in the sea water level. See Section 6.3.2 for details.
The responses during the flow- and recovery period are despite this fact consistent and give similar values on the hydraulic parameters. Pseudo-radial flow transiting to pseudo-spherical (leaky) flow is dominating during both the flow- and recovery period.

# 7 References

**/1/ 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.

**/2/ Ludvigson J-E, 2004.** Brunnsinventering i Forsmark. SKB P-04-72, Svensk Kärnbränslehantering AB (In Swedish).

**/3/ 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.

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

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

**/6/ Hantush M S, Jacob**, **1955.** Non-steady radial flow in an infinite leaky aquifer. Am. Geophys. Union Trans, vol 36, 95–100.

**/7/ 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.

## List of data files

Files are named "logger S/N"_Interferens_"BhID"_"secup"_"seclow"_"YYYYMMDD"_"hhmmss". Interferens 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 | Con-tent (parame-ters)[2] | Comments |
|---|---|---|---|---|---|---|---|---|---|---|
| HFM18 | 9–181 | 1B | | 2004-06-30 15:48:42 | 2004-07-05 09:57:44 | 2004-06-30 15:48:42 | 2004-07-05 09:57:44 | Interferenstest_Pumphål_HFM18_ 20040630_1548_Pumpin00.DAT | P, Q | Pressure and flow registration in HFM18, 9–181 m for interference. |
| HFM18 | | | | | | 2004-06-30 13:22:29 | 2004-07-07 08:57:54 | Interferenstest_Pumphål_HFM18_ 20040630_1548_Ref_Da00.DAT | C, R | |
| KFM03A | 12–385 | 2 | | 2004-06-30 15:48:42 | 2004-07-05 09:57:44 | 2004-06-30 15:16:09 | 2004-07-05 12:36:09 | SN09981_interferens_KFM03A_12_ 385_20040630_151609.bin | P | Pressure response to pumping in HFM18 9–181 m. |
| KFM03A | 386–391 | 2 | | 2004-06-30 15:48:42 | 2004-07-05 09:57:44 | 2004-06-30 15:14:26 | 2004-07-05 12:34:26 | SN12115_interferens_KFM03A_386_ 391_20040630_151426.bin | P | Pressure response to pumping in HFM18 9–181 m. |
| KFM03A | 392–1,001 | 2 | | 2004-06-30 15:48:42 | 2004-07-05 09:57:44 | 2004-06-30 15:12:25 | 2004-07-05 12:32:25 | SN12572_interferens_KFM03A_392_ 1001_20040630_151225.bin | P | Pressure response to pumping in HFM18 9–181 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 data diagrams

### *HFM18: 9.0–180.65 m*

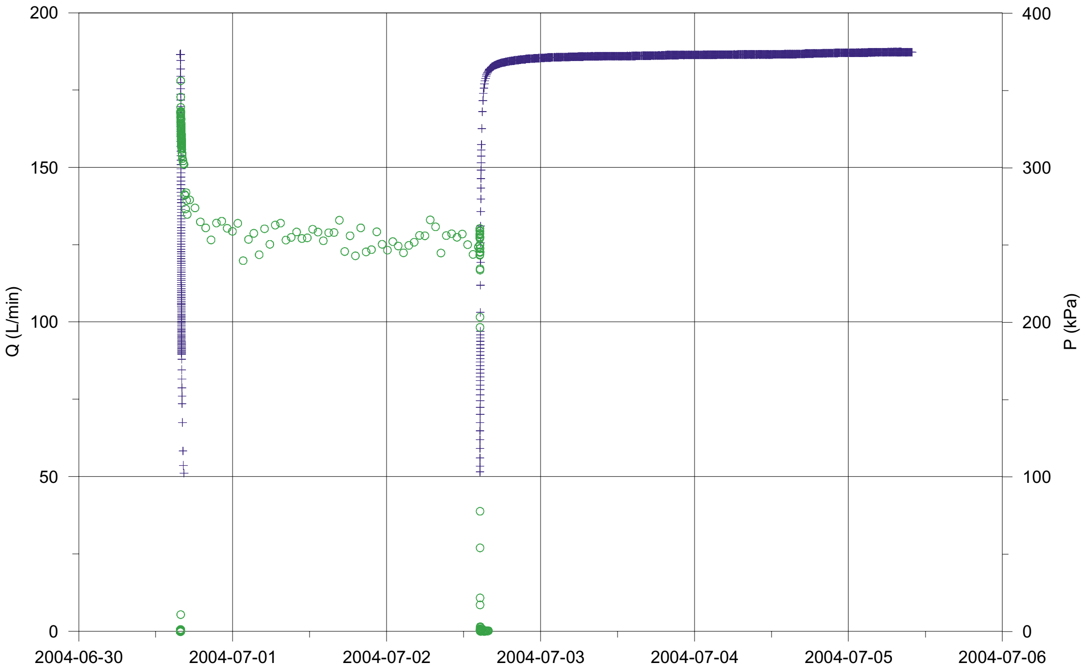



***Figure A2-1.*** *Linear plot of flow rate (green) and pressure (blue) versus time in the pumping borehole HFM18.*

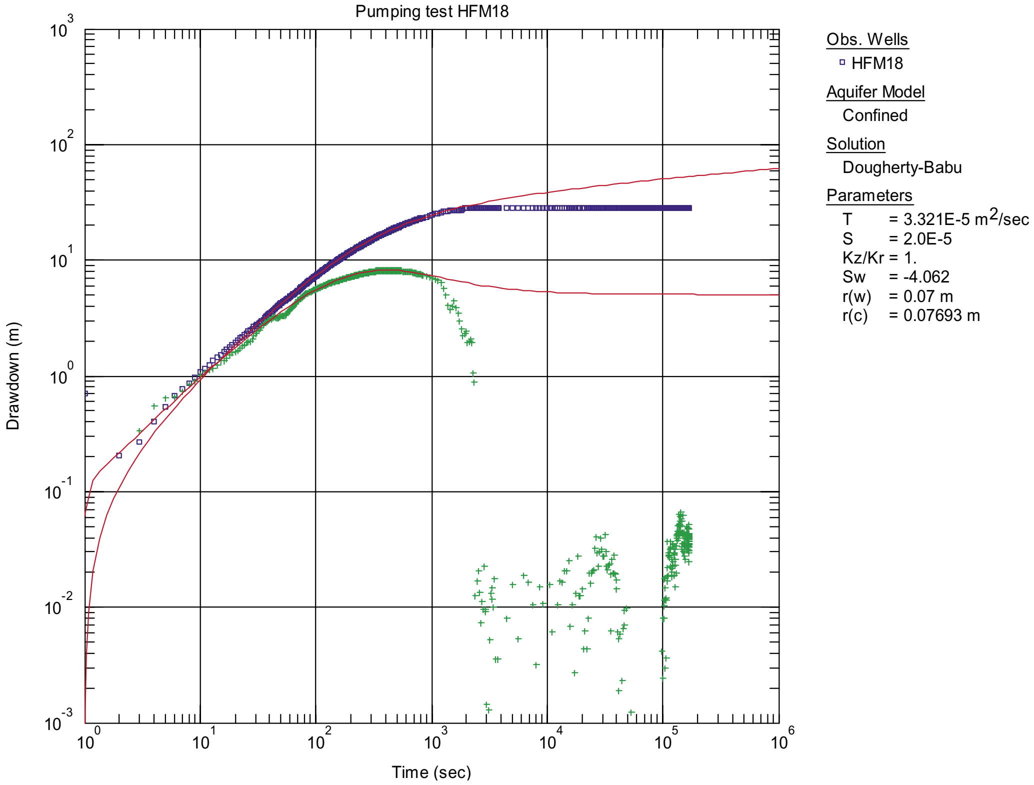



***Figure A2-2.*** *Log-log plot of drawdown versus time during the open-hole pumping test in HFM18.*

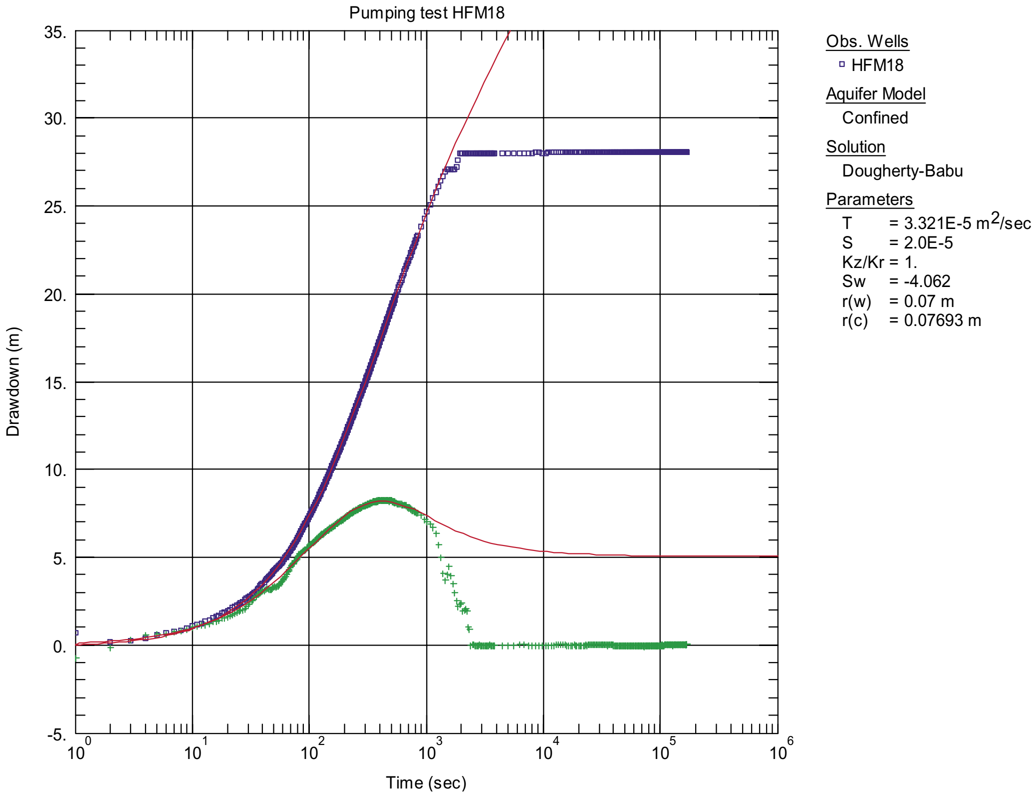



***Figure A2-3.*** *Lin-log plot of drawdown versus time during the open-hole pumping test in HFM18.*

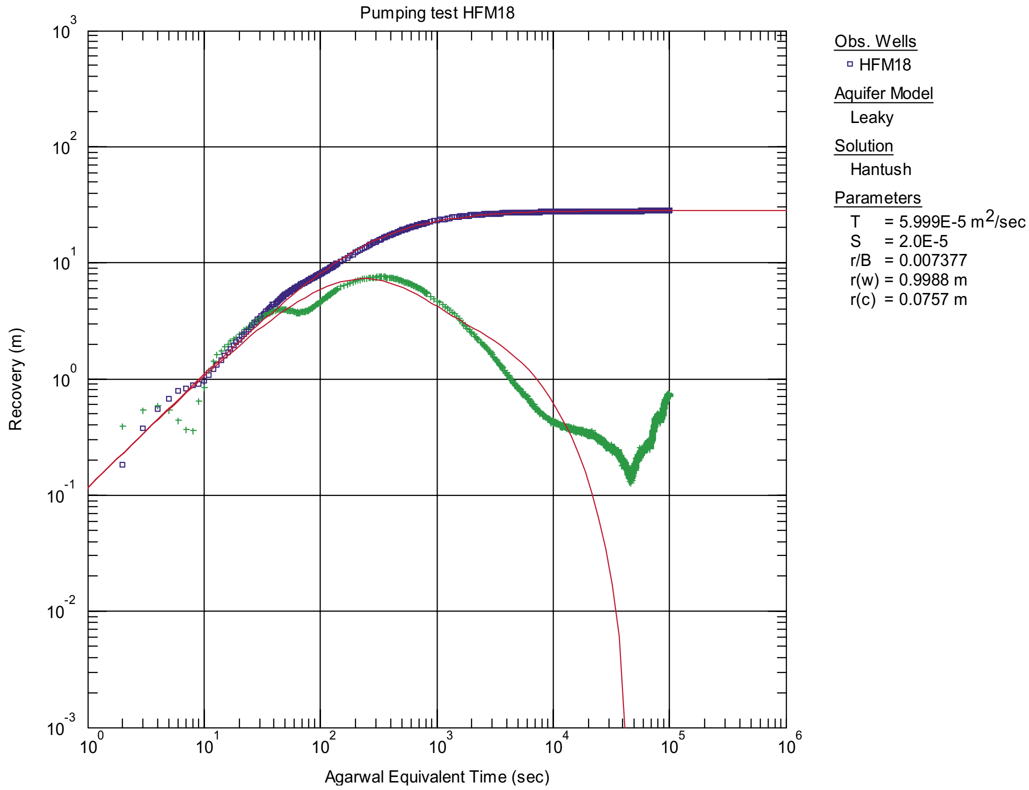



***Figure A2-4.*** *Log-log plot of pressure recovery versus equivalent time from the open-hole pumping test in HFM18.*

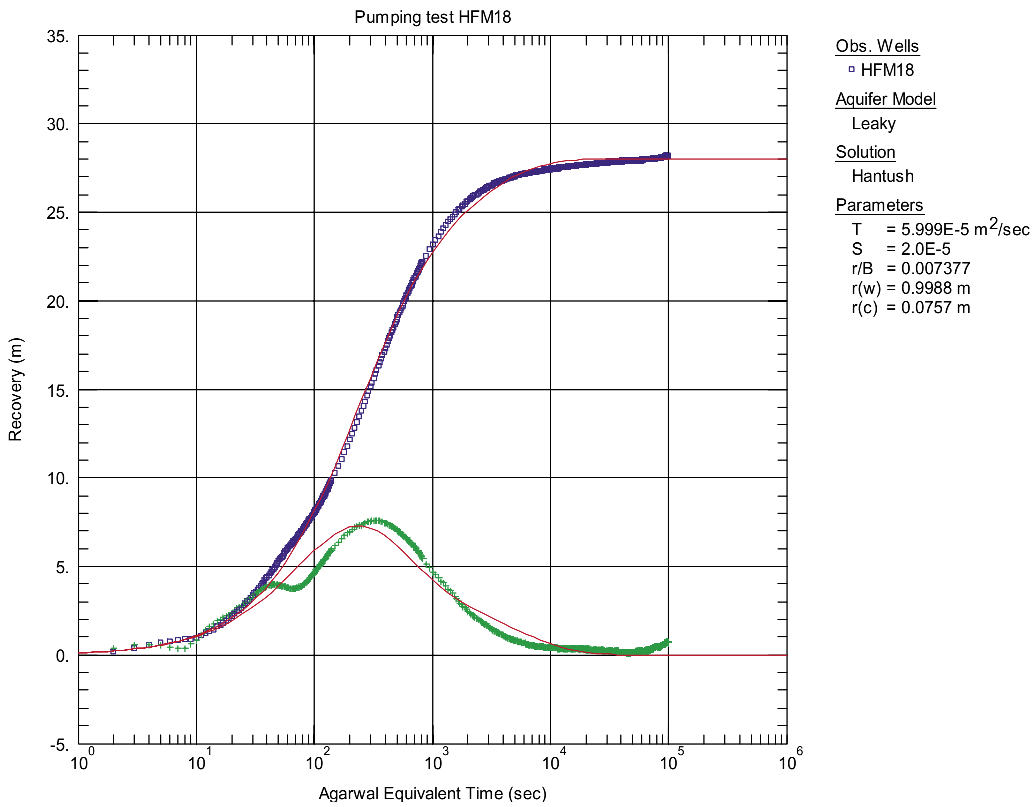



***Figure A2-5.*** *Lin-log plot of pressure recovery versus equivalent time from the open-hole pumping test in HFM18.*

### *KFM03A: 386–391 m*

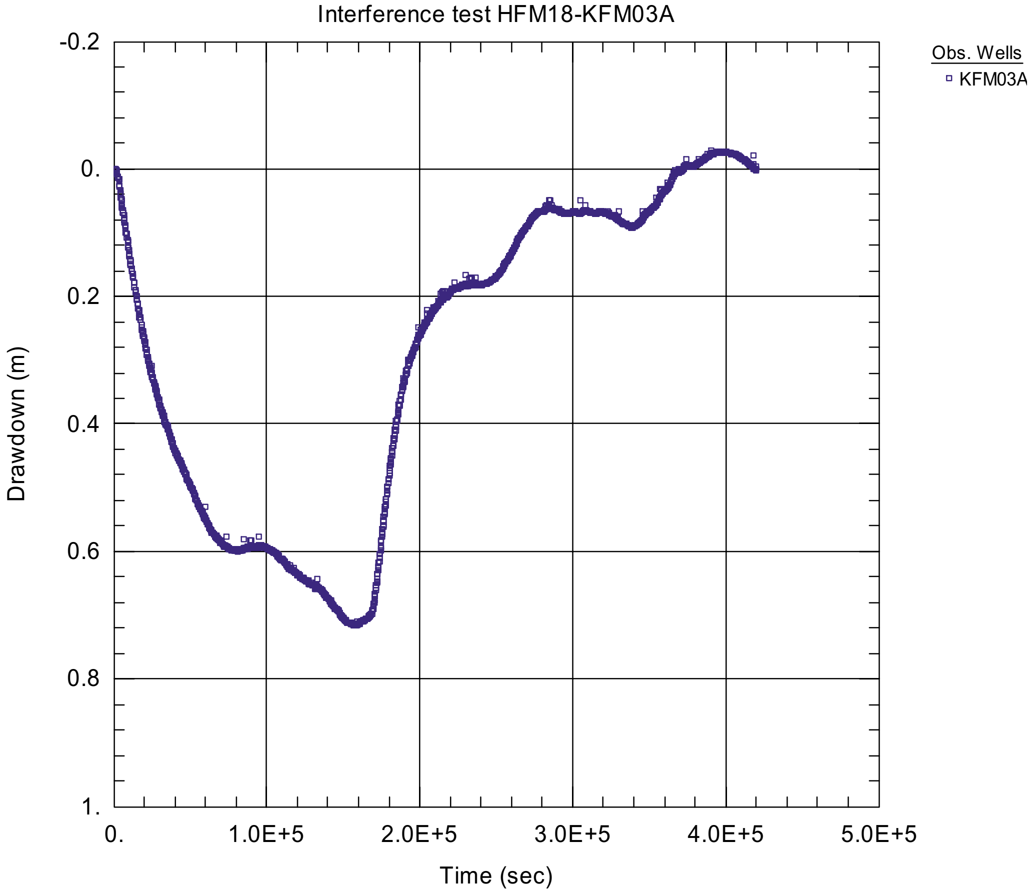



***Figure A2-6.*** *Lin-lin plot of drawdown versus time in observation section KFM03A: 386–391 m.*

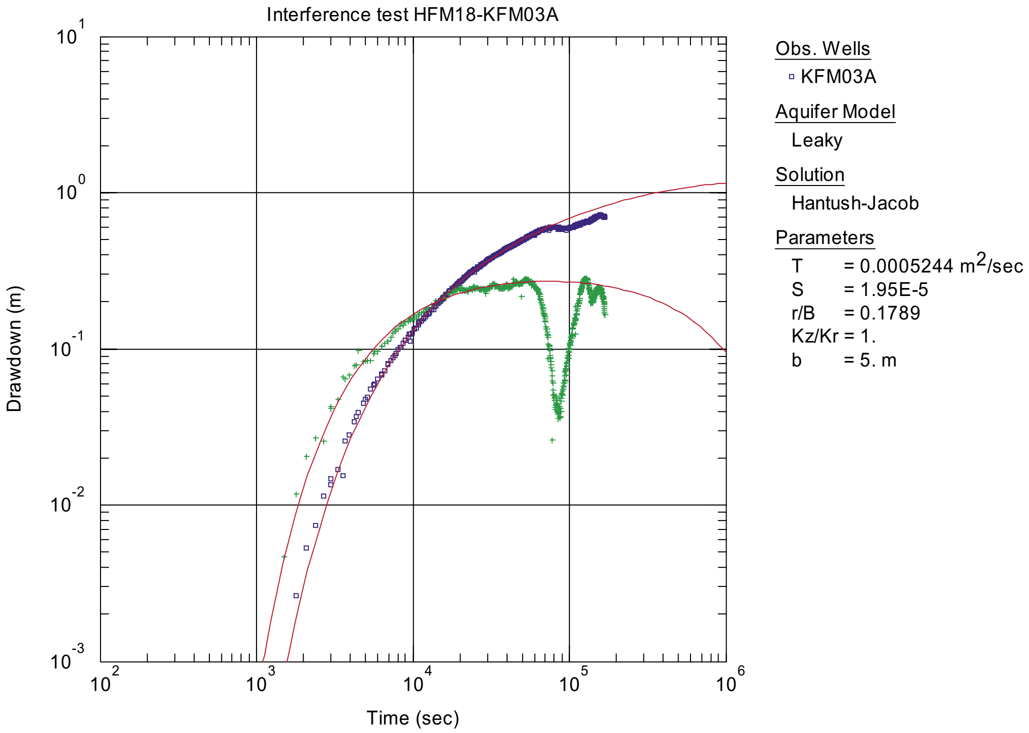



***Figure A2-7.*** *Log-log plot of drawdown (s) versus time (t) in observation section KFM03A: 386–391 m.*

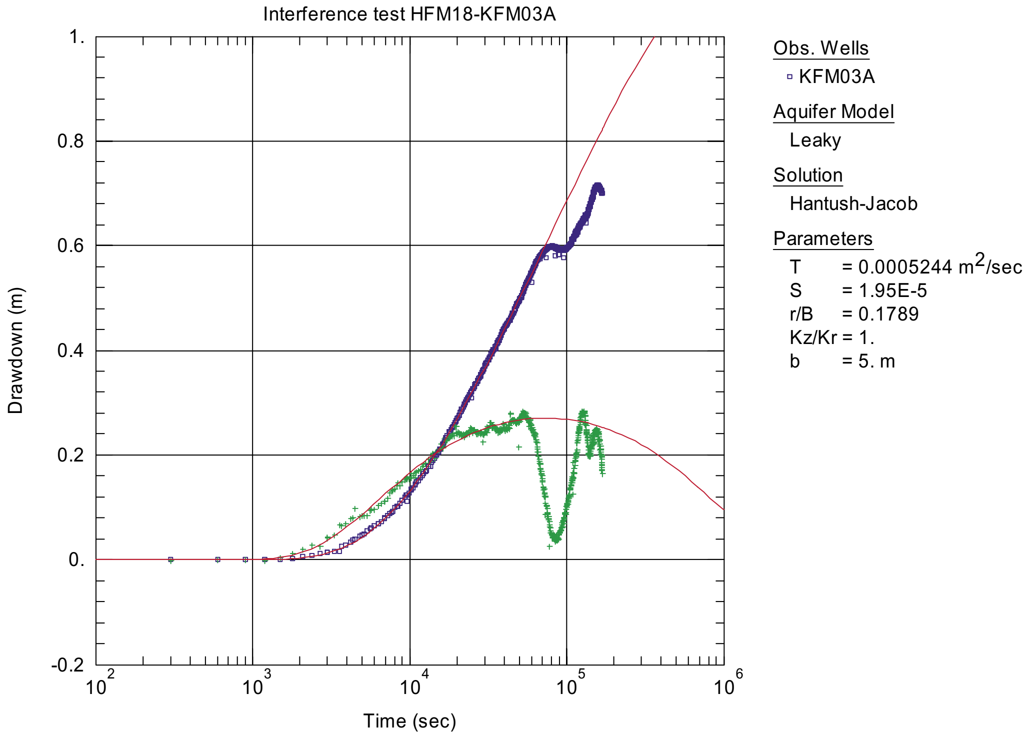



***Figure A2-8.*** *Lin-log plot of drawdown (s) versus time (t) in observation section KFM03A: 386–391 m.*

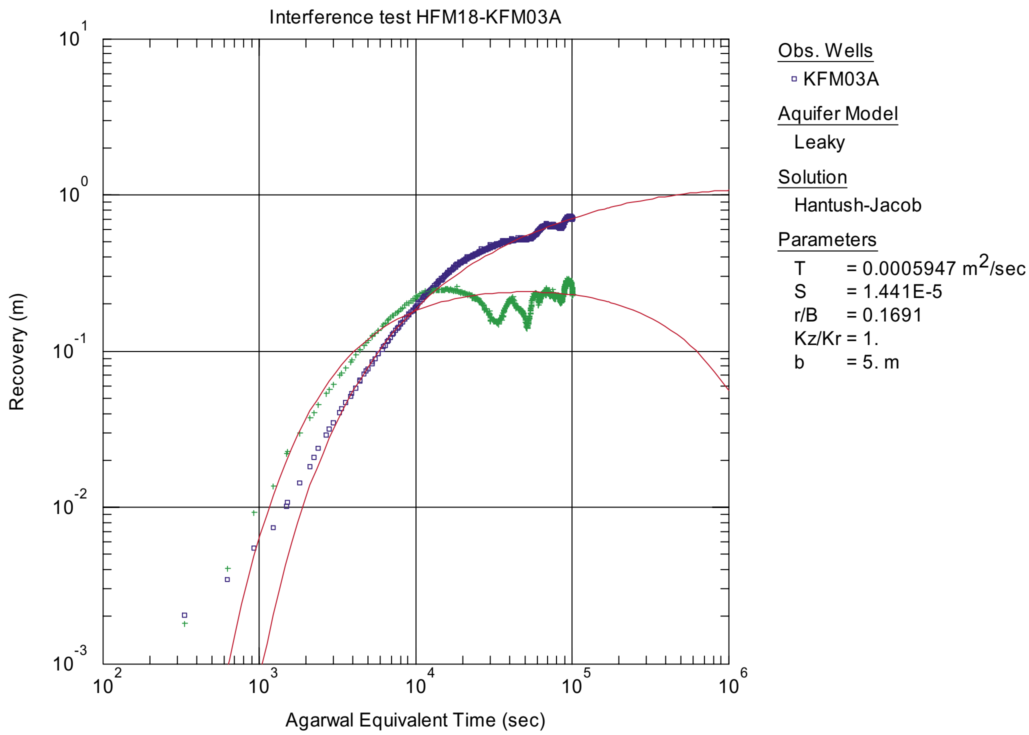



***Figure A2-9.*** *Log-log plot of pressure recovery versus equivalent time in observation section KFM03A: 386–391 m.*

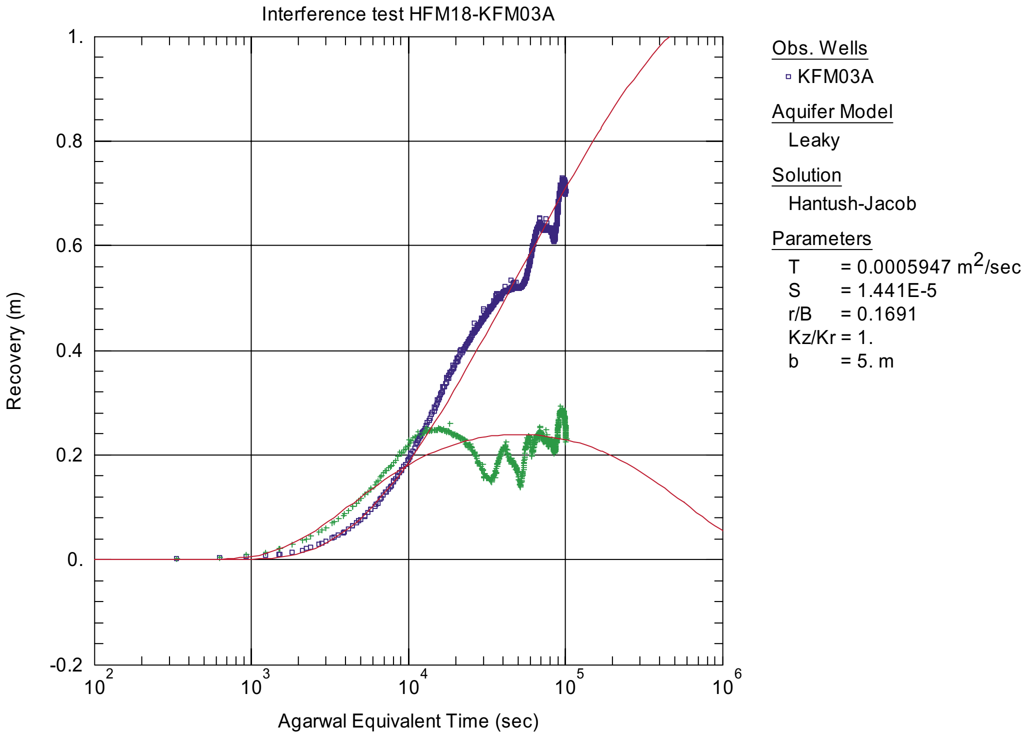



*Figure A2-10.* *Lin-log plot of pressure recovery versus equivalent time in observation section KFM03A: 386–391 m.*

### Atmospheric pressure and precipitation

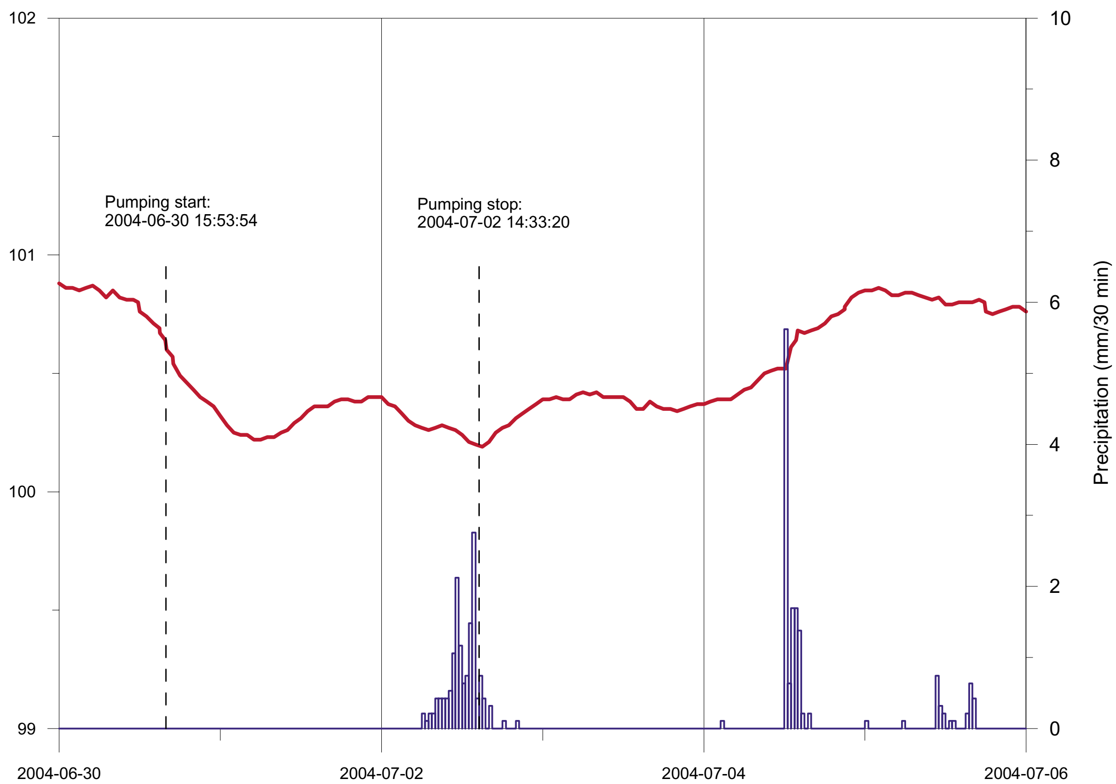



*Figure A2-11.* *Atmospheric pressure (red) and precipitation at Storskäret (blue) during the interference test in HFM18.*

# Appendix 3

## Result tables to Sicada

### Result table to SICADA for the single-hole test in HFM18

**plu_s_hole_test_d**

| idcode | start_date | stop_date | secup | seclow | section_no | test_type | formation_type | start_flow_period | stop_flow_period | mean_flow_rate_qm | flow_rate_end_qp | value_type_qp | q_measl__l | q_measl__u |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HFM18 | 2004-06-30 15:48 | 2004-07-05 09:57 | 9.00 | 180.65 | | 1B | 1 | 2004-06-30 15:53:54 | 2004-07-02 14:33:20 | 2.1000E–03 | 2.1000E–03 | 0 | 1.8E–05 | 2.8E–03 |

**cont.**

| tot_volume_vp | dur_flow_phase_tp | dur_rec_phase_tf | 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 | fluid_elcond_ecw | fluid_salinity_tdsw | fluid_salinity_tdswm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.5900E+02 | 167,966 | 242,640 | | | | 373.40 | 98.10 | 374.70 | | | | |

**cont.**

| reference | com-ments | lp |
|---|---|---|
| | | 42.20 |

## plu_s_hole_test_ed1

| idcode | start_date | stop_date | secup | seclow | section_no | test_type | formation_type | lp | seclen_class | spec_capacity_q_s | value_type_q_s | transmissivity_tq | value_type_tq | bc_tq | transmissivity_moye |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HFM18 | 2004-06-30 15:48 | 2004-07-05 09:57 | 9.00 | 180.65 | | 1B | 1 | 42.20 | | 7.05E–05 | 0 | | | | 9.09E–05 |

## cont.

| bc_tm | value_type_tm | hydr_cond_moye | formation_width_b | width_of_channel_b | tb | l_measl_tb | u_measl_tb | sb | assumed_sb | leakage_factor_lf | transmissivity_tt | value_type_tt | bc_tt | l_measl_q_s | u_measl_q_s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 5.30E–07 | 171.65 | | | | | | | | 6.00E–05 | 0 | 1 | 3.0E–07 | 5.0E–03 |

## cont.

| storativity_s | assumed_s | leakage_koeff | hydr_cond_ks | value_type_ks | l_meas_limit_ks | u_meas_limit_ks | spec_storage_ss | assumed_ss | c | cd | skin | stor_ratio | interflow_coeff | dt1 | dt2 | transmissivity_t_ilr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2.00E–05 | | | | | | | | 1.80E–06 | | –2.65 | | | 0 | 600,000 | |

## cont.

| storati-vity_s_ilr | value_type_t_ilr | bc_t_ilr | c_ilr | cd_ilr | skin_ilr | stor_ratio_ilr | interflow_coeff_ilr | transmissivity_t_grf | value_type_t_grf | bc_t_grf | storativity_s_grf | flow_dim_grf | comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | |

## SICADA – description of s_hole_test_d

## PLU interference tests, Observation section data

| Header | Unit | Explanation |
|---|---|---|
| Borehole | | ID for borehole. |
| Borehole secup | m | Length coordinate along the borehole for the upper limit of the test section. |
| Borehole seclow | m | Length coordinate along the borehole for the lower limit of the test section. |
| Test type (1– 7) | (–) | 1A: Pumping test – wireline eq., 1B: Pumping test-submersible pump, 1C: Pumpingtest-airlift pumping, 2: Interference test, 3: Injection test, 4: Slug test, 5A: Difference flow logging-PFL-DIFF-sequential, 5B: Difference flow logging-PFL-DIFF-overlapping, 6: Flow logging_Impeller, 7: Grain size analysis. |
| Date for test start | | Date for the start of the pumping or injection test (YYYYMMDD hh:mm). |
| Start flow/injection | | Date and time for the start of the pumping or injection period (YYMMDD hh:mm:ss). |
| Start flow/injection | | Date and time for the end of the pumping or injection period (YYMMDD hh:mm:ss). |
| $Q_m$ | $m^3/s$ | Arithmetic mean flow rate of the pumping/injection period. |
| $Q_p$ | $m^3/s$ | Flow rate at the end of the pumping/injection period. |
| Value type | – | Code for $Q_p$-value; –1 means $Q_p$ < lower measurement limit, 0 means measured value, 1 means $Q_p$ > upper measurement value of flowrate. |
| Q-measl_L | $m^3/s$ | Estimated lower measurement limit for flow rate. |
| Q-measl_U | $m^3/s$ | Estimated upper measurement limit for flow rate. |
| $V_p$ | $m^3$ | Total volume pumped (positive) or injected (negative) water during the flow period. |
| $t_p$ | s | Time for the flowing phase of the test. |
| $t_F$ | s | Time for the recovery phase of the test. |
| $h_i$ | m | Initial formation hydraulic head. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z = 0 m. |
| $h_p$ | m | Final hydraulic head at the end of the pumping/injection period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z = 0 m. |
| $h_F$ | m | Final hydraulic head at the end of the recovery period. Measured as water level in open stand pipes from borehole section with reference level in the local coordinates system with z = 0 m. |
| $p_i$ | kPa | Initial formation pressure. |
| $p_p$ | kPa | Final pressure at the end of the pumping/injection period. |
| $p_F$ | kPa | Final pressure at the end of the recovery period. |
| $Te_w$ | gr C | Fluid temperature in the test section representative for the evaluated parameters. |

| Header | Unit | Explanation |
|---|---|---|
| $EC_w$ | mS/m | Electrical conductivity of the fluid in the test section representative for the evaluated parameters. |
| $TDS_w$ | mg/L | Total salinity of the fluid in formation at test section based on EC. |
| $TDS_{wn}$ | mg/L | Total salinity of the fluid in formation at test section based on water sampling and chemical analysis. |
| Sec.type, | (–) | Test section (pumping or injection) is labeled 1 and all observation sections are labeled 2. |
| Q/s | $m^2/s$ | Specific capacity, based on Qp and s = abs(pi-pp). Only given for test section (label 1) in interference test. |
| $T_Q$ | $m^2/s$ | Transmissivity based on specific capacity and a a function for T = f(Q/s). The fuction used should be refered in “Comments”. |
| $T_M$ | $m^2/s$ | Transmissivity based on Moye (1967). |
| b | m | Interpreted formation thickness representative for evaluated T ot TB. |
| B | m | Interpreted witdth of a formation with evaluated TB. |
| TB | $m^3/s$ | 1D model for evaluation of formation properties. T = transmissivity, B = width of formation. |
| TB-measl-L | $m^2/s$ | Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or less than TB-measlim. |
| TB-measl-L | $m^2/s$ | Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or greater than TB-measlim. |
| SB | m | 1D model for evaluation of formation properties. S = Storativity, B = width of formation. |
| SB* | m | 1D model for evaluation of formation properties. Assumed SB. S = Storativity, B = width of formation. |
| $L_f$ | m | 1D model for evaluation of Leakage factor . |
| $T_T$ | $m^2/s$ | 2D model for evaluation of formation properties. T = transmissivity. |
| T-measl-L | $m^2/s$ | Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or less than T-measlim. |
| T-measl-U | $m^2/s$ | Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or grater than T-measlim. |
| S | (–) | 2D model for evaluation of formation properties. S = Storativity. |
| S* | (–) | 2D model for evaluation of formation properties. Assumed S. S = Storativity. |
| K´/b´ | (1/s) | 2D model for evaluation of leakage coefficient. K´= hydraulic conductivity in direction of leaking flow for the aquitard, |
| | | b´ = Saturated thickness of aquitard (leaking formation). |
| $K_S$ | m/s | 3D model for evaluation of formation properties. K = Hydraulic conductivity. |
| $K_S$-measl-L | m/s | Estimated measurement limit for evaluated KS. If estimated KS equals KS-measlim in the table actual KS is considered to be equal or less than KS-measlim. |

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

# Result table to SICADA from the interference test in HFM18

## plu_inf_test_obs_d

| idcode | start_date | stop_date | secup | seclow | section_no | test_type | formation_type | start_flow_period | stop_flow_period | test_borehole | test_secup | test_seclow | lp | radial_distance_rs | shortest_distance_rt |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KFM03A | 2004-06-30 15:48 | 2004-07-05 09:57 | 386.00 | 391.00 | | 2 | | 2004-06-30 15:53:54 | 2004-07-02 14:33:20 | HFM18 | 9.00 | 180.65 | | 840.10 | |

## cont.

| time_lag_press_dtl | initial_head_hi | head_at_flow_end_hp | final_head_hf | initial_press_pi | press_at_flow_end_pp | final_press_pf | fluid_temp_teo | fluid_elcond_eco | fluid_salinity_tdso | fluid_salinity_tdsom | reference | comment |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2,700.00 | | | | 3,862.47 | 3,855.15 | 3,862.79 | | | | | | |



## plu_inf_test_obs_ed

| idcode | start_date | stop_date | secup | seclow | section_no | test_borehole | test_secup | test_seclow | formation_width_b | width_of_channel_b | tbo | l_meas_limit_tb | u_meas_limit_tb | sbo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| KFM03A | 2004-06-30 15:48 | 2004-07-05 09:57 | 386.00 | 391.00 | | HFM18 | 9.00 | 180.65 | 171.65 | | | | | |

## cont.

| leakage_factor_lfo | transmissivity_tto | value_type_tto | l_meas_limit_t | u_meas_limit_t | storativity_so | leakage_coeff_o | hydr_kond_kso | l_meas_limit_ks | u_meas_limit_ks | spec_storage_sso | dt1 | dt2 | comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5,24E-04 | 0 | | | 1,95E-05 | 2,38E-11 | | | | | 1500 | 70000 | |

## SICADA – description of plu_inf_test_obs

## PLU interference tests, Observation section data

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

| Header | Unit | Explanation |
|---|---|---|
| $Te_o$ | gr C | Fluid temperature in formation at obsevation section |
| $EC_o$ | mS/m | Electrical conductivity of the fluid in formation at observation section |
| $TDS_o$ | mg/L | Total salinity of the fluid in formation at observation section based on EC |
| $TDS_{om}$ | mg/L | Total salinity of the fluid in formation at observation section based on water sample and chemical analysis |
| b | m | b: Interpreted formation thickness or section lengthrepresentative for evaluated T ot TB. |
| B | m | B: Interpreted witdth of a formation with evaluated TB |
| $TB_o$ | $m^3/s$ | $TB_o$: 1D model for evaluation of formation properties. T = transmissivity, B = width of formation |
| TB-measl-L | $m^2/s$ | Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or less than TB-measlim |
| TB-measl-U | $m^2/s$ | Estimated measurement limit for evaluated TB. If estimated TB equals TB-measlim in the table actual TB is considered to be equal or greater than TB-measlim |
| $SB_o$ | m | $SB_o$: 1D model for evaluation of formation properties. S = Storativity, B = width of formation |
| $Lf_0$ | m | 1D model for evaluation of Leakage factor |
| $Tt_0$ | $m^2/s$ | 2D model for evaluation of formation properties. T = transmissivity |
| T-measl-L | $m^2/s$ | Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or less than T-measlim |
| T-measl-U | $m^2/s$ | Estimated measurement limit for evaluated T (TT, TQ, TM). If estimated T equals T-measlim in the table actual T is considered to be equal or greater than T-measlim |
| $S_o$ | (–) | 2D model for evaluation of formation properties. S = Storativity |
| $K'/b_{\cdot 0}$ | (1/s) | 2D model for evaluation of leakage coefficient. K´= hydraulic conductivity in direction of leaking flow for the aquitard, b´= Saturated thickness of aquitard (leaking formation) |
| $K_{S0}$ | m/s | 3D model for evaluation of formation properties. K = Hydraulic conductivity |
| $K_S$-measl-L | m/s | Estimated measurement limit for evaluated $K_S$. If estimated $K_S$ equals $K_S$-measlim in the table actual $K_S$ is considered to be equal or less than $K_S$-measlim |
| $K_S$-measl-U | m/s | Estimated measurement limit for evaluated $K_S$. If estimated $K_S$ equals $K_S$-measlim in the table actual $K_S$ is considered to be equal or greater than $K_S$-measlim |
| $S_{S0}$ | 1/m | 3D model for evaluation of formation properties. Ss = Specific Storage |
| $dt_1$ | s | Estimated start time after pump/injection start OR recovery start, for the period used for the evaluated parameter |
| dt2 | s | Estimated stop time after pump/injection start OR recovery start, for the period used for the evaluated parameter |
| References | | SKB report No for reports describing data and evaluation |
| Comments | | Short comment to the evaluated parameters (Optional) |

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